Waters of LIFE

Framework of Best Practice Measures and Guidelines for the Protection and Restoration of High Status River Water Bodies

www.watersoflife.ie

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1.1 Introduction

This document develops a framework for selecting and implementing the most suitable measures to protect or restore, as appropriate, High Status Objective (HSO) river waterbodies in their Irish environmental settings. A Literature Review and Measures Report was prepared by RPS Group (Environmental Consultants) to initially identify the range of potential best practice measures of relevance in this process. This was advanced further by a series of consultations with Water of Life stakeholders which produced tables of measures for mitigating impacts from significant issues arising from the main sectoral pressures in the catchment areas of HSO waterbodies – agricultural activities, forestry, peat extraction, domestic wastewater treatment systems and quarries. In this report, a framework is presented that facilitates consideration of all the potential measures identified to select those that are: i) most suited to the issues, pressures and impacts at a specific site in a catchment context; ii) deliver the greatest multiple benefits; iii) are compliant with relevant environmental legislation and policy; and iv) allow appraisal of measure performance for future refinement.

The Water Framework Directive (2000/60/EC, WFD)[1] underpins the management of surface waters (rivers and lakes, transitional and coastal waters) and groundwater across the EU. It aims to prevent deterioration, protect, and enhance the overall status of surface waters, and the quantitative status and chemical status of groundwaters. In addition, it aims to ensure the reduction of pollution and promotes the sustainable use of water. The success of WFD implementation is evaluated through national monitoring programmes, carried out by Member States and reported to the EU in six-year cycles. In Ireland the WFD was given legal effect in 2003 through the European Communities (Water Policy) Regulations (S.I. No. 722 of 2003)[2].

The fundamental WFD reporting unit is the waterbody. Within surface waterbodies, monitoring aims to provide a coherent and comprehensive understanding of aquatic ecosystem condition and the likelihood of potential impacts that may result in degradation. The overall WFD status of surface waters is based on their ecological status and their chemical status. For rivers, ecological status is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters. It is based on biological elements (flora, invertebrates and fish), hydromorphological elements (flow quantity and dynamics, groundwater connection, river depth and width variation, riverbed structure and substrate, riparian zone structure), and chemical and physico-chemical elements that support the biological elements (thermal and oxygenation conditions, salinity, acidification status, nutrient conditions, specific pollutants). For surface waters, ecological status may range from High Status through Good, Moderate, Poor and Bad Status. Chemical status is either Good or Failing to Achieve Good.

Although the WFD specifies that all waterbodies should achieve at least Good Status, HSO waterbodies, which show very minor to no alteration to physico-chemical, hydromorphological and biological quality elements, are required to maintain their status. Where status degrades, the WFD requires the implementation of a programme of measures (POMs) to restore it.

Ireland has witnessed a long-term decline in the condition of these waters resulting in the loss of HS in some rivers and streams. Under this directive, HSOs have been set for particular surface waterbodies, which aim to protect those currently identified as High Status, and to restore those which are currently less than High Status. A diverse range of actions exists with potential for inclusion

[1] *EU Water Framework Directive (2000): https://ec.europa.eu/environment/water/water-framework/index_en.html*

[2] https://www.irishstatutebook.ie/eli/2003/si/722/made/en/print

as measures within POMs, aiming to protect or restore HS. The suitability of measures varies with physical, pollutant, pressure and socio-economic setting. This report provides a framework for the identification of suitable measures to be applied in those rivers and streams that are currently, or were formerly, classified as HS and requiring protection or restoration.

1.2 Assessment of Status and Objectives

The rules for assignment of waterbody status are determined by individual member states and thus vary across the EU. In Ireland, assessment of river status builds on historical monitoring programmes, notably the findings of biological monitoring extending back to 1971. Such monitoring has been based on biotic indices (Q Values) that reflect average water quality at any location and are based primarily on the relative proportions of pollution sensitive to tolerant macroinvertebrates resident at a river site.

In accordance with the WFD, ecological status is determined for surface waterbodies (including rivers) using intercalibrated biological quality elements (BQEs) and supported by physico-chemical and hydromorphological quality elements. Ecological status for surface waterbodies is primarily driven by the BQEs, namely fish, aquatic fora, macroinvertebrates and phytoplankton. The overall ecological status classification for any waterbody is determined, according to the 'one out, all out' principle, by the element with the worst status out of all the biological and supporting quality elements. In Ireland, macroinvertebrates are the main BQE determining the ecological status in rivers, although WFD Status also considers abiotic ecosystem elements.

The WFD requires BQE scores, including Q-values, to be expressed as an Ecological Quality Ratio (EQR) varying between 0 and 1, to standardize and provide a common scale of ecological quality across participatory Member States using differing national methods. Status and equivalent EQR and Q-value scores are provided in Table 1-1.

Table 1-1: Q-Value with EQR and equivalent WFD Status.

Q-value Score	EQR	WFD Status
Q5	1	**High**
Q4-5	0.9	**High**
Q4	0.8	**Good**
Q3-4	0.7	**Moderate**
Q3	0.6	**Poor**
Q2-3	0.5	**Poor**
Q2	0.4	**Bad**
Q1-2	0.3	**Bad**
Q1	0.2	**Bad**

Currently, more than 2,400 river survey stations across the country are monitored at least every three years, using macroinvertebrates, complemented by aquatic plant, diatom and/or fish data where available. In addition, other elements monitored include water quality (dissolved oxygen, nutrients, hazardous substances, temperature and pH), hydromorphology and physical hydrology (flow). Monitoring of these abiotic elements can take place more frequently but is implemented at fewer locations. This gives rise to contrasting levels of understanding concerning the drivers impacting waterbodies and can lead to status being assigned based on a reduced number of metrics. Classification is further complicated by the implementation of more recent biological assessment methods and the requirement to monitor new physico-chemical parameters, e.g. newly identified priority substances.

In addition, it needs to be noted that the Q-score system employed to assign status was developed for application in a wide range of physical settings across Ireland. The sensitivity of the index to various pollutants and stressors differs and changes in Q-Value may not reflect subtle alterations within HS sites, and therefore, may prove insufficiently accurate to reflect disturbances that impact more sensitive species, e.g. Freshwater pearl mussel (*M. margaritifera*). Where measures aim to target these species as a metric of POM success, supplemental waterbody-specific measures may prove necessary; these would address not only fundamental ecological requirements to achieve HS, but further conditions needed to support the restoration of populations of more sensitive species.

This report focuses on those rivers having a HSO in the third-cycle River Basin Management Plan (available to download from the EPA's Geoportal). It incorporates 334 river waterbodies for which a HSO has been identified (Figure 1-1). Of these 148 are currently classified at High Status, and the remaining 186 waterbodies are at Good Status or less, and therefore not achieving their WFD objective.

The catchment areas of HSO waterbodies can therefore be categorised as follows:

1. '*Areas for Protection'*, where the requirement is protection/maintenance of their High Status.
2. '*Areas for Restoration, '*where the requirement is improvement/restoration to High Status.

This distinction has consequences for the measures undertaken for each category and therefore it is important to differentiate between them, as the approaches and resource requirements will be somewhat different.

1.3 Relevant Concepts for Decision-making on Measures

1.3.1 Introduction

An overarching context for the Water of Life Project is the recognition of the interconnections and interdependencies between the various components of our natural environment: water resources, aquatic and terrestrial ecosystems, air, soils, rocks, land and landscapes. While the project focuses primarily on the implementation of measures in the catchment areas of HSO waterbodies and on WFD implementation, there is nevertheless an awareness of the need to take a holistic view of water in catchments and to take account of other directives, such as the Habitats Directive, and all other components such as terrestrial ecosystems, spatial planning, climate change adaptation and mitigation, and food and timber production. This 'whole of environment' approach and philosophy are encompassed in a conceptual framework called 'A Framework for Integrated Land and Landscape Management' (FILLM) published by An Fóram Uisce (2021).

A structured approach that is systems-based, risk-based, evidence-based, holistic and integrated provides an effective and efficient means of considering all the relevant issues and helps ensure that the desired environmental outcomes are achieved. The recommended process, which is used by the EPA Catchments Unit, the Local Authorities Water Programme (LAWPRO) and the National Federation of Group Water Schemes (NFGWS), is the operational element of the FILLM, and is shown in Figure 1-2. The process is subdivided into three components:

1. Catchment characterisation.
2. Evaluation and establishment of protection and mitigation measures.
3. Monitoring progress and making adjustments, if considered beneficial.

A summary of each component is given below.

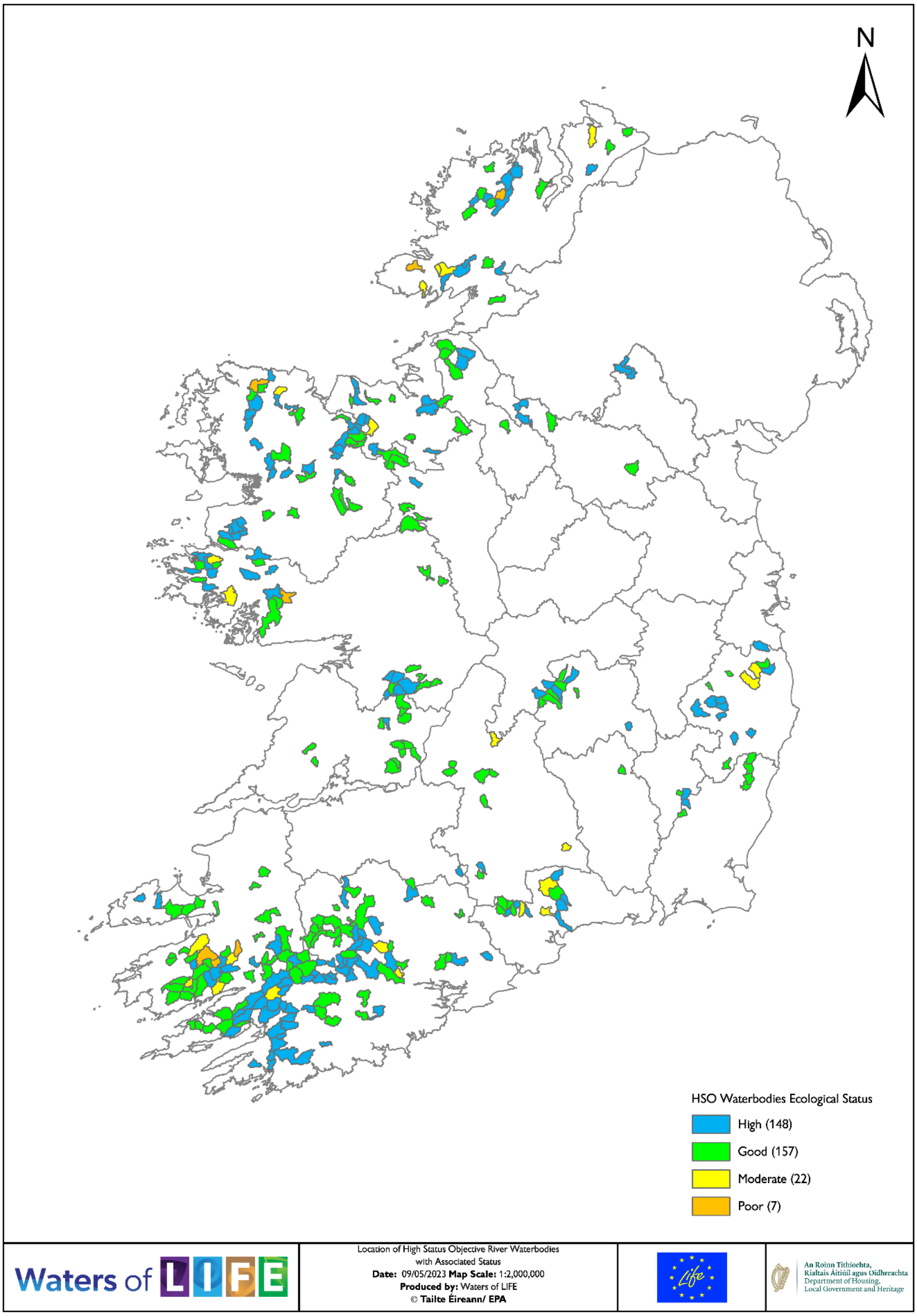


Figure 1-1: Location of High Status Objective Rivers

(Map produced April 2023)

1.3.2 A Framework for Integrated Land and Landscape Management (FILLM)

Integrated catchment management (ICM) was developed in Ireland as a framework for water management that linked the various components in catchments, and has been used as a fundamental approach in the development of River Basin Management Plans. With the realisation in recent years of the connectedness of our natural environment, which is a 'system' comprised of several 'realms' such as water, air and atmosphere, ecosystems, geosystems and land/landscapes (as illustrated in Figure 1-3), An Fóram Uisce/The Water Forum concluded that ICM would benefit from broadening its' scope and, as a consequence, developed the Framework for Integrated Land and Landscape Management (FILLM)[3] to explicitly include not only water resources and aquatic ecosystems but also terrestrial ecosystems, greenhouse gas emission reduction and carbon sequestration, thereby making it a more powerful and relevant means of protecting and enhancing our environment. This is illustrated in Figure 1-4. While the FILLM approach is relevant to all waterbodies, it is particularly appropriate as a framework for HSO waterbodies as their catchment areas have optimal concentrations of natural capital. In addition, it has benefits for the Water of Life project in that it: i) provides a basis for a shared vision that is broader than water; ii) provides the opportunity and encouragement for policy coherence and integration in land, landscape and nature management; iii) makes environment management more understandable and, perhaps, appealing to local communities; and iv) encourages consideration of environmental co-benefits (see Section 7), thereby helping achieve optimum environmental outcomes.

1.3.3 Characterisation HSO Waterbody Catchment

Prior to decision-making and establishment of measures, a key requirement is to understand the relevant waterbody by means of a characterisation process. This process considers the existing condition of the HSO waterbody and requires data/information collection and evaluation of the various relevant elements of the source-pathway-receptor (SPR) model of environmental risk assessment (Figure 1-5), thereby helping ensure that decisions are evidence-based.

The land-based unit for water and aquatic ecosystem management is the waterbody catchment. Catchment characterisation is normally a two-stage process: i) a desk-based and ii) a field-based assessment.

The desk-based assessment consists of four components:

1. An evaluation of the receptor condition, e.g. the status and water quality. An important outcome is a decision on whether the HSO waterbody or is *At Risk* of not achieving its objective and is therefore in, or projected to be in, an unsatisfactory condition (with the waterbody catchment categorised as an *Area for Restoration)* or is *Not at Risk* of not achieving its objective and is therefore satisfactory (with the waterbody catchment categorised as an *Area for Protection*). Where the condition is unsatisfactory, the *significant issue(s)* (e.g. phosphate or reduced water level) that is/are causing failure to meet the HS objective is/are established – this is a major driver for determining appropriate mitigation measures. Where the condition is satisfactory, potential issues and pollutants of concern that could pose a threat to the HSO waterbody in the future are assessed and recorded.
2. Location of *significant pressures* (in *Areas for Restoration*) and *potential pressures* (in *Areas for Protection*) are then established. Once a pressure is designated as "significant", mitigation measures are needed to achieve the WFD high status objective.
3. Analysis and a decision on the relevant pathways as these determine how and where the pollutants might reach the HSO waterbody, and whether or not sufficient attenuation occurs along the pathway. In particular, critical source areas (CSAs) are located.

[3] An Fóram Uisce, 2021. A Framework for Integrated Land and Landscape Management. https://thewaterforum.ie/app/uploads/2021/03/TWF-FILLM-Report-Feb21-v9WEB.pdf

4. An interim risk assessment or ‘story’ which integrates all relevant components of the SPR framework assessed during the desk-based assessment and which provides the basis for focusing future work.

The desk-based assessment is followed by a field-based assessment, involving catchment walks, to enable the location of pressures and associated critical source areas (CSAs) with sufficient accuracy to facilitate establishment of targeted protection or mitigation measures. The outcome is the final risk assessment or ‘story’, which describes and advises on both the categories and locations of the required mitigation/protection measures/actions.

1.3.4 Evaluation and implementation of measures

The following factors need consideration when choosing and implementing measures to ensure that they are effective and efficient, and achieve optimum environmental outcomes:

- Following **the right measure in the right place** philosophy and approach.
- Taking account of the outcome of the characterisation process and, in particular, the relevant issues, pressures, pathways and CSAs in the catchment areas of the HSO waterbodies.
- Considering the measures as two types:
    - i) Mitigation measures in *Areas for Restoration*; and
    - ii) Protection measures in *Areas for Protection*.
- Categorising measures based on whether they are:
    - i) Mandatory.
    - ii) Incentivised.
    - iii) Voluntary.
- Taking account of co-benefits for other environmental components, such as terrestrial biodiversity, flood mitigation, carbon sequestration and greenhouse gas emission reduction.

1.3.5 Monitoring progress

Monitoring the impact of protection and mitigation measures is both a critical and challenging component of the Water of Life project in view of the multiple stressors on the ecosystems in HSO waterbodies, the multifaceted physical settings, the varying effectiveness of measures and the time delays for improvement in the *Areas for Restoration*.

1.4 Report Structure

The structure of this report follows the logical progression of the recommended process for catchment management shown in Figure 1-2. The flowchart illustrates this sequential process and how it is structured into chapters within this document.

Section 2 considers the receptor (i.e. HSO waterbody) condition as the starting point for consideration of measures. It highlights that some HSO waterbodies are achieving their objective and that the goal for these is protection, whereas for those not achieving their objective, the goal is restoration. It summarises the *significant issues*, such as phosphate, sediment and habitat morphological impacts that are causing HSO waterbodies to fail to achieve their objective in *Areas for Restoration*.

Section 3 outlines the landscape setting for HSO waterbodies, including topography, land cover, surface water drainage, aquifers and soil hydrology. The analysis is used to describes the role of pathways conceptual models in providing the background information for considering effective and efficient measures in the different land and landscape settings.

Section 4 addresses the relevant sectoral pressures – the significant pressures in *Areas for Restoration* and the potential pressures in *Areas for Protection*. It focuses on the threats posed by hydromorphology, agriculture, forestry and peat extraction, and summarises the role of critical source areas in enabling the 'right measure in the right place' to be achieved.

Section 5 describes the final outcome of the characterisation process – the risk-based assessment or 'story' of the HSO waterbody catchment – comprised of the desk-based and field-based assessments.

Section 6 outlines the principles underlying measures selection and the differing approaches taken *in Areas for Restoration* and *Areas for Protection*. The details on the measures for mitigating the impacts of agricultural activities, forestry, peat extraction, quarries and domestic wastewater treatment systems in *Areas for Restoration* are given in separate Annexes (see Section 6):

Annex 1: Agricultural Activities.
Annex 2: Forestry.
Annex 3: Peat Extraction.
Annex 4: Quarrying.
Annex 5: Domestic Wastewater Treatment Systems.

Section 7 highlights the relevance of the environmental co-benefits of many of the measures described in the Appendices.

Section 8 describes the role of monitoring, a critical component of the Water of Life project. In addition, the role of citizen science as a means of contributing environmental information and facilitating community awareness and involvement is underscored.

Additional information on catchment science and management is given in the following LAWPRO/EPA Guidance Handbooks

LAWPRO/EPA (2022a). An overview of catchment science and management. A Guidance Handbook. Volume 1. Local Authority Waters Programme and Catchment Science and Management Unit, Environmental Protection Agency.
https://lawaters.ie/app/uploads/2022/01/Print_CSM-Volume-1_April-2022.pdf

LAWPRO/EPA (2022b). Pressures and catchment walks. A Guidance Handbook. Volume 2. Local Authority Waters Programme and Catchment Science and Management Unit, Environmental Protection Agency. https://lawaters.ie/app/uploads/2022/09/Print_CSM-Volumes-23_April-2022.pdf

LAWPRO/EPA (2022c). Measured indicator parameters – catchment walks. A Guidance Handbook. Volume 4. Local Authority Waters Programme and Catchment Science and Management Unit, Environmental Protection Agency.
https://lawaters.ie/app/uploads/2022/09/Print_CSM-Volumes-23_April-2022.pdf

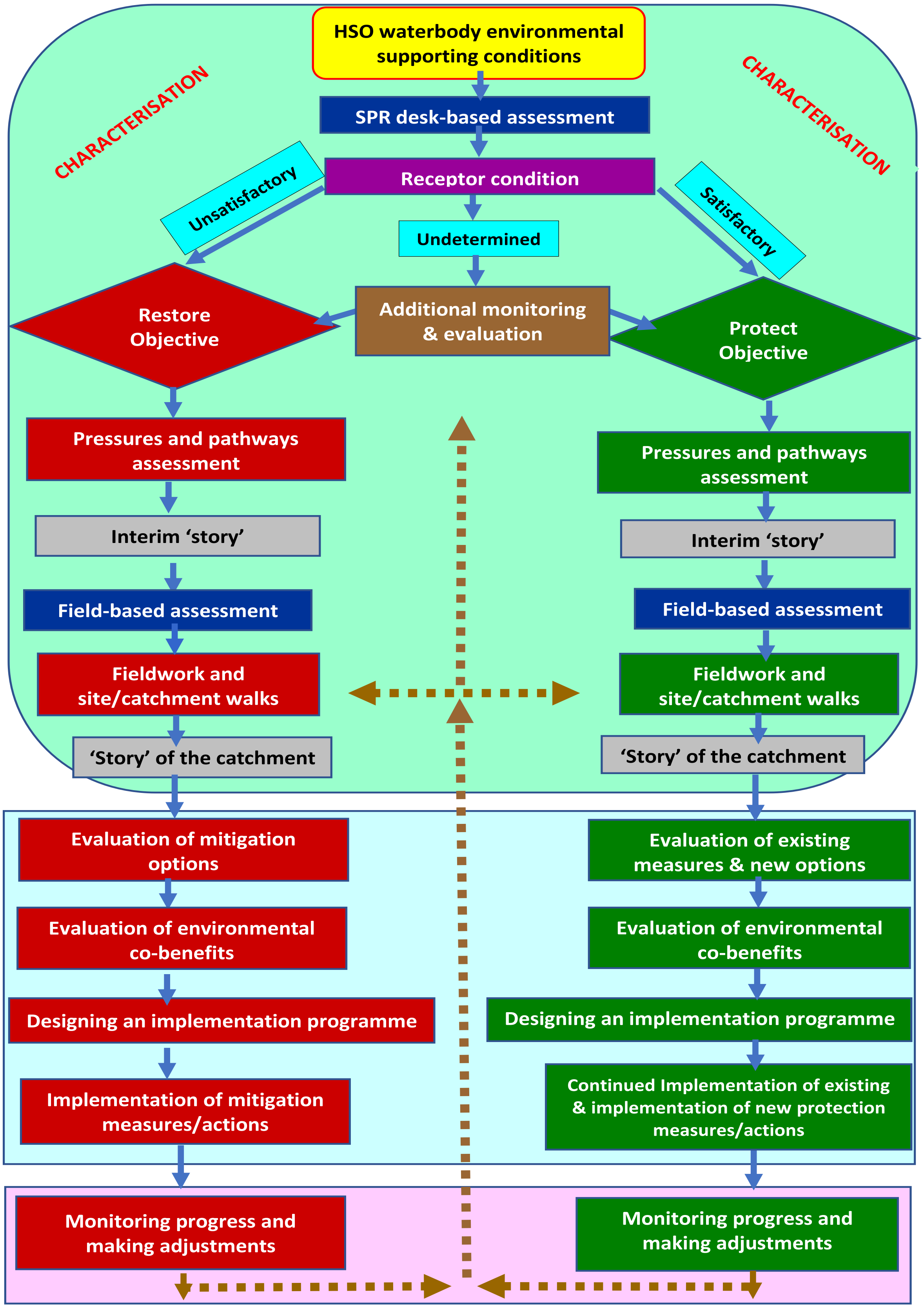


Figure 1-2: Flowchart illustrating the recommended process and approach for water resources and ecosystems protection and management.

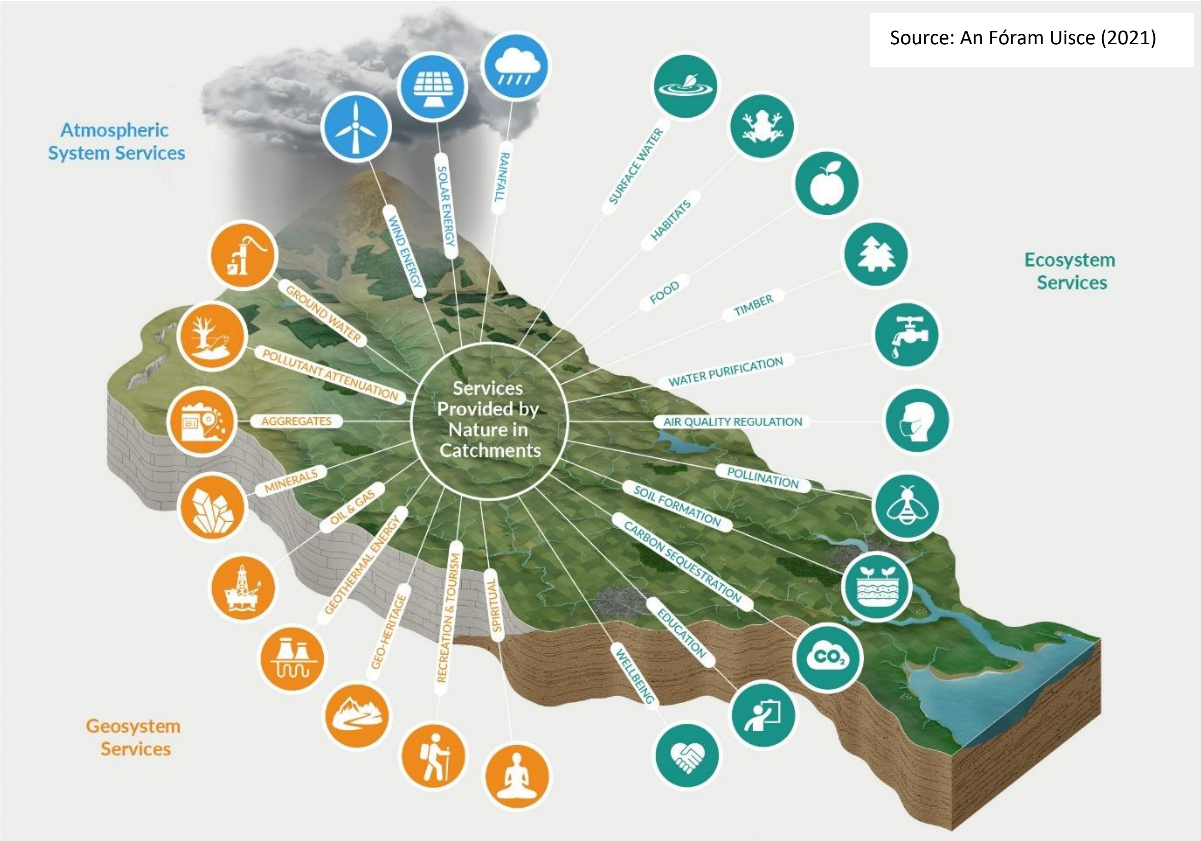
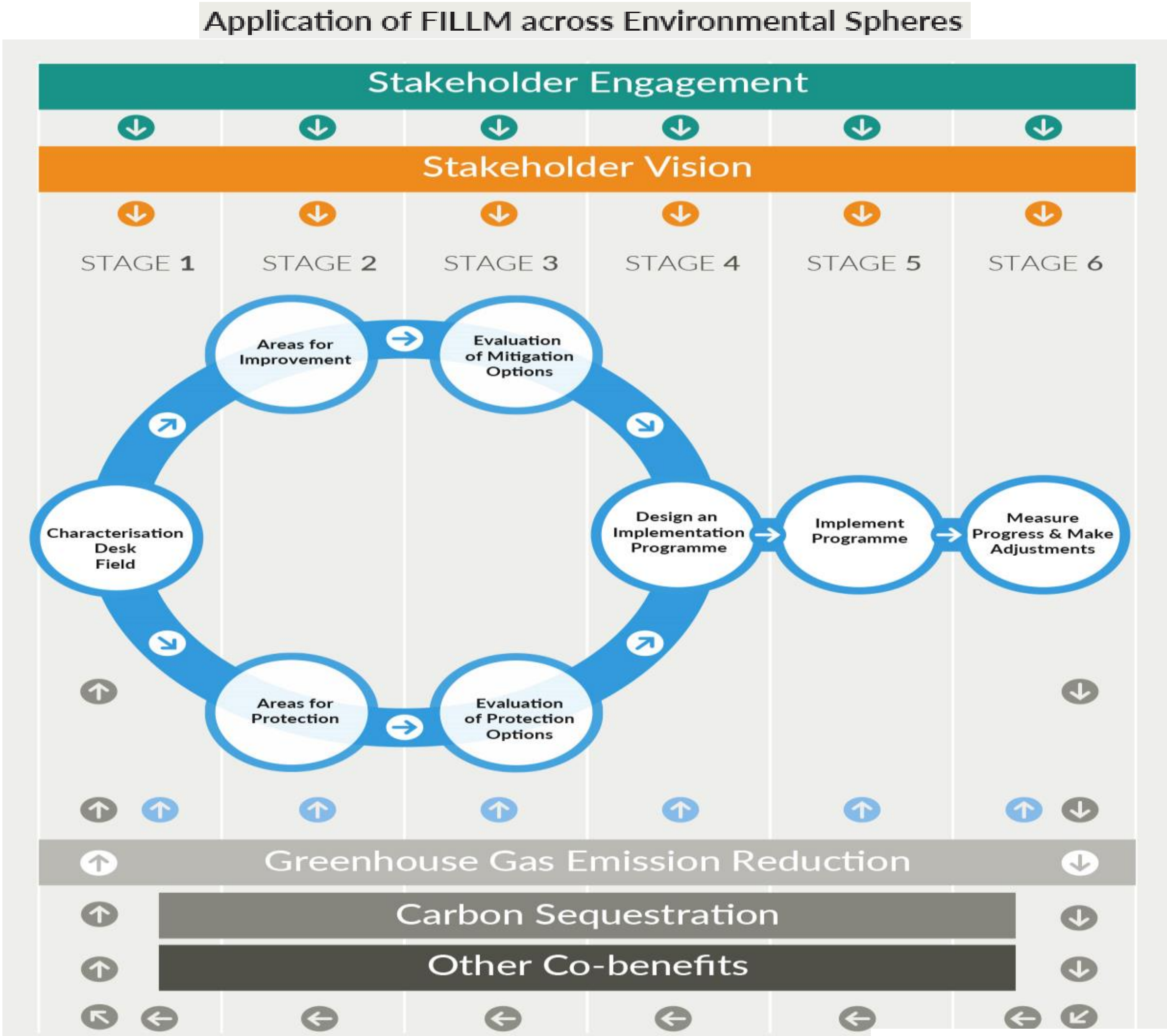


Figure 1-3: Schematic diagram of a catchment highlighting the three natural capital systems and the potential benefits provided by nature to people living in catchments.



Source: An Fóram Uisce (2021)

Figure 1-4: Components of the reconceptualised Integrated Catchment Management (ICM) approach as a Framework for Integrated Land and Landscape Management (FILLM) aimed at achieving WFD, Urban Waste Water Treatment Directive, Drinking Water Directive, Floods Directive and Habitats Directive objectives, and linking with carbon sequestration and GHG emission reduction.

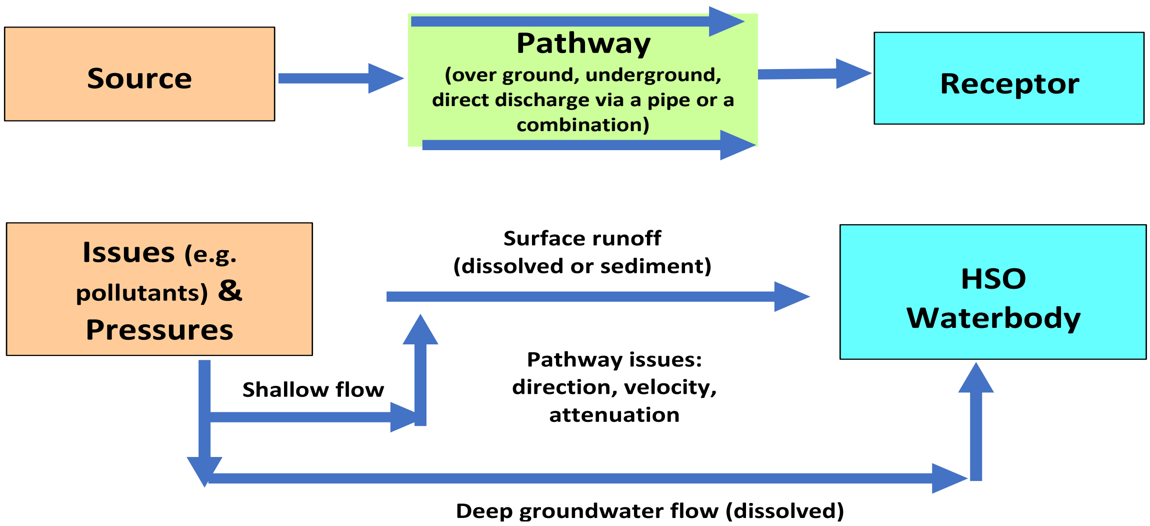


Figure 1-5: The source-pathway-receptor (SPR) model for environmental management.

2 The HSO Waterbody Condition

2.1 Introduction

The receptor (HSO waterbody) condition is the starting point for consideration of measures. There are two options, which are determined by the EPA:

1. Waterbody is *At Risk* of not achieving the WFD HS objective. The catchment area is therefore an *Area for Restoration* with a Restore goal.
2. Waterbody is *Not at Risk* and is achieving the WFD HS objective. The catchment of this HSO waterbody is therefore an *Area for Protection* with a Protect goal.

The condition of HSO waterbodies is determined by the impacts from pollutants such as phosphate, sediment, nitrate, ammonium, BOD, MCPA and FIOs, and issues such as hydrology and morphology.

2.2 HSO waterbodies in Areas for Restoration

The characterisation process[4] undertaken for the 2022-2027 River Basin Management Plan has assessed and established the *significant issues*, such as nutrients and hydromorphological issues, that are impacting on each HSO waterbody. The outcomes have been recorded in the WFD App on the EPA EDEN platform and are summarised on www.catchments.ie.

The issues arising from the *significant pressures* (details given in Section 4-2) that are causing failure of the HSO and the measures are summarised in Figure 2-1.

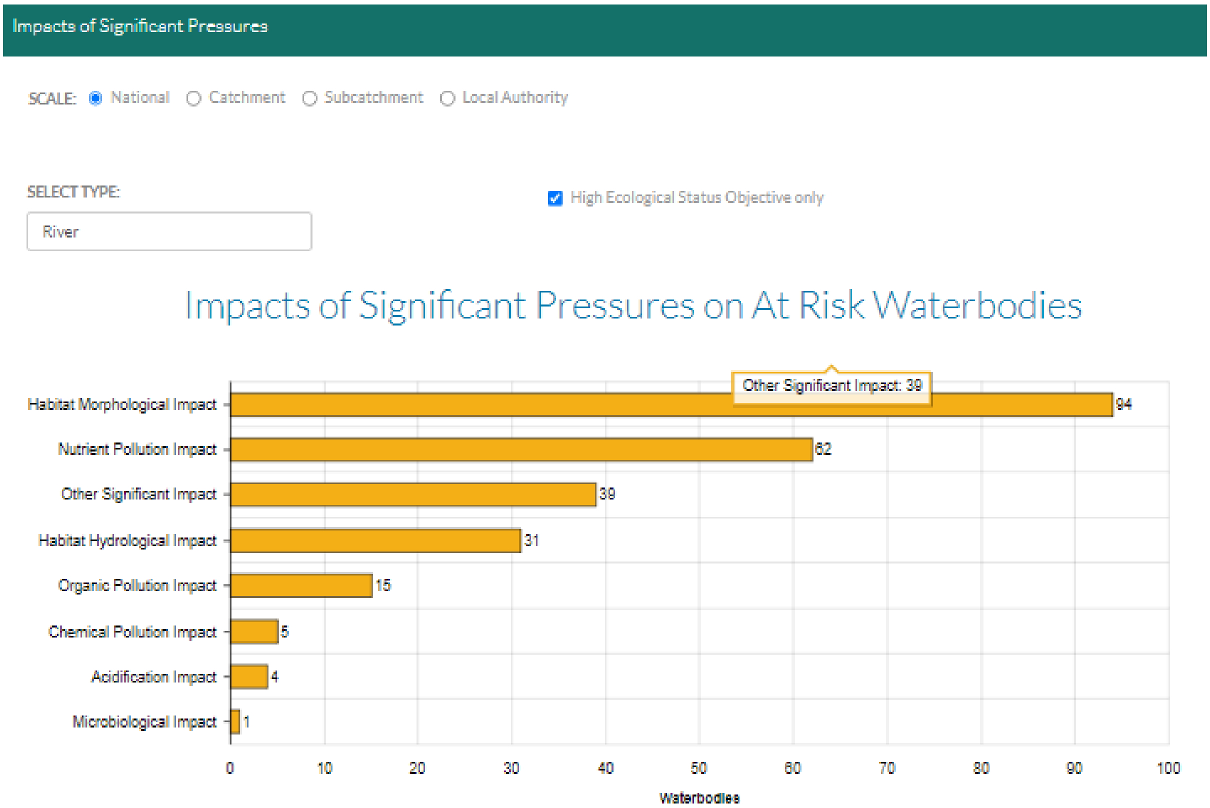


Figure 2-1: Significant issues causing deterioration in high status.

Source: https://www.catchments.ie/data/#/dashboard/pressure?_k=1w2yq0

[4] This was undertaken by the EPA Catchments Unit and LAWPRO in consultation with other public bodies such as local authorities and IFI.

In addition, a new 'Targeting Agricultural Measures' layer has been added to EPA Maps: https://gis.epa.ie/EPAMaps/Water under the 'Taking Action' tab. The information in the map layer is available in spreadsheets for stakeholders. An overview of the map is shown in Figure 2-2. This shows the categories of *significant issues* that have been identified for every waterbody that is failing to meet the WFD objective, whether High or Good status. These are:

i) phosphorus/sediment (in practice, mainly phosphate) – Navy Flag;
ii) farm point (mainly BOD and ammonium) and phosphorus/sediment – Red and Navy Flags;
iii) phosphorus/sediment and nitrate – Navy & Orange Flags;
iv) farm point source, nitrate and phosphorus/sediment – Red, Orange & Navy Flags;
v) nitrate – Orange Priority Flag; and
vi) risk of nitrate losses (review the PIP-N map) – Orange Flag.

In all the waterbody catchment areas, targeting of 'restore' farming measures by, for instance, using the Pollution Impact Potential (PIP) maps is recommended. In the White Flag area, the water quality is not considered to be impacted by farming and therefore 'protect' farming measures are appropriate.

The Orange Priority Flag and Orange Flag categories take account of transitional and coastal (TraC) waterbodies as a receptor. The Orange Flag (risk of high NO_3 losses (review PIP-N)) category is based on those areas where the downstream TraC waterbody is impacted by excess nitrate, but where there is no evidence that the nitrate is >2.6 mg/l in the HSO waterbodies, and that therefore the PIP-N maps need to be reviewed to identify appropriate measures.

This information has been compiled for HSO sub basins in Table 2-1, which gives the percentage areas for each *significant issue* category arising from agricultural activities, as well as the percentage area where 'protect' farming measures are required.

While 38% of the HSO sub basin areas require farming measures to mitigate the various *significant issues*, Figure 2-2 and Table 2-1 also indicate that a high proportion of these areas – 62% – is not impacted significantly by farming. In addition, it is likely that in a substantial portion of the Orange Priority Flag and Orange Flag areas, nitrate from agricultural activities is not impacting on HSO river waterbodies. Therefore, the predominant *significant issue* category impacting on HSO river waterbodies that needs mitigation is phosphorus/sediment. Even in the sub basins where phosphate, sediment, ammonium and BOD are the *significant issues*, impacts from them will not arise throughout the sub basin areas. This highlights the importance of catchment characterisation and using the Pollution Impact Potential (PIP) maps to enable targeting of measures.

Table 2-1: Statistics for the categories of agricultural measures including protect measures and targeted restore measures to mitigate the various *significant issues* impacting on HSO waterbodies.

	Targeting agricultural measures – category						
	Restore Farming Measures						Protect Farming Measures
	P/sed	Point & P/sed	P/sed & NO_3	Point, NO_3 & P/sed	NO_3	Risk of high NO_3 losses (review PIP-N)	
Number of SubBasins	27	5	22	2	5	69	204
Area (km^2)	488	103	459	47	128	1120	3850
%age area	8	2	7	1	8	13	62

Source: Source: Data from Catchment Science and Management Unit, EPA.

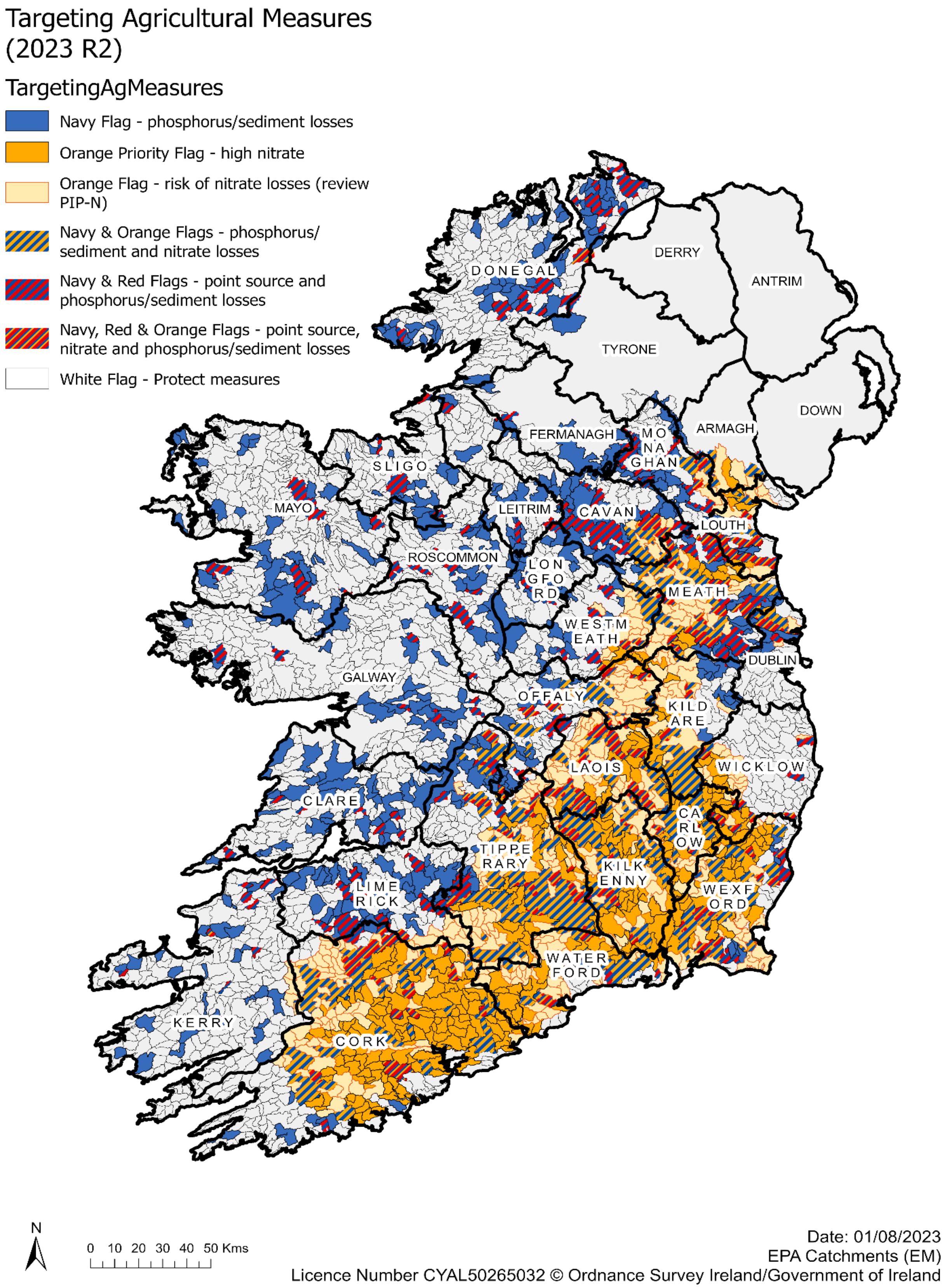


Figure 2-2: Overview of the “Targeting Agricultural Measures” Layer on Catchments.ie.

(Further details are given at this link: https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/water-quality-monitoring-report-on-nitrogen-and-phosphorous-concentrations-in-irish-waters-2022.php

2.3 HSO waterbodies in Areas for Protection

Article 4.1 of the WFD states that "*In making operational the programmes of measures specified in river basin management plans ……Member States shall implement measures to prevent deterioration of the status of all bodies of surface water…..*"; therefore, the protect goal is a critical one not only for WFD implementation but also for ensuring that the relative pristine aquatic ecosystems in HSO waterbodies are sustained.

Information on potential issues, such as potential pollutants, that might cause a HSO waterbody to fail in the future has not been assessed specifically by the characterisation process that has been undertaken, which tends to concentrate on *significant issues* causing waterbodies to fail to achieve their required objective. Therefore, additional assessment is needed. The recommended approach is as follows:

i) Check the waterbody requirement, i.e. High or Good Status.
ii) Note the metrics that need to be achieved for the potential pollutants; these are shown for phosphate, ammonium and BOD in Table 2.2.
iii) Evaluate existing water quality data for the monitoring point.
iv) Note any upward trends that might indicate possible failure of the status objective in the future. (The trend need not be statistically or environmentally significant, but may be an indication of increased losses to water.)
v) Note whether any parameter value is close to the metric, e.g. within 90%.
vi) Check for any observations from the EPA, LAWPRO, IFI and NPWS, particularly regarding habitat morphological and hydrological issues.
vii) Decide on whether there are any likely potential pollutants and other issues that might pose a threat in the future.
viii) Consider the likelihood of future land use changes, e.g. clearfelling of forestry, land drainage and intensification, new rural housing, as a step change can cause significant impacts.
ix) Assess the likelihood of reaching a tipping point to a deterioration in status from pressures to watercourses that increase the pollutant loads or change the flows or morphology.
x) Inform public bodies responsible for regulation and inspections, e.g. Local Authority Planning and Environment Sections, EPA, IFI, DAFM, of the results of this assessment, highlighting the potential issues, potential pressures and their location.
xi) Decide whether further monitoring is needed.

Table 2-2: Nutrient environmental quality standards (EQSs) for river waterbodies.

Nutrient conditions	**Environmental quality standards**
Molybdate Reactive Phosphorus (MRP) (mg P/l)	High status ≤0.025 (mean) or ≤0.045 (95%ile) Good status ≤0.035 (mean) or ≤0.075 (95%ile)
Total Ammonia (mg N/l)	High status ≤0.040 (mean) or ≤0.090 (95%ile) Good status ≤0.065 (mean) or ≤0.140 (95%ile)
Biological Oxygen Demand (BOD) (mg O_2/l)	High status ≤1.3 (mean) or ≤2.2 (95%ile) Good status ≤1.5 (mean) or ≤2.6 (95%ile)

Source: Surface Water Regulations (S.I. No 272 of 2009 & S.I. No 77 of 2019).

The outcome of this process is a decision on potential pollutant(s) or other potential issues, such as morphology or flows, that have some likelihood of posing a threat to the waterbody status in the future. This outcome is critical to deciding on potential pressures contributing the potential pollutant(s) and on the relevant pathways to the waterbody that are needed for determining appropriate measures.

2.4 Overview of Issues Posing a Threat to HSO Waterbodies

2.4.1 Context

An understanding of the properties of the pollutants and other issues that threaten HSO waterbodies helps determine the likely pressures, relevant pathways, pollutant attenuation, the potential impact and the possible mitigation and protection measures.[5]

2.4.2 Phosphate

High orthophosphate (PO_4) concentrations are the dominant pollutant in causing eutrophication of surface water. While particulate P is not readily bioavailable, it can be a long-term source of phosphate for aquatic biota.

One feature to note about phosphate is that it takes very little PO_4 load loss (for instance in farming areas, typically 1-5% of the applied phosphorus) to impact on aquatic ecosystems. This is particularly relevant for HSO waterbodies because the EQS – 0.025 mg/l PO_4 (mean) – is low and small losses can cause failure of the high status objective.

The main pressures contributing PO_4 are inorganic and organic fertilisers, faeces and urine from grazing animals, farmyards, wastewater treatment plants, domestic wastewater treatment systems (DWWTSs) and afforestation (after clear felling).

Important characteristics of phosphate are that it is both relatively immobile and is attenuated in freely draining mineral soils and permeable subsoils[6]. In contrast, in poorly draining mineral soil areas, it is prone to being 'washed off' into ditches and watercourses after heavy rainfall. Unlike mineral soils, peaty soils cannot store phosphorus and, therefore, losses can readily occur if over-applied.

2.4.3 Sediment

Sediment is the loose sand, silt or clay that settles at the bottom of a watercourse or lake, shown up by a plume when kicking the stream gravel. Sediment transport and deposition are natural processes within a river system, but alteration of these processes can often be an indicator of disturbance and damage to riverine habitats. The effect of excessive siltation is recognised as a major impact on river water quality and ecological status. High levels of fine deposited sediment can deplete oxygen levels within gravel beds, affect habitats and early life stages of a range of aquatic species. Organic-rich suspended sediments can also indirectly reduce dissolved oxygen (DO) levels in the water column and, once deposited, reduce the supply of oxygen in the spawning gravels.

There is no EQS for sediment. However, in the Freshwater Pearl Mussel Regulations, there is an Ecological Quality Objective that requires 'no artificially elevated levels of siltation'.[7]

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[5] LAWPRO/EPA (2022c) is the source of some of the information in this Section and it provides additional information on water quality indicators.

[6] An exception is the freely draining soils and permeable subsoils, which are derived from Old Red Sandstone bedrock, located close to the coast in County Cork where the geochemistry, particularly the high iron content, facilitates leaching of phosphate to groundwater and subsequent ingress as baseflow to watercourses.

[7] https://www.irishstatutebook.ie/eli/2009/si/296/made/en/print

The main potential sources of sediment are:

- Channelisation (and channel maintenance) or other morphological modifications to the watercourse.
- Land drainage activities.
- Land cultivation with associated runoff close to the watercourse.
- Runoff from farmland, particularly tillage, close to the watercourse.
- Cattle access, poaching and accelerated erosion of river banks.
- Farm roadways.
- Forestry planting and clear-felling.
- Peat extraction.
- Quarrying close to watercourses.
- Infrastructural developments and construction of individual houses and farmyards.
- Changes to river flows.

2.4.4 Nitrate

Dissolved inorganic nitrogen (DIN), mainly comprised of nitrate (NO_3), tends to drive eutrophication impacts in coastal waters. The environmental quality standard (EQS) for coastal waters is 2.6 mg/l as N at the freshwater-saline interface. High nitrate in drinking water can cause methemoglobinemia or the blue baby syndrome where excess nitrates interferes with a baby's blood's ability to carry oxygen – the maximum admissible concentration is 11.3mg/l as N (or 50mg/l as NO3) and the groundwater threshold value (TV) is 37.5mg/l (8.5 as N) (mean). There are no standards for nitrate for freshwater ecosystems – in general phosphate tends to drive eutrophication impacts rather than nitrate.

Diffuse agriculture (organic and inorganic fertilisers, and grazing animals) is the main pressure contributing nitrate in water, with point sources having the potential to create small, localised nitrate plumes in groundwater.

Nitrate is an 'unreactive' pollutant and is not readily adsorbed on mineral or organic matter in soils and subsoils. The main pathway is vertically through freely draining soils and permeable subsoils to groundwater and then horizontally or laterally to watercourses or drinking water sources. In poorly draining areas and in certain aquifer/bedrock types, geochemical processes (denitrification) attenuates nitrate, reduces the loading to water and mitigates impacts naturally.

2.4.5 Ammonium

Ammonia is toxic to fish and other aquatic organisms at low concentrations – the Good/Moderate EQS is 0.065 mg/l (mean) and the High/Good EQS is 0.04 mg/l (mean). In the presence of oxygen, it converts to nitrate (but doesn't usually add significantly to nitrate concentrations). Therefore, it tends to indicate localised pollution.

The main pressures contributing ammonium (NH_4) are organic wastes arising from urban wastewater treatment and domestic wastewater treatment systems (urban and industrial), animal slurry, farmyard soiled water and landfill leachate. In addition, ammonium is a breakdown product of organic matter in peatlands and peaty soils when drained.

Ammonium is relatively immobile in soil and subsoil and does not generally leach underground unless it gets directly into bedrock. However, it readily converts to nitrate (nitrification) and so is not as persistent in water as nitrate or phosphate. Therefore, the main pathways to watercourses in addition to direct piped discharges are i) overland and near surface flows resulting in run-off into watercourses or ii) underground where bedrock is close to surface, although in this circumstance, the ammonium converts to nitrate in the oxygenated groundwater environment.

2.4.6 BOD

Biochemical oxygen demand (BOD), which represents how much oxygen is needed to break down organic matter, is a key indicator of organic pollution in water. It negatively affects aquatic ecosystems, causing loss of oxygen, changes in species composition and potentially deterioration of ecological status.

The main pressures contributing ammonium are organic wastes arising from urban wastewater treatment and domestic wastewater treatment systems (urban and industrial), animal slurry/manure, farmyard soiled water and landfill leachate. Silage effluent and milk, in particular, have very high BOD concentrations.

2.4.7 Microbial pathogens

A microbiological impact has occurred to one HSO waterbody (Figure 2-1). The main potential sources in the catchment areas of HSO waterbodies are farmyards, grazing animals, landspreading of slurry/manure, cattle access to watercourses, farm roadways and DWWTSs, birds and 'wild' animals/mammals.

Faecal indicator organisms (FIOs) die-off and are attenuated in soils and subsoils. However, they can get into surface water in poorly draining areas where there is rapid (or flashy) runoff from the land. In addition, they can enter groundwater in freely draining areas where there is outcropping or shallow bedrock.

2.4.8 MCPA

MCPA is the pesticide that is most frequently noted to breach the limit for pesticides in drinking water sources. Because of its selective action on broad-leaved plants, it is widely sprayed for the control of soft rush (Juncus effusus) in wet pastures. It is more hydrophilic than other widely used herbicides, such as Glyphosate, and thus tends to reach receptors as a solute. Recent investigations into the mobility of MCPA reveal that it undergoes decomposition under aerobic conditions, whereas the anaerobic conditions encountered in many saturated mineral soils and organic subsoils (and peat) result in its persistence in the environment.

2.4.9 Hydrology

Physical hydrological processes influence the condition of intact and disturbed ecosystems as follows:

1. The hydrological regime determines the magnitude, duration and variability of water levels and flow rates.
2. Hydrological regimes influence the morphology of rivers and streams, including both banks and in-channel (riverbed) features.
3. The hydrological regime dictates the manner by which solutes and particulate material reach rivers from the surrounding catchment; this can affect a stream's overall water quality, morphological condition and ecological status.
4. The variability of flow regime, along with solute and particulate delivery, will determine the stresses experienced by the organisms in an ecosystem.

Hydrological regimes are naturally variable. For example, stream flow will typically increase shortly after a period of intense rainfall to higher discharge levels than those during a prolonged dry period. Moreover, responses to rainfall vary within and between catchments, being influenced by a range of characteristics, including geology, climate, topography and land use.

The combination of these characteristics in most Irish catchments with a HSO results in widespread natural water logging. Artificial drainage aims to reduce waterlogging by lowering water tables. It assists in removing surface and near surface water to rivers and streams more rapidly than naturally, maintaining lowered groundwater levels over longer periods of time in the process. This can be readily observed in stream hydrographs (plots of flow with time). Figure 2-2 presents synthetic hydrographs that compare the response of a stream to the same amount of (effective) rainfall under drained and undrained conditions.

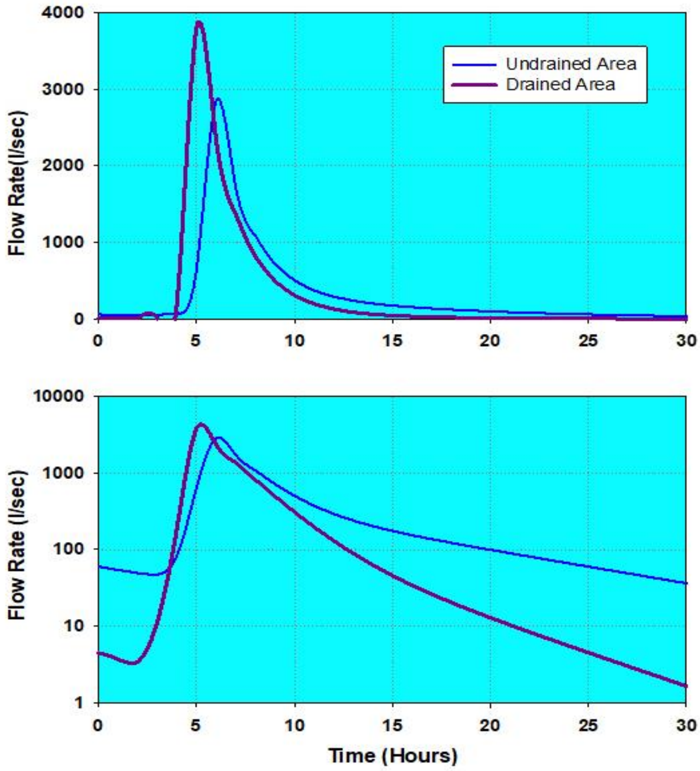


Figure 2-3: Comparative hypothetical hydrographs (plots of stream flow with time) from artificially drained and undrained catchments for an equivalent volume of effective rainfall.

(Note: Upper graph – the arithmetic plot shows greater peak flow from the artificially drained catchment (purple). Lower graph – the log-linear plot reveals greater flow stability in the undrained area (in Blue) during dry weather.)

The upper graph shows that, despite receiving the same volume of rainfall, water leaves the artificially drained catchment more quickly, resulting in higher flood peaks (and greater associated risk of flooding). Conversely the lower graph, presenting the same responses on a logarithmic scale, reveals that the flow regime in the undisturbed (undrained) catchment is more stable as more of the water enters a river by slower pathways. Artificial drainage can interact with receiving waterbodies in a number of direct and indirect ways:

1. **Water levels:** Receptor water levels prove more variable in catchments impacted by artificial drainage, with higher flows resulting in elevated flood water levels, while levels during drier periods prove lower than their undrained equivalent. For the former issue, this can result in elevated downstream flood risk, while in the latter, larger portions of formerly submerged river and stream beds can be exposed to the air, while in extreme cases stream segments may dry up. Water levels are a particularly important environmental supporting condition for bog ecosystems. For instance, raised bogs require the water table to be 0-20 cm during the year, while blanket bogs require the water table to be within 10 cm in Winter and 20 cm in Summer. (Flynn, et al. 2019[8]).

[8] https://www.epa.ie/publications/research/water/Research_Report_378.pdf

2. **Shear stress:** Higher flows are accompanied by higher flow velocities at flood peak. This results in greater shear stresses instream water that make aquatic environments more stressful for many organisms, particularly species that attach to substrate materials.
3. **Sedimentation regime:** Greater variation in flow velocities impacts on instream sediment dynamics. Reduced stream flow/velocity can allow for the deposition of finer grained material. Critically this can include lower density materials, including peat silt, whose presence can have particularly negative consequences for the life cycles of some sensitive aquatic species. Conversely increased flood flows/velocity can alter the in-channel transportation and erosion regime again leading to additional sedimentation downstream.
4. **Land cover change – physical impacts:** Much of the land cover change observed in HSO waterbody catchments involves artificial drainage. These activities may impact on the hydrological regime, including the amount of water available, and the timing of delivery. Critically, some changes in land cover, such as the development of plantation forestry can result in greater evapotranspiration, and thus reduced effective rainfall, resulting in lower contributions to stream flow. Similarly, drainage impacts on the hydrological properties of peats can lead to steeper slopes, particularly in the vicinity of drains, and reduced infiltration capacity. This in turn promotes more rapid loss of water.
5. **Land cover change – water quality impacts:** Changes in land cover can impact stream water quality even in the absence of introduced external substances. Reduced water levels can result in the introduction of oxygen into naturally anaerobic water-logged ground. This in turn can lead to:
    a) Increased loss of organic carbon accumulating plant communities, often resulting in die-back and exposure of bare ground that can be more rapidly eroded, thereby contributing sediment and particulate organic carbon (POC).
    b) The accelerated decomposition of organic matter, leading to the release of greater amounts of dissolved organic carbon (DOC) and organic nitrogen; the latter may subsequently degrade to ammoniacal nitrogen.
    c) The more rapid delivery of reactive substances to receptors results in reduced time for attenuation reactions (which might otherwise reduce concentrations) to take place.
6. **Stream water quality regime:** Higher variability in flow from areas affected by artificial drainage results in greater variation in stream water quality. Streams draining blanket bogs receive discharge from naturally acidic poorly mineralised water, which passes through peat directly to streams. Over much of the year, this process dominates stream flow. However, water can become more mineralised during drier spells, reflecting the greater relative contribution of water flowing out of inorganic subsoils to surface water. Critically, the contribution made by more mineralised water proves consistent between intact areas and those affected by artificial drainage. On the other hand, contributions of less mineralised bog water prove significantly more variable in areas affected by artificial drainage.

Overall, artificial drainage results in greater variation in abiotic conditions in receiving waterbodies, which in turn can impact aquatic biota and potentially result in a decline in WFD status. In addition, artificial drainage can result in degradation of other ecosystem services. These include the loss of water dependent terrestrial biodiversity, increased greenhouse gas emissions from peat, and degraded water quality in downstream drinking water supplies.

2.5 Summary

The information provided by this stage of the process on significant issues in Areas for Restoration and potential issues in Areas for Protection is critical in ensuring that 'right measures' and the 'right places' are chosen so that they can be located to achieve the required environmental outcomes in an effective and efficient manner. The next stage is to understand the pathways that link the issues with the pressures that are contributing the issues.

3 The Landscape Setting of HSO Waterbody Catchments

3.1 Introduction

Characterising the landscape and associated physical settings is key to understanding and locating the relevant pathways for water and potential pollutants as these determine:

- For point pressures, the input locations to HSO waterbodies.
- For diffuse pressures i) the critical source areas and ii) whether or not sufficient attenuation occurs before the pollutants reach a HSO waterbody.

The following land and landscape components are described below:

- Topography.
- Land cover.
- Surface water flows.
- Aquifer type.
- Soils hydrology.
- Effective rainfall and recharge.
- Groundwater vulnerability.
- Pathway susceptibility.

An outcome from these components is a pathways conceptual model that summarises and enables the physical setting for water and pollutants to be visualised and described.

3.2 Topography

Ireland displays a wide range of topographic conditions, ranging from mountainous areas having significant differences in elevation (relief) and slope, to flatter, low lying areas. These conditions play a key role in determining dominant hydrological processes. A national digital terrain model (10m resolution) has permitted investigation of the range of topographic conditions in HSO river sub basins. Figure 3-1 summarises this variation by current waterbody status.

Figure 3-1a shows considerable variation in median elevation across sites, with values clustering at between 150 metres above mean sea level (AMSL) and 200 m AMSL for all waterbodies irrespective of status. This suggests that the elevation of those HSO sites that are currently at High Status displays no significant difference from those where status is less than High.

Characterising the role of relief (here determined as the difference between the highest and lowest elevation in a waterbody) proves more challenging. Figure 3-1b reveals significant differences across all river sub-catchments, with HSO waterbody catchments having Good and High status displaying greater variability. However, this assessment is complicated by sub-catchment size, since large areas can be anticipated to display greater differences in elevation.

Standardising relief (relief divided by catchment area) reveals (Figure 3-1c) that much of the difference observed between those river sub-catchments classed as less than Good and those with Good or High Status, can be attributed to differences in catchment area, and that no significant differences in overall relief per unit area exists between sites based on waterbody status.

This was confirmed through statistical analysis (non-parametric Anova, using the Kruskall Wallis Method) of relief. Findings suggested that significant differences in status may exist, depending on relief. However, re-analysis by the same approach following standardisation revealed no significant difference ($p<0.025$). Despite these findings, it should still be noted that significant local variations in relief may occur within individual catchments and contribute disproportionately to flow and fluxes of substances. This, coupled with geological variations and human modifications to the landscape, e.g.

through artificial drainage, can give rise to critical source areas, which display potential to contribute disproportionately to contaminant loads.

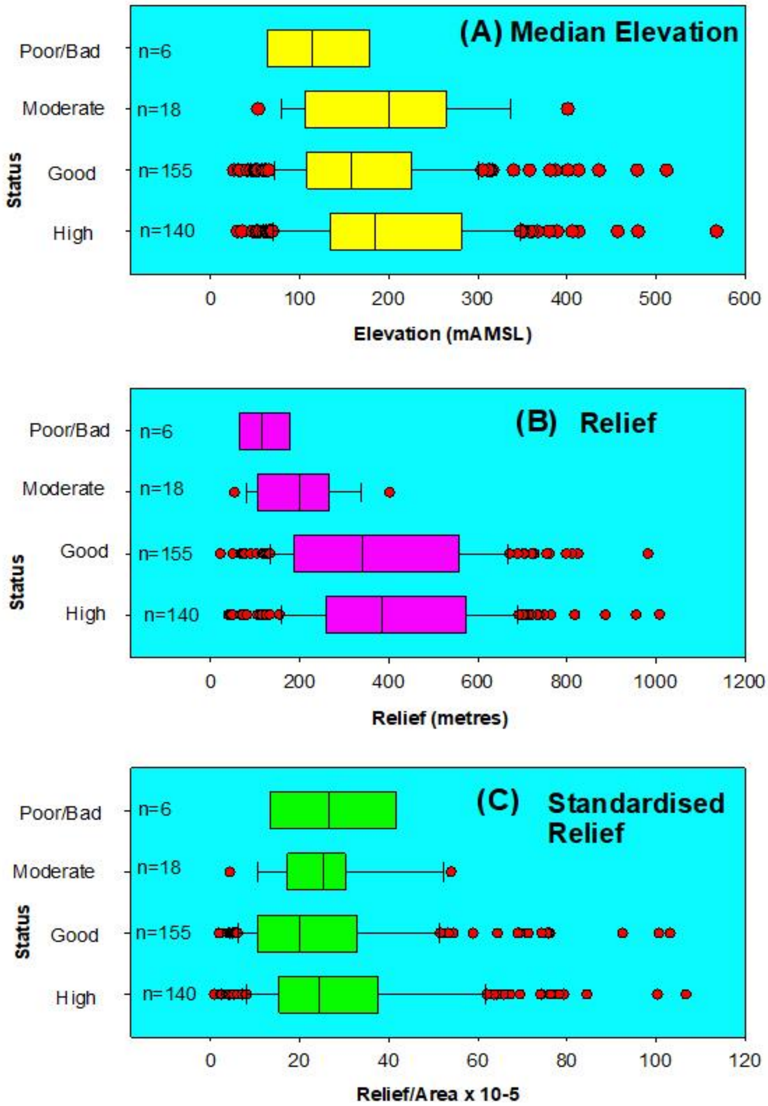


Figure 3-1: Box and whisker plots summarising the variability in topographic conditions in HSO waterbody catchments based on their currently assigned status.

3.3 Land Cover

Ireland has a dynamic landscape, which has been strongly influenced by human activity for thousands of years. Consequently, any consideration of a baseline (undisturbed) condition for the landscape in those catchments identified as High Status needs to factor in human influence. The WFD uses the term 'reference conditions', which are defined in terms of the conditions for an ecological system which prevail in the absence or near absence of human disturbance.

Analysis of soil maps and Corine Land Cover data suggests that HSO catchments are dominated by blanket bog/moorland and low intensity agricultural land/scrub. This is corroborated by Table 3-1, which reveals peat bogs to form the dominant land cover in HSO river sub basins, irrespective of status. It is likely that some of the area categorised under other land cover activities may be peatland converted to other land cover types, including agriculture and forestry.

Table 3-1: Summary of principal land cover activities in HSO waterbody catchments.

			Land Cover (km²)							
			Peat bogs	Pastures	Coniferous forestry	Land principally occupied by agriculture, with significant areas of natural vegetation	Transitional woodland-shrub	Moors and heathland	Others	Totals
Status	**High**	**Area**	858	638	272	244	157	82	200	2451
		%	35	26	11	10	6	3	9	100
	Less than High	**Area**	1094	1110	293	326	120	148	407	3498
		%	31	32	8	9	3	4	12	100

3.4 Surface Water Flows

Examination of topographical data indicates that the majority of HSO waterbody catchments, outside the southwest of Ireland, occur as headwater catchments, becoming second to third order streams (using the Strahler classification) at their downstream limit. Although very limited stream flow (runoff) data exist for the majority of sites, available information suggests that regimes are typically flashy (having highly variable flow), with stream discharge responding rapidly to rainfall. On the other hand, discharge also declines rapidly at the end of rainfall events, leading to low flow rates during prolonged dry periods. Assessing the 'flashiness' of a river can be undertaken using the median flow (Q50) and low flow (that encountered for 5% of the time or less, Q95), by calculating the Q5/Q95 ratio. This analysis indicated that the majority of streams had values greater than 5, which is a reflection of flashy runoff conditions within HSO catchments.

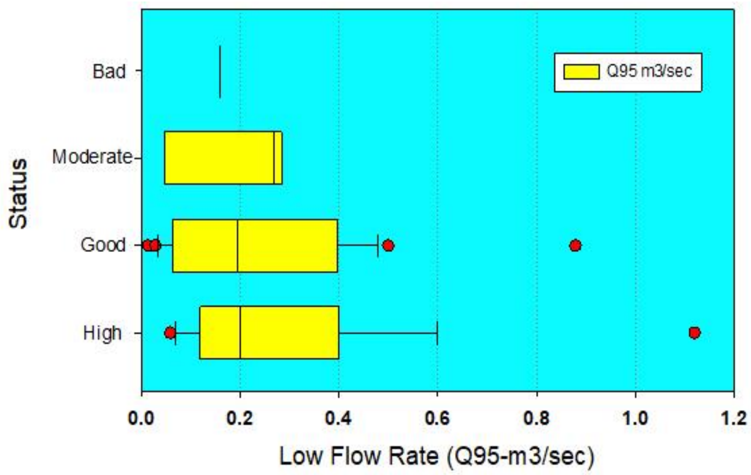
Figure 3-2 graphically summarises low flow runoff rates (Q95 values) for gauged HSO river sub basins. Low flow conditions play a key role in supporting aquatic ecosystems, particularly in responding to (natural and human) disturbances, during prolonged dry periods, when ecosystems are often most stressed. This includes stream capacity to stabilise natural water quality, transport sediment and dilute contaminants. Under these low flow conditions, groundwater contributions to stream flow, discharging from groundwater-bearing deposits, can play a fundamental role in maintaining flow and water quality.

The limited available data indicate no significant differences in low flow rates or runoff rates according to waterbody status.

3.5 Aquifer Type

The GSI database reveals that no significant sand and gravel aquifers occur in any of the HSO waterbody catchments investigated. According to the aquifer classification systems, this implies that all aquifers considered are based on bedrock type. For the purposes of the current study, the six bedrock aquifer categories defined and mapped by the GSI (DOE/EPA/GSI, 1999)[9] have been grouped into Regionally Important Aquifers, Locally Important Aquifers and Poor Aquifers. Figure 3-3 graphically summarises aquifer types underlying HSO river catchments. It provides an indication of the relative proportions of all HSO river sub basins underlain by the dominant aquifer categories by area. These data underscore the dominance of locally productive and poorly productive aquifers as bedrock types, while revealing the reduced importance of regionally important aquifers (dominated by karstified limestone).

[9] https://www.gsi.ie/documents/Groundwater_Protection_Schemes_report.pdf



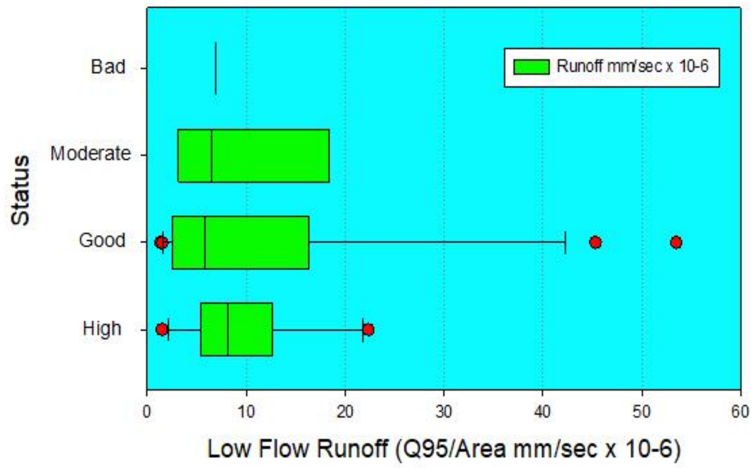


Figure 3-2: Low flow (Q95) flow and runoff rates for HSO waterbody catchments according to status.

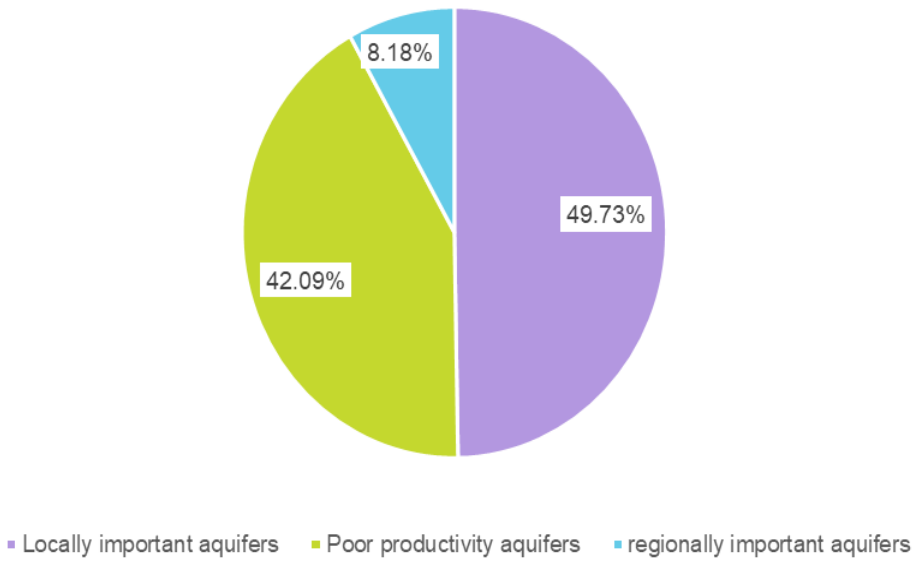


Figure 3-3: Pie chart summarising dominant aquifer types underlying HSO waterbody catchments.

Knowledge of the underlying aquifer types can assist in understanding the water flow regime in a HSO waterbody catchment (LAWPRO/EPA, 2022a). The main characteristics are summarised below.

Regionally Important Karstified Aquifers

- 'Karstification' is the process whereby limestone is slowly dissolved away by percolating waters. Solution and fissuring are widespread to a significant depth, resulting in focussed flow in conduits and caves, and more diffuse flows in the joints and along the bedding planes.
- A more permeable zone due to solution, called epikarst, which can be several metres thick, is often present at the top of the bedrock.
- Distinctive karst landforms can be present, such as such as swallow holes, sinking streams, collapse features, dry valleys and caves.
- Substantial quantities of water can flow through these aquifers and flowpaths can be several kms long and 10s metres deep.
- The degree of karstification ranges from slight to intense. The GSI recognises two types of karst aquifer: those dominated by diffuse flow (**Rkd**) and those dominated by conduit flow (**Rkc**). Large springs are common particularly in the latter.
- There is strong interconnection between surface water and groundwater.
- The overlying subsoils are generally silty and so have a moderate permeability, with freely draining soils present.
- Drainage density is low.
- Groundwater provides more than 70% of average stream flows in these areas. However, in **Rkc** aquifer areas, baseflow can reduce substantially in summer, due to the low storage potential.

Regionally Important Sandstone and Volcanic Aquifers

- In these aquifers, groundwater flows through a network of well-connected and widely dispersed fractures, fissures and joints, resulting in a relatively even distribution of highly permeable zones.
- There is good aquifer storage and groundwater flow paths can be up to several kilometres in length and 10s metres deep.
- There is likely to be substantial groundwater discharge to surface waters ('baseflow') and large springs may be associated with these aquifers.
- Where these are sandstone aquifers, the overlying subsoils are generally sandy or silty and so have a moderate permeability, with freely draining soils present.

Locally Important Aquifers

- These have a limited and relatively poorly connected network of fractures, fissures and joints, giving a low fissure permeability which tends to decrease further with depth.
- The main flowpaths are in the upper fractured zone (often several metres thick), fault zones and, where present, the transition zone (between the overlying subsoil and the bedrock).
- Permeability decreases with depth.
- Small streams and drainage ditches are frequent.
- Groundwater discharge to streams ('baseflow') can significantly decrease in the drier summer months; this can lead to the presence of intermittent streams.

Poor aquifers

- The main flowpaths are in a thin upper fractured zone (which is not always present).
- Generally, the landscape is poorly draining and blanket peat is common.
- Underground flowpaths are short – a few 10s metres at most.
- Deep groundwater flow is limited and groundwater is likely to contribute <20% of average flows in rivers.
- Runoff in rivers is flashy, there is a high drainage density with many of the small watercourses and drainage ditches intermittent.

3.6 Soils Hydrology

The key driver for water and pollutant movement in the landscape is the permeability of the soil, subsoil and bedrock. Therefore, soils and subsoils overlying bedrock play a fundamental role in determining the relative importance of near surface and deeper hydrological processes. Published soil maps for Ireland aim to encompass a wide range of soil types, determined by both texture and geochemistry. Although soil and subsoil composition can prove important for influencing the natural water quality of receiving waterbodies, texture (grain size distribution) proves the overriding factor in determining hydrological response and, more precisely, how permeable the soil is. As with bedrock, variations in geological, hydrological and topographic conditions mean that drainage characteristics rarely prove uniform across catchments. Consequently, a single catchment often hosts a range of drainage categories.

Table 3-2 summarises the occurrence/area of each soil drainage category for the HSO waterbody catchments:

- Poorly draining mineral soils (a combination of Imperfect, Poor and Very Poor in Table 3-2) are the dominant category – 42.5% of the area.
- 30% of the catchment areas are comprised of poorly draining peat and peaty soils. Both result from a combination of low permeability subsoil, low transmissivity bedrock (poor aquifers) and high rainfall. Approximately 40% of the area is cut-over peat.
- Approximately 23.9% of the area is freely draining.
- Areas of alluvium (river deposits) occur in all catchment categories. However, these deposits cover a relatively small proportion of the total area (2.6%), occurring in the immediate vicinity of rivers. Although sometimes highly permeable, alluvial deposits can host elevated water tables and may be associated with poor drainage. Moreover, investigations have suggested alluvium erosion and deposition to be highly dynamic in high relief catchments, where their composition may play a critical role influencing waterbody hydromorphology and the rate of sediment turnover.

The impact of these conditions on hydrological processes are important characteristics that influence the effectiveness of measures aimed at tackling waterbody degradation.

Table 3-2: Soil drainage categories for HSO waterbody catchments

Soil drainage category	Poorly draining mineral			Poorly draining peat	Freely draining	Alluvium
	Imperfect	Poor	Very poor			
Area (km^2)	16	2282	327	1856	1483	164
% Area	0.3	36.9	5.3	30	23.9	2.6

Source: National soils hydrology map https://gis.epa.ie/EPAMaps/Water and data from EPA.

3.7 Effective Rainfall and Recharge

Ireland's cool humid climate experiences roughly even year-round rainfall. By contrast, evapotranspiration proves seasonal, with significantly higher levels occurring during the hydrological summer (April-September). Moreover, both rainfall and evapotranspiration vary across Ireland. Effective rainfall (ER) (rainfall minus evapotranspiration) varies seasonally and is reflected in part by the greater sensitivity of rainfall/runoff responses in winter periods when evapotranspiration has significantly less influence. Figure 3-4 summarises effective rainfall conditions in HSO waterbody catchments. The values shown for these catchments are generally higher than national averages, yet follow a left skewed distribution.

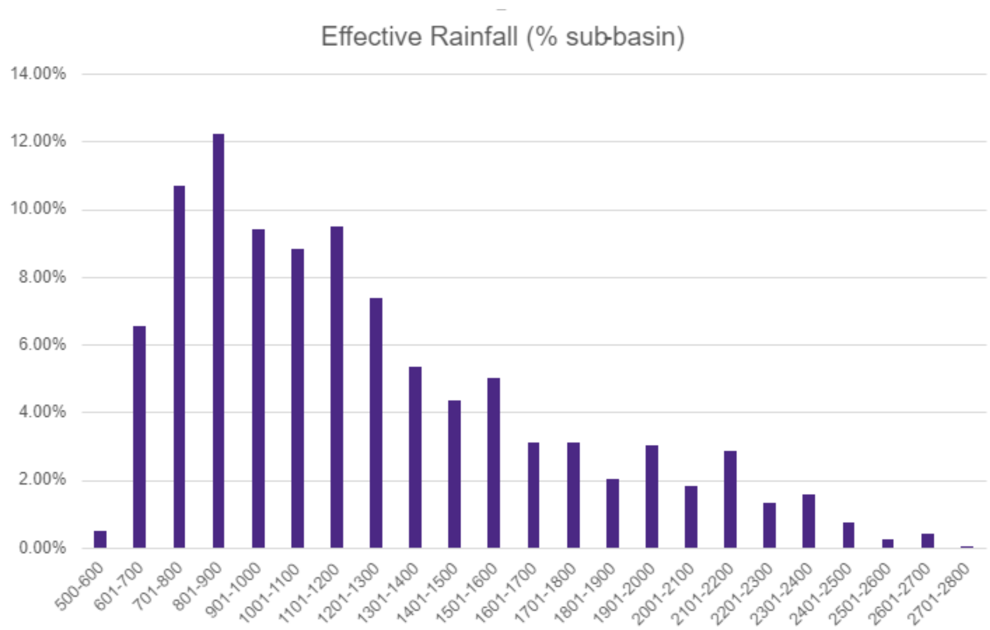


Figure 3-4: Histogram of the variation in effective annual rainfall (mm/yr) across HSO waterbody catchments.

Evaluation of these data in more detail reveals that effective rainfall proves higher on more elevated ground and further west. Those areas where HSO waterbody catchments are encountered correspond strongly to where average annual rainfall exceeds 1000mm/yr. Critically most of these areas experience more than 225 rain days per year, which occur approximately evenly during the year. Under natural conditions these circumstances can give rise to persistently high water tables, and can lead to the development of peat, and water logging in many other soil types.

Effective rainfall rates contrast with recharge rates for HSO river catchments (Figure 3-5), reported by the Geological Survey of Ireland, which suggests that little effective rainfall becomes a groundwater resource available for abstraction and for contributing to baseflow in summer in the bedrock aquifers underlying HSO waterbody catchments. As a corollary to this point, most effective rainfall is discharged through shallower, typically more rapid flowing (and usually intermittent) pathways in the upper fractured zone of bedrock and as overland and shallow subsurface flows. This is consistent with the rapid response or flashy regimes observed in stream flow data.

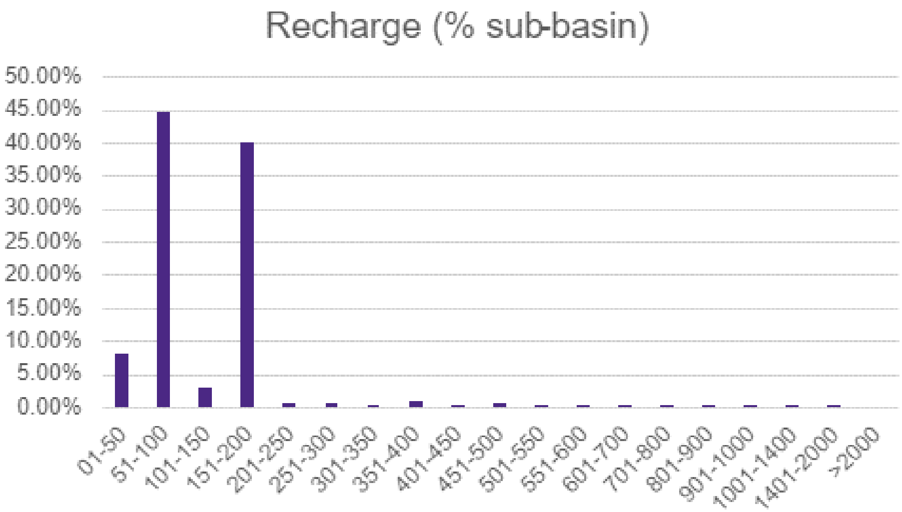


Figure 3-5: Histogram of recharge rates across Irish HSO waterbody catchments in mm/yr.

Figure 3-6 provides a comparison of rainfall and recharge rates, classified according to status and reveals that neither parameter displays a statistically significant difference between status groups. The ostensibly higher effective rainfall rate in the Poor/Bad category arises as a consequence of the small sample size and corresponds to the range encountered in the other categories.

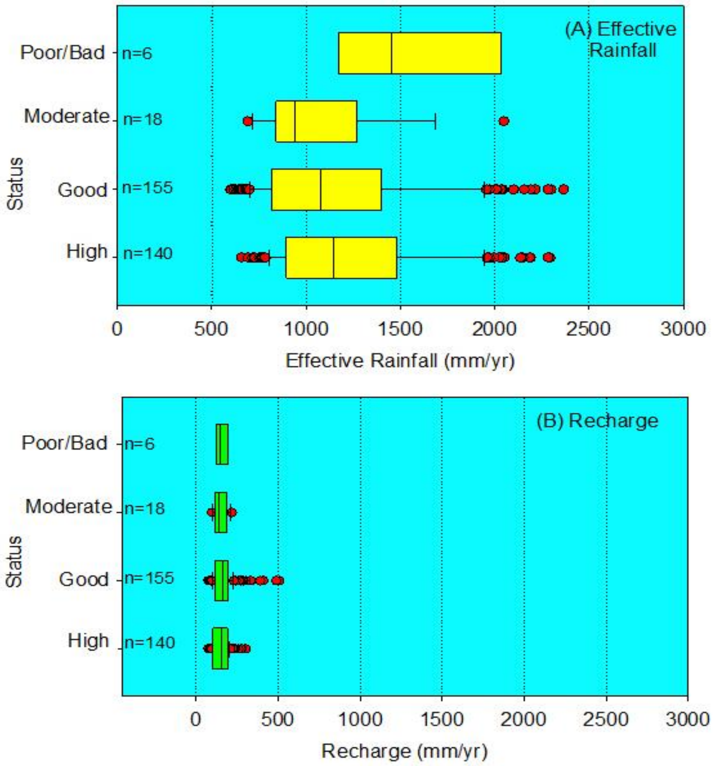


Figure 3-6: Box and whisker plots of annual effective rainfall and recharge rates against HSO waterbody status.

3.8 Groundwater vulnerability

Groundwater vulnerability is a concept used to represent the natural ground characteristics that determine the ease with which groundwater may be contaminated by human activities. Vulnerability depends on the permeability and thickness of subsoil, the presence of point recharge via karst features in limestone areas and the thickness of the unsaturated zone in the case of sand/gravel aquifers. The vulnerability category assigned to a site or an area is thus based on the relative ease with which infiltrating water and potential mobile pollutants, such as nitrate, may reach groundwater in a vertical or sub-vertical direction. Vulnerability mapping has been undertaken country-wide by the Groundwater Programme of the Geological Survey of Ireland (GSI)[10]. There are five groundwater vulnerability categories: i) Extreme (X) where bedrock is at or near surface (<1 m)); ii) Extreme, where the subsoil/bedrock boundary is the 3 m contour; iii) High (H); iv) Moderate (M) and v) Low (L), where there is >10 m low permeability (clayey) subsoil.

While the vulnerability categories themselves may not be needed in most circumstances in deciding on and establishing measures, the information on depth to bedrock[11] provided by vulnerability maps may be relevant, for instance, to certain measures and to estimating the time lag for nitrate to reach the groundwater in aquifers.

[10] Maps can be accessed at these links: i) https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx#Vulnerability and ii) https://gis.epa.ie/EPAMaps/Water.
[11] For further information, see DOE/EPA/GSI (1999) and LAWPRO/EPA (2022a).

3.9 Pathway susceptibility

Pathway 'susceptibility' is a measure of the degree of attenuation between a pressure source and receptor. It depends on a combination of the pollutant and hydrogeological (or water flow regime) properties on land and in the landscape. Susceptibility maps are available for two potential pollutants – phosphate and nitrate. They are generated by linking soils, subsoils, groundwater vulnerability and aquifer types with phosphate or nitrate attenuation and transport factors, giving areas ranging in susceptibility from Very High to Very Low (5 categories)[12i].

3.10 HSO Waterbody Pathways Conceptual Models

3.10.1 Introduction

A pathways conceptual model is a 3-D representation and visualisation of a complex system, in this case, catchment areas for HSO waterbodies. It is used as a systematic mechanism for integrating data/information on the physical setting in which measures are established. It starts as a mental model or visualisation, and is produced as brief text summarising the physical setting for water and pollutants. Schematic diagrams are a useful means of enabling the 3-D visualisation, whether as hand drawn sketches or more formalised diagrams. Developing these models aims to provide a basis for generating hypotheses concerning the conditions operating in individual catchments. The model can thus act as a precursor and a basis for assessing the correspondence to site-specific conditions encountered in individual catchments.

3.10.2 Conceptualising poorly draining scenarios

Albeit fairly limited, runoff data suggest that stream/river flow regimes in most catchments are naturally 'rapid response' to rainfall in HSO waterbody catchments. This is consistent with the presence of poorly productive aquifers, which underlie approximately 90% of all HSO waterbody catchments by area, while the dominance of poorly draining soil and subsoil cover favours shallower hydrological processes in rainfall/runoff responses. It is this flow regime which influences the mobilisation, transport and delivery of dissolved and particulate substances to rivers and streams. Areas of high relief and flashy rainfall runoff responses can lead to naturally dynamic landscapes in which fast flowing water can lead to fast flowing streams which are dominated by coarser grained sediments, ranging from sands up to boulders.

The dominance of poorly productive aquifers and low recharge rates means that groundwater makes a minor contribution to total runoff. However, rivers and streams can maintain significant year-round flow in these areas, largely due to high and frequent effective rainfall. Nonetheless, it needs stressing that the relative contribution of groundwater to runoff varies during the year; it becomes more important, and in many cases dominant, during the summer.

3.10.2.1 Poorly draining mineral soil scenario

The characteristics of the poorly draining mineral soils setting can be summarised as follows:

- The dominant flowpath is horizontal via overland and near surface flows.
- Catchments are 'rapid response' (to rainfall) (also termed 'flashy') with peaky hydrographs.
- Drainage density is high and installation of artificial drainage is common, thereby increasing the speed of runoff.
- Small streams are often intermittent as groundwater baseflow in summer is limited.
- Slope is an important factor in determining where the water and associate pollutants go.
- Vegetation indicators of poor drainage, such as rushes, are common.

[12] Susceptibility maps for phosphate along the near surface pathway and for nitrate entering either groundwater or surface water are available at this link: https://gis.epa.ie/EPAMaps/Water

- Where pressures are present, runoff of pollutants such as phosphate, sediment, ammonium, pesticides (e.g. MCPA) and microbial pathogens can occur readily.
- Nitrate does not generally pose a threat as this setting is suitable for denitrification.
- Groundwater is often well protected and recharge to groundwater is relatively low.

3.10.2.2 Poorly draining peat and peaty soil scenario

In the case of catchments containing significant peatland cover, a significant proportion of dry weather flow (base flow) also derives from groundwater flowing directly from peat to watercourses, coupled with a subordinate proportion that flows through peat and into the underlying inorganic/mineral subsoil, before discharging. Consequently, bogs can release water to streams to maintain flow over prolonged periods, thus helping to stabilise aquatic ecosystems.

Where peat and organic-rich soil cover proves significant, stream waters may also contain significant levels of dissolved organic carbon (DOC), reflecting the incomplete decomposition of plant material. This derives from groundwater which is naturally high in DOC, yet otherwise remains acidic and mineral poor, due to the absence of significant concentrations of reactive mineral material in peat. Nonetheless DOC levels prove lower than in disturbed settings, principally due to the natural scarcity of oxygen in undrained peat. Water following pathways that bring it into contact with inorganic materials (including that flowing from the base of peat) can dissolve more reactive substances, to give a more mineralised signature. Overall, sustained high groundwater levels, and significant relief encountered over many HSO waterbody catchments ensure that this water can discharge to rivers and streams at a near constant rate throughout the year in peatland areas.

Combining physical and chemical data helps to develop a coherent model of the abiotic parameters supporting aquatic ecosystems. The variable flow of groundwater from peat, mixed with more mineralised groundwater, accounts for the majority variations in stream water quality observed; additional contributions may be made by overland flow in response to intense rainfall. Natural cycles of lower flow and reduced sensitivity to rainfall occur during the hydrological summer, when streams generally contain more mineralised water. By contrast, the reduced importance of evapotranspiration during hydrological winter gives rise to more sensitive rainfall/runoff responses in which flow is dominated by less mineralised water. Despite these differences, rainfall/runoff responses remain flashy throughout the year; this affects morphology. Flashy flow leads to a dominance of coarse (alluvial) sediments in watercourses hosting a range of habitat types over short distances. By contrast, sustained rates of streamflow during drier periods help to remove finer-grained and less dense deposits, along with precipitates which may form when anaerobic mineralised groundwater comes into contact with oxygen in surface water.

Drainage of peat means a disturbance of the natural conditions. It removes the excess water, stops peat accumulation, causes peat subsidence and changes physical properties, such as permeability, of the peat. The causes of peat subsidence are as follows:

i) Shrinkage due to drying.
ii) Consolidation by loss of buoyant force.
iii) Contraction by capillary force.
iv) Biochemical oxidation.

Shrinkage: Peat holds a relatively large volume of water, which, although it depends on the degree of humification of the peat, is greater than 80% by volume. Drying or dewatering of peat causes a loss of some of the water thereby reducing the volume of the peat and causing a lowering of the peat surface. If drainage lowers the groundwater table a relatively shallow distance the shrinkage may be reversible, but if the lowering is appreciable and prolonged then the shrinkage will be irreversible.

Consolidation by loss of buoyant force: Peat is formed in and under water. As the specific weight of organic material is only slightly above 1.0, its weight under water is very low. The pressure of overlying layers on the underlying ones is only slight due to the buoyant force of the water. When the water table is lowered this buoyant force is lost and the effective pressure increases to a greater degree than for normal mineral soils. This causes compression of peat layers below the water table. The degree of compression depends on the thickness of these layers, their compressibility and the depth to which the water table is lowered. Thus, thicker peat areas will compress more than thin areas. This can change the surface topography of an area, and therefore the drainage pattern.

Contraction by capillary force: Peat has a high pore volume, most of which is filled with water. After drainage, the peat dries out and the resulting capillary forces causes compression of the soil skeleton and a decrease in the pore volume. Vertical contraction leads to subsidence and horizontal contraction to crack formation. The importance of this factor will depend on the depth to which the water table is lowered.

Biochemical oxidation: When the water table is lowered by drainage, oxidation of organic matter by aerobic soil micro-organisms converts this solid fraction into water, carbon dioxide and ammonium, each of which are lost from the soil, thereby causing peat wastage. The rate of wastage due to oxidation depends on the depth of the watertable, land use (grassland or arable), climate, fertilizer application and type of peat. Depth and intensity of drainage are the two most important factors because they allow air to enter the peat. Tilling increases aeration of the soil, so that in peatland under grass and forestry oxidation is reduced. Oxidation is greater in warmer climates. High pH values accelerates the oxidation process so liming of the soil has this effect. Fen peat is oxidised more readily than acid bog peat. The addition of nitrogen fertilizer aids oxidation.

In the poorly draining peat setting, the characteristics are as follows:

- The dominant flowpath is horizontal via overland and near surface flows.
- Areas are 'rapid response' (to rainfall) with peaky hydrographs.
- Small streams are often intermittent as groundwater baseflow in summer is limited, although flows may be maintained in unimpacted peatlands.
- Vegetation indicators such as rushes are common on peaty soils.
- Drainage results in losses of ammonium, DOC and POC to watercourses, as well as losses of CO_2 to the atmosphere.
- The depth to the water table is a key factor in determining impacts to water quality.
- Peatland drainage causes subsidence of the peat by shrinkage, compaction and decomposition. Continued drainage, if feasible, allowing entry of oxygen will result in complete wastage of the peat.
- In bare peat areas, sediment poses a threat to aquatic ecosystems.

3.10.2.3 Schematic diagrams

Figure 3-7 summarises the physical conditions that significantly influence hydrological processes in HS catchments. While the model focuses on the dominant conditions encountered, each catchment must be considered individually. It needs to be recognised that due to the highly heterogeneous (variable) nature of the Irish landscape, cases will arise where deviations from this model will prove significant, notably in terms of drainage conditions.

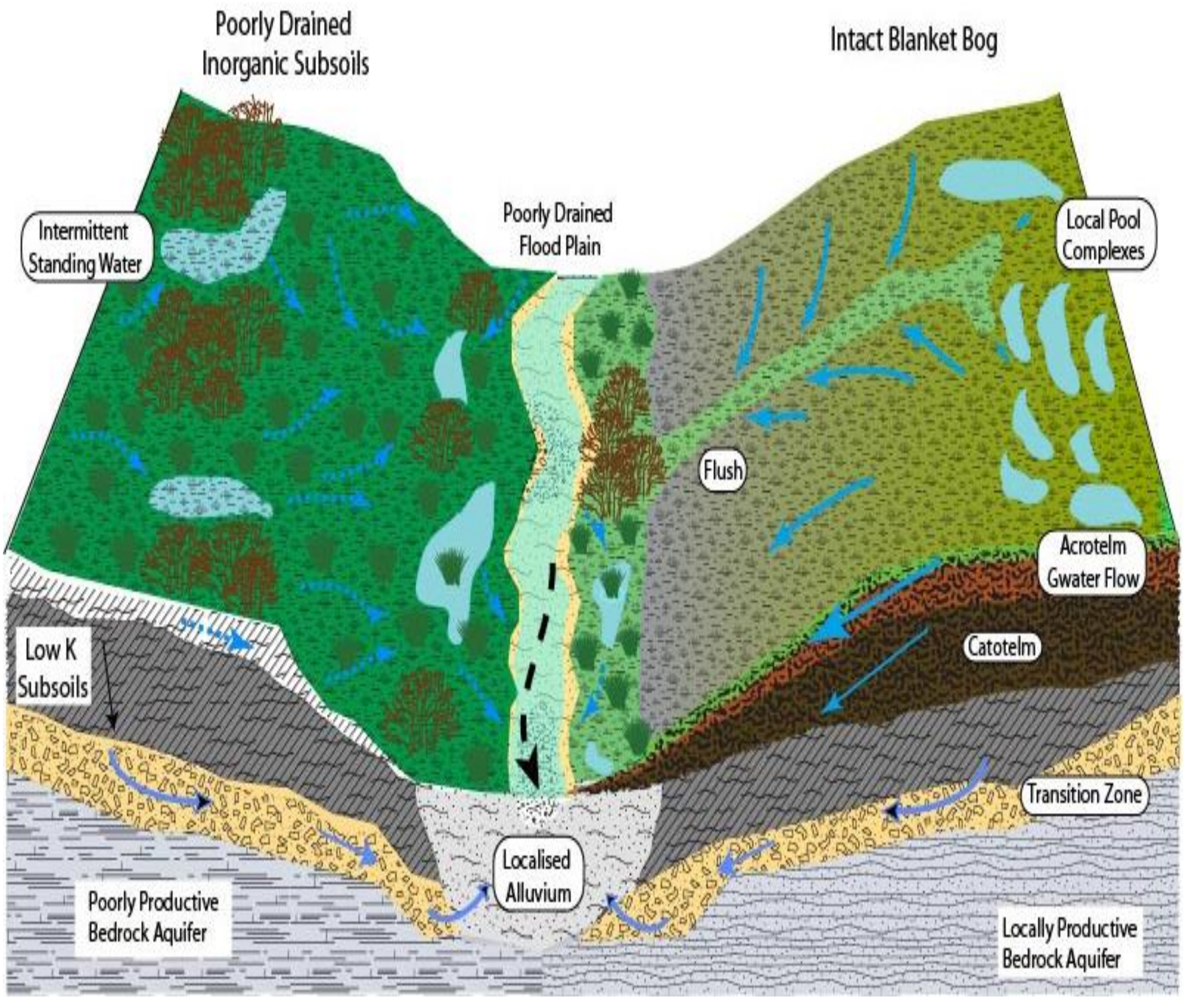


Figure 3-7: Schematic model of intact high status waterbody catchment.

An illustration of an intact blanket bog is given in Figure 3-8 (Flynn *et al*. 2021)[13]. In A, rainfall during periods of high water table and limited available storage passes rapidly to streams as runoff. In B, low water tables isolate intervals of more permeable peat, requiring storage deficits to be met before interconnection and discharge as runoff.

Many pathway interception measures will be located in the riparian zones of HSO waterbodies, and are of particular relevance in poorly draining scenarios. The Smarter_BufferZ project[14] team and the EPA Catchments Unit have developed pathway conceptual models of the physical settings in the vicinity of watercourses, as shown in Figures 3-9, 3-10, 3-11, 3-11 and 3-12. An understanding of the various scenarios that can occur will help ensure that any measures decided on and established will be effective.

[13] https://www.epa.ie/publications/research/water/Research_Report_378.pdf
[14] www.smarterbufferz.ie

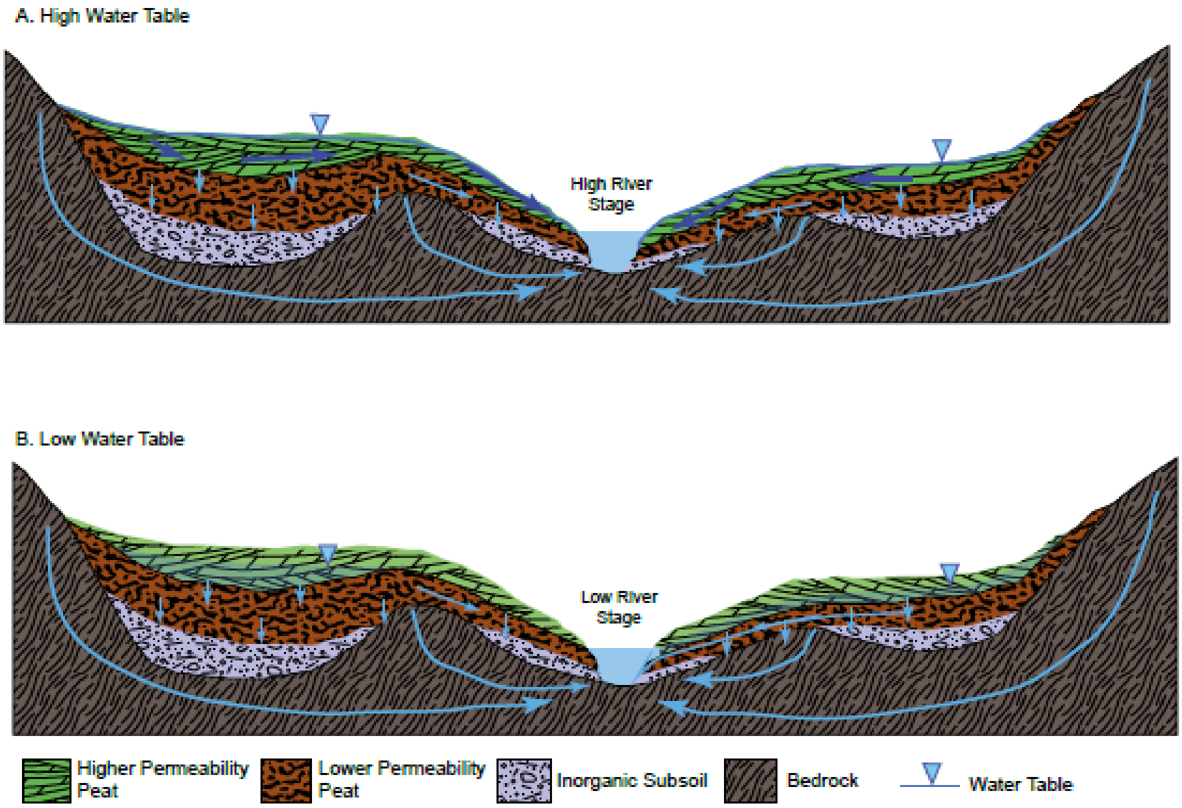


Figure 3-8: Schematic conceptual model of contributions of peat and substrate groundwater to stream flow in blanket peat-covered catchments.

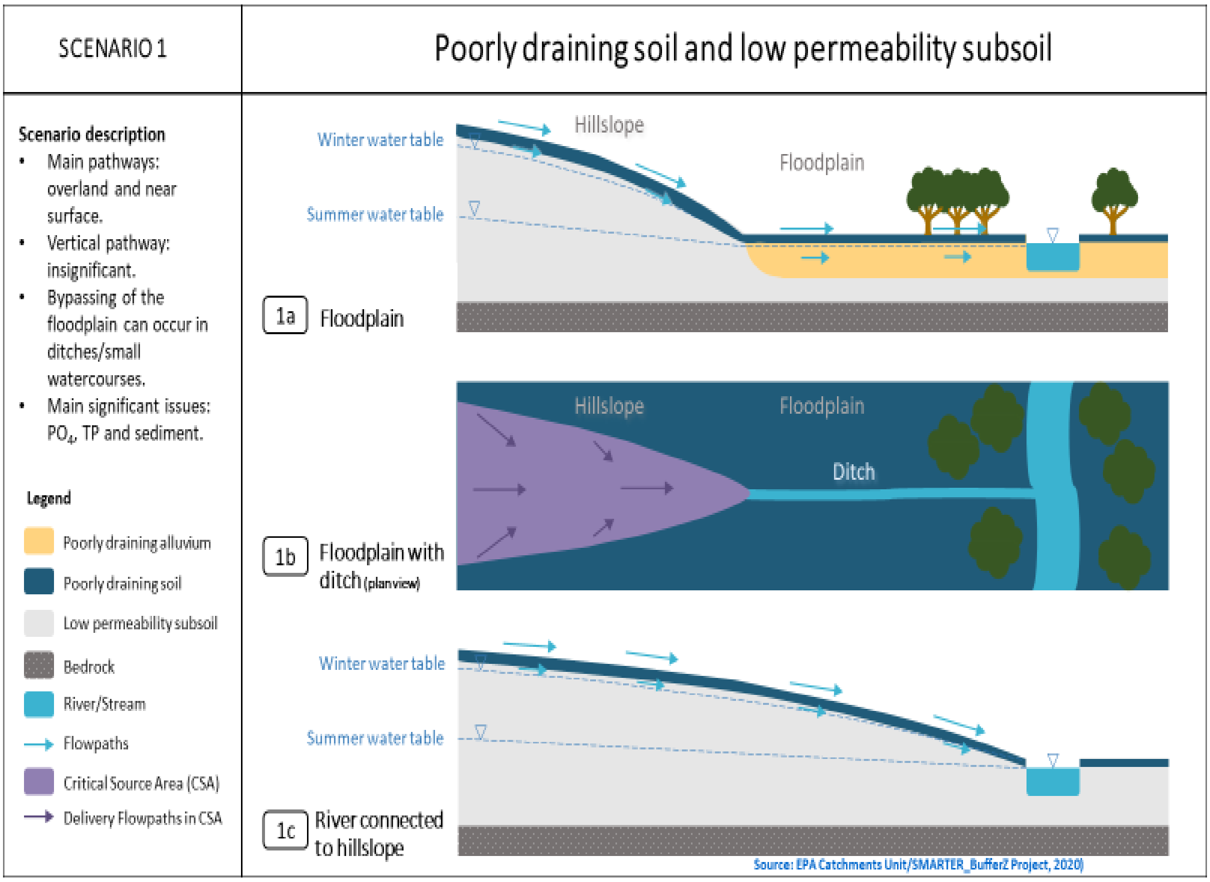


Figure 3-9: Pathway conceptual model for poorly draining scenario in vicinity of a watercourse.

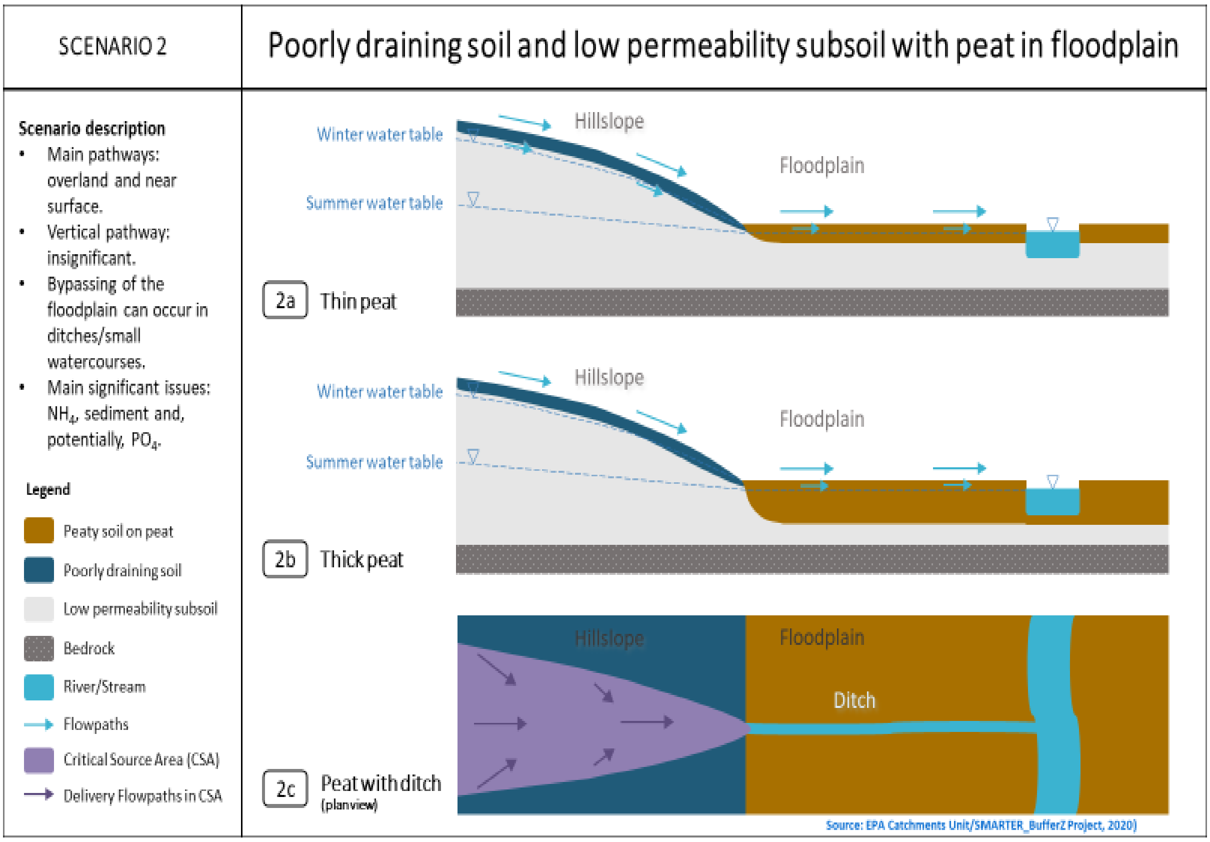


Figure 3-10: Pathway conceptual model for poorly draining scenario including peatland in vicinity of a watercourse.

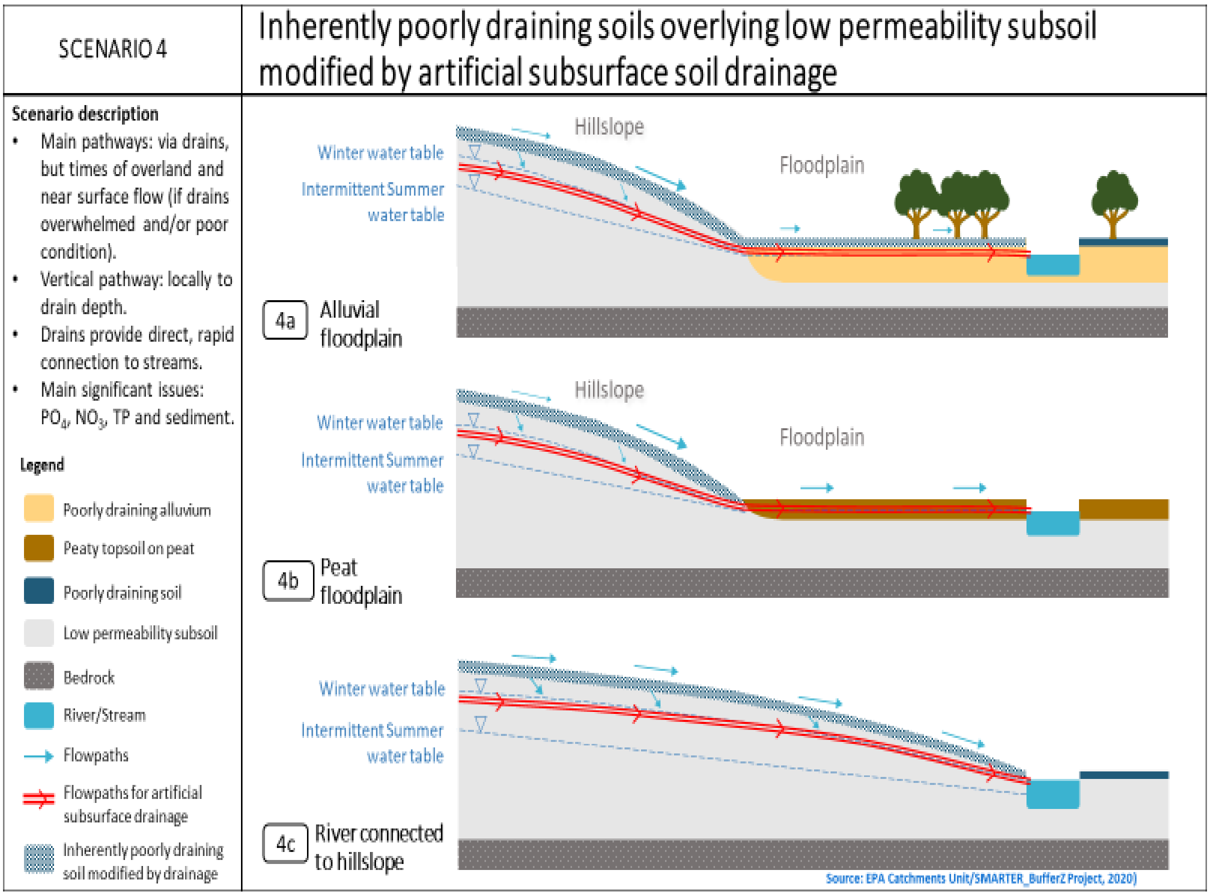


Figure 3-11: Pathway conceptual model for poorly draining scenario with artificial drainage installed.

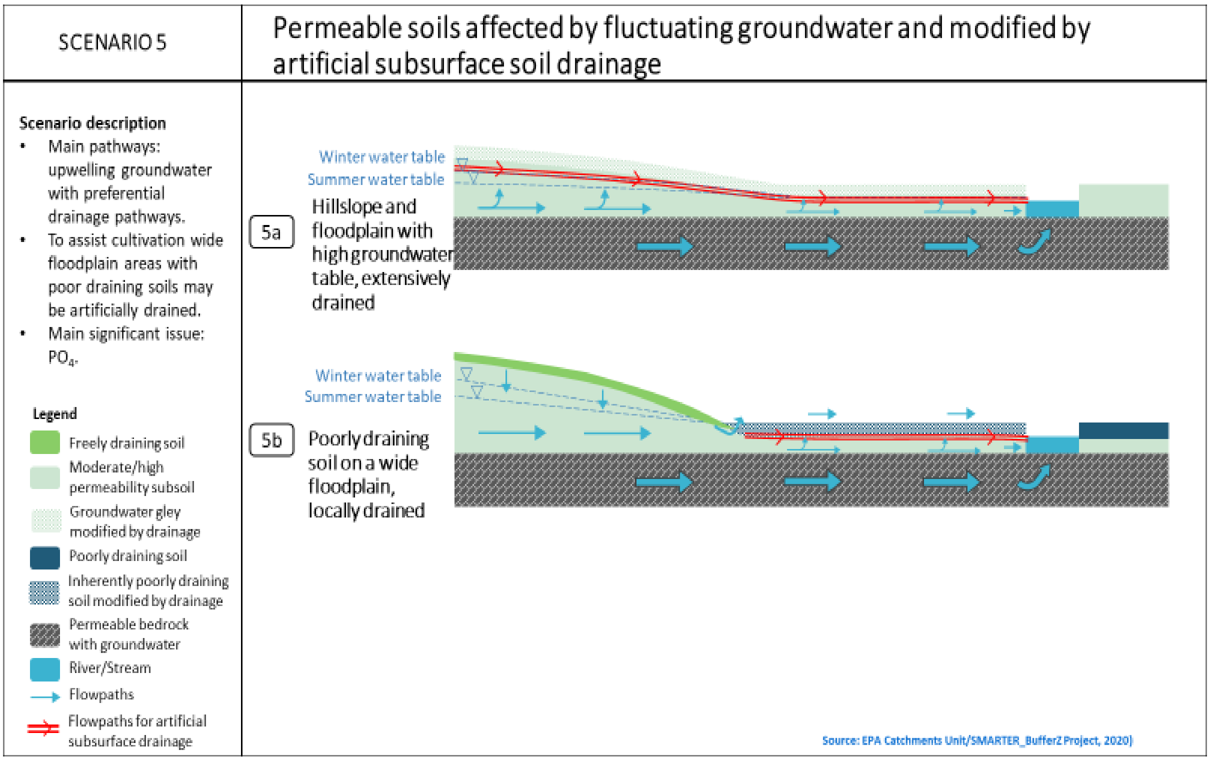


Figure 3-12: Pathway conceptual model for scenario where groundwater gleys (caused by a high water table) overly permeable subsoils.

(This can occur where the topographic slope is gentle and the hydraulic gradient is low, with the water table rising close to the ground surface in wet weather. Artificial drainage is installed.)

3.10.3 Freely draining scenarios

While less common, consideration needs to be given to the freely draining settings as they may be present in the midst of poorly draining areas, and therefore the approach to assessing and establishing measures needs to be completely different.

Figure 3-13 summarises the physical conditions that significantly influence hydrological processes in freely draining settings. It illustrates the dominance of underground pathways that reflect the presence of permeable soils, subsoils and transition zone, and transmissive bedrock (either productive aquifers or the upper fractured zone of poorly productive bedrock aquifers). Figure 3-14 illustrates the pathways in the vicinity of watercourses in freely draining areas.

The characteristics are as follows:

- ♦ The dominant flowpath is vertically to the water table. Vertical water movement in soil and subsoil is relatively slow (generally 1 to a few cms/d), which facilitates adsorption and ion exchange.
- ♦ The response to rainfall is relatively slow with lower flood peaks.
- ♦ Drainage density is relatively low.
- ♦ Slope is an indicator of groundwater flow direction (apart from karstified scenarios).
- ♦ E. coli are filtered out and die-off.
- ♦ Phosphate is attenuated by adsorption in soil and subsoil, but not in bedrock.
- ♦ Ammonium is attenuation by conversion to nitrate.
- ♦ Minimal attenuation of nitrate occurs, which can readily move vertically and enter groundwater, and then flow horizontally to wells and/or nearby watercourses.
- ♦ Groundwater is more vulnerable to pollution.

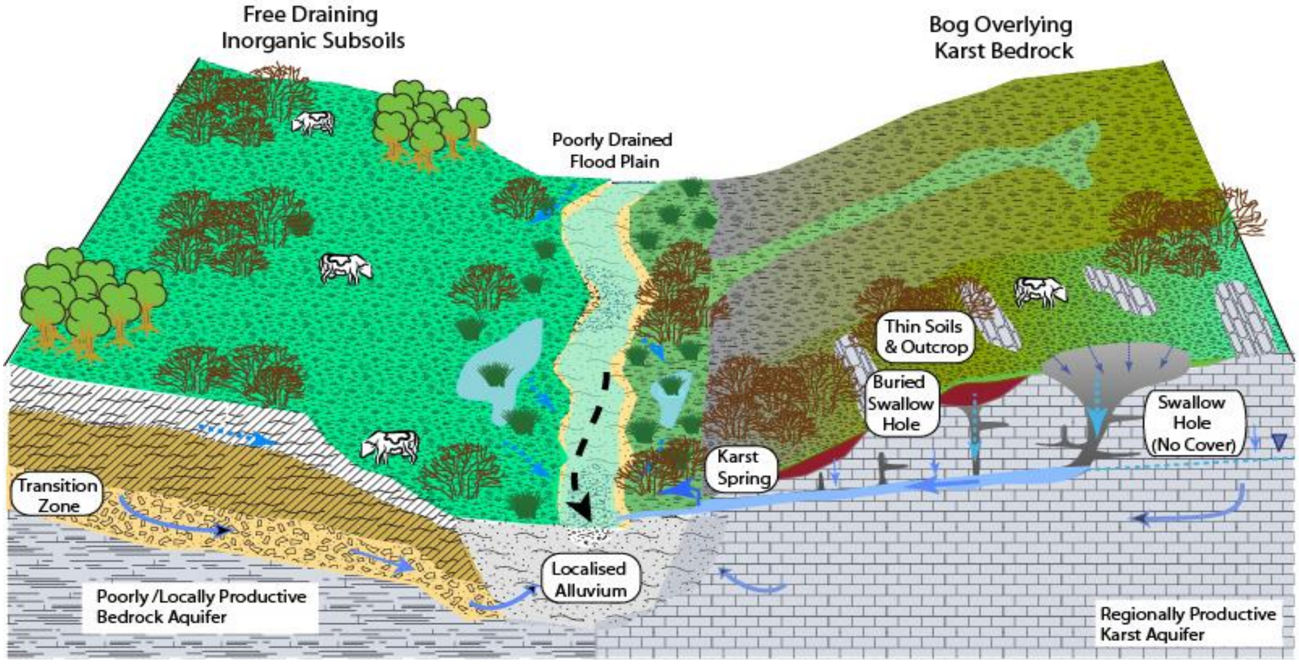


Figure 3-13: Schematic illustration of hydrological conditions operating in undisturbed freely draining conditions in a near-natural setting.

The left side illustrates a catchment underlain by significant sequences of freely draining subsoils with groundwater discharging to a stream flowing through a locally waterlogged alluvial plain. Illustrated on the right is a catchment underlain by karstified limestone. Thin soils and karst landscape features, such as swallow holes can allow water to rapidly reach the water table. Where thicker low permeability subsoil sequences occur, the influence of the underlying bedrock reduces considerably, and in areas of high and frequent effective rainfall this can give rise to development of bogs. Low (dispersed) grazing pressure is suspected to have minimal supplemental impacts on water quality.

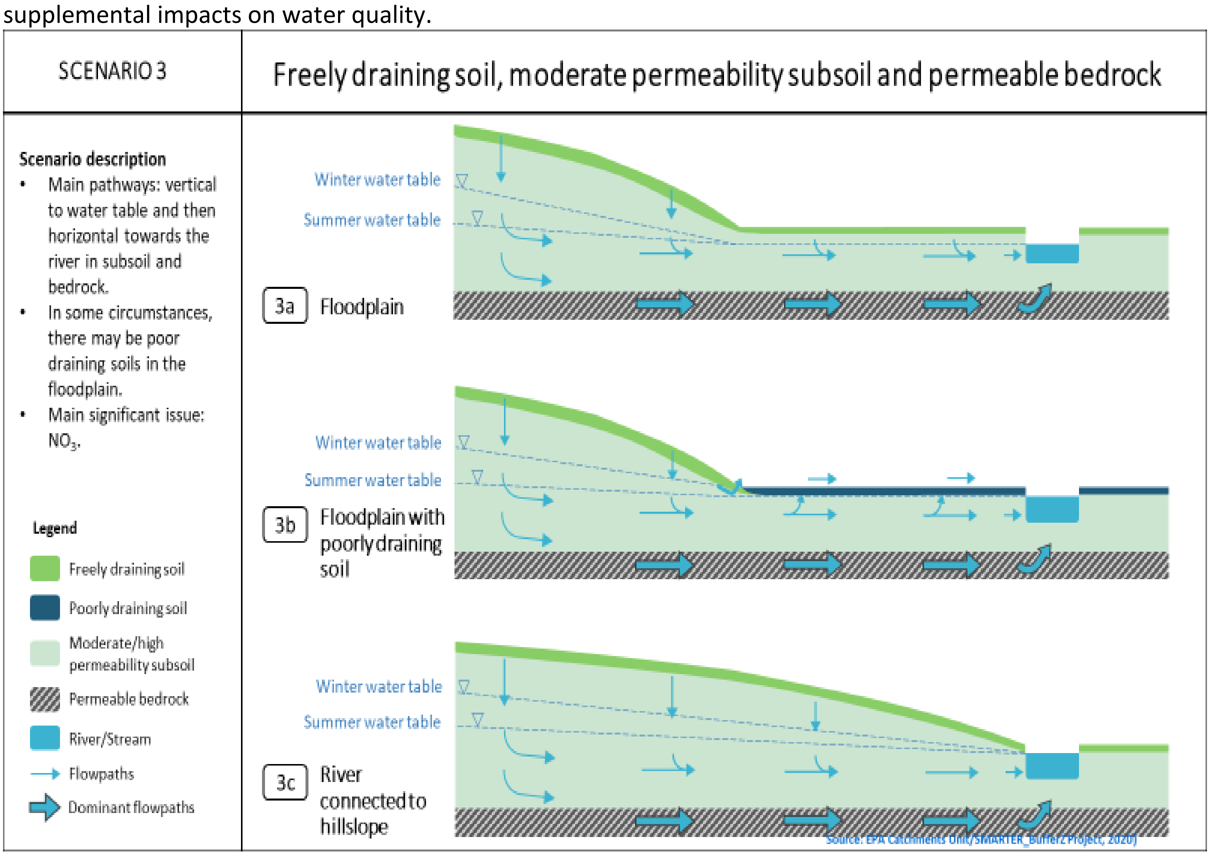


Figure 3-14: Pathway conceptual model for freely draining scenario in vicinity of a watercourse.

4 Pressures in HSO Waterbody Catchments

4.1 Introduction

Human activity, typically land uses that interfere with hydrological processes and/or water quality, can result in status degradation. The approach to assessing the impacts, potential or actual, of pressures depends on whether the HSO waterbody is *At Risk* (i.e. an Area for Restoration) *or Not at Risk* (i.e. an Area for Protection).

4.2 Assessment of Pressures in Areas for Restoration

Figure 4-1 summarises the activities identified as driving losses in status in the catchment areas of HSO waterbodies. It highlights the dominance of three *significant pressures* – hydromorphology, agriculture and forestry – which contribute to the deterioration of 70% of the HSO waterbodies, with hydromorphology the greater pressure.

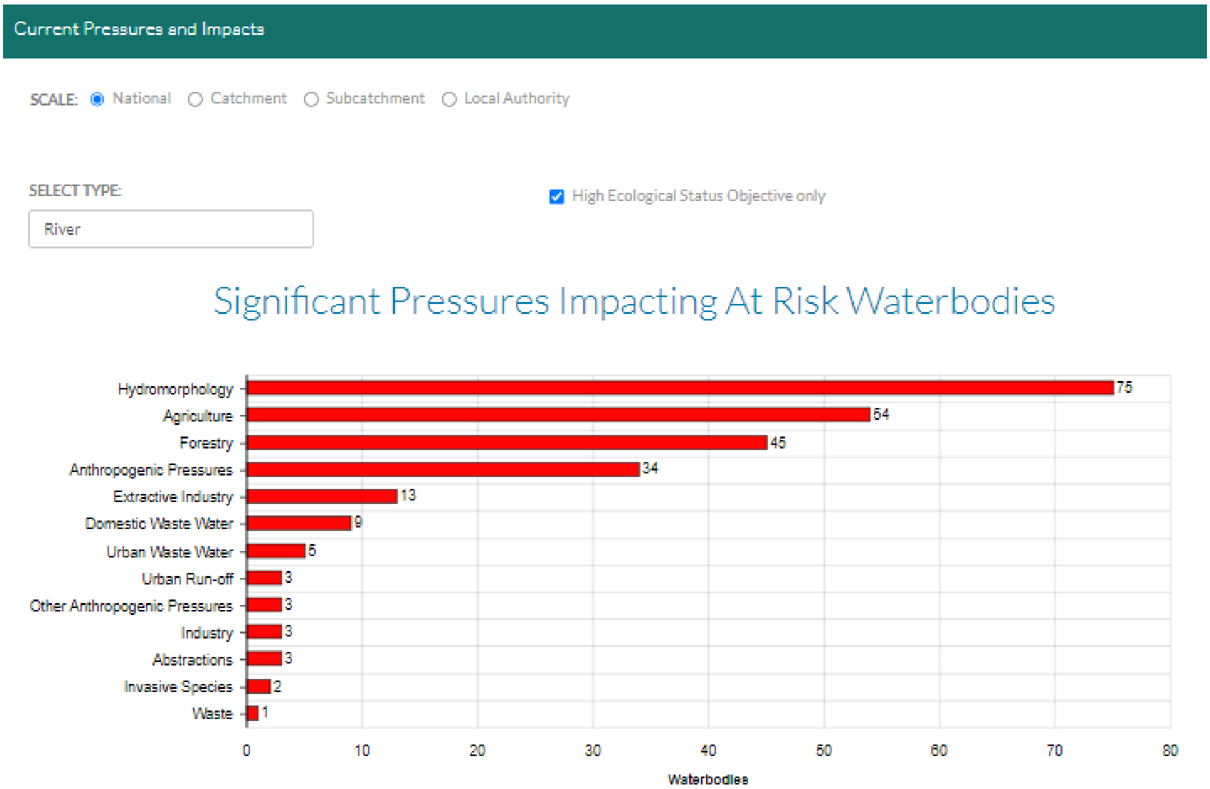


Figure 4-1: Significant pressures causing deterioration of high status.

(Source: Figure copied from https://www.catchments.ie/data/#/dashboard/pressure?_k=1w2yq0)

Figure 4-2 illustrates a generic conceptual model that provides a summary of the principal sectoral activities that may impact WFD status. Summary information on those activities is given in the sections below.

While environmental analysis on the role of nutrients, such as phosphate, nitrate and ammonium, arising from the pressures tends to focus on concentrations as the metric of relevance, nutrient loadings analysis of a pollutant that is causing significant impacts is a beneficial approach in locating the associated pressure and the areas they are arising.

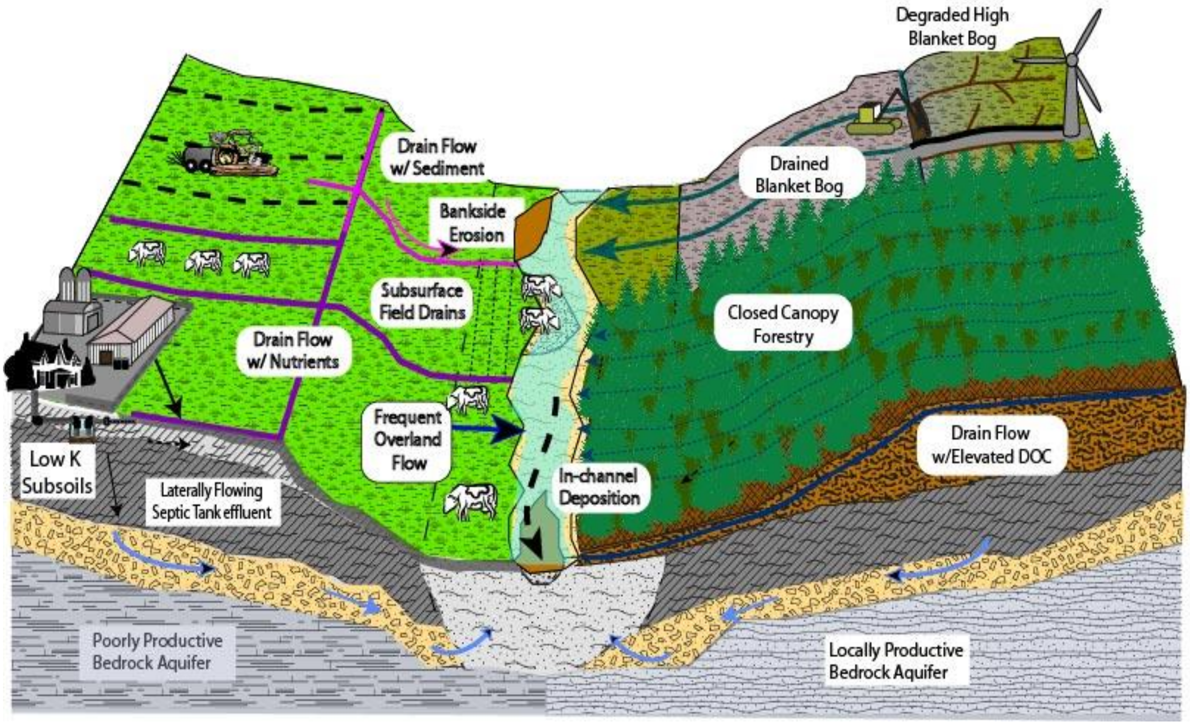


Figure 4-2: Schematic conceptual model of pressures giving rise to the degradation of HSO rivers and streams.

4.2.1 Nutrient loading analysis

Quantifying the impact of measures in the wider environment proves particularly challenging, given the high levels of heterogeneity encountered in Irish catchments. Under these circumstances, Before-After-Control-Impact (BACI) experimental design proves useful. Figure 4-3 provides a schematic illustration of this approach. In this example monitoring points installed at the outlets of a control catchment, where no measures are undertaken, and an impacted catchment, where measures are undertaken, allow the response between both catchments to be compared before and after measures implementation. The response presented suggests significant reaction to measures, although peaks suggest that additional parameters affect the efficacy of the works.

Analysis of data should take a holistic view of physical, water quality and biological data to develop a systems-based view of catchment ecohydrology. This should be compared against original catchment conceptual models to assess if, and how models should be adapted to better inform programmes of measures. More generally this approach allows for considerable cross-disciplinary synergies.

Figure 4-4 provides a simplified example of this approach and shows how combining flow and concentration data can be applied to identify areas requiring measures. Combining flow and concentration data allows determination of fluxes (concentration x flow/catchment area) for particular areas. This allows identification of source areas, thereby allowing (a) measures to be focused, (b) identification of those areas where measures are not required or less critical (where declines in flux may be noted). The approach highlights the benefit of monitoring in allowing a more effective targeting of resources.

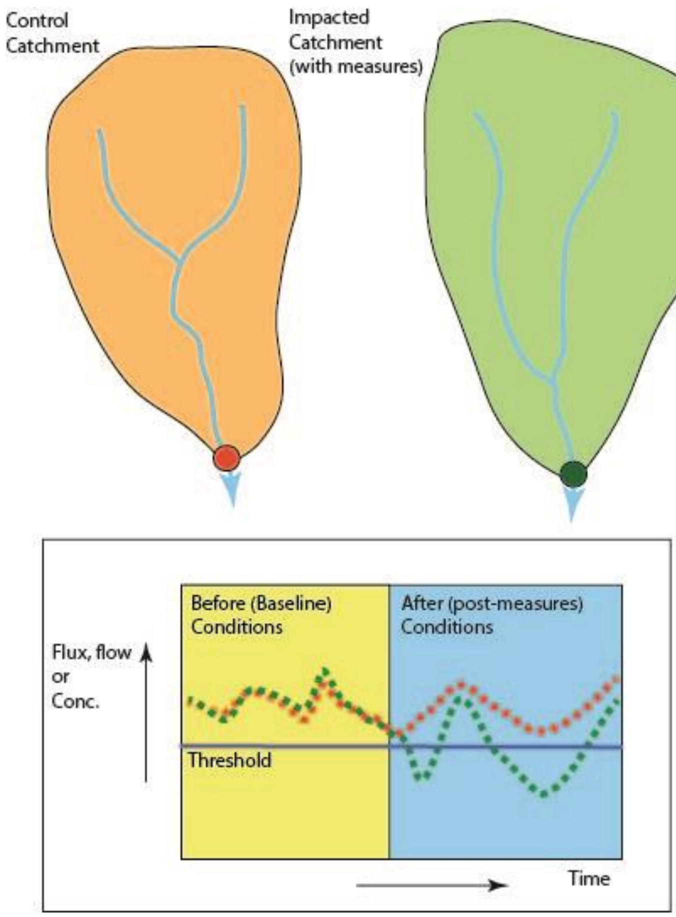


Figure 4-3: Schematic illustration of the before-after-control-impact (BACI) approach to quantifying the impact of measures on a HSO catchment.

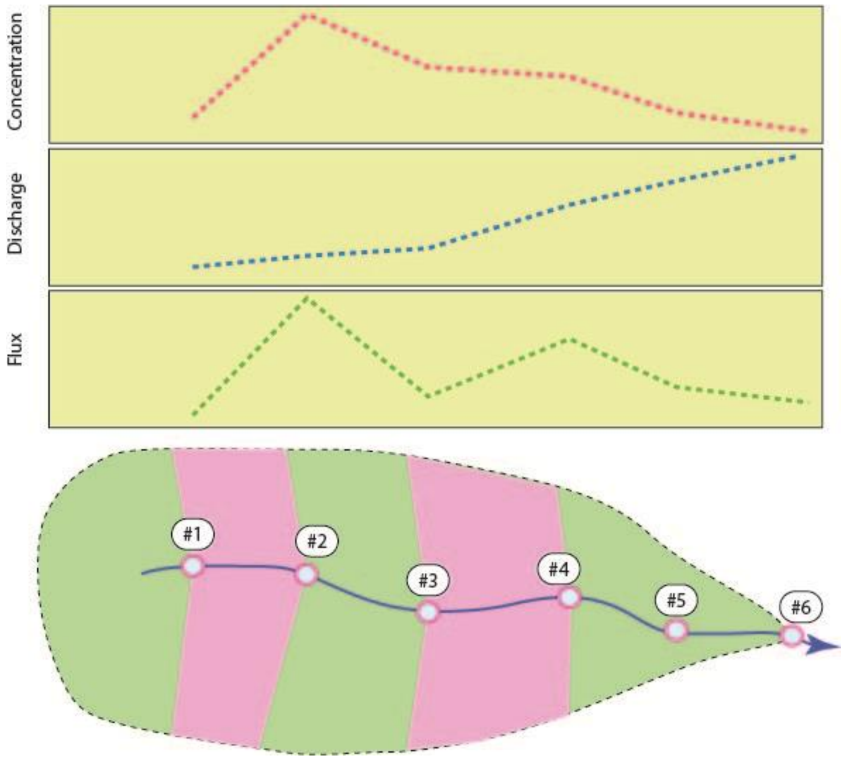


Figure 4-4: Schematic diagram illustrating how the combined use of flow and concentration data can be used to identify critical source areas.

4.2.2 Hydromorphology

Hydromorphology is the study of physical form, condition and processes within a surface water body that create and maintain habitat. The hydromorphological condition of a waterbody is a supporting element of the Water Framework Directive (WFD) ecological status, in particular high ecological status. Impacts to the hydromorphological condition relate to damage to aquatic habitat including the riparian zone, the lateral connectivity with the flood plain and longitudinal connectivity through the catchment, and natural riverine processes. The human activities and physical modifications that cause these impacts include for example, removal of natural riparian vegetation, channelisation, land drainage, dams, weirs, barriers and locks, overgrazing, embankments and culverts. The sectors driving hydromorphological pressures are varied and may overlap with the sectors driving other impacts, for example the pressures from agricultural activities may include hydromorphological impacts caused by land drainage and removal of riparian vegetation, as well as eutrophication impacts caused by nutrient emissions. Hydromorphological impacts may also arise from forestry, peat extraction, mines and quarries and the urban environment.

The physical habitat condition may be impacted by abnormally high fine sediment and siltation levels, which are increasingly internationally recognised as a cause for concern. Sediment is a naturally occurring material, derived from the weathering and erosion of underlying bedrock and steam banks, which is then subsequently transported downstream. Sediment transport is part of normal riverine function. However, excessive losses of fine sediment, such as fine sand, silt and clay, can significantly impact the condition of freshwater habitats, resulting in a deterioration of ecological health. In addition, physical barriers in rivers, such as impassable weirs, can impede the movement of water and sediment, and can also prevent the migration of certain protected fish species, consequently affecting the health of their populations. More details on hydromorphological pressures are given in LAWPRO/EPA (2022b)[1].

The principal issues of concern arising from hydromorphological pressures in HSO river catchments are high levels of fine sediment, deterioration of instream habitat and riparian zone condition, and altered hydrology (flows and water levels). Hydromporphological issues related to sediment and hydrology are dealt with in this report insofar as they are associated with sectoral pressures such as agriculture and forestry. Mitigation measures for these issues are specified in the measures tables for the relevant sectors.

Another important element of hydromorphology is riparian zone condition (e.g. vegetation/land cover). This will be assessed and recorded within the project demonstration catchments, along with impacts from agricultural and forestry activities. The project will also work with project partners and other stakeholders to establish suitable riparian conditions for the protection and restoration of high status objective waterbodies which reflect the waterbody type, setting and adjacent land use.

4.2.3 Agriculture

Agriculture forms the principal economic land cover activity (by area) across most HSO waterbody catchments, and it has impacted on a high number of HSO waterbodies (Figure 3-1). Although encompassing a wide variety of activities, Corine Land Cover data, which subdivides agriculture into a number of subsets, indicates that pasture/livestock rearing is dominant in HSO river sub basins. This, and associated activities, can potentially give rise to widespread point and diffuse pollution and impact water quality.

Traditionally the catchments represented by HSO waterbody catchments have supported limited agriculture, and usually of an extensive type. The nature of potential agricultural practices in such areas was severely curtailed due to poorly draining soils and high water tables. Economic and policy drivers, technical and husbandry innovations, and the widespread availability of mechanical plant has likely facilitated the recent expansion and intensification of agriculture in these areas. Central to this intensification is the installation of drainage, which fundamentally alters the natural hydrology of the catchment, and the pursuant need to fertilise the newly improved lands. Such changes result in more rapid delivery of pollutants to watercourses and increased pollutant loads, e.g. fertiliser and pesticides.

It is clear that the reason that many HSO waterbody catchments have retained high quality environmental status is not because of an inherent capacity to absorb additional pressures, but largely due to their remoteness, and limited suitability for agricultural development. Nevertheless, 54 waterbodies are failing to meet their high status objective due to the impacts of agricultural activities. The principal issues of concern arising from agricultural activities in HSO river catchments are phosphate, sediment, nitrate, ammonium, BOD, MCPA and hydrology (flows and water levels) (see Section 2-2).

More details on farming pressures are given in LAWPRO/EPA (2022b)[15].

4.2.3.1 Critical source areas for diffuse losses to water

Critical source areas (CSAs) are areas that deliver a disproportionally high amounts of pollutants from diffuse sources compared to other areas of a waterbody catchment, and they represent the areas with the highest risk of impacting on a waterbody. By locating CSAs, it enables mitigation activities to be targeted and, in the process, increases the effectiveness of the activities by ensuring the implementation of "***the right measure in the right place***".

CSA maps, called Pollution Impact Potential (PIP) maps, have been produced by the Catchments Science and Management Unit of the EPA for diffuse sources of phosphate and nitrate[16]. They are derived by combining the relevant susceptibility map (described in Section 3.8) with the estimated loadings of phosphorus and nitrogen. The nutrient loadings are derived from:

i) The DAFM Farm Management Data that provides information on farm livestock units.
ii) Using typical application rates for different crop types in tillage areas.
iii) CSO data for areas not covered by DAFM data.

An example of a PIP map for nitrate is shown in Figure 4-5.

An example of a PIP map for phosphate is shown in Figure 4-6 (map source: EPA Catchments Unit). It consists of three components:

i) The phosphorus critical sources areas – blue areas (High PIP Rank 1-3).
ii) Focussed Delivery Flow Paths.
iii) Focussed Delivery Flow Points.

The **phosphorus CSAs** are areas of moderate to high P loading on the land and moderate to high pathway susceptibility, largely driven by the presence of poorly draining soils. Therefore, they are the areas providing the phosphate source loading to watercourses.

Focussed delivery flow paths are initiated by a varying topography and associated changes in slope, and the poorly draining nature of the fields that cause converging runoff resulting in an increasing accumulation of flow. It is important to consider the available source of phosphorus in these contributing areas when deciding whether to target measures (check the underlying PIP-CSA rank). The red flow paths have the highest surface runoff. Where these cross High PIP areas, expect higher

[15] https://lawaters.ie/app/uploads/2022/09/Print_CSM-Volumes-23_April-2022.pdf
[16] PIP maps for phosphate and nitrate are available at this link: https://gis.epa.ie/EPAMaps/Water.

P losses. The map can highlight areas to target phosphorus pathway interception actions. Drainage ditches are often located in these areas.

Focussed delivery flow points are where focussed delivery flow paths enter a watercourse. The size of the point indicates the relative volume of flow delivered to water. It is important to consider the available source of phosphorus in the upslope contributing areas. The map can highlight areas to target phosphorus pathway interception actions e.g. spatially targeted extended buffers, woodlands, two-stage channels.

While the PIP-P map focusses on phosphorus as the significant issue, it can also be used for predicting where other significant issues, such as sediment, ammonium or microbial pathogens might arise.

PIP maps are not field-scale maps and therefore are intended a guide to the situation on farmland, which needs 'ground truthing' before any measures are decided on and established.[17]

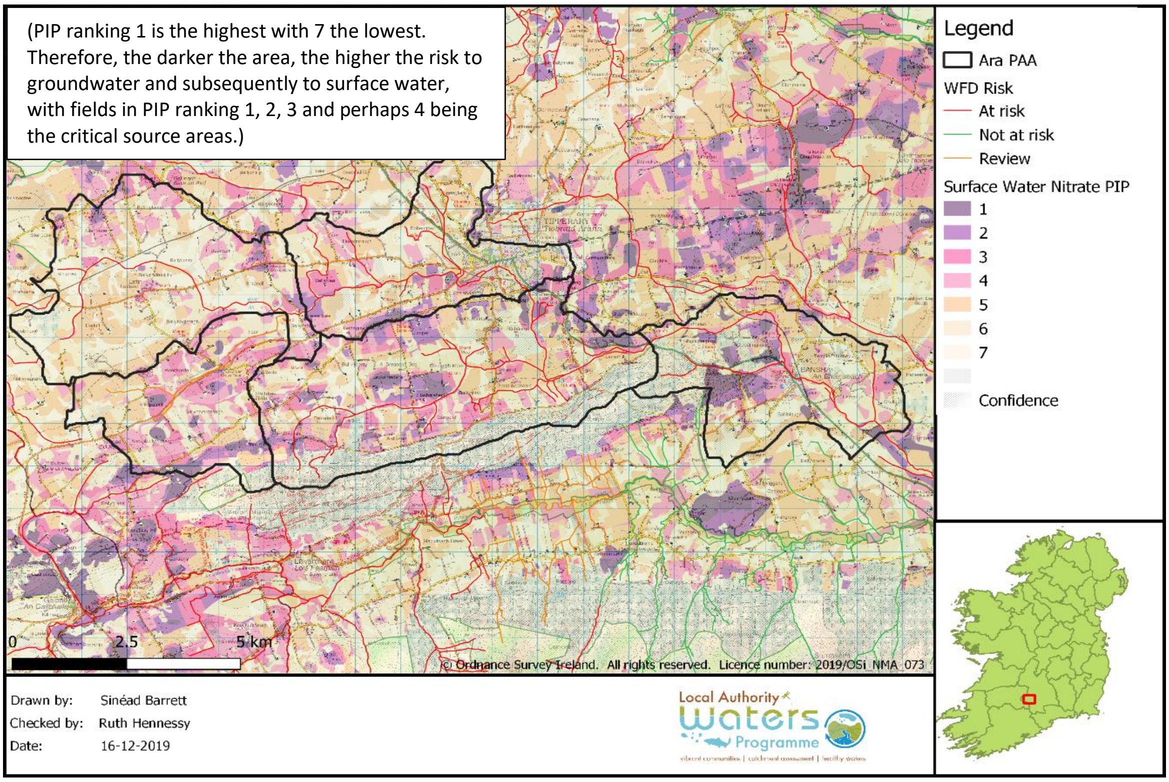


Figure 4-5: An example of a Pollution Impact Potential (PIP) map for nitrate entering surface water arising from diffuse agricultural sources.

4.2.4 Forestry

Although much of Ireland was historically covered by native forest, many of the areas encountered in HSO waterbody catchments are naturally treeless while others have lacked significant forest cover for centuries. Over the past 100 years considerable effort has aimed to increase the area under forestry, principally through plantations of exotic (non-native) coniferous species. Although plantation forestry covers a relatively limited area of all HSO waterbody catchments (typically no more than 10% in each status category) (see Table 3-1 in Section 3.2), it appears to have a disproportionate impact on waterbody status – there are 45 waterbodies where forestry has been cited as a driver of status loss in comparison to 54 for agriculture, which covers an area three to four times larger. Afforestation often targeted marginal uplands where soils were water-logged and required ground alteration

[17] For further information, see LAWPRO/EPA (2022a).

(artificial drainage) to facilitate commercially productive tree growth. While policy in relation to planting such areas has changed, the previous planting of peatlands has resulted in legacy forestry issues.

Apart from the potential episodic impacts associated with particular stages in the forest rotation, afforestation of such areas has profoundly altered their hydrology (see 2.4.9). As these forests reach maturity and require felling, other acute impacts may also be expected and, given the vulnerability of the peat soils involved, will require implementation of substantial measures to mitigate impact on HSO waterbody catchments.

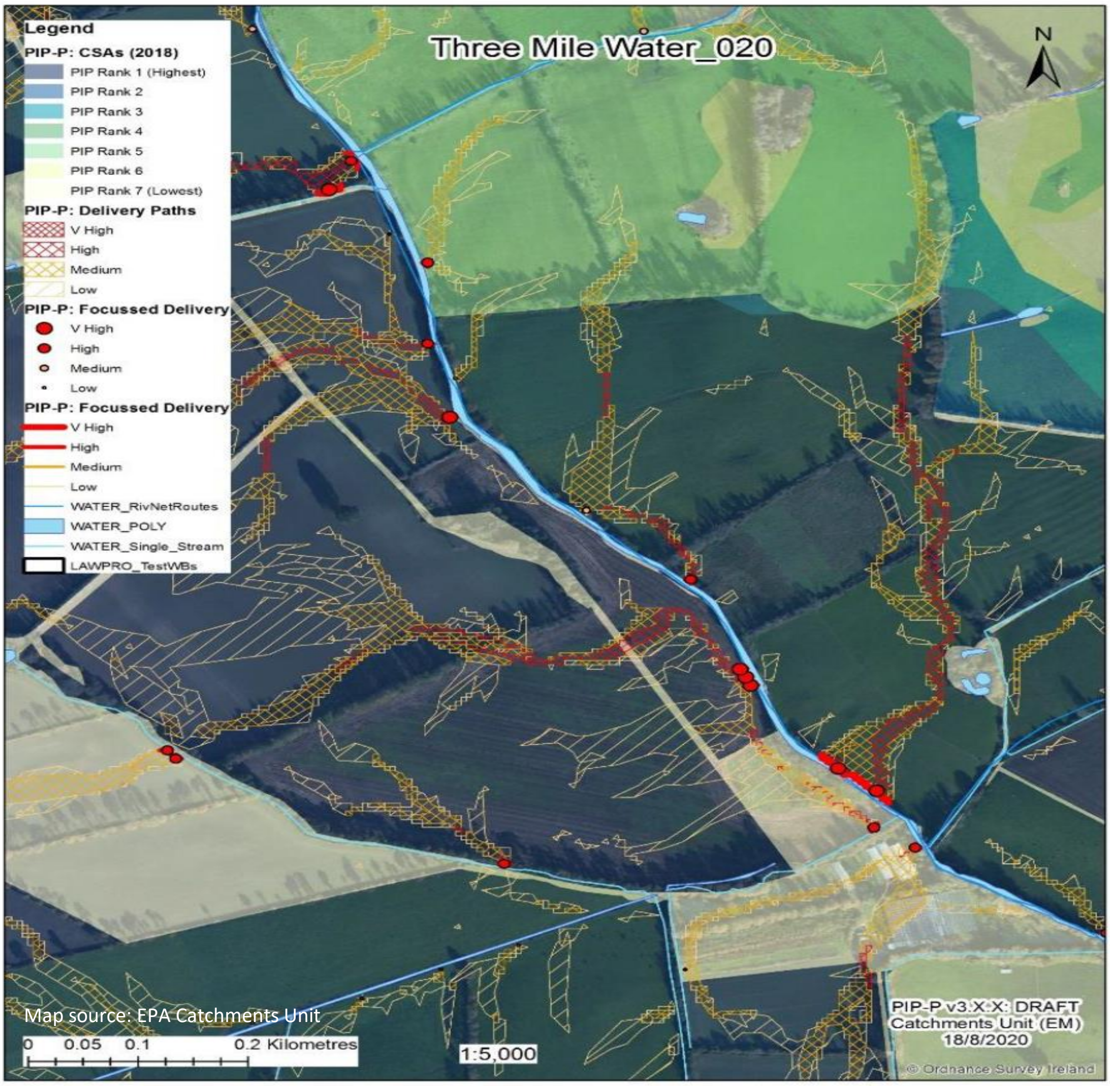


Figure 4-6: An example of a Pollution Impact Potential (PIP) Map for phosphate entering surface water arising from diffuse agricultural sources.

Mature forestry also affects the volume of effective rainfall in a catchment. As trees mature, the proportion of water returned to the atmosphere by interception and transpiration increases. This results in lower rates of runoff, particularly during summer periods when the relative air humidity is lower. Groundwater hydrographs below closed canopy forest reveal consistently lower water tables than equivalent areas lacking tree cover. This reduction in effective rainfall impacts shallower hydrological pathways disproportionately and has knock-on effects on water quality with the proportion of less mineralised water, derived from poorly drained soils proving less during baseflow. By contrast, once the storage capacity of the canopy has been exceeded, stem flow (water flowing down a tree trunk from the canopy) can result in rapid runoff responses, facilitated by the presence of ridge/furrow microtopography, which is installed in naturally waterlogged areas at the start of the planting cycle. Overall, mature plantation forestry in areas that are naturally poorly drained can result in more variable stream runoff and water quality. Crucially, it needs to be noted that scientific first principles suggest these processes also apply in the case of broadleaf species, including natives, particularly during the summer periods when canopies may be closed (and when stresses to aquatic ecosystems may be greatest).

In summary, the principal issues of concern arising from forestry activities in HSO river catchments are sediment, phosphate, Total phosphorus, ammonium, acidification, pesticides and hydrology.

More details on forestry pressures are given in LAWPRO/EPA (2022b)[18].

4.2.5 Peat extraction

Ireland has a long history of exploiting peatlands for domestic fuel, industrial peat extraction, commercial forestry and agriculture. Exploitation in HSO waterbody catchments is largely in the form of private turf cutting for domestic fuel, and in many instances occurs on long established plots, most (if not all) of which are less than 10ha in extent. As such these activities are largely exempt from licensing consent and planning permission requirements. However, large scale peat extraction projects (exceeding 50 ha) are required to obtain both planning permission and licensing consent from the EPA. Environmental Impact Assessment (EIA) is mandatory for proposed peat extraction projects which would involve a new or extended area of 30 ha or more, and both planning permission and licensing consent is required.

Although individual turbary plots may be relatively small, they usually occur in close proximity over extensive areas of peatland. They also entail drainage and road networks beyond the boundary of individual plots that impact the wider peatland. Peat extraction, including domestic cutting, is now almost entirely a mechanised process. This has led to an accelerated loss of uncut bogland. Analysis of subsoil and Corine Land Cover data has revealed that although peat covers a large proportion of HSO river sub basins, extensive areas are occupied by cut peat, in part reflecting this accelerated loss. Mechanisation has not only resulted in increased areal losses, the capacity to cut (and drain) to greater depths has led to disturbance to hydrological conditions and the die back of peat accumulating vegetation extending further inwards from cutting faces (face banks) into uncut (or high) bog. Similarly, changes in hydrology are also suspected to support the spontaneous development of subsurface piping. Both drains and piping convey water from peatlands at rates above those naturally encountered. This disturbs natural water balances with the resulting dieback leading to loss of peat accumulating vegetation. Figure 4-7 illustrates an intact area of blanket bog and a damaged blanket bog through installation of surface drainage and the development of subsurface piping.

The consequences of changes in hydrological conditions include more variable flow conditions and water quality in receiving waterbodies. In extreme cases, changes in peatland hydrological regimes can give rise to catastrophic slope failure, which can result in the acute release of large volumes of organic matter to watercourses, with catastrophic consequences. Despite being relatively widespread, the underlying drivers for this process remain poorly understood. This arises in part due to the challenges in determining peat geotechnical properties.

[18] For further details see LAWPRO/EPA (2022b) at this link: https://lawaters.ie/app/uploads/2022/09/Print_CSM-Volumes-23_April-2022.pdf

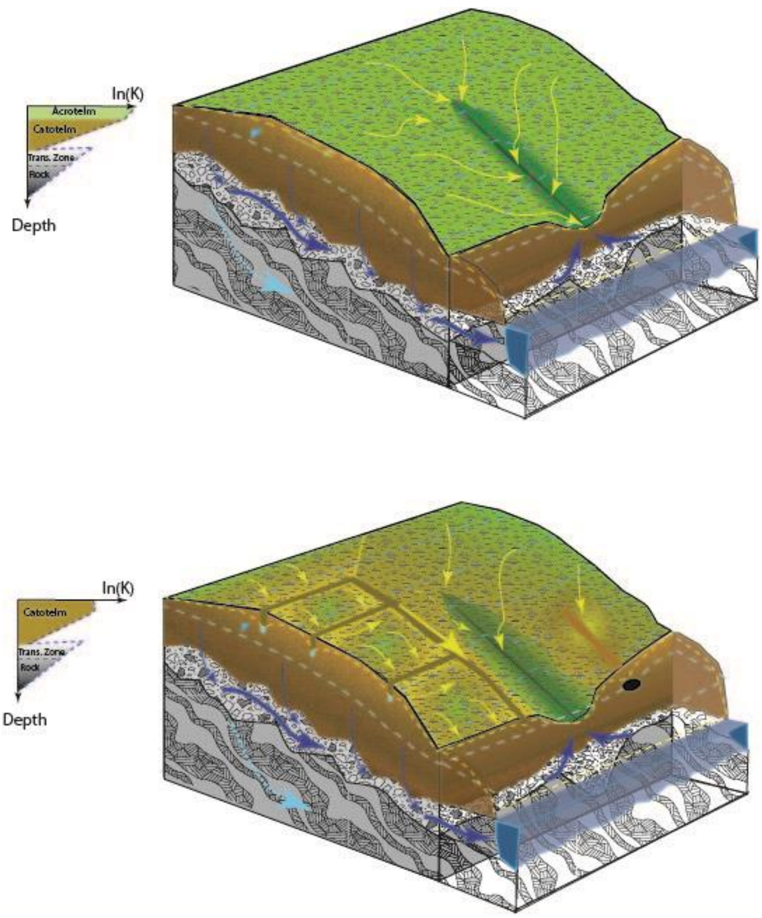


Figure 4-7: Illustration of an intact area of blanket bog and a damaged blanket bog through installation of surface drainage and the development of subsurface piping.

Determining the hydraulic conductivity of peat is challenging, due in part to its highly compressible nature. Nonetheless widely used conceptual models view peat as consisting of a highly permeable upper layer (acrotelm), dominated by living or slightly decayed vegetation, overlying more decomposed and less permeable material (catotelm). This arrangement of hydraulic conductivity in the peat implies that flow through it occurs predominantly in a horizontal direction in the uppermost layers, with a small fraction of water discharging to the inorganic substrate. Both bog water and the more mineralised substrate groundwater ultimately discharge to streams, albeit in differing proportions, depending on hydrological conditions.

The upper peat layer in intact bog systems experiences intermittent aerobic conditions linked with small scale groundwater level fluctuations (less than 10cm magnitude for more than 90% of the time). Deeper into an intact peat profile, although water remains acidic and poorly mineralised, persistent highly anaerobic (methanogenic) conditions occur. Drainage and disruption of bog hydrology results in oxidation of peats, increasing dissolved organic carbon concentration and nitrogen emissions to receiving waters. Accelerated decomposition results in erosion and elevated particulate organic carbon loading to watercourses.

Measures undertaken in bogs exploited for peat extraction that aim to improve the condition of aquatic receptors need to recognise the intimate linkage that exists between terrestrial ecosystems and receiving waterbodies. Although harder engineering measures such as silt traps can deal with certain water quality issues in the shorter term (e.g. peat silt), measures that tackle the condition of terrestrial ecosystems (at source) are needed for longer term solutions. These measures should aim to raise water tables in peat to encourage the re-establishment of peat accumulating vegetation and revegetation of bare peat.

In summary, the principal issues of concern resulting from peat extraction and associated peat drainage in HSO river catchments are sediment, ammonium, DOC, acidification and hydrology. In certain circumstances, high BOD concentrations occur in watercourses due to the reducing conditions present in peatland areas.

More details on peatland activities pressures are given in LAWPRO/EPA (2022b)[19].

4.2.6 Quarries

More than 230 active quarries are recorded nationally by the Geological Survey of Ireland (GSI, 2014)[20]. Quarries are of two basic types: rock quarries and sand and gravel pit quarries. Rock quarries tend to be deep, and may involve dewatering so operators can access and extract materials from deeper "benches" rather than expanding laterally. Rock faces are often broken by mechanical or controlled blasting techniques. Large trucks subsequently transport materials to stone crushing machines where they are broken down into aggregates of different sizes. Sand and gravel pits are much shallower than rock quarries but may also involve dewatering operations. The material is excavated mechanically and carried by trucks or conveyor belts to a plant where it is crushed, washed and screened into different sizes.

The main pressures arising from quarrying are mainly related to:

- Sediment load to, and re-activation (erosion) of sediments in, streams at discharge locations;
- Release of pollutants to surface water and groundwater; and
- Abstractions from dewatering operations.

These activities can result in the degradation of physical habitats and environmental supporting conditions of surface waters and groundwater dependent wetlands, as well as the pollution of both surface water and groundwater receptors (e.g. public water supply wells). Lowering of groundwater levels from dewatering operations can furthermore affect the baseflow of streams (particularly during the drier summer months), groundwater levels beneath wetlands, and water levels in wells, if these are located within the zone of influence of quarry dewatering operations. The associated discharges of water from quarries can also cause or contribute to flood risk downstream of quarry sites.

Thew principal issues of concern arising from quarrying activities are sediment, hydrocarbons, ammonium, phosphate, BOD, FIOs, pH and hydrology.

More details on quarries pressures are given in LAWPRO/EPA (2022b).

4.2.7 Domestic wastewater treatment systems

One-off housing is a feature of most HSO waterbodies. While houses are generally present at low densities, the domestic wastewater treatment systems (DWWTSs) associated with such housing can have significant local impacts particularly in HSO water as relatively small pollutant loads of, for instance, phosphorus can breach the EQS in headwater streams. Nine HSO waterbodies are impacted by DWWTSs (Figure 4-1).

[19] For further details see LAWPRO/EPA (2022b) at this link: https://lawaters.ie/app/uploads/2022/09/Print_CSM-Volumes-23_April-2022.pdf

[20] GSI (2014). Directory of Active Quarries and Pits in Ireland. https://www.gsi.ie/en-ie/publications/Pages/Quarry-Directory.aspx

DWWTSs can threaten public health and water quality when: i) they are in unsuitable areas and ii) when they fail to operate satisfactorily.

Site suitability is determined by two factors arising from the hydrogeological conditions:

1. The **hydraulic** factor
    - ♦ Where percolation is satisfactory, for instance in moderately permeably subsoil, effluent will migrate vertically to the underlying water table.
    - ♦ Where the percolation rate is too low, usually due to the presence of low permeability subsoil, surface ponding of effluent often occurs, particularly during wetter periods, with frequent bypassing of the percolation area either directly in pipes or indirectly in overland and shallow subsurface flows to surface water. This is a common scenario in the catchment areas of HSO waterbodies where 42% of the area is underlain by poorly draining mineral soils and 30% by poorly draining peatland (see Section 3-5).
2. The **attenuation** factor
    - ♦ Where percolation is satisfactory, good attenuation of pollutants occurs, provided the minimum thicknesses of subsoil are complied with, and therefore the threat to surface water and groundwater is minimised.
    - ♦ Where the percolation is inadequate, there is insufficient treatment of the effluent prior to reaching a water receptor, such as watercourses, groundwater and wells/springs, thereby posing a pollution threat.

The threat from domestic wastewater arises from existing systems in circumstances where the site suitability was not assessed adequately or designed correctly, or from treatment systems that are not either suitable or adequately maintained under a maintenance contract or regularly de-sludged. Untreated domestic wastewater can lead to water pollution, risk to public health and to degradation of habitats and ecosystem heath, where inadequately treated effluent is piped to streams, flows via overland flow or shallow subsurface flow to streams where percolation is inadequate or by entering groundwater.

The main pollutants of concern arising from DWWTSS in HSO river catchments are phosphate, nitrogen present as ammonium, BOD and microbial pathogens.

More details on DWWTSs as a pressure are given in LAWPRO/EPA (2022b).

4.3 Assessment of Pressures in Areas for Protection

While numerous pressures are present currently in all *Areas for Protection*, a key requirement is to focus on those that are more likely to cause deterioration of the high status in the future, so that time and resources are used efficiently, and effective measures are decided on and established. The recommended approach to assessing and locating potential pressures is as follows:

- ♦ Use the assessment of potential pollutants of concern as the starting point (see Section 2-3).
- ♦ Locate and assess relevant potential pathways for those potential pollutants of concern.
    - o Use the National Soils Hydrology map and the phosphate and nitrate susceptibility maps.
- ♦ Decide on and note areas where pressures could present the greater threat from the pollutants of concern, in particular the susceptible areas.
- ♦ Note the pressures in these areas.
    - o The relevant PIP map if either N or P are potentially a threat are an important means of highlighting the higher risk areas.

- As HSO waterbodies are sensitive ecosystems in which a small pollutant load could impact detrimentally, where phosphate is a potential pollutant of concern, PIP-P areas ranked from 1-5 should be categorised as areas for further assessment, and where nitrate is the pollutant of concern, PIP-N areas ranked from 1-3 should be categorised as areas for further assessment.

- Capture the knowledge of relevant organisations, such as local authorities and IFI.
- Locate developments that previous knowledge indicated threats to water quality.
- Locate known potential point sources with a large pollutant loading, e.g. UWWTPs, intensive dairy farms.
- Where a potential pressure is established, locate the potential CSAs and, if relevant, the flow delivery pathways and points for the pollutant of concern.

5 The Risk-based Assessment

5.1 Introduction

A risk-based assessment is required in advance of deciding on and undertaking either protection or mitigation measures. It encompasses two stages:

1. A desk-based assessment.
2. A field-based assessment.

The desk-based assessment requires compilation and assessment of the HSO waterbody catchment components described in Sections, 2, 3 and 4:

i) HSO water body condition giving potential and significant issues.
ii) Physical settings, pathways and CSAs.
iii) Potential and significant pressures.

The outcome is an assessment or interim 'story' of the situation. Based on this assessment, a work plan for the field-based assessment is needed.

The field-based assessment consists of catchment walks, which provide the opportunity to check the conclusions in the interim risk-assessment. In particular, it involves:

i) Measuring and recording hydrochemical (e.g. specific electrical conductivity, dissolved oxygen) and biological indicators (Small Stream Impact Scores (SSISs)) of HSO waterbody quality.
ii) Locating, checking and describing the pressures.
iii) Assessing the relevant pathways and locating the CSAs.

The final outcome of the characterisation process is a HSO waterbody catchment report, which integrates and summarises all the relevant data, graphs and information, and draws definitive conclusions which provide the basis for consideration of measures[21]. The report content will vary depending on whether the measures need to be established in *Areas for Restoration or Areas for Protection*.

5.2 HSO Waterbody Catchments with a Restoration Objective

The risk assessment and accompanying report involves asking and answering questions, such as:

i) What is the water quality situation in terms of status and risk categories, pollutant concentrations, trends, etc.
ii) What is causing the unsatisfactory situation, i.e. what is/are the *significant issue*(s)?)
iii) What is/are the *significant pressures*?
iv) What is the pathway conceptual model that explains the pathways for water and contaminants in the catchment?
v) Where are the CSAs?
vi) In poorly draining areas and within CSAs for phosphate and/or sediment, where are the main focussed delivery flow paths and points?
vii) Where pollutant load reduction analysis has been undertaken, what reductions are needed?
viii) What further information is needed, if any?
ix) What strategies are needed to improve/restore the water quality. What and where should mitigation measures/actions be established?
x) What further monitoring is required?

[21] For further details see LAWPRO/EPA (2022a) at this link:
https://lawaters.ie/app/uploads/2022/01/Print_CSM-Volume-1_April-2022.pdf

xi) What consultation and collaboration are needed, both with other public bodies and with local communities?

The outcome provides details on the *significant pressures*, their impacts on the aquatic ecosystem including status and the *significant issues,* and, importantly, the points and/or areas where mitigation measures are needed.

5.3 HSO Waterbody Catchments with a Protection Objective

Reporting involves asking and answering questions, such as:

i) What is the water quality situation in terms of status and risk categories, pollutant concentrations, trends, etc.
ii) Are there any tributaries with relatively high pollutant loads that could pose future problems?
iii) What pollutant might cause an unsatisfactory situation in the future?
iv) What is the pathway conceptual model that explains the pathways for water and contaminants in the catchment? (In many instances, this need not be as comprehensive as that undertaken for the restore objective scenario; it is intended to help focus on pressures in susceptible areas that have potential to cause a future threat and impacts. It should focus on the parameters that potentially might pose a threat to the water quality.)
v) Depending on whether and what this pollutant is, are there susceptible areas and potential CSAs where losses to a watercourse could occur and where are they?
vi) What are the potential pressures that are/could pose a threat to the water quality? (Keeping in mind that the presence of a pressure does not mean that an impact will occur).
vii) What further information is needed, if any?
viii) What is the likelihood of future land use changes occurring that could result in reaching a tipping point to a deterioration in status caused by an increase of pollutant loads or change in flows or morphology? Where might these changes occur?
xii) What strategies are needed to protect the water quality? Where should protection measures/actions be focussed?
ix) What further monitoring, if any, is required?
x) What consultation and collaboration are needed, both with other public bodies and with local communities?

The outcome provides details on the potential pressures, potential issues arising from these pressures and points and areas that pose the greatest threat to the HSO waterbody and where protection measures need to be focussed.

6 Mitigation and Protection Measures

6.1 Introduction

Deciding on and establishing measures, whether for HSO waterbody restoration or protection, is often complex, challenging and both time and resource intensive. Undertaking the characterisation process described in the previous sections in advance of implementing measures is an essential means of providing the understanding and information needed to ensure that, in so far is practicable, the measures are effective and efficient. A recommended systematic approach to considering measures, which connects the characterisation to the measures, is given in Figure 6-1.

6.2 Principles Underlying Measures Selection

6.2.1 Right measure in the right place

The fundamental approach in deciding on and establishing measures is **"right measure in the right place"**. Determining the 'right measure in the right place' is based on a number of factors, such as the following:

i) The **issue of concern** (pollutants, hydrology, morphology). The main pollutants of concern are: PO_4, TP (for lakes), NO_3, NH_4, BOD, sediment, MCPA, pH and FIOs. Each has differing potential both in their impact and abilities to be transported in water and, in particular, to be attenuated on the land and in the landscape.

ii) The **pressure(s**) causing the issues of concern. In the case of pollutants, the relative **loading** from the pressure and the **likelihood** of the loading reaching the receptor are important factors that require consideration and assessment.

iii) The hydrogeological characteristics that determine whether the physical setting is **freely draining (FD)** or **poorly draining (PD)** as this influences the flowpaths of water and associated pollutants, and the attenuation potential. Within the poorly draining setting, it may be relevant to distinguish between mineral soils and peatland/organic soils.

iv) Whether the objective is to **'restore' (improve)** ***in*** *Areas for Restoration* ***or*** **'protect' (maintain**) in *Areas for Protection*, as more stringent and resource intensive measures are likely to be needed to achieve the restore/improve objective.

6.2.2 The landscape setting

In a landscape-based framework, it is beneficial to consider measures in terms of what is called 'the pollutant transfer continuum', which has the following four elements:

1. The presence of a pressure (or pressures) with an associated load of pollutants. This pressure can either be a point or diffuse (non-point) source.
2. Mobilisation, whereby in the case of diffuse pressures, the potential pollutant – such as nitrate or MCPA – becomes soluble or attaches to soil particles and starts the journey to a receptor, such as a HSO waterbody.
3. Delivery/transport in a pipe in the case of many point sources or more diffusely along pathways, underground or over ground, to the surface waterbody.
4. The HSO waterbody which is in either satisfactory or unsatisfactory condition and which can vary, for instance, in terms of flow rates, upstream water quality and sensitivity (e.g. high status or pearl mussel objectives).

The reason for making the distinction between these elements is that it is more effective to consider protection and mitigation options according to the point in the source/pressure-pathway-receptor continuum on which they take effect on the land and in the landscape. The recommended categories of measures are therefore:

i) Pollutant source reduction or elimination.

ii) Mobilisation control.
iii) Pathway interception.
iv) Receptor/instream works.

Approach to Selecting Protection/Mitigation Measures

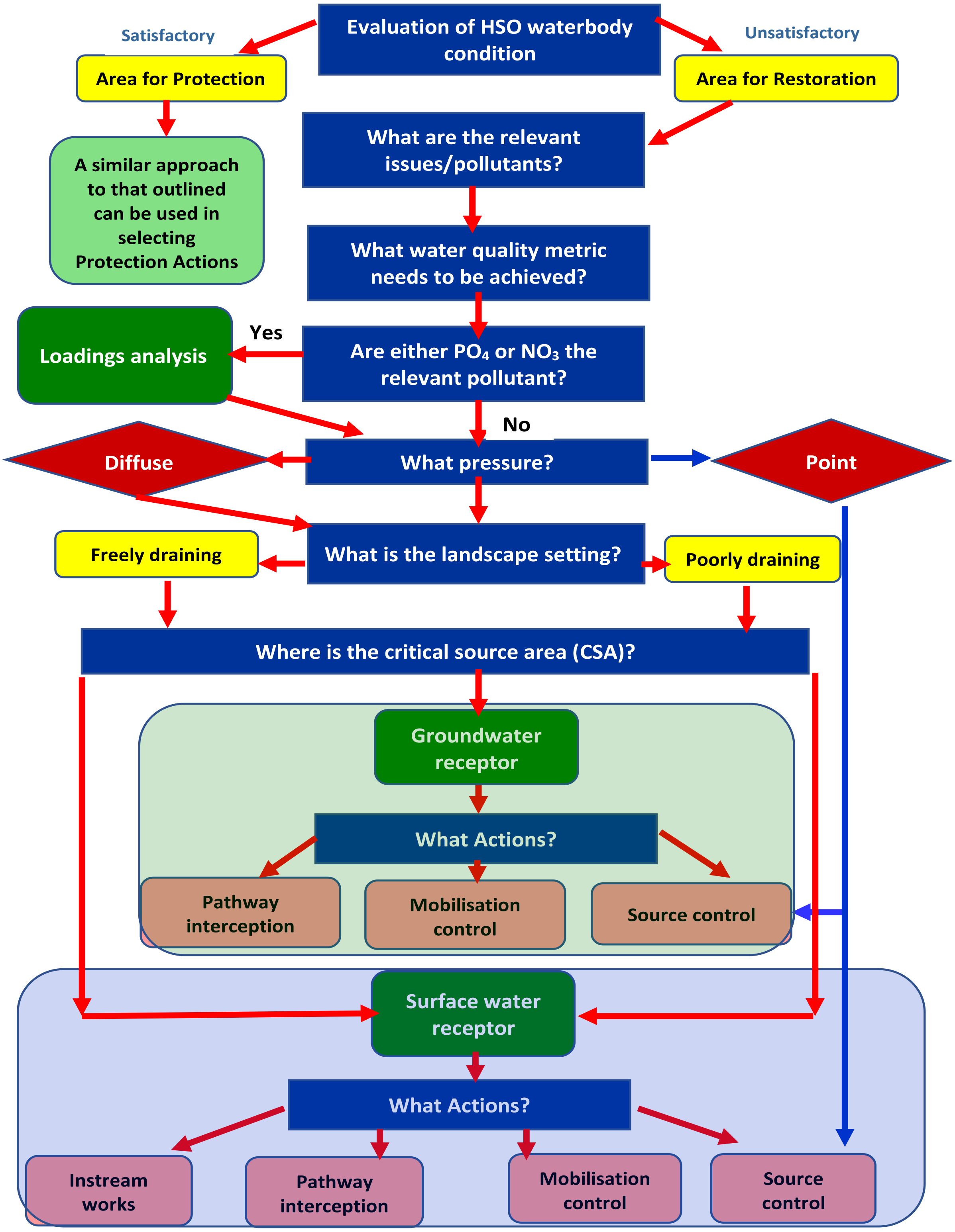


Figure 6-1: Process flowchart illustrating a recommended approach to deciding on measures.

6.2.3 The pollutant properties

In considering which point along the continuum that a measure to protect or restore the HSO waterbody would be most effective, account needs to be taken of the properties of the pollutant of concern (see Section 2) as well as the landscape setting (see Section 3).

For instance, if nitrate is the issue of concern and, as it is highly mobile in freely draining soils and travels vertically from the soil into groundwater, source reduction and mobilisation control measures are needed, and pathway interception is not effective. By contrast, if phosphate is the issue, while source and mobilisation control measures (such as nutrient management planning) are beneficial and necessary, pathway interception measures are essential. For MCPA, both source reduction and pathway interception are needed. Therefore, careful analysis of the mitigation and protection options is essential if the effort undertaken is to be effective and justifiable. Table 6-1 provides a guide on the point along the continuum where measures are most effective in dealing with various pollutants in catchments.

6.2.4 Time lags

In advance of the implementation of measures, it is worthwhile assessing the likely time lag or delay before pollutant concentrations start to decrease in surface waterbodies after effective measures are established and functioning. This time lag depends on the pollutant source – whether point or diffuse – and the properties of the pollutant of concern, e.g. phosphate in comparison to nitrate.

The time lag for reduction in pollutant concentrations from point source *significant pressures* is immediate once the mitigation measure is in place, and therefore water quality monitoring will record an improving trend.

While source reduction and mobilisation control measures are necessary for mitigating impacts from phosphate and sediment arising from diffuse sources, pathway interception measures, especially at flow delivery paths and points (see Figure 4-6), are usually essential to attain sufficient reductions in phosphate and sediment loads to achieve water quality objectives. Once pathway interception measures are established and are effective (this may take several months), a reduction in concentrations will be evident, although for some measures it may take time to achieve optimal effectiveness and therefore optimal reductions in pollutant loads.

For waterbodies impacted by nitrate, the pathway is vertically through freely draining soil and permeable subsoil to the water table, and then horizontally, usually in bedrock, to surface waterbodies. The estimated time delay for nitrate applied on the land to reach the water table in the freely draining setting depends primarily on soil and subsoil thickness as velocities in bedrock are far faster than in soil/subsoil. Estimates of vertical travel times through soil and subsoil for the different depth to bedrock scenarios illustrated in Figure 6-2 are given in Table 6-1. Varying depths to bedrock, including shallow depths, are representative of the situation present in many areas where nitrate is a *significant issue*. Once nitrate enters groundwater in bedrock, horizontal velocities are rapid, typically in the range 1-10 m/d in rock fractures (velocities in conduits in karstified limestones are 10s metres/day). In addition, nitrate fertilisers can potentially be applied to within 3 m of watercourses. Therefore, the lag time provided by groundwater flowing in bedrock is typically limited to between 1 to perhaps 100 days, depending on the distance to the watercourse. Therefore, once nitrate mitigation measures are established in scenarios where there are varying soil/subsoil thicknesses and, in places, shallow depths, groundwater with reduced concentrations should start to reach watercourses within less than 6 months, with the start of a downward trend likely. However, in view of the varying depths to bedrock, it could take a number of years to get the substantial reductions in nitrogen load needed to achieve the water quality objectives.[22]

Table 6-1: Estimated travel times for nitrate leached from soil to reach the water table.

Depth to bedrock (m)	0-1	2	5	10
Travel time (years)	<1	1-2	2.5-5.0	5-10

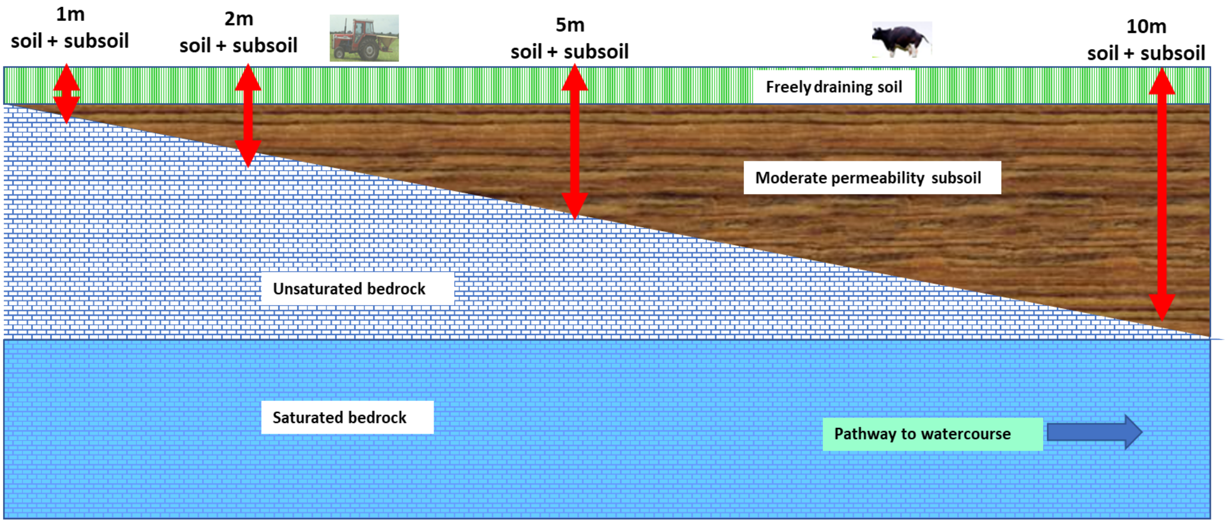


Figure 6-2: Illustration of the varying depth to bedrock scenarios that influence travel times for water and nitrate to the water table.

6.2.5 Mandatory, incentivised and voluntary measures

All the significant pressures impacting on waterbodies have mandatory measures to prevent or reduce impacts. For instance, a key requirement for agricultural activities is compliance with the measures in the Good Agricultural Practices Regulations (2022) (SI 113 of 2022 as amended by SI 393 of 2022 and SI 716 of 2022). However, while essential and beneficial for preventing impacts, even when implemented fully, they may not be adequate without additional supplementary measures. The reasons are that they tend to be ‘one size fits all’ and are not usually sufficiently risk-based or localised to achieve the ‘right measure in the right place’ requirement. In general, they are more likely to have a greater role in *Areas for Protection* than in *Areas for Restoration*, as improvement usually requires specifically targeted (location and type) measures, for instance in CSAs and flow delivery pathways. Therefore, incentivised and voluntary measures are critical, particularly in *Areas for Restoration* but also in many instances in *Areas for Protection.*

Planning control has a critical role in HSO waterbody catchments (Ní Chatháin *et al*. 2013)[23]. High status objective waterbody catchments should be integrated into public authority mapping systems, so that priority can be given to protecting these sensitive aquatic ecosystems.

6.3 Measures Selection in Areas for Restoration

Measures for the following *significant pressures* have been assessed: agriculture, forestry, peat extraction, quarries and domestic wastewater treatment systems (DWWTSs). Reports, in the form of

[22] Further more detailed information is available in Appendix 12, LAWPRO (2022a) and at this link: *https://thewaterforum.ie/app/uploads/2020/06/Time-Delays_May2020.pdf*
[23] https://www.epa.ie/publications/research/water/strive-report-99.php

annexes to this document, with tables of measures and accompanying advice on the measures for each pressure have been produced. They include consideration of the following components that are relevant to the choice of measures in *Areas for Restoration*:

- The pollutants and issues impacting on waterbodies, such as sediment, phosphate, nitrate, ammonium, BOD, MCPA, FIOs, DOC, pH, hydrocarbon and hydrology (water levels and flows).
- The location of the pressures in the landscape.
- The soil drainage characteristics.
- An estimate of the effectiveness of measures to be used as a guide in assessing and deciding on possible measures. Four categories are given – High (H), Medium (M), Low (L), Insignificant (-).
- Whether the measure is mandatory or incentivised/voluntary.

The Annexes and web links are as follows:

- Annex 1: Agriculture: Measures from Mitigating Significant Issues arising from Agricultural Activities (Water of Life 2023b).
- Annex 2: Forestry: Measures from Mitigating Significant Issues arising from Afforestation (Water of Life 2023c).
- Annex 3: Peat Extraction: Measures from Mitigating Significant Issues arising from Peat Extraction (Water of Life 2023d).
- Annex 4: Quarrying: Measures from Mitigating Significant Issues arising from Quarries (Water of Life 2023e).
- Annex 5: Domestic Wastewater Treatment Systems: Measures from Mitigating Significant Issues arising from Domestic Wastewater Treatment Systems (Water of Life 2023f).

Habitat morphological impact is the *significant issue* that causes most failures of the high status objective. Hydromorphology as a pressure is being assessed currently by the EPA Catchments Unit and LAWPRO, and the outcomes will be used by the Water of Life project.

6.4 Measures Selection in Areas for Protection

6.4.1 Introduction

Prevention of deterioration of HSO waterbodies is a critical goal where they are in a satisfactory condition. The risk-based assessment or 'story' for the *Areas for Protection* provides the basis for consideration of protection measures as it provides information on the following:

- Pollutants of concern: Whether is evidence from the water quality assessment (hydrochemical and/or biological) that there is a pollutant of concern that might pose a threat in the future.
- Pathways in the landscape:
  i) Poorly draining and freely draining areas.
  ii) Susceptible areas for the pollutant of concern.
  iii) Flow delivery pathways and points (from the PIP-P maps)
- Potential pressures:
  i) Where there is evidence that there is a pollutant of concern, what the likely pressure is that is contributing these pollutants.
  ii) PIP maps showing relative pressures where nitrate or phosphate are the pollutants of concern.
  iii) Where there is no clear evidence (this is a common scenario), known pressures with a relatively high pollutant loading, e.g. a small WWTP, intensive dairy farms.
  iv) Input from regulatory bodies such as local authorities and IFI.

6.4.2 Recommended approach

The focus for measures has tended to be in *Areas for Restoration*. However, increased attention needs to be given to measures in *Areas for Protection*, particularly as HSO waterbodies represent relatively pristine aquatic ecosystems. Allocating resources for and decisions on protection measures is, arguably, more challenging and less clear-cut in *Areas for Protection* because i) pressure owners, such as farmers, foresters and householders, have maintained satisfactory water quality and ecosystems, ii) pressures are potential not actual and are not easy to locate, and iii) relevant pathways are more difficult to determine.

The recommended approach is as follows:

- Inspections for mandatory measures need to be targeted on the higher risk pressures (both point and diffuse) and areas that have been determined by the risk-based assessment. This is critical as the number of inspections undertaken are generally far less per unit area in *Areas for Protection* than in *Areas for Restoration*.
- Depending on the pollutant of concern and potential pressure highlighted by the risk-based assessment, the measures listed for the various pressures in the Water of Life Measures Annexes should be assessed. The effectiveness ratings for the measures need to be considered on a case by case basis. However, in general, the effectiveness ratings would be higher than shown on the tables because the objective is to maintain the existing satisfactory situation.
- Voluntary measures should be encouraged by awareness-raising and funding of communities to establish measures.
- Results-based payments schemes can play an important role in both the protection and restoration of high status objective water bodies. In areas for protection, payments focused on management practices which can be easily evaluated and directly linked to positive water quality outcomes can encourage landowners to continue with these practices. An example of such a positive management practice could be minimising drain maintenance and allowing drains to become vegetated as this can reduce losses of sediment and phosphorus to rivers.

6.4.3 Results Based Payments Schemes.

Results-based payment schemes (RBPS) can play a crucial role in protecting environmental assets, including water quality, by providing financial incentives for achieving specific conservation and sustainability outcomes. These schemes are designed to reward individuals, communities, or organizations for delivering measurable and verified environmental results.

The key principle behind results-based payment schemes is that payments are linked to actual environmental outcomes rather than specific activities or inputs. This approach ensures that funds are allocated efficiently, as payments are contingent upon achieving predefined targets or standards. Monitoring and evaluation systems are put in place to measure and verify the results, ensuring transparency and accountability. By providing financial incentives, results-based payment schemes encourage stakeholders to adopt sustainable practices and invest in conservation efforts. They promote the efficient allocation of resources, as payments are directly tied to environmental performance. Additionally, these schemes can facilitate collaboration and partnerships among different actors, fostering collective action and knowledge sharing to protect water quality and other environmental assets.

To date most results-based payments schemes in Ireland have focused on terrestrial biodiversity, for example the Burren Programme[24] and the Hen Harrier Project[25]. However, The Pearl Mussel Project[26]

[24] http://burrenprogramme.com
[25] http://www.henharrierproject.ie
[26] http://www.pearlmusselproject.ie

introduced a whole card scorecard which assessed risk to water courses on a whole farm basis and was an important step in adapting results-based payment schemes to deliver for water quality.

All of the schemes introduced in Ireland have been hybrid schemes. In this model, landowners are supported to implement measures (called non productive investments and landscape measures) which help to increase their scores related to the results-based element of the scheme. In this way, RBPS can play an important role in restoring as well as protecting environmental assets.
To date RBPS in Ireland have focused on areas of less intensive land use and high nature value farming. There will be challenges in adapting this model for areas of more intensive land management.

Table 6-2: Summary of categories of options and their effectiveness in surface water catchments.

Pollutant	**Protection & Mitigation Options**				**Main landscape setting & pathway**
	Source Reduction	**Mobilisation control**	**Pathway interception**	**Instream works**	
Sediment	High	Very low	High	Very low	• Poorly draining areas. • Runoff after heavy rainfall.
Phosphate	Moderate	Moderate	High	Very low	• Poorly draining areas. • Overland and along flow delivery pathways.
Nitrate	High	Low	Very low	Very low	• Freely draining areas. • Underground to groundwater.[27]
Ammonium	High	Very low	High	Very low	• NH_4 usually indicates a nearby pressure as it readily converts to NO_3. • Surface or underground pathways.
BOD	High	Very low	Low	Very low	• Usually an indicator of organic matter from a point source. • May arise in drained raised bog areas.
FIOs	Low	Very low	High	Low	Excessive pathogen numbers are likely to arise mainly from land runoff, dirty water from farmyards and cattle in streams.
MCPA	High	Low	High	Very low	• Wet, poorly draining areas. • Overland flow.

Note: The symbol size is a guide to the likely effectiveness of options in each category.

High Moderate Low Very low

Acknowledgement: This table is an amended version of a table in NFGWS (2020).[28]

[27] Along every stream, groundwater is slowly percolating, usually unnoticeable except where there are springs, into the stream bottom throughout its length. Groundwater contributes between 20-70% of average stream flows, depending on the geology in the catchment – a higher proportion where the stream is underlain by a Regionally Important or productive aquifer and a lower proportion where underlain by a poor or relatively unproductive aquifer.
[28] https://nfgws.ie/nfgws-source-protection-publications/

7 Environmental Co-benefits

The effectiveness ratings for the measures listed in the Annexes are assessed from a water quality and aquatic ecosystem perspective. However, reflecting the interconnectedness and interdependencies of our earth system, many of the measures described in this report have benefits not only for water quality and aquatic ecosystems but also for other environmental realms, as shown in Figure 7-1 (An Fóram Uisce, 2021)[29]. In addition, it is increasingly being recognised that 'water is the bloodstream of our earth system'[30], thereby emphasising the general environmental relevance and importance of the measures undertaken in HSO waterbody catchments. Therefore, where individual measures described in the Appendices have environmental co-benefits, a brief description of these co-benefits is given.

Source: An Fóram Uisce (2021)

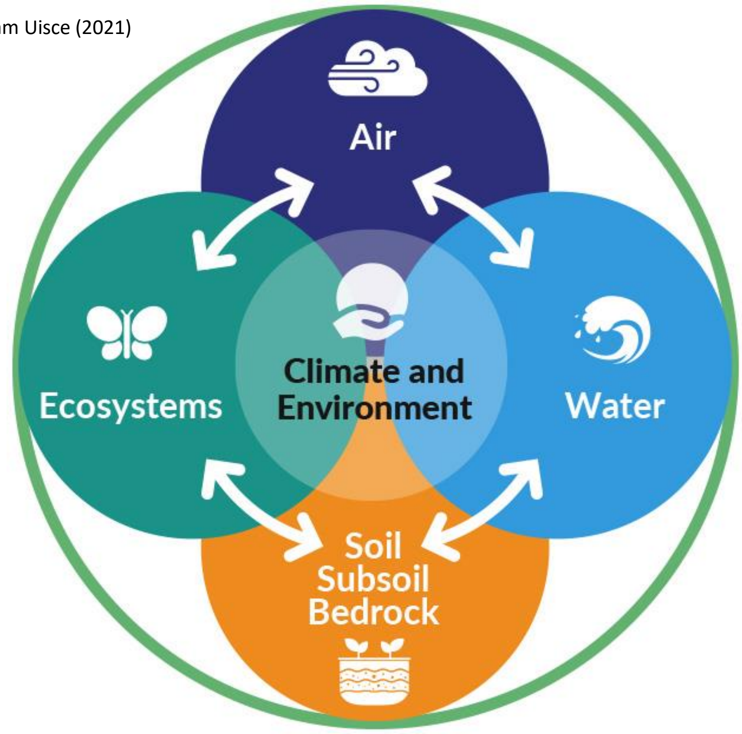


Figure 7-1: Illustration of the interconnectedness and interdependencies of the environmental realms.

[29] An Fóram Uisce, 2021. A Framework for Integrated Land and Landscape Management. https://thewaterforum.ie/app/uploads/2021/03/TWF-FILLM-Report-Feb21-v9WEB.pdf

[30] https://www.stockholmresilience.org/research/research-news/2019-03-30-water-as-the-bloodstream-of-the-biosphere.html

8 Monitoring

8.1 The Role of Monitoring

Monitoring of water quality condition and trends is an essential tool in assessing the effects of measures implemented and of changes in land use or land management which might impact on the aquatic environment. Monitoring supports policy development and its implementation, and provides information for reporting to national policymakers, international forums and the public.

Additionally, monitoring provides valuable data for adaptive management. By regularly collecting and analysing information, project teams can identify any unexpected or unintended impacts of the restoration activities and make necessary adjustments to improve future outcomes. This iterative process ensures that restoration strategies are continuously refined and optimized based on empirical evidence.

Furthermore, monitoring allows for accountability and transparency. It enables project stakeholders, including regulatory agencies, community members, and funding organizations, to evaluate the project's performance and ensure that resources are being used effectively. By demonstrating measurable progress and successful outcomes, monitoring helps build trust and support among stakeholders

8.2 Water Framework Directive Monitoring

The EPA operates an extensive water quality monitoring network covering 3,206 water bodies, including 2,345 rivers. This information is used to assign status to individual water bodies under the Water Framework Directive. The EPA monitors rivers for a range of parameters including:

- Biology (e.g macro invertebrates, fish, macrophytes, phytoplankton).
- Supporting water quality physico-chemcial conditions (e.g. nutrients, BOD, metals).
- Supporting hydrology and morphology (high status objective rivers only).
- Priority substances and priority hazardous substances (e.g. pesticides, hydrocarbons).

Status is assigned based on the lowest quality element. For example, if a water body has high status based on Q value but only good status based on fish, it is considered to be at good status. However, not all parameters are assessed at every site and the most commonly used parameter for the assignment of status is Q value. This is linked to status as shown in Table 1-1.

8.3 Project Level Monitoring

The EPA monitoring is essential for assessing long term trends in water quality and for reporting to the European Commission on Ireland’s performance with respect to the objectives of the Water Framework Directive. However, it is not sufficiently high resolution to allow identification and isolation of individual pressures on a water body or to assess the impact of measures that are implemented. For these latter purposes, detailed catchment characterisation and higher resolution data capture, which is specifically tailored to the circumstances in question, is required.

The nature of monitoring carried out will be determined by its objectives. For example, in catchment characterisation, rapid biological assessment techniques such as the small streams impact score (SSIS) are used by catchment scientists to quickly identify areas where rivers may be adversely affected by pressures in the catchment and where further investigation is required. In-situ measurements of temperature, pH and conductivity can also be useful in helping to isolate pressures.

However, for assessing the effectiveness of measures a more comprehensive monitoring programme may be required. In such cases, the monitoring programme should be established prior to implementation of the measures. This will allow base line conditions to be assessed with respect to relevant parameters, with particular emphasis on pollutants of concern or *significant issues* within a given waterbody. A sufficient number of monitoring points should be included to ensure that localised impacts and spatial variations can be isolated, and sampling should be sufficiently frequent to allow seasonal and climatic fluctuations to be identified.

The monitoring programme should be designed to complement a particular programme of measures and with the objectives of the latter programme in mind from the outset. Monitoring should also consider the catchment characteristics and the pathways that are likely to exist (e.g. groundwater monitoring might be considered where nitrate is the significant issue in a river). This will allow tailoring of the monitoring system to effectively and efficiently assess whether the programme of measures is meeting its objectives. A set of Key Performance Indicators should be developed that can be used to track the effectiveness of measures in protecting or improving the condition of the relevant waterbodies.

8.4 The Role of Citizen Science

Citizen science is a valuable form of public participation that involves non-professional scientist volunteers in collaborative scientific investigations, providing professional researchers with access to localised data at extensive spatial and temporal scales that would otherwise be impossible or prohibitively expensive to obtain (Dickinson *et al*. 2012)[31].

Citizen Science is now part of the European Commission's agenda and work programme, and has been given high level support as one of the 10 actions in their policy document on 'Actions to Streamline Environmental Reporting'. The Commission's action is to "promote the wider use of citizen science to complement environmental reporting".

Citizen science water-related projects can focus on monitoring various aspects of the aquatic environment including habitat, water chemistry (e.g. nutrient levels), biology, invasive species and abiotic conditions. The Local Authority Waters Programme (LAWPRO) is actively involved in trialling and promoting citizen science approaches to monitoring water quality. In particular, it has been involved in trialling the Citizen Science Stream Index which was developed in collaboration with the EPA, DCU and UCC.

Links to useful information on water related citizen science programmes

https://dcuwater.ie/water-blitz/#:~:text=It%20was%20found%20that%2081,%2C%20with%2019%25%20lower%20quality
https://catchmentbasedapproach.org/learn/citizen-science-volunteer-monitoring/
https://lawaters.ie/citizen-science/
https://www.freshwaterwatch.org/

Not only have data gathered by citizen scientists informed researchers of environmental conditions, but citizen science activities also help to build local community awareness of those environmental conditions. This can increase ecological identity and a sense of place that can motivate and empower

[31] https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/110236

individuals to take action or to become involved in volunteering and in policy and decision-making to remedy environmental issues within their local communities (Weiner *et al.* 2022)[32].

Where possible, citizen science approaches should be considered in the development of water quality monitoring programmes in order to supplement the data collected by project teams and also to leverage the benefits of increased awareness and stewardship mentioned above.

[32] https://theoryandpractice.citizenscienceassociation.org/articles/10.5334/cstp.447/