Catchment Science and Management
A Guidance Hand Book

Volume 1
An overview of Catchment Science and Management

April 2022

Local Authority Waters Programme – vibrant communities | catchment assessment | healthy waters

epa Catchments – Healthy • Resilient • Productive – Valued water resources supporting vibrant communities

An Roinn Tithíochta, Rialtais Áitiúil agus Oidhreachta
Department of Housing, Local Government and Heritage

LASNTG

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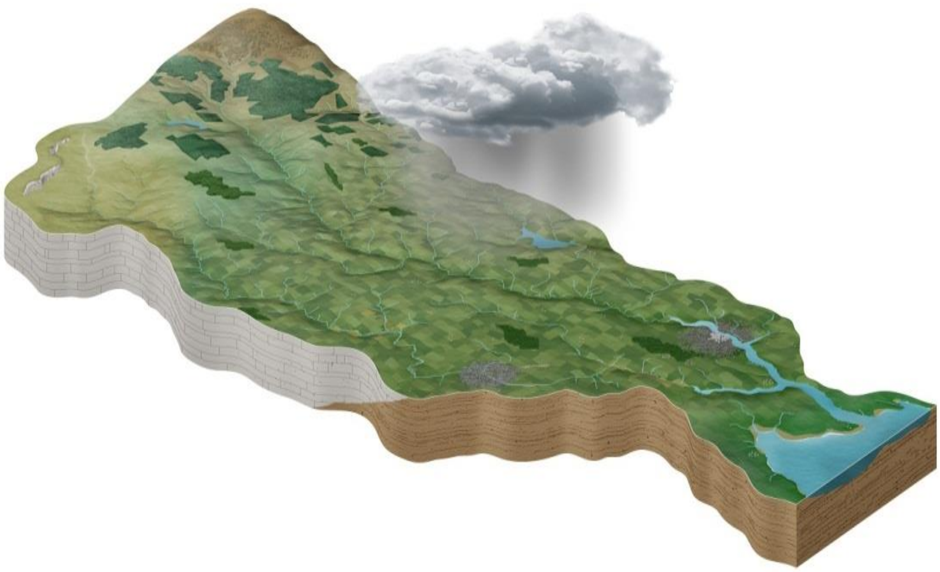

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Preface

Successful water management is challenging and resource intensive; it is also essential as a means of protecting our water resources and the associated ecosystems. Therefore, it needs to be a priority for the broad range of public bodies with responsibilities for different components of the water environment – see Box.

Public bodies with water resources management roles

Government Departments, Local Authorities (including the Local Authority Waters Programme (LAWPRO)), Environmental Protection Agency (EPA), Inland Fisheries Ireland (IFI), National Parks and Wildlife Service (NPWS), An Fóram Uisce, Teagasc, Irish Water, OPW, etc.

Considerable progress has been made in water resources management over several decades. In recent years, the implementation of EU Directives, such as Water Framework, Groundwater, Habitats, Drinking Water, Nitrates, Floods and Urban Wastewater Treatment, has led to increased efforts and resources for water protection and management. Improvements occurred in some water bodies due to the efforts of public bodies, such as local authorities. However, in spite of these efforts, our water quality and ecosystems deteriorated in other water bodies. In addition, national and international policies and recommendations are requiring a more integrated approach to environmental management, with water being one of several interconnected and interdependent components that include sustainable food production, a new biodiversity strategy, and climate change adaptation and mitigation.

In recent years, the work of the EPA Catchment Science and Management Unit (hereafter called the Catchments Unit), LAWPRO, the Teagasc and Dairy Co-op Agricultural Support and Advisory Programme (ASSAP), the Teagasc Agricultural Catchments Programme (ACP), National Federation of Group Water Schemes (NFGWS), European Innovation Partnership (EIP) projects and research projects, has led to an improved understanding of our water resources, including water abstraction, water quality, aquatic ecosystems, groundwater and pressures on water in the Irish landscape. This understanding is becoming the basis for the actions and measures needed to manage, protect and improve our water resources and associated ecosystems, as required.

In 2018, the EPA Catchments Unit prepared a document on **Guidance on Further Characterisation for Local Catchment Assessments (Version 1)** primarily intended for use by the new LAWPRO teams and staff in Local Authorities tasked with undertaking Local Catchment Assessments. The content of the Guidance reflected a collaborative effort between invited specialists from several stakeholders in environmental management in Ireland who were members of an Investigative Assessment Development Group. Also in 2018, courses that combined integrated catchment management and local catchment assessments were organised by the EPA Catchments Unit and were attended by LAWPRO catchment scientists and ASSAP advisors.

Since 2018, the work of LAWPRO in 189 Priority Areas for Action (PAAs), EPA Catchments Unit, ASSAP, EIP projects, NFGWS and others has expanded our knowledge of catchment science and management. It has also led to the conclusion that the approaches used by LAWPRO and the EPA Catchments Unit need to become more prevalent among the public sector bodies with responsibilities for the various interrelated environmental components, including water.

Consultation between the Water Quality Section in the Department of Housing, Local Government and Heritage (DHLGH) and LAWPRO led to funding being made available in 2021 and 2022 to rollout the training to local authority and public agency staff.

The Guidance Handbook consists of the following volumes:

Volume 1: An Overview of Catchment Science and Management
Volume 2: Pressures and Catchment Walks.
Volume 3: Observed Indicator Features and Catchments Walks.
Volume 4: Measured Indicator Parameters and Catchment Walks.
Volume 5: Urban Catchment Assessments.

Volumes 2, 3and 4, were written in 2018, and Volume 5 was written in 2020. These are retained in this Handbook with no or minimal changes – where they have been changed, this is stated.

Volume 1 is an outline of catchment science and management that takes account of progress made and lessons learned by LAWPRO and the EPA Catchments Unit since 2018. Throughout Volume 1, reference is made to the additional explanatory information in the other volumes.

This Guidance Handbook (and the linked training course) covers the catchment science and management aspects for the following areas:

1. Water Framework Directive (WFD) and River Basin Management Plan implementation.
    i) Protecting water quality where it is *Not at Risk* of meeting the required status objectives.
    ii) Restoring water quality where it is *At Risk* of not meeting the required status objectives.
2. Drinking water source protection.
    i) Protecting untreated source water where it is satisfactory.
    ii) Improving untreated source water where it is unsatisfactory.
3. Protection of sensitive receptors, such as shellfish and bathing waters.
4. Compliance assurance.
5. Site environmental assessments.
6. Co-benefits of measures/actions, thereby linking with terrestrial ecosystem management and climate actions.

While the focus is oriented primarily towards watercourses in a catchment/sub-catchment context, the content, processes and approaches described are also applicable to groundwater, water abstraction, developments on sites and inspections.

When referencing this Volume of the Guidance Handbook on Catchment Science and Management, please use the following citation:
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Contents

1 Introduction

The variability and complexity of our biophysical environment – soils, subsoils, bedrock, ecosystems and weather – makes assessing and determining water movement in the Irish landscape both interesting and demanding. Add to this situation the heterogeneity of human activities locally and regionally, whether in towns or in rural areas, then the challenge of achieving effective water resources and related ecosystem management, and attaining the required environmental objectives is apparent. However, in the current context of i) deteriorating water quality and biodiversity, ii) increasing greenhouse gas emissions, iii) our food system in Ireland, and iv) our socio-economic needs, progress in protecting, managing and enhancing our environment, including our water resources, is absolutely essential.

While this is undoubtedly a challenging and complex situation, managing our water resources effectively and efficiently to achieve water quality objectives is also straightforward and achievable. There are **fundamental principles** and **processes** that, if followed, will enable this. The key to successful protection and management of our water resources is **understanding** the situation in catchments or at sites, and then basing the **actions/measures** to protect water quality, where it is satisfactory, or improve/restore, where it is unsatisfactory, on this understanding. We now have extensive information and knowledge, sufficient understanding and the 'tools' (see Table 2-1). What we do not have are sufficient trained scientists and engineers or the necessary resources.

Once we understand, based on adequate evidence and an appropriate assessment of the evidence, arriving at decisions on the actions/measures needed is generally 'common sense'. The real challenge is making the actions/measures happen. However, if they 'make sense' they are more likely to be established and successful.

Water resources management and WFD implementation are based around catchments (or river basins) as the appropriate landscape units. Even when it is a site assessment or an inspection, it needs to be undertaken in a catchment as well as a site context. Currently, those undertaking the roles in these areas are from a wide variety of disciplines. In recent years, an emerging field called **catchment science** has become the means of studying the connections and relationships between the physical landscape, ecosystems and human activities within a catchment (as illustrated in Figure 1-1), thereby providing the required understanding for decisions on the measures and actions needed. These three elements are linked within the source-pathway-receptor (SPR) framework. Therefore, catchment scientists must have a firm knowledge of all the source (pressure), pathway and receptor elements, a good grounding in appropriate measures, and a capacity to integrate, analyse and synthesise that knowledge to gain new understanding for the purposes of answering relevant catchment science and management questions. As catchment science is a relatively new discipline, **the purpose of Volume 1 is to provide an outline of catchment science and management, including the fundamental principles and processes, information of the water receptors, the pressures, the pathways and the process for deciding on protection and mitigation measures and actions.** The aim is that this Volume and the four accompanying Volumes in the Handbook, together with the training course, will provide scientists from different disciplines and backgrounds with sufficient knowledge on all the relevant scientific areas so that we, as catchment scientists, can collect, understand and integrate the wide variety of necessary information, collaborate and communicate our findings.

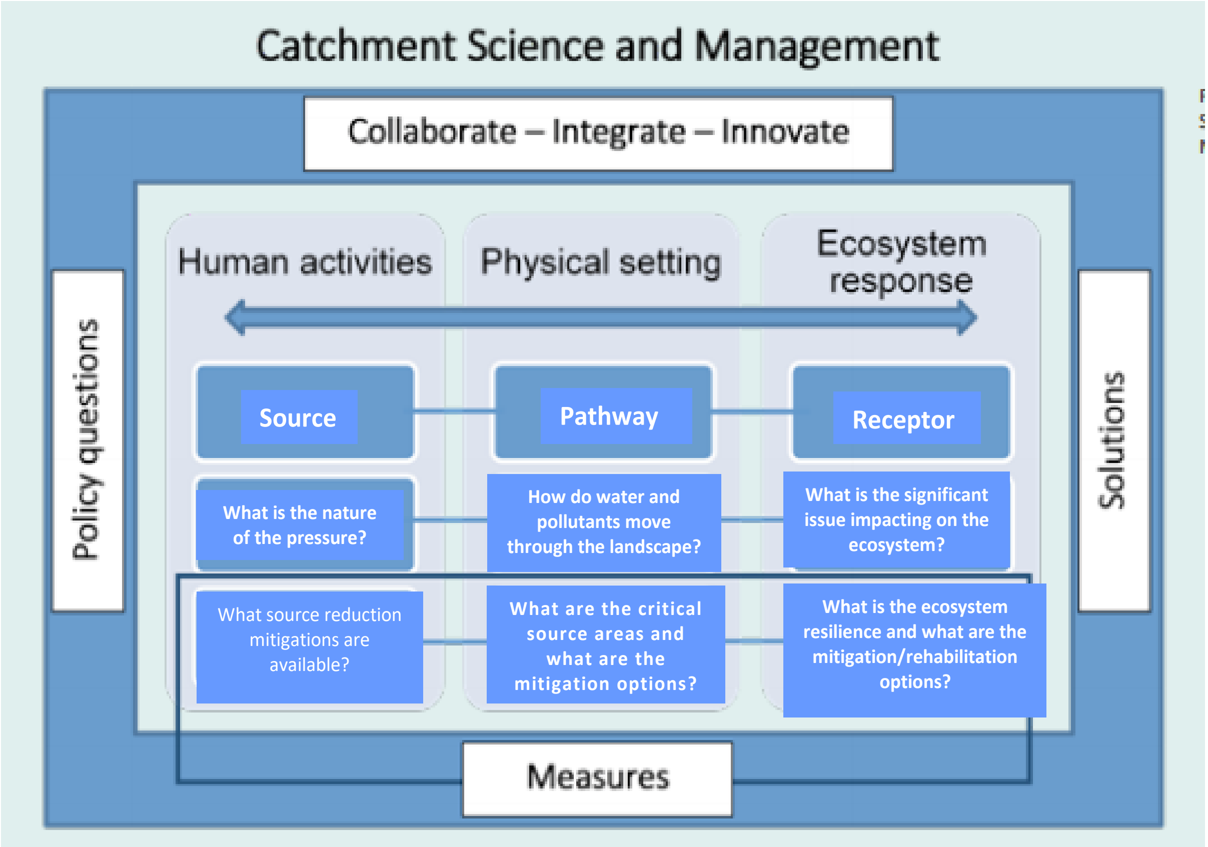

Figure 1.1: Illustration of the catchment science and management nexus (Copied from Deakin (2017). Catchments Newsletter, Issue 7 https://www.catchments.ie/download/catchments-newsletter-sharing-science-stories-winter-2017/)

The requirements of a catchment scientist in a public body, such as a local authority, are broad ranging. They include:

- Protecting water quality in catchments/sub-catchments where it is satisfactory.
- Mitigating impacts in catchments/sub-catchment where it is unsatisfactory.
- Protecting drinking water sources, both groundwater and surface water.
- Fulfilling requirements for, for instance, bathing waters, shellfish waters, water pollution complaints.
- Undertaking an inspection.
- Assessing a development on a site.
- Communicating with senior management.
- Communicating and collaborating with the public.

In addition, there may be roles and responsibilities (or are likely to be in the future) for biodiversity protection and climate actions.

In a context of limited resources – time, staffing, financial – basing work on a logical process enables achievement of the required objective in as effective and efficient a way as practicable. **Three elements are recommended:**

1. **Set a realistic objective[1] and then focus on it.**

[1] If achieving a required objective, such as good status in a water body, isn't realistic in the short-term, then we can set intermediate objectives and benchmarks, and show progress towards reaching the required objective.

2. **Use the source-pathway-receptor (SPR) framework (Figure 1-2)** (see Section 6.4 for greater detail) **as the overarching thought process and work structure.**
3. **Use the process flowchart in Figure 1-3 as the recommended approach.**

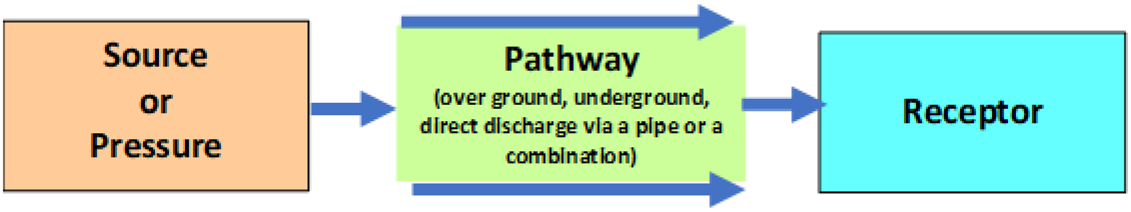

Figure 1-2: The source-pathway-receptor (SPR) model for environmental management.

The process outlined in Figure 1-3 provides a systematic, focussed approach to deciding on and implementing protection (where situation is satisfactory) and mitigation (where situation is unsatisfactory) measures and actions as a means of increasing the likelihood of achieving the desired environmental outcomes (**Section 8**). The process includes three broad stages, each of which are described in this Volume:

1. Characterisation.
2. Protection and mitigation actions.
3. Monitoring progress and making adjustments.

Characterisation is undertaken generally in stages. The starting point is the receptor and its requirements (**Section 9**). Then a desk-based assessment of existing data and information is undertaken (**Section 10.2**) to decide whether the situation is 'satisfactory', 'unsatisfactory' or 'undetermined'. This leads automatically to a decision on whether the environmental objective is to 'protect' (or 'maintain'), 'restore' (or 'improve') or collect more information (**Section 10.3**). It also leads to a conclusion on the pollutants of concern, if present. Then the pressures providing the pollutants are assessed (**Section 10.4**). Where diffuse and small point activities are the pressures, an understanding of the pathways between the pressure and the receptor is essential (**Section 10.5**). The integration of all this information allows an interim 'story' to be told (**Section 10.6**), which enables a work plan to be determined (**Section 10.7**). At this stage, the options depend on the situation: i) where the water quality situation is 'undetermined' and samples need to be taken for analysis or the biology needs to be checked (**Section 11.1**); ii) a point source discharge assessment is needed (**Section 11.2**); or a site or facility inspection is needed (**Section 11.3**). Where diffuse and small point sources are the pressures, it is usually necessary to undertake a 'catchment walk'[2] and a field-based assessment (**Section 12**). The outcome will be the 'Story of the Catchment' (**Section 12.6**) or the 'Story of the Site', which include a summary of the situation and the conclusions which now provide a basis for the actions and measures needed to protect or improve, as relevant, the water quality.

While characterisation is an essential pre-requisite to protection or mitigation, it is **implementation of protection/mitigation measures/actions** that are key to achieving water quality outcomes. Options need to be assessed (**Section 14.3**) as well as the likely time delays where improvement is required (**Section 14.4**). Then, an implementation programme of targeted measures and actions is designed and planned (**Section 14.5**), followed by implementation (**Section 15**).

Finally, **progress needs to be monitored** and adjustments made to the measures/actions, if necessary (**Section 16**).

[2] This is sometimes called a 'stream walk'. However, 'catchment walk' is more appropriate because it is necessary to note and evaluate features in the catchment area to the stream as well as in the stream itself.

Throughout the Handbook, **catchments** are taken as the landscape units for water management (**Section 5**). While the orientation of the process outlined above is towards either protecting from impacts or mitigating impacts in catchment areas of streams varying from drainage ditches to large rivers, much if not all of it is also relevant to site inspections and facility assessments.

The context for catchment science and management is important to understand. It is driven by **EU Directives**, particularly the Water Framework Directive (WFD) (**Section 3**). In 2000, when the WFD was enacted, there wasn't agreement on how to deal with groundwater. In 2006, the Groundwater Directive, with its own requirements, was ratified (**Section 4**). Groundwater (**Section 13**) is not only a major source of drinking water, but also provides substantial proportions of flows in watercourses and critical inputs to many ecosystems.

Overarching frameworks are needed to 'tie together' and integrate all the various components of not only water resources management but also environmental management as a means of considering 'whole of environment' components and linkages. In recent years, **Integrated Catchment Management (ICM)** (**Section 6.2**) was the approach used to enable this. More recently, **the Framework for Integrated Land and Landscape Management (FILLM)** (**Section 6.3**), which encompasses ICM, has been proposed as the means of connecting and managing all the environmental components – water quality and quality, air and climate, habitats and biodiversity, landscape, soils and geological materials – as well as the relevant disciplines and organisations.

The content of this Volume is based on the experiences and knowledge gained in recent years by Local Authorities Waters Programme (LAWPRO) and the EPA Catchments Unit.[3] It is not 'set in stone' and continued learning is essential. Readers can contribute to this by communicating with both organisations.

The climate crisis is the greatest environmental threat facing not only Irish society but also humankind. Our biodiversity is declining. Our water quality is deteriorating. At the same time, the world population is increasing, maintaining safe, secure and stable water supplies and managing our wastes is challenging, and there is a need for a sustainable and resilient food production system. All these issues are interconnected and interdependent. Many if not most of the solutions will be on our land and landscapes. Therefore, those who understand the many facets of our land and landscapes, including the interactions with human activities, have a crucial role in developing effective and efficient solutions, and enabling establishment of these solutions.

Catchment science as a discipline and catchment scientists as a profession are well placed to contribute to achieving these solutions.

[3] Acknowledgement: This Volume was drafted largely by Donal Daly (formerly EPA Catchments Unit) on behalf of LAWPRO and the EPA Catchments Unit and is based on their work and catchment science and management approaches.

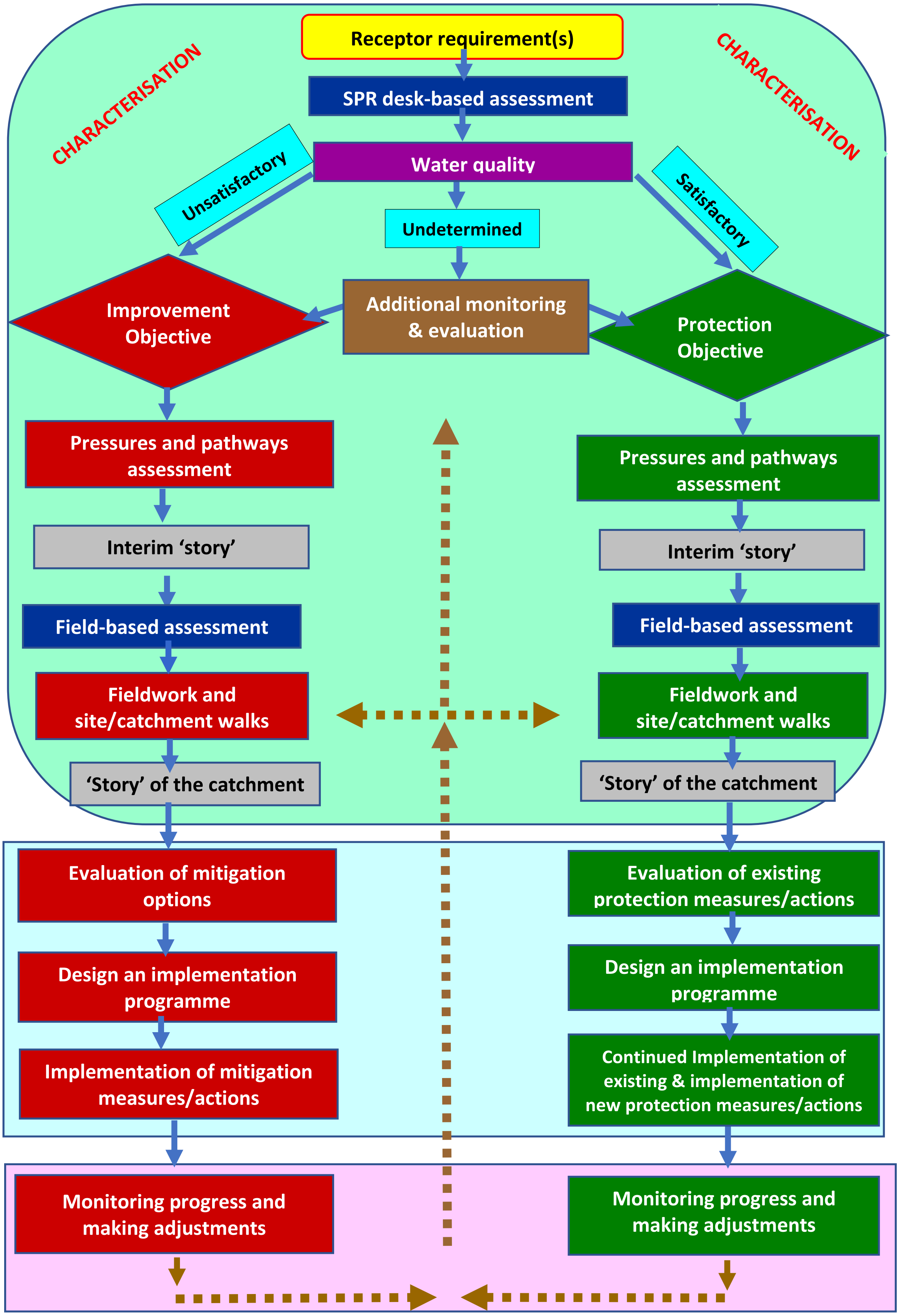

Figure 1-3: Flowchart illustrating the recommended approach for water resources and ecosystems protection and management.

2 Characterising & Managing Our Water Resources – Some Basic Principles

2.1 Introduction

Characterising and managing our water resources involves using a multitude of techniques and methods, many of which are associated with specific disciplines. While these techniques and methods are relevant and important, and are generally well known, they nevertheless can be inefficient and ineffective unless they are part of a framework that encourages targeting as a means of achieving environmental outcomes. Without this, they may result in being just 'activities without achievement' or at least insufficient achievement for the effort made. This is summed up by the quotation, slightly amended from H. Emerson, *"As to **methods** there may be a million and then some, **but principles are few**. The person who grasps **principles** can successfully select their own **methods**. The person who tries **methods**, ignoring **principles**, is sure to have trouble."* Or, more simply, 'principles before methods/techniques'.

50 principles that guide characterisation and management of water resources in the context of EU Directives, such as **Water Framework Directive (WFD), Drinking Water Directive (DWD), Shellfish Directive, Bathing Water Directive and Habitats Directive (HD),** are outlined in this Section.

2.2 Principles

2.2.1 Overarching Principles

1. **Focus on the objective, the achievement of environmental outcomes,** particularly water quality objectives, but also objectives for flood mitigation, biodiversity enhancement, carbon sequestration and soil protection. Therefore, **environmental outcomes** are the key gauge of success, rather than the account of the activities undertaken.

2. **Subdivide the objective into two categories[4]:**
   i) **Protection**/maintenance, where the situation, e.g. water quality, is satisfactory in '*Areas for Protection*'.
   ii) **Improvement/restoration** requiring mitigation, where the situation is unsatisfactory, for instance in '*Areas for Restoration'*.

3. Use **multi-disciplinary[5], multi-organisational and integrated approaches**. Allied to this is consideration of **co-benefits** (for biodiversity and carbon sequestration, for instance) when considering strategies and activities.

4. **Design policies and regulations** which are focussed on achieving the environmental outcomes.

5. **Use targeted approaches** to improve efficiency in achieving water quality goals.

6. **Pick important problems and fix them.** In any area, such as a catchment, there will be a multitude of environmental stressors (e.g. pollutants) and pressures. The key is to pick those that will 'make a difference' and to fix them as the means of achieving whatever the objective is.

[4] This subdivision is necessary because the focus and the measures/activities will differ for each. For water bodies, while restoration to a required status is a WFD objective, the WFD also has a 'prevent deterioration' objective. For a further illustration of this point, see the NFGWS Framework for Drinking Water Source Protection at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/.

[5] For example: hydrogeologists, hydrologists, biologists, engineers, environmental scientists, agricultural scientists, geographers, social scientists, planners, environmental economists, etc.

7. **Use "the right measure in the right place."** Measures must be 'tailor made' and specifically targeted and prioritised on the environmental stressors and pressures, and on the relevant areas, as the means of achieving the desired environmental outcomes.

8. **Remember, "Pressure ≠ Impact".** A fundamental error is often made in catchment assessments that "the greater the pressure, the greater the impact". In addition, in many instances where there is an impact, such as unsatisfactory water quality, an assumption is made that the nearby and visible pressure is the cause. While understandable perhaps, these are generalisations and simplifications that are often, although not always, incorrect. Therefore, conclusions such as these can lead to efforts that do not achieve the objective of mitigating the impacts. More detailed analysis is needed prior to drawing conclusions.[6]

9. **Take account of scale**. Analysis and decision-making will vary depending on the scale – whether field/street, waterbody, sub-catchment, catchment or river basin district.

10. Think of **monitoring as a means not an end**. It is an activity that is necessary to measure outcomes and contribute to understandings but, on its own, is not an activity that achieves outcomes.

11. Always remember, **there is no one way!**[7]

2.2.2 Language Matters

12. **Use the right words** to 'paint the picture' **and 'tell the story'**. Precision in concepts, language and definitions is essential for achieving objectives efficiently and effectively, including WFD and DWD implementation. In addition, language must take account of and be appropriate for the recipient/audience.

13. **Categorise** water bodies in two ways for WFD implementation purposes:
    - **Status**, which is based on the state of water bodies at a point in time (2009, 2015, 2021, 2027), and is reported to the EU Commission.
    - ***Risk*** (of not meeting WFD objectives) builds on status by incorporating trends and distance to thresholds, and considers the environmental objectives. It looks forward by considering whether a water body is likely to meet its' water body objectives.

14. Pollutants and water level impacts are termed environmental stressors or 'issues'. In any catchment, there will be many potential environmental stressors/issues and pressures that contribute to impacts. In *Areas for Improvement*, where an issue or pressure is categorised as '**significant**', they need to be targeted as part of either WFD or DWD implementation to achieve the improve objective. Therefore, the focus of resources (time, staff and financial) must be on ***significant issues*** and ***significant pressures*** as the means of achieving environmental outcomes, rather than on, what might be termed, 'marginal' issues and pressures which are not causing a water body to fail to achieve its' objective. In *Areas for Protection*, **potential issues/environmental stressors** and **potential pressures**, if present, need to be assigned and managed.

[6] See Section 10.4.4 for further discussion on this issue.

[7] Catchment scientists and managers must think and act like chefs not like cooks – in view of the variety of circumstances in catchments, the so-called cookbook approach will not be effective.

15. Divide the pressures into **point**[8] and **diffuse**[9]. It is relevant to distinguish between them because the approaches to understanding, locating and mitigating them, while having some similarities, have substantial differences.

2.2.3 Catchments

16. Use "**catchments**" as the appropriate land-based organising framework and landscape units for water resources management, and also the interlinked components, such as habitat protection/improvement and greenhouse gas (GHG) emission reduction.

17. Think of catchments as **3-D entities**.

18. **Catchments link all water body types** – groundwater, rivers/streams, lakes, estuaries and coastal.

19. As **catchments are 'systems'**, adopt systems thinking[10] and the systems approach[11]. The catchment system includes ecosystems, geosystems and atmospheric systems that comprise the natural environment, and the human socio-economic system.

20. **Visualise and define the catchment** as more than topographical and hydrological features; a more holistic and appropriate definition is as follows:

    A catchment is a multi-functional, topographically-based, dynamic, multiple-scale socio-biophysical system; defined by over ground and underground hydrology; connecting land, water, ecosystems, geosystems, atmospheric systems and people; and used as the basis for environmental analysis, management and governance.

2.2.4 Integrated Catchment Management and the Framework for Integrated Land and Landscape Management

21. **Integrated Catchment Management (ICM)** provides a generic approach and a framework for water management in Ireland. The **Framework for Integrated Land and Landscape Management (FILLM)**[12] encompasses and expands ICM to include the related areas of biodiversity, carbon sequestration and GHG emission reduction.

22. **Think of ICM as a series of interconnected tasks**: i) building partnerships; ii) creating and communicating a vision of ICM; iii) characterising the physical and ecological components; iv) identifying and evaluating possible management strategies and measures; v) designing an

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[8] **Point** are discharges from pipes directly to watercourses and discharges to localised areas such as soakage pits and percolation areas. They can be subdivided into 'large' and 'small'.

- Large: UWWTPs, IPPC licenced discharges, storm overflows, major spillages & leakages
- Small: Farmyards, DWWTSs, cattle drinking points, ring feeder areas, misconnections in urban areas, areas where sprayers are filled and/or washed out, minor spillages & leakages.

[9] **Diffuse** are widespread activities in the landscape. Examples include: fertilizer (organic & inorganic) application, faeces & urine from grazing animals, spraying of pesticides, leaking sewers in urban areas, polluted groundwater in urban areas.

[10] An integrated, holistic approach to analysis that focuses on the way that a system's constituent parts interrelate and how systems work over time and within the context of larger systems.

[11] A multi-disciplinary, multi-objective and multi-stakeholder framework supporting a balanced evaluation of all relevant issues.

[12] An Fóram Uisce (2021). Protecting and enhancing our environment: A Framework for Integrated Land and Landscape Management. Available from: https://thewaterforum.ie/app/uploads/2021/03/TWF-FILLM-Report-Feb21-v9WEB.pdf

implementation programme; and vi) implementing the programme and making adjustments, if necessary. Each component is essential, and 'integration' is the key process.

23. Use all the potential '**tools',** in an integrated way, to make ICM efficient and effective. The "**toolkit**" for implementation of the ICM and FILLM approaches is summarised in Table 2-1.

Table 2-1: The 'Toolkit' for the ICM and FILLM Approaches

	'Tools in the toolkit'	Linkages
Participation & Partnership ↓ Enforcement	**Public engagement** ➢ Sharing knowledge ➢ Awareness raising and learning ➢ Collaboration & participation **A vision** ➢ Both science and people ➢ 3-D integrated catchment science, using ICM/FILLM as the framework **Characterisation at catchment scale** ➢ Analysis using SPR approach ➢ Decisions on *significant issues* & *significant pressures* ➢ Location of *significant pressures* **Characterisation at local scale** ➢ 'Walking the catchment' ➢ Location of critical source areas (CSAs) ➢ Decisions on measures/actions **Programmes of measures** ➢ Measures targeted spatially ➢ Local knowledge and participation ➢ A focus on outcomes **Incentives** **New/Upgrading infrastructure** **Inspections** **Policy changes/new Regulations** (as required)	

2.2.5 Learning and Public Engagement[13]

24. **Social science** and social learning are two essential components of ICM.

25. Be mindful of **learning,** as both a process and an outcome. When dealing with characterisation and management of water resources, **learning is a never-ending process** whether dealing with the scientific aspects or when collaborating with stakeholders.

[13] Acknowledgement: Micheál O'Cinnéide advised on and contributed to this Section.

26. **Be open** to learning – without the involvement, cooperation and co-ownership of water management by local people and communities, and the opportunity to learn from these communities, the objectives will not be achieved. Therefore, social learning and community involvement are key to achieving the desired environmental outcomes.

27. **Public participation is a core Principle** of the WFD. **Engage** with and **listen** to the stakeholders (agencies, farmers, communities) from the outset to inform the catchment management work and make it an on-going process. Avoid merely responding to expert-driven approaches or top-down initiatives.

28. **Interact with the pressure owners**, as a key protection/mitigation action. This can involve two elements: i) consultation and collaboration; and ii) compliance assurance. Compliance assurance, while an essential '*tool in the toolkit'*, is a sanctions-based approach to achieving environmental objectives that can cause alienation towards environmental protection, particularly in rural communities. Therefore, consultation and collaboration are the primary interaction means of achieving environmental outcomes with inspections being the last resort 'tool' in the 'toolkit'.

2.2.6 Characterisation

29. **Understand all the key components of the landscape.** The Irish landscape is complex from many perspectives – hydrological, hydrogeological, ecological, pollutant movement and attenuation. The environmental stressors and pressures vary. In addition, the environmental objectives vary (e.g. high or good status for water bodies, conservation objectives for SACs). **Successful environmental and catchment management is dependent on our understanding** of all relevant components.

30. Use the **Source-Pathway-Receptor (SPR)** approach (Figure 2-1) as the framework for environmental management and to provide an **understanding** of all relevant components in the landscape. The SPR approach supports effective decision-making on what the stressors and pressures are and where they are arising, and what needs to be done to achieve either the protect or improve objectives. Each of these elements can exist independently, but they create a risk only when they are linked together, so that a particular pollutant or environmental stressor affects a particular receptor via a particular route or pathway.

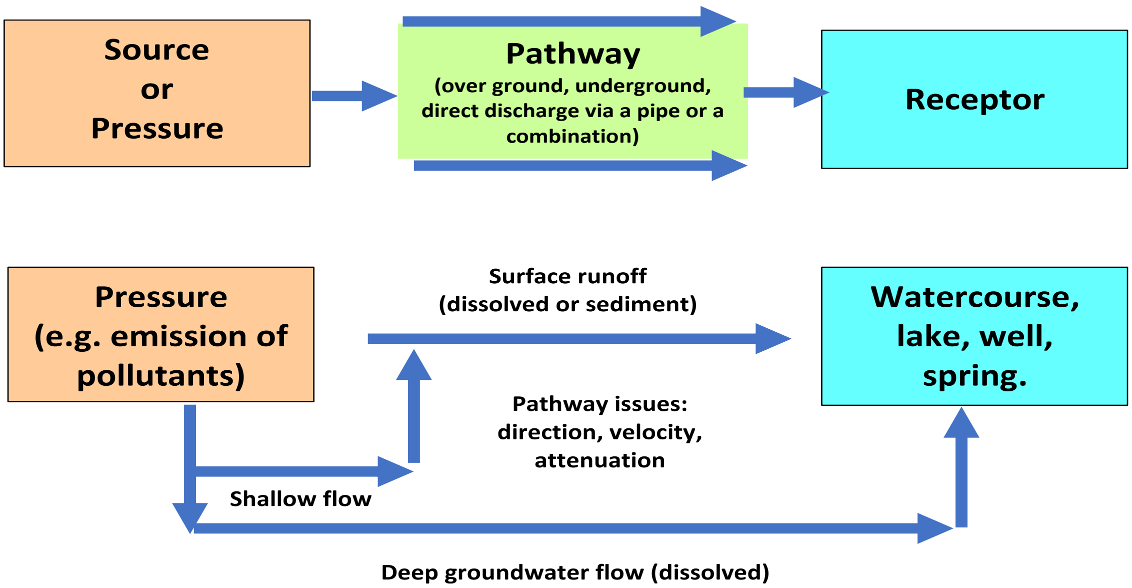

Figure 2-1: The source-pathway-receptor (SPR) model for environmental management.

31. **Base the understanding of water in catchments on a 'mental model'**[14] , which evolves as an iterative and ongoing process during **characterisation**.

32. **Make use of characterisation** to evaluate the water and pollutant movement in the landscape. It provides the understanding of how catchments work. This includes: i) the physical, hydrochemical and ecological characteristics; ii) impacts; iii) pressures; and iv) quantification of pollutant loads and abstraction amounts, as relevant, in the catchment, using the **source-pathway-receptor concept** as an overarching framework. In *Areas for Improvement*, the aim is to use characterisation to identify the ***significant issues*** and ***significant pressures*** (i.e. the pressures causing the significant issues), and in *Areas for Protection*, identification of potential issues and pressures, so that strategies, measures and resources can be prioritised and targeted to enable effective protection or restoration, as required, of our water resources.

33. For **diffuse sources, evaluate the pathway**. For many **point sources**, the link between a source pressure and a receptor is via a pipe, which makes the situation easier to understand, evaluate and deal with than diffuse sources. However, for some point sources, such as percolation areas, spillages and leakages, the pathway usually needs to be evaluated.

34. In considering the pathway, there are two main elements:

    i) The **hydraulic element**
    - Is the water (either rainfall and/or pollutants discharged onto/into land) moving away:
        - As underground flow?
        - As overland flow and/or close to the land surface?

    ii) The **attenuation element**
    - How much attenuation occurs along the pathway before a receptor is reached?

35. The **key driver** for water and pollutant movement in the landscape is **permeability** or **drainage characteristics**.
    - Permeability (or hydraulic conductivity) is more important than slope in determining whether the initial flowpaths for effective rainfall are horizontal or vertical.
    - If freely draining (moderate to high permeability scenario), the main pathway is underground, vertically to the water table and then horizontally to a surface water receptor or to a well or spring.
    - If poorly draining (low permeability scenario), the main pathways are overland and shallow subsurface to a surface water receptor.
    - In poorly draining areas, slope is the critical factor that determines the direction of water flows, and the delivery paths and points to surface water receptors.

36. **Identify the critical sources area (CSA);** this is essential to success. CSAs are areas that deliver a disproportionally high amounts of pollutants from diffuse sources compared to other areas of a catchment and represent the areas with the highest risk of impacting on a water body. Therefore, their location enables mitigation activities to be targeted and, in the process, increases the effectiveness of the activities by ensuring the implementation of **"the right measures in the right place".**

[14] A **mental model** is an explanation of the thought process about how something works in the real world (in our case the landscape and associated catchments). It is a representation and **visualisation of the surrounding world**, the relationships between its various parts and our intuitive perception about how this world functions.

37. **Determine the CSAs, through a systematic process.** This process has been provided by the EPA Catchments Unit by means of an approach that involves using 'pathway susceptibility'[15] and 'pollution impact potential maps'[16].

38. **Set out the characterisation tasks**, as part of ICM. The tasks subdivide generally into the following components:
    i) Desk study.
    ii) Field-based catchment walks or local catchment assessments (all three terms are used).
    iii) Determining the 'story' of the catchment in question, including whether the objective is 'protection' or 'improvement'.
    iv) Concluding on possible protection or mitigation options, as relevant.

39. Make full use of both **chemical and biological monitoring data,** so that optimum benefits are achieved from the resources (staffing, time, financial) used.[17]

40. Build the **story of the catchment**, based on an evaluation of: i) the receptor information; ii) the pressures; and iii) the pathways, in the catchment landscape. The starting point or 'driver' for characterisation is the receptor water quality (biology status, hydrochemistry, ecological status) and hydromorphology (habitat conditions), and determination of whether there is a *significant issue* or not impacting on the water quality. Follow this by an assessment of the pressures and determine whether there is a *significant pressure* or not. The pathway component is provided by a **pathway conceptual model (PCM).**

41. Set out the **pathways conceptual model** as a 'mental model', in written form. It **is a systematic means** of integrating information – topographical, hydrological, hydrogeological, biological, hydrochemical, hydromorphological, etc. – to determine relevant pathways and, in the process, the types and locations of mitigation or protection options required.

42. In assessing impacts on a waterbody in a sub-catchment during characterisation, **pollutant concentrations** are the critical basis for assessing impacts at monitoring points. They may need to be accompanied by **nutrient** (phosphate, nitrate and ammonium) **loading analysis** using both concentration and flow data as an efficient and effective way of setting and achieving **nutrient reduction targets** and the related water quality objectives in the following circumstances:
    i. For load apportionment to enable a focus on the main pressures contributing to water bodies.
    ii. To determine the extent to which an input of nutrient from a tributary is impacting water quality within the main channel (and at the monitoring station further downstream).

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[15] '**Pathway susceptibility**' is a measure of the degree of attenuation between the source and the receptor. Therefore, susceptibility maps are a key basis for assessing phosphate and nitrate attenuation in the landscape. EPA hydro(geo)logical susceptibility maps for phosphate and nitrate are generated by linking data on soils, subsoils, groundwater vulnerability and aquifer types with attenuation and transport factors, partitioning the landscape into five areas ranging in susceptibility from Very High to Very Low.

[16] **Pollution Impact Potential (PIP)** maps show the CSAs for phosphate and nitrate from diffuse pressures in rural areas. They are located by combining the nutrient loadings (phosphorus and nitrogen) applied to the land surface with the hydro(geo)logical susceptibility of either a surface water body or a groundwater body to these nutrients.

[17] This means: i) targeted sampling to help achieve the set objective; ii) a full evaluation of the meaning of the hydrochemical concentrations and the trends, with conclusions on whether there are *significant issues* or not; and iii) more extensive use of biological indicators, e.g. using assessments of macroalgae and macrophytes as well as macroinvertebrates.

iii. To enable an estimate of the approximate annual quantity of nutrients in a water body that need to be reduced as a means of achieving the water quality objectives.

43. **Build on the interim 'story' as the basis for future work.** The next steps might, depending on the circumstances, include targeted monitoring and catchment walks, consultations with pressure owners, inspections, targeted measures and actions. **The final 'story' is the tale of success!**

2.2.7 Protection and Mitigation Actions

44. Following characterisation, subdivide the landscape into '***Areas for Protection***' and '***Areas for Restoration/Improvement***', with protection and improvement/restoration objectives, respectively. **Both objectives need to be achieved** in every catchment. However, it is important to distinguish between them as the approaches and resource requirements will be different, with normally less resources needed for the *Areas for Protection*.

45. Use the '**pollutant transfer continuum'** as a landscape-based framework, to consider the threats to water quality and risk mitigation. It consists of four components (Figure 2-2):
    i) The **presence of a pressure with an associated load of pollutants**. This pressure can either be a point or diffuse source or both.
    ii) **Mobilisation**, whereby in the case of diffuse pressures, the potential environmental stressor or pollutant becomes soluble or attaches to soil particles and starts the journey to a receptor, such as a stream.
    iii) **Delivery/transport** in a pipe in the case of many point sources or more diffusely along pathways, underground or over ground, to a receptor, such as a watercourse or drinking water source or groundwater in an aquifer.
    iv) The **receptor** which is impacted; in the case of surface water, it can vary for instance, in terms of flow rates, upstream water quality and sensitivity (e.g. high or good status or pearl mussel objectives), whereas in the case of groundwater in an aquifer, the existing water quality and the dilution potential can vary.

46. **Consider the protection and mitigation actions, according to the point in the source-pathway-receptor continuum on which they take effect.** This allows management strategies, the design of protection and mitigation measures/actions to deal with relevant pollutants, and their implementation, to be 'followed' conceptually from application to impact, and provides clarity on what role a particular measure has. The recommended relevant points along the continuum for consideration of specific measures and actions are:
    i) source reduction or elimination;
    ii) mobilisation control;
    iii) pathway interception;
    iv) receptor/instream works; and
    v) treatment in the case of drinking water sources (as part of the multi-barrier approach).

When considering and outlining possible measures and actions, it is worthwhile using this subdivision as a framework.

47. Ensure that **implementation levels,** for instance in CSAs, **are high** to achieve water quality goals.

2.2.8 Monitoring Progress and Making Adjustments

48. **Use monitoring** as a key link in the chain. Once implementation has commenced, **monitoring and tracking of progress is required** – sampling, analysis, assessments and trends for water quality, water levels for abstraction pressures, tracking the execution of measures and actions, learning lessons, and making adjustment, if necessary.

2.2.9 Time Delays for Improvement

49. **Predict the time delays for improvement.** This is an essential component of catchment science and management for the following reasons:
    - For work and resource planning.
    - To enable predictions of when objectives are likely to be achieved.
    - To encourage realistic expectations.

    The time needed for improvements in both water quality and water body status depends on a variety of components, each of which have a time delay element (Figure 2-3). Some or all of these may apply depending on the circumstances. The time delay varies with the pollutant or *significant issue* that is causing the impacts. By taking each relevant component in turn for both phosphate and nitrate, for instance, and adding the projected time delays for each component, it is possible to estimate the **dates** by which improvements, either in water quality or status, will occur.

2.2.10 Co-benefits

50. **Consider the co-benefits as a core part of the 'story'**. While integrated catchment management (ICM) was developed as the approach in Ireland for water management, an increasing realisation of the connectedness of our natural environment (water, habitats, soils, GHG emissions) and of the co-benefits of considering all as one system means that catchments are now seen as landscape units that encompass all the environmental realms – water, ecosystems, geosystems, air and atmosphere and land/landscape. This is the basis for extending ICM to the more all-encompassing Framework for Integrated Land and Landscape Management (FILLM). Many of the measures and actions undertaken in catchments to protect or improve water quality benefit these realms. These additional benefits emphasise the connectedness of nature and are a means of delivering environmental and economic sustainability for communities. These co-benefits are appealing to local communities, because householders and farmers 'see' the surrounding landscape as a mosaic of physical, ecological, cultural and infrastructural features, with no clear boundaries between them. Placing an emphasis on co-benefits encourages relevant disciplines and organisations to collaborate in the pursuit of mutually beneficial objectives.

2.3 Conclusions

The 50 principles provide a framework for the catchment science and management work undertaken for both WFD, DWD and HD implementation, and for drinking water source protection. They apply to both groundwater and surface water as receptors. They are intended as an encouragement – '**stand back**' and consider the desired outcomes, and then the means of achieving those outcomes.

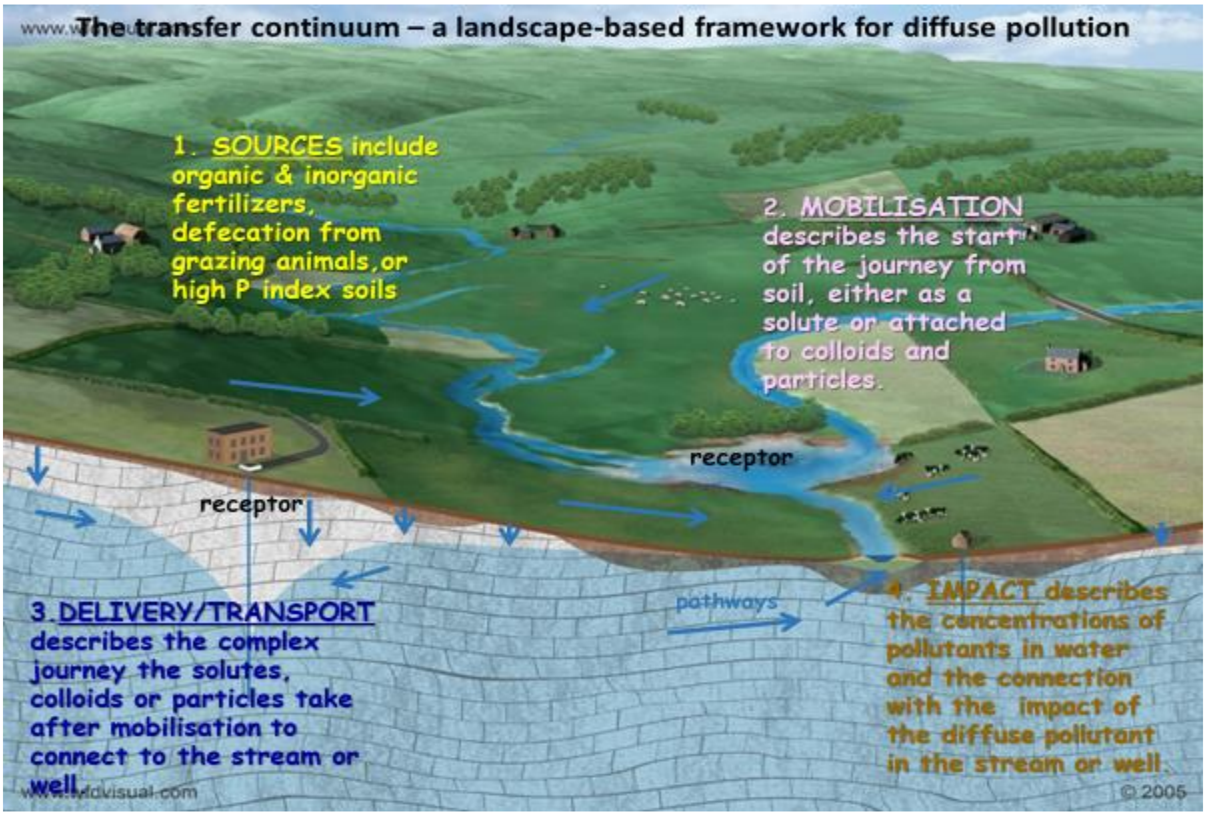


Figure 2-2: Representation of the pollutant transfer continuum (copied from NFGWS, 2019)

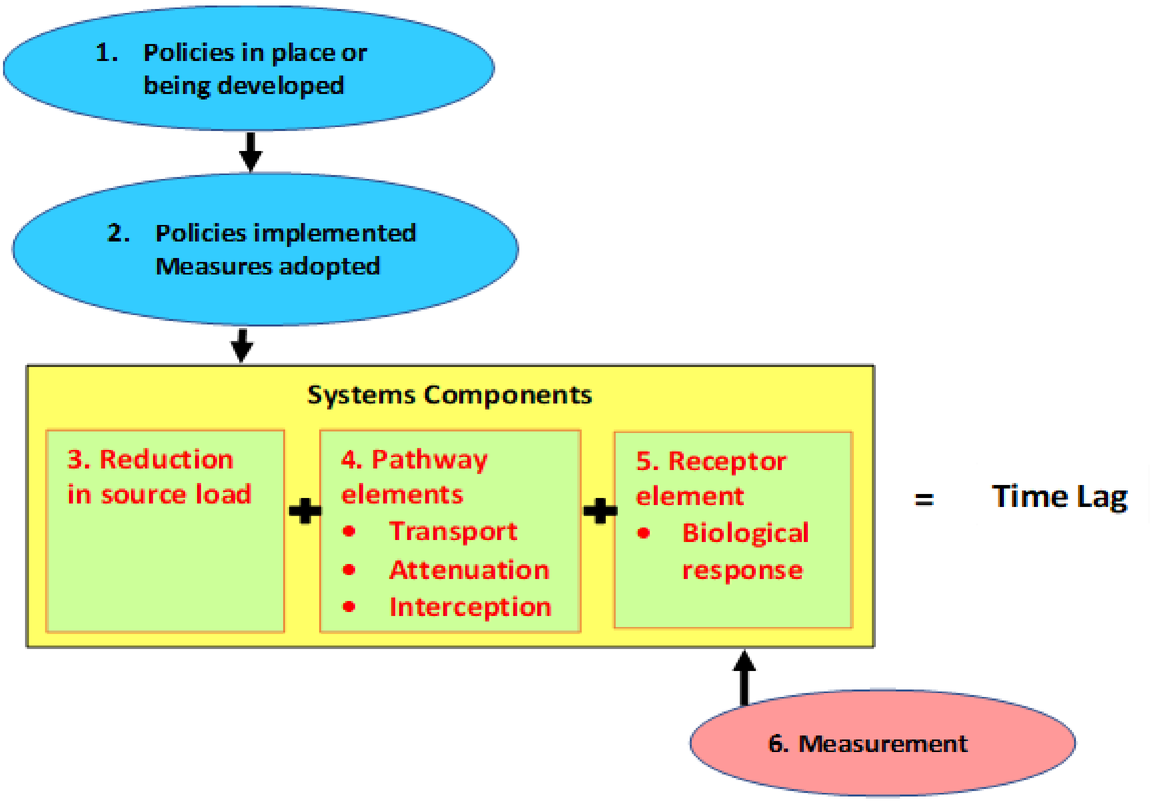


Figure 2-3: Schematic showing the major elements of the potential time delay for water quality improvement, including policy development and implementation component, catchment time lag components and the time needed to undertake monitoring.

3 A Summary the Water Framework Directive (2000)

3.1 Overview

- The WFD is a common **framework** for water management in Europe[18].
- It applies to all waters:
    - Groundwater, surface water, coastal, estuarine water bodies;
    - Human-made and natural water bodies.
- It sets environmental objectives that water bodies have to achieve by certain dates.
- It is implemented through a Programme of Measures.
- River Basin Management Plans (RBMPs) are published in 6 year cycles.
- It is the most important piece of European water legislation to-date.
- It connects several other related Directives – see Figures 3-1 and 3-2.
- Why a WFD?
    - Consolidated water policy needed.
    - Integrated water resources management seen as essential.
    - To give the public an opportunity to participate.
    - To have a common EU approach.

Figure 3-1: WFD Interaction with other EU Legislation (Source: Draft River Basin Management Plan 2022-2027 (https://www.gov.ie/en/consultation/2bda0-public-consultation-on-the-draft-river-basin-management-plan-for-ireland-2022-2027/)

18 : https://ec.europa.eu/environment/water/water-framework/index_en.html

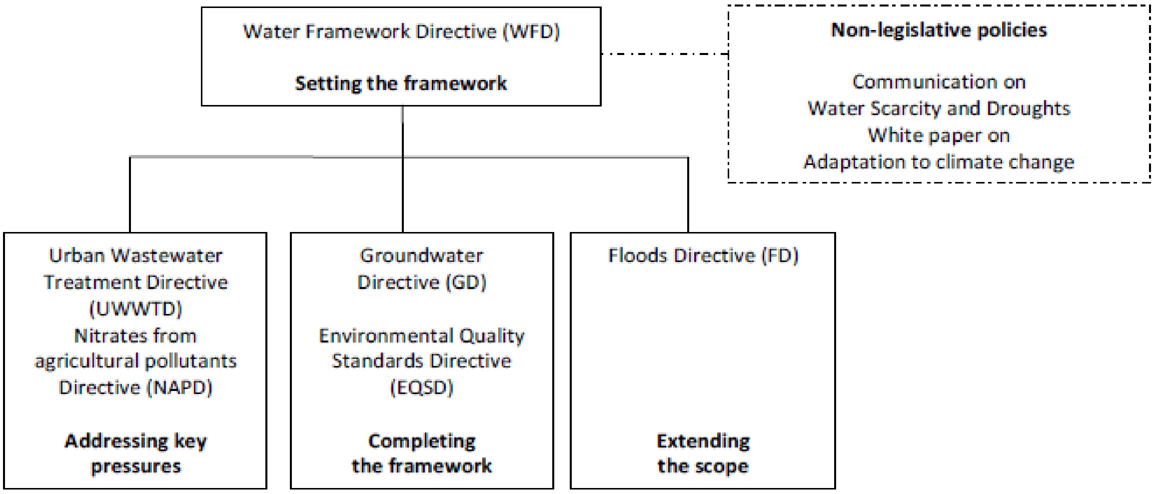


Figure 3-2: Copied from "Support to Fitness Check Water Policy" – a report by Deloitte and the Institute for European Environmental Policy (2011).

- The Groundwater Directive (2006) (GWD) and the Environmental Quality Standards Directive (2008) (EQSD) are 'daughter' directives. They provide operational guidance & additional criteria that must be met, e.g. the GWD specifies how chemical status is assessed and specifies that upward trends must be reversed.

- The Urban Wastewater Treatment Directive (UWWTD) and the Nitrates Directive (ND) are the corner stones of the emission-oriented approach to water protection, and they support the WFD.

- The Floods Directive (FD) is designed for flood risk management and for mitigating the impact of floods. There are close links and similarities with the WFD:
  - Both use catchments as their geographical basis.
  - Measures taken under one Directive may influence the objectives under the other. **Coordination** provides an opportunity to maximise synergies by identifying **cost-effective measures which serve multiple purposes** and can result in "win-win" measures being implemented.
  - An expectation from many stakeholders that an **integrated approach** will be taken.
  - **Flood hazard and risk maps** contain information that is consistent with relevant information in the WFD.
  - Development **of flood risk management plans (FRMPs) should be carried out in coordination** with and may be integrated into reviews of RBMPs.

- The WFD also links with the Habitats and Birds Directives[19] as it requires areas designated for the protection of habitats or species where the maintenance or improvement of the status of water is an important factor in their protection, including relevant Natura 2000 sites under the Habitats Directive or the Birds Directive. The provisions of the WFD relate to **water dependent** Natura 2000 sites, which are certain Special Areas of Conservation (SACs) or Special Protection Areas (SPAs). SACs and SPAs must be maintained or restored at favourable conservation status under their respective directives.

- The WFD has unique/important features:
  - It requires **a holistic, integrated approach** to water management.

[19] https://ec.europa.eu/environment/nature/natura2000/management/docs/FAQ-WFD%20final.pdf

- It is based primarily on ecology – the biological quality in terms of the animals and plants is the driver for surface water.
- It is based on **catchments** as the landscape units, not county boundaries. Catchments connect all that is happening in a catchment area.
- Public participation essential, i.e. community involvement.

♦ It is a **complicated** Directive, but also 'excellent' in the logical way it connects all relevant elements and the way it approaches water management. It takes a 'helicopter view' of water resources management.

3.2 Water Bodies

♦ The WFD sees water in catchments in terms of **water bodies (WBs)**.

♦ **5 categories**: groundwater, rivers, lakes, transitional (estuaries) and coastal – the latter two are often called **TraC** WBs.

♦ The EPA have designated 4,933 water bodies in total: 513 groundwater bodies; 3,192 river water bodies; 818 lake water bodies; 196 transitional water bodies; and 111 coastal water bodies.

3.3 Status

♦ Water body **status** is the parameter used by the WFD to determine the degree of impact by human activities on water resources. It reflects the situation at a point in time and is reported to the EU Commission. Status, which is the basis of the classification of all water bodies, is the starting point for the characterisation process.

♦ Monitoring data – biological, chemical, hydromorphological and, in the case of groundwater, water levels – provide the basis for status determinations. A 'one out, all out' approach is taken, where a single failing sub-element is required to dictate the overall reported status of the water body.

♦ Despite a substantial national monitoring programme being in place, not all water bodies have an associated monitoring station and nor will it be feasible, or desirable in the future to monitor them all.

♦ Rivers, lakes, transitional and coastal waters can be categorised as one of five statuses – High, Good, Moderate, Poor and Bad – as illustrated in Figure 3-3.
- ➢ 'High status' means no or very low impacts from human pressure,
- ➢ 'Good status' means a 'slight' deviation from this condition,
- ➢ 'moderate status' means 'moderate' deviation, and so on.

♦ SW body **ecological** status is assessed under the following headings (see Figure 3-4):
- ➢ Biological quality
    - Benthic invertebrates – Q-values are the main measure.
    - Fish
    - Aquatic plants.
- ➢ Hydromorphological quality – this is how a river flows, and can be affected by river bank structure, river continuity, or the substrate of the river bed.
- ➢ Physical-chemical quality such as temperature, oxygenation and nutrient conditions.
- ➢ Chemical quality for specific pollutants.

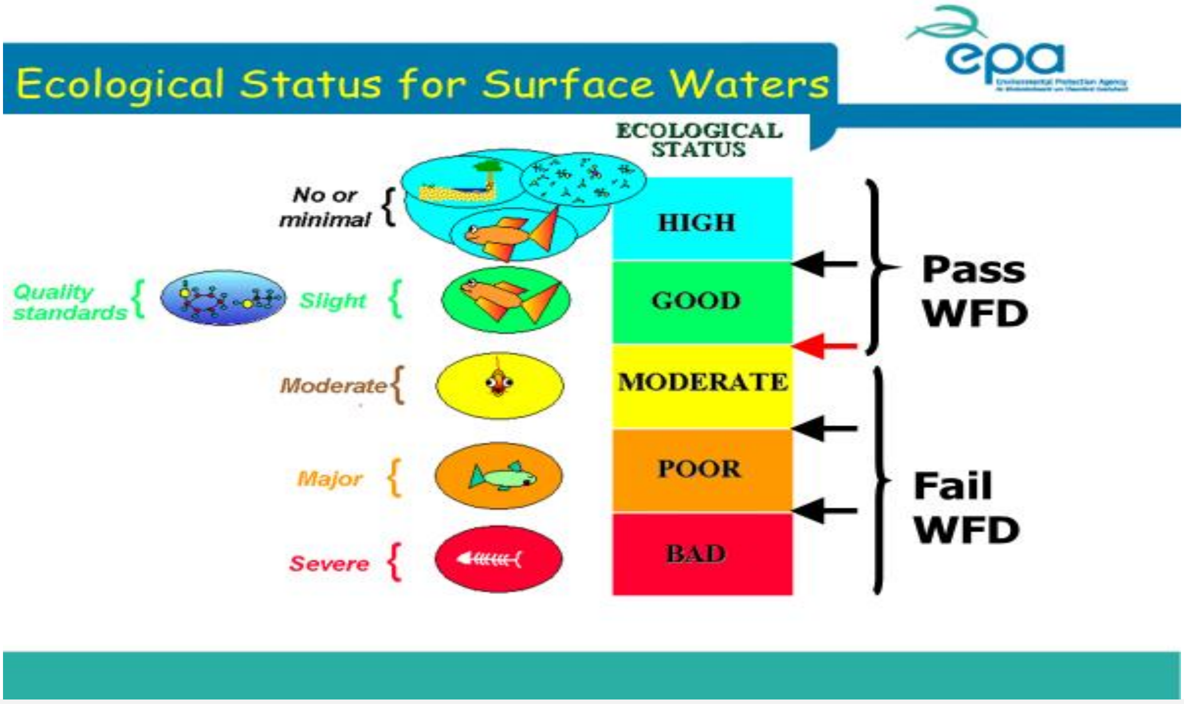


Figure 3-3: Five status categories. WFD objective is to achieve either Good or High status.

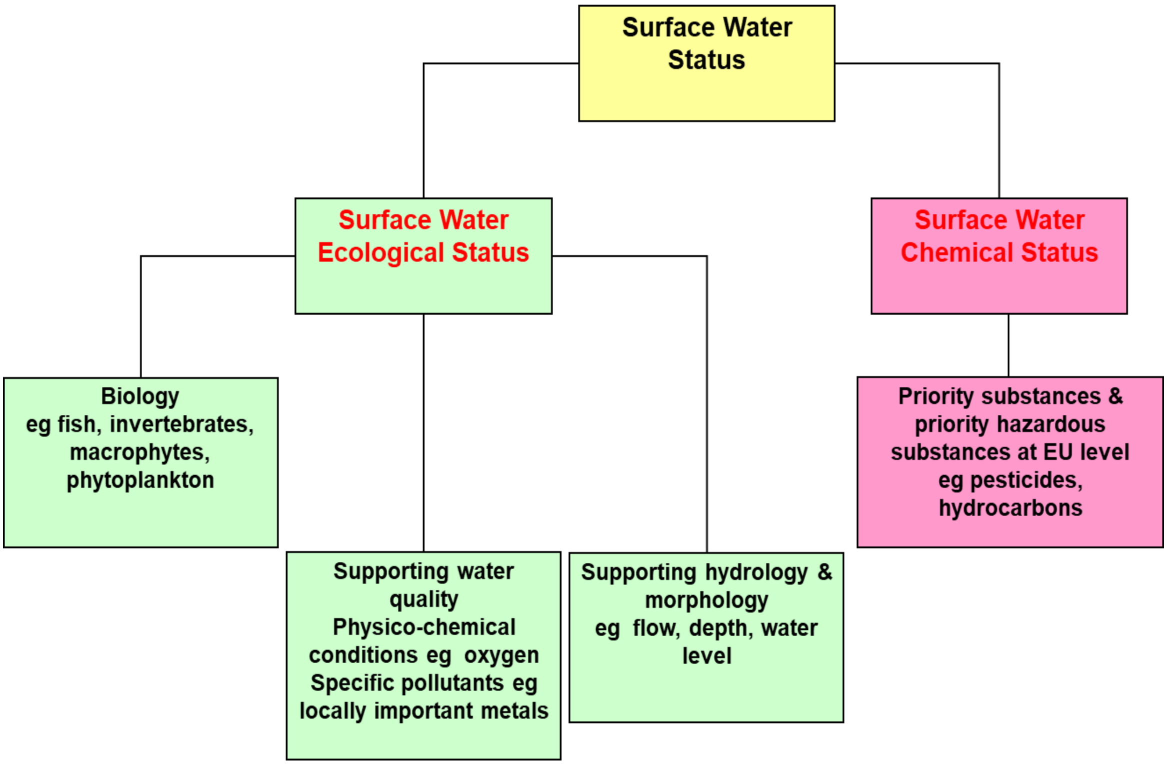


Figure 3-4. The components of surface water body status

- The surface water chemical status is based on the presence of priority substances and priority hazardous substances.

- **'One out, all out'**: An important point to note is that the rule when assessing the waters is 'one out, all out'. In other words, if, for example, a water body is at 'good' status in three of the above categories, but 'poor' in the fourth, the entire water body is judged to be poor. It is the lowest result that determines status.

- The high status of water bodies is defined by the biological, chemical and morphological conditions associated with no or very low human pressure. This is also called the 'reference condition' as it is the best status achievable and provides the benchmark. There has been a long-term decline in the number of high status water bodies. As these represent our 'best' water quality conditions, this is a major concern. As a consequence, a 'Blue Dot Catchments Programme' has been established to with the aim of protecting and where possible restoring high status objective water bodies. Further details on this programme are given in Appendix 1.

3.4 Objectives of the WFD

- The environmental objectives (Article 4) are summarised in Table 3-1.

- In summary, they are:
  1. Prevent deterioration in the status of waterbodies.
  2. Restore all waterbodies to at least good status by 2015 (exceptions allowed – see Table 3-2).
  3. Prevent or limit the input of pollutants to groundwater.
  4. Reduce chemical pollution of surface waters.
  5. Achieve objectives for 'protected areas'.

Table 3-1: The WFD objectives

WFD ENVIRONMENTAL OBJECTIVES		
Surface Waters	**Groundwater**	**Protected Areas**
Prevent deterioration of surface water*	**Prevent or limit the input of pollutants into groundwater and prevent deterioration of groundwater***	**To achieve compliance with standards and objectives under which individual protected areas have been established for:**
Protect, enhance and restore surface water with aim of achieving good status*	**Protect, enhance and restore groundwater, ensure a balance between abstraction and recharge, with the aim of achieving good status***	**- drinking water; - economically significant aquatic species; - Recreational waters; - Nutrient sensitive areas;**
Protect and enhance all artificial and heavily modified bodies of water with aim of achieving good ecological potential and good surface water chemical status*	**Reverse any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity**	**- Areas designated for the protection of habitats and species where water is an important factor in their protection. (All the Natura 2000 sites with water dependent habitats and species have been included in the WFD Register of Protected Areas).**
Progressively reduce pollution from priority substances		
***subject to: (but not limited to) temporary deterioration the result of natural causes; failure to prevent deterioration as a result of new sustainable development activity subject to conditions (Art. 4.7 of the WFD).**		

- Alternative objectives may be set, such as:
    - An extended deadline, e.g. good status by 2027.
    - A less stringent objective. Examples:
        - Moderate status by 2027
        - 'Natural conditions' – a legitimate reason to extend the deadline.

- Justifications must be given.

Table 3-2: Reasons for extending the 2015 deadline for achieving the WFD objectives

Technically infeasible	**No known technical solution is available**
	Cause of adverse impact unknown
	Practical constraints of a (technical) nature prevent implementation of the measure by an earlier deadline
Disproportionately expensive	**Unfavourable balance of costs and benefits**
	Disproportionate burdens
Natural conditions	**Ecological recovery time**
	Groundwater status recovery time
	Background conditions

3.5 Risk of Not Meeting WFD Objectives

- Risk builds on the status, by incorporating trend information and distance to the threshold of the next lowest status class, as a means of looking forward to predict whether a water body is likely to meet its environmental objectives throughout the monitoring cycle. Risk is used to highlight the areas where monitoring and measures need to be implemented and/or adjusted so that the objectives can be met on time. Three risk categories are used: ***Not at Risk***, ***At Risk*** and ***Review***; where *Not At Risk* water bodies require maintenance of existing measures to protect the satisfactory status of the water bodies; *At Risk* water bodies require new, often more targeted, mitigation measures requiring resources in terms of both finances and staff; and *Review* water bodies require additional monitoring and assessment.

- Assigning risk is based on:
    i) Consideration of the ecological status of the water bodies, (high, good, moderate, poor and bad for surface water bodies, and good and poor for groundwater bodies).
    ii) The trends in hydrochemistry, particularly of phosphate, nitrate and ammonium for groundwater and rivers, chlorophyll and total phosphorus in the case of lakes, and chlorophyll, phosphate and dissolved inorganic nitrogen for transitional and coastal water bodies. Trends are considered to be significant where they are both statistically significant (90% confidence) and environmentally significant (statistically significant trends that suggest a change in status by the end of the planning cycle is likely).
    iii) The distance to thresholds, such as environmental quality standards. The 'distance to threshold' can be either 'near' (i.e. within 25% of the threshold boundary), or 'far'. The purpose of the assessment is to determine if the water body is at risk of deteriorating to a lower water quality status, based on the proximity of the concentration of the parameter to the relevant threshold.
    iv) Whether a measure is in place, but monitoring hasn't been undertaken to confirm the required improvement.

- Therefore, decisions on the environmental objectives and associated measures are based on the risk category and not on the status class alone. Three levels or tiers of characterisation are being undertaken so that the level of assessment is commensurate with the degree of risk posed.

3.6 Water body characterisation

- The characterisation process (Article 5) is summarised in the questions in Figure 3-5.

Figure 3-5: The questions that summarise the characterisation approach.[20]

- Essentially, it is the process of **understanding** water bodies as the basis for decision-making on measures:
  - Physical, chemical and biological components.
  - Functioning: 'Source-pathway-receptor'.
  - Linkages between water bodies.
  - Impacts of human activities.

- A level of risk (of not meeting WFD objectives) – *At Risk*, *Not at Risk* and *Review* – is assigned to water bodies. '**Risk**' looks forward to the future by taking account of i) existing status, ii) trends and iii) distance to a threshold, such as an EQS, and iv) whether measures have already been put in place or not. The *Review* category is for circumstances where there are insufficient data to decide on the category or where a measure has been put in place and the benefits are not yet seen. Note difference with Status, which is the formal requirement that records the situation at a point in time and therefore, in a sense, looks back at the situation.

3.7 Register of protection areas

- A register of protected areas must be established (Article 6).
  - This links with the Habitats and Birds Directives (Natura 2000 sites such as SACs and SPAs), Drinking Water Protected Areas, nutrient sensitive areas, bathing waters, economically significant aquatic species.

3.8 Water used for the abstraction of drinking water

- The WFD connects with the Drinking Water Directive (DWD) (Article 7) in the following ways:
  - All WBs capable of providing >10 m^3/d or serving more than 50 people must be identified. (All of country is a DWPA)

[20] EPA Guidance on the characterisation approach used is available at this link: https://wfd.edenireland.ie/help/help

- Monitoring WBs supplying >100 m^3/d required.
- Member States must ensure the necessary protection with the aim of avoiding deterioration of water quality in order to reduce the level of purification treatment.
- Safeguard zones may be established, according the Directive. However, the revised DWD will require them to be established.

3.9 Monitoring water body status and protected areas

- Member States must ensure the establishment of programmes for the monitoring water status (Article 8) including flows, levels and ecological and chemical status.

3.10 Programmes of Measures (PoMs)

- Each MS must establish a programme of measures (PoMs) (Article 11) taking account of the objectives and characterisation results. POMs are those actions in the RBMPs that are designed to address identified pressures in a catchment, e.g.:
  - Control of urban waste water discharges.
  - Control of domestic waste water discharges.
  - Control of agricultural pollution sources.
  - Forestry controls.
  - Sustainable drainage (e.g. SUDS).

- There are two categories:
  - Basic – the minimum requirements.
  - Supplementary – to provide additional protection or improvement.

- Basic measures:
  - EU legislation:
    - Habitats & Birds Directives
    - Nitrates Directive
    - Drinking Water Directive
    - Bathing Water
    - Urban Wastewater Treatment Directive
    - Plant Protective Products Directive
    - Environmental Impact Assessment
    - Sewage Sludge Directive
    - Integrated Pollution Prevention Control
  - Controls (examples)
    - Control of abstractions and impoundments
    - Control of point source and diffuse source discharges
    - Protection of drinking water sources
    - Cost recovery for water use
    - Protection and reduction of the impact of accidental pollution incidences.

- Supplementary measures:
  - Used in addition to Basic Measures as a means of achieving the WFD objectives
  - Examples (Annex VI)
    - Codes of good practice
    - Abstraction controls
    - Emission controls
    - Restoration of wetlands
    - Efficiency and reuse measures

  - Educational projects
  - Research, development and demonstration projects
  - Targeted measures in critical source areas
  - Etc.

3.11 River basins management plans (RBMPs)

- Member States must produce a RBMP for each river basis district (RBD) every six years (Article 13). The WFD has a 6-year cycle (Figure 3-6): the first plan was published in 2009; the second in early 2018 (two years late) and the third will be published in late 2021 or early 2022.

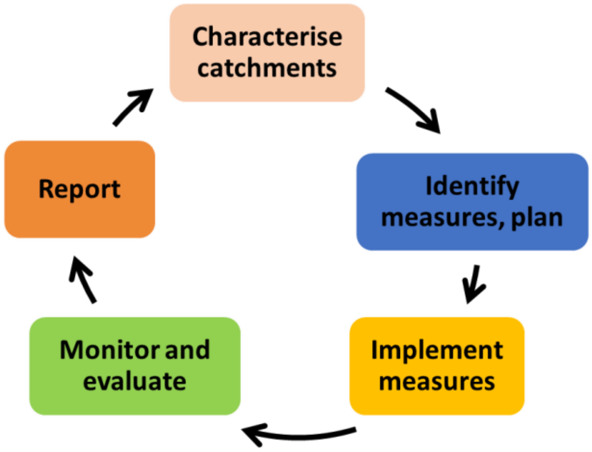


Figure 3-6: The WFD river basin management planning cycle.

- The RBMP must include:
  - A general description of characteristics.
  - A summary of pressures and impacts.
  - Identification & mapping of protected areas.
  - The environmental objectives.
  - An economic analysis.
  - Details on the programmes of measures (PoMs) that must be implemented to achieve the WFD objectives.
  - A summary of public information and consultation measures taken, and changes to the plan made as a consequence.
  - A list of competent authorities.

- For the 1st cycle, seven RBDs were defined; this was reduced to one for the 2nd cycle and is being used for the 3rd Cycle – see Figure 3-7.

3.12 Public information and consultation

- Active involvement of all interested parties must be encouraged, particularly in the production, review and updating of the RBMP (Article 14).
- Information must be made available in advance for comments before final decisions are adopted.
- This is regarded as a key component of the WFD.

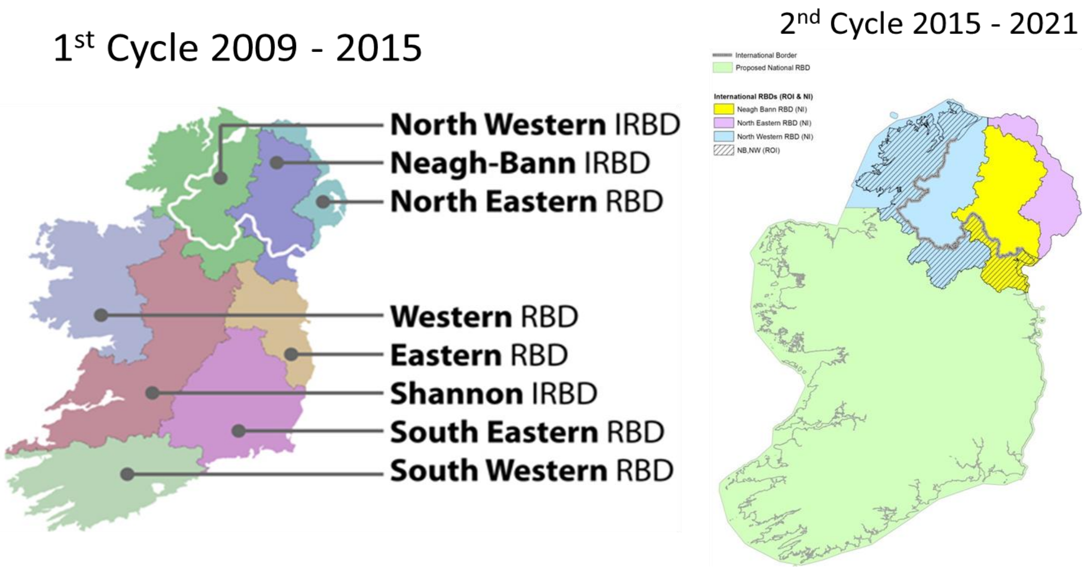


Figure 3-7: The River Basin Districts

4 A Summary of the Groundwater Directive (2006)

4.1 Overview

- The Groundwater Directive (GWD) is a 'daughter' directive of the WFD[21].
- Provides the details and means of complying with Article 17 of the WFD – "Strategies to prevent and control pollution of groundwater".
- Requires public bodies to take account of groundwater as well as surface water bodies.
- Groundwater Regulations (S.I. No. 9 of 2010[22] and S.I. 366 of 2016[23]) set out the details on implementation.

4.2 Requirements of the GWD

- Prevent deterioration of status by preventing (in the case of hazardous substances) or limiting (in the case of non-hazardous substances) the input of pollutants (Figure 4-1).
- Protect, enhance, restore water bodies so that GOOD Status (Quantitative and Chemical) is achieved.
- Reverse any significant and sustained upwards trend in concentrations.

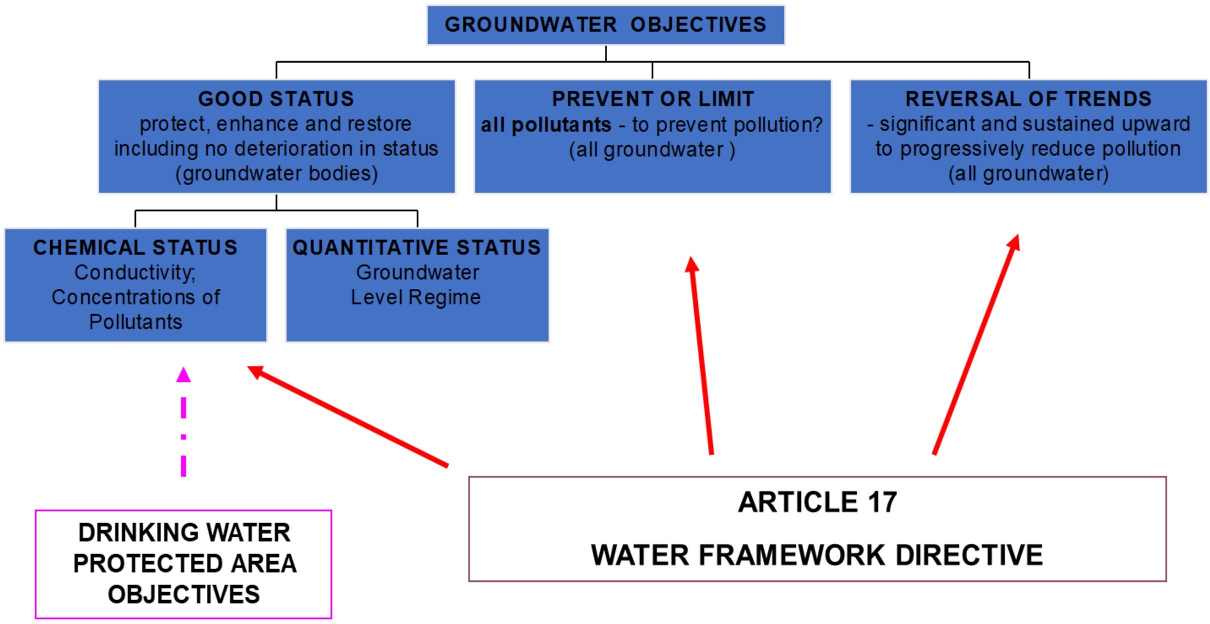


Figure 4-1: Illustration of the GWD requirements

4.3 Groundwater Bodies

- Groundwater bodies (GWBs), rather than aquifers, are the management units of the WFD. GWBs are normally large (10s to 100s km^2) and most have several surface water bodies in each one.

- They should be seen as 3-D entities with boundaries that are based on a combination of topographical and hydrogeological features (see Figure 4-2).

- There are 513 GWBs in total.

[21] https://www.eea.europa.eu/policy-documents/groundwater-directive-gwd-2006-118-ec
[22] http://www.irishstatutebook.ie/eli/2010/si/9/made/en/print
[23] http://www.irishstatutebook.ie/eli/2016/si/366/made/en/print

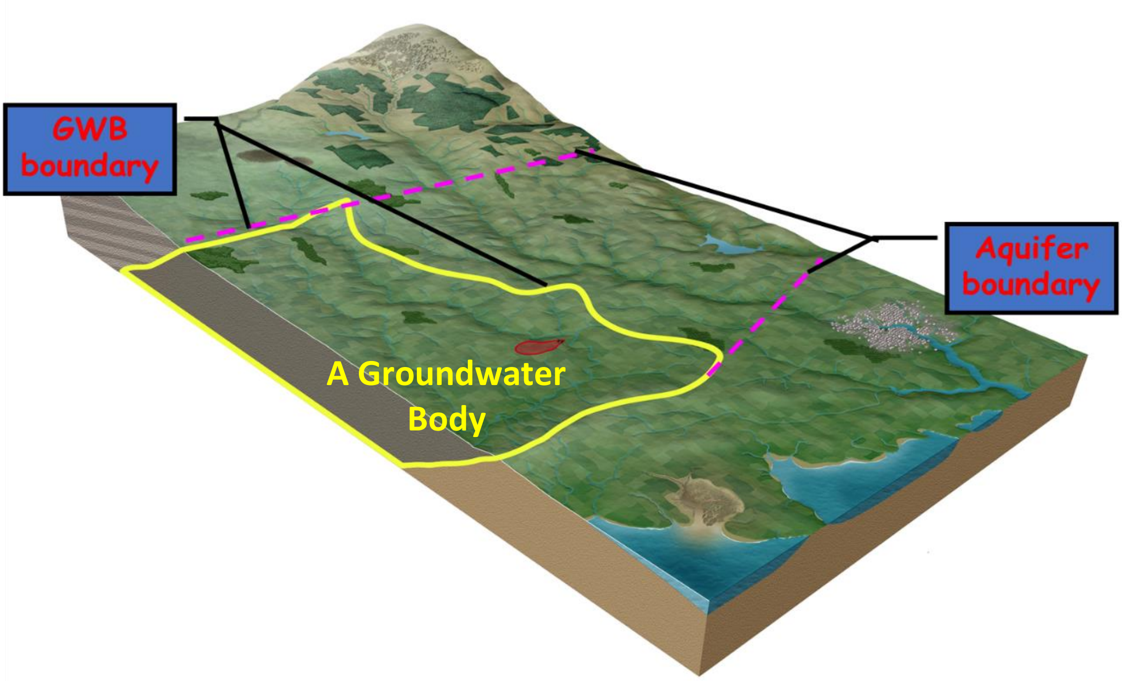


Figure 4-2: An illustration of a GWB as a 3-D entity, illustrating the association with geology, topography and surface water bodies.

4.4 Classification of GWBs

- There are two status categories – Good and Poor.

- Classification of groundwater bodies differs from that undertaken for surface water bodies, in that the surface water standards relate to ecological status and these standards define the classification boundaries. Groundwater status does not directly assess ecology, but the classification process takes account of the ecological needs of the relevant rivers and terrestrial ecosystems that depend on contributions from groundwater (GWDTEs). Another key component of the groundwater classification is assessment of the impact of pollution on the uses (or potential uses) of groundwater from the groundwater body, e.g. for water supply. The four receptors that must be considered by the GWD are illustrated in Figure 4-3.

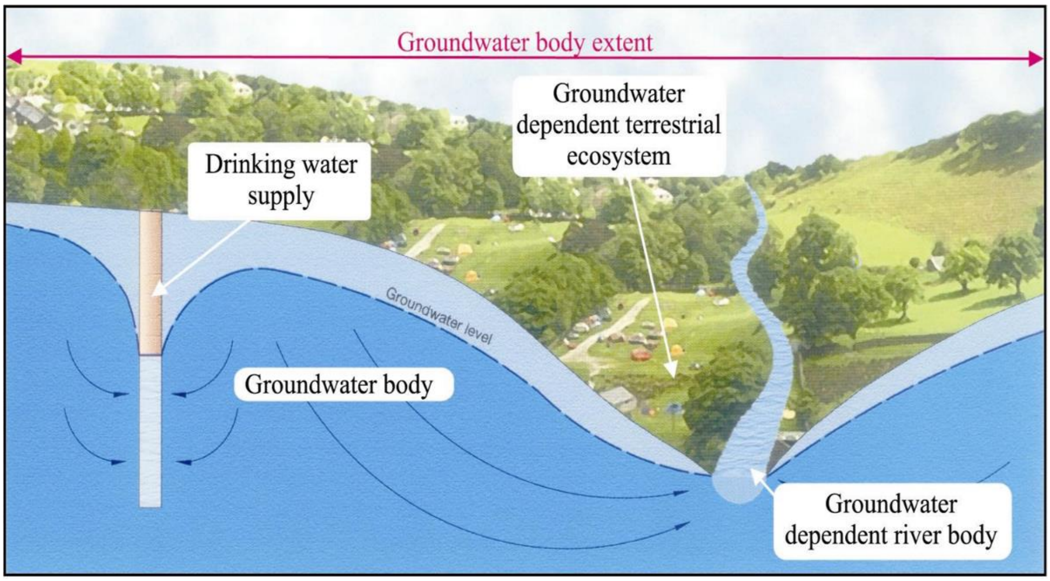


Figure 4-3: Illustration of the four receptors that influence status classification.

- The groundwater body classification is based on the "objectives" defined in Annex V of the Water Framework Directive and Annexes I – III of the Groundwater Daughter Directive (GWD). These objectives are:
  1. No saline or other intrusions.
  2. Achieving the objectives of the WFD for dependent surface waters including no deterioration in status (all surface water bodies are included).
  3. No damage to any wetlands that depend on the groundwater body (GWDTEs).
  4. No impact on Drinking Water Protected Areas.
  5. No significant impairment of human uses of groundwater.

- A number of tests must be undertaken to determine status – five for groundwater chemical status and four for quantitative status. These are summarised in Figure 4.4.

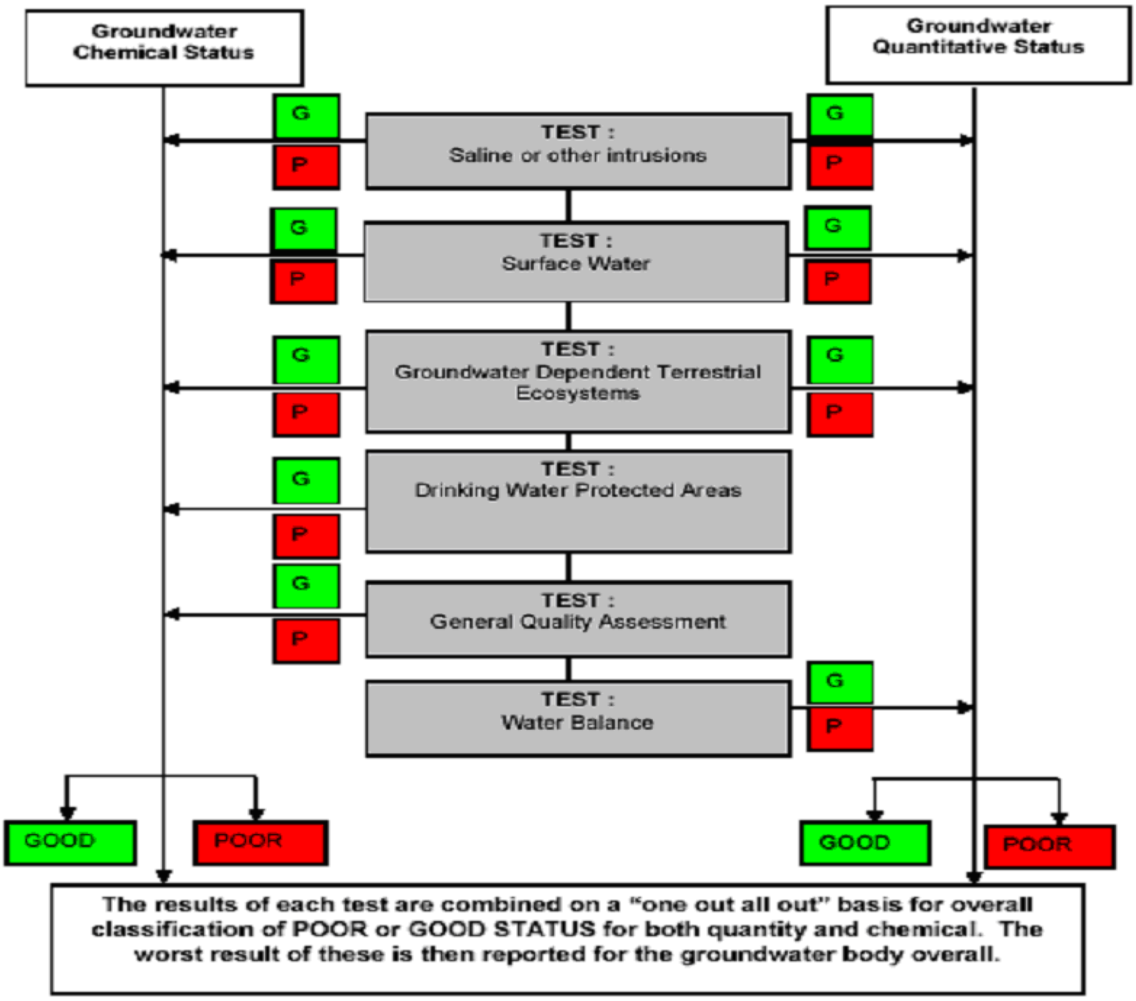


Figure 4-4: Overall procedure of classification tests for assessing groundwater status.

4.5 Threshold values

- In determining chemical status, groundwater quality standards for nitrate (50 mg/l) and pesticides (0.1 µg/l and 0.5 µg/l (total)) and threshold values (TVs) for pollutants or indicators of pollutants are used.

- TVs, which are mean concentrations, are given in Schedule 5 of the Groundwater Regulations (S.I. No. 9 of 2010 at this link: http://www.irishstatutebook.ie/eli/2010/si/9/made/en/pdf. Examples are given in the Table below.

- TVs are trigger values that prompt further investigation: they are not the boundary between GOOD and POOR status

Table 4-1: Examples of TVs.

Parameter	Threshold Value	Test	Reason for TV
Nitrate	37.5 mg/l NO_3	Drinking Water/General GWQ	Protect Human Use
TCE/PCE	7.5 ug/l	General GWQ	Protect Human Use-Point Source
Chloride	24 mg/l Cl	Saline Intrusion	Upper Limit of NBL
Conductivity	800 uS/cm	Saline Intrusion	Upper Limit of NBL
MRP	35 ug/l P	Surface Water Quality	SW EQS
Ammonium	65 ug/l N	Surface Water Quality	SW EQS

4.6 Trend identification and reversal

- Article 5 of the GWD concerns the identification of sustained upward pollution trends and their reversal. The reversal obligation establishes that any significant and sustained upward trend will have to be reversed when reaching 75% of the values of the groundwater quality standards and/or threshold values, although local circumstances may justify different values, for example the PO_4 TV is 0.035 mg/l and therefore the starting point for trend reversal is 0.026 mg/l. The WFD programmes of measures are intended to provide the means of reversing trends.

4.7 Measures to prevent or limit pollutant inputs

- Member States (MS) must ensure that the Programme of Measures includes:
  - All measures necessary to aim to prevent inputs of hazardous substances.
  - All measures necessary to limit input of pollutants not considered hazardous. Such measures take account of established best practice, such as BAT.
  - An indicative list of pollutants is given in the WFD.

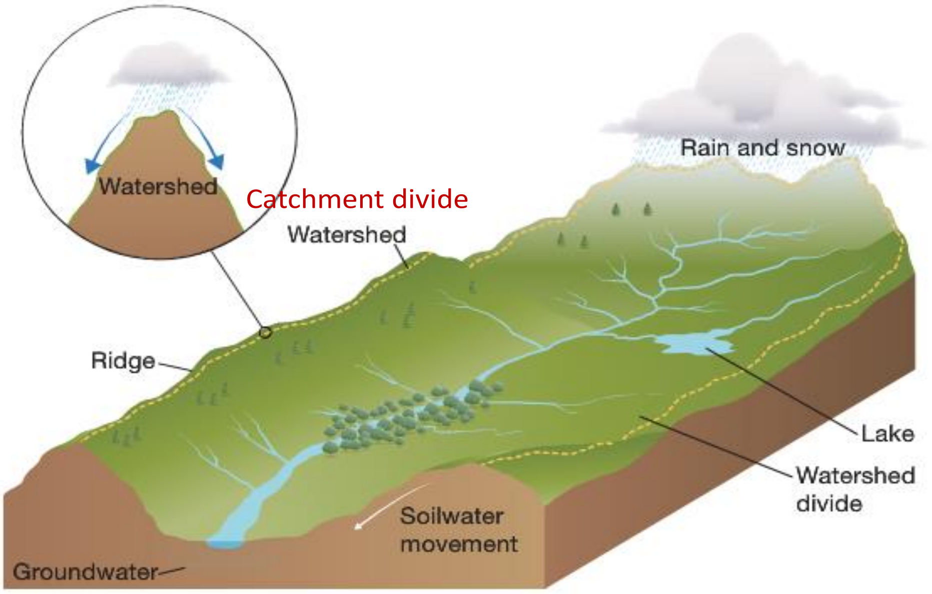
4.8 Conclusions

The Groundwater Directive, as a ‘daughter’ directive of the WFD, highlights the importance of groundwater and the difficulty of dealing with it in river basin management. It provides the detail on the means by which the requirements to prevent and control groundwater pollution are met. In particular, it sets out criteria and procedures for assessing groundwater chemical status, requires identification of significant and sustained upward trends and reversal of these trends where they are posing an environmental risk. Account must be taken not only of the need to protect groundwater for environmental reasons, but also for human health reasons. Groundwater quality standards are set for two pollutants – nitrate and pesticides – by the EU. Member States must set threshold values for 10 listed pollutants and any other substances regarded as putting groundwater at risk; this has been undertaken by the EPA and are included in the Groundwater Regulations. A programme of measures must reverse trends, and where necessary, prevent input of hazardous substances into groundwater, and limit input of other pollutants not considered hazardous.

5 Catchments – the Landscape Units for Environmental Management

5.1 Catchments

Water resources management in general and WFD implementation in particular are based around catchments as the appropriate landscape units. Catchments are coherent topographically-based features, defined by the natural hydrology and hydrogeology, with water in continuous connection over ground and underground from the highest areas along the topographic divide to the lowest areas alongside rivers (see Figure 5-1). As a consequence, the river catchment has become the land-based unit for water management.



http://sncyear7geography.weebly.com/catchment.html

Figure 5-1: Illustration of a catchment as a topographical entity.

While this is accurate from a hydrological perspective, in reality in any catchment area, in addition to the human-social system in the area, there are three systems provided by nature – ecosystems, geosystems and atmospheric systems – as illustrated in Figure 5-2. All can be considered to be interconnected, interacting and interdependent to varying degrees.

Therefore, catchments are complex, multi-dimensional entities encompassing not only natural systems, but also people working and living in them. They connect water 'from the mountains to the sea' via over ground and underground pathways and in the process connect all human activities in catchment as well as many habitats from mountainous to riverine to estuarine to coastal, particularly aquatic habitats. Consequently, a broader definition of river catchment is needed and is appropriate, such as the one below (Daly, 2017)[24].

> ***A catchment is a multi-functional, topographically-based, dynamic, multiple-scale socio-biophysical system; defined by over ground and underground hydrology; connecting land, water, ecosystems, geosystems, atmospheric systems and people; and used as the basis for environmental analysis, management and governance.***

[24] https://www.iah-ireland.org/conference-proceedings/2017.pdf

Recommendation: Use this definition of catchment in the future as the 'mental model' for not only water management but also environmental management.

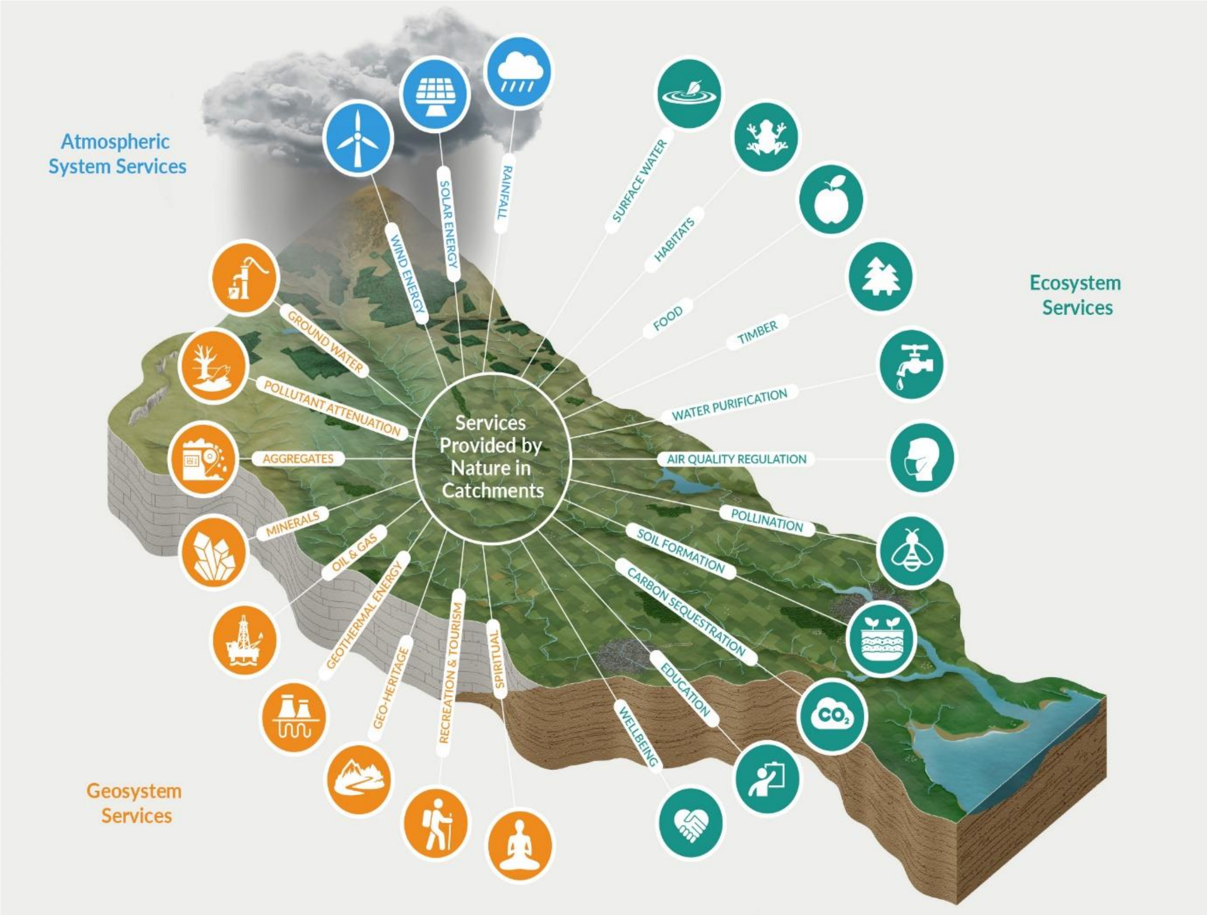


Figure 5-2: Schematic diagram of a catchment highlighting the three natural capital systems and the potential benefits provided by nature to people living in catchments (Copied from An Fóram Uisce (2021)[25]).

5.2 Catchment Scales

Clearly, catchments exist at multiple scales and scale is not an objective construct. There is no one right scale, but scale is nevertheless all-important. In principle, the activities needed to achieve the various water/catchment objectives must be at a scale that is appropriate to achieving these objectives, and, in particular, to enable the problems, solutions and consultations to be targeted effectively. Depending on the scale, different parties may take different roles. For example, for an RBD, national state agencies will lead catchment management efforts, while at the local, detailed scale, local authorities and local community groups/stakeholders, will take the lead in developing and implementing solutions.

In following the principle outlined above, five scales are relevant (see summary in Table 5-1). While these are defined here, linkages across the scales are essential to successful water/catchment management. It is not possible to manage and understand our water resources by focusing on one scale. We can't "fix" at the national and RBD scale without paying attention to necessary issues and changes at the scales below, and we can't ensure the future well-being of the water resources we all

[25]: https://thewaterforum.ie/app/uploads/2021/03/TWF-FILLM-Report-Feb21-v9WEB.pdf

care about without paying attention to changes/developments at the national scale. It is also important not to focus only on one scale. Therefore, we will need to think 'multiple scales'.

The scales being used in WFD implementation are outlined in Figure 5-3 and are as follows:

- **Site/field scale:** Most pressures are investigated and dealt with at this detailed scale (e.g. urban wastewater treatment plants, septic tank systems, farmyards, landfills, nutrient and sediment runoff from fields).
- **Water body (WB) scale:** Water bodies are the 'units' for monitoring and reporting of status and risk characterisation results.
- **Sub-catchment scale**: Water bodies have been aggregated into sub- catchments, varying in area from approximately 70 to 200 km^2. This is the scale at which most of the scientific elements of characterisation is undertaken. Community engagement is also carried out primarily at this scale.
- **Catchment Scale:** These are the catchments as defined, with some additions in the Shannon catchment, by the nationally-defined hydrometric units, giving 46 catchments in the Republic of Ireland. They are coherent landscape units encompassing and connecting: i) water flowing from upland areas to the coast or, in the case of the Shannon catchment, the Shannon itself; and ii) all pressures with the potential to impact on all the water types in the catchment. They are at a practical scale for deciding on, planning and coordinating activities; in effect, this is a practical management and 'governance' scale for water. In the Draft RBMP 2022-2027, it is proposed that 46 catchment plans as sub-plans of the national plan will be implemented.
- **River Basin District (RBD) scale:** The seven RBDs used for the 1st cycle of the WFD have been merged to form one national RBD and two cross-border RBDs. The outputs at this scale are the River Basin Management Plans.

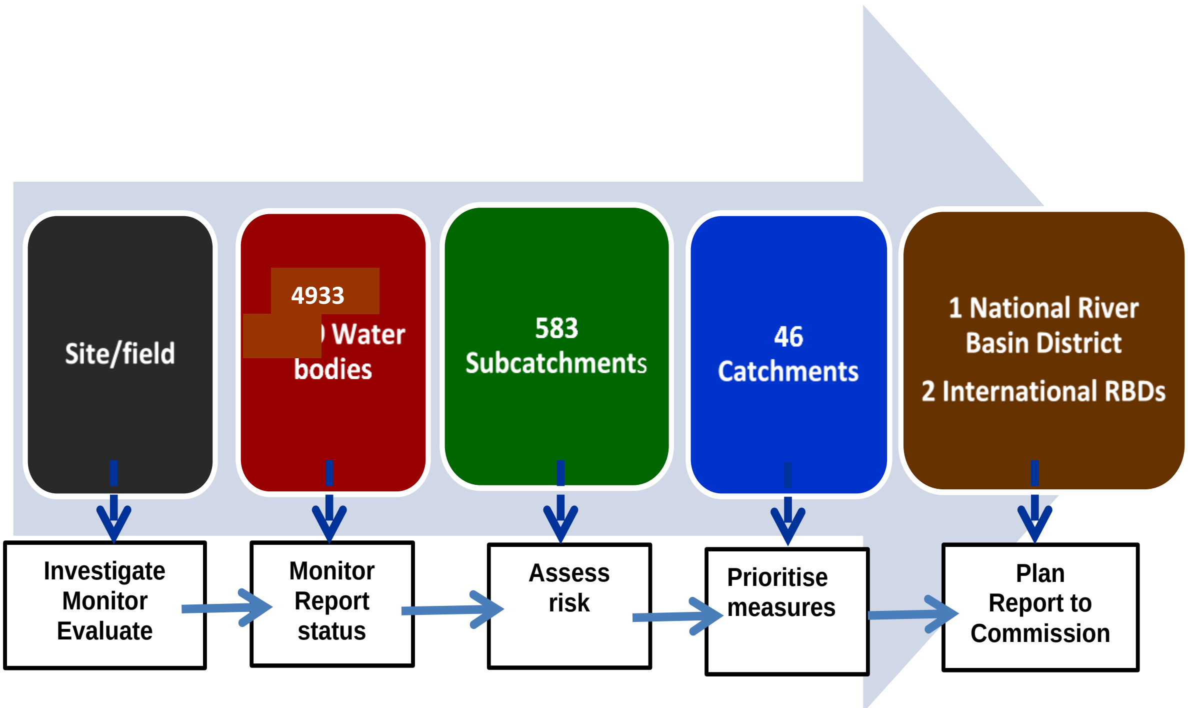


Figure 5-3: Scales used in catchment management and WFD implementation. (Copied from: https://www.catchments.ie/download/water-framework-directive-guidance-characterisation-methodology-v2-0-september-2016/)

Table 5-1: Summary details on the proposed scales for successful ICM

Level of Detail	Scale	Main Driver	Purpose/Objective	Main Actors
Low	National	Achievement of WFD objectives	Where policy is made.	Government departments mainly
	RBD (1,000s km^2)	WFD River Basin Plan	Where reporting to EC is undertaken.	DHLGH, EPA
	Catchment (100s km^2)	Overall assessments of risks & impacts, and required responses to both	Where delivery is organised; evaluation is undertaken; reports are written; plans are made.	EPA; LAWPRO; local authorities; other public bodies such as IFI, MI, NPWS, IW, OPW; SWAN; NFGWS, farming organisations.
	Sub-catchment (70-100 km^2)	Delivering to achieve agreed objectives. Monitoring.	Local community involvement. Catchment walks. Investigative monitoring. Inspections. Public awareness and participation.	LAWPRO, local authorities, local communities, local env. groups, farming organisations, NFGWS. EPA monitoring and characterisation.
	Water body	Status & Risk	For reporting to EC	EPA
High	Site-specific or project-specific assessments (e.g., a WWTP)	Dealing with specific issues/problems	Detailed investigations. On the ground solutions. Inspections.	Local authorities, consultants, local 'owners' of issue, appropriate regulatory body

5.3 Catchments as 3-D entities

"Looking" at the landscape holistically – underground and over ground – is critical to understanding water and pollutant movement, pollutant attenuation and, if needed, mitigation actions. To enable this understanding, we must 'see' catchments in 3-D. Therefore, when considering a water-related issue, whether it is site/field or catchment/sub-catchment scale, virtually or 'in the field', it is essential to be able to visualise and have a 'mental model' of the situation overground and underground. Different scenarios are illustrated in Figure 5-4, 5-5 5-6 and 5-7.

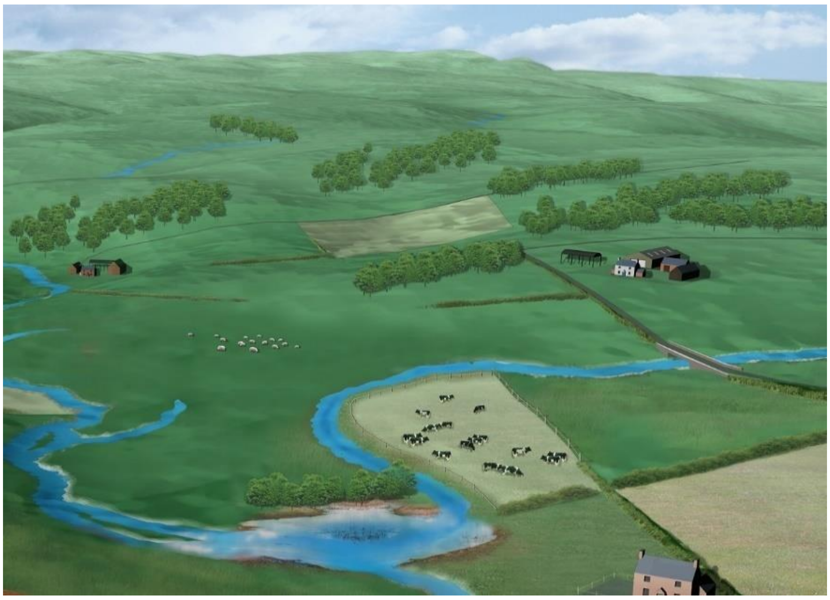


Figure 5-4: The 2-D view of an area in a catchment

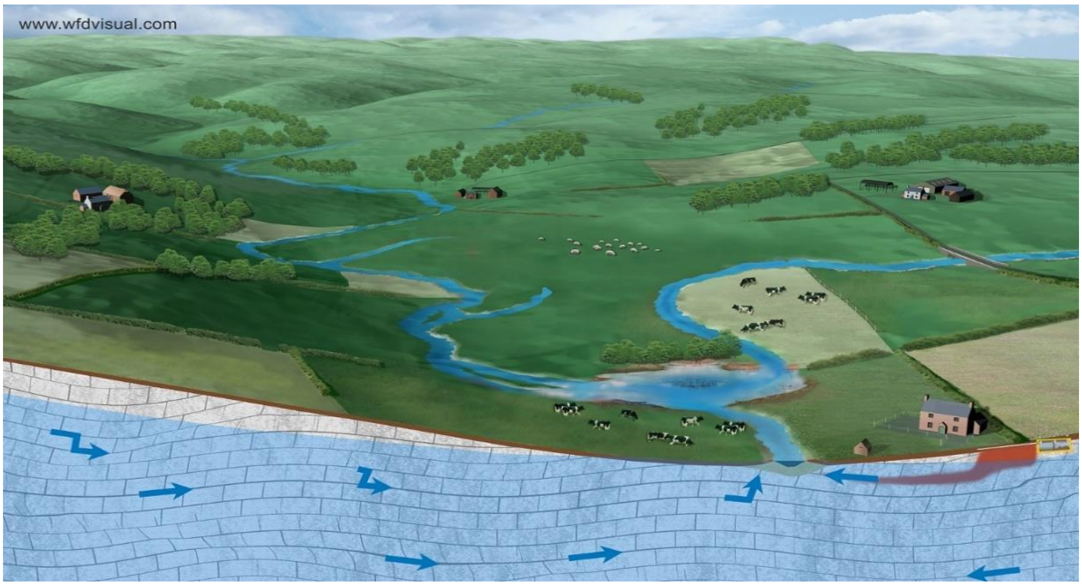


Figure 5-5: The 3-D reality

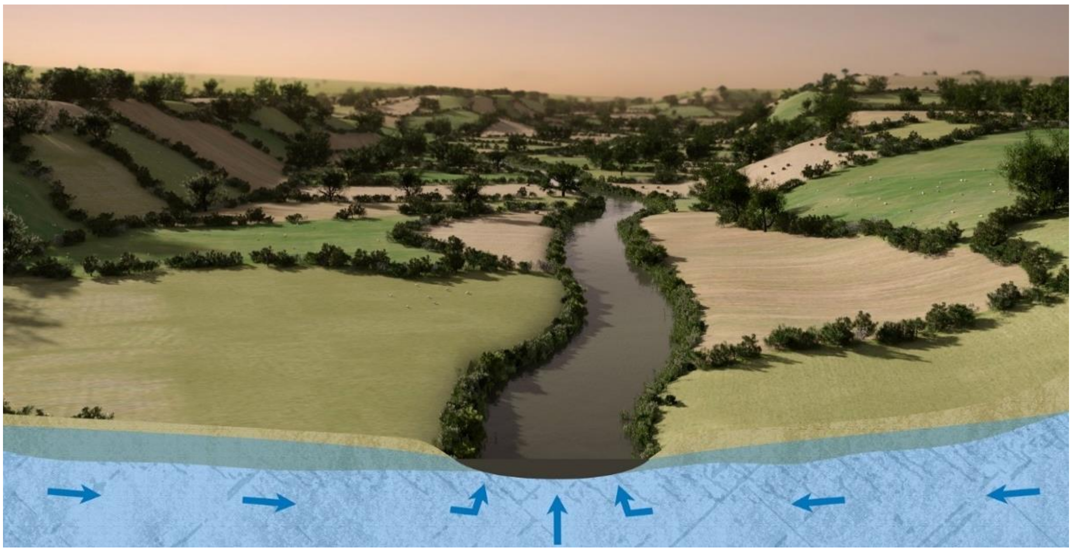


Figure 5-6: The 3-D conceptual model of a watercourse in a flood plain.

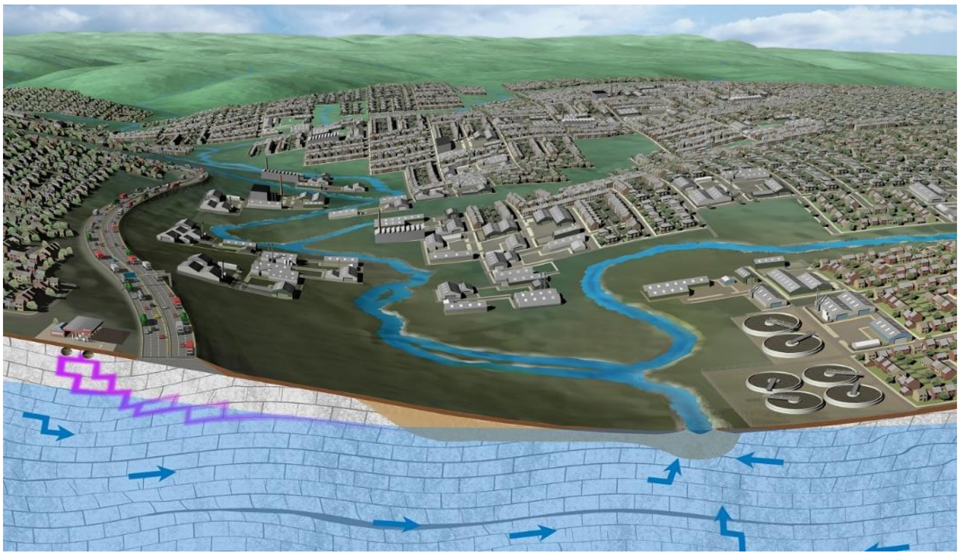


Figure 5-7: A 3-D conceptual model of an urban area.

5.4 Catchment science – what is it?

This section is an article by Jenny Deakin, Catchments Unit, in the EPA Catchments Newsletter, Issue 7 at this link: https://www.catchments.ie/download/catchments-newsletter-sharing-science-stories-winter-2017/.

Catchment Science is the study of the connections and relationships between the physical landscape, ecosystems, and human activities within a water catchment.

Living in a catchment that has healthy water can help a community have a better quality of life – the water can make sure local people have high quality drinking water, support livelihoods like food production, facilitate recreational angling or water sports, and support local ecosystems, so plants, animals, fish and insects that depend on having healthy water can thrive and flourish.

To protect and improve our rivers, lakes and coastal waters, we need to understand how they flow through and are connected with the diverse landscapes that surround them, and what is causing pressures on their ability to support the communities, livelihoods and ecosystems that depend on them for clean and healthy water. This emerging field is called catchment science.

Catchment science is the study of the dynamic interactions between the physical catchment landscape, the ecosystems that sit within that landscape, and the human activities that can cause impacts to ecosystems in that landscape.

These three elements are all linked within the source pathway receptor framework (Figure 5-8). The fourth element in the catchment science and management nexus is the identification of efficient and effective mitigation measures based on this catchment science understanding. Understanding all the elements within the framework equally, and more importantly the linkages between them, is essential for carrying out the pressure-impact analyses which is central for identifying 'the right measure in the right place'.

The importance of the physical setting in understanding problems and identifying appropriate measures was not well developed in the last Water Framework Directive cycle, and in our experience, it is still missing right across the water sector. There is still an assumption that pressure equals impact, or in other words that only two elements of the framework (source and receptor) are needed to arrive at solutions. However, the physical landscape creates the pathway links between the human activities (sources) and the ecosystems (receptor). Where there is no pathway link between sources and receptors, there is no requirement for measures. This is a fundamental principle that underpins the way we need to address diffuse pressures, which are our greatest problem. The physical landscape also influences the inherent nature of the ecosystems that depend on it and therefore the types of rehabilitation or measures that may be required. There is a need therefore to strengthen our national capacity in understanding the physical setting. This is the main reason that the dominant scientific expertise within the Catchment Science and Management Unit when it was initially established in 2014 was physical science disciplines rather than biological sciences.

The ideal catchment scientist has a firm knowledge and understanding of all the source, pathway receptor elements of catchments, a good grounding in appropriate measures, and most importantly, the capacity to integrate, analyse and synthesise that knowledge to gain new understanding for the purposes of answering relevant catchment science and management questions. Catchment science is a relatively new discipline however, and inevitably practitioners have different strengths and training across the elements. Examples of the types of disciplines applicable to each of the elements is provided in Table 5-2.

While practitioners can gain experience and training in elements they haven't studied in, and this is to be encouraged, it is more difficult for them to reach the same standard as someone with a relevant postgraduate degree, i.e. a physical landscape scientist is unlikely to be able to learn enough biology to match the skills and expertise of a biologist with a PhD; and similarly, a biologist is unlikely to be able to learn enough physical landscape science to match the skills and expertise of a geologist, or a soil scientist, or a geomorphologist, or a hydrogeologist with a PhD. This makes the ability to collaborate, integrate, drive innovation and clearly communicate between multiple disciplines that often have their own scientific jargon more important. The best catchment scientists are strong in their respective disciplines and score highly in their abilities to collaborate, integrate, innovate, and communicate their findings.

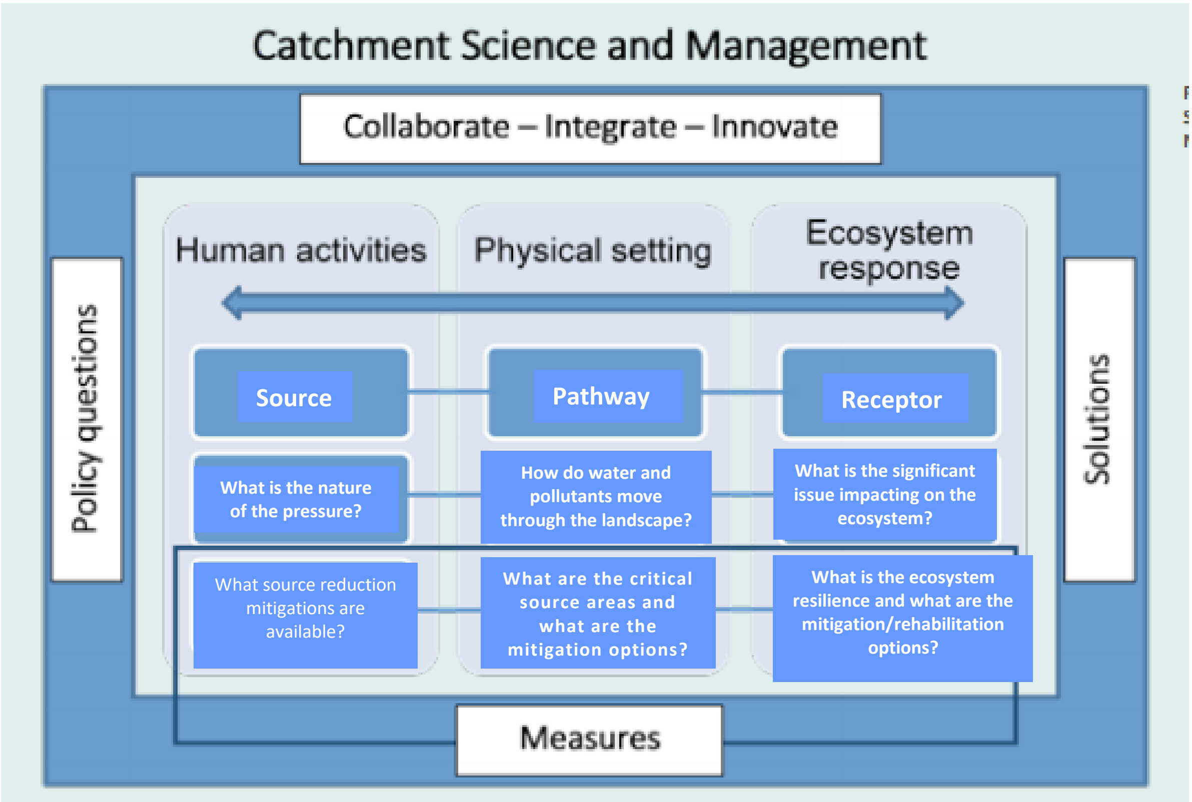


Figure 5-8: The catchment science and management nexus

Table 5-2: Examples of the types of disciplines appropriate to each of the three catchment science elements

Human activities (Source and Measures)	*Physical setting (Pathway)*	*Ecosystem response (Receptor)*
Engineering	*Earth science*	*Ecology*
Agricultural science	*Geology*	*Botany*
Environmental science	*Physical geography*	*Zoology*
Forestry science	*Hydrogeology*	*Limnology*
	Geomorphology	*Aquatic science*
	Soil science	*Biology*
Communicating, building partnerships and encouraging understanding between different disciplines and sectors		

Suggesting solutions, helping build partnerships, and promoting understanding

Understanding the catchment, what are the significant pressures, and suggesting measures that will enhance the environment in these areas are only part of the catchment scientist's role in Integrated Catchment Management – helping others understand the outcomes of the catchment scientist's assessment is also key.

The first step in Integrated Catchment Management is building partnerships, which are vital when trying to implement measures that will often need significant buy-in from the local community. A key part of this work is developing and communicating a vision for the catchment, by asking the local community what is important to them. Catchment science can then help inform the local community and any government agencies involved in managing a catchment in deciding on what actions to take to help them achieve this vision. While they may not always be directly involved, the outcomes of characterisation by catchment scientists can be very useful in helping local communities decide what actions they should take.

To sum it all up in one simple phrase… 'By working together, we will achieve more'.

"You can't manage what you don't understand"
(quote from a John Cherry (renowned hydrogeologist) lecture, April 2021)

'Understanding' is a core concept and objective in this Handbook.

6 Catchment Science and Management – the Frameworks

6.1 Taking a helicopter view

The recognition and appreciation in recent years of the interconnections and interdependencies between the various components of our natural environment – water, air, ecosystems, soils, rocks, land, landscapes, as illustrated in Figure 6-1 – is encouraging a move away from treating each component as siloes, dealt with by particular specialists, processes and organisation. In addition, the increasing prominence of 'systems thinking'[26] and taking a 'systems approach'[27] is resulting in a broader 'mental model' of environmental management based on holistic, integrated approaches. By taking a whole systems approach (including multi-disciplinary, multi-objective and multi-stakeholder inputs), consideration of linkages, co-benefits, disbenefits and trade-offs can enable effective and efficient outcomes for the environment from the actions that are undertaken and the resources (staff and financial) that are applied.

While this Catchment Science and Management Handbook focusses primarily on water, there is nevertheless an awareness of the need to take account of all the other components of our natural environment, such as terrestrial ecosystems, soil conservation, spatial planning, climate change adaptation and mitigation, and sustainable food and timber production.

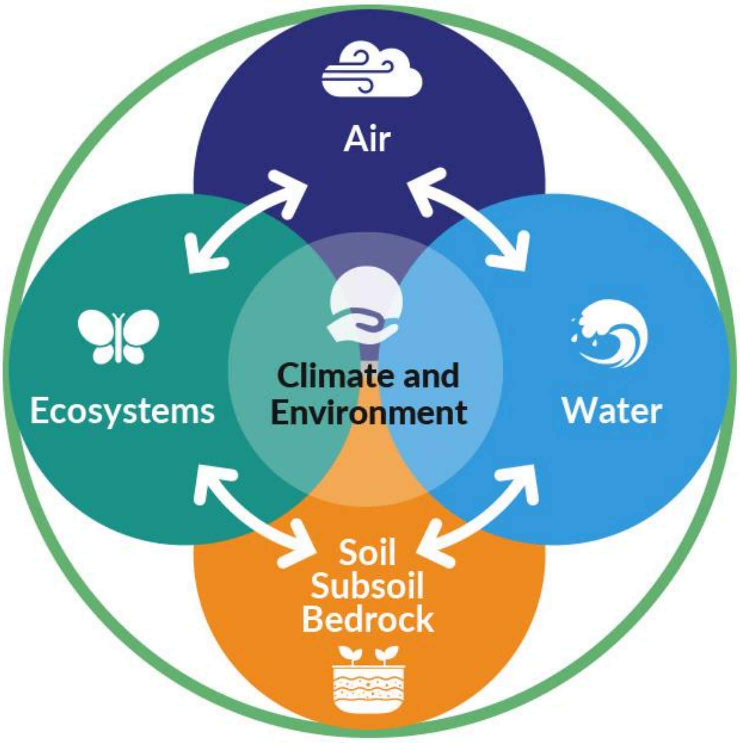


Figure 6-1: Illustration of the 'whole of environment' components and linkages (Copied from An Fóram Uisce, 2021)[28]

[26] An integrated, holistic approach that focuses on the way that a system's constituent parts interrelate and how systems work over time and within the context of larger systems.

[27] A multi-disciplinary, multi-objective and multi-stakeholder framework supporting a balanced evaluation of all relevant issues.

[28] An Fóram Uisce (2020). Protecting and enhancing our environment: A Framework for Integrated Land and Landscape Management. Available from: https://thewaterforum.ie/app/uploads/2021/03/TWF-FILLM-Report-Feb21-v9WEB.pdf

While the broader definition of catchments given in Section 5.1 encourages a more holistic view of water in catchments, that in itself does not provide the processes (thought and work) that enable the necessary systems and 'whole of environment' approaches to catchment science and management. Therefore, this Section provides frameworks in which our work as catchment scientists fits as a means of ensuring:

- Integration and successful environmental protection and enhancement of ALL the environmental spheres (air, water, soils, ecosystems) together.
- Local community involvement.
- The economic and social wellbeing of local communities.
- Compliance with the multitude of EU Directives and associated regulations.
- That both synergies and trade-offs are considered.
- That all are linked together for optimum efficiency and effectiveness.

While advances were made when producing the 1st Cycle RBMP in 2009, weaknesses in approaches were evident. Subsequently, integrated catchment management (ICM) became the agreed approach for achieving WFD objectives and the sustainable use of water and land resources. This is acknowledged in the RBMP for Ireland 2018-2021[29] as follows: "*A new approach to implementation known as 'integrated catchment management' is being used to support the development and implementation of the RBMP, using the catchment (an area that contributes water to a river and its tributaries, with all water ultimately running to a single outlet) as the means to bring together all public bodies, communities and businesses.*"

More recently, An Fóram Uisce/The Water Forum has proposed the adoption of a systems approach in the form of a Framework for Integrated Land and Landscape Management (FILLM) as '*the overarching framework for environmental management, as a means of connecting and achieving, for instance, the UN Sustainability Goals for 2030 and the Water Framework Directive, Urban Waste Water Treatment Directive, Habitats Directive, Floods Directive, Drinking Water Directive, the European Landscape Convention, climate change adaption and mitigation, soil conservation, and sustainable food production and land-use planning requirements*.'[30] FILLM builds on the ICM approach and both includes and reconfigures it to include all other environmental components, including for instance, all environmental objectives, spatial planning, infrastructural development, and food and timber production.

While the FILLM (including ICM) approach provides an overarching framework, the source-pathway-receptor (SPR) model for environmental management underpins consideration of all water protection issues as well as WFD and GWD implementation.

6.2 Integrated catchment management (ICM)

Integrated catchment management (ICM) is based on the concepts of i) catchments as biophysical units in which natural resources use, and ecological and water protection takes place, ii) integration of local community and scientific involvement, and iii) appropriate organisational structures and policy objectives. Specifically, ICM is[31]:

- A ***philosophy*** – to foster an organisational culture and associated attitudes that view i) cooperation and collaboration as essential and ii) interactions between natural resources and human activities or responses in a holistic way.

[29] https://www.housing.gov.ie/water/water-quality/river-basin-management-plans/river-basin-management-plan-2018-2021

[30] https://thewaterforum.ie/app/uploads/2021/03/TWF-FILLM-Report-Feb21-v9WEB.pdf

[31] This definition is adapted from: Bellamy *et al*., 2002.

- A ***process*** – an overarching planning framework and implementation process that reflects the philosophy of ICM and provides the 'vehicle' through which ICM is delivered. The process needs to provide a flexible, adaptive, on-going and dynamic integrated mechanism, which coordinates the activity of many people, both in the public sector and the community.
- An ***outcome*** – the planning and implementation of sustainable resource use practices, which will vary from place to place, depending on conditions and needs, and the achievement of planned environmental outcomes, which are based on environmental, regulatory, economic and social considerations.

ICM involves a series of interconnected steps (see Figure 6-2): (1) building partnerships; (2) creating and communicating a vision of ICM; (3) characterising the physical and ecological components; (4) identifying and evaluating possible management strategies; (5) designing an implementation programme; and (6) implementing the programme and making adjustments, if necessary. This approach has the following benefits:

- ♦ It is catchment-based, aiming not only to provide the hydrological/hydrogeological basis for water resources management, but also to connect people with their local stream, river, lake, coastal water, spring or borehole.
- ♦ It integrates all water types and all relevant disciplines, including social science.
- ♦ It provides for 'characterisation' of the catchment. This, in turn, assists in the identification of the causes and sources of pollution, critical source areas (CSAs) and possible management strategies and mitigation options.
- ♦ It employs a broad range of 'tools' in its 'toolkit, starting with local participation and partnership to encourage behavioural change and including an evidence-based 'hearts and minds' approach provided by catchment characterisation, the implementation of appropriate measures and incentivising actions and, finally, inspections and enforcement (Figure 6.3).
- ♦ It requires close collaboration between relevant public bodies.
- ♦ It requires a combination of 'bottom-up' and 'top-down' approaches.
- ♦ It involves awareness-raising, engagement and consultation with local communities.
- ♦ It presents a vision of a healthy, resilient, productive and valued water resource that supports vibrant communities.

6.3 The Framework for Integrated Land and Landscape Management (FILLM)

The ICM approach was developed as a framework for water management and has been relatively successful in linking the various relevant components in catchments, including the people and socio-economic components in catchments. In recent years there has been an increasing realisation of the connectedness of our natural environment, which is a 'system', comprised of several critical 'realms': i) water; ii) air and atmosphere; iii) ecosystems; iv) geosystems; and v) land/landscapes(as illustrated in Figure 5-2). These realms are linked physically, biologically, socially and economically. Our climate crisis, biodiversity losses and water quality dis-improvements are now requiring cross-realm analysis, interactions and planning.

In reviewing ICM and considering how our environmental objectives for water could be achieved, An Fóram Uisce/The Water Forum concluded that there was scope for broadening it to incorporate public participation (there has been some criticism that ICM as illustrated in Figure 6-2 did not take this into account adequately), biodiversity and ecosystems, greenhouse gas emission reduction and carbon sequestration more explicitly and comprehensively, thereby connecting all the environmental components shown in Figure 6-1 and making ICM a more powerful and relevant means of protecting and enhancing our environment, and achieving co-benefits from measures. ICM, as illustrated in Figure 6-2, has been expanded, reconfigured and rebranded as the Framework for Integrated Land & Landscape Management (FILLM).

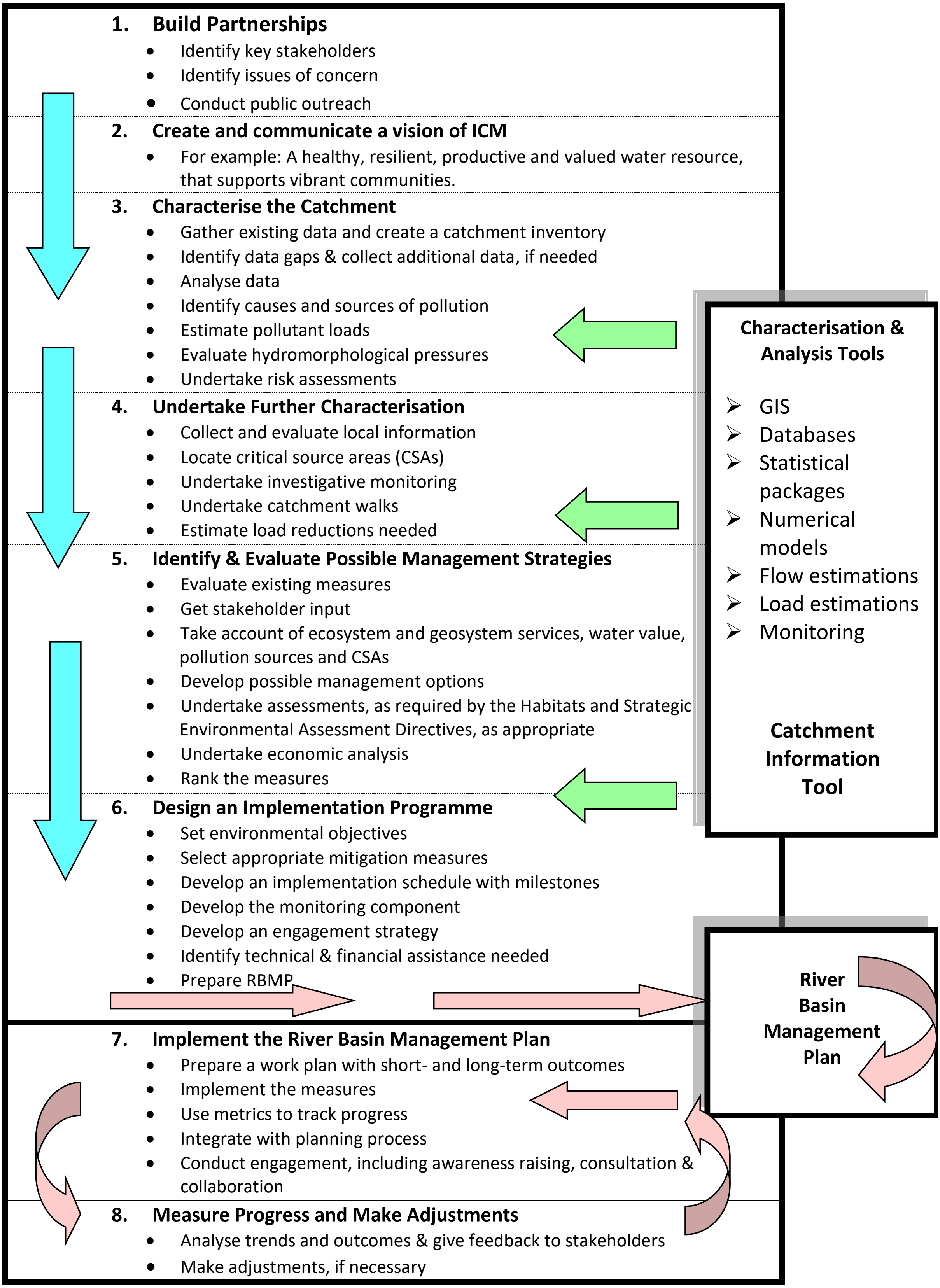


Figure 6-2: Steps in the integrated catchment management process. (See article at this link for further information: http://www.jstor.org/stable/10.3318/bioe.2016.16 .)

	Tools	Challenges/likelihood of success
Participation & Partnership	**A vision** ➢ 3-D integrated catchment science ➢ Catchment management ➢ Both science and people ➢ Healthy and vibrant communities.	A new vision. If approached properly, a high likelihood of success. *["Catchments: connecting land, water and people from the mountains to the sea"]*
	Public engagement ➢ Awareness raising ➢ Sharing knowledge ➢ Collaboration & engagement with local communities	Complex area & resource intensive. Means of achieving successful outcomes unclear. Essential, for long term results.
	Characterisation at catchment scale ➢ Bio-physical (hydrogeology, biology, hydrochemistry, etc.) ➢ Monitoring ➢ Location of *significant pressures* ➢ Evaluation of impact of *significant pressures* ➢ Analysis using SPR approach (detailed evaluation of hydrochemistry, pollutant loading, biological indicators, etc.)	Multi-disciplinary. Must be scientifically defensible and catchment specific. More than just monitoring. Produces the information needed as the basis for catchment walks.
	Characterisation at local scale ➢ 'Walking the catchment' ➢ Location of critical source areas (CSAs) ➢ Decisions on measures/actions	Resource intensive. Essential as a means of choosing the optimum mitigation options.
	Programmes of measures ➢ Best Management Practices (BMPs) ➢ Measures targeted spatially ➢ Costed and prioritised ➢ A focus on outcomes ➢ Input of local knowledge ➢ Local participation	Some measures/actions costly. Must be prioritised and outcome oriented. These are the means of achieving water quality outcomes.
	Incentives ➢ Greening of the CAP ➢ Grants for native woodlands	Incentives need to be focussed on CSAs and relevant pressures
	New/Upgrading infrastructure	Continued investment needed
Enforcement	**Inspections** Farming; DWWTSs; UWWTPs; Drinking water audits; IPPC inspections	Needs to be risk-based. Necessary, particularly when other 'tools' are not effective.
	Court/loss of money	The last resort!
	Policy changes/new Regulations	Essential, but challenging and potentially slow to achieve.
	Over-arching requirement • Modelling, GIS, databases, communications	

Figure 6-3: The 'Toolkit' for the ICM Approach From: Daly, 2013 (with amendments) at this link: https://www.iah-ireland.org/conference-proceedings/2013.pdf

The reconfigured ICM as FILLM is shown in Figure 6-4. When Figure 6-2 and 6-4 are compared, it is clear that the steps of ICM are mirrored by the stages of FILLM. In addition, FILLM includes consideration of stakeholder engagement, GHG emission reduction and carbon sequestration at all stages. Also, the FILLM process can be used not only where water (for WFD implementation, for instance) is the main receptor being considered, but also where ecosystems, both terrestrial and aquatic, are the main receptor, for example SACs and SPAs (for Habitats Directive implementation). Stage 2 of FILLM is not replicated explicitly in ICM. It is included because the decision on whether the objective is 'improve/restore' or 'protect' is an important one as it determines the subsequent focus and the measures (see Section 10.3 for more details).

Some beneficial outcomes of expanding and reframing ICM to FILLM are as follows:

1. It provides a basis for a shared vision of land utilisation and management that includes all stakeholders, all human activities and all environmental components and, in the process, encourages a multifunctional approach to land-use, encompassing all the particular ecosystem, geosystem and atmospheric system services in a catchment area.
2. It provides the opportunity and encouragement for policy coherence and integration in land, landscape and nature management in a context where there are multiple environmental and socio-economic needs.
3. It makes environmental management more understandable and appealing to local communities because many householders and farmers 'see' the surrounding landscape as a mosaic of topographical, physical, ecological, cultural and infrastructural features and functions with no clear boundaries between them, particularly those that are the natural capital of an area.
4. It encourages optimum location of protection and improvement measures. For instance, many of the mitigation activities undertaken to either protect or improve water quality also improve biodiversity and increase carbon sequestration. Examples of co-benefits are given in Table 6-1.
5. It discourages 'one-off' actions to deal with a singular environmental issue without consideration of the potential for ensuring optimum environmental benefits and cost-effectiveness.
6. It enables and encourages different relevant disciplines and organisations to collaborate in the pursuit of mutually beneficial objectives.
7. It takes account of situations where pressures that are seen to impact on one element of the environment in a catchment often impact on others, e.g. intensive farming can impact not only water quality, but also biodiversity, and can increase carbon and ammonia emissions unless actions are taken to mitigate impacts.
8. It fits well as a concept and approach with the broad range of local authority responsibilities and work, particularly for Water Services, Planning and Environment Section staff.

6.4 The SPR Approach

The scientific assessment of issues relating to water, such as discharges whether intentional from point sources or unintentional from point or diffuse sources, needs to be **risk-based** and **receptor-focussed**. The **source-pathway-receptor (SPR)** model for environmental management provides an essential environmental risk management framework for considering and tackling pressures than could or are impacting on water quality. Many activities in catchments carry a degree of risk of impact on either surface water or groundwater or both. The challenge is differentiating between degrees of risk and assigning appropriate effort and resources where the risk is higher. **It is crucial that the level of assessment required should be proportionate to the risk posed, so that optimal use is made of resources, such as time, effort and finances**.

For a threat to be present to a waterbody, there must be a **source** of a hazard, a **receptor** and a linkage between the source and the receptor. Each of these elements can exist independently, but they create a risk only when they are linked together, so that a particular pollutant (or water abstraction) affects a particular receptor through a particular route or **pathway**. Utilising this SPR approach, which is illustrated in Figure 6-5, helps ensure that decisions are evidence-based and can be justified. Further details are given in Section 3, Volume 6.

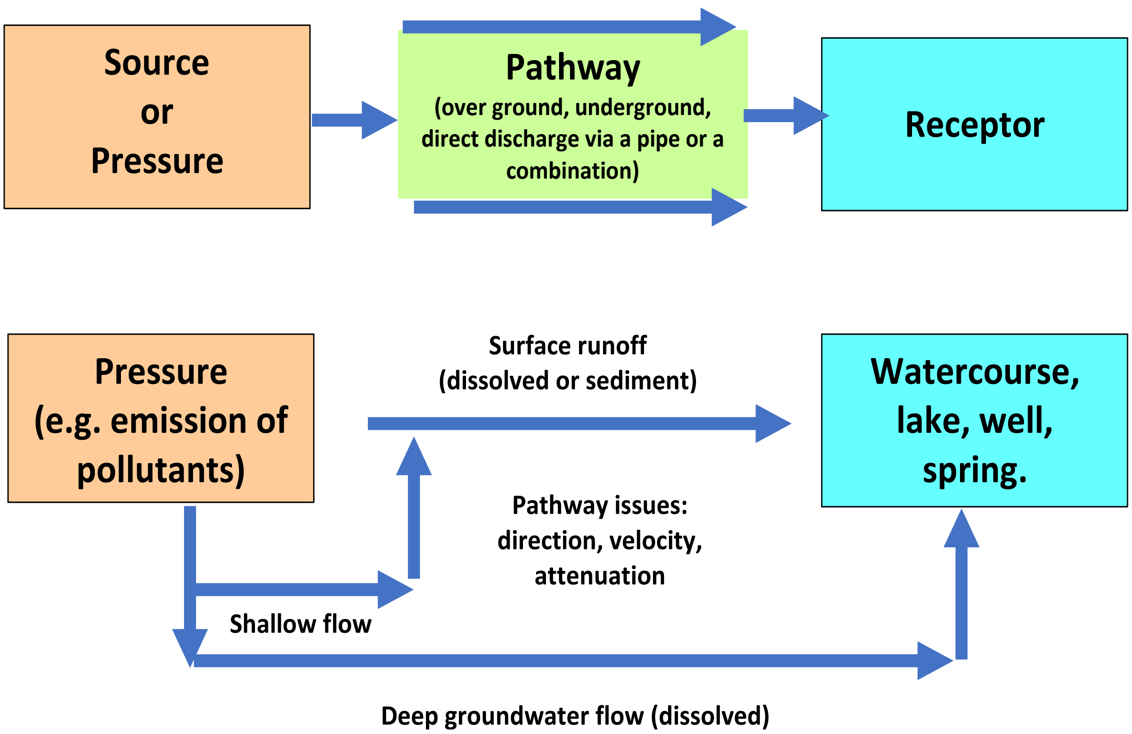


Figure 6-5: The source-pathway-receptor (SPR) model for environmental management

Table 6-1: Illustration of the range of environmental benefits provided by different farming and forestry practices. (Copied from An Fóram Uisce, 2021)

Management option to address pressures	Water quality	Biodiversity	Flood mitigation	Soil conservation	Landscape	Climate Change Mitigation	Climate Change Adaptation
Creation of buffer strips, e.g. riparian zones, grass margins.	●	●	○	●	○	●	○
Planting of clover and multi-species grasses	●	●	–	●	–	●	–
Planting hedges alongside watercourses & across slopes	●	●	○	●	○	●	○
Liming of mineral soil to ensure optimum pH	●	–	–	●	–	●	○
Agroforestry	●	●	○	●	○	●	○
Planting with native woodlands	●	●	●	–	○	●	○
Interception ponds and constructed wetlands	●	●	○	○	●	●	●
Rewetting peatlands	●	●	○	–	○	●	●

● = Management option contributes directly to an environmental benefit

○ = Management option contributes indirectly to an environment benefit

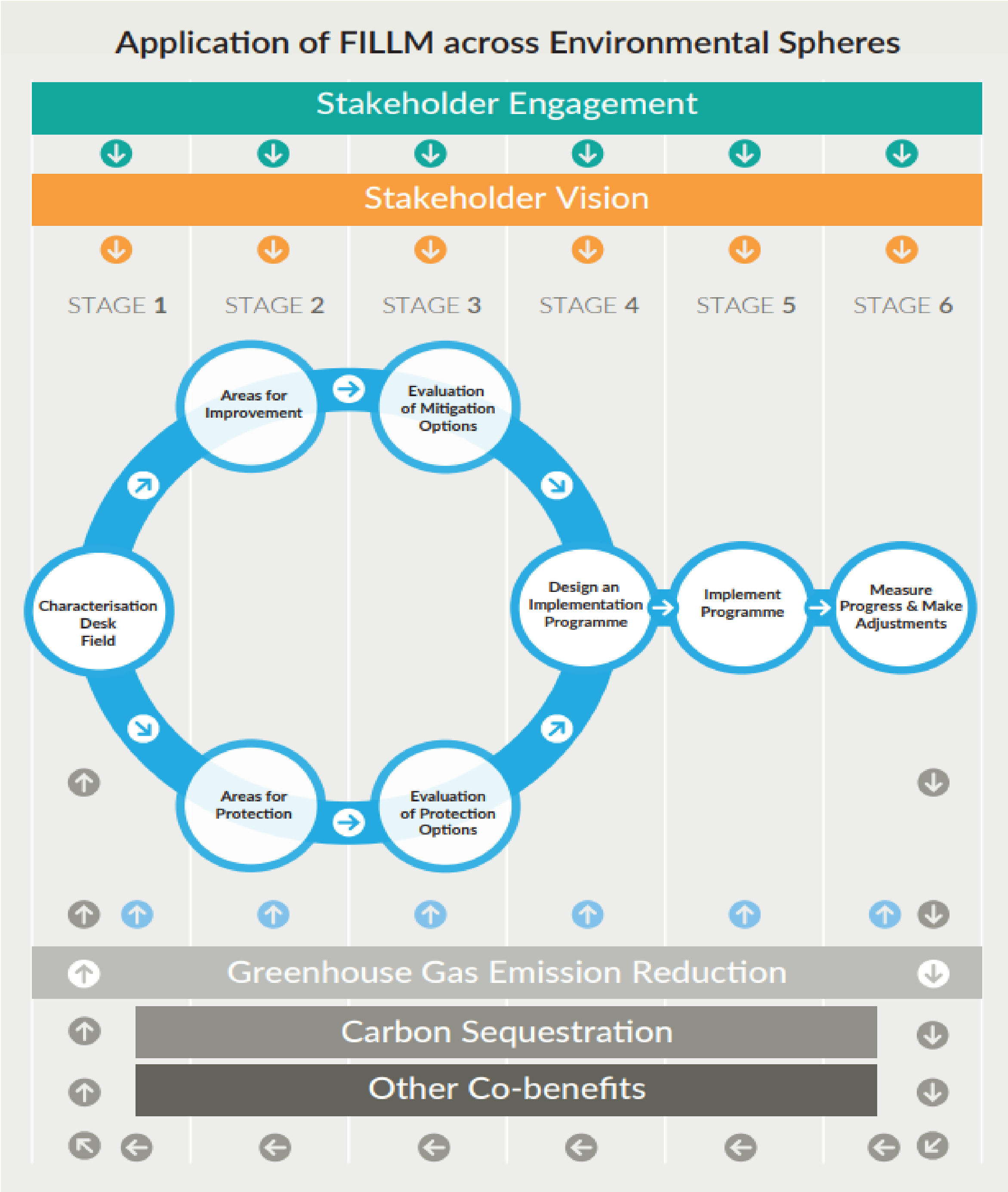


Figure 6-4: Components of the reconceptualised Integrated Catchment Management (ICM) approach as a Framework for Integrated Land and Landscape Management (FILLM) aimed at achieving Water Framework Directive, Urban Waste Water Treatment Directive, Drinking Water Directive, Floods Directive and Habitats Directive objectives, and linking with carbon sequestration and GHG emission reduction. (Copied from An Fóram Uisce, 2021).

7 Sources of Data and Information

7.1 Introduction

There are a wide variety of relevant datasets, information and maps available from public bodies and on their websites (see Table 7-1)..

7.2 WFD Application

The WFD App is the subject of a separate EPA guidance document[32]. The WFD App is a web-based application that is accessible through EDEN (https://wfd.edenireland.ie/help/help) to staff from EPA, other public agencies, and Local Authorities. It is a tool which can be used to access WFD-related information, record information, and prepare reports as part of the Investigation Assessment process. The intent of the WFD App is to facilitate the movement and sharing of data and information between Local Authority and EPA staff at the water body scale. Information is recorded, managed, reported and disseminated in a structured format that is consistent with EC reporting schemas.

A typical output of the information available for all 4,842 water bodies is shown in Table 7-2. The information in the WFD App is based on the national biological and chemical monitoring dataset and it is carried out at the waterbody scale. All water bodies are given a status and risk category. A significant proportion of water bodies have no monitoring data and therefore are classed as Unassigned status, with a risk category of *Review*[33].

Table 7-2: Summary table of water bodies in a sub-catchment

				Ecological status					
WB Code	**WB Name**	**WFD Risk**	**Status Obj.**	**2009**	**2012**	**2015**	**Pressure Category**	**Pressure Subcat.**	**Sig. Pressure**
IE_SE_etc	Xxxx_010	*Not at risk*	Good	Good	High	Good	N/A	N/A	N/A
IE_SE_etc	Xxxx_020	*At risk*	Good	Good	Good	Mod	Anthropogenic Pressures	Unknown	Yes
IE_SE_etc	Yyyy_010	*At risk*	High	High	High	Good	Agriculture	Farmyards	No
							Domestic Waste Water	Waste Water discharge	No
							Forestry	Forestry	Yes
IE_SE_etc	Yyyy_020	*Review*	Good	Unass	Unass	Unass	Agriculture	Pasture	???
IE_SE_etc	Zzzz_01	*Not at risk*	Good	Good	Good	Good	N/A	N/A	N/A
IE_SE_etc	Xxxx_030	*At risk*	G	Good	Good	Mod	Abstractions	Water supply	Yes
							Agriculture	Pasture	Yes
							Urban wastewater	Agglomeration PE of 2,001 to 10,000	Yes

Acknowledgement: this table is based on a LAWPRO desk study report, which has extracted the information from the WFD App.

[32] http://www.epa.ie/water/watmg/wfd/wfdapp/

[33] For further information on the difference between status and risk, see Sections 3-3 and 3-4. In the River Basin Management Plan 2022-2027, 26% of all water bodies were categorised as in 'Review' because "(1) the measure is in place but the water quality improvement has not yet been realised or that there is some improvement but not enough yet to put it at Not at Risk, or more commonly, (2) that there is currently inadequate evidence to determine whether or not the water body is At Risk. because of insufficient monitoring."

Another important source of information, which can be readily accessed both in the office and in the field, is the website www.catchments.ie. Not only are there a wide variety of maps (Figure 7-1 and Figure 7-2 show two examples) but also data, graphs and reports. For example, the report on the River Brosna can be accessed at this link: https://catchments.ie/wp-content/files/catchmentassessments/25A%20Lower%20Shannon%20Catchment%20Summary%20WFD%20Cycle%202.pdf

Recommendation

That we become familiar with and use the www.catchments.ie website as an essential source of information.

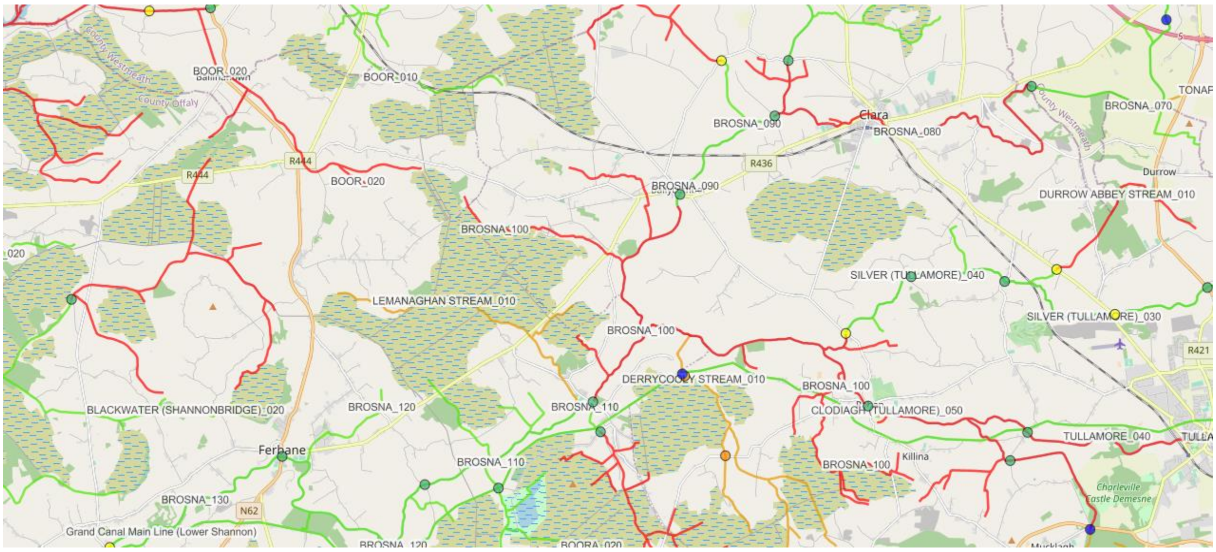


Figure 7-1: Map downloaded from catchments.ie showing river water body risk and Q-values at EPA monitoring points.

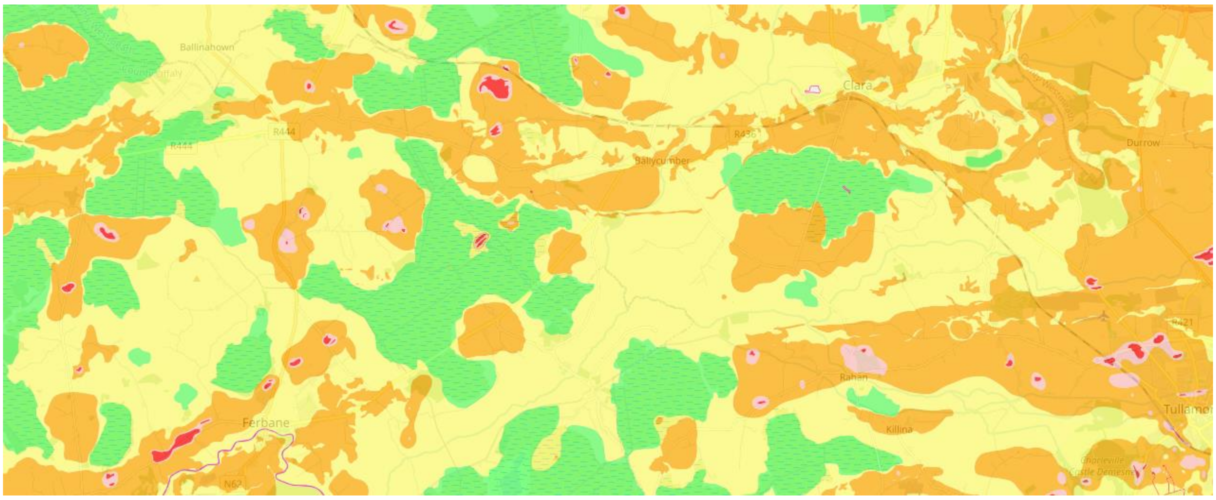


Figure 7-2: Map downloaded from catchments.ie showing groundwater vulnerability.

Table 7-1: Sources of Data for Catchment Characterisation and Environmental Assessment

Organisation	Data and Information	Source
EPA	*WFD App; Water quality reports and data; Biological data; Groundwater and hydrometric data (e.g. streamflows); Lake bathymetric data; WFD-related reports and data; Research reports and data; Industrial, extractive industry and waste licenses, permits and enforcement records; Public water supplies; Aquifer type map; Soils and National Soils Hydrology maps); Subsoil map; Pollution Impact Potential maps; Susceptibility maps; National CORINE landcover dataset; Groundwater Zones of Contribution reports; Advisory notes; Guidance documents (many topics).*	https://wfd.edenireland.ie/ www.epa.ie https://gis.epa.ie/EPAMaps/ www.catchments.ie https://data.gov.ie/dataset
GSI	*Groundwater vulnerability map; Subsoils; Subsoil permeability map (associated with Groundwater recharge map); Physiographic units map; Bedrock hydrostratigraphic rock unit groups; Aquifer maps (bedrock and sand/gravel) Groundwater recharge map; Database of karst features; Groundwater tracing results; Groundwater body maps and descriptions; Groundwater Zones of Contribution and Source Protection Zone reports and maps for public and group water schemes; Aquifer properties report; TELLUS geochemical and geophysical data.*	https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx https://www.gsi.ie/en-ie/programmes-and-projects/Pages/default.aspx http://www.tellus.ie/
Teagasc	*Agricultural statistics; Soil and subsoil maps and information; Soil drainage; Advisory notes (e.g. good farming practice); Research reports (e.g. agricultural catchments programme).*	www.teagasc.ie
DAFM	*Action plans and strategy documents; Fact sheets; Advisory notes; Agricultural statistics; Pesticide (usage) data records; Forest Inventory and Planning System (FIPS) map.*	www.agriculture.gov.ie https://www.gov.ie/en/publication/642e6-forestry/

Organisation	Data and Information	Source
IFI	*Research reports;* *Fisheries data and reports;* *Monitoring data;* *Species guides;* *Barrier data;* *Fisheries protection reports;* *Rehabilitation programmes;* *Environmental Drainage Maintenance guidelines;* *Invasive species guides, alerts, and best practice documents for control.*	www.fisheriesireland.ie
OPW	*Hydrometric (stream gauge) data;* *Flood risk maps and related reports;* *Flood relief schemes;* *Drainage and embankment schemes.*	www.opw.ie http://maps.opw.ie/drainage/map/
Met Eireann	*Climate data, including rainfall;* *Statistical summaries and reports;* *Event summaries and reports.*	www.met.ie
OSI	*Discovery Series mapping (1:50000);* *Orthophotography;* *Aerial imagery;* *Historical 6-inch maps;* *Historical 25-inch maps;* *Coordinate conversion functions.*	www.osi.ie
Coillte	*Forest and forestry information (areas, practices, management)*	www.coillte.ie
Irish Water	*Public water supplies;* *Wastewater treatment plants;* *Abstraction records;* *Wastewater effluent data;* *Wastewater collection networks.*	www.irishwater.ie
Local Authorities	*Discharge licences and related files;* *Waste facility permits/certificates of registrations;* *Environmental monitoring data;* *Planning files;* *Land zoning and plans;* *Complaints datasets;* *EIA documents for infrastructure;* *Groundwater Protection Scheme information;* *Development and flood mitigation schemes;* *Information available from Environmental Officers, Heritage Officers, Biodiversity Officers, Parks Department, etc.*	LA-specific
NFGWS	*Group water scheme data;* *Source protection reports.*	www.nfgws.ie
NPWS	*Registers, information and reports on protected sites;* *Related maps and data;* *Habitats and species reports;* *Wildlife manuals;* *Biodiversity action plan.*	www.npws.ie

Organisation	Data and Information	Source
National Biodiversity Data Centre	*Biodiversity maps and reports;* *Species records;* *Species red list;* *Non-native and invasive species;* *Online tutorials for recording and viewing observations.*	www.biodiversityireland.ie
Irish Environmental Network	*Advocacy, public engagement campaigns, training, advisory services;* *Themed reports.*	www.ien.ie
SWAN network	*Advocacy, pro-active following and reporting on WFD implementation in Ireland*	https://www.swanireland.ie/
Google	*Google Earth* *Google Street View*	https://www.google.com/earth/ https://www.google.com/maps

8 A Structured Process for Water Resources Protection and Management

8.1 Introduction

Local authorities and other public sector bodies have a wide range of responsibilities for water and deal with a wide variety of water-related issues. Some issues are simple to resolve and some tasks are easy to undertake within the wider water resources protection and management context. However, many are complex due to the variability and complexity of our biophysical environment – soils, subsoils, bedrock, ecosystems and weather – which makes assessing and determining water movement in the Irish landscape demanding. Add to this situation the heterogeneity of human activities locally and regionally in terms of either or both pollutant and abstraction pressures, whether in towns or in rural areas, then the challenge of achieving the environmental objectives required for our water resources and ecosystems is apparent.

As a means of dealing with this wide range of responsibilities and issues, a structured process provides a means of considering them which increases the likelihood of achieving the desired or required environmental outcomes in an efficient and effective manner.

8.2 Catchment and site assessment scenarios

A wide variety of scenarios arise in every local authority area that need to be dealt with. Assessment of these scenarios can take many forms, depending on the questions and topics to be addressed. Eleven main scenarios – see details in Table 8-1 – are used by LAWPRO. These scenarios reflect different levels of complexity and settings. While they are intended primarily for WFD implementation and reporting, they nevertheless have a general relevance and are a useful way of subdividing the issues that arise and that need to be dealt with.

Scenarios CA1 through CA4 are mostly or completely desk-based, although Scenarios CA3 and CA4 may involve single field visits to check on specific features such as the coordinate (actual location) of a discharge pipe from a wastewater treatment plant or grabbing a single sample of effluent for laboratory analysis. Case-specific analyses may also be carried out, such as assimilative capacity or water balance calculations. In some circumstances, the desk study will provide sufficient information to enable the *significant pressure* to be determined with confidence. In such cases, appropriate mitigation options may be recommended.

8.3 Outline of the Process

Within the overarching framework for environmental management provided by FILLM (and ICM), a structured process to considering the particular issues that arise for water resources that is systems-based, risk-based, evidence-based, holistic and integrated will enable the required objectives to be achieved efficiently and effectively. This section provides a **recommended Process** or approach and a way of thinking; while it is a recommendation, it is not meant to be prescriptive, and it can be adapted in a flexible manner to suit the particular circumstances or needs.

Table 8-1: Catchment Assessment Scenarios

Scenario ID	Scenario Name	Comment
CA1	Provision and further evaluation of existing information	There are circumstances where there is further information and/or data within organisations or in the WFD App that can be evaluated before the necessity for field visits.
CA2	Point source desk-based assessment	Conducted where slightly more analysis, e.g. assimilative capacity calculations, or checking for trends or compliance in new datasets, might be sufficient to draw conclusions on what needs to be done.
CA3	Unassigned status and *Review* risk category waterbodies, requiring field visits	Additional monitoring data, mainly, are required.
CA4	Regulated point sources, requiring field visits	Sampling discharge, and stream upstream and downstream for compliance and load/impact.
CA5	Inspections	Farmyard, domestic wastewater treatment systems and complaints.
CA6	Catchment (stream) walk – general (in defined 1 km river stretch)	This IA category has been used to estimate the resources required to locate and evaluate the significant pressures in a catchment area of a 1km stretch of stream/river, and then subsequently to estimate the resources required for longer stream/river stretches.
CA7	Catchment (stream) walk in urban areas	Multiple pressures will be present in this scenario.
CA8	Catchment (stream) walk in rural areas for streams that are >1km in length.	Multiple pressures will often be present in the catchment areas of these streams
CA9	Lakes field assessment	This will generally involve taking lake water samples and consideration of stream and groundwater inputs. In some circumstances, an IA11 will be required with inputs from technical specialist(s), e.g. freshwater ecological studies, limnological characterization, sediment sampling.
CA10	Groundwater body field assessment	Following the desk study, this will generally involve location and assessment of pollution sources, groundwater vulnerability, karst features and presence of wells and springs. In many circumstances an IA11 will be required with inputs from technical specialist(s), e.g. hydrogeologists, drilling of boreholes, groundwater modelling.
CA11	Specialist input	Requires contracted technical specialist(s), e.g. surface geophysical surveying, biological studies (e.g. determining Q values or SAC requirements).

The Process fits within the SPR model, which in turn is encompassed by the overarching ICM and FILLM frameworks, as is illustrated in Figure 8-1.

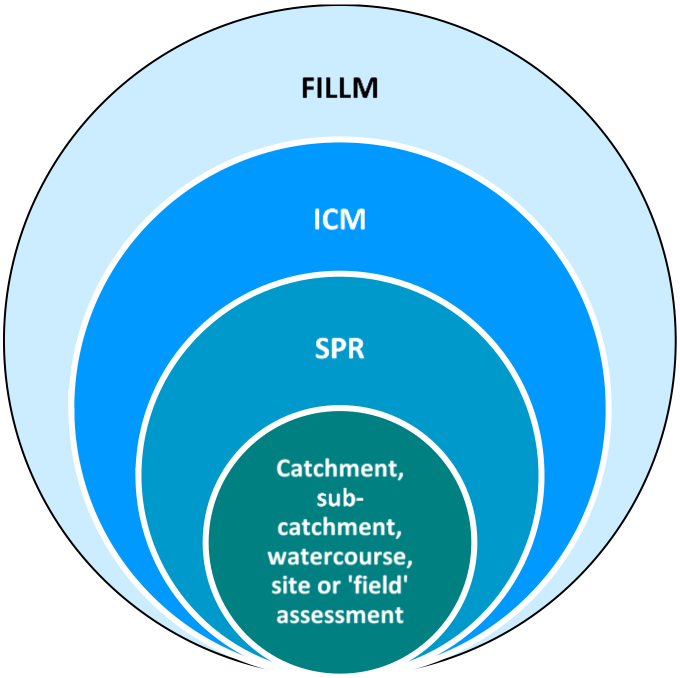


Figure 8-1: Illustration of the hierarchy of frameworks in which a sub-catchment or site or 'field' assessment is undertaken; firstly, embedded in the source-pathway-receptor (SPR) model for environmental management, then within ICM which in turn is encompassed within the FILLM approach.

The Process is summarised in the flow chart in Figure 8-2. It consists of three main components:

1. Characterisation
   - i) The requirement(s) of the receptor in question.
   - ii) Initial characterisation involving a desk-based compilation and evaluation of relevant information and maps for the catchment area/ZOC[34].
     - ♦ Evaluation of the water quality of the receptor.[35]
     - ♦ An important outcome is a decision, based on comparison of the data with the requirements of the receptor, as to whether the objective is 'protect' or 'improve/restore'.
     - ♦ Where there are insufficient data, further monitoring data collection and evaluation is needed.
   - ii) Assessment of the pressures.
   - iii) A pathway conceptual model where diffuse sources are a pressure or where there are discharges from a point source to groundwater.
   - iii) An interim 'story' of the source catchment area/ZOC or site.
   - iv) Further characterisation, involving fieldwork and catchment walks.

2. Protection or mitigation/restoration, as relevant
   - i) Analysis and conclusions on the potential protection or mitigation strategies and activities needed.

[34] A ZOC is the zone of contribution or catchment area to a well or spring.

[35] It some circumstances, it might be consideration of the impact of water abstraction on a receptor; while this situation is not dealt with in this Guidance Handbook, the approach outlined is still generally applicable.

ii) Implementation of specific targeted and appropriate protection or mitigation activities.

3. Monitoring progress and adjusting, if necessary, as this is an iterative process. (

Each of these components are now considered in turn. **Note how they match the steps in Figure 6.2 and the stages in Figure 6.4.**

Characterisation

Characterisation provides the understanding that is needed to i) protect satisfactory water quality situations, ii) mitigate unsatisfactory water quality situations and iii) enable site/development inspections to be undertaken effectively. It provides the understanding and appreciation of the overground and underground pathways water and associated pollutants take travelling from the source to the receptor. It requires data/information collection and evaluation of the various relevant elements of the source-pathway-receptor (SPR) model of environmental risk assessment.

Compliance assurance (including enforcement action) of pressures is a requirement for Local Authority staff. When evaluating the compliance, it is worthwhile considering the pressure in the context and 'mental model' provided by the process in Figure 8-2. By taking the receptor rather than the pressure as the starting point, it places the primary focus on achieving the required environmental outcome.

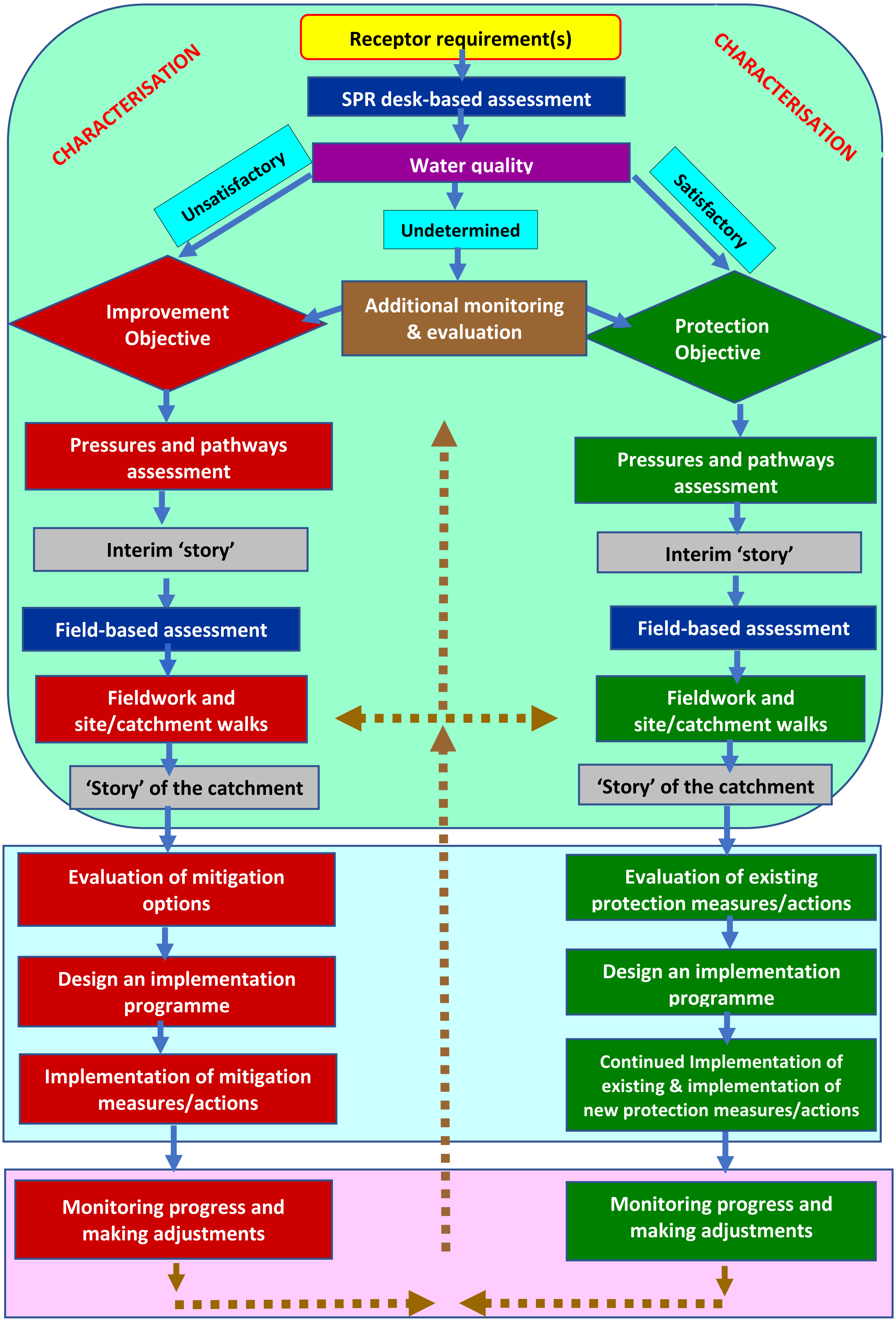


Figure 8-2: Flowchart illustrating the recommended process that fits within the SPR model for environmental management. (Flowchart adapted from Figure 4 in NFGWS (2019).

This Handbook does not attempt to describe a Process that encompasses <u>all</u> the water-related circumstance and issues that local authority and other public bodies must deal with. It focuses mainly on surface water in a sub-catchment where there is a requirement to evaluate either the impact of a particular activity or the situation in a sub-catchment with a number of stream water bodies and initiate whatever actions that are needed to maintain and protect water quality where it is satisfactory and mitigation actions to improve water quality where it is unsatisfactory.

For issues and circumstances that do not fall into these settings, assess the Process that is followed and the lessons that can be learned from them as they may be helpful.

9 The Requirements of the Receptor

As a first principle, **consider the water receptor in the area of interest as the starting point**.[36] There are a wide variety of receptors that might be relevant, depending on the circumstances:

- Watercourses varying is size from a drainage ditch or small stream to a large river.
- Lakes, estuaries and coastal waters.
- Wells (domestic, group water and public), springs and aquifers.
- Special protection areas (SPAs).

Therefore, focus on what the relevant water receptor(s) is/are, or if it is not clear, work it out. In this Volume, the focus is on watercourses in a sub-catchment and with some references to group water scheme wells.

Then **check or decide on the requirement(s) of the receptor** in terms of water quality or other relevant outcomes. Examples:

- Good or High status for a surface water body or Good for a groundwater body.
- Satisfactory untreated water quality for a group water scheme.
- A reducing trend in pollutant concentrations and/or pollutant loads to a water receptor.
- Compliance with an effluent treatment licence, for instance, in terms of wastewater discharges.
- Satisfactory situations for water quality in the vicinity of a point pressure being inspected by a local authority staff member.

Once the requirement is known, **examine what the requirement means in terms of relevant metrics,** such as receptor-based water quality standards. Depending on the situation being evaluated, these could one or some of the following:

i) Pollutant concentrations.
ii) BOD values
iii) *E. coli* numbers.
iv) Water flows, e.g. a 95%ile flow.
v) Water levels, e.g. a minimum level in a lake or well.

This Volume does not cover iv) and v) above. However, the outlined process for water quality is likely to apply or be relevant to them.

The most common relevant metrics are as follows:

- Environmental Quality Standards (EQSs) given in the Surface Water Regulations (S.I. No. 77 of 2019 at this link: http://www.irishstatutebook.ie/eli/2019/si/77/made/en/pdf). Note: these are given as both mean and 95%ile concentrations.

- Groundwater Threshold Values (TVs) (S.I. 366 0f 2016. Available at this link: http://www.irishstatutebook.ie/eli/2016/si/366/made/en/pdf). Note: these are given as mean concentrations.

- Drinking water parametric values (S.I. No. 122 of 2014. Available at this link: http://www.irishstatutebook.ie/eli/2014/si/122/made/en/pdf). Note: parametric values are maximum admissible concentrations.

[36] It may seem strange to a reader, who would have been involved with many water-related issues, to start with this. Experience has shown those of us involved in recent years with catchment characterisation that this is an effective approach.

- NFGWS untreated water guide values (NFGWS, (2019). Available at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/). Note: these are given as mean concentrations.

- Informal warning/trigger levels for certain pollutants, based on experience.

- Presence of macroalgae or sewage fungus in a small stream or drainage ditch in the vicinity of a point source.

Why check what the relevant metric is? For the following reasons:

1. They can vary depending on the receptor and the particular requirement of the receptor. This variation is shown for phosphate and nitrate in Table 9-2 and Table 9-3, respectively.
2. They become a target that needs to be considered when continuing the characterisation process.
3. They become the basis for deciding on the target for appropriate protection/mitigation actions, as the pollutant concentration needs to be lower than the mean values given in the tables. Achieving one of the mean value concentrations given above in a water body may not be sufficient to achieve the status objective as, by definition, values below the mean can cause impacts. Therefore, it is recommended that targets as mean values should be set lower than, for instance, mean EQS values. For example, it is recommended that in order to achieve *Good* status where PO_4 is the significant issue, the aim could be to reduce mean values to approximately 0.03 mg/l.

The value of undertaking this first stage is that it enables the questions that need to be answered to be framed and facilitates a focus on the environmental objectives and outcomes that need to be achieved.

Table 9-2: Variations in the phosphate concentrations for different requirements

	Mean concentration (mg/l P)	**95%ile (mg/l)**
River		
♦ **High status**	0.025	0.045
♦ **Good status**	0.035	0.065
Groundwater TV	0.035	N/A
Drinking Water Standard	N/A	N/A
NFGWS guide value	0.035	N/A

Table 9-3: Variations in the nitrate concentrations for different requirements

	Mean concentration mg/l	**MAC (mg/l)**
River		
♦ **High status**	N/A	N/A
♦ **Good status**	N/A	N/A
♦ **Trigger value**	3.5 as N	N/A
Coastal water		N/A
♦ **Good status**	2.6 as N	
Groundwater TV	37.5 as NO_3 (8.5 as N)	N/A
Drinking Water Standard	N/A	50 as NO_3 (11.3 as N)
NFGWS guide value	28 as NO_3 (6.3 as N)	N/A

10 Desk-based Assessment – Sub-catchment Scenario

The setting being considered is a generic sub-catchment with a variety of biophysical, watercourse and water quality situations and objectives. The work requirement could be to either consider activities and impacts in all the watercourses/water bodies in the sub-catchment or in one of the watercourses, or it could be to consider one activity/pressure in the catchment area of one of the watercourses. While the description below assumes that the receptor is more than one watercourse, the process is the same where it is just a small tributary stream, and even then, it may be necessary to take account of upstream issues. Where the issue of concern is at a site, the overall approach outlined in this Section is still relevant.

In a sub-catchment, water quality can be:
i) Unsatisfactory (*At Risk*);
ii) Satisfactory (*Not at Risk*);
iii) Undetermined (*Review*).
In approaching each of these situation, there are similarities and differences that need to be considered.

10.1 Overall approach to carrying out the desk study

- **Use the source-pathway-receptor (SPR) framework** as the over-arching model and thought process.

- For the desk study, the following order of work and reporting is recommended:
  1. Receptor information and assessment.
  2. Pressure information and assessment.
  3. Pathway information and analysis.
  4. Interim Conclusions on the 'catchment area'[37] based on the desk study.
  5. Work plan.
  6. Review of mitigation options.

- In compiling and evaluating the data and information, **think in terms of catchment areas of watercourses**, including the potential influence of watercourses upstream of, or linked to (e.g. groundwater) the area of interest.

- Only collect and evaluate information that is relevant.

- **Use information in the WFD App as the starting point.** All EPA water quality data (hydrochemical and Q-values) can be accessed, and plots of hydrochemistry can be downloaded. For *At Risk* water bodies details are given on:
  i. The *significant issue* (e.g. phosphate).
  ii. The *significant pressure* (e.g. agriculture).

[37] This could be for a sub-catchment, an individual water body or watercourse or a site.

iii. The location of the *significant pressure* (e.g. the specific location for large point sources and the general location of the *significant pressure* for diffuse and small point sources).

In the case of *Review* water bodies, *significant pressures* have not been formally identified, however in some cases there may be information recorded about pressures that could be problematical and need checking should the water body turn out to be *At Risk*.

♦ **Check for other existing relevant data** in your own and other organisations where appropriate (e.g. local authorities, Inland Fisheries Ireland, Irish Water) **and updated information**, if available (e.g. status from EPA, compliance and/or incident data from local authorities).

♦ **For the catchment areas of *At Risk* water bodies** (water quality is unsatisfactory)[38] where the *significant pressure* includes diffuse and small point sources, produce a '**pathways conceptual model'** for the sub-catchment as the basis for understanding the pathways for water and relevant parameters, which in turn assists in determining the critical source areas (CSAs). **Use the *significant issue* as the driver for the pathways conceptual model,** e.g. for PO_4 and MCPA, the main pathway in poorly draining soils is overland flow or in land drains. Therefore, the pathways conceptual model (PCM) should focus on the scenarios that have these pathways.

♦ If the *significant pressure* is a large point source with a direct discharge or a point source, such as a quarry where the location is known, a pathways conceptual model is not needed.

♦ **For the catchment areas of *Not at Risk* water bodies** (water quality is satisfactory)[39], assess the water quality data for trends. Also, check for pressures located in susceptible areas.

♦ **For the catchment areas of *Review* water bodies** (i.e. water quality is undetermined), assess and collect the additional information that it needed – this will usually be water sampling and a Small Stream Impact Score (SSIS) assessment. A Q-value may be needed for a final decision on whether the water body is *At Risk* or *Not at Risk* (of meeting the WFD objective).

♦ **Integrate all the relevant information** on the receptor, pathways and *significant pressur*es (in Areas for Improvement/Restoration) or potential pressures (in Areas for Protection) together as the "story" of the sub-catchment or site on which subsequent work is based.

♦ Where a field-based assessment is not required:

i. **Clarify** the objectives, (e.g. i) return to high status or ii) determine the risk category for a *Review* water body or iii) protect the existing untreated water quality for a drinking water source).

ii. **Integrate and assess** the information.

iii. Confirm/conclude on the ***significant issue(s)*** or **potential pollutants,** as applicable.

iv. Confirm/conclude on the ***significant pressure(s)*** or **potential pressures,** as applicable.

v. Tell the '**story**' of the PAA.

vi. Conclude on the **mitigation options**, if any.

vii. If appropriate, enter the results and conclusions into the **WFD App**.

♦ Where a field-based assessment is required, in addition to the list above, and in advance of the catchment walk:

[38] In this Handbook, these areas have also been called and can be seen as 'Areas for Restoration' to achieve a status objective or 'Areas for Improvement' for instance where an untreated water quality guide value needs to be achieved.

[39] These can be called 'Areas for Protection'.

i) **Clarify** the objectives, (e.g. i) return to good status or ii) determine the risk category for a *Review* water body) or iii) improve the existing untreated water quality for a drinking water source).
ii) **Integrate and assess** the information.
iii) Confirm/conclude on the ***significant issue(s)*** or **potential pollutants**, as applicable.
iv) **Evaluate** the information and maps that will assist the fieldwork and the pathways conceptual model.
v) **Produce a pathways conceptual model** for the relevant pathways in the sub-catchment if diffuse and/or small point sources are either *significant pressures* or might become significant is not carefully managed. Use the *significant issue* or potential pollutant as the driver for the pathways conceptual model.
vi) Confirm/conclude on the ***significant pressure(s)*** in *At Risk* water bodies, possible future significant pressures in *Not at Risk* water bodies and possible significant pressures in *Review* water bodies.
vii) Tell the '**story**' of the sub-catchment (or site, if that is the setting). This involves developing a conceptual understanding and 'mental model' that integrates all the components of the SPR framework. For diffuse and small point sources, it involves taking account of two different, but inter-related, landscape units and the associated datasets – the catchment areas to the monitoring points (MPs) (where water quality must be improved) and the pathways conceptual model compartments (which don't coincide with the water bodies and MPs locations). Linking these two landscape units and the associated information, using SPR relationships, is critical to get the understanding needed (for instance, identifying critical source areas (CSAs) to enable the mitigation actions to be targeted, to arrive at solutions and get the required improvements at the designated MPs.)
viii) If appropriate, enter the results and conclusions into the **WFD App**.
ix) **Plan** an appropriate catchment walk/fieldwork programme, e.g. to target the *significant issue* and the *significant pressure* (both type and location). Produce recommendations on:
   - how to undertake the catchment walk/fieldwork;
   - potential H&S issues;
   - where relevant, informing the local community and farmers.
x) **Review** the possible mitigation options.

- **Engage with stakeholders as appropriate**, for instance, local communities, landowners, other public bodies.

10.2 Receptor information and assessment

It is critical that the receptor is the starting point for the analysis undertaken as part of the desk study, as it enables the other components to be focussed, effective and efficient. The following approach is recommended.

- Review information for each river water body or watercourse[40] in the sub-catchment initially, starting with the upstream water body. Note which of them are on tributaries versus the main channel, etc.

[40] 'Water bodies' are specifically designated by the EPA for WFD implementation purposes. However, the purpose of the assessment may be for another reasons, e.g. a drinking water source, and so 'watercourse' may be more applicable. They are often used interchangeably in this Handbook to avoid repetition.

Sub-catchments, water bodies, watercourses, drainage ditches!
The above receptors are often mentioned in this Handbook and this can be confusing. From the perspective of the assessment process, it generally doesn't matter which of them is the receptor. Where the reason for the desk study is WFD implementation, then 'water bodies' (see Section 3.2) in sub-catchments (see Section 5.3) are the receptors. The terms *At Risk*, *Not at Risk* and *Review* apply to water bodies (see Section 3.4).
For some public bodies, such as local authorities or the NPWS, there will be circumstances not connected to WFD implementation where a watercourse or even a drainage ditch might be the receptor that is relevant. In this situation, the equivalent water quality terms are 'unsatisfactory', 'satisfactory' or 'undetermined'. Therefore, in using this Handbook, we should think in terms of the receptor and use whichever terminology that is appropriate to our needs.

- In certain circumstances, protected areas are receptors with specific objectives that need to be taken into account.[41]
- Table 10-1 (for a single water body) and Table 10-2 (for situations where water bodies are connected) are recommended as a means of compiling relevant receptor information. They provide a check list of factors for which information needs to be checked and considered. Data and Figure numbers are included in Figure 10-1 as an illustration. Table 10-2 enables changes as water flows downstream from one water body to the next to be highlighted.
- A good starting point is to check the WFD App (see Section 7-2 for further details) and compile information on the relevant water body or bodies. A typical output of the information available is shown in Table 7-2.
- In addition, check the files of the organisation you work in for additional data, and include in the summary table.
- Closely evaluate the biological data and hydrochemical data (if available), e.g. concentrations of different parameters, variability, and trends using simple regression analysis, at each monitoring point and between monitoring points, for clues that would aid understanding of the situation, and would help in focussing on relevant pathway factors that are considered and summarised as part of the pathways conceptual model (PCM).
- Include plots of the water quality data. Examples are given in Figure 10-1, 10-2 and 10-3.
- The 'Baseline Value' for phosphate, ammonia and TON is the average of the last 3 years data; it gives a good overview of the water quality.
- Conclusions can be drawn on variability within the sub-catchment (if any).
- **The key outcome of the receptor assessment is a conclusion on whether the water quality is:**
    - **Satisfactory.**
    - **Unsatisfactory.**
    - **Undetermined.**

[41] Where the water quality metric is not known, assumptions may need to be made such as a Good status objective and the metrics that apply to this status category.

- Where the water quality is unsatisfactory, conclude on the *significant issue(s)*:
  - Pollutants such as PO_4, NH_4, NO_3, sediment, habitat conditions, pesticide.

The terms '*significant issues*' and '*significant pressures*' are used as phrases both in the context of WFD implementation and drinking water source protection to indicate that the issues and pressures require mitigation. In the WFD context, *significant issues* and *significant pressures* are those that are having a significant impact on ecological status and need to be addressed before the status will improve. In the context of NFGWS group water schemes, *significant issues* are those that are higher than the guide values for untreated water. *Significant pressures* are only identified for water bodies that are *At Risk* of not achieving their objectives. See Appendix 2 for further details.

10.2.1 Water quality sorter and graph generator

Simple water chemistry analysis can help determine what the likely significant issues and pressures are at WFD monitoring points. A large volume of water chemistry data is available to download from the WFD app, on a monitoring point by monitoring point basis. The data is downloaded as a CSV file, which is often very large and difficult to work with. Developing the CSV data into a format that is readily interpretable can be both time consuming and repetitive.

The "Water Quality Sorter" (see link below)[42] was designed to condense the processing and analysis of the CSV data into a simple "Run" button. The sorter takes the raw CSV data from the WFD App and organises it into a formatted excel table. The table is organised by sample date and collates all available historical data (2007-2021) for all measured parameters at each monitoring point. The table is designed to allow the user to specify an Environmental Quality Standard (EQS) for each of the measured parameters. Exceedances of these thresholds are colour highlighted within the table, allowing a visualisation of the issues affecting water quality at the monitoring point within minutes.

A graph generating template was also developed to accompany the formatted table. The template generates summary statistics from the water chemistry dataset (i.e. annual average concentrations). In addition, the template automatically creates a timeseries graph for each of the tabled parameters. The graphs include annual average concentrations, spot sample values and a comparison against EQS threshold lines. The graph structure is editable and can be tailored by the user to suit their needs. A short "how to" video is provided at the link below, while Figure 10.4 shows an excerpt of the modelled results for the TOLKA_10 waterbody.

The link to the Sorter is available on the LAWPRO website under the 'Local Authority Catchment Science and Management Course' link.

[42] The 'Water Quality Sorter' was developed by Eoin McAleer and Cormac Mc Conigley, LAWPRO. The text for this section was written by Eoin McAleer.

Table 10-1: Summary of receptor information for a single water body

Factor		Figures Tables	Details
Monitoring station type			Operational
Risk Category		F. 1-2	*At Risk*
Biological Status	**2010-2015**	F.2-5	3 (Poor)
	2016-2018	F. 2-5	3 (Poor)
	Trends in Q values		No change since 2008
Hydrochemistry Data			
Ortho-P (mg/l P)	**Baseline** **Indicative quality** **Trends - significant?**	F. 2-7	2016-2018: **0.047 mg/l** Moderate Upwards - No
NH4-N (mg/l N)	**Baseline** **Indicative quality** **Trends - significant?**	F. 2-8	2016-2018: 0.033 mg/l High Downwards - No
TON (mg/l N)	**Baseline** **Trends - significant?**		2016-2018: 2.2 No
Supporting Conditions	**Chemical conditions?** **Oxygenation Conditions** **Acidification Conditions**		Good Pass Pass
Hydromorphology			
	RHAT		N/A
	Evidence of Arterial drainage		No
Ecological Status (2013–2018) **Trends (2013-2018)**			Poor No change
Protected Areas			No
WFD Objective			Good
EPA biologist notes (if any)			------
Condition of water quality			Unsatisfactory
Significant issue			Orthophosphate

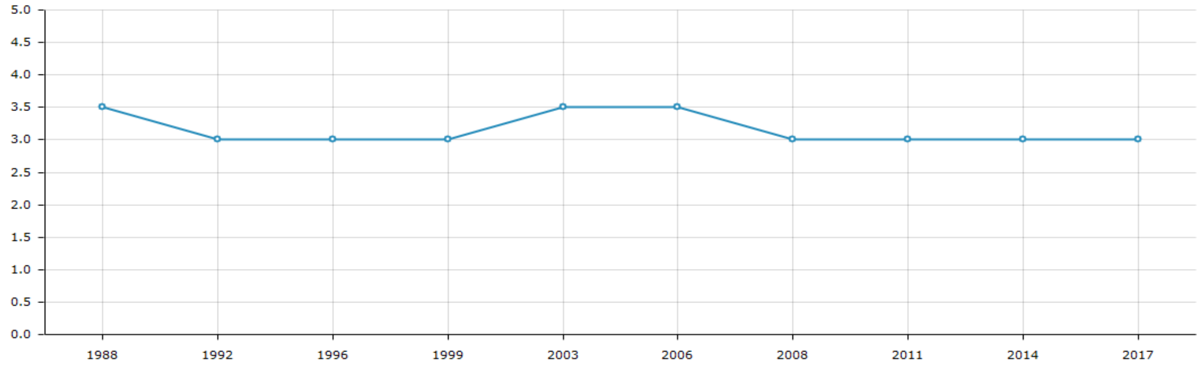
Acknowledgement: Table is based on one used by LAWPRO.

Table 10-2: Summary of receptor information for multiple water bodies and monitoring points

Waterbody		*Xxxxxx_010*		*Yyyyy_010*		**Xxxxxx_020**
Risk Category						
Environmental Objective						
Monitoring station		***25 metres d/s confluence***	***Bridge u/s Lough***	***N River, Br 1. d/s Lough***	***G River Bridge***	***K Bridge***
Monitoring station type		*Operational*	*Operational*	*Investigative*	*Operational*	*Operational*
Biological Status						
Q values	*2009*					
	2010					
	2011					
	2012					
	2013					
	2014					
	2015					
	2016					
	2017					
	2018					
	2019					
Water chemistry						
PO_4+	*2010*					
	2011					
Ecological Threshold <u>≤</u>0.025 (high status) <u>≤</u>0.035 (good status) as an annual mean	*2012*					
	2013					
	2014					
	2015					
	2016					
	2017					
mg P/L	*2018*					
	2019					
Baseline PO4						
NH_4+	*2010*					
	2011					
Ecological Threshold <u>≤</u>0.040 (high status) <u>≤</u>0.065 (good status) as an annual mean	*2012*					
	2013					
	2014					
	2015					
	2016					
	2017					
mg N/L	*2018*					
	2019					
Baseline NH4						
NO_3-	2010					

Waterbody		*Xxxxxx_010*		*Yyyyy_010*		Xxxxxx_020
Risk Category						
Environmental Objective						
Monitoring station		***25 metres d/s confluence***	***Bridge u/s Lough***	***N River, Br 1. d/s Lough***	***G River Bridge***	***K Bridge***
***Indicative* Ecological Threshold 3.5 for good status as an annual mean (none for high status at this point) mg N/L**	*2011*					
	2012					
	2013					
	2014					
	2015					
	2016					
	2017					
	2018					
Baseline NO_3						
Hydromorphology						
RHAT						
Evidence of drainage (OPW Scheme, Drainage District or other)						
Comments						
Conceptual model required (Y/N)		Y	Y	Y		Y
Ecological Status						
2010 – 2015						
2013 – 2018						
EPA Biologist comments						
Condition of water quality						
Significant issue						

Acknowledgement: Table is based on one used by LAWPRO.



	1988	1992	1996	1999	2003	2006	2008	2011	2014	2017
Result	3.5	3	3	3	3.5	3.5	3	3	3	3
Classification	Moderate	Poor	Poor	Poor	Moderate	Moderate	Poor	Poor	Poor	Poor
Q-Value	3-4	3	3	3	3-4	3-4	3	3	3	3

Figure 10-1: Q-Values recorded at Br SE of Xxxxxx. (Copied from the WFD App)

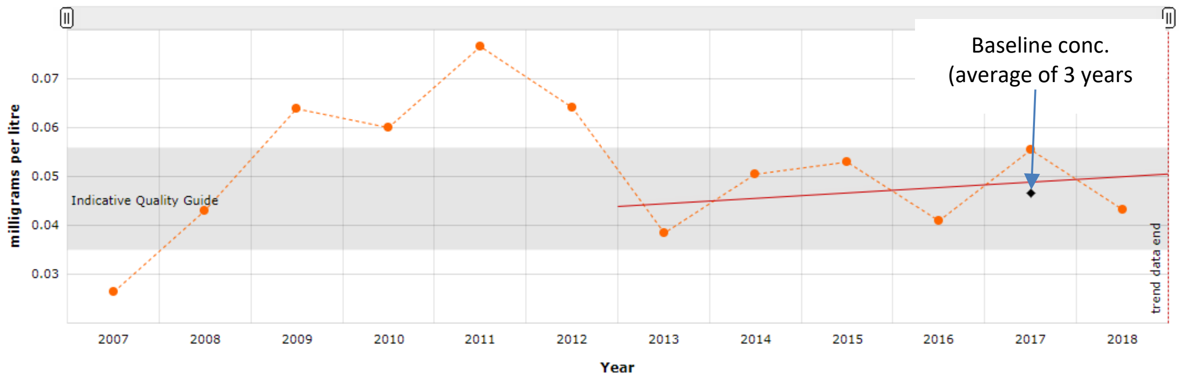


Figure 10-2: Graph of orthophosphate concentrations. (Copied from the WFD App)

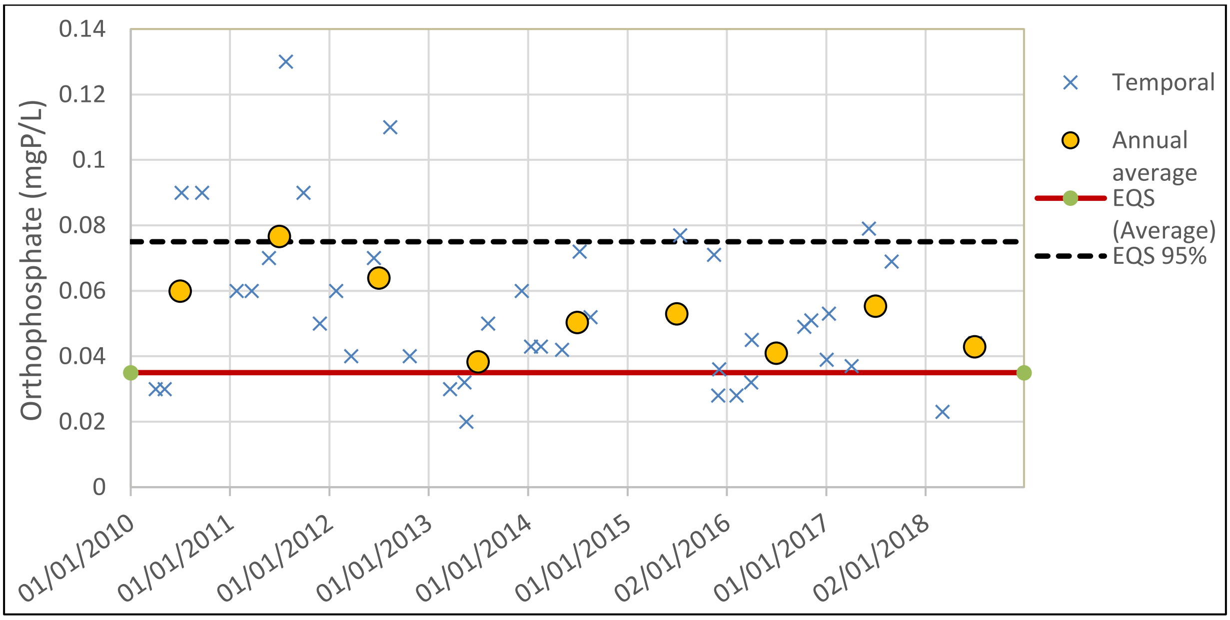


Figure 10-3: Orthophosphate concentrations at Br SE of Xxxxxxx showing both average annual and individual values. (Copied from a LAWPRO report)

Sample date	Alkalinity-total	Conductivity	Dissolved Oxygen	Temperature	ortho-Phosphate	TON	Total Hardness	Ammonia-Total	Dissolved Oxygen	Nitrite	pH	True Colour	Chloride	BOD - 5 days (Total)
Br at Black	mg/l	µS/cm	%	°C	mg/l	mg/l	mg/l	mgN/l	mg/l	mgN/l	pH units	Hazen	mg/l	mg/l
SampleDate	EQS	900.00	80.00	EQS	0.075	2.60	EQS	0.14	8.50	EQS	EQS	25.00	EQS	2.60
23/01/2007	312.000	668.00	92.40	4.400	0.088	2.87	324.00	0.10	11.87	0.04	7.94			
22/02/2007		676.00	92.10	8.100	0.103	2.43		0.10	10.39	0.04	8.00	43.00		
20/03/2007	360.000	750.00	96.10	5.800	0.119	1.82	392.00	0.09	11.85	0.03	8.27	16.00	27.1	1.74
18/04/2007		732.00	108.30	13.800	0.124	1.24		0.12	11.23	0.02	8.26			
16/05/2007	380.000	740.00	96.80	11.000	0.218	1.12	376.00	0.18	10.44	0.04	8.12	11.00	29.7	2.32
26/06/2007		762.00	96.90	12.900	0.180	1.48		0.05	10.17	0.03	8.27			
17/07/2007		750.00	85.10	14.400	0.152	1.02		0.06	8.61	0.02	8.07			
23/08/2007	400.000	759.00	91.50	14.700	0.123	1.15	396.00	0.04	9.34	0.02	8.16	10.00	17.4	2.00
26/09/2007		725.00	93.20	11.200	0.184	1.62		0.10	10.30	0.02	8.11			
24/10/2007		776.00	95.60	7.700	0.211	0.78		0.10	11.53	0.02	8.33			
21/11/2007	344.000	713.00	86.90	9.600	0.110	1.91	376.00	0.08	9.69	0.03	8.03	28.00	20.3	1.43
17/12/2007		767.00	94.10	6.200	0.084	1.43		0.08	11.81	0.02	7.91			
28/01/2008		733.00	91.20	7.600	0.094	1.91		0.07	10.98	0.02	8.10			
27/02/2008	364.000	770.00	106.50	7.200	0.109	1.34	394.00	0.10	12.80	0.01	8.29	9.00	27.2	4.00
29/04/2008		747.00	119.50	11.900	0.128	0.89		0.10	12.56	0.02	8.35			
28/05/2008	344.000	763.00	101.60	12.600	0.169	0.74	372.00	0.09	10.60	0.03	8.20	17.00	29.7	1.55
18/07/2008		768.00	107.20	14.900	0.151	0.81		0.08	10.70	0.04	8.25			
20/08/2008	344.000	706.00	87.30	14.600	0.122	0.96	360.00	0.07	8.80	0.03	7.98	27.00	18.9	1.12
20/11/2008	392.000	783.00	93.00	9.800	0.073	0.85	416.00	0.05	10.56	0.02	8.16	12.00	18.9	0.87
17/02/2009	392.000	793.00	94.90	6.800	0.055	1.30	400.00	0.06	11.73	0.01	8.24	5.00	24.0	1.01
26/05/2009	394.000	789.00	113.80	11.700	0.076	0.99	412.00	0.08	12.31	0.02	8.23	14.00	20.9	1.58
20/08/2009	160.000	412.00	72.20	15.800	0.245	1.44	192.00	0.20	7.07	0.05	7.60	92.00	14.7	7.90
12/11/2009	190.000	427.00	80.70	8.400	0.216	0.79	202.00	0.12	9.14	0.04	7.62	67.00	14.4	4.05
11/02/2010	382.000	809.00	95.00	2.700	0.059	0.88	416.00	0.09	13.04	0.01	8.31	8.00	23.2	1.46
25/05/2010	328.000	724.00	151.40	15.800	0.060	0.67	358.00	0.05	14.95	0.04	8.24	15.00	28.4	1.72
01/09/2010	336.000	773.00	115.20	13.300	0.123	0.60	400.00	0.02	12.05	0.01	8.29	20.00	25.1	1.53
17/11/2010	358.000	759.00	88.30	8.600	0.074	1.10	408.00	0.13	10.07	0.02	8.19	17.00	32.1	1.31

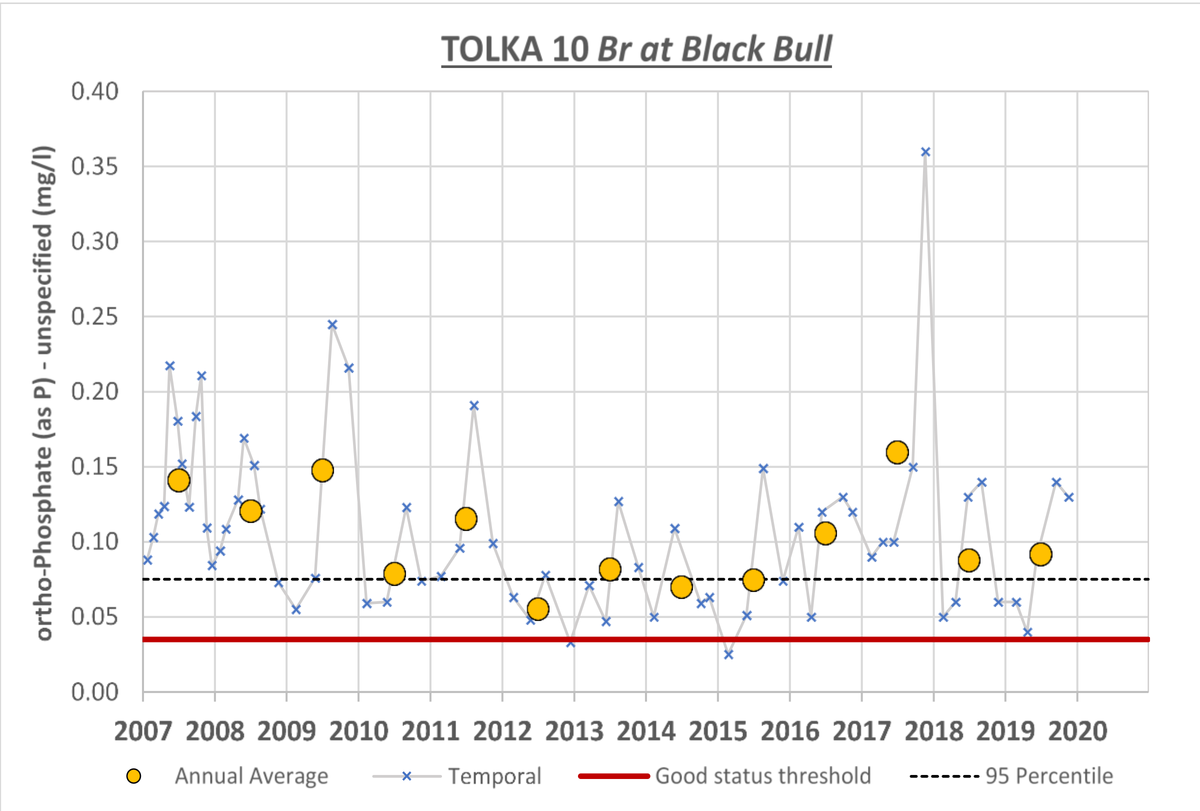


Figure 10.4: Example of the Water Quality Sorter and Graph Generator results for the TOLKA_10 waterbody.

10.3 Deciding on the objective

At this stage in the Process, a preliminary decision can be made on whether the objective is:

i) Improvement/restoration, where the water quality is unsatisfactory:
ii) Protection/maintenance, where the water quality is satisfactory; or
iii) Undetermined, where there are inadequate data to make a decision.

This is a key decision as it influences the work that needs to follow.

While these conclusions apply to a sub-catchment or the catchment area of a water body or watercourse, the same approach can be applied to assessment of the water quality implications of a development.

10.3.1 Improvement/restoration objective

The *significant issue* is now known. The next stage is to assess the pressures and decide on the *significant pressure(s)*. If there are diffuse *significant pressures* or point *significant pressures* discharging to the ground, then pathway information and analysis are needed as the basis for determining measures to mitigate the impact of the particular *significant issue(s)* and *significant pressures* of concern.

10.3.2 Protection/maintenance objective

In the situation where the water quality is satisfactory, the next stage is check for the location of pressures that have the potential to impact on water quality in the future to see whether they are in susceptible or vulnerable areas.

The emphasis and objective of LAWPRO work is on improvement/restoration of *At Risk* water bodies to the required ecological status; clearly this is a priority for WFD implementation and reporting to the EU. However, a substantial proportion of water bodies are *Not at Risk* and are achieving their required status. Maintaining this satisfactory situation means that 'protection' is also important not only in principle, but also because the WFD has a '**prevent deterioration'** objective. This means ensuring that the regulations that are in place, which have helped achieve this situation, continue to be applied and that general protection practices are maintained. It also means reviewing the pressures in *Not at Risk* sub-catchment areas, perhaps estimating what additional load of nutrients might be sufficient to cause impacts, and then deciding on whether any could become a *significant pressure* that would impact on the water body, and cause deterioration. This review might or might not, depending on the conclusion, require additional actions to protect the water body.

10.3.3 Undetermined objective

This situation arises where there are insufficient data to enable a conclusion on the water quality situation. Where the purpose of the assessment is WFD implementation, the status will be unknown and the risk category will be *Review*. Clearly, the next stage is to collect and assess water quality data. A good starting point is to collect samples for analysis and evaluate the results. For WFD implementation purposes, a determination of the Q-value will be needed, although the hydrochemistry data and an SSIS check will give a good indication of the likely status category.

10.4 Pressure Information

10.4.1 Pressure Types

The main environmental pressure types in Irish catchments are summarised in Table 10-3, together with the parameters that can be used to provide evidence of impacts from these pressures. Many pressure types are typically present in all catchments, but some are more significant than others, influenced by physiography, geology, climate, land use and pressure magnitude and/or intensity. Common *significant pressures* are discharges from municipal wastewater treatment plants, agriculture (diffuse and/or farmyards), domestic wastewater treatment systems, afforestation, industry, urban areas, the extractive industry (mines, quarries and peat), invasive species and hydromorphological.

An important in considering pressures is between **point** and **diffuse** because the ways they need to be approached and mitigated are different.

- **Point Sources:** Discharges from pipes directly to watercourses or indirectly via ditches, and discharges to localised areas such as soakage pits and percolation areas. They are subdivided into 'large' and 'small'.
  - ***Large point***
  - UWWTPs, storm overflows, and industrial discharges, which are subject to licensing/authorisations and inspections.
  - ***Small point***
  - Farmyards, domestic wastewater treatment systems (DWWTSS), cattle drinking point areas, cattle crossing points, ring feeder areas, misconnections and pipe discharges in urban/town areas, areas where pesticide sprayers are filled, etc. *(Note: some of these 'small' point sources could be discharging a pollutant load equivalent to a small WWTP, e.g. a badly managed farmyard discharging silage effluent, slurry and soiled water to a watercourse.)*

- **Diffuse (non-point) sources**
  - **Widespread** activities in the landscape such as fertilizer (organic & inorganic) application, deposition of faeces and urine by grazing animals, spraying of pesticides, sediment arising from forestry areas, atmospheric deposition, leaking sewers in urban areas, polluted groundwater in urban areas, etc.

Further details on the difference between them are given in Appendix 3.

Each pressure type is described in detail in **Volume 2** (see Table 10-4), with notes and photographic examples, as well as features that can influence risks of impact(s) on receptors. Individual pressure sections are accompanied by tabulations of potentially applicable mitigation options.

10.4.2 Locating pressures

Information on pressures in sub-catchments has been compiled by the Catchments Unit from a range of datasets held by various public agencies including EPA, Geological Survey Ireland (GSI), Office of Public Works (OPW), Department of Agriculture, Food and Marine (DAFM), Irish Water (IW), Inland Fisheries Ireland (IFI) and Local Authorities (LAs). Many of these datasets are available on the EPA's mapping website "Envision", on the WFD App web application (see Section 7-2) and on www.catchments.ie where the full metadata are also presented. Examples of two maps showing the locations of pressures are shown in Figure 10.4 and 10.5.

In certain circumstances, where the role of the water scientist or engineer is to assess a particular development that is a pressure for water, the location is already known.

Table 10-4: Guidance material on pressures in Volume 2

Pressure	Location in Volume 2
Agriculture	• Section 2
Hydromorphological	• Section 3
Urban wastewater	• Section 4
Diffuse urban	• Section 5 and Volume 5
Domestic wastewater treatment systems	• Section 6
Afforestation	• Section 7
Peatland activities	• Section 8
Quarries	• Section 9
Mines	• Section 10
Industrial discharges	• Section 11
Landfills and fly tipped sites	• Section 12

10.4.3 Significant pressures

While all pressures are considered in this desk-based assessment, the key outcome is the understanding of which of the pressures are significant where the objective is to improve/restore, and which ones might potentially cause significant impacts in the future where the objective is protect/maintain.

A *significant pressure* is any pressure that on its own, or in combination with other pressures, that may lead to a failure to achieve one of the WFD objectives of "at least Good Status". *Significant pressures* only arise for *At Risk* water bodies. Once a pressure is designated as 'significant', mitigation actions are needed to alleviate potential or known impact(s). Accordingly, human and/or financial resources are also needed. In view of this, an adequate level of confidence in the assessment of pressures and environmental risks is needed before further actions are taken. The assessment of significance is undertaken in two steps: first at the sector level through the desk-based process – this is often sufficient for large point sources; and second at the site/field level, which is usually the appropriate scale to consider the selection of specific, possible mitigation options, for instance for diffuse and many small point sources.

An initial assessment of the *significant pressures* will already have been undertaken by the EPA in collaboration with local authorities and the IFI. The assessment to identify which pressures are significant has been extensive, involving over 140 datasets, a range of modelling tools, local information and experience from local authority and IFI staff, and peer reviewed by the relevant pressure regulators. Although some changes to the *significant pressures* may be required, based on new evidence collected during the desk study and catchment walk, the existing *significant pressure* list is considered to be the best available information at the outset of the desk study stage.

It is generally worthwhile either copying or summarising the information in the WFD App or in local authority files in this Section.

There are some water bodies where the significant pressure is 'anthropogenic unknown' and so for those it might be more suitable to leave consideration of the *significant pressure* until after consideration of the main pathway, as the evaluation of the pathway may enable the likely *significant pressure* to be determined.

If it is not possible to determine the *significant Issue(s)* (for instance where there is no hydrochemistry information), use the *significant pressure* information and the Pollution Impact Potential (PIP) maps (see Section 10.5.6). to enable the possible and likely *significant issue(s)* to be predicted, although confidence in this conclusion cannot be as high as when hydrochemistry information is available.

For further details on *significant pressures*, see Appendix 2.

For the most up to date information on the *significant pressures* nationally for all water bodies, check the RBMP or the most recent EPA Indicators Report or www.catchments.ie .

10.4.4 Pressure ≠ impact

A fundamental error is often made in catchment assessments that the larger the pressure, the greater the impact. In addition, in many instances where there is an impact, such as unsatisfactory water quality, an assumption is made that the nearby and visible pressure is the cause. While understandable perhaps, these are generalisations and simplifications that are often, although not always, incorrect. Therefore, conclusions such as these can lead to efforts that do not achieve the objective of mitigating the impacts. More detailed analysis is needed prior to drawing conclusions.

So, what does the impact of an environmental stressor, such as pollutants or abstractions, on water depend on? The answer is several factors, which, in itself, illustrates the complexity. In answer to this question, it is assumed that the objective is to mitigate impacts from pressures on the water quality of a surface water body or a surface source for drinking water; similar approaches apply to abstraction pressures and to situations where the receptor is groundwater. But before outlining these factors, let us go back to first principles and, in particular, to the Source-Pathway-Receptor (SPR) approach to environmental management and the 'pollutant transfer continuum' in the landscape.

For a threat to be present to a water body, there must be a **source** of a hazard, a **receptor** and a linkage via a **pathway** between the source and receptor. Each of these elements can exist independently, but they create a risk only when they are linked together, so that a particular pollutant or environmental stressor affects a particular receptor via a particular route or pathway.

The 'pollutant transfer continuum' consists of four components (see Section 14):

- The presence of a pressure with an associated load of pollutants. This pressure can either be a point or diffuse (non-point) source.
- Mobilisation, whereby in the case of diffuse pressures, the potential environmental stressor or pollutant becomes soluble or attaches to soil particles and starts the journey to a receptor, such as a stream.
- Delivery/transport in a pipe in the case of many point sources or more diffusely along pathways, underground or over ground, to a receptor, such as a watercourse or drinking water source.
- The receptor[43]. In the case of surface water, it can vary in terms of flow rates, upstream water quality and sensitivity (e.g. high or good status or pearl mussel objectives). In the case of groundwater in an aquifer, the existing water quality and the dilution potential can vary.

[43] Different receptors may be connected, such as a stream water body entering a lake or entering transitional and coastal water bodies. In certain circumstances, the status of these water bodies may vary.

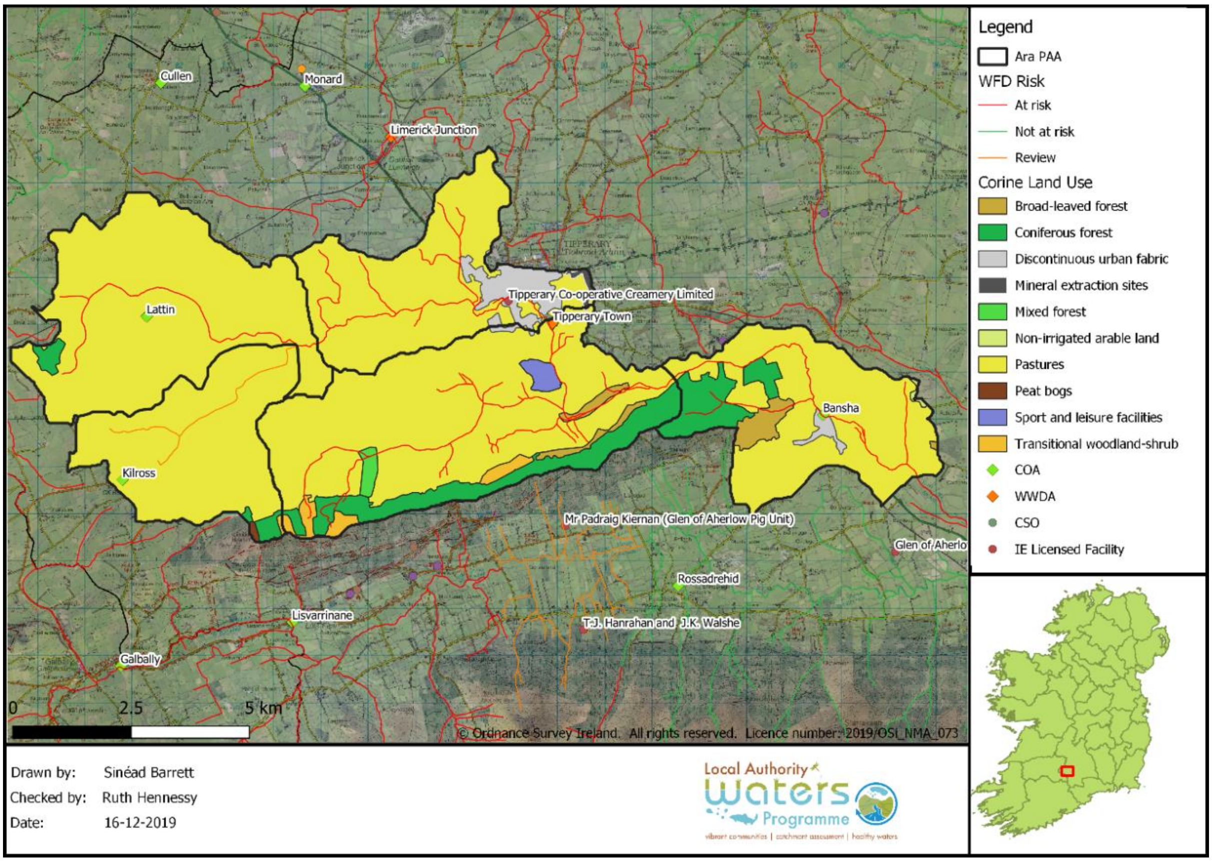


Figure 10-4 Land uses within the Ara PAA. Source: EPA (2018).

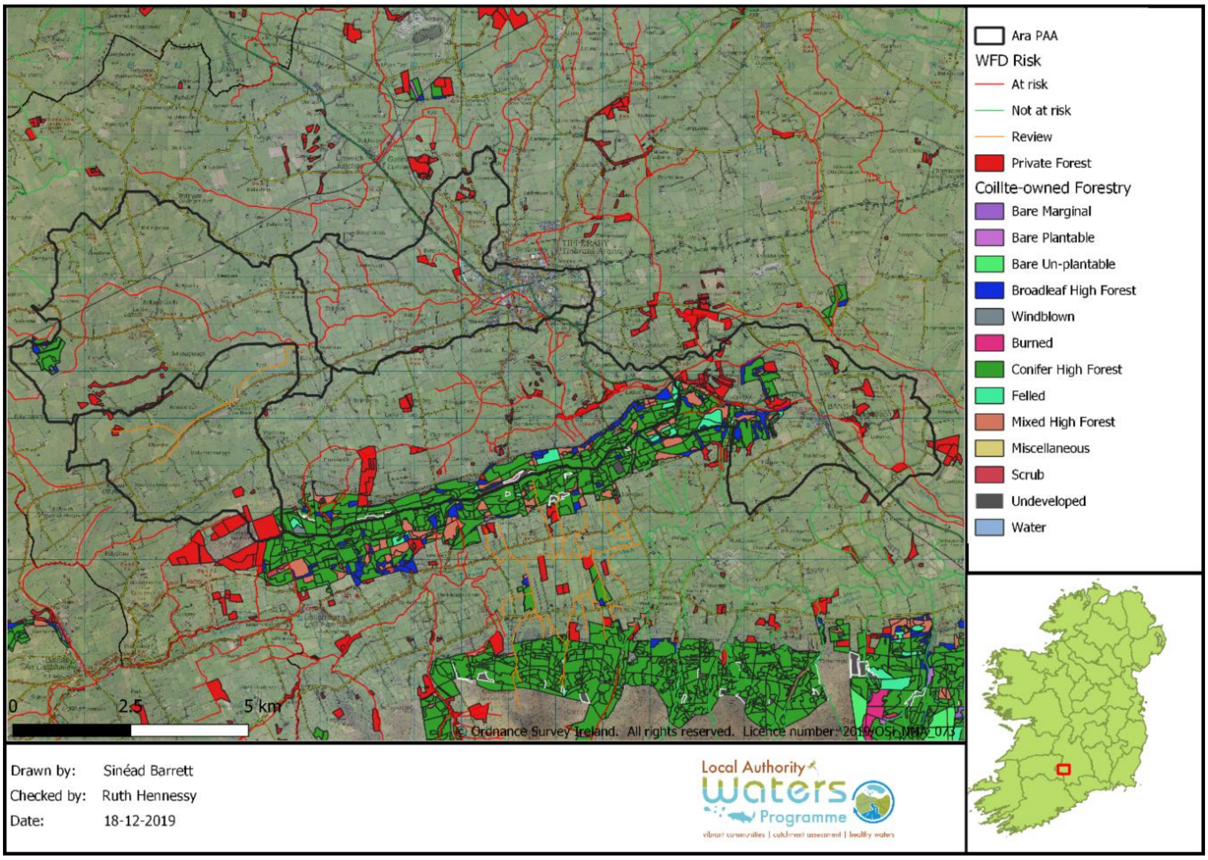


Figure 10-5: Forestry within the Ara PAA. Source: Coillte (2019).

For diffuse sources, all of these components must be considered in analysing the cause of an impact and the mitigation measures/actions needed. Even in the case of point sources, which are usually easier to understand, evaluate and deal with (as the means of delivery of pollutants in a pipe is usually easily recognisable), a proper analysis of the situation must be undertaken, taking account of several of the relevant factors outlined below.

The factors that influence whether an environmental stressor (e.g. phosphate) and an associated pressure (e.g. farming) cause a watercourse to fail to achieve its' objective are as follows:

- The presence/absence of a pathway link between the pressure and receptor. Therefore, it is essential that potential pathways are evaluated and understood at the outset as several of the factors that follow depend on this analysis.
- The physical setting that dictates the flowpaths for water and pollutants in the landscape. For example, is the dominant pathway underground or over ground?
- Where a link exists, whether the link is effective or ineffective in mitigating impacts. For example, freely draining soil and subsoil will attenuate phosphate.
- That the link has not been broken by source control, mobilisation control and/or interception measures and actions. For example, hedges, trees and riparian woodlands where present could be intercepting phosphate and sediment.
- The *significant issue* (or environmental stressor) that is impacting on the waterbody, e.g. nitrate, phosphorus, sediment, ammonia, pathogens, chemicals, etc., because each issue has different sources, different pathways, different degrees of attenuation and different levels of impact on receptors. For example, nitrate is a conservative pollutant and can readily leach to groundwater and then flow to surface water receptors in freely draining areas, but not in poorly draining areas.
- The sensitivity of the receptor. For example, a given nutrient load will have a much greater impact on high status objective water bodies (EQS ≤0.025 mg P/l (mean)) than on good status objective water bodies (EQS ≤0.035 mg P/l (mean)).
- The flow rate in a watercourse, which determines the degree of dilution, and therefore whether a given load results a significant impact or not.
- The pollutant load lost from the landscape relative to the load applied. For instance, a 1-2% loss of phosphorus where 20-30 kg P/ha is applied would cause the concentration of phosphate in water leaving an area of farmland to be above the EQS. Preventing a loss of such a low proportion of the applied load in poorly draining areas without interception measures is unlikely to be feasible, and therefore concentrations below the EQS will not be achieved unless there is significant dilution from upstream by water with low PO_4 concentrations.
- The pollutant loading required to make the water body unsatisfactory. For instance, 1 kg P (present as phosphate) will pollute (i.e. bring the concentration above the EQS for rivers of 0.035 mg/l) 29 million litres (6.4 million gallons) of water. In contrast, 1 kg N will pollute (i.e. bring the concentration above the EQS for coastal waters of 2.6 mg/l N) 400,000 litres (0.1 million gallons). One litre of MCPA will pollute (bring the concentration above the drinking water limit) 1,000,000,000 litres (220 million gallons) (this is equivalent to one drop in an Olympic-sized swimming pool).

Resources, whether time, financial or intellectual, are needed to achieve the desired environmental outcomes – in this case, surface water quality objectives. Therefore, the activities designed and needed to achieve these objectives should not be based on suppositions but must be based on an adequate environmental assessment that evaluates <u>all</u> relevant components.[44]

[44] Acknowledgement: this section is based on input from and discussions with Jenny Deakin, EPA Catchments Unit.

10.4.5 Nutrient losses – how much does it take?

It can be revealing and helpful to estimate the **load losses of P and N** from either soils or point pollution sources that are sufficient to breach the EQSs in water bodies.

10.4.5.1 How much phosphate loss to water causes pollution?

- Pollution = concentrations greater than the EQS of 0.035 mg P/l (mean).
- 1 kg P when present as PO_4 will pollute 29,000,000 litres of water (or 6.4 million gallons).
- What does this mean for potential losses from farmland?
  - Figure 10-6 shows the relationship between P loss and annual infiltration for both the Good and High status EQSs.
  - For a 50ha farm, in an area with poorly draining soils, where the effective rainfall (rainfall minus actual evapotranspiration) is 500mm, a loss of 9 kg P from this area (**or 0.2kg P/ha**) would bring the water leaving this area above the EQS.[45]
  - Assume 50% (25ha) at soil P index 2 and 50% at soil P index 3. The P application requirement for the farm would be 1,300 kg or 26kg/ha (to reach/maintain P index 3 for a grassland stocking rate of 131-170kg/ha/yr) (based on 2014 GAP Regs).
    - 9kg represents 0.8% of the application rate, assuming losses happened from all of the 50ha.
  - If it is assumed that the CSA comprises 25ha (50% of area), a loss of 1.6% of the applied P from this area would mean that the EQS would be exceeded (assumes no other losses) and pollution caused.
  - If the CSA area is 12.5 ha (25% of area), a loss of 3% would be sufficient to exceed the EQS.
- Conclusions
  - Very little loss of P from farmland causes significant impacts.
  - The proportion of the load of P generally applied to farmland that can cause significant impacts is very small.
  - Dilution by water from areas of land with low or minimal PO_4 losses will reduce the concentrations at EPA monitoring points; the lower proportionally this area is in the catchment area of a monitoring point, the greater the reduction of PO_4 losses from high PIP farmland needed.

10.4.5.2 How much nitrogen loss to water causes pollution?

- Pollution = concentrations greater than the groundwater threshold value of 37.5 mg/l (mean).
- 1 kg of NO_3 will pollute 27,000 litres groundwater (or 88,500 litres if the TraC EQS of 2.6 mg/l N is used).
- What does this mean for potential losses from farmland?
  - Figure 10-7 shows the relationship between N loss from soil and annual infiltration.
  - The Figure indicates that at infiltration rates of 300 and 600 mm/year, the loss would need to exceed 25.4 and 50.8 kg N/ha/year, respectively to exceed the groundwater threshold value in water.
  - Dilution by water from areas of land with low or minimal NO_3 losses will reduce the concentrations at EPA monitoring points; the lower proportionally this area is in the catchment area of a monitoring point, the greater the reduction of NO_3 losses from high PIP farmland needed.

[45] While the EQS as a mean has been used in these calculations, it would be preferable to use a lower concentration (e.g. 0.03 mg/l) when estimating required load reductions.

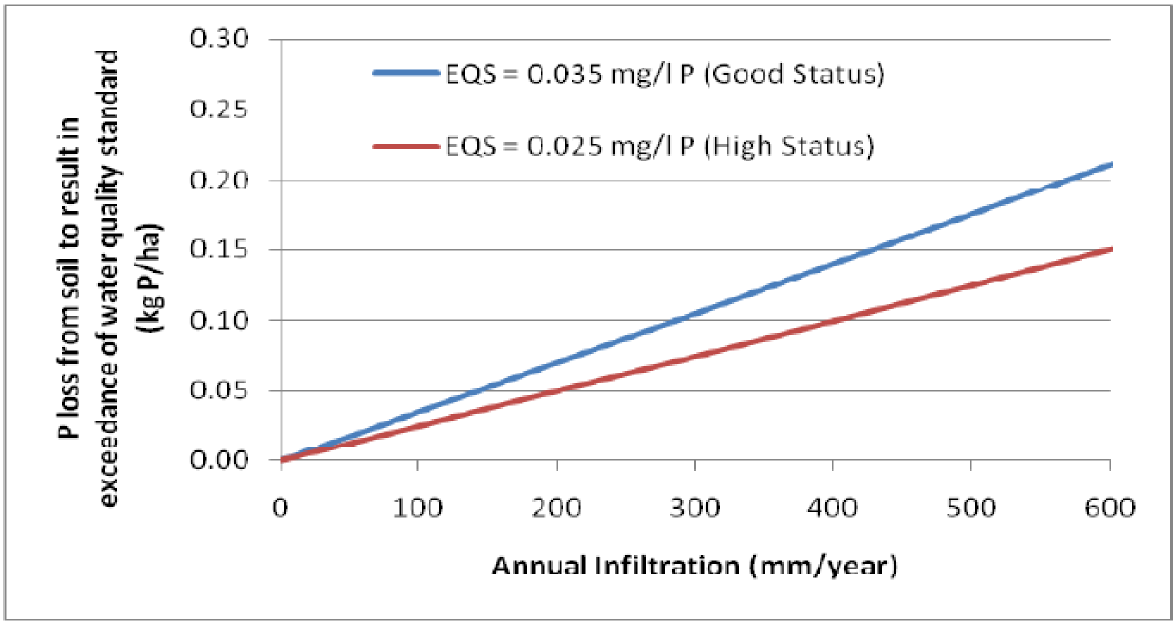


Figure 10-6: Calculation of P loss required to exceed the PO4 EQS. (Source: Mannix & Daly (2010) at this link: https://www.gsi.ie/documents/GWNewsletterNo48.pdf)

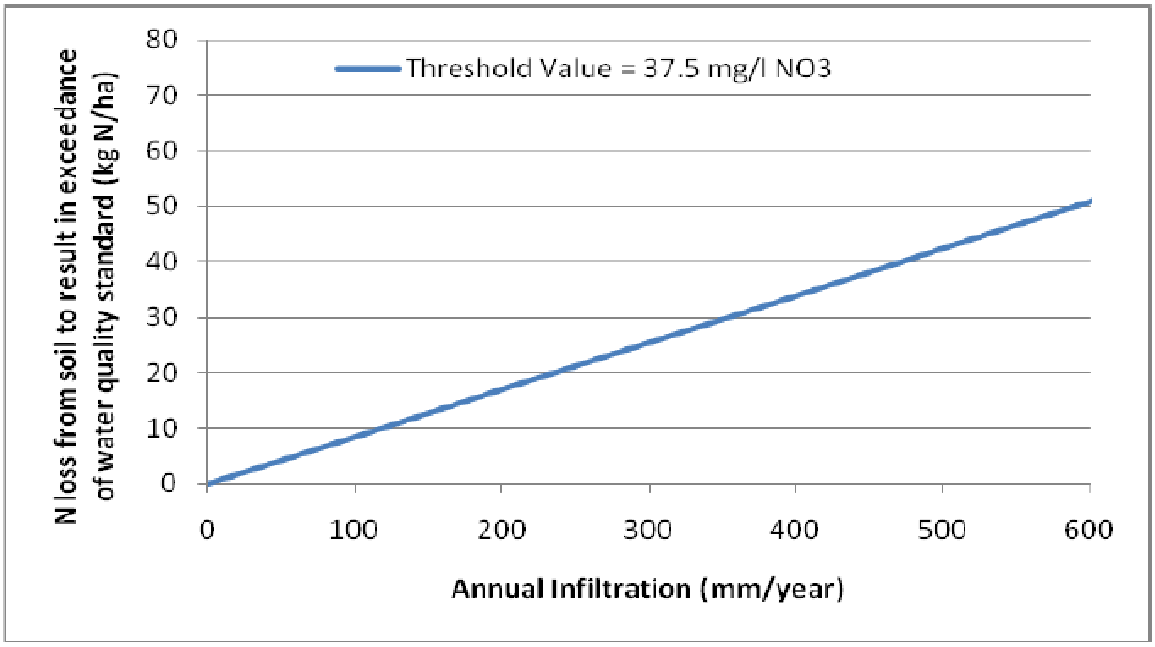


Figure 10-7: Calculation of N loss required to exceed the NO_3 threshold value. (Source: Mannix & Daly (2010))

10.4.5.3 Implications

- It takes very little P loss from farmland to breach the EQSs for PO_4.
- In sub-catchments with areas of high phosphate PIP ranking, reducing P levels in soils via NMP to soil P index 3, while beneficial, is highly unlikely to be sufficient to achieve concentrations below either the Good or High status EQSs in nearby watercourses, unless perhaps where there are large areas of low PIP upstream to provide dilution.
- Therefore, pathway interception measures and actions, particularly in the delivery areas, are a critical means of i) achieving concentrations below the EQS, ii) reducing particulate P losses and iii) reducing the time delays for improvement.

- As nitrate is mobile in freely draining soils, relatively small proportions leached in intensive farming areas can impact on groundwater and, more particularly, on coastal waters as they have a lower impact threshold.
- Increasing the percentage area in a sub-catchment with low or minimal nutrient losses is an effective means of reducing concentrations at EPA monitoring points.
- In circumstances where nutrient loading analysis has been undertaken to estimate the reduction needed in a water body to achieve the required concentrations and the area of high PIP (either PO_4 or NO_3) is known, then the reduction in kg/ha can be approximated. This can be a useful means of providing a target that needs to be achieved and for deciding on the required mitigation measures/actions.

10.4.6 Nutrient loadings analysis – a useful 'tool' in characterisation

Environmental analysis of the role of nutrients (e.g. PO_4, NO_4, NH_4) arising from pressures tend to focus on concentrations as the metric of relevance; this is understandable because standards are given as concentrations. However, while concentrations are a target to be achieved (see Section 9), they are not usually sufficient on their own in answering the 'what', 'where' and 'how' questions. Estimating and analysing the load reduction of a particular pollutant needed in a water body can help answer these questions.

Why undertake loadings analysis?

1. To enable an estimation of the approximate load reduction needed, either as a daily or annual quantity from a point source such as a WWTP, or as kg/ha/yr from diffuse agricultural sources.
2. To enable comparison of the loads coming from different tributaries to a monitoring point, and therefore enabling targeting of mitigation measures/actions.
3. To enable comparison of the loads coming from point courses, e.g. an UWWTP, as a comparison with those arising from diffuse sources, e.g. from farmland.
4. To enable an estimate of the load contributed by springs (groundwater) to watercourses.
5. To enable targeting of effort and resources to the catchment areas of the watercourse needing improvement.
6. Ultimately, the way to achieve the required nutrient concentrations is to reduce the inputting load; without loading information, it is not possible to set a target for the reductions needed.

The value of loadings analysis is illustrated by the example outlined below.

Watercourse with high phosphate concentrations

- Moderate status: Q-value = 3-4.
- Significant issue: PO_4.
- Significant pressure: Diffuse agriculture – mainly pasture with some tillage.
- Catchment area to monitoring point: 3,000 ha (30 km^2).
- Water samples taken and analysed four times each year.
- Mean flow: 710 l/s (EPA Hydrotool).
- Phosphate load and load reduction assessment:
  - 2018-2020 average concentration = 0.05 mg/l (EQS = 0.035 mg/l).
  - Load = (710 x 86400 x 365)[46] x 0.05/1000000[47] = 1,120 kgP/yr.
  - P load reduction target = (710 x 86400 x 365) x (0.05-0.03[48])/1000000 = 450 kg/year

[46] Converted from seconds to year.
[47] Converted from mg to kg.
[48] Note that 0.03 mg/l is the target concentration as a mean rather than the EQS; see Section 9 for an explanation.

- Approximately 20% of the area (600 ha) is a critical source area for P losses, based on the EPA Pollution Impact Potential (PIP) map.
- Therefore, the reduction needed in kg/ha is ~0.75 kg/ha/year in the 600 ha.

- This value now provides a target to aim at when considering mitigation measures/actions.

Further examples and explanations are given in Appendix 4 and in Section A6 of NFGWS (2021)[49] for drinking water sources.

EPA report on Catchments that Need Reductions in Nitrogen Concentrations to Achieve Water Quality Objectives

This report estimates the nitrogen load discharging to sea in 18 catchments. It also estimates the load reduction needed to keep the nitrogen concentrations below the EQS of 2.6 mg/l as N (as a mean). The scale of the reduction needed ranged from zero in some years to just over 8,000 tonnes or nitrogen in the Barrowe in 2018. The report also highlights the role of targeting measures using critical source areas using PIP-N maps.

Link to report: https://www.catchments.ie/assessment-of-the-catchments-that-need-reductions-in-nitrogen-concentrations-to-achieve-water-quality-objectives/

10.4.7 A review of where we are in the Process

We now have a good indication of (keeping in mind that the field-based assessment, if undertaken, might change our understanding):

- What the *significant issue(s)* (in Areas for Restoration/Improvement) or potential pollutants (in Areas for Protection) is/are.
- What the *significant pressure(s)* or potential pressures is/are.
- Whether we need more data to help decide whether the water quality is satisfactory or not.
- What pollutant loading reduction is needed to achieve the water quality objective.

Where the *significant pressure* is a large point source, such as a WWTP, discharging directly to a watercourse, a decision needs to be made whether there are sufficient water quality data to enable the assessment of the impact to be undertaken. This situation is not covered further in this Handbook.

Where the *significant pressures* or potential are diffuse and small point sources, then an understanding of link and the pathways between the pressure and the receptor is needed.

[49] NFGWS (2020) 'A Handbook of Source Protection and Mitigation Actions for Farming' at this link: https://nfgws.ie/nfgws-source-protection-publications/

Table 10-3: Pressure Types and Indicator Parameters (principal indicators in green)

Pressure Type	Indicator Parameter																		
	Chemical/Physico-chemical														Hydro-morphological				Comment
	Ammonia	Nitrate	Phosphorus	Microbiology/pathogens	Temperature	Dissolved Oxygen	Acidisation (pH)	Turbidity and Colour	BOD/COD	Total Suspended Solids	Salinity[1]	Pesticides	Hydrocarbons	Heavy Metals	Flow/level	Depth/width	Sediment	Structure/substrate	
Agriculture	●	●	●	●		●		●	●	●	●	●	●				●		
Hydromorphology (modification)			●					●		●					●	●	●	●	Habitat degradation; increased sedimentation, and mobilisation of nutrients in sediments
Urban Wastewater	●	●	●	●	●	●		●	●	●	●		●	●					
Forestry	●		●				●	●		●		●					●		
Domestic Wastewater	●	●	●	●		●		●	●	●	●	●							
Urban (diffuse & small point)	●		●	●		●	●	●	●	●	●	●	●	●	●		●		
Peat	●					●	●	●	●	●							●		Dissolved organic carbon is also a possible pollutant
Industry	●		●		●			●	●	●	●		●	●					Depends on the nature of industry
Quarries	●			●				●		●	●		●	●	●	●	●	●	
Mines							●			●				●					Iron especially. Also, poor biological indicators (fish, macroinvertebrates), see **Volume 3**
Abstraction/flow diversions											●				●	●	●	●	Saline intrusion in coastal aquifers
Landfills, fly tips	●			●		●		●	●		●		●	●					

Notes:

[1] - as Chloride, Sodium Chloride or Electrical Conductivity (Specific Conductivity)

10.5 Pathway information and analysis

10.5.1 General

Pathway analysis of the movement of water and pollutants is needed where:

i) Diffuse sources are *significant pressures* or potential pressures.
ii) Small point sources are the *significant pressures* or potential pressures.
iii) Discharges to groundwater are being assessed.
iv) The objective is to protect/maintain existing water quality.

It is not needed where there is a direct discharge to a watercourse.

In general, there are four mechanisms of preventing an impact from pressures:

- Remove/reduce the pollutant load.
- Reduce/prevent mobilisation of pollutants.
- Break the pathway by intercepting pollutants as they move from the pressure source to the receptor (particularly for PO4, sediment, pathogens and MCPA).
- Remediate the receptor.

Therefore, an assessment and understanding of the pathway is critical.

Mental models – vital in developing our understanding

- **A mental model is an explanation of the thought process about how something works in the real world. It is a representation and visualisation of the surrounding world, and the relationships between its various parts and our intuitive perception about how this world functions.**
- **The 'world' for us is the landscape and the associated catchments, sub-catchments and sites.**
- **We need to be able to develop our mental model of a situation effectively as a means of ensuring that the targeting of investigations, actions and resources is effective.**
- **This requires having adequate knowledge and understanding on how water and pollutants move in the landscape.**
- **The aim of this section is encourage and enable development of our mental model in the form of a 'pathway conceptual model (PCM)', which allows us to decide on the most appropriate and effective protection or mitigation measures.**
- **For scientists and engineers who are not hydrogeologists or geologists, this may appear challenging. In reality, it is usually 'common sense' based on some basic information and knowledge. In complicated, high risk situations (Scenario CA11 in Table 8-1), specialist input can be obtained.**
- **The end product is intended to enable the scientist or engineer to 'stand' (virtually or literally) on a river bank, or at the monitoring point or at a site, looking upstream (or upgradient) at the catchment area, asking where is/are the pollutant(s) arising, from what pressure and along what pathway(s)?**
- **These questions need to be answered as the basis for the 'Story', the work plan and decisions on the protection/mitigation options.**

A check list of potentially relevant information sources, which may need to be accessed and assessed, is given in Table 7-1. Two of the most relevant sources are: i) https://www.catchments.ie/ and ii) https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx. A quick check on the information on the relevant groundwater bodies at this link is recommended: https://www.gsi.ie/en-ie/programmes-and-projects/groundwater-and-geothermal-unit/activities/understanding-ireland-groundwater/Pages/Groundwater-bodies.aspx

10.5.2 The pathway elements

In developing the 3-D mental model of the physical/hydrogeological setting in a catchment area (or on a site where effluent is being discharged to the ground), we need to think in terms of:

- The hydraulic element.
    - Is the water (either rainfall and/or effluent discharged onto/into land) moving away:
        - As underground flow?
        - As overland flow and/or close to the land surface?
- The attenuation element.
    - Will pollutants be treated adequately before a receptor is reached (or how much attenuation occurs along the pathway before the receptor is reached?).

And, we need to consider them separately; flows first, then attenuation after the flow regime is understood.

Visualising in 3-D!!
In considering the pathway elements, our mental model must encompass land/landscapes/sites in three dimensions, and even four in certain circumstances when the dynamic nature of an area due to seasonal or time changes needs to be taken into account.

10.5.3 The hydraulic element

A good starting point question is: what happens to rain falling on the area? Or alternatively and more precisely, what happens to effective rainfall (rainfall less actual evapotranspiration) on the land and in the landscape? This can be determined by the basic question: **is the area freely draining or poorly draining?** If freely draining a high proportion of water flows in the landscape will be underground. If poorly draining, it will be by overland and shallow subsurface flows.

10.5.3.1 Our geological setting

The underground environment consists of three layers:

- Topsoil or soil (See national soils map at this link: https://gis.epa.ie/EPAMaps/Water and an example of a downloaded map in Figure 10-8.)
- Subsoil: This is the 'loose' uncemented (unlithified) sediments present between topsoil and bedrock. The main subsoil types are glacial till, fluvioglacial sand/gravel, wind-blown sands and fluvial sand, silt and clay (called alluvium and present in flood plains). (See national subsoils map at this link: https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx and an example in Figure 10-9)
- Bedrock: The most common bedrock is limestone, followed by sandstone, and including others such as granites, shales and metamorphic rocks. (See national bedrock map in Figure

10-10 and maps are available at a detailed scale at this link: https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx).[50]

10.5.3.2 Permeability

Permeability (or hydraulic conductivity) is a measure of the ability of soil or subsoil or bedrock to transmit water (or let water flow through it). It depends on the sizes of the water transmitting openings (pore and fissures/joints/fractures/bedding planes). The permeability of geological materials varies by many orders of magnitude, and therefore there is great variability in the capacity of bedrock and subsoils in Ireland to transmit water. Further details are given in **Section 5.3, Volume 5**.

In topsoils, the permeability depends on the grain sizes and the depth to the water table. On sloping land, clayey soils will be poorly draining whereas silty/sandy soils will generally be freely draining. In flat areas or at the bottom of slopes where the water table rises close to the ground surface during wet periods, gleying results in a relatively low permeability, poorly draining soil. A map showing soil drainage characteristics, called 'National Soils Hydrology Map' can be accessed at this link: https://gis.epa.ie/EPAMaps/Water. An example of a downloaded map (without a legend) is shown for illustration in Figure 10-11.

In subsoils, the permeability value depends mainly on the grain size: the greater the proportion of clay and to some degree silt, the lower the permeability. Subsoils have what is called an 'intergranular' permeability – the water moves between the grains. There are three permeability categories for subsoils:

- Therefore, coarse grained **sand/gravel**, in which the finer grains of silt and clay have been washed out by water (fluvio-glacial or fluvial) or winnowed out by wind (this is called sorting by geologists), and which has a lot of interconnected openings, has a **'high' permeability**[51].
- **Subsoils** that have been deposited directly by ice (beneath, such as drumlins, or on front, such as moraines) with a **silt-dominated matrix** has a '**moderate**' permeability.
- **Subsoils** with a **clay-dominated matrix** has a '**low**' permeability.

The subsoil permeability map for the country can be accessed at this link: https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx . An example is shown in Figure 10-12.

Bedrock has no intergranular permeability but has what is called a 'fissure' permeability, where water flows in discrete, usually planar features, such as joints and bedding planes. Why? Bedrock in the Republic of Ireland is relatively old – the youngest bedrock is ~300 million years old (there are younger rocks in Country Antrim (basalts and Chalk). In this period, the original/primary porosity has been obliterated and infilled due to geological processes such as precipitation of mainly calcareous 'cement' in the pores, and pressure and temperature events in the crust of the earth that have welded the rocks together[52]. However, these moving plate events have caused the rocks to buckle and fracture, to varying degrees, giving the fissure permeability.

As a generalisation, the permeability of bedrock is usually appreciable immediately beneath the subsoil (comprising the 'transition zone' and 'the upper fractured zone'). These zones can vary from a few 10s cms to several metres, usually depending on the bedrock type. At deeper depths, the permeability varies depending on the bedrock and associated aquifer category.

[50] When accessing bedrock maps, check the 'Groundwater Rock Units' maps under 'Hydrostratigraphic Rock Unit Groups' rather than the Bedrock 100k maps.
[51] The permeability of subsoils has been classified as 'high', 'moderate' and 'low' by the Groundwater Section of the GSI.
[52] The crust of the earth is dynamic rather than static as it is made up of a number (30) of plates moving slowly (a velocity equivalent to the rate of growth of toe nails and hair); some are colliding and causing earthquakes and volcanoes today, e.g. Italy, Indonesia; others are moving apart, giving volcanic eruptions, e.g. in Iceland.

The link between bedrock type and water flow regime is summarised in **Table 5-1 in Section 5, Volume 5**.

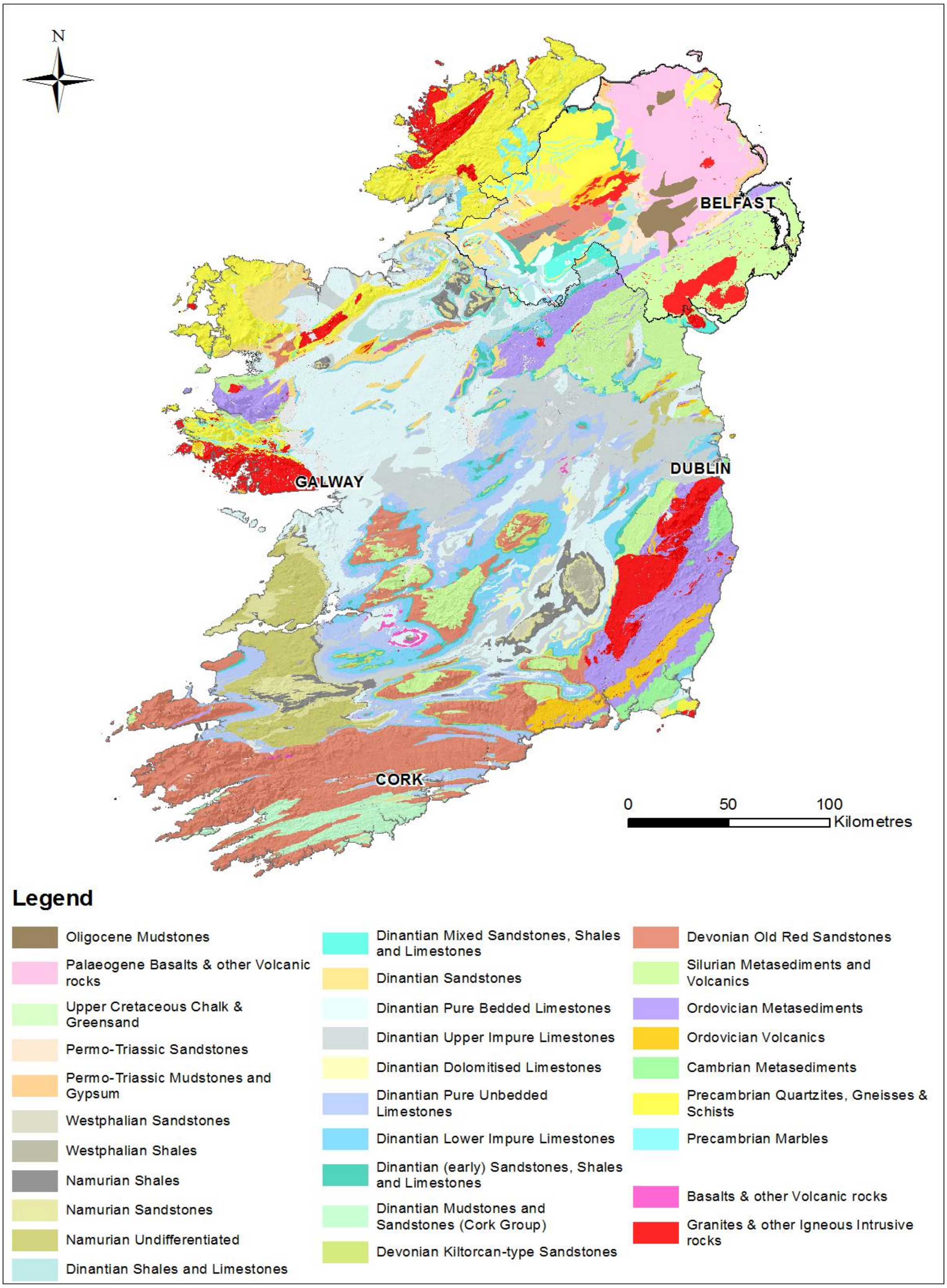


Figure 10-10: Bedrock map (Source: GSI).

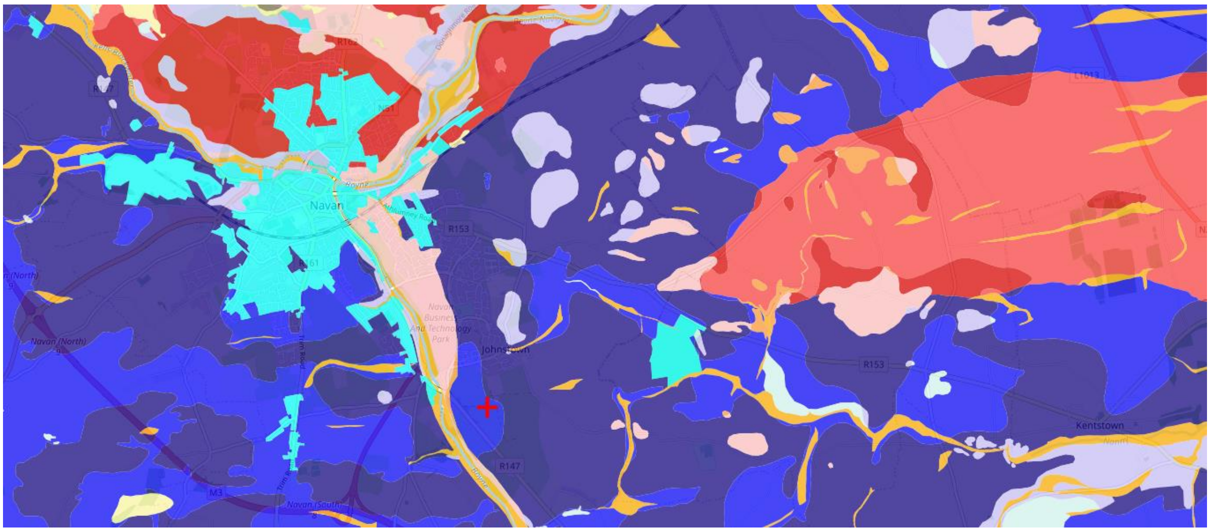


Figure 10.8: A screenshot of the soil map of Navan area (https://gis.epa.ie/EPAMaps/Water)

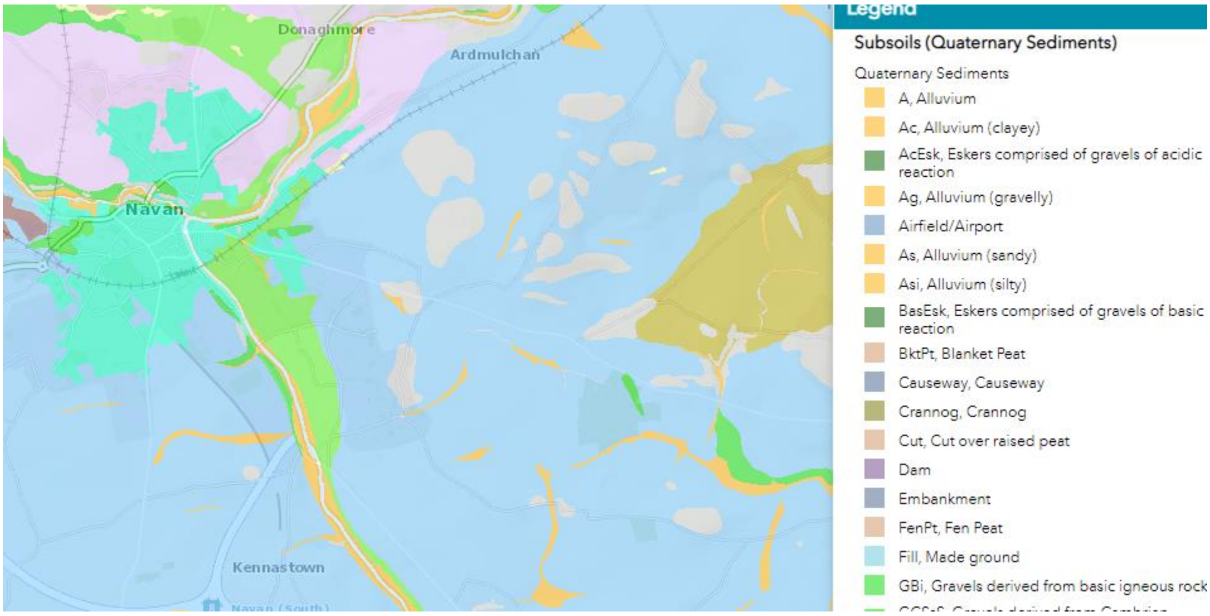


Figure 10-9: Subsoils map for the Navan area: (https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx)

Figure 10-11: A screenshot of the soil drainage map (https://gis.epa.ie/EPAMaps/Water)

Figure 10-12: Subsoil permeability map for the Navan area: (https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx)

10.5.3.3 Water movement pathways in catchments

The movement of water in catchment areas can occur along seven possible pathways depending on the hydrogeological setting present. These are illustrated in Figure 10.13. Further details are given in Archbold, *et al*. (2010)[53].

The potential pathways for water movement are as follows:

1. **Infiltration** is the downward movement of water from the land surface through the underlying geological materials and unsaturated zone to the water table. It occurs most readily and in greater quantities in moderate and high permeability soils/subsoils. In circumstances where infiltration reaches the water table in aquifers, it is equivalent to groundwater recharge.
2. **Overland flow and shallow subsurface flows** occur when the topsoil becomes saturated or where low permeability bedrock is at the surface causing water to flow on the land surface or at shallow depths (upper few cms) and in land drains.
3. **Interflow** is the lateral/horizontal movement of water in moderate and low permeability subsoil. It can occur in both saturated and unsaturated conditions.
4. **Transition zone flows** occur where a transition zone is present at the boundary between the subsoil and unaltered bedrock in poorly productive aquifer areas. It is usually thin, varying in thickness from 0-2 m. It can arise from physical (e.g. ice sheets moving over the landscape) or chemical processes. Its physical appearance is often 'rubbly', represented by broken pieces of bedrock and a dense network of shallow fractures which may be infilled to varying degrees by subsoil and/or weathered bedrock (Moe *et al*. (2020)[54]. Depending on the hydrogeological properties, it can transmit relatively large quantities of groundwater when saturated where it is dominated by bedrock fractures or can be an impediment to flows where it is clogged by clays. It can change in thicknesses over short distances. In low lying areas, it is likely to be saturated all year round, whereas in sloping areas it is generally unsaturated in dry weather.

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[53] Archbold, M., Bruen, M., Deakin, J., Doody, D., Flynn, R., Kelly-Quinn, M., Misstear, B. and Ofterdinger, U. 2010. Contaminant Movement and Attenuation along Pathways from the Land Surface to Aquatic Receptors – A Review. EPA STRIVE Report. https://www.epa.ie/publications/research/water/contaminant-movement-and-attenuation-along-pathways-from-the-land-surface-to-aquatic-receptors---a-review-.phpsubsoils

[54] Moe, H., Craig, M. and Daly, D. (2010). Poorly productive aquifers. Monitoring installations and conceptual understanding. https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/EPA-Poorly-Productive-Aquifers-Summary-Report.pdf

5. **Shallow bedrock flows** occur in the upper (a few metres generally) fractured zone of poorly productive aquifers. In many circumstances, it is the main zone for underground flows when it is saturated. In sloping areas, it may be unsaturated in dry weather.
6. **Deep bedrock flows** occur in the main body of bedrock aquifers and in sand/gravel aquifers. It is the groundwater resource available for drinking water supply and the source of baseflow to streams. Clearly, flows are much greater in productive aquifers, such as Regionally Important Aquifers, than in poorly productive aquifers.
7. **Discrete fault or conduit** (not illustrated in Figure 10.13) **flows** which can occur along fault zones and in karst areas.

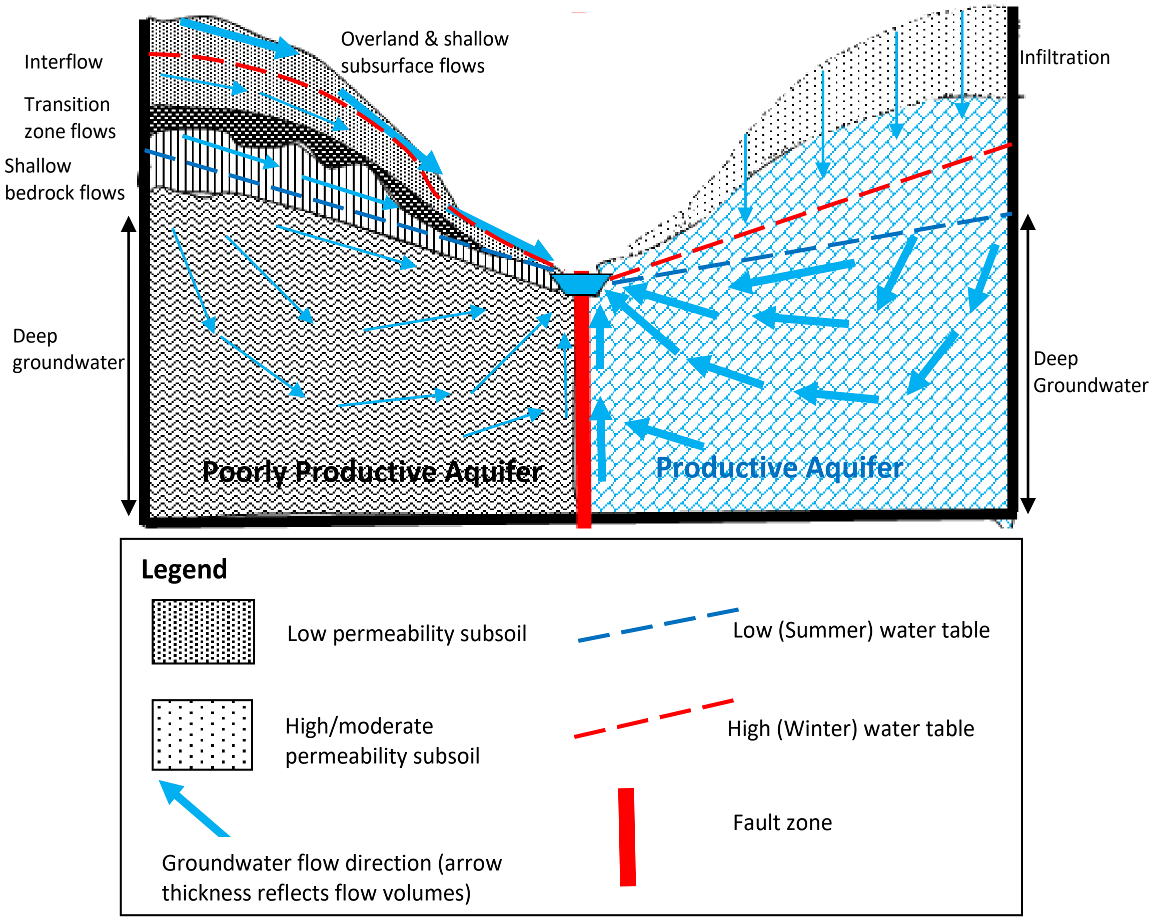

Figure 10.13: Components of surface water and groundwater flow in poorly productive (left) and productive (right) bedrock aquifer settings. Low- or high-permeability subsoil may overlie either bedrock aquifer type.

Recommendation

When visualising water movement in catchments, think in terms of these seven potential flowpaths.

10.5.3.4 Discharge hydrographs as indicators of water flow regimes

The concept that is the basis for this section is that the variations in stream discharges (and water levels) can be useful indicators of water flow pathways in catchments.

A **discharge hydrograph** is a graph of the discharge volume of water at a specific point in a stream or river with respect to time. It represents the response in a catchment to effective rainfall (ER) (rainfall (R) less actual evapotranspiration (AE)). An example of a discharge graph is given in Figure 10.14. where the various components of flow have been separated out.

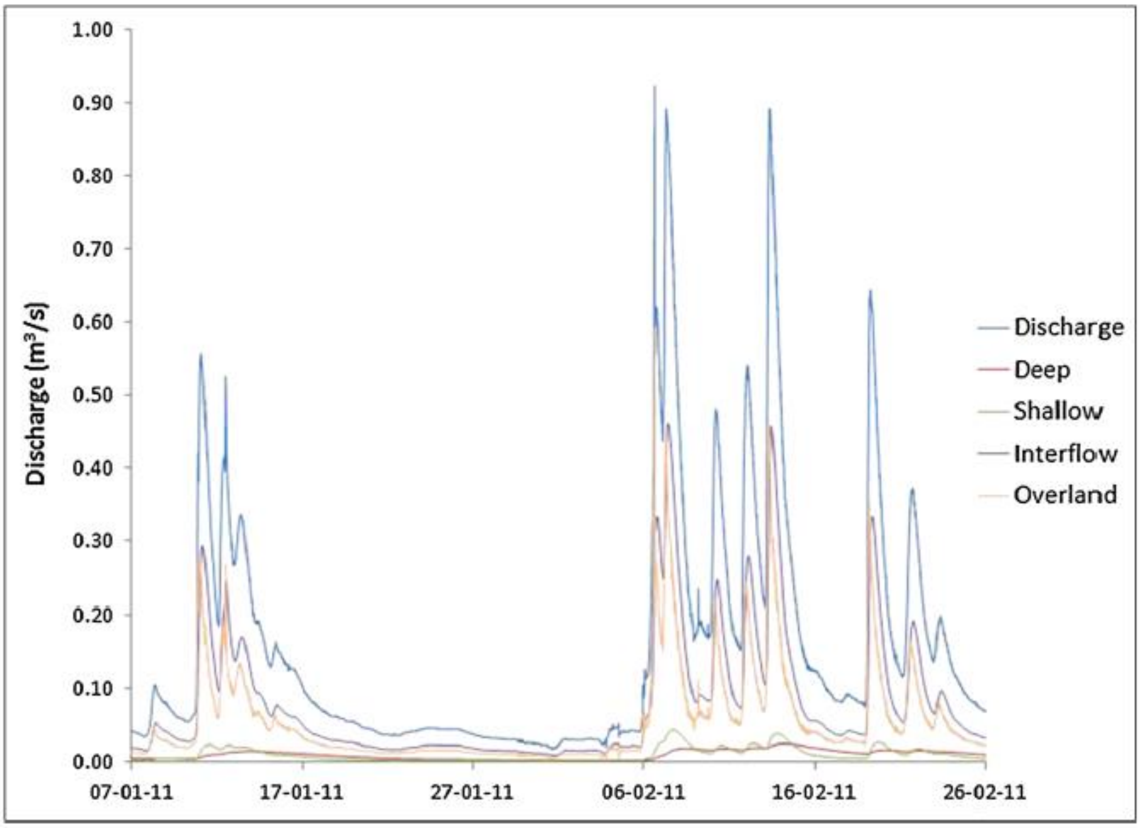

Figure 10.14: Discharge hydrograph for the Glenburn catchment (Source: O'Brien, *et al*. 2014[55])

A storm hydrograph is shown in Figure 10.15. This shows how a rivers' discharge responds to a period of rainfall (precipitation) over a short period – hours generally. It illustrates the following features:

- **Peak rainfall:** the highest rainfall during the storm.
- **Peak discharge:** the highest discharge.
- **Lag time:** the period of time between peak rainfall and peak discharge.
- **Response time**: the time between the first rain falling and the first change in discharge.
- **Rising limb:** the period of time that a river is experiencing an increase in discharge.
- **Recession limb:** the period of time that a rivers' discharge is falling after a storm event.
- **The six components of flow** combined into the following categories: i) groundwater/baseflow/deep groundwater flows; ii) interflow/shallow bedrock/transition zone flows; and overland and shallow subsurface flows.

[55] O'Brien, R.J., Misstear, B.D., Gill,L., Johnston, P.M., and Flynn, R. 2014. Quantifying flows along hydrological pathways by applying a new filtering algorithm in conjunction with master recession curve analysis. Hydrol. Process. 28, 6211–6221.

Developing stage-discharge relationships

At each station, the EPA hydrometric officers use data loggers to measure the water level (stage) every 15 minutes. Over time, spot flow measurements are also taken at the station, from low flows to high flows. Where the river bed shape is stable, it is possible to fit a line to the relationship between water level and flow. Once this relationship has been established, it is possible to produce a continuous time series of flow at a station using the continuous water level measurements and the rating equation. At many stations, changes to the river bed or weir due to erosion or deposition, or backwatering effects caused by weed growth downstream, can change the relationship between water level and flow. For this reason, a minimum of six spot flows are taken at each station annually to ensure that the rating equation is still accurate, or if not, whether rating curves need to be modified.

Using hydrometric station flow duration curves

A flow-duration curve is a cumulative frequency curve that shows the proportion of time specified discharges were equalled or exceeded during a given period. It is a time-bound statistic. As flow percentiles relate to time, and not volume, the Q50 does not equal the mean flow, but rather the flow that is equalled or exceeded 50% of the time. In Irish conditions, the Q30 is usually more likely to represent the mean flow. Flow duration curves at hydrometric stations are quality controlled and, where it is available, this observed data should always be used in preference to modelled data such as HydroTool estimates. It is also important to note that hydrometric stations measure the actual flow in the river, i.e. the flow actually present in the river taking into account the impacts of any upstream abstractions and/or discharges.

Using HydroTool flow duration curves

The HydroTool outputs are provided in flow duration curve format as described above. However, in this case they are produced using donor data, i.e. they are modelled. Hydrological models are better at accurately predicting mean flows, but less effective at estimating very low or very high flows. Therefore, when using HydroTool estimates, the following uncertainty estimates should be borne in mind. For mean flow (provided as NATAMF in HydroTool) the actual flow is estimated to be within +/-16% of the modelled flow 95% of the time. For the Q95 flow (provided as NATQ95 in HydroTool) the actual flow is estimated to be within +/-56% of the modelled flow 95% of the time. Where actual spot flow or hydrometric data is available, it should always be used in preference to HydroTool or other modelled data. It is also important to note that HydroTool estimates the *naturalised* flow, i.e. the flow that would be present in the river without the impacts of any upstream abstractions and/or discharges that may exist. For this reason, HydroTool estimates may not be accurate downsteam of significant abstraction or discharge influences, especially at low flows. Furthermore, as topographic catchment size is the primary influence on flow volumes, HydroTool estimates may not be accurate in catchments with a significant karst influence, i.e. where the actual catchment does not match the topographic catchment.

(Acknowledgement: This box was contributed by Conor Quinlan, Hydrometric and Groundwater Section, EPA.)

Links

EPA HydroNet portal: http://epa.ie/hydronet

Hydrotool: https://gis.epa.ie/EPAMaps/Water (under Monitoring & Flows/River Flow Estimates – Hydrotool)

OPW hydrometric data: https://waterlevel.ie/hydro-data/

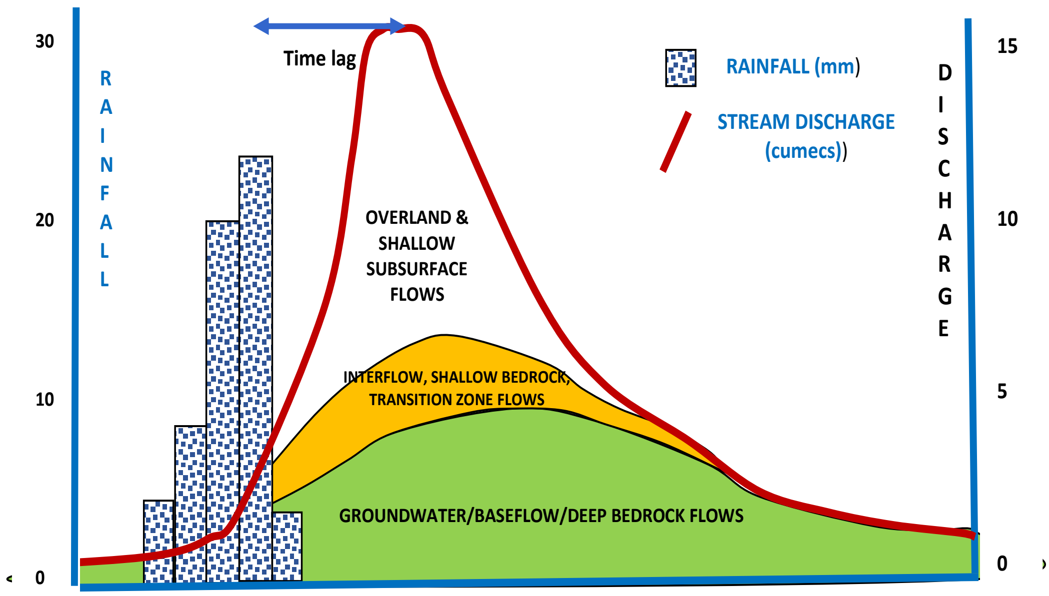

Figure 10.15: Schematic diagram illustrating the various components of a storm hydrograph for a stream/river

The proportion of effective rainfall that gives rise to the different components of flows in stream discharges and the shape of stream discharge hydrographs are influenced by factors such as:

- Rainfall intensity.
- Soil permeability.
- Subsoil permeability.
- Bedrock permeability where soil/subsoil thickness is thin (<1-2 m).
- Drainage density, including natural and artificial (arterial and land) drainage.
- Available storage (for accepting potential recharge) (in poorly productive aquifer areas where bedrock has a low ability to store water, the recharge may be 'rejected' in wet weather when the water table is high).
- Slope/gradient.
- Land use, e.g. agriculture, afforestation, urbanisation, reservoirs, abstractions.
- Catchment size.

Stream hydrographs indicate whether a catchment can be considered 'rapid response' (to rainfall) (also termed 'flashy') or 'slow response'. Rapid response and peaky hydrographs occur where a greater proportion of effective rainfall follows overland and near surface pathways influenced primarily by the presence of relatively low soil, subsoil and bedrock permeability, poorly productive aquifers, saturated conditions and artificial drainage installations. Drainage density is relatively high in rapid response catchments and installation of artificial drainage can increase the speed of runoff. Slow response and shallow hydrographs are present where the soils and subsoils are permeable, and where the bedrock is a productive aquifer. In these settings, minimum overland and shallow subsurface flows occur and baseflows/groundwater inputs to streams are relatively high. The different shapes on the resulting hydrographs are illustrated in Figure 10.16.

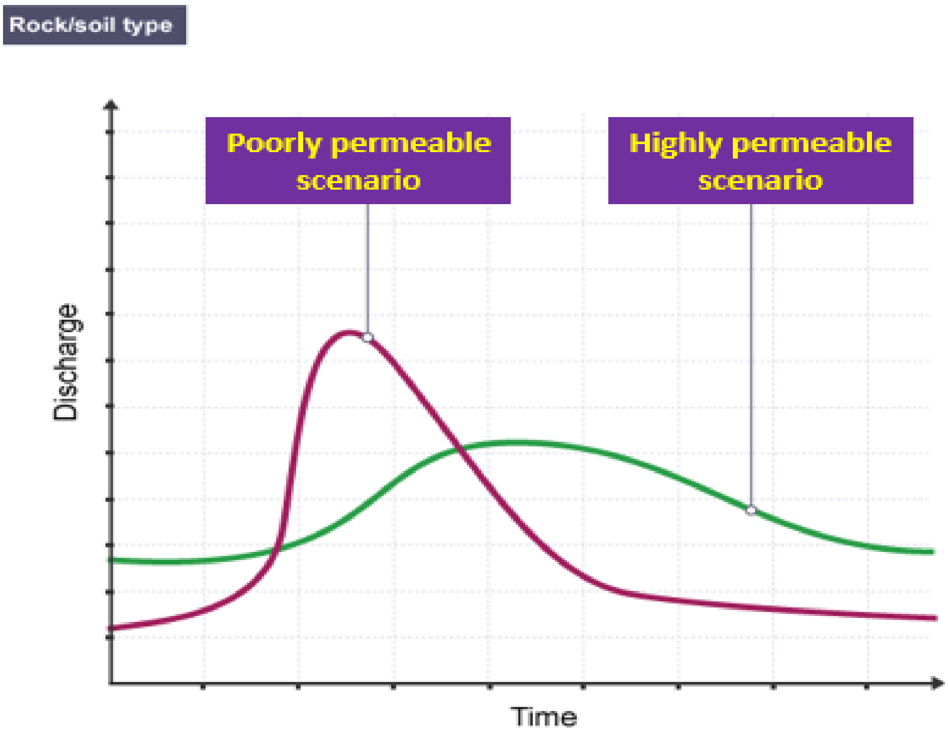

Figure 10.16: Illustration of the role of hydrogeological setting (Source: Interpretation of hydrographs at this link: https://www.bbc.co.uk/bitesize/guides/zpqwwmn/revision/2)

Recommendation

Where a sub-catchment or a catchment area to a water body or a site is being assessed, it can be worthwhile thinking in terms of whether it is a rapid response (flashy) or slow response (to rainfall) area, even in circumstances that EPA or OPW hydrographs are not available for a nearby hydrometric station.

10.5.3.5 Aquifers as indicators of water flow regimes

Bedrock or subsoil that contain sufficient voids to **store water** and are permeable/transmissive enough **to allow water to flow** through them in significant quantities are termed **aquifers**.

The only subsoil material that can be classed as an aquifer, where it is extensive enough and has a sufficient saturated thickness, is sand/gravel (approx. 3% of the country). While clayey subsoil can store substantial quantities of water, as the permeability is relatively low it cannot transmit water readily and so is not an aquifer.

In contrast, all our bedrock in the Republic of Ireland is classed as an aquifer (sufficient water for a domestic supply can be found almost everywhere). However, the capacity of our various bedrock units to store and transmit varies, depending on the rock type. The GSI has subdivided our sand/gravel and bedrock units into nine aquifer categories, which are listed below:

Regionally Important (R) Aquifers

(i) Karstified aquifers (**Rk**)
(ii) Fissured bedrock aquifers (**Rf**)
(iii) Extensive sand/gravel **(Rg)**

Locally Important (L) Aquifers

(i) Sand/gravel (**Lg**)
(ii) Karstified bedrock (**Lk**)
(iii) Bedrock which is Generally Moderately Productive (**Lm**)
(iv) Bedrock which is Moderately Productive only in Local Zones (**Ll**)

Poor (P) Aquifers

(i) Bedrock which is Generally Unproductive except for Local Zones (**Pl**)
(ii) Bedrock which is Generally Unproductive (**Pu**).

The national aquifer map is shown in Figure 10-17 and a map of a catchment is shown in Figure 10-26.

Knowledge of the aquifer category can assist in understanding water flows in an area. The language used in defining our aquifers is intended to be intuitive, with Regionally Important (R) aquifers being far more productive, permeable and transmissive than Poor (P) aquifers.

- As the Rk, Rg, Lg, Lk and Lm aquifers can readily allow water to move through them:
    - Deep (30+ m) and lengthy (up to several kms) groundwater flowpaths occur.
    - Land overlying these aquifers will often be freely draining. However, there are some circumstances where they are overlain by poorly permeable soils and/or subsoils.
- The poorly productive aquifers (Ll, Pl and Pu) having a low bulk permeability or transmissivity:
    - Deep flow paths seldom occur and groundwater flowpaths tend to be a relatively short (10s to 100s metres).
    - They often have a permeable 'upper fractured zone' and can also have a relatively permeable 'transition zone', allowing significant shallow groundwater flows in wet weather.
    - They can be overlain by either poorly draining or freely draining soils, depending on the rock type, the presence of an upper fractured zone and the overlying subsoils.
    - In areas where the poor (P) aquifers outcrop at the surface, there tends to be minimal infiltration to groundwater.

A summary of the water flow regimes in the different aquifer areas is given in Table 10-5. A more detailed description is given at this link: https://www.gsi.ie/documents/GSI%20Aquifer%20Category%20Descriptions.pdf. Aquifer maps can be accessed at : https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx# and details on aquifers can be accessed here: https://www.gsi.ie/en-ie/publications/Pages/Irish-aquifer-categories.aspx.

10.5.3.6 Water flow regimes – a summary

- The key driver for water and pollutant movement in the landscape is the **permeability** of the soil, subsoil and bedrock.
- Once a certain permeability threshold is reached, irrespective of slope, the water (effective rainfall) cannot infiltrate readily (or recharge an aquifer readily) and therefore is available for runoff to drainage ditches and watercourses (just like a concrete yard where, irrespective of the slope, the water must run off, with the slopes determining where the water goes).
- **Subsoil thickness** has an influence, but relative to permeability, it is secondary.
- Essentially, where the subsoil permeability is 'low', then only a relatively small proportion infiltrates underground. **Low permeability subsoil** is generally overlain by poorly draining soils. A high proportion of the remainder runs off as 'quick flow', either overland or shallow subsurface. Such catchments are termed '**flashy**' or '**rapid response'** (to rainfall) **catchments**.
- **Low permeability/transmissivity bedrock**, indicated by Ll, Pl and Pu aquifers (these are sometimes called unproductive aquifers), can only accept a small proportion of effective rainfall,

resulting in **runoff via overland and shallow subsurface flows, and high drainage densities**. Intermittent flow watercourses are common as baseflow inputs from groundwater are limited in dry weather.

- **High transmissivity** (high bulk permeability) **bedrock,** indicated by aquifer categories such as Rk, Rf, Rg, Lm, Lk and Lg (these are sometimes called productive aquifers), can accept infiltration of effective rainfall, resulting in a dominance of underground flows, low drainage densities and substantial baseflows to watercourses.
- Productive aquifers underlie approx. 30% of the country.
- Limestone aquifers underlie 45% of the Republic of Ireland.
- **Karstified limestones** underlie ~20% of the country. In these areas, landforms are of dominantly solutional origin, and the drainage is underground in solutionally-enlarged fissures and conduits. Further details are given in **Section 5, Volume3**.
- **Slope** is a secondary factor regarding whether water runs off or not. However, slope is the primary factor in dictating **where** the water goes 'horizontally' in the landscape in **poorly draining areas.**
- The **water table** is the upper limit of the saturated zone (see **Section 5.4, Volume 3**.)
  - It can be visualised as a planar surface that is a subdued reflection of topography (except in karst areas (see **Section 5, Volume 3**)).
  - Therefore, groundwater flow direction generally follows the topographic slope.
  - The depth to the water table depends on the permeability/transmissivity of the geological materials and the topographic location (see **Section 5.4 in Volume 5**).
- Groundwater **velocities** are low relative to surface water – **a few metres per day usually** (with the exception of karst areas where is can be 10s metres/hour).
- **Springs** are a natural discharge of groundwater at the land surface (see **Section 5.5 in Volume 5**) that occur where the water table intercepts the ground surface.
- There are seven **potential pathways for water movement in the landscape** – the number that applies in any particular sub-catchment depends on the hydrogeological setting. These are: i) infiltration; ii) overland and shallow subsurface flows; iii) interflow; iv) transition zone flow; v) shallow bedrock flows; vi) deep bedrock flows; and vii) discrete fault or conduit flows.
- Evaluating whether a sub-catchment area (or a smaller area such as a farm) responds quickly or slowly to rainfall events aids understanding of water and pollutant movement.
- Stream discharge hydrographs indicate whether a catchment or sub-catchment can be considered i) 'rapid response' or 'flashy' or 'quick flow' or ii) 'slow response'.

Suggestion

For you own area, check out the maps on www.catchments.ie and https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx for information on the status and risk categories of nearby water bodies, and on the subsoil and subsoil permeability, bedrock, aquifer category, soil drainage, groundwater vulnerability, susceptibility for phosphate and nitrate losses, etc.

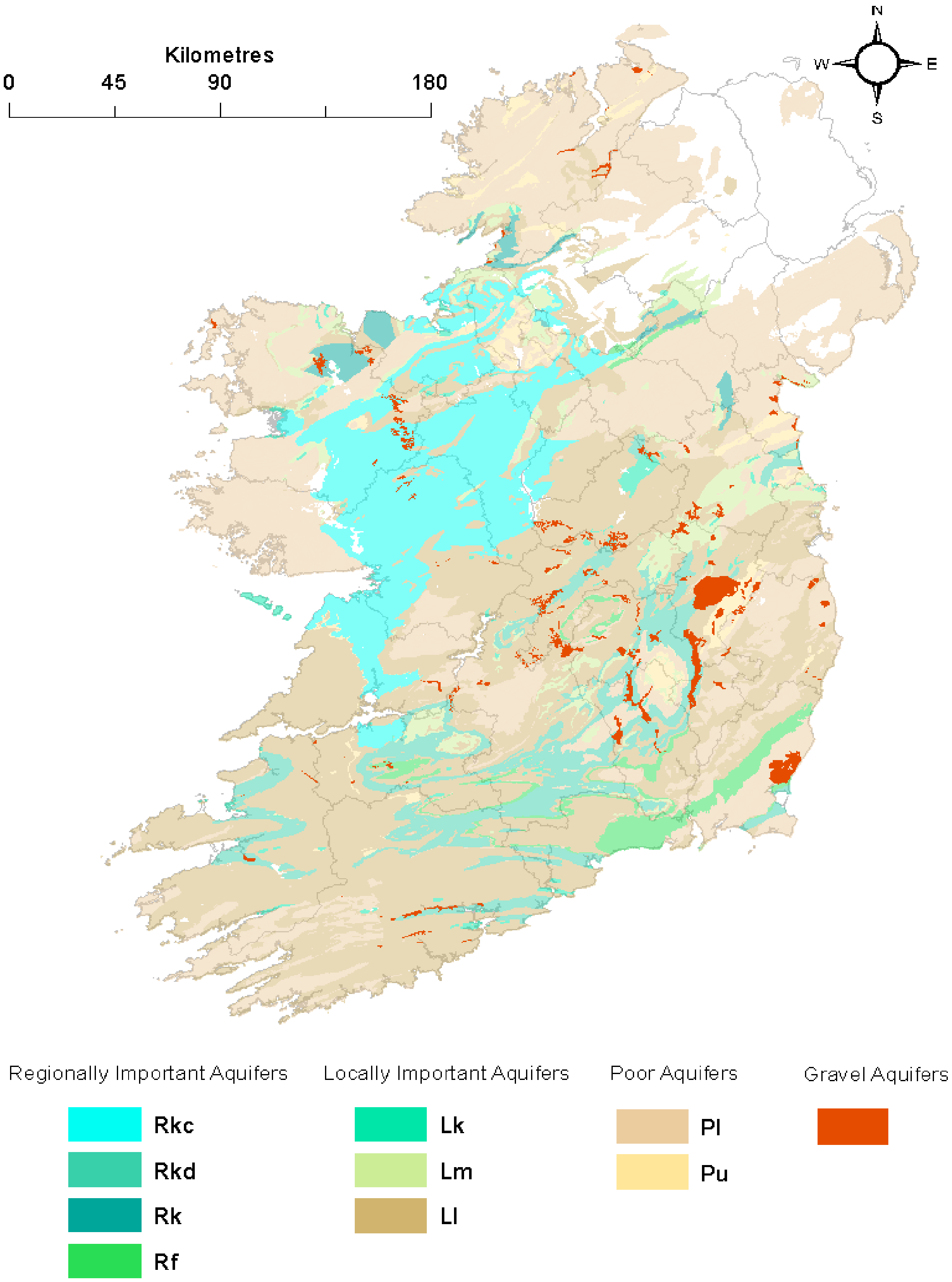

Figure 10-17: National aquifer map (Source: GSI)

Table 10–5: Summary of the flow regimes in the different aquifer category areas

Aquifer category	Hydrogeological flow regime
Regionally Important (**R**) – karstified (**Rk**)	• These are limestone aquifers, which are the most productive aquifers in the country for water supplies. • '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 (**R**) – fissured bedrock aquifers (**Rf**)	• 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. • An exception to this is the volcanic aquifer in Wexford and Waterford where intervening shaly layers can lead to both freely draining and poorly draining conditions.
Regionally Important (**R**) – sand/gravel aquifer (**Rg**)	• A sand/gravel aquifer is classed as **regionally important** if it can supply regionally important abstractions, is highly permeable, more than 10 m thick or has a saturated thickness of at least 5 m, and normally extends over *at least* 10 km^2. • Groundwater flows through the pore spaces between sand/gravel grains, and the permeability is mainly determined by the grain size (larger grains give larger pore spaces), and the 'sorting' of the material (the more uniform, the higher the permeability). There is a relatively uniform distribution of groundwater, good aquifer storage and long groundwater flow paths, typically limited by the aquifer's extent. • Groundwater gradients are typically low ('flatter' water tables), giving relatively low groundwater velocities (typically 1-2 m/d). • The overlying soil is freely draining. • Provides good baseflow to watercourses. • Drainage density is low.

Locally Important (**L**) – sand/gravel aquifer (**Lg**)	• Similar to the properties of an **Rg** aquifer, but with a smaller continuous area (c.1-10 km^2) and/or less consistent permeability. • Provides good baseflow to watercourses.
Locally Important (**L**) – karstified aquifer (**Lk**)	• Essentially similar to the **Rk** aquifers but with a smaller continuous area (<c. 25 km^2).
Locally Important (**L**) – Bedrock which is moderately productive (**Lm**)	• Similar to **Rf** aquifers, with a network of fractures, fissures and joints, through which groundwater flows, is reasonably well connected and dispersed throughout the rock, but with a 'moderate' transmissivity and groundwater throughput. • In some circumstances, their designation is due to a lower areal extent than **Rf** aquifers. • Provides good baseflow to watercourses. • Overlying soils are generally freely draining and drainage density is relatively low.
Locally Important (**L**) – Bedrock which is moderately productive only in local zones (**Ll**)	• Aquifer with 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, fault zones and, where present, the transition zone. • Permeability decreases with depth. • The upper fractured zone is often several metres thick. • Subsoils generated from this rock unit are often somewhat clayey, with a permeability often at the low end of 'moderate' or, sometimes, the upper end of 'low'. • Small streams are fairly frequent. • Groundwater discharge to streams ('baseflow') can significantly decrease in the drier summer months; this can lead to the presence of intermittent streams.
Poor (**P**) – Bedrock which is generally unproductive except for local zones (**Pl**)	• The main flowpaths are in a thin upper fractured zone (which is not always present), occasional fault zones (most of the fault zones shown on the geological map are not transmissive) and, where present, the transition zone, which usually consists of loose granular sandy material. • Deep groundwater flow is limited. • Generally, the landscape is poorly draining and blanket peat is common. West Wicklow and east Carlow are an exception as several metres of weathered granite may be present, giving a freely draining situation. • Underground flowpaths are short – a few 10s metres at most. • Runoff in rivers is flashy, there is a high drainage density with many of the small watercourses and drainage ditches intermittent. • Groundwater is likely to contribute <20% of average flows in rivers.
Poor (**P**) – Bedrock which is generally unproductive (**Pu**)	• The lowest transmissivity aquifers in the country, with limited fracturing. A thin upper fractured zone and a transition zone may be present, but even in these, the permeability is likely to be limited. • Subsoil generated from this rock unit will generally be clayey and have a low permeability. • Stream density will be high, runoff will be flashy and many of the small watercourses and drainage ditches will be intermittent. • Groundwater input to surface water will be low (<20% of average flows in streams).

Recommendation

For those of us whose home or areas of interest are underlain by limestone, check out 'Karst of Ireland' by David Drew at this link: https://www.gsi.ie/en-ie/publications/Pages/Karst-of-Ireland-Landscape-Hydrogeology-Methods-David-Drew.aspx

10.5.4 The attenuation element

The key drivers for pollutant attenuation on the land and in the landscape are:

i) The pollutant properties.

ii) The water flow regime – primarily whether freely draining or poorly draining.

10.5.4.1 The role pollutant properties in determining attenuation

In most circumstances, one or more of the following pollutants may be the stressor: phosphate, nitrate, ammonium, BOD, microbial pathogens, colour and pesticides such MCPA. Each pollutant has specific characteristics that influence its movement and attenuation; an understanding of these characteristics is essential in deciding on the strategies and actions for dealing with them in an effective and efficient manner. Summary information on each of these pollutants is given below. More comprehensive information is given in Section 8, Volume 4.

Phosphate

- High phosphate concentrations are the main cause of eutrophication of surface water. In water courses, this is often indicated in summer by slimy growths. This can cause taste, odour and treatment operational issues in drinking water sources.
- High phosphate concentrations can arise from i) large point sources, such as WWTPS discharging directly to water courses; ii) small point sources such as farmyards and inadequate septic tank systems; and iii) diffuse agricultural sources (fertilisers, both organic and inorganic) from the land in poorly draining areas.
- Phosphate is relatively immobile and is attenuated in freely draining soils and moderately permeable subsoils. However, in poorly draining areas, it is prone to being 'washed off' into ditches and watercourses after heavy rainfall as overland or shallow subsurface flows.
- **Therefore, the landscape scenario that it can be a *significant issue* and a threat to water quality is in poorly draining areas where the receptor is surface water.**
- One feature to note about phosphate is that it takes very little to cause water quality impacts – 1 kg phosphorus when present as phosphate will pollute 29,000,000 litres of water (or 6.4 million gallons). Keeping in mind that farmers might apply between 20-30 kg P/ha, a loss of 1-5%, depending on the circumstances, could cause eutrophication in the nearby watercourse. (See **Section 10.4.5.1**)
- In some situations, relatively low PO_4 concentrations in combination with high NO_3 concentrations can impinge on the ecology. In this instance, it may be more effective to focus initially on reducing the PO_4 further as this may be easier to achieve than reducing the nitrate concentrations.
- If PO_4 concentrations are high in the upper reaches or headwaters of a catchment, as a generalisation, it would probably indicate point pollution sources rather than diffuse as agriculture is usually extensive rather than intensive in these areas and small inputs can have an impact.

Nitrate

- 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. In addition, high nitrate can also impact on surface water ecosystems, particularly estuaries and coastal waters. The link between nitrate concentrations is less clear for Q-values; however, high concentrations (~>3.5 mg/l as a mean value) could be a *significant issue* for watercourses.

- High nitrate concentrations in water arise mainly from i) organic and inorganic fertilizers, ii) urine from grazing animals and iii) UWWTPs.
- **Nitrate is a 'conservative' pollutant that readily leaches from the soil in freely draining areas and where these coincide with relatively intensive farming, nitrate concentrations in underlying groundwater and associated surface water bodies can be problematical.**
- In poorly draining areas and in certain bedrock types, e.g. impure limestone, nitrate denitrifies and does not cause impacts to groundwater generally.

Ammonium

- Ammonia is toxic to fish and other aquatic organisms at low concentrations.
- Ammonium is relatively immobile in soil and subsoil and does not generally leach underground. However, it readily converts to nitrate in the presence of oxygen (nitrification) and therefore it tends to indicate localised pollution. It is not as persistent in water as nitrate or phosphate.
- High ammonium concentrations in watercourses generally indicate that pollution is occurring from an organic waste source, such as farmyard dirty water or untreated effluent from septic tank systems or runoff after slurry spreading in poorly draining areas. Slurry spreading immediately before heavy rainfall in areas with a high phosphate susceptibility ranking (poorly draining areas) can result in a pulse of high NH_4 in the watercourse.
- For groundwater sources, it usually indicates a localised source such as a septic tank system or farmyard in situations where the bedrock is close to the ground surface, such that the ammonium doesn't have the time or opportunity to be oxidised to nitrate (when it converts to nitrate the concentrations as nitrate are not generally problematical). The presence of ammonium often indicates that microbial pathogens might be an issue as well.
- Main pathways: overland and near surface flows in poorly draining areas to watercourses or underground where bedrock is close to surface.
- Ammonium in watercourses can also arise for drained peatlands and peaty soils areas due the decomposition of the peat. It is usually associated with dissolved organic carbon (DOC).

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. It is a natural component of streams, but can also be a pollutant giving turbid water.
- It can destroy stream habitats where organisms such as macroinvertebrates and the pearl mussel live, and can cause declines in fish stocks.
- In addition, phosphorus can be attached to it and therefore it can contribute phosphate to surface water.
- **Sediment can be a *significant issue* mainly in poorly draining areas**, arising from the following pressures – land drainage, drainage maintenance, channel maintenance, land reclamation, cattle poaching near watercourse, runoff from tillage fields, construction near watercourses, peat loss and poorly managed forest clear-felling and runoff from roads and concreted areas.
- Unlike with nutrients, 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'.[56]
- Information on sediment and assessment methodologies is given in **Section 7 in Volume** 4.

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

Biological Oxygen Demand (BOD)

- Biological oxygen demand (BOD) generally represents how much oxygen is needed to break down organic matter in water. Healthy water needs the presence of some oxygen, which sustains aquatic life, such as fish and plants, and the aesthetic quality of streams and lakes.
- Organic pollutant sources, such as effluent from wastewater treatment plants and septic tank systems, dirty water from farmyards and runoff of slurry from fields, can use up the oxygen in the water and then impact of the aquatic life. Silage effluent and milk have very high BOD concentrations (see **Section 2, Volume 2**), and entry to water is likely to cause fish kills.

Microbial pathogens

- The main microbial pathogens that pose a threat to both groundwater and surface water drinking water sources are *E. coli*, *Cryptospiridium* and viruses. They cause diarrhoea and gastrointestinal infections, particularly in children and the elderly, and are a threat to shellfish and bathing waters.
- *E. Coli* is used as the main indicator of the presence of pathogens – the Drinking Water standard is 0/100ml.
- Microbial pathogens die off and are attenuated in the landscape. However, they can get into groundwater readily in freely draining areas where there is outcropping and shallow bedrock, and into surface water in poorly draining areas where there is rapid (or flashy) runoff from the land. In addition, urban wastewater treatment systems, farmyards and septic tank systems can be a source of microbial pathogens.
- In summary, it can be a *significant issue* in i) poorly draining areas, ii) where bedrock is at/close to the surface and iii) where there are effluent discharges to watercourses.

MCPA

- MCPA is used mainly to control rushes.
- MCPA is soluble in water and is slow to break down in saturated conditions. Therefore, **in poorly draining areas** it can be carried off the land after heavy rainfall. The limit for MCPA is very low – 0.1ug/l or 0.1 of a part per billion, which is the equivalent of one drop of MCPA in an Olympic-sized swimming pool.

Conductivity

- Conductivity values reflect the dissolved anions and cations (predominantly made up of bicarbonate and calcium). As a result, unless there is gross pollution, a conductivity value on its own may not reflect high phosphate levels. However, phosphate is often associated with chloride which would raise the conductivity. Nitrate does contribute to conductivity but to a far lower degree than bicarbonate.
- The main use of conductivity readings is to check for variability when walking along a watercourse as it may indicate points and areas of pollutant input.
- See **Section 6, Volume 4** for more details.

10.5.4.2 The role of the water flow regime in determining pollutant attenuation

Attenuation of the various pollutants depends not only on the pollutant properties but also on the contrasting flow regimes in the various subsoil types and in bedrock.

Attenuation in soil/subsoil

- Subsoils have an intergranular permeability (water flows between the sand, silt and clay grains).

- Moderate permeability subsoils (sandy and silty glacial tills) (Figure 10-18):
  - The dominant flowpath is vertically to the water table. Vertical water movement is relatively slow (<1- a few cms/d) which facilitates adsorption and ion exchange.
  - E. coli are filtered out and die-off.

- Phosphate is attenuated by adsorption.
- Ammonium is attenuation by conversion to nitrate.
- However, minimal attenuation of nitrate occurs, which can move readily vertically and enter groundwater, and then flow horizontally to wells and/or nearby watercourses.
- The situation for high permeability subsoils (sands/gravels) is similar, although somewhat less attenuation is likely.

♦ Low permeability soil/subsoil (e.g. gley & clayey till):
  - Water 'cannot' move downwards and this is indicated by a high drainage density and vegetation indicators, such as rushes.
  - Dominant water flowpath is horizontal via overland and near surface flows.
  - Therefore, runoff of pollutants such as PO_4, NH_4 pesticides (e.g. MCPA) and pathogens can occur readily.
  - Nitrate does not generally pose a threat due to denitrification.
  - As infiltration is limited, groundwater achieves good protection.

Attenuation in bedrock

♦ Pollutant attenuation is minimal in bedrock. Reasons:
  - Rock too 'solid' for interactions between pollutants and rock grains.
  - Fissures, joints, bedding planes and conduits have openings that are too large for filtration of microbial pathogens (Figure 10-19 and Figures 5-15 and 5-16 in **Section 5, Volume 3**).
  - There is not enough water stored in bedrock for dilution to be effective (storage capacity (porosity) varies between 0.1-3% (and <1% in most bedrock) of the rock volume in contrast to sand/gravel in which it is 12-20% generally).

♦ Therefore, once pollutants enter bedrock, contamination of groundwater is inevitable.

♦ Pollutants can then be transferred in the groundwater to wells/springs and watercourses.

Summary

- **In considering impacts of pressures on surface water receptors and possible protection/mitigation measures, understanding how the pollutant properties and the water flow regime combine provides the answers needed.**
- **Phosphate, ammonium, MCPA and microbial pathogens pose a threat in poorly draining areas.**
- **Microbial pathogens are also a threat in areas where the bedrock is at or close to the ground where the groundwater is vulnerable (see Section 13.2).**
- **Nitrate is a threat in freely draining areas.**

The availability of relevant EPA and GSI maps means that we can now i) predict what will happen to various pollutants on land and in the landscape, and ii) propose measures to prevent or reduce impacts.

10.5.5 Pathway susceptibility for phosphate and nitrate

The availability of relevant maps has enabled the EPA Catchments Unit to produce **pathway susceptibility maps** for both phosphate and nitrate arising from potential diffuses source of pollution.

'Pathway susceptibility' is a measure of the degree of attenuation between the pressure source and receptor. It depends on the properties that have been outlined in the last two sections – pollutant properties and the hydro(geo)logical properties (or the water flow regime).

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

Figure 10-20 shows a **susceptibility map for phosphate** along the near surface pathway. The darker areas (or Very High and High categories) are areas that are most susceptible to transporting phosphate along the near surface water pathway to rivers and lakes. As one of the primary drivers for these categories is the poorly draining nature of an area, the maps can also be used to indicate areas of high drainage density, areas where impacts from farmyards might arise, and where sediment, microbial pathogens and MCPA could be *significant issues*.

Figure 10-21 shows a cross section through the land that illustrates contrasting hydrogeological situations and susceptibility on each side of the watercourse.

Figure 10-18: Moderate permeability sandy glacial till (Photo: Donal Daly).

Figure 10-19: Joints in limestone (Photo: Donal Daly).

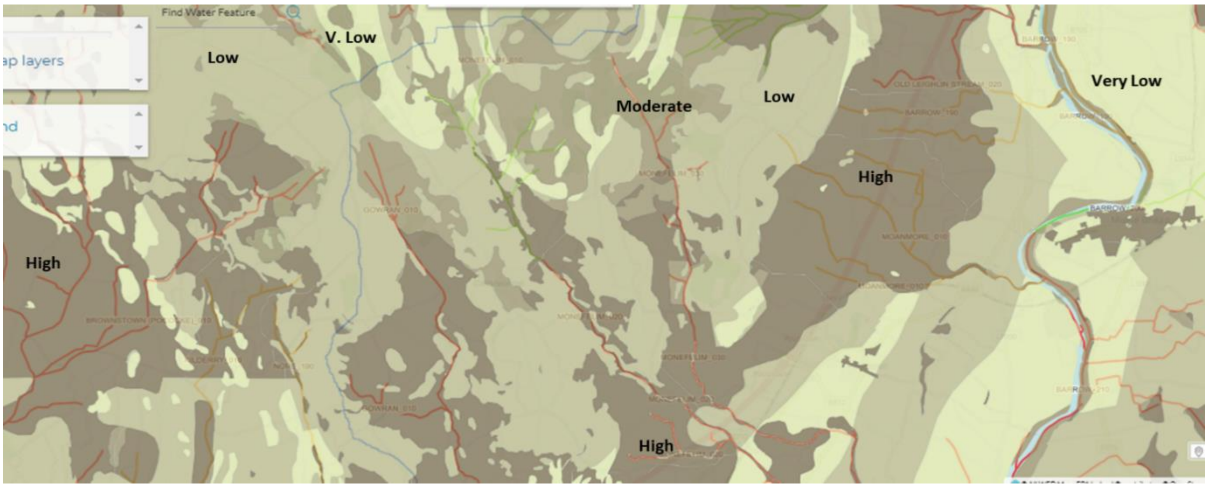

Figure 10-20: Map showing the phosphate susceptibility ranking along the near surface pathway *(Source: EPA Catchments Unit* https://gis.epa.ie/EPAMaps/Water*).*

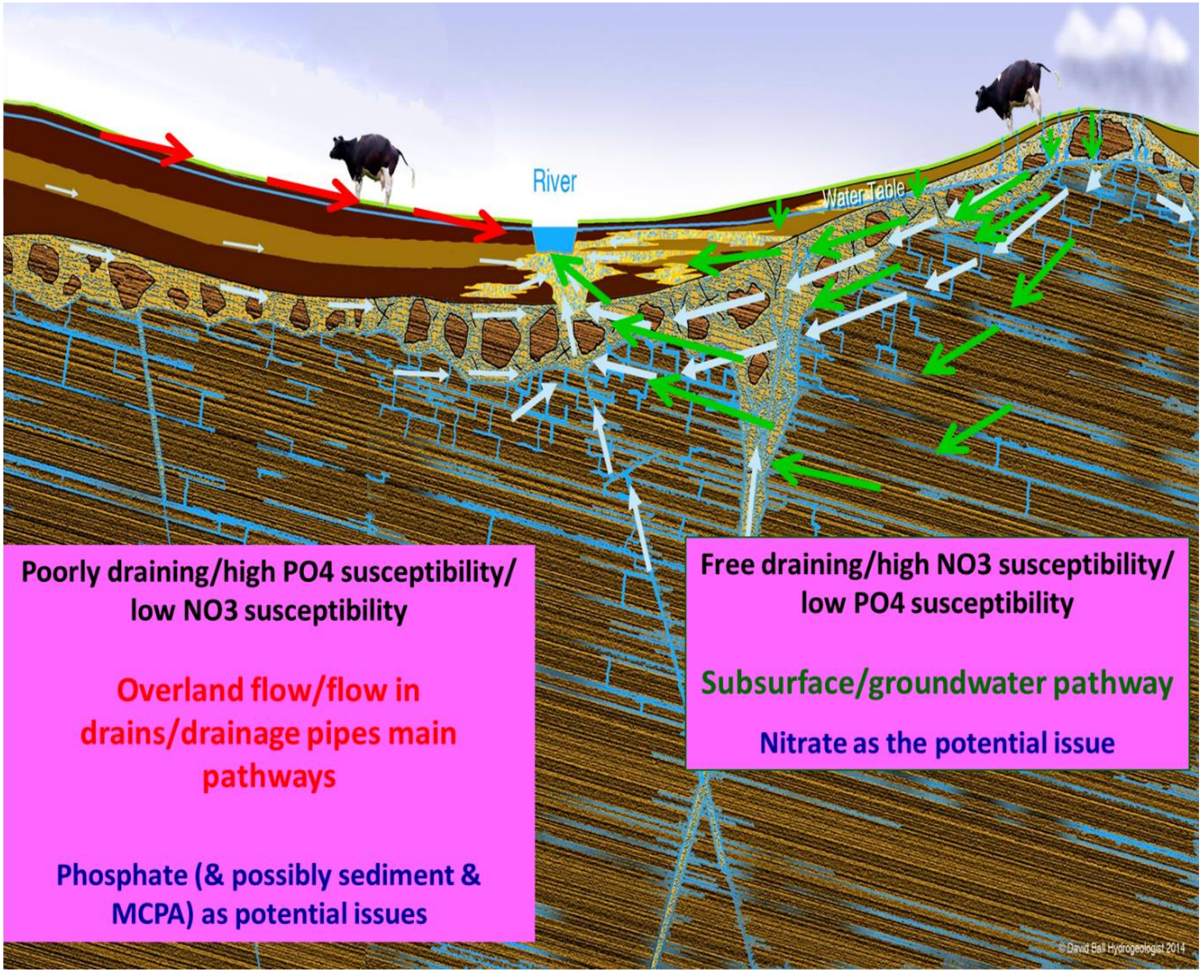

Figure 10-21: Illustration of contrasting hydrogeological settings, with poorly draining soils and low permeability subsoils on the left side and freely draining soils and moderately permeable subsoils on the right side.

Susceptibility maps, which are based on the intrinsic characteristics of an area, show the likelihood of losses of phosphate and nitrate to water if they were applied to the land. Suppose we know the approximate application rates across the landscape, could we achieve an even more useful map? The answer is 'yes'.

10.5.6 Critical source areas for diffuse pollutant losses to water

Losses to water from diffuse sources, such as farming and afforestation, will vary depending on i) on the pathway susceptibility (which in turn depends on the hydrogeological setting and the pollutant properties) and ii) the varying pollutant loadings. By combining information on both of these, critical source areas (CSAs) are obtained (See Figure 10-22). **CSAs are areas that deliver a disproportionally high amounts of pollutants from diffuse sources compared to other areas of a water body or subcatchment and represent the areas with the highest risk of impacting on a water body.** 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 measures in the right place***".

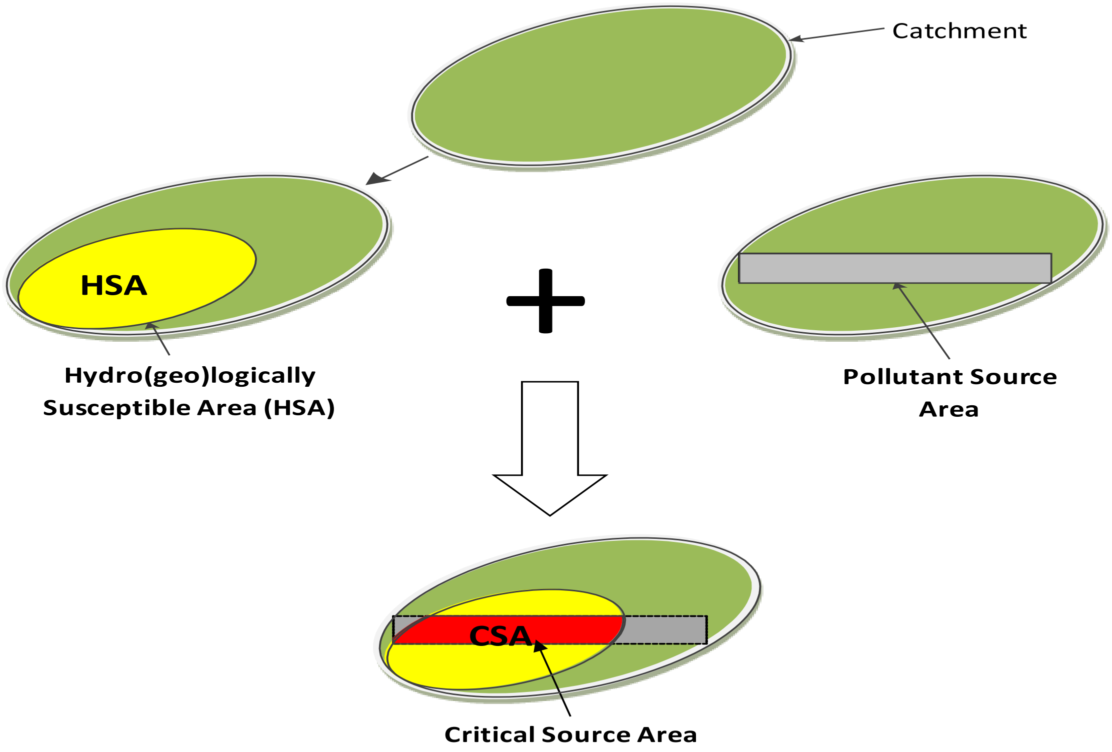

Figure 10-22: Illustration of the components of CSAs

The application of the nutrients phosphorus and nitrogen on land can be estimated from the following sources:

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.

By combining these loading data with the pathway susceptibility, the Catchments Unit of the EPA have produced two CSA maps, called **Pollution Impact Potential (PIP) maps**, to assist in targeting Actions to the areas where they will be most effective. Note the word 'Potential' in the title: i) the map scale is 1:25,000 and so they are not field-scale maps; ii) they are based on the best readily available information and not on either 'walking the land' or on direct discussions with farmers, and iii) farmers may be ensuring no losses to water. The location of farmland in a CSA does not mean that a *significant pressure* is present, as either best management practices are already in place or the farming system might have changed. Therefore, their value is that they act as a signpost to where there is a potential CSA and so should be considered as a **guide** to the situation on any farm, which needs 'ground truthing' before any measures are decided on and established.

10.5.6.1 Nitrate PIP map

An example of a nitrate PIP is shown in Figure 10-23. The main areas where losses of nitrate to water will occur are in the darker areas – categories 1, 2 and 3. Therefore, if nitrate is a *significant issue* in a water body, these are they areas where targeted mitigation actions/measures are needed.

10.5.6.2 Phosphate PIP map

There have been two phases in the production of PIP maps. An example of the first phase maps[57] is shown in Figure 10-24. The blue areas (High PIP Rank 1-3) are the critical sources areas for potential losses of phosphorus to watercourses. These high risk areas have moderate/high livestock intensity that coincide with poorly drained areas, meaning that in these areas phosphate is more likely to flow overland to surface waters rather than being retained in the soil and subsoil. For locating the "the right measures in the right place" these High PIP areas should be targeted in the catchment areas of *At Risk* water bodies where phosphorus is the *significant issue* and agriculture is the *significant pressure*. If the work purpose is to maintain existing satisfactory water quality, then these are the areas that can be focussed on as they are the relatively high risk areas.

An example of the second phase updated maps is shown in Figure 10-25[58]. This map shows the following:

i) The phosphorus critical sources areas – blue areas (High PIP Rank 1-3) similar to those shown in Figure 10-20.
ii) Focussed Delivery Flow Paths.
iii) Focussed Delivery Flow Points.

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 P losses. The map can highlight areas to target phosphorus pathway interception actions e.g. hedgerows. Drainage ditches can sometimes be 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. riparian/buffer zones, woodlands, engineered ditches.

While this PIP 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.

Pathways conceptual models (PCMs)

The information given so far in Section 10.5 provides the basis for producing a pathways conceptual model for an area being assessed.

[57] These are an outcome of the Pathways research project undertaken by a consortium of scientists from QUB, TCD and UCD.

[58] These have been produced by the EPA Catchments Unit based on the outcomes of the DiffuseTools research project undertaken by UCD and Teagasc.

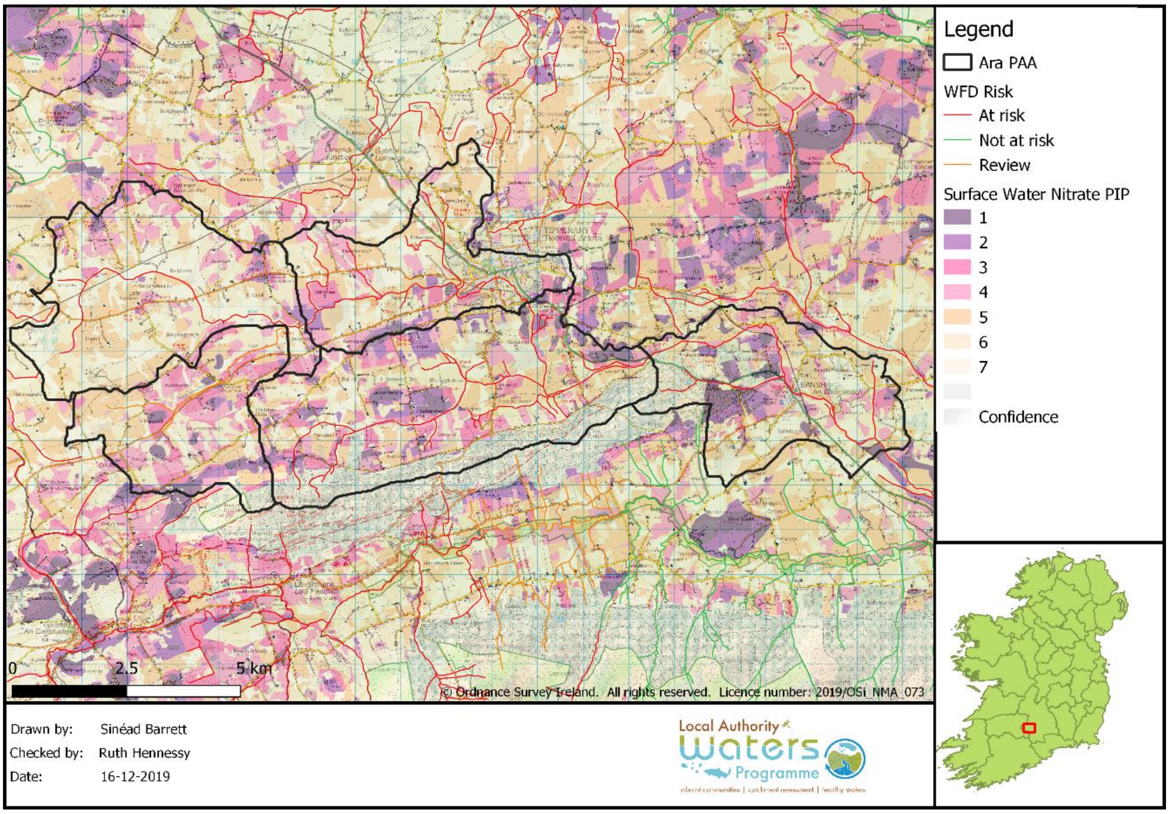

Figure 10-23: Pollution impact potential (PIP) map for nitrate entering surface water arising from diffuse agricultural sources such as spreading of fertilisers and grazing animals. PIP ranking 1 is the highest with 7 the lowest. Therefore, the darker the area, the higher the risk to groundwater, with fields in PIP ranking 1, 2, 3 and perhaps 4 being the critical source areas.

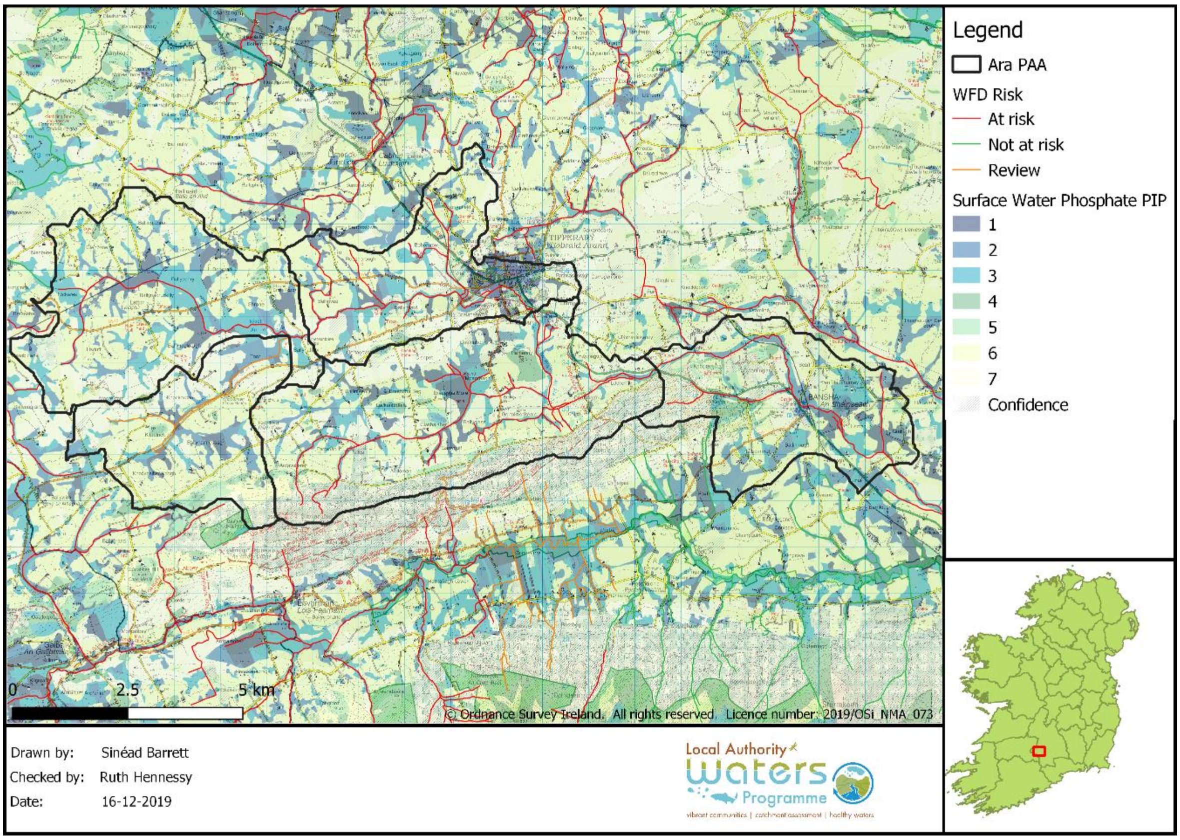

Figure 10-24: Phosphate PIP map

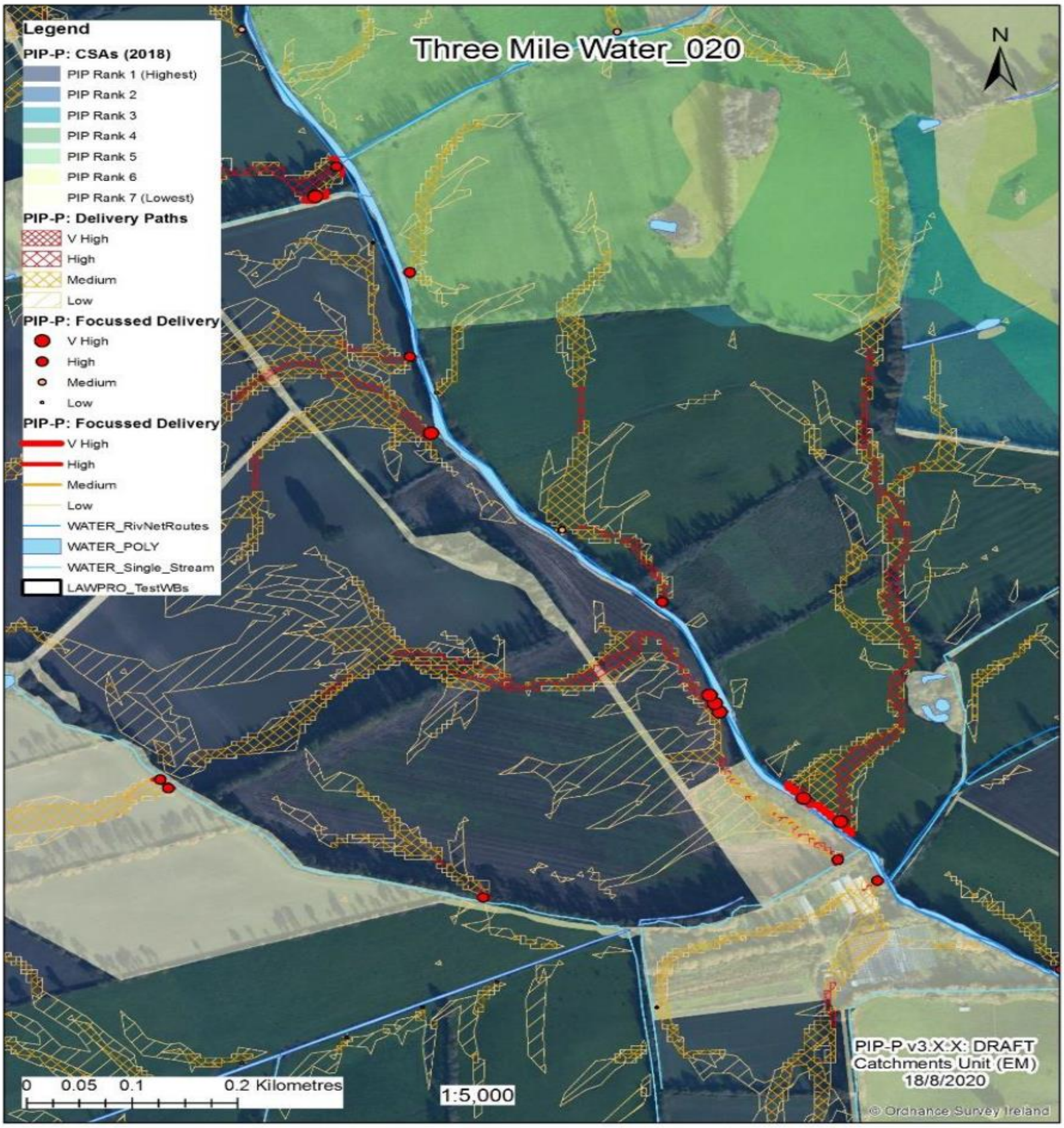

Figure 10-25. Updated Pollution Impact Potential Maps for Phosphorus (PIP-P V3) (Source: EPA Catchments Unit)[59].

10.5.7 Pathway conceptual models

10.5.7.1 Introduction

Where diffuse and/or small point sources are the significant pressures, the location of CSAs and an understanding of the movement and attenuation of pollutants along the pathways taken from the pressure location to a receptor, such as a watercourse, **provides the basis for decisions on protection measures/actions where the water quality is satisfactory and mitigation measures/actions where it is unsatisfactory.** Therefore, a '**pathways conceptual model**' of the catchment area to the

[59] Susceptibility and PIP maps can be accessed at this link: https://gis.epa.ie/EPAMaps/Water .

watercourse is needed.[60] This is a 3-D conceptualisation or visualisation of the physical/hydrological/hydrogeological setting in the catchment area/ZOC of the source. Further details on pathways conceptual models are given in **Appendix 6**.

The 'driver' for the pathways conceptual model is the identified *significant issue* or potential pollutant, e.g. phosphate, nitrate, microbial pathogens, as these dictate the pathways that are most relevant.

There are two characteristics of pollutants that vary depending on the pollutant:

- The pollutant **load** and **resulting concentration** that can affect water quality varies depending on the pollutant (see Section 10.4.5.3).
- The pollutants have different attenuation capacities (i.e. different abilities to reduce as they move through the landscape), as described in Section 10.5.4.1.

These characteristics influence: i) the potential impact the various contaminants have on water; ii) the diverse pathways along which the contaminants move either over ground or underground; iii) the reduction (if any) that occurs along the pathways; and iv) the protection/mitigation options that are needed to prevent or, at least, reduce impacts. Therefore, the pathways conceptual model should summarise all the pathways and conclude on the scenarios and areas that have pathways that are relevant to the *significant issues* or pollutants that are impacting on, or might potentially impact on in the future, the water quality, as the protection/mitigation measures and actions must be located in these areas.

10.5.7.2 Recommended Approach

The 'driver' is/are the *significant issue(s)* in 'improve' objective sub-catchments or potential pollutants in 'protect' objective sub-catchments as these dictate the pathways that are relevant. For instance, if either phosphate or MCPA are the *significant issues* or potential pollutants, the main pathway is overland flow in poorly draining soils areas or in land drains. Therefore, the pathways conceptual model (PCM) should provide information on the scenarios that have these pathways.

The concept is to subdivide the sub-catchment area into pathway compartments, based on the hydrogeological settings described in Section 10.5.3, therefore delineating areas into i) areas where either groundwater or surface water flows are dominant and ii) freely draining and poorly draining areas. Then, depending on what the *significant issue* or potential pollutant is, locate the likely critical sources areas (CSAs), and in the case of phosphate and sediment, the likely flow delivery paths.

The following steps are recommended:

1. A good starting point in deciding on the **pathway compartments** are the aquifer maps (both bedrock and sand/gravel) (see example in Figure 10-26) as this provides the regional surface water and groundwater flow settings. In Rk, Rf, Rg, Lm, Lk, Lg aquifer areas, underground flows will generally be dominant, whereas in Ll, Pl and Pu aquifer areas, surface flows will be dominant. See Section 10.5.3.3 and Table 10-4 for details on the aquifer categories and their properties. The groundwater body descriptions are also worthwhile checking for relevant information as they include a conceptual model description. (https://www.gsi.ie/en-ie/programmes-and-projects/groundwater-and-geothermal-unit/activities/understanding-ireland-groundwater/Pages/Groundwater-bodies.aspx). In addition, relevant information may also be present in the sub-catchment reports in the WFD App.

[60] While the main focus in this section is on the catchment area(s) to a watercourse or a number of water bodies, the information also applies to a development on a site that is discharging effluent to the ground/groundwater.

2. As, in many circumstances, an aquifer category might include more than one bedrock unit, it can be worthwhile examining the hydrogeological properties of these bedrock units as described in **Table 5-1, Section Volume 5** to check whether these improve the understanding.

3. Then examine the soil drainage map (Figure 10-27).

4. Conclude on the potential **pathway sub-compartments** and, if feasible, show on a map (an example is shown in Figure 10-28 with conclusions on the sub-compartments). Focus on the sub-compartments that are relevant to the *significant issue(s)* or pollutants. An example of a table summarising the pathway sub-compartments is given in Table 10-6.

5. Where either phosphate or nitrate arising from diffuse or small point source pressures are *significant issues* or potential pollutants, check the relevant pathway susceptibility map (see example in Figure 10-20) as this is based on more comprehensive information than the soil drainage maps.

6. Check the relevant PIP map to locate the CSAs and, if relevant, the location of the focussed delivery paths and points (as shown in Figure 10-25).

7. Conclude on the pathways conceptual model and on the CSAs. This will generally be written text, backed up by relevant maps. Hand drawn conceptual model sketches may be beneficial and, in certain circumstances, a more formalised drawing may be required for formal reports and publications as a means of explaining the outcomes (see Appendix 6 for examples.

Table 10-6: Main pathways in a sub-catchment area

	Compartment 1		**Compartment 2**	
Aquifer	Pu & Pl		Lm & Lk	
Rock Units	Namurian Sandstone, Namurian Shale, Westphalian Shale		Westphalian Sandstones, Dinantian Pure Bedded Limestones	
	Sub-Compartment 1A	**Sub-Compartment 1B**	**Sub-Compartment 2A**	**Sub-Compartment 2B**
Soil type	Predominantly poorly draining	Predominantly freely draining	Predominantly poorly draining	Predominantly freely draining
Subsoil	Shale and sandstone till	Bedrock outcrop, glaciofluvial sands and gravels, Shale and sandstone till	Shale and sandstone till	Bedrock outcrop, glaciofluvial sands and gravels, Shale and sandstone till
Subsoil K	Low	High, N/A	Low	N/A
Groundwater Vulnerability	L, M, H, E	X, H, E	L, M, H, E	E, H
P04 Susceptibility	Moderate, High	Very Low, Low	Moderate, High	Very Low, Low
P04 PIP	**High in northern area catchment. High close to the water intake.**		**Small area of High near western tributary**	Low
NO3 Susceptibility	Very Low, Low	Very High, High	Very Low, Low	Very High, High
NO3 PIP	Low	**Small areas of High**	Low	**Extensive areas of High**
Main Flow Paths	Overland	Near surface in bedrock and deeper in gravels	Overland and near surface in bedrock	Groundwater

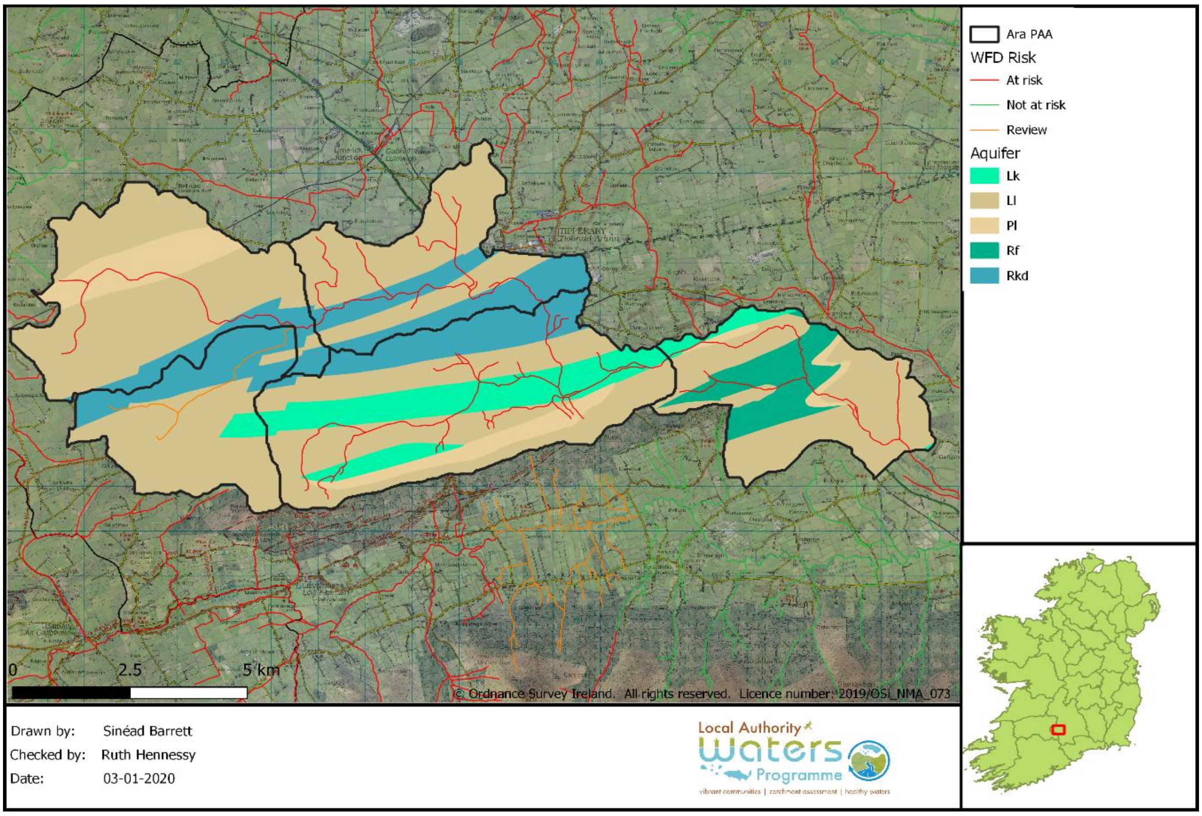

Figure 10-26: Aquifer map for the Ara catchment.

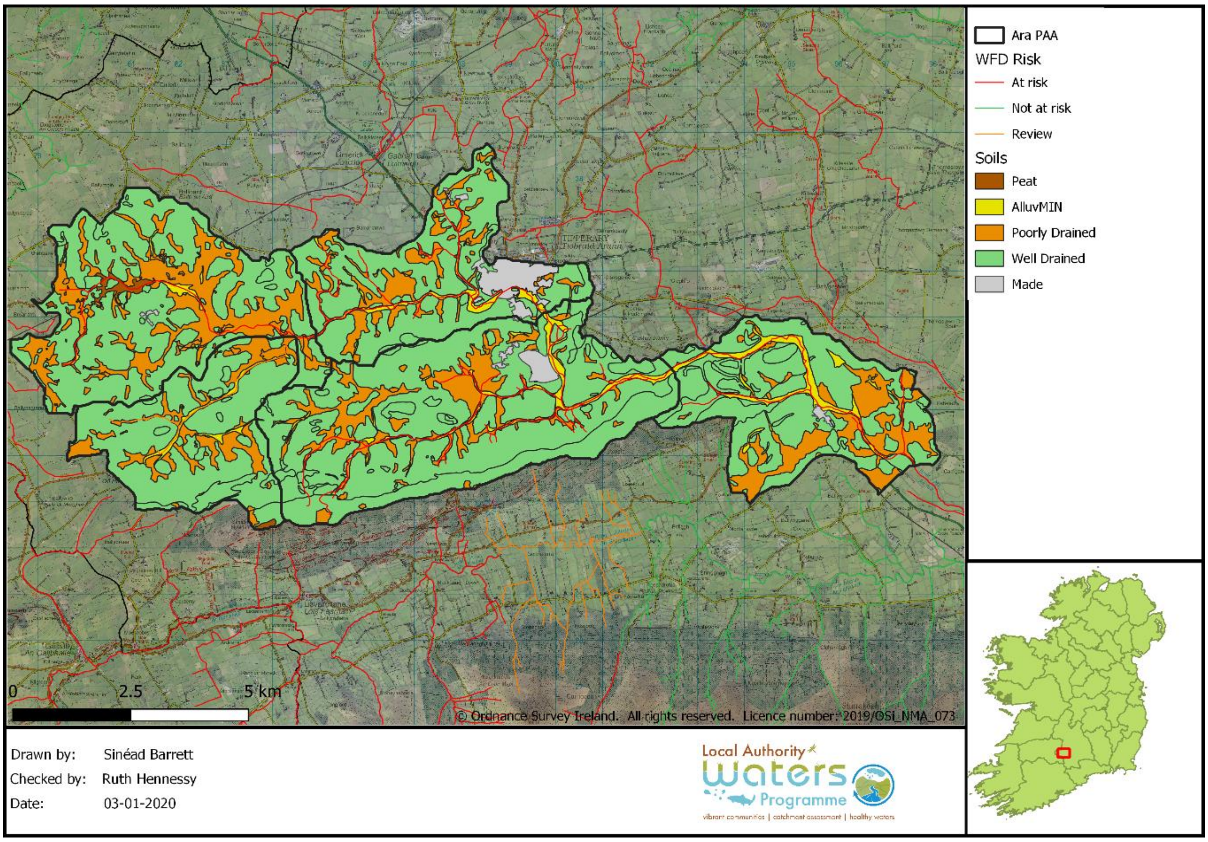

Figure 10-27: Soil drainage map for the Ara catchment.

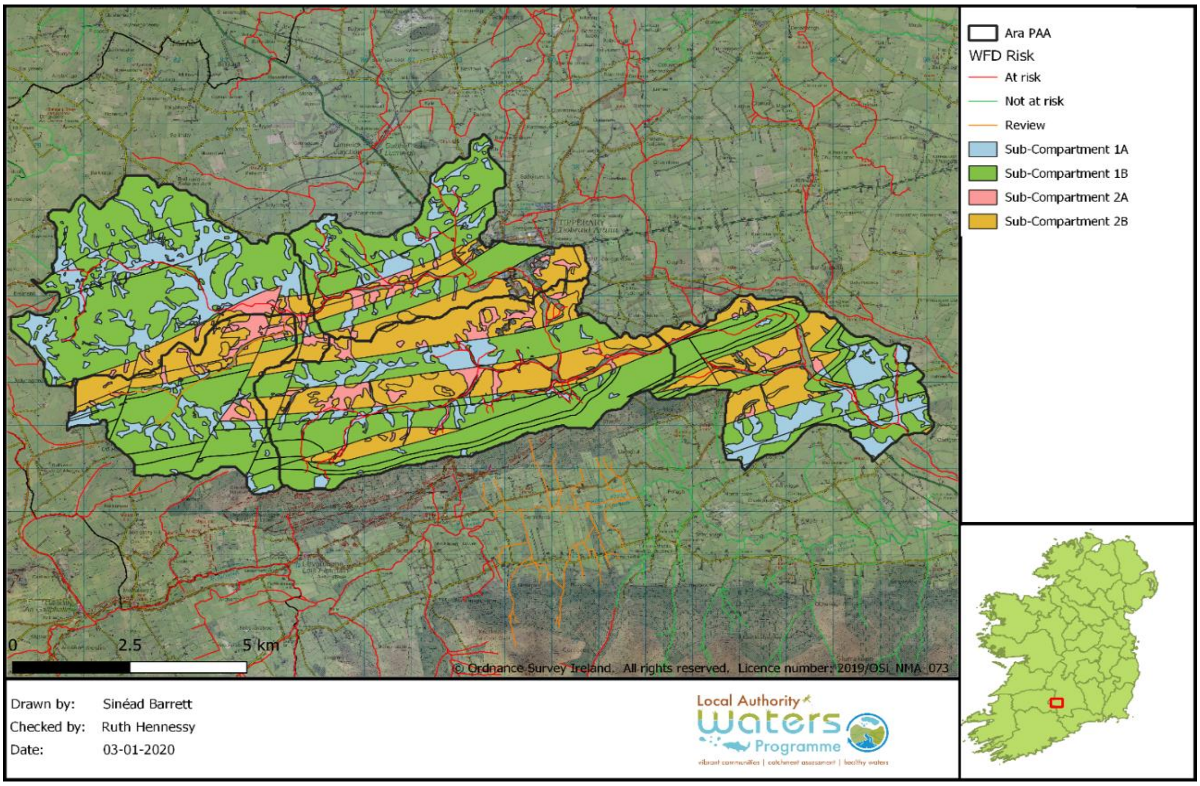

Figure 10-28: Sub-Compartments within the Ara catchment – details given below:

- Sub-Compartment 1A: poorly draining soils overlaying Ll and Pl aquifers. This sub-compartment has the potential to sustain a phosphate pathway via overland and near surface flows.
- Sub-Compartment 1B: freely draining soils overlaying Ll and Pl aquifers. This sub-compartment has the potential to sustain a nitrate pathway via shallow groundwater flow.
- Sub-Compartment 2A: poorly draining soils overlaying Lk, Rf and Rkd aquifers. This sub-compartment has the potential to sustain a phosphate pathway via overland and near surface flows.
- Sub-Compartment 2B: well-drained soils overlaying Lk, Rf and Rkd aquifers. This sub-compartment has the potential to sustain a nitrate pathway via groundwater.

10.6 The interim 'story' of the sub-catchment

This is a critical section in the desk study as it summarises and integrates all the information, and then acts as the basis for the work plan and for consideration of possible protection or mitigation options, as appropriate. It is based on integration of all the relevant components of the SPR framework during the desk study, which is critical to providing the basis for focusing further work. It is recommended that a three-dimensional 'mental model', aided by the pathways CM, is developed as an ongoing process as the information/evidence is collected and assessed in relation to *significant issues* or potential pollutants, pressures and relevant pathways. The thought processes arising from this can be captured as interim conclusions (in most instances, fieldwork will be needed before the final and decision-making conclusions can be drawn). The SPR framework should be used in telling the 'story', with emphasis placed on the **linkages** between each component.

It may be more effective to produce consider the catchment areas of each water body initially and then combine the assessments to give the sub-catchment 'story'.

10.6.1 Sub-catchments with an improvement objective

In this situation, the pollutant concentrations in the watercourse exceed the relevant concentrations (see Section 9) indicating unsatisfactory water quality; often the water body will be categorised as being *At Risk*. For NFGWS drinking water sources, the untreated source water will be unsatisfactory, i.e. concentrations above the guide values. Therefore, improvement or restoration to the required WFD water body status or the guide values is the core objective.

In preparing the interim 'story', the following elements should be considered and described:

- Risk categories of all water bodies in the sub-catchment.[61]
- Status (separate out biological and ecological, if relevant) of all water bodies.
- Hydrochemistry summary, including trends.
- Significant issues. (If the *significant issue* cannot be determined from water quality data, state this.)
- Significant pressures. (Where the *significant issue* cannot be determined from water quality data, use the *significant pressure* information to conclude on the likely *significant issue*. This conclusion then 'drives' the orientation of the pathways analysis and conclusions.)
- For diffuse and small point significant pressure, outline the CSAs, including a description of main relevant pathways, and where they are (what sub-compartment). Refer to pathways CM table and maps.
- For poorly draining CSAs, describe and locate the focussed delivery paths and points.
- For large point sources, give their locations relative to the monitoring point.
- If feasible and relevant, give estimates of pollutant load reductions required.
- A **brief overview** of the sub-catchment.

Where there is more than one water body in the sub-catchment, details on all the water bodies are needed.

The 'Story'

- **It starts as a mental exercise that synthesises, links and integrates all the receptor, pathway and pressure information together to arrive at an interim understanding & conclusions on the situation.**
- **As written down, it is the 'story' (albeit interim) of the sub-catchment (or drinking water source protection area), summarising and describing what the *significant issue(s)* is/are, the *significant pressure(s)*, the linkages between them, the main pathways, the CSAs (the where question), the improvements that are needed, etc.**
- **If diffuse & small point sources are the *significant pressures*, then as you are thinking it through, imagine you are standing at the monitoring point, looking upstream keeping in mind the *significant issue*, ask yourself, what are the relevant pathways, where are they and the CSAs, and what are *significant pressures* that are causing the impacts.**

10.6.2 Sub-catchments with a protection objective

In this situation, the pollutant concentrations in the watercourse are lower than the relevant concentrations (see Section 9) and therefore indicating satisfactory water quality; often the water body will be categorised as being *Not at Risk* from a WFD perspective or alternatively there will be no significant upward trends in concentrations. For NFGWS drinking water sources, the untreated source water will be satisfactory, i.e. concentrations below the guide values. Therefore, continued protection is the core objective, and protection measures are required to ensure achievement of this objective. In preparing the interim 'story', the following elements should be considered and described:

1. Risk and status categories of water bodies where WFD implementation is the objective.

[61] Where a local authority is evaluating the situation in the catchment of one water body with either a protect or restore objective, the same process can be followed. However, it will usually be necessary to consider upstream water bodies as part of the process.

2. Hydrochemistry summary, including any indications in the water quality data of issues or pollutants that potentially might be problematical in the future (e.g. phosphate with a mean value between 0.03 -0.035 mg/l).
3. The susceptible areas for the pollutants that might be of concern (e.g. poorly draining areas where MCPA is used).
4. The management of pressures, particularly in the susceptible areas (e.g. are containment measures in place in the event of a spillage from facilities in the vicinity of the watercourse) or in high PIP areas (e.g. farming intensification).
5. Implementation of existing protection activities (e.g. inspections).
6. In circumstances where it is considered that diffuse pressures might pose a threat in the future and that protection measures are needed, a pathways conceptual model should be drafted.

Conclusions on the following is recommended:

1. The adequacy of the available water quality data on which the assessment is based.
2. Point or diffuse pressures that are located in susceptible areas or are poorly managed and therefore have the potential to pose a future threat.
3. Whether further inspections are needed for facilities in the high risk areas.
4. Whether field checking of diffuse and small point pressures is needed and, if so, where and what type.
5. Whether the planning section needs to be informed of concerns.
6. Whether a public awareness campaign would be beneficial in ensuring continued maintenance of the satisfactory water quality.
7. Any other additional actions that might be needed.

10.7 Work plan

This needs to be a detailed plan, which is based on the scenario that is applicable (see Table 8-1) and the conclusions in the Interim Story, with sufficient information to enable an estimation of the time and resources required to undertake the catchment walk. Therefore, detailed plans will be needed for the next steps, particularly when field work is involved. It is recommended that, in deciding on the work plan, consideration be given to the County level RBMP Implementation Plans and the RMCEI requirements.

These may include some or all of the following, depending on the circumstances:

- Collection of further monitoring data[62], including the locations for water sampling.
- Details on visits to facilities that are considered to be impacting on the water quality or potentially could.
- Areas to drive around to get an overview of pressures, drainage characteristics, etc.
- Stream stretches requiring catchment walks, with collection of appropriate information.
- Details on other public bodies that need to be consulted or could provide useful information.
- Details on planned **engagement with stakeholders as appropriate**, for instance, local communities, landowners, other public bodies.

The importance of the Desk Study

It is fundamental not to undertake field visits without first completing the desk study as a means of focusing the efforts for optimum efficiency and effectiveness.

Recommendation

Contact the regional LAWPRO Catchment Manager to get a copy of a typical desk study undertaken for a Priority Area for Action (PAA).

[62] A minimum of three rounds of sampling during different flow conditions is recommended.

11 Field-based Assessment – Scenarios CA3, CA4 and CA5

Field-based assessments for catchment assessment scenarios CA3 and CA4 (See Table 8-1) involve brief targeted walkover surveys, for the purposes of:

- Observation of relevant issues;
- Measurement and monitoring;
- Evaluation of pressures, pathways and impacts; and
- Identifying appropriate and possible mitigation options.

11.1 CA scenario 3 – unassigned water body assessment

The WFD status for a proportion of water bodies have not been determined as it is not feasible to monitor every water body in the country. A risk category has been assigned to all water bodies, including those with no monitoring data. However, the risk category assigned to most of these water bodies is *Review*. A field visit will usually be needed to determine whether these water bodies are *At Risk* or *Not at Risk*. For streams/rivers, this is likely to include, for instance: a visual assessment, determining a small stream impact score (SSIS; **Section 10.11, Volume 4** and **Appendix B, Volume 7**), taking conductivity and dissolved oxygen readings, and taking perhaps up to three water samples at different flow conditions, followed by an evaluation and recording the conclusions of the assessment.

11.2 CA scenario 4 – point source assessment

This assessment may be required where there is a known point source discharge identified as a potential pressure on a water body and where no recent water quality data are available. This would involve initially undertaking a desk study and a review of specific relevant information for the site (e.g. Section 4 licence files), liaising with colleagues and recording any known issues, accessing any old water quality data if available for the water body. A site visit should then be undertaken comprising a river walk along the portion of river channel to confirm the location of the discharge point and also to check for any additional discharge points and sources. This will inform where a suitable upstream and downstream sample should be taken (SSIS and taking a water sample). The results and observations should then be recorded. Further assessment (e.g., visit/sampling or measures) may be required.

11.3 CA scenario 5 – Inspections

Courses on farm inspections and domestic wastewater treatment system inspections have been undertaken by local authority staff and therefore they are not considered further in this Volume.

In undertaking inspections, it is recommended that they be undertaken in the context of the catchment science and the ICM/FILLM approaches. These provide the understanding and context needed to help ensure that compliance assurance is effective and efficient in achieving water quality and other environmental outcomes.

12 Field-based Assessment – The Catchment Walk

The Catchment Walk

Catchment walks can be the most interesting and enjoyable elements of catchment science. Particularly where the pressures are diffuse and/or small point sources, being an environmental detective working out the 'what', 'where', and 'what do we do about it' issues, using the 'tools in the toolkit' described in this Handbook, are often both stimulating and challenging, and, above all, important and relevant.

Without catchment walks, the locations of the pressures and CSAs cannot be determined with sufficient accuracy to enable targeted protection/mitigation measures and actions.

12.1 The catchment walk approach

Use the SPR model as the framework:

- Start with the receptor conditions – the 'driver' for the catchment walk is the receptor, not pressures[63].
- Then look for pathways and input areas/points (pipes, ditches, CSAs); when standing or walking along the watercourse, it is important to look out into the landscape at biophysical features that help explain what is seen/measured in the receptor – that is why this part of the Process is called 'catchment walk' rather than 'stream walk'.
- Then look for the pressures, what and where they are.
- Think about and note possible mitigation options.

Use desk study work plan as the basis; therefore, it is important to be familiar with the content – particularly the water quality and relevant pathways.

- Consider the objective that needs to be achieved – improve to a certain quality or protect the existing quality.
- The *significant issue(s)* and *significant pressure(s)* where the water quality is unsatisfactory or the potential issues/pollutants and potential pressures where it is satisfactory.
- Note the areas and stretches of watercourses that need to be prioritised for visits, e.g. using the PIP maps.
- Decide whether and where water samples need to be taken.
- Determine whether SSISs and/or rapid assessments are needed.
- Have access to relevant maps.
- Plan in detail where to go and in what order, and assess the time and resources needed.
- Consider using 'bridge hops' and going to the highest vantage point as a means of getting an overview.
- Schedule the catchment walks.
- Allocate resources – personnel, equipment, materials that may be needed.
- Make arrangements with analytical laboratories, if relevant.
- Engagement with local communities and 'pressure owners' may be advisable or necessary – therefore plan this in advance.
- Check weather forecasts (which could influence or affect the timing of the catchment walk).

[63] Even in circumstances where the purpose of the field visit is an inspection, it is worthwhile keeping a focus on the receptor.

12.2 Preparing the Catchment Walk

A checklist of possible equipment, tools and materials that may be needed for catchment walks are: Raingear and high-visibility vests;

- Maps and map covers;
- Waterproof notebooks and forms;
- Markers and pens;
- GPS unit(s);
- Camera(s), with or without thermal imagery capability);
- Waders
- Tape measurer(s);
- Stopwatch;
- Staff gauge(s);
- Flow meter(s);
- Hand-held water quality multi-meter(s);
- Test strips (water quality parameters);
- Sample bottles for impromptu sampling;
- Water level meter(s) ("dippers");
- Weighted measuring tape or string (for depth measurements, e.g. in lakes, deep streams or open boreholes);
- 10-L plastic bucket(s);
- Shovel(s) and hand-auger(s);
- Biosecurity Kit – boot-wash basin (x2), to incl. wipes, hand brush, water and Virikon (or similar)[64];
- Personal identification and proof of insurance;
- Authorisation papers (if applicable); and
- Reference materials on testing or measurement equipment calibration (although good practice dictates that equipment calibration is done regularly, and in an office environment, prior to bringing the equipment to the field).

Health and Safety equipment:

- Mobile phone and charger;
- Safepass card;
- Hard-hats (e.g. for visits to quarries, industry or active drilling sites)
- Life jacket;
- Food and drink (especially for sampling in isolated areas);
- First aid kit;
- Relevant contact numbers;
- Personal protective equipment (refer to employers Health and Safety plan);
- High visibility Jacket;
- Disposable gloves;
- Hand sanitiser gels; and
- Disinfectant (approved list of disinfectants is on the DAFM website).

12.3 Conducting the Catchment Walk

The focus will be on **features** that are relevant to the pollutants and pressures that the desk study has highlighted, for instance the *significant issues* and *significant pressures* where the water quality is unsatisfactory – if PO_4 from agriculture is the *significant pressure*, then target poorly draining areas using the PIP-P map and not freely-draining areas. And vice versa for NO_3. In particular, locating the

[64] See http://www.biodiversityireland.ie/check-clean-dry/

precise area/s or points that deliver significant loads of pollutants to a watercourse is an essential outcome of the catchment walk. Three catchment walk components are described below:

1. Pressures.
2. Measured indicator parameters.
3. Reading the landscape, noting indicator features

Catchment walks in circumstances where the objective is to 'protect' will generally be less detailed and onerous than in those where the objective is to 'improve'. While the orientation of the remaining sections below is on scenarios with an 'improve' objective, the details given will nevertheless still be relevant and helpful to both 'protect' and site specific situations.

In all circumstances, it is critical that the information collected should focus on the issues and situations that are relevant to achieving the environmental objectives.

12.3.1 Pressures

The catchment walk provides the opportunity to locate and describe potential pollution sources, such as farmyards, domestic wastewater treatments systems, rural industries, etc. and potential diffuse sources, such as intensive farming, tillage crops, afforestation (during planting and felling), towns and villages.

Volume 2 provides details and guidance on the main pressures present in catchments – agriculture (**Section 2**), hydromorphological (**Section 3**), urban wastewater (**Section 4**), diffuse and small point urban (**Section 5**), domestic wastewater treatment systems (**Section 6**), afforestation (**Section 7**), peatland activities (**Section 8**), quarries (**Section 9**), mines (**Section 10**), industrial discharges (**Section 11**) and invasive species (**Section 12**).

12.3.2 Measured indicator parameters

In all circumstances, measurement of a variety of parameters will be required as they can be used to provide evidence of responses to pressures and the location of those that are causing impacts – see Table 10-3. Different indicators are associated with different physical-chemical processes, and different indicator parameter values can mean different things. Moreover, different environmental pressures can be associated with the same indicator parameters. Indicators are, therefore, not in themselves, conclusive pieces of evidence, but they point to possible pressures, conditions or responses. They are used and contextualised with other observations and pieces of information to infer or interpret where environmental problems in a catchment originate, and what the specific nature of problems is/are.

The indicator parameters include:

- **Biological indicators** using, for instance, Small Stream Impact Scores (SSISs) and Rapid Assessments as a critical means of locating stretches and tributaries that are either satisfactory or are impacted and unsatisfactory. Details on biological indicators are given in **Section 10, Volume 5** and a field guide is given in **Volume 7**.

- The following measurements can be helpful in **narrowing down the pollutant input areas and points**:

- Temperature (**Section 3, Volume 4**).
- Dissolved Oxygen (**Section 4, Volume 4**).
- pH (**Section 5, Volume 4**).
- Specific electrical conductivity (**Section 6, Volume 4**).
- Turbidity and sediment (**Section 7, Volume 4**).
- Field measurements of nutrients, e.g. using test strips (**Section 3, Volume 4**).

♦ An example of a recording of indicator parameters is given in Table 12-1.

♦ **Stream flow measurements** may be needed, particularly when doing loadings analysis at a point in time as a means of narrowing down the areas contributing pollutants (see **Appendix 4**). Details on undertaking flow measurements are given in **Section 9, Volume 4**.

Table 12-1: The tabulated compilation of the indicator parameters for a watercourse (Source: Glenree PAA fieldwork report undertaken by Noreen Shryane, Western Region, LAWPRO).

Date	Site	Site location	Co-Ordinates (ITM)	Impact (SSIS Score)	DO%	pH	Temperature (Degree Celsius)	Conductivity (µS)	Site Observations
04/03/2019	Site 4	Bridge at Carrownaglogh (EPA station)	536022.5, 819528.0	Probably Impacted (Score of 6.4)	95.4%	6.6	6.4	173	There was a high density and abundant vegetation cover of Moss in the river channel. There was no obvious sedimentation when the river bed was disturbed.
13/06/2019	Site 4		536022.5, 819528.0	Probably not Significantly Impacted Score of 8.8	101.3%	7.03	11.3	287	There was a high density and abundant vegetation cover of Moss in the river channel. Macroalgae was absent from this site in June. The higher conductivity reading at this site is geology related.
04/03/2019	Site 3	Upstream of 1st major trib u/s of EPA station. D/s large area of green agricultural land	536579.0, 818951.6	Probably not Significantly Impacted (Score of 8)	97%	6.4	5.24	138	This section of the PAA has agricultural activity with a number of reclaimed fields which can be seen in **Figure 2**. There is blanket peat within 200m to the West and East of this Site There was no obvious sedimentation when the river bed was disturbed.
13/06/2019	Site 3		536579.0, 818951.6	Probably not Significantly Impacted Score of 9.6	97.6%	6.63	11.5	97.6	
04/03/2019	Site 2	d/s of large forestry plantation	537213.2, 817470.9	Probably Impacted (Score of 6.4)	94%	-	6.7	96	This site is downstream of the Coillte Plantation and is surrounding by blanket peat. There was a high density and abundant vegetation cover of Moss in the river channel.
13/06/2019	Site 2		537213.2, 817470.9	Not Assessed	-	-	-	-	The SSIS results scored high at Site 3 and Site 4 in June therefore Site 2 was not assessed.
04/03/2019	Site 1	On large tributary which flows through forestry plantation	537434.3, 816786.9	Probably not Significantly Impacted (Score of 8)	93.5%	5.1	5.5	84	This site is surrounded by blanket peat. There is a Sitka spruce (Coillte owned) plantation on the banks of the river which was planted in 1987 with no observed buffer zone There was no obvious sedimentation when the river bed was disturbed.
13/06/2019	Site 1		537434.3, 816786.9	Not Assessed	-	-	-	-	The SSIS results scored high at Site 3 and Site 4 in June therefore Site 1 was not assessed.

12.3.3 Reading the land and landscape

While driving around a sub-catchment area and walking along streams, 'reading the land and landscape'[65] by focusing on, noting and interpreting landscape features that are relevant to water and pollutant movement, and to protection or improvement measures, is an essential role for catchment scientists. Rather than provide a metric such as concentrations obtained from water analyses or values

[65] While this section focuses on catchment areas of water courses, both large and small, the content is also applicable to farmyard and DWWTSs inspections, and environmental assessments of developments, both existing and planned.

obtained from measured indicator parameters, an **indicator feature** can provide information on the natural characteristics of a catchment, whether it be drainage, geology or hydrogeology, and biology. For example: the presence of rushes and/or field drains are characteristic features of poorly drained soil conditions; the presence of swallow holes is a characteristic feature of karst landforms; turbidity or colour problems in a groundwater supply indicates a surface water influence; and the presence of Japanese knotweed implies the presence of alien invasive species.

Observing and recording indicator features are needed to:

i) Enable our 3-D mental model and visualisation on water and pollutants on land and delivery to either surface water or groundwater.
ii) Tell the final 'story' of the assessment.
iii) Locate areas for possible protection or mitigation measures/actions.
iv) Help justify proposed protection or mitigation measures/actions in particular areas.

Therefore, the effort will usually be worthwhile. However**, it is important to focus this effort on the areas and factors that are relevant** – the interim 'story' and work plan will have highlighted these.

A list of possible indicator features is given in Table 12-1.

Details on key indicator features that describe important pathway characteristics and biological conditions of catchments, which should be noted during catchment walks, are provided in **Volume 3**.

12.3.3.1 Geological features

Invariably during a catchment walk there will be exposures of soil and subsoil, for instance, in drains and stream banks, and on occasions outcrops of bedrock may be present. A quick check can confirm the accuracy of the information in the desk study, keeping in mind that the desk study mapping information is at a scale of 1:25,000 and therefore should be considered as a guide, which may or may not be accurate at field scale.

It is not necessary to be a geologist or hydrogeologist to be capable of examining, understanding and recording the significance of geological features satisfactorily. The main function is to assess and be able to explain the evidence, as an environmental detective, and evaluate whether water is flowing overland or near surface to drainage ditches and watercourses or is infiltrating underground to groundwater. Keeping this in mind, a 'common sense' knowledge and understanding is sufficient.

The relevant soil/topsoil components are:

- Freely draining (permeable with infiltration underground)
- Poorly draining (gleys) (poorly permeable with overland and shallow subsurface flows)
- Peaty (high organic matter) (potential ammonium and phosphate issues).
- Iron pans (an impermeable layer preventing vertical flows, resulting in runoff. They can occur in permeable subsoils) (see Figure 12-1).
- Preferential flow paths which can allow rapid vertical movement of water and pollutants through dessication cracks and worm burrows, enabling bypassing of the topsoil by pollutants such as microbial pathogens and phosphate (see Figure 12-2).

The relevant subsoil components are:

- Sands/gravels – high permeability.

- Silty/sandy subsoils (tills) – moderate permeability (see Figure 10-14).
- Clayey subsoils – low permeability (see Figure 12-3).
- Alluvium in floodplains– varying permeability depending on grain size distribution, which in turn depends on the velocities of stream flows. However, most are dominated by silt and clay, and so the permeability is likely to be low. Also, the water table is usually close to the surface.
- Made ground – variable permeability.
- Mottling – indicating periodic saturation in low permeability subsoils (see Figure 12-4).

The relevant bedrock outcrop components are:

- Weakly fractured, low transmissivity bedrock, resulting in surface runoff (see Figure 12-5).
- Highly fractured, high transmissivity bedrock (see Figure 10-15 in this Volume and Figure 5-5 in Volume 5)).
- Solution features in limestone indicate karstification (see Table 10-4 and **Section 5, Volume 3**), underground and relatively high velocity groundwater flows in karst aquifer areas (see typical solution features in Figure 12-6).
- Bedrock type: if possible, note the bedrock type, e.g. limestone, sandstone, shale, granite.

In addition, the presence of bedrock at the surface indicates that groundwater in the bedrock is vulnerable to pollution (see Section 13-2).

Figure 12-1: Iron pan (Photo: Robbie Meehan).

Figure 12-2: Desiccation crack in clayey subsoil (Photo: Donal Daly).

Figure 12-3: Grey, low permeability subsoil. Note grey colour and 'plasticine-like' nature of the subsoil. (Photo: Donal Daly)

Figure 12-4: Mottling indicating periodic saturation and runoff to watercourses (Photo: Donal Daly).

Figure 12-5: Weakly fractured, low transmissivity bedrock with relatively low groundwater flows (Photo Donal Daly).


Figure 12-6: Solution of limestone boulders (Photo: Donal Daly)

12.3.3.2 Vegetation indicators

Vegetation can be an excellent and easily recognised indicator of soil drainage and the potential for rainfall to become groundwater recharge or to run off overland and near surface. Where species indicative of poor drainage are found near rivers or in low-lying areas, it may be reflective of a high groundwater table rather than low permeability soils or subsoils. In contrast, where vegetation indicators of poor drainage occur on slopes, this provides evidence of low permeability soils or subsoils (Figure 12-7). **Section 3 in Volume 3** gives details on plant indicator species.

Figure 12-8 shows a low permeability subsoil ridge with rushes growing on part of the ridge. The rushes are absent on the right side indicating spraying of the rushes; therefore, account needs to be taken of land management when considering vegetation indicators.

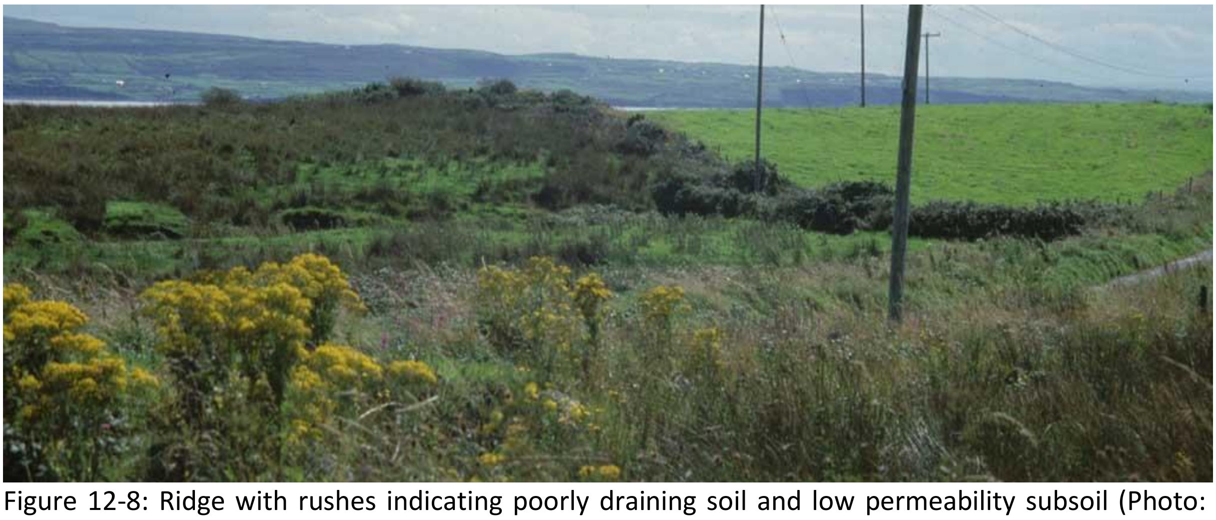
Figure 12-8: Ridge with rushes indicating poorly draining soil and low permeability subsoil (Photo: Donal Daly).

Figure 12-7: Grey, low permeability subsoil beneath a sloping, rushy field prone to runoff after rainfall (Photo: Donal Daly).

12.3.3.3 Hydrogeological features

The following features can provide useful information on the water flow regime in an area and may therefore be worth noting:

- Drainage ditches (see Figure 12-9 and Figure 12-10).
- Springs and seeps (see Figure 12-11).
- Swallow holes and sinking streams (See Figure 12-12).

In many ways, the most useful and readily apparent indicator is the presence or absence of drainage ditches alongside roads and field boundaries (see **Section 2, Volume 3** for more details on issues relating to drainage ditches). If drainage ditches are present, then clearly it indicates surface runoff at some time during the year, with the density demonstrating how prevalent it is. In some situations, (piped) land drains may be present, which can give a false impression of large fields with a low density of drainage ditches.

Springs and seeps occur where the water table intercepts the ground surface; therefore, the flowpaths on land at the same topographic level and lower is likely to be as surface runoff.

In karst areas, swallow holes and sinking streams can be common.

When driving around a sub-catchment area, walking along a watercourse or visiting a site, look out particularly for the presence/absence of drainage ditches and vegetation for evidence of the water flow regime.

12.3.3.4 Biodiversity indicators

The roles and responsibilities of catchment scientists are expanding to include, for instance, biodiversity and carbon sequestration. In particular, catchment walks provide the opportunity to record indicators of biodiversity along water channels. Further information is given in **Section 4, Volume 3**.

12.3.3.5 Talking to landowners

Often the most useful information can be obtained from talking to local people, particularly farmers. For instance, they will know the location of flow delivery paths that arise in wet weather – paths that may not be shown on the PIP-P maps or may not be easy to locate during a catchment walk. Alternatively, they may confirm the PIP-P flow delivery paths and points.

12.3.4 Winter fieldwork

Fieldwork for assessing surface water quality tends to be associated with and undertaken in the Spring, Summer and Autumn months. This is understandable as i) biological monitoring, such as Q-value determination, Small Stream Impact Scores (SSISs) and Rapid Assessments must be undertaken in this period, ii) water levels are relatively low facilitating fieldwork and iii) the weather is generally suitable. However, there are circumstances where winter fieldwork, while challenging, is needed. There are a number of circumstances which require winter fieldwork:

- To see runoff events 'on the ground' after heavy rainfall.
    - To locate pathways for water and contaminants (mainly phosphate, particulate P and sediment) in poorly draining areas.
    - To help map likely critical source areas (CSAs).
    - To locate or confirm delivery points/areas along watercourses.
    - To enable suitable pathway interception options to be considered, decided on and established.
    - To locate intermittent watercourses and ditches.
    - To locate temporary springs.
- To check ditch/drain runoff (many of these are dry for several months of the year), particularly those that are located close to farmyards and taking runoff from CSAs. For instance, Summer checking would not usually locate beef farmyards contributing dirty water, and discharges from some DWWTSs might not be obvious then.
- To check for pipe discharges in a period when they are not masked by vegetation.
- To undertake thermal imaging (see **Section 3.3, Volume 4** for further details) while there are temperature contrasts as a means of locating pipe and groundwater discharges.
- In circumstances where water samples are needed, to take a water sample during relatively high flows.
- To enable consideration of possible mitigation options.

Further details on undertaking winter fieldwork are given in **Appendix 7**.

12.3.5 Field photography

Taking photographs is essential to provide evidence of relevant features seen on catchment walks and as a reminder afterwards when drafting reports. Recommendations on field photography are given in **Section 7, Volume 3**.

Figure 12-9: Intermittent drainage ditch which is dry in summer but flowing in winter (Photo: Donal Daly).

Figure 12-10: Free draining area (underlain by karstified limestone) shown by vegetation indicators and absence of ditches and streams (Photo: Donal Daly).

Figure 12-12: Small spring (Photo: Donal Daly)

Figure 12-13: Swallow hole and sinking stream in North Roscommon (Photos: Donal Daly).

12.4 The sub-catchment report

This is a crucial report that updates the desk study[66]. It includes and summarises all the relevant data, graphs, information and photos, and concludes on what further actions and measures, if any, are needed. For instance, depending on the circumstances, new chemistry data can be plotted, SSIS and Rapid Assessment results can be tabulated (see example in Table 12-1) and relevant geological, vegetation and hydrogeological features can be described (see Table 12-2).

The 'interim story' (Section 10-6) can now be updated, finalised and reported on as the 'Story of the Sub-catchment' (see McAleer (2021) for an interesting and relevant example)[67] based on the information and understanding gained during the catchment walk (or site visit in the case of a point source) and definitive conclusions can be drawn.

12.4.1.1 Sub-catchments with an improvement objective

Reporting involves asking and answering questions, <u>such as</u>:

i) <u>What</u> is the water quality situation in terms of status and risk categories, pollutant concentrations, trends, etc.
ii) <u>What</u> is causing the unsatisfactory situation, i.e. what is/are the *significant issue*(s)?)
iii) <u>What</u> is/are the *significant pressures*?
iv) <u>What</u> is the pathway conceptual model that explains the pathways for water and contaminants in the catchment?
v) <u>Where</u> are the CSAs?
vi) In poorly draining areas and within CSAs for phosphate and/or sediment, <u>where</u> are the main focussed delivery flow paths and points?
vii) Where pollutant load reduction analysis has been undertaken (see Section 10.4.6 and Appendix 3), <u>what</u> reductions are needed?
viii) <u>What</u> further information is needed, if any?
ix) <u>What</u> strategies are needed to improve/restore the water quality. <u>What</u> and <u>where</u> should mitigation measures/actions be established?
x) <u>What</u> further monitoring is required?
xi) <u>What</u> consultation and collaboration are needed, both with other public bodies and with local communities?

12.4.1.2 Sub-catchments with a protection objective

Reporting involves asking and answering questions, <u>such as</u>:

i) <u>What</u> is the water quality situation in terms of status and risk categories, pollutant concentrations, trends, etc. (It is worthwhile plotting the chemistry data for trends and to check whether average concentrations are close to a relevant metric, e.g. an EQS (see Section 9)).
ii) <u>Are there</u> any tributaries with relatively high pollutant loads that could pose future problems?
iii) <u>What</u> pollutant might cause an unsatisfactory situation in the future?
iv) <u>What</u> 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 improve 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.

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[66] Much of this advice can also apply to site reports

[67] McAleer, 2021. Local catchments assessment: from desk studies to referrals. Proceedings of the IAH (Irish Group) Conference "Catchment Science and Management – the Role of Geoscience and Groundwater", https://www.iah-ireland.org/conference-proceedings/2021.pdf. Presentation recording: https://www.youtube.com/watch?v=Bwe3VGRVSDY

v) Depending on whether and what this pollutant is, <u>are there</u> susceptible areas and CSAs where losses to a watercourse could occur and <u>where</u> 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 (see Section 10.4.4)).
vii) <u>What</u> further information is needed, if any?
xii) <u>What</u> strategies are needed to protect the water quality? <u>Where</u> should protection measures/actions be established if they are needed?
viii) <u>What</u> further monitoring, if any, is required?
ix) <u>What</u> consultation and collaboration are needed, both with other public bodies and with local communities?
x) <u>Does</u> the local authority planning section need to be informed of the conclusions?

Table 12-2: Checklist of catchment walk indicator parameters and features

General	Specific	
Biological	Invertebrates	
	Macroalgae	
	Macrophyte	
	Aquatic insects	
Physical/chemical	Temperature	
	Specific electrical conductivity	
	Dissolved Oxygen	
	pH	
	Turbidity and sediment	
	Field measurements of nutrients, e.g. using test strips	
	Stream flows	
Geological	Topsoil	Freely draining
		Poorly draining
		Peaty
		Iron pans
		Preferential flowpaths
	Subsoil	Sand/gravel
		Silty/sandy
		Clayey
		Alluvium
		Made ground
		Mottling
	Bedrock	Weakly fractured
		Highly fractured
		Solution features
		Bedrock type
Vegetation	Example: rushes	
Hydrogeological	Drainage ditches	
	Springs and seeps	
	Swallow holes	
	Sinking streams	
Biodiversity	Examples: Otters, kingfisher, dippers, sand martins.	

Note: Prior to undertaking a catchment walk, decide on which parameters and features will assist in providing the required understanding that is needed to tell the final 'story' in the sub-catchment report.

The Environmental Supporting Conditions of Ecosystems

When considering the protection of ecosystems and associated habitats and species that depend on water (e.g. rivers, lakes, bogs (raised and blanket), fens, machairs, dune slacks, turloughs, petrifying springs, fish, freshwater pearl mussel, macroinvertebrates, marsh saxifrage, otters, kingfishers), it is worthwhile thinking in terms of their required 'environmental supporting conditions'. These provide a target and metric for the abiotic requirements (e.g. hydrochemistry, water levels, water flows, stream morphology) of an ecosystem. It is an alternative, and perhaps more intuitive, way of considering EQSs (see Section 9) and conservation conditions, and may be more effective as a concept when explaining the requirements of ecosystems in public fora.

As catchment scientists, our role doesn't end with characterisation; we need to contribute to decisions on and establishment of either protection or mitigation measures/actions, as appropriate. We are also catchment managers!

13 Groundwater Scenarios

13.1 Introduction

There are a number of reasons for providing the information on groundwater in this Handbook including:

i) Groundwater drinking water sources are far more numerous than surface water sources and they supply ~30% of drinking water from public, group scheme and individual private wells.

ii) Groundwater cannot be seen except when rising from a spring or pumped from a well, therefore it can be 'out of sight, out of mind'.

iii) Understanding of water and pollutant movement in the underground (the 3rd dimension) is essential when:
- Characterising surface water situations.
- Deciding on protection and mitigation actions for surface water.
- Management of catchments in an integrated manner as required by ICM and the FILLM.

iv) Many developments and facilities discharge effluent to groundwater, either permitted, e.g. percolation areas linked to septic tank systems, or unauthorised, e.g. from yards and leaking pipes.

v) There is a requirement to protect groundwater and mitigate impacts for the following reasons:
- It is a source of drinking water throughout the country.
- It provides the water for groundwater dependent ecosystems, such as turloughs.
- It provides between ~20-80% of average flows in watercourses (depending on the underlying aquifer category), and a greater proportion during dry weather periods.
- Groundwater bodies must achieve the 'no deterioration' objectives of the WFD and Groundwater Directive.

Four topics are chosen to illustrate relevant groundwater aspects:
1. Groundwater vulnerability to pollution.
2. Wells – groundwater as a drinking water source.
3. Drinking Water Source Protection using the NFGWS Framework.
4. Discharges to groundwater.

Brief details on each are given below. Further information is given in **Section 5** and **Section 6**, **Volume 3**, and **Section 5.4, Volume 5**.

13.2 Groundwater vulnerability

Groundwater vulnerability is a term used to represent the natural ground characteristics that determine the ease with which groundwater may be contaminated by human activities. The concept is based largely on the question 'can water and contaminants move in the subsurface materials (soil and subsoil) and get down to groundwater in a bedrock or sand/gravel aquifer easily?' 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. Groundwater that readily and quickly receives water (and pollutants) from the land surface is considered to be more vulnerable than groundwater that receives water (and pollutants) more slowly, and in lower quantities. The slower the movement and the longer the pathway, the greater is the potential for attenuation of many pollutants, particularly microbial pathogens such as *E coli*.[68]

[68] A detailed description of the vulnerability concept and mapping process is given in: Fitzsimons, V., Daly, D. and Deakin, J (2003). *GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination*. Internal Groundwater Section, Geological Survey of Ireland Report.

Vulnerability mapping has been undertaken country-wide by the Groundwater Programme of the Geological Survey of Ireland (GSI). There are five groundwater vulnerability categories: X (rock at or near surface and karst features such as sinking streams; E (extreme, where the subsoil/bedrock boundary is the 3 m contour); H (high); M (moderate) and L (low, where there is >10 m low permeability (clayey) subsoil). The basis for the categories is shown in Table 13-1 and a groundwater vulnerability map is shown in Figure 13-1.

In summary, 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 map represents a conceptual model of any area based on those factors and is a model of the vertical movement of water and conservative or mobile contaminants.[69] Conceptually:

- Water takes >10 years and, in some circumstances, decades to move through the low permeability subsoil in **low (L) vulnerability areas** and pollutants are unlikely to reach the underlying aquifer. These are areas of overland and shallow flow, and a high density of water courses, many of which are intermittent as there is minimal baseflow provided by groundwater.
- In **high (H) vulnerability areas**, microbial pathogens are generally attenuated by filtration and die-off in the soil and subsoil before reaching an underlying bedrock aquifer; however, mobile chemical pollutants, such as nitrate, can reach the aquifer.
- In **extreme (E) vulnerability areas**, both microbial pathogens and mobile pollutants can reach the aquifer. Watercourse density is low in these areas.

Table 13-1: Vulnerability Mapping Criteria *(amended from DELG/EPA/GSI (1999))*[70]

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

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

[69] Note the similarities with the susceptibility concept described in 10.5.5, which focuses on two contaminants (nitrate and phosphate), all potential pathways and both groundwater and watercourses as receptors. Susceptibility maps are partly based on vulnerability map.
[70] DELG/EPA/GSI, 1999. Groundwater Protection Schemes. https://www.gsi.ie/en-ie/publications/Pages/Groundwater-Protection-Schemes.aspx

Further details on groundwater vulnerability and access to vulnerability maps are available at these links: https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/Pages/default.aspx and https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=7e8a202301594687ab14629a10b748ef, respectively.

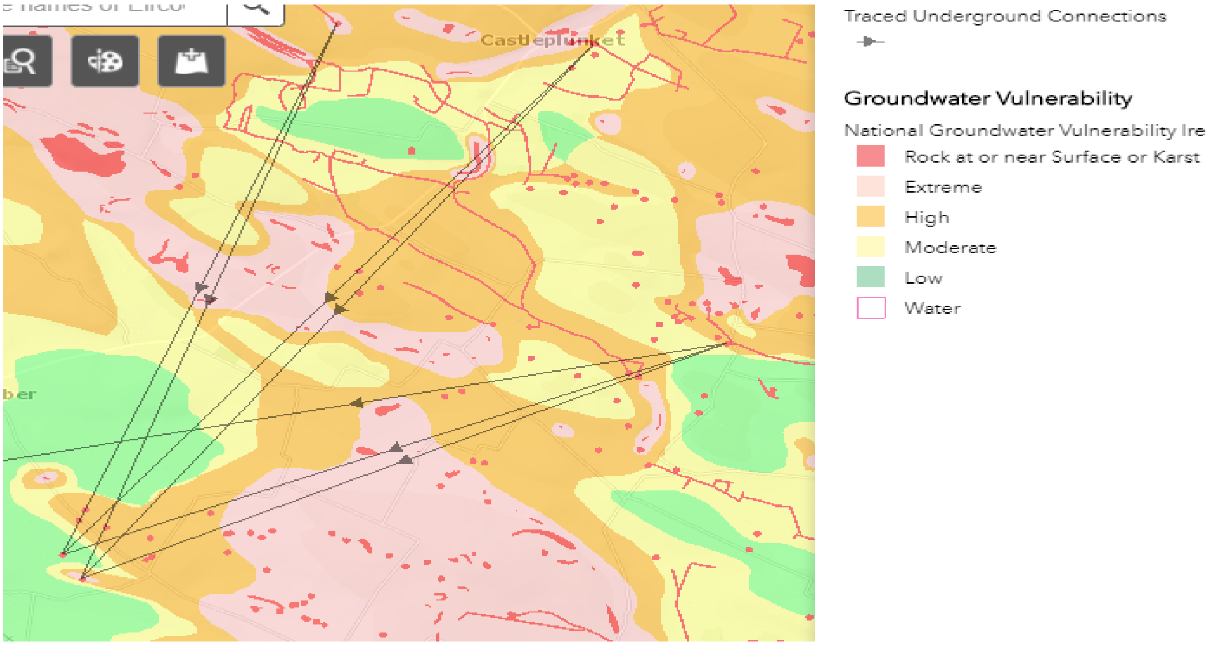


Figure 13-1: Groundwater vulnerability map (Source: GSI).

13.3 Groundwater flow to wells

13.3.1 Zones of contribution for wells

Prior to drilling and pumping water from a bored well, the water table is a subdued reflection of topography with groundwater being recharged by rainfall and then flowing relatively slowly to provide baseflow to streams (see Figure 13-2).

When water is pumped from a well, the water level in the well and the area surrounding the well is lowered. A hydraulic gradient is set up towards the well from all around in the aquifer, forming what is called 'a cone of depression' (Figure 13-3). The change in water level is called the 'drawdown'.

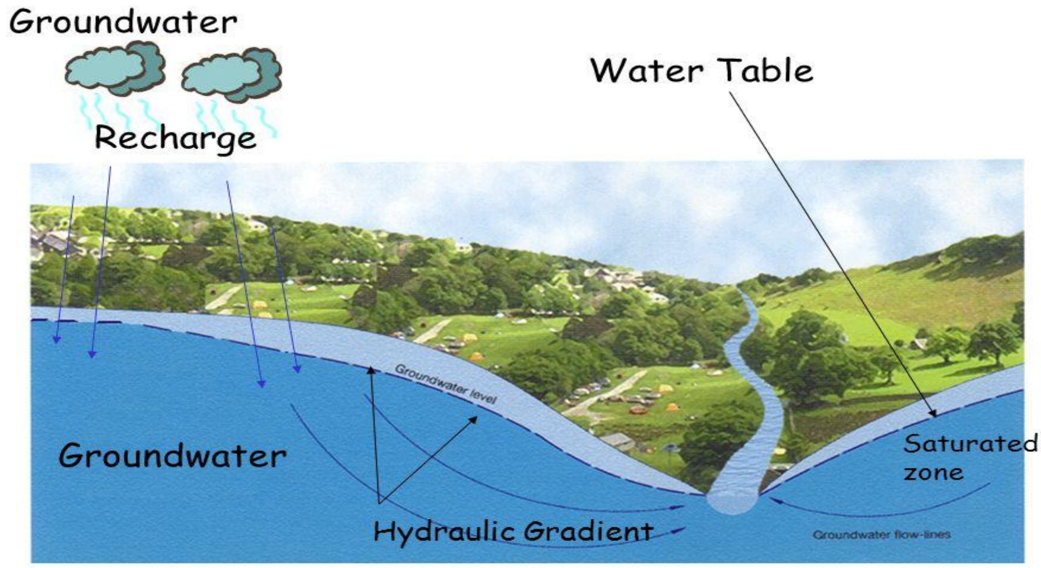
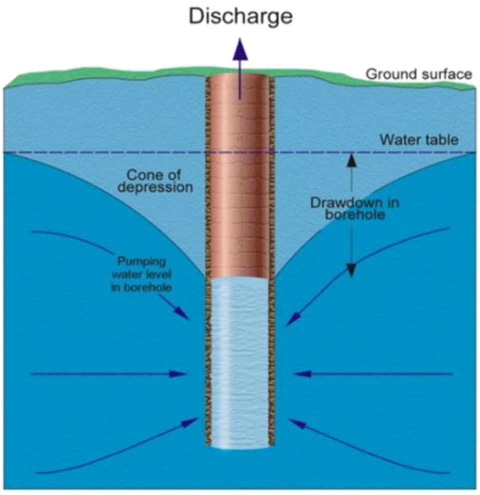


Figure 13-2: A cross-section through the landscape showing water flowing to a river.



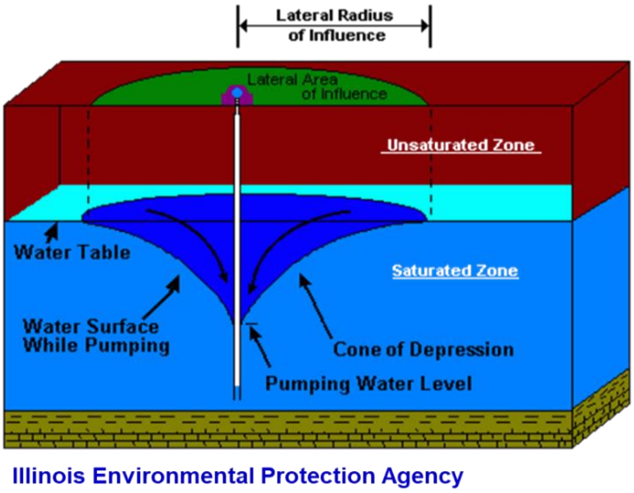


Figure 13-3: Illustration of the lowering of the water table by pumping.

While Figure 13-3 assumes a flat water table, in practice it is sloping and therefore most of the water being pumped out comes from upgradient, as shown in Figure 13-4 and Figure 13-5. If a high yielding well is located too close to a stream, it can draw water from the stream. This might cause significant reductions in flows in dry weather.

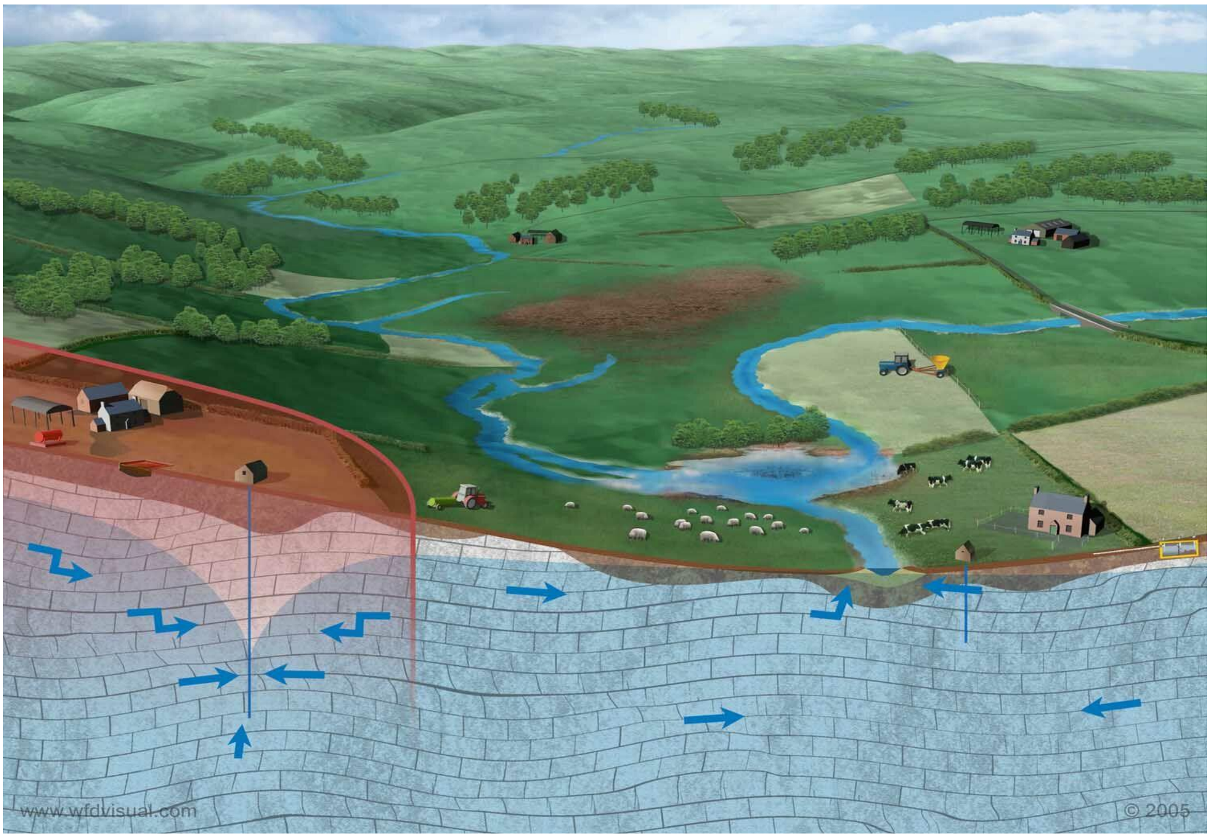


Figure 13-4: Illustration that most of water abstracted from the well come from upgradient. The red line is the boundary of the 'zone of contribution' of the well.

The catchment area for a well is called the 'zone of contribution (ZOC)', with the size and shape depending on the abstraction rate, aquifer transmissivity (bulk permeability) and recharge rate (see

Section 6.4.1.2 in Volume 3 for more details). An illustration of a ZOC, in both cross-section and plan views, is given in Figure 13-5. This shows:

i) the total area contributing water to the well;
ii) that most of the area is upgradient of the well;
iii) the 100 day time of travel (TOT) to the well, i.e. groundwater outside of TOT boundary takes greater than 100 days to get to well and vice versa.

Some examples of estimated areas of ZOCs are given in **Section 6.4.1.2 in Volume 3**. For instance, based on those calculations, the ZOC for a public or group scheme well with an abstraction rate of 1,000 m^3/d (9,000 gph) would be approx. 130 ha (1.3 km^2) based on a recharge rate of 280 mm/yr and allowing for expansion of the ZOC in dry periods. Copies of source reports for 190 public and group scheme groundwater sources in 25 counties are accessible at this link: https://www.gsi.ie/en-ie/programmes-and-projects/groundwater-and-geothermal-unit/projects/protecting-drinking-water/what-is-drinking-water-protection/county-groundwater-protection-schemes/Pages/Source-Protection-Zone-Reports.aspx

There are over 100,000 **private (domestic supply) wells** throughout the country. When considering the location of nearby potential pollution sources, such as septic tank systems and farmyards, it may be worthwhile being able to visualise the ZOC. For a well with an abstraction rate of ~600 l/d, the ZOC would be 15-30 m wide, the downgradient distance would be ~10 m, the upgradient distance would be 150->500 m upgradient and the area would be 0.1-0.25 ha.

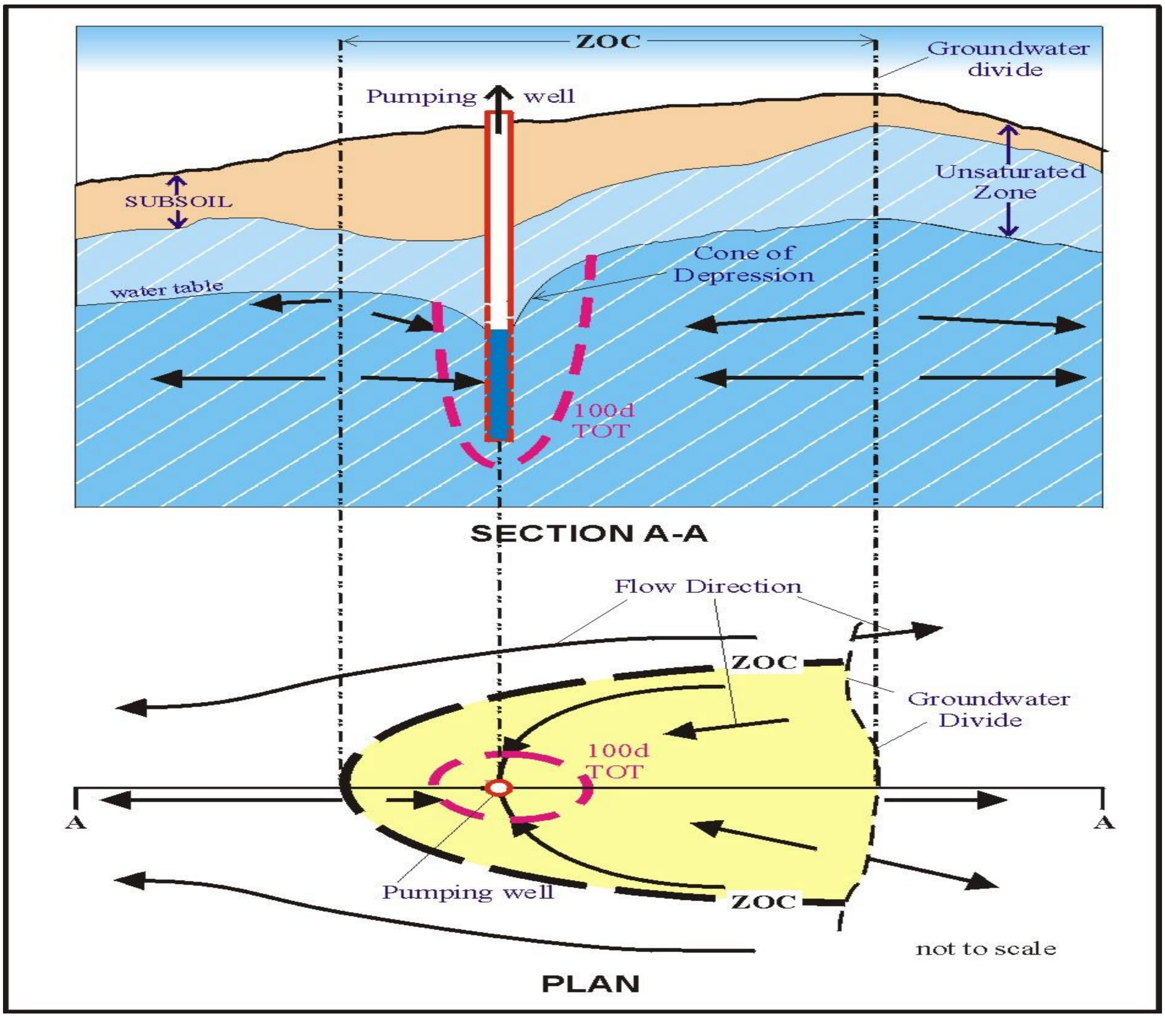


Figure 13-5: Conceptual model of a ZOC for a pumping well (adapted from US EPA, 1987).

13.3.2 Well water quality

The main potential sources of pollution of wells are *E.coli* and nitrate.

13.3.2.1 E.coli

The presence of microbial pathogens in well water requires some or all of the following conditions:

i) Extremely vulnerable areas in the ZOC.
ii) A source of *E.coli*.
iii) Being inside the 100-day TOT or Inner Protection Area.
iv) Poor well design and construction.

- Subsoil and, to some degree soil (it usually has preferential flowpaths, as shown in Figure 12-2, which can allow bypassing of the soil) is capable of attenuating *E.coli* by filtration and die-off. Therefore, even 1-2 m subsoil can provide good protection.

- The most common sources of pathogens are effluent from domestic wastewater treatment systems, dirty water from farmyards, faeces from grazing animals and slurry when spread on the land. However, it is advisable to take a precautionary approach and assume that *E.coli* will be present in groundwater even when there are no obvious human activities as wild animals and birds are also sources, and extremely vulnerable areas are common in at least some proportion of most ZOCs.[71]

- Source protection zones have and are being delineated for many public and group scheme wells – these include part Inner (SI) and Outer (SO) Protection Areas.[72] The boundary of the SI area is the 100-day TOT boundary. *E.coli* arising outside this boundary will die-off before the well is reached.

- A common problem associated with private wells is poor well construction, which allows surface water and shallow groundwater (shallow groundwater is more likely to have E.coli present than deeper groundwater) to enter the well by flowing down the outside of the well casing. This can occur when the outside of the well casing isn't grouted, as shown in Figure 13-5. A properly constructed well is illustrated in Figure 13-6.

For further information on wells, well design and private wells, check the following links: http://www.epa.ie/pubs/advice/drinkingwater/EPA_DrinkingWater_AdviceNoteNo14b_web.pdf and **http://www.epa.ie/water/dw/hhinfo/protprivwell/**

Recommendation for private well owners
As the presence of *E.coli* can indicate a threat to human health, particularly for old and young people, installation of a UV system to treat the water is advised.

13.3.2.2 Nitrate

The presence of nitrate in well water requires the following conditions:

[71] However, where new public and group scheme wells are being planned, it is advisable to locate them on sites where the likelihood of significant impacts from human activities is low. In particular, account should be taken of the vulnerability of the groundwater as shown on the **vulnerability maps**.
[72] Further information on groundwater protection schemes can be accessed at this link: https://www.gsi.ie/en-ie/publications/Pages/Groundwater-Protection-Schemes.aspx

i) Areas susceptible to nitrate leaching in the ZOC.
ii) A source of nitrate.
iii) The absence of denitrification in bedrock aquifers.

- Nitrate is susceptible to leaching where the soil is freely draining and the subsoil has a high or moderate permeability. The aquifer category can also be an influence, for instance, leaching is more common in productive aquifers – Rk, Rf, Rg, Lk, Lm and Lg aquifers (see Section 10.5.3.3). A nitrate susceptibility map is shown in Figure 13-8. The darker areas are the more susceptible areas.

- The nitrate loading is a key factor. Relatively high nitrate loadings occur in intensive farming areas, such as dairy and tillage farms. Susceptibility and loading are combined in nitrate PIP maps. An example is shown in Figure 13-9 for the same area as in Figure 13-8. The darker the purple areas shown, the greater the likelihood of losses of nitrate to the underlying groundwater.

- In some bedrock aquifers, denitrification can occur, which reduces the nitrate concentrations in the groundwater and in the watercourses that the groundwater discharges to. This can explain why nitrate concentrations in some watercourses are lower than expected based on the nitrate loadings and the hydrogeological setting. Examples include some of the Old Red Sandstone aquifers in freely draining areas in County Cork and some of the impure limestone areas.

13.4 The NFGWS Framework for Drinking Water Source Protection

In 2019, the National Federation of Group Water Schemes (NFGWS) published a framework document[73] for professionals involved in developing source protection plans that connected with the characterisation approaches used by the EPA Catchments Unit and LAWPRO.

The Executive Summary of the Framework is given in Appendix 8. **The Framework follows the Process outlined in this Volume and is now used by the NFGWS in undertaking source protection**. This process is recommended for other drinking water sources. One innovative feature of the Framework is the use of 'guide values' for pollutants in untreated or raw water to determine whether the objective is 'protect' (concentrations below guide value) or 'improve' (concentrations above guide value) (see Appendix 1 in the Framework for details). Some examples are given in Table 13-2.

The paper by Kelly *et al* (2021)[74] shows the application of the Framework in a karst environment.

Table 13-2: Guide values for untreated water

Parameter	Surface water guide value	Groundwater guide value
Nitrate	28 mg/l NO_3 (mean)	28 mg/l NO_3 (mean)
Ammonium	0.175mg/l N (mean)	0.175mg/l N (mean)
Phosphate	0.035 mg/l P (mean)	0.035 mg/l P (mean)
MCPA	0.075 µ/l (mean)	0.075 µ/l (mean)
Colour	100 mg/l Pt/Co (mg/l Hazen)	20 mg/l Pt/Co (mg/l Hazen)
E. coli	1,000/100ml	100/100 ml (wells) 1,000/100 (springs in karst areas)

[73] NFGWS (2019). 'A Framework for Drinking Water Source Protection' at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/

[74] Kelly, C., Meehan, R., Lee, M., Corrigan, S. and Daly, D. (2021). Determining mitigation actions using the pollutant transfer continuum. Proceedings of the International Association of Hydrogeologists (Irish Group) Conference 'Catchment Science and Management – The Role of Geoscience and Groundwater' April 2021. https://www.iah-ireland.org/conference-proceedings/2021.pdf

Figure 13-6: Water containing pollutants can readily flow down the outside of the casing if not grouted properly (Photos: David Ball.

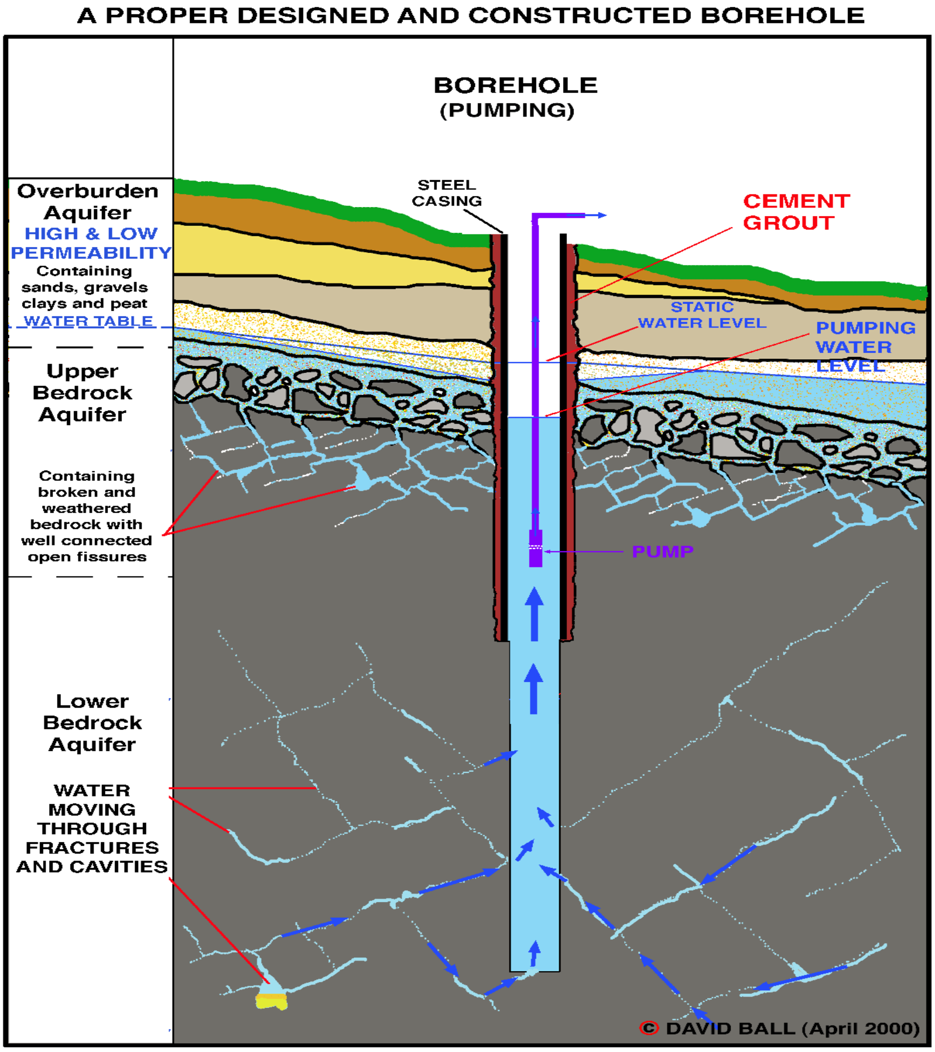


Figure 13-7: Illustration of a properly designed and constructed bored well.

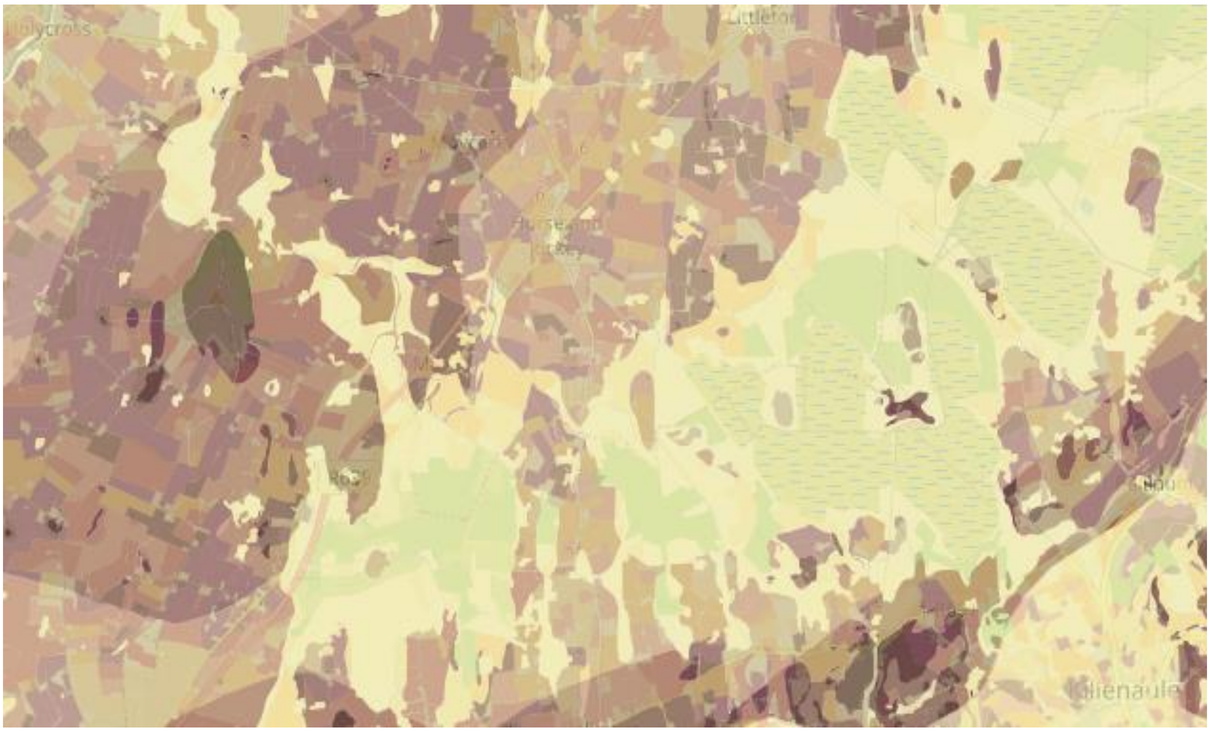


Figure 13-8: Sub-surface nitrate susceptibility map (Source: https://gis.epa.ie/EDENMaps/WFD)

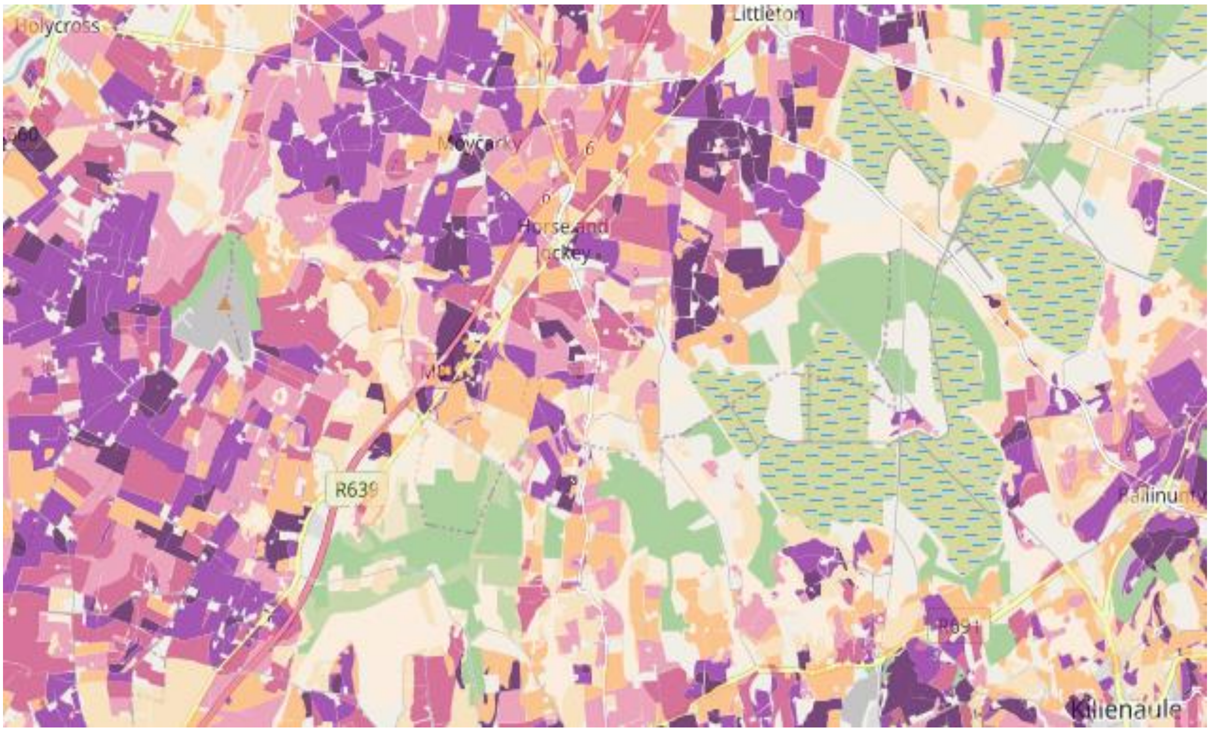


Figure 13-9: Nitrate Pollution Impact Potential (PIP) map (Source: https://gis.epa.ie/EDENMaps/WFD)

13.5 Discharges to groundwater

The authorisation of discharges to groundwater is regulated by local authorities and the EPA. EPA Guidance (2011) on the authorisation of discharges to groundwater[75] for the following point sources:

- Small scale discharges from on-site wastewater treatment systems (OSWTSs) – septic tanks and package treatment plants;
- Discharges to ground from larger wastewater works, including integrated constructed wetland systems;
- IPPC and other industrial/commercial releases;
- Infiltration of urban stormwater through infiltration basins (Sustainable Urban Drainage Systems); and
- Escape of leachate from landfills (beyond engineered and/or geological barriers).

The guidance provides a practical framework for the criteria considered important for granting or refusing an authorisation for discharge to groundwater. It addresses risk screening, appropriate levels of technical assessment, prediction of impact on groundwater quality and appropriate monitoring for different types and scales of discharges.

The technical assessment of a discharge to groundwater activity is risk-based and receptor-focussed. It follows the source-pathway-receptor (SPR) model which underpins all groundwater protection schemes in Ireland, the WFD and Groundwater Directive on which the Groundwater Regulations are based, and is a basic framework for the content in this Handbook.

The EPA (2011) Guidance provides advice on:

- Three different tiers of assessment that depend on the risk posed by the discharge activity.
- Predicting impacts on groundwater.
- Compliance monitoring.
- Compliance checking.

Recommendation

The EPA (2011) Guidance on the Authorisation on Discharges to Groundwater is worthwhile reading even for those of us not dealing with this issue as it i) provides readable content on protection of groundwater, ii) is relevant to surface water, and iii) provides an example of the Process followed in this Handbook.

[75] It can be accessed at this link: https://www.epa.ie/pubs/reports/water/ground/dischgw/ .

14 Protection and Mitigation Measures

While characterisation is essential to understanding the situation in a sub-catchment or at a site, it is the consequential measures/actions that are key to achieving the water quality objectives. Whether it is protection or mitigation measures/actions that are needed, they are often complex, challenging and, on occasions, both time and resource intensive to implement. Even in circumstances where catchment scientists aren't responsible for establishing the measures/actions, they have a critical role in advising on what and where they should be, and may have to monitor and track progress afterwards. To assist, this Section expands the second component of the Process outlined in Figure 8-2 to help ensure that measures/actions are undertaken in an efficient and effective manner.

14.1 Introduction

This Section outlines a recommended process[76] for considering what measures/actions are needed to either protect/maintain water quality where it is satisfactory or improve/restore it where it is unsatisfactory. The thought processes and approach for agricultural activities is summarised in Figure 14-1 – this process can also be used for other activities and is a useful stepwise approach to arriving at and providing explanations for decisions. The various elements are illustrated in Figure 14-2. Details on the measures/actions themselves are not described here; however, links to sources of information are provided. The focus is primarily on diffuse and small point pressures.

14.2 Some principles

There are certain principles for water management that are the 'stepping stones' for achieving the outcomes needed. Some of these are outlined below. While most are repetition of points already made, they are given to help us keep the focus on achieving environmental outcomes.

1. The objective – is it to **protect** or to **improve/restore** the water quality?

2. **Understand** (via characterisation) **the land and landscape setting of the sub-catchment or site,** including:
   i) Pathways for water movement.
   ii) Location of relevant receptors, e.g. streams, ditches, wells, etc.
   iii) The pollutants that might threaten or are causing water quality problems.
   iv) The pressures, potential or actual.
   v) The susceptible areas for the pollutant(s) in question, the critical source areas (CSAs) and, where relevant, the focussed delivery flow paths and points to watercourses in CSAs.

   Therefore, using the characterisation outcomes is vital in ensuring that the measures/actions are efficient and effective.

3. **Pick important problems and fix them.** In any area, such as a sub-catchment, there will be a multitude of environmental stressors and pressures. The key is to pick those that will 'make a difference' in achieving the objective and to focus on them as a priority.

[76] This Section is based largely on NFGWS (2020) 'A Handbook of Source Protection and Mitigation Actions for Farming' at this link: https://nfgws.ie/nfgws-source-protection-publications/

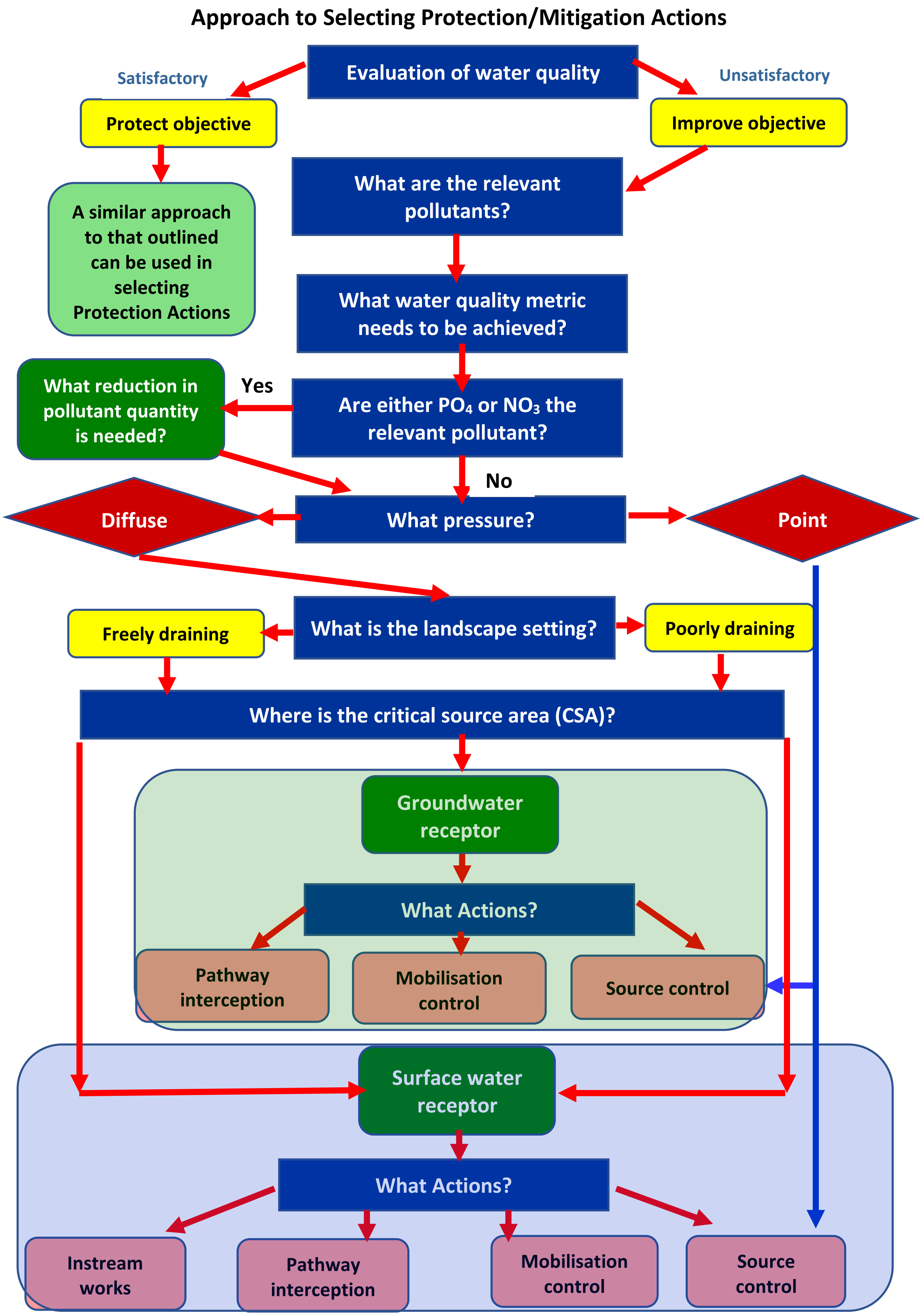


Figure 14-1: Process flowchart illustrating a recommended approach to deciding on appropriate mitigation Actions.

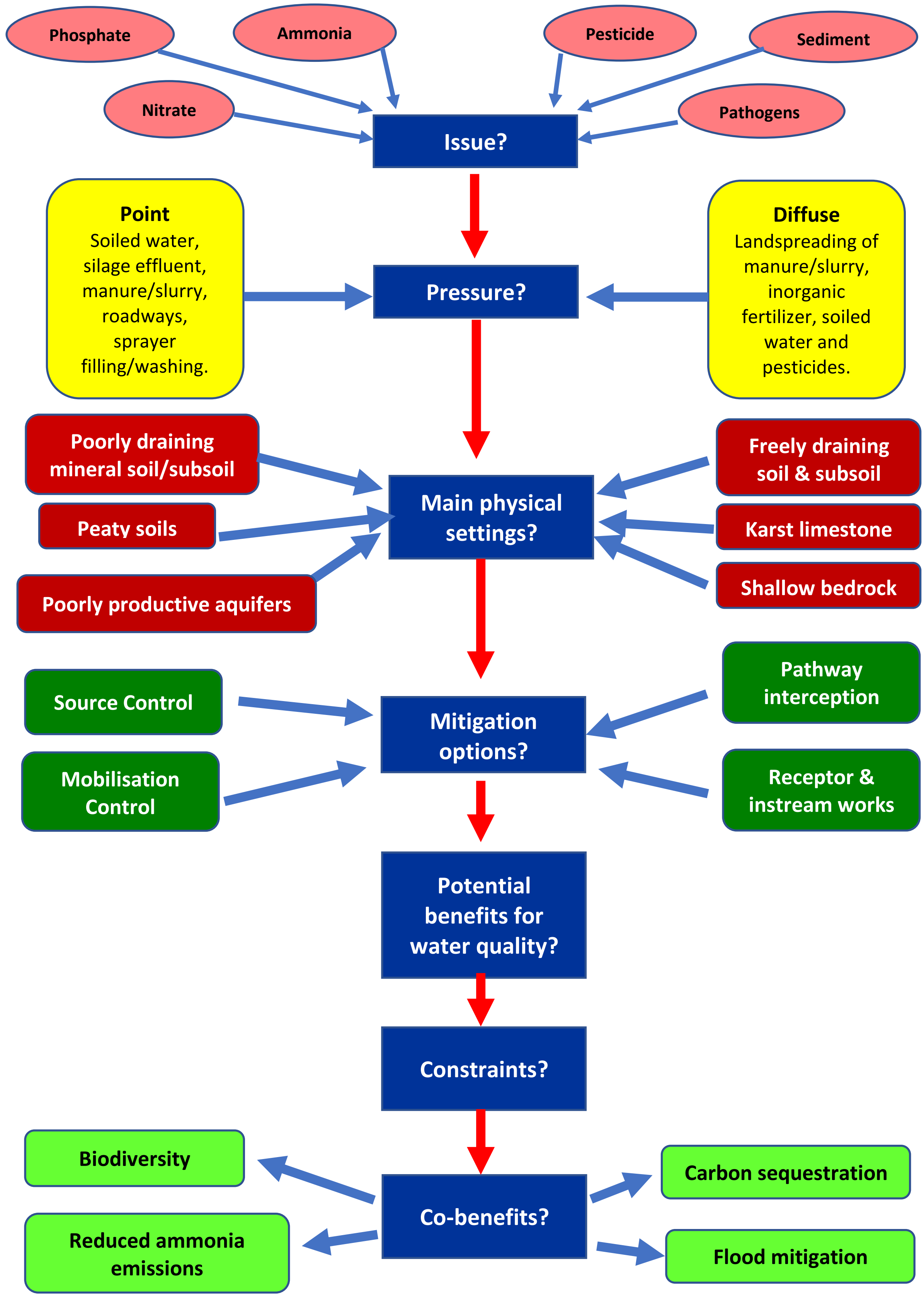


Figure 14-2: Illustration of the various elements relevant to considering protection/mitigation measures/actions in rural areas (adapted from NFGWS (2019).

4. **Use "the right measure in the right place."** Measures and actions must be 'tailor made' and specifically targeted and prioritised on the environmental stressors and pressures and on the relevant areas, as the means of achieving desired environmental outcomes.

5. Use the '**pollutant transfer continuum'** as a landscape-based framework, to consider the threats to water quality and risk mitigation. It consists of four components (Figure 14-3 and Figure 14-4)):
   - v) The **presence of a pressure with an associated load of pollutants**. This pressure can either be a point or diffuse source or both.
   - vi) **Mobilisation**, whereby in the case of diffuse pressures, the potential environmental stressor or pollutant becomes soluble or attaches to soil particles and starts the journey to a receptor, such as a stream.
   - vii) **Delivery/transport** in a pipe in the case of many point sources or more diffusely along pathways, underground or over ground, to a receptor, such as a watercourse or drinking water source or groundwater in an aquifer.
   - viii) The **receptor** which is impacted or might be impacted in the future; in the case of surface water, it can vary for instance, in terms of flow rates, upstream water quality and sensitivity (e.g. high or good status or pearl mussel objectives), whereas in the case of groundwater in an aquifer, the existing water quality and the dilution potential can vary.

6. **Consider the protection and mitigation actions, according to the point in the source-pathway-receptor continuum on which they take effect.** This is a means of achieving 'the right measure in the right place'. It allows management strategies, the design of protection and mitigation measures/actions to deal with relevant pollutants, and their implementation, to be 'followed' conceptually from application to impact, and provides clarity on what role a particular measure has. The recommended relevant points along the continuum for consideration of specific measures and actions are:
   - i) source reduction or elimination;
   - ii) mobilisation control;
   - iii) pathway interception;
   - iv) receptor/instream works; and
   - v) treatment in the case of drinking water sources (as part of the multi-barrier approach).

7. **Predict the time delays for improvement.** This is an essential component of catchment science and management for the following reasons:
   - ♦ For work and resource planning.
   - ♦ To enable predictions of when objectives are likely to be achieved.
   - ♦ To encourage realistic expectations.

8. **Consider the co-benefits from the measures/actions.** Many of the activities undertaken to either protect or improve water quality also improve biodiversity and increase carbon sequestration. In choosing the measures/actions, we need to take account of the overall environmental outcomes and benefits, as outlined in the FILLM approach (see Section 6-3), and even give priority to those that have more than one environmental benefit.

9. **Interact with the pressure owners**, as a key protection/mitigation action. This can involve two elements: i) consultation and collaboration; and ii) compliance assurance. Compliance assurance, while an essential '*tool in the toolkit'*, can be seen as a sanctions-based approach to achieving environmental objectives that can cause alienation towards environmental protection, particularly in rural communities. Therefore, consultation and collaboration are the primary interaction means of achieving environmental outcomes with inspections being the last resort 'tool' in the 'toolkit'.

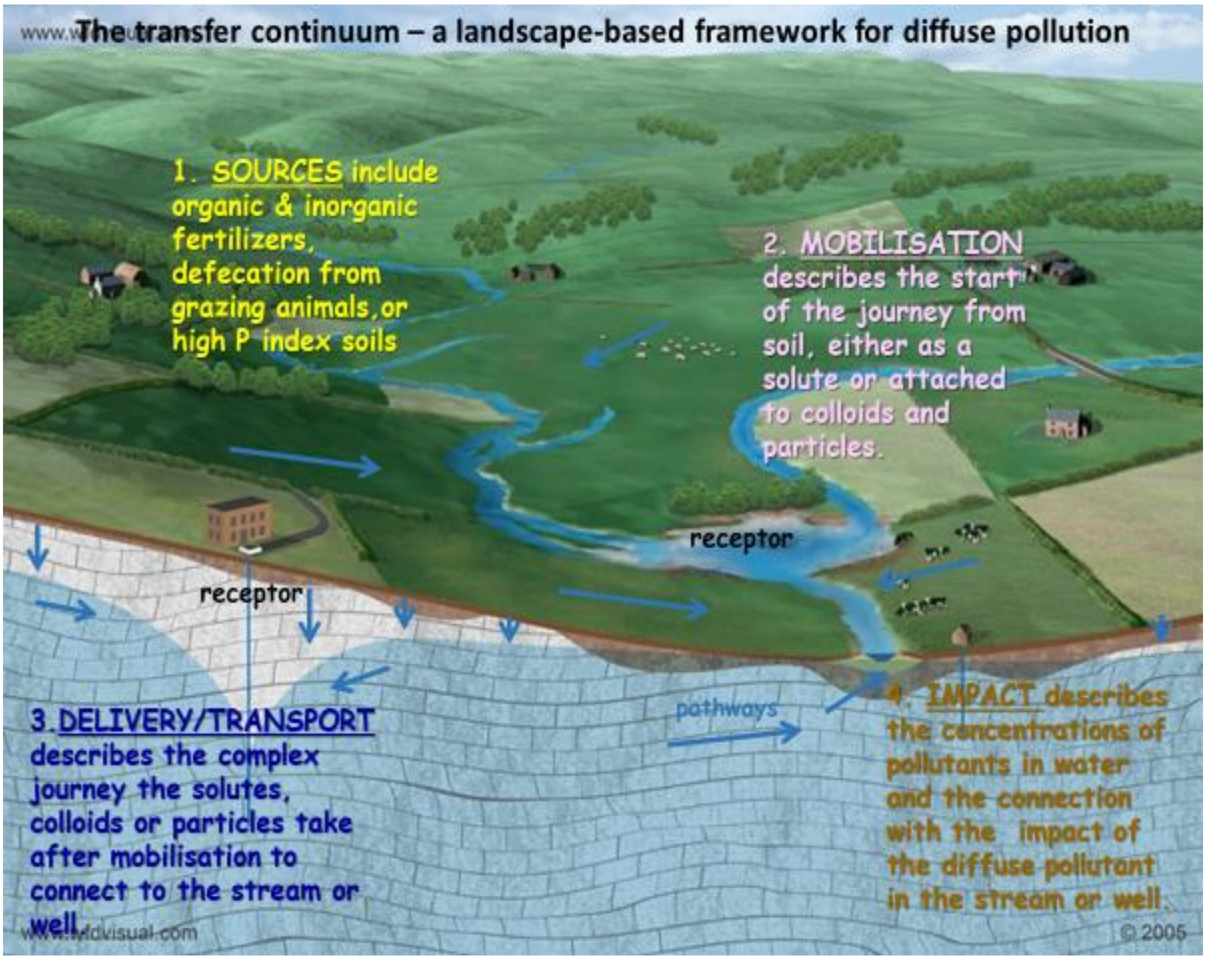


Figure 14-3: Representation of the pollutant transfer continuum (Source: NFGWS, 2019)

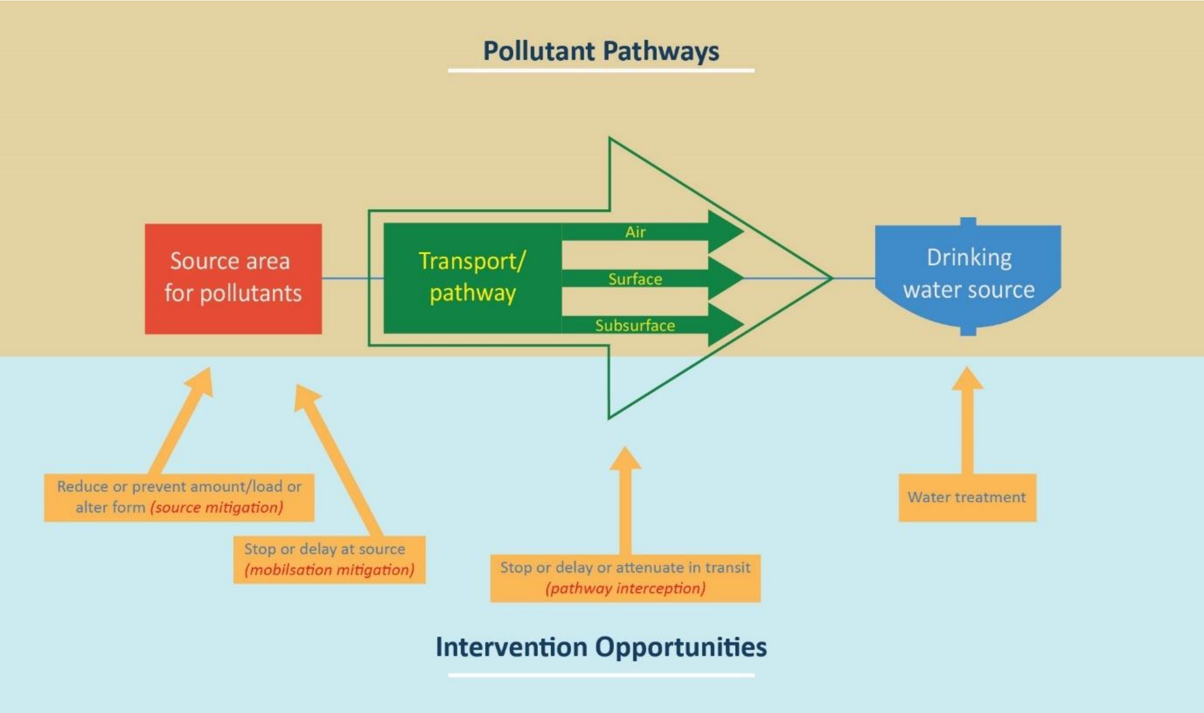


Figure 14-4: Factors and considerations for CSA delineation and selection of protection/mitigation options where the receptor is a drinking water source (Source: NFGWS, 2019).

14.3 The Protection and Mitigation Options

Mitigation options can be placed in three categories:

1. Regulatory measures that must be complied with, for example, the GAP (DAFM, 2017), Pesticide Use Regulations (DAFM, 2012) and the Urban Waste Water Treatment Regulations (DELG, 2001).
2. Incentivised voluntary actions such as the Green, Low-carbon, Agri-environment Scheme (GLAS) and the DAFM native woodland and agroforestry schemes.
3. Voluntary actions undertaken by landowners.

A decision on the appropriate measures/action depends on a number of factors: i) the environmental stressor or pollutant; ii) the activity; iii) the landscape and land setting, in particular whether it is a freely draining or poorly draining scenario; and iv) the input of and acceptability to the property/landowner. In addition, the objective – protect or improve – may also be relevant.

There are four categories of protection/mitigation measures/actions that depend on their location in the landscape:

1. Actions to reduce or eliminate the pollutants.
2. Actions to reducing mobilisation of pollutants on land.
3. Pathway interception Actions.
4. Receptor/instream works.

Table 14-1 illustrates the use of these categories, taking agricultural activities as an example, by listing different possible measures/actions in each category. In addition to those at the different points of the pollutant transfer continuum, there is one vital overarching Action that applies to all of them **–** farmer engagement and collaboration.

Figure 14-5 illustrates the three categories of mitigation actions – pollutant reduction, mobilisation reduction and pathway interception – applied to the poorly draining, high PIP-P area shown in Figure 10-21. Figure 14-6 illustrates possible pathway mitigation actions along the focussed flowpaths for the same area.

Three case studies on mitigation actions based on the nutrient transfer continuum are described in Appendix 9.

Buffer zones are one of the most common and important measures used to mitigate impacts of farming and afforestation on water quality from a large range of pollutants/*significant issues* such as phosphate, total phosphorus, sediment, nitrate, ammonium, pesticides and microbial pathogens. They are generally given as a **constant or uniform width** alongside watercourses. From a water quality perspective, the main benefit of buffer zones is that they enable interception of pollutants by slowing runoff; intercepting P, sediment, pesticides, ammonium and microbial pathogens; enabling P take-up; and by breaking up the hydrological connectivity. They are beneficial for not only water quality, but also generally create beneficial ecosystems and capture carbon, and therefore fit well with the co-benefits concept. However, it can be argued that 'one size fits all' uniform width buffer zones, while beneficial for the environment, are not as beneficial as generally thought and are not an optimum use of land taken out of farm 'food' production. Using the SPR model for deciding on mitigation actions, particularly in the context of results-based payments for these actions, provides an opportunity to consider **spatially targeted larger buffer areas**, designed and shaped to suit the local situations, as a more effective and efficient means of achieving water quality outcomes and probably also biodiversity outcomes, and as a more effective use of land apportioned to buffer zones. Further details are given in Appendix 10.

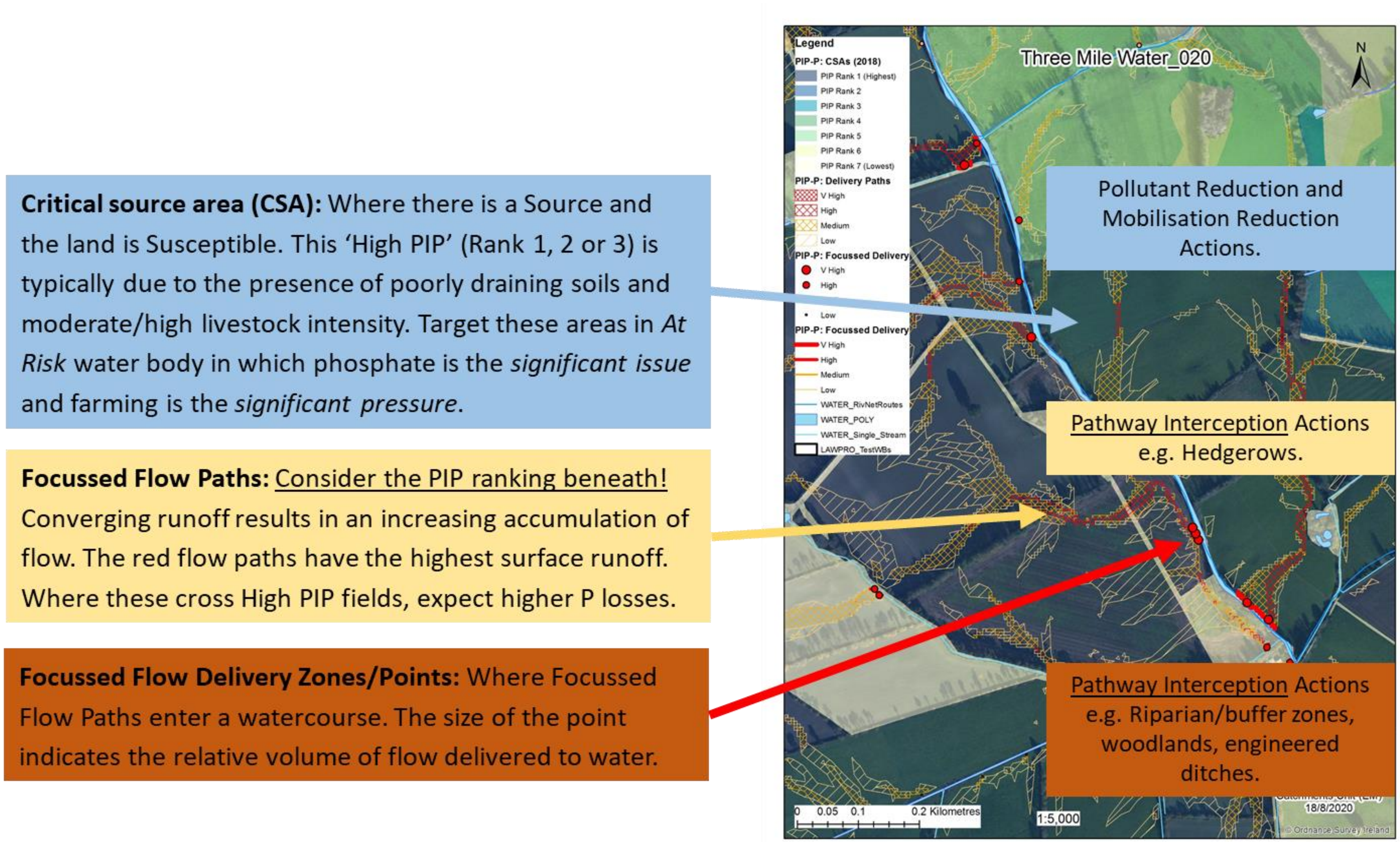


Figure 14-5: Three categories of mitigation actions pollutant reduction, mobilisation reduction and pathway interception – applied to the setting shown in Figure 10-21. (Source: slide from Mockler, EPA Catchments Unit).

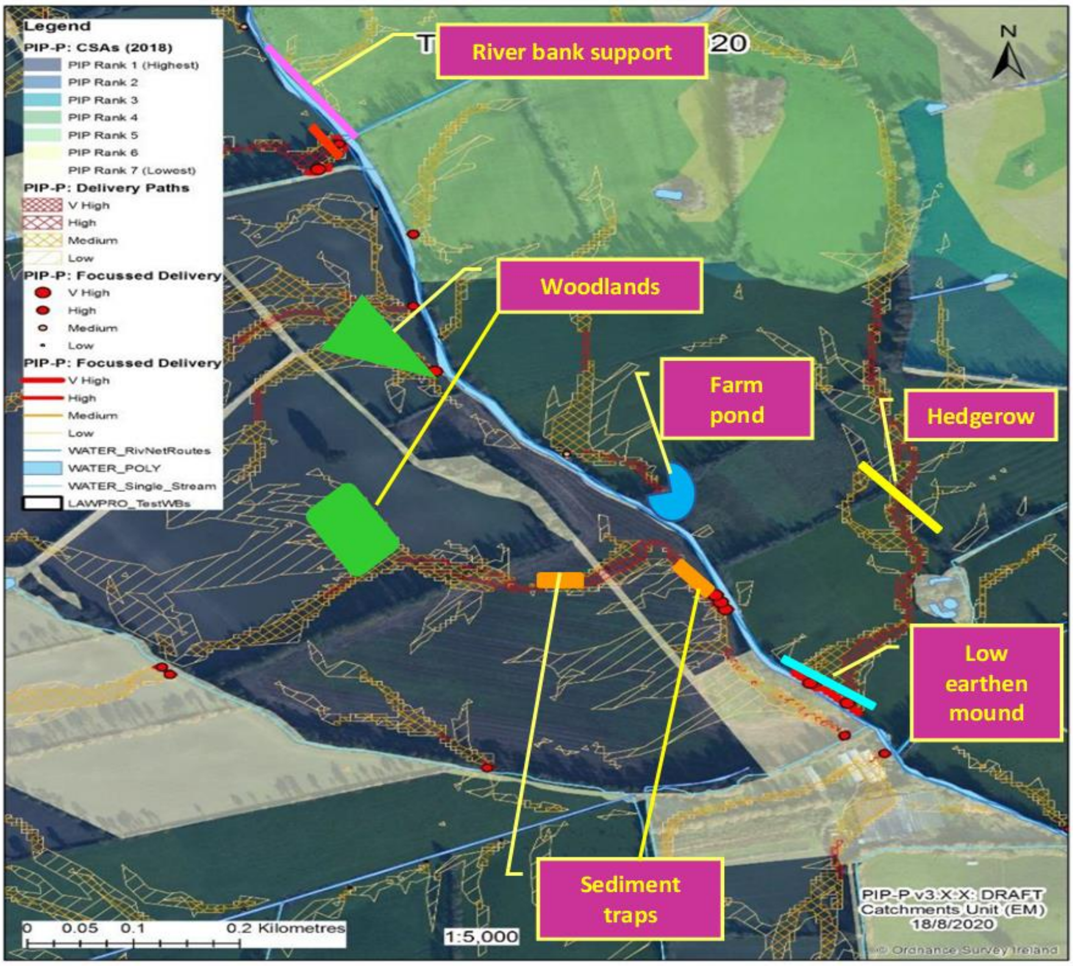


Figure 14-6: Examples of possible pathway mitigation actions located in focussed along focussed flow delivery paths.

14.4 Factors determining time delays for improvement

For *At Risk* water bodies or sites from which impacts on water quality is arising, a critical question is: '**how long will take for improvements to occur after the measures are established?**' Of course, the answer is: '**it depends**'. And, this is a reasonable answer. However, it is a question that needs consideration in advance of establishing measures. Therefore, an analysis of and an estimation of these time delays are essential not only for communication purposes, but also to assist work and resource planning and to enable projections on dates for restoration to the required water quality condition.

Recommendation

Expectations and predictions on achieving improvements can be unrealistic – either too short or too long. For those who expect an impossibly immediate response, it can lead to frustration and unfair criticism of public bodies. For those predicting an unjustifiable long response time, it can become a reason for not implementing adequately or enforcing the measures. Therefore, it is worthwhile doing an upfront analysis of time delays and time lags (for instance by using Tables 3 and 4 in Appendix 11), firstly to aid in choosing the appropriate measures/actions, and secondly, to be in a position to communicate the results.

The factors considered relevant to estimating time delays are illustrated in Figure 14-7 below. Appendix 12 provides further information on this as well as a means of estimating time delays for improvement for water bodies impacted by two *significant issues* – phosphate and nitrate.

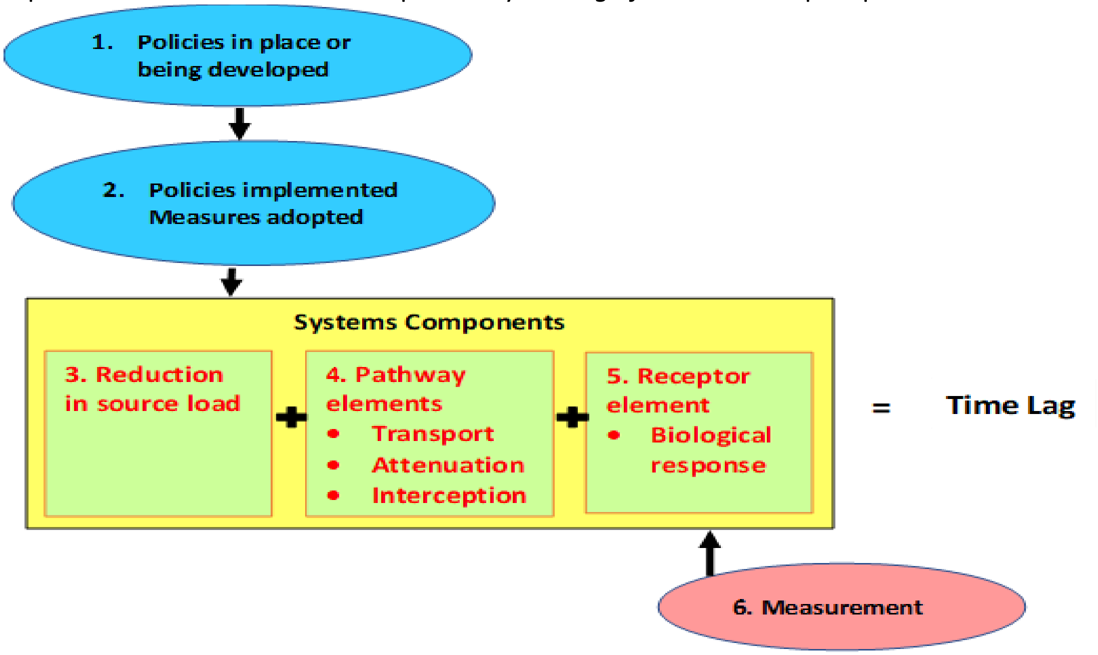


Figure 14-7: Schematic showing the major elements of the potential time delay for improvement.

14.5 Sources of information

Sources of guidance material on protection/mitigation measures/actions are listed in Table 14-2.

Table 14-2: Guidance material on protection/mitigation options

Pressure	Guidance material
Agriculture	• Appendix 10: A summary of the measures in the GAP Regs. • NFGWS (2020) 'A Handbook of Source Protection and Mitigation Actions for Framing' at this link: https://nfgws.ie/nfgws-source-protection-publications/ • McNally (2017), which can be accessed at this link: https://www.catchments.ie/download-category/objectives-and-measures/. • NFGWS (2019). 'A Framework for Drinking Water Source Protection'. Appendix 6 at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/ • DAFM (2018). An explanation of the GAP Regulations at this link: https://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/nitrates/2018Nitratesexplanatoryhandbook03042018.pdf
Hydromorphological	• Section 3.4, Volume 2. • Morrisey, *et al*. (2021). Nature-based catchment management – restoring our waters whilst also achieving multiple benefits. Proceedings of the IAH (Irish Group) Conference “Catchment Science and Management – the Role of Geoscience and Groundwater”,
Diffuse urban	• Volume 6 and Section 5.5, Volume 2.
DWWTSs	• Section 6.4, Volume 2.
Afforestation	• Section 7.4, Volume 2.
Peatland activities	• Section 8.5, Volume 2.
Quarries	• Section 9.4, Volume 2
Mines	• Section 10.4, Volume 2.
Industrial discharges	• Section 11.6, Section 2.

Table 14-1: Landscape locations, associated types of actions and protection/mitigation options for farming activities (adapted from NFGWS (2020).

Location in landscape	Category of action	Action	Protection/mitigation options
All farmland	Discussion with farmers	1	Farmer engagement and collaboration.
At the source of the pollution pressure	Pollutant reduction, or elimination	2	Farmyard management to prevent runoff to watercourses and/or infiltration to groundwater.
		3	Appropriate application of N fertiliser.
		4	Appropriate application of P fertiliser.
		5	Use of precision technology.
		6	Management of farm roadways, drinking troughs, supplementary feeders and gateways.
		7	Using low crude protein animal feed.
		8	Integrated weed management.
		9	Proper storing, handling and disposal of chemicals.
		10	Use of boom sprayers.
		11	Weed-wiping application.
		12	Petrol/diesel & waste oil management.
		13	Management of land reclamation.
		14	Organic farming.
	Reducing mobilisation of pollutants on land	15	Liming of soils.
		16	Timing of fertiliser applications.
		17	Low emission slurry spreading.
		18	Use of protected urea.
		19	Multi-species grassland swards.
		20	Red and white clover.
		21	Cover/catch crops.
		22	Reducing soil compaction.
		23	Land preparation for tillage and grassland.
		24	Rewetting peat soils areas.
Along the pollution pathway	Pathway interception	25	Riparian buffers.
		26	In-field grass buffers.
		27	Hedgerows.
		28	Wild bird cover crops planted alongside watercourse.
		29	Agro-forestry.
		30	Woodlands.
		31	Drainage ditch management and sediment traps.
		32	Low earthen mounds/bunds.
		33	Farm ponds and wetlands.
At the polluted watercourse	Receptor/instream works	34	Livestock exclusion from watercourses.
		35	Bank stabilisation.
		36	Removal of riparian invasive species.

14.5.1 Designing the programme of protection/mitigation actions

It is at this stage that information (described and given as a recommended Process in this Handbook) on some or all of following needs to be evaluated.

- The receptor that is the starting point.
- The receptor requirements.
- Whether the objective is **Protection** or **Improvement/Restoration**.

- The potential pollutant where the water quality is satisfactory or *significant issue* where it is unsatisfactory.
- The potential pressure or *significant pressure*.
- The pollutant load reductions required, if any, to achieve the water quality objective.
- The critical source areas (CSAs).
- The location of the focussed delivery pathways in poorly draining areas.
- The protection/mitigation options.
- Whether they are regulatory, incentivised or voluntary.
- The effectiveness of existing actions.
- The benefits for water quality of the protection/mitigation options being considered.
- The time delays for responses and improvements from the protection/mitigation options.
- The co-benefits of the various options.
- The role of compliance assurance.
- The scientific and engineering disciplines required.
- The required resources (staffing and financial) for the different options.
- The inputs, where necessary or advisable, of other public bodies.
- Where relevant, the acceptability or likely acceptability to the pressure owner.
- The views of stakeholders, such as local communities, landowners, etc., to the conclusions of the assessment being undertaken and the options being considered.

The outcome will be a decision on an action/measure or suite of actions/measures designed to protect and maintain water quality where it is satisfactory and improve/restore where it is unsatisfactory.

The essential role of local authorities

The Draft River Basin Management Plan 2022-2027 is assigning important roles for local authorities. For instance:

i) **County level WFD implementation Plans.**

ii) **Compliance assurance (including enforcement) actions for agricultural activities with increased targeting of inspections based on water quality results, critical source areas and the EPA's PIP maps.**

iii) **Prioritising inspections of domestic wastewater treatment systems to areas of greatest environmental and public health risk.**

iv) **Each local authority will conduct assessments of water bodies with unknown pressures (those not within priority areas for action) to identify the significant pressures in these areas with a high level of confidence.**

v) **The implementation of new planning guidelines that take account of WFD assessments.**

15 Implementation of Mitigation and Protection Measures

At this stage, the recommended management measures and actions have been decided on. Now a focussed implementation programme needs to be delivered. This could involve some or all of the following:

- An information/education/communication component to support public participation (Appendix 13).
- Communication and consultation with and input from relevant public bodies, such as the Local Authority Environment and Planning Sections, the Local Authority Catchment Assessment Teams, Inland Fisheries Ireland, National Parks and Wildlife Service, EPA, OPW.
- Input from relevant scientific, engineering and technical staff, such as catchment, water and agricultural scientists.
- An implementation plan with a schedule of works to be undertaken. (This can be included in the County Level Implementation Plans.)
- Criteria for evaluating and measuring progress.
- Measurable progress milestones for the criteria. While the milestones should be ambitious, they should also be realistic. Therefore, they may need to take account of time lags, with progress verified by interim milestones.
- Implementation.

Achieving the objective – what is needed?

- **Setting a realistic objective or setting intermediate objectives.**
- **An adequate characterisation resulting in decisions on measures/actions that are appropriate and effective.**
- **The choice of the 'right measure'.**
- **Proper establishment of the measure in the '*right place*' and, where appropriate, at the '*right time*'.**
- **Sufficient consultation with stakeholders.**
- **Support from stakeholders, particularly landowners and local communities.**
- **Adequate follow-up and maintenance of measures.**
- **Consideration and understanding of time lags.**
- **Sufficient and suitable inspections, where they are required by Regulations.**
- **Planners knowing and taking account of water quality requirements.**

Setting realistic and achievable objectives

In circumstances where the current water quality is unsatisfactory with concentrations far higher than the metric that determines satisfactory water quality, and where the pressures are diffuse and small point, it is worthwhile setting intermediate objectives in terms of, for instance, mean concentrations, reduced loadings and/or improving trends.

16 Monitoring Progress and Making Adjustments

There are many assumptions, approximations and uncertainties associated with characterisation, particularly CSA determination and selection of protection/mitigation measures and actions. It is essentially impossible to develop a perfect plan, and even more difficult to ensure complete and precise implementation of catchment/sub-catchment/site measures and actions. For these reasons, we need to establish and implement a progress monitoring system to determine if interim implementation milestones and pollutant removal targets are being met on schedule and whether the desired water quality impacts are being achieved.

Once implementation has commenced, monitoring and tracking of progress needs to be undertaken at the intervals determined in the implementation plan. This is likely to involve at least some but probably all of the following:

- Sampling and analysis of water samples at intervals based on the understanding provided by the characterisation process.
- Evaluation, including trend analysis, of the monitoring data.
- Instantaneous flow measurements and water sampling to estimate loads for comparison with the load reduction targets.
- Undertaking SSISs.
- Tracking of the execution of the measures and actions.
- Learning lessons as part of an evolving and iterative process.
- Undertaking catchment walks or site visits on occasions at different times of the year, including after intense and sustained rainfall in poorly draining areas.

If interim targets and the implementation milestones are not being met, an evaluation needs to be undertaken to determine why this is so. This evaluation will inform adjustments to the implementation plan.

Final Message

- **Achieving the required environmental outcomes, whether in Areas for Protection or Areas for Improvement/Restoration or at sites that contain potentially polluting materials is essential for our future wellbeing. It is also a massive challenge for us.**
- **The Process outlined in this Guidance Handbook is aimed at meeting this challenge in an efficient and effective manner.**
- **Sufficient resources in terms particularly of trained staff will be needed to enable the Process to be undertaken.**
- **The necessary Regulations will need to be in place to ensure that the required protection and mitigation measures/actions are established.**

The challenges ahead are enormous. The water quality, biodiversity and climate situation mean that they must be ‘taken on’.

17 Appendix 1: Blue Dot Programme

17.1 Introduction

High status waterbodies are the least impacted waters and are closest to natural biological, chemical, hydrological and morphological condition.[77] Though not always true, as there can be some minimal levels of impact, it is common for high status waterbodies to be referred to as "pristine" or the best of the best.

It is often the case that a high status waterbody will be in a catchment with very low levels of human activity. For this reason, they are often found in the upper reaches as headwaters of river systems. There are exceptions, and some lowland rivers have maintained high status.

To achieve high biological status a waterbody must have adequate diversity and abundances of the most sensitive species. It is generally the case that these waters will have a more diverse community and will have very low concentrations of nutrients (e.g. oligotrophic lakes) compared to good status waterbodies. Relatively small increases in pressures can cause the status of a water body to deteriorate from high to good faster than it would cause reduction from good to moderate, therefore high status waterbodies exhibit a very low capacity to assimilate significant pressures.

In Ireland 19.9% of monitored river sites are at high invertebrate status (Macroinvertebrate Q values of 4-5 or 5) (Figure 17.1). While 8% of monitored rivers are at high ecological status after other quality elements are considered e.g. chemical condition, fish community, hydromorphology etc. (Figure 17.2). This places Ireland in the upper third of EU countries in terms of the percentage of monitored rivers at high status behind Norway, Austria, Croatia, Finland, Spain and Sweden. Many other European countries have few high status rivers left, with Germany, Romania, Poland, the Netherlands and others having fewer than 1 percent of rivers at high status (https://www.eea.europa.eu/data-and-maps/dashboards/wise-wfd accessed 29 09 2021).

There has been a long-term trend of decline in the number of high status river sites. Figure 1 illustrates the extent of the decline since 1987[78]. High status sites have declined from 31.5% (1987-1990) to 19.9% (2017-2020) of monitored sites. Particularly concerning is the decrease in the numbers of sites that were considered of the highest quality, which score a Q5. In the 1980s, Q5 sites made up 13.4% of all monitored sites; now only a small minority of the monitored sites are at Q5 (1.4%). The recent draft River Basin Management Plan (2022-2027) also highlights the decline in high status surface water since Water Framework Monitoring began (Figure 3).
See separate folder for details.

17.2 Water Framework Directive & Blue Dots

Under the Water Framework Directive (WFD), Member States are required to prevent deterioration of the status of all surface waters and achieve at least good status in all surface waters. The first objective of preventing deterioration means that waterbodies that are at high status must not deteriorate to good status. Waterbodies which have a high status objective have been defined for Ireland in the River Basin Management Plan for Ireland 2018 – 2021 following analysis by the Environmental Protection Agency (EPA). These waterbodies are now more commonly referred to as Blue Dot waterbodies or Blue Dots.

[77] This Appendix was contributed by Bernie White and Cormac McConigley, LAWPRO.
[78] https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/water-quality-in-2020.php

For a river waterbody to be assigned a high status objective (HSO) it should:

- follow a pattern whereby high status has been achieved regularly throughout its monitoring history, and
- if deterioration has occurred, it will only have only occurred recently, i.e. since WFD monitoring commenced (2007 – 2009).

What is a Blue Dot?
The Water Framework Directive has several objectives. One is to prevent deterioration of the status of all surface waters. This means that water bodies that are High Status should not decline to Good Status or worse. The EPA have identified the waters in Ireland that should have a high status objective, and these are more commonly known as Blue Dot waters or Blue Dots. Our Blue Dot Waters include rivers, lakes, estuaries, and coastal waters

The EPA has applied these criteria to monitoring data and identified which rivers have a HSO (Table 17.1). Lakes tend to be less changeable than rivers over time, therefore the criteria used was if a lake achieved high status during any of the monitoring cycles since WFD monitoring began in 2007, it would have a HSO (Table 17.1). The situation for transitional and coastal waterbodies is somewhat more complicated as the assessment methods for particular elements changed during the first 3 WFD monitoring cycles (2007 – 2009, 2010 – 2012 and 2013 – 2015), and direct comparisons between years is not possible. For these waterbodies, the HSO has been assigned by the EPA based on a weight of evidence approach using all the available elements and confidences in the assessments at each monitoring period.

The RBMP was published by the Minister for Housing, Planning and Local Government in April 2018. Ireland undertook a comprehensive re-characterisation of its waters as part of its preparation. This led to the publication in the RBMP of all HSO waterbodies. Characterisation has been updated and included as part of the recently published draft RBMP 2022-2027.

At present only 165 (43%) of the 384 Blue Dot waterbodies are achieving their high status objective (Table 17.2). Characterisation has determined that 179 (46.6%) Blue Dot waters are At Risk of not achieving their high status environmental objective (Table 17.1). This is slightly greater than the number currently at less than high status as characterisation takes trend data and other factors into account not just current monitoring results. A further 32 (8.3%) require further assessment or monitoring to assess their risk. Therefore, protection measures are required for the 165 (43%) of Blue Dot waters that are at high status to ensure they do not deteriorate; restoration measures for those not achieving high status where Risk has been determined 193 (50.3%); and further investigation into the remaining 26 (6.8%) where status is less than high and risk has not been determined.

In the 2nd Cycle of the RBMP 53% of Blue Dot rivers and 33% of Blue Dot lakes that were At Risk were included in the Priority Area for Action work programme of the Local Authority Waters Programme (LAWPRO) (Figure 17.9).

In the 3rd Cycle of the RBMP 78% of Blue Dot rivers and 84% of Blue Dot lakes that are At Risk are proposed for inclusion in an Area for Action. In the 3rd cycle a Sub-Catchment approach was used for delineation of the Area for Action which results in a number of Not at Risk and Review HSO waterbodies being incorporated which was not the case in the 2nd cycle (Table 17.3).

Table 17.1: Numbers of High Status Objective Waterbodies and their current risk classification*

Water Body Type	High Status Objective	*At Risk*	*Review*	*Not at Risk*
River (FPM)	319 (28)	160 (21)	23	136 (7)
Lake	37	19	4	14
Transitional	11	0	4	4
Coastal	17	0	1	16
Totals	384	179	32	173

*Figures in brackets are for Freshwater Pearl Mussel river water bodies within Ireland's Top 8 catchments for this species.

Table 17.2: Status of the 384 Blue Dot waterbodies in each of the WFD monitoring cycles

Status of Blue Dot Waterbodies	2007-2009	2010-2012	2010-2015	2013-2018
High	269	289	248	165
Good	75	70	121	191
Moderate	6	10	10	18
Poor	0	0	2	5
Bad	0	0	0	1
Unassigned	34	15	3	4
Total	384	384	384	384

Table 17.3: Number and Percentage of Blue Dot Waterbodies proposed to be included within an Area for Action for the 3rd Cycle RBMP

Water Body Type	Total	*At Risk*	*Review*	*Not at Risk*
River	204 (64%)	125 (78%)	16 (70%)	63 (46%)
Lake	27 (73%)	16 (84%)	3 (75%)	8 (57%)
Coastal	2 (12%)	-	-	2 (13%)
Transitional	5 (45%)	-	-	5 (71%)

HSO waterbodies are most common along the Western Seaboard (Figure 17.3). There are a number in the Wicklow mountains in the East and the Slieve Blooms in the midlands and others less densely spread across the remainder of the country (Figure 17.4). Spatial layers of the HSO waterbodies are available from the EPA and are viewable on catchments.ie.

17.3 Significant Pressures - 2nd cycle

The types of pressures acting on At Risk HSO waterbodies have a different profile to pressures acting on all At Risk waterbodies nationally, reflecting that HSO waterbodies are often in upper catchment areas where agriculture tends to be less intense but on poorer land and where forestry is more widespread (Figure 17.5). For HSO waterbodies, forestry was the number one significant pressure, followed by hydromorphology (mostly channelisation and land drainage) and agriculture based on 2nd cycle characterisation undertaken by the EPA. Whereas across all At Risk waterbodies, agriculture was the number 1 pressure followed by hydromorphology and Urban Waster Water (Figure 17.6).

17.4 Significant Pressures - 3rd cycle

The risk profile for significant pressures acting on HSO water bodies has now changed as a result of updated characterisation by the EPA for the 3rd cycle. Hydromorphology is now the dominant significant pressure, followed by agriculture with forestry now in third position (Table 17.4).

The number of waterbodies impacted by changes to hydromorphology, has increased for all water bodies (whether with a high or good status objective) since the second cycle. It should be noted that improved methods of assessment for hydromorphology have contributed to the increase.

Evidence from LAWPRO local catchment assessments indicates that land drainage of poorly draining and peat soils for agricultural use, is a significant and damaging activity leading to impacted sites. An additional concern recorded is older forestry plantations on unsuitable soils, with inappropriate drainage (drains leading directly to water courses and poor or no buffers). While currently not impacting, the future risk from these sites in the absence of mitigation measures, or poorly implemented mitigation measures, is a concern. This means that a large percentage of the waters that are under pressure from hydromorphology are in effect under pressure from agriculture and forestry.

Hydromorphology, Agriculture and Forestry between them are significant pressures either alone or in combination with other pressure in 151 Blue Dot waters, this is 84% of At Risk Blue Dots and 39% of all Blue Dots.

Table 17.4: Numbers of Blue Dot waterbodies significantly impacted by the various pressures in the 2nd and 3rd cycle.

	Blue Dots			
	2nd cycle	3rd cycle	Change	%change
Hydromorphology	40	77	37	93%
Agriculture	39	58	19	49%
Forestry	42	52	10	24%
Anthropogenic pressures	18	29	11	61%
Extractive industry	15	14	-1	-7%
Domestic Waste Water	10	12	2	20%
Abstraction	3	6	3	100%
Industry	2	4	2	100%
Invasive Species	2	4	2	100%
Other Anthropogenic Pressures	1	3	2	200%
Urban Waste Water	3	3	0	0%
Atmospheric	1	1	0	0%

17.5 Blue Dot Catchments Programme

The River Basin Management Plan (2018–2021) set out that a “Blue Dot Catchments Programme” (here after the Programme) would be delivered through local authority structures, integrating with wider implementation structures, and will facilitate focussed deployment of resources with the aim of protecting, and where possible, restoring high ecological status. The intention for the Programme is to ensure that high status waters are prioritised for the implementation of supporting measures and for available funding. The Programme was set up in early 2019 with the formation of the National Blue Dot Steering Group (hear after the Steering Group). The Steering Group includes key stakeholders involved in delivering sectoral measures within Blue Dot catchments (Table 17.5).

Table 17.5: Composition of the Blue Dot Steering Group

National Blue Dot Steering Group
Department of Housing, Local Government and Heritage (Water Policy Advisory Unit and National Parks and Wildlife Service)
Department of Agriculture, Food and the Marine (Agriculture & Forest Service)
Local Authority Waters Programme
Environmental Protection Agency
Representative Local Authorities (Kerry, Wicklow, Donegal and Mayo)
Coillte
Inland Fisheries Ireland
Office of Public Works
Irish Water

The overall Programme aim is "*to protect and restore high status waters in Ireland*". To achieve this ultimate aim, a number of programme objectives were agreed. The Steering Group have been progressing each of the objectives and are now developing a detailed work programme for the third cycle of the RBMP (2022-2027) which will build on the advances made between 2018 and 2021.

The 2nd Cycle Blue Dot Catchments Programme objectives are:

1. Agree a vision for the protection and restoration of high status waters in Ireland.
2. Determine what constitutes a Blue Dot water body / site / catchment, and agree on a spatial network of high status waters in Ireland.
3. Agree branding for high status / blue dot waters.
4. Prepare a communications and engagement plan.
5. Establish pilot projects for community engagement and action.
6. Work together with DHPLG to establish appropriate planning guidance for the protection of Blue Dot waters.
7. Influence national schemes and programmes which can prioritise the protection and restoration of Blue Dot waters.
8. Assist in improving the exchange of information within and between local and public authorities and with Government Departments.
9. Consider areas where further research is required.
10. Review proposals for site specific measures for high status objective water bodies from LAWPROs work programme and the *Waters of LIFE* Integrated Project.
11. Contribute to the development of a long term strategy for high status waters.

A key component of the Work Programme was the development of a Communications and Engagement Plan which sets up the programme well for delivery in the 3rd Cycle.

The communications goals are to:

- Generate awareness amongst key audiences regarding the quality of our Blue Dot waters, focusing firstly on the key sectoral stakeholders who have the most impact on our Blue Dot waters; and thereafter on communities.
- Turn awareness into engagement and action, in the form of stewardship of our Blue Dot waters.

The engagement will be delivered on a phased basis where the programme will initially engage with the forestry sector followed by the agricultural sector. The prioritisation of sectors was determined based on the number of Blue Dots where the sector was identified as a significant pressure in the 2nd cycle of the RBMP.

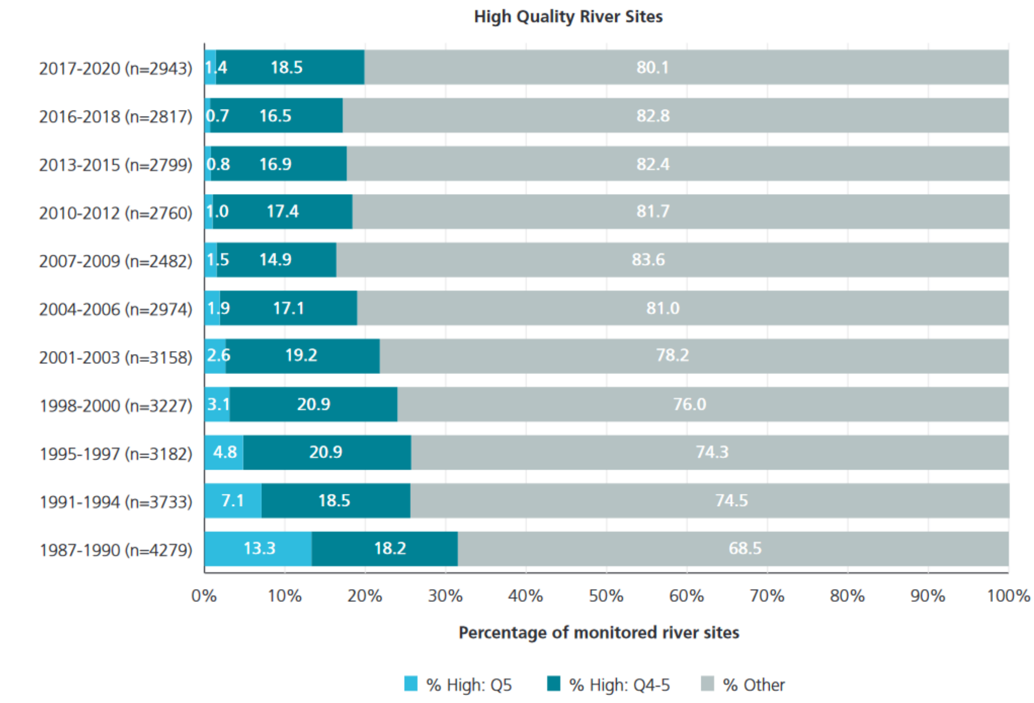
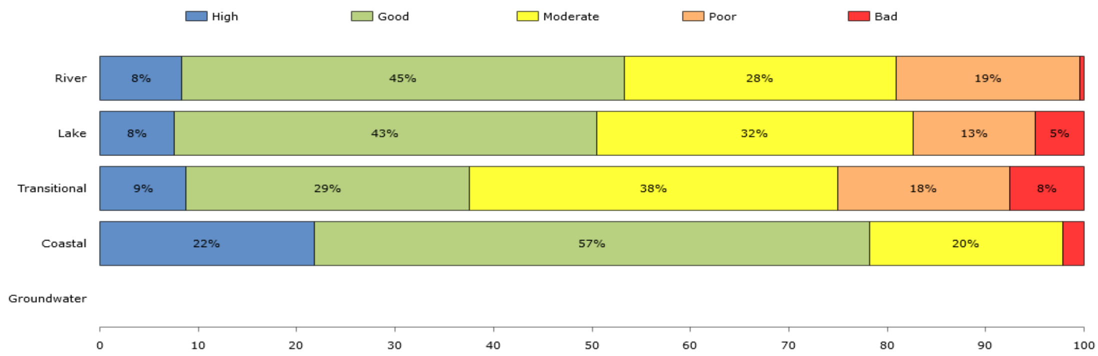


Figure 17.1: Number of high ecological quality river sites[79]



Status of Irish Waters	High	Good	Moderate	Poor	Bad
River	8%	45%	28%	19%	0%
Lake	8%	43%	32%	13%	5%
Transitional	9%	29%	38%	18%	8%
Coastal	22%	57%	20%	0%	2%
Groundwater	0%	0%	0%	0%	0%

Figure 17.2: Surface water status 2013-2018 (catchments.ie accessed 29-09-2021)[80]

[79] Source: Water Quality In 2020 An Indicators Report page 9 (https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/EPA_Water_Quality_2020_indicators-report.pdf)
[80] Dashboard can be accessed via the catchment's website (www.catchments.ie/data/#/dashboard/waterquality)

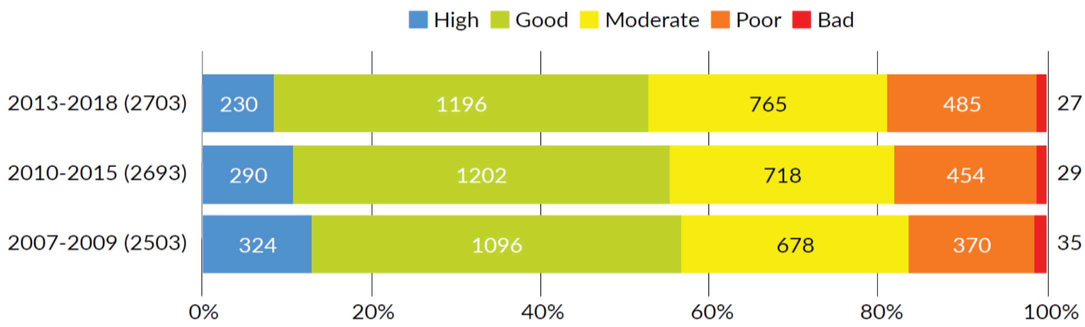


Figure 17.3: Change in status categories over three assessment periods for all surface waters.[81]

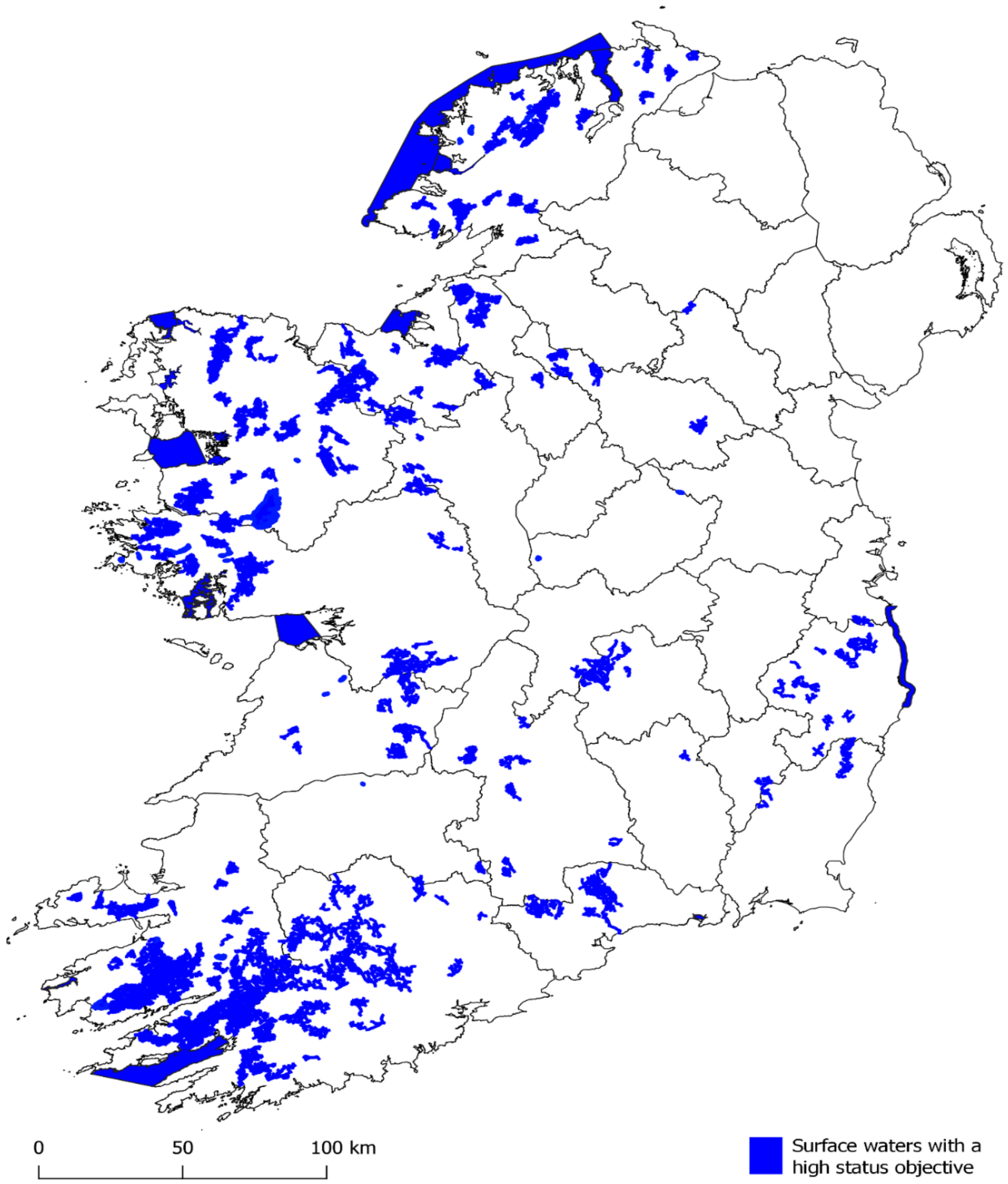


Figure 17.4: HSO distribution

[81] Source: Draft River Basin Management Plan for Ireland 2022 – 2027. Figure 12 in the plan

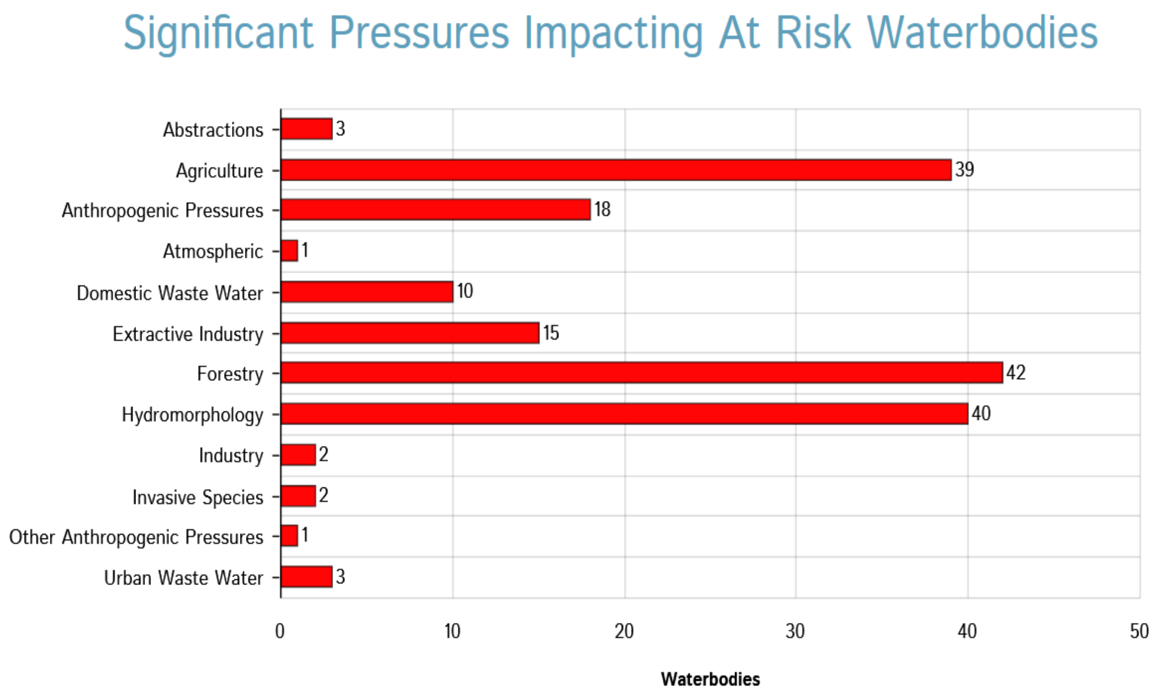


Figure 17.5: Significant pressures on Blue Dot waterbodies in the second cycle

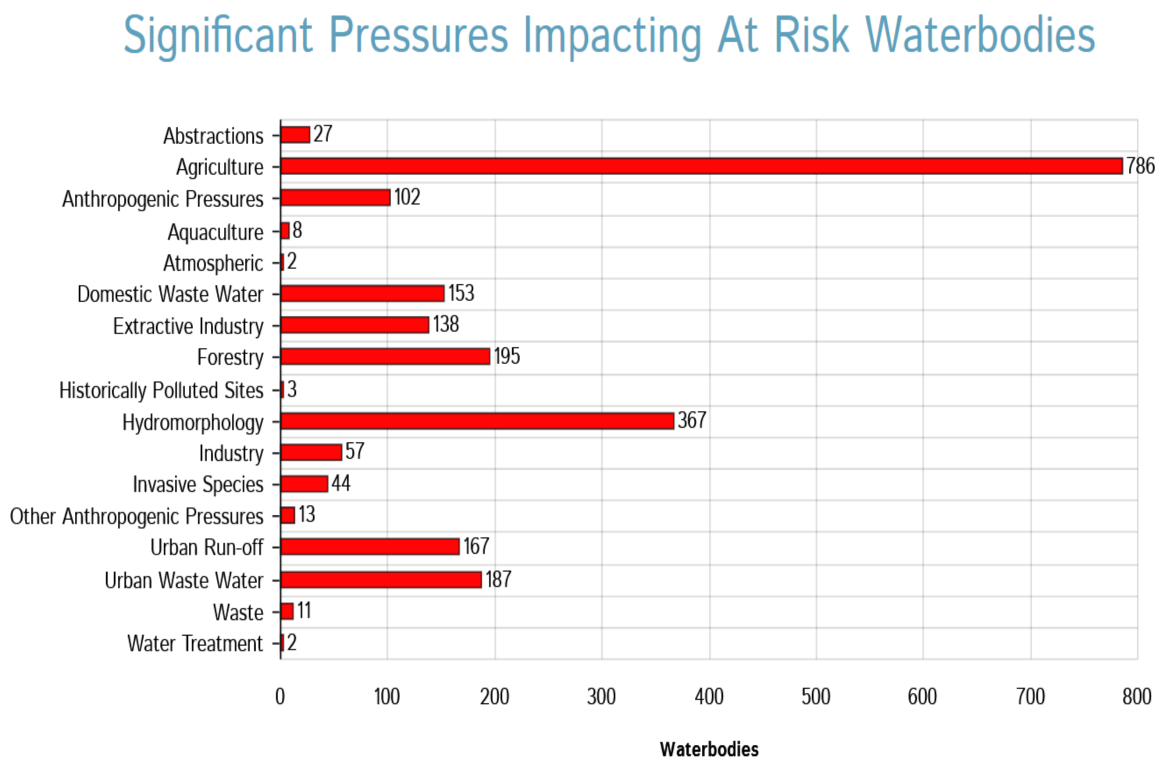


Figure 17.6: Significant pressures on all waterbodies in the second cycle

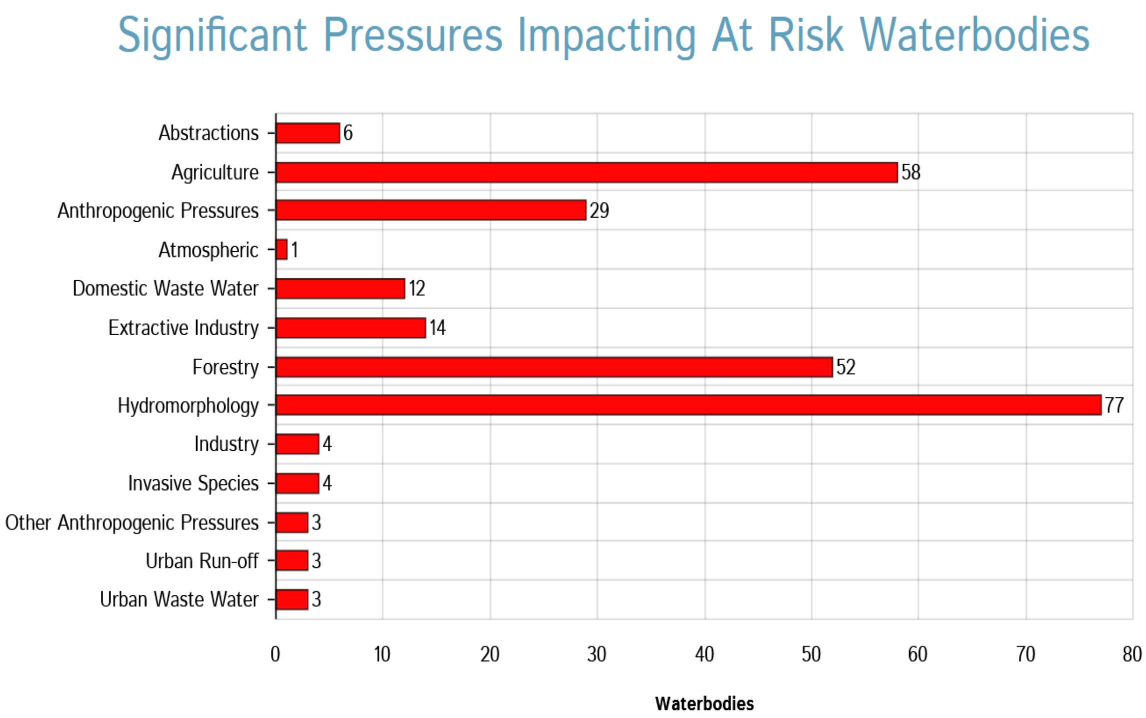


Figure 17.7: Significant pressures on Blue Dot waterbodies in the third cycle

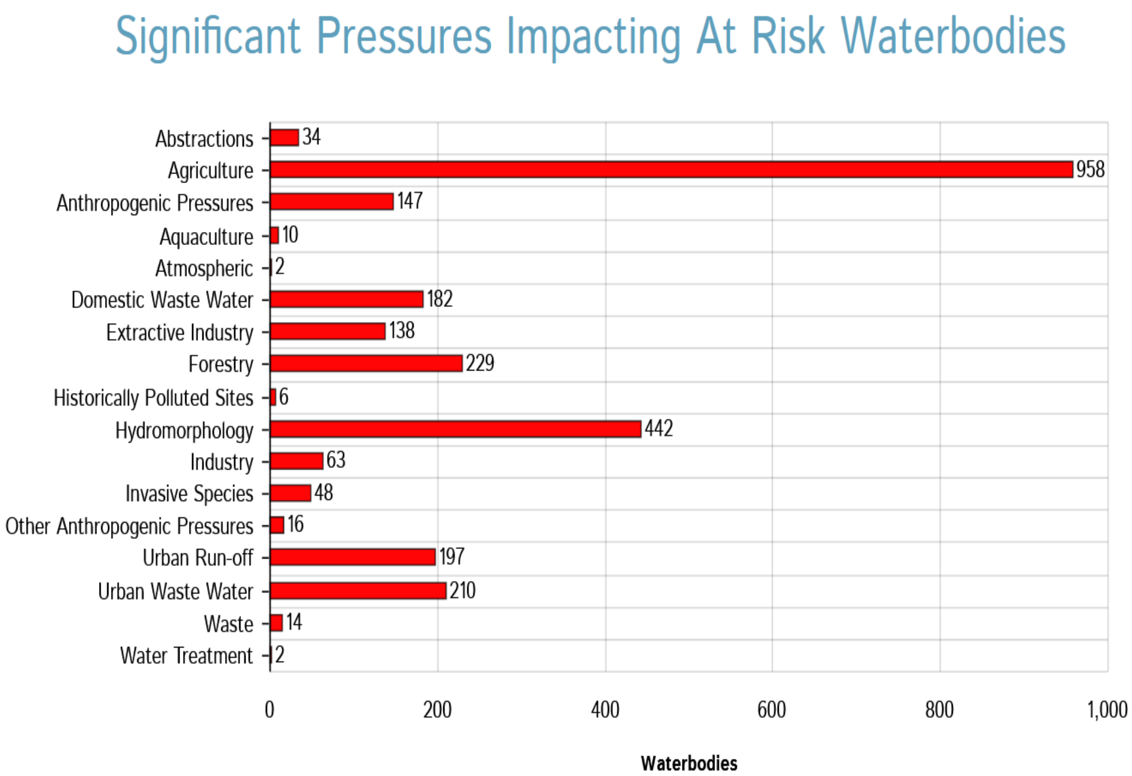


Figure 17.8: Significant pressures on all waterbodies in the third cycle

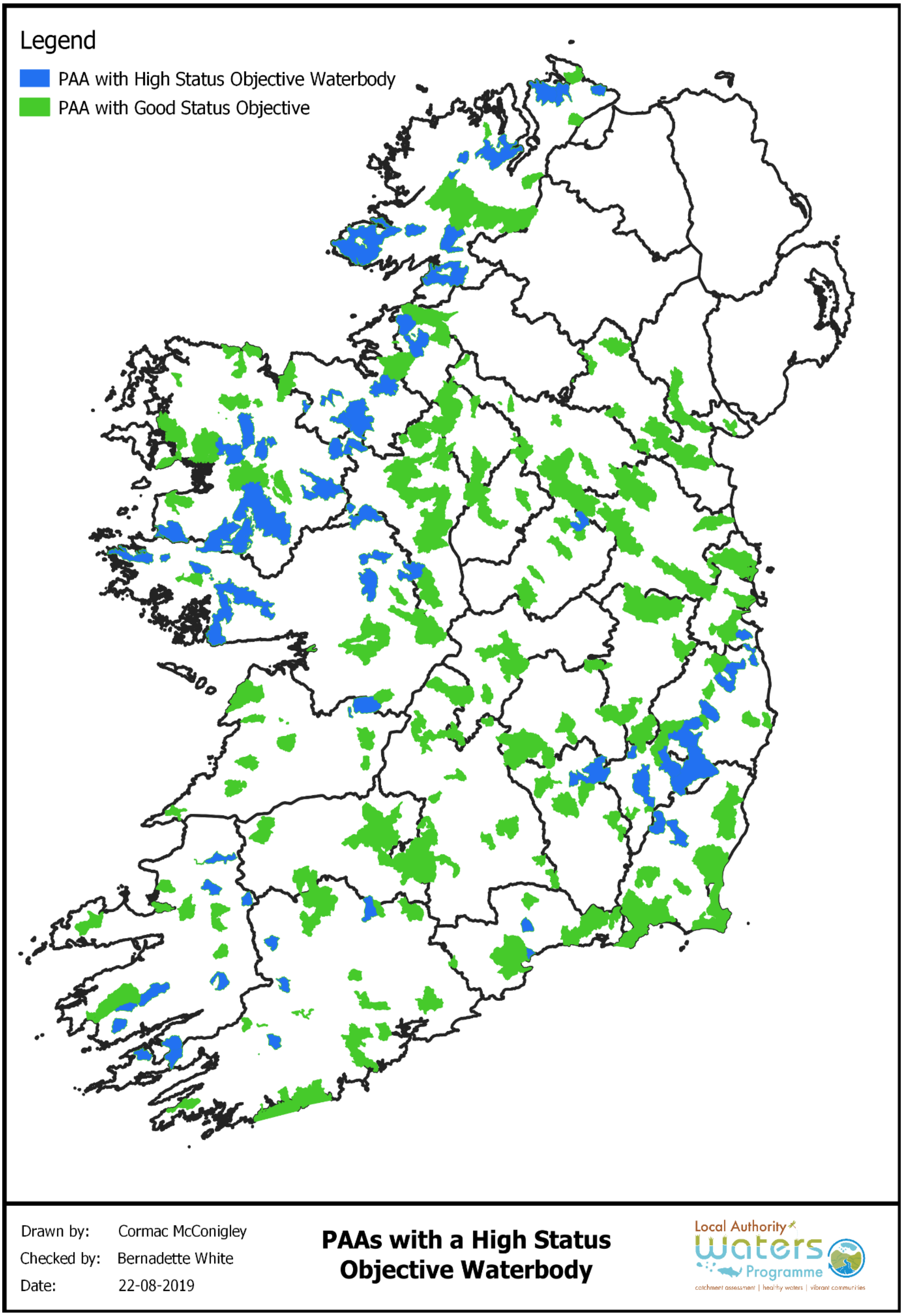


Figure 17.9: Water bodies with a high status objective overlap with Priority Areas for Action

17.6: LAWPRO PAA Case Studies

17.6.1: Lough Nastackan, Border Region

Lough Nastackan is a PAA that includes the Blue Dot river LOUGH NASTACKAN STREAM_010. The waterbody dropped from high to poor in 2013.

LAWPRO carried out surveys around the monitoring point on 11th September 2019 and scored an SSIS of 8. However, from just this score it is not possible to determine if the waterbody is impacted due to its high status objective.

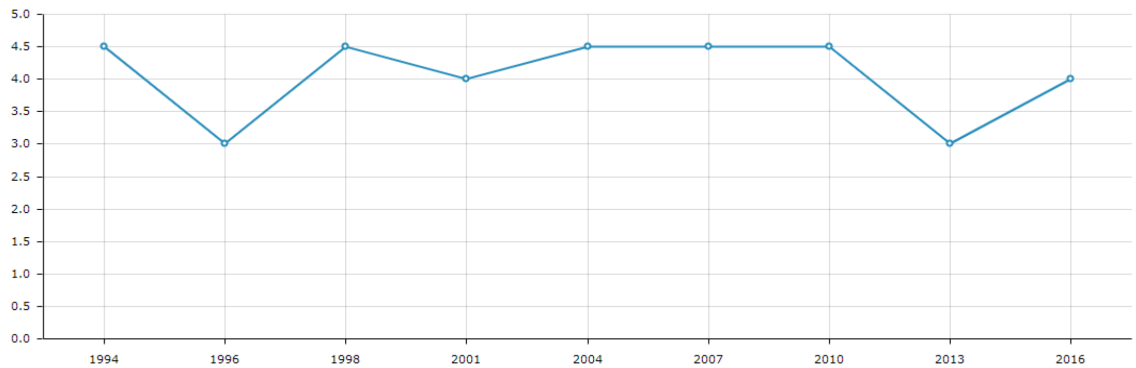
Applying the rules developed by LAWPRO in consultation with the EPA in relation to interpretation of scores for HSO sites, LAWPRO determined that this site is "Probably not Significantly Impacted for HSO" as there were three Group A taxa present, 2 in good numbers and the total abundance over 30% of the community, while tolerant taxa were not present in high numbers (Figure 17.10).

In this case the EPA surveyed the site again on the 19th of September, just 8 days after LAWPRO. They determined that the site had returned to high status. For a complete breakdown of the taxa captured by the EPA and LAWPRO see Table 6 below.

In this case, land drainage activities were identified as being the most probably source of the deterioration noted in 2013, when the evidence collated from both the deskstudy stage and LCA stages were reviewed. Key lines of evidence in this case were EPA Q value data, including an additional Q value sample the EPA biologist had taken at the time the deterioration was recorded in 2013; a review of aerial imagery timelines for landuse activities in the subbasin, and LCAs are strategic sites on the water body to determine current SSIS scores.

Q value history reviewed at deskstudy stage:

WB Code	WB Name	WFD Risk	Status Obj.	Status				Pressure Category	Pressure Sub-category	Sig. Pressure
				07-09	10-12	13-15	13-18			
IE_NW_40L0 30400	Lough Nastackan Stream_010	*At Risk*	High 2021	H	H	P	G	Agri.	Pasture	Yes
IE_NW_40L0 10200	Long Glen_010	*At Risk*	Good 2027	H	U	P	P	Agri.	Pasture	Yes



	1994	1996	1998	2001	2004	2007	2010	2013	2016
Result	4.5	3	4.5	4	4.5	4.5	4.5	3	4
Classification	High	Poor	High	Good	High	High	High	Poor	Good
Q-Value	4-5	3	4-5	4	4-5	4-5	4-5	3	4

Review of available data at deskstudy stage include EPA characterisation notes:

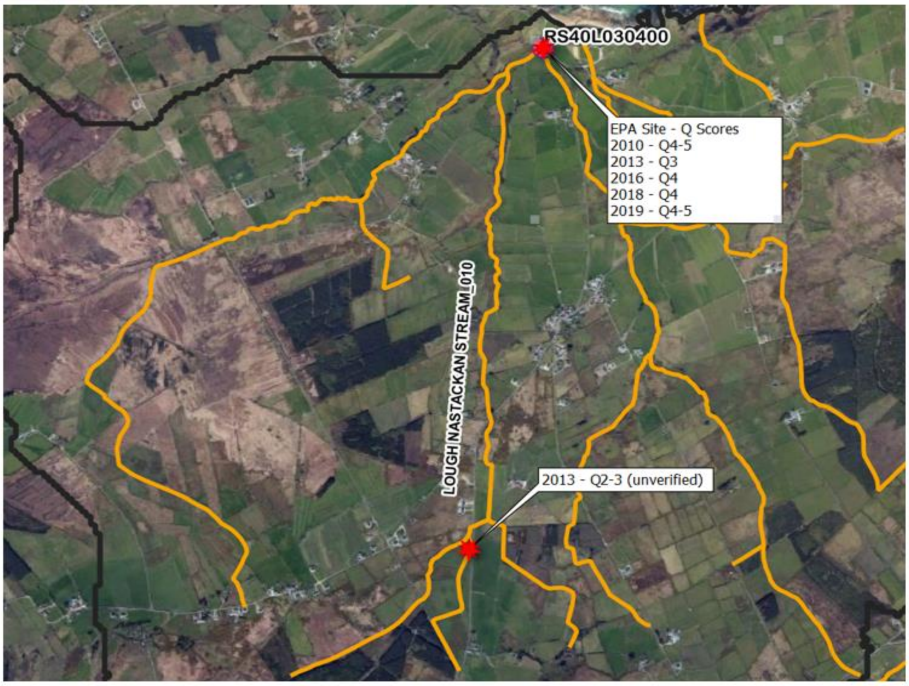
Local Authority Waters Programme
vibrant communities | catchment assessment | healthy waters

Initial Characterisation

- Pressure – Agriculture (pasture)
- Further IA – IA1 - *Provision of Information - EPA for a watching brief to liaise with Loughs Agency 6 monthly monitoring*
- Desk study
  - '13-'15 Baseline chemistry seems fine (OrthoP = 0.010mg/l, Amm = 0.027mg/l), limited data pre-'13 but '12 & '13 were both below LOD for OrthoP and Amm
  - Loughs Agency nothing to add
  - Low stocking densities
  - Potential forestry pressures at headwaters

Review of EPA monitoring point locations to help inform LCA site selection:

Local Authority Waters Programme
vibrant communities | catchment assessment | healthy waters



Review of aerial imagery from pre deterioration to post deterioration e.g.:

17.6.2 Caha_020, South Western Region

The Caha_020 is a Blue Dot river that dropped to good status in 2015. LAWPRO sampled the monitoring point in April 2019 and the SSIS score resulting was 9.6 (Probably not Significantly Impacted). However, with additional interpretation of the assemblage, the waterbody was determined to be Probably Impacted. There were several Group A taxa present but they did not make up 30% of the community. There were quite high numbers of GOLD taxa and non-scoring taxa which lowered the percentage of the community made up of Group A taxa (see Figure 17.11).

Note also that the sample was collected in April, not in the summer (June to September), which is the prime time for assessment of HSO water bodies. We would expect this site to score better in April than in the summer. It is likely that if a site is impacted in spring it will be in a poorer condition in the summer.

The EPA monitored the location again on the 13th of June 2019 and confirmed that the site was at Good status. A comparison of the assemblages from both surveys is presented in Table 17.6 below.

In this case, EPA characterisation had identified that the potential pressures might be forestry, a quarry and hydromorphology. LCA was undertaken and analysis of the assemblages showed that the sensitive invertebrate taxa were present but outnumbered by abundant tolerate taxa. In addition, there were moderate silt plumes evident when the river bed was disturbed at a number of sites, and macrophyte growth had established in many parts of the channel due to the additional sediment deposited on the river bed. Water chemistry sampling found elevated orthophosphate, ammonium in areas where land drainage had been undertaken, and a single high nitrate value was also recorded in one location.

Using several lines of evidence, catchments walks and recording of observations etc., the conclusions were:

- No issues found associated with the quarry.
- Only minor issues from forestry (sediment)
- Most issues were associated with agricultural activities (nutrient and hymo)
- Agricultural practices leading to these issues were intensification, drainage, cattle access and point sources.
- A windfarm also created an issue with alum floc in this water body.

Actions taken included:

- Cork County Council monitoring wind farm activities.
- Referrals to ASSAP who liaised with farmers in the referral areas.
- A group of local farmers are also taking action to reduce sediment loss and working with the Bandon Rivers Trust. Work includes fencing of river banks.

Caha_020 LCA sampling sites:

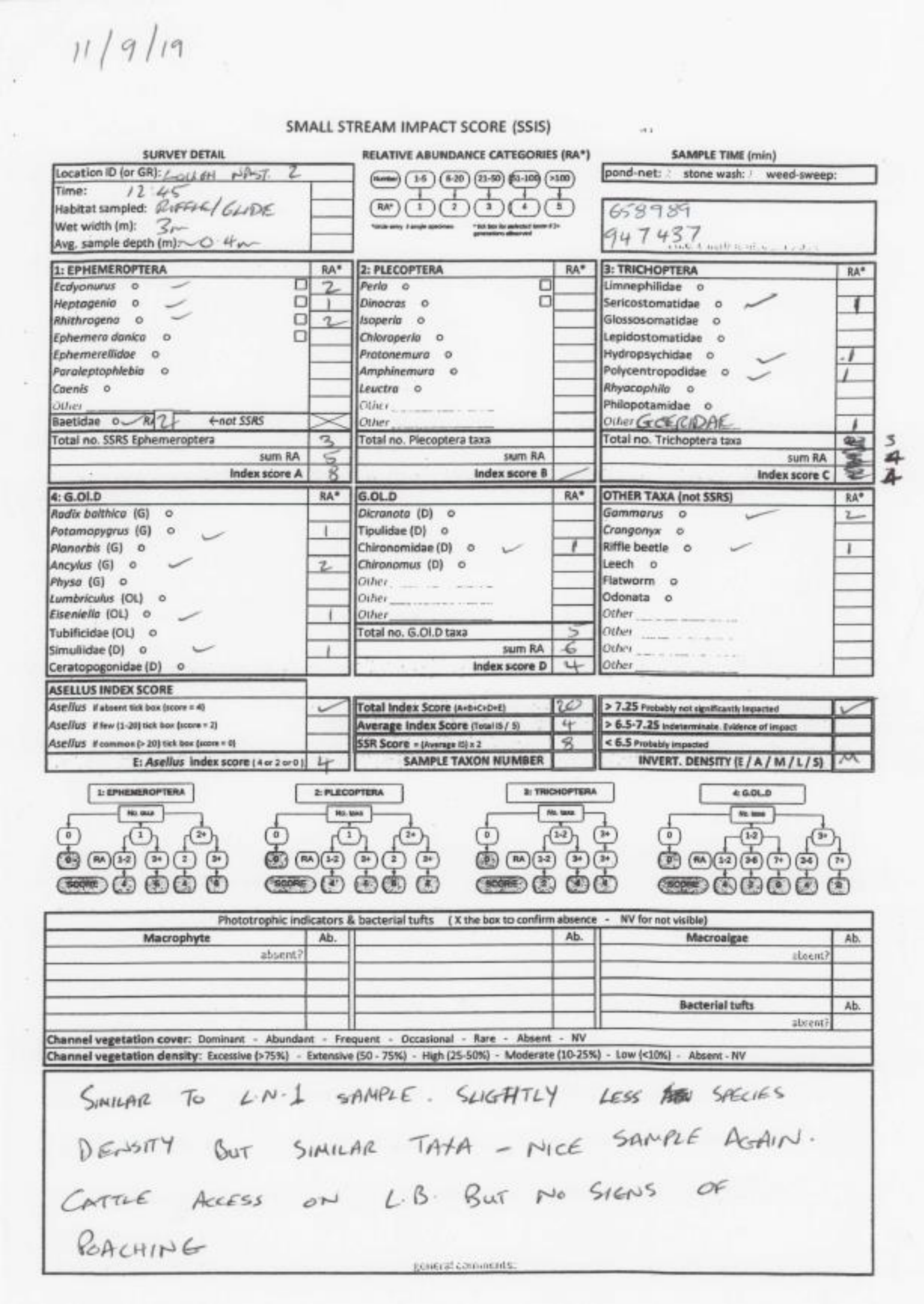
Example of LCA water chemistry collected:

Entity	Cond	DO (%)	pH	MRP_P	NH4_N	TON
Caha 1	121	94.9	7.72	0.023	0.032	0.92
Caha 2	119	93.5	7.47	0.026	0.115	0.88
Caha 3	187	85.8	7.57	0.044	0.02	3.33
Caha 4	114	92.6	7.38	0.042	0.183	0.76
Caha 5	165	85.5	7.35	0.037	0.05	1.71
Caha 6	119	92.9	7.21	0.023	0.03	0.46
Caha 7	105	94.4	7.34	0.039	0.236	0.57
Caha 8	113	94.1	7.68	0.015	0.02	0.5
Caha 9	98	92.3	7.18	0.011	0.02	0.53
Caha 10	101	87.2	6.68	0.01	0.02	0.47

Land drainage activities were documented and photographed:

Referrals issued for the Caha_020

Category	subcategory	Impact assessment	Pressure & Impact details
Agriculture	Pasture	Elevated ortho P, ammonia in water chemistry samples	Nutrient pollution
Agriculture	Agriculture	Elevated ortho P, nitrate and ammonia in water chemistry samples	Nutrient pollution
Agriculture	Farmyards	Pipe discharging to tributary stream from farmyard – sewage fungus evident	Organic Pollution
Agriculture	Pasture	Multiple cattle access points on main channel (including SAC) and tributary streams: evidence of bank erosion, sedimentation, poaching of bank	Nutrient pollution Other significant impact (sediment)
Hydromorphology	Land Drainage	Agricultural land 'reclamation' - channelisation of tributary streams - resectioning, overdeepening, embankment, removal of riparian vegetation.	Altered habitat due to morphological changes
Other Anthropogenic Pressures	Windfarms	Siltation from windfarm construction. Elevated suspended solids in drain immediately d/s of substation site.	Other significant impact (sediment)



11/9/19

SMALL STREAM IMPACT SCORE (SSIS)

SURVEY DETAIL	
Location ID (or GR): LOUGH NAST. 2	
Time: 12:45	
Habitat sampled: RIFFLE/GLIDE	
Wet width (m): 3m	
Avg. sample depth (m): ~0.4m	

RELATIVE ABUNDANCE CATEGORIES (RA*): (Number) 1-5, 6-20, 21-50, 51-100, >100 → RA* 1, 2, 3, 4, 5

SAMPLE TIME (min): pond-net: stone wash: weed-sweep:

658989
947437

1: EPHEMEROPTERA	RA*
Ecdyonurus ✓	2
Heptagenia ✓	1
Rhithrogena ✓	2
Ephemera danica	
Ephemerellidae	
Paraleptophlebia	
Caenis	
Other	
Baetidae ✓ RA 2 ← not SSRS	
Total no. SSRS Ephemeroptera	3
sum RA	5
Index score A	8

2: PLECOPTERA	RA*
Perla	
Dinocras	
Isoperla	
Chloroperla	
Protonemura	
Amphinemura	
Leuctra	
Other	
Other	
Total no. Plecoptera taxa	
sum RA	
Index score B	

3: TRICHOPTERA	RA*
Limnephilidae	
Sericostomatidae ✓	1
Glossosomatidae	
Lepidostomatidae	
Hydropsychidae ✓	1
Polycentropodidae ✓	1
Rhyacophila	
Philopotamidae	
Other GOERIDAE	1
Total no. Trichoptera taxa	3
sum RA	4
Index score C	4

4: G.OI.D	RA*
Radix balthica (G)	
Potamopygrus (G) ✓	1
Planorbis (G)	
Ancylus (G) ✓	2
Physa (G)	
Lumbriculus (OL)	
Eiseniella (OL) ✓	1
Tubificidae (OL)	
Simuliidae (D) ✓	1
Ceratopogonidae (D)	

G.OI.D	RA*
Dicranota (D)	
Tipulidae (D)	
Chironomidae (D) ✓	1
Chironomus (D)	
Other	
Other	
Other	
Total no. G.OI.D taxa	5
sum RA	6
Index score D	4

OTHER TAXA (not SSRS)	RA*
Gammarus ✓	2
Crangonyx	
Riffle beetle ✓	1
Leech	
Flatworm	
Odonata	
Other	
Other	
Other	
Other	

ASELLUS INDEX SCORE	
Asellus if absent tick box (score = 4)	✓
Asellus if few (1-20) tick box (score = 2)	
Asellus if common (> 20) tick box (score = 0)	
E: *Asellus* index score (4 or 2 or 0)	4

Total Index Score (A+B+C+D+E)	20
Average Index Score (Total/5)	4
SSR Score = (Average IS) x 2	8
SAMPLE TAXON NUMBER	

> 7.25 Probably not significantly impacted	✓
> 6.5-7.25 Indeterminate. Evidence of impact	
< 6.5 Probably impacted	
INVERT. DENSITY (E / A / M / L / S)	M

Phototrophic indicators & bacterial tufts (X the box to confirm absence - NV for not visible)

Macrophyte	Ab.		Ab.	Macroalgae	Ab.
absent?				absent?	
				Bacterial tufts	Ab.
				absent?	

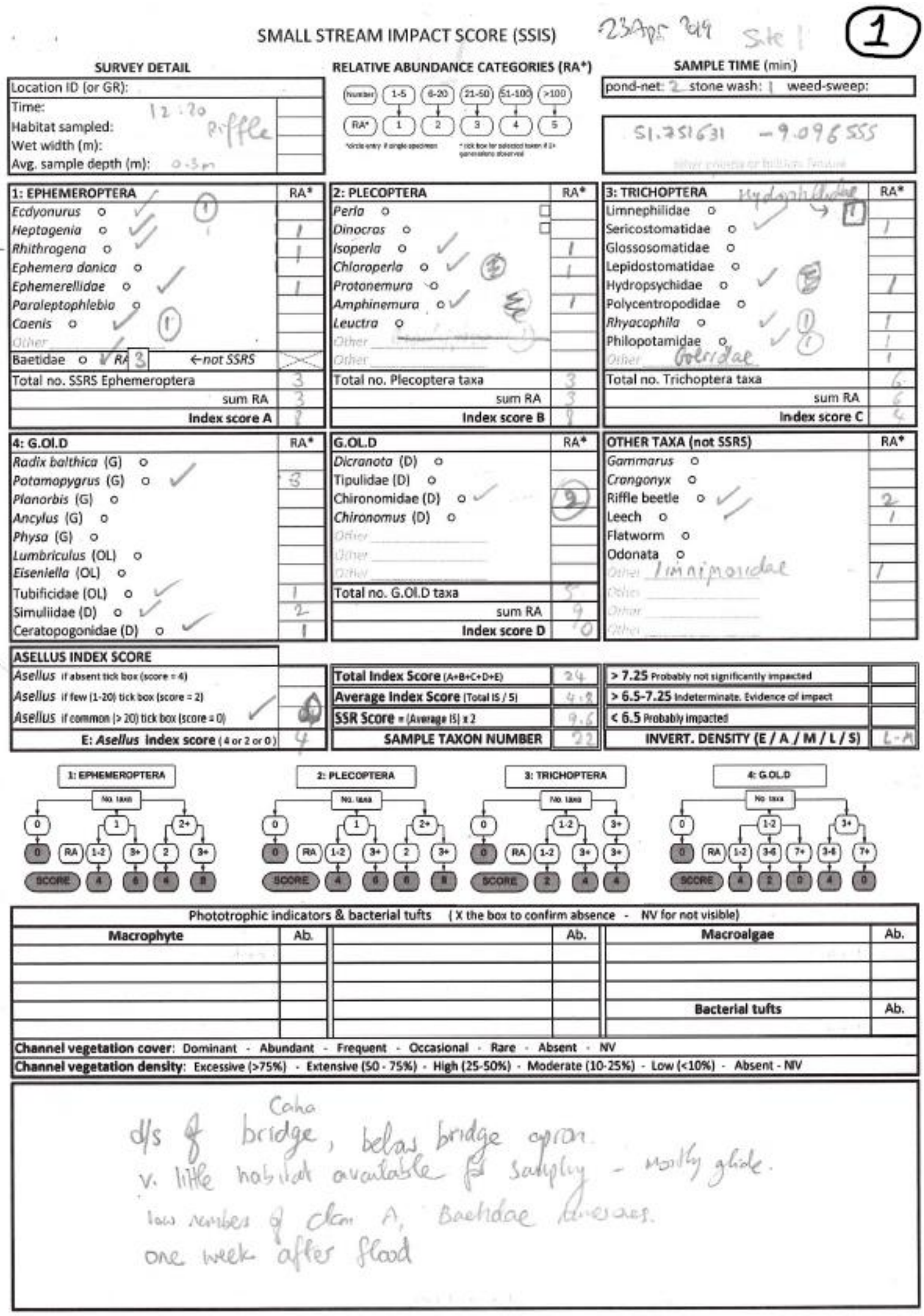
Channel vegetation cover: Dominant - Abundant - Frequent - Occasional - Rare - Absent - NV

Channel vegetation density: Excessive (>75%) - Extensive (50 - 75%) - High (25-50%) - Moderate (10-25%) - Low (<10%) - Absent - NV

SIMILAR TO L.N.1 SAMPLE. SLIGHTLY LESS [illegible] SPECIES DENSITY BUT SIMILAR TAXA - NICE SAMPLE AGAIN. CATTLE ACCESS ON L.B. BUT NO SIGNS OF POACHING

general comments:

Figure 17.10: SSIS sheet from Blue Dot waterbody lough Nastackan (Version D01 of fieldsheet)



SMALL STREAM IMPACT SCORE (SSIS) 23 Apr '19 Site 1 (1)

SURVEY DETAIL		RELATIVE ABUNDANCE CATEGORIES (RA*)	SAMPLE TIME (min)
Location ID (or GR):		Number: 1-5, 6-20, 21-50, 51-100, >100	pond-net: 2 stone wash: 1 weed-sweep:
Time: 12:20		RA*: 1, 2, 3, 4, 5	51.751631 −9.096555
Habitat sampled: Riffle		*circle entry if single specimen; * tick box for selected taxon if 2+ generations observed	
Wet width (m):			
Avg. sample depth (m): 0.3 m			

1: EPHEMEROPTERA	RA*	2: PLECOPTERA	RA*	3: TRICHOPTERA (Hydroptilidae)	RA*
Ecdyonurus		Perla		Limnephilidae	1
Heptagenia	1	Dinocras		Sericostomatidae	1
Rhithrogena	1	Isoperla	1	Glossosomatidae	
Ephemera danica		Chloroperla	1	Lepidostomatidae	
Ephemerellidae	1	Protonemura		Hydropsychidae	1
Paraleptophlebia		Amphinemura	1	Polycentropodidae	
Caenis		Leuctra		Rhyacophila	1
Other		Other		Philopotamidae	1
Baetidae RA 3 ←not SSRS		Other		Other Goeridae	1
Total no. SSRS Ephemeroptera	3	Total no. Plecoptera taxa	3	Total no. Trichoptera taxa	6
sum RA	3	sum RA	3	sum RA	6
Index score A	8	Index score B	8	Index score C	4

4: G.OL.D	RA*	G.OL.D	RA*	OTHER TAXA (not SSRS)	RA*
Radix balthica (G)		Dicranota (D)		Gammarus	
Potamopyrgus (G)	3	Tipulidae (D)		Crangonyx	
Planorbis (G)		Chironomidae (D)	2	Riffle beetle	2
Ancylus (G)		Chironomus (D)		Leech	1
Physa (G)		Other		Flatworm	
Lumbriculus (OL)		Other		Odonata	
Eiseniella (OL)		Other		Other Limnephilidae	1
Tubificidae (OL)	1	Total no. G.OL.D taxa	5	Other	
Simuliidae (D)	2	sum RA	9	Other	
Ceratopogonidae (D)	1	Index score D	0	Other	

ASELLUS INDEX SCORE					
Asellus if absent tick box (score = 4)	✓	Total Index Score (A+B+C+D+E)	24	> 7.25 Probably not significantly impacted	
Asellus if few (1-20) tick box (score = 2)		Average Index Score (Total IS / 5)	4.8	> 6.5-7.25 Indeterminate. Evidence of impact	
Asellus if common (> 20) tick box (score = 0)		SSR Score = (Average IS) x 2	9.6	< 6.5 Probably impacted	
E: Asellus index score (4 or 2 or 0)	4	SAMPLE TAXON NUMBER	22	INVERT. DENSITY (E / A / M / L / S)	L-M

1: EPHEMEROPTERA — No. taxa: 0 → 0; 1 → RA 1-2 → 4, 3+ → 6; 2+ → 2 → 6, 3+ → 8

2: PLECOPTERA — No. taxa: 0 → 0; 1 → RA 1-2 → 4, 3+ → 6; 2+ → 2 → 6, 3+ → 8

3: TRICHOPTERA — No. taxa: 0 → 0; 1-2 → RA 1-2 → 2, 3+ → 4; 3+ → 3+ → 4

4: G.OL.D — No. taxa: 0 → 0; 1-2 → RA 1-2 → 4, 3-6 → 2, 7+ → 0; 3+ → 3-6 → 4, 7+ → 0

Phototrophic indicators & bacterial tufts (X the box to confirm absence - NV for not visible)					
Macrophyte	Ab.		Ab.	Macroalgae	Ab.
				Bacterial tufts	Ab.

Channel vegetation cover: Dominant - Abundant - Frequent - Occasional - Rare - Absent - NV

Channel vegetation density: Excessive (>75%) - Extensive (50 - 75%) - High (25-50%) - Moderate (10-25%) - Low (<10%) - Absent - NV

Caha
d/s of bridge, below bridge apron
v. little habitat available for sampling - mostly glide.
low numbers of class A, Baetidae dominant.
one week after flood

Figure 17.11: Field sheet from monitoring point of Caha_020 (Version D01 of field sheet)

Table 17.6: Comparison of taxa captured my LAWPRO and EPA in Lough Nastackan and Caha

		EPA	LAWPRO	EPA	LAWPRO
	Waterbody Code	IE_NW_40L030400		IE_SW_20C010700	
	Waterbody Name	LOUGH NASTACKAN STREAM_010		CAHA_020	
	Q value status or SSIS Score	High	SSIS 8	Good	SSIS 9.6
Group	**Fieldsheet Date**	19/09/2019	11/09/2019	13/06/2019	23/04/2019
A	**Amphinemura**			Single	1
A	**Chloroperlidae**			Few	1
A	**Ecdyonurus**	Common	2	Common	Single
A	**Heptagenia**	Few	1		1
A	**Isoperla**	Few		Few	1
A	**Nemouridae**	Few			
A	**Rhithrogena**			Few	
A	**Rhithrogena semicolorata**	Common	2		1
B	**Baetis muticus**	Few			
B	**Glossosomatidae**			Few	
B	**Goeridae**	Few	1		1
B	**Hydroptila**				1
B	**Leuctra**	Few		Few	
B	**Sericostomatidae**	Few	1	Few	1
C	**Ancylidae**	Common	2		
C	**Baetis rhodani**	Common	2	Numerous	3
C	**Caenis**			Few	1
C	**Ceratopogonidae**			Few	1
C	**Chironomidae**	Few	1	Few	2
C	**Dicranota**	Few		Few	
C	**Eiseniella**	Few	1		
C	**Elmidae sp.**		1		2
C	**Elmis aenea**			Few	
C	**Esolus / Oulimnius aggregation**			Few	
C	**Gammarus**	Dominant	2		
C	**Hydrachnidae**			Few	
C	**Hydraenidae**	Few			
C	**Hydropsyche**	Few	1	Few	1
C	**Lumbricidae**	Few			
C	**Philopotamidae**	Few		Few	1
C	**Polycentropodidae**		1	Few	
C	**Potamopyrgus antipodarum**	Few	1	Common	3
C	**Rhyacophila**	Few			1
C	**Serratella ignita**			Common	1
C	**Simuliidae**	Common	1	Few	2
D	**Hirudinea**				1
E	**Oligochaeta**			Few	
E	**Tubificidae**			Few	1

*Note – Taxa identified by the EPA that would not be separated by LAWPRO are highlighted e.g., EPA - Rhithrogena semicolorata and Rhithrogena are equivalent to LAWPRO - Rhithrogena, EPA - Esolus/Oulimnius aggregation and Elmis aenea are equivalent to LAWPRO - Elmidae sp. (Riffle Beetle)

18 Appendix 2: Significant Issues and Significant Pressures

18.1 Introduction

The terms 'significant issues' and 'significant pressures' are used specifically as phrases both in the context of WFD implementation and drinking water source protection to indicate that the issues and pressures require mitigation. In the WFD context, *significant issues* and *significant pressures* are those that are having a significant impact on ecological status and need to be addressed before the status will improve. *Significant pressures* are only identified for water bodies that are *At Risk* of not achieving their objectives.

The aims of this section are to:

- Distinguish between contaminants or issues that are significant as against those that are not deemed significant.
- Distinguish between situations where the objective is to 'protect' a water body as against 'improve' or 'restore'.

In the catchment area of any water body, there is likely to be a multitude of contaminants or issues that, depending on the circumstances, might or might not be impinging on the water resources in the catchment. Examples include: phosphorus (either as phosphate or total phosphorus), nitrate, ammonium, sediment, BOD, pesticides, trace organics (such as PAHs), microbial pathogens. While some or all of these might be present in water, the question is: are any 'significant'? or, in other words, does the concentration or amount need to be reduced so that the water quality is deemed to be satisfactory, either in terms of the hydrochemistry, sediment content or ecology, or all of these? Where a reduction in a contaminant is needed, then it is termed a '***significant issue***' because planning, effort and resources are required to enable mitigation.

Likewise, in the catchment area of any water body, there are a range of contamination sources or pressures contributing the contaminants or issues that might or might not be impinging on the water resources in the catchment. Examples include: forestry, farming activities, industry, domestic wastewater treatment systems, wind farms, urban wastewater treatment plants, storm water overflows, pesticide usage, misconnections in urban/town areas. Once again, the question is: is any of these 'significant'. If significant, it is a '***significant pressure***' that requires measures and/or actions to mitigate the impacts and, in the process, improve the water body to have satisfactory water quality.

18.2 What is characterisation?

Four quotations (in italics) from different perspectives are used below to describe 'characterisation':

1. *To develop a plan, we need to understand what is happening within our catchments, a process called characterisation. Simply put, characterisation means finding out where the problems are, what is causing them and why, and how we can fix them. Resources will always be limited, so it is important that the focus is on key actions that will improve water quality and provide the best return for investment. It is a key principle for this cycle that we target the right measure in the right place.* This quotation focuses on characterisation as a vital element of WFD implementation. From: Deakin, 2018 (page 14, Issue 9, Catchments Newsletter). The article can be accessed at: https://www.catchments.ie/catchments-newsletter/.

2. *Catchment characterisation provides an understanding of the physical, hydrochemical and ecological characteristics, impacts, pressures in the catchment, and therefore is the foundation of ICM. The aim is to use characterisation to identify the significant pressures so that strategies, measures and resources can be prioritised and targeted to enable effective protection or restoration, as required, of our water resources*. This quotation focuses on

characterisation in the context of integrated catchment management (ICM). From: Daly, *et al*. 2016. The paper can be accessed at: http://www.jstor.org/stable/10.3318/bioe.2016.16.

3. *Characterisation provides an understanding and appreciation of the over ground and underground pathways water can take travelling from the land surface to the drinking water source, so that strategies, measures and resources can be prioritised and targeted to enable effective source water protection or restoration, as required. It involves data collection and evaluation of the various relevant elements of the* ***source-pathway-receptor*** *(SPR) model of environmental risk assessment, including the potential pollution sources or pressures, the physical characteristics of the area that influence water movement, mobilisation and transport of potential pollutants, the location of critical source areas for diffuse pollutants, and the impacts at the receptor – the drinking water source.* This quotation focuses on characterisation from a drinking water source protection perspective. From: NFGWS, 2019 'A Framework for Drinking Water Source Protection', which can be accessed at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/.

4. *The characterisation process integrated inputs from specialists in many different fields of study, including environmental science, biology, hydrology, hydromorphology, and hydrogeology and incorporated a broad range of data and information, as follows:*
   - *Ecological, hydrochemical, hydrological and hydrogeological maps and data;*
   - *Information on pressures (e.g. urban waste water treatment plants, agriculture, domestic wastewater treatment systems, forests) from different sector-based public bodies;*
   - *Results from "source load apportionment modelling"*[82] *(estimates of the load contributions from different pressures);*
   - *Development of pollution impact potential (PIP) maps; and*
   - *Results of previous investigative monitoring and inspections undertaken by Local Authorities, the EPA and other public bodies.*

   Analysis of these data identified the significant issues impacting the water bodies. For example, if the issue was related to nutrients or sediment, this then allows the "significant pressures" that are preventing water bodies from achieving the required environmental objectives to be identified. Knowledge about significant pressures, and their relationship with potential receptors via pathways, enabled the impacts to be understood and potential mitigation actions to be considered in each water body.
   From: Volume 1 of the Guidance on Further Characterisation for Local Catchment Assessment (2018) produced by the EPA Catchment Science and Management Unit.

18.3 Deciding on significant issues and significant pressures

The approach to this is outlined below.

- Start at the receptor (e.g. surface water body, groundwater body, watercourse or drinking water source).
- Is the situation satisfactory or is it sub-standard? (e.g. Is the WFD objective met? Is the water body *At Risk*? Does the untreated source water for a drinking water source require improvement? Is the watercourse polluted, for instance, with concentrations above the EQS for particular contaminants?)
- If the situation is unsatisfactory, what is the issue that is causing impairment? (e.g. is it PO_4, sediment, NO_3, NH_4, microbial pathogens, etc.)

[82] Mockler E.M., Deakin, J., Archbold, M., Gill, L. Daly, D. and M. Bruen (2017). Sources of nitrogen and phosphorus emissions to Irish rivers and coastal waters: Estimates from a nutrient load apportionment framework. Science of The Total Environment. Volumes 601–602, 1 December 2017, pages 326-339.

- If there is an issue or pollutant causing impairment, then this is the ***significant issue***.
- From what pressure is the *significant issue* arising from? This pressure is the ***significant pressure***.

All of these questions are dealt with and answered by a characterisation process.

Several relevant articles on the *significant pressures* identified by the characterisation process for the 2nd Cycle of the WFD and reported on in the River Basin Management Plan 2018-2021 are given in Issue 9, Winter 2018 of the Catchments Newsletter.

18.3 Why are decisions on Issues and Pressures Important?

They are important for three reasons:

1. To enable a decision on whether the objective is 'protection/maintenance' or 'improvement/restoration'. Where characterisation concludes that the water quality is satisfactory, then the objective is 'protection', whereas if unsatisfactory clearly it is 'improvement'. This distinction is important because the approaches to 'protection' will be different than those needed to achieve the 'improvement' objective. In addition, often there will be a greater focus, with more effort and resources, on water bodies requiring 'improvement', and it is for this reason that the issues and pressures that need to be dealt with are called *significant issues* and *significant pressures*. Where the objective is 'protection', the key is to ensure that the existing measures and actions are maintained, rather than requiring new measures or actions. For further information on this, read Section 3.1 in the NFGWS framework for drinking water source protection (NFGWS, 2019) at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/. The framework is summarised in Figure 1.

2. To enable decisions on the most appropriate, achievable and effective measures and actions that will accomplish either the protection or improvement objective, as required for a particular water body. Contaminants (or issues) have different characteristics in the landscape.
   - The contaminant load and resulting concentration that can affect water quality varies depending on the contaminant. For instance, 1 kg P (present as phosphate) will pollute (i.e. bring the concentration above the Environmental Quality Standard (EQS) for rivers of 0.035 mg/l) 29 million litres (6.4 million gallons) of water. In contrast, 1 kg N will pollute (i.e. bring the concentration above the Threshold Value (as a mean in groundwater) of 37.5 mg/l) 120,000 litres (26,400 gallons). In addition, the contaminants can have different attenuation capacities (i.e. different abilities to reduce as they move through the landscape).
   - As contaminants have different properties, they move in diverse ways along various transport pathways and are attenuated at different rates. For instance, phosphate and MCPA are relatively immobile in soils and subsoils, and the relevant pathway is as overland and near-surface flow in poorly drained soils to nearby watercourses and ditches, with little attenuation along this pathway. In contrast, nitrate is highly mobile in free-draining soils and high to moderate permeability subsoils, and is easily leached into groundwater where it can impact on boreholes or flow underground and enter rivers.

   Where the objective is improvement and a contaminant is deemed to be a *significant issue*, the measures and actions needed for mitigation must take these characteristics into account, otherwise efforts to establish them could be ineffective and the resources used wasted.

3. To enable the ‘owner’ of a *significant pressure* that is impacting on water body and preventing it from achieving its WFD status objective to be determined, for example, an urban WWTP that is the responsibility of Irish Water, farmers with land in a critical source area contributing PO4 or a forestry owner with afforested land contributing sediment.

18.4 Conclusion

Words ‘paint the picture’ and ‘tell the story’ thus influencing our actions, and therefore need to be precise. There are many potential issues and potential pressures in our landscape either not impacting at all on our environment or are impacting to varying degrees. For those that are impacting ‘to a degree’, the concern and decision for a public body, with a limit in the availability of resources, is whether the ‘degree’ is great enough to require expending the resource on the issue and pressure. The two main water quality priorities are, arguably, achieving WFD objectives and achieving drinking water source protection objectives. The designation of issues and pressures as ‘*significant*’ should influence the type of approaches required to achieve either a ‘protection’ or ‘improvement’ objective, and also help target and prioritise resources and efforts, thereby achieving effective catchment management. Therefore, it is recommended that the phrases *significant issues* and *significant pressures* continue to be used where current mitigation measures and actions are insufficient, and new or additional measures and actions are needed.

19 Appendix 3: Point and Diffuse Pollution Sources

19.1 Introduction

In achieving effective catchment management, it is worthwhile being clear on our definitions of point and diffuse sources, and consistent in the use of the terms. The text below provides some information and conclusions on both.

19.2 Definitions

The following definitions are recommended.

Point Sources

Discharges from pipes directly to watercourses or indirectly via ditches, and discharges to localised areas such as soakage pits and percolation areas. They are subdivided into 'large' and 'small'.

Large point

UWWTPs, IPPC licenced discharges, storm overflows, which are subject to licensing/authorisations and inspections.

Small point

Farmyards, domestic wastewater treatment systems (DWWTSS), cattle drinking point areas, cattle crossing points, ring feeder areas, misconnections and pipe discharges in urban/town areas, areas where pesticide sprayers are filled, etc. *(Note: some of these 'small' point sources could be discharging a pollutant load equivalent to a small WWTP, e.g. a badly managed farmyard discharging silage effluent, slurry and soiled water to a watercourse.)*

Diffuse (non-point) sources

Widespread activities in the landscape such as fertilizer (organic & inorganic) application, deposition of faeces and urine by grazing animals, spraying of pesticides, sediment arising from forestry areas, atmospheric deposition, leaking sewers in urban areas, polluted groundwater in urban areas, etc.

19.3 A starting point in evaluating point and diffuse sources

What is the objective of the evaluation?[83]

- Is it to check compliance with the Regulations? For example, an inspection?
- Is it to decide whether the activity is a *significant pressure* (see Section 6 for details) or not and, if so, is therefore causing a water body to fail to meet its WFD objectives? For example, an *At Risk*, Moderate status water body in a Priority Area for Action which is subject to a local catchment assessment and where the objective is to restore to Good status.
- Is it to evaluate the impacts on small watercourses, for example, the headwaters where stream flows are low particularly in summer? Or a ditch/drain, with either permanent flows or intermittent flows?
- Where the water quality is already satisfactory, is it to protect this situation from dis-improvement?
- Is it to 'protect' or 'restore' a water body used for drinking water (see the NFGWS publication 'A Framework for Drinking Water Source Protection' for details at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/).

It is important that the objective is set out clearly at the outset as this helps focus on the approaches and resources needed, and helps target the required mitigation actions.

[83] Note: the objectives being considered are oriented on water quality and not health.

19.4 Summary Comments on Point Sources

- Point sources are pressures that are numerous and widespread in the Irish landscape.

- Local authorities, IFI and EPA staff have considerable experience and expertise in dealing with point sources.

- They are sources mainly of organic and chemical pollution, as indicated by the presence of, for instance, phosphorus/phosphate, ammonium, BOD, increases in conductivity, pesticides (e.g. from foot baths, spillages, sheep dip tanks). This in turn leads to impacts on ecology. Nitrate is not generally a *significant issue* arising from point sources.

- DWWTSs can contribute to watercourses and groundwater all year round, and therefore can be a potent source particularly in summer when stream flows are relatively low. For example, if all P from a typical DWWTSS entered a stream without any attenuation, an average flow of >3l/s would be needed to keep the concentration below the Environmental Quality Standard of 0.035 mg/l (good/moderate status boundary as a mean in the Surface Water Regulations).

- Farmyards can be subdivided into dairy and beef farms. Beef-rearing farmyards are unlikely to contribute nutrients to water courses for 6-10 months of the year (depending on location) when the cattle are in the fields. In contrast, dairy farms (~15% of farms) can contribute all year round. Both can contribute high BOD effluent from silage pits in summer if collection systems are not adequate. The phosphorus load in soiled water from a dairy farmyard has the potential to pollute streams if the soiled water is allowed to flow directly into it; clearly a number of such farmyards can have a greater impact.

- Cattle access points are small point sources that can be readily located during catchment walks. Their impact in watercourses is usually localised. While they may be a possible *significant pressure* in water bodies that are sensitive to nutrients and sediment, such as High status objective water bodies that are not achieving their objective, they are unlikely to be a *significant pressure* in Moderate status water bodies where the objective is Good status; usually pressures contributing greater pollutant loads are the *significant pressures*.

- Large point sources can contribute (by definition) relatively large loads of pollutants. However, their locations are known and they are regulated. In addition, evaluating their significance for water quality is less onerous than for small point and diffuse sources.

- Small potential point sources can be located readily as they are visible in the landscape, e.g. farmyards and houses that are in unsewered areas, and most are subject to inspections, even if only a small proportion are inspected.

- Local catchment assessments, involving catchment walks, are an effective means of assessing impacts by using indicators such as conductivity, DO readings, thermal imaging and rapid biological assessments. Sampling for chemical analysis might be needed in certain circumstances.

- Point sources can be a relevant pressure in all physical settings as they often consist of direct pipe discharges or direct runoff from a site, such as a farmyard or car park, thereby bypassing the potential for attenuation in soil and subsoil.

- The physical setting is relevant when considering the likelihood of impacts of point sources:
    - Point sources are likely to pose a greater threat to surface water in poorly-draining areas than in well-draining areas as surface or near-surface runoff is more likely and infiltration

is usually low. In addition, there is a greater density of ditches and small watercourses in these areas with farmyards and DWWTSs more likely to be located near them; these can act as channels for soiled water and effluent to streams. The EPA phosphate susceptibility maps can be used to locate these areas.

- In free-draining areas (as indicated by the EPA nitrate susceptibility map or the EPA National Soils Hydrology map) where phosphate has been shown to be a *significant issue* impacting on a water body, point sources are likely to be the *significant pressure* rather than diffuse sources (there is minimal runoff and phosphorus is bound up in the soil). A possible exception to this is in karstified aquifer areas, although even there it is likely to be sinking streams that is inputting phosphate to groundwater rather than loss from the soil.
- Flows in drains and streams in the vicinity of catchment boundaries will usually be relatively low as the contributing catchment area is small. In addition, they are likely to be intermittent in poorly productive aquifer areas, as there is no groundwater to sustain the flows in summer. Therefore, a point source or a low number of point sources can result in high pollutant concentrations in these circumstances.

♦ It is advisable not to take the presence of a high concentration of pollutants and/or the presence of a localised biological indicator, such as sewage fungus, in a ditch or small stream alone as the indicators of significant impact. While this situation is unsatisfactory, it should be evaluated in the context of the objectives mentioned in Section 9; for instance, it might require actions in circumstances where a farm inspection is being undertaken, but might not require any immediate actions where it is not deemed to be a *significant pressure* and resources and effort are targeted on achieving WFD objectives. This may seem contradictory and can be an issue of concern for those undertaking catchment walks and local catchment assessments, but it is suggested that focusing on and achieving the set objective is critical; for example, for staff with a responsibility to achieve the WFD objectives of either Good or High status, small, 'insignificant' (in the context of the WFD objective) point sources can be a distraction. In saying this, it needs to be determined that a small point source or a number of them are 'insignificant'.

♦ In catchment areas of waterbodies that are achieving their WFD objective, farmyards and DWWTSs may be impacting on small headwater streams and ditches. In this instance, the farmers and householders in these catchments could be usefully targeted collectively as part of the Local Authority 'protect' function to promote improved farmyard practices and to prevent any further deterioration.

♦ Some point sources, such as wastewater treatment plants and a proportion of domestic wastewater treatment systems with continuous piped discharges to streams, contribute P and N during the biologically-active May to October period when inputs of diffuse sources may be limited.

♦ The loading of nutrient to a water body may be as relevant as, or even more relevant, than the concentration in making a decision on whether point sources and/or diffuse sources are the pressure causing the impact on the receptor in question, and that therefore need to be dealt with. Undertaking loading analysis (see Appendix 4 for details) and source load apportionment, even if approximate, may be a worthwhile as a way of deciding on what the *significant pressure* is that needs to be dealt with.

♦ Overall, most small point sources, such as DWWTSs and farmyards, are unlikely to be either a *significant pressure* or the only *significant pressure* at subcatchment scale, i.e. the scale of WFD monitoring, reporting and characterisation, where the WFD objective is Good status, although there will be exceptions to this.

- However, they undoubtedly cause localised impacts in 'small' streams and ditches, and localised plumes in groundwater. In addition, they could be a *significant pressure* where the WFD objective is High status where less nutrients are needed to cause a failure in their status objective.

- Water bodies where domestic wastewater treatment systems are a *significant pressure* have been located during 3rd cycle characterisation and their locations are shown on the EPA catchments.ie website (https://gis.epa.ie/EPAMaps/Water).

19.5 Summary Comments on Diffuse Sources

- Diffuse sources are more difficult to manage and deal with that point sources in both the rural and urban settings. There is less understanding of their role and, in general, less effort and emphasis went on dealing with them in the past.
  - Their location in the landscape is not readily visible.
  - Their impact depends on an understanding and integration of i) the issues/pollutants arising (e.g. nitrate, phosphate, sediment), ii) the pathways in the landscape (overland flow, near surface, shallow groundwater or deeper groundwater), iii) the source (e.g. inorganic or organic fertilizer, pesticide, grazing animals) and iv) the load (e.g. the livestock units per hectare as a proxy for the load of P and N applied).
  - While the scientific understanding has improved in recent years, it is still an on-going area for research.
  - Most diffuse sources have not been inspected and therefore implementation of suitable mitigation measures is not common.
  - Mitigation options are more difficult to decide on and to implement.

- Diffuse sources generally cause chemical rather than organic pollution, although heavy rain soon after landspreading of organic fertilizers in poorly draining areas can cause high BOD and ammonium concentrations in watercourses.

- The physical setting, based on the pathways for water and pollutants, is a critical factor in determining the impacts from diffuse sources, and therefore in determining whether issues from diffuse sources need to be dealt with or not.
  - In free-draining areas, the only (in most circumstances) potential *significant issue* arising from diffuse sources will be nitrate. However, the loading rate of nitrogen is also relevant; nitrate can be a *significant issue* in intensive farming areas, whereas in general, it is not a *significant issue* in extensive farming areas, except perhaps in the catchment areas of High status objective water bodies.
  - In free-draining areas, neither phosphate, ammonium nor BOD arising from diffuse sources tend to be a *significant issue* (see the EPA Phosphate and Nitrate Susceptibility maps and the EPA PIP maps for confirmation of this). An exception to this may be some iron-rich soils which favour P mobilisation.
  - In poorly-draining areas where overland and near surface flows predominate, the main *significant issues* arising from diffuse sources will be phosphate (MRP), particulate P, sediment and MCPA. Nitrate will not usually be a *significant issue* due to denitrification.

- At catchment and subcatchment scale with *At Risk* water bodies requiring improvements, diffuse sources will generally contribute a greater load of P and N, depending on the physical setting, to both surface water and groundwater bodies than small point sources. Therefore, they are more likely to be the *significant pressure(s)* rather than small point sources. There are undoubtedly exceptions to this.

- While diffuse source inputs are reduced during the drier May to September period when there are fewer high rainfall events and flows are relatively low, diffuse losses of particulate P via sediment during high flow periods and subsequent sedimentation in stream channels can result in the availability of P during the biologically-active May to October period when the likelihood of eutrophication is greatest.

- There is one circumstance where diffuse and small point sources may act in combination, with both being *significant pressures*. This arises in well-draining, groundwater-fed watercourses with relatively high nitrate and where a small input of phosphorus from small point sources might act in combination with the high nitrate to cause the water body to fail its WFD objective. In this circumstance, dealing with the small point sources may be the most efficient and resource-effective action.

19.6 Mitigation options

- Point source mitigation actions are usually far easier to decide on and implement than diffuse source mitigation actions.

- In dealing with *significant issues* arising from diffuse sources, the location of critical source areas (CSAs) is necessary (see Section 10.5.6); otherwise efforts to mitigate the impacts will not be effective in terms of resources used, maintaining the goodwill of landowners and achieving the necessary water quality protection and/or improvement.

- See further details on mitigation options in Section 14.

19.6 Conclusions

1. Deciding on the relative roles of point and diffuse sources in impacting on water quality is not always easy. However, there are sufficient means using all readily available data on water quality, pathways, loading analysis and information from catchment walks to enable effective decision-making.

2. There has been a tendency in the past to concentrate on point sources. This is understandable as there are regulatory systems in place to deal with them, they can be located visually and there is considerable experience and expertise in dealing with them in the relevant public bodies.

3. Poorly managed DWWTSs and dairy farmyards are the <u>main</u> small point sources that could contribute phosphorus and ammonium all year round, and therefore cause major impacts on watercourses. This situation can arise particularly in High status objective water bodies and in watercourses in poorly draining areas with small flows.

4. At water body/subcatchment scale, the main *significant pressures* will usually be large point sources and/or diffuse sources as the potential loading needed to cause an impact is much greater. However, there will be some circumstances and *At Risk* water bodies where small point sources, such as a number of inadequate DWWTSs in an area of poor percolation or a number of farmyards allowing soiled water to enter watercourses directly, would be a *significant pressure*.

5. In general, the location of small and large point source *significant pressures* and implementation of appropriate measures and actions is easier than for diffuse sources. The utilisation of the CSA

approach for diffuse *significant pressures* is an essential means of locating and managing these pressures.

- Loading analysis is recommended as a means of helping decide on the *significant pressure* in circumstances where the decision is not easy to determine.

6. Local catchment assessments, involving catchment walks, are an essential means of locating all pressures that are significant and, as a follow-on, in deciding on the mitigation actions needed.

20 Appendix 4: The Role of Nutrient Loadings Analysis for Watercourses

20.1 Introduction

Environmental analysis of the role of nutrients, such as phosphorus and nitrogen in their various forms, tends to be based on the **concentrations** found in water. This is understandable because environment quality standards and drinking water standards are based on concentrations. However, the concentration of, for instance, phosphate or nitrate in water does not always tell 'the full story'. The aim of this Note is to show that the **load** of nutrients can also be relevant, if not essential, in catchment characterisation and management.

Why undertake loading analysis?[84]

1. To enable an estimation of the approximate load reduction needed, either as a daily or annual quantity from a point source such as a WWTP, or as kg/ha/yr from diffuse agricultural sources.
2. To enable comparison of the loads coming from different tributaries to a monitoring point, and therefore enabling targeting of mitigation measures/actions.
3. To enable comparison of the loads coming from point courses, e.g. an UWWTP, as a comparison with those arising from diffuse sources, e.g. from farmland.
4. To enable an estimate of the load contributed by springs (groundwater) to watercourses.
5. To enable targeting of effort and resources to the catchment areas of the watercourse needing improvement.
6. Ultimately, the way to achieve the required nutrient concentrations is to reduce the inputting load; without loading information, it is not possible to set a target for the reductions needed.[85]

Keep in mind that the approaches described here provide rough estimates intended to assist in a catchment assessment as there will be variability in both flows and concentrations, not all of which might be captured by average data. For regulatory purposes, a more detailed analysis may be required.

20.2 What is meant by 'load'?

In this Note, it is **an average annual load using available flow and water quality data** at a relevant monitoring point, such as an EPA monitoring point in a WFD water body or the outlet point of a tributary to a water body.

Nutrient load = Average annual stream flow X average annual nutrient concentration

In certain circumstances, it can be beneficial to estimate the load at a point in time – when a flow measurement and a water sample is taken at the same time.

20.3 Estimating average annual stream flows

The flow equation is as follows:

Flow (Q) = **Effective Rainfall x Stream Catchment Area**

[84] You may hear of criticism of using average data for evaluating the impact of phosphate on watercourses as higher P loads are lost during periods of heavy rainfall and this may not be 'picked up' by EPA monitoring, which is on a quarterly or monthly basis. However, recent research findings (including by Stephen Davis, LAWPRO) has shown that chronic nutrient enrichment with P and N has a greater impact on macroinvertebrates, and therefore on water body status, than acute sources. Therefore, missing concentrations and loads during all high flows isn't critical to the analysis. In addition, the phosphate EQS of 0.035 (as a mean) is based on quarterly and monthly data; no doubt if 15 minute data were available as a basis for an EQS, the value would be different.

[85] Insufficient attention is given to loadings analysis and often there is too much dependence on using concentration data.

This equation assumes no loss of water out of the catchment underground, such as can occur via sinking streams in karst areas.

A number of different approaches to estimating average flows are outlined below.

20.3.1 Back of envelope calculation

This equation is a simple and easy means of estimating flows.

Q l/s = A x R x 0.5 x 0.032, where:
- A = catchment area (km^2).
- R = average annual rainfall (mm).
- 0.5 = factor converting rainfall to effective rainfall (0.6 could be used in wetter areas).
- 0.032 = conversion to l/s.

This equation is taken from page 97 of DELG, 2010. *Integrated Constructed Wetlands. Guidance document on farmyard soiled water and domestic wastewater applications*. Department of Environment, Heritage and Local Government. Available at: https://www.housing.gov.ie/sites/default/files/migrated-files/en/Publications/Environment/Water/FileDownLoad%2C24931%2Cen.pdf

Rainfall data can be obtained from the Met Éireann website at this link: https://www.met.ie/climate/available-data/historical-data.

The catchment area may need to be estimated manually from maps depending on the location and size. However, catchment areas for many catchments are available on the OPW website at this link: https://opw.hydronet.com/ and the EPA website at this link: : http://epa.ie/hydronet.

20.3.2 Using data from existing hydrometric stations

Where the monitoring point coincides with a hydrometric station, average flow data may be available, which can be accessed via the EPA HydroNet portal at this link: http://epa.ie/hydronet. It is important to note that average flow data are not available for all stations. Many OPW and Waterways Ireland stations produce water level data only, while some OPW and nearly all EPA/local authority stations produce water level and flow data.

20.3.3 Using the EPA model for stream flows at ungauged points

The EPA have produced an updated data set of modelled river flows across Ireland. This data set is available at https://gis.epa.ie/EPAMaps/Water (under Monitoring & Flows/River Flow Estimates – Hydrotool). The new modelled outputs provide estimates of the *Naturalised* stream flow at a given point. The naturalised flow is the flow that would be in the river if there were no human induced abstraction or discharge related impacts on the flow. It does not therefore estimate the actual real-world flow in the channel downstream of such influences. At all data points, flow percentiles and catchment descriptors (e.g. catchment area, average precipitation, average evapotranspiration, etc.) are available. Nationally, the model results are estimated to have a 95% Factorial Standard Error (FSE) of +/-16% at the Q30 (approx. average flow) and +/-56% at the Q95 (low flow) level. Flow estimates are not available for catchments underlain by conduit karst, or in controlled catchments, as the modelled results are unreliable in such areas. The accompanying detailed description and disclaimer should be read before model outputs are used. The 30%ile flow can be taken as an approximate mean flow.

An example of a downloaded map is shown in Figure 20.1 below.

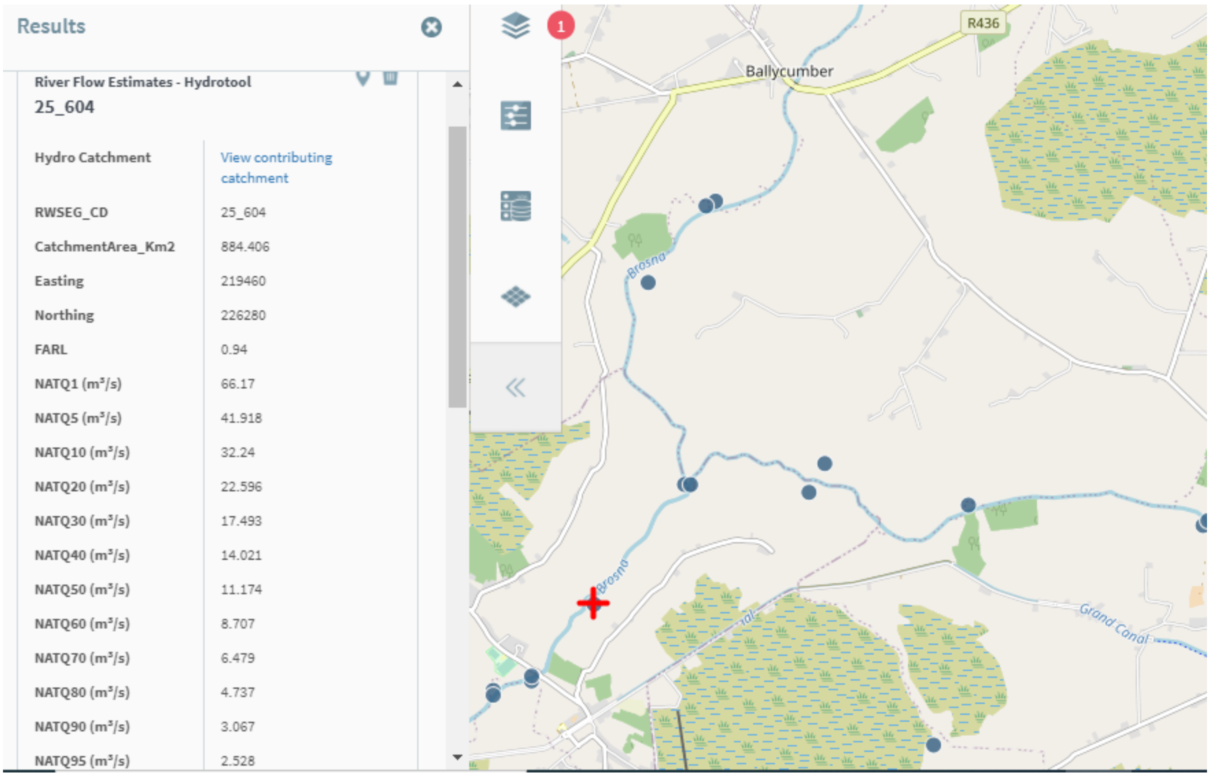


Figure 20.1: A screenshot giving catchment details and estimated flow data at an ungauged point on the River Brosna

20.3.4 Stream flow spot measurement

In some circumstances, it may be beneficial to have a flow measurement in tributary streams as well as at the EPA monitoring point at the same time that water samples are taken. This can be achieved by taking spot flow measurements using an impeller flow meter or by using the simple and quick 'float method'. The latter is a useful means of getting an estimated flow and can be sufficiently accurate where, for instance, comparisons are being made between different streams on the one day. Another quick but 'rough' approach to estimating an average flows in circumstances where there is an EPA or OPW hydrometric station downstream would be to use the catchment areas upstream of the sampling point relative to the catchment area to the hydrometric station; this assumes that the same physical and climatic setting applies throughout.

Further information of measuring streamflow and spring discharges are outlined in **Section 2, Volume 4**.

20.3.4 Average nutrient concentrations

The average annual nutrient concentration used in the analysis should preferably be a 3-year rolling average as this smooths out large variations in annual loads caused by flow variability. This concentration is used by LAWPRO in their local catchment assessments. Also, it is given as the 'baseline concentration' in the trend graphs of phosphate, ammonia and nitrate for EPA monitoring points in the WFD App. Alternatively, if concentration data are available for one year only at a hydrometric station, then the flow for that year could be used in the analysis.

It will often be necessary to take water samples in tributaries upstream of the EPA monitoring point as a means of locating significant pressures and enabling targeting of the mitigation measures/actions. In this circumstance, it is recommended that the aim should be to take three samples (at least) in a ~12 month period during different flow regimes – high, low average – as a means of estimating representative annual average concentrations, while still being able to note the ranges.

20.4 Extract from NFGWS (2019)

The following text on nutrient load reduction assessment is copied from the NFGWS "Framework for Drinking Water Source Protection", which can be accessed at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/

Nutrient Load Reduction Assessment

Where either or both nitrogen and phosphorus concentrations in a water body are above the guide value, a reduction of the nutrient is needed. Load reductions for a river water body (L_{rd-WB}) *are calculated from annual averages as follows:*

$L_{rd-WB} = (\bar{C} - GV) * \bar{Q} * K$

where,

$\bar{C}$ *= average concentration (mg* l^{-1}*) from source monitoring data.*
GV = Guide value (mg l^{-1}*).*
$\bar{Q}$ *= mean streamflow (*m^3s^{-1}*) obtained from a nearby hydrometric station or estimated as the 30%ile flow from the EPA HydroTool (a model for estimating flows in ungauged catchments that can be accessed at this link: http://watermaps.wfdireland.ie/HydroTool/).*
K *= unit conversion factor.*

The estimated load reductions should be taken as a guide which is aimed at: i) enabling resources to be targeted to specific areas requiring improvement; ii) estimating the amounts of reductions needed so that appropriate measures can be considered; and iii) sub-catchments in a larger catchment in terms of the scale of load reduction effort needed to help prioritise measures.

Scenario analysis can be undertaken using the results. For instance, in circumstances where wastewater treatment plants are present, an assessment can be made on whether upgrading alone would be sufficient to mitigate the water quality issues or what proportion of the required load reduction would be obtained by an upgrade. Alternatively, the reduction in the loss of phosphorus or nitrate for farmland can be estimated in terms of kg/ha, thereby assisting in the evaluation of measures to reduce the losses.

If nitrate is a significant issue in the groundwater source, a similar approach could be taken.

20.5 Paper on load apportionment by Mockler *et al.*, 2016

This paper[86] is recommended. In particular, note the scenario analysis for Aherlow on page 254 – this shows how effective load reduction assessments can be in selecting possible measures.

20.6 Nutrient load reduction examples

Three examples of calculations and approaches are given below:

- Example 1 shows how a load reduction calculation can be undertaken.
- Example 2 takes a water body with several tributaries and shows how the water quality data and loadings analysis enable the area needing mitigation measures and actions to be located as a means of achieving the required status objective at the EPA monitoring point.
- Example 3 shows how possible impacts from domestic wastewater treatment systems (DWWTSs) might be approached.

[86] Mockler, E. M., Deakin, J., Archbold, M., Daly, D. and Bruen, M. 2016. Nutrient load apportionment to support the identification of appropriate Water Framework Directive measures. Biology and Environment 116B (3):245–263. Available at: http://www.jstor.org/stable/10.3318/bioe.2016.22. BIOLOGY AND ENVIRONMENT: PROCEEDINGS OF THE ROYAL IRISH ACADEMY, VOL. 116, NO. 3, 245_263 (2016). # ROYAL IRISH ACADEMY

A Load Reduction Assessment was completed for the Suir River Catchment (Mockler et al., 2016), which estimated that the total load reduction required to reduce the average annual concentration of P below the threshold for 'Good' of 0.035 mg/l was 8.4 t yr^{-1}. This is equivalent to reduction of 7% of the total P load emissions from the catchment. Analysis showed that the load reduction targets are confined to just 13% of the catchment area from areas of high pollution impact potential for phosphorus loss to water.

Similarly, a Load Reduction Assessment was conducted for the Derryvalley Subcatchment within the White Lough Catchment, Co. Monaghan as part of the NFGWS Phase II Surface Water Pilot Project. This indicated that a total load reduction of P of 537 kg yr^{-1} was required within the sub catchment to reduce the average annual concentration below the threshold for 'Good' status. This example is highlighted through the calculation for phosphate below:

Average Concentration 0.067 mg/l
Guide Value 0.035 mg/l
Mean Streamflow 0.532 m^3/s
Calculation of load reduction:

*= (0.067 – 0.035) mg/l * 0.532 m^3/s * ((1000 l/m^3 * 86400 seconds/day * 365 days per year)/1,000,000 mg/kg)*
*= 0.032mg/l * 0.532 m3/s * 31,536 (conversion to kg/year)*
= 537 kg/yr.

Example 1

This example was provided by Eoin McAleer, LAWPRO, based on an analysis undertaken for a subcatchment with water quality problems.

Scenario: An *At Risk* water body where the status is poor and phosphate is the significant issue.

WFD objective: Restoration to good status by 2027.

Question: What load reduction in phosphorus is needed to reduce the concentration to the EQS.
Proposed Action: Undertake a phosphate load calculation to assist in the assessment and the provision of evidence.

Calculations:

- Catchment area = 25 km^2
- Total rainfall = 695 mm
- Effective rainfall = 383 mm (55% of rainfall)
- Mean 2018 streamflow (Q) calculation
  - Q m3/yr = 0.383 x 25000000 m^2
  - = 9575000 m^3/yr
  - = 26,233 m^3/d
  - = 0.303 m_3/s (86400 secs in one day)
  - = **303 l/s** (1000 l on 1 m^3)
- 2018 average P concentration = 0.19 mg/l PO_4
- EQS = 0.035 mg/l (mean)
- Target = 0.03 m/l (mean).

- **Required load reduction**

$$= 303\ (l/s) \times 86400 \times 365 \times \frac{(0.19 - 0.03)}{1{,}000{,}000}$$

= **1530 kg P/yr**

- **Required load reduction per ha**
  - Catchment area = 25 km^2 = 2500 ha.
    = 1530/2500 = 0.6 kg P/ha
  - Therefore, required load reduction is 0.6 kgP/ha/yr to reduce the average P concentration to 0.03 mg/l.
  - If the area of high PIP-P is known, then this can be used to estimate the load reduction needed in kg/ha in this area.

Comment: If the load contributed by a large point source, such as an UWWTP, to the water body was estimated, then the loads arising from various activities can be apportioned, in a manner similar to the Mockler Aherlow example, thereby enabling scenario analysis for mitigation to be undertaken.

Example 2

Scenario: An *At Risk* water body where the status is moderate, phosphate is the *significant issue* and the *significant pressures* are diffuse agriculture and farmyards.

Objective of assessment:

- Restoration of water body to good status by 2027 to achieve compliance with the WFD.

Questions:

1. What load reduction in phosphorus is needed to reduce the concentration to the EQS.
2. Where should the focus be for achieving the load reductions.

Proposed Actions:

- Undertake phosphate load calculations for the different tributaries to enable targeting of measures and actions.
- Use phosphate susceptibility and PIP map for the catchment areas of the relevant tributaries to help a further focus on the fields and point sources that need mitigation.

Phosphate Load Calculations:

The scenario (which is hypothetical) is shown in Figure 20.2. MP 6 is the EPA monitoring point on which ecological status is based. Water samples are taken at this MP for analysis quarterly. Three water samples were taken at different dates in one year at the other five MPs; therefore, the average PO_4 concentrations at each MP are based on the analyses of these three samples. SSISs were undertaken at all the MPs; the result for MPs 1, 3 and 5 were 'probably impacted'.

- The annual P load at MP 6 is estimated to be 207 kg P.
- The aim is to reduce the average PO_4 concentration to 0.03 mg/l[87].
- This means **an annual load reduction of 55 kg P** (the answer to question 1 above).
- If it was assumed that 60% of the area was farmed relatively intensively with a P application rate of 20 kgP/ha/yr, this would mean an annual application of 12,000 kg/yr.
- The reduction required is ~0.5% of the applied amount.

[87] It is recommended that this value is used as the objective rather than the EQS of 0.035; the EQS is a mean and it would be advisable to aim for a mean concentration below the EQS to increase the likelihood of achieving the status objective.

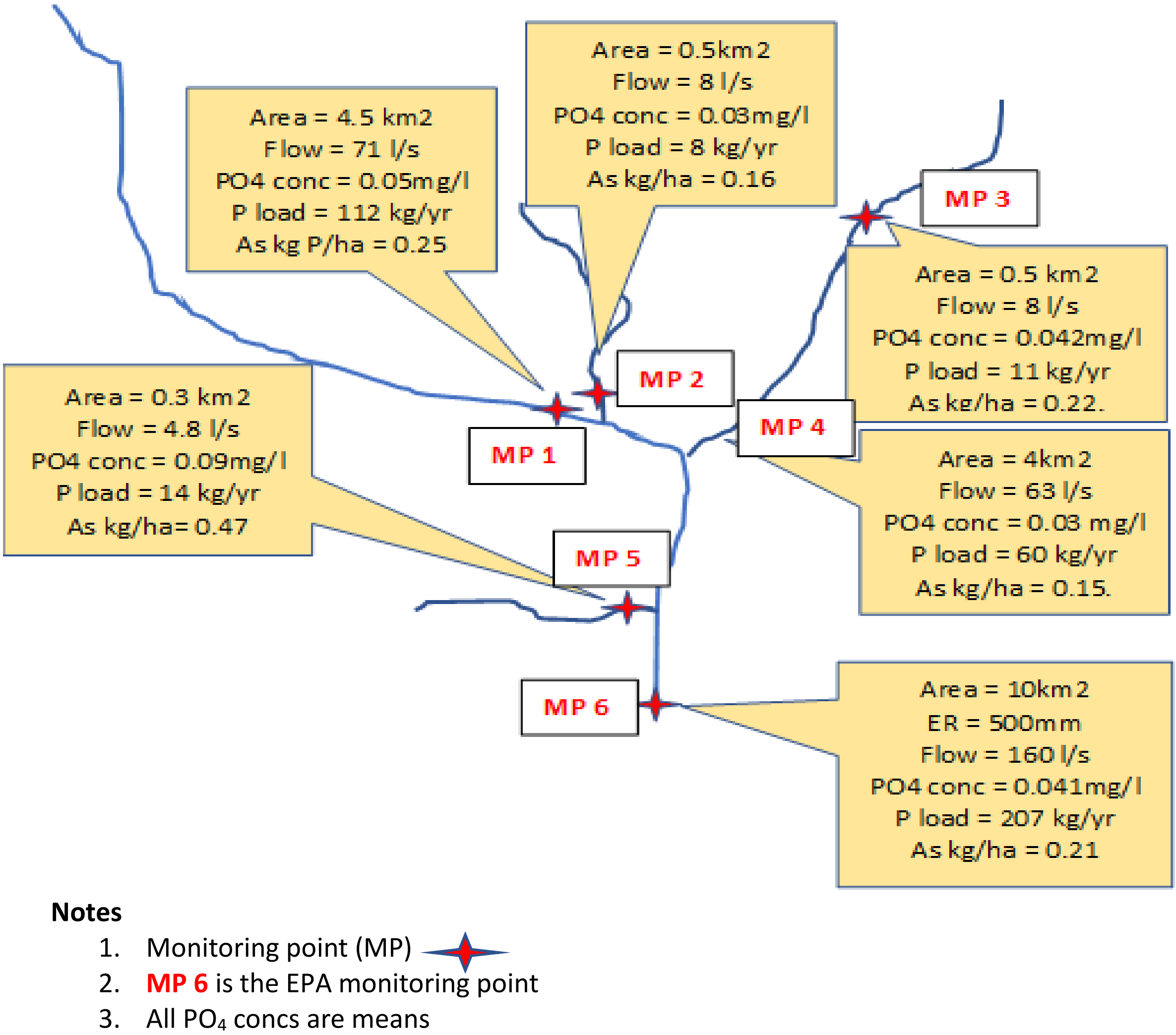


Figure 20.2: Schematic map of a hypothetical water body.

Comment: Keep in mind that it is not the values given in this Figure that are important – they are estimates based on reasonable assumptions. It is the conclusions that can be drawn from this analysis on future work requirements to improve the water quality that are the key feature.

- Therefore, the reduction needed is a fraction of the applied load.
- Question: what is the most effective (in terms of resources and likelihood of success) means of achieving the reduction?
- Background information from desk study and catchment walk:
    - The EPA Sanicose model indicates 4 high risk DWWTSs in the catchment area upstream of MP 3.
    - A catchment walk has indicated 2 problematical dairy farmyards in the catchment upstream of MP 5.
    - The phosphate pollution impact potential (PIP) map shows areas of high phosphate PIP upstream of MP 1.
- The initial reaction might be to focus on the catchment areas of tributaries 3 and 5, which have high PO4 concentrations. Both of these are known to be impacted by point sources. Point sources, such as farmyards[88] and DWWTSs, can be seen as 'low hanging fruit' and dealing with

[88] Teagasc research in the late 1990s on a dairy farm in the south of Ireland concluded that an estimated 30% of total annual P losses came from farmyards, with the remainder in overland and shallow subsurface flow. This conclusion was based on data from one farmyard, which was classed as 'high risk' and wasn't necessarily typical

them as easy wins. However, while they are usually a good starting point for consideration, in my experience achieving improvements in water quality by focusing on point sources alone has not always proven successful. In addition, as the combined P loads are 25 kg in total, dealing with the point sources in these areas will not be sufficient, particularly as the likely achievable reduction would be ~15 kg/yr at best.

- Therefore, if the objective of reducing the P load at MP 6 by 55 kg P/yr is to be achieved, **it will be necessary to focus efforts in the catchment area upstream of MP 1** (this answers question 2 above). Catchment walks should focus on the watercourse and the streams and ditches feeding into it in areas of high PO4 susceptibility and PIP as a means of locating the diffuse and point (particularly dairy farmyards) sources contributing excessive phosphorus. Mitigation measures and actions can then be focussed on relevant point sources and critical source areas.

Example 3

Scenario:

- Take the situation upstream on MP 3 in the last example where there are four DWWTSs that are likely to be contributing PO4 to the watercourse and are causing a 'probably impacted' result from the SSIS undertaken at the MP.

Objective:

- Reduce the P input from the DWWTSs to improve the SSIS score to 'satisfactory'.

Questions:

1. What load reduction in phosphorus is needed to reduce the concentration to the EQS.
2. Where should the focus be for achieving the load reductions.

Proposed Actions:

- Undertake a phosphate load calculation to assist in the assessment and the provision of evidence.

Phosphate Load Calculations:

- Estimate the total phosphate loading from one DWWTS assuming that there is no attenuation (i.e. a worst case scenario where all the effluent enters directly into the stream).
    i. Assume that the phosphate load in kg/person/year = 0.5.
    ii. Assume persons per house = 2.8.
    iii. Therefore, load per house = 1.4 kg/year[89]
- Load generated by 4 houses = 5.6 kg/year.
- Therefore, the worst case scenario (all P piped to the watercourse) is a contribution of 5.6 kg/yr. (In practice, it is probable that some of the houses have ineffective percolation areas with ponding of effluent and runoff in winter but with some attenuation in summer and therefore the actual loading to the watercourse is likely to be reduced.)
- The load reduction needed to bring the concentration to 0.03 mg/l is 3 kg/yr.
- Therefore, upgrading the DWWTSs would be likely to be sufficient to achieve the improvement at MP3.
- It is clear that this would not provide a significant reduction in the load required at MP 6.

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of all farms in the area, and the surrounding fields consisted of poorly draining soils. Other more recent Teagasc research on 60 dairy farms has concluded that each cow can contribute approximately 2 kg/year in dairy soiled water. This indicates the potential of soiled water from dairy farmyards to pollute watercourses.

[89] These data are from EPA (2013). A risk-based methodology to assist in the regulation of domestic wastewater treatment systems. Environmental Protection Agency. Available at this link: http://www.epa.ie/pubs/reports/water/wastewater/dwwtriskranking.html.

21 Appendix 5: Groundwater in Subsoil and Bedrock – the Role of Hydrogeological Properties

21.1 Background

The underground environment of relevance to Local Catchment Assessments (LCAs) consists of three layers:

- Topsoil
- Subsoil (This is the 'loose' uncemented (unlithified) sediments present between topsoil and bedrock. Most Irish subsoils are glacial deposits – till and sand/gravel. Till is the sediment deposited *directly* from melting ice (i.e. without any significant intervention of water) either beneath or on front of the ice sheet. Till can be variable in composition, with different amounts of sand, cobbles and boulders in either a clay or silt dominated matrix (and therefore is sometimes called 'boulder clay'). Fluvio-glacial sand/gravel is deposited by water, either as river deposits in and beneath the ice sheet or deltas on front of the ice sheet. Since the ice melted about 10,000 years ago, subsoils such as peat, wind blown sand and fluvial sand, silt and clay have been deposited.
- Bedrock (the most common bedrock is limestone[90], followed by sandstone, and including others such as granites, shales and metamorphic rocks), which is subdivided into the following components from a groundwater flow perspective:
    - Transition zone[91].
    - Upper fractured zone.
    - Lower fractured zone.

Effective rainfall (rainfall less actual evapotranspiration) flows to rivers along four pathways:

1. Overland and shallow subsurface flow (often regarded as 'quick flow');
2. Interflow (lateral subsurface flow that occurs in the topsoil and subsoil between the ground surface and the water table);
3. Shallow groundwater flow; and
4. Deep groundwater flow.
5. Fault zone flow.

These pathways are illustrated in Figure 21-1.

21.2 Purpose

Surface water flow is easy to conceptualise as it can be observed and is accessible. In contrast, groundwater is 'out of sight' and more effort is needed to understand and conceptualise it. Yet, it is essential that water flow in subsoil and bedrock is understood and can be taken into account in LCAs. Why?

- Depending on the aquifer category and hydrogeological setting, the **average** contribution of groundwater in rivers varies between 20-75%. In summer, up to 90% of **low flows** in many rivers is groundwater.

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[90] 45% of the Republic of Ireland area is underlain by limestones. Half of this area is karstified to a significant degree; this situation is described in detail in Section 5 of **Volume 3** and will not be considered in any detail in this section. In these areas, solution is an additional and sometimes overriding influence on the three components.

[91] Transition zone flows occur where a transition zone is present at the boundary between the subsoil and unaltered bedrock in poorly productive aquifer areas. It is usually thin, varying in thickness from 0-2 m. It can arise from physical (e.g. ice sheets moving over the landscape) or chemical processes. Its physical appearance is often 'rubbly', represented by broken pieces of bedrock and a dense network of shallow fractures which may be infilled to varying degrees by subsoil and/or weathered bedrock. Depending on the hydrogeological properties, it can transmit relatively large quantities of groundwater when saturated where it is dominated by bedrock fractures or can be an impediment to flows where it is clogged by clays. It can change in thicknesses over short distances. In low lying areas, it is likely to be saturated all year round, whereas in sloping areas it is generally unsaturated in dry weather. Photos of transition zones can be accessed at: https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/projects/gw3d/Pages/Transition-Zone.aspx .

- Groundwater can contribute substantial loads of nutrients, particularly nitrate but also phosphate, pesticides and pathogens, to rivers, in certain scenarios. However, in other scenarios it can provide relatively 'clean' water that dilutes pollutants in rivers.
- As water flows underground, there is a varying capacity for pollutants to be attenuated, which depend on the hydrogeological properties.
- Flow velocities are far slower underground than over ground. The exception to this is in karst areas, where conduit flow is dominant – this is described in Section 5 of Volume 3, and is not dealt with further here.

The purpose of this section is enable Assessors to conceptualise and understand groundwater movement and flow regimes to assist in two situations:

- Assessing the influence, if any, of groundwater inputs to rivers and, where relevant, the mitigation actions required.
- Assessing measures to protect groundwater abstracted from wells and springs.

In the process, it is intended that a 'common sense' knowledge of groundwater, that is relevant to LCAs, will be gained.

Note

Where the situation is complex refer to a groundwater expert.

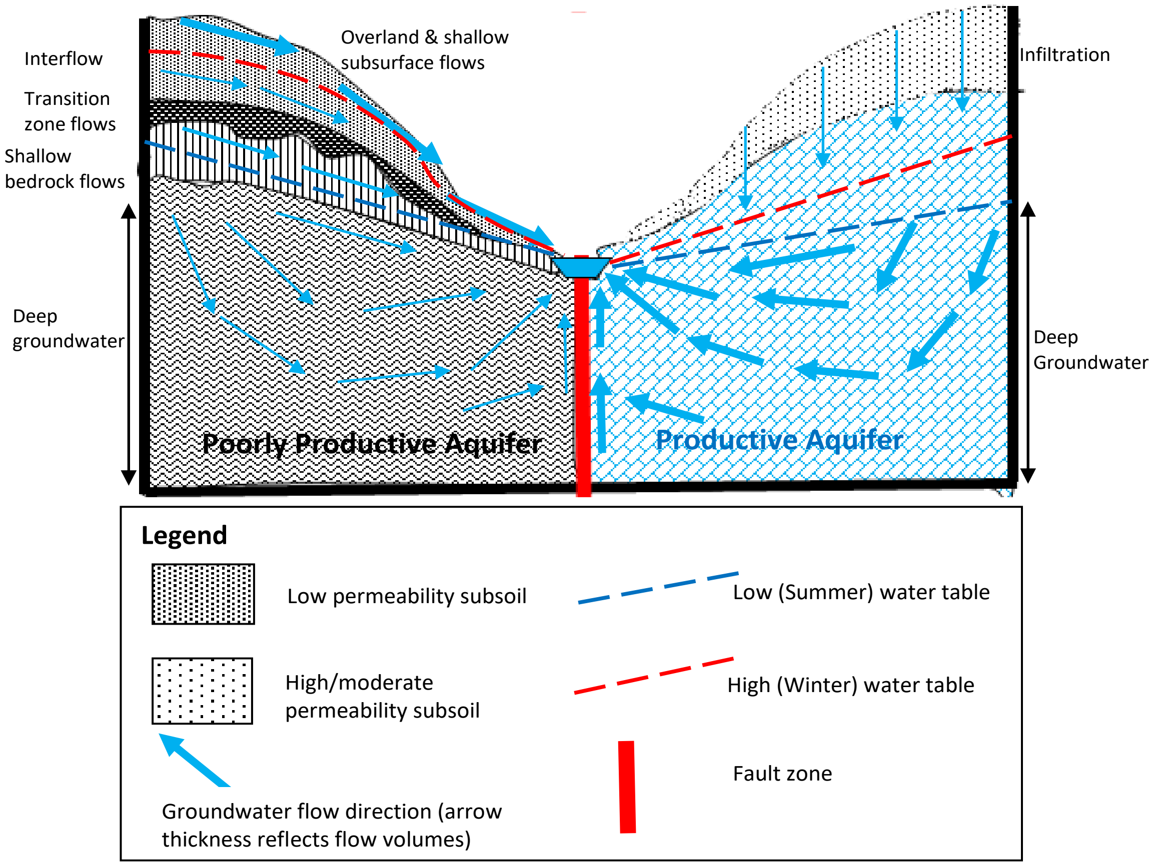

Figure 21.1: Components of surface water and groundwater flow in poorly productive (left) and productive (right) bedrock aquifer settings. Low- or high-permeability subsoil may overlie either bedrock aquifer type.

This section describes the contrasting properties of subsoil and bedrock (water flow in topsoil is generally similar to water flow in subsoil, but it is not considered specifically here). It also deals with the above 3rd and 4th underground pathways to rivers given above (shallow and deep groundwater flows), which are also the pathways for water flow to wells and springs, although the final pathway – deep groundwater – is the critical one for ensuring sustainable yields.

The following topics are described:

- Physical properties of bedrock and subsoil.
    - Porosity and effective porosity.
    - Permeability and transmissivity.
- Groundwater movement
    - The water table.
    - Groundwater flow direction.
    - Recharge and discharge of groundwater.
    - Groundwater flow velocity.
- Springs.
- Attenuation of pollutants in subsoils and bedrock.
- Understanding the role of hydrogeological settings.
- A summary of groundwater flow regimes in Irish bedrock units.

21.3 Physical properties of bedrock and subsoil

21.3.1 Porosity and effective porosity

Porosity is the ratio of opening (voids or pore spaces) to the total volume of subsoil or bedrock, and gives the storage capacity. It is expressed as a percentage of bulk volume, e.g. 0.2 or 20%. Let's take the three geological materials: sand/gravel; clayey subsoil; and fractured bedrock.

Sand/gravel

The porosity sand/gravel is in the range 15-25%. In other words, a container of 1.0 m^3 of dry sand/gravel will take 0.15-0.25 m^3 water before overflowing. If there was a hole in the bottom of the container, virtually all the water would flow out, which means that the 'effective porosity' is the same as porosity.

Clayey subsoil

A clayey subsoil might have a porosity of ~40%, i.e. it holds more water than sand/gravel. However, clay being fine grained means that a hole in the bottom of the container would result in a loss of perhaps 1-2% of the water only. Therefore, the 'effective porosity' is far lower than the porosity.

Bedrock

The porosity of Irish bedrock varies from 0.1% in rocks like granite and metamorphic rocks to 2.5% in certain limestones. In general, effective porosity and porosity are the same. In addition, this shows that the ability of bedrock to store water is far less than for subsoil.

23.3.2 Permeability and Transmissivity

Permeability (or hydraulic conductivity) is a measure of the ability of bedrock or subsoil to transmit water (or to let water flow through it). It depends on the size of the water transmitting openings (pores and fissures/joints/fractures/bedding planes). The permeability of geological materials varies by many orders of magnitude, and therefore there is great variability in the capacity of bedrock and subsoils in Ireland to transmit water. While Assessors will not need to know the permeability values themselves, it is relevant to be able to conceptualise and take account of this variability. As well as the variability in actual values, the type of permeability is also relevant.

Type of permeability

There is a distinct and important difference between the properties of subsoil and bedrock in Ireland. There are two types of permeability:

- Where the water moves between the grains of subsoils, it is called primary or **intergranular permeability.**
- Where the water moves through fractures or fissures or joints and along bedding planes, it is called secondary or **fissure permeability**.

In the Republic of Ireland, the only **geological materials that exhibit an intergranular permeability are the subsoils**. **The bedrock exhibits a fissure permeability only** (this is not the case in Britain where several bedrock types, such as the Chalk, have both an intergranular and fissure permeability). This difference will be critical when we consider contaminant movement and attenuation, and groundwater vulnerability.

In subsoils, the permeability value depends mainly on the grain size; the greater the proportion of clays and to some degree silt, the lower the permeability:

- Therefore, coarse grained **sand/gravel** (Figure 21-2), in which the finer grains of silt and clay have been washed out by water (fluvio-glacial or fluvial) or winnowed out by wind (this is called sorting by geologists), and which has a lot of interconnected openings, has a **'high' permeability**[92].
- **Subsoils/tills** that have been deposited directly by ice (beneath, such as drumlins, or on front, such as moraines) with a **silt-dominated matrix** (see Figures 21-3 and 21-4) has a '**moderate**' permeability.
- **Subsoils/tills** with a **clay-dominated matrix** (see Figures 21-5 and 21-6) has a '**low**' permeability.

Bedrock has no primary or intergranular permeability. Why? Bedrock in the Republic of Ireland is relatively old – the youngest bedrock is ~300 million years old (there are younger rocks in Country Antrim (basalts and Chalk). In this period, the original/primary porosity has been obliterated and infilled due to geological processes such as precipitation of mainly calcareous 'cement' in the pores, and pressure and temperature events in the crust of the earth that have welded the rocks together[93]. However, these moving plate events have caused the rocks to buckle and fracture, to varying degrees, giving the secondary or fissure permeability. Examples of the rock openings that are capable of enabling groundwater movement and storage are shown in Figures 21-7, 21-8, 21-9, 21-10 and 21-11.

There are circumstances where subsoils can contain 'preferential flowpaths', which can allow rapid movement of water in a somewhat similar manner to flow in fractures in bedrock. This generally occurs in the topsoil and in the upper part of the subsoil, particularly in unsaturated clayey subsoil, even when this is intermittent. They can be caused by plant roots, worm burrows or desiccation. Examples are shown in Figures 21-12 and 21-13. The contrasts between subsoil, bedrock and the intervening transition zone are shown in Figures 21-14 and 21-15.

21.3.3 Transmissivity

The permeability of bedrock usually varies and often reduces with depth (see example in Figure 21-9). Transmissivity is the term that takes account of this variability as it measures the rate that water moves through the full thickness of aquifer. For example, a poorly productive, low transmissivity

[92] The permeability of subsoils has been classified as 'high', 'moderate' and 'low' by the Groundwater Section of the GSI.
[93] The crust of the earth is dynamic rather than static as it is made up of a number (30) of plates moving slowly (a velocity equivalent to the rate of growth of toe nails and hair); some are colliding and causing earthquakes and volcanoes today, e.g. Italy, Indonesia; others are moving apart, giving volcanic eruptions, e.g. in Iceland.

bedrock may have high permeability layers, particularly the upper fractured zone. So, transmissivity is a measure of the 'bulk permeability'.

Figure 21-2: Sorted, high permeability, limestone-dominated sand/gravel deposited by water towards the end of the Ice Age between 10,000-13,000 years ago (Photo: Donal Daly).

Figure 21-3: Unsorted, silt- and sand-dominated, free draining subsoil (glacial till). Note the angular stones which contrast with the rounded stones in fluvioglacial, water-lain gravel. (Photo: Donal Daly)

Figure 21-4: Moderate permeability, free-drained subsoil (glacial till (sometimes called 'boulder clay')). Note brown tinge to an originally grey material (grey as it is a limestone till), indicating oxidation and unsaturated conditions. (Photo: Donal Daly)

Figure 21-5: Low permeability, poorly drained glacial till as shown by the presence of rushes. Note the grey colour indicating saturated, reducing conditions in the subsoil. (Photo: Donal Daly)

Figure 21-6: Grey, low permeability subsoil. Note 'plasticine' nature of the subsoil. (Photo: Donal Daly)

Figure 21-7: Folded red sandstone with water movement possible in the joints and along the bedding planes (Photo: Donal Daly).

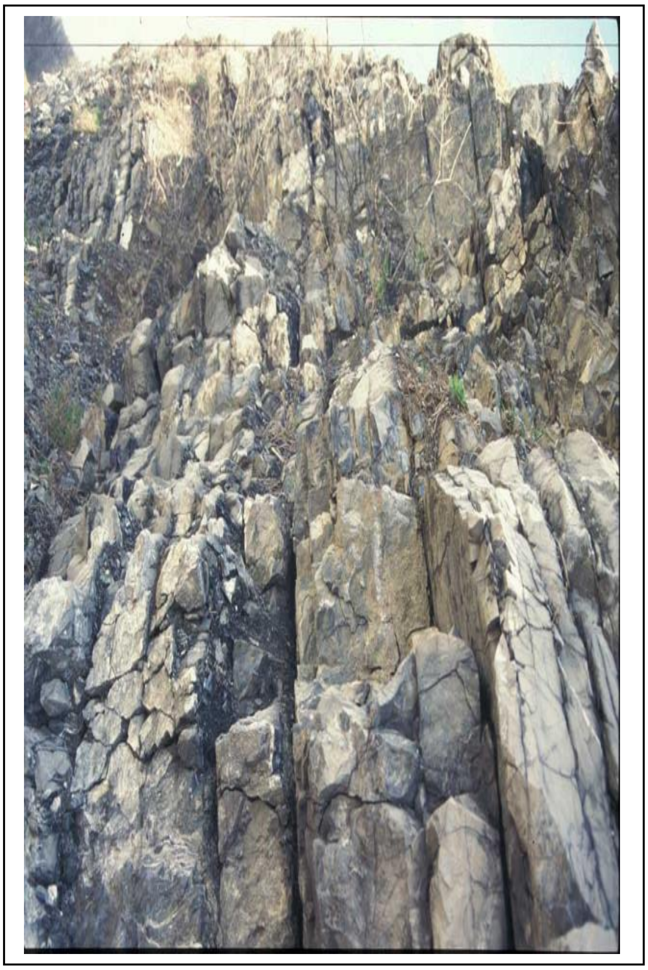


Figure 21-8: Pathways for water and pollutants in bedrock fractures (Photos: Donal Daly). Note the relatively unfractured nature of the bedrock apart from at the main fractures in the right photo

Figure 21-9: Horizontal bedding planes with vertical fractures/joints in a limestone quarry. Note greater degree of fracturing in the top 1.5 m. (Photo: Donal Daly)

Figure 21-10: Bedding and fracturing in limestone, with an intervening shale bed (above the hammer) with minimal fracturing (Photo: Donal Daly).

Figure 21-11: Flowpaths present along horizontal bedding planes and vertical fractures in limestone (Photo: Donal Daly).

Figure 21-12: Roots in soil and subsoil. When the roots decompose, they leave vertical openings in clayey soil and subsoil. (Photo: Donal Daly)

Figure 21-13: Desiccation cracks in clayey subsoil (Photo: Donal Daly).

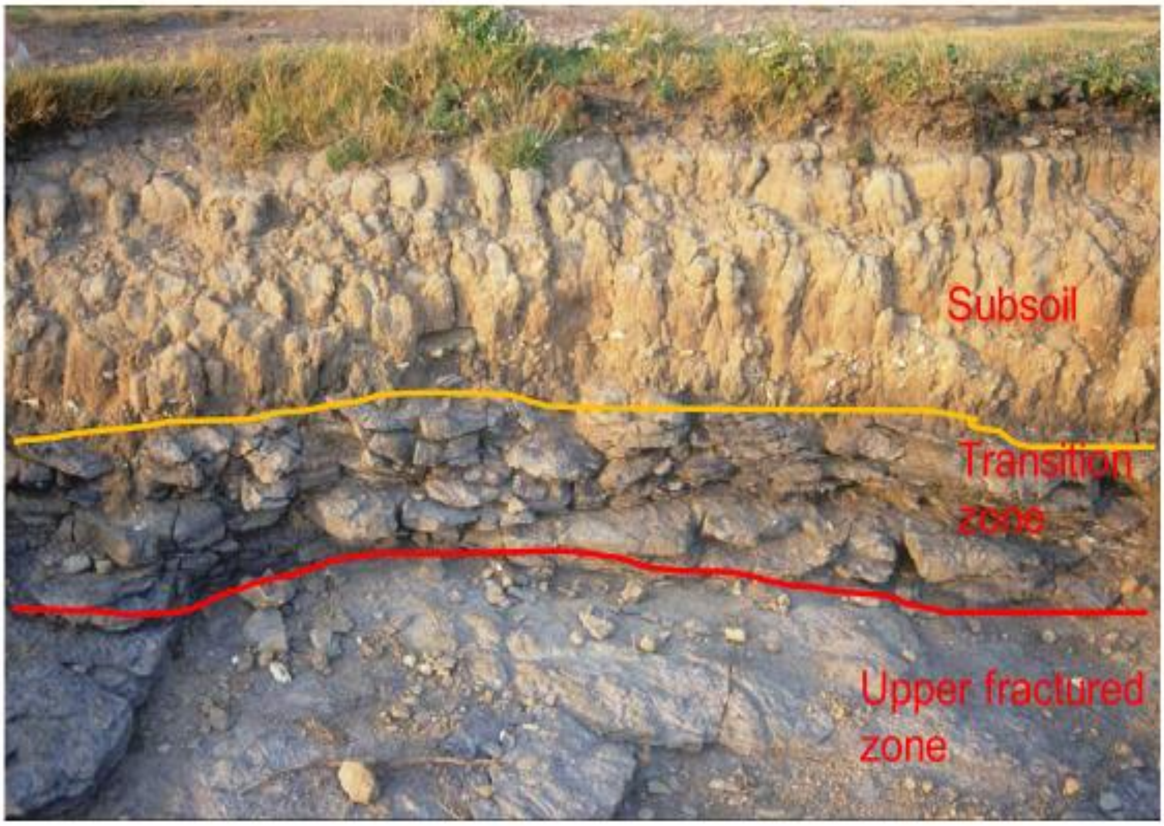

Figure 21-14: Illustration of four layers – soil, subsoil, transition zone and upper fractured zone in a free draining scenario. Note the brown colour of the soil and subsoil. (Photo: Donal Daly)

Figure 21-15: Illustration of four layers – soil, subsoil, transition zone and upper fractured zone in a poorly draining scenario. Note the grey colour. (Photo: Wexford County Council)

21.4 Groundwater Movement

When doing an LCA in circumstances where groundwater needs to be taken into account, you are likely to need to conceptualise the groundwater situation in three dimensions. In particular, you may need to visualise some or all of the following:

- The water table as a planar surface.
- Water table fluctuations.
- Groundwater flow direction.
- Groundwater flow velocity.

21.4.1 The water table

The water table is the upper limit of the saturated zone. This can be visualised as a planar feature beneath the land surface (Figures 21-17 and 21-18). The depth of this planar feature depends on the permeability or transmissivity of the subsoil and/or bedrock and the topographic location. The depth to the water table is obtained by measurements in wells.

21.4.2 Water table fluctuations

The water table fluctuates almost continuously due to a variety of hydrological phenomena, some natural and some induced by human activity. When rain falls, water infiltrates into the ground; if the amount exceeds evapotranspiration, it recharges the groundwater and the water table rises. In dry weather, water is flowing out of the ground into rivers and lakes, and so the water table drops. As a consequence, water levels are higher in Winter and early Spring, and lowest in late Summer and early Autumn. The most common human induced effects on the water table are pumping from wells for drinking water and drainage, which can lower the water table. The magnitude and rate of water level fluctuations depend on a number of factors: the main ones are i) the amount and intensity of rainfall; and ii) the effective porosity (and related to this, transmissivity) of the geological materials.

Poorly draining, low permeability clayey subsoils become saturated during wet weather conditions, frequently leading to overland flow and rapid runoff. However, during dry weather these subsoils 'dry out' and there is no evidence of a high water table. A close examination of the subsoil in this situation will indicate whether saturation occurs or not. Mottling (specks of brown indicating oxidation in an otherwise grey subsoil indicating saturation and reduction) indicates a seasonally high water table (Figure 21-17).

21.4.3 Groundwater flow direction

Gravity is the dominant driving force and so, under natural conditions, groundwater moves 'downhill' until it reaches the land surface at a spring or through seeps into stream channels. Consequently, the water table in the ground tends to be a subdued reflection of topography, with the depth to the water table being greatest at the topographic divides and least near streams. Topographic divides are generally also groundwater divides. The driving force of groundwater flow is the 'hydraulic gradient' or slope of the water table, which is the difference in head or height between the recharge and discharge areas divided by the length of the flow paths. Therefore, a difference in height of 10 m over a 5 km distance gives a hydraulic gradient of 0.002.

Evaluating the groundwater flow direction

A water table map will seldom be available in undertaking LCAs. In general, assume that the water table mirrors the topography and therefore topography can be used as the likely indicator of groundwater flow direction. However, take account of the following:

- This may not apply in the karstified aquifers that underlie 20% of the country (see Section 5 in **Volume 3**).

- In permeable/transmissive areas, small changes in topography will not influence the water table; for example, where esker sand/gravel ridges are present and in karst limestone areas. Use the regional topographic gradient for the former situation.
- In a sloping area, the depth to the water table and the hydraulic gradient in winter is largely a reflection of the permeability/transmissivity. Where the transmissivity is relatively low (e.g. in clayey subsoil or granite), the water cannot flow away readily, so it fills the voids leading to a 'high' water table (or thin unsaturated zone) and a steep hydraulic gradient. (Figure 5-18). Where the transmissivity is relatively high (e.g. in sand/gravel or highly karstified limestone or fissured sandstone), the water that recharges the ground and reaches the water table can flow away readily, thereby keeping the water table 'low', the hydraulic gradient shallow and giving a thick unsaturated zone (Figure 21-19).

Figure 21-17: Mottling indicating periodic saturation due to a high water table (Photo: Donal Daly).

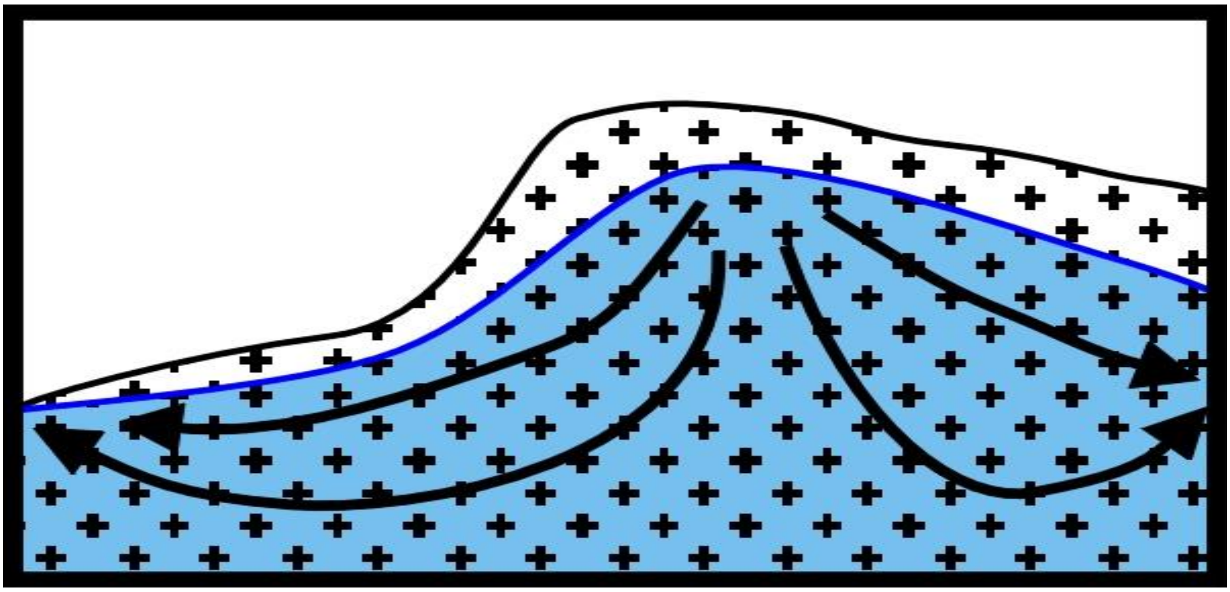

Figure 21-18: In low transmissivity aquifers, high hydraulic gradients are needed for groundwater flow, so the water table is steep and forms a subdued version of topography

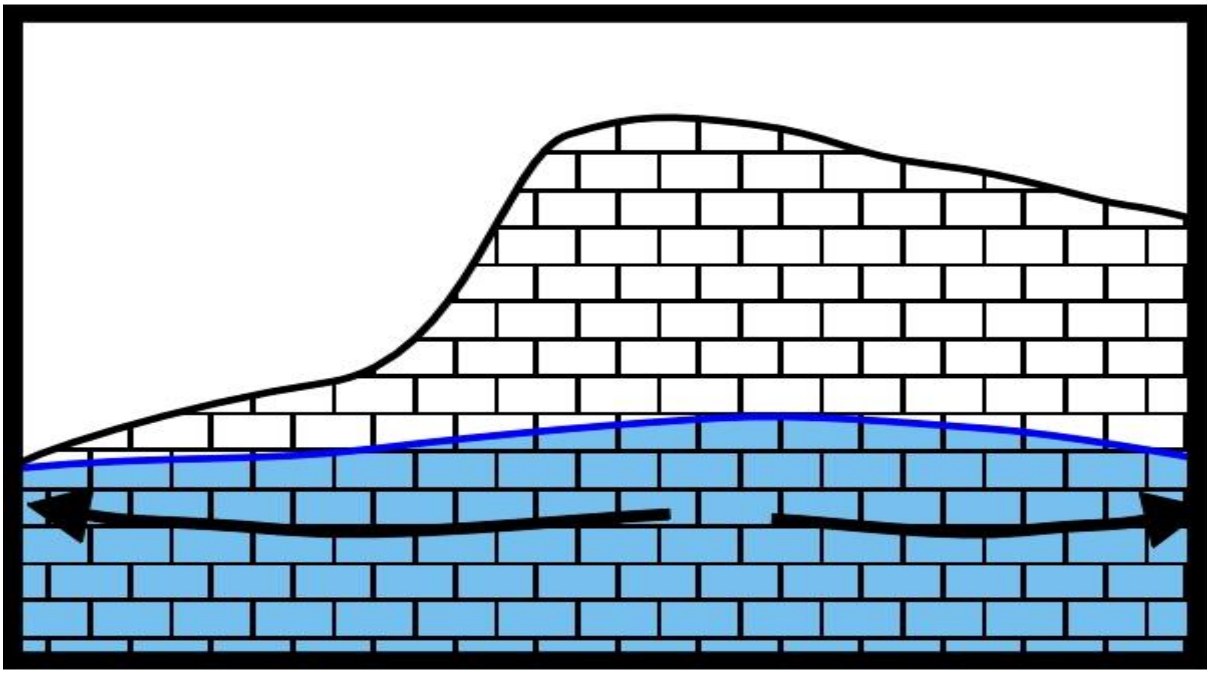

Figure 21-18: In high transmissivity aquifers, only low hydraulic gradients are needed for groundwater flow, so the water table is deep below hilly areas.

Two regional overviews are given in Figures 21-19 and 21-20. Figure 21-19 indicates that: i) the level of water in the river can be taken as the groundwater level in the immediate vicinity of the river; and ii) the level represents the lowest groundwater level in the area. Both Figures show that the stream/river and the associated riparian area is a linear discharge zone for water leaving the ground and aquifers.[94]

21.4.4 Groundwater flow velocity

The rate of groundwater flow, or velocity, depends on the permeability, the hydraulic gradient and the effective porosity. Knowing the groundwater velocities helps in the following ways:

- In conceptualising the flow of water and pollutants underground.
- In a qualitative way, in enabling an assessment of how quickly pollutants will reach a stream, well or spring.
- In a quantitative way, in estimating the time of travel for pollutants, particularly faecal bacteria and viruses to wells and springs used as drinking water sources. (Faecal bacteria generally die-off within 50 days in groundwater.)

The following are some general statements on groundwater flow velocities that can aid conceptualising water flow that is 'out of sight':

- Groundwater flow velocities are relatively slow. For example:
  - Horizontal velocities of 0.5-2.0 m/d would be typical in unpumped sand/gravel aquifers.
  - Horizontal velocities of 1.0-10.0 m/d would be typical in unpumped fissured sandstone and limestone aquifers.
- Karstified/cavernous limestones have velocities more typical of surface streams – 10s metres/hour in the conduits but with velocities more typical of fissured bedrock in the intervening bedrock.

[94] Streams in Ireland are generally 'gaining' groundwater, with the water table sloping towards the rivers. However, there are circumstances where the groundwater flow direction changes and streams are 'losing' water to groundwater. This can occur during dry weather when water levels in sand/gravel drop below river levels.

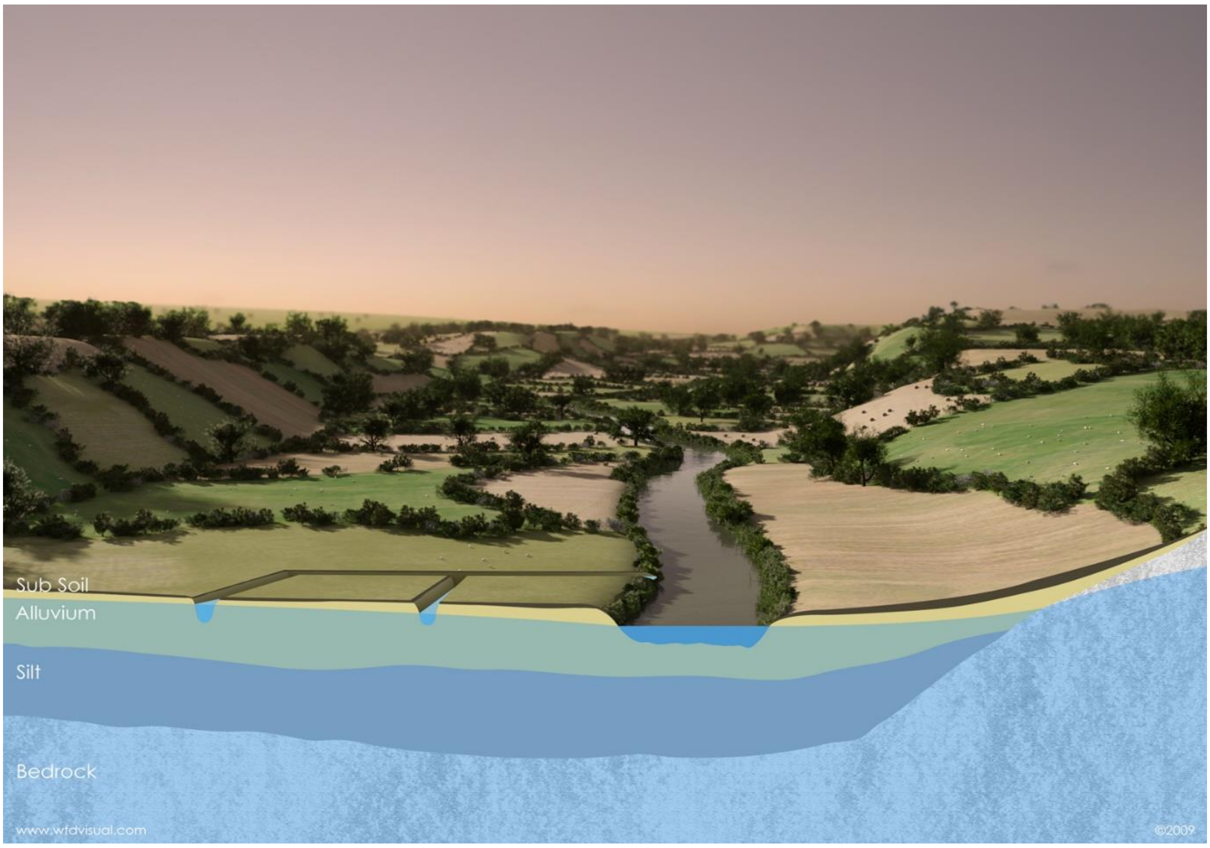

Figure 21-19: A 3-dimensional representation of a river valley, showing a thin unsaturated zone with the water table close to the surface in the river flood plain, and with the unsaturated zone thickening beneath the sloping hill in the right side of the Figure.

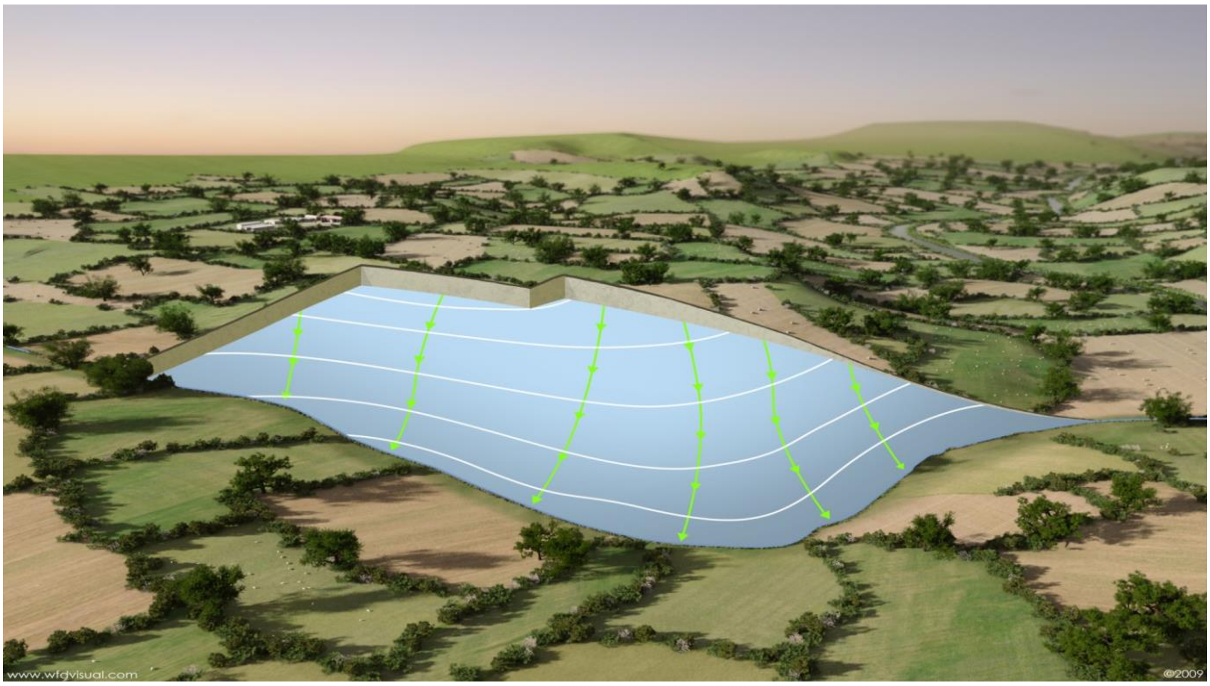

Figure 21-20: In this 3-dimensional representation, the geological deposits above the water table are cut out to show i) a relatively thick unsaturated zone in the higher areas, which thins in the vicinity of the stream, ii) the water table contours and iii) the groundwater flowlines at right angles to the contours, illustrating the flow of water to the river (shown faintly in blue on the left and right sides of the Figure).

- In a typical unkarstified bedrock, velocities will usually be faster in the upper, more fissured layers.
- Flow velocities in bedrock are frequently faster than in permeable subsoils, such as sand/gravel; this reflects the lower effective porosities of bedrock relative to subsoils.
- Vertical flow velocities in subsoils are slower in unsaturated conditions than in saturated conditions. However, preferential flowpaths in topsoil and the upper meter of clayey subsoil can result in bypass flow, although the proportion of flow by this means is generally small.
- Due to slow vertical flow velocities in low permeability clayey subsoils, it is estimated that it takes >10 years (and often much longer) for water to flow through 10 m of this subsoil; this is the Low vulnerability situation mapped by the GSI.

21.5 Springs

A spring (Figure 21-21) is a natural groundwater discharge at the land surface. The presence of a spring at a particular location can be due to a number of factors – topography, geology, hydrogeology or a combination of these. Figure 21-22 shows three types of springs:

1. **Depression spring** – formed where the ground surface intercepts the water table.
2. **Contact spring** created:
   - where a permeable water bearing rock overlies a less permeable rock that intersects the water table, thereby ‘forcing’ the water out of the ground.
   - Where a less permeable rock is faulted against the permeable rock.
   - Where low permeability subsoil, such as glacial till or peat, is deposited on the permeable rock.
3. **Solution spring** – issuing from solution channels in karstic limestones.

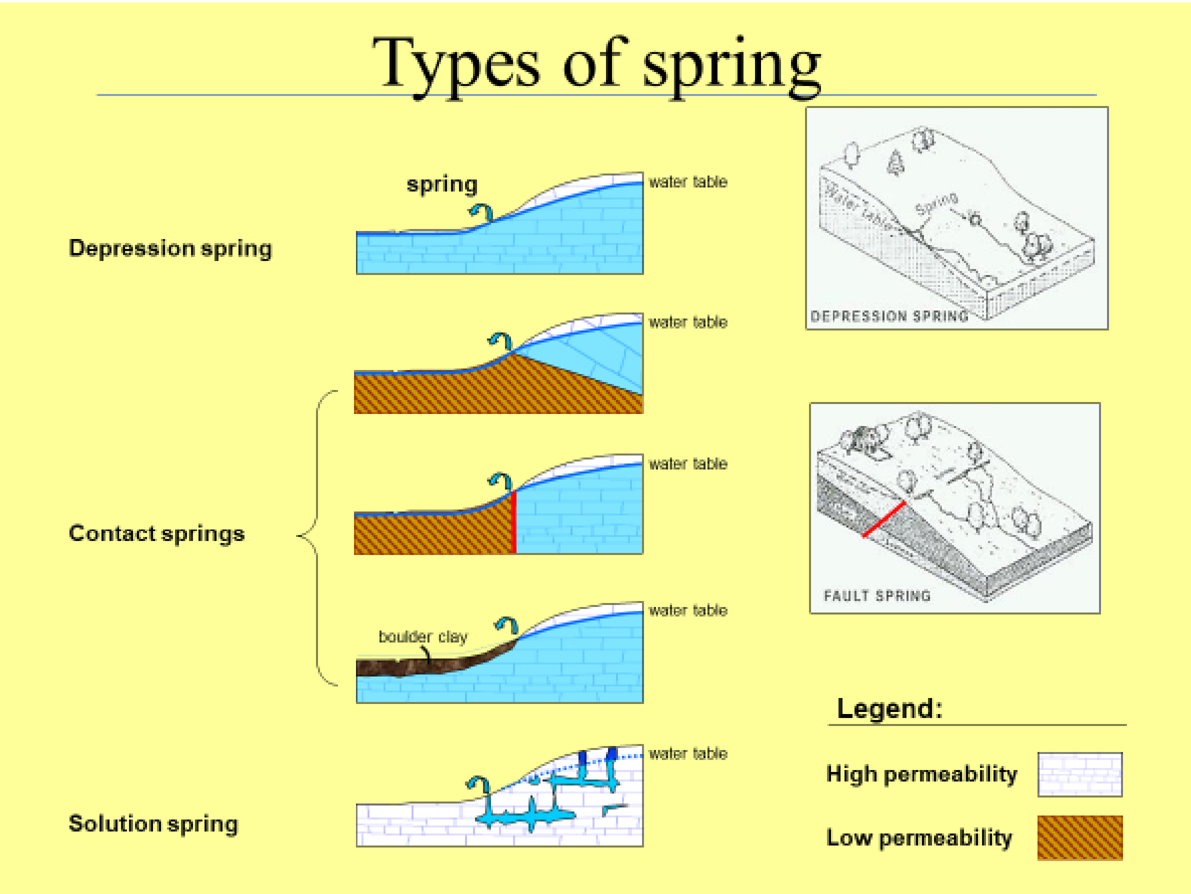

Figure 21-22: A schematic representation of different spring types.

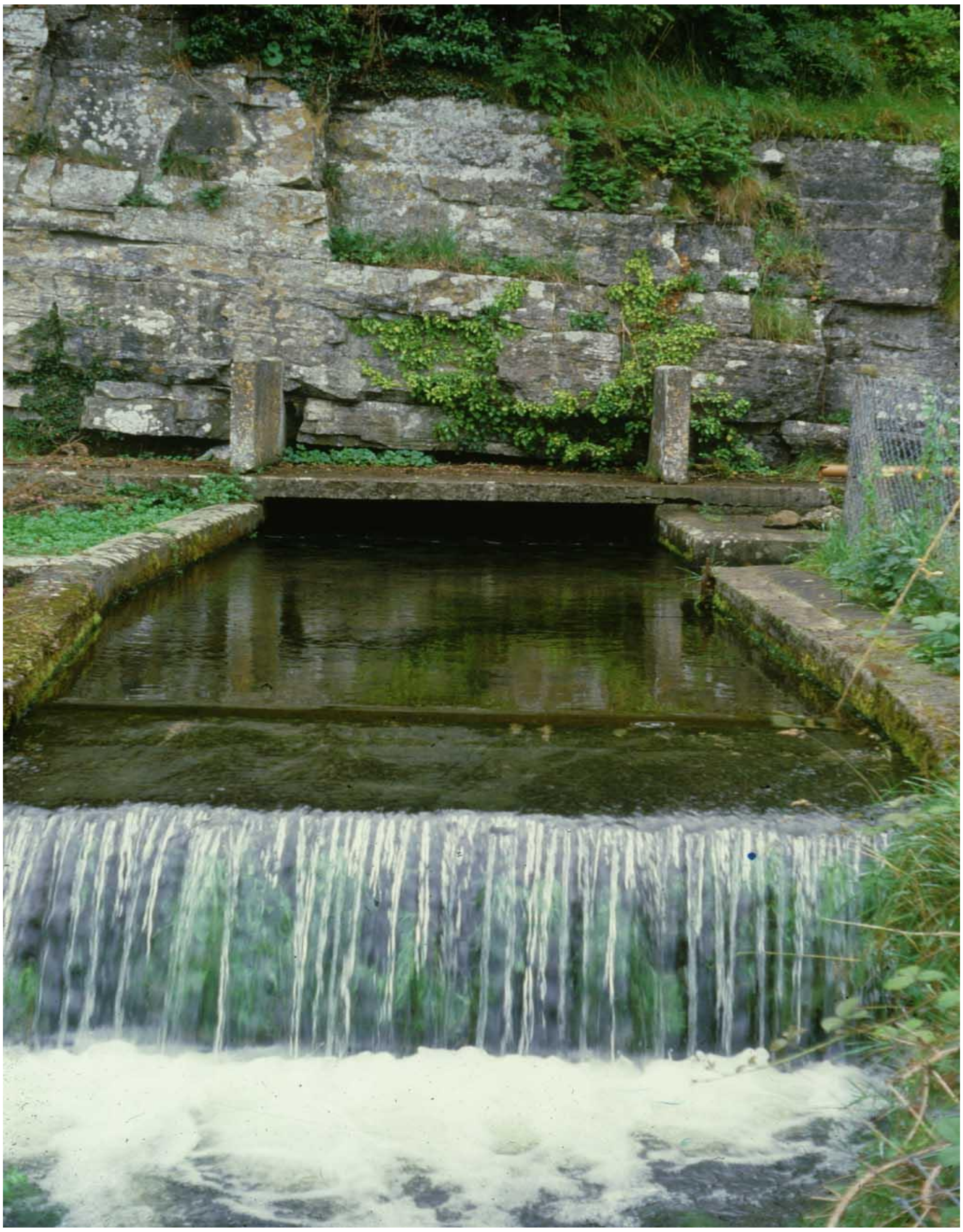

Figure 21-21: A spring issuing along a bedding plane in limestone bedrock (Photo: Donal Daly).

21.6 Attenuation of pollutants

21.6.1 Attenuation in bedrock

Bedrock has a fissure permeability only. The openings are much larger than in subsoils (see Figures 21-7, 21-8 and 21-11) and there is minimal potential for interaction with the bedrock. Therefore, there is generally minimal pollutant attenuation in bedrock in Ireland. Once pollutants enter bedrock, contamination of groundwater is inevitable.

21.6.2 Attenuation in subsoils

In considering the pathway for pollutant movement from the source to the receptor, the following hydrogeological characteristics will often be relevant to Assessors:

- Subsoils have an intergranular permeability, i.e. water flows in the openings between the grains. This slows movement down and facilitates attenuation of pollutants by adsorption and ion exchange, and, in the case of microbial pathogens, by filtration as the pores/openings are small and die-off as water movement is slow.

- Sand/gravel, the high permeability subsoil, overlies ~4% of the Irish landscape (Robbie Meehan, pers. comm.). In places, where their size and saturated thickness is sufficient, they are an aquifer, covering an area of ~2% of the country. Their high permeability means that there is minimal attenuation of conservative pollutants such as **nitrate** and certain **mobile pesticides.** However, ammonia will generally be quickly converted to nitrate in the aerobic conditions, thereby reducing the hazard from nitrogen. **Phosphate** will also generally be attenuated where the gravel is a few metres thick due to the interaction with the small proportion of silt present. **Microbial pathogens** will either be filtered out, or will die off. Areas of sand/gravel have a very low drainage density, free-draining soils and vegetation that indicate good drainage (see Section 3, **Volume 3**). In summary, **the main flowpath will be vertical** and the drainage density will be very low.
- Moderate permeability subsoil, such as silt-dominated till, will allow relatively slow, vertical movement of water and therefore will be free-draining. The presence of silt and clay, and the intergranular nature of the permeability means that it provides good attenuation of **phosphate**, **ammonia**, **pesticides** and **microbial pathogens**, but seldom of **nitrate** (there are occasional circumstances where denitrification can occur when the parent material is muddy limestone containing iron pyrite (FeS_2), which can cause reducing conditions). Few drains will be present in these areas and the soil will be free draining, with the exception of low lying areas where a high water table may facilitate formation of groundwater gleys. **In summary, the main flowpath will be vertical**, but will be slower than in the sand/gravel areas, and the drainage density will be relatively low generally but will vary somewhat i.e. will be higher than sand/gravel areas, but much lower than clayey subsoil areas. As the permeability of these subsoils vary by three orders of magnitude, there will be a higher drainage density in the lower end of moderate permeability.
- The presence of low permeability subsoil, such as clayey till, means that water cannot readily move vertically downwards. Therefore, **the dominant flowpath is horizontal**. Indicators of this situation are poorly draining soils, such as gleys, high water tables, a high density of streams and ditches and vegetation indicators, such as rushes. Groundwater is well protected in these areas. However, phosphate, ammonia, pesticides and pathogens, if present, can readily runoff into streams unless the pathway is intercepted by mitigation actions. Nitrate will not generally be a hazard due to denitrification.
- In general[95], it is the subsoils that overlie our bedrock aquifers that act as the protecting, filtering layer over groundwater.

21.6.3 Role of the unsaturated zone

The **unsaturated zone** in free draining, **permeable subsoils** has the following beneficial effects on pollutants:

- Contaminants have to travel farther to reach groundwater.
- Flow rates are normally slower than in the saturated zone.
- It is usually an aerobic environment which promotes chemical processes that aid attenuation.

Therefore, attenuation is higher in the unsaturated zone above the water table than beneath the water table.

With regard to pollutant attenuation, the **unsaturated zone in bedrock** provides little benefit.

[95] The main subsoil types and the proportion of the land surface covered by each type is as follows (information provided by Robbie Meehan): glacial till (62.5%), sand/gravel (4.3%), alluvial sediments (0.6%), lacustrine silts and clays (0.4%), beach/wind blown sediments (0.2%), peat (18.9%) and made ground (1.2%). The remainder of the land surface (11.9%) consists of outcrop/subcrop.

21.7 Understanding the role of hydrogeological settings

As a means of developing the ability to conceptualise the implications of differing hydrogeological settings, two typical scenarios are shown in the cross-section illustrated in Figure 21-23:

- This represents the hydrogeology of poorly productive, relatively low transmissivity aquifers (i.e. Ll, Pl and Pu aquifers that underlie 70% of the country – see Section 6, **Volume 3** for details on aquifer categories), which are overlain by soil and subsoil.
- On the left hand side of the image, fissured bedrock is overlain by poorly permeable soil and subsoil. On the right hand side, the soil and subsoil are permeable and free-draining, and there is an area of outcropping and shallow bedrock at the top of the hill.
- In the poorly draining scenario, the effective rainfall (rainfall less evapotranspiration) cannot infiltrate readily underground and therefor most will runoff, as shown by the blue arrows. In contrast, for the free draining scenario, effective rainfall will infiltrate vertically through the soil and subsoil to the water table, and then will flow 'horizontally' towards the stream, mainly in the upper fractured zone.

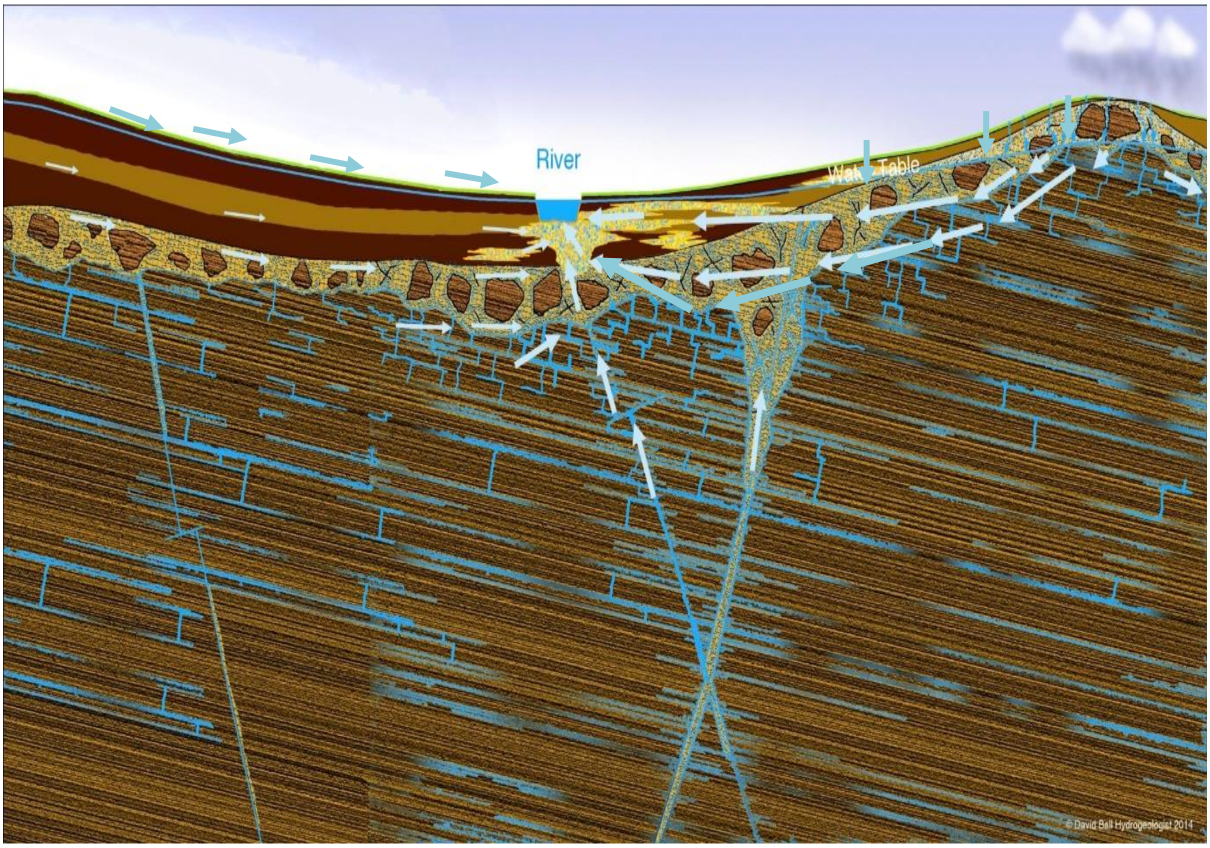

Figure 21-23: A schematic representation of a cross-section through a landscape where a stream is the receptor and showing two contrasting scenarios (Image source: David Ball).

The situation when a pressure is applied (in this case grazing animals, but it could be fertilizer spreading) is shown in Figure 21-24:

- On the left hand side, the red arrows show the flowpath for phosphate, i.e. overland and in the topsoil. This has implications for decisions on suitable mitigation actions; the pollutants moving along this flowpath must be intercepted before the stream is reached.
- On the right hand side, the flowpaths are underground. With the exception of the area at the top of the hill, phosphate, ammonia and pathogens will be attenuated in the free draining topsoil and subsoil. However, infiltration of phosphate and pathogens could occur in the extremely vulnerable area at the top of the hill. Nitrate has the potential to leach to

groundwater throughout this area. Mitigation actions are more difficult to arrive at in this scenario.

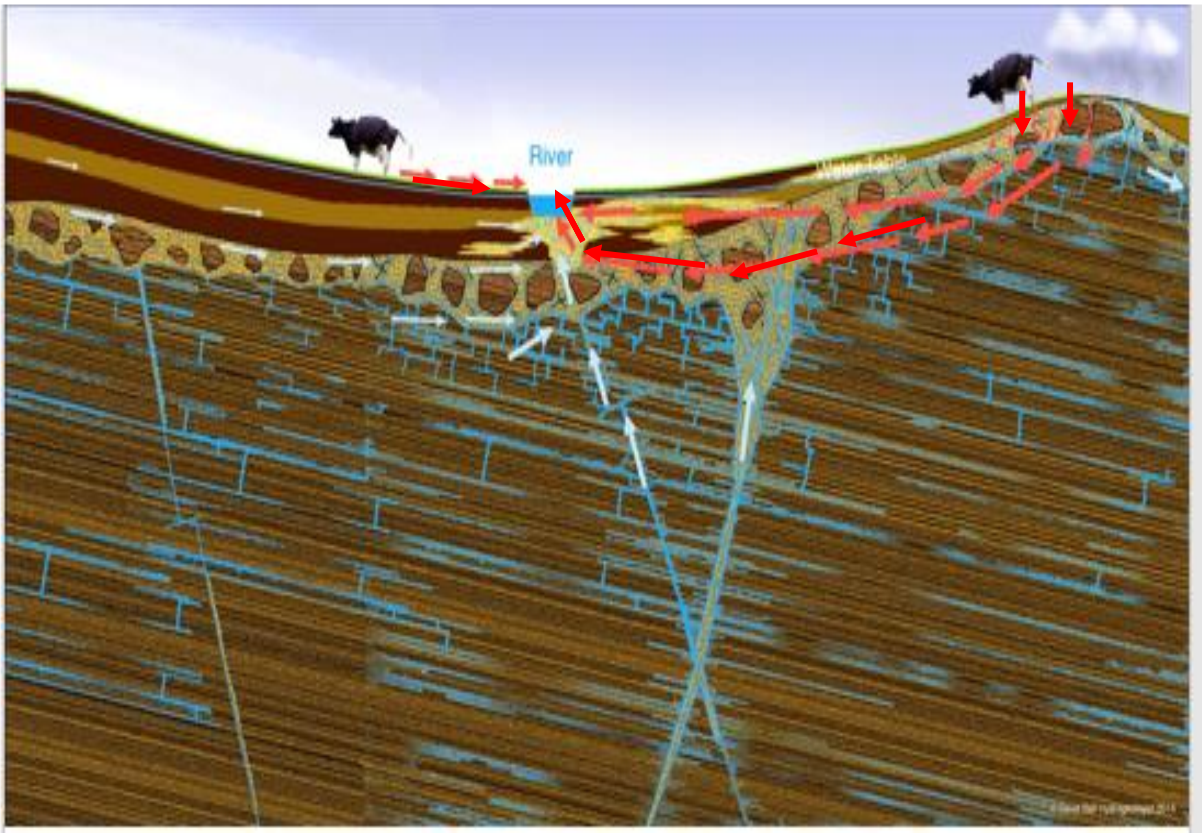

Figure 21-24: The red arrows show the main pathways for pollutants; at the land surface on the left hand side and underground on the right hand side. (Image source: David Ball).

21.8 Groundwater flow regimes in Irish bedrock

One of the most relevant maps that is available in undertaking LCAs is the bedrock map. There are 27 rock units in the Republic of Ireland (Figure 21-24). A brief summary of the hydrogeological flow regimes likely to be present in each of these rock units is given in Table 21-1, starting with the oldest bedrock types. More details are given in Kelly, et al., (2015)[96]. This is intended to assist in conceptualising the situation in the catchment areas of the water bodies being assessed during LCAs. However, keep in mind that where bedrock is overlain by subsoils, the landscape appearance may be due to the subsoil properties rather than the bedrock properties, or be a combination of both.

[96] Kelly, C., Hunter Williams, T., Misstear, B.M., Motherway, K. 2015. *Irish Aquifer Properties – A reference manual and guide.* Prepared on behalf of the Geological Survey of Ireland and the Environmental Protection Agency. Available at: https://www.gsi.ie/en-ie/publications/Pages/IrishAquifersPropertiesAreferencemanualandguideVersion10March2015.aspx

Table 21-1: Summary of hydrogeological flow regimes in the main bedrock units (Version 1.1).

Rock Unit(s)	Aquifer category	Hydrogeological flow regime
Precambrian Quartzites, Gneisses, Schists & Marbles, Cambrian Metasediments Silurian and Ordovician Metasediments	Pl	• The main flowpaths are in a thin upper fractured zone, occasional fault zones (most of the fault zones shown on the geological map are not transmissive) and, where present, the transition zone. • Deep groundwater flow is limited. • Runoff in rivers is flashy and drainage density is high. • Groundwater is likely to contribute <20% of average flows in rivers. • Some solution features may be present in the Marble.
Ordovician Volcanics	Rf	• Within this rock unit, shales are interlayered with the volcanic rocks. • The volcanic rocks have a substantial fissure permeability down to a depth of over 100 m, although an upper fractured zone is likely to have the highest permeability. • This rock unit is one of the main drinking water sources in County Wexford. • The intervening shaly layers will have a low transmissivity, but may have a thin high permeability layer immediately beneath the subsoil (see Figure 3-15). This can lead to contrasting ground conditions. • The groundwater has a low alkalinity and low conductivity.
Devonian Red Sandstones	Ll	• The main flowpaths are in an upper fractured zone[97], along fault zones and, where present, the transition zone. • Deep groundwater flow is limited, so there is an appreciable drainage density generally. • The overlying subsoil is usually sandy and therefore often looks free-draining, although there are many exceptions to this. • Denitrification can occur at depth; however, as the groundwater contribution from depth is relatively limited, this will not usually be sufficient to mitigate impacts of leaching of nitrate on surface water.
Devonian Kiltorcan-type Sandstones	Rf	• Well bedded sandstone with substantial fissure permeability to depths >60 m. Wells in this rock unit at Clonaslee supply Tullamore.
Dinantian Mudstones and Sandstones (Cork Group)	Pl	• The main flowpaths are in the upper fractured zone, occasional fault zones and, where present, the transition zone. • The upper fractured zone is likely to be thicker where sandstone is present. • Deep groundwater flow is limited. • Runoff in rivers is flashy and drainage density is high. • Groundwater is likely to contribute <20% of average flows in rivers.

[97] The upper fractured zone is usually thicker in Ll aquifers than in Pl or Pu aquifers, and therefore the groundwater contribution to streams is greater.

Dinantian (early) Sandstones, Shales and Limestones	Ll	Similar to other Ll aquifers.
Dinantian Lower Impure Limestones	Ll	• The main flowpaths are in the upper fractured zone, fault zones and, where present, the transition zone. • Permeability decreases with depth. • The upper fractured zone is often several metres thick. • Subsoils generated from this rock unit are often somewhat clayey, with a permeability often at the low end of 'moderate' or, sometimes, the upper end of 'low'. • Small streams are fairly frequent.
Dinantian Pure Unbedded Limestones *south of a line from the Shannon estuary to Wexford*	Rk	• These limestones are the most productive aquifers in the country for water supplies. • Solution and fissuring is 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. • The overlying subsoils are generally silty and so have a moderate permeability, with free-draining soils present. • Drainage density is low. • Groundwater provides more than 60% of average stream flows in these areas.
Dinantian Pure Unbedded Limestones *north of a line from the Shannon estuary to Wexford*	Ll	• The main flowpaths are in the upper fractured zone which can be several metres thick, fault zones and, where present, the transition zone. • Permeability decreases with depth. • The upper fractured zone is often several metres thick. • Subsoils generated from this rock unit are silty, with a moderate permeability. • These areas generally have a free-draining appearance.
Dinantian Dolomitised Limestones	Rf	A highly transmissive aquifer of limited extent in Kilkenny and Laois.
Dinantian Upper Impure Limestones	Ll mostly, with areas of Lm in south Meath and north Kildare	• This covers an extensive area from Dublin and Meath in the east, stretching through Offaly and Westmeath into east Galway. • In outcrop, it appears well bedded and dark grey. • In the Ll areas, most groundwater flow is in the upper fractured zone, which can be several metres thick. • In the Lm areas, the fracturing is more widespread and deeper. • High iron is common in wells. • Reducing conditions are often present below the upper fractured zone, which can result in denitrification. • Subsoils generated from this rock unit are somewhat clayey, with a permeability often at the low end of 'moderate' or, sometimes, the upper end of 'low'. • Small streams are fairly frequent.
Dinantian Pure Bedded Limestones	Rk[c] and RK[d]	• The most extensive Regionally Important aquifer in the country. • In outcrop, it appears bedded and pale grey. • In the west of Ireland (e.g. Burren, mid Galway, Roscommon) groundwater flow is dominated by conduits, and karst features such as swallow holes and large springs are common.

		• East of the Shannon, while there are some karst features, flow is more diffuse in fractures, bedding planes and small conduits. Therefore, high yielding wells are common. • An upper more fractured zone, called epikarst, is frequently present. • Subsoils are often thin or absent west of the Shannon and groundwater is commonly Extremely (E) vulnerable. Where subsoils overlie this aquifer, they are usually silt dominated and free draining.
Dinantian Sandstones. Dinantian Mixed Sandstones, Shales and Limestones. Dinantian Shales and Limestones.	Rf, Lm and Ll	• These rock units are present in the border counties. • There is a lot of variability in these rock units, depending on the aquifer category. • The descriptions given in this table for other similar rock units and associated aquifer categories can be applied.
Namurian sandstones & shales	Pl & Ll	• This is classed as an Ll aquifer in Clare and north Kerry, with small areas of Pl aquifers. • It is classed as a Pl aquifer in the Castlecomer plateau. • Drainage density is high.
Westphalian shales	Pu	• The lowest transmissivity aquifers in the country, with limited fracturing. A thin upper fractured zone and a transition zone may be present, but even in these, the permeability is likely to be limited. • Subsoil generated from this rock unit will generally be clayey and have a low permeability. • Stream density will be high and runoff will be flashy. • Groundwater input to surface water will be low (<20% of average flows in streams).
Westphalian Sandstones	Ll	• The main flowpaths are in the upper fractured zone, which can be several metres thick, fault zones and, where present, the transition zone. • Permeability decreases with depth.
Permo-Triassic Mudstones and Gypsum	Pu	• See description for the Pu aquifer above.
Permo-Triassic Sandstones	Lm	• This has a small outcrop area at Kingscourt. • It has a high fissure permeability and may have an intergranular permeability. • It is classed as an Lm aquifer because of the limited extent.
Granites	Pl	• The main flowpaths are in a thin upper fractured zone (which is not always present), occasional fault zones (most of the fault zones shown on the geological map are not transmissive) and, where present, the transition zone, which usually consists of loose granular sandy material. • In west Wicklow and east Carlow, several metres of weathered granite may be present, giving a free-draining situation. • In other areas, the landscape is poorly draining and blanket peat is common. • Deep groundwater flow is limited. • Runoff in rivers is flashy and there is a high drainage density. • Groundwater is likely to contribute <20% of average flows in rivers.

Basalt	Ll	• The main flowpaths are in the upper fractured zone which can be several metres thick, fault zones and, where present, the transition zone. • Permeability decreases with depth.

Regionally Important (**R**) Aquifers

(iv) Karstified aquifers (**Rk**)
(v) Fissured bedrock aquifers (**Rf**)
(vi) Extensive sand/gravel **(Rg)**

Locally Important (**L**) Aquifers

(v) Sand/gravel (**Lg**)
(vi) Karstified bedrock (**Lk**)
(vii) Bedrock which is Generally Moderately Productive (**Lm**)
(viii) Bedrock which is Moderately Productive only in Local Zones (**Ll**)

Poor (**P**) Aquifers

(iii) Bedrock which is Generally Unproductive except for Local Zones (**Pl**)
(iv) Bedrock which is Generally Unproductive (**Pu**).

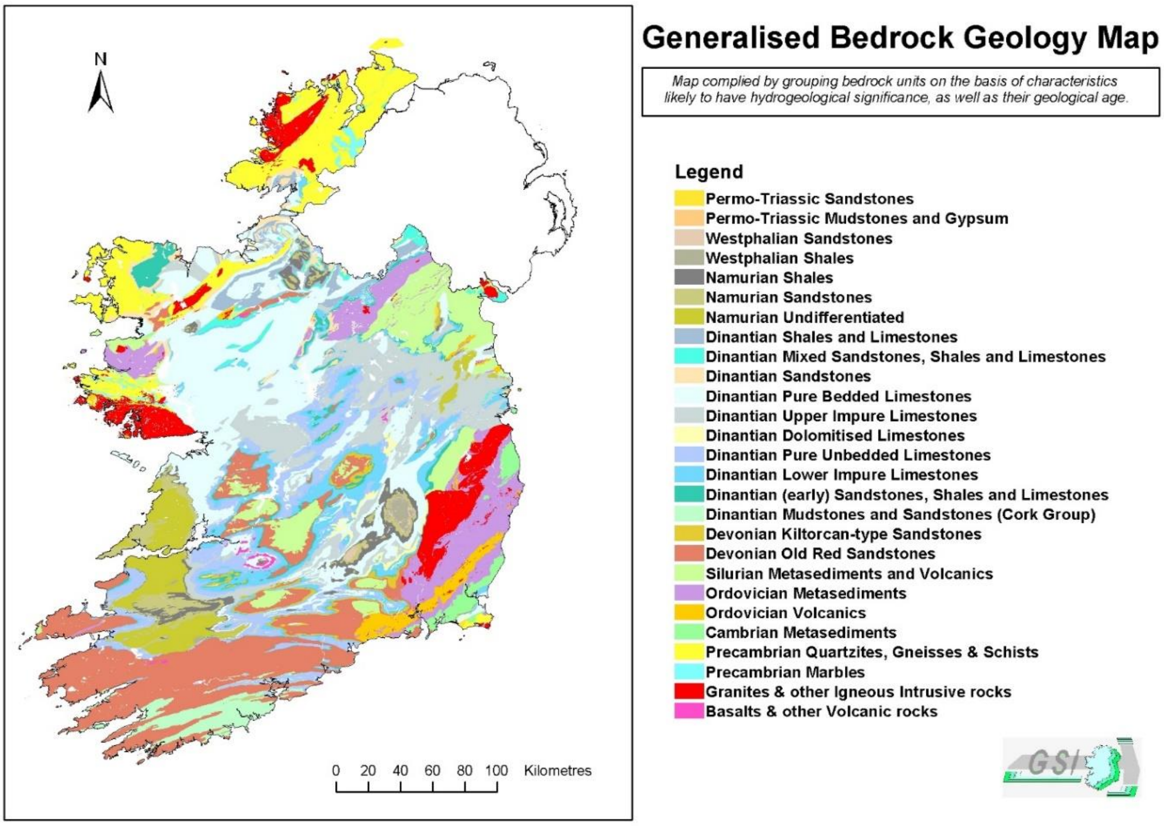

Figure 21-24: Map of main bedrock units (Source: GSI).

22 Appendix 6: The Pathways Conceptual Model

What is it?

- A representation of a complex system, in this case the catchment or ZOC in question, which is used to make the system/catchment understandable for all who are involved.
- It is based on data/information, and an evaluation of these data.
- It provides the information and understanding required to enable the main pathways for water and contaminants to be determined.
- It is an iterative and evolving process (see Figure 22.1 below), that is improved as more data/information become available, and as the understanding improves.
- The complexity/quality of the pathways conceptual model (PCM) should be appropriate to the situation that needs resolving, and no greater.
- It is an aid to decision-making in that decisions will be based on the understanding given by the conceptual model.

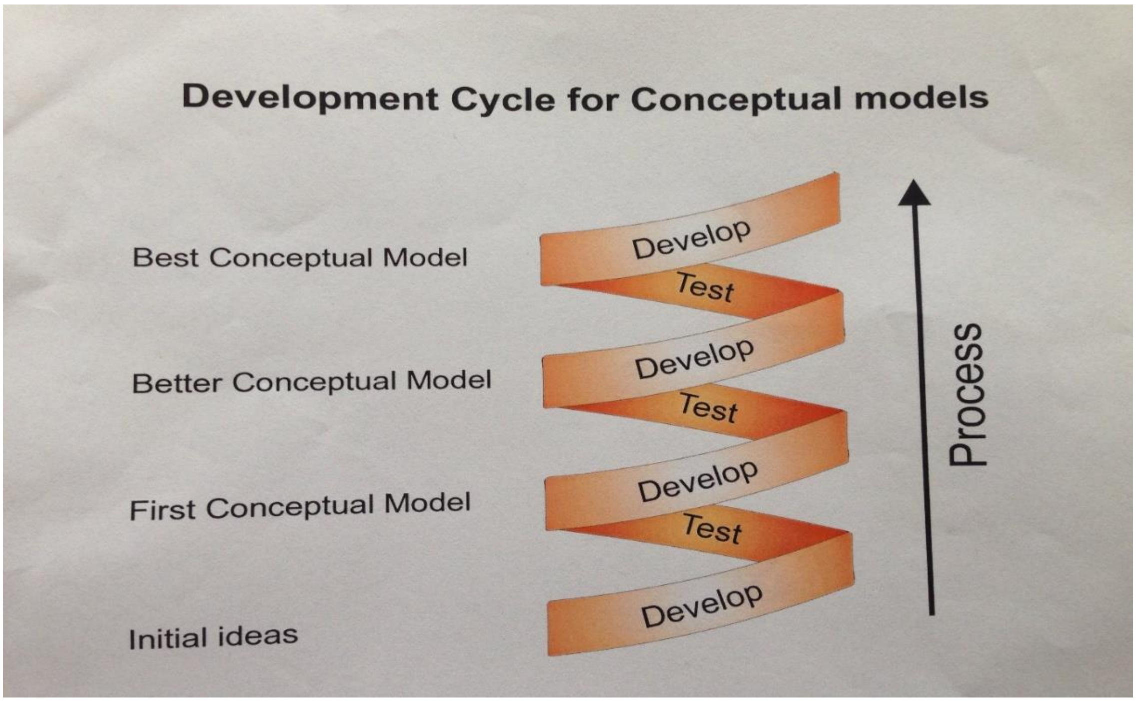

Figure 22.1: Illustration of the iterative and evolving process in developing conceptual models (Source: Steve Fletcher, Environment Agency, UK).

What it isn't.

It is not data, but is based on data. There is a danger that the emphasis becomes data collection, without reaching decisions and undertaking the mitigation actions.

Why use pathway conceptual models?

- As a systematic mechanism for integrating data/information on the physical setting – topographical, geological, hydrological, hydrogeological and hydrochemical.
- Formalising helps to stimulate and sort out ideas as to how the catchment system works.
- Helps see gaps in the information and understanding.
- Helps produce or decide on tools (analytical, such as the EPA source load apportionment tool, or numerical) with which predictions can be made.
- Enables the catchment/ZOC system to be described in a logical way.
- Improves decision-making.

What does it look like?

- It will generally be written text, backed up by relevant maps. It should always adopt the 3-D approach. Hand drawn conceptual model sketches may be beneficial, and in certain circumstances, a more formalised drawing may be required for more formal reports and publications as a means of explaining the outcomes.

After the fieldwork is undertaken, it is recommended that the pathways CM be updated as a summary of the understanding of the pathways gained and as a basis for proposed mitigation actions. If a formal report is required, a proper drawing may be needed to illustrate the hydrogeological setting, the pathways and the mitigation actions. Examples of CMs are given in Figures 22.2, 22.3, 22.4, 22.5, 22.6, and 22.7.

Many pathway interception measures and actions will be located in the riparian zones of watercourses. Therefore, an understanding of the physical setting is an important precursor to considering mitigation options. The Smarter_BufferZ Project Team and the EPA Catchments Unit have developed pathway conceptual models (PCMs) of the physical settings in the vicinity of watercourses (see Figures 22.8, 22.9, 22.10, 11 and 22.12). When considering what measures/actions would be most applicable in the particular setting being dealt with, evaluating this setting in the context of the PCMs illustrated below would assist in the decision-making, and help ensure that the measures/actions are both efficient and effective. *(The EPA-funded SMARTER_BufferZ research project is being undertaken by Teagasc and the James Hutton Institute. Its objectives include improving the understanding of critical factors for siting of riparian buffers and provide recommendations on best management options that take account of the biophysical settings found in riparian areas in Ireland. Daire Ó hUallacháin, Teagasc and Marc Sutter, James Hutton Institute, are the Principal Investigators.)*

The suggested approach to producing the pathways conceptual model (PCM) is as follows:

- Think in terms of:
  - The hydraulic issue.
    - Is the water (either rainfall and/or effluent discharged onto/into land) moving away:
      - As underground flow?
      - As overland flow/close to the land surface?
  - The attenuation issue.
    - How much attenuation occurs along the pathway before the receptor is reached?
- The 'driver' for the conceptual model is/are the **significant issue(s)** as these dictate the pathways that are relevant. For instance, if either phosphate or MCPA are the significant issues, the main pathway is overland flow in poorly draining soils areas or in drainage ditches. Therefore, the pathways CM should focus on the scenarios that have these pathways.
- Start with the aquifer map and their associated transmissivities to decide on the **pathway compartments**. These compartments describe the regional flowpaths for water, both over ground and underground.
- Check the bedrock map to see whether the bedrock units present improve the understanding, e.g. a Locally Important Bedrock Aquifer which is moderately productive only in local zones (Ll) might be either a limestone or sandstone and this variation would influence the hydrochemistry and might influence groundwater movement.
- Then examine the soil drainage, pathway susceptibility, groundwater vulnerability, etc., maps to give more detail on the localised pathways present in the catchment/ZOC. Conclude on the potential **pathway sub-compartments** based on these maps, and highlight those that are relevant to the significant issue(s). Table 10-6 in Section 10.5.7 illustrates the situation for a surface water source where phosphate and associated macroalgae in summer is the significant issue. The pathways relevant to phosphate loss from the land and therefore the potential CSAs are located in Sub-Compartments 1A and 2A.

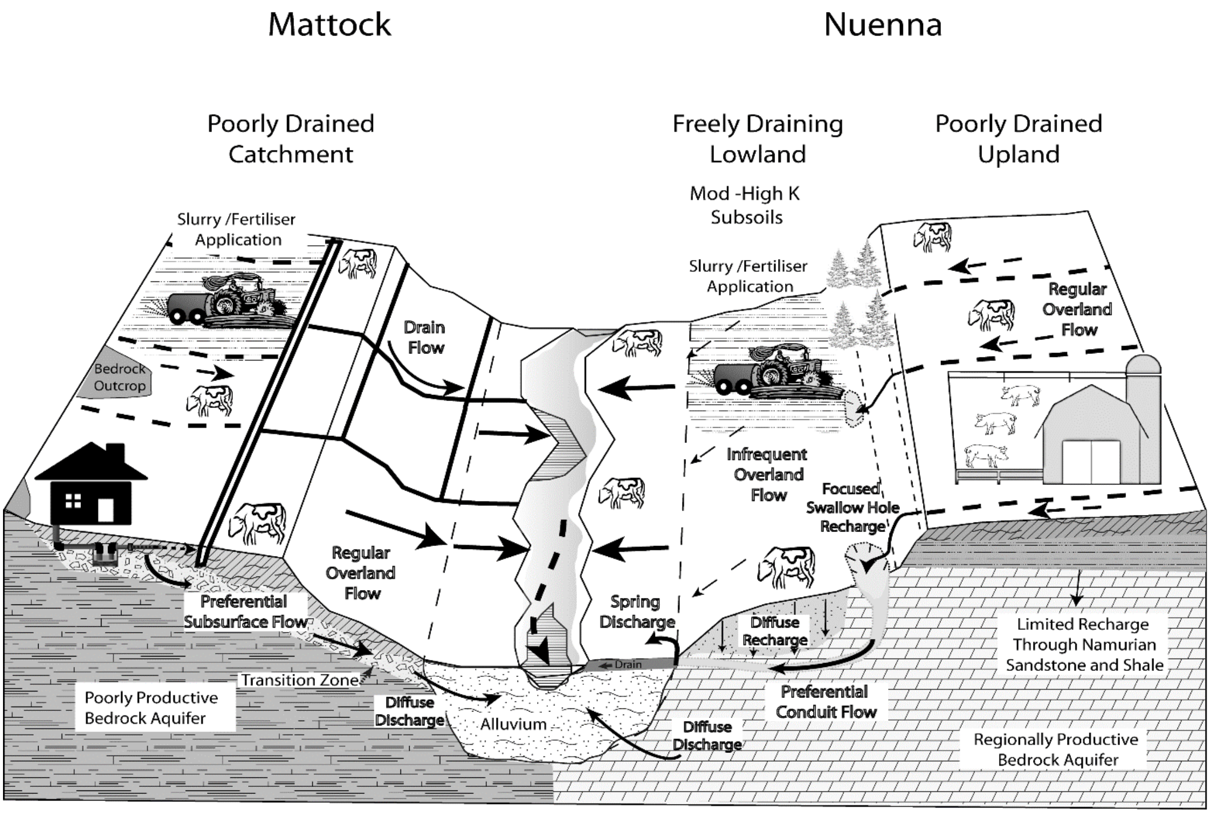

Figure 22.2: Schematic representation of the contrasting hydro(geo)logical pathways contributing flow and nutrients to the stream in the poorly drained Mattock catchment (left) and freely draining karst catchment (right). The thicker arrows represent a larger relative flow component than the thinner arrows. Dashed arrows represent intermittent flow (Copied from Deakin *et al.*, 2016).

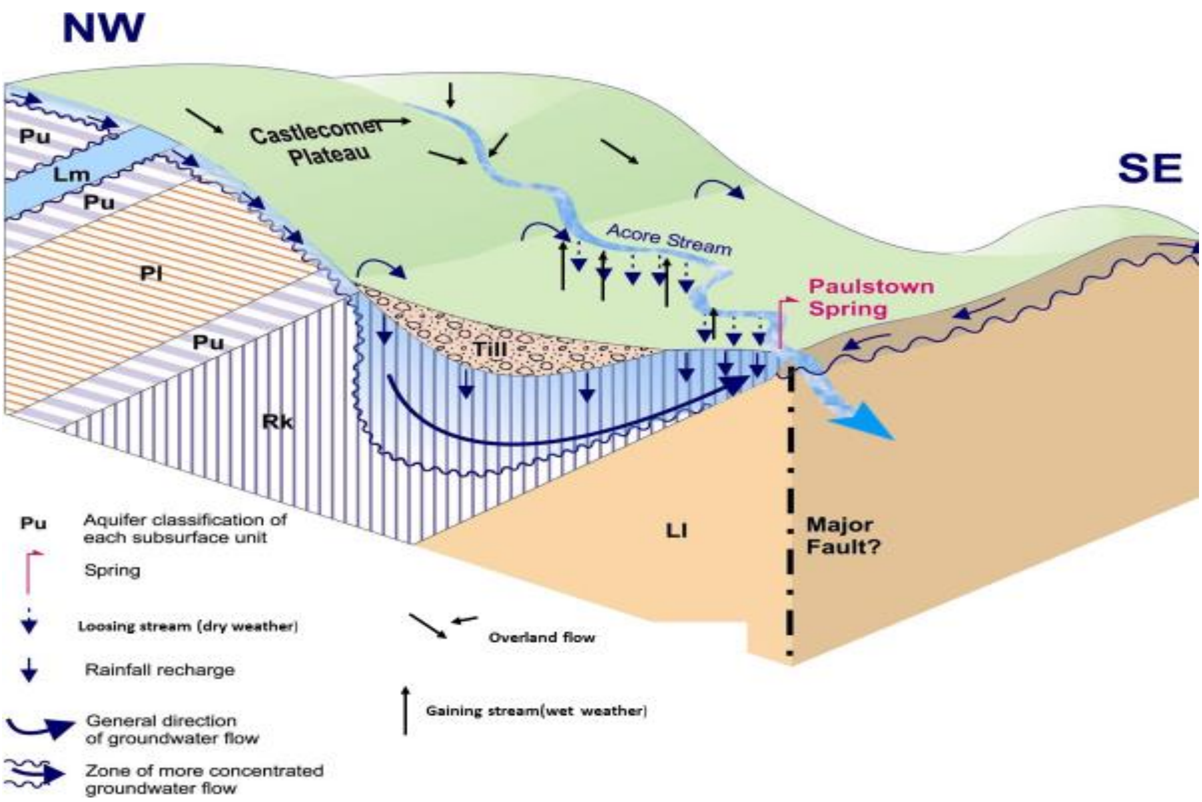

Figure 22.3: Schematic diagram drawn by the Groundwater Section, GSI, for the Paulstown Source Protection Report.

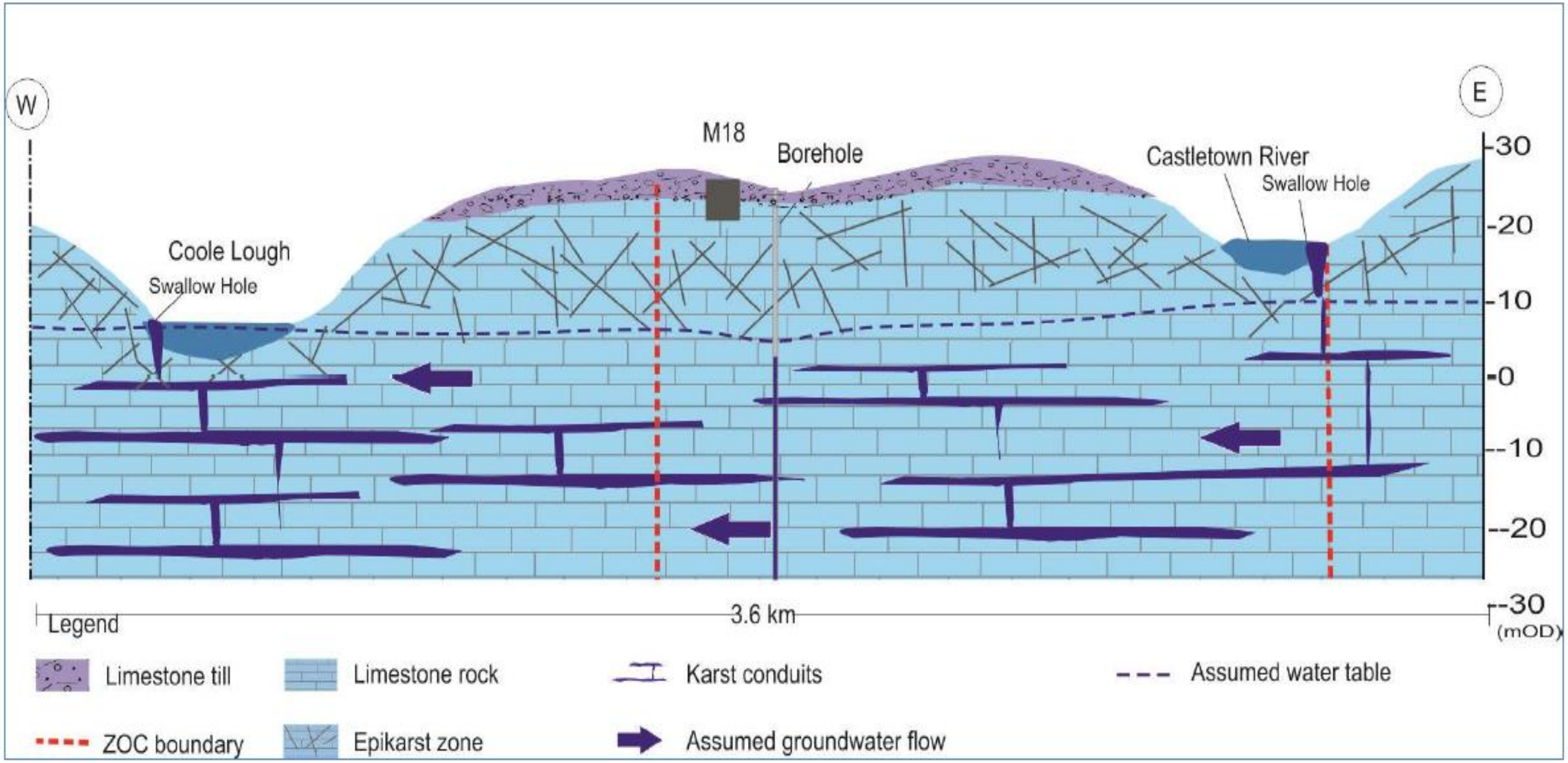

Figure 22.4: The pathways conceptual hydrogeological model for Coole GWS (Source: Tobin Consulting)

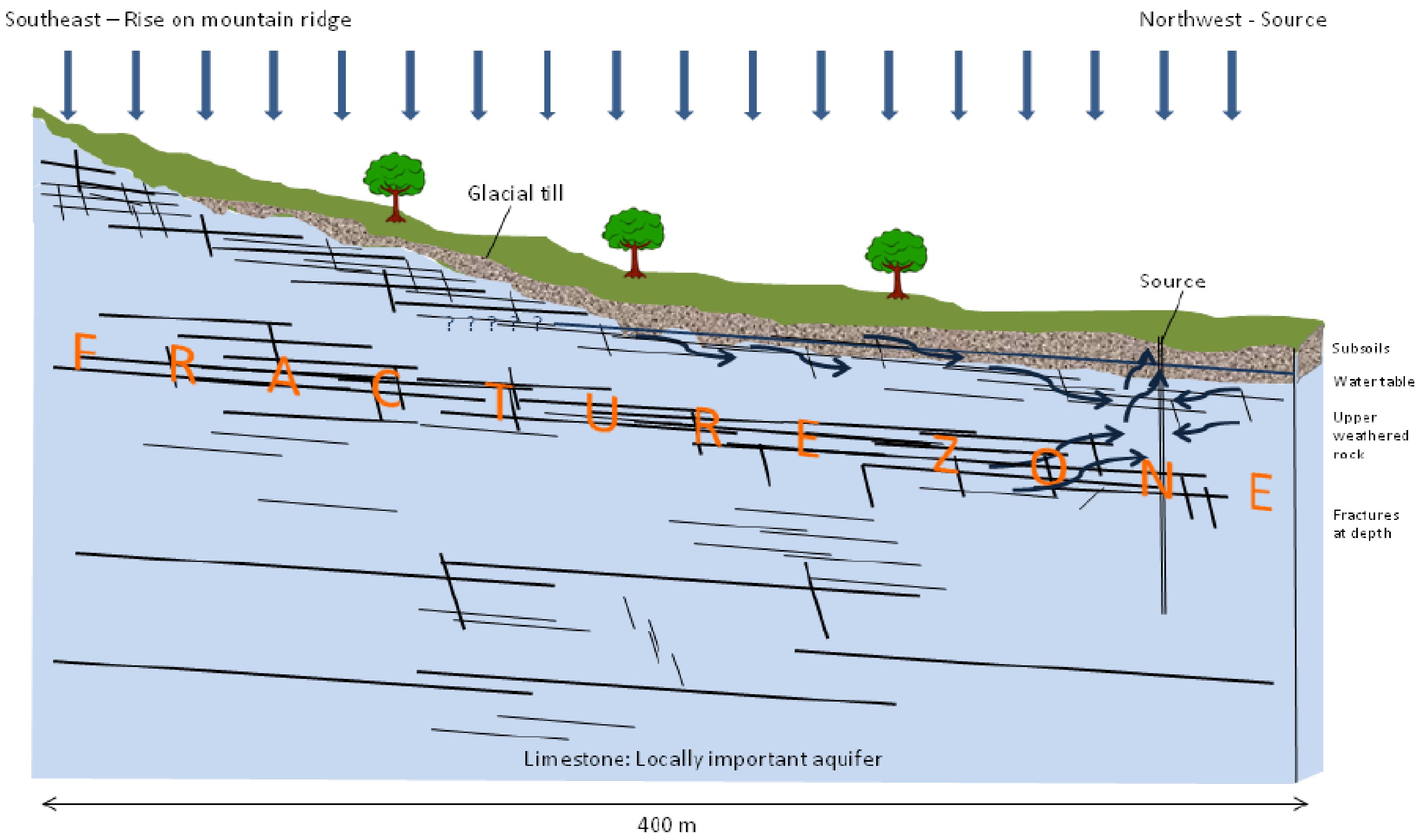

Figure 22.5: The pathways conceptual model for Shalee and Kiltyrome GWS (Source: Robbie Meehan, Talamhireland).

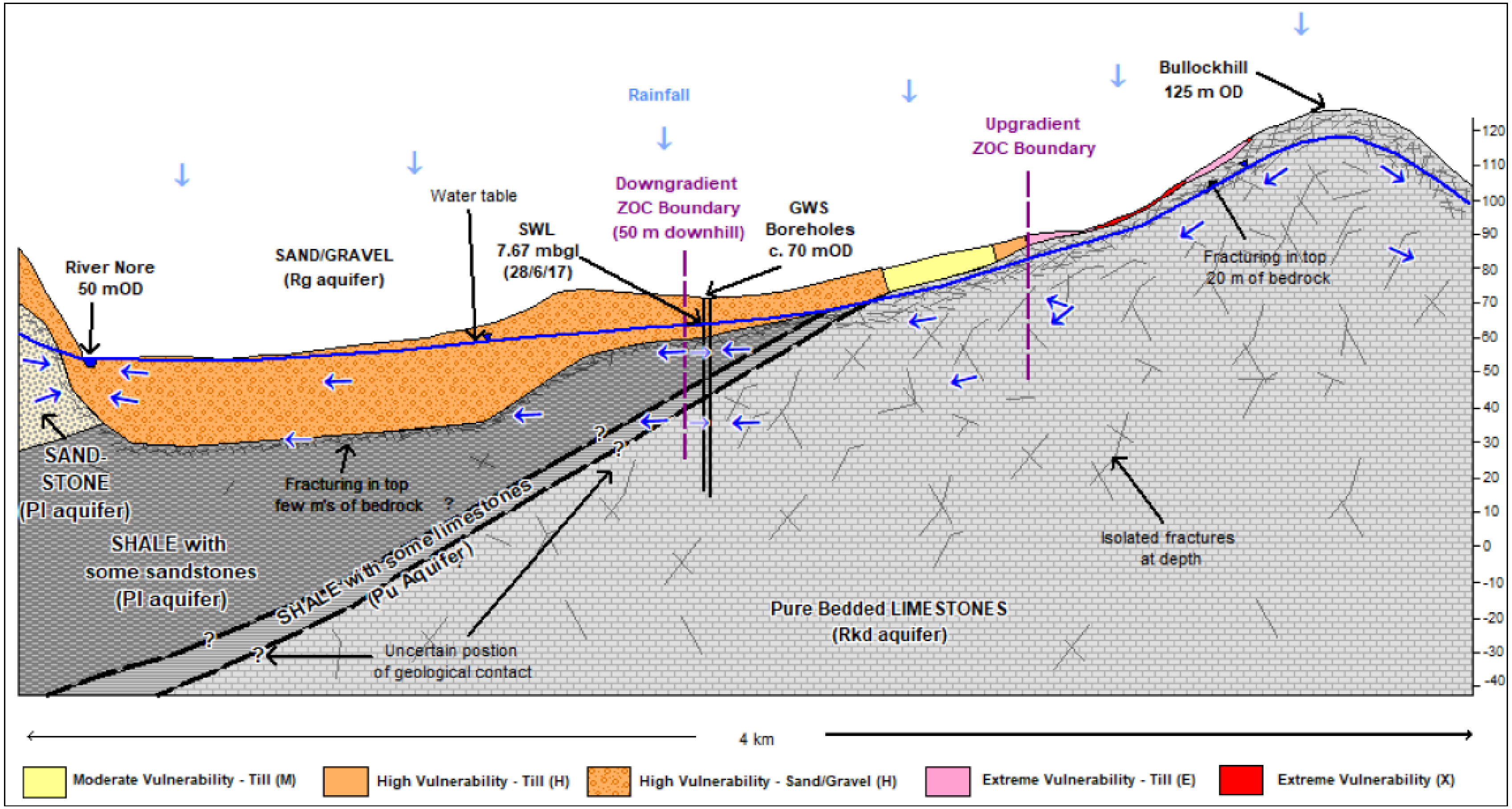

Figure 22.6: The pathways conceptual model for Dunmore GWS (Source: IE Consulting)

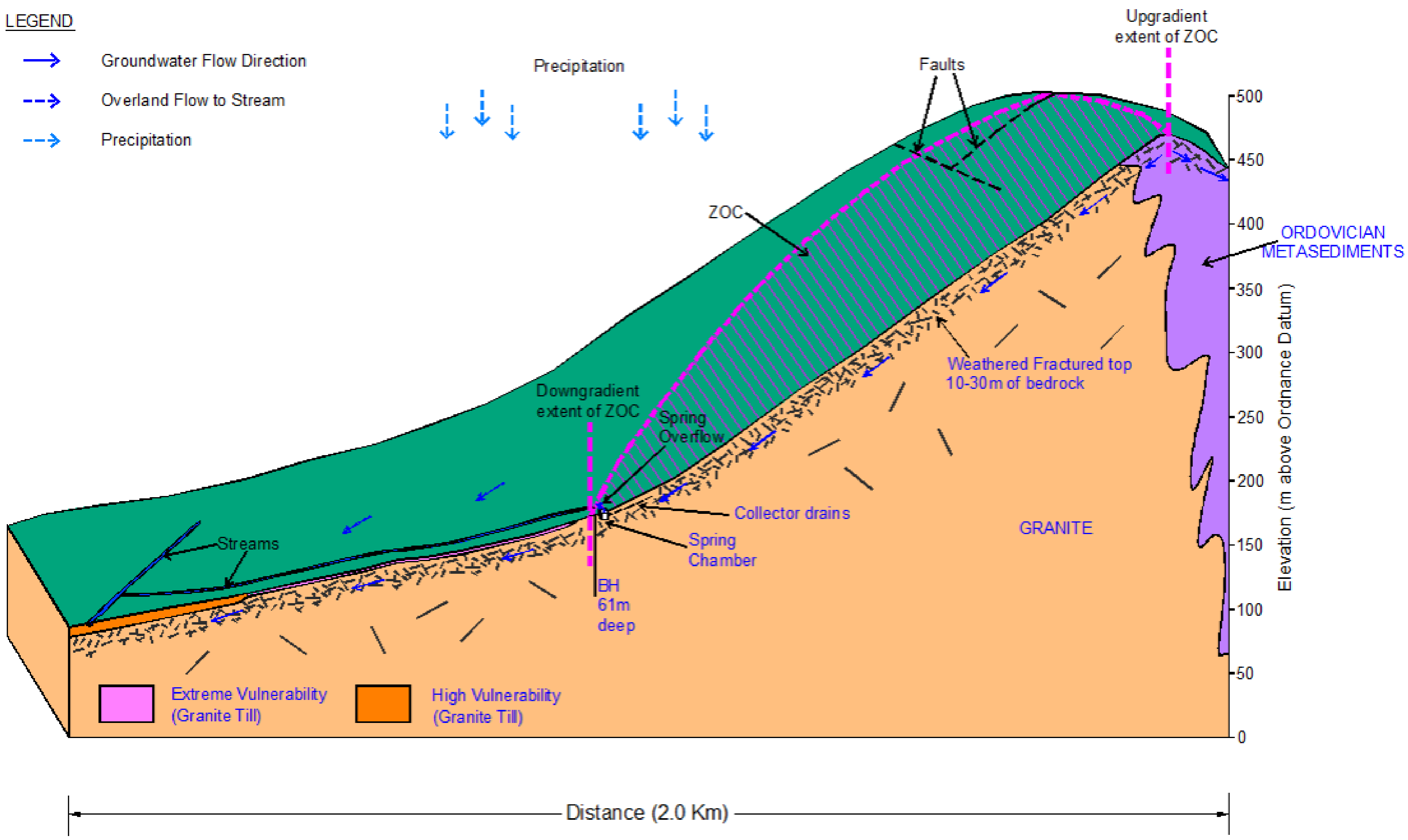

Figure 22.7: The pathways conceptual model for the St. Mullins parish GWS.

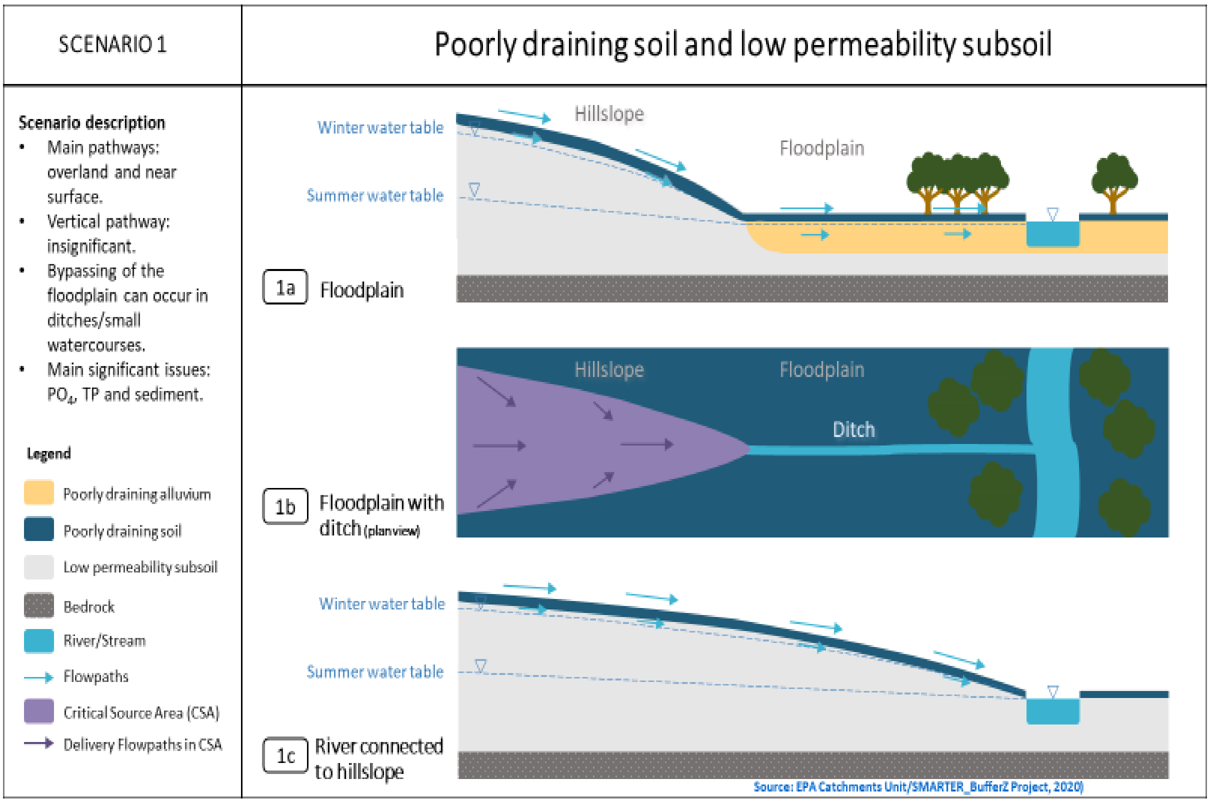

Figure 22.8: Pathway conceptual model for poorly draining scenario in vicinity of a watercourse.

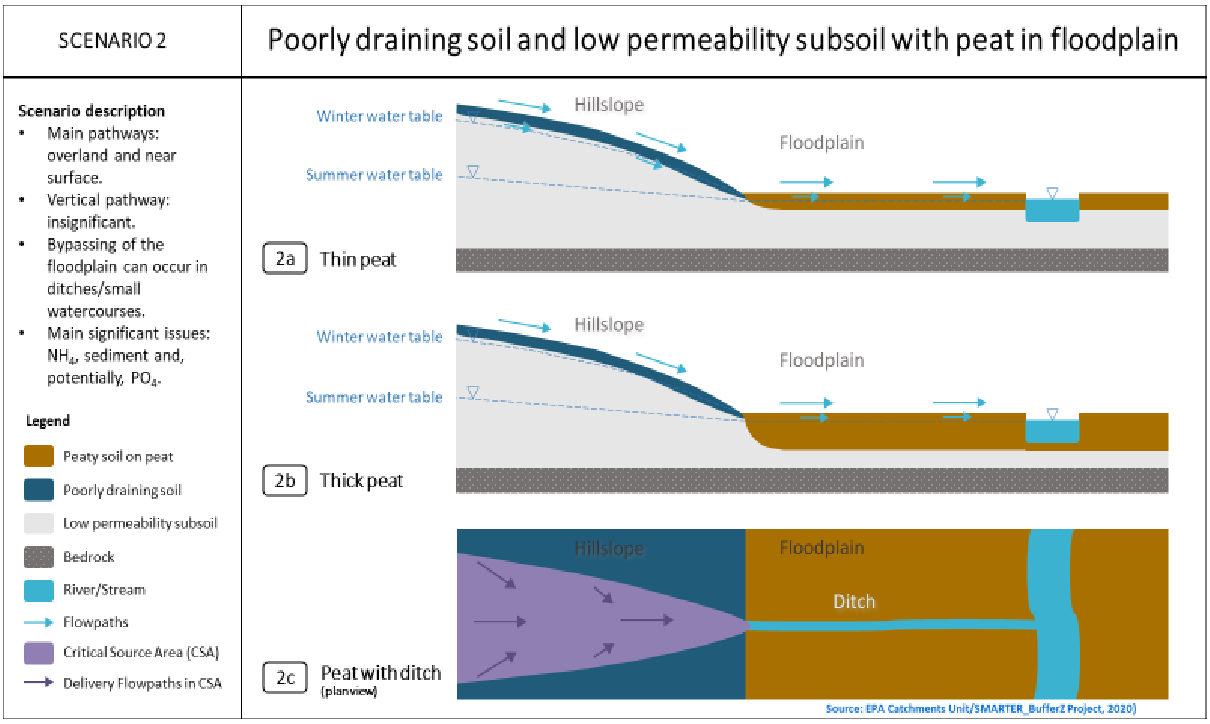

Figure 22.9: Pathway conceptual model for poorly draining scenario including peatland in vicinity of a watercourse.

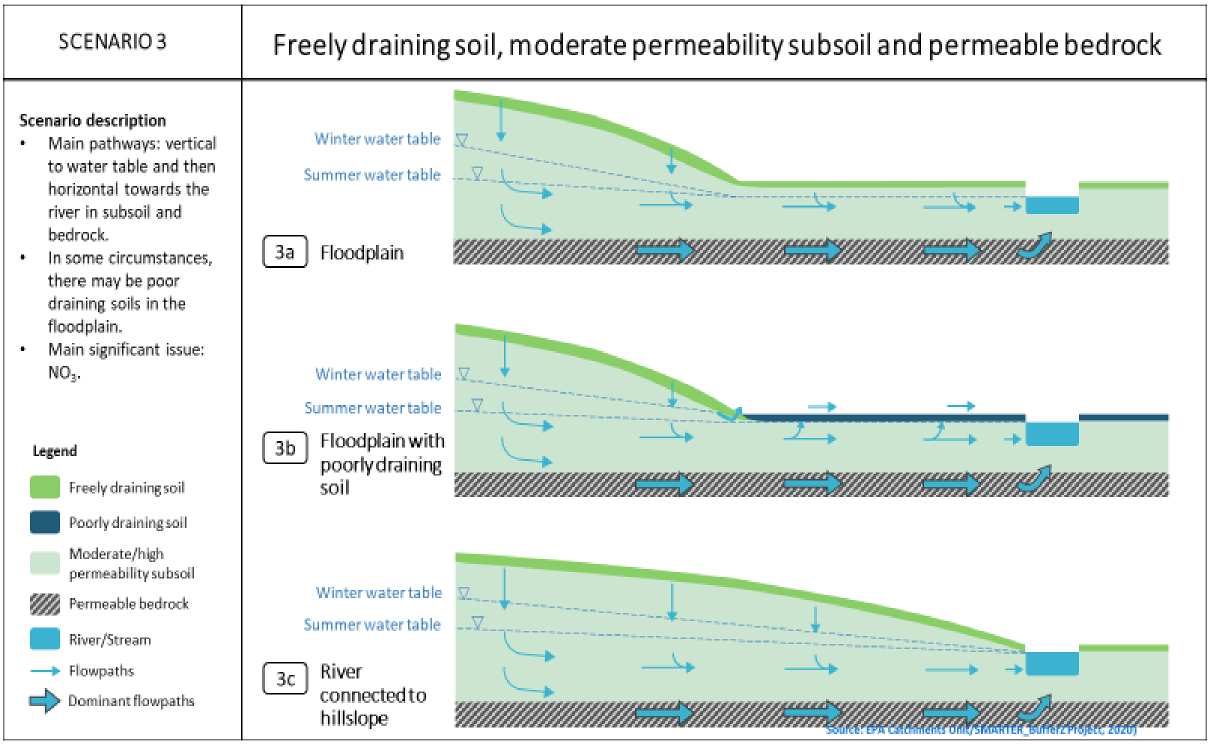

Figure 22.10: Pathway conceptual model for freely draining scenario in vicinity of a watercourse.

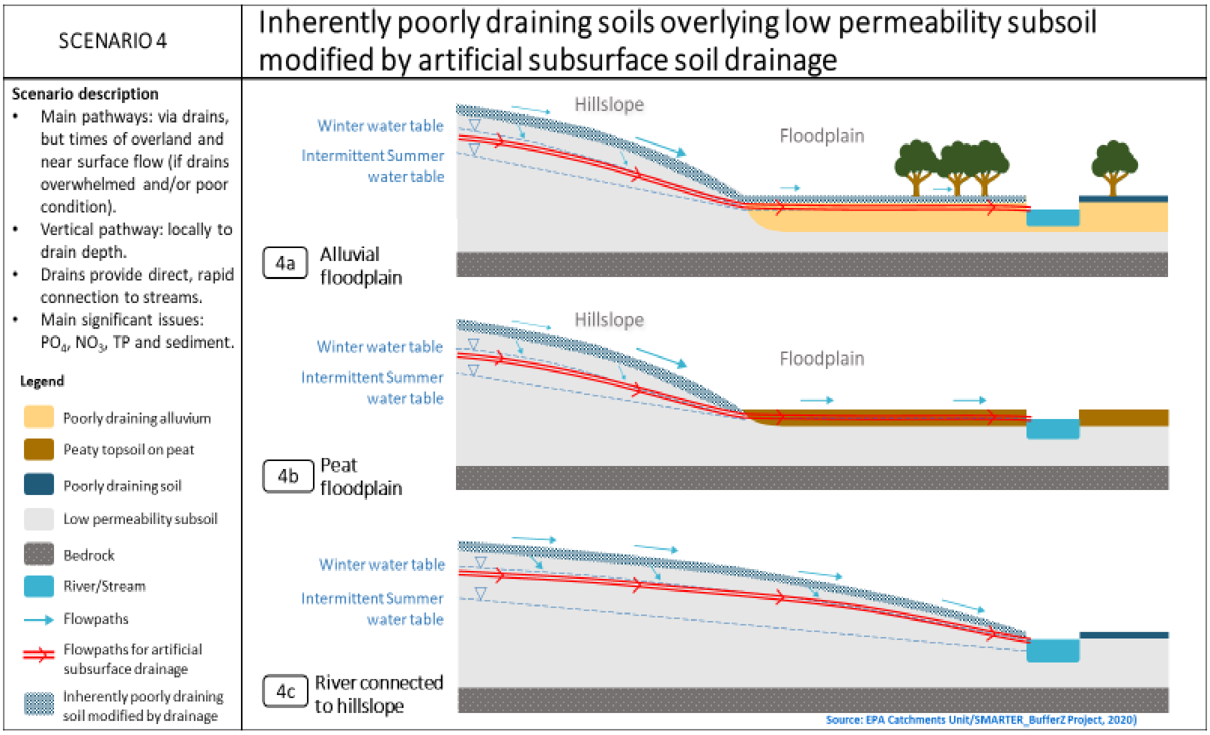

Figure 22.11: Pathway conceptual model for poorly draining scenario with artificial drainage installed.

SCENARIO 5	Permeable soils affected by fluctuating groundwater and modified by artificial subsurface soil drainage

Scenario description

- Main pathways: upwelling groundwater with preferential drainage pathways.
- To assist cultivation wide floodplain areas with poor draining soils may be artificially drained.
- Main significant issue: PO_4.

Legend

- Freely draining soil
- Moderate/high permeability subsoil
- Groundwater gley modified by drainage
- Poorly draining soil
- Inherently poorly draining soil modified by drainage
- Permeable bedrock with groundwater
- River/Stream
- Flowpaths
- Flowpaths for artificial subsurface drainage

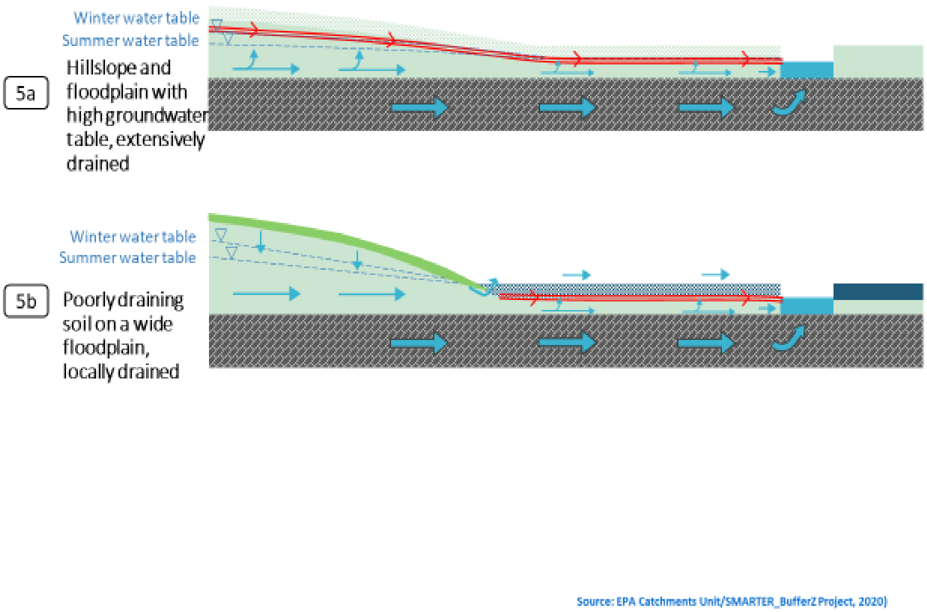

Figure 22.12: Pathway conceptual model for scenario where groundwater gleys (caused by a high water table) overly permeable subsoils. This can occur where the topographic slope is gentle and the hydraulic gradient is low, with the water table rising close to the ground surface in wet weather. Artificial drainage is installed.

23 Appendix 7: The Role of Winter Fieldwork

23.1 Introduction

Fieldwork for assessing surface water quality and investigating *At Risk* water bodies tends to be associated with and undertaken in the Spring, Summer and Autumn months. This is understandable as i) biological monitoring, such as Q-value determination, Small Stream Impact Scores (SSISs) and Rapid Assessments must be undertaken in this period, ii) water levels are relatively low facilitating fieldwork and iii) the weather is generally suitable. However, there are circumstances where winter fieldwork, while challenging, is needed.

EPA biologists have identified that there is a good relationship between the Q-value and mean annual phosphorus concentrations. This is because the macroinvertebrates have life cycles of up to two years in some circumstances and require good water quality all year round, not just in the summer. The sources of phosphorus that make up the mean annual load that contributes to this relationship include point sources and diffuse sources. An assessment of both point sources and diffuse sources is therefore required to properly assess the impacts on the biology. While point sources can discharge all year round, they are often more prominent in summer because there is little dilution from surface runoff and other sources to mask them. Carrying out fieldwork in the summer is therefore very useful for identifying the point source contribution, especially the small point sources which are very difficult to see in winter. Diffuse sources require rainfall to provide the pathway to the stream. Diffuse sources are therefore often more dominant in winter, especially in the shoulder seasons in October/November with the first flush effect after the summer, and in January and February when the first landspreading takes place. Carrying out fieldwork in late Autumn, Winter and early Spring is therefore more important for investigating the diffuse source component of the total load impacting on the biology. The desk study should provide a preliminary assessment of whether there are point sources or diffuse sources or both, and the conclusion can then be used to decide when the fieldwork should take place. If fieldwork is not carried out in the correct season to assess the relevant P sources, there is a significant likelihood that only part of the overall total phosphorus load will be characterised, and that that portion becomes the sole focus of the measures. For example, in a rural setting, carrying out fieldwork only in the summer months often leads to a focus on small point sources as the issue, when diffuse sources often make up the much larger contribution to the overall load. It is unlikely that sufficient water quality improvements will be achieved by addressing small point sources on their own in many circumstances.

23.2 Why Winter fieldwork?

There are a number of reasons:

- To see runoff events ‘on the ground’ after heavy rainfall.
    - To locate pathways for water and contaminants (mainly phosphate, particulate P and sediment) in poorly-draining areas.
    - To locate or confirm delivery points/areas along watercourses.
    - To help map likely critical source areas (CSAs).
    - To enable suitable pathway interception options to be considered, decided on and established.
    - To locate intermittent watercourses and ditches.
    - To locate temporary springs.
- To check ditch/drain runoff (many of these are dry for several months of the year), particularly those that are located close to farmyards and taking runoff from CSAs. For instance, Summer checking would not usually locate beef farmyards contributing dirty water, and discharges from some DWWTSs might not be obvious then.
- To check for pipe discharges in a period when they are not masked by vegetation.

- To undertake thermal imaging while there are temperature contrasts as a means of locating pipe and groundwater discharges.
- In circumstances where water samples are needed, to take a water sample during relatively high flows.
- To enable consideration of possible mitigation options.

23.3 Where should Winter fieldwork be undertaken

- Along segments of watercourses that a desk study and 'summer' fieldwork have concluded are the likely areas contributing pollutants in overland and near-surface flows, and in ditches/drains, and that need to be confirmed before mitigation measures/actions and their location are decided on.

23.4 When should Winter fieldwork be undertaken?

- During and soon after heavy rainfall is the best time. Therefore, planning ahead using weather forecasts is needed.

23.5 What can be performed?

- A visual assessment of water flows in watercourses, ditches/drains and overland; this is the most important benefit.
- A visual assessment of topography and the delivery points/areas to watercourses and ditches/drains for runoff. The maps of critical source areas (CSAs) compiled as part of the desk study should be used to help focus on the fields that are likely to be contributing nutrients, and therefore where mitigation measures/actions need to be targeted.
- A visual assessment of the role of hedges in intercepting runoff.
- A visual assessment of sediment content in watercourses.
- A visual assessment of watercourse and drain bank erosion contributing sediment.
- Water sampling[98].
- Thermal imaging.
- Measurements of turbidity, conductivity, temperature, pH.
- Flow measurements, if considered helpful. However, undertaking flow measurements will usually be difficult, with potential H&S issues, in high flows. Therefore, in circumstances where approximate nutrient loadings are being estimated to enable comparisons between different tributaries to a river water body, it may be advisable to use relative comparisons with flows in nearby EPA or OPW hydrometric stations for the day of sampling. For example, if the sampling day coincided with the 15%ile flow in the nearby station, it would mean that flows will only be higher 15% of the time and therefore is a relatively high flow.
- Targeted auto-sampling, in particular upstream of lakes. This can be useful for catching hydrograph peaks and also helps determine contributing pathways depending on whether nutrients get diluted or increase in loads. Also, if there is a H&S issue, going near certain rivers in high flow, the flow can trigger the sampler starting.
- Consideration, while walking the catchment, of possible mitigation measures/actions and where they might be located. (Asking all the time, what are the pressures causing the problems, where exactly are they arising and what might be done about them.)[99]

[98] In circumstances where the receptor is a Moderate status, *At Risk* water body, there is no need to prioritise taking a sample immediately after heavy rainfall as the concentrations would be less relevant than general Winter concentrations. If there was an *At Risk* lake downstream, sampling in both scenarios is recommended as the total load entering the lake is relevant.

[99] Where phosphate from farmland is the *significant issue*, consider pathway mitigation options in particular. Keep in mind that at delivery points or areas of focussed overland and near-surface flows, the relatively narrow buffer zones in the Regulations are unlikely to be sufficient to mitigate the impacts, and that much wider riparian

23.6 Conclusions

Winter fieldwork is challenging to undertake due to high water levels, relatively fast flows and poor weather conditions. However, it is possible to 'see' features that are not obvious during other periods. Where there is uncertainty on the location of CSAs in poorly-draining areas, the role of intermittent streams and ditches/drains, the location of point sources, etc., after the desk study and 'summer' fieldwork is undertaken, as will be the case in some circumstances at least, then Winter fieldwork is essential. In addition, it generally needs to be more than just 'bridge hopping'; it needs to include catchment/stream walks.

buffers or woodlands or farm ponds are likely to be needed (see Section 12 for more details on mitigation options) to provide sufficient interception of nutrients and sediment.

24 Appendix 8: A Framework for Drinking Water Source Protection

The NFGWS appreciates the importance of source protection and has taken the initiative to produce a framework to facilitate this. The aim was to provide a generic framework for the catchment component of drinking water source protection that takes account of and builds on the progress made in the area of water resources management and source protection in the last 10 years, the availability of new information and maps, and lessons learned. The objectives are to:

- provide a high level vision and structure for source protection;
- integrate and link groundwater and surface water source protection;
- connect with the characterisation approaches used by the EPA Catchment Science and Management Unit and the Local Authority Catchment Assessment Teams as part of Water Framework Directive (WFD) implementation;
- link with and expand on the NFGWS Strategy for Source Protection on Group Water Schemes (NFGWS, 2012a) and the NFGWS Quality Assurance (HACCP) system (NFGWS, 2012b);
- encourage a focus on the main issues and pressures that need to be dealt with in any given source catchment;
- enable identification of the main susceptibilities in source catchment areas as a means of future proofing the protection of water quality;
- provide a means of concentrating efficiently and effectively on the most appropriate and cost-effective protection/mitigation measures and actions; and
- provide a focussed narrative that will be used in public consultation and collaboration.

The framework was published in 2019 and is available at this link: https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/. The Executive Summary is given below. It is included in this Handbook to illustrate the how the framework process outlined parallels that described in the Handbook and to highlight drinking water sources as a receptor.

Executive Summary

Background and Objectives

Protecting our drinking water sources from contaminants is a major national priority in safeguarding public health through ensuring a clean, safe and secure drinking water supply. This is achievable by developing and using a framework that is founded on structured, systems-based, risk-based, holistic and integrated approaches. Integrated catchment management (ICM) is now providing the overarching framework for the implementation of the Water Framework Directive in Ireland and the philosophy for water management, including drinking water source protection. The multiple-barrier approach, which is an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap, is recognised internationally as an effective and transparent means of achieving the provision of 'safe and secure' drinking water.

The National Federation of Group Water Schemes (NFGWS) is undertaking a Source Protection Pilot Project – Phase II for surface water sources, with the assistance of Dundalk IT, and groundwater sources, with the assistance of the Geological Survey of Ireland (GSI) and Tobin Consulting Engineers. As a component of this work, this document – A Framework for Drinking Water Source Protection – has been developed as generic guidance for the catchment component of drinking water source protection. It is based not only on the ICM and multiple-barrier approaches but is also influenced by and builds on the progress made in the area of source protection in recent years and the new information and maps produced by the EPA.

The main objectives are to:

- *Provide a high level vision and structure for the catchment components of the multiple- barrier approach for source protection.*

- *Integrate and link groundwater and surface water source protection approaches.*
- *Connect with the characterisation approaches used by the EPA and the Local Authority Waters Programme (LAWPRO) as part of WFD implementation.*
- *Encourage targeting of the main issues and pressures, and the most appropriate and cost-effective protection/mitigation measures and actions that need to be dealt with in any given source catchment.*
- *Provide a narrative that will be understandable and effective in public consultation and collaboration.*

The guidance provided by this framework is not meant to be prescriptive and can be adapted in a flexible manner to suit the particular circumstances or needs in a source catchment.

Summary of Framework

The Framework consists of a number of components:

1. *Evaluation of the quality of the untreated source water.*
2. *Delineation of the catchment area of a surface water source or the zone of contribution (ZOC) of a groundwater source.*
3. *Initial characterisation involving a desk-based compilation and evaluation of relevant information and maps for the catchment area/ZOC.*
4. *An interim 'story' of the source catchment area.*
5. *Further characterisation, involving fieldwork and catchment walks.*
6. *Analysis and conclusions on the potential mitigation strategies and activities needed.*
7. *Implementation of specific targeted and appropriate mitigation activities.*
8. *Monitoring progress and making adjustments, if necessary, as this is an iterative process.*

Evaluation of the quality of untreated source water

The requirement is to provide drinking water users with water that complies with the Drinking Water Directive and related regulations. Treatment is an essential element in the multiple-barrier approach. Therefore, the objective of the catchment component of source protection is not necessarily to provide water to a potable standard, although that would be a good outcome, but to reduce the risks from human activities in source catchments, lessen dependence on treatment processes, reduce the costs of treatment and desludging and enable compliance with Article 7.3 of the WFD. In addition, the word 'protection' in source protection can be nebulous unless targets are set that measures/activities are designed to achieve and are achievable in practice. Therefore, 'guide values' have been determined that provide a target, as a metric for different pollutants, that can realistically be set as the objective for the catchment component of source protection. Where concentrations in the untreated source water are above the guide values, mitigation activities are needed to reduce the concentrations caused by the significant pressures. Where concentrations are below the guide values, while there will be pressures, none are significant and, therefore, there are none that need to be dealt with by specific mitigation measures/activities, although general protection practices need to be maintained. The outcome is a decision as to whether the objective for a source is 'improvement' or 'protection', with the improvement scenario requiring a greater resource input generally.

Delineation of the source catchment area/ZOC

The area providing the water needs to be known. For groundwater sources in particular, this generally involves investigations and analysis, with associated time and resource requirements.

Initial characterisation

In circumstances where improvement of untreated water quality is needed, the initial characterisation process enables the significant issues and significant pressures to be determined and, where diffuse sources are posing a threat to water quality, the location of the critical source areas (CSAs). Where *protection is the objective, initial characterisation enables an understanding of the reasons for the satisfactory water quality as well as an evaluation of possible areas with associated pressures that are susceptible to impacts from present or future activities.*

Interim 'story' of source catchment area

This summarises and integrates the information collected and evaluated as part of initial characterisation. It provides the basis for a targeted work plan and for possible mitigation and protection options.

Further characterisation of the source catchment area

Field or street scale assessments involving fieldwork and catchment walks that focus on the issues, pressures and critical source areas provided by the interim 'story', are an essential component of the source protection framework. The work, resources and time required for sources with an improvement objective will generally be greater than for sources with a protection objective.

Mitigation and protection strategies and activities

Details on the recommended approach to the selection of management practices and on possible mitigation options for all the main issues and pressures (both point and diffuse) are given in this guidance document. In addition to meeting water quality objectives, consideration of the additional benefits from the mitigation options for related environmental objectives – biodiversity, carbon sequestration and flood mitigation – is recommended as a means of achieving optimal outcomes for the environment and, perhaps, public acceptance for the activities.

Implementing mitigation and protection strategies

While all the components described above are necessary, the most critical factor in achieving the objective of 'safe and secure' drinking water supplies is the undertaking of targeted and appropriate mitigation activities, based on an implementation plan and measurable outcomes.

Monitoring progress and making adjustments

Monitoring and tracking progress need to be undertaken at appropriate intervals, with consideration given, in particular, to learning lessons as part of an evolving and iterative process.

In conclusion

This is a high level, overarching framework that is intended to encourage an integrated and targeted approach to source protection. It builds on the groundwater protection scheme model and the understandings provided by the catchment characterisation work undertaken in recent years. It is influenced by and benefits from international approaches. It links intentionally with the WFD implementation and catchment management approaches being undertaken by the EPA and LAWPRO, and, in the process, with the physical settings, issues and pressures relevant to Ireland.

While a framework such as this is beneficial, the work 'on the ground' by scientists and engineers, in collaboration with local communities, is essential for success. By combining the framework with work specific to each source, the GWS sector will become exemplars for drinking water source protection in Ireland and internationally.

25 Appendix 9: Case Studies on Mitigation Actions Using the Pollutant Transfer Continuum

Three case studies are given below. They are based on the work of the National Federation of Group Water Schemes and are copied directly from a paper by Patrick McCabe, NFGWS.[100].

Extract from paper

ACTIONS AIMED AT TACKLING THE POLLUTANT SOURCE

As previously alluded to, a decision on the appropriate actions required depends on a number of factors: i) the environmental stressor or pollutant; ii) the pressures in the catchment / ZOC; iii) the landscape setting, in particular whether it is a freely draining or poorly draining scenario; and iv) the input of and acceptability to the landowner. Whilst famer engagement and collaboration may be required for actions targeted at different points on the continuum, source reductions / eliminations certainly cannot be achieved without the farmer's agreement. Within the GWS sector, there are numerous examples of where GWSs have worked in conjunction with landowners to reduce source loadings as a direct response to water quality deterioration. A prime example of such is evident from an examination at the water quality results over the preceding 20 years for Kilcorran Lough, Co. Monaghan, the source of the Aughnashalvey GWS.

The Integrated Water Quality Report for Monaghan and Louth (EPA, 2013) identified that Kilcorran Lough was at a 'Moderate' physico-chemical and ecological status during this period. In the previous years, water quality data derived from both the GWS and Monaghan County Council's annual monitoring programme also highlighted periodic elevations in total phosphorus and chlorophyll a concentrations. In response to and acting on recommendations contained within 'A Preliminary Report on Source Protection' completed by DkIT (2011) for the scheme, a series of source protection measures were implemented through the co-operation of the local farming community. A key action included group discussions with all landowners in the catchment in 2013 and a subsequent commitment to reduce organic and inorganic fertiliser application on lands bordering the lough. A marked improvement in the nutrient conditions of the lough has been observed since source reductions commenced, where the waterbody has now returned to a 'Good' water quality status. Furthermore, chlorophyll a conditions when considered in isolation would signify a 'High' water quality status. Whilst paleolimnological investigation of the sedimentary record for Kilcorran Lough would suggest that significant water deteriorations commenced c. the 1960's (i.e. in line with a period synonymous with agricultural intensification), there are several examples of water quality decline in more recent times. Agricultural diversification within the Inner Protection Area (SI) of the Ballybricken–Luddenmore borehole in Co. Limerick resulted in nitrate concentrations exceeding the Groundwater Threshold Value (GTV) in 2019 (Figure 3). Through consultation with the landowner in question, a reduction in nitrate usage within the SI zone was agreed, which has resulted in nitrate concentrations declining to below the GTV for the proceeding monitoring years.

BREAKING THE PATHWAY (CASE STUDY)

In certain situations, it may not be feasible to reduce the contaminant load at source, sufficiently enough to achieve the desired objective. In these circumstances, measures aimed at intercepting the pathway are essential. Such actions may also be implemented in combination with a reduction in pollutant loading or mobilisation. In 2018, the Stranooden GWS, which abstracts circa 1,900m^3 of water per day from White Lough in County Monaghan, was selected to participate in the NFGWS's

[100] McCabe, P. (2021). Determining mitigation actions using the pollutant transfer continuum. Proceedings of the International Association of Hydrogeologists (Irish Group) Conference 'Catchment Science and Management – The Role of Geoscience and Groundwater' April 2021. https://www.iah-ireland.org/conference-proceedings/2021.pdf

Phase II Source Protection Pilot Project, primarily due to the elevated concentrations of MCPA and TP within the lake.

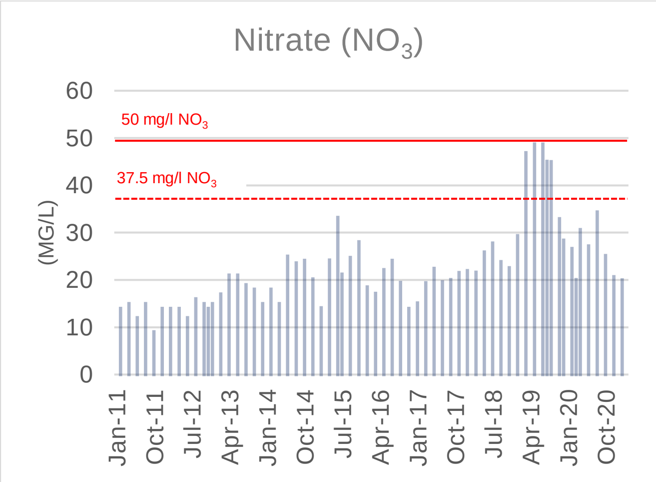

Figure 3. Nitrate concentrations recorded within the Ballybricken GWS - Luddenmore borehole from January 2011 – February 2021 (Data supplied by EPS Water). Concentrations ranging from 28 mg/l NO_3 to 49 mg/l NO_3 were recorded from January 2019 to December 2019, which coincides with a change in land management practices within the Inner Source Protection Area.

BREAKING THE PATHWAY (CASE STUDY)

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Within the Derryvalley sub-catchment (a sub-catchment covering 33% of the overall White Lough catchment), over 75% of the lands are found to be highly susceptible to near surface phosphate runoff, as identified by the EPA's susceptibility mapping (Figure 4). Additionally, a substantial portion of the sub-catchment has been attributed a high Pollution Impact Potential (PIP) risk score (i.e. Rank 1 – 3) – this area therefore is the CSA for phosphate loss, and consequently is the area where mitigation actions were targeted. Conversely, the remainder of the overall catchment is recognised as having a higher proportion of freely draining soils with a predominance of PIP scores ranging from 5 – 8, thus explaining the lower P concentrations found within the associated watercourses. Whilst free draining, annual average concentrations of nitrate and ammonium where below their respective NFGWS source protection framework 'Guide Values'.

A load reduction assessment, using the approach outlined by Mockler et al. (2016), was undertaken for the Derryvalley subcatchment. The mean phosphate concentration was 0.067 mg/l and the mean flow available from the hydrometric station located on the outflow from this sub-catchment was estimated as 0.0532 m^3/s. Therefore, in order to reduce the concentration to below 0.035 mg/l, it was estimated that a phosphorus load reduction of approximately 540 kg/year was needed.

Eighteen farmers, who were identified within the critical source area (CSA) for phosphorus losses to watercourses by overland and near surface flows, agreed to implement a series of measures to break the diffuse pathway. For example, targeted, field specific buffer margins were established, meaning that extended buffers were specified at the perceived runoff discharge points, whilst reduced buffer distances were to be created outside of these zones. This approach, as an alternative to a generic buffer width, was met with a greater approval from the landowner, who recognised the compromise needed to meet the water quality objective. A number of landowners also opted for inclusion within the existing

Native Woodland Establishment Scheme, whereby the woodlands are to be strategically planted within phosphorus CSAs.

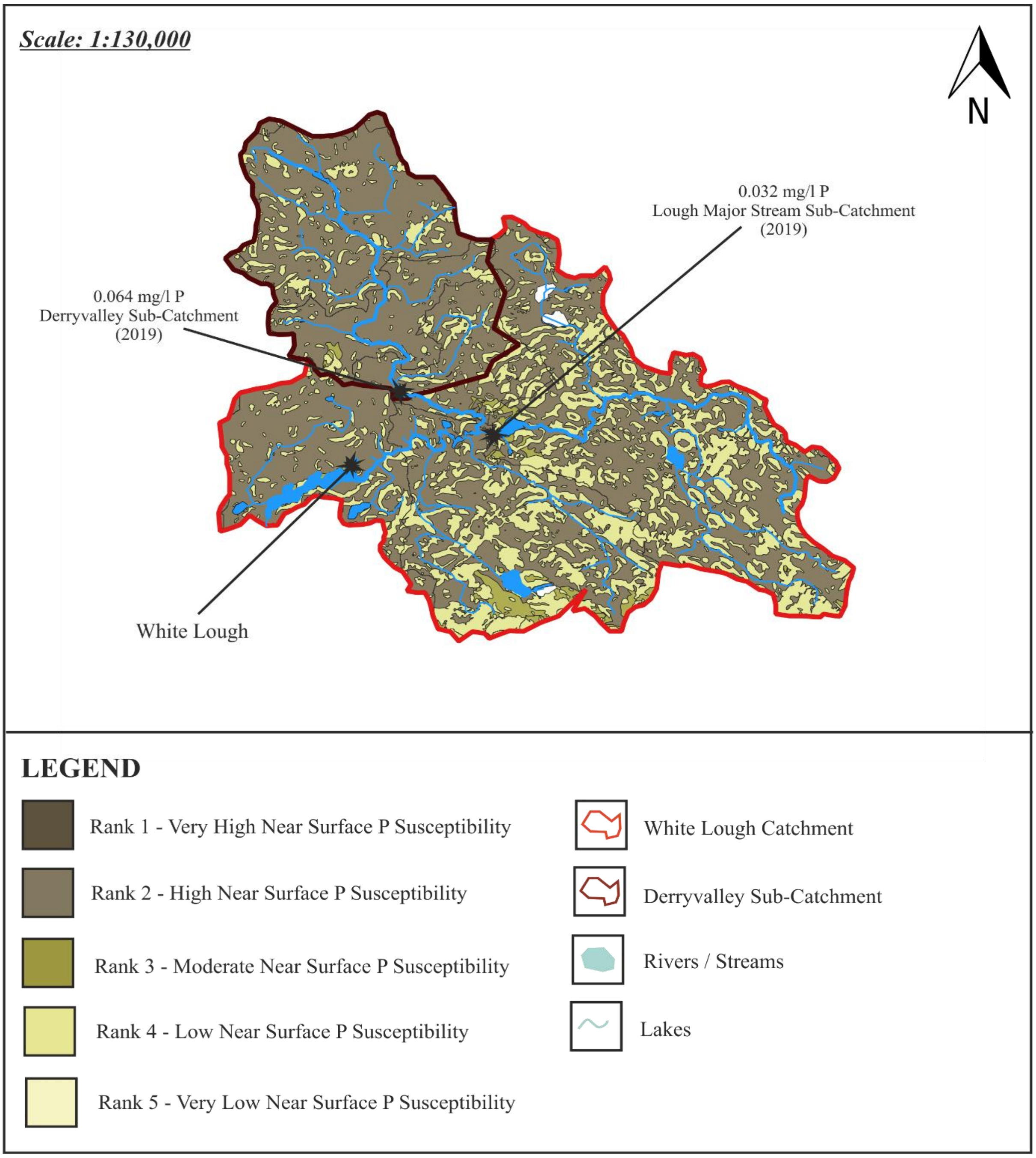


Figure 4. Near Phosphorus Susceptibility map for the White Lough Catchment, Co. Monaghan (Based on the susceptibility map provided by the EPA Catchments Unit).

RECEPTOR / INSTREAM WORKS

Due to the natural geochemical makeup of the environments in which certain sources are situated, water treatment will be an essential component of the multi barrier approach when trying to deliver safe drinking water. For example, elevated iron and manganese concentrations in the absence of other indicators of organic pollution at the Kildallan GWS source in County Cavan, is attributed to geological processes (GSI, 2015). In other instances, careful management of abstraction regimes may prevent the introduction of naturally occurring chemicals into drinking water supplies. For example, reduced groundwater levels during extended dry periods appeared to trigger an increase in fluoride *concentrations in the Tydavnet GWS source during the 1995 – 2001 period (JOD, 2001). It was determined that the presence of elevated fluoride was linked to whether the aquifer was confined or unconfined as a result of the abstraction regime.*

Conversely, physical works at both surface water and groundwater abstraction points may be appropriate when trying to mitigate against anthropogenic pressures. Sediment was found to be a significant pressure on the Dromore River system in Co. Monaghan which forms the principal inflow into White Lough. Bank erosion, as a consequence of livestock poaching, was identified to be a major contributor to the problem. Thus, as a means of alleviating the issue, riverbank rehabilitation will commence in 2021 at a number of sites on the river system. Where flow velocities are greatest, a deep bank revetment technique will be utilised, while willow spiling will be established on the lower order tributaries. At some groundwater supplies, improvements in well head construction have seen a reversal in rising coliform trends (see Figure 5a & 5b). Well head protection may also be a suitable action when trying to protect against natural processes. For example, fluvial flooding from the Templeport Lake Stream has historically contributed to increases in the turbidity levels of the Templeport GWS's borehole (GSI, 2016), once inundated with flood waters (see Figure 6). In this instance, raising the well head above the flood level, would break the hydrological connection and remove the potential for contamination from diffuse sources within the largely agricultural catchment draining into the stream.

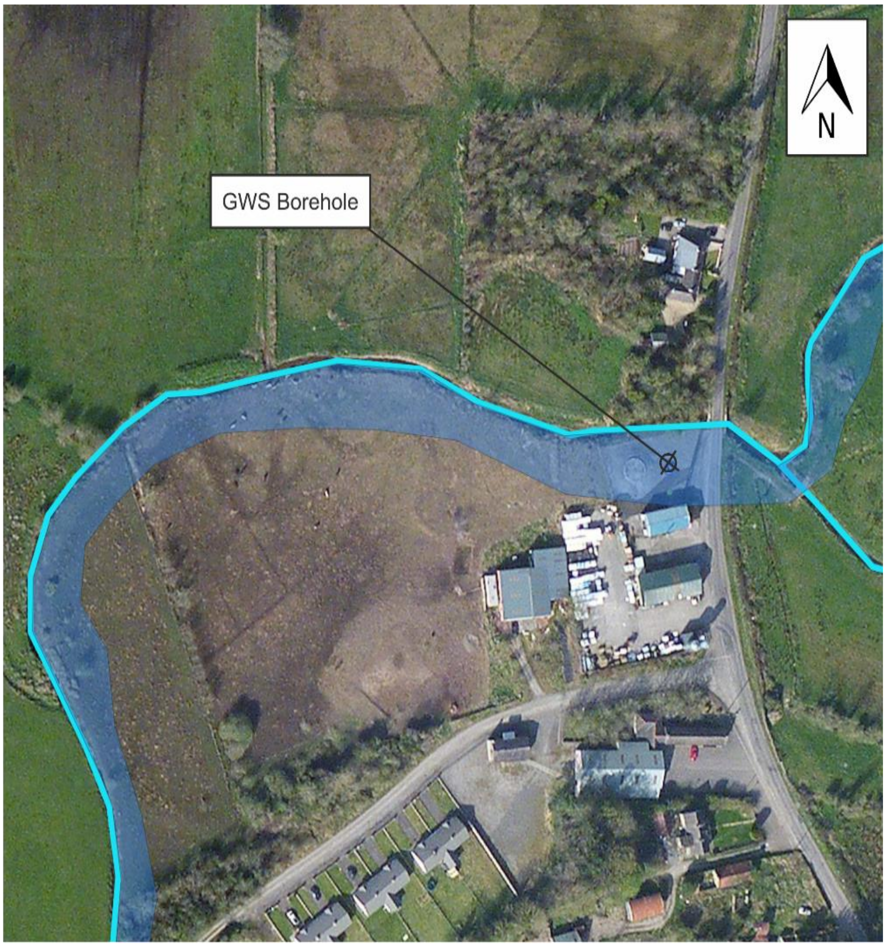


Figure 5a (Top Left). Borehole at Ballyallen GWS, Co. Carlow. Figure 5b (Bottom Left). Borehole at Ballyallen GWS, post well head improvement works.
Figure 6. (Right). Location of Templeport GWS's abstraction borehole within potential fluvial flood zone (i.e. blue hatch is indicative of the 1 in 100-year fluvial flood zone predicated during the Preliminary Flood Risk Assessment (2011)).

OPPORTUNITY FOR MULTIPLE BENEFITS

In addition to meeting water quality objectives, consideration of the additional benefits from the mitigation options for related environmental goals (e.g. biodiversity, carbon sequestration and flood mitigation) is recommended as a means of achieving optimal outcomes for the environment and, perhaps, public acceptance for the activities.

The NFGWS Source Protection Pilot Project Phase 2 in Roscommon is trialling initiatives aimed at improving water quality using a novel approach involving collaboration and awareness raising through biodiversity enhancement. As part of the characterisation process, elevated levels of MCPA and glyphosate were identified as significant pressures in a number of GWS catchments. The "Let it Bee" initiative, which is being trialled in the Corracreigh and Mid Roscommon GWSs, has given a selected number of farmers beehives, equipment, mentoring and training with a view to changing the mindsets and practices on pesticide usage on their farm, ultimately improving water quality through a biodiversity focus (NFGWS, 2020).

Similarly, a campaign called "I've planted a tree and my garden is pesticide free" has been developed as a national school project and is currently being rolled out across County Roscommon. Every child attending national school in Roscommon will receive a tree along with information about the damaging consequences of pesticide use and on how to go pesticide free in their garden. It is envisaged that projects like this will raise local consciousness about the importance of environmental appreciation and protection.

OTHER CONSIDERATIONS

Undoubtably, source protection actions, which aim to improve water quality conditions, is a positive objective. However, it is imperative that we don't become siloed in our thinking when designing such measures. Actions which have a positive impact on water quality need to be considered against any potential detrimental risk to other aspects of our environment. For instance, many of our GWS catchments / ZOCs are positioned within or partially overlap areas designated as Natura 2000 sites. Whilst actions aimed at improving water quality from a drinking water perspective may have a co-benefit to designated sites with water related conservation objectives, similar actions elsewhere may cause a disturbance. Fencing works for example in the portion of the Glaslough Tyholland GWS catchment that encroaches upon the Sliabh Beagh Special Protection Area (SPA), would need to be cognisant of the potential presence of grounding nest birds such the Hen Harrier (Circus cyaneus). Similarly, the aforementioned bank reprofiling works scheduled for the Dromore River will need to give due deference to any potential impact to White-clawed Crayfish (Austropotamobius pallipes) populations known to inhabit the waterbody.

CONCLUSIONS

The protection of drinking water sources is a cornerstone of the recently introduced recast Drinking Water Directive (DWD). Where drinking water suppliers formerly relied solely on treatment barriers to contamination, the battle now begins in the source catchment / ZOC. Improving or protecting source water quality and implementing effective measures to minimise risks at catchment level will provide reassurance to consumers that everything that can be done is being done to halt preventable contamination. This will, in turn, increase public confidence in the tap water supply. With that being said, careful analysis of the mitigation and protection options is essential if the effort undertaken is to be effective and justifiable. Furthermore, monitoring needs to be undertaken at appropriate intervals to track progress and to determine if the implemented actions are effective or if catchment / ZOC activities are changing. Finally, and where appropriate, prioritising mitigation actions with more than one environmental benefit should be considered. These additional benefits emphasise the connectedness of nature and are, therefore, a means of delivering genuine environmental and economic sustainability for communities.

26 Appendix 10: Buffer Zones/Setback Distances as Measures to Improve Surface Water Quality. *Do they Need to be Re-envisioned?*

26.1 Context

- Buffer zones[101] are one of the most common and important measures used to mitigate impacts of farming on water quality from a large range of pollutants/significant issues such as phosphate, total phosphorus, sediment, nitrate, ammonium, pesticides and microbial pathogens.

- As setback distances, they are an essential component of the GAP Regulations.

- They are the topic of many academic studies and papers which indicate varying and sometimes contradictory benefits, although in general the conclusion from these studies is that i) they are beneficial for water quality and ii) the greater the width the greater the benefit.

- When applied to diffuse pollution from agriculture, they are given as a **constant or uniform width** alongside watercourses; for example, Article 17 (1) of the GAP Regs require that chemical fertiliser should not be applied within 2 m of any surface waters and Article 17 (2) requires that organic fertilisers shall not be applied within 5 m of any surface water.

- From a water quality perspective, the main benefit of buffer zones is that they enable interception of pollutants by slowing runoff; intercepting P, sediment, pesticides, ammonium and microbial pathogens; enabling P take-up; and by breaking up the hydrological connectivity.

- Fenced off buffer zones bring land out of production for farmers. For instance, a 2 m buffer alongside watercourses removes 2,000 m^2/km (or 0.2 ha).

- Buffer zones are beneficial for not only water quality, but also generally create beneficial ecosystems and capture carbon, and therefore fit well with the co-benefits concept.

26.2 Question: Should the requirement that buffer zones be a constant/uniform width be amended?

- This Note contends that 'one size fits all' uniform width buffer zones, while beneficial for the environment, are not as beneficial as generally thought and are not an optimum use of land taken out of farm 'food' production. A suggestion is made here on how the land apportioned to buffer zones could be made more effective and efficient at achieving water quality outcomes and probably also biodiversity outcomes.

- In assessing the environmental benefits of buffer zones, it is relevant to consider two contrasting physical settings – freely draining and poorly draining.

26.3 An Overview of Mitigation Actions/Measures in Freely Draining Areas

- The main pollutants posing a threat to water quality in freely draining areas are nitrate and certain pesticides, and microbial pathogens in extremely (X) vulnerable areas. High nitrate concentrations arise mainly in moderate and high intensity farming situations.

[101] For more details on riparian buffers and in-field grass buffers, see Sections 7.1 and 7.2 respectively in the NFGWS Handbook of Source Protection and Mitigation Actions for Farming at this link: https://nfgws.ie/nfgws-source-protection-publications/

- The moderate and high intensity areas have been delineated by the EPA Pollution Impact Potential Map (PIP-N), which gives the critical source areas (CSAs) for nitrate.

- As outlined in Section 14.3, there are four categories of mitigation Actions:
  i) Pollutant reduction or elimination at source.
  ii) Reducing mobilisation of pollutants on land
  iii) Pathway interception of pollutants.
  iv) Receptor/instream works.

- The Actions that are applicable for mitigating impacts from nitrate are i), ii) and iv). Pathway interception Actions are far less effective.

26.3.1 Buffer Zones in Freely Draining Areas

- In freely draining areas, a high proportion of effective rainfall infiltrates underground and therefore the main flowpath for water is vertically to the water table and then horizontally to watercourses. Therefore, most if not all water flows will bypass buffer zones in the vicinity of water courses. Consequently, their effectiveness for mitigating impacts on water quality is much less in freely draining areas than in poorly draining areas. (In addition, this groundwater is unlikely to contain high concentrations of phosphate as the phosphate is attenuated by the soil and subsoil.)

- This is not saying that surface runoff does not occur on occasions in sloping freely draining areas; following intense rainfall, the infiltration rate may be 'overwhelmed' and some runoff can occur. However, in these circumstances the impact on water quality from pollutants such as phosphate is much less than in poorly draining areas for the following reasons:
  - The proportion of the flows in watercourses arising from this surface runoff is relatively low and therefore the pollutant load reflects this proportion.
  - Phosphate more readily binds to soils in freely draining areas and is less available to be 'washed off' by surface runoff – mobilisation is less than in poorly draining areas.

- Therefore, buffer zones in freely draining areas have limited benefits for water quality.

- The main environmental benefit of buffer zones in freely draining areas is for biodiversity.

- ***Question 1: In a circumstance where there are varying soils drainage characteristics in the vicinity of a watercourse on a farmer's land, should varying widths that take this into account be allowed, while keeping the total required area of buffer zone (e.g. 2,000 m^2/km where the requirement is for a 2 m buffer)?***

- ***Question 2: From a water quality perspective, should buffer zones be a priority in freely draining areas where the main threat is from nitrate.***

- ***Conclusion: while minimum width uniform buffer zones in freely draining areas will benefit biodiversity and might have minor benefits for water quality, incentivising wider buffer zones does not seem to be necessary or advisable in these areas.***[102]

[102] There is one possible exception to this: where groundwater with high nitrates is discharging in a relatively wide saturated flood plain riparian zone where denitrification can occur. This is probably not a common situation, but it might be possible to create it in certain circumstances.

26.4 An Overview of Mitigation Actions/Measures in Poorly Draining Areas

- The main pollutants impacting on surface water quality and causing failure of achieving the WFD and drinking water objectives in these areas are: phosphate, total P, sediment, MCPA and microbial pathogens. They arise in moderate and high intensity farming situations, and occasionally can arise in low intensity situations, particularly where a watercourse has a high status objective.

- The moderate and high intensity areas have been delineated by the EPA Pollution Impact Potential (PIP-P) Map, which gives the critical source areas (CSAs) for phosphate.

- As outlined in Section 14.3, there are four categories of mitigation Actions:
    - i) Pollutant reduction or elimination at source.
    - ii) Reducing mobilisation of pollutants on land
    - iii) Pathway interception of pollutants.
    - iv) Receptor/instream works.

- Individual Actions (which are described in the NFGWS Handbook) from each of these categories need to be applied as a means of reducing phosphate losses and subsequent impacts. Figure 14.4 illustrates this.

- In most circumstances, Actions from categories i), ii) and iv) will not be sufficient on their own to reduce the P load loss and the PO_4 concentrations in a watercourse to enable the WFD status objective to be achieved. An exception to this might be where there is dilution by 'clean' water from upstream, such as might occur in a river valley surrounded by mountains or extensive farming. However, this is not likely to be a common situation.

- Therefore, **pathway interception Actions are usually essential**. Why this is the case, and where they need to be established is influenced by the mechanism for water flows in poorly draining areas.

26.4.1 Water Flows in Poorly Draining Areas

- The primary driver for initiating surface flows is the **permeability** of the soil/subsoil/bedrock. In poorly draining/low permeability situations, a high proportion of effective rainfall must 'run off' either as overland flow or shallow subsurface flow from all of this area, irrespective of the slope.

- The new EPA soil drainage map enables these areas to be outlined for any subcatchment area. When considering phosphate as the significant issue, the EPA phosphate susceptibility map (Very High and High susceptibility) can be used.

- The **slope** dictates i) **where** the water flows 'horizontally' in the landscape, ii) **the degree of flow concentration** in certain areas and iii) the **delivery areas/zones/points** of water to watercourses.

- Water inputs to a watercourse are illustrated in Figure 25.1 below. During wet weather, it is likely that most flow inputs would be at flow delivery zones and points, with slower flows and lower proportions generally from dispersed delivery zones and from groundwater. The photos below show examples of flow delivery zones and points.

- Flow quantities are likely to correspond with pollutant, particularly phosphate, load inputs to watercourses. Knowledge of locations of flow inputs therefore enable pathway interception Actions to reduce phosphate contributions to be evaluated.

26.4.2 Current Buffer Zones as Pathway Interception Actions

- In a context where a high proportion of runoff from land and therefore pollutant load into watercourses in poorly draining areas tends to be focussed to delivery zones and points, either as overland flow or in drainage ditches, how effective are uniform width buffer zones in terms of both pollutant reduction and effort/cost?

- There are three relevant watercourse bank scenarios shown in Figure 25.1.
    i) No surface flow inputs.
    ii) Dispersed flow delivery inputs.
    iii) Focussed flow delivery zones and points (see Photos).

No surface flows

- This situation is common where the topography is undulating, usually caused by the uneven deposition of glacial till. Watercourses may have either eroded through till mounds or may have been artificially created during land drainage.

- A buffer zone in this area has no benefit for water quality.

- The environmental benefit of a buffer zone is for biodiversity.

Dispersed flow delivery zones

- A relatively narrow buffer (e.g. 2-5 m) will benefit not only biodiversity but also water quality. However, flows in wet weather and therefore pollutant loads from these areas are likely to be a small proportion of total flows and loads to watercourses in most circumstances.

- Bypassing of buffer zones by land drains is common in this scenario.

Focussed flow delivery zones and points

- In wet weather, a high proportion of runoff and therefore pollutant loads to watercourses will occur in these areas.

- Therefore, these are the areas where pathway interception Actions will have the greatest benefit.

- However, a narrow buffer, while better than no buffer, will have a limited ability only to intercept flows and pollutants.

- Along any watercourse stretch, there will be a variation of inputs from focussed flow delivery zones/points in terms of P or sediment load. Therefore, it may be worthwhile locating those with or likely to have the greatest contributions so that the mitigation Actions can be targeted for optimum effectiveness and benefits. So, what might be done to locate the areas making the greatest inputs? Some suggestions using the new EPA PIP-P map as the basis:
    - During the catchment walk, check for impacts (SSIS or rapid assessment of the biology, presence of macroalgae and/or sediment, higher EC, etc) immediately downstream of the zone/point.
    - Check the PIP categories in the catchment areas of the focussed flow delivery zones – some may have higher PIP categories than others, and therefore have a greater load available to be washed off.
    - Estimate relative catchment areas using the PIP-P map and a visual assessment during the catchment walk.
    - Doing winter fieldwork after heavy rain to see where the main inputs are occurring.

26.4.3 Implications

- Relatively narrow (2-5 m) buffer vegetated zones, while beneficial, have a limited capacity in poorly draining areas to mitigate impacts from phosphate runoff in moderately to highly intensive farming areas **where the WFD Objective is Good status**.

- Relatively narrow buffer vegetated zones, while beneficial, have a limited capacity in poorly draining areas to mitigate impacts from phosphate runoff in low intensive farming areas, such as high nature value farming areas, **where the WFD Objective is High status.**

- A buffer such as this requires, from the perspective of most farmers, **a significant land uptake**, e.g. 3,000 m^3 per km of watercourse length for a 3 m buffer.

- If these conclusions are defensible, it suggests that **uniform buffer zones are not as effective or efficient at achieving environmental outcomes as commonly thought**.

26.5 Re-envisioning Buffer Zones

- Clearly uniform buffer zones alongside watercourses will continue to be included in regulations such as the GAP Regs, and will be a requirement of CAP, as a means of improving biodiversity and protecting water quality. Consequently, they will be a requirement for farmers and be subject to inspections.

- In most poorly draining situations, they will not be an adequate means of intercepting pollutants such as phosphate and sediment.

- **Spatially targeted larger buffer areas**, designed and shaped to suit the local situation, are essential where impacts are occurring to waterbodies as a means of enabling the required environmental outcomes to be achieved – see Figure 25.2 below and Figure 14-5 for examples.

- There are two possible means of enabling buffer areas such as these to be established:
  1. Paying farmers for the environmental services that they would provide, e.g. i) using a results-based payment scheme or ii) grants for woodlands or agro-forestry.
  2. Allowing narrower buffers while maintaining the total area but repositioning some of the area to where most benefit for water quality would be achieved. For example, if a required 3 m buffer was reduced to 2 m, this would leave 1,000 m^2 area to be targeted to focussed flow delivery zones – equivalent to two triangular buffers 32 m wide and 32 m high, or two semi-circular areas 18 m radius. Clearly, if properly located, these would be far more effective than a 2 or 3 m uniform buffer zone.

26.6 Conclusions

1. Uniform width setback distances/buffer zones are a requirement of the Regulations and are one of the most common mitigation measures advocated for mitigating impacts from farming and afforestation. While compliance with the Regulations will continue to be required, the increasing emphasis on results-based rather than activities-based payments provides an opportunity to consider and establish spatially targeted extended buffer zones in appropriate locations.

2. Buffer zones in freely draining areas provide limited protection for water quality but have environmental benefits for biodiversity.

3. Spatially targeted and extended buffer zones in focussed delivery paths in poorly draining areas have the potential to have major environmental benefits.

- Reduction in phosphate and sediment loss to waters from critical source areas in a catchment, achieved by use of extended buffer zones and targeting biodiversity measures in focused flow delivery zones and zone outlets.
- Enhanced aquatic and terrestrial biodiversity.
- Enhancing riparian planting to stabilise banks and intercept sediment pathways can minimise the requirement for frequent channel maintenance in headwater streams.
- Because collaboration with farmers would be essential, it enables improved engagement and awareness among farmers of water quality issues and biodiversity in their local area.
- A more cost-effective policy tool to achieving national biodiversity and water quality targets.

When undertaking a catchment walk, consider and note down possible mitigation actions/measures taking account of the potential of spatially targeted extended buffer zones.

One of the reasons for including this Appendix is that it shows the relevance and importance of using the source-pathway-receptor (SPR) model for environmental management as our 'mental model' and means of facilitating 'the right measure in the right place'.

This photo shows a relatively flat area in a flood plain where dispersed flow to the watercourse will occur. Drainage ditches cross/bypass the flood plain at field margins.

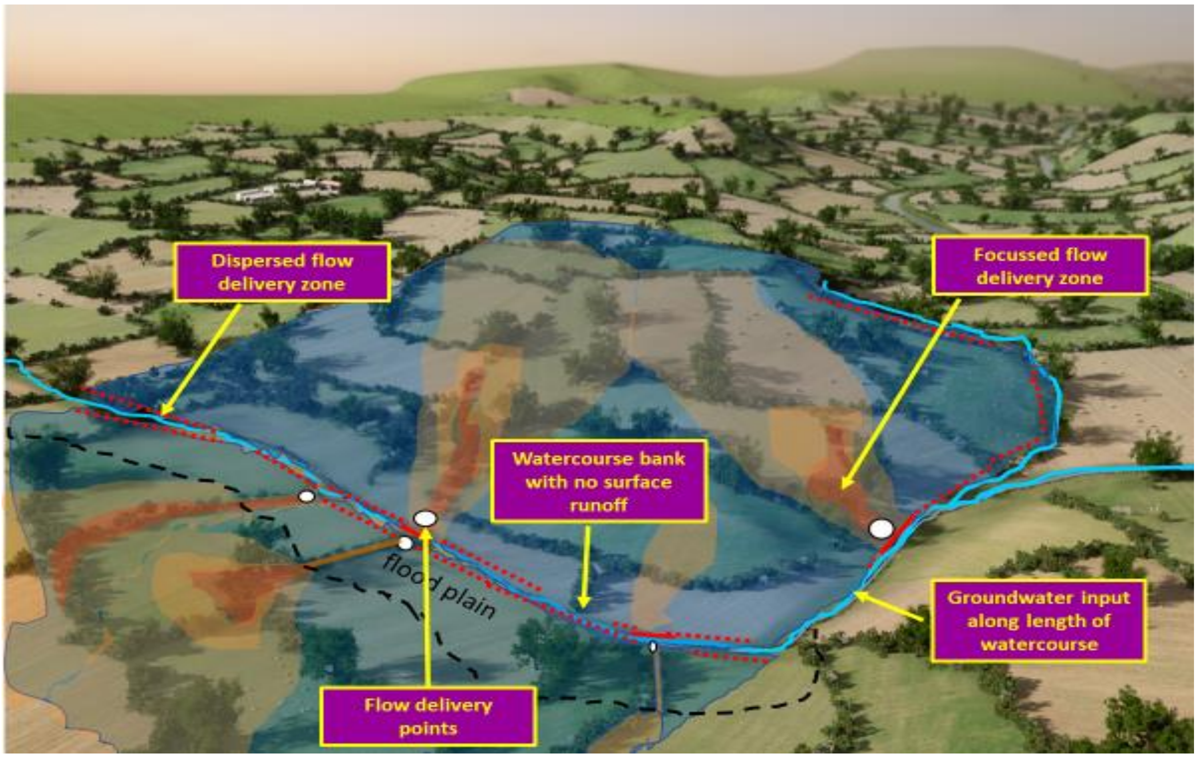


Figure 25.1: Illustration of a phosphate critical source area (CSA) where water enters the watercourse along three pathways: i) focussed by topography and/or a drainage ditch to a delivery zone or point; ii) dispersed where the slope does not cause a concentration of flow; and iii) as groundwater baseflow along the watercourse. Note that i) there are lengths of bank that, due to the topography, have no surface runoff inputs and ii) that groundwater will contribute baseflow throughout the length of channel. (Drawn in collaboration with Eva Mockler, Catchments Unit.)

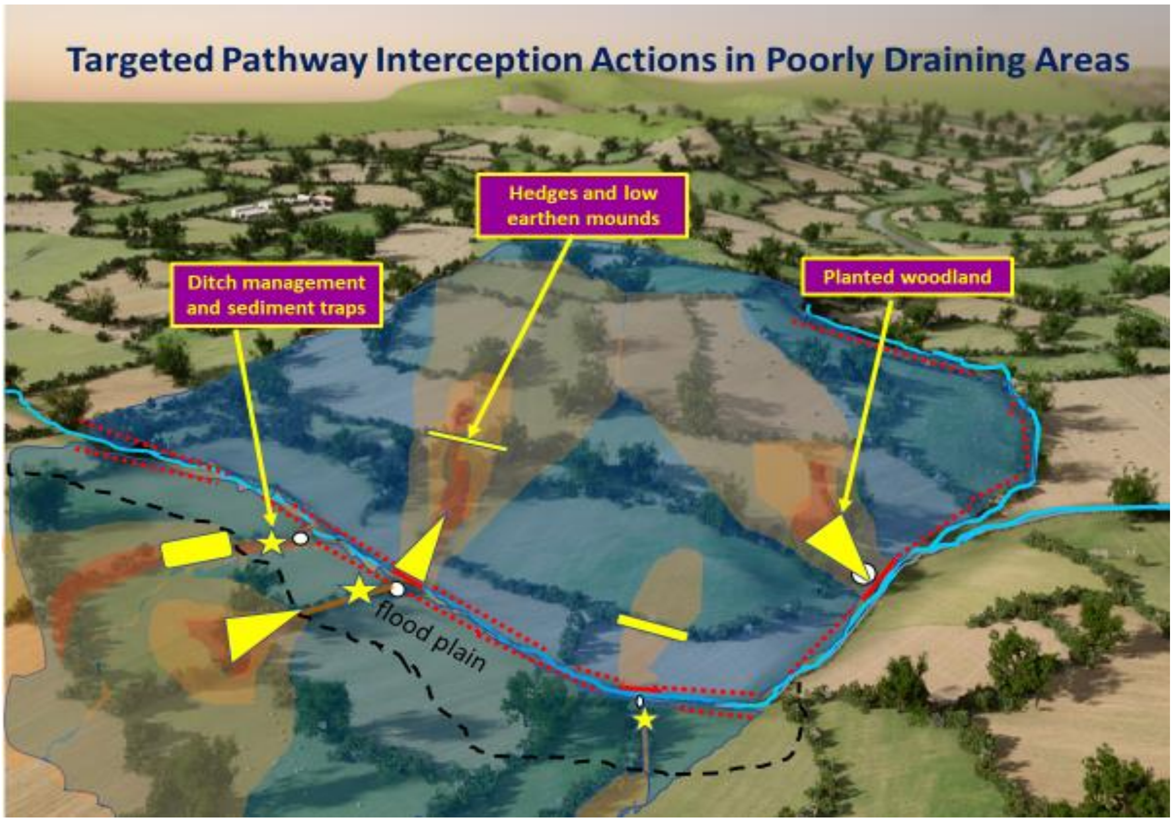


Figure 25.2: Illustration of possible targeted mitigation Actions. Further details on these Actions are given in the NGWS Handbook. (Available at this link: https://nfgws.ie/nfgws-source-protection-publications/)

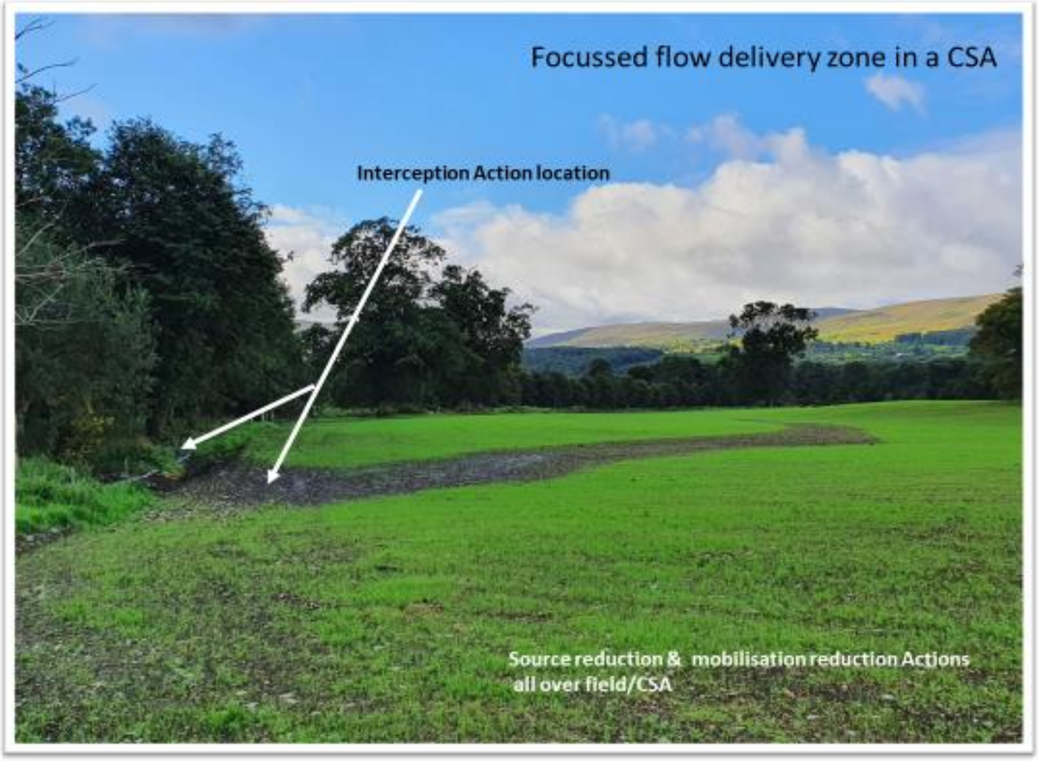


Photo: Jenny Deakin, Catchments Unit, EPA

Both photos show focussed delivery zones and points. In the field shown in the bottom photo, no water flows into the watercourse in the top left. Therefore, a buffer zone alongside that watercourse will have no benefit for water quality.

27 Appendix 11: Summary of Measures in GAP Regulations

	MEASURE	GAP REF.	CATEGORY
1	Chemical fertiliser shall not be applied to land within 2m of any surface waters.	17 (1)	SETBACK DISTANCES
2	Organic fertiliser or soiled water shall not be applied to land within 200m of an abstraction point supplying 100m3 or more of water per day or serving 500 or more persons; 100m for schemes supplying 10m3 or more or serving 50 or more; 25m of any abstraction of water for human consumption; 20m of lake shoreline, or a turlough likely to flood; 15m of exposed cavernous or karstified limestone features; 5m of any surface water (not a lake), or 10m where slopes are >10%, or for 2 weeks preceding and following the periods specified in Schedule 4.	17 (2)	
3	Alternative landspreading setback distances may be set by the Local Authority or Irish Water on the basis of technical and risk assessments and prior assessments.	17 (3)-(7)	
4	Organic fertiliser or soiled water shall not be applied to land within 10m of any surface waters where the land has an average incline greater than 10% towards the water	17 (12)	
5	Where farmyard manure is held in a field prior to landspreading it shall be held in a compact heap and shall not be placed within 250m of an abstraction point supplying 10m3 or more of water per day or serving 50 or more persons; 50m of any other abstraction source; 20m of a lake shoreline or turlough likely to flood; 50m of exposed cavernous or karstified limestone features (such as swallow-holes and collapse features); 20m of other surface waters (other than a lake).	17 (13)	
6	Farmyard manure shall not be held in a field at any time during the periods specified in Schedule 4.	17 (14)	
7	Silage bales shall not be stored outside of farmyards within 20m of waters or a drinking water abstraction point in the absence of adequate facilities for the collection and storage of any effluent arising.	17 (15)	
8	No cultivation shall take place within 2m of a watercourse identified on the OSI 1:10560 map except in the case of grassland establishment or the sowing of grass crops.	17 (16)	
9	Supplementary feeding points shall not be located within 20m of waters and shall not be located on bare rock.	17 (17)	
10	On holdings with stocking rates of 170kgs of nitrogen or more: bovines shall not be allowed to drink directly from water from 1 January 2021; Where bovines have direct access to water, a fence at least 1.5m from the waters edge shall be installed by 1 January 2021;Livestock can be moved to isolated land parcels across a watercourse if both sides are fenced; Supplementary drinking water points must be at least 20m from watercourses by 1 January 2021.	17 (18) (19)	
11	Take steps to minimise soiled water produced in a farmyard	5(1)	SOILED WATER
12	Ensure that rainwater from roofs and clean yards and water flowing from higher ground onto a farmyard is diverted without contamination to a clean water outfall and is not allowed to enter soiled yards or storage areas for soiled water. Ensure rainwater gutters and downpipes are maintained in good working condition.	5(2) (a)(b)	
13	There shall be no runoff of soiled water from farm roads to any waters from 1 January 2021.	18 (20)	
14	There shall be no direct runoff of soiled waters resulting from poaching to any waters.	18 (21)	
15	All slurry, soiled water, effluents, farmyard manure etc produced in a building or yard, shall be collected and held in a manner that prevents run-off or seepage, directly or indirectly, to groundwaters or surface waters.	6(1)	COLLECTION AND HOLDING
16	Thew occupier of a holding shall not cause or permit slurry, soiled water, effluents, farmyard manure etc., to enter waters.	6(2)	
17	All storage facilities (including out-wintering pads, earthen-lined stores, and integrated constructed wetlands) for slurry, soiled water, farmyard manure etc. shall be maintained and managed in good condition.	7(1) (3) (4)	PROVISION AND MANAGEMENT OF STORAGE
18	New storage facilities shall be designed, sited, constructed, maintained and managed to prevent run-off or seepage into groundwaters or surface water, and comply with construction specifications of DAFM.	7 (2) (a)(b)	
19	The capacity of storage facilities for livestock manure and other organic fertilisers, soiled water and effluent from dungsteads, farmyard manure pits and silage pits shall be adequate to provide for storage for such a period as to comply with these Regulations and to avoid water pollution.	8 (1)(3)(4); 9; 10; 11; 12; 13; 14	
20	An occupier shall have due regard to the storage capacity which may be required during periods of adverse weather conditions. The application to land of livestock manure or soiled water is precluded.	8 (2)	
21	The capacity of facilities for the storage of effluent produced by ensiled forage and other crops shall equal or exceed the capacity specified in Table 5 of Schedule 2, and for soiled water being shall equal or exceed the capacity required to store all	9 (a)(c)	

	soiled water likely to arise on the holding during a period of 15 days.		
22	The capacity of facilities for storage of livestock manure may be less than that specified in Article 10, 11, 12 or 13, as appropriate, in the case of a holding where the occupier has a contract providing exclusive access to adequate alternative storage capacity located outside the holding, or for access to a treatment facility for livestock manure, or a contract for the transfer of the manure. Storage capacity may also be less in certain cases where deer, goats, sheep and livestock (other than dairy cows) are outwintered subject to specified maximum stocking rates and other conditions.	14 (1) (2) (3) (4)	CAPACITY OF STORAGE
23	The amount of fertiliser applied to promote the growth of a crop or grassland shall not exceed that specified in the Regulations.	15; 16	NUTRIENT MANAGEMENT – CROPS & GRASSLANDS
24	Livestock manure, other organic fertilisers, effluents, soiled water and chemical fertilisers shall be applied to land in as accurate and uniform a manner as is practically possible.	18 (1)	MANNER OF APPLICATION
25	Organic and chemical fertilisers or soiled water shall not be applied to land in any of the following circumstances— (a) the land is waterlogged; (b) the land is flooded or likely to flood; (c) the land is snow-covered or frozen; (d) heavy rain is forecast by Met Eireann within 48 hours, or (e) the ground slopes steeply and there is a risk of water pollution having regard to factors such as surface runoff pathways, the presence of land drains, the absence of hedgerows to mitigate surface flow, soil condition and ground cover.	18 (2) (3)	
26	(4) Organic fertilisers or soiled water shall not be applied to land— (a) by use of an umbilical system with an upward-facing splashplate, (b) by use of a tanker with an upward-facing splashplate, (c) by use of a sludge irrigator mounted on a tanker, or (d) from a road or passageway adjacent to the land irrespective of whether	18 (4)	
27	Soiled water shall not be applied to land— (a) in quantities which exceed in any period of 42 days a total quantity of 50,000 litres per hectare, or by irrigation at a rate exceeding 5 mm per hour.	18 (5)	
28	In an area which is identified on maps compiled by the Geological Survey of Ireland as "Extreme Vulnerability Areas on Karst Limestone Aquifers", soiled water shall not be applied to land— (a) in quantities which exceed in any period of 42 days a total quantity of 25,000 litres per hectare, or (b) by irrigation at a rate exceeding 3 mm per hour unless the land has a consistent minimum thickness of 1m of soil and subsoil combined.	18 (6)	
29	Application of fertiliser to land is prohibited during the periods specified in Schedule 4 (Closed Periods).	19 (1)	CLOSED PERIODS
30	Closed periods do not apply in relation to the application to land of soiled water, or chemical fertilisers to meet the crop requirements of Autumn-planted cabbage or of crops grown under permanent cover, or fertilisers whose application rate or usage rate is less than 1kg per hectare of available nitrogen or phosphorus.	19 (2)	
31	The amount of livestock manure applied in any year to land on a holding, together with that deposited to land by livestock, shall not exceed an amount containing 170 kg of nitrogen per hectare.	20 (1)	APPLICATION LIMITS
32	Where arable land is ploughed between 1 July and 30 November the necessary measures shall be taken to provide for emergence, within 6 weeks of ploughing, of green cover from a sown crop. A rough surface shall be maintained prior to a crop being sown in the case of lands ploughed between 1 December and 15 January.	21 (1)	CULTIVATION AND GREEN COVER
33	Where grassland is ploughed between 1 July and 15 October the necessary measures shall be taken to provide for emergence by 1 November of green cover from a sown crop.	21 (2)	
34	Grassland shall not be ploughed between 16 October and 30 November.	21 (3)	
35	When a non-selective herbicide is applied to arable land or to grassland in the period between 1 July and 30 November the necessary measures shall be taken to provide for the emergence within 6 weeks of the application, of green cover from a sown crop or from natural regeneration.	21 (4)	
36	Where green cover is provided for in compliance with this Article, the cover shall not be removed by ploughing or by the use of a non-selective herbicide before 1 December unless a crop is sown within two weeks of its removal.	21 (5)	

Acknowledgement: This table is copied from McNally (2017), which can be accessed at this link: https://www.catchments.ie/download/review-of-potential-local-measures-for-mitigating-farm-impacts-in-catchments/

28 Appendix 12: Time Delays – How Long Will It Take for Improvements to Occur?

28.1 Summary

- WFD objectives have been set for all 4,829 water bodies. While many water bodies are achieving their objectives, a substantial number are not. In addition, untreated water in some of our drinking water sources needs to be improved.

- Estimating the time delay for improvements to occur is a critical issue for a variety of reasons, including ensuring that expectations are realistic.

- In general terms, there are three groups of components influencing the time delays for improvement – policy factors, landscape and water factors, and measurement factors.

- Policies in place/policy development/policy implementation is the fundamental starting point. There are many good policies in place, and many are being implemented satisfactorily. However, some are not effective as is indicated by, for instance, our dis-improving water quality, nutrient pollution by urban wastewater treatment plants (UWWTPs) and farming activities, ammonium emissions from peatlands, unsatisfactory domestic wastewater treatment systems (DWWTSs), misconnections in urban areas. In addition, there are policy gaps and further policy development is needed, particularly for dealing with diffuse (non-point) agricultural activities because the current regulations are not sufficient. Incentivisation and 'payments for public goods' provided by farmers need to be considered, in my view.

- Even when the policies are in place, they then have to be implemented. This takes time and resources obviously, continued learning and, in some instances, further research. For large point sources, their locations are known and implementation is generally a matter of resources and time taken to implement in practice. For small point sources, such as DWWTSs and farmyards, the locations of some are known, but many are not. For diffuse sources, such as runoff from fields, work on locating the critical source areas where mitigation measures are needed has only commenced recently with the work of LAWPRO and the EPA Catchments Unit, and this work will need to continue for many years. As mentioned above, even when they are located, there may not be a means of implementing effective mitigation measures, other than voluntary actions by land owners.

- So, let us assume that all the necessary policies are in place and are being implemented satisfactorily; what is the situation then? There are some where the time delays for improvement are short, but for many there are complex interacting factors, including existing water quality, resources availability, natural settings and monitoring requirements, all leading to likely time delays that vary from medium to lengthy.

- Where point sources are the *significant pressure*, then once they are dealt with, the reduced pollutant concentrations will start to have an immediate impact on water quality. It should be kept in mind that not all point sources are '*significant*' from a WFD perspective. Therefore, in my view, time, effort and resources should be targeted at those that are *significant,* even though this might not be a 'comfortable' situation for those with responsibilities for water quality.

- For diffuse sources, the situation is more demanding. Working out the time lag for P (phosphorus/phosphate) and N (nitrogen/nitrate) (two of the main pollutants) reduction in water is complex for a number of reasons:
    - P and N have different hydrochemical properties and this influences their movement, attenuation and impact in the landscape and on water. For instance, phosphate issues arise generally in poorly-draining areas, while high nitrate arises in freely-draining areas.

- As they move from their source to water in the landscape, lessening of the P and N loads entering water can occur to varying degrees: i) reduction of source load in the soil is critical for nitrate but, while beneficial, is not sufficient on its own for P reduction generally; ii) mobilisation control mitigation actions, e.g. liming, cover/catch crops, are beneficial for both P and N; iii) pathway interception, e.g. buffer zones, is the main means of ensuring that P does not impact on watercourses, but is not so effective for nitrate.
- Each of these have their own time lags.
- Therefore, it is vital that the *significant issue*, either phosphate or nitrate or both, is known in advance of measures implementation; otherwise time and resources will be wasted, and the process undermined.

♦ Even when all the required mitigation measures/actions are in place, there will still be a biological response time delay. Where the water quality is satisfactory upstream, then the likely response will be rapid – probably <1 year. Where the situation has been unsatisfactory for a number of years it may take 2-4 years for the required biological status to be achieved. However, in the meantime, progress can be shown by monitoring and plotting the chemical concentrations.

♦ There is one last time delay component – the time it takes to undertake the biological monitoring, as monitoring takes place once every three years, and finalising the status value is time consuming.

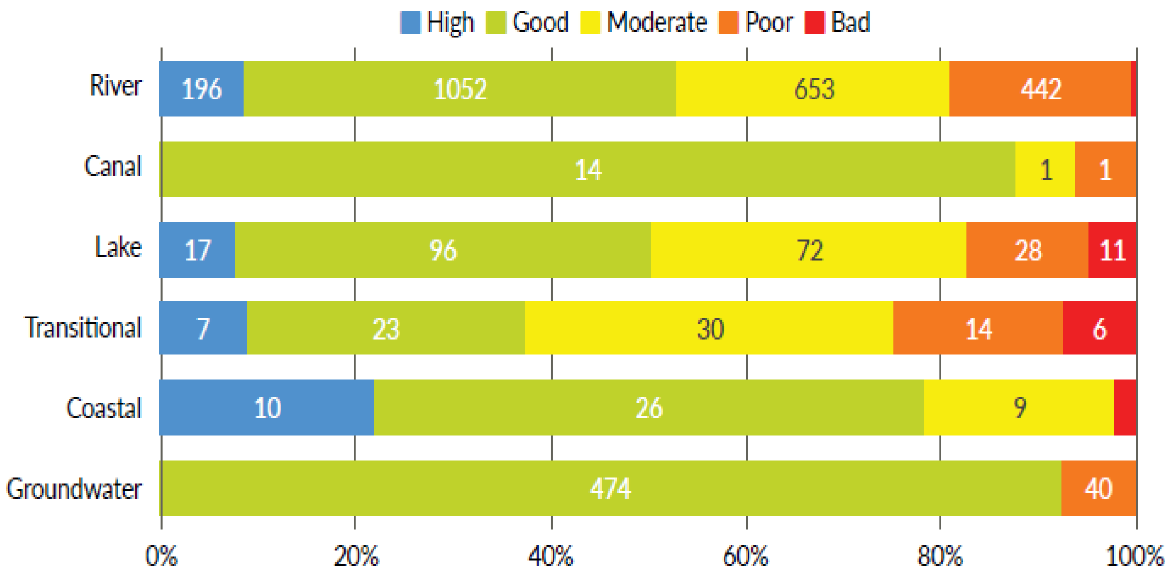
♦ What does this mean in likely actual time delays? Tables 28.4 and 28.5 provide a means of estimating time delays. In summary:
- While some improvements are likely, major improvements in the water body status statistics for reporting in the 2021 RBMP are unlikely due to the time delays for the components mentioned above. Therefore, the focus should be on improvements in status and nutrient concentrations for the 2027 RBMP. The current work being undertaken, and its continuation, will be essential to achieving progress.
- As the 4th River Basin Management Plan has to be completed by December 2027, this means that, in practice, improvements in water quality must have occurred by 2025 so that required biological responses have occurred and the status has been monitored and reported on.
- An analysis of policy gaps and augmentation of some of the regulations is needed urgently, particularly for water bodies that are impacted by diffuse issues and pressures.
- Characterisation by LAWPRO and EPA Catchments Unit is a vital precursor to deciding on mitigation options and their location; this takes time and for some water bodies is challenging.
- Responses in water quality to upgrading of large point sources, for instance by Irish Water, will be quick – improvements in hydrochemistry within 1 year and in biology between 1-3 years. Also, the work of LAWPRO and ASSAP are likely to be resulting in improvements already or will in the near future in (probably) a small proportion of the unsatisfactory water bodies where small changes in either water quality and/or mitigation activities are sufficient.
- Significant improvements for reporting in the 2027 RBMP will be achieved in the Areas for Action provided the effort is sustained.
- For water bodies outside the PAAs, provided that the approaches used by LAWPRO and ASSAP continue to be resourced, developed further and used by local authorities, improvements in nutrient concentrations and reducing trends will occur, but for a proportion of these water bodies, it may not be possible to show improvements in status due to the time delay issue; however, reduced nutrient concentrations, which can be reported in the RBMP, should be evident.

♦ In conclusion, further consideration of the time delay issue is recommended. This Note is an initial appraisal.

28.2 Introduction

Many water bodies are not achieving their WFD objectives of either Good or High status – see details in the Figure below, which is copied from the Draft River Basin Management Plan 2022-2027: https://www.gov.ie/en/consultation/2bda0-public-consultation-on-the-draft-river-basin-management-plan-for-ireland-2022-2027/.

Figure 10. The percentage of waterbodies achieving each status class for each waterbody type



One of the aims of the work being undertaken currently by a range of public bodies is to improve and restore the water quality in those water bodies that are unsatisfactory as a means of not only achieving WFD objectives, but also a good quality environment. In general terms, those water bodies that haven't yet achieved their required WFD objectives must meet them by either 2021 or 2027. One of the main objectives for both surface water and groundwater bodies is restoration to Good status, and, for certain surface water bodies, restoration to High status. The 2027 deadline may be extended in circumstances where "*natural conditions*" do not allow the required improvements; however, no further deterioration must occur.

While drinking water sources have their own specific objectives; for some sources, restoration/improvement in untreated water quality (see NFGWS (2019) for details) will be required, and therefore the issue of the time is takes for achievement of improvement is relevant.

A critical question is: how long will it take for the required improvements to occur? Is it weeks, months, years or decades? The answer is: it depends!

The terms 'time lag' or 'lag time' are used when evaluating the length of time for improvement. **Time lag in this Appendix is defined as the time elapsed between installation or adoption of a mitigation activity at a level projected to reduce pollution and the response to that action which, for WFD implementation purposes, is the achievement of the required status in the target water body.**

The aim of this Note is to describe the main components that influence the length of time as a means of enabling the following:

- An understanding of the processes involved that determine improvements in water quality and achievement of WFD or drinking water objectives.

- Setting the dates in the 3rd River Basin Management Plan for achieving WFD objectives.

- Evaluation of resource needs and work planning.

- Consideration and establishment of the optimum mitigation options.

- Estimation of the likely time taken for improvement and restoration so that expectations on how quickly improvements can occur in practice are realistic. This, in my view, is an important issue as there can be an impatience and a lack of understanding summarised by the question; 'why it is taking so long?'. In some instances, the time delay is caused by inadequate implementation of the measures that are available; in others, it is because the required policies are not in place. But even when the policies are in place and are being implemented satisfactorily, the reality is that there will often be a time delay for improvements to occur and to be measured. In addition, there is a danger that it is convenient to project a long time delay as this reduces the sense of urgency in tackling the issues that are causing the dis-improvement in water quality.

While the 'official' WFD objective for a water body is determined by water body status, it can be advisable to set interim objectives, such as a decreasing trend at the monitoring point in the two main nutrients (PO_4, NO_3) that impact on water quality, for two reasons: i) reductions in these nutrients would often be required as a precursor to status improvements and ii) water samples are taken either quarterly or monthly, whereas status is determined every three years for surface water bodies and every six years for groundwater bodies, and therefore trends in these parameters provide a more immediate means of tracking and reporting on improvements.

28.3 Process for achieving WFD objectives

The general process for achieving the required objectives is as follows:

- Having relevant policies in place.
- Characterisation to enable the *significant issues* and *significant pressures* (see Section 6 for more details) to be determined and critical source areas for diffuse pressures to be delineated.
- Evaluation and decisions on the means of protecting our water resources, where the situation is satisfactory, and of improving/restoring our water resources where the situation is unsatisfactory.
- Implementing the measures and actions decided on[103].
- Monitoring progress and making adjustments where necessary.

Time lags is an issue that fits within and influences this process.

This Appendix focusses mainly on two *significant issues*, phosphate (PO_4) and nitrate (NO_3), arising from spreading of fertilizer (organic and inorganic) on farmland and impacting on watercourses and groundwater; however, some of the content is relevant to point sources and to sediment from diffuse sources. It does not cover impacts due to poor habitat conditions (hydromorphology) or water abstraction.

28.4 Factors that determine the time delay for improvement

The length of time for improvement includes <u>six</u> components, which are illustrated in Figure 27.1:

[103] In this Note, the distinction is made between regulatory 'measures' which are obligatory, and voluntary 'actions', some of which may be incentivised.

1. Satisfactory policies in place and, if necessary, further policy development.
2. Policy implementation/adoption of measures.
3. **Time lag for reduction in source load.**
4. **Time lag due to relevant pathway elements:**
   - **Transport time along pathway.**
   - **Attenuation along pathway.**
   - **Pathway interception.**
5. **Receptor (in-stream) time lag:**
   - **Source reduction (from sediment).**
   - **Biological response.**
6. Measurement component.

Components 3, 4 and 5 above are considered under the term 'time lag'. However, components 1, 2 and 6 are also critical to determining the length of time for improvement. While this Note is aimed primarily for consideration of diffuse sources, components 1, 2, 3, 5 and 6 are relevant to point sources.

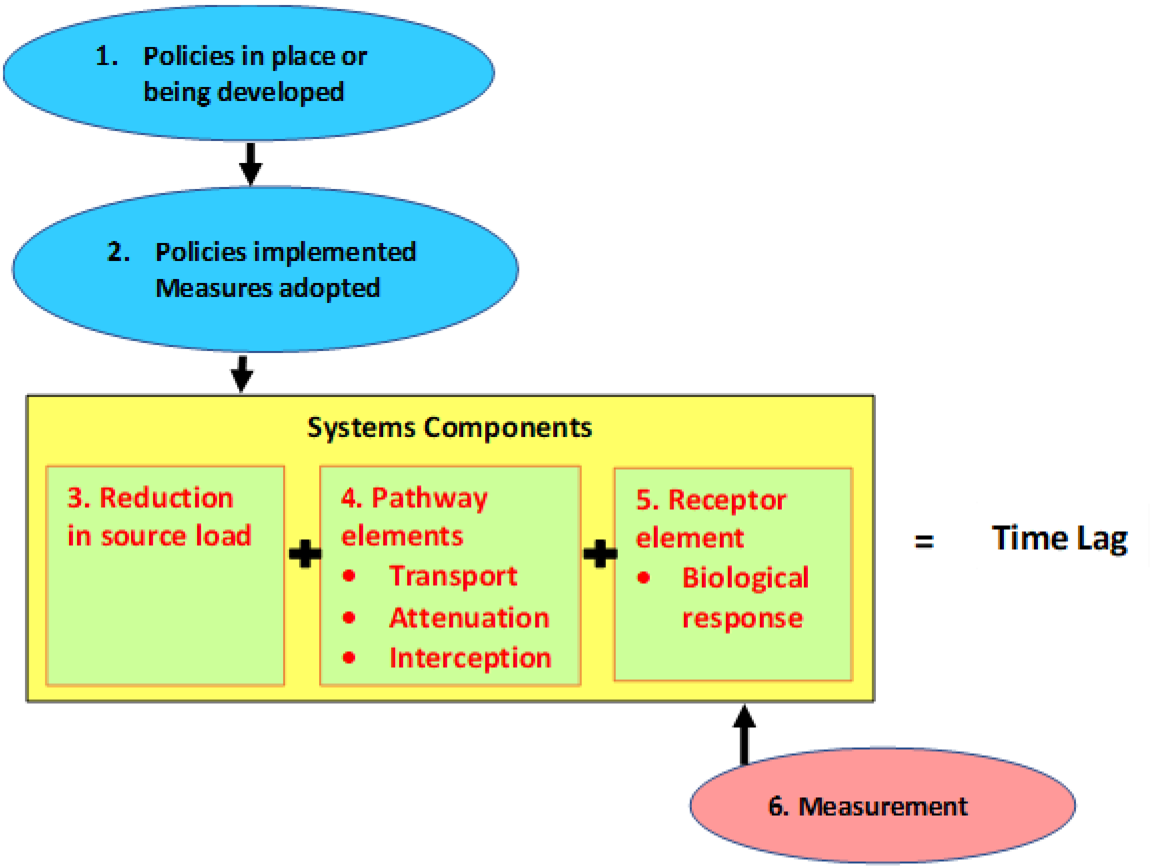


Figure 28.1: Schematic showing the major elements of the potential time delay for water quality improvement, including policy development and implementation component, catchment time lag components and the time needed to undertake monitoring. [104].

[104] Diagram based on Figure in Meals, D.W., Dressing, S.A. and Davenport, T.E. (2010). Lag time in water quality response to best management practices: a review. J. Environ. Qual. 39, 85-96. Available at: https://pdfs.semanticscholar.org/aab9/6b90bc9d48349b8fb6ca0c4fbf4cc6458931.pdf?_ga=2.186609578.208240954.1569077850-2011213208.1563976070

Clearly, the actual time it takes for sufficient improvements to occur depends not only on the establishment of the components shown above, but also on ensuring that they are effective.

This Note considers each of these components in turn. Section 13.9 provides an overview and a discussion on some relevant issues.

28.5 The role of policy and policy implementation

While some beneficial environmental activities are occurring on a voluntary basis, government policies, implementation of these policies and development of new policies are key to successful environmental management, whether as regulations or incentives.

There are many policies already in place that are the basis for implementation measures. Examples include the European Union (Good Agricultural Practices) Regulations, the Water Services (Amendment) for the regulation of domestic wastewater treatment systems and the Urban Waste Water Treatment Regulations. However, the level of implementation varies and there is a need for further policy development to deal with diffuse sources in particular.

The content of Sections 13.6, 13.7, 13.8, and 13.9 below are intended for the following situations:

- The required policies are in place. The implications for situations where further policy development is needed are outlined in Section 13.10.2.
- River and groundwater water bodies that are *At Risk* of not meeting WFD objectives and therefore require restoration to the required WFD objective.
- Drinking water sources that requires improvement to satisfactory water quality using catchment-based mitigation measures and actions.
- The *significant issue(s)* and *significant pressure(s)* is/are known following a catchment characterisation process.
- The load of P and/or N entering a water body has been sufficient to cause impacts and mitigation is required.
- The critical source areas have been delineated and the appropriate measures and/or actions have been determined.
- The required measures and/or actions have been put in place to mitigate the impacts of the *significant issue(s)* and *significant pressure(s).*

28.5.1 Mitigation measures and actions

The 'pollutant transfer continuum' (see Section 8), which is a landscape-based framework for considering diffuse pollution, is a useful concept when considering mitigation options as it encourages/enables a focus according to the point in the source-pathway-receptor continuum on which they take effect. The recommended relevant points along the continuum for consideration of specific measures and actions are:

vi) source reduction or elimination;
vii) mobilisation control;
viii) pathway interception; and
ix) receptor/instream works.

Consideration of time lag follows this framework.

Comprehensive details on mitigation options are given in Appendix 6 of the NPWS 'Framework for Drinking Water Source Protection, which can be accessed at this link: https://nfgws.ie/development-of-nfgws-strategy/ and in McNally (2017), which can be accessed at this link: https://www.catchments.ie/download-category/objectives-and-measures/. Details on mitigation options for phosphate and nitrate are summarised from these sources in Tables 1 and 2. In addition, Teagasc have published relevant material, such as the booklet at this link:

https://www.teagasc.ie/media/website/crops/soil-and-soil-fertility/Efficient-Use-of-Phosphorus-In-Agriculture-Tech-Bulletin-No.-4.pdf.

28.6 Time lag for reduction in source load

Phosphorus (P) and nitrogen (N) are applied to land by three means:

1. Spreading of inorganic fertilizer;
2. Spreading of organic manures, slurries and soiled/dirty water;
3. Faeces and urine deposited from grazing animals.

Once the P and N reach the soil, they are the **source load** intended to aid crop growth, but which can be subject to loss to water (and air in the case of N). P and N in the soil respond differently depending on their own specific properties and on the hydro(geo)logical setting, largely indicated by soil type. (The geochemistry of soil, subsoil and bedrock can also be an influence, but hydrology/hydrogeology is usually the dominant one.) Therefore, P and N are considered separately.

28.6.1 Time lag for reduction of phosphorus in soils

Some of the P load is taken up by crops, but a portion remains in the soil for varying periods of time during which loss to water can occur. Phosphorus is relatively immobile and is attenuated by mineral soils and subsoils. Therefore, the main pathways for loss of P to water is overland and near-surface. These pathways arise in poorly-draining or low permeability mineral soils and subsoils, and low permeability bedrock where it is exposed at the surface or overlain by thin soils.[105] They also arise in organic soils, which are unable to retain P. (These areas can be located by examination of the phosphate pathway susceptibility map for the near surface pathway (see Archbold (2016) at this link for further details: https://www.catchments.ie/catchments-newsletter/). They are available for viewing on the WFD App.)

The load of P in soil that is available for crops and loss to water is measured by soil tests and the level of P available in soils is indicated by the soil phosphorus index – 1 being a relatively low concentration and 4 the highest. The agronomic optimum soil P index is 3. While soil P index 3 is often seen as satisfactory from a water quality perspective, **there are circumstances where soil P index 2 soils and even soil P index 1 soils can pose a threat to water quality**; these arise in poorly-draining settings and also in the catchment areas of high status objective water bodies, which are sensitive to relatively small nutrient loadings. The reason is that it takes very little P loss (a small proportion of the amount generally applied) to bring the concentrations in water above the EQS of 0.035 mg/l PO4 (as a mean) – see Section 15.6 for further details. As a counter balance to this, soil P index 4 in well drained soils, underlain by subsoils, will generally not pose a threat to water as phosphate is not mobile in this situation and there isn't an effective pathway to a water body, either groundwater or surface water (but see footnote for an exception to this). Therefore, consideration of the pathway for P loss is a critical factor is assessing potential impacts and mitigation options.

However, while impacts on water can occur at all soil P index situations, the greatest threat is in soil P index 4 soils where P concentrations are greatest. A key question in considering time lag is 'how long

[105] Teagasc research in the Timoleague catchment in south Cork, which is dominated by free-draining soils, has shown leaching of PO_4 to groundwater and then input to watercourses via the groundwater pathway, with concentrations in summer exceeding the EQS. This is attributed to the geochemistry of the soil, particularly the relatively low Al and high Fe contents, which facilitates leaching. The underlying bedrock is Old Red Sandstone (ORS), where the red colour is due to oxidised iron. In my experience of other ORS areas, PO_4 concentrations in groundwater are relatively low. However, if high PO4 concentrations are found in surface water where the soils are free-draining and it has been shown that point sources alone are not the only pressure, advice from Teagasc researchers is recommended. This situation may arise in some areas in the south of the country where the soils and subsoils are dominated by the ORS bedrock.

will it take for soil P depletion to bring the index from 4 to 3 or even 2 or 1?' This depends on a few factors:

- The initial soil P concentrations, which can be much higher than the boundary concentration between soil P index 3 and 4.
- The crop take off of P (e.g. for fields used for silage alone and where no further applications are occurring, 'mining' of P in the soil occurs).
- Any additional loadings, for instance, by grazing animals,
- The soil type.

Therefore, the answer can vary from field to field. Teagasc research has shown that many years of appropriate land management are needed to reduce the P load in soils after mitigation commences, with the actual number of years varying with the factors mentioned above. Recent research by Teagasc on two farms in the River Allow catchment examined 10 fields with soil P index 4 and predicted that the time taken to reach soil P index 3 ranged from 1-8 years, with six fields requiring ≥4 years. In other research outcomes, Teagasc have predicted time lags of as low as 3 years and over 20 years depending on the circumstances.

So, suppose there is a scenario where a critical source area for P loss has been located in the catchment area of an *At Risk* water body and mitigation activities have been put in place to reduce the source load. Without the detailed research such as that undertaken by Teagasc, it is not feasible to estimate the time lag for the P concentrations to decline to soil P index 3 or 2 concentrations in the different fields. My suggestion is to assume that it will take approximately six years (the same duration as a river basin management cycle), while realising that it could be as low as one year or more than 10 years. If the objective is to reduce the P concentrations in the soil further, for instance in the catchment area of a sensitive water body, such as a High status objective water body, then a longer time could be assumed. While this is a long period, keep in mind that is only one component in the time delay story, and that the time lag can be reduced by other components, which are described below.

28.6.2 Time lag for reduction of nitrate in the soil

Nitrate is not adsorbed on clay or organic matter. Therefore, it is highly mobile and, in a free-draining setting and under recharge conditions, is easily leached out of the rooting zone.[106] **The time lag for this to occur is probably a matter of months.**

28.7 Time lag due to relevant pathway elements

The pathway is the route water and associated pollutants must travel along from the location of a pressure in a field or at a site to a water body – either a watercourse or groundwater.

28.7.1 Transport time along pathway

The properties of phosphate and nitrate and the relevant physical settings and associated pathways for each differ. Therefore, consideration of the role of attenuation is considered separately for each.

Transport time for phosphorus along pathway

The pathway for phosphorus is overland and near-surface mostly in poorly-draining areas. If phosphorus is mobilised after rainfall, the transport time to a watercourse is short – **hours to days**. This assumes that no mobilisation or pathway mitigation measures and/or actions are in place.

Transport time for nitrate along pathway

[106] Research has shown that some organic N can be retained in a well-drained soil and can be available subsequently for leaching or denitrification. However, this is not considered to be significant in the context of this Section.

The pathways for nitrate are underground to both groundwater and surface water bodies in free-draining areas. Groundwater is not only a receptor (an aquifer or well or spring) that can be impacted by nitrate but is also the main pathway for nitrate to get from diffuse sources on the land to surface water. Nitrate does not enter surface water via overland flow and near-surface pathways generally, in contrast to phosphorus, as denitrification occurs along those pathways.[107]

The time lag for nitrate to reach a receptor depends on the following:

- The receptor itself, whether groundwater in an aquifer or a well or spring, or a watercourse.
- The permeability of the soil, subsoil and bedrock (keeping in mind that the permeability has to be sufficient to enable water containing nitrate to migrate vertically to the water table and then horizontally to a well, spring or watercourse).
- The depth to bedrock or thickness of soils and subsoil. (Water flows much slower generally in subsoil than in bedrock, although preferential flowpaths can cause bypassing of the matrix of soil and subsoil).
- The unsaturated zone in subsoil. Flows in unsaturated subsoils are slower than in saturated subsoils.
- Denitrification in certain soil, subsoil and bedrock types.
- For surface water receptors, distance from the fields that are a source of nitrate.

Because of the variability of the hydrogeology of the Irish landscape and because the relevant receptor could be either groundwater or surface water or both, the time lag varies. Therefore, generalising is difficult, but is attempted here to 'give a feel' for the likely situations.

Vertical travel times

Most physical settings where nitrate is a *significant issue* for either groundwater receptors or surface water receptors or both tend to have soil and subsoil thicknesses no greater than 5-6 m. Where the soil/subsoil is ≤ 1 m, the bulk of the nitrate is likely to reach the water table in <1 year (it will often be a matter of months). Where the soil/subsoil thickness is 5/6 m, the main load of nitrate leached from the soils is likely to reach the water table in a range between 2.5-5 years (see Table 28.1).[108]

Table 28.1: Estimated travel times for nitrate applied on land to reach the water table when leached depending on the soil/subsoil thickness

Soil/subsoil thickness (m)	0-1	2	5	10
Travel time (years)	<1	1-2	2.5-5	5-10

Horizontal travel times

Horizontal velocities in bedrock (excluding karst) are likely to be in the range 1-10 m/d, say an average of 5 m/d. Take a catchment with nitrate issues and a distance of 1 km between the watercourses with a groundwater divide half way between the watercourses, giving 500 m as the greatest distance from a watercourse. So, the land on which nitrate is applied will vary between 2 m to 500 m from the watercourse, with horizontal travel times of <1 to 100 days, depending on the distance for

[107] Therefore, where the physical setting is constant in an area, high phosphate and nitrate concentrations arising from diffuse sources will not generally be present in the same water body. An exception to this is areas with soils similar to those in the Timoleague catchment.

[108] Estimating **vertical velocities** for water movement in soil, subsoil and bedrock is complex. It depends on a variety of (often interrelated) factors: permeability, type of permeability (intergranular or fissure), effective porosity, presence of preferential flowpaths, hydraulic gradient (often <1 in moderate permeability subsoils), degree of saturation, effective rainfall, length of recharge period, presence of zero flux plane. In taking account of these factors, the GSI Groundwater Vulnerability Guidelines assumed a vertical velocity during the recharge period in moderately permeable subsoil of 0.01 m/d.

groundwater to reach the watercourse. Concentrations reaching the watercourse will start to reduce from the first day that the nitrates reduce in the groundwater in the bedrock due to the mitigation measures at the surface. The same calculation applies to where the receptor is a well.

For sand/gravel aquifer scenarios, the time lags would be greater, although this is not a common situation.

28.7.2 Attenuation along pathways

Attenuation of P along pathways

Phosphate is readily attenuated in free-draining soils (with the exception of soils such as those at Timoleague). Therefore, diffuse loss from farmland is not generally a *significant pressure* and PO_4 is not a *significant issue* in these areas as a transport pathway to watercourses and groundwater is not present.

Attenuation of phosphate occurs in poorly-draining scenarios by crop take-up and adsorption in the upper centimetres of mineral soil. However, in these areas, where the hydrology is 'flashy', and overland and near surface pathways for water and pollutants are dominant, P in both soluble and particulate forms can be readily 'washed off' the land after heavy rainfall. Most of the impacts on water quality from diffuse sources occur in this setting. Therefore, the timing of application of P can have an influence in reducing losses to watercourses, both in terms of the time of the year and the number of days that spreading occurs before heavy rainfall – the regulations require a 48 hour gap, but a greater gap would be beneficial and therefore is advisable.

In poorly-draining areas, sediment with associated particulate P can be deposited in ditches/drains, and can therefore act as an ongoing source of P. However, these ditches/drains can also be an excellent pathway interception measure. Careful 'cleaning' of the drains will remove this pressure (see Section 2, Volume 3 of the Guidance on Further Characterisation for Local Catchment Assessment). In addition, these ditches/drains could readily be designed and engineered to act as sediment traps, either by deepening and/or widening in places, or by installation of small farm ponds at suitable locations along the ditches/drains or perhaps close to the outlet to the watercourse.

In conclusion, in poorly-draining areas attenuation is not sufficient generally to prevent loss of P to water. Thus, P can enter a watercourse in a matter of hours and days during and after rainfall and impact on the ecology, or may remain available as particulate P in the watercourse and cause impacts particularly during low flow periods. Therefore, the time lag due to attenuation is a matter of **hours and days** for soluble P (PO_4) and perhaps **weeks and months** for (a high proportion) of particulate P.

Attenuation of nitrate along pathways

Attenuation of nitrate as it moves through soils, subsoils and bedrock can occur due to denitrification. These situations arise where anaerobic and reducing conditions are present. Typically in soils, this might arise where there are layers of lower permeability due to a higher clay, silt and organic content than in the other layers. Denitrification occurs in certain bedrock types, such as impure (clayey) limestones. In addition, where the pathway for water is as overland and near-surface flows in poorly-draining settings, denitrification generally reduces the concentrations before the receptor is reached. As a consequence, a relatively high loading of nitrate fertilizer, for instance on nitrate derogation farms, will have different impacts depending on the underlying hydrogeological and hydrochemical setting.

Where nitrate has been specified as a *significant issue*, it indicates that attenuation has not been sufficient to mitigate the impacts, and that therefore mitigation actions are needed. Therefore, in these circumstances, attenuation need not be taken to influence the time lag.

28.7.3 Time lags due to pathway interception

As highlighted above, the pathways for phosphate and nitrate vary, with phosphate typically reaching waterbodies by overland and near-surface pathways whereas nitrate reaches waterbodies via underground pathways. Therefore, the role of pathway interception differs for each – highly relevant for phosphate and particulate P, and not so relevant for nitrate.

Role of pathway interception for phosphate

As the main pathways for P entering a watercourse are overland and near-surface either directly into the watercourse or via ditches/drains, pathway interception installations (see Table 28.2) are feasible. Once they are established and working effectively, their impact will be immediate, **with no time lag**, as they intercept the P and either prevent it from entering or reduce it before entering a watercourse. They also have the benefits of mitigating not only PO_4, but also particulate P and sediment. **Therefore, while source load reduction and mobilisation measures and actions are beneficial, they need to be accompanied by pathway interception as this is the most important and effective means of mitigating impacts.**

Role of pathway interception for nitrate

As the main pathways for nitrate entering a waterbody are underground, pathway interception (see Table 28.3) is not always a viable option, particularly where groundwater is the receptor. In some circumstances, the installation of riparian buffers or wetlands could encourage denitrification of groundwater discharging to a watercourse. However, it would be difficult to quantify the benefits, which might be minor, and therefore to justify their installation for this purpose alone, unless there were significant co-benefits for biodiversity and carbon sequestration. **Therefore, load reduction and mobilisation measures and actions are the most effective means of mitigating impacts from nitrate.**

28.8 Receptor time lag

There are two relevant elements: i) the time it takes for particulate P stored temporarily in river sediments to convert to soluble P and ii) the biological response, for instance the time it takes for the Q-value to reach the required objective of either Good or High biological status once the nutrient concentrations have reduced below the EQS.

28.8.1 Particulate phosphorus

In circumstances where sediment containing particulate P enters a watercourse on a regular basis, then this acts as an ongoing source of phosphate. In lakes where there is a legacy of P input, such as in the Cavan-Monaghan region, it may take decades for the P levels in both the lake and river waterbodies to reduce. In watercourses without inputs of P from lakes and where the *significant issue* is sediment, it is probable that, **once the source is minimised**, the P would be leached from the sediment and concentrations would reduce after 1-2 years, although there are likely to be some exceptions to this where there are substantial deposits of sediment in the watercourse channel.

Particulate P is likely to be present in the sediment in ditches/drains in poorly-draining areas with moderately intensive to intensive agriculture. However, unlike in the main channels of watercourses, this sediment can be removed readily and landspread, and the ditches/drains can be 'engineered' as an interception measure.

28.8.2 Nutrients

The biological responses to measures and/or actions being in place and being effective in reducing concentrations to below the relevant EQSs or threshold values, can vary from one year to several years. Recovery from a once-off pollution event in a water body meeting its objective can be rapid; for instance a high status objective water body in north Cork recovered in one year after a pollution event because of migration of macroinvertebrates from upstream to the polluted portion (Fran Igoe, personal communication). Where the water quality is unsatisfactory for all or most of the channel length, then recovery to the required Q-value would, take longer (**2-3 years** perhaps) after the mitigation measures and/or actions are in place, with a longer period of time where improvement by two status classes is needed. The biological responses in transitional and coastal waters are not considered in this Note.

28.9 Measurement component

Water samples are taken for analysis on a quarterly or monthly basis. Therefore, reduced concentrations would become obvious almost immediately and would be a means of indicating improvement. Samples sufficient for the trend analysis needed to confirm improvements might require 2-3+ years of monitoring data.

Biological monitoring at EPA monitoring points occurs every three years. Therefore, evidence of biological status improvement might not be available until **1-3 years** after an improvement in Q-values occurs. However, perhaps more frequent monitoring might be feasible in certain circumstances to provide evidence of improvement.

28.10 Overview and discussion

28.10.1 Findings from the literature

I have picked out below a few general findings from the literature, both Irish and international:

- The mitigation of impacts on watercourses and groundwater by phosphate and nitrate, and as a consequence, the estimation of the length of time for improvements is complicated and difficult.
- Research outcomes often highlight the long length of time for improvements – >10 years – after mitigation measures have been put in place, either based on monitoring or modelling results.
- While improvement at field scale can be relatively quick (<5 years), improvements at catchment scale can take far longer (>10 years). This is relevant as monitoring for WFD implementation purposes is at subcatchment scale.
- Small point sources, such as domestic wastewater treatment systems and farmyards, are an important source of P, particularly during low flow periods. Although they generally contribute a much lower load of P to streams overall, they need to be dealt with as well as diffuse sources. (They could be seen as 'low hanging fruit' which are easier to locate than CSAs for diffuse sources, and they have measures that are easier to undertake.)
- The loading of nitrate to water is far greater from diffuse sources than from small point sources.

Dealing with phosphorus is challenging:

- It takes very little P loss from farmland to breach the EQS for PO4.
- Reducing P levels in soils via NMP is beneficial for water quality as there is a relationship between soil P Indices and PO4 concentrations in runoff.
- Reducing P levels in soil does not have a significant impact in reducing particulate P loss.
- Reducing the P level to Index 3 is unlikely to be sufficient <u>on its own</u> to lower concentrations to below the EQS. An exception to this would be where there is significant dilution from areas surrounding 'high' pollution impact potential (PIP) areas in a subcatchment.
- There is a significant time delay for reducing soil P Index 4 to Index 3.
- Pathway interception, particularly in the delivery areas, is a critical measure to i) achieve concentrations below the EQS, ii) reduce particulate P losses and iii) reduce the time delays for improvement.

There is a danger, it seems to me, that those familiar with the literature will be pessimistic about when improvements will be seen, while those not familiar with it will have unrealistic expectations on when improvement might occur, and while others might decide to concentrate on point sources only. In my view, there are solutions to achieving significant improvement by the time of the 4th RBMP reporting date (2027), but the improvements in many situations (but not all) will not be in the immediate future. This Note tries to provide a basis for estimating realistic time frames for improvement.

28.10.2 Estimating time delays

In Tables 28.4 and 28.5, I have attempted to examine each of the components that influence the time for improvement (as outlined in Section 13.4) based on estimations of the situation**. The sum of the time delays from all the components is the time taken for the improvement to occur and for it to be indicated by monitoring/measurement.**[109]

The 'final' date for implementing the WFD, with the exception of catchments where 'natural conditions' do not enable the objectives to be met, is 2027. Taking account of the time needed to write the 4th River Basin Management Plan, the fact that biological monitoring is undertaken every three years and the time needed to analyse the field results, then improvements in Q-value would need to have taken place and have been verified by 2025 for some water bodies and 2026 for others. Therefore, 2027 should be seen as the date for reporting and not for improvement.

I have drawn some conclusions below for consideration:

- Many policies are in place for dealing with point sources.
- Some further policy development is needed for diffuse sources, in my view.
    - The current setback distances/buffer zones in the Regulations are narrow strips of land along watercourses. While they are beneficial (for instance, for biodiversity) and should be complied with in poorly-draining areas in particular, even if followed everywhere, they would not be sufficient to prevent nutrients and sediment entering water courses. As water runs off the land, it converges due to the micro-topography and enters watercourses at delivery points and areas that are a small proportion of the watercourse length. The role of pathway mitigation measures and actions would be to intercept the flowpaths, both in the vicinity of the watercourse banks and also, preferably, further back in the critical source area as well. Policy changes are needed to take this situation into account.
    - Issues such as incentivisation and 'payments for public goods' may need to be considered, including expansion of the results-based payments approach.

- The location of the *significant issues*, *significant pressures* and critical source areas for diffuse pressures, is an essential precursor for deciding on and establishing mitigation measures and/or actions.
    - Some *significant pressures* are already known, such as large point sources. But, the location of most of the small point and diffuse sources isn't know with a sufficient degree of accuracy to enable the execution of appropriate mitigation measures/actions.
    - Locating the critical source areas (CSAs) and delivery points for diffuse sources requires resources and time. This is now achievable by using the results of the EPA-funded DiffuseTools Project at subcatchment scale and the Local Catchment Assessments, which include catchment walks, being undertaken by LAWPRO and farm advisors at field scale. The CSAs need to be located so that measures and actions are targeted so that it can be ensured that they are effective.

[109] While the time delays given for each component are my estimations, they can be replaced with alternatives and then be used to arrive at an estimated time for improvement for different likely scenarios.

  - The ongoing work of LAWPRO and the EPA Catchments Unit is critical to future success; without knowing where precisely measures/actions need to be targeted, they will not be effective and water quality will not improve. **Without this detailed scientific and advisory work, followed up by establishment of the appropriate mitigation measures/actions, it will not be feasible, in my view, to reduce the impacts of diffuse sources, and therefore not be feasible to show improvements in water quality or achievement of the WFD objectives in many *At Risk* waterbodies in the short- to medium-term.**

- Local catchment assessments, the input of farm advisors, programmes such as the Smart Framing initiative and EIP projects will make a difference in enabling greater awareness of the role diffuse sources of pollution and will encourage mitigation actions for diffuse sources to be undertaken.

- The work undertaken by EPA Catchments Unit and LAWPRO together with consultation with other public bodies, particularly local authorities, has enabled the location of the significant pressures and critical source areas (CSAs) in *At Risk* water bodies.

- The time lag for reduction in source load from point sources is immediate once the mitigation measure(s) is/are in place.

- The time lag for reduction in phosphorus source load in soils on farmland (using nutrient management planning) could vary, depending on the circumstances, from 1-10+ years. I suggest taking the duration of a WFD cycle – 6 years – as a reasonable average. While this will seem long, pathway mitigation measures and actions, if they are established, can reduce this time lag. In any case, in water bodies where phosphate is the *significant issue*, reducing the source load to soil P index 3 alone as a measure is unlikely to be sufficient to reduce the phosphate concentration below the environmental quality standard (EQS) in many water bodies. A possible exception to this is a scenario where there is significant dilution from upstream by water with low PO_4 concentrations and a relatively small reduction of PO_4 load entering water would be sufficient to reduce concentrations below the EQS. However, the long time delay for source load reduction will still apply, therefore even in this scenario, pathway interception is recommended.

- Pathway interception, particularly in the delivery areas, is a critical measure to: i) achieve concentrations below the EQS; ii) reduce particulate P losses; and iii) reduce the time delays for improvement.

- **For situations where phosphorus is a *significant issue*, pathway interception measures and actions are the main means of reducing losses to watercourses. Therefore, while reductions in source P load in the soil is beneficial and needs to be implemented, the long time lag for reduction in source load need not be a determining issue or reason not to require the shorter time lags that pathway measures and actions give, provided that they are established in CSAs.**

- Pathway interception in critical source areas, particularly at **delivery points** to watercourses may need to be extensive, e.g. a woodland or a wetland 10s of metres wide, or a hedge planted on a low mound. Therefore, installation of these will need to be incentivised, in my view. Development of policies to facilitate this is urgent.

- For nitrate as a *significant issue*, load reduction and mobilisation control measures are the main means of reducing losses to groundwater and watercourses.

- It is advisable, in my view, to not set achievement of the status objectives as the only measure of improvement. Reducing trends in phosphate and nitrate concentrations at water body monitoring points could also be used as a measure of improvement. This has the advantage that improvements can be seen and recorded before biological responses occur and are recorded.

- The sum of the time delays from all the components is the time taken for the improvement to occur and for it to be verified by monitoring/measurement. The estimated time delays given for each of the six components in Tables 28.4 and 28.5 enable approximate time delays to be estimated depending on the various possible scenarios. The numbers given in Tables 28.4 and 27.5 can be substituted for other numbers by those who don't agree with those used in this Note.

- The analysis in this Note does not take account of sediment as a pollutant and *significant issue* in itself; there are water bodies where sediment entry to watercourses, due for instance to poaching adjacent to watercourses or land drainage, has caused failure to achieve the WFD status objectives. However, an estimated time for improvement could be estimated by using the approach shown in Table 28.4.

- Examples of time delays for different scenarios are given below:
    - If PO_4 is the *significant issue* arising from agriculture as a diffuse *significant pressure* in the catchment area of a surface water body, and <u>if the necessary policies are in place and are implemented</u>, then reduction in PO_4 concentrations would be feasible in one year, and would be measurable in the water chemistry, with improvements in the Q-value requiring 1-3 years, and then verified within 1-2 years. If the starting point (measures/actions in CSAs in place) was January 2022, improvement in water chemistry could be evident in 2022, with improvement in the Q-value by perhaps 2024/2025, which could be verified by monitoring in 2025 or 2026. This may be the optimum scenario for this situation, which is a common one for *At Risk* water bodies in poorly draining areas.
    - If the scenario above is taken as a starting point, but the required policies to enable targeting and establishment of appropriate measures and/or actions are not in place, then the projected 2025 or 2026 dates for showing improvements in Q-values are not likely to be achievable. However, if they are in place by, say, end 2022, and implementation occurs in 2023, improvements in water quality (e.g. reducing PO_4 concentrations) are likely to be evident by end of 2024 and conclusive by, perhaps, 2025-2026. There may not be the time in this circumstance to record improvements in status in the 2027 RBMP, but improvements in water quality could be recorded.
    - If an urban wastewater treatment plant (UWWTP) discharging to a water course is the sole *significant pressure* in a water body, upgrading of the treatment plant would result in an immediate reduction of nutrients which would be evident in the water quality monitoring results, and would result in achievement in a satisfactory Q-value 1-2 years later, which would then be shown by monitoring within two further years. If the treatment plant upgrade took place before end 2022 or perhaps even 2023, then evidence of improved biological status would be available for the 2027 RBMP.
    - If nitrate is the *significant issue* for a drinking water source in a limestone aquifer overlain by 5-6 m permeable soil and subsoil and if adequate measures and actions

were in place, it could take perhaps 2-3 years before some reduction in nitrate would be evident and 3-6 years before a significant reduction occurs.

28.11 Conclusions

The time needed for improvements in both water quality and water body status depends on a variety of components, each of which have a time delay element. In addition, the time delay varies with the pollutant or *significant issue* that is causing the impacts.

By taking each component in turn for both phosphate and nitrate, and adding the projected time delays for each component, it is possible to estimate the dates by which improvements, either in water quality or status, will occur.

Estimation of the time delay for improvement assists in work and resource planning, enables projections on dates for improvements and allows expectations to be realistic.

This Appendix originated as a Briefing Note for An Fóram Uisce/The Water Forum entitled 'Achieving Water Framework Directive Objectives – The Issue of Time Delays. How Long Will It Take for Improvements to Occur?' It is available at this link:
https://thewaterforum.ie/app/uploads/2020/06/Time-Delays_May2020.pdf

Table 28.2: Summary of mitigation options to prevent/reduce loss of phosphorus to water from diffuse sources/farmland (This list is not intended to be comprehensive.)

Point along pathway	**Mitigation option**
Source control (reduction or elimination)	• Appropriate application rates, including no application on soil P index 4 soils. • Reduced stocking rates and therefore reduced load to soil. • Precision technology, e.g. using GPS & calibrated spreading equipment, to optimise spreading. • Organic farming.
Mobilisation control	• Liming to ensure optimum pH. • Timing of applications; in particular application in spring, and before end June. • Soil incorporation of slurry. • Cover/catch crops.
Pathway interception	• Riparian buffers. • Hedges • Woodlands • In-field grass buffers & beetle banks in tillage fields. • Contour farms in tillage fields. • Interception ponds & constructed wetlands. • Low earthen bunds. • Field interception ponds. • Ditches/drains that are 'engineered' and managed to intercept sediment.

Table 28.3: Summary of mitigation options to prevent/reduce loss of nitrate to water from diffuse sources/farmland

Point along pathway	**Mitigation option**
Source control (reduction or elimination)	• Appropriate application rates to optimise take-up by crops. • Reduced stocking rates and therefore reduced load to soil. • Precision technology, e.g. using GPS & calibrated spreading equipment, to optimise spreading. • Organic farming. • Use of low crude protein animal feeds.
Mobilisation control	• Greater use of clover in place of inorganic N fertilizer. • Use low emission slurry spreading (LESS). • Use multi-species grass mixtures. • Use of protected urea instead of urea and CAN. • Liming to ensure optimum pH. • Timing of applications; in particular application in spring, and before end June. • Soil incorporation of slurry. • Cover/catch crops.
Pathway interception	• Riparian buffers. • Constructed wetlands. • Permeable reactive barriers.

Table 28.4: Time it may take for improvement where phosphorus is the *significant issue*

Components	**Point source *significant pressures***	**Diffuse source *significant pressures***
Policy in place?	Policies in place **Time delay: none**	Some 'one size fits all' policies in place, but are insufficient as they do not enable targeted measures in CSAs. Issues such as incentivisation and paying for public goods may need to be considered. **Time delay: depends, might be years. Probably 1-2 at least.**
Policy implementation Four elements: *1.* Location of *sig. pressures.* 2. Research needs. 3. Consultation & collaboration 4. Execution of measures/actions.	1. Location of sig. pressures Large point sources known **Time delay: none** Small point sources being located by LAWPRO, assisted by LAs. **Time delay: until 2021 for PAA areas; for water bodies outside PAAs could be 2025 depending on resources.** 2. No obvious research needs. **Time delay: none** 3. LAWPRO undertaking this element. **Time delay: none.** **4. Time delay: 2020 for some PAAs, but completion not likely until ~2022.** **Outside PAAs some ongoing work by LAs, but assistance from LAWPRO & farm advisors needed and not likely to be completed for all WBs until at least 2025.**	1. Location of sig. pressures by LAWPRO, assisted by EPA Catchments Unit. **Time delay: until 2021 for PAA areas; for water bodies outside PAAs could be 2025 depending on resources.** 2. Some further research would be beneficial, e.g. on the optimum design and costings of pathway measures/actions and on paying farmers for public goods. However, these need not delay execution of measures/actions. **Time delay: none.** 3. LAWPRO undertaking this element. **Time delay: none.** 4. The time taken to implement appropriate mitigation options (see Table 1) will vary; source and mobilisation control actions could be undertaken and be effective, in general, more quickly than pathway interception actions, such as planting of trees and hedges. **Time delay in PAAs: Several of the source and mobilisation options could start to be in place due to voluntary actions by farmers following collaboration with farm advisors from 2020 for some PAAs, but completion not likely until ~2022. The pathway interception actions, which will also be needed, could be implemented within 1-2 years if the policies to facilitate them were in place, although it might take somewhat longer for some of them to reach optimum effectiveness.** **Time delays outside PAAs: Some ongoing work by LAs, but assistance from LAWPRO & farm advisors needed and not likely to be completed for all WBs until at least 2025 unless more resources are available.**
Reduction in source load	**Time lag: immediate once implemented.**	**Time lag: 1-10+ years depending on the circumstances; suggest taking 6 years.** *(Note: this time delay can be reduced significantly by interception and attenuation along the pathway and therefore need not be used in the time delay estimation.)*
Transport time along pathway	N/A	**Time lag: hours to days**
Attenuation along pathway	N/A	**Time lag: hours to days for soluble P and weeks to months for particulate P.**

Pathway interception	N/A	**Time lag: weeks to months after establishment, but 1+ years for optimum effectiveness.**
Hydrochemical response	**Time lag: none**	**Time lag: gradual improvement in effectiveness, weeks, months with optimum efficiency after 1 year.**
Biological response	**Time lag: 1 year where an upstream water body is satisfactory**	**Time lag: might be as low as 1 year where a small reduction in nutrients and sediment is needed and the situation is satisfactory in an upstream stretch of watercourse, but 2-4 years, with the longer time needed where an inadequate biological status has been persistent and where an improvement in two status classes is required.**
Monitoring component	**Time lag: ~1 year for hydrochemistry. 1-3 years for biology and ecology status.**	**Time lag: ~1 year for hydrochemistry. 1-3 years for biology and ecology status.**
Estimated time delay for improvement		

*PAAs = Priority Areas for Action

Notes:

1. The final row enables you, the reader, to take scenarios that are relevant to you and to work out approximately how long it would take for improvements to occur.
2. This table only applies to *significant pressures* in *At Risk* water bodies that need to enable either WFD or drinking water objectives to be met, and not all pressures.

Table 28.5: Time it may take for improvement where nitrate is the *significant issue*

Components	Point source *significant pressures*	Diffuse source *significant pressures*
Policy in place?	Policies in place **Time delay: none**	Some 'one size fits all' policies in place, but are insufficient as they do not enable targeted measures in CSAs. Issues such as incentivisation and paying for public goods may need to be considered. **Time delay: depends, might be years. Probably 1-2 at least.**
Policy implementation Four elements: *1.* Location of *sig. pressures.* 2. Research needs. 3. Consultation & collaboration 4. Execution of measures/actions.	1. Location of *sig. pressures* Large point sources known **Time delay: none** Small point sources are not a significant contributor of nitrate.	1. Location of *sig. pressures* by LAWPRO, assisted by EPA Catchments Unit. **Time delay: until 2021 for PAA areas; for water bodies outside PAAs could be 2025 depending on resources.** 2. Some further research on source reduction and mobilisation mitigation options might be beneficial. **Time delay: none.** 3. LAWPRO undertaking this element. **Time delay: none.** 4. The time taken to implement appropriate mitigation options (see Table 3) will vary; source and mobilisation control actions, which are the main options, could be undertaken and be effective. **Time delay in PAAs: Several of the source and mobilisation options could start to be in place due to voluntary actions by farmers following collaboration with farm advisors from 2020 for some PAAs, but completion not likely until ~2022.** **Time delays outside PAAs: Some ongoing work by NFGWS, but assistance from LAWPRO & farm advisors needed and not likely to be completed for all WBs until at least 2025 unless more resources are available.**
Reduction in source load	**Time lag: immediate once implemented.**	**Time lag: <1 year.**
Transport time along pathway	N/A	**Time lag: <1-6 years.**
Attenuation along pathway	N/A	**Time lag: None** (where NO3 is a *significant pressure*, any attenuation that occurs is inadequate).
Pathway interception	N/A	**Time lag: None.**
Hydrochemical response	**Time lag: none**	**Time lag: gradual improvement in effectiveness, weeks, months with optimum efficiency after 1 year.**

Biological response	**Time lag: 1 year where an upstream water body is satisfactory**	**Time lag: might be as low as 1 year where a small reduction in nitrate is needed and the situation is satisfactory in an upstream stretch of watercourse, but 2-4 years, with the longer time needed where an inadequate biological status has been persistent and where an improvement in two status classes is required.**
Monitoring component	**Time lag: ~1 year for hydrochemistry.** **1-3 years for biology and ecology status.**	**Time lag: ~1 year for hydrochemistry.** **1-3 years for biology and ecology status.**
Estimated time delay for improvement		

Notes:

1. The final row enables you, the reader, to take scenarios that are relevant to you and to work out approximately how long it would take for improvements to occur.
2. This table only applies to *significant pressures* in *At Risk* water bodies that need to enable either WFD or drinking water objectives to be met, and not all pressures.

29 Appendix 13: Community Participation in Management of Waters

29.1 Introduction

In this Appendix[110], the meaning of community and public are one and the same. I have written this in a narrative style as opposed to a technical or academic piece for a reason; facilitating community participation is not a series of logical steps or a linear process. Just like communities every participation process is/must be different. Adaptability and flexibility are key.

If you google community participation in management of waters, words and phrases such as sustainability, legitimacy, integrated catchment management, holistic, core component, essential, social inclusion, behavioural change, democracy, empowerment, engagement, education and awareness raising all appear regularly. There is no definition or defined methodology. If we were to try and define it, it might look like this; listen to the people and take their views into account.

29.2 But what is meant by participation?

Article 14 of the Water Framework Directive (WFD) states that "*Member States shall encourage the active involvement of all interested parties in the implementation of this Directive, in particular in the production, review and updating of the river basin management plans*." The Aarhus Convention states "*for the public to prepare and participate effectively during the environmental decision-making.*" From this it is clear that participation means being involved from the beginning, before decisions are made.

This is not something that sits well with public servants such as myself, it means giving up some of the power (which it has taken many years of hard work and career advancement to accumulate) and handing it over to possibly an uninformed group of people with little expertise. But literature and studies have shown that engaging the public and communities early in the process has great benefits for project outcomes and decision making. I don't intend to go into these benefits here, the reader I am sure can search online themselves but just to mention one of the great Irish community initiatives and success stories worldwide, the Tidy Towns movement. To see where it has come from since its foundation in 1958 to where it is now, I know every reader will be familiar with it, if not engaged in some way; can we imagine if we had the same for Water!

Irelands River Basin Management Plan 2018 – 2021 mentions that " *Community engagement requires real participatory structures where communities can have their voices heard, and where they can be included in the decision-making process*", I think this is the real challenge of all of us, it requires new thinking and is a new area of work outside of our normal technical comfort boxes.

29.3 So, what does participation look like?

To start with, one size will not fit all, just as no two water landscape settings are the same, no two communities are the same even though they could be from the same parish and have gone to the same school. Participation will also mean different things to different people and communities. Some will be happy doing the river clean-up while others will want a say in water resource management be it in terms of flooding measures, pollution control, habitat restoration, etc.

Therefore, the first element of participation is listening; active listening and understanding what the community wants. To do this, opportunities will need to be created for communities to have their voice heard. This can be through hosting traditional "consultation" type events, (not effective in terms of achieving real participation), most effective will be to travel to communities and engage them in a setting of their own where they will feel most comfortable and therefore more willing to speak. This can be done by attending existing community fora and seeking space on their agenda or organising

[110] This Appendix was contributed by Ray, Spain, LAWPRO.

specific purpose events in the local area in the form of community meetings, on-the-river festival day, Water Heritage Day, etc.

We also must be careful in how we seek to engage and attract people to such events. It is good to have met with and developed a relationship with a local community animator who can provide context and background to water in the area thus providing an “in”. During the consultation phase for the current River Basin Management Plan, when we used the slogan “What does your River (name) mean to You?”, we soon found out that while all local issues are national issues, not all national issues are local. People were most vociferous when the water issue was (made) relevant to them personally or to their local area and much less so when the issue was not.

There is also a need for a translation service. Professionals tend to speak in their own colloquial language often using acronyms and technical definitions which while speeding up inter professional discourse has the disadvantage of disenfranchising communities and the public from the conversation. This also holds through for advertising events. How often have you had to read a statutory public notice 2 or 3 times to figure out what it is all about. As Maya Angelou said, “easy reading is damn hard writing” and the same goes for the spoken word.

29.4 Facilitating Participation

In facilitating community participation, we also must manage expectation. Participation opportunities have increased and improved especially since the advent of the Local Authorities Waters Programme and Community Water Officers, government initiatives such as the Public Participation Network (PPN’s) and Local Community Development Committees (LADC’s), the establishment of An Fóram Uisce and other community based programmes such as LEADER.

However, communities may want more than what is provided for currently and there will always be technical and regulatory issues. Participation opportunities are increasing all the time and with the knowledge and assistance of public servants, avenues for communities to have their voice heard can usually be identify and accessed.

It still remains incumbent on us to manage expectation which may not be an easy pill to swallow and can lead to difficult conversations. The Community Water Officers will attest to integrity being key here. No political speak, no fobbing off, tell it like it is, honesty is appreciated and leads to relationship building. Also, active listening, understanding their point of view, assisting them in developing their discussion and finally translation into WFD speak for feeding into WFD structures.

Communities not only want their voice heard but be seen to be heard and listened too. This can be facilitated through capturing in a document, the conversations, views and issues raised. Such a document can then be fed up into WFD governance structures and thus taken into account in decision making. Final plans should then reference (where appropriate) amendments, changes, as a result of community input, thus providing feedback and showing communities that their voice is included in water management.

Giving communities a voice is one of the primary objectives of Community Water Officers but it also a responsibility for all us public servants (as they say, it’s in the name).

29.5 Assisting Communities

The foregoing has already discussed some areas such as translating messages and feeding the community voice into decision making structures but there may also be “understanding” of issues on the community side which may require our assistance. Note: I have not used the term education here as this implies that communities may be uneducated. Indeed, some communities have a far better understanding and knowledge of the local issues than we have and most definitely we will come across individuals with a knowledge that far out strips our own.

But there may be a requirement to assist communities in developing their understanding of an issue. We do not have to be experts in everything, nor indeed do we want to be seen as experts in everything water, but usually we can find an expert who is willing to share their knowledge. Sometimes an expert with independent credentials can assist the community and us in a difficult situation.

Many communities are interested in carrying out projects which can range from a clean up to river and habitat restoration and catchment scale management initiatives. They will typically be very enthusiastic and want to start work immediately, however this is usually not possible until required consents are in place and relevant stakeholders have been engaged. Outlining and facilitating a path forward is critical at this stage not to dampen enthusiasm and in the long term can be beneficial. For well-established communities with "big-plans", a visioning exercise and document is an excellent first step. Although it may slow progress towards getting boots-in-the-river, it will demonstrate community agreement and commitment to long term vision and objectives and will prove a useful tool in engaging with stakeholders and indeed seeking funding.

29.6 Funding Communities

To be able to provide funding or assist in identifying funding is a great door opener to developing relationships. The Communities Water Development Fund administered by LAWPRO is specifically focused on water quality and is readily accessible but there are also numerous other sources of funding, Local Agenda 21, LIFE, Interreg, Tidy Towns and many more. Contacting the local Community Water Officer who can provide details is worthwhile but also thinking outside of the box should be considered. River clean-ups can be funded under waste management funding streams, river walks and signage under urban renewal schemes, river restoration under Inland Fisheries Ireland and Office of Public Works schemes. Small modifications to project specification can open the door to numerous funding schemes.

Funding is also available through the LEADER Programme under the protection and sustainable use of water resources theme (€8.5m in 2019). LAWPRO has engaged with the Department of Rural and Community Development (DRCD) to ease access and remove blockages which communities were experiencing. DRCD have responded by developing a clearer process and also allowing funding for development of plans and costs associated with planning permission including AA and SEA which are not allowed under other thematic areas. LAWPRO have also development guidance for communities – "Working with Water and Biodiversity" which can be accessed at https://www.catchments.ie/leader-working-with-water-and-biodiversity-a-guide-for-community-groups/

29.7 Integrated Catchment Management

Section 3 of these notes tells us about Integrated Catchment Management (ICM) and its benefits but just to bring a community focus, it is worth reiterating that the first 2 steps are:

1. Build Partnerships
2. Create and Communicate a Vision of ICM

These often get overlooked in our rush into the technical aspects of water management or we interpret the partnerships to only include other public agencies. Building partnerships with communities is difficult and time-consuming work but it has great benefits which often go unseen or unrecognised. Hindsight is a wonderful thing and we only have to look at Bellanaboy and others to what might have been.

29.8 Behavioural Change

Behavioural change often gets mentioned in water management discourse, if we could only change people's behaviour, if they only had an appreciation for the environment, if they were more aware, if they knew what I know, if they only understood, if we provide more education, if, if, if. The only thing that can bring about behavioural change is people themselves.

We can influence and provide people with the tools which might lead to behavioural change through, providing information, data and evidence, facilitating discussion or even arguing. But we have to temper our expectations (You can bring a horse to water, but you can't make him drink). I went to primary and secondary school with a lot of the same classmates, so we all received the same education, yet we all developed different social and environmental values. To really influence people, we must see water issues through their eyes, from their perspective and gain an understanding of their position.

Research about behaviour change programs aiming to address water quality are in-conclusive about what works and what does not. Studies indicate that effective communication techniques, combining good information and suitable message framing, can build support for new policies. For complex issues, it is recommended to consider face-to-face or social mobilisation initiatives rather than relying on advertising alone. To quote Dr. Tom Collins, chair of An Forum Uisce, "what we help create, we look after" which in itself is a great reason to facilitate communities participation in water resource management.

29.9 What do Communities Expect of Us?

Up to now the focus here has been outward looking but if we were to put on community glasses and look at it from their perspective, what would they want from us? During consultation for the 2nd cycle RBMP, the single biggest issue raised by the public was "lack of joined up thinking". This included too many agencies, agencies not working together, polices which were conflicting, agencies working in silo's and no single clear direction coming from government.

What was obvious from the consultation was that communities look at their social, economic, community and local area as been one-in-the-same. They do not see silo's or even a series of interconnected silo's but rather the "whole". Community Water Officers are very aware of this and have become adept at connecting water and the water quality objective to history, sports, cultural, literary, social, etc. While their focus is water and water quality, they work with and assist communities in diverse projects once there is a water element. LAWPRO has many examples of communities starting out to develop a walking path (or such like) beside a river, then starting to ask questions about the river, progressing to establishing a water quality improvement project and in some instances into a catchment management organisation.

From the community perspective we must all work together and be seen to work together. We have fora such the Regional WFD Operational Committees where 23 different public agencies come together to discuss and seek areas for collaboration but at a local/community scale we need to include for development of forums for local actors to interact and engage as part of WFD implementation actions.

29.10 And Finally!

Communication is something we all do every day but to what effect? Communities want to be communicated with, they want to hear, to be included in the conversation and just because they do not always reply or engage does not mean they did not listen or that do not want to hear. As professionals who work in the water nexus and therefore with communities, the onus is on us to communicate. To quote George Bernard Shaw "The single biggest problem in communication is the illusion that it has taken place" and I will add, therefore, we must work at it.

30 Appendix 14: Glossary of Terms

Aquifer

A subsurface layer or layers of rock, other geological strata, of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater.

There are nine aquifer categories, which are listed below:

Regionally Important (R) Aquifers

(vii) Karstified aquifers (**Rk**)
(viii) Fissured bedrock aquifers (**Rf**)
(ix) Extensive sand/gravel **(Rg)**

Locally Important (L) Aquifers

(ix) Sand/gravel (**Lg**)
(x) Karstified bedrock (**Lk**)
(xi) Bedrock which is Generally Moderately Productive (**Lm**)
(xii) Bedrock which is Moderately Productive only in Local Zones (**Ll**)

Poor (P) Aquifers

(v) Bedrock which is Generally Unproductive except for Local Zones (**Pl**)
(vi) Bedrock which is Generally Unproductive (**Pu**).

Further details on aquifers in Ireland and access to aquifer maps are available at these links: https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/Pages/default.aspx and https://www.gsi.ie/documents/IrishAquifersPropertiesAreferencemanualandguideVersion10March2015.pdf. Information on karstified aquifers is given in Drew (2018).

Attenuation

A decrease in pollutant concentrations, numbers in the case of microbial pathogens, flux, or toxicity as a function of physical, chemical and/or biological processes, individually or in combination, in the water and landscape environment. Attenuation processes include dilution, dispersion, filtration, sorption, decay and retardation.

Catchment

1. A basin shaped area of land, bounded by natural features such as hills or mountains from which surface and sub surface water flows into streams, rivers and wetlands. Water flows into, and collects in, the lowest areas in the landscape. The outlet of a catchment is the mouth of the main stream or river.
2. A multi-functional, topographically-based, dynamic, multiple-scale socio-biophysical system; defined by over ground and underground hydrology; connecting land, water, ecosystems and people; and used as the basis for environmental analysis, management and governance.

Conservative Contaminants

Pollutants which do not readily or easily react or biodegrade in the subsurface environment, e.g chloride. Nitrate is a conservative in most subsurface environments in freely draining areas, with the exception of some impure limestone and Old Red Sandstone areas.

Environmental Quality Standard (EQS)

The concentration of a particular pollutant or group of pollutants in a receiving water which should not be exceeded in order tom protect human health and the environment.

Groundwater Dependent Terrestrial Ecosystems (GWDTEs)
These are groundwater dependent wetlands, whereby the dependency is either on groundwater flow, level or chemistry as the controlling factors or qualifying interests of associated habitats. Examples are raised bogs, alkaline fens, machairs and turloughs. GWDTES are listed on the EPAs' register of protected areas. A key requirement in protecting GWDTEs is a knowledge and understanding of the environmental supporting conditions.

A conceptual framework for assessing the environmental supporting conditions of GWDTEs under the WFD is presented in Figure 20.1. The three axes aim to incorporate the main geohydrological and hydrochemical attributes of GWDTEs. The location of a habitat within this cube can inform the key monitoring and management issues for different GWDTE types by highlighting important environmental supporting conditions. The three axes, which are described in more detail below, represent the main intrinsic groundwater conditions required by different wetlands to maintain their habitats in good condition.

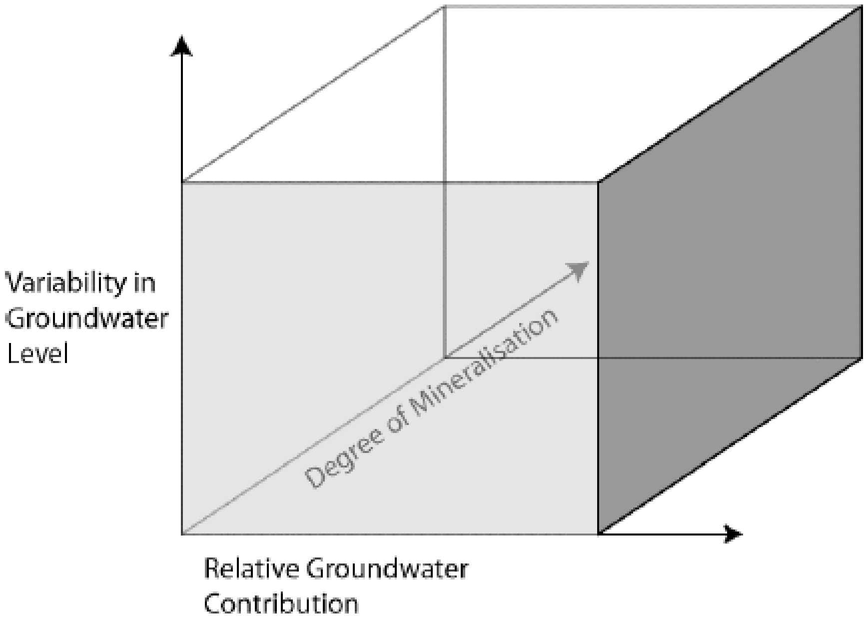


Figure 30.1: A conceptual framework encompassing the main environmental supporting conditions of GWDTEs. The location of a particular habitat within the cube highlights its key geohydrological and hydrochemical supporting conditions and thus informs monitoring and management priorities. (Source: Kilroy, G., Coxon, C., Daly, D., O'Connor, A., DUNNE, F., Johnston, P., Ryan, J., Moe, H. and Craig. (2007). *A geohydrological basis for assessing risk, monitoring requirements and ecological sensitivity for groundwater dependent wetlands for management purposes under the Water Framework Directive*. Groundwater and Ecosystems. Proceedings of IAH Congress, Lisbon.)

Groundwater Vulnerability
The term used to represent the intrinsic geological properties that determine the ease which groundwater may be contaminated by human activities. There are five groundwater vulnerability categories; X (rock at or near surface and karst features such as sinking streams; E (extreme, where the subsoil/bedrock boundary is the 3 m contour); H (high); M (moderate) and L (low, where there is >10 m low permeability (clayey) subsoil). The basis for the categories is shown in the Table 30.2. In summary, 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 map represents a conceptual model of any area based on those factors and is a model of the vertical movement of water and conservative or mobile contaminants.

Conceptually:

- Water takes decades to move through the low permeability subsoil in low (L) vulnerability areas and pollutants are unlikely to reach the underlying aquifer. These are areas of overland and shallow flow, and a high density of water courses, many of which are intermittent.
- In high (H) vulnerability areas, microbial pathogens are generally attenuated in the soil and subsoil before reaching an underlying bedrock aquifer; however, mobile pollutants, such as nitrate, can reach the aquifer.
- In extreme (E) vulnerability areas, both microbial pathogens and mobile pollutants can reach the aquifer. Watercourse density is low in these areas.

Table 30.2: Vulnerability Mapping Criteria

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

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

Further details on groundwater vulnerability and access to vulnerability maps are available at this link: https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/Pages/default.aspx

Environmental Flows

Environmental flows or e-flows are the river flows required to support and maintain healthy river ecology and the rivers function, including its ability to provide amenity and assimilate point source and diffuse pressures. For further details, see paper by Quinlan and Quinn (2018) at this link: http://hydrologyireland.ie/wp-content/uploads/2018/11/05-Quinlan-C-Characterising-environmental-flows-in-Ireland.pdf and report by Webster *et al*. (2017) at this link: https://www.epa.ie/pubs/reports/research/water/EPA%20RR%20203%20final%20web-3.pdf.

Karst

A distinctive landform characterised by features such as surface collapses, sinking streams, swallow holes, caves, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged cracks and conduits. The main process (called karstification) is dissolution of limestone (calcium carbonate) mainly by carbonic acid produced when carbon dioxide dissolves in water.

Mitigation Measures and Actions

1. Measures are those that are listed in the Regulations (e.g. DAFM, 2017) and are the minimum requirements that must be complied with.
2. Actions are those that are either incentivised voluntary (e.g. GLAS) or voluntary.

Permeability

A measure of a soil or rock's ability or capacity to transmit water under a potential hydraulic gradient (synonymous with hydraulic conductivity).

Preferential Flow

A generic term used to describe water movement along favoured pathways through a geological medium, bypassing other parts of the medium. Examples include pores formed by soil fauna, plant root channels, weathering cracks.

Saturated Zone

The zone below thew water table in an aquifer in which all the pores and fissures and fractures are filled with water at a pressure that is greater than atmospheric.

Significant Issues & Significant Pressures

Significant issues are the pollutants or hazards that are posing a threat to the drinking water source and that are therefore 'significant' and must be mitigated by measures and actions to protect the source. Examples include: microbial pathogens, nitrate, MCPA.

There are many pressures generally in the catchment areas/ZOCs of drinking water sources. Significant pressures are the pressures that are posing a threat to the source. Once a pressure is designated as 'significant', measures and actions are needed to mitigate the impact(s). Examples include: landspreading of fertilizers containing Phosphorus and microbial pathogens in poorly draining areas, DWWTPs in extremely vulnerable areas. The assessment of significance is undertaken in two steps consistent with the tiered approach to characterisation, first at the sector level through the initial characterisation process, and secondly at the site/field level through further characterisation, which is usually the scale needed for the selection of specific measures to mitigate the issue.

Soil (topsoil)

The upper layer above the subsoil in which plants grow.

Source Pathway Receptor (SPR) Model

A SPR Model involves identifying whether and how pollution sources are connected to a receptor via a pathway.

Source Protection Area

The catchment area around a groundwater source which contributes water to that source (Zone of Contribution (ZOC)), divided into two areas: the Inner Protection Area (SI) and the Outer Protection Area (SO). The SI is designed to protect the source against the effects of human activities that may have an immediate effect on the source, particularly in relation to microbiological pollution. It is defined by the 100-day time of travel (TOT) from any point below the water table to the source. The SO covers the remainder of the zone of contribution of the groundwater source.

Spring

Point of discharge of groundwater, characteristic of karst areas, but common in other landscapes. The point at which groundwater becomes surface water.

Subsoil
Unlithified (uncemented or loose) geological strata or materials beneath the topsoil and above bedrock.

Swallow hole
The point at which a surface a stream sinks underground in karst limestone areas.

Unsaturated Zone
The zone between the land surface and the water table, in which pores, fractures and fissures are only partially filled with water. Also known as the vadose zone.

Water table
The upper level of saturation in an aquifer at which the pressure is atmospheric.

Zone of Contribution (ZOC)
The land area over which some of the rainfall percolates downwards to the groundwater table that eventually ends up at the well or spring. Essentially it is the catchment area to a well or spring.