National Federation of Group Water Schemes

A Framework for Drinking Water Source Protection

Acknowledgements

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- Department of Housing, Planning and Local Government
- Dundalk Institute of Technology
- Environmental Protection Agency
- Geological Survey of Ireland
- Irish Creamery Milk Suppliers Association
- Irish Co-operative Organisation Society Limited
- Irish Farmers Association
- Local Authority Waters and Community Office
- Local Authority Waters Programme
- Monaghan County Council
- National Federation of Group Water Schemes
- An Fóram Uisce
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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.

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1 Introduction

While the principle focus of the Rural Water Programme (RWP) was and remains the installation of treatment systems and the improvement of distribution networks and management in order achieve a safe drinking water service, the National Federation of Group Water Schemes (NFGWS) has long recognised that source protection and enhancement is an equally important element of the overall process of water safety planning.

Following participation in a number of source protection pilot studies and projects encompassing both groundwater and surface water GWS sources[1], the NFGWS developed a comprehensive strategy for source protection on group water schemes as an aid to their putting in place scheme-specific source protection plans. This strategy, published in November 2012, identified that:

> *The first step in making informed decisions is to know the catchment of a source (i.e. the area from which a lake, river, spring or borehole is fed). Accurate mapping is, therefore, a priority. It provides committees and communities with an understanding of the geographic extent of their water supply and of those streams, rivers, swallow holes etc. that are contributing to the source and that need to be protected. It will also provide the framework for the identification of hazards and pathways, risk categorisation and the development of sensible and defensible strategies and actions. Furthermore, it will form a key element in any informational and educational initiatives aimed at encouraging community participation in source protection.*

A 5-year programme of work was initiated in 2013 to assist all GWSs with the identification, mapping and preliminary risk assessment of their source zones of contribution (ZOCs) and catchment areas as a first step in the development of scheme-specific source protection plans. Grant aid of 85%, up to a maximum of €2,550 per group water scheme (GWS), was made available through the Rural Water Programme. By the end of 2018, virtually all GWS source catchments had been mapped/delineated and the second phase of the NFGWS strategy had begun. This involves the completion of model source protection plans. When completed, these will inform the roll-out of source protection planning and its implementation on all group water schemes.

This framework document is a technical and scientific document written for professionals involved in developing source protection plans. An information document on source protection for GWS boards of management and staff will also be available from the NFGWS.

The aim of this framework is 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;

[1] National Source Protection Pilot Project 2005-2010 (DkIT) and Groundwater ZOC Pilot Project on GWS sources 2010-2012. The Groundwater ZOC Pilot Project was based on the resource and source protection principles given in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999).

- 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.

This drinking water source protection framework is intended to provide guidance as an aid in achieving safe and secure water supplies; it is not intended to be prescriptive. Therefore, the framework may be followed in a flexible manner that suits the particular circumstances of a source catchment.

2 Existing Water Resources Management Frameworks

2.1 Integrated Catchment Management

Integrated Catchment Management (ICM) is a generic approach (Figure 1) that provides the overarching framework for the implementation of the Water Framework Directive (WFD) and the philosophy for water management – achieving water body status objectives, drinking water protection and flood mitigation – and biodiversity protection in Ireland. The River Basin Management Plan 2018-2021 (DHCLG, 2018) states: *"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 the water ultimately running off to a single outlet) as the means to bring together all public bodies, communities and businesses."*

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 – and attempts to link with biodiversity, flood mitigation and reduction in greenhouse gas emissions.
- It provides for 'characterisation' of the catchment. This, in turn, assists in the identification of the causes and sources of pollution, critical source areas 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.
- 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 'new' vision of a healthy, resilient, productive and valued water resource that supports vibrant communities.

The scientific principles, philosophy and language of ICM enable a consistent approach to both drinking water source protection and protection or restoration, as applicable, of water bodies to satisfactory status, as required by the WFD. While the objectives of both are interrelated, there are also differences in the objectives, pollutants of concern (e.g. microbial pathogens are of greater concern to drinking water than to ecological status), and the threshold values for certain pollutants.

The GWS sector has always adopted a collaborative approach towards providing a water supply to its members. Co-operative in nature, GWSs are formed by people coming together to resolve a local issue (i.e. provision of a drinking water supply). This structure fits with the ICM approach and provides the opportunity and basis for successful implementation of source protection and management.

2.2 Drinking Water Safety Plans and the Multiple Barrier Approach

The provision of 'safe and secure' drinking water is the objective of a Drinking Water Safety Plan (DWSP) (EPA, 2011; WHO, 2016). This can be achieved by adopting 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 in order to reduce risks to public health. The components of the multiple barrier approach are as follows:

- **Assessment of untreated water quality at source.**
- **Delineation of the source catchment area/zone of contribution (ZOC).**
- **Characterising the catchment area/ZOC.**
- **Identifying and evaluating mitigation measures and actions.**
- Source infrastructure and site management (e.g. borehole design and installation).
- Public engagement.
- Drinking water treatment.
- Distribution system maintenance/upgrades.
- Assessment of treated water quality.
- Implementation of a management plan.
- Measuring progress and making adjustments.

All components of this multiple barrier approach are described and dealt with in the NFGWS Strategy for Source Protection on Group Water Schemes (2012) and the NFGWS Quality Assurance (HACCP) Scheme (2012b) (in which they are organised as 'critical control points'). A typical GWS source scenario is illustrated in Figure 2.

The framework outlined in this document considers the first four components above (in bold) – assessment of untreated water quality, source catchment delineation and characterisation, and associated mitigation measures and actions. It focusses on achieving outcomes that lessen the risk to human health, foster resilience and future proofing of water supplies, and reduce the cost of water treatment and over-reliance on end-of-pipe technological solutions to untreated water contamination.

The framework assists in complying with Article 7 the Water Framework Directive (WFD) (European Parliament and Council, 2000) which requires that the WFD should deal specifically with '*waters used for abstraction of drinking water*'. Article 7.3 states that "*Member States shall ensure the necessary protection for water bodies identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water. Member States may establish safeguard zones for those bodies of water."* Figure 3 illustrates the relative scope of and the compliance points for the WFD and the Drinking Water Directive (DWD).

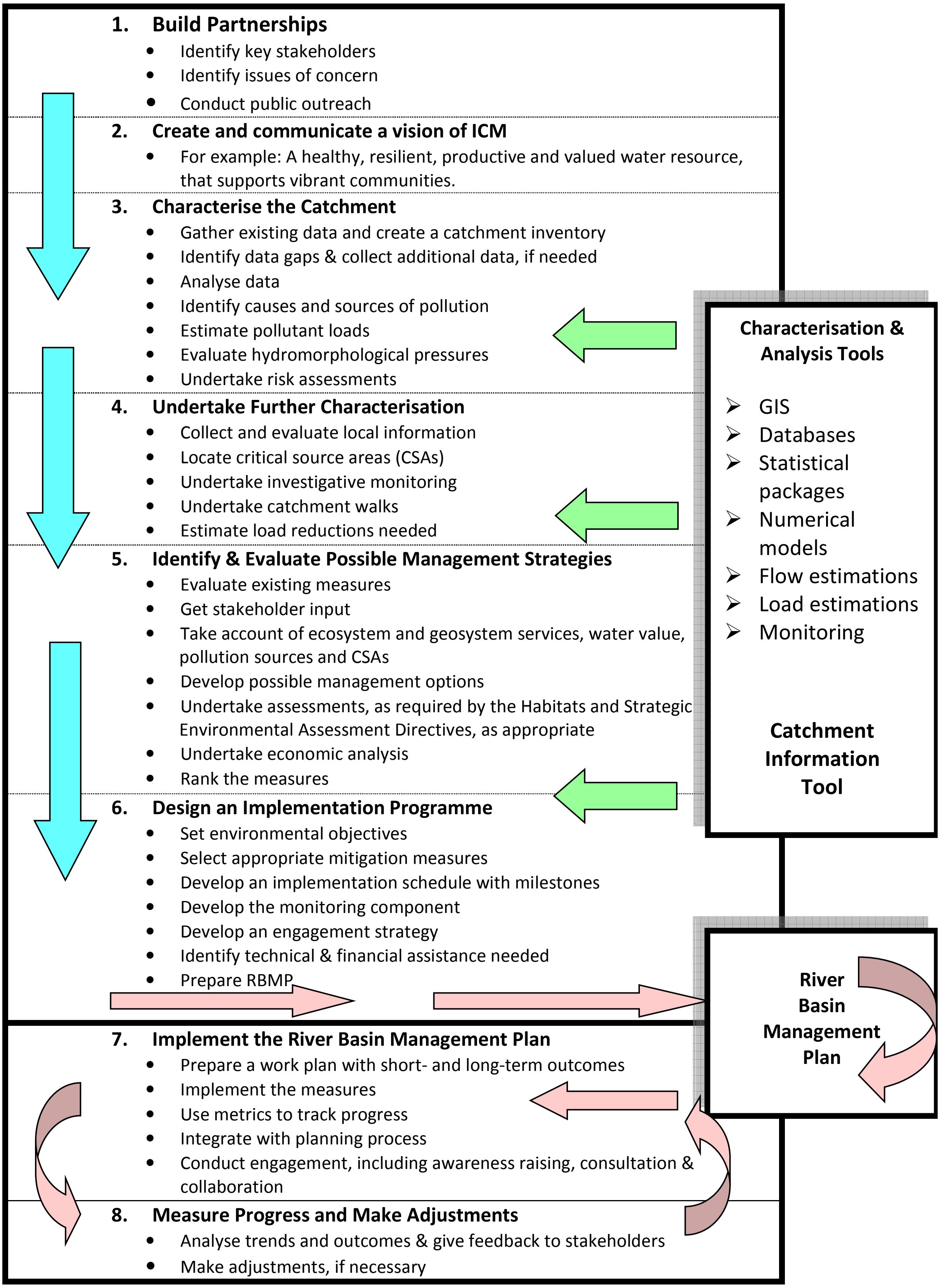


Figure 1: Steps in integrated catchment management process (Daly, et al. 2016)

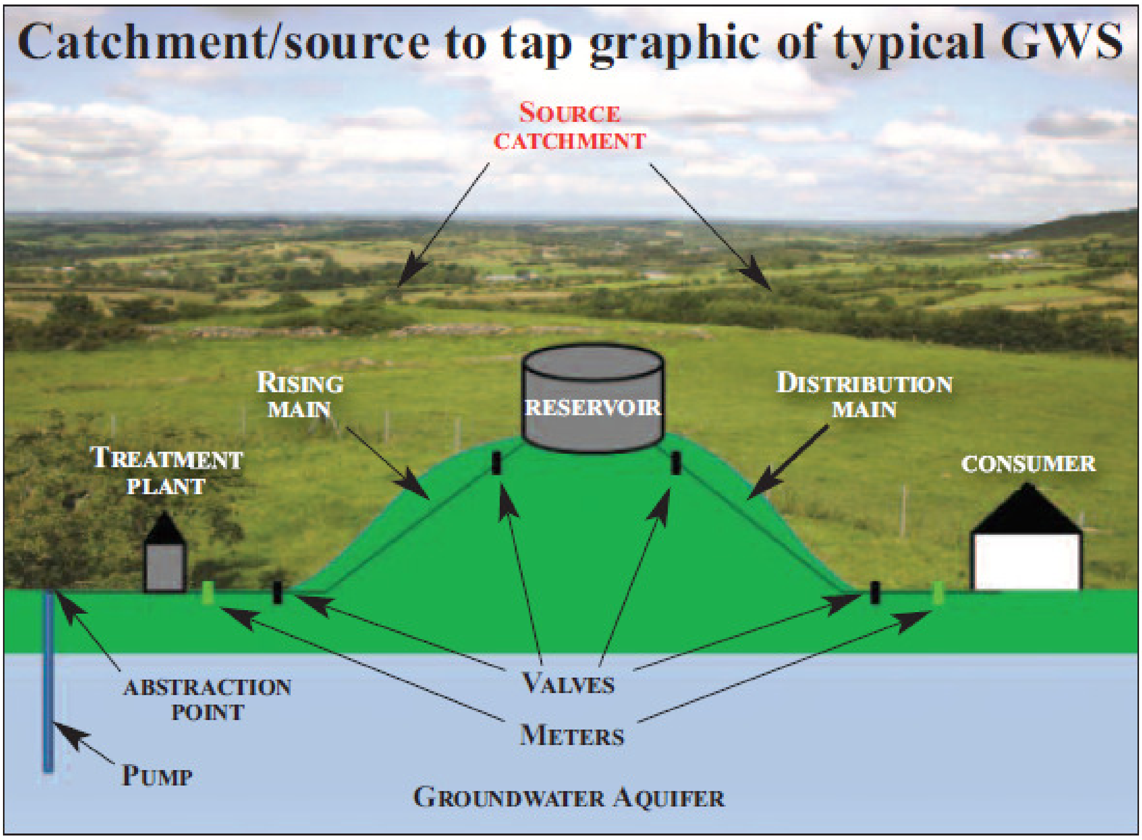


Figure 2: Illustration of the components of a typical GWS scenario (NFGWS, 2012b).

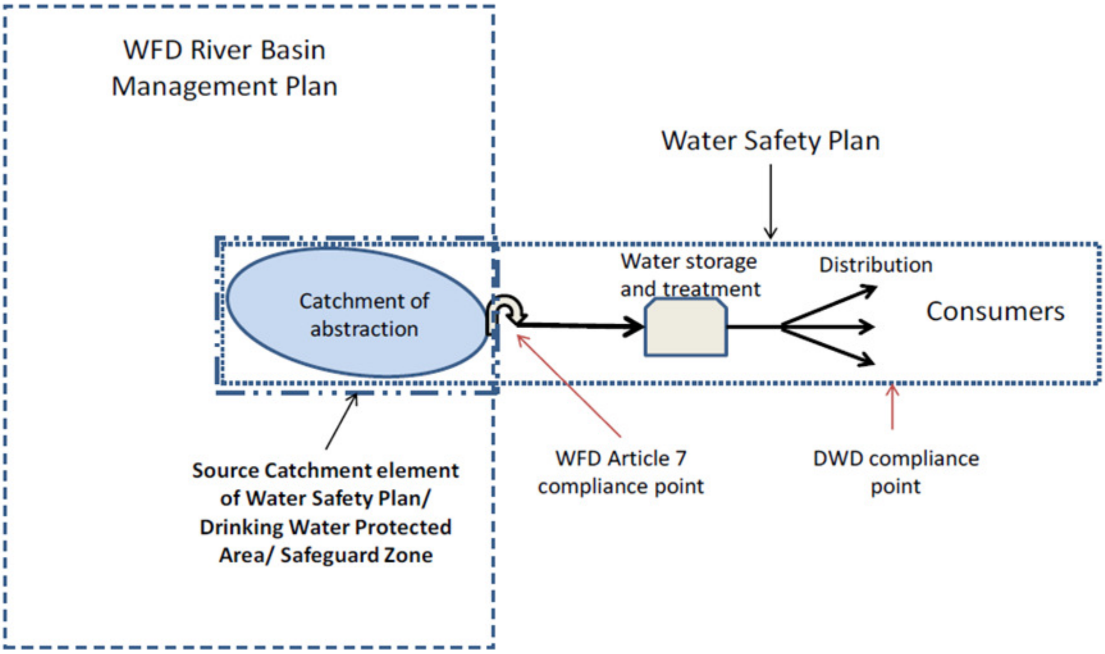


Figure 3: Illustration of the relative scope of the Water Framework Directive and the Drinking Water Directive (Ferretti et al., 2016.)

3 The Drinking Water Source Protection Framework

The framework consists of a number of steps and components. These vary depending on the quality of the untreated source water. The process is outlined in the flowchart in Figure 4 and is summarised below.

1. The first step is an assessment of the source water quality to determine if:
   - there are issues/contaminants that are capable of being addressed and need to be addressed in order to improve the GWS untreated water supply and/or as a means of improving the efficiency and consistency of treatment processes (e.g. by reducing seasonal algal growth caused by nutrients); or
   - water quality is satisfactory and, therefore, that an assessment of potential threats be undertaken, in addition to maintaining existing source protection measures and actions.

   Such an evaluation will inform the source protection objective – either improvement or protection/maintenance of untreated water quality. This is a critical decision, as it helps determine the subsequent work plan, the resources required to implement it and, in particular, the mitigation or protection strategies to be employed in the source catchment area.

2. Irrespective of whether the objective is improvement or protection/maintenance, the catchment area/zone of contribution needs to be known to answer the question: 'Where is my water coming from?'.

3. Initial characterisation (see Appendix 5), involving a desk-based compilation and evaluation of relevant information and maps for the catchment area/zone of contribution (ZOC)[2] of the source, is required. In circumstances where improvement of the 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/maintenance 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.

4. Arising from the initial characterisation, a summary that integrates all the information is needed as an interim 'story' of the situation both at the source itself and in the catchment area/ZOC of the source. This provides the basis for focussing further work including, in particular, the field-based further characterisation process. Additionally, some consideration can be given at this stage to either mitigation options or protection practices, as appropriate.

5. While initial characterisation is undertaken at subcatchment scale (approximately 1:25,000) generally, further characterisation involves field-scale collection and analysis of relevant data and information. Where improvement is the objective, the precise locations of point source significant pressures need to be ascertained. For diffuse sources, the precise location and extent of CSAs needs to be confirmed. Where protection/maintenance is the objective, there should be an assessment of potential risks and consideration given to the means of maintaining or improving water quality.

[2] In this document, the term 'catchment area' is used for surface drinking water sources, and 'zone of contribution (ZOC)' is used for groundwater sources.

6. Mitigation options and protection options need to be evaluated and those that are potentially most appropriate and most effective adopted.

7. Implementation, which is an evolving and iterative process, needs to be monitored, with adjustments made as necessary.

For many group water scheme sources, several of these components have already been completed and, therefore, a brief re-evaluation of available information will be sufficient. However, there is a deficit of data on untreated water quality on most groundwater sources, in particular, so that further sampling and analysis will be required before a definitive decision can be made as to whether the objective is improvement or protection/maintenance. The recommended parameters for analysis are given in Appendix 2.

3.1 Evaluation of Quality of Source Water

An evaluation of the water analyses is needed to assess the quality of the source water and to determine if it is satisfactory. Analysis of samples of potable water can be used for parameters not affected by particular treatment processes. [Historical treated water records collated by the EPA are available from the NFGWS]. Analysis of samples of untreated water is essential for assessing parameters affected by treatment. Operational water quality data for both treated and untreated waters, recorded by GWSs as part of their quality assurance implementation, should also be evaluated. In the case of both surface water and groundwater sources, data from nearby EPA monitoring points may also be accessed and assessed. It is advisable to plot the data and evaluate trends in parameters that pose, or will potentially pose, a threat to the supply. In addition, account should be taken of seasonal variations in raw water quality and of parametric variations caused by the abstraction regime (e.g. increased turbidity as a result of inappropriate pumping of a borehole).

Appendix 1 provides a list of ‘guide values’ that help determine whether an issue or contaminant in the source water needs to be dealt with by the implementation of mitigation measures and/or actions in the source catchment. If a water quality parameter in the untreated water has concentrations **higher than the guide value**, it is a potentially **significant issue** that may require mitigation to lower the concentrations. Whether or not specific mitigation would be appropriate will be assessed during the more detailed characterisation stage. If the parameter has concentrations **below the protection value**, then there are no pressures that need to be dealt with by specific mitigation measures and actions, although general protection practices need to be maintained. Trend analysis and extrapolation should be undertaken to determine if there is a likelihood that concentrations might exceed the guide value within a certain period (e.g. by 2027 for groundwater sources). The outcome would be an informed decision on whether protection/maintenance of the source will be sufficient (where the water quality condition is satisfactory/adequate, with parametric values below the guide values) or improvement is required (where water quality is unsatisfactory, parametric values being higher than the guide values). Where improvement is needed, the significant issue(s) and problematic contaminant(s) will drive much of the subsequent strategy since pollutant movement and the attenuation in the landscape is influenced by the characteristics of the pollutant. Mitigation strategies will need to take this into account.

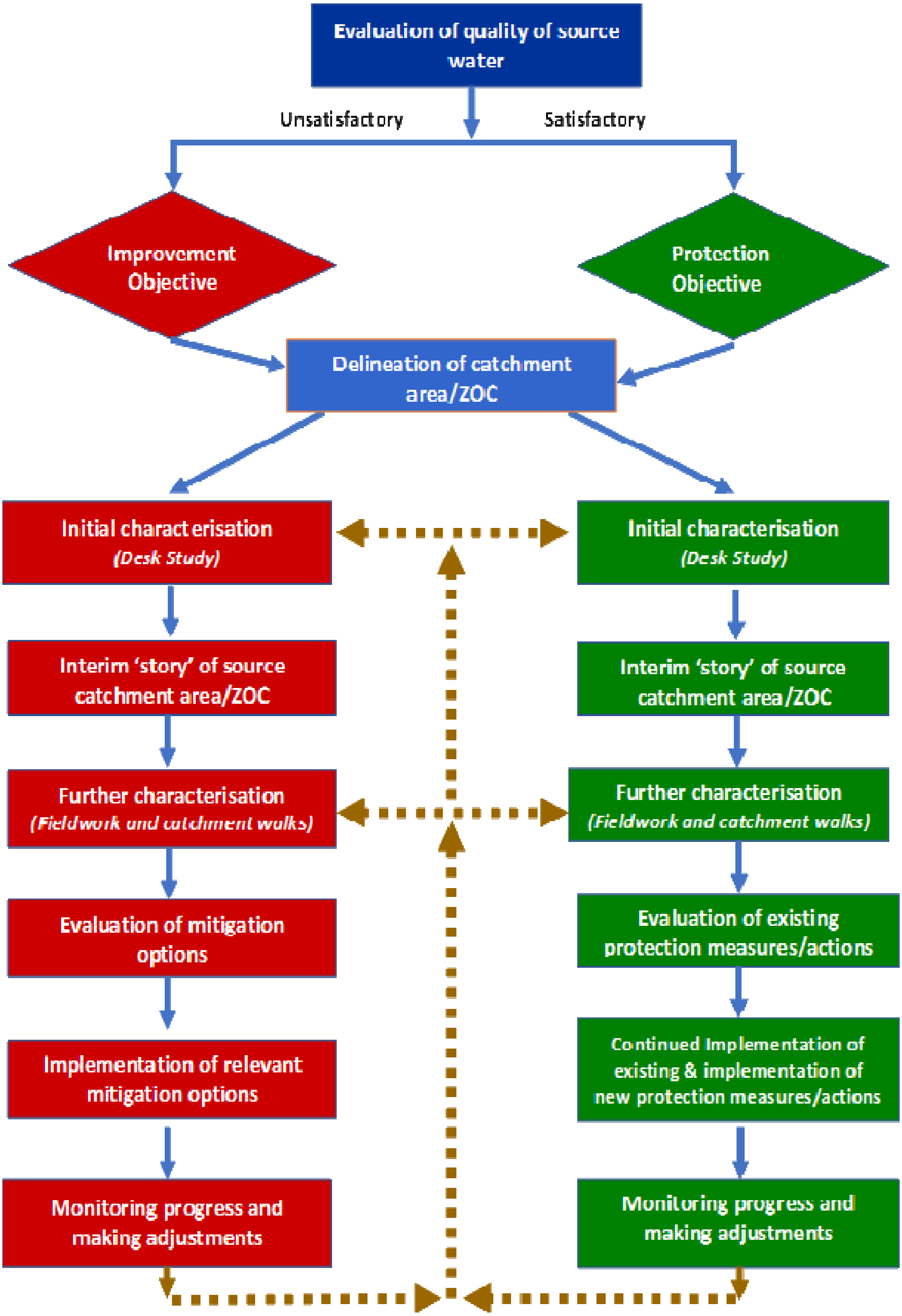


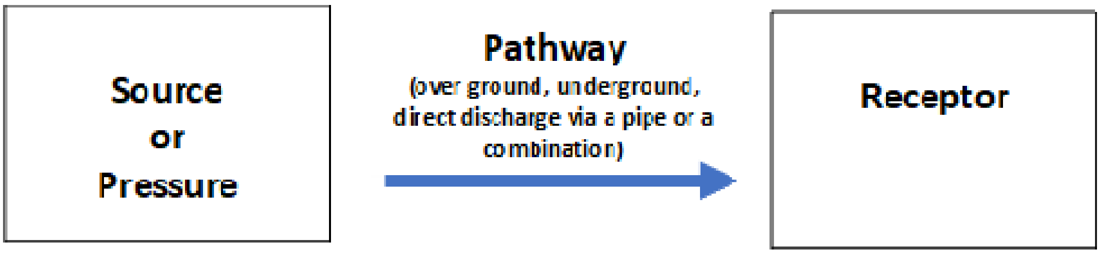
Figure 4: Summary of source protection framework

3.2 Delineation of the Catchment Area or Zone of Contribution (ZOC) of the Source

The boundaries of the area providing the water to the drinking water supply and, therefore, the area to be protected needs to be delineated. Information and advice on demarcating the catchment area of surface water sources is given in NFGWS (2012a). For large catchments upstream of a surface water source, delineation of sub-catchments is likely to be necessary. Information on zones of contribution of groundwater sources (including spring sources) - and the terminology used - is given in DELG (1999) and Hunter Williams *et al*. (2017).

3.3 Initial Characterisation of the Catchment Area or ZOC of the Source

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 (Figure 5), 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.



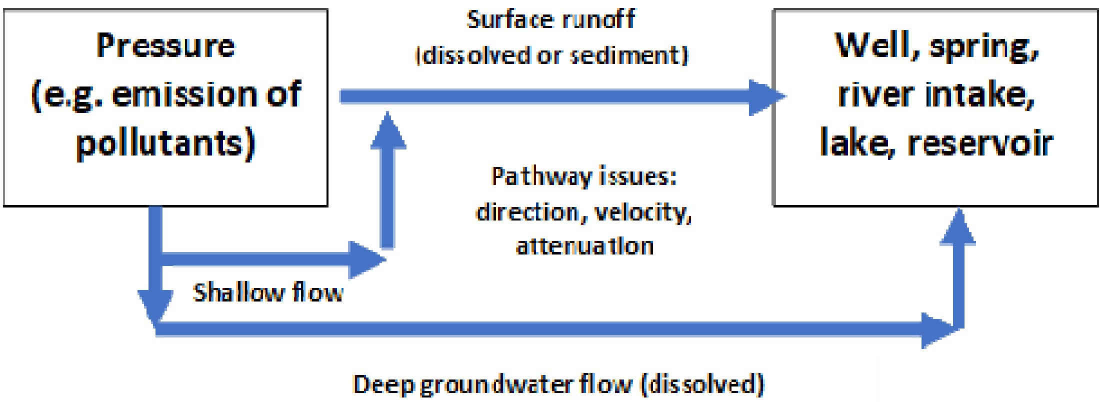


Figure 5: The source-pathway-receptor (SPR) model for environmental management.

Initial characterisation is a desk-based assessment, at sub-catchment scale (approximately 1:25,000), involving the compilation and analysis of relevant, readily available data, information and maps, together with a brief site visit and discussion with the group water scheme representative. It is the key to ensuring that subsequent work, particularly resource intensive fieldwork, is focussed, efficient and effective.

At this stage in the process, it will be known whether the objective is:

i) Improvement, where the water quality condition is unsatisfactory; or
ii) Protection, where the water quality condition is satisfactory.

Although not requiring any measures to be undertaken, it may be worthwhile noting and evaluating issues arising in the catchment that are a natural characteristic of the source water (e.g. metals, iron, manganese).

As part of characterisation, it is worthwhile considering the role of the abstraction itself as a means of ensuring that it sustainable both from yield and environmental (Including climate change) perspectives. Environmental flows (e-flows) / levels (e-levels) are the river flows and lake water levels required to support and maintain the ecology and function (e.g. for amenity use or to assimilate discharges) of rivers and lakes. Indirectly, groundwater levels should not be reduced in an unsustainable manner such that they induce poorer quality water to the aquifer or potentially reduce the baseflow to rivers and lakes. In essence, e-flows/e-levels comprise the water you want to leave in rivers, lakes and groundwater to ensure these waters do not degrade and can support a variety of other uses/purposes. Consequently, all abstractions, discharges and transfers in a catchment must be co-managed in an environmentally sustainable manner to ensure that e-flows/e-levels are maintained.

3.3.1 Catchments/ZOCs with an Improvement Objective

The key outcome of the evaluation of the untreated water quality is a conclusion on the significant issue/s or contaminant/s that have concentrations higher than the guide values and, therefore, need to be reduced by mitigation measures and actions. A number of questions need to be answered as part of both the 'initial' and 'further' characterisation processes:

1. What are the main pressures (or significant pressures) that are contributing to the significant issues? Are they emanating from a large point (e.g. a UWWTP), small point (e.g. farmyards, domestic wastewater treatment systems (DWWTSs), quarries) and/or diffuse pressures (e.g. pasture, tillage, forestry, run-off from urban areas)?
2. Where are they arising? For diffuse pressures (e.g. fertilizers in areas contributing nutrients, afforested areas contributing sediment), where are the likely critical source areas (CSAs)? Further information on CSAs is given in Appendix 3.
3. What are the main pathways along which the significant issue/s migrate/s to the source?
4. Is attenuation along those pathways likely to reduce the contaminant load entering the receptor, thereby reducing any negative impact?
5. What mitigation measures and actions are likely to be most effective?
6. Are there knowledge gaps that require investigation as part of the further characterisation process?

3.3.1.1 Pressure information

In a catchment area/ZOC of a drinking water source, there will generally be a wide range and a large number of pressures that could potentially pose a threat to the source. The key issue that requires answering is which pressure/s is/are 'significant' and require mitigation. The answer will ensure that resources are effectively targeted.

In some instances, 'significant' pressures may be obvious (e.g. where they originate from a large point source). However, where they originate from small point and/or diffuse sources, an integrated assessment of the following is needed:

1. Water quality.
2. Pressures in the source catchment/ZOC.
3. Analysis of pathways with a focus of identifying significant pressures and critical source areas.
4. An assessment of existing mitigation measures and actions.

A wide range of information on potential pressures in a source catchment/ZOC is readily available to assist such a desk study. Details are given in Appendix 5.

3.3.1.2 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 $(\mathrm{L_{rd-WB}})$ are calculated from annual averages as follows:

$\mathrm{L_{rd-WB}} = (\bar{\mathrm{C}} - \mathrm{GV}) * \bar{\mathrm{Q}} * K$

where,

$\bar{\mathrm{C}}$ = average concentration (mg l^{-1}) from source monitoring data.

GV = Guide value (mg l^{-1}).

$\bar{\mathrm{Q}}$ = mean streamflow ($m^3 s^{-1}$) 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.

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.

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.[3]

If nitrate is a significant issue in the groundwater source, a similar approach could be taken.

3.3.1.3 Pathway information and analysis

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 the drinking water source provides the basis for decisions on mitigation measures and actions. Therefore, a '**pathways conceptual model**' of the catchment area/ZOC is needed. 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 4.

The 'driver/s' for the pathways conceptual model is/are the identified 'significant' issues, 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. For instance, 1 kg P (present as phosphate) will pollute (i.e. bring the concentration above the Environmental Quality Standard (EQS) for rivers) 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 (545,520 gallons). One litre of MCPA will pollute (bring the concentration above the drinking water limit) 1,000,000,000 litres (220 million gallons) (Or equivalent to one drop in an Olympic-sized swimming pool).
- The pollutants have different attenuation capacities (i.e. different abilities to reduce as they move through the landscape). For instance, phosphate and MCPA are relatively immobile in soils and subsoils (although spray drift can also be an issue), and the relevant pathway is overland flow in poorly drained soils to nearby watercourses and ditches. 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.

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 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 the drinking water source, as the mitigation measures and actions must be located in these areas.

3.3.1.4 Locating critical source areas

The pathways conceptual model will give the details and locations of areas in which pathways are identified that are relevant to the migration of particular contaminants. This, in conjunction with the determination of the most 'significant' pressures and their location, provides the basis upon which CSAs may be determined. CSAs will be the focus of fieldwork and for the consideration of appropriate mitigation options. **The location and extent of CSAs will vary depending on the**

[3] Further information on this approach is available in Mockler *et al*. (2016) and in an internal EPA Catchment Science & Management Unit report (2016) "*Explanatory Document to Accompany the Catchment Assessments, including an Overview of the Catchment Assessment Methodology*".

'significant' issue being considered; for instance, if nitrate, ammonium and phosphate are 'significant' issues in a particular catchment, each of these contaminants would most likely require the identification of separate and distinct CSAs.

3.3.2 Catchments/ZOCs with a Protection Objective

In this situation, the concentrations in the untreated water are lower than the guide values and trend analysis has shown that exceedances are unlikely in the medium term. Therefore, continued protection is the core objective. A number of questions need to be answered as part of the initial and further characterisation processes:

1. Are there any indications in the water quality of issues or pollutants that potentially might be problematical in the future (e.g. chloride concentrations in groundwater as an indicator parameter)
2. Where are the susceptible areas for the pollutants that might be of concern (e.g. poorly draining areas where MCPA is used)?
3. Are the pressures in these areas properly managed (e.g. are containment measures in place in the event of a spillage from a facility in the vicinity of a stream or in a vulnerable area within the catchment area or zone of contribution of the drinking water source)?
4. Are existing protection activities being implemented adequately and are further protection activities needed (e.g. is there a need for greater public awareness of the source and its protection)?

For drinking water sources in this category, the general approach outlined in Section 3.3.1 can be followed. Further information on locating susceptible areas for pollutants such as phosphate, MCPA and nitrate is given in Appendix 3.

3.4 Interim 'Story' of the Source Catchment Area

This is a critical section in the desk study, as it summarises and integrates all of the information and then provides a basis for the work plan and for the consideration of possible mitigation options. It is based on an integration of all the relevant components of the **SPR** framework. If one of these components is missing, the continuum is broken. It is recommended that a three-dimensional 'mental model', aided by the pathways conceptual model, is developed as an ongoing process while the information/evidence is being collected and assessed in relation to 'significant' issues in the catchment area/ZOC, the 'significant' pressures and the main relevant pathways.

Outcomes required at this stage of the process, which need recording, include:

- identification of the 'significant' issue(s).
- deciding on the likely 'significant' pressure(s).
- locating large point sources where they are considered to be 'significant' pressures.
- a summary pathways conceptual model.
- determining the likely CSAs for diffuse and small point sources.
- an evaluation of data gaps (e.g. water quality data, borehole efficiency, aquifer properties).
- a detailed work plan based on the conclusions in the Interim 'Story', with sufficient information to inform an estimation of the time and resources that will be required to undertake the Further Characterisation process/fieldwork.

3.5 Further Characterisation of the Source Catchment Area

Field or street scale assessments, involving fieldwork and catchment walks, are an essential component of the source protection framework. They should focus on the issues, pressures and CSAs provided by the interim 'story', as well as on data gaps. For boreholes, it may be necessary to undertake pumping tests to assist in the delineation of the boundaries of the ZOC and the Inner Protection Area (see Appendix 7 for further details). For larger surface water catchments, a focus on sub-catchments may be necessary. For both groundwater and surface water sources, further sampling and analysis of untreated water may be needed.

The work required and the resources needed for sources with an improvement objective will generally be greater than for sources with a protection objective.

3.5.1 Catchments/ZOCs with an Improvement Objective

The purpose is primarily to:

1. Collect relevant field information to understand the impact of large point significant pressures, if present.
2. Visit and confirm or amend the boundaries of the CSAs for diffuse significant issue(s) and pressure(s), if present.
3. Locate small point sources that are causing a threat to the drinking water source.
4. Fill in information gaps on the significant issues and significant pressures (e.g. noting the presence of riparian buffer zones or the absence of a 2 m uncultivated zone alongside streams in tillage areas, and by undertaking additional investigations, such as pumping tests, water sampling, Small Stream Impact Scores etc.).

This information then becomes the basis for considering mitigation options. It is advisable to consider possible mitigation options during the field visit.

Abstraction infrastructure should be evaluated to ensure that there are no failings that could pose a threat to the source. For example, borehole design and construction should be examined. Site management should also be assessed (e.g. to identify the storage of potentially polluting liquids). The NFGWS Quality Assurance system implementation manual (NFGWS 2012b) provides a range of other hazards that may arise at the abstraction critical control point.

3.5.2 Catchments/ZOCs with a Protection Objective

The purpose is primarily to:

1. Fill in information gaps arising from the initial characterisation process.
2. Visit and check the pressures that are located in susceptible or vulnerable areas as they might be a future hazard.
3. Assess Quality Assurance records in relation to critical control points 1 and 2.

In addition, infrastructure and site management at the source should be checked.

3.6 Mitigation and Protection Strategies

3.6.1 Introduction

One of the main objectives of the catchment component of source protection is to specify proposals or decisions, depending on the circumstances, on the protection strategies that are needed to protect drinking water sources. Sources with satisfactory water quality will still require protection strategies, while unsatisfactory situations present in some sources will require more robust mitigation strategies as a means of ensuring effective achievement of safe and secure water supplies. Therefore, reviewing, analysing, proposing and undertaking protection and mitigation activities are an essential component of source protection. **A key goal is to ensure that decisions are targeted to achieving the required objectives, and therefore are efficient and effective in terms of water quality outcomes, resources required including staffing and costs, and acceptability among stakeholders.**

3.6.2 Selection of management practices

Once the characterisation process has been undertaken, management strategies and practices can be assessed as a means of achieving the source objectives. The recommended approach to considering management practices are summarised in the steps in Table 1.

Table 1: Recommended steps in selection of management practices.

1	Undertake a brief inventory of existing management efforts, including quality assurance implementation.	
2	Evaluate their effectiveness.	
	Where the objective is Improvement	***Where the objective is Protection***
3	Note 'significant' issues and 'significant' pressures.	Check if there are point or diffuse pressures in susceptible areas that have the potential to pose a future threat to source water quality.
4	Take account of whether they are point source and/or diffuse source pressures.	Evaluate whether or not existing measures and actions are adequate and if consideration should be given to checking that the measures are being undertaken satisfactorily and/or whether some additional actions are needed.
5	If feasible, undertake an analysis of the pollutant reduction that is required.	Where additional actions would be beneficial, identify them and evaluate for cost, acceptability and achievability.
6	Identify the measures and actions that have the potential to achieve the objectives for the particular issues and pressures in question.	Consult with relevant public bodies (e.g. planning authorities).
7	Evaluate the likely effectiveness of these measures and actions in terms of, for instance, pollutant reduction and usage in the relevant critical source areas.	Select those additional actions that are recommended to be undertaken. Consider giving priority to those that have more than one environmental benefit.
8	Assess their cost, if feasible, and do a comparison between options.	-
9	Consult with relevant public bodies (e.g. planning authorities).	-
10	Assess whether they are likely to be acceptable and assess the constraints.	-
11	Note any co-benefits, and consider giving preference to those with more than one benefit.	-
12	Decide on the preferred mitigation measures and recommended voluntary actions, and in the process, take account of the regulatory nature of the 'measures' and the voluntary nature of the 'actions'.	-

3.6.3 Attaining multiple benefits

There are several drivers for a better environment that relate to drinking water source management including biodiversity, greenhouse gas emission reductions and flood mitigation. Many of the measures and actions undertaken in source catchments benefit these themes. These additional benefits emphasise the connectedness of nature and are, therefore, a means of delivering genuine environmental and economic sustainability for communities. Also, additional benefits are 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. In addition, by placing some emphasis on co-benefits, it encourages relevant disciplines and organisations to collaborate in the pursuit of mutually beneficial objectives.

3.6.4 Point Source Pressures

The key management practices are aimed at either treating and reducing the pollutants discharged from licensed sources, such as wastewater treatment plants, or preventing ingress of pollutants from small point sources, such as domestic wastewater treatment systems, farmyards and misconnections in urban areas.

Appendix 5 provides information and web links to both descriptions of the pressures as well as possible mitigation options for the following: domestic wastewater treatment systems; urban wastewater treatment pressures; diffuse and small point sources urban pressures; quarries and industrial discharge pressures. Mitigation options for point sources arising from agricultural activities are given in Appendix 6.

3.6.5 Diffuse Source Pressures

Diffuse sources identified as significant pressures, such as pasture, tillage, forestry and urban/town areas, are challenging to deal with, as the CSAs for these sources are more difficult to locate in the landscape than point sources. Their CSAs may cover a wide area and the mitigation options being implemented will have varying levels of effectiveness (depending on factors such as local topography). Securing the acceptance of measures by individuals across the larger CSA will inevitably be more difficult to achieve.

The 'pollutant transfer continuum', shown in Figure 6 and Figure 7, is a landscape-based framework for considering diffuse (non-point) contamination. It consists of four components:

- The presence of a pressure or source with an associated load of potential pollutants, such as organic and inorganic fertiliser applications, faeces and urine from grazing animals and high concentrations of P in poorly draining soils.
- Mobilisation, whereby a potential pollutant – such as ammonia or MCPA – becomes soluble or attaches to soil particles and starts the journey from the soil to a receptor, such as a stream or borehole.
- Delivery/transport along the pathways, underground or over ground to a drinking water source.
- Impact in terms of pollutant concentrations in untreated water.

Therefore, it is recommended that mitigation options (measures and actions) be considered according to the point in the source-pathway-receptor continuum on which they take effect. This allows management strategies and mitigation measures/actions designed to deal with relevant pollutants to be 'followed' conceptually from application to impact and provides clarity on what role a particular measure has[4]. 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

[4] This is similar to what has been called the 'treatment train approach' by practitioners dealing with stormwater management.

v) treatment (as part of the multi-barrier approach).

In considering which point along the continuum would be most effective, account needs to be taken of the properties of the issue/pollutant of concern. For instance, if nitrate is the issue of concern – and as it is highly mobile in freely draining soils and travels vertically from the soil into groundwater – source reduction and mobilisation control actions will have to be considered. By contrast, if phosphate is the issue – while source and mobilisation control measures (such as nutrient management planning) are beneficial – pathway interception measures are essential. For MCPA, both source reduction and pathway interception are needed. Therefore, careful analysis of the mitigation and protection options is essential if the effort undertaken is to be effective and justifiable.

There is a wide range of possible mitigation and protection options. These can be subdivided into:

i) Regulatory measures (e.g. Good Agricultural Practices Regulations, Sustainable Use of Pesticides Regulations and the Code of Practice for domestic wastewater treatment systems (EPA, 2009); and
ii) Additional/supplementary actions (e.g. agroforestry riparian buffers).

This distinction is relevant as regulatory measures are obligatory, while mitigation/protection actions are voluntary and may be incentivised.

Details and links to information on possible mitigation and protection options for forestry and peatland activities are given in Appendix 5. A summary of mitigation options for agricultural activities is given in Appendix 6.

3.7 Implementing Mitigation and Protection Strategies

At this stage, the recommended drinking water source management measures and actions are known. Now a focussed implementation programme needs to be designed and delivered (USEPA, 2018). This could involve some or all of the following:

- An information/education/communication component to support public participation.
- 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.
- Input from scientific and technical staff, such as catchment, water and agricultural scientists.
- An implementation plan with a schedule of works to be undertaken.
- 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.

3.8 Monitoring Progress and Making Adjustments

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:

- Sampling and analysis of untreated water samples at intervals based on the understanding provided by the characterisation process.
- Evaluation, including trend analysis, of the monitoring data.
- Tracking of the execution of the measures and actions.
- Learning lessons as part of an evolving and iterative process.

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.

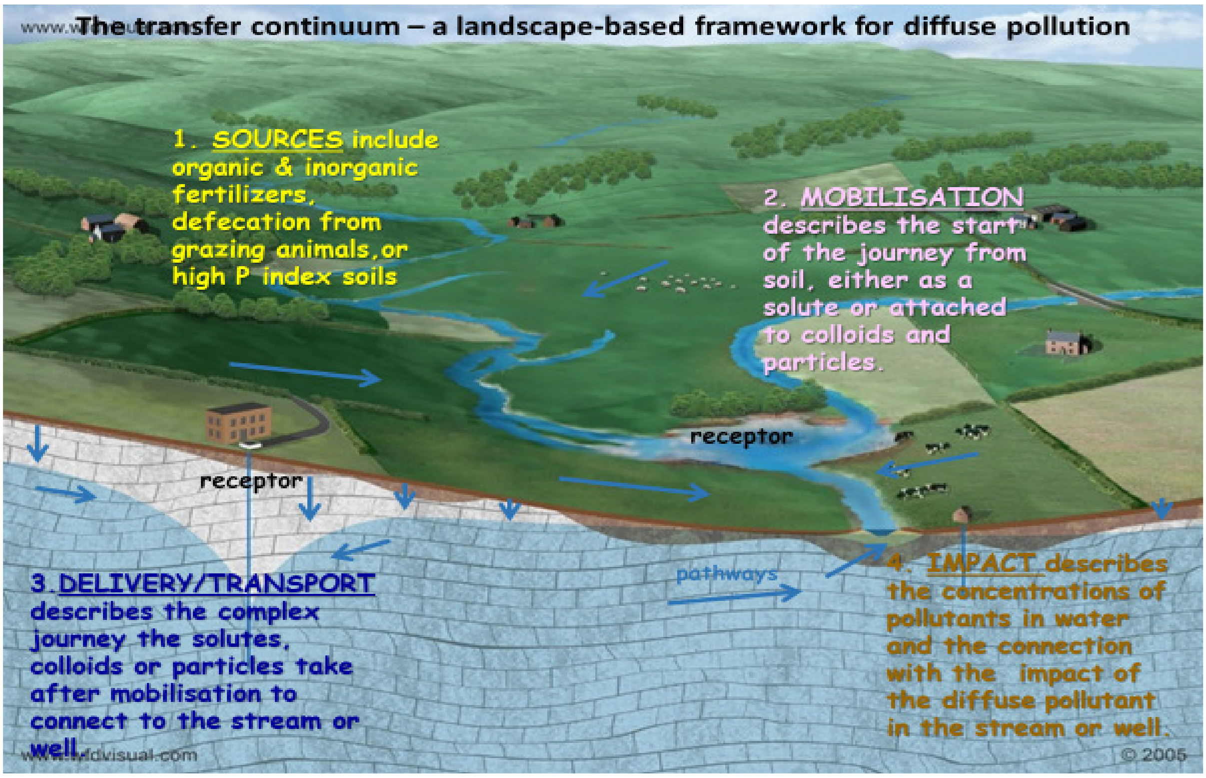


Figure 6: Representation of the pollutant transfer continuum

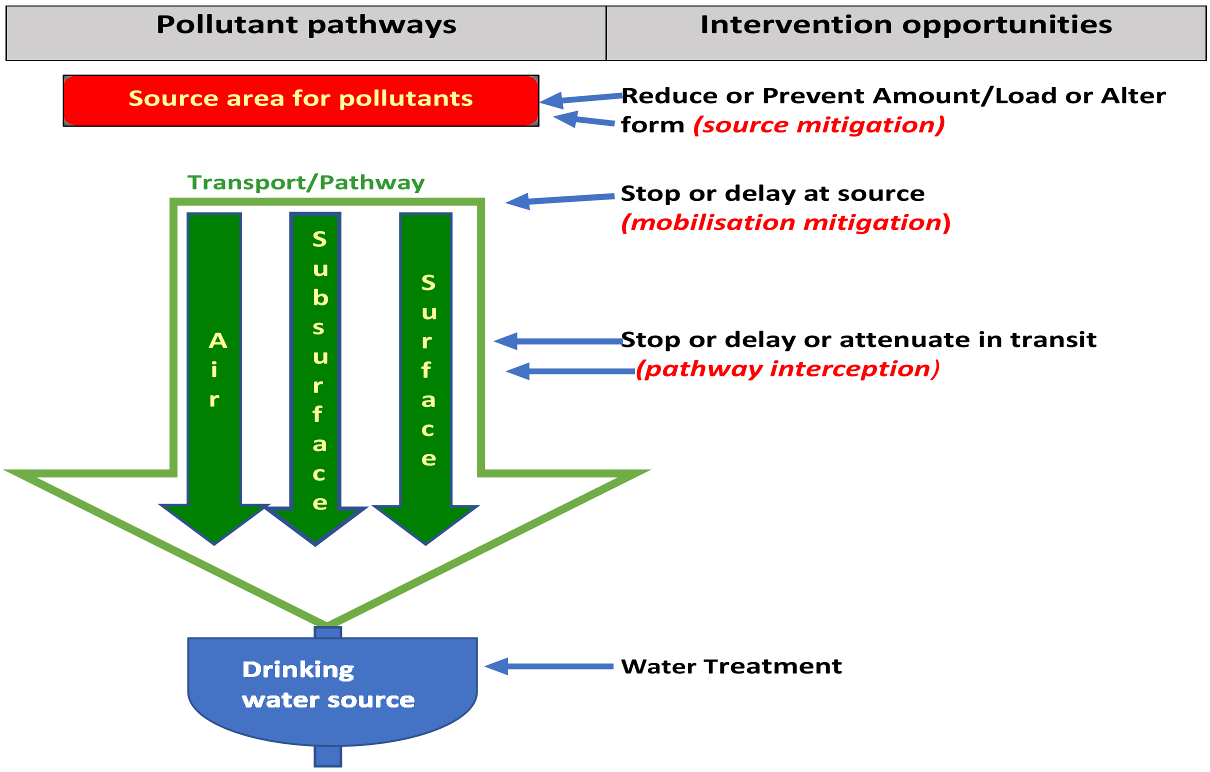


Figure 7: Factors and considerations for CSA delineation and selection of mitigation options (adapted from USEPA, 2018.

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Appendix 1: Untreated Water Guide Values for Main Potential Significant Issues

There are a wide variety of potential issues (or hazards or pollutants) in the catchment areas of drinking water sources posing either a threat to human health or causing water treatment difficulties: these are microbial pathogens such as *E.Coli* and *Cryptospiridium*, nitrate, ammonia, phosphate, BOD, turbidity, MCPA, other pesticides, trace organics such as PAHs, TOC, colour. They differ in terms of:

i) the degree of threat to human health (e.g. *Cryptospiridium* is more significant than phosphate);
ii) the degree and type of water treatment needed for certain issues at the treatment plant;
iii) the pressure from which the issue arises (e.g. farming, domestic wastewater treatment systems (DWWTSs), urban wastewater treatment plants, etc.); and
iv) the properties of the pollutant in terms of movement and attenuation in the landscape (e.g. microbial pathogens are readily attenuated in free-draining subsoil in contrast to nitrate which is mobile and not attenuated).

For source protection to be focussed and cost-effective, these differences need to be taken into account in an explicit manner. In addition, rather than have a general objective of 'protecting' the source, a more specific objective of an untreated groundwater and surface water management value (called 'guide value') for each potential significant issue in the source water provides a metric and target that protection can endeavour to achieve[5]. This value can be used to help determine whether the issue is significant and therefore needs dealing with by specific catchment-based mitigation measures and actions. In determining a 'guide value' that is effective and useful, account needs to be taken of both the practical achievability and the role of water treatment, as well as the drinking water standards; it is this aspect that distinguishes protection of drinking water sources from protection of water bodies for river basin management and WFD implementation purposes.

Each of the significant issues are considered below in terms of the main pressure(s) contributing them, their properties from the perspective of movement and attenuation[6] in the landscape as these are relevant to the practicality of achieving reduction of the risk posed, the drinking water standard and the guide values that are the target for source protection. In particular sources, other issues may be arising which are not considered here. Also, some of the guide values used for any particular drinking water source may need to be varied depending on the site specific conditions that have been assessed during the characterisation process.

For additional information, the GWS guide to the drinking water parameters is recommended (NFGWS, 2011) and also the Irish Water website at this link: https://www.water.ie/water-supply/water-quality/parameters/.

[5] This mirrors the WFD implementation approach where there are either environmental quality standards or threshold values for pollutants, which are used as a target that need to be reached from the WFD management strategies and measures. While the drinking water guide value might be the same as the WFD values, this will not be the case in all circumstances. For instance, the nitrate concentration needed to protect surface water ecosystems will be lower than the drinking water guide concentration.

[6] There are three main pathways for water movement – surface runoff as overland flow or near surface flow and groundwater flow. Pollutants have different attenuation capacities along these pathways, and this influences the likelihood of the pollutant reaching the water source, and the type and capacity of measures and actions needed to mitigate impacts.

E. Coli

Main pressure: Warm blooded animals such as wildlife and farm animals, domestic wastewater treatment systems, urban wastewater treatment plants.

Pathway and attenuation properties: *E. coli* move readily in water as particles along overland and near-surface pathways where limited (only) attenuation occurs from predation and die-off. Attenuation occurs in soils and subsoils due to filtration, die-off and predation, and *E. coli* are generally only present in groundwater/aquifers where the vulnerability is 'extreme'. Therefore, groundwater usually has substantially lower numbers than surface water.

Drinking water standard: 0

Groundwater guide value: 100/100 ml

Surface water guide value & groundwater spring guide value: 1,000/100 ml or whatever is deemed appropriate for the site-specific circumstances of the source water.

Explanation: Prevention of access of microbial pathogens to surface water is not feasible. However, the numbers entering water can be reduced by mitigation measures and actions, thereby reducing the numbers and the threat to human health. Prevention of access of microbial pathogens to groundwater in areas of extreme vulnerability is also not feasible, although sources in other areas with thicker subsoils are usually free of microbial pathogens. The guide values given are considered to be practical and achievable targets for the source protection process.

Nitrate

Main pressures: Inorganic and organic fertilizers, and wastewater discharges.

Pathway and attenuation properties: The main pathway is via groundwater in situations where the soils/subsoils are permeable and where attenuation is generally limited.

Drinking water standard: 50 mg/l NO_3 as a Maximum Admissible Concentration (MAC).

Groundwater guide value: 28 mg/l NO_3 as an (annual arithmetic) mean value.

Surface water guide value: 28 mg/l NO_3 as a mean value.

Explanation: 37.5 mg/l is the Threshold Value in the Groundwater Regulations intended to prevent exceedances of the MAC. The 28 mg/l value is 75% of the Groundwater Threshold Value (TV) (37.5 mg/l as a mean value) and is used by the EPA as a target to reduce the likelihood of exceeding the TV.

Ammonium

Main pressures: Organic sources from sewage, animal slurry, farmyard soiled water, wastewater, leachate and drained peatlands.

Pathway and attenuation properties: Ammonium has low mobility and is attenuated in soil and subsoil. Therefore, the main pathways are overland and near-surface drainage. However, it readily converts to nitrate over short distances and therefore tends to indicate a nearby pressure. An exception to this is in poorly draining areas when landspreading of manure/slurry takes place immediately prior to heavy rainfall, resulting in overland flow and high ammonium concentrations for considerable distances downstream.

Drinking water standard: 0.3 mg/l NH_4 (or 0.23 mg/l N) as a Maximum Admissible Concentration (MAC).

Groundwater guide value: 0.175 N[7] as a mean value (or 75% of the drinking water standard).

Surface water guide value: 0.175 N as a mean value.

Explanation: Ammonium in itself is not a health risk but is classed as an indicator parameter of possible bacterial, sewage and animal waste pollution (EPA, 2015).

[7] In the drinking water standard, the value is quoted as NH_4 whereas in both the Groundwater and Surface Water Regulations values are given as N. The conversion factor from NH_4 to N is 0.778.

Phosphate
Main pressures: Agricultural activities and wastewater discharges.
Pathway and attenuation properties: Phosphate[8] is relative immobile and is attenuated in mineral soils and subsoils, but is mobile in organic soils and bedrock. Therefore, the main pathways are overland and near-surface. However, phosphate can enter groundwater in areas of outcrop and shallow bedrock and in sinking streams, and can then be transported to surface water bodies.
Drinking water standard: No standard.
Groundwater guide value: 0.035 mg/l P as a mean value.
Surface water guide value: 0.035 mg/l P as a mean value.
Explanation: Phosphate in itself is not a health risk but is classed as an indicator parameter of possible algae growth leading to taste, odour and treatment operational issues. Therefore, the value taken is the Good status EQS in the Surface Water Regulations (2009).

Total Phosphorus
Main pressures: Agricultural activities, wastewater discharges and sediment.
Pathway and attenuation properties: Phosphate is relative immobile and is attenuated in mineral soils and subsoils. Therefore, the main pathways are overland and near-surface.
Drinking water standard: No standard.
Lake & reservoir guide value: 0.025 mg/l P as a mean value.
Explanation: Phosphorus in itself is not a health risk but is classed as an indicator parameter of possible algae growth leading to taste, odour and treatment operational issues. While not an EQS, the value taken is used by the EPA Ecological Monitoring and Assessment in lake status assessments as the minimum value needed to support Good status.

Colour
Main pressures: Drainage of peatlands mainly, but also from soils and decaying vegetable matter. The resulting aerobic decomposition causes mineralisation of carbon, nitrogen, sulphur and phosphorus, and production of humic and fluvic acids. The colour is caused by Dissolved Organic Carbon (DOC). Therefore, high water colour levels are associated with peatland drainage either from peat extraction, forestry planting or agricultural activities.
Pathway and attenuation properties: The main pathways are in water discharging from the peatland areas, either as overland flow, groundwater flow in the peat and, particularly in the case of blanket bogs, groundwater from beneath the peat. The main attenuation process is the presence of saturated conditions achieved by maintaining high water levels by measures such as drain blocking and dams.
Drinking water standard: No standard: Regulations state "Acceptable to consumers and no abnormal change". The EC (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989 (DoE, 1989) recommends a standard of 20 mg/l Pt/Co for A1 waters (simple physical treatment and disinfection undertaken), 100 mg/l for A2 Waters (normal physical & chemical treatment & disinfection undertaken) and 150 for A3 Waters (intensive physical and chemical treatment, extended treatment and disinfection undertaken).
Groundwater guide value: 20 mg/l Pt/Co [mg/l Hazen] as a maximum concentration.
Surface water (river) guide value: 100 mg/l Pt/Co [mg/l Hazen] as a maximum concentration or whatever is deemed appropriate for the site-specific circumstances of the source water. *(Note: This value will be re-evaluated as more data on colour become available and a greater understanding is developed.)*
Explanation: Colour in untreated water reflects the presence of organic molecules originating from humic matter such as peat. Colour does not pose a high health risk in itself, but can react with chlorine used during the treatment process in the treatment plant to form trihalomethanes, which

[8] Known as either Molybdate Reactive Phosphorus or ortho-phosphate (PO_4).

are a potential threat to human health. In addition, high colour levels add significantly to the cost of treatment.

MCPA

Main pressures: Spraying of rushes and thistles, roadside verges, household gardens, sports grounds, golf courses, etc.

Pathway and attenuation properties: MCPA is relative immobile and is attenuated in free-draining mineral soils and subsoils, but is mobile in bedrock. Therefore, the main pathways are overland and near-surface, point discharges resulting from poor practices, and also aerial via spray drift. However, MCPA in sinking streams in karst aquifers can then be transported to spring drinking water source and surface water bodies.

Drinking water standard: 0.1 µg/l.

Groundwater guide value: 0.075 µg/l as a mean value.

Surface water guide value: 0.075 µg/l as a mean value.

Explanation: The 0.075 µg/l value represents 75% of the Drinking Water Parametric Value and has been adopted as a target to reduce the likelihood of exceeding 0.1 µg/l. The lower guide value is intended to reduce the likelihood that the drinking water standard would be breached. These guide values will also apply to other individual pesticides, for example, clopyralid which is commonly used in thistle treatment and triclopyr commonly used in dock treatment.

Total Pesticides

Main pressures: Spraying of agricultural weeds (as other pesticides will target nettle, ragwort, dock, etc) roadside verges, household gardens, sports grounds, golf courses, etc.

Pathway and attenuation properties: pesticides are relative immobile and are attenuated in free-draining mineral soils and subsoils, but are mobile in bedrock. Therefore, the main pathways are overland and near-surface, point discharges resulting from poor practices, and also aerial via spray drift. However, pesticides in sinking streams in karst aquifers can then be transported to spring drinking water source and surface water bodies.

Drinking water standard: 0.5 µg/l.

Groundwater protection value: 0.375 µg/l as a mean value.

Surface water protection value: 0.375 µg/l as a mean value.

Explanation: The 0.375 µg/l value represents 75% of the Drinking Water Parametric Value and has been adopted as a target to reduce the likelihood of exceeding 0.5 µg/l.

Polycyclic Aromatic Hydrocarbons (PAH)

Main pressures: Fuel spills from domestic heating systems, fuel storage tanks on industrial sites/commercial premises.

Pathway and attenuation properties: PAH is mobile in free-draining mineral soils and subsoils and bedrock. The main pathways are overland and near-surface, point discharges resulting from poor practices. However, PAH in sinking streams in karst aquifers can then be transported to spring drinking water source and surface water bodies.

Drinking water standard: 0.1 µg/l.

Groundwater protection value: 0.075 µg/l as a mean value.

Surface water protection value: 0.075 µg/l as a mean value.

Explanation: PAH poses a significant health risk if consumed. If elevated levels are detected in drinking water, a “do not use” notice is likely to be issued by the HSE.

Benzo(a)pyrene

Main pressures: Fuel spills from domestic heating systems, fuel storage tanks on industrial sites/commercial premises

Pathway and attenuation properties: Benzo(a)pyrene is a PAH and is mobile in free-draining mineral soils and subsoils and bedrock. The main pathways are overland and near-surface, point discharges resulting from poor practices. However, PAH in sinking streams in karst aquifers can then be transported to spring drinking water source and surface water bodies

Drinking water standard: 0.01 µg/l.

Groundwater protection value: 0.0075 µg/l as a mean value.

Surface water protection value: 0.0075 µg/l as a mean value.

Explanation: Benzo(a)pyrene is a known carcinogen and its undesirability in drinking water is emphasised by its inclusion as an individual parameter, separate from other PAHs. It has a lower drinking water Parametric Value when compared with other PAHs/total PAHs and therefore needs to be assessed individually.

Appendix 2: List of parameters for analysis of untreated drinking water

Groundwater Sources

Field Analysis

pH; Dissolved Oxygen; Temperature; Specific Conductivity (at 25°C).

Microbiological Analysis

Total Coliforms; Faecal Coliforms (E-Coli); Enterococci; Clostridium perfringens[9].

Laboratory Chemical Analysis

Essential suite:

Conductivity (at 25°C); pH; Turbidity; Colour; Calcium; Magnesium; Sodium; Potassium; Alkalinity; Total Hardness; Chloride; Sulphate; Nitrate; Ammonia; Nitrite; Iron; Manganese; Total Organic Carbon.

Additional suite:

Total Phosphorus; Molybdate Reactive Phosphorus; Cadmium; Arsenic; Zinc; Mercury; Silica; Lead; Copper; Boron; Aluminium; Nickel; Chromium; Fluoride; Barium; Molybdenum; Silver; Cobalt; Strontium; Beryllium; Antimony; Uranium, PAHs, pesticides, other organic pollutants where risk is indicated during the characterization process.

Surface Water Sources

Field Analysis

pH; Dissolved Oxygen; Temperature; Specific Conductivity (at 25°C).

Microbiological Analysis

Total Coliforms; Fecal Coliforms (E. coli); Enterococci; Clostridium perfringens.

Laboratory Chemical Analysis

Essential suite:

Turbidity; Colour; TOC; Alkalinity; Molybdate Reactive Phosphorus; Total Phosphorus; Nitrate; Nitrite; Ammonia; Ammonium; Chloride; Sulphate; Iron, Manganese; Chlorophyll a.

Additional suite:

Cadmium; Arsenic; Zinc; Mercury; Silica; Lead; Copper; Boron; Aluminium; Nickel; Chromium; Fluoride; Barium; Molybdenum; Silver; Cobalt; Strontium; Beryllium; Antimony; Uranium, PAHs, pesticides, other organic pollutants where risk is indicated during the characterization process.

[9] Used as an indicator parameter for Cryptosporidium.

Appendix 3: Critical Source Areas

Critical sources areas are areas that deliver a disproportionally high amount 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. Critical source areas are located by combining the nutrient loadings (phosphorus and nitrogen) applied to the land surface with the hydro(geo)logical susceptibility of the water body to these nutrients (Figure A1). 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*".

High hydro(geo)logically susceptible areas are areas from which nutrients, if present or applied, have a high probability of reaching a water body of interest due to the underlying hydrogeological conditions and pathways (i.e. the areas that have significant pathway linkages from the source of pollution or pressure to surface water or groundwater receptors).

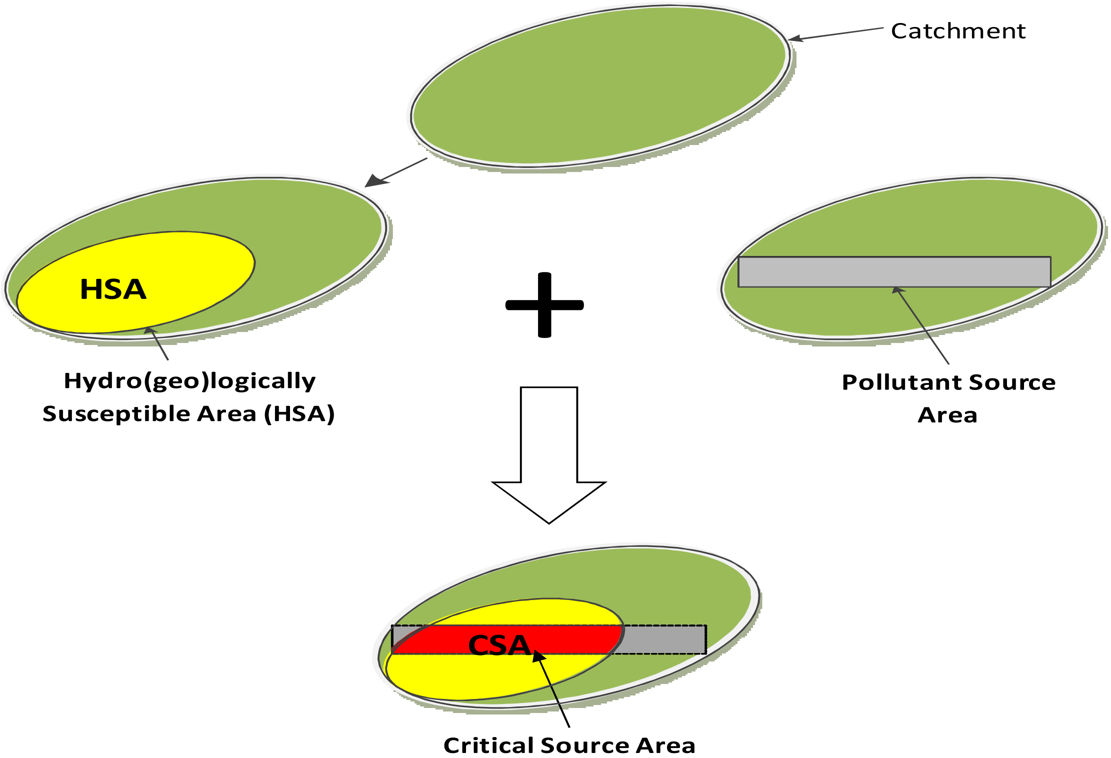

Figure A1: Diagrammatic representation of the components of CSAs

Pathway susceptibility is a measure of the degree of attenuation between source and receptor or alternatively a measure of the ability of the pathway factors to reduce the impact of a pressure, in terms of time to reach the receptor, proportion of pollutant load reaching the receptor, pollutant concentration level in the receptor, and duration of the pollution event. The pathway susceptibility depends on:

- The hydro(geo)logical properties of the area; and
- The properties of the pollutants.

Susceptibility maps (Archbold, 2016; Mockler *et al.*, 2016) are now available for phosphate along the near surface pathway and for nitrate along the near surface and groundwater pathways. These are generated by linking data on 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. Figure A2 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. This phosphate susceptibility map could also assist in showing areas where MCPA, if applied, could be posing a threat to a drinking water source. Similar maps are available for nitrate entering groundwater and for nitrate entering surface water.

Pollution Impact Potential maps (PIP) (or critical source area maps) are generated by combining the susceptibility maps with nutrient loadings data calculated from the Land Parcel Information System (LPIS) data provided by the Department of Agriculture, Food and the Marine and the Central Statistics Office. An example of Pollution Impact Potential map for phosphate to surface water is shown in Figure A3. The darker the blue, the higher the risk. The highest risk areas for phosphate to surface water are the poorly drained areas with relatively high loads from intensive farming, meaning that in these areas phosphate is more likely to flow overland to surface waters rather than being attenuated in the soil and subsoil. In addition, farmyards in the high PIP areas are more likely to pose a threat to surface water quality than those in low PIP areas. Similar maps are available for nitrate in surface water and groundwater.

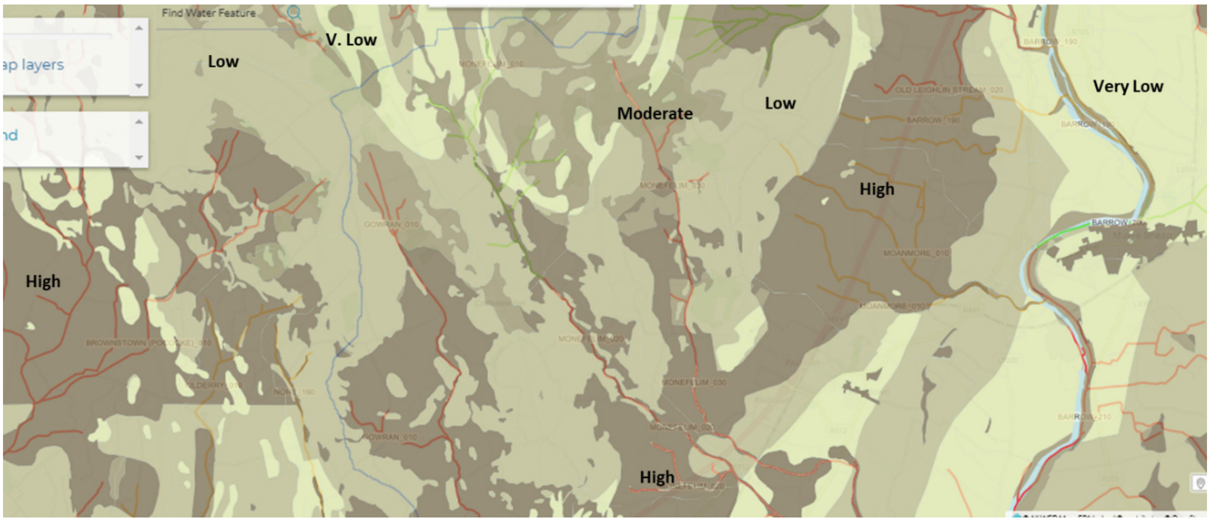

Figure A2: Map showing the phosphate susceptibility ranking along the near surface pathway *(Source: EPA Catchments Unit).*

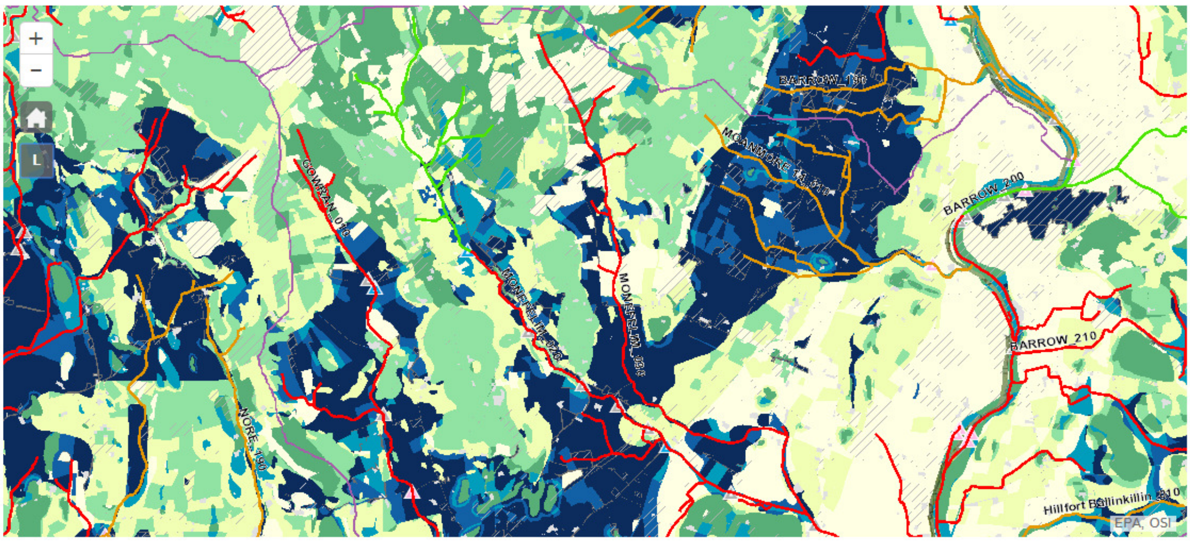

Figure A3: Map of pollution impact potential for phosphate to surface water from diffuse agricultural sources *(Source: EPA Catchments Unit).*

In the catchment areas/ZOCs of drinking water sources with unsatisfactory water quality, the Pollution Impact Potential (PIP) maps help focus on the areas and sources that might be causing the impacts. They help determine whether agriculture is a significant pressure and can be used to target areas for further investigative assessment at field scale. They are available at a maximum scale of 1:25,000 (e.g. water body scale) and are not designed or suitable to be used on their own as a basis for decisions at a farm or field scale. Consequently, these maps act as signposts for where local catchment assessments, mitigation options and engagement activities should be prioritised. The maps can be accessed on the EPA WFD Application.

Appendix 4: The Pathways Conceptual Model

What is it?[10]

- 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 A4 below), that is improved as more data/information become available, and as the understanding improves.
- The complexity/quality of the conceptual model (CM) 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.

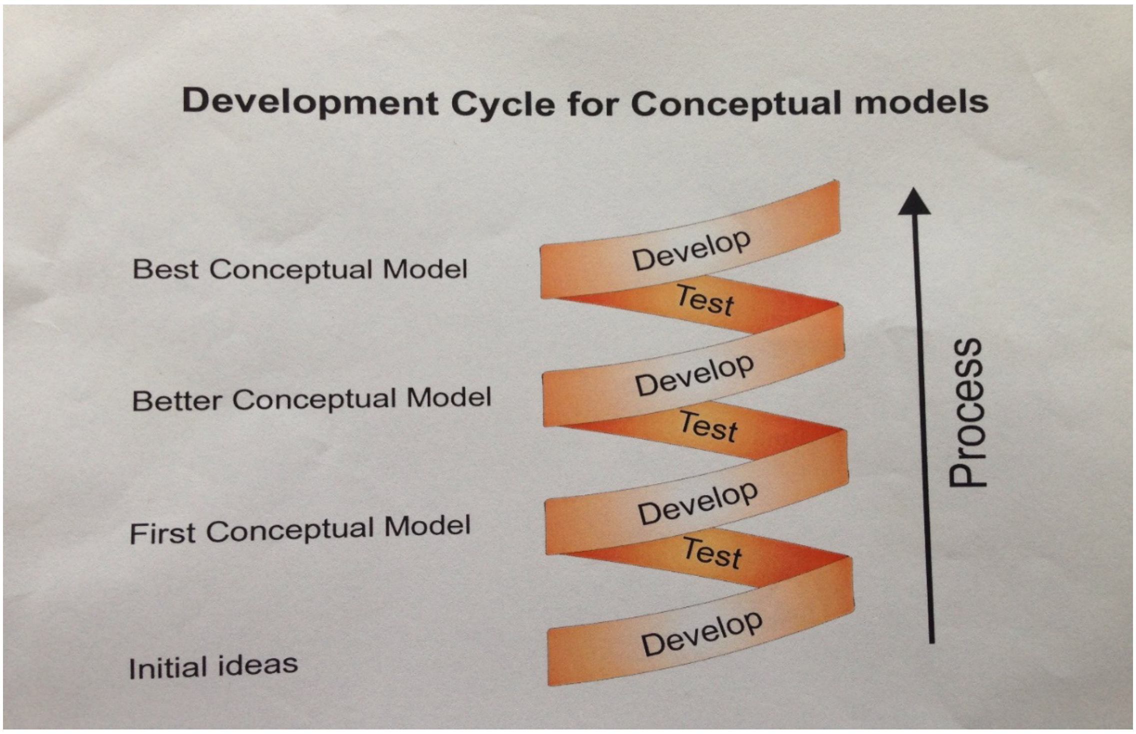

Figure A4: Illustration of the iterative and evolving process in developing conceptual models (Source: Steve Fletcher, Environment Agency, UK).

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.

[10] Much of the text in this Section is copied from an EPA Catchments Unit unpublished report 'Local Catchment Assessments. Desk Studies for Areas for Action – EPA Recommendations (2018)'.

- 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 A5, A6, A7, A8, A9, A10, A11 and A12.

The suggested approach to producing the pathways conceptual model (CM) 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 A1 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.

Table A1: Main pathways in the source catchment area

	Compartment 1		Compartment 2	
Direct[11]	No large, likely to be small point sources, such as DWWTSs and farmyards in poorly draining areas		One UWWTP and likely to be small point sources, such as DWWTSs and farmyards in poorly draining areas	
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 drained	Predominantly well drained	Predominantly poorly drained	Predominantly well drained
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

[11] Point discharges to the water body

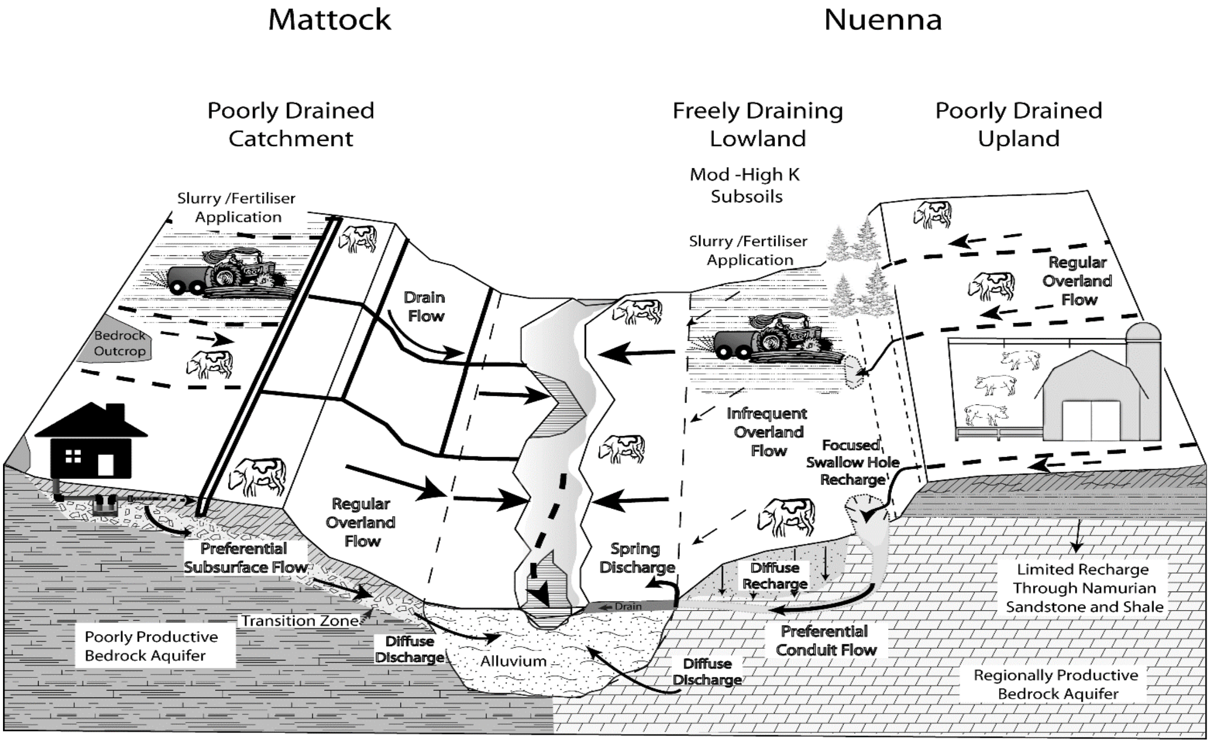

Figure A5: Schematic representation of the contrasting hydro(geo)logical pathways contributing flow and nutrients to the stream in the poorly drained Mattock catchment (left) and freely draining karst catchment (right). The thicker arrows represent a larger relative flow component than the thinner arrows. Dashed arrows represent intermittent flow (Copied from Deakin *et al.*, 2016).

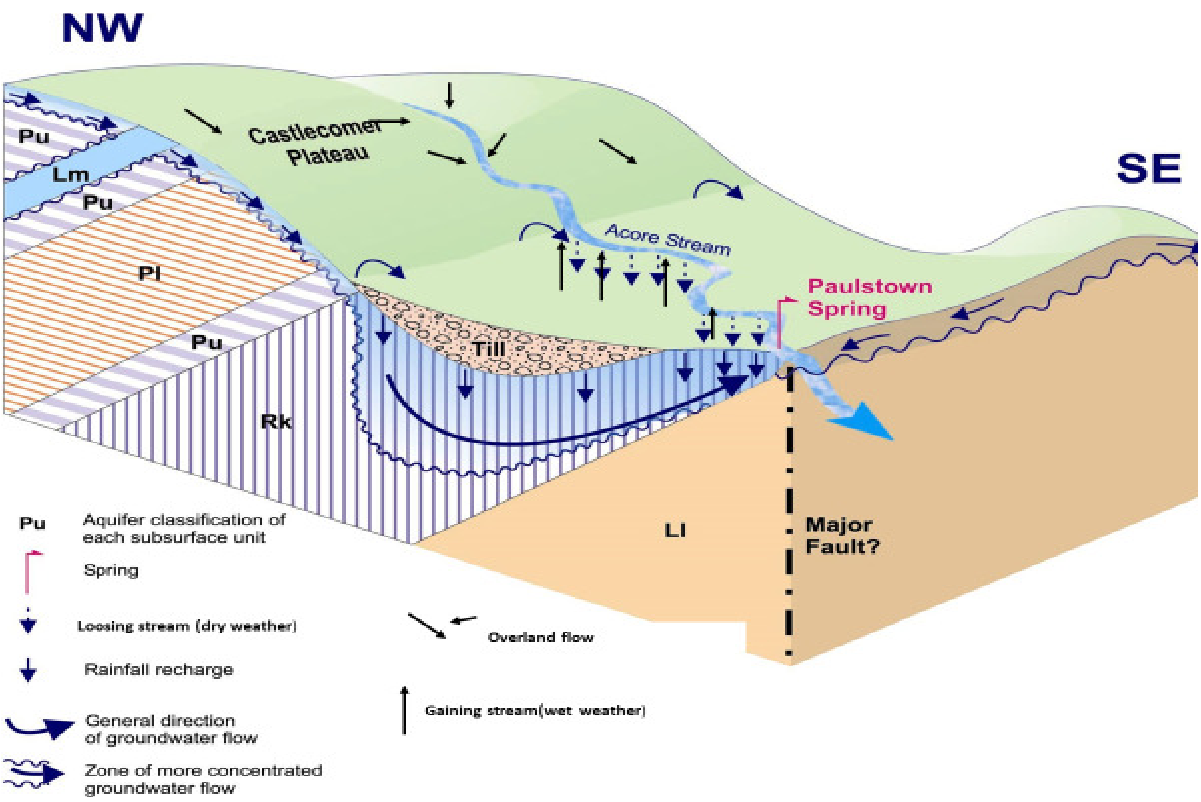

Figure A6: Schematic diagram drawn by the Groundwater Section, GSI, for the Paulstown Source Protection Report.

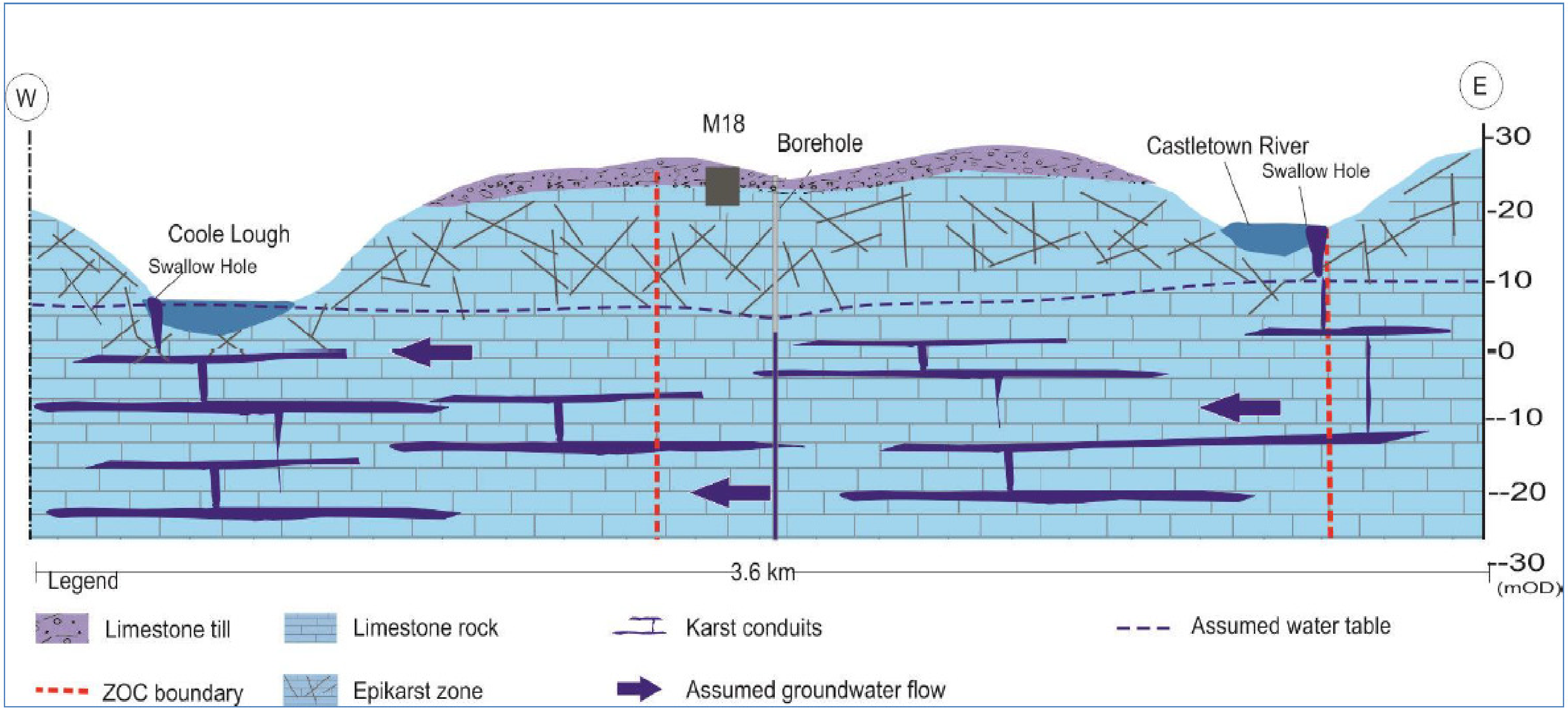

Figure A7: The pathways conceptual hydrogeological model for Coole GWS (Source: Tobin Consulting)

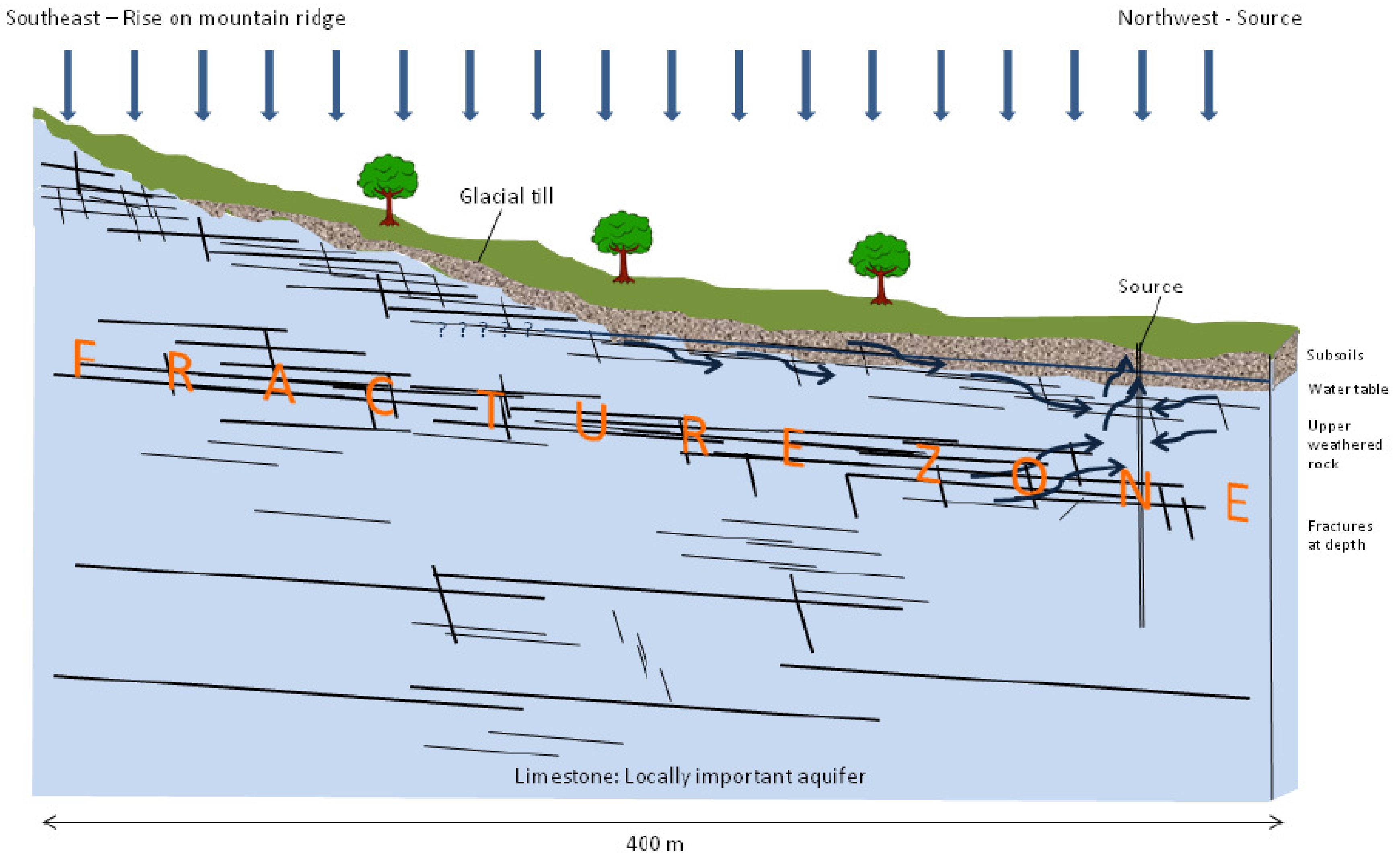

Figure A8: The pathways conceptual model for Shalee and Kiltyrome GWS (Source: Robbie Meehan, Talamhireland)

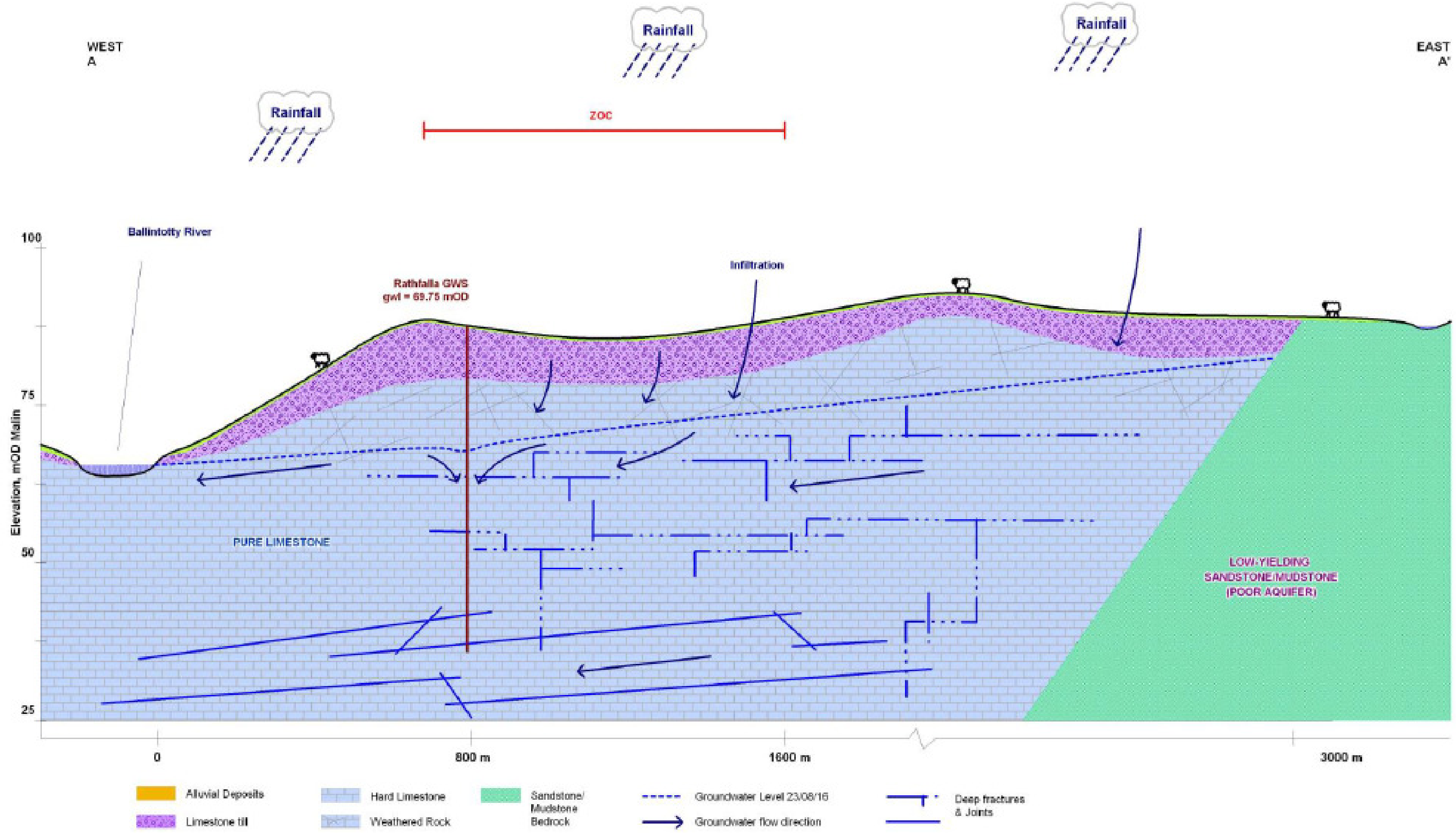

Figure A9: The pathways conceptual model for Rathfalla GWS (Source: Envirologic Ltd)

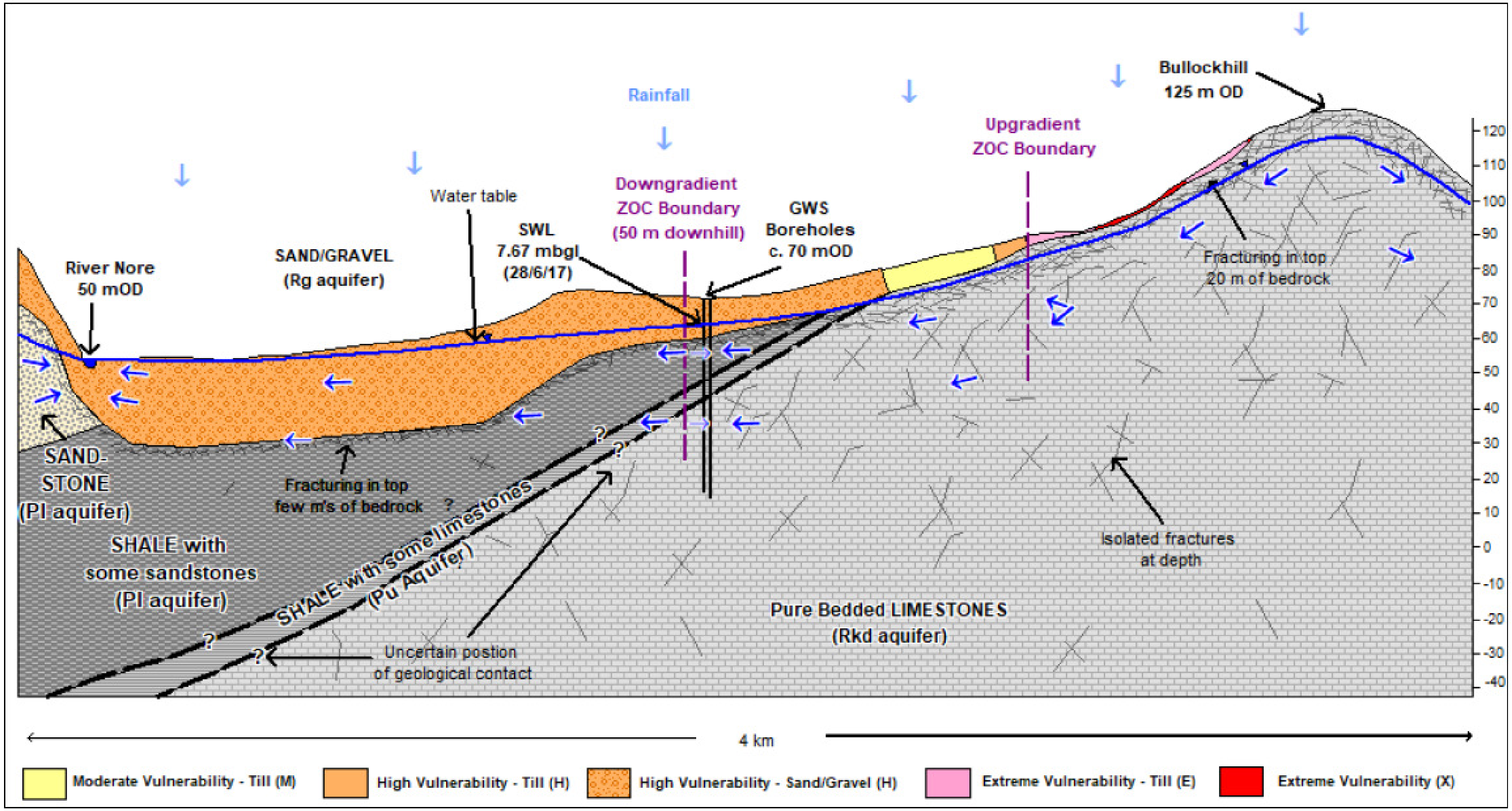

Figure A11: The pathways conceptual model for Dunmore GWS (Source: IE Consulting)

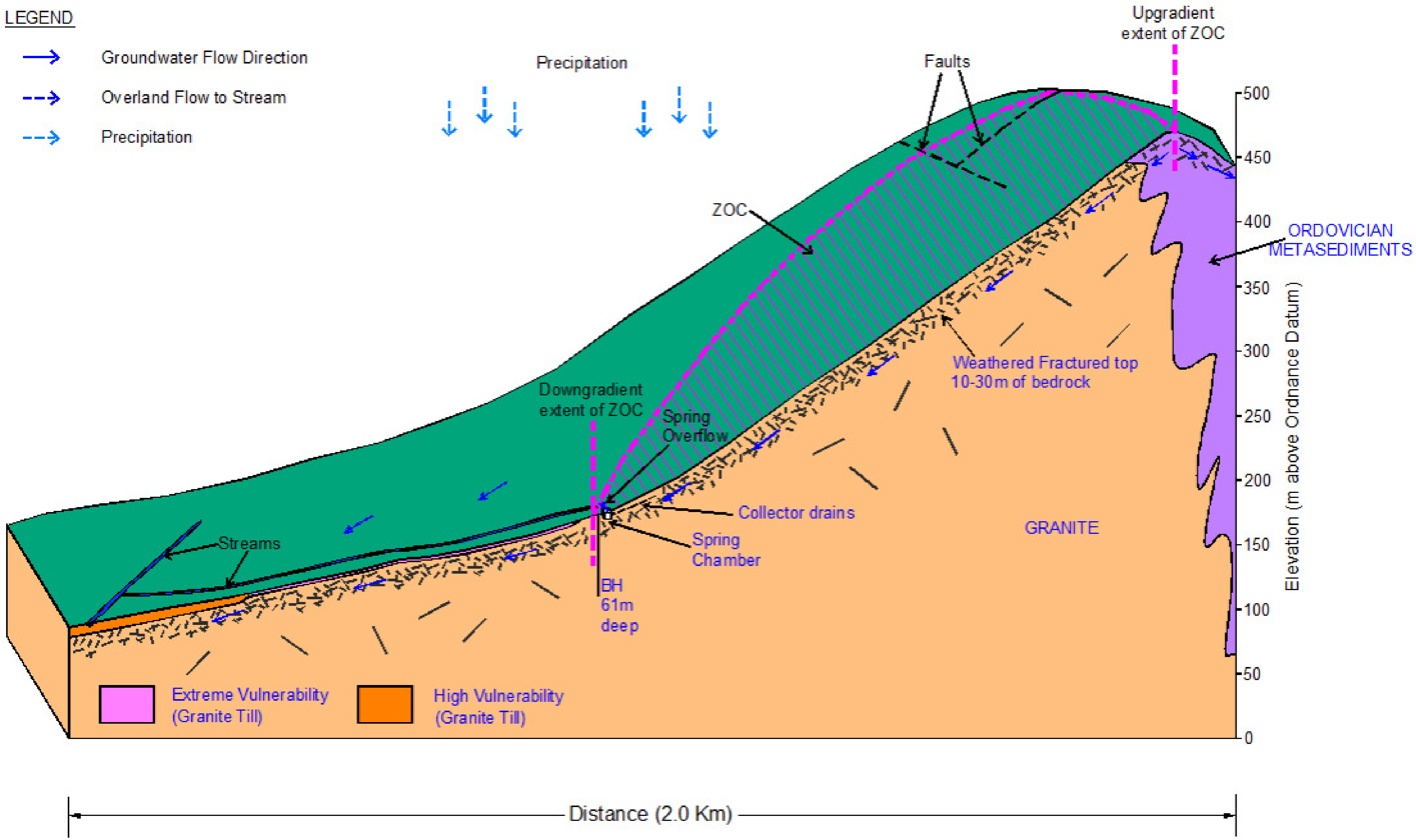

Figure A12: The pathways conceptual model for the St. Mullins parish GWS.

Appendix 5: Mitigation and Protection Strategies and Options

Linking the Strategies and Options to the Objectives

The characterisation process provides the following information:

- An analysis of the catchment/ZOC conditions.
- A conclusion on whether the objective is improvement or protection based on a comparison of the water quality with the guide values.
- Where relevant, an estimate of the pollutant reduction required.
- An evaluation of whether point and/or diffuse pressures are posing a threat to the drinking water source.
- Where the objective is improvement and diffuse significant pressures are present, the significant issue(s) has/have been determined as well as the location of the CSAs and, for some surface water sources, the subcatchments that need to be targeted. Where point significant pressures are present, they have been located. In addition, possible mitigation measures and actions have been determined.
- Where the objective is protection, pressures in susceptible areas that might pose a threat to the source have been located and evaluated, existing measures and actions have been assessed, and possible additional actions have been noted.

This information provides the basis for consideration of and decisions on the source management strategies and activities.

This Appendix takes each of the main significant pressures in turn and, with the exception of agriculture, provides some information and web links to the main pressures and to possible mitigation options that can be evaluated, decided on and then undertaken. These pressures and mitigation options are outlined in Volume 2 of the Guidance on Further Characterisation for Local Catchment Assessment (LCA) produced by the EPA Catchment Science & Management Unit; they can be accessed at this link: https://epaireland.sharefile.com/d-s272b26a938e4f7a8.

As mitigation options for agricultural activities are not given in the Local Catchment Assessment Guidance volumes, they are summarised in Appendix 6.

Domestic Wastewater Treatment Systems

General details are given in Section 6 of Volume 2 and possible mitigation options are described in Section 6.4.

An inspection regime is in place that is conducted under the Water Services (Amendment) Act (No.2 of 2012); details on the salient aspects of the Inspection Regime are given in the Box. It is not the intent or purpose of developing or implementing a source protection plan to determine compliance under the Water Services or Planning Acts.

Upgrades to a DWWTs may require planning permission and a site assessment in accordance with the EPA Code of Practice (2009) may be required. An update of this document is currently out for consultation. There is only an exemption on foot of an Advisory Notice issued under the Water Services Act.

A public awareness campaign is recommended, for instance, based on the readily available EPA leaflets and website information.

Domestic Waste Water Treatment Systems (DWWTSs) – The National Inspection Plan and the Inspection Regime

The Water Services (Amendment) Act (No. 2 of 2012) augmented the Water Services Act (No. 30 of 2007) and placed responsibilities on owners, water services authorities, the EPA, and Inspectors (authorised and trained Water Services Authority staff).

The EPA is responsible for establishing a National Inspection Plan, that includes a risk assessment that provides a basis of prioritising areas where inspections should be focussed and providing direction to the Water Services Authorities and engaging with the public. The current NIP plan is from 2018 to 2021.

The Water Services Authorities are responsible for maintaining a register of DWWTSs and for carrying out the inspections and the Inspectors are currently authorised staff of the Water Services Authorities that have passed the specific training course.

The Owner is required to register their system and "*shall ensure that the system does not constitute, and is not likely to constitute, a risk to human health or the environment …*".

The purpose of the Inspection is to determine compliance with the legislation and/or regulations. Currently, the Water Services Authorities choose where they carry out the specified number of inspections with reference to the risk categories as advised by the EPA.

Where a DWWTS fails the inspection, the water services authority issues an Advisory Notice that directs the Owner to rectify the problem.

There is an exemption for remedial works on foot of an Advisory Notice issued under the Water Service (Amendment) Act, 2012.

The regulations also set out the framework and conditions for providing financial assistance toward remediation, repair, upgrading or replacement of DWWTSs (S.I. No. 222 of 2013, *Domestic Waste Water Treatment Systems (Financial Assistance) Regulations 2013*). Currently, the financial assistance only applies to advisory notices issued under the Water Services Act.

Urban Wastewater Pressures

General details on are given in Section 4 of LCA Volume 2 and possible mitigation options are described in Section 4.5.

Diffuse and Small Point Urban Pressures

General details on this significant pressure are given in Section 5 of LCA Volume 2 and possible mitigation options are described in Section 5.4.

Forestry Pressures

General details are given in Section 7 of LCA Volume 2 and possible mitigation options are described in Section 7.4.

Peatland Activities

General details are given in Section 8 of LCA Volume 2 and possible mitigation options are described in Section 8.5.

Quarries

General details are given in Section 9 of LCA Volume 2 and possible mitigation options are described in Section 9.4.

Industrial Discharge Pressures

General details are given in Section 11 of LCA Volume 2 and possible mitigation options are described in Section 11.6.

Invasive Species

General details on Giant Hogweed, Japanese knotweed, Himalayan balsam, Gunnera (Giant Rhubarb) and Winter heliotrope are given in Section 12.

Sources of Data and Maps for Identifying Pressures, CSAs and Mitigation Options

Useful and relevant sources of data and maps, with web links, are given in Table 4-1 in LCA Volume 1.

Appendix 6: Mitigation Options for Agricultural Activities

This Appendix provides a generic list in summary form of possible mitigation options using the relevant points along the pollutant transfer continuum as the structure:

- Table A2 provides a summary of the source control mitigation options.
- Table A3 provides a summary of the mobilisation control options.
- Table A4 provides a summary of the pathway interception mitigation options.
- Table A5 provides a summary of the receptor/instream works.

As the appropriate mitigation options depend, to a large degree, on the properties of the significant issues, e.g. nitrate, MCPA, and their associated pressures, e.g. landspreading of slurry, spraying of MCPA, these provide the basis for the other components of the decision-making approach, as illustrated in the process flowchart (Figure A13) and described in the tables.

While the tables list the technical mitigation options, an overriding component is a philosophy and approach that includes discussion and collaborative working with farmers, co-developing practical on-farm measures and actions, and awareness-raising, knowledge exchange and capacity building in the GWS communities on environmental protection and management.

Mitigation options can be placed in three categories:

1. Regulatory measures that must be complied with, in particular, the GAP (DAFM, 2017) and Pesticide Use Regulations (DAFM, 2012).
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.

This Appendix does not distinguish between these categories, but they can be taken into account when evaluating and deciding on the options.

Background information on the possible impacts of agriculture activities on water quality is given in Section 2, Volume 2 of the Guidance on Further Characterisation for Local Catchment Assessments produced by the EPA Catchment Science & Management Unit, which can be accessed at this link: https://epaireland.sharefile.com/d-s272b26a938e4f7a8. Comprehensive details on mitigation options are given in McNally (2017), which can be accessed at this link: https://www.catchments.ie/download-category/objectives-and-measures/.

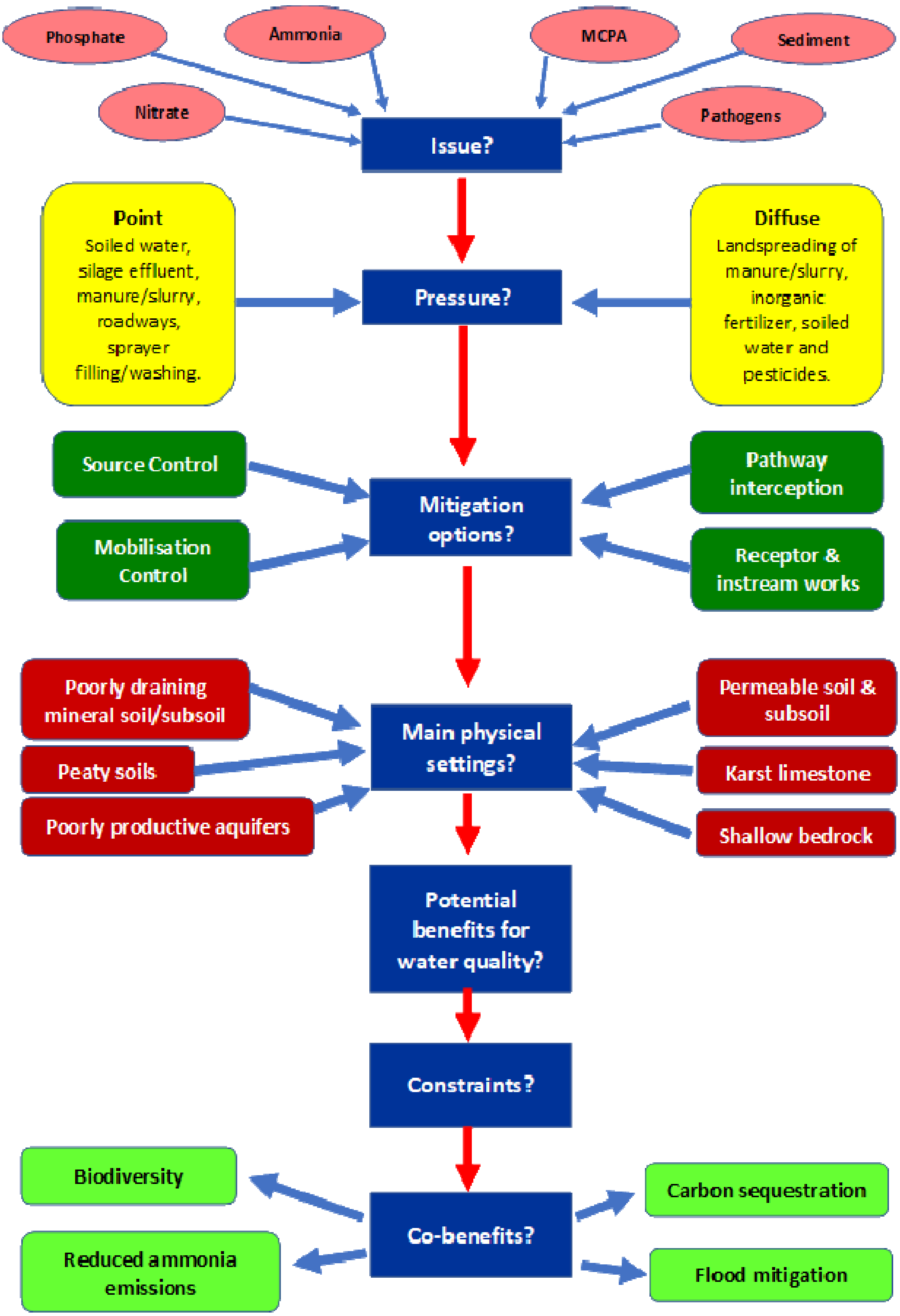

Figure A13: Process flowchart illustrating the format of Tables A2, A3, A4 and A5.

Table A2: Summary of Source Control Mitigation Options

Pressure Type	Issue(s)	Mitigation option(s)	Physical setting	Mechanism	Potential water quality benefit	Constraints	Co-benefits
Soiled water in farmyard	PO_4; NH_3; BOD; sediment; microbial pathogens.	• Minimisation. • Collection • Landspreading. • Integrated constructed wetlands (ICWs). • Low bunds alongside watercourses/ditches.	Farmyards i) close to watercourses & ditches, ii) in poorly draining areas and iii) where bedrock is at or close to the surface pose greatest threat to water.	• Effective roof gutters and channels to separate clean water from dirty water; regular yard scraping. • Suitable collection system. • Landspreading in compliance with Article 18 of the GAP Regs (2017). • Treatment & storage of N, P and sediment, & die-off of pathogens in ICWs. • Prevention of surface runoff to watercourses.	Reduced localised inputs to watercourses. Reduced infiltration, without adequate attenuation, to groundwater.	Cost. For ICWs, compliance with DEHLG Guidance (2010).	Reduced ammonia emissions to air. Fertilizer value (although limited) of nutrients in soiled water.
Silage effluent from pits.	BOD (high) (can cause fish kills); manganese (can pollute nearby wells).	• Collection, storage. • Landspreading.	Silage slabs where bedrock is at or close to the surface pose a threat to groundwater. Slabs on low permeability subsoil give extra protection.	• Maintained, leak proof floor, walls and collection channels. • Separation of water from effluent. • Effective collection system.	Reduces likelihood of impact on water.	Cost to maintain silage pit as effluent is corrosive.	-
Silage effluent from bales	BOD; manganese.	• Store ≥20 m from watercourses. • Don't store on bare bedrock.	Presence of soil and subsoil decreases risk of impacts.	• Locate in a suitable area such that entry of effluent to water doesn't occur.	Reduces likelihood of impact on water.	-	-
Slurry & manure in farmyard	PO_4; NH_3; BOD; microbial pathogens.	• Adequate storage. • Covered manure heaps.	All	• Need sufficient storage that takes account of animal numbers, farm soil types, average rainfall and likelihood of unsuitable weather for landspreading. • Covering reduces nutrient leaching from upper layers of manure.	Reduced loss of nutrients and pathogens to water.	Cost. Weather. Requirement for planning permission for new large developments.	Reduced ammonia emissions to air.

Manure stored in fields	PO4; NH3; BOD; microbial pathogens.	• Compliance with Article 17 (13) of the GAP Regs (2017).	All	-	Reduced loss of nutrients to water.	-	-
Farm roadways, drinking troughs, ring/mobile feeders (often causing poaching).	Sediment & microbial pathogens if located close to watercourses.	• Directing road runoff away from watercourses and ditches, e.g. by suitable road cambering. • Locating drinking troughs and feeders as far as practicable from watercourses and ditches. • Not locating ring feeders on exposed bedrock. • Shifting locations of feeders regularly.	Likelihood of impacts greatest on poorly draining soils and where bedrock is at/close to the surface.	• These are hotspots for pollutants and therefore entry to water must be mitigated by interception, appropriate location and, in the case of roadways, appropriate design.	Reduced losses to water.	Cost. Appropriate design and implementation needed.	-
Open drains/ditches and watercourses	Sediment	• Prevent cattle access by fencing. • Clean drains in appropriate manner (see Section 2, Volume 3 of LCA Guidance).	Drains & watercourses more common in poorly draining soils areas.	• Cattle cause bank damage. • Drain cleaning mobilises sediment.	Reduces input of sediment and impacts on stream fauna.	Cost of fencing. Alternative water sources needed. Cleaning needs to be appropriate to situation.	-
Tillage fields	Sediment.	• Minimum till cultivation. • Contour ploughing. • Tramline management.	Likelihood of impacts greatest on poorly draining soils.	• Reduced likelihood of entry to water.	Reduced losses to water.	Specialist machinery required for min till.	Reduced soil loss.
Land reclamation	Sediment	• Account taken of likelihood of heavy rainfall. • Undertake in appropriate stages.	Likelihood of impacts greatest on poorly draining soils.	• Prevention of entry to water.	Reduced losses to water.	Potential delays due to weather. Appropriate work planning needed.	-

Fertilizer (organic & inorganic) application	Phosphate; Nitrate.	• Appropriate application rates. • Precision technology, e.g. GPS. • Calibrated spreading equipment. • Reduced stocking rate. • Organic farming. • Identification of suitable landbanks and estimations of loads where there are off-farm sources, e.g. pig or poultry manure.	All	• Use NMP process. Rates should match crop requirements. • Precision placement & calibrated equipment to help ensure no excess loading. • Reduced nutrient loading from livestock reduces likelihood of loss to water. • Need to address off-farm sources specifically as the loads are additional and may result in over fertilisation.	Reduced losses to water.	Soil test needed. Additional storage may be needed. Need precision technology on tractors. Reducing stocking rates & organic farming may need to be incentivised.	Reduced GHG emissions. Reduced and more effective use of fertilizers.
	Phosphate	• No applications on P index 4 soils.	Poorly draining soils.	• Rates should match crop requirements, except where a decision is made to mine the P by keeping application below agronomic need.	Reduced losses to water.	Soils tests needed.	Reduced GHG emissions. Reduced costs for farmer.
	Nitrate	• Use of low-crude protein animal feeds.	-	• Low-crude animal feeds reduce total nitrogen excreted.	Reduced losses to water.		Reduced ammonia emissions to air.
Pesticide application	MCPA	• Appropriate application rates. • Appropriate application methods, e.g. low drift nozzles and weed wipers. • Care filling and cleaning sprayers. • Appropriate storage of pesticides. • Physical control by cutting of rushes.	Poorly draining soils areas.	• Reduced loading and appropriate application decreases likelihood of loss to water. • Sprayers should be filled where losses to streams cannot occur. A specific appropriate designated area may be needed. • Sprayers should be cleaned appropriately after spraying.	Reduced risk to drinking water.	H&S requirements. Wind, which causes spray drift. Cost of application treatments.	-

	Sheep dip	• Appropriate design and location of sheep dip facilities. • Proper disposal of spent liquid. • Proper disposal of old containers.	-	• Required practices should be followed. • Spent dip should be landspread in suitable areas away from watercourses and areas of extreme vulnerability.	Reduced risk to drinking water sources.	Requires proper facilities.	-

Table A3: Summary of Mobilisation Control Mitigation Options

Pressure Type	Issue(s)	Mitigation option(s)	Physical setting	Mechanism	Potential water quality benefit	Constraints	Co-benefits
Fertilizer (organic & inorganic) application	Phosphate; nitrate.	• Liming to ensure optimum pH. • Timing of application. • Soil incorporation of slurry. • Cover/catch crops. • Take account of the differing CSAs for both PO_4 and NO_3 (see Appendix 3) when planning landspreading.	Phosphate losses can occur in poorly draining areas; nitrate can losses occur in areas with permeable soil and subsoil.	• Liming enables optimum uptake of nutrients, and can also reduce fertilizer requirements and soil reserves. • Apply slurry in spring on cool, overcast days. Utilising weather forecasts essential; spreading should not occur within 48 hours of heavy rainfall but greater durations preferable (e.g. 3/4/5 days if possible) to reduce likelihood of runoff of nutrients particularly in poorly draining areas • Incorporation reduces runoff. • Catch crops protect soil from erosion and reduce potential for winter runoff and leaching. • CSAs are the 'hotspots' for losses to water.	Reduced losses to water. Spring applications decrease NO_3 leaching. Cover crops reported to reduce NO_3 leaching by up to 50%, TP by over 50% and sediment by 15%. Incorporation can reduce P loss by up to 60%.	Need soils test. Weather forecasts need to be checked and used. Wet weather might prevent achieving good conditions for spreading. Heavy machinery can cause compaction – low pressure tyres may be needed. Need to know locations of CSAs.	Reduced GHG & ammonia emissions. Reduced costs for farmer. Soil health.
	Phosphate	• Apply 50% in spring and all by end June.	Poorly draining areas.	• Enable optimum utilisation of P.	Reduced losses to water.	Weather.	Reduced GHG emissions. Reduced costs for farmer.
	Nitrate	• 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.	Well drained areas.	• Clover utilises N from the air. • LESS increases value and utilisation of N. • Multi-species mixtures increase N capture, and enable higher resilience to droughts and therefore reduced nitrate leaching. • Protected urea has less leaching potential than CAN.	Reduced losses to water, e.g. by up to 20% from use of clover.	Use of clover requires more management of the grass sward. Protected urea slightly more expensive than urea.	Reduced i) nitrous oxide emissions & greater biodiversity from clover. Protected urea results in less ammonia emissions.

	Microbial pathogens	• Timing of application. • Soil incorporation of slurry. • No spreading on bedrock outcrops.	The greatest risk to surface water sources is in poorly draining areas, and to groundwater sources in shallow bedrock areas.	• Spreading should not occur within 48 hours of heavy rainfall but greater durations (e.g. 3/4/5 days if possible) preferable to reduce runoff in poorly draining areas and to enable die-off. • Incorporation reduces runoff.	Reduced impact on surface water in poorly draining areas and groundwater in areas of shallow bedrock (X-extreme vulnerability).	Weather forecasts need to be checked and used.	-
Pesticide application	MCPA	• Timing of application.	The greatest risk is in poorly draining areas where runoff occurs after heavy rainfall.	• Spraying soon before heavy rainfall can result in wash off to watercourses. • Spraying during windy conditions can cause pesticide spray drift.	Reduced risk to drinking water.	Weather forecasts need to be checked and used.	-

Table A4: Summary of Pathway Interception Mitigation Options

Pressure Type	Issue(s)	Mitigation option(s)	Physical setting[12]	Mechanism	Potential water quality benefit	Constraints	Co-benefits
Fertilizer (organic & inorganic) application	Phosphate & Sediment	• Riparian buffers	All settings, but particularly those with overland flow pathways. Greater slopes facilitate runoff.	No P input; vegetation slows & filters runoff; interception of sediment and uptake of PO_4 and N (as NO_3). Optimum benefits achieved when located in runoff hotspots.	• 5-10m wide = 20-90% TP/PP removal. • 5m wide = 55-97% sediment reduction. • The wider the better generally. • Reduce time lags for improvements in water quality.	Depends on physical setting, vegetation & pollutant properties. Can become sources of dissolved P unless harvested (grazing or cutting + removal). Bypassing by land drains & ditches. Areas of focussed flows/inputs need to be located.	Biodiversity; carbon sequestration; flood mitigation; reduced soil loss.
		• Hedges	The main benefit is in poorly draining areas with overland flow pathways.	Slows (and reduces) runoff; interception of P & sediment; P take-up. Breaks up hydrological connectivity. Stabilises stream banks.	• 10-20% particulate phosphorus (PP) and PO4 reduction. • Reduces sediment loss.	Need to be planted alongside watercourses or across slopes.	Biodiversity; carbon sequestration; shading of stream; reduction in soil loss.
		• Woodlands	The main benefit is in poorly draining areas with overland flow pathways.	Reduces mobilisation of sediment. Intercepts sediment & runoff to watercourses. Intercepts nutrient runoff. Stabilises banks.	• Reduced PP, PO4 & sediment input to watercourses. • Optimum benefits achieved when located in CSAs and runoff hotspots.	Need to be planted alongside watercourses or across slopes & in CSAs. Bypassing can reduce benefits.	Restores riparian ecosystem carbon sequestration; helps regulate flooding; recreation potential. Income from agroforestry.
		• In-field grass buffers & beetle banks in tillage fields.	Greatest benefit where there is overland and shallow flow in poorly drained areas.	No P input; grass vegetation slows runoff & intercepts sediment.	• 20-80% PP & sediment loss reduction.	Need to be located alongside watercourses or across slopes. May need to be wider and planted with trees in areas of focussed flows.	Biodiversity; reduction in soil loss.

[12] Phosphate susceptibility, nitrate susceptibility, aquifer and groundwater vulnerability maps provide information on the relevant physical settings and on likely 'hotspots' for losses to water.

		• Contour farming in tillage fields.	Greatest benefit where there is overland and shallow flow in poorly drained areas.	Hinders easy water movement downhill.	• Reduces PP and sediment.	H&S depending on slope.	Reduced soil loss.
		• Interception ponds & constructed wetlands.	At bottom of slopes beside watercourses.	Interception of water and nutrients & trapping of sediment.	• Significant reductions in PP, PO_4 & sediment.	Uses land area; depends on hydraulic residence times & veg. composition; might not be efficient for clay particles; needs 'cleaning out'.	Biodiversity; flood mitigation; carbon sequestration.
		• Low earthen bunds.	Runoff 'hotspots' in poorly draining areas with overland flow.	Interception of sediment and PP in runoff water.	• Reductions in sediment and PP.	Hotspots need to be located and bunds constructed.	Reduced soil loss.
		• Field drain interception ponds.	Poorly draining areas with field piped drains.	Interception of nutrients and sediment.	• Reductions in nutrients & sediment.	Reduces land area for farming. Need to be located in the appropriate areas.	Biodiversity.
	Nitrate	• Riparian buffers. • Constructed wetlands. • Permeable reactive barriers.	Areas where groundwater is discharging to watercourses and lowlying areas close to watercourses.	Biogeochemical transformation of NO_3 (denitrification, decomposition) where anaerobic conditions are present.	• Reduced input to surface water.	Usually needs to be designed and constructed appropriately. Loss of land for farming.	Biodiversity; carbon sequestration; flood mitigation; reduced soil loss.
	Microbial pathogens	• Riparian buffers. • Hedges & woodlands on banks of watercourses. • Interception ponds and constructed wetlands. • Low earthen bunds. • Landspreading where there is >1 m soil/subsoil.	Poorly draining areas where surface water is the receptor and extreme vulnerability areas where groundwater is the receptor.	Filtration, predation and die-off in soils and subsoils.	• Reduction and, in certain circumstances (e.g. where there is greater than 3 m permeable soil/subsoil over bedrock) elimination.	As listed above.	As listed above.

Pesticide application	MCPA	• Appropriate setback distances (≥5 m).	Rushes present in poorly draining and low-lying areas.	MCPA highly mobile in water; therefore interception needed. Biobeds may be needed where sprayers are filled and washed out.	• Reduced risk to drinking water.	Soil saturated conditions not suitable. Allocation of area for and construction of biobed.	-
Land reclamation	Sediment	• Sediment traps. • Silt fences. • Constructed wetlands.	-	Intercepts sediment & enables removal.	• Reduced losses to water.	-	-
Pasture and tillage on high organic soils	Phosphate	• Riparian buffers. • Constructed wetlands. • Woodlands (e.g. birch, willow).	Peaty areas alongside water courses with high organic soils.	PO_4 is mobile in peaty soils. Therefore, landspreading of P must match crop requirements.	• Reduced input to surface water.	-	Biodiversity; carbon sequestration; flood mitigation.
	Ammonia & DOC	• Raising the water table.	Peaty areas alongside water courses.	Saturation prevents decomposition of peat, and NH_3 and DOC production (which causes high colour).	• Reduced input to surface water.	Requires drain blocking. Reduces grass production.	-

Note: The effectiveness of buffer zones or setback distances generally depend on their width and on their location. While standardised widths along watercourses are beneficial, they will not be adequate in areas of focussed flows and inputs to watercourses from critical source areas.

Table A5: Summary of receptor/instream works

Pressure Type	Issue(s)	Mitigation option(s)	Physical setting	Mechanism	Potential water quality benefit	Constraints	Co-benefits
Cattle access	PP, PO_4, sediment, microbial pathogens.	• Access prevention and provision of alternative drinking water sources.	All. This pressure is often significant in catchment areas of high status objective water bodies.	• Fencing of stream. • Alternative water supply, e.g. nose pumps for cattle. • Constructing bridges at crossing points or alternatively designated and managed crossing points.	No/reduced pollutant inputs. Preservation of watercourse banks.	Cost.	Reduces threat to downstream drinking water sources.
Pollutants in watercourses	Sediment mainly. Also phosphorus in the sediment.	• Sediment traps. • Woody debris dams. • Stream / riverbank restoration, e.g. willow spiling.	Small watercourses, often intermittent, containing sediment after heavy rainfall. Karst limestone areas where there are sinking streams.	• Slows down flows enabling settling of sediment. • Removal of sediment. • Reduces bank erosion.	Reduced sediment and particulate phosphorus inputs.	Effective designs needed. Removal of sediment can be challenging.	Biodiversity.
Invasive species	Sediment	• Removal.	Banks of watercourses (permanent and intermittent).	• Spraying or physical removal, depending on species.	Reduces sediment input and preserves watercourse banks.	Time & effort. H&S.	Biodiversity.

Appendix 7: 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

(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**).

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.

Diffuse Pressures

Potential sources of pollution that are spread over wider geographical areas rather than individual point locations. Examples include landspreading of organic and inorganic fertilizers, forestry, peatland activities, urban areas.

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 Table A5. 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 A5: 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**

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

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.

Point Pressures

Any discernible, confined or discrete conveyance from which pollutants are or may be discharged. These exist in the form of pipes, leakages, containers and sheds, or may exist as distinct percolation areas, integrated constructed wetlands, or other surface application of pollutants at individual locations. Examples are discharges from domestic wastewater treatment systems (DWWTSs), farmyards, quarries, misconnections in urban areas.

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.

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.

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 (Hunter Williams *et al*., 2017).