# Achieving Water Framework Directive Objectives

## The Issue of Time Delays

## *How Long Will It Take for Improvements to Occur?*

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# The Issue of Time Delays – How Long Will It Take for Improvements to Occur?

## 1 Summary


- WFD objectives have been set for all 3,126 water bodies. While many water bodies are achieving their objectives, a substantial number are not. In addition, untreated water in some of our drinking water sources needs to be improved.

- Estimating the time delay for improvements to occur is a critical issue for a variety of reasons, including ensuring that expectations are realistic.

- In general terms, there are three groups of components influencing the time delays for improvement – policy factors, landscape and water factors, and measurement factors.

- Policies in place/policy development/policy implementation is the fundamental starting point. There are many good policies in place, and many are being implemented satisfactorily. However, some are not effective as is indicated by, for instance, our dis-improving water quality, nutrient pollution by urban wastewater treatment plants (UWWTPs) and farming activities, ammonium emissions from peatlands, unsatisfactory domestic wastewater treatment systems (DWWTSs), misconnections in urban areas. In addition, there are policy gaps and further policy development is needed, particularly for dealing with diffuse (non-point) agricultural activities because the current regulations are not sufficient. Incentivisation and 'payments for public goods' provided by farmers need to be considered, in my view.

- Even when the policies are in place, they then have to be implemented. This takes time and resources obviously, continued learning and, in some instances, further research. For large point sources, their locations are known and implementation is generally a matter of resources and time taken to implement in practice. For small point sources, such as DWWTSs and farmyards, the locations of some are known, but many are not. For diffuse sources, such as runoff from fields, work on locating the critical source areas where mitigation measures are needed has only commenced recently with the work of LAWPRO and the EPA Catchments Unit, and this work will need to continue for many years. As mentioned above, even when they are located, there may not be a means of implementing effective mitigation measures, other than voluntary actions by land owners.

- So, let us assume that all the necessary policies are in place and are being implemented satisfactorily; what is the situation then? There are some where the time delays for improvement are short, but for many there are complex interacting factors, including existing water quality, resources availability, natural settings and monitoring requirements, all leading to likely time delays that vary from medium to lengthy.

- Where point sources are the *significant pressure*, then once they are dealt with, the reduced pollutant concentrations will start to have an immediate impact on water quality. It should be kept in mind that not all point sources are '*significant*' from a WFD perspective. Therefore, in my view, time, effort and resources should be targeted at those that are *significant,* even though this might not be a 'comfortable' situation for those with responsibilities for water quality.

- For diffuse sources, the situation is more demanding. Working out the time lag for P (phosphorus/phosphate) and N (nitrogen/nitrate) (two of the main pollutants) reduction in water is complex for a number of reasons:

- P and N have different hydrochemical properties and this influences their movement, attenuation and impact in the landscape and on water. For instance, phosphate issues arise generally in poorly-draining areas, while high nitrate arises in freely-draining areas.
- As they move from their source to water in the landscape, lessening of the P and N loads entering water can occur to varying degrees: i) reduction of source load in the soil is critical for nitrate but, while beneficial, is not sufficient on its own for P reduction generally; ii) mobilisation control mitigation actions, e.g. liming, cover/catch crops, are beneficial for both P and N; iii) pathway interception, e.g. buffer zones, is the main means of ensuring that P does not impact on watercourses, but is not so effective for nitrate.
- Each of these have their own time lags.
- Therefore, it is vital that the *significant issue*, either phosphate or nitrate or both, is known in advance of measures implementation; otherwise time and resources will be wasted, and the process undermined.

♦ Even when all the required mitigation measures/actions are in place, there will still be a biological response time delay. Where the water quality is satisfactory upstream, then the likely response will be rapid – probably <1 year. Where the situation has been unsatisfactory for a number of years it may take 2-4 years for the required biological status to be achieved. However, in the meantime, progress can be shown by monitoring and plotting the chemical concentrations.

♦ There is one last time delay component – the time it takes to undertake the biological monitoring, as monitoring takes place once every three years, and finalising the status value is time consuming.

♦ What does this mean in likely actual time delays? Tables 3 and 4 provide a means of estimating time delays. In summary:
  - While some improvements are likely, major improvements in the water body status statistics for reporting in the 2021 RBMP are unlikely due to the time delays for the components mentioned above. Therefore, the focus should be on improvements in status and nutrient concentrations for the 2027 RBMP. The current work being undertaken, and its continuation, will be essential to achieving progress.
  - As the 4th River Basin Management Plan has to be completed by December 2027, this means that, in practice, improvements in water quality must have occurred by 2025 so that required biological responses have occurred and the status has been monitored and reported on.
  - An analysis of policy gaps and augmentation of some of the regulations is needed urgently, particularly for water bodies that are impacted by diffuse issues and pressures.
  - Characterisation by LAWPRO and EPA Catchments Unit is a vital precursor to deciding on mitigation options and their location; this takes time and for some water bodies is challenging.
  - Responses in water quality to upgrading of large point sources, for instance by Irish Water, will be quick – improvements in hydrochemistry within 1 year and in biology between 1-3 years. Also, the work of LAWPRO and ASSAP are likely to be resulting in improvements already or will in the near future in (probably) a small proportion of the unsatisfactory water bodies where small changes in either water quality and/or mitigation activities are sufficient.
  - Significant improvements for reporting in the 2027 RBMP will be achieved in the Priority Areas for Action (PAAs) provided the effort is sustained.
  - For water bodies outside the PAAs, provided that the approaches used by LAWPRO and ASSAP continue to be resourced, developed further and used, improvements in nutrient concentrations and reducing trends will occur, but for a proportion of these water bodies it may not be possible to show improvements in status due to the time delay issue; however, reduced nutrient concentrations, which can be reported in the RBMP, should be evident.

♦ In conclusion, further consideration of the time delay issue is recommended. This Note is an initial appraisal.

## 2 Introduction

Many water bodies are not achieving their WFD objectives of either Good or High status – see details in the Figure below, which is copied from the River Basin Management Plan 2018-2021: https://www.housing.gov.ie/sites/default/files/publications/files/rbmp_report_english_web_version_final_0.pdf .

A summary of status for all monitored waters in the 2010-2015 period is provided in Figure 4.1.

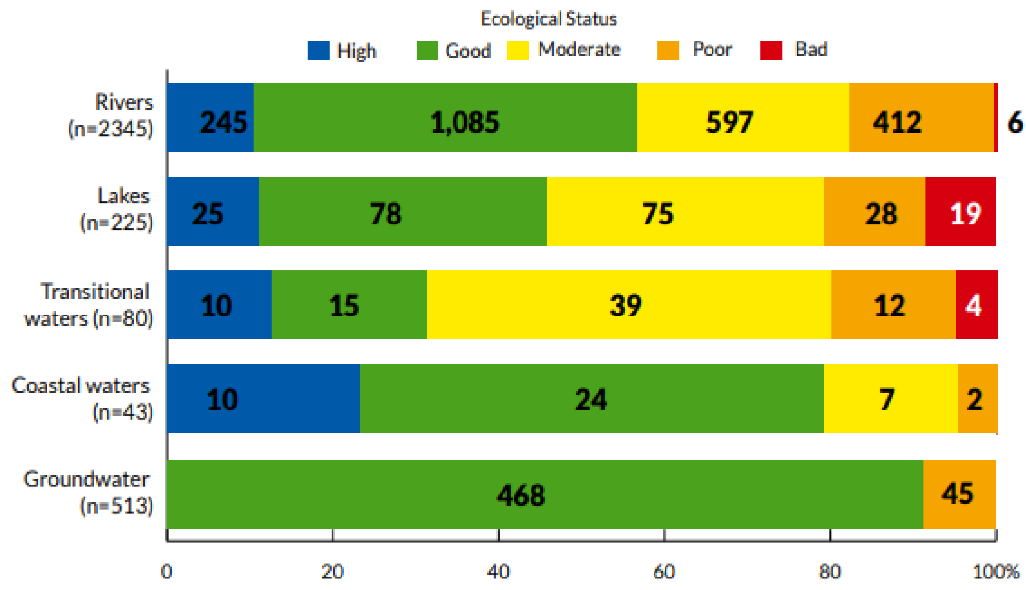


**Figure 4.1** - Surface water ecological status for rivers, lakes, transitional and coastal waters and groundwater (2010-2015)[11]

One of the aims of the work being undertaken currently by a range of public bodies is to improve and restore the water quality in those water bodies that are unsatisfactory as a means of not only achieving WFD objectives, but also a good quality environment. In general terms, those water bodies that haven't yet achieved their required WFD objectives must meet them by either 2021 or 2027. One of the main objectives for both surface water and groundwater bodies is restoration to Good status, and, for certain surface water bodies, restoration to High status. The 2027 deadline may be extended in circumstances where "*natural conditions*" do not allow the required improvements; however, no further deterioration must occur.

While drinking water sources have their own specific objectives; for some sources, restoration/improvement in untreated water quality (see NFGWS (2019) for details[1]) will be required, and therefore the issue of the time is takes for achievement of improvement is relevant.

A critical question is: how long will it take for the required improvements to occur? Is it weeks, months, years or decades? The answer is: it depends!

The terms 'time lag' or 'lag time' are used when evaluating the length of time for improvement. **Time lag in this Note is defined as the time elapsed between installation or adoption of a mitigation activity at a level projected to reduce pollution and the response to that action which, for WFD implementation purposes, is the achievement of the required status in the target water body.**

[1] https://nfgws.ie/a-framework-for-drinking-water-source-protection-2/.

The aim of this Note is to describe the main components that influence the length of time as a means of enabling the following:

- An understanding of the processes involved that determine improvements in water quality and achievement of WFD or drinking water objectives.

- Setting the dates in the 3rd River Basin Management Plan for achieving WFD objectives.

- Evaluation of resource needs and work planning.

- Consideration and establishment of the optimum mitigation options.

- Estimation of the likely time taken for improvement and restoration so that expectations on how quickly improvements can occur in practice are realistic. This, in my view, is an important issue as there can be an impatience and a lack of understanding summarised by the question; 'why it is taking so long?'. In some instances, the time delay is caused by inadequate implementation of the measures that are available; in others, it is because the required policies are not in place. But even when the policies are in place and are being implemented satisfactorily, the reality is that there will often be a time delay for improvements to occur and to be measured. In addition, there is a danger that it is convenient to project a long time delay as this reduces the sense of urgency in tackling the issues that are causing the dis-improvement in water quality.

While the 'official' WFD objective for a water body is determined by water body status, it can be advisable to set interim objectives, such as a decreasing trend at the monitoring point in the two main nutrients ($PO_4$, $NO_3$) that impact on water quality, for two reasons: i) reductions in these nutrients would often be required as a precursor to status improvements and ii) water samples are taken either quarterly or monthly, whereas status is determined every three years for surface water bodies and every six years for groundwater bodies, and therefore trends in these parameters provide a more immediate means of tracking and reporting on improvements.

## 3 Process for achieving WFD objectives

The general process for achieving the required objectives is as follows:

- Having relevant policies in place.
- Characterisation to enable the *significant issues* and *significant pressures* (see Section 6 for more details) to be determined and critical source areas for diffuse pressures to be delineated.
- Evaluation and decisions on the means of protecting our water resources, where the situation is satisfactory, and of improving/restoring our water resources where the situation is unsatisfactory.
- Implementing the measures and actions decided on[2].
- Monitoring progress and making adjustments where necessary.

Time lags is an issue that fits within and influences this process.

**This Note focusses mainly on two *significant issues*, phosphate ($PO_4$) and nitrate ($NO_3$), arising from spreading of fertilizer (organic and inorganic) on farmland and impacting on watercourses and groundwater; however, some of the content is relevant to point sources and to sediment from diffuse sources.** It does not cover impacts due to poor habitat conditions (hydromorphology) or water abstraction.

[2] In this Note, the distinction is made between regulatory 'measures' which are obligatory, and voluntary 'actions', some of which may be incentivised.

## 4 Factors that determine the time delay for improvement

The length of time for improvement includes six components, which are illustrated in Figure 1:

1. Satisfactory policies in place and, if necessary, further policy development.
2. Policy implementation/adoption of measures.
3. **Time lag for reduction in source load.**
4. **Time lag due to relevant pathway elements:**
   - **Transport time along pathway.**
   - **Attenuation along pathway.**
   - **Pathway interception.**
5. **Receptor (in-stream) time lag:**
   - **Source reduction (from sediment).**
   - **Biological response.**
6. Measurement component.

Components 3, 4 and 5 above are considered under the term ‘time lag’. However, components 1, 2 and 6 are also critical to determining the length of time for improvement. While this Note is aimed primarily for consideration of diffuse sources, components 1, 2, 3, 5 and 6 are relevant to point sources.

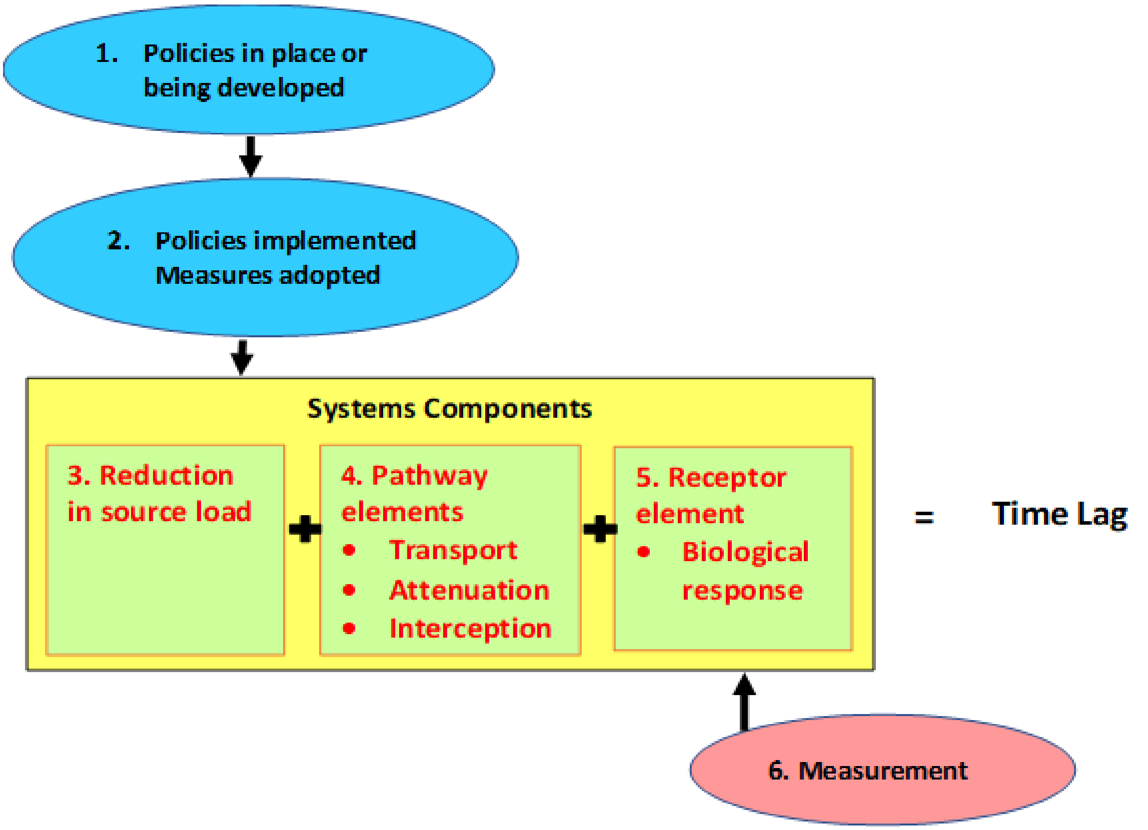


Figure 1: Schematic showing the major elements of the potential time delay for water quality improvement, including policy development and implementation component, catchment time lag components and the time needed to undertake monitoring. [3].

[3] Diagram based on Figure in Meals, D.W., Dressing, S.A. and Davenport, T.E. (2010). Lag time in water quality response to best management practices: a review. J. Environ. Qual. 39, 85-96. Available at: https://pdfs.semanticscholar.org/aab9/6b90bc9d48349b8fb6ca0c4fbf4cc6458931.pdf?_ga=2.186609578.208240954.1569077850-2011213208.1563976070

Clearly, the actual time it takes for sufficient improvements to occur depends not only on the establishment of the components shown above, but also on ensuring that they are effective.

This Note considers each of these components in turn. Section 13.9 provides an overview and a discussion on some relevant issues.

# 5 The role of policy and policy implementation

While some beneficial environmental activities are occurring on a voluntary basis, government policies, implementation of these policies and development of new policies are key to successful environmental management, whether as regulations or incentives.

There are many policies already in place that are the basis for implementation measures. Examples include the European Union (Good Agricultural Practices) Regulations, the Water Services (Amendment) for the regulation of domestic wastewater treatment systems and the Urban Waste Water Treatment Regulations. However, the level of implementation varies and there is a need for further policy development to deal with diffuse sources in particular.

The content of Sections 13.6, 13.7, 13.8, and 13.9 below are intended for the following situations:

- The required policies are in place. The implications for situations where further policy development is needed are outlined in Section 13.10.2.
- River and groundwater water bodies that are *At Risk* of not meeting WFD objectives and therefore require restoration to the required WFD objective.
- Drinking water sources that requires improvement to satisfactory water quality using catchment-based mitigation measures and actions.
- The *significant issue(s)* and *significant pressure(s)* is/are known following a catchment characterisation process.
- The load of P and/or N entering a water body has been sufficient to cause impacts and mitigation is required.
- The critical source areas have been delineated and the appropriate measures and/or actions have been determined.
- The required measures and/or actions have been put in place to mitigate the impacts of the *significant issue(s)* and *significant pressure(s).*

## 5.1 Mitigation measures and actions

The 'pollutant transfer continuum' (see Section 8), which is a landscape-based framework for considering diffuse pollution, is a useful concept when considering mitigation options as it encourages/enables a focus according to the point in the source-pathway-receptor continuum on which they take effect. The recommended relevant points along the continuum for consideration of specific measures and actions are:

i) source reduction or elimination;
ii) mobilisation control;
iii) pathway interception; and
iv) receptor/instream works.

Consideration of time lag follows this framework.

Comprehensive details on mitigation options are given in Appendix 6 of the NPWS 'Framework for Drinking Water Source Protection, which can be accessed at this link: https://nfgws.ie/development-of-nfgws-strategy/ and in McNally (2017), which can be accessed at this link: https://www.catchments.ie/download-category/objectives-and-measures/. Details on mitigation options for phosphate and nitrate are summarised from these sources in Tables 1 and 2. In addition, Teagasc have published relevant material, such as the booklet at this link: https://www.teagasc.ie/media/website/crops/soil-and-soil-fertility/Efficient-Use-of-Phosphorus-In-Agriculture-Tech-Bulletin-No.-4.pdf.

# 6 Time lag for reduction in source load

Phosphorus (P) and nitrogen (N) are applied to land by three means:

1. Spreading of inorganic fertilizer;
2. Spreading of organic manures, slurries and soiled/dirty water;
3. Faeces and urine deposited from grazing animals.

Once the P and N reach the soil, they are the **source load** intended to aid crop growth, but which can be subject to loss to water (and air in the case of N). P and N in the soil respond differently depending on their own specific properties and on the hydro(geo)logical setting, largely indicated by soil type. (The geochemistry of soil, subsoil and bedrock can also be an influence, but hydrology/hydrogeology is usually the dominant one.) Therefore, P and N are considered separately.

## 6.1 Time lag for reduction of phosphorus in soils

Some of the P load is taken up by crops, but a portion remains in the soil for varying periods of time during which loss to water can occur. Phosphorus is relatively immobile and is attenuated by mineral soils and subsoils. Therefore, the main pathways for loss of P to water is overland and near-surface. These pathways arise in poorly-draining or low permeability mineral soils and subsoils, and low permeability bedrock where it is exposed at the surface or overlain by thin soils.[4] They also arise in organic soils, which are unable to retain P. (These areas can be located by examination of the phosphate pathway susceptibility map for the near surface pathway (see Archbold (2016) at this link for further details: https://www.catchments.ie/catchments-newsletter/ ). They are available for viewing on the WFD App.)

The load of P in soil that is available for crops and loss to water is measured by soil tests and the level of P available in soils is indicated by the soil phosphorus index – 1 being a relatively low concentration and 4 the highest. The agronomic optimum soil P index is 3. While soil P index 3 is often seen as satisfactory from a water quality perspective, **there are circumstances where soil P index 2 soils and even soil P index 1 soils can pose a threat to water quality**; these arise in poorly-draining settings and also in the catchment areas of high status objective water bodies, which are sensitive to relatively small nutrient loadings. The reason is that it takes very little P loss (a small proportion of the amount generally applied) to bring the concentrations in water above the EQS of 0.035 mg/l PO4 (as a mean) – see Section 15.6 for further details. As a counter balance to this, soil P index 4 in well drained soils, underlain by subsoils, will generally not pose a threat to water as phosphate is not mobile in this situation and there isn't an effective pathway to a water body, either groundwater or surface water (but see footnote for an exception to this). Therefore, consideration of the pathway for P loss is a critical factor is assessing potential impacts and mitigation options.

[4] Teagasc research in the Timoleague catchment in south Cork, which is dominated by free-draining soils, has shown leaching of $PO_4$ to groundwater and then input to watercourses via the groundwater pathway, with concentrations in summer exceeding the EQS. This is attributed to the geochemistry of the soil, particularly the relatively low Al and high Fe contents, which facilitates leaching. The underlying bedrock is Old Red Sandstone (ORS), where the red colour is due to oxidised iron. In my experience of other ORS areas, $PO_4$ concentrations in groundwater are relatively low. However, if high PO4 concentrations are found in surface water where the soils are free-draining and it has been shown that point sources alone are not the only pressure, advice from Teagasc researchers is recommended. This situation may arise in some areas in the south of the country where the soils and subsoils are dominated by the ORS bedrock.

However, while impacts on water can occur at all soil P index situations, the greatest threat is in soil P index 4 soils where P concentrations are greatest. A key question in considering time lag is 'how long will it take for soil P depletion to bring the index from 4 to 3 or even 2 or 1?' This depends on a few factors:

- The initial soil P concentrations, which can be much higher than the boundary concentration between soil P index 3 and 4.
- The crop take off of P (e.g. for fields used for silage alone and where no further applications are occurring, 'mining' of P in the soil occurs).
- Any additional loadings, for instance, by grazing animals,
- The soil type.

Therefore, the answer can vary from field to field. Teagasc research has shown that many years of appropriate land management are needed to reduce the P load in soils after mitigation commences, with the actual number of years varying with the factors mentioned above. Recent research by Teagasc on two farms in the River Allow catchment examined 10 fields with soil P index 4 and predicted that the time taken to reach soil P index 3 ranged from 1-8 years, with six fields requiring ≥4 years. In other research outcomes, Teagasc have predicted time lags of as low as 3 years and over 20 years depending on the circumstances.

So, suppose there is a scenario where a critical source area for P loss has been located in the catchment area of an *At Risk* water body and mitigation activities have been put in place to reduce the source load. Without the detailed research such as that undertaken by Teagasc, it is not feasible to estimate the time lag for the P concentrations to decline to soil P index 3 or 2 concentrations in the different fields. My suggestion is to assume that it will take approximately six years (the same duration as a river basin management cycle), while realising that it could be as low as one year or more than 10 years. If the objective is to reduce the P concentrations in the soil further, for instance in the catchment area of a sensitive water body, such as a High status objective water body, then a longer time could be assumed. While this is a long period, keep in mind that is only one component in the time delay story, and that the time lag can be reduced by other components, which are described below.

### 6.2 Time lag for reduction of nitrate in the soil

Nitrate is not adsorbed on clay or organic matter. Therefore, it is highly mobile and, in a free-draining setting and under recharge conditions, is easily leached out of the rooting zone.[5] **The time lag for this to occur is probably a matter of months.**

## 7 Time lag due to relevant pathway elements

The pathway is the route water and associated pollutants must travel along from the location of a pressure in a field or at a site to a water body – either a watercourse or groundwater.

### 7.1 Transport time along pathway

The properties of phosphate and nitrate and the relevant physical settings and associated pathways for each differ. Therefore, consideration of the role of attenuation is considered separately for each.

[5] Research has shown that some organic N can be retained in a well-drained soil and can be available subsequently for leaching or denitrification. However, this is not considered to be significant in the context of this Note.

## 7.2 Transport time for phosphorus along pathway

The pathway for phosphorus is overland and near-surface mostly in poorly-draining areas. If phosphorus is mobilised after rainfall, the transport time to a watercourse is short – **hours to days**. This assumes that no mobilisation or pathway mitigation measures and/or actions are in place.

## 7.3 Transport time for nitrate along pathway

The pathways for nitrate are underground to both groundwater and surface water bodies in free-draining areas. Groundwater is not only a receptor (an aquifer or well or spring) that can be impacted by nitrate but is also the main pathway for nitrate to get from diffuse sources on the land to surface water. Nitrate does not enter surface water via overland flow and near-surface pathways generally, in contrast to phosphorus, as denitrification occurs along those pathways.[6]

The time lag for nitrate to reach a receptor depends on the following:

- The receptor itself, whether groundwater in an aquifer or a well or spring, or a watercourse.
- The permeability of the soil, subsoil and bedrock (keeping in mind that the permeability has to be sufficient to enable water containing nitrate to migrate vertically to the water table and then horizontally to a well, spring or watercourse).
- The depth to bedrock or thickness of soils and subsoil. (Water flows much slower generally in subsoil than in bedrock, although preferential flowpaths can cause bypassing of the matrix of soil and subsoil).
- The unsaturated zone in subsoil. Flows in unsaturated subsoils are slower than in saturated subsoils.
- Denitrification in certain soil, subsoil and bedrock types.
- For surface water receptors, distance from the fields that are a source of nitrate.

Because of the variability of the hydrogeology of the Irish landscape and because the relevant receptor could be either groundwater or surface water or both, the time lag varies. Therefore, generalising is difficult, but is attempted here to 'give a feel' for the likely situations.

Most physical settings where nitrate is a *significant issue* for either groundwater receptors or surface water receptors or both tend to have soil and subsoil thicknesses no greater than 5-6 m. Where the soil/subsoil is ≤ 1 m, the bulk of the nitrate is likely to reach the water table in <1 year (it will often be a matter of months). Where the soil/subsoil thickness is 5/6 m, the main load of nitrate leached from the soils is likely to reach the water table in a range between 3-6 years.[7] Once the nitrate has reached the water table and assuming a watercourse or well is ~300 m away from the field contributing nitrate, it would then typically take 1 month to 1 year to reach the receptor[8]. (For sand/gravel aquifer scenarios, the time lags would be greater, although this is not a common situation and is therefore not dealt with here.)

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[6] Therefore, where the physical setting is constant in an area, high phosphate and nitrate concentrations arising from diffuse sources will not generally be present in the same water body. An exception to this is areas with soils similar to those in the Timoleague catchment.

[7] Estimating **vertical velocities** for water movement in soil, subsoil and bedrock is complex. It depends on a variety of (often interrelated) factors: permeability, type of permeability (intergranular or fissure), effective porosity, presence of preferential flowpaths, hydraulic gradient (often <1 in moderate permeability subsoils), degree of saturation, effective rainfall, length of recharge period, presence of zero flux plane. In taking account of these factors, the GSI Groundwater Vulnerability Guidelines assumed a vertical velocity during the recharge period in moderately permeable subsoil of 0.01 m/d.

[8] Horizontal groundwater velocities in bedrock would be several metres/day typically.

## 7.4 Attenuation along pathways

### 7.4.1 Attenuation of P along pathways

Phosphate is readily attenuated in free-draining soils (with the exception of soils such as those at Timoleague). Therefore, diffuse loss from farmland is not generally a *significant pressure* and $PO_4$ is not a *significant issue* in these areas as a transport pathway to watercourses and groundwater is not present.

Attenuation of phosphate occurs in poorly-draining scenarios by crop take-up and adsorption in the upper centimetres of mineral soil. However, in these areas, where the hydrology is 'flashy', and overland and near surface pathways for water and pollutants are dominant, P in both soluble and particulate forms can be readily 'washed off' the land after heavy rainfall. Most of the impacts on water quality from diffuse sources occur in this setting. Therefore, the timing of application of P can have an influence in reducing losses to watercourses, both in terms of the time of the year and the number of days that spreading occurs before heavy rainfall – the regulations require a 48 hour gap, but a greater gap would be beneficial and therefore is advisable.

In poorly-draining areas, sediment with associated particulate P can be deposited in ditches/drains, and can therefore act as an ongoing source of P. However, these ditches/drains can also be an excellent pathway interception measure. Careful 'cleaning' of the drains will remove this pressure (see Section 2, Volume 3 of the Guidance on Further Characterisation for Local Catchment Assessment). In addition, these ditches/drains could readily be designed and engineered to act as sediment traps, either by deepening and/or widening in places, or by installation of small farm ponds at suitable locations along the ditches/drains or perhaps close to the outlet to the watercourse.

In conclusion, in poorly-draining areas attenuation is not sufficient generally to prevent loss of P to water. Thus, P can enter a watercourse in a matter of hours and days during and after rainfall and impact on the ecology, or may remain available as particulate P in the watercourse and cause impacts particularly during low flow periods. Therefore, the time lag due to attenuation is a matter of **hours and days** for soluble P ($PO_4$) and perhaps **weeks and months** for (a high proportion) of particulate P.

### 7.4.2 Attenuation of nitrate along pathway

Attenuation of nitrate as it moves through soils, subsoils and bedrock can occur due to denitrification. These situations arise where anaerobic and reducing conditions are present. Typically in soils, this might arise where there are layers of lower permeability due to a higher clay, silt and organic content than in the other layers. Denitrification occurs in certain bedrock types, such as impure (clayey) limestones. In addition, where the pathway for water is as overland and near-surface flows in poorly-draining settings, denitrification generally reduces the concentrations before the receptor is reached. As a consequence, a relatively high loading of nitrate fertilizer, for instance on nitrate derogation farms, will have different impacts depending on the underlying hydrogeological and hydrochemical setting.

Where nitrate has been specified as a *significant issue*, it indicates that attenuation has not been sufficient to mitigate the impacts, and that therefore mitigation actions are needed. Therefore, in these circumstances, attenuation need not be taken to influence the time lag.

## 7.5 Time lags due to pathway interception

As highlighted above, the pathways for phosphate and nitrate vary, with phosphate typically reaching waterbodies by overland and near-surface pathways whereas nitrate reaches waterbodies via underground pathways. Therefore, the role of pathway interception differs for each – highly relevant for phosphate and particulate P, and not so relevant for nitrate.

### 7.5.1 Role of pathway interception for phosphate

As the main pathways for P entering a watercourse are overland and near-surface either directly into the watercourse or via ditches/drains, pathway interception installations (see Table 1) are feasible. Once they are established and working effectively, their impact will be immediate, **with no time lag**, as they intercept the P and either prevent it from entering or reduce it before entering a watercourse. They also have the benefits of mitigating not only $PO_4$, but also particulate P and sediment. **Therefore, while source load reduction and mobilisation measures and actions are beneficial, they need to be accompanied by pathway interception as this is the most important and effective means of mitigating impacts.**

### 7.5.2 Role of pathway interception for nitrate

As the main pathways for nitrate entering a waterbody are underground, pathway interception (see Table 2) is not always a viable option, particularly where groundwater is the receptor. In some circumstances, the installation of riparian buffers or wetlands could encourage denitrification of groundwater discharging to a watercourse. However, it would be difficult to quantify the benefits, which might be minor, and therefore to justify their installation for this purpose alone, unless there were significant co-benefits for biodiversity and carbon sequestration. **Therefore, load reduction and mobilisation measures and actions are the most effective means of mitigating impacts from nitrate.**

# 8 Receptor time lag

There are two relevant elements: i) the time it takes for particulate P stored temporarily in river sediments to convert to soluble P and ii) the biological response, for instance the time it takes for the Q-value to reach the required objective of either Good or High biological status once the nutrient concentrations have reduced below the EQS.

## 8.1 Particulate phosphorus

In circumstances where sediment containing particulate P enters a watercourse on a regular basis, then this acts as an ongoing source of phosphate. In lakes where there is a legacy of P input, such as in the Cavan-Monaghan region, it may take decades for the P levels in both the lake and river waterbodies to reduce. In watercourses without inputs of P from lakes and where the *significant issue* is sediment, it is probable that, **once the source is minimised**, the P would be leached from the sediment and concentrations would reduce after 1-2 years, although there are likely to be some exceptions to this where there are substantial deposits of sediment in the watercourse channel.

Particulate P is likely to be present in the sediment in ditches/drains in poorly-draining areas with moderately intensive to intensive agriculture. However, unlike in the main channels of watercourses, this sediment can be removed readily and landspread, and the ditches/drains can be 'engineered' as an interception measure.

## 8.2 Nutrients

The biological responses to measures and/or actions being in place and being effective in reducing concentrations to below the relevant EQSs or threshold values, can vary from one year to several years. Recovery from a once-off pollution event in a water body meeting its objective can be rapid; for instance a high status objective water body in north Cork recovered in one year after a pollution event because of migration of macroinvertebrates from upstream to the polluted portion (Fran Igoe, personal communication). Where the water quality is unsatisfactory for all or most of the channel length, then recovery to the required Q-value would, take longer (**2-3 years** perhaps) after the mitigation measures and/or actions are in place, with a longer period of time where improvement by two status classes is needed. The biological responses in transitional and coastal waters are not considered in this Note.

# 9 Measurement component

Water samples are taken for analysis on a quarterly or monthly basis. Therefore, reduced concentrations would become obvious almost immediately and would be a means of indicating improvement. Samples sufficient for the trend analysis needed to confirm improvements might require 2-3+ years of monitoring data.

Biological monitoring at EPA monitoring points occurs every three years. Therefore, evidence of biological status improvement might not be available until **1-3 years** after an improvement in Q-values occurs. However, perhaps more frequent monitoring might be feasible in certain circumstances to provide evidence of improvement.

# 10 Overview and discussion

## 10.1 Findings from the literature

I have picked out below a few general findings from the literature, both Irish and international:

- The mitigation of impacts on watercourses and groundwater by phosphate and nitrate, and as a consequence, the estimation of the length of time for improvements is complicated and difficult.
- Research outcomes often highlight the long length of time for improvements – >10 years – after mitigation measures have been put in place, either based on monitoring or modelling results.
- While improvement at field scale can be relatively quick (<5 years), improvements at catchment scale can take far longer (>10 years). This is relevant as monitoring for WFD implementation purposes is at subcatchment scale.
- Small point sources, such as domestic wastewater treatment systems and farmyards, are an important source of P, particularly during low flow periods. Although they generally contribute a much lower load of P to streams overall, they need to be dealt with as well as diffuse sources. (They could be seen as 'low hanging fruit' which are easier to locate than CSAs for diffuse sources, and they have measures that are easier to undertake.)
- The loading of nitrate to water is far greater from diffuse sources than from small point sources.

Dealing with phosphorus is challenging:

- It takes very little P loss from farmland to breach the EQS for PO4.
- Reducing P levels in soils via NMP is beneficial for water quality as there is a relationship between soil P Indices and PO4 concentrations in runoff.
- Reducing P levels in soil does not have a significant impact in reducing particulate P loss.
- Reducing the P level to Index 3 is unlikely to be sufficient on its own to lower concentrations to below the EQS. An exception to this would be where there is significant dilution from areas surrounding 'high' pollution impact potential (PIP) areas in a subcatchment.
- There is a significant time delay for reducing soil P Index 4 to Index 3.
- Pathway interception, particularly in the delivery areas, is a critical measure to i) achieve concentrations below the EQS, ii) reduce particulate P losses and iii) reduce the time delays for improvement.

There is a danger, it seems to me, that those familiar with the literature will be pessimistic about when improvements will be seen, while those not familiar with it will have unrealistic expectations on when improvement might occur, and while others might decide to concentrate on point sources only. In my view, there are solutions to achieving significant improvement by the time of the 4th RBMP reporting date (2027), but the improvements in many situations (but not all) will not be in the immediate future. This Note tries to provide a basis for estimating realistic time frames for improvement.

## 10.2 Estimating time delays

In Tables 3 and 4, I have attempted to examine each of the components that influence the time for improvement (as outlined in Section 13.4) based on estimations of the situation**. The sum of the time delays from all the components is the time taken for the improvement to occur and for it to be indicated by monitoring/measurement.**[9]

The 'final' date for implementing the WFD, with the exception of catchments where 'natural conditions' do not enable the objectives to be met, is 2027. Taking account of the time needed to write the 4th River Basin Management Plan, the fact that biological monitoring is undertaken every three years and the time needed to analyse the field results, then improvements in Q-value would need to have taken place and have been verified by 2025 for some water bodies and 2026 for others. Therefore, 2027 should be seen as the date for reporting and not for improvement.

I have drawn some conclusions below for consideration:

- Many policies are in place for dealing with point sources.
- Some further policy development is needed for diffuse sources, in my view.
    - The current setback distances/buffer zones in the Regulations are narrow strips of land along watercourses. While they are beneficial (for instance, for biodiversity) and should be complied with in poorly-draining areas in particular, even if followed everywhere, they would not be sufficient to prevent nutrients and sediment entering water courses. As water runs off the land, it converges due to the micro-topography and enters watercourses at delivery points and areas that are a small proportion of the watercourse length. The role of pathway mitigation measures and actions would be to intercept the flowpaths, both in the vicinity of the watercourse banks and also, preferably, further back in the critical source area as well. Policy changes are needed to take this situation into account.
    - Issues such as incentivisation and 'payments for public goods' may need to be considered, including expansion of the results-based payments approach.

- The location of the *significant issues*, *significant pressures* and critical source areas for diffuse pressures, is an essential precursor for deciding on and establishing mitigation measures and/or actions.
    - Some *significant pressures* are already known, such as large point sources. But, the location of most of the small point and diffuse sources isn't know with a sufficient degree of accuracy to enable the execution of appropriate mitigation measures/actions.
    - Locating the critical source areas (CSAs) and delivery points for diffuse sources requires resources and time. This is now achievable by using the results of the EPA-funded DiffuseTools Project at subcatchment scale and the Local Catchment Assessments, which include catchment walks, being undertaken by LAWPRO and farm advisors at field scale. The CSAs need to be located so that measures and actions are targeted so that it can be ensured that they are effective.
    - The ongoing work of LAWPRO and the EPA Catchments Unit is critical to future success; without knowing where precisely measures/actions need to be targeted, they will not be effective and water quality will not improve. **Without this detailed**

[9] While the time delays given for each component are my estimations, they can be replaced with alternatives and then be used to arrive at an estimated time for improvement for different likely scenarios.

**scientific and advisory work, followed up by establishment of the appropriate mitigation measures/actions, it will not be feasible, in my view, to reduce the impacts of diffuse sources, and therefore not be feasible to show improvements in water quality or achievement of the WFD objectives in many *At Risk* waterbodies in the short- to medium-term.**

- Local catchment assessments, the input of farm advisors, programmes such as the Smart Framing initiative and EIP projects will make a difference in enabling greater awareness of the role diffuse sources of pollution and will encourage mitigation actions for diffuse sources to be undertaken.

- The location of all of the significant pressures and the diffuse source CSAs in the PAAs should be completed by end 2021. Their location in the catchment areas of *At Risk* water bodies outside the PAAs could be undertaken between 2022-2025, provided the staff and other resources are available.

- The time lag for reduction in source load from point sources is immediate once the mitigation measure(s) is/are in place.

- The time lag for reduction in phosphorus source load in soils on farmland (using nutrient management planning) could vary, depending on the circumstances, from 1-10+ years. I suggest taking the duration of a WFD cycle – 6 years – as a reasonable average. While this will seem long, pathway mitigation measures and actions, if they are established, can reduce this time lag. In any case, in water bodies where phosphate is the *significant issue*, reducing the source load to soil P index 3 alone as a measure is unlikely to be sufficient to reduce the phosphate concentration below the environmental quality standard (EQS) in many water bodies. A possible exception to this is a scenario where there is significant dilution from upstream by water with low $PO_4$ concentrations and a relatively small reduction of $PO_4$ load entering water would be sufficient to reduce concentrations below the EQS. However, the long time delay for source load reduction will still apply, therefore even in this scenario, pathway interception is recommended.

- Pathway interception, particularly in the delivery areas, is a critical measure to: i) achieve concentrations below the EQS; ii) reduce particulate P losses; and iii) reduce the time delays for improvement.

- **For situations where phosphorus is a *significant issue*, pathway interception measures and actions are the main means of reducing losses to watercourses. Therefore, while reductions in source P load in the soil is beneficial and needs to be implemented, the long time lag for reduction in source load need not be a determining issue or reason not to require the shorter time lags that pathway measures and actions give, provided that they are established in CSAs.**

- Pathway interception in critical source areas, particularly at **delivery points** to watercourses may need to be extensive, e.g. a woodland or a wetland 10s of metres wide, or a hedge planted on a low mound. Therefore, installation of these will need to be incentivised, in my view. Development of policies to facilitate this is urgent.

- For nitrate as a *significant issue*, load reduction and mobilisation control measures are the main means of reducing losses to groundwater and watercourses.

- It is advisable, in my view, to not set achievement of the status objectives as the only measure of improvement. Reducing trends in phosphate and nitrate concentrations at water body monitoring points could also be used as a measure of improvement. This has the advantage that improvements can be seen and recorded before biological responses occur and are recorded.

- The sum of the time delays from all the components is the time taken for the improvement to occur and for it to be verified by monitoring/measurement. The estimated time delays given for each of the six components in Tables 3 and 4 enable approximate time delays to be estimated depending on the various possible scenarios. The numbers given in Tables 3 and 4 can be substituted for other numbers by those who don't agree with those used in this Note.

- The analysis in this Note does not take account of sediment as a pollutant and *significant issue* in itself; there are water bodies where sediment entry to watercourses, due for instance to poaching adjacent to watercourses or land drainage, has caused failure to achieve the WFD status objectives. However, an estimated time for improvement could be estimated by using the approach shown in Table 3.

- Examples of time delays for different scenarios are given below:
    - If $PO_4$ is the *significant issue* arising from agriculture as a diffuse *significant pressure* in the catchment area of a surface water body, and <u>if the necessary policies are in place and are implemented</u>, then reduction in $PO_4$ concentrations would be feasible in one year, and would be measurable in the water chemistry, with improvements in the Q-value requiring 1-3 years, and then verified within 1-2 years. If the starting point (measures/actions in CSAs in place) was January 2022, improvement in water chemistry could be evident in 2022, with improvement in the Q-value by perhaps 2024/2025, which could be verified by monitoring in 2025 or 2026. This may be the optimum scenario for this situation, which is a common one for *At Risk* water bodies in poorly draining areas.
    - If the scenario above is taken as a starting point, but the required policies to enable targeting and establishment of appropriate measures and/or actions are not in place, then the projected 2025 or 2026 dates for showing improvements in Q-values are not likely to be achievable. However, if they are in place by, say, end 2022, and implementation occurs in 2023, improvements in water quality (e.g. reducing $PO_4$ concentrations) are likely to be evident by end of 2024 and conclusive by, perhaps, 2025-2026. There may not be the time in this circumstance to record improvements in status in the 2027 RBMP, but improvements in water quality could be recorded.
    - If an urban wastewater treatment plant (UWWTP) discharging to a water course is the sole *significant pressure* in a water body, upgrading of the treatment plant would result in an immediate reduction of nutrients which would be evident in the water quality monitoring results, and would result in achievement in a satisfactory Q-value 1-2 years later, which would then be shown by monitoring within two further years. If the treatment plant upgrade took place before end 2022 or perhaps even 2023, then evidence of improved biological status would be available for the 2027 RBMP.
    - If nitrate is the *significant issue* for a drinking water source in a limestone aquifer overlain by 5-6 m permeable soil and subsoil and if adequate measures and actions were in place, it could take perhaps 2-3 years before some reduction in nitrate would be evident and 3-6 years before a significant reduction occurs.

## 11 Conclusions

The time needed for improvements in both water quality and water body status depends on a variety of components, each of which have a time delay element. In addition, the time delay varies with the pollutant or *significant issue* that is causing the impacts.

By taking each component in turn for both phosphate and nitrate, and adding the projected time delays for each component, it is possible to estimate the dates by which improvements, either in water quality or status, will occur.

Estimation of the time delay for improvement assists in work and resource planning, enables projections on dates for improvements and allows expectations to be realistic.

Donal Daly
October 2019, minor amendments May 2020

Table 1: Summary of mitigation options to prevent/reduce loss of phosphorus to water from diffuse sources/farmland. (This list is not intended to be comprehensive.)

| Point along pathway | Mitigation option |
|---|---|
| Source control (reduction or elimination) | • Appropriate application rates, including no application on soil P index 4 soils.<br>• Reduced stocking rates and therefore reduced load to soil.<br>• Precision technology, e.g. using GPS & calibrated spreading equipment, to optimise spreading.<br>• Organic farming. |
| Mobilisation control | • Liming to ensure optimum pH.<br>• Timing of applications; in particular application in spring, and before end June.<br>• Soil incorporation of slurry.<br>• Cover/catch crops. |
| Pathway interception | • Riparian buffers.<br>• Hedges<br>• Woodlands<br>• In-field grass buffers & beetle banks in tillage fields.<br>• Contour farms in tillage fields.<br>• Interception ponds & constructed wetlands.<br>• Low earthen bunds.<br>• Field interception ponds.<br>• Ditches/drains that are 'engineered' and managed to intercept sediment. |

Table 2: Summary of mitigation options to prevent/reduce loss of nitrate to water from diffuse sources/farmland. (This list is not intended to be comprehensive.)

| Point along pathway | Mitigation option |
|---|---|
| Source control (reduction or elimination) | • Appropriate application rates to optimise take-up by crops.<br>• Reduced stocking rates and therefore reduced load to soil.<br>• Precision technology, e.g. using GPS & calibrated spreading equipment, to optimise spreading.<br>• Organic farming.<br>• Use of low crude protein animal feeds. |
| Mobilisation control | • Greater use of clover in place of inorganic N fertilizer.<br>• Use low emission slurry spreading (LESS).<br>• Use multi-species grass mixtures.<br>• Use of protected urea instead of urea and CAN.<br>• Liming to ensure optimum pH.<br>• Timing of applications; in particular application in spring, and before end June.<br>• Soil incorporation of slurry.<br>• Cover/catch crops. |
| Pathway interception | • Riparian buffers.<br>• Constructed wetlands.<br>• Permeable reactive barriers. |

Table 3: Time it may take for improvement where phosphorus is the *significant issue*

| **Components** | **Point source *significant pressures*** | **Diffuse source *significant pressures*** |
|---|---|---|
| Policy in place? | Policies in place<br>**Time delay: none** | Some 'one size fits all' policies in place, but are insufficient as they do not enable targeted measures in CSAs. Issues such as incentivisation and paying for public goods may need to be considered.<br>**Time delay: depends, might be years. Probably 1-2 at least.** |
| Policy implementation<br>Four elements:<br>*1. Location of sig. pressures.*<br>2. Research needs.<br>3. Consultation & collaboration<br>4. Execution of measures/actions. | 1. Location of sig. pressures<br>Large point sources known<br>**Time delay: none**<br>Small point sources being located by LAWPRO, assisted by LAs.<br>**Time delay: until 2021 for PAA areas; for water bodies outside PAAs could be 2025 depending on resources.**<br>2. No obvious research needs.<br>**Time delay: none**<br>3. LAWPRO undertaking this element.<br>**Time delay: none.**<br>**4. Time delay: 2020 for some PAAs, but completion not likely until ~2022.**<br>**Outside PAAs some ongoing work by LAs, but assistance from LAWPRO & farm advisors needed and not likely to be completed for all WBs until at least 2025.** | 1. Location of sig. pressures by LAWPRO, assisted by EPA Catchments Unit.<br>**Time delay: until 2021 for PAA areas; for water bodies outside PAAs could be 2025 depending on resources.**<br>2. Some further research would be beneficial, e.g. on the optimum design and costings of pathway measures/actions and on paying farmers for public goods. However, these need not delay execution of measures/actions.<br>**Time delay: none.**<br>3. LAWPRO undertaking this element.<br>**Time delay: none.**<br>4. The time taken to implement appropriate mitigation options (see Table 1) will vary; source and mobilisation control actions could be undertaken and be effective, in general, more quickly than pathway interception actions, such as planting of trees and hedges.<br>**Time delay in PAAs: Several of the source and mobilisation options could start to be in place due to voluntary actions by farmers following collaboration with farm advisors from 2020 for some PAAs, but completion not likely until ~2022. The pathway interception actions, which will also be needed, could be implemented within 1-2 years if the policies to facilitate them were in place, although it might take somewhat longer for some of them to reach optimum effectiveness.**<br>**Time delays outside PAAs: Some ongoing work by LAs, but assistance from LAWPRO & farm advisors needed and not likely to be completed for all WBs until at least 2025 unless more resources are available.** |
| Reduction in source load | **Time lag: immediate once implemented.** | **Time lag: 1-10+ years depending on the circumstances; suggest taking 6 years.**<br>*(Note: this time delay can be reduced significantly by interception and attenuation along the pathway and therefore need not be used in the time delay estimation.)* |
| Transport time along pathway | N/A | **Time lag: hours to days** |
| Attenuation along pathway | N/A | **Time lag: hours to days for soluble P and weeks to months for particulate P.** |

| | | |
|---|---|---|
| Pathway interception | N/A | **Time lag: weeks to months after establishment, but 1+ years for optimum effectiveness.** |
| Hydrochemical response | **Time lag: none** | **Time lag: gradual improvement in effectiveness, weeks, months with optimum efficiency after 1 year.** |
| Biological response | **Time lag: 1 year where an upstream water body is satisfactory** | **Time lag: might be as low as 1 year where a small reduction in nutrients and sediment is needed and the situation is satisfactory in an upstream stretch of watercourse, but 2-4 years, with the longer time needed where an inadequate biological status has been persistent and where an improvement in two status classes is required.** |
| Monitoring component | **Time lag: ~1 year for hydrochemistry.<br>1-3 years for biology and ecology status.** | **Time lag: ~1 year for hydrochemistry.<br>1-3 years for biology and ecology status.** |
| Estimated time delay for improvement | | |

*PAAs = Priority Areas for Action

Notes:

1. The final row enables you, the reader, to take scenarios that are relevant to you and to work out approximately how long it would take for improvements to occur.
2. This table only applies to *significant pressures* in *At Risk* water bodies that need to enable either WFD or drinking water objectives to be met, and not all pressures.

Table 4: Time it may take for improvement where nitrate is the *significant issue*

| Components | Point source *significant pressures* | Diffuse source *significant pressures* |
|---|---|---|
| Policy in place? | Policies in place<br><br>**Time delay: none** | Some 'one size fits all' policies in place, but are insufficient as they do not enable targeted measures in CSAs. Issues such as incentivisation and paying for public goods may need to be considered.<br>**Time delay: depends, might be years. Probably 1-2 at least.** |
| Policy implementation<br>Four elements:<br>*1.* Location of *sig. pressures.*<br>2. Research needs.<br>3. Consultation & collaboration<br>4. Execution of measures/actions. | 1. Location of *sig. pressures*<br>Large point sources known<br>**Time delay: none**<br>Small point sources are not a significant contributor of nitrate. | 1. Location of *sig. pressures* by LAWPRO, assisted by EPA Catchments Unit.<br>**Time delay: until 2021 for PAA areas; for water bodies outside PAAs could be 2025 depending on resources.**<br>2. Some further research on source reduction and mobilisation mitigation options might be beneficial.<br>**Time delay: none.**<br>3. LAWPRO undertaking this element.<br>**Time delay: none.**<br>4. The time taken to implement appropriate mitigation options (see Table 3) will vary; source and mobilisation control actions, which are the main options, could be undertaken and be effective.<br>**Time delay in PAAs: Several of the source and mobilisation options could start to be in place due to voluntary actions by farmers following collaboration with farm advisors from 2020 for some PAAs, but completion not likely until ~2022.**<br>**Time delays outside PAAs: Some ongoing work by NFGWS, but assistance from LAWPRO & farm advisors needed and not likely to be completed for all WBs until at least 2025 unless more resources are available.** |
| Reduction in source load | **Time lag: immediate once implemented.** | **Time lag: <1 year.** |
| Transport time along pathway | N/A | **Time lag: <1-6 years.** |
| Attenuation along pathway | N/A | **Time lag: None** (where NO3 is a *significant pressure*, any attenuation that occurs is inadequate). |
| Pathway interception | N/A | **Time lag: None.** |
| Hydrochemical response | **Time lag: none** | **Time lag: gradual improvement in effectiveness, weeks, months with optimum efficiency after 1 year.** |

| | | |
|---|---|---|
| Biological response | **Time lag: 1 year where an upstream water body is satisfactory** | **Time lag: might be as low as 1 year where a small reduction in nitrate is needed and the situation is satisfactory in an upstream stretch of watercourse, but 2-4 years, with the longer time needed where an inadequate biological status has been persistent and where an improvement in two status classes is required.** |
| Monitoring component | **Time lag: ~1 year for hydrochemistry.<br>1-3 years for biology and ecology status.** | **Time lag: ~1 year for hydrochemistry.<br>1-3 years for biology and ecology status.** |
| Estimated time delay for improvement | | |

Notes:

1. The final row enables you, the reader, to take scenarios that are relevant to you and to work out approximately how long it would take for improvements to occur.
2. This table only applies to *significant pressures* in *At Risk* water bodies that need to enable either WFD or drinking water objectives to be met, and not all pressures.