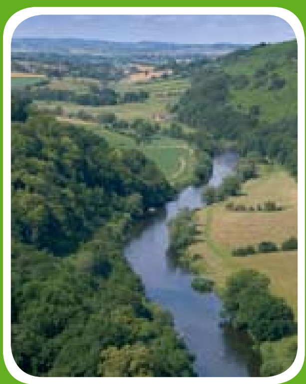

# NITRABAR

Recommendations Report

## A NOVEL TOOL TO ASSIST IN THE REDUCTION OF AGRICULTURAL DIFFUSE NITRATE POLLUTION IN EUROPE

The NITRABAR project has been made possible due to the contributions of the partners involved and the contributions of the LIFE financial instrument of the European Community.

Life

Recommendations Report

# A NOVEL TOOL TO ASSIST IN THE REDUCTION OF AGRICULTURAL DIFFUSE NITRATE POLLUTION IN EUROPE

**JULY 2009**



NITRABAR

This report is not a definitive guide to the application of the NITRABAR system. The NITRABAR Project strongly recommends that individuals/organisations interested in using this technology retain the services of experienced environmental professionals.

# Executive Summary

NITRABAR is a novel tool to assist in the reduction of agricultural diffuse nitrate pollution.

Nitrate pollution is a widespread problem across Europe. Most diffuse nitrate pollution comes from agricultural sources such as chemical fertilisers and manure. As a result, levels of nitrates in many groundwater bodies and rivers throughout Europe have increased over the last 50 years. This affects the ecological quality of freshwater and coastal habitats, which has knock-on effects on the recreational value and rural economy of the affected areas.

NITRABAR is intended to be a cost-effective measure for installation within a catchment to reduce diffuse nitrate pollution.  Most agricultural management options are designed to restrict the amount of nitrate entering the environment. The unique attribute of a NITRABAR system is that it can reduce the legacy of nitrate contamination in shallow groundwater that may be the result of fertiliser and manure application 20 or 30 years ago.

The NITRABAR technology may have a role in helping to meet the requirements of the Water Framework Directive which states that all inland and coastal waters within defined river basin districts must reach at least good status by 2015.

The NITRABAR system uses permeable reactive barrier technology and consists of a trench containing a mixture of natural materials, which removes nitrate from shallow groundwater immediately before it enters rivers or lakes. Both soil and groundwater contain bacteria which naturally degrade nitrate into nitrogen gas. The NITRABAR trench creates the conditions for these bacteria to flourish. NITRABAR is intended for placement between a field and a surface watercourse and may be used strategically to deal with major fluxes in a catchment or reduce flux to sensitive receptors.

The NITRABAR Project has successfully demonstrated the technology at a site in Northern Ireland at which nitrate concentrations were reduced by over 90%. The 46-month Project started in December 2005 and involves partners from Belgium, Malta, Poland, and the UK.  NITRABAR is a European Commission LIFE Environment Project.

This report consolidates the results of the NITRABAR Project and presents recommendations to encourage, where appropriate, the uptake and application of the NITRABAR system throughout Europe.

## Acknowledgements

The NITRABAR project has been made possible due to the contributions of the partners involved and the contributions of the LIFE financial instrument of the European Community.

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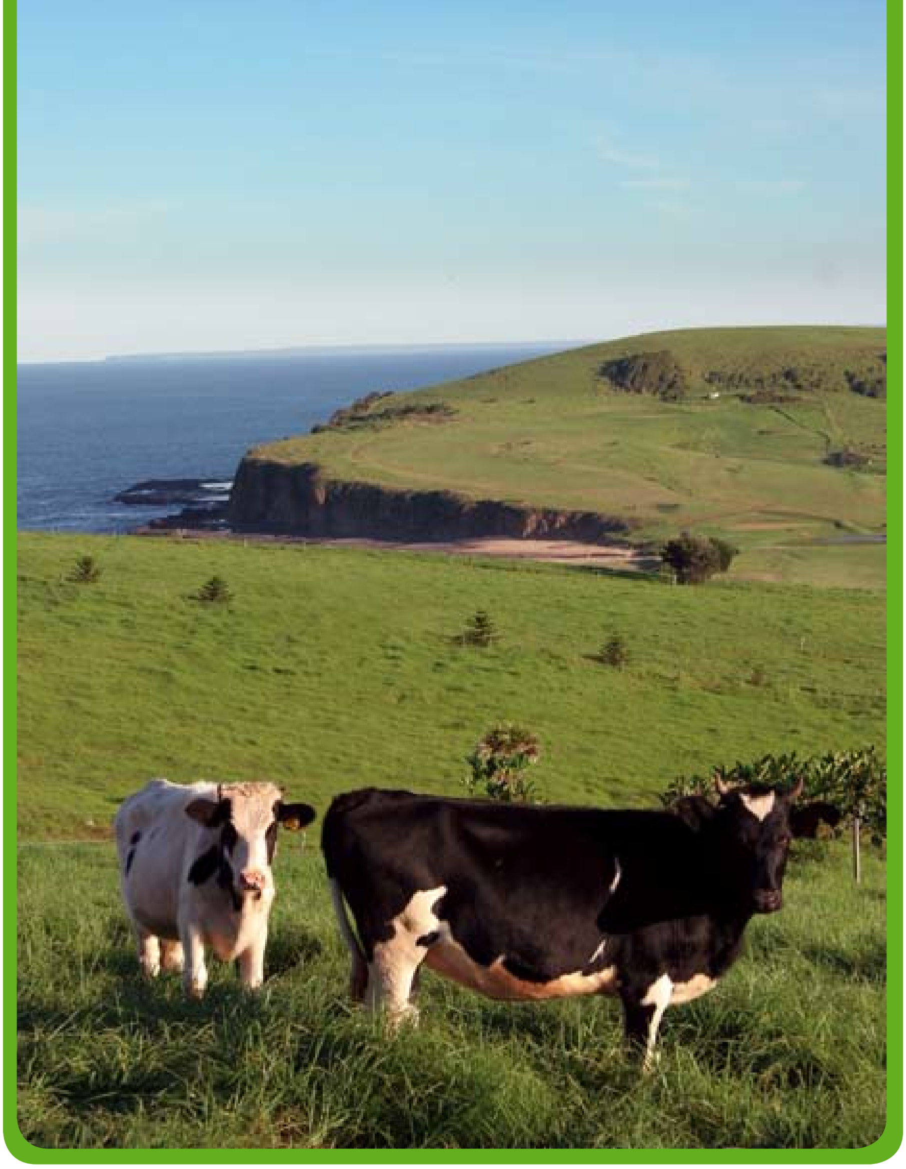
Key representatives from each Project Partner are listed on the NITRABAR website (www.nitrabar.eu).

The Project is also grateful for the input of Queen's University Belfast (Northern Ireland) and Greensan SA (Belgium) as Project Partners.

# Contents



# Introduction

NITRABAR

# 1. Introduction

This chapter presents the background to the issue of diffuse agricultural nitrate pollution in Europe, and provides the answers to the following questions:

- What is nitrate and why is it a problem?
- What is the scale of the nitrate problem in Europe?
- What is being done about the nitrate problem?
- What is the NITRABAR Project?
- How can the NITRABAR system help?
- What is the purpose and structure of this report?

## 1.1 What is nitrate and why is it a problem?

Nitrate ($NO_3^-$) has become a widespread contaminant in groundwater and surface water in many parts of Europe (Stålnacke et al. 2004; Johnson et al. 2007). The application of nutrients to land in the form of chemical fertilisers or manure is an essential part of modern farming practice. Nitrogen is one of the key nutrients applied, and is taken up by plants as nitrate to enhance growth. Nitrate is, however, also highly soluble and the excess easily passes into the soil and on into groundwater as well as being carried directly to surface waters in run-off and field drains.

As a result, levels of nitrates in many groundwater bodies and rivers throughout Europe have increased over the last 50 years. This affects the ecological quality of freshwater and coastal habitats, which has knock-on effects on the recreational value and rural economy of the affected areas. It has been estimated (EEAb, 2005) that agriculture is typically responsible for 50-80% of the total nitrate load in European waters.

High levels of nitrate can cause eutrophication in surface water bodies, leading to excessive plant (usually algal) growth, low oxygen levels and lower biodiversity (see Figure 1.1). In extreme cases the oxygen depletion results in death of invertebrates and fish.

Figure 1.1: Example of eutrophication on Loch Neigh, Northern Ireland (Source: A. McGarel)

Nitrate is not directly toxic to humans, but in highly reducing conditions (oxygen-free) such as in the human gut it converts to nitrite, which can be toxic. For this reason the drinking water standards in Europe have been set to safeguard against this, but at considerable cost of treatment to the consumer.

The cost of nitrate reduction through changes in land management, manure storage and fertilizer application lies in the range of €50-150 per hectare per year, but this is estimated to be 5 to 10 times cheaper than removing nitrate from polluted water (European Commission, 2002). In the UK alone, the cost to the water industry to reduce high nitrate levels caused by diffuse pollution in drinking water supplies has been estimated at €310 million[1] (capital expenditure) and €6.5 million[1] per annum (operating expenditure) for the 2005-2010 period. These costs are not static and are set to rise as groundwater concentrations continue to increase (Defra, 2007).

It should be noted that direct application of nitrate to land either by chemical fertilizers or manure, however, is not the only source. Atmospheric deposition, discharge from septic tanks and leaking sewers, the spreading of sewage sludge to land and seepage from landfills can all contribute to the pollutant load (Wakida and Lerner, 2005).

## 1.2 What is the scale of the nitrate problem in Europe?

The European Environment Agency (EEA) reports that the concentration of nitrate in European rivers and groundwater has remained constant over the past 10 years. This is despite the steady decrease of other parameters in rivers, such as phosphate and organic matter, as a result of improved standards of wastewater treatment and is largely due to diffuse pollution from agricultural land being the main source of nitrate in rivers (EEAb, 2005).

Whilst farming is not the sole source of diffuse nitrate pollution, it is widely accepted throughout the EU as the most significant. This is not difficult to comprehend in light of the fact that there are over 12 million farmers throughout the EU covering over 144 million hectares of land (European Commission, 2009).

To exemplify the scale of the problem; from 1950 to 2000 the annual use of mineral nitrogen increased in the EU from c1 million to nearly 10 million tonnes (European Commission, 2002). A further 7.6 million tonnes of manure is spread annually on agricultural soils throughout the EU, taking the total nitrogen pressure from agricultural nutrient improvements to 16.5 million tonnes in 2003 (European Commission, 2007). However these figures are dwarfed by the quantities of manure that are excreted by animals onto farmland. In England and Wales, 45 million tonnes of excreta was deposited on fields by grazing cattle, sheep and pigs in 2000 which constituted 75% of the nitrate input to its diffuse waters (Defra, 2003).

1 The exchange rate in March 2009 (1 Euro = £0.9281) has been used to convert the cost in Pound Sterling to Euros.

An indicator of nitrogen pressures from agricultural sources is shown in Figure 1.2 as the "gross nutrient balance", which represents the difference between nitrogen inputs (from mineral fertilisers, manure, atmospheric depositions, fixation by leguminous crops and other minor sources) and nitrogen outputs (uptake by crops, grassland and fodder crops) per hectare of utilised agricultural land. According to EEA calculations (EEAb, 2005), the gross nitrogen balance at EU 15 level in 2000 was 55 kg/ha, a decline of 16% compared to 1990, with a range from 37 kg/ha (Italy) to 226 kg/ha (the Netherlands). Gross nitrogen balance surplus decreased in all Member States except Ireland and Spain. Relatively small surpluses in nitrogen gross balance at national level underestimate surpluses in specific regions. The highest national nitrogen surpluses are found in regions of the Netherlands and Belgium (> 150 or 200 kg N/ha). The same levels of surplus, however can be found in Brittany (France) and in Vechta Cloppenburg (Lower Saxony, Germany). These regional surpluses can be clearly identified in Figure 1.3 with red and orange colours showing the areas with the highest surpluses.

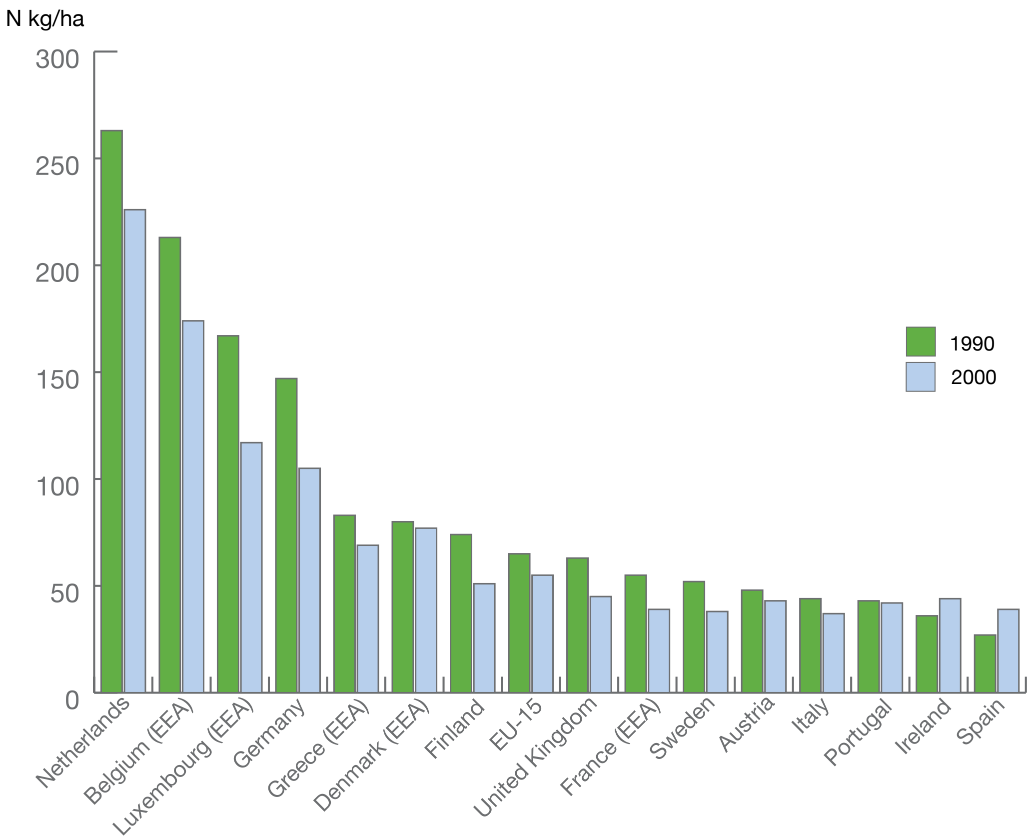



Figure 1.2: Gross nutrient balance from 2000 and 1990 for EU 15 Member States (Source: EEA (2005c))

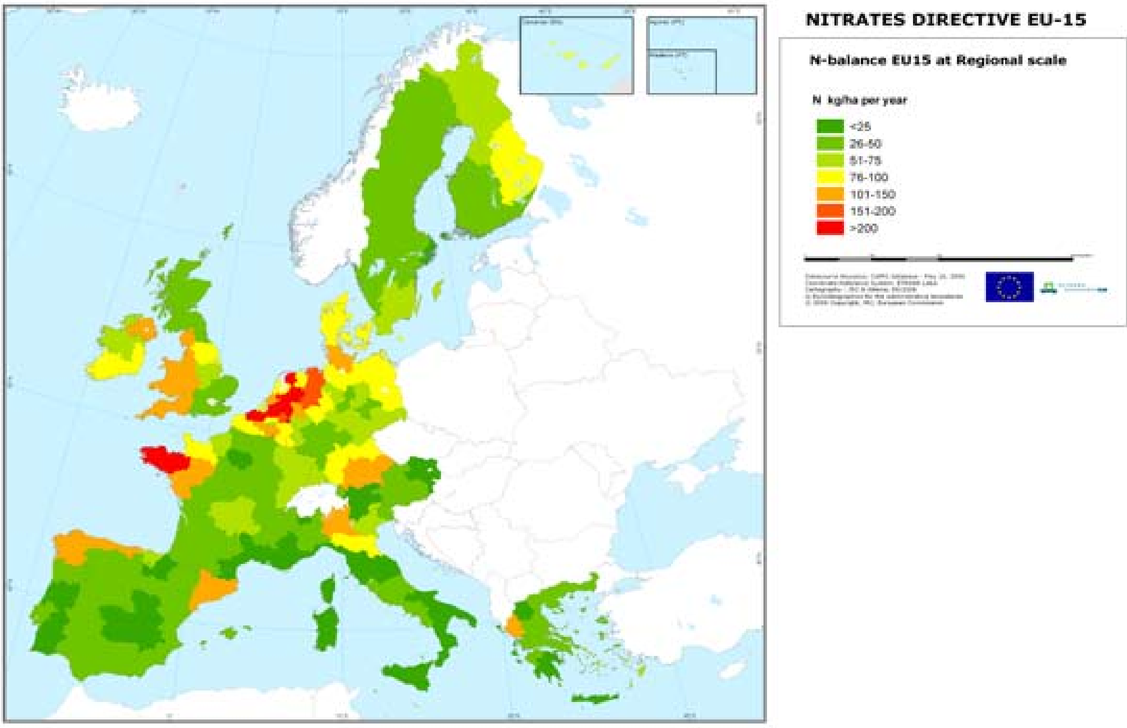



Figure 1.3: Nitrogen surplus in the EU 15 at regional scale
Source: European Commission (2007)

## 1.3 What is being done about the nitrate problem?

Three key regulatory instruments drive the reduction in nitrate levels in water bodies in Europe - Nitrates Directive, Water Framework Directive and Common Agricultural Policy and these are described in more detail below:

### Nitrates Directive (91/676/EC)

In 1991 Europe adopted the Nitrates Directive. It is an environmental measure designed to reduce water pollution by nitrate from agricultural sources and to prevent such pollution occurring in the future. The Directive requires Member States to:

- Designate as Nitrate Vulnerable Zones (NVZs) all land draining to waters that are affected by nitrate pollution.
- Establish a voluntary code of good agricultural practice to be followed by all farmers throughout the country.
- Establish an Action Programme of measures for the purposes of tackling nitrate loss from agriculture. The Action Programme should be applied either within NVZs or throughout the whole country.
- Review the extent of their NVZs and the effectiveness of their Action Programmes at least every four years and to make amendments if necessary.

The Nitrates Directive sets a limit of 11.3 mg N/l (50 mg $NO_3^-$/l) for use in identifying polluted waters.

## Water Framework Directive (2000/60/EC)

In 2000 the Water Framework Directive (WFD) came into force and it is the most substantial piece of water legislation ever produced by the European Commission, and will provide the major driver for achieving sustainable management of water in Europe for many years to come.

It requires that all inland and coastal waters within defined river basin districts must reach at least good status by 2015 and defines how this should be achieved through the establishment of environmental objectives and ecological targets for surface waters. The result will be a healthy water environment achieved by taking due account of environmental, economic and social considerations.

The WFD also introduced the river basin management planning system. This will be the key mechanism for ensuring the integrated management of: groundwater; rivers; canals; lakes; reservoirs; estuaries and other brackish waters; coastal waters; and the water needs of terrestrial ecosystems that depend on groundwater, such as wetlands.

The planning system will provide the decision-making framework within which costs and benefits can be properly taken into account when setting environmental objectives, and proportionate and cost-effective combinations of measures to achieve the objectives can be designed and implemented (www.wfduk.org/about_wfd).

Under Article 11 of the WFD, from 2006-2012, member states will need to develop the Program of Measures (POMs) for each River Basin District (RBD) which may include wide-ranging actions such as:

- Measures to manage specific pressures arising from: forestry, agriculture, urban development, etc
- Control regimes or environmental permitting systems
- Water demand management measures
- Economic instruments such as incentives, taxes on fertilizers, etc
- River restoration strategies, etc

How these are applied will depend on identifying the most cost-effective mechanism to meet the objectives set for each RBD. POMs are required to be operational by 2012.

## Common Agricultural Policy reforms

In 2003, the EU adopted a fundamental reform of the Common Agricultural Policy (CAP) which changed the way the EU supports its farming sector. Although the principle that farmers should comply with environmental protection requirements as a condition for benefiting from market support was incorporated into the Agenda 2000 reform, the 2003 CAP reform put greater emphasis on cross-compliance which has become compulsory. Cross-compliance is defined as the requirement to keep all farmland in good agricultural and environmental condition.

## Options for managing nitrate within a catchment

The regulatory instruments described above have been translated into national measures and action programmes at country level throughout Europe. Whilst some degree of success in reducing the nitrate problem has been reported (e.g. Denmark (NOVA 2003), Belgium (Prop'eau-Sable) and France (Ferti-Mieux)) the emphasis has primarily been on providing advice/education, promoting/enforcing good practice, and financial measures (incentives/penalties). There is, therefore, still a heavy reliance on the farming community to respond to and, consequently, deliver the desired reduction. Furthermore, it can do little to address the legacy of nitrate contamination already in the ground and groundwater which represents a long-term threat as it reaches surface waters over future decades. Nor does it address the input from excreta deposited directly on farmland. It is highly probable that these sources are responsible for the "considerable time lag between the improvements at farm and soil level and a response in water body quality" as stated in the European Commission *Synthesis from year 2000 Member States Report* concerning the implementation of the Nitrate Directive (European Commission, 2002).

A number of options can be considered for reducing nitrate loadings to water. These range from agricultural management changes to high technology treatment processes. The methods can be generally grouped into the following categories:

- Land use change
- Soil management
- Livestock management
- Fertiliser management
- Manure management
- Farm infrastructure
- Water treatment
- Groundwater interception

Water treatment has been considered to be a last resort due to its high cost and the benefits of managing pollution as close as possible to the source. The potential for interception of groundwater on farms has not been explored, with the exception of a small number of research and development projects (e.g. Schipper and Vojvodić-Vuković, 2001) that have established the potential viability of permeable reactive barrier technology to treat nitrate in groundwater.

Several European projects have been established in this subject area, such as the European Commission LIFE funded Water Resources Management in Cooperation with Agriculture (WAgriCo) project (www.wagrico.org), and the EU INTERREG Water4All and WaterCost (www.watercost.org) projects.

## 1.4 What is the NITRABAR Project?

The NITRABAR system is a trench containing a mixture of natural materials, which removes nitrate from shallow groundwater before it enters rivers or lakes. Both soil and groundwater contain bacteria which naturally degrade nitrate into nitrogen gas. The NITRABAR trench creates the conditions for these bacteria to flourish. NITRABAR is intended for placement between a field and a surface watercourse and may be used strategically to deal with major fluxes in a catchment or reduce flux to sensitive receptors.

The NITRABAR Project aims to demonstrate a field-scale permeable reactive barrier for removing nitrate from shallow groundwater at an agricultural site and assist others in the replication of the technology across Europe. The 46-month Project started in December 2005 and involves partners from Belgium, Malta, Poland, and the UK. NITRABAR is a European Commission LIFE Environment Project.

A number of challenges were faced by the NITRABAR project and these included:

- Identifying a suitable site for the demonstration
- Determining data requirements to design a PRB
- Evaluating a range of candidate material available throughout Europe
- Benchmarking the performance at one site against a variety of climatic and topographic settings
- Assessing performance under continuous and sporadic flow conditions
- Predicting the effective life of reactive materials

## 1.5 How can the NITRABAR system help?

This section introduces how the NITRABAR permeable reactive barrier (PRB) system can be considered as a nitrate management option. PRB technology has the potential to reduce nitrate inputs from field drains and groundwater by intercepting groundwater flow using a trench filled with suitable material to encourage denitrification (the conversion of nitrate into nitrogen gas). The material is also selected to make sure that water can flow through and to permit treated water to return to groundwater and ultimately to our surface waters. Further information on the technology can be found in Chapter 2.

A unique attribute of the NITRABAR system is that while the management options listed in section 1.3 are generally methods to restrict the amount of nitrate entering the environment, NITRABAR can reduce the legacy of nitrate contamination in shallow groundwater that may be the result of fertiliser and manure application 20 or 30 years ago.

## 1.6 What is the purpose and structure of this report?

This report consolidates the results of the NITRABAR project and presents recommendations to encourage, where appropriate, the uptake and application of the NITRABAR system throughout Europe.

Chapter 2 provides a brief background to permeable reactive barrier technology, which is the basis of the NITRABAR system. Chapter 3 describes the technical considerations that should be evaluated when deciding whether a site is suitable for the application of a NITRABAR system. It details the stepwise links between site baseline conditions, treatability parameters, design and implementation, and verification through monitoring. Chapter 4 estimates the potential cost of using the NITRABAR system in two different scenarios and also presents the results from a cost-effectiveness analysis of the NITRABAR system in comparison with a number of alternative management options. Chapter 5 considers the ease with which the NITRABAR system can be replicated throughout Europe with regard to both regulatory and climatic factors. Chapter 6 explores the decision process for implementing NITRABAR. Chapter 7 examines alternative applications of the NITRABAR technology to diffuse agricultural nitrate pollution and Chapter 8 provides the final conclusions.

## What is the Technology?

# NITRABAR

# 2. What is the Technology?

This chapter will provide a brief background to permeable reactive barrier technology, which is the basis of the NITRABAR system.

## 2.1 Permeable reactive barriers

A permeable reactive barrier (PRB) involves the placement of reactive material below the ground within which contaminants (such as nitrate) are changed to less harmful compounds or immobilised, whilst allowing groundwater to flow through. The technology has been used for over a decade to treat contaminants from industrial sites, and has been tested for nitrate treatment on a number of sites around the world (Smith et al., 2002; Schipper et al., 2005; US Air Force, 2008).

A PRB can be installed in a continuous trench or form reactive 'gates' between sections of wall that do not allow water to flow through. As a PRB is designed to intercept flowing groundwater it is ideal for dealing with nitrate released from a number of sources and is therefore a useful tool for dealing with diffuse agricultural pollution.

Once installed most of the PRB remains below ground and the only restriction on land use is to maintain an access strip to the barrier and protection of the headworks to monitoring points. There is therefore little visual impact or interference with most agricultural practices. In addition, a PRB typically has relatively low operation and maintenance costs.

The type of reactive material that is used within a PRB will vary according to the type(s) of contaminant(s) to be treated. Iron and other metals/minerals, and readily available carbon substrates such as tree bark, wood chippings, sawdust or leaf compost are used to induce reactions. The NITRABAR system takes advantage of microorganisms that are naturally present in the water which take part in a denitrification process.

## 2.2 The denitrification process

Denitrification is the microbial process whereby nitrate ($NO_3^-$) is reduced to nitrogen gas ($N_2$) through a sequence of enzymatic reactions:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$ [Equation 1]

This respiratory process is performed by bacteria that use $NO_3^-$ and $NO_2^-$ as electron acceptors instead of oxygen. Denitrification is generally inhibited by the presence of oxygen and is therefore limited to anoxic environments. The overall biological denitrification reaction can be expressed as follows:

$$5CH_2O + 4NO_3^- \rightarrow 2N_2 + 5HCO_3^- + 2H_2O + H^+ \qquad \text{[Equation 2]}$$

where $CH_2O$ represents a generic organic compound.

Organic carbon-based PRBs have been installed in two configurations with either horizontal or vertical layers. Horizontal layers are typically installed beneath new designed sources of nitrate, such as in infiltration systems serving septic tanks, whereas vertical layers are typically installed downstream of existing pollutant sources (Robertson and Cherry, 1995). The NITRABAR project is demonstrating the application of a vertical layer system, to intercept shallow groundwater as it flows in the horizontal plane towards a surface water course. Figure 2.1 shows a schematic diagram of a PRB for the treatment of nitrate.

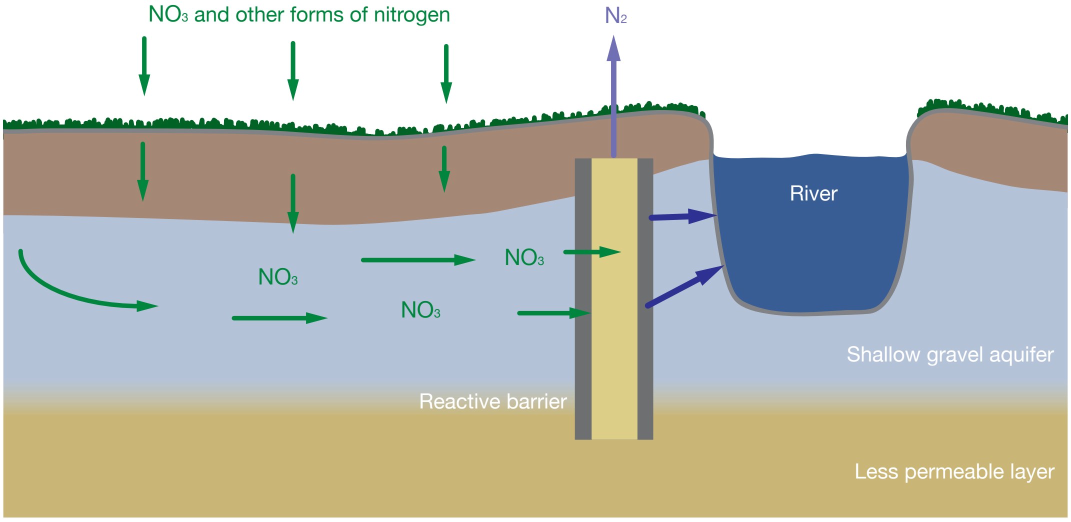



Figure 2.1: Schematic diagram of a PRB for treating nitrate-contaminated water.

## 2.3 The NITRABAR permeable reactive barrier

The NITRABAR permeable reactive barrier is a technology concept which innovatively integrates readily available and well understood components with the aim of providing European stakeholders with a means of installing a complex biological process as simply and cheaply as possible. All these components may not be needed in every application of NITRABAR but they have been used in the demonstration described in this report. Alternative methods for applying the technology in different forms are considered in Chapter 7.

The key components are briefly described below (see Chapter 3 for more details):

- A **gravel pre-chamber** connects the PRB to field drains and provides a highly permeable zone within the shallow groundwater environment, thereby drawing, capturing and retaining the primary diffuse sources of nitrate pollution, equalising the pressure of the head and delivering controlled flow rates.

- A **low permeability clay layer or liner** acts as a barrier between the nitrate pathway and the watercourse, enhances the retention of the captured contaminated waters, and eliminates the potential of preferential pathways

- **Gabion technology** retains the pre-chamber material (gravel) and the reactive media in discrete modules and facilitates maintenance of the PRB.

- An organic substrate is used as the **reactive media** in the barrier. This material is chosen based on performance in laboratory treatability tests. It is typically mixed with an inert filling material such as sand or gravel to ensure a high permeability in the PRB.

- A **gravel post-chamber** is installed to equalise flow back into the groundwater.


# Application of NITRABAR Technology

# NITRABAR

# 3. Application of NITRABAR Technology

## 3.1 Introduction

This chapter will describe the technical considerations that should be evaluated when deciding whether a site is suitable for the application of a NITRABAR system. Each aspect will be referred back to the demonstration site to provide an evidence-based example that the technology can be successfully applied.

NITRABAR is intended as a tool to be applied at the catchment scale. Therefore, an understanding of the zones of greatest contamination in a catchment and the vulnerability of rivers is important. A source-pathway-receptor approach can be taken to understand the different factors involved.

Figure 3.1 illustrates some typical sources of nitrate within a catchment (this image is taken from the NITRABAR online learning tool – see www.nitrabar.eu) such as the storage and application of fertilizer, grazing livestock and a slurry storage lagoon. Pathways are the means by which nitrate travels toward the river and include the slow movement of nitrate through the ground, which may take decades, or the more rapid movement of water through land drains, which can create a high speed link to surface waters. The most obvious receptor in Figure 3.1 is the river, however, as river reaches are long and linear it is not always obvious where a NITRABAR should, or could, be installed. A strategic decision needs to be taken so that it will intercept the most significant fluxes of nitrate, for instance, to intercept field drainage systems at time of storm flow to control peak nitrate releases, or to protect any particularly sensitive receptor. Another receptor in the diagram is the wetland area, which may be constructed or used to promote biodiversity, trap excess sediments and nutrients, and to provide water storage capacity. A NITRABAR could be installed to prevent excess nitrate from groundwater getting into a wetland – a clearly defined receptor with more finite boundaries than the river system.

Once a catchment-level understanding of areas where NITRABAR would be of value is achieved, the specific application of NITRABAR technology can take place as the following four key stages:

Stage 1: Understanding the site conditions
Stage 2: Designing the system
Stage 3: Installing the system
Stage 4: Verifying system performance

These stages will be explored in more detail in the following sections.

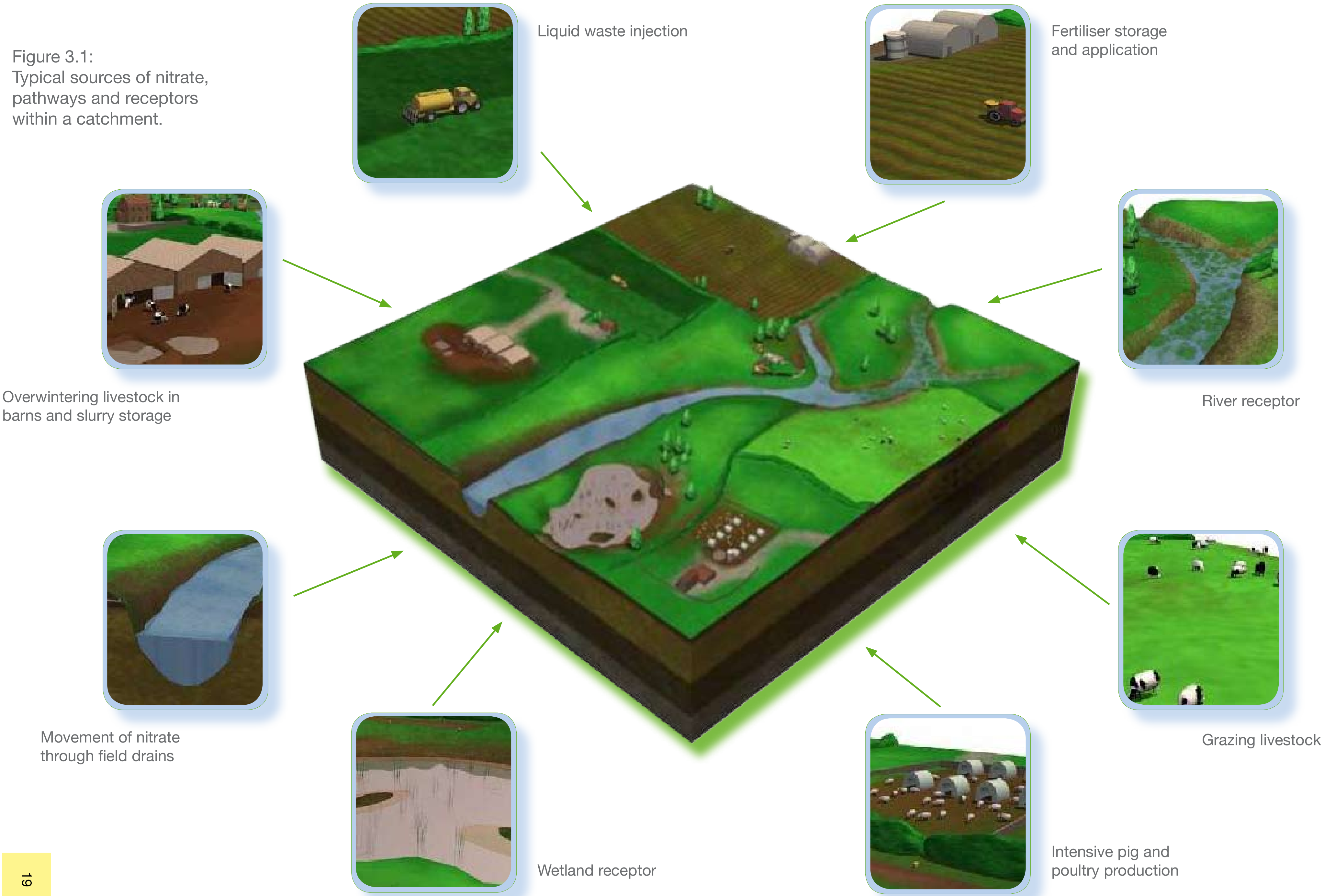



Figure 3.1:
Typical sources of nitrate, pathways and receptors within a catchment.

Application of Technology

## 3.2 Stage 1 - Understanding site conditions

The purpose of measuring and understanding the conditions at a site is to enable decisions to be made on the suitability of a NITRABAR system, and other measures that may be deployed. If the site conditions are suitable then this information is used in the design, installation and verification stages. Please note that this chapter is concerned with the technical feasibility of a NITRABAR system and that costs and wider benefits, which must form part of the decision-making process, are considered in Chapter 4.

Table 3.1 presents the key factors that should be considered in understanding the site conditions which are then expanded upon in the text below.

Table 3.1: Understanding site conditions

| Key stage | Key considerations |
|---|---|
| Site conditions | • Site topography, layout and future use<br>• Nitrate concentration and distribution<br>• Hydrology<br>• Hydrogeology<br>• Lithology<br>• Groundwater geochemistry<br>• Microbiology |

## Site topography, layout and future use

The current site topography should be assessed for suitability. This includes, for example, considering access for construction plant and stand-off from river banks (e.g. stability of ground), Also, NITRABAR is potentially a long-term tool, so future agricultural land use should be anticipated along with access rights to the site for time periods of years to decades.

## Nitrate concentration and distribution

It is important to determine the level of regulatory compliance by measuring the peak and mean nitrate concentrations.

## Hydrology

It is important to assess the significant pathways for nitrate transport (run-off vs infiltration) and groundwater to surface water interaction.

## Hydrogeology

It will be important to consider the following parameters: rate and direction of groundwater flow, aquifer permeability and heterogeneity (presence of preferential flow paths), and depth to water table. It is preferable that the NITRABAR system be installed to a lower confining layer. NITRABAR is dependent on the occurrence of shallow groundwater up to 3-5 m depth with a relatively stable hydraulic gradient toward the receptor. Any deeper and the installation costs rise sharply as more specialized plant and equipment will be needed.

## Lithology

Unsuitable lithologies include formations that are too hard or consolidated (e.g. competent bedrock) for trenching or excavation by available construction equipment, or sediments that are too unconsolidated (e.g. flowing sands) to remain open while the substrate mixture is being emplaced. In addition, the presence of permeable, high-yielding aquifer materials may result in a water-filled trench, making placement of the substrate mixture problematic. Similarly, very shallow drift over hard rock would not be ideal, or where the relief is too steep or variable to achieve predictable groundwater levels in unconsolidated substratum (US Air Force, 2008).

## Groundwater geochemistry

The following groundwater geochemical parameters will affect the efficiency of the denitrification process within the NITRABAR system: dissolved oxygen concentrations; redox potential; pH; temperature; and the presence of other species such as iron and sulphate. It should also be noted that phosphate concentrations may be an important consideration in system design, as, along with a carbon source, they have a role in maintaining microbial populations (Hunter, 2003).

## Microbiology

It will be necessary to confirm the presence of denitrifying bacteria. These bacteria are usually present, but not necessarily in sufficient numbers. Confirmation will typically be carried out when establishing the nitrate transformation kinetics from the treatability work that is needed to support the barrier design.

## Demonstration Site: Determining the site conditions

### Topography

The site is relatively flat. There is a significant meander present in the river which adds complexity to the hydrology.

### Hydrogeology and Hydrology

The following parameters were determined by groundwater measurements and calculations: hydraulic conductivity, transmissivity, specific storage, stream-aquifer interaction and baseflow analysis and quantification. The site hydrology was then modelled along with the reaction kinetics established in Stage 2, to help determine the location, orientation and dimensions of the NITRABAR.

### Lithology

A total of 29 boreholes were drilled at the site to determine the site lithology, which consisted of an upper layer of silt and clay to a depth of approx. 1.5 m below ground level (mbgl); an interval composed of coarse material (medium to coarse gravel and sand, with local beds of silt) that ranges in thickness from 1.5 to 3.0 mbgl; and a relatively stiff glacial till, which acts as a natural impermeable layer. Photographs of the borehole drilling are shown in Figure 3.2.

### Geochemistry

Analysis of subsurface soil and groundwater samples provided the nitrate concentrations at the site.

### Microbiology

The site groundwater was demonstrated to be a suitable source of denitrifying bacteria from the treatability study results.

Further details on the site investigation at the demonstration site can be found in the Deliverable D12: Site Investigation Project Report which is available from the NITRABAR website (www.nitrabar.eu).

Figure 3.2: Drilling of boreholes (part of the Site Investigation)

## 3.3 Stage 2 – Designing the system

Laboratory treatability studies are a key step in the design of the NITRABAR system. These studies, based on the data obtained from the site investigation, provide the operating window of the barrier and criteria such as residence time, attenuation rates, nitrate reduction and longevity of the media which help to determine the system configuration and dimensions.

The key considerations for system design are provided in Table 3.2 and expanded upon in the text below.

Table 3.2: Considerations for system design

| Key stage | Key considerations |
|---|---|
| Design of NITRABAR, based on site specific conditions determined above | • Selection of suitable materials for NITRABAR construction using laboratory treatability studies<br>• Positioning of NITRABAR<br>• Dimensions of the NITRABAR in relation to degradation rates, contaminant concentrations, and residence time |

### Selection of suitable materials for NITRABAR construction

A range of candidate materials should be considered for the reactive media in the NITRABAR. It is envisaged that the materials used will be low cost, readily available and ideally locally sourced to keep costs to a minimum. Some materials which have the potential to be used in a NITRABAR system are listed below:

- Tree bark
- Wood chippings
- Sawdust
- Organic waste compost
- Leaf compost
- Vegetable oil*
- Liquorice*
- Cotton*
- Newspaper* (*Della Rocca, 2007)

The most appropriate material would be determined using laboratory treatability studies to assess their nitrate reducing potential before a final decision could be made. Consideration should also be given to the hydraulic conductivity requirement and also the possibility of mixing reactive and non-reactive materials (e.g. gravel) to meet the required specification.

## Positioning of the NITRABAR

The NITRABAR will typically be installed perpendicular to the groundwater flow direction. Consideration should also be given to bank stability, the flood regime at site and the presence of field drains.

## Dimensions of the NITRABAR

Laboratory treatability studies will be necessary to calculate degradation rates and residence time, which are the two key design parameters in determining the dimensions of the NITRABAR. Currently there is limited information on reaction kinetics, but it is anticipated that, as the NITRABAR technology is used more widely there will be a choice of designing for a conservative reaction rate (from a more mature knowledge base) or carrying out site-specific studies. This is in keeping with the advance of any new technology as both knowledge and experience is gained.



## Demonstration Site: Designing the NITRABAR

### Selecting the materials

Laboratory treatability studies were undertaken on seven organic substrates to assess their capacity at promoting denitrification. The optimal organic substrate was then selected for bench-scale dynamic column experiments to better reflect flow conditions.

Laboratory studies showed that denitrification promoted by native soil was low and carbon limited, but it could clearly be enhanced by the use of an organic substrate.

Batch and column experiments demonstrated that mulch was a suitable organic substrate to promote denitrification and that it was a good candidate as filling material for the PRB to be installed at the site.

The results of the column experiments indicated that mulch successfully removed nitrate from an initial concentration of 50 mg/l $NO_3^-$- N to residual concentrations (<3 mg/l $NO_3^-$ - N) under continuous flow conditions, a reduction of >90% (see Figure 3.3). Denitrification (see Equations 1 and 2, pages 14 & 15) accounted for >90% (and mostly >95%) of the nitrate removal, while other processes such as dissimilatory nitrate reduction to ammonia (a competing process) contributed <10% (and mostly <5%).

The results emphasised the importance of residence time ($t_R$) in the performance of the NITRABAR system. Higher flow rates (lower $t_R$) clearly decreased the success of mulch at removing nitrate from the groundwater and, in practice, would result in an increase in the required thickness.

Further details on the treatability studies and system design can be found in the Deliverable D13: Treatment Capacity Parameters Project Report and the Deliverable D14: System Design Project Report which are available from the NITRABAR website (www.nitrabar.eu).

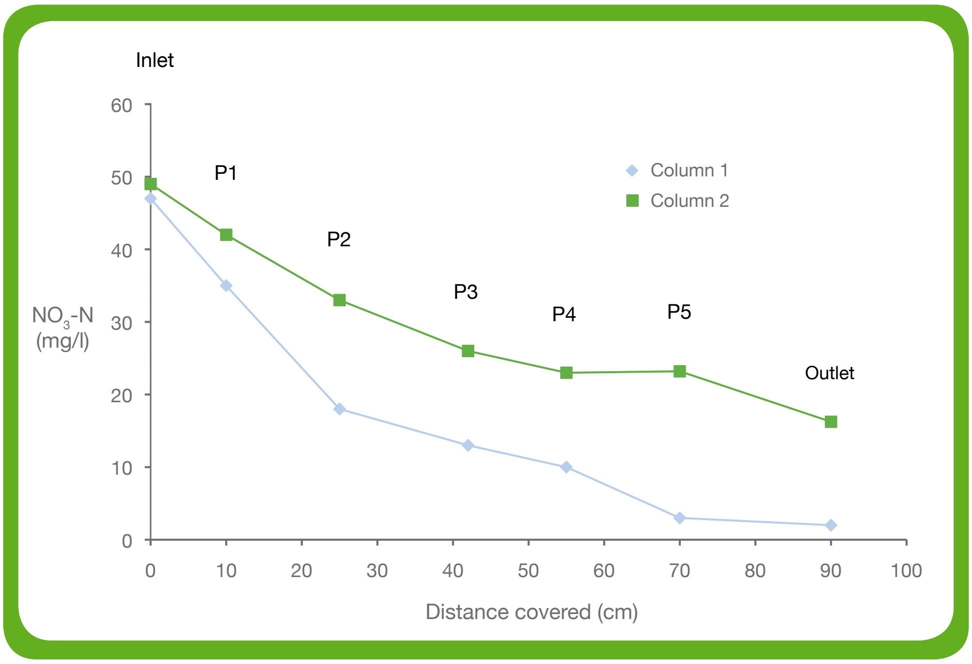



Figure 3.3: Results from the column experiments. Profile of nitrate concentrations (expressed as $NO_3^-$-N) along Columns 1 and 2. Different flow rates which equated to average residence times of 6.5 and 1.6 days for Column 1 and 2, respectively.

## 3.4 Stage 3 – Installing the system

Once the NITRABAR has been appropriately designed it is time to move towards installation. The general approach to be used for construction of a NITRABAR system is to use established construction techniques (e.g. conventional backhoe) to place the materials in an excavated trench.

The key considerations for system installation are provided in Table 3.3 below and expanded upon in the text below.

Table 3.3: Considerations for system installation

| Key stage | Key considerations |
|---|---|
| Installation of NITRABAR | • Installation and construction methods, including groundwater management during construction<br>• Engaging with suitable contractor<br>• Consultation with the regulator/appropriate person<br>• Establishing a monitoring network (tie in with Stage 1) |

## Installation and construction methods

At its simplest, the NITRABAR concept involves placement of a permeable (>10x strata hydraulic conductivity) reactive material to intercept and treat nitrate contaminated groundwater that flows through it (as shown in Figure 2.1). The construction can be carried out using readily available civil engineering plant and methods for trenching, filling and groundwater control. A range of modifications to the design concept can be made, for example to equalize flows/fluxes, to lengthen the flow pathway, or to control places of entry and exit from the barrier.

## Engaging with suitable contractor

During initial take up of NITRABAR (e.g. first 5 years), it is suggested that those seeking to promote the installation of NITRABAR systems on a regional scale would conduct a basic assessment of potential contractors by checking the track record for their core business (e.g. land drainage, trenching, water treatment systems). A health and safety plan for the installation of NITRABAR systems should be a requirement for all contractors. Public liability and professional indemnity insurance must also be considered. Engineering contractors should be registered with an appropriate body.

Once NITRABAR has become an accepted tool in any one area (estimated 5-10 years onwards), it is recommended that appropriate national organisations (e.g. the UK National Association of Agricultural Contractors or the Land Drainage Contractors Association) should set up schemes for registering companies that can install NITRABAR systems. This would help to secure confidence of those in the farming and land management sectors.

## Consultation with the regulator/appropriate person

It will be important to consult with the appropriate bodies relevant to regulation in your country. For project partners, these organizations could include:

- Belgium – Flemish Land Agency, Flemish Environmental Agency, Flemish Water Agency
- England and Wales – Local authorities, Environment Agency, Department for Environment, Food and Rural Affairs
- Malta – Malta Environment and Planning Authority
- Northern Ireland – Department of Agriculture and Rural Development, Northern Ireland Environment Agency
- Poland – Ministry of Agriculture and Rural Development
- Scotland – Scottish Government, Scottish Environment Protection Agency

## Establishing a monitoring network (tied in with Stage 1)

In the majority of cases, a NITRABAR will be installed to help meet objectives under the WFD. Strategically there will be a need to monitor on a water body basis to assess whether good status is being achieved and continues to be achieved. A monitoring network will inform if WFD goals are going to be breached in the future and may also provide information on the performance of the barrier and whether maintenance is required. It is conceivable that, in some cases, monitoring may not be required, but this will be at the discretion of the appropriate regulator, not the contractor or client.

## Demonstration Site: Installing the NITRABAR (1)

At the NITRABAR demonstration site the design included the following elements:

1. Open excavation and groundwater control
2. Gabion technology
3. Gravel pre-chamber
4. Reactive barrier
5. Gravel post-chamber

### 1. Open excavation and groundwater control

Prior to installation, ground conditions were checked by excavating a trial pit. A water strike was encountered at 1.3 m, from the first layer of gravel and the water entered the excavation. It was impossible to excavate any deeper than 2.7 m because of the amount of the incoming water, believed to have been influenced by the water level in the river. This influx of water resulted in some changes to the original design, which primarily involved the addition of a shallow trench on the downgradient side of the barrier to allow water ingress to be collected and diverted via a pipe to the dewatering point. This in conjunction with a shallow trench on the upgradient side of the barrier ensured that the excavation remained dry during the installation and backfilling process.

### 2. Gabion technology

The purpose of the gabions is to retain the pre-chamber material (gravel) and the reactive media in discrete modules and facilitate its maintenance.

### 3. Gravel pre-chamber

The gravel water capture chamber creates a highly permeable zone which draws and retains the site drainage and groundwater. The design of this chamber is such that it equalises the pressure of the head to deliver a controlled flow for water to the permeable reactive chamber.

It is important to ensure a hydraulic seal at the bottom of the NITRABAR during installation to prevent groundwater flowing under the barrier when complete. This can be done by using a low permeability clay liner or keying it into an underlying clay layer (if present) as at the demonstration site. The clay layer acts as a barrier to downflow, enhances the retention of the captured contaminated waters, and reduces the potential of preferential pathways.

### 4. Reactive barrier

Mulch was selected as the reactive material for the NITRABAR installed at the demonstration site, since it was the top-performing organic substrate to promote and sustain denitrification, identified during the treatability tests. The mulch mainly consists of hardwood (branches and bark), with small amounts of leaves (see Figure 3.4). It was supplied by a local business. For the installation of the PRB, a trench was dug and backfilled with a mixture 50% (v/v) of mulch and gravel (c5-10 mm size) previously homogenised. The gravel was added as an inert filling material to ensure a high permeability in the PRB. This composition was identical to that used in the laboratory experiments.

### 5. Gravel post-chamber

Another gravel layer adjacent to the downgradient side of the PRB enables water flow to equalize before returning to groundwater and flowing into the river.

Figure 3.4: Mulch (left) and 5-10 mm gravel (right) used in the NITRABAR

## Demonstration Site: Installing the NITRABAR (2)

Health and Safety Plan and Method Statements were prepared.

Given the site hydrogeology and hydrology, the NITRABAR system was installed perpendicular to the groundwater flow direction and parallel to the river approximately 13 m from the riverbank. The vertical position of the PRB was selected in order to be keyed into the underlying clay and to intercept the groundwater in the shallow aquifer. The thickness of the barrier was determined taking into account the groundwater velocity, the targeted influent nitrate concentration (50 mg/l $NO_3^-$-N) and the laboratory-derived denitrification half-life, which are crucial parameters that dictate the rate (or the time) needed for a targeted removal of contaminant.

The dimensions of the installed PRB are 80 m long, 1.7 m deep and 1.8 m thick, and it is installed 1.5 to 3.2 m below the ground.

Once these preparations were complete the excavation of the trench began using a 25 tonne hydraulic 360° excavator. The trench was excavated section by section (approx. 3.5 m depth x 4 m width at the bottom and 8 m width at the top x 12-14 m length). The distance between the barrier and the river was kept at approximately 13 m from the bank of the river during the installation process.

Excavated material (top soil and aquifer material) was brought to the surface and stockpiled separately on site. To minimize the risk of collapse and assist stability the excavation was partially sloped back to a safe angle of approximately 45°. The base of the trench was excavated a minimum of 200 mm into the underlying clay layer to prevent flow pass under the barrier when complete.

The trench was backfilled with a mixture of 50% (v/v) mulch and gravel previously homogenised. The gravel was added as an inert filling material to ensure a high permeability in the PRB. On completion of the works the excavation was reinstated with the various layers of excavated material.

Once the excavation and backfilling were complete the compaction of the site above the barrier was carried out to allow passage of agriculture type equipment. The site, access roads and storage area were cleaned of all surplus material and equipment daily. Once the groundwork was completed the site was made good and all access roads and storage areas were cleaned.

The monitoring wells were included in the installation works and were surrounded with security fencing to protect against vandalism and enable easy visibility during agriculture works.

Tracer tests were applied to confirm that both the natural gradient of the water table and the permeability of the reactive material permit water flow through the system and that specific design parameters are achieved, e.g. residence time.

Further details on the installation can be found in the Deliverable D14: System Installation Project Report which is available from the NITRABAR website (www.nitrabar.eu).

## 3.5. Stage 4 – Verifying system performance

The purpose of this stage is to objectively verify that the NITRABAR installation will deliver significant nitrate concentration reductions. The demonstration site is taking the verification one stage further to provide a robust and comparative quantification of system performance and the hydrogeological effects of installation.

As NITRABAR systems begin to be deployed across Europe, verification will be the responsibility of the problem-holder, whether it is an individual farmer on a single field system or wider "catchment manager" protecting a sensitive receptor from multiple diffuse and point sources. Long term performance data will be needed to assure regulators and land managers that NITRABAR is making an effective contribution to the reduction of nitrate levels in sensitive river catchments. It should be noted that NITRABAR will only contribute, rather than be wholly responsible for nitrate reduction, as it is likely that within a catchment a NITRABAR system will not be the only measure being employed to address agricultural diffuse nitrate pollution. It will be the combined effectiveness of all measures that will contribute to improvement in the status of a water body.

The key considerations for system performance verification are provided in Table 3.4 below and expanded upon in the text below.



Table 3.4: Considerations for verifying system performance

| Key stage | Key considerations |
|---|---|
| Verification of NITRABAR performance | • Verification objectives and criteria<br>• Frequency of monitoring and location of monitoring points<br>• Type of monitoring required, deciding which parameters to monitor<br>• Longevity of system |

### Verification objectives and criteria

These will be set during the project design (Stage 2), but will be up for periodic review once the NITRABAR is installed.

### Frequency of monitoring and location of monitoring points

The location of monitoring points will be guided by the verification objectives and any regulatory requirements. Monitoring points will typically be located upgradient, within, and downgradient of the NITRABAR system, parallel to the direction of groundwater flow. Additional points may be located to the side and below the barrier to provide assurance that nitrate polluted water does not flow around or under the barrier. In terms of monitoring frequency, it is likely that initial monitoring will be more frequent and more extensive than longer term monitoring.

## Type of monitoring required, deciding which parameters to monitor

As above, the parameters to be monitored will be linked to objectives and regulatory requirements and are likely to include some of the following parameters (taken from Environment Agency, 2002):

Field parameters: Water level, pH, dissolved oxygen, temperature, redox potential (Eh)
Target pollutants: Nitrate and denitrification products ($NO_2^-$, NO and $N_2O$)
Inorganic parameters: Alkalinity, sulphate, potassium, phosphorous etc

The chosen parameters may have their own monitoring frequencies and locations.

## Longevity of system

The lifetime of a NITRABAR system can be considered in terms of its hydraulic performance and any potential clogging, and also in terms of it maintaining an effective source of carbon. As long as the NITRABAR was designed properly, then it would be expected to achieve a lifetime of >10 years.



## Demonstration Site: Performance of the NITRABAR

### Monitoring wells

Monitoring was carried out in 24 wells located upgradient and downgradient of the NITRABAR system, and also in the river up and down stream of the barrier. Two additional sets of monitoring wells were installed to monitor groundwater inside the barrier. Both of these consist of 3 nested piezometers with a 0.5 m slotted screen each, terminated at depths of 2.0, 2.5 and 3.0 m below ground.

### Monitoring schedule

Samples were taken periodically over a 10 month period and submitted for analysis at a UKAS accredited laboratory.

### Results

The results show that nitrate is being effectively removed within the barrier, with concentrations at the inlet being reduced by over 90% as water moves through the barrier. Evidence that denitrification is occurring and that nitrate is not being lost to the environment has been gathered and, since monitoring is ongoing, the most recent laboratory results, which clearly show the effectiveness of the barrier, are available to view on the NITRABAR website (www.nitrabar.eu).

# Economic Considerations

NITRABAR

# 4. Economic Considerations

This chapter will provide a discussion of the costs and benefits of using the NITRABAR system to treat diffuse nitrate pollution from agriculture with reference to the demonstration site and the wider application of the technology.

The chapter is divided up into three sections which address the following questions:

- What are the costs of installing a NITRABAR system?
- How does NITRABAR compare to other measures which deal with diffuse nitrate pollution from agriculture?
- What are the wider costs to society of diffuse nitrate pollution from agriculture and the benefits to reducing its impact?

## 4.1 Costs of installing a NITRABAR system



Two approaches have been taken in order to provide indicative costs for the installation of a NITRABAR system, one based on the demonstration site (Scenario 1) and the other based on trenching technology (Scenario 2), which is considered a lower cost alternative of implementing the NITRABAR technology. The installation cost for both scenarios does not include site characterisation and monitoring costs.

### Scenario 1 – demonstration site

This scenario is for the installation of a single 100 m barrier, 1.7 m deep and 1.8 m wide constructed using a 360 degree excavator, utilising the materials and equipment that were used at the demonstration site. Table 4.1 shows the cost items which have been split into four categories – plant, materials, equipment, and labour. It is interesting to note that the cost of materials is approximately 12% of the total installation costs, which corresponds well with other installations in which material costs are seen to fall within the 10-15% of the installation costs (US Air Force, 2008). In addition, free mulch can often be obtained from a local supplier, but there may be handling and delivery requirements which need to be met.

Table 4.1: Cost of Scenario 1 installation

| Item | Cost Estimate (Euros) |
|---|---|
| Plant – excavator, dumper | 3,800 |
| Materials – mulch, aggregate, gravel | 2,700 |
| Equipment – gabions, geotextile liner, pump, fencing, monitoring wells | 8,600 |
| Labour | 7,800 |
| Total | 22,900 |

It is important to make clear that these costs, based on the demonstration site, will be much higher than a typical installation using the same design and materials. This is common in proof of concept schemes where extra rigour and robustness is required. For example, it would be expected that the labour element could be reduced significantly with a shorter installation period (10 days in this instance). In addition, it does not take into account savings that could be made through economies of scale, where several hundred metres or even a few kilometres are installed, and using established material suppliers or contractors. Nevertheless, it provides a useful approximate costing for this report.

### Scenario 2 – installation by trencher

This scenario is for the installation of a single 100 m barrier, 1.7 m deep and 0.6 m wide using a trencher. It should be noted that the width of the barrier has been reduced to one third of the width in Scenario 1, which corresponds to the width of a trencher blade. The efficiency of the NITRABAR at the demonstration site suggests that reducing the barrier width and hence the barrier materials in this way would not significantly affect barrier performance in this instance. Table 4.2 shows the cost items and the estimates of their cost. Within the cost estimate for the trenching subcontractor is a 3600 Euro mobilisation fixed cost, which makes up 47% of the total installation costs. The relative cost of mobilising the trencher will fall as the length installed increases. For example, if a 500 m trench was installed using the same method and materials, then the mobilisation cost would only equate to 15% of the total costs. One of the advantages of trenching is speed and the 100 m installation could be carried out in a single day, compared with the 10 days used for Scenario 1.

Table 4.2: Cost of Scenario 2 installation

| Item | Cost Estimate (Euros) |
|---|---|
| Trenching subcontractor (incl mobilisation) | 6,500 |
| Materials – mulch, gravel | 800 |
| Equipment – monitoring wells | 100 |
| Site labour | 300 |
| Total | 7,700 |

The total cost for this scenario is significantly less than that given above. However, it is not the intention that the two scenarios are compared directly as assumptions would need to be made about the relative performance of the barriers given that the width of the barrier is one third of that in Scenario 1, the volume of reactive material used is one third, and the material costs are proportionally reduced (incidentally, material costs are about 10% of total installation costs).

As in the case of Scenario 1, savings will be made through economies of scale and by using established material suppliers or contractors, but the cost estimate represents an indicative cost for this type of work.

## 4.2 A comparison of NITRABAR with other measures that deal with diffuse nitrate pollution from agriculture

There are number of options or measures which can be considered for reducing the impact of diffuse nitrate pollution from agriculture. These range from agricultural management changes (which tackle the problem at or close to the source) to high technology water treatment processes (which deal with the problem much closer to the receptor).

Cuttle et al., (2007) produced an inventory of agricultural management methods to control diffuse water pollution from agriculture and they grouped the methods into the following categories:

- Land use change (e.g. changing arable land to native grassland)
- Soil management (e.g. establish cover crops in the autumn)
- Livestock management (e.g. reduce numbers of livestock)
- Fertiliser management (e.g. avoid spreading fertilizer to fields at high risk times)
- Manure management (e.g. increase capacity of farm manure stores)
- Farm infrastructure (e.g. establish riparian buffer strips)



The majority of these options relate to practices which aim to prevent or reduce new nitrate sources from impacting the environment, but do little to address the nitrate that is already present in the groundwater and which continues to feed into rivers.

Two other options, not related to agricultural management, are water treatment (e.g. water companies treating drinking water to remove nitrate) and groundwater interception and treatment. The former was estimated to cost the UK water industry around €25m per year (2004 prices) (eftec, 2004) and the latter is the category that NITRABAR falls in to.

In order to compare NITRABAR with the types of alternative options mentioned above it was necessary to conduct a cost-effectiveness analysis (CEA). CEA is a process for identifying the least cost option for meeting an objective. For example, in the context of the Water Framework Directive (WFD), where there are a number of potential measures that could be implemented to achieve good ecological status for a water body, CEA is used to compare each of the options and identify which option delivers the objective for the least overall cost. CEA is different from Cost-Benefit Analysis (CBA). CBA compares the costs and benefits of undertaking an action (or achieving an objective). CBA therefore addresses the question of whether the objective (or action) is economically worthwhile: do the benefits exceed the costs? In contrast, CEA does not assess the benefits that may result from achieving the objective. The CEA process is simply used to identify the most cost-effective option of achieving the objective. CBA is discussed further in section 4.3.

## The CEA Process

A CEA was conducted for this project by ADAS UK Ltd and is discussed further below.

If NITRABAR was adopted as an effective measure and used on a significant scale it is likely that it would be installed using a trencher machine as described in Scenario 2 in section 4.1, for a 100 m long barrier, 0.6 m wide and 1.7 m deep. The CEA was carried out at 2009 prices and in pounds sterling, however, the exchange rate in March 2009 (1 Euro = £0.9281) has been used to convert the cost to Euros.

## Calculation of Nitrates Removed and Cost-Effectiveness

To calculate the cost effectiveness of NITRABAR it is necessary to calculate the amount of nitrate removed from the groundwater that flows through the barrier in a year. Table 4.3 shows these values for two flow rates and two upstream concentrations of nitrate. The fastest and slowest measured flow rates at the demonstration site are used and the concentrations of nitrate were chosen to represent "very high" (120 mg/l) and "high" (60 mg/l) agricultural conditions both reducing to 10 mg/l. The calculation assumes that the measured flow rate is the annual average and also that the concentration of nitrate in the groundwater does not vary seasonally or annually. The calculated range of nitrate removed is from 11 to 42 kg per year depending on flow rate.

Table 4.3: Annual nitrate removal

| | Faster flow rate of 1.04 $m^3$/day | Slower flow rate of 0.632 $m^3$/day |
|---|---|---|
| Kilograms of nitrate removed for high initial nitrate concentration of 60 mg/l | 19.0 | 11.5 |
| Kilograms of nitrate removed for very high initial nitrate concentration of 120 mg/l | 41.8 | 25.4 |

The cost of intercepting the nitrates in water using NITRABAR depends on the economic life of the barrier. In practice the barrier has a decay curve and the persistency of its effect would be defined by its half life. The economic life would be the number of years for which it would remove sufficient nitrates to achieve the standard set for the river. In the analysis 10 years have been assumed. The capital cost is converted to an annual cost using an amortisation table, in which a 3.5% discount rate has been used which is currently the test discount rate used by the UK Treasury. Two assumptions are also made. Firstly there is no maintenance cost and secondly the barrier can be left in the ground at the end of its life.

Table 4.4 shows the cost-effectiveness of NITRABAR in Euros/kg of nitrate removed for two flow rates and for two nitrate reductions and the range is from 22 to 80 Euros/kg nitrate.

Table 4.4: Summary of cost-effectiveness

| | | |
|---|---|---|
| Amortisation Factor @ 3.5% for 10 year barrier life (Euros/1000 Euros) | 120 | |
| Cost for 100 m (Euros/year) | 924 | |
| | **Faster flow rate of 1.04 $m^3$/day** | **Slower flow rate of 0.632 $m^3$/day** |
| Cost effectiveness for high initial nitrate concentration of 60 mg/l | 48.6 | 80.1 |
| Cost effectiveness for very high initial nitrate concentration of 120 mg/l | 22.1 | 36.4 |

The cost-effectiveness of other agricultural methods for reducing diffuse nitrate pollution from agriculture has been measured by Sorensen et al., (2006) and a selection of these methods is presented in Table 4.5 to illustrate the wide range of values. The cost information is at 2006 prices.

Table 4.5: A selection of nitrate abatement measures and costs

| Method | Cost (Euro/kg N) |
|---|---|
| Increase manure and/or slurry storage capacity to prevent nutrient rich run-off | 1.56 |
| Integrate fertiliser and manure applications to reduce nutrient loading | 4.85 |
| Reduce livestock numbers to achieve an acceptable N&P surplus to reduce nutrient loading | 31.34 |
| Install and operate dirty water collection and treatment system to prevent nutrient rich run-off | 170.14 |

When the results for NITRABAR are compared with the values in Table 4.5, it is clear that the range of cost-effectiveness of NITRABAR (22 to 80 Euros per kg) overlaps the range of other agricultural methods. It should be noted that although NITRABAR is toward the upper range of values, it would become more cost-effective in longer installations than 100 m due to economies of scale.

In the same way that the methods listed by Sorensen et al., (2006) will not be applicable to every farm or every location, NITRABAR is also dependent on location and the other site condition factors discussed in section 3.2. It is simply another option to manage diffuse nitrate pollution from agriculture, and importantly, it can be used to target legacy pollution without impacting on groundwater resource (unlike the tree planting involved in buffer strips and reed beds that will evapo-transpire). For example, methods which reduce the source of nitrate (for example reduced fertiliser applications) have a time lag where it takes many years for groundwater to reach water courses. These methods will have little impact on some rivers which are struggling to meet good ecological status by 2015. In these cases, NITRABAR may be a feasible and cost-effective solution.

## 4.3 What are the wider costs to society of diffuse nitrate pollution from agriculture and the benefits to reducing its impact?

In the previous two sections the costs of implementing NITRABAR have been assessed and compared with the costs of other potential solutions to agricultural diffuse nitrate pollution. However, before considering any option thought must be given to whether it is worth doing anything at all, that is, assessing whether the benefits of reducing diffuse nitrate pollution outweigh the costs of dealing with the problem. One of the ways of looking at this further is through cost-benefit analysis (CBA), and this is discussed in more detail below.

CBA has long been used as an economic decision-making support tool to identify and quantify the total costs and benefits to society of a policy, activity or investment, not simply the costs to one business or organisation. However, in practice, it can be difficult to value all the costs and benefits of decisions in monetary terms since some attributes are either not easily valued (e.g. an improvement in biodiversity due to a reduction in water pollution) or the cost of doing so is prohibitive.

A good general approach to doing CBA is as follows:

- Understand the policy, activity or investment thoroughly
- Look for cause and effect
- Decide who are the cost bearers and beneficiaries
- Gather information and data which will help quantify the costs and benefits
- Think about when costs and benefits arise
- List and put a monetary value on the costs and benefits

Undertaking a CBA can be extremely complex and costly and is therefore outside the scope and budget of this project; a full CBA would a useful task for any follow-on work. However, there is information available on the costs and benefits of diffuse water pollution from agriculture (Tables 4.6-4.8), although this does not often separate nitrate from other major agricultural pollutants - phosphate, pesticides and faecal indicator organisms, therefore in this discussion they are simply grouped together as diffuse water pollution from agriculture.

Table 4.6 provides the annual cost of damage to freshwater from diffusion water pollution from agriculture in England and Wales (2008 prices), and the values are reported as a significant underestimate. Table 4.7 goes into more detail on the annual costs of freshwater eutrophication in the UK in terms of social and ecological damage costs as well as policy response costs incurred in responding to eutrophication (2003 prices). This table gives an idea of the complexity of CBA in which 10 different costs have been provided for the social damage alone.

The total costs in each table, not directly comparable due to different assumptions made in their calculation, are of the same order of magnitude, although the five years between publication dates and the fact that Table 4.6 only has data for England and Wales should be taken into account. It is clear, however, that the cost of diffuse pollution from agriculture is considerable.

Table 4.6: Cost of damage to freshwater from diffuse water pollution from agriculture – England & Wales (Jacobs, 2008)

| Category | € million per year (converted using July 2008 exchange rate) |
|---|---|
| Rivers (Rivers of less than 'good' quality due to agricultural diffuse pollution) | 58 |
| Lakes (Eutrophication in lakes due to agricultural diffuse pollution) | 34 |
| Abstraction | 47 |
| Drinking water | 163 |
| **Total cost** | **303** |

Table 4.7: Summary of annual costs of freshwater eutrophication in the UK (Pretty et al., 2003)

| Cost categories | € million per year (2003 prices) |
|---|---|
| (A) Damage Costs: Reduced Value of Clean or Non-Nutrient-Enriched Water | |
| (A1) social damage costs | |
| (i) reduced value of waterside properties | 14.7 |
| (ii) reduced value of water bodies for commercial uses (abstraction, navigation, livestock watering, irrigation, and industry) | 0.7-1.5 |
| (iii) drinking water treatment costs (treatment and action to remove algal toxins and algal decomposition products) | 28.4 |
| (iv) drinking water treatment costs (to remove nitrogen) | 30.0 |
| (v) cleanup costs of waterways (dredging, weed-cutting) | 0.7-1.5 |
| (vi) reduced value of nonpolluted atmosphere (via greenhouse and acidifying gas emissions) | 7.6-11.9 |
| (vii) reduced recreational and amenity value of water bodies for water sports (bathing, boating, windsurfing, canoeing), angling, and general amenities (picnics, walking, aesthetics) | 14.4-50.1 |
| (viii) revenue losses for formal tourist industry | 4.4-17.4 |
| (ix) revenue losses for commercial aquaculture, fisheries, and shell-fisheries | 0.04-0.2 |
| (x) health costs to humans, livestock, and pets | Near zero |
| (A2) ecological damage costs | |
| (i) negative ecological effects on biota (arising from changed nutrients, pH, oxygen), resulting in changed species composition (biodiversity) and loss of key or sensitive species | 11.0-15.1 |
| Total | 112-171 |
| | |
| (B) Policy Response Costs: Costs Incurred in Responding to Eutrophication | |
| (B1) compliance control costs arising from adverse effects of nutrient enrichment | |
| (i) sewage treatment costs (to remove P from large point sources) | 75.1 |
| (ii) costs of treatment of algal blooms and in-water preventative measures (biomanipulation, stratification, straw bale deployment) | 0.7 |
| (iii) costs of adopting new farm practices that emit fewer nutrients | 5.1 |
| (B2) direct costs incurred by statutory agencies for monitoring, investigating, and enforcing solutions to eutrophication | |
| (i) monitoring costs for water and air | 0.7 |
| (ii) cost of developing eutrophication control policies and strategies | 0.3 |
| Total | 82.1 |
| | |
| Total Costs (Damage (A) + Policy Response (B)) | 194-253 |

In terms of understanding the potential benefits to society from reducing diffuse water pollution from agriculture, Table 4.8 provides some estimates for England (2006/07 prices). These benefits are measured in two principal ways (Defra, 2006):

- The public's willingness to pay (WTP) for improvements in water quality. This measures the total benefit to the public from a policy intervention.
- Reductions in the cost of current measures that address water pollution.

These potential benefits to society include effects through improved terrestrial and aquatic habitats (biodiversity), amenity, recreation (including fishing), drinking water quality and health.

Table 4.8: Estimates of benefits from improved water quality due to agricultural measures in England (Defra, 2006)

| Water quality benefit category | Benefit from agricultural mitigation in € million per year (2006/07 values) |
|---|---|
| Drinking water quality (surface and groundwater) | 19-106 |
| Improved river water quality (amenity) | 22-56 |
| Improved fishing | 22-55 |
| Freshwater eutrophication | 251-493 |
| Ecosystems, natural habitat impacts – rivers etc | 552-773 |
| **Total** | **867-1483** |

It could be argued that the total value of potential benefits from improved water quality due to agricultural measures is significant and when compared with the costs shown in Tables 4.6 and 4.7, that the action to reduce diffuse water pollution from agriculture is economically worthwhile. It should be noted that this very crude comparison of cost and benefit data from different sources is at a national scale and that individual measures or treatment options (e.g. NITRABAR) or combinations of measures, will have to be assessed on their own merit.

As a final point, it is worth considering what could happen if no action were taken to reduce diffuse nitrate pollution from agriculture. This could be at a farm-scale or a catchment-scale where payment of fines or other penalties could arise from elevated nitrate concentrations due to farm practices, or at a national or trans-national scale where failure to meet "good ecological status" by 2015 outlined in the Water Framework Directive could have serious implications for the governments of those countries involved.

## Replication throughout Europe

# NITRABAR

# 5. Replication throughout Europe

## 5.1 Introduction

This chapter will consider the ease with which the NITRABAR system can be replicated throughout Europe, with regard to both policy/regulatory and climatic factors, highlighting any potential barriers or limitations to its use. The NITRABAR project partners represent the following countries and have provided valuable input to this analysis:

- Belgium (Flanders) - Large agricultural sector, high use of fertilisers and several trans-national river basins.
- Malta - A small, isolated island country where land is at a premium, agricultural dependence is high, soil nutrient value are low and nitrogen fertiliser application is high.
- Poland - A transitional state with growing demands on agriculture and the highest use of nitrogen fertilisers in Europe.
- UK, consisting of England, Northern Ireland, Scotland and Wales – A medium-sized country with large agricultural sector and high pressures within many regions to significantly change agricultural practice to achieve the WFD objectives.



The scale of the nitrate problem in each of these countries has been summarised in Table 5.1, expressed as the percentage of Nitrate Vulnerable Zones per total country area.  Details of the key organisations responsible for implementing and regulating the Nitrate Directive are also presented along with existing farm support mechanisms, or the organisation responsible for these, available in each country.

Table 5.1: The scale of the nitrate problem and relevant organisations from partner countries.

| Country | Scale of problem | Key organisations | Farm support mechanisms |
|---|---|---|---|
| Belgium (Flanders) | Whole region designated as NVZ (c13,520 km$^2$) | • Flemish Land Agency<br>• Flemish Environmental Agency<br>• Flemish Water Agency | • Flemish Fund for Agricultural Investments |
| England | 70% of country designated as NVZ (c91,000 km$^2$) | • Department for Environment, Food & Rural Affairs<br>• Environment Agency | • Rural Development Programme for England 2007-2013 e.g. Environmental Stewardship Scheme and England Catchment Sensitive Farming Delivery Initiative (ECSFDI) |
| Malta | Whole country designated as NVZ (c320 km$^2$) | • Malta Environment and Planning Authority | • Malta Environment and Planning Authority |
| Northern Ireland | Whole country designated as NVZ (c14,000 km$^2$) | • Department of Agriculture and Rural Development<br>• Department of Environment | • Northern Ireland Rural Development Programme 2007-2013 e.g. Countryside Management Scheme |
| Poland | 2% of country designated NVZ (21 zones) of area of c6,200 km$^2$ | • Ministry of Agriculture and Rural Development<br>• Ministry of Environment | • Rurality-Environment-Development (RED) |
| Scotland | 14.2% of country designated as NVZ (c1,100 km$^2$) | • Scottish Government<br>• Scottish Environment Protection Agency | • Scotland Rural Development Programme e.g. Land Managers Options (LMO) |
| Wales | 3% of country designated as NVZ (c630 km$^2$) | • Welsh Assembly Government<br>• Environment Agency | • Rural Development Plan for Wales 2007-2013 e.g. Tir Gofal and Tir Cynnal agri-environment schemes |

## 5.2 Funding

The results of the NITRABAR stakeholder engagement process showed that farm support schemes and grants are the best way of ensuring widespread replication of NITRABAR (see Figure 5.1). It is recommended that funding assistance for NITRABAR should be integrated into action programmes that take a catchment management approach.

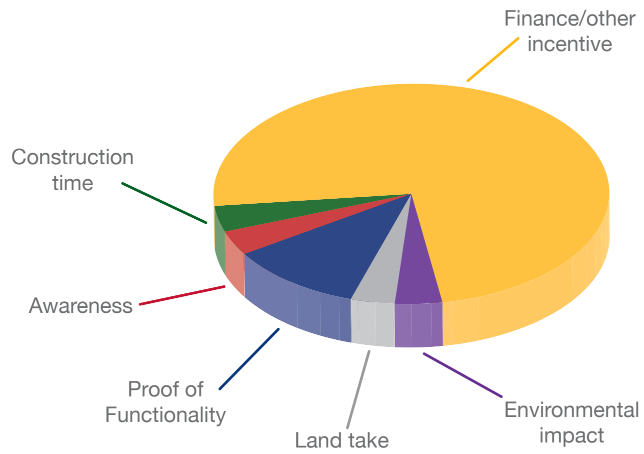



Figure 5.1. Results from stakeholder engagement (31 people) on key factors likely to affect the uptake of NITRABAR systems.



The funding mechanisms will clearly need to be country, or even region, specific, and are considered necessary if NITRABAR is to be included as a measure at both state and catchment level. The early engagement with representatives of the farming sector will be particularly important if NITRABAR technology is to be replicated across Europe.

The NITRABAR system provides a robust demonstration of a technology that could be considered as a measure, particularly to deal with nitrate from historical sources. NITRABAR represents added benefit or cost to measures already being considered. The next step will be to make the case that NITRABAR should be eligible for grants, but that will come after the technology has been demonstrated.

In strictly regulated regions, such as Flanders, where there are penalties for exceeding nitrogen loading to a soil, a further potential application of NITRABAR, subject to local regulation, is that a farmer could use it to apply more manure/fertiliser than typically permitted without increasing the nitrate input to the local watercourse. Or, rather than pay the fines for exceeding the nitrate levels, the farmer could agree to install a NITRABAR system.

## 5.3 Regulatory requirements

It will be of prime importance to consider the following regulatory issues:

- Planning permission
- Water discharge consents
- Waste regulation
- Environmental assessments
- Restrictions for wildlife conservation areas
- Landownership issues
- Verification of implementation
- On-going responsibility for monitoring and maintenance
- Health and safety considerations during construction
- Land use restrictions.

## 5.4 Availability of materials

The successful replication of NITRABAR throughout Europe will be aided because it can be constructed with locally sourced materials at low cost.

## 5.5 Availability of suitable skills and expertise

In most European countries, there is an established environmental consultancy sector. A catchment management approach, advocated by the Water Framework Directive and fundamental for the selection of sites for implementation of NITRABAR, is widely accepted. There is also a good network of agricultural contractors. In addition, permeable reactive barriers are becoming an increasingly accepted way of removing contaminants from shallow groundwater.

## 5.6 Geographical considerations

Europe can be broadly classified by two climate types: temperate and Mediterranean.

Temperate climatic regions are characterised by relatively cold winters and warm summers. The NITRABAR approach has the potential to be used across these regions of Europe (e.g. Belgium, Poland and UK), similar to where the demonstration site is located.

In contrast, the Mediterranean climatic regions in southern Europe (e.g. Malta), are characterised by hot, dry summers and mild, wetter winters. It is possible that the kinds of NITRABAR application in Mediterranean regions will be different. This could be as a result of both geology (large areas of limestone bedrock) and climate (lower rainfall, higher evapotranspiration). However, Mediterranean regions do have some important wetland areas where control of diffuse sources of nitrate may be important and where NITRABAR may be applicable.

Although there is some merit in considering how the application of NITRABAR systems can be easily applied under different climatic regions, it should be noted that the factors mentioned in Chapter 3, such as topography, hydrology, hydrogeology, lithology and geochemistry will still need to be addressed on a local site by site basis. Put simply, there will be areas in each country where NITRABAR can be installed simply and cost-effectively and others where it will not be appropriate (e.g. depth to groundwater will typically be a financial barrier to installation regardless of whether it is in Malta or Poland).

# Decision Process for Implementing NITRABAR

NITRABAR

# 6. Decision Process for Implementing NITRABAR

This chapter presents a decision process for policy-makers, farmers and consultants for deciding on the most appropriate application of the technology.

## Policy maker

1. Does the nitrate in surface water result in a compliance issue for the Nitrate Directive or Water Framework Directive? Is the farm in a Nitrate Vulnerable Zone?
2. Does it work – i.e. convert nitrate to nitrogen gas without resulting in undesirable products such as $N_20$, $NO_2$, $NH_4$, $CH_4$?
3. How long does it work for – i.e. what are the performance curves for different materials?
4. On what scale could it be effective – in what size of river catchment and with what length of barrier / proportion of groundwater fed flow?
5. Does it fit in with any existing funding or grant schemes?
6. What does the cost-benefit analysis tell me?
7. What are the other management and technical options and how can they be combined?

## Farmer / land owner / land manager

1. Why should I use a NITRABAR system?
2. What are the incentives?
3. What are the other management and technical options?
4. What will it cost?
5. Are grants available to meet this cost?
6. How would I use it?
7. Will existing land use be disrupted by the installation and presence of NITRABAR?
8. What are the maintenance requirements?

## Expert/Consultant

1. Does the nitrate in surface water result in a compliance issue for the Nitrate Directive or Water Framework Directive? Is the farm in a Nitrate Vulnerable Zone?
2. What is the time predicted flux of nitrate from groundwater to surface water?
3. Does groundwater flush in a short period (1-5yrs)?
4. What is the flooding risk and likely extent?
5. What are the prospects for farm development and future use of the land?
6. What options do I have for construction?
7. Who will pay for it?
8. What are the maintenance requirements?


# Alternative Applications

NITRABAR

# 7. Alternative applications

This chapter briefly examines alternative applications of the NITRABAR technology to those described in this report for diffuse nitrate pollution from agricultural sources. A more detailed examination of these potential applications is outside the scope of this report.

The NITRABAR approach has the potential to be easily transferable to manage a number of other environmental problems and some of these are listed below:

- Protecting surface waters threatened by other diffuse contaminants that enter surface waters from agricultural practices (e.g. phosphates and pesticides) by applying alternative or sequential reactive media within the same engineered system.
- Protecting other important resources threatened by nitrates including coastal zones and natural lowland habitats (e.g. Sites of Special Scientific Interest) through basic civil engineering adaptations (also compatible with other contaminants by applying alternative reactive media as described above).
- Protecting the catchment area where shallow groundwater is pumped for drinking water production.
- Protecting against nitrate pollution from agricultural point sources (e.g. cattle stocking areas) by using a horizontal orientation to intercept vertical flux.
- Integrating the technology within flood defence systems to treat contaminated flood waters (for nitrate or other contaminants), or simply, more cost-effective installation as plant/equipment is already on site.
- Integrating the technology within other permeable reactive barrier systems treating contaminated groundwater exiting industrial sites (for nitrate or other contaminants).

# Conclusions

NITRABAR

# 8. Conclusions

This chapter assesses the advantages and disadvantages of the NITRABAR system.

## 8.1 Advantages of NITRABAR systems

### Economic opportunities

- Maintenance of agricultural land in production. Continuation of agriculture in areas with high nitrate levels, subject to local regulation. Value depends on the farm product concerned, but the loss of livelihoods and potential financial impact is likely to be substantial when the importance of the farming sector in rural areas is considered.
- Development of the market for green waste (mulch). Green waste is a commodity in increasing demand in urban areas, where it is used for land restoration and horticulture. NITRABAR may serve to enhance this market in rural areas.
- Advisory services to farmers. It is anticipated that farmers will require advice over the design and positioning of NITRABAR systems, and that some of this may be offered on a commercial basis.
- Equipment. If equipment not already available on-farm is recommended for the installation of NITRABAR systems, there are likely to be increased markets for suppliers. This includes the provision of trenching technology.
- The cost-effectiveness of NITRABAR was demonstrated to be comparable to other options of managing diffuse nitrate pollution from agriculture, but was the only option that can address the legacy of nitrate in groundwater.

### Technical advantages

- In an optimised system, denitrification completely removes the nitrate from the groundwater by converting it to nitrogen gas.
- Inexpensive and locally available materials: Mulch, compost, and gravel are relatively inexpensive when purchased in bulk quantities.
- Low operation and maintenance requirements, such as periodic performance monitoring.
- NITRABAR is effective for shallow groundwater plumes in moderate permeability or highly heterogeneous formations. Although this demonstration went down only to 3-4 m, the depth that could be trenched or excavated in a practical and cost-effective manner may extend to up to 10 m. In addition to the actual installation zone, the effective reaction zone may extend downgradient of the barrier due to release and migration of soluble organic carbon.

## 8.2 Disadvantages of NITRABAR systems

- Installation of a NITRABAR may result in changes to the subsurface environment, and the degree of success may be subject to hydrogeological, geochemical, and biological limitations.
- The depth that can be trenched or excavated in a practical and cost-effective manner is limited to approximately 10 m. Other site-specific limitations may be related to difficult geology (e.g. bedrock or large cobbles), hydrogeology (e.g. very high or very low rates of groundwater flow), contaminant distribution, or geochemistry (e.g. adverse pH conditions).
- Disposal of arisings from large systems, particularly if spreading is not permitted.
- Disturbance of strata in excavation although this can be mitigated by using alternative trenching technology.
- Pumping and, when necessary, disposal of groundwater.
- Length of time the NITRABAR system will be able to sustain denitrification processes without replenishment of the carbon source is unknown. While the mulch fraction may last 10 to 15 years or longer, it may not provide enough readily biodegradable organic carbon to sustain degradation.
- Limited residence time: Because NITRABAR is of finite thickness, the contaminant residence time and the substrate loading rate (i.e. the hydrolysis rate of insoluble organic carbon from mulch that yields smaller and more fermentable dissolved carbon molecules) is limited.

However, it should be noted that while these potential limitations should be considered when assessing the application of a NITRABAR system many of them can be mitigated or compensated for by understanding the hydrogeological and biogeochemical conditions of the aquifer system and using an appropriate design.

# References

NITRABAR

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# Notes

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A pan-European EC LIFE Environment Project to demonstrate a passive system for the removal of nitrates derived from agricultural practices

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