## For more information...


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N°5

# Improving control over nutrients by restoring river hydromorphology


Véronique Nicolas,
Frédérique Oraison,
Yves Souchon and Kris Van Looy


Increasing quantities of nutrients in rivers have led in many cases to significant eutrophication of environments. This complex process affects all ecosystem compartments via physical, chemical and biological disturbances and, more generally, the use value of aquatic environments. Many research projects, notably in agronomy, have studied how to reduce inputs, reduce nitrate and phosphorus losses and limit transfers within river basins.

Eutrophication is caused primarily by excess quantities of nitrogen and phosphorous-based fertiliser in water. However, other factors also weigh, including the amount of sunlight, water temperature and current velocity, all parameters that depend to a large extent on river hydromorphology.

The operation of hydrosystems contributes to regulating various ecological processes, including physical (water storage in floodplains, aquifer recharging and mitigation of low flows by wetlands), chemical and biological processes.

Scientific research on the relations between hydromorphology and nutrient-transformation processes has increased over the past few years. The Onema-Irstea hydroecology centre published in 2011 a review of the literature presenting the most noteworthy aspects of current knowledge and a number of examples.

## Contents



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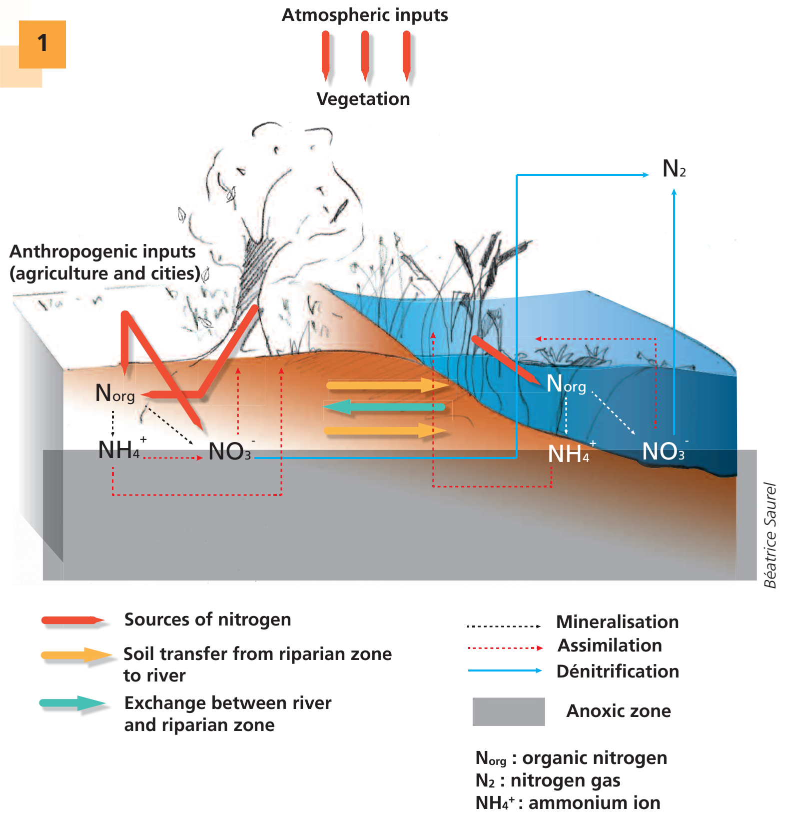
# The fate of nutrients in rivers

Under natural conditions, river ecosystems receive nutrients[1] and organic matter from their basin in quantities that depend on the local conditions (basin size, type of soil, land use, etc.). These inputs result in increasing trophic levels from upstream to downstream in the receiving rivers, levels that depend on the environmental conditions.

1

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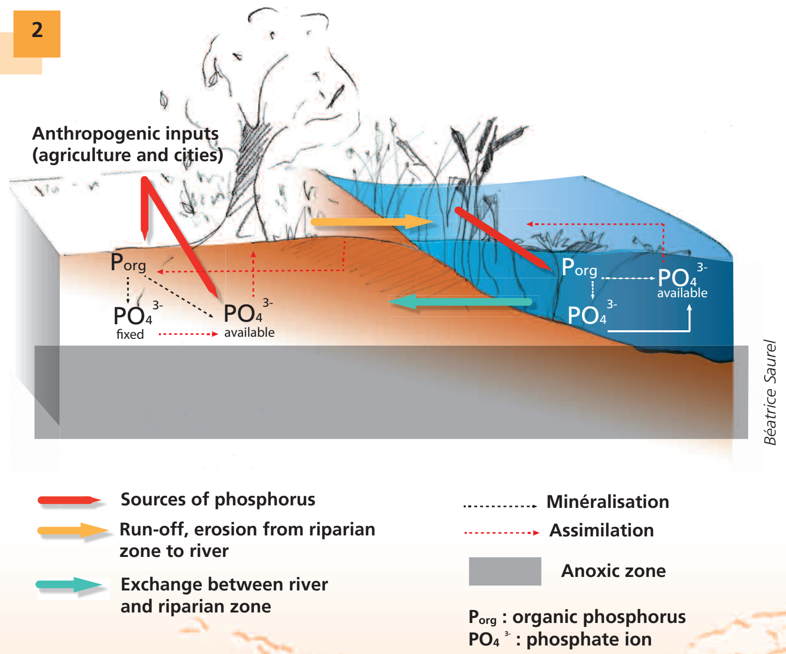


Rivers can store and transform part of the inputs[2], thus limiting the quantities transported to the mouth of the river. This is called the self-purification capacity of rivers. It is determined by the morphological characteristics of the river, its banks and the riparian zone which influence overall capacity in terms of storage, transformation and elimination of natural and anthropogenic inputs from the river basin.

### Nitrogen

Nitrogen, in the form of nitrates, is a nutritive element used in agriculture as a chemical and organic fertiliser. Other sources exist (atmospheric nitrogen, discharges from wastewater-treatment plants), but the majority comes from excessive use of nitrogen-based fertiliser and the natural production of nitrates through the mineralisation of organic matter in soil. The nitrogen in the water is in the form of nitrates ($NO_3^-$).

The main means of nitrogen elimination is biological, via denitrification. The transformation of nitrogen into $N_2$ gas results in a net reduction for the aquatic environment because the nutrient transfers to the atmosphere. Denitrification requires anoxic conditions, contrary to nitrification, i.e. the production of nitrates from other forms of nitrogen, which requires oxygen to take place.

The nitrogen can also be assimilated by vegetation, in which case it is stored only temporarily. Recycling of organic nitrogen takes place rapidly and only small quantities are stored in soil.

### Phosphorus

Phosphorus is a nutritive element that is essential for plants. It is used in agriculture as a fertiliser, but other sources are urban (notably discharges from wastewater-treatment plants). It is subsequently found in surface waters in particle form (attached to suspended matter) or, to a lesser extent, in dissolved form.

It cannot be transferred to the atmosphere because it does not exist as a gas. Consequently, it can only be stored over more or less long periods in sediment or transported downstream. The local environmental conditions and the type of soil determine the storage capacity. An environment under anoxic conditions will tend to free the stored phosphorus.

**Nitrification,** the production of nitrates from other forms of nitrogen, requires oxygen to take place.
**Denitrification, the transformation of nitrogen to its gas phase,** requires anoxic conditions.
Consequently, it is essential to have a succession of areas located close to each other and having different oxygen levels for nitrogen processes to take place.

**The phosphorus** stored in sediment is released to the environment under anoxic conditions.

# A fate that depends on morphological conditions

A river is linked to a body of groundwater and the volume of exchanges between the two depends on the characteristics of the riverbed (porosity, type of substrate, fine-sediment deposition, etc.). Intense interaction and exchanges also take place between the river, the banks and the riparian zone, particularly during periods of high discharge. Any modifications in river compartments caused by human activities therefore impact the exchange, storage and elimination of nutrients and other elements arriving from the river basin.
It follows that efforts to restore or preserve the natural morphological characteristics of rivers can limit impacts and, above all, enhance the resilience of aquatic environments, i.e. their capacity to maintain or return to a certain equilibrium following a disturbance.
Situations involving nutrient imbalances and various pollutants in aquatic environments are all too common and require the use of every means at our disposal to limit the disturbances. The most obvious measure is to reduce the source of pollutants as much as possible. This issue is the topic of specific work that will not be discussed here. Below we present the results of research on hydromorphological-restoration projects that studies the effects of the projects on the processes discussed above.

# Some examples of restoration and the effects on nutrients

To date, a majority of the studies has been carried out in the United States. These studies, increasingly numerous, have produced results, particularly concerning nitrates, that are judged encouraging even though the field is fairly new and comparisons between studies are difficult due to the great variety in restoration methods, the types of environments, the pressures, etc. Below are three examples of study results.

### Monitoring the effects of stream restoration on denitrification in a Piedmont river basin near an urban area, Maryland, United States (Kaushal et al., 2008).

The project included recreating meanders with alternating facies, measures to limit down-cutting, reconnection of side channels and vegetating the riparian zone over a length of 150 metres. The upstream section (head of the basin) of the reach had already been restored a few years earlier (Figures 3 and 4).

1- Nutrients are organic and mineral compounds that may be assimilated by living organisms for their development. Some (nitrogen and phosphorus) are central components in agricultural fertiliser.
2- See Malavoi et al. (2011) for information on the main processes involved in exchanges with rivers.

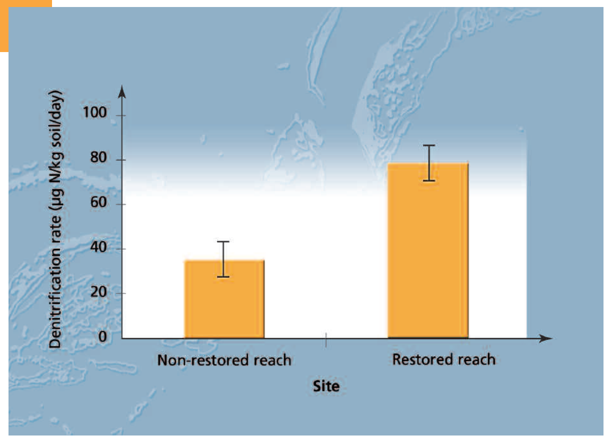


**Figure 3.** Mean denitrification rates in situ, for all sites in the restored reaches versus the non-restored reaches (three samples drawn from each site between May and June 2004).

→ The restored sites exhibited higher mean denitrification rates (ANOVA analysis of variance, P=0.01) compared to non-restored sites.

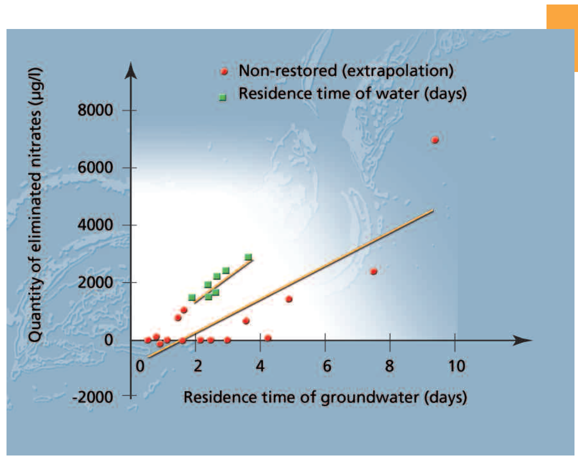


**Figure 4.** Relationship between the residence time of water and the quantity of nitrates eliminated by non-restored reaches (extrapolation of denitrification data and groundwater inputs) and by restored reaches (scenario using denitrification data for restored zones in 2003-2004 and underground flows measured in 2004).

This example of a restoration project on a small river revealed a relationship between the residence time of water and the quantity of eliminated nitrates. Longer residence times encourage the development of hypoxic conditions contributing to denitrification. Denitrification rates were higher at restored sites.

## Monitoring various parameters following remeandering work in an agricultural zone straddling Kentucky and Indiana, United States.

This study focussed on rivers in hilly regions that were rectified for agricultural reasons. The restoration work addressed reaches having less than 10% of their length comprising alternating riffles and pools. During the project, meanders were restored in order to recreate alternating facies and diverse environments. The author of the study (Bukaveckas, 2007) showed that the reaches with the new meanders eliminated more nitrogen and phosphorus. The uptake coefficient was 30 times greater for nitrogen and 4 times greater for phosphorus at the restored sites than at the channelised sites. The table below presents the mean values of the parameters selected to characterise water quality, river hydrology and nutrient uptake on three sites with different morphologies:

- channelised site (Wilson Creek before restoration);
- restored site (Wilson Creek after restoration);
- control site (Harts Run).

Comparison of different parameters between channelised, restored and control sites.
The letters (a), (b) and (c) signal statistically significant differences between values (two values with different letters are statistically different) (ANOVA on repeated measurements and comparison of control data vs. channelised data and restored data vs. channelised data).

| | Channelised | Restored | Control |
|---|---|---|---|
| Phosphorus-SRP (µg/l) | 10.8 (a) | 7.2 (b) | 6.7 (b) |
| Nitrogen-$NO_3$ (µg/l) | 375 (a) | 456 (a) | 63 (b) |
| Discharge (l/s) | 125 (a) | 109 (a) | 62 (b) |
| Velocity (m/s) | 11.9 (a) | 8.7 (b) | 6.1 (c) |
| Mean transit time in % | 14 (a) | 17 (a) | 30 (b) |
| Nitrogen-uptake coefficient ($m^{-1}$) | 0.00005 (a) | 0.00162 (b) | 0.00012 (a) |
| Phosphorus-uptake coefficient ($m^{-1}$) | 0.00073 (a) | 0.00263 (b) | 0.00193 (b) |



Demand for nitrogen and phosphorus, both biotic and abiotic (indicated by the uptake coefficients) was even greater on the restored reach than on the control reach. The author expressed reserves, however, given the short time span since the restoration because the work resulted in greater luminosity that contributed to plant growth and consequently increased the biological demand. The baring of the riverbed down to the clay substrate may also have facilitated phosphorus fixation. Monitoring of this project lasted only two years. Longer-term monitoring would be required to determine any effects once an equilibrium has been more completely re-established after the work.
That being said, the significant differences in the uptake coefficients suggests that a decisive role is played by the morphological reconditioning. In the case of the control reach, the alternating facies contribute to the creation of diverse types of flow conducive to phosphorus fixation and nitrogen elimination.

## Comparison of the denitrification capacity of two streams, one channelised and the other meandering, in the upper reaches of a basin in a zone of intensive agriculture exporting high levels of nitrates, Illinois, United States (Opdyke et al. 2006).

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Artificialised stream at the head of a basin in an agricultural zone.

The authors showed that denitrification levels were higher in the meandering stream than in the channelised stream. The alternating facies, sinuosity and the diversity of substrates (presence of fine sediment containing organic matter required for denitrification) were the factors put forth to explain the difference. The rate of denitrification reached 50 mg N/m²/h (quantity of nitrogen per square metre per hour) in the summer and 10 to 20 N/m²/h in winter, particularly in the convex sections of meanders where fine sediment and organic matter are deposited. Sinuosity is an important indicator in favour of denitrification.

In this example, a sinuosity index of 1.9 improved nitrate elimination by 91%. It should be noted that an index greater than 1.5 corresponds to a meandering river.
The authors also determined the river length required to eliminate the nitrates measured in the spring. In channelised rivers, 40 000 kilometres would be necessary whereas only 2 900 km would suffice for a meandering river. At the end of the summer, the above distances are reduced to 35 km for a channelised river and 6.9 km for a meandering river.
Unfortunately, nitrate inputs are so great that denitrification has a limited impact, i.e. it does not eliminate more than 15% of the nitrate load in the river.

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Artificialised stream.

The morphological conditions, alternating facies and meanders play a non-negligible role in the capacity of rivers to limit the quantities of nutriments exported downstream.

## The riparian zone, an important element in the system

Riparian vegetation is an integral part of river morphology and constitutes both a transition zone and a key factor in hydrosystem operation. For phosphorus as well as for many other pollutants transported by sediment particles, the presence along rivers of riparian zones that are sufficiently wide and dense, providing a continuous barrier to pollutants, constitutes an effective means to enhance nutrient-transformation processes.

Figures 5 and 6 illustrate the filtration capabilities of riparian vegetation.

Even though the reduction rates vary depending on the environmental context and the elements making up the riparian vegetation, the role played by riparian corridors in reducing the lateral inputs of non-point source pollution (nitrates, phosphorus) is acknowledged. These wooded corridors slow the arrival of flows from the river basin and increase infiltration in the soil. The Scientific council for the natural heritage and biodiversity (CSPNB, 2008) has indicated that a continuous riparian corridor 10 to 20 metres wide can reduce flows of the two pollutants by up to 80%. However, beyond certain levels of nutrient input, a river can no longer eliminate the excess nitrogen. It is necessary to reduce the quantities at the source and to limit their progression to the river.

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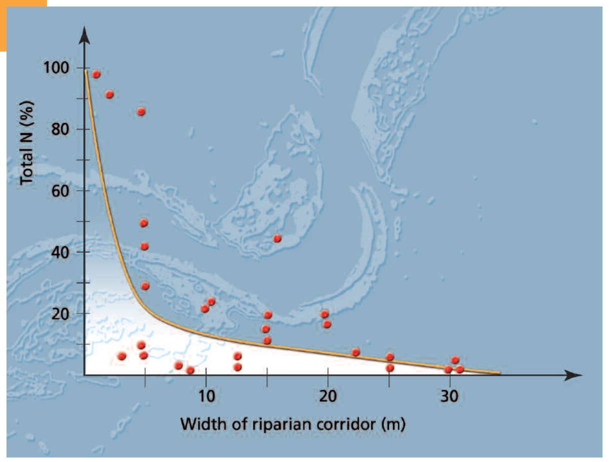


**Figure 5.** Average change in the total nitrogen content of river waters as a function of the width of the riparian corridor (data compiled from reviews by Peterson et al. (1992), Vought *et al.* (1994) in Maridet (1995)..

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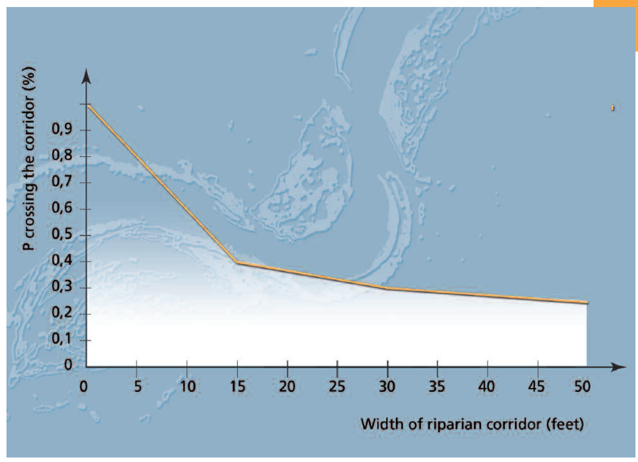


**Figure 6.** Average change in the total phosphorus content of waters reaching the river as a function of the width of the riparian corridor (Osmond *et al.*, 2002).

## Guidelines for restoration projects targeting enhanced resilience

The examples above indicate that restoration work to diversify facies, dechannelise, recreate meanders and protect rivers with riparian corridors would appear to be the most effective means to enhance the self-purification capacity of the river system and consequently limit degradation of the immediate environment, but also environments further downstream, e.g. lakes and estuaries that are the ultimate outlets.

The differences in the behaviour of nitrogen, phosphorus and the other pollutants likely to be stored in the soil, as well as the diversity of environments make it difficult to set criteria for "optimum" restoration. Research has now begun on modelling the transfer of contaminants within rivers, taking into account control factors such as hydromorphology.

### Recommended features for restoration projects

■ Be aware of the **differences between nitrogen and phosphorus.**

■ Take into account the various forms of nitrogen. Denitrification is the only means to eliminate it, but the nitrogen must be in the form of nitrates. It is therefore necessary to encourage the nitrification process and then denitrify, or to use other means to intercept the nitrogen (vegetation, storage, etc.) more similar to those used to retain phosphorus. It is best to do both because a restoration project based exclusively on denitrification could fail to significantly reduce nitrogen.

■ Evaluate **the maximum elimination capacity of the river** (see the Total Maximum Daily Load criterion established in the United States) and note that nitrogen elimination increases with the diversity of the physical features of the river (meanders, facies, riparian vegetation) until a **saturation level** is reached. Once the limit has been reached, the river can no longer eliminate the excess nitrogen. That is why it is necessary to keep in mind that restoration complements efforts to reduce the source of the pollution and to limit its transfer to the river. Concerning transfer, the river basin is the relevant scale for work in two main directions:

- try to **intercept** nutrients along their entire path in the river basin in order to limit the load reaching the river. Many different types of buffer zone may be used, e.g. grass strips, permanent meadows, wooded areas, hedgerows, artificial wetlands, etc. Their effectiveness varies depending on the type of pollutant and how the various areas drain;
- devise systems capable of **reducing direct flows during storms** (likely to provoke major nutrient transport), notably cover crops.

■ Use cover crops to avoid leaving fields bare in the winter.

■ Encourage sinuosity and the **diversity of substrates and facies** (note that processes and exchanges take place primarily at the head of each riffle).

■ Plant, restore and facilitate the return of riparian vegetation, paying attention to its continuity, width and avoiding any "short-circuits" (drainage to the river). Technical guides on this subject are available in certain regions, notably from the Water agencies.

■ Restoration projects must be sufficiently large scale. Though it is difficult to say at what point a project will be effective, it is certain that excessively limited intervention will most probably have very little impact, even locally.

■ Take into account the links between **nitrogen load, river discharge and elimination capacity,** etc. (Wolheim *et al.*, 2008). Long exchange times in interface zones (riffle bottoms and banks) are conducive to elimination. Given their significant lengths and rich interfaces, small, undisturbed rivers at the heads of basins are prime candidates for this work. Restoration of the heads of river basins should receive priority because denitrification and phosphorus-fixation processes are most active there and any work may be expected to produce highly effective results that contribute to the quality of the entire hydrographic network.

## Conclusion

When undertaken on a sufficiently large scale, work to restore the morphology of rivers and their internal processes contributes to improving their capacity to purify themselves of excess nutrients. Such work may be considered a "no-regrets" measure.

On the other hand, limited measures undertaken on too small a scale, targeting a single biotic or abiotic factor and not integrated in an overall restoration plan risk producing very insufficient results in terms of an improvement in the general operation of hydrosystems.