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City, country, river:

Modelling and managing nutrient pollution in lakes and rivers

moneris

Contents

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Research for the future of our lakes and rivers

Nutrients like nitrogen and phosphorus are of fundamental importance for life in lakes and rivers. Overfertilisation of these waters, however, does not only negatively impact their chemical quality. It also affects the aquatic ecosystems – sometimes leading to a loss of biodiversity in these habitats. The emission of nutrients into the lakes and rivers is changing as the countryside changes. One example of a current development is the increased cultivation of energy crops in place of food crops.

The EU Water Framework Directive (WFD) obliges Member States to transform the ecological and chemical conditions of their rivers and waters into a 'good' state by 2015, both within and beyond state borders.

Inland waters are closely interlinked to the surrounding countryside, the groundwater and the marine systems. It is therefore essential to understand these interactions in order to implement the WFD. Synergies must also be developed between land uses which frequently compete with one another.

At the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), we investigate the fundamental processes in lakes and rivers and develop measures for their sustainable management. In doing so, we use interdisciplinary, multi-scale approaches. The development of the MONERIS nutrient emission model is one example of these approaches. Using MONERIS enables nutrient emissions to be quantified and their whereabouts in the river system to be analysed – both on a regional level and for whole river catchments. The example of MONERIS shows that many years of basic research are often necessary in order to develop an excellent, usable tool. In addition, the close exchange of information between the authorities and with those working in the field has led to the continuous further development of MONERIS. One of the factors making MONERIS so special is the scenario manager for analysing and comparing the different management options in terms of economic efficiency and sustainability. Today, MONERIS is already being used in 18 countries worldwide and on over 450 river systems, with the aim of improving the water quality – for the benefit of mankind and nature.

Nutrients in the water – and why a surplus can be damaging

Life could not exist in fresh waters without nutrients: nitrogen, phosphorus, silicon – to name a few of the most important ones – are nutrients for primary producers such as algae (phytoplankton) as well as for vegetation growing on the bottom (phytobenthos). Small animals like water fleas feed on the phytoplankton and are then eaten by fish. Nutrients under relatively natural conditions are often limiting, meaning that when the available nutrients are used up, plant or algal growth is restricted, limiting all aquatic life. Land use surrounding our freshwaters frequently results in higher nutrient emissions into lakes and rivers. This usually leads to excessive growth of plants and algae. When these plants die, decomposition processes can cause lower oxygen levels in the water. This has negative consequences for plant life and, in the most severe cases, can even result in fish deaths. Some forms of algae, known as cyanobacteria (formerly known as blue-green algae), can also release toxic compounds which may restrict the use of the waters for swimming or as a source of drinking water. Only a very small number of surface waters in Germany, and across Europe as well, currently have relatively natural conditions.

Relatively natural lakes and rivers – important habitats, a source of drinking water, and leisure spots for the local people.

The self-cleaning power of nature

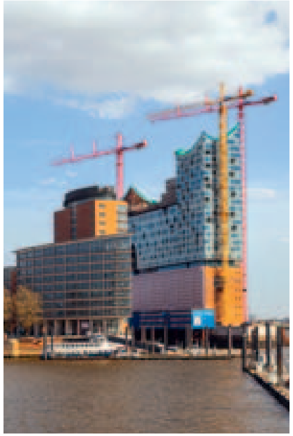
Nutrients are in this continuous cycle of plant growth, death and decomposition. In this process they are partly removed from the waters through self-cleaning or retention. The process of removing nitrogen from water is known as denitrification: bacteria use oxygen from nitrogen compounds, and the nitrogen part (N_2 or – in the case of an incomplete reaction – N_2O) escapes into the atmosphere. The extent of the denitrification depends on a number of factors. For example, it increases with rising water temperature and low flow velocity (a long retention time).

Scientists use complex methods to try to measure and understand the retention in lakes and rivers. These results are later used in models, for example.

Phosphorus is a little bit different. The substance is deposited temporarily or permanently in the sediments or on riverbanks and lake shores. This is why very high phosphorus concentrations are often found on flood plains. Once phosphorus is in the water, it can stay there for many decades. It can be released from sediments again under certain conditions and introduced into the nutrient cycle. Water plants also absorb nutrients. Removing these plants before they die down in winter will permanently remove the nutrients from the cycle.

Silicon is another important nutrient in freshwaters. Unlike nitrogen and phosphorus, it is carried into lakes and rivers almost exclusively via natural routes. Silicon is produced from the weathering of rocks and organisms like mussels need it to build their shells. Silicon can therefore also limit the growth of some animal species. However, high silicon concentrations do not have a negative impact on the ecosystem.

Emission pathways: Where do the nutrients come from?



Crowded urban areas and intensive farming are often the most significant sources of nutrient emissions.

Freshwaters under relatively natural conditions are usually low in nutrients. However, land use surrounding our freshwaters has, in many cases, led to increased nutrient emissions. A fundamental differentiation is made between diffuse and point source emissions. This is necessary because the nutrient sources, processes and the concentrations on which they are based deviate significantly from each other. Point source emissions, such as those from municipal wastewater treatment plants and industrial direct dischargers, are directly transported to the water, while diffuse nutrient emissions enter surface waters indirectly at various locations via pathways like erosion or groundwater.

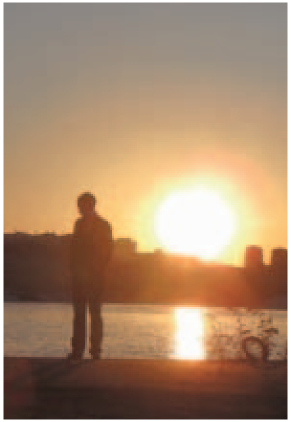
Agriculture plays a key role in the diffuse nutrient emissions. Processes such as harvesting continuously remove nutrients from the soils. In order to prevent nutrient deficiencies in the soils, fertilisers containing nitrogen, phosphorus and potassium are added, depending on the crop. Only a portion of this actually stays in the soil or is taken up by plants – the rest ends up in the groundwater or is transported to surface waters via various pathways.

This increases if the fertilisers are not applied properly. In addition, areas which are less suitable for arable farming are also upgraded for agricultural use through adding water (artificial irrigation) or removing water (tile drainages).

Drainage systems result in a type of shortcut between fertilisers and water bodies: the nutrient-rich water from the field passes quickly and directly into the next natural lake or river, bypassing nutrient removal or retention processes in the lower soil layers.

Many pathways lead to the water

For nitrogen and phosphorus, the different emission pathways into both the groundwater and surface waters are important: nitrogen dissolves well in water and seeps away easily. Phosphorus, on the other hand, accumulates in the soil and enters surface waters as a result of surface run-off and erosion. The dominant emission pathways for nitrogen are usually tile drainages and groundwater. The dominant pathways for phosphorus are erosion, surface run-off and, depending on population density, wastewater treatment plants.



Rivers flow through most of our larger cities. They serve us in a variety of ways, but we must not overuse them. Otherwise they will not remain useful in the future.

Maintaining lakes and rivers as lifelines: The clock is ticking

Rivers and lakes are home to a large number of species. They are also very important for people: they provide drinking water, are used for transport (shipping), for swimming, and also to remove sewage from cities.

The EU Water Framework Directive (WFD) was established in 2000 to safeguard all these functions. It demands that lakes, rivers and groundwater in Europe achieve a good ecological status by 2027.

"Good ecological status" does not mean that the water bodies have to be returned to their original, natural state. Instead, it means countries must ensure that the chemical and biological status will allow the water to be used in the future and that it will again or continue to be home to animals and plants. To this end, the (negative) impacts of human use have to be reduced to a low and resource-saving level.

A flood plain on the River Elbe near Bad Schandau. The flood plain is part of the river – but it is often used. When flooding occurs it quickly becomes problematic for nearby buildings.

Stress for lakes and rivers

Around 56 percent of Europe's rivers, 44 percent of its lakes and 25 percent of its groundwater are currently in a moderate or even bad condition. In some central European countries the proportion is significantly higher. These waters are negatively affected by several so-called stressors: changes to the river bed and canalisation cause a deteriation to the living conditions of fish and other aquatic life. Reservoirs affect the ability of fish to travel through waterways and have a great impact on run-off and algae growth.

Intensive farming leads to soil erosion, among other things, causing increased sediment formation: this fills the natural spaces between small stones or pebbles and removes a habitat for microorganisms. The loss of river banks and lake shores means many species are lacking the vegetation they use for protection and as homes. Another stressor can also be increasing water temperatures. In addition, climate change increases the risk of flooding in some areas while less rain means too little water in other areas.

Good ecological status by 2027?

Despite the wide variety of problems, time is running out to implement measures to improve the water quality. Even now, there are already indications that the transformation of many European rivers, lakes and groundwater sources into a good ecological status will not be possible by 2027.

The political and planning processes are often very long-winded and sometimes even conflict with or restrict existing uses. In addition to this, there is the fact that in Germany and many other central European countries, so much has already been done that the saving potential of point sources is now quite limited.

Not all conditions in flowing freshwaters are as close to natural as this small river in Ireland.

In many European countries there is currently a stagnation or slight increase in nitrogen surpluses. This follows a decrease in surplus levels between 1990 to 2000 and makes a further reduction even more difficult.

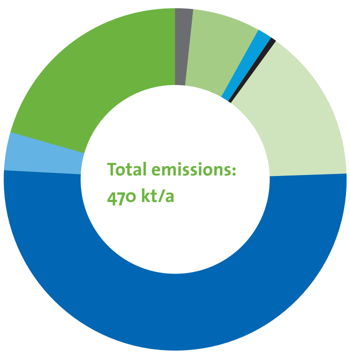
Moreover, the accumulation of nutrients in the countryside as well as in the ground and surface waters means the measures implemented usually only become effective after decades have passed.

Harmonising data and methods

A further challenge is that methods for measuring and determining water quality and the improvement goals still need to be harmonised across Europe. As an integrated approach for entire river systems, MONERIS can contribute to the formation of a uniform database – and simultaneously offer a comprehensive approach with which it is possible to consider regionalised measures when determining the quality of our surface waters.

Tracking down the nutrients

At present, around 470 kt of nitrogen enter Germany's lakes and rivers every year, mostly via the groundwater. This has continually decreased in recent years, as a result of a reduced use of fertilisers and improved wastewater treatment technology.



- Atmospheric deposition
- Surface run-off
- Erosion
- Drained grassland
- Drained arable land
- Groundwater
- Urban areas
- Point sources

How do nutrients get into the surface waters and what are the key factors involved? Where are lakes and rivers in a particularly critical condition? And what can be done to improve water quality? In order to answer these and many other questions, researchers at the IGB have been working on this topic since 1995 and have developed the MONERIS (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) model.

This nutrient emission model is used to perform water quality studies in river systems at the regional, national and international levels. The IGB can be commissioned to apply the model, or you can do it yourself. MONERIS makes it possible to identify nutrient sources and emission pathways, to analyse the transport and retention of nutrients in river systems, and to test and evaluate management options for the affected regions.

The different pathways via which nutrients are transported to surface waters are the central issue for MONERIS. MONERIS considers the following seven pathways, as well as the retention, i.e. the self-cleaning capacity of water:

01 Direct emissions from atmospheric deposition on the surface of the water

02 Nutrient emissions from surface run-off

03 Nutrient emissions from erosion

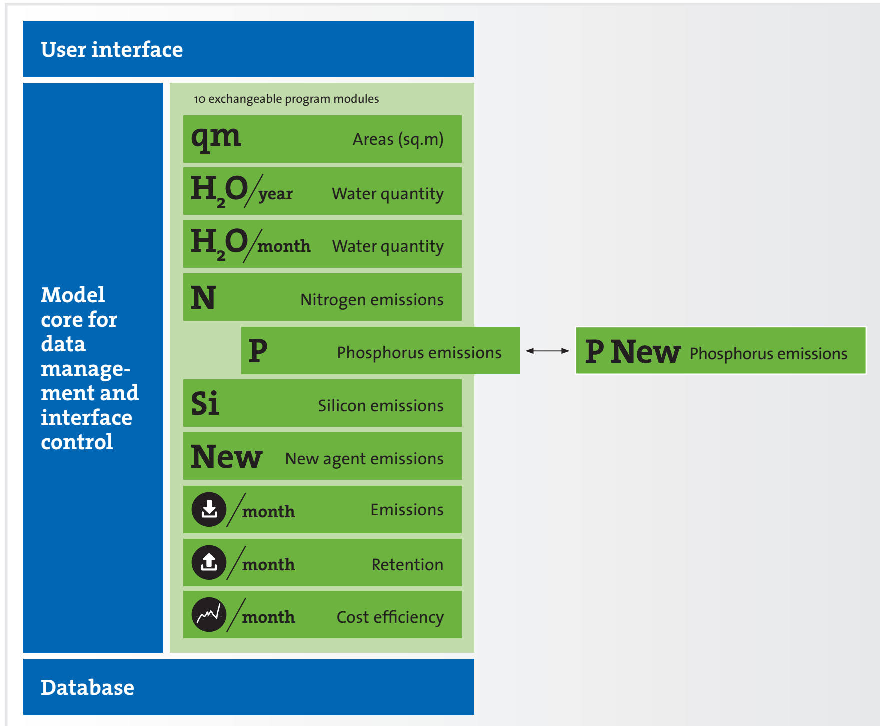
04 Nutrient emissions from tile drainages

05 Nutrient emissions via the groundwater

06 Nutrient emissions from sealed urban areas (e.g. streets, developed land or house roofs)

07 Point sources (nutrient emissions from municipal wastewater treatment plants and industrial direct dischargers)

08 Nutrient retention



01 Direct emissions from atmospheric deposition on the surface of the water

Rain brings lots of nitrogen into waters and soils – 30 percent on average of all emissions in Germany!

Deposition is when dissolved, particulate or gaseous substances from the air are deposited onto surfaces – in this case lakes and rivers. Rates of deposition vary greatly depending on the area investigated,

and usually depend on the type of vegetation (the coarseness): In Germany, phosphorus deposition is roughly between 0.22 and 0.37 kg per hectare, and the rates for nitrogen vary between 20 and 30 kg per hectare. Both rates are within European averages. A differentiation is made for nitrogen between the oxidised (NO_x) and reduced (NH_y) forms. NO_x is released during combustion in households, cars and industry. NH_y compounds originate mainly from farming, mostly from cows chewing the cud, and are released into the atmosphere as digestive gases.

In the future, improvements in filter technology should reduce the deposition rates of NO_x in particular. NH_y reductions are possible by placing lids on manure storage tanks or quickly mixing the manure into the soil, but the main problem – the cows' digestive gases – can hardly be avoided.

02 Nutrient emissions from surface run-off

Surface run-off occurs when materials from the surface are washed away by the rain. It depends on factors such as the type and amount of precipitation, the type of vegetation and the slope angle. Surface run-off is therefore very similar to erosion but, unlike erosion, it refers to fine materials dissolved in the water.

The amount of phosphorus dissolved by surface run-off depends on the concentration of this substance in the soil. Phosphorus binds very well to clay minerals. This nutrient is bound until all so-called "binding sites" are taken and the soil does not absorb any more phosphorus. Then, like nitrogen, it is easily transported with the surface run-off. For this reason, the history of the land use must be taken into account in order to be able to estimate how much phosphorus has accumulated in the soil. Surface run-off at places which have been used for farming for a long time can amount to 10 to 20 percent of the total emissions.

Measures to reduce surface run-off are often only effective after a long period of time, due to the accumulation in the soil. River banks, lake shores and ground cover, as well as increasing the water-retention capacity in the soil can help to reduce surface run-off.

They may be small, but watch out!

The dissolved phosphorus emissions from surface run-off are usually readily available to plants. They may often only play a minor role, but they can have a great impact on the water quality.

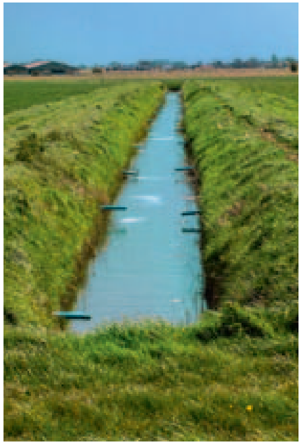
A lack of ground cover like on this tropical field can cause significant soil and crop loss due to erosion. Once erosion has reached this level, it is very difficult to control.

03 Nutrient emissions from erosion

Erosion causes phosphorus in particular to enter surface waters. MONERIS calculates the nutrient emission due to erosion using the soil removed from arable and grass lands and that from areas with natural cover which are not used for agricultural purposes.

Since the force of the water flowing off the surface increases with increasing gradient, arable land which is particularly susceptible to erosion is also assigned slope gradient classes. This results in the following four parameters, from which this emission pathway is calculated: soil removal, slope gradient, clay and nutrient content in the top soil, and land use. MONERIS also considers the climate factor for this emission pathway, whose conditions change from year to year.

We are well aware of the special significance of arable land for erosive emissions. More and more locations are therefore being managed in ways to reduce erosion – for example by ploughing parallel to the slope, using soil-conserving measures, using mulch tilling, working the soil without ploughs or by planting on arable land through the winter. Buffer stripes, which keep back emissions into the water, are increasingly being established as well.



Drainage pipes channel the water and the nutrients it contains directly into the drainage ditches. They thus impact the water balance in the countryside and can lead to high nutrient concentrations in surface waters.

04 Nutrient emissions from tile drainages

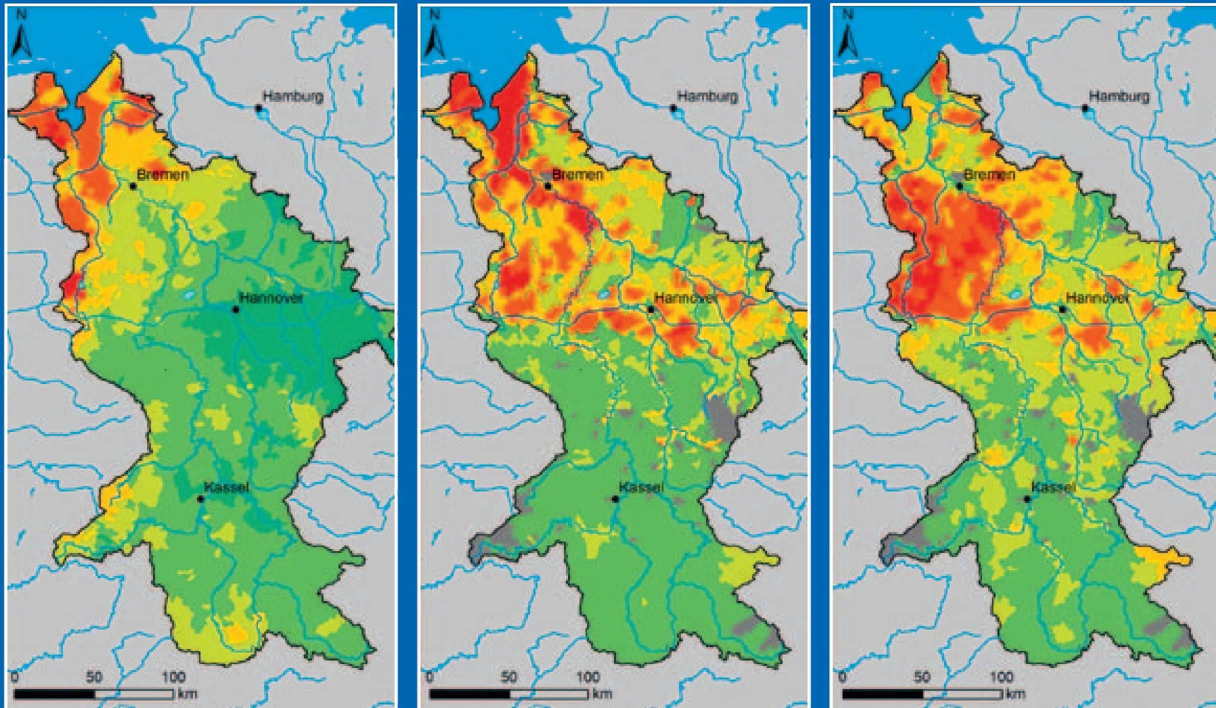
Tile drainages channel excess water from the fields into ditches, which are then linked to river systems. Tile drainages are water-permeable pipes laid in the ground at a depth of around 1m. The water therefore only seeps through the top part of the soil until it reaches the drain pipe. Wet areas are usually drained so that heavy machines can drive on them and crop yields are improved.

Irrigated areas are also drained. The rule of thumb which applies is: no irrigation without drainage, otherwise the soil will be salinated. Not all substances contained in the water (e.g. salts or even heavy metals) are absorbed by the plants. When the water evaporates, these substances remain in the soil. In order to remove excess salts, more irrigation than is required for plant growth is carried out, and the surplus water and salts are subsequently removed by drainage.

Unfortunately drainage systems also remove nutrients – especially nitrogen – and channel them into the lakes and rivers.

Since a great many fields are drained in Western Europe, this emission pathway is of particular significance for nitrogen emissions. Like groundwater, it is essentially determined by the annual nutrient surplus of the land used for agriculture.

There are areas where almost 100 percent of the arable land is drained, but also regions where there is no drainage at all. In the future, climate change will cause Germany and Europe to become drier, meaning more irrigation will be necessary. This emission pathway could therefore increase in significance. Emissions from drainage systems can be reduced by constructing retention ponds or via drainage control.



N balance surplus in kg/(ha·a)

- < 50
- > 50–75
- > 75–100
- > 100–125
- > 125–150
- > 150

Proportion of drained arable land in %

- 0
- < 20
- > 20–40
- > 40–60
- > 60–80
- > 100

N emissions via drainage systems in kg/(ha·a)

- 0
- < 1
- > 1–5
- > 5–10
- > 10–20
- > 20

This example of the German River Weser shows how emissions from tile drainages can differ greatly from region to region. About 6 percent of Germany is drained in total. These areas provide around 15 percent of the total nitrogen emissions, however.

05 Nutrient emissions via the groundwater

The most important emission pathways for nitrogen are usually those via the groundwater. Agricultural land is fertilised, but the arable crops (wheat, barley, etc.) do not use all the nutrients for their growth. This leads to excess or surplus nutrients. They are the most important factor for the emission of nitrogen from agriculture, because these emissions reach the surface waters via the groundwater and via tile drainages (see Point 04). On the way through the soil and the groundwater a large portion of the nutrients – but not all – is removed.

The groundwater flows underground to the deepest point of the groundwater body, from where it enters the surface waters.

An IGB scientist takes a groundwater sample.

The important point here is how long the nutrients remain in the groundwater: sometimes nitrogen applied as fertiliser 50 years ago is only reaching the surface waters today. This also means that it can take a long time until the effects of reduction measures become noticeable in the lakes and rivers.

What can we do?

Intensive farming and high crop yields often go hand in hand with high surpluses.

Groundwater can contribute to over 50 percent of the total emissions in these intensively farmed areas. In large parts of Germany – with the exception of areas with intensive cattle farming – the nitrogen surpluses have already been brought back to a relatively low level. On the European level, a renewed increase is not unlikely, however, because Eastern European farming will probably be intensified and agropolicy trends such as the increased production of bio-energy has already caused an intensification of agriculture in Western Europe as well.

Extensive cattle farming such as here in Ireland is often not a problem. However, industrial meat production results in very large amounts of liquid manure, which must be spread over the surrounding fields and often leads to high nitrogen emissions.

06 Nutrient emissions from sealed urban areas

Phosphates in washing powders and dishwashing detergents have, to a large extent, been replaced by other substances. This has made it possible to eliminate a main source of emissions from urban areas, contributing to a significant reduction in the phosphorus emissions.

This pathway covers emissions from sealed urban areas – such as streets, car parks or house roofs – as well as emissions from households, toilets and industry, which enter sewers and are subsequently either cleaned in a wastewater treatment plant or channelled directly into the surface water.

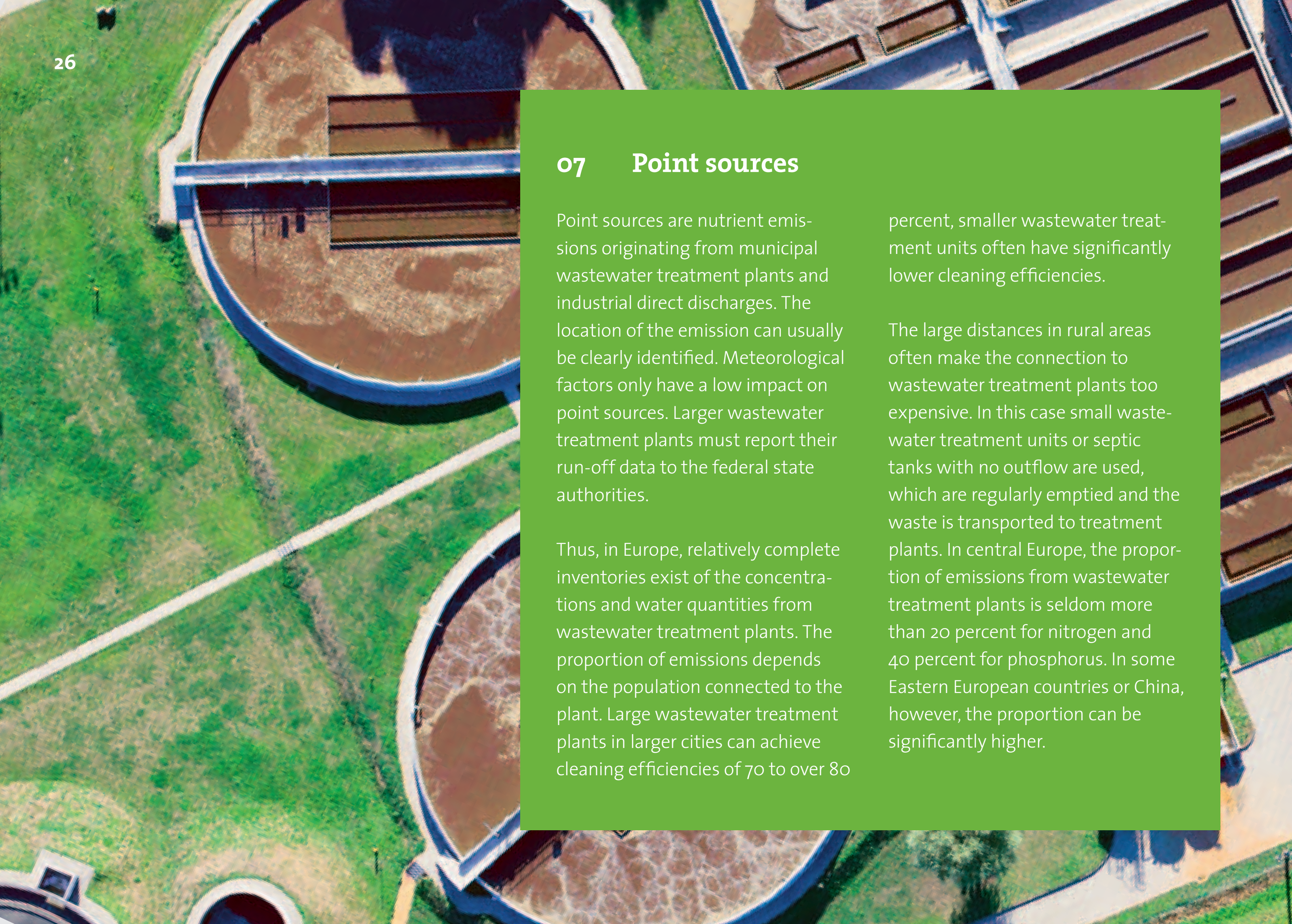
In principle, there is a difference between connected areas and not-connected areas and households: not-connected or unsealed urban areas/households direct flowing rainwater via the soil into the groundwater. Connected areas/households can be connected to either a separate or combined sewer system. In a separate sewer system, rainwater and wastewater, from toilets for example, are led away separately. The rainwater can then be channelled directly into the lakes and rivers, or after it has been precleaned. The remaining wastewater is fed to a wastewater treatment plant and cleaned there. In the combined sewer system, rainwater and wastewater are collected together and then cleaned in a wastewater treatment plant.

And when it rains?

During heavy rainfall, the capacity of the waste-water treatment plant can be exceeded in the case of combined sewer systems so that excess water is channelled via an overflow directly into the surface waters without being treated.

Emissions from this pathway can vary greatly from city to city and also between different countries, and depend on the degree of development of the sewerage networks and also the storage capacity of the combined sewer system. There are also differences in the use of phosphates in washing powders and dishwashing detergents, which MONERIS takes into account.

At specific locations and for short periods, discharges from urban areas can lead to high loads. Attempts are therefore being made to reduce the high emissions from urban areas by expanding the sewer system network and filter plants as well as unsealing urban areas (so that more rainwater can seep into the soil).



07 Point sources

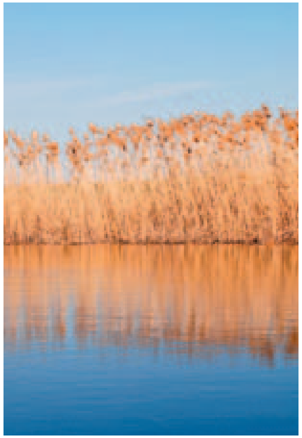
Point sources are nutrient emissions originating from municipal wastewater treatment plants and industrial direct discharges. The location of the emission can usually be clearly identified. Meteorological factors only have a low impact on point sources. Larger wastewater treatment plants must report their run-off data to the federal state authorities.

Thus, in Europe, relatively complete inventories exist of the concentrations and water quantities from wastewater treatment plants. The proportion of emissions depends on the population connected to the plant. Large wastewater treatment plants in larger cities can achieve cleaning efficiencies of 70 to over 80 percent, smaller wastewater treatment units often have significantly lower cleaning efficiencies.

The large distances in rural areas often make the connection to wastewater treatment plants too expensive. In this case small wastewater treatment units or septic tanks with no outflow are used, which are regularly emptied and the waste is transported to treatment plants. In central Europe, the proportion of emissions from wastewater treatment plants is seldom more than 20 percent for nitrogen and 40 percent for phosphorus. In some Eastern European countries or China, however, the proportion can be significantly higher.

Point source emissions from wastewater treatment plants, industry or the sewer system have been significantly reduced in recent years, but can still be responsible for high local nutrient pollution levels.

08 Nutrient retention



Vegetation close to the banks and shores can retain nutrient emissions, shade the water, serve as an important habitat and make a crucial contribution to the nutrient retention because of its high turnover rates.

When nutrients enter surface waters, they are not only transported towards the sea by rivers, but they are also subjected to a large variety of plant uptake, decomposition and transformation processes. The sum of these processes is called retention. It is an important part of the nutrient cycle.

Denitrification is the dominant retention process for nitrogen, while sedimentation plays the most important role for phosphorus. The extent of retention depends on various factors; in slowly flowing rivers more nutrients are retained by sedimentation, for example, and also by biological processes such as denitrification. The water temperature is also important – more denitrification takes place in summer than in winter.

While denitrification permanently removes nitrogen from the water, sedimentation can be reversed by remobilisation (stirring up at increased run-off) and other processes like desorption or re-dissolution. The retention in river systems such as the Elbe accounts for more than 60 percent of the emissions for nitrogen and phosphorus – which means that the self-cleaning capacity of lakes and rivers alone ensures that less than half of the emissions reach the sea as load.

Large lakes often have an enormous amount of nutrient retention.

At the source of the Elbe in the Czech Riesengebirge there are still pronounced winters with lots of snow, but in other parts the precipitation and temperatures have already changed and will affect the future run-offs of the Elbe.

From the Elbe to Mongolia:

Five examples of how MONERIS can be applied

01 A changing river – the Elbe

The Elbe is one of the largest river systems in Germany. As a lowland river it has a large number of lakes – more than 3,000 in Brandenburg alone. The Elbe region has relatively low levels of precipitation; the middle region has only 550 to 600 mm/m^2 rainfall annually. The intensive agricultural use means the most important pathways for nutrient emissions into the River Elbe are groundwater and tile drainages. In the Czech part of the Elbe, there are additional emissions from wastewater treatment plants.

The total nitrogen concentrations measured in the lower reaches of the Elbe are currently around 3.8 mg/litre on average. This is too much: the average which is being aimed for, as set by the River Basin Community (RBC) Elbe, taking into account the ocean conservation goals, is 2.8 mg/litre. This means a reduction of around 28 percent. The water in the Elbe flows quite slowly, and thus has a long residence time, which can result in large levels of algae growth in both lakes and rivers of the Elbe catchment area.

Low water levels in the River Elbe near Dresden:
The Elbe has often had low water levels in the past, but with climate change the high and low water levels could be more extreme in the future. Functioning flood plains can retain not only water, but also nutrients when flooding occurs.

The region is already relatively dry today; climate scenarios have shown that the summers could become even drier, but the winters wetter. The River Havel and the middle reaches of the Elbe are particularly affected by this. The possible consequences include water quality problems, restricted navigability of the Elbe, and also an increased risk of flooding.

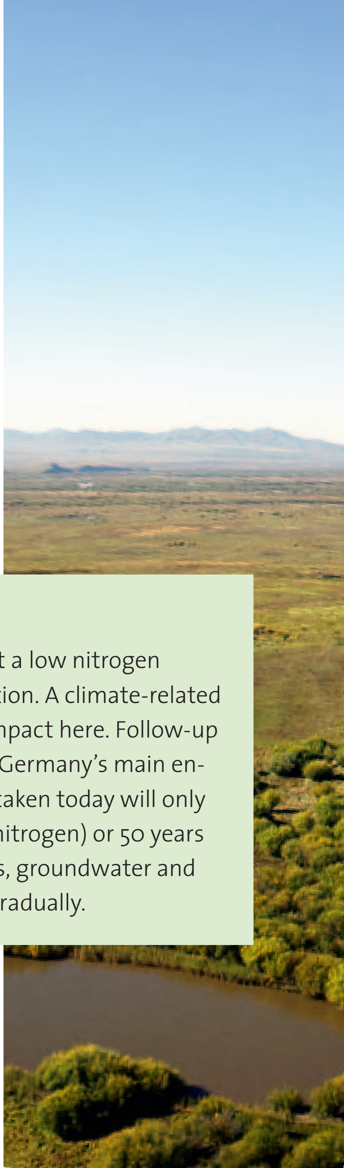
What effects can climate change have?

The "GLOWA Elbe" project used MONERIS to investigate, for example, what impact climatic change has on nitrogen concentrations in the Elbe. According to the modelling, there could be a climate-related decrease in emissions of 5 percent. At the same time, the lower dilution would result in a 7 percent increase in the nitrogen concentration, which would make it significantly more difficult to reach the goals of the RBC Elbe.

In a further step, possible measures to reduce nitrogen for the RBC Elbe were investigated. A reduction of approx. 25 percent of the emissions can be achieved by wide-ranging measures such as buffer stripes, more effective use of fertilisers, advising farmers and carrying out soil-conserving measures. In the Czech part of the River Elbe in particular, these must be supplemented by the expansion of the wastewater treatment plants and the sewerage networks.

… and if we act now?

The BMBF research project NITROLIMIT has proven that a low nitrogen content in most of our lakes limits the primary production. A climate-related increase in the concentrations could have a negative impact here. Follow-up modelling on behalf of the UBA (Umweltbundesamt – Germany's main environmental protection agency) shows that measures taken today will only reach their maximum effectiveness in 30 to 40 years (nitrogen) or 50 years (phosphorus): Both nutrients have accumulated in soils, groundwater and sediments and are only removed from these systems gradually.



02 Water resources management in the Kharaa river basin (Mongolia)

Mongolia, situated in the north-eastern corner of Central Asia, is characterised by a rapid transition from the Soviet-style centrally administered economy to a parliamentary democracy. Under the influence of a market economy and globalisation, the pressure on natural resources is growing – this applies in particular to the quality and quantity of the freshwaters of Mongolia.

Water is a rare resource in general; at the same time water withdrawals are increasing and the quality of the surface and groundwater is impaired by mining, industry and pastural farming. Outdated infrastructures for the supply and disposal of water, along with a continuous influx of the rural population into the cities aggravate the existing difficulties.

The Kharaa river basin was selected for the project "IWRM in Central Asia: Model Region Mongolia" ("MoMo", www.moneris.igb-berlin.de/index.php/momo), funded by the German Federal Ministry of Education and Research (BMBF). This region was selected to implement Integrated Water Resources Management (IWRM) by way of example. The Kharaa region covers 14,500 km^2 and is characterised by a semi-arid climate, making it part of Mongolia's bread basket; a good fifth of the national wheat crop is grown there. In addition, the country's most profitable gold mines are found in central Kharaa. The majority of the gross domestic product is generated in the mining sector, and its importance is increasing. The pollutants released by mining have negative impacts on the ecosystem. On top of this, there is increasing pressure to use the land for agricultural purposes, which will go hand in hand with more irrigation of arable land.

The situation is made even more critical by Mongolia's widespread overgrazing and nomadic animal husbandry, which causes significant quantities of manure to enter directly into the river when the animals drink. Informal settlement belts of yurts (so-called ger districts), whose non-registered inhabitants live without a supply of drinking water or wastewater disposal, are springing up on the outskirts of the towns. Around half of the urban population now lives in ger districts.

Growing numbers of livestock are causing increasing problems in Mongolia. The animals often drink directly from the surface waters and also leave their excrement there. In addition to this, trampling of the embankment can lead to erosive emissions.

By using MONERIS, the urban systems could be identified as the most important emission pathway. Due to the lack of wastewater disposal, the nutrients accumulate in the ger districts. The nutrient balances on agricultural land are negative, however, because no fertiliser is used and so more nutrients are removed from the soil by the crop than are introduced. With the aid of MONERIS it was possible to work out measures for improving settlement water management and to calculate their cost-effectiveness. In the project phase 2010 to 2013, German partner institutes tested several pilot plants (decentralised wastewater treatment plants with the option of connection to biogas reactors, installation of special toilets to separate urine and faeces) in order to safely dispose of the municipal wastewater and recycle the residual waste. The next step is to incorporate agriculture and farming into the recycling chain. The plan for the future involves introducing these measures into a nutrient management system in the form of a lifecycle management system between settlement water management and urban farming.

There is enormous pressure to act: under the noticeable effects of climate change (gradual increase in the annual average temperature, changes to the distribution of precipitation), land-use intensity and an annual population growth of over 1 percent, a deterioration in the quality of the water in the lower course of the Kharaa can already be seen, while the water in the tributaries from the almost uninhabited regions of the Khentii mountains is still unpolluted.

03 Danube: Water management at the “multi-national river”

The Danube is the world’s most international water and river system: Nineteen countries share its catchment area, which covers around 800,000 km^2. Twelve large cities are located on its banks, including Vienna, Belgrade and Budapest; 28 million people live in the total Danube catchment area. Due to the various nutrient emissions into the river system, the ecological status of the Danube is still far from “good”. This applies in particular to the Black Sea, into which the river flows.

Five species of sturgeon live in the Danube. Re-establishing animals threatened by extinction is part of the national biodiversity strategy. The IGB provides the scientific support for the project.

On account of the steadily increasing anthropogenic uses of the Danube during the last century, the state of the Black Sea declined progressively until 1992. The continually increasing nutrient emissions and loads which took place until the political upheavals of 1992 led to symptoms of entrophication such as algal blooms and mass development of jellyfish. As a consequence, the fish population in the Danube was both changed and reduced drastically. However, the situation eased somewhat in the following years due to political changes in the Eastern European countries and the accompanying economic collapse of agriculture and industry. The goal of international agreements is now to get the emissions of nutrients and other harmful substances back down to the levels of the 1960s.

Nutrient pollution levels in the Danube region are determined by the different hydrological and bio-geographic conditions, land use intensity, as well as

the type and quality of wastewater treatment. Which nutrient loads result from this? How do different measures effect nutrient emissions, and how long does it take to reduce nutrient loads? To clarify these questions, MONERIS was used to carry out an in-depth analysis of individual nutrient

emission pathways and to model different scenarios in the Danube river catchment.

Many countries – complex problems

Groundwater, with its share of 50 percent, is the dominant pathway for nitrogen emissions. The most important emission pathways for phosphorus are urban systems (35 percent) and wastewater treatment plants (32 percent). Reducing nitrogen emissions depends significantly on reducing the nitrogen surpluses on agricultural land. However, in most countries in the Danube catchment area, these are already significantly below the European average as well as below the target levels of 60 kg per hectare and year which Germany is striving to achieve.

At the moment, meat consumption and bioenergy production are increasing. Generally speaking, an intensification of agriculture can be expected, meaning a significant reduction in nitrogen surpluses is far from probable – neither in the upper nor the lower countries of the Danube regions. If agricultural production is not adapted, this trend will make it more difficult – or even impossible – to achieve the reduction goals.

It has been possible to reduce phosphorus emissions from wastewater in particular by increasing the number of households connected to a municipal wastewater treatment plant, or by expanding the network of small wastewater treatment units, as well as further improving existing treatment plants. Positive reductions in phosphorus emissions can also be expected due to the ban of phosphates from washing powder and dishwashing detergents across Europe.

In 1880 many households were not connected to a sewage system or a wastewater treatment plant. Instead, excrement was often used on the fields or in urban farming as fertiliser and reintroduced into the cycle.

04 Insightful: a look at the history of the Oder river system

Nutrient emissions are usually only modelled for a few years or decades in the past. Looking at a longer historical timespan, however, can also be worthwhile: in order to understand the paths taken by emissions under relatively natural conditions and use them to derive goals for a good ecological status, IGB researchers reconstructed nutrient emissions for the years 1880 to 1940 using the River Oder as an example.

The basin of the Oder river system is the Baltic Sea's third largest river catchment, measuring approx. 120,000 km² and represents one of its most important suppliers of nutrients. During the period investigated this catchment area was dominated by agriculture: two thirds of the area was arable land and one quarter was forest. While these variables remained almost constant during the period under investigation, industrialisation and population growth led to the cities expanding and the beginning of urban sprawl. The proportion of urban area thus increased from 1.3 to 5.7 percent of the total area of the Oder basin – cities more than quadrupled in size. More people, more industry, more intensive agriculture: these were the main factors which, from 1880 onwards, caused the nutrient emissions into the Oder river system to increase – and the IGB investigation using MONERIS was able to show the reasons for this development as well as its extent.

The consequences of a gradual intensification of agriculture

The key results: between 1880 and 1940 the overall nitrogen emissions increased – the reasons for this were mainly industrialisation, an increase in burning fossil fuels and more intensive animal husbandry. As a whole, the total nitrogen emissions into the surface waters of the Oder river system doubled over this period.

Land was being used more and more intensively. This increased the proportion of artificially drained arable land in the Oder region from 9 (1880) to 28 percent (1940). In conjunction with the rising nitrogen surpluses, the emission proportion by tile drainages thus increased from 2 to 10 percent.

Statistical data on animal husbandry, crops and fertilisers were evaluated to determine the land use intensity in the region investigated. Before the start of the agricultural intensification (between 1880 and 1890), the nitrogen surplus was 5 kg/ha per year on average. Between 1893 and 1920 the nitrogen balances became negative, however. Because of the population growth it became necessary to achieve higher and higher crop yields. At the same time, the use of mineral fertiliser decreased, especially during the First World War (1914 to 1918), because it was not possible to import products such as Chile saltpeter and guano.

In addition, human excrement was no longer used as fertiliser on the fields. From 1920 onwards, nitrogen surpluses increased steadily to around 26 kg/ha annually (1939). The crucial factor here was the invention of the Haber-Bosch process, which made it possible to produce inorganic fertilisers. However, compared to current nitrogen surpluses in the Oder basin, which sometimes reach more than 50 kg/ha, these reconstructed values still seem low.

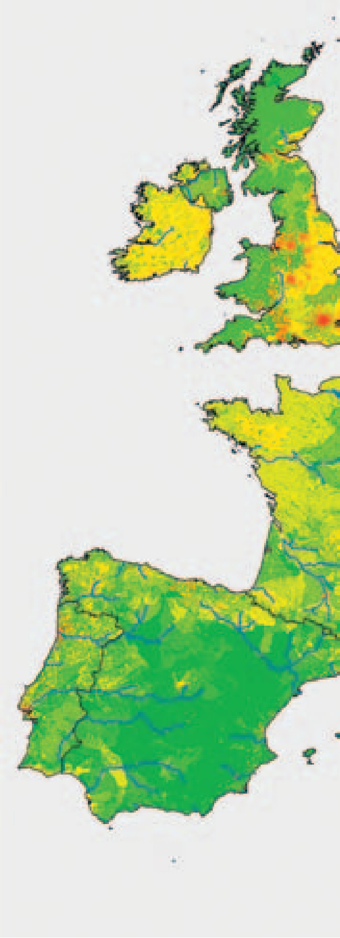
05 State, country, river: harmonised modelling in Europe

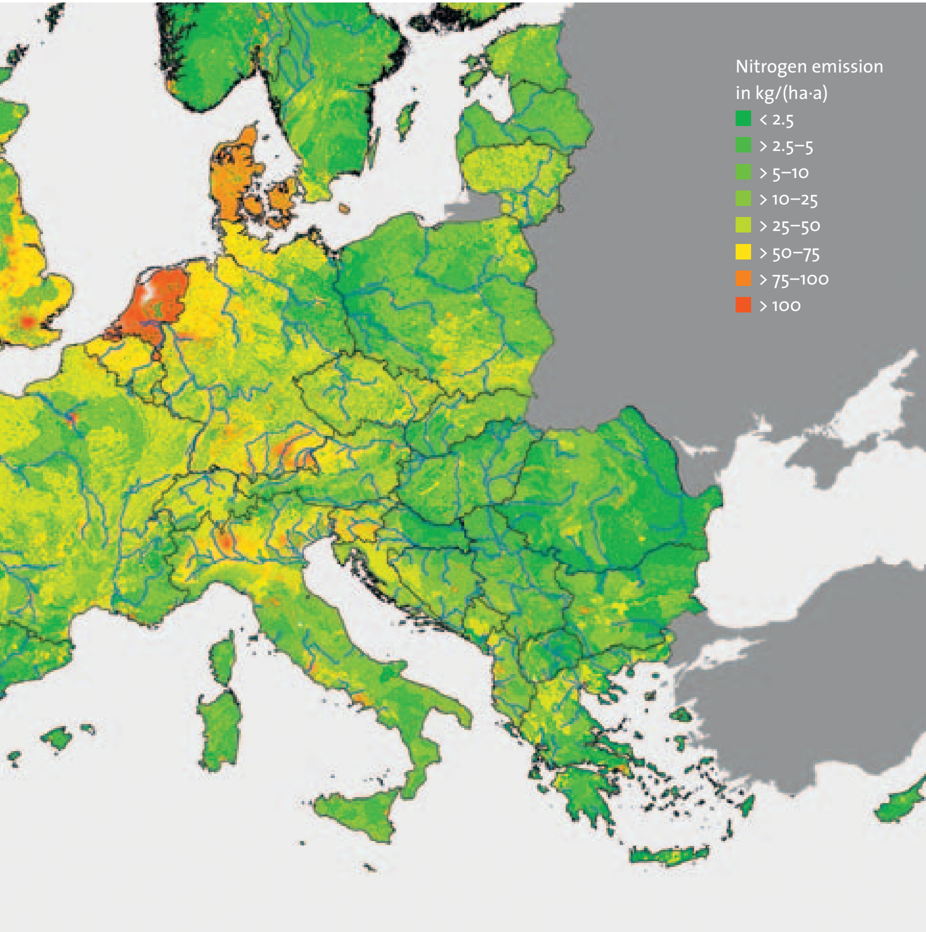
While, as is the case with the Danube, one river catchment often encompasses many countries, it is also possible that different catchments lie within one country. The determination of nutrient emissions at river catchment level and for individual countries is often not coordinated and is done with different calculation bases. Only a joint consideration of nutrient emissions and water quality in river systems, national territories and coastal waters provides a comparable assessment basis in order to derive reduction goals and actions needed.

In order to improve water quality and to implement the aims of the EU Water Framework Directive and other international agreements such as the "Baltic Sea Action Plan", it is necessary to significantly reduce nutrient emissions overall. Until now, the EU Member States have been using different models with different methods for their EU reporting obligations; the quality of the input data was also not uniform. Comparability of the findings, identification of regions with particularly high emissions and deriving measures to reduce the nutrient emissions can only be realised to a limited extent on this basis.

With the aid of a harmonised database and a model such as MONERIS, a comparative consideration of the nutrient emission situation in different European regions becomes possible – and thus cross-European planning of measures to improve the nutrient situation in the surface waters. Freely available data from European or international institutions are used as the data basis for the European modelling.

The nutrient emissions were calculated with MONERIS for the EU 27, Switzerland, Norway and the Balkan region. An area of 5,000,000 km² and around 2,400 river catchment areas with an average size of 2,100 km² were considered. The finding was that 5.4 million tons of nitrogen and 330,000 tons of phosphorus are being introduced into European river systems every year.





At more than 70 percent, the main emission pathways for phosphorus here are urban and point sources (wastewater treatment plants), while nitrogen enters surface waters mainly via the groundwater (57 percent). Accordingly, especially high nitrogen emissions are found in regions with intensive agriculture such as the Netherlands, Belgium, Denmark, Northern Germany and Great Britain.

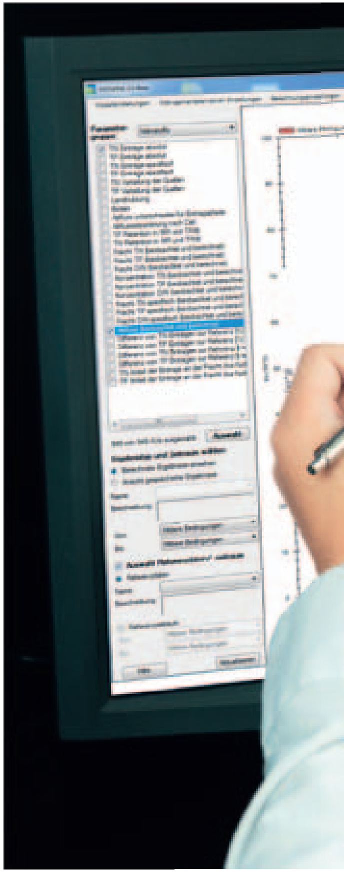
MONERIS shows that effective reduction of the emissions could be achieved in central Europe by improving wastewater treatment plants, by erosion protection measures and by reducing the use of fertilisers. Nutrient emissions via atmospheric deposition play an important role in Scandinavia in contrast. According to calculations by MONERIS, overall there are clear potentials to reduce the emissions. However, this requires measures adapted to the different European regions. As a next step, the modelling undertaken by MONERIS will be expanded by extending the calculated period and by taking into account the effects of climate change in order to be able to derive information on possible consequences of future nutrient emissions.

06 MONERIS – made easy to use

MONERIS was developed as a scientific tool. In the past, authorities, universities and other users repeatedly asked whether they were allowed to use the model for their own studies or whether existing projects could be understood, checked and developed further with it. Members of river basin communities in particular wanted to have a detailed look at the results, to test the measures implemented to reduce emissions and check the possible potential for reduction. In order to do this, the company DHI-WASY was commissioned by the IGB and started to reprogramme MONERIS in 2010 and equip it with a user interface. Since then, the software has been continually expanded and maintained. By now, MONERIS provides several options to present the results in the form of tables or diagrams, and also as a map in different levels of resolution.

MONERIS has been programmed in a C# environment. The concept of an open software under application of a GNU General Public Licence is being looked into for passing on the software. This means that the software is freely available and can be passed on free of charge to all interested users. The GNU General Public Licence is intended to ensure that all further developments will be made available to the user community free of charge and in their entirety. Users can only modify the actual calculation modules, however. The data administration and the interface control are passed on in compiled form and cannot be changed easily.

The MONERIS software can be downloaded from the IGB or the MONERIS website; the project-related databases cannot usually be made available on the website for free download due to data protection and copyright reasons, however. If you are interested in such data, please contact the relevant IGB member of staff directly.



The emissions and loads for selected regions and years can be displayed clearly via the user interface and can easily be exported into other programmes.

For more detailed information on the model, the methods and the source code, please feel free to contact the IGB team. They will set up access to the development section for you, where the developments and modifications as well as the source code are accessible and your own developments can also be introduced. MONERIS has a modular structure. Thus, enclosed calculated modules can be modified and passed on to other users, who can simply copy them into a special directory on their computer and use them immediately.

Since MONERIS continues to be a scientific tool which is freely available, user support can only be provided to a very limited extent. If you are interested in training sessions or technical advice, this can be organised on an individual basis with the IGB or DHI-WASY.

The IGB working group “Nutrient balance in river systems”

Dr Markus Venohr,
Head of the working group at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)

Dr Markus Venohr was born in 1972 in Duisburg. He studied Geography, Meteorology, Oceanography and Technical Climatology at the universities of Bochum, Zurich and Kiel. He completed his doctoral thesis at the Humboldt-Universität in Berlin on modelling the nitrogen retention and transformation in river systems. Since 2001 he has been a scientist at the IGB where he has headed the “substance emissions and reactions” working group since 2009. The working group is composed of 10 to 20 scientists, doctoral students, technical assistants and students and has been participating in many national and international projects for more than 15 years.

Apart from continuously developing MONERIS, he participates in a large number of scientific projects in Germany, Europe and worldwide, for example in Canada, Brazil, China and Mongolia, and works at the interface between research, application and political consultation.

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