JRC Scientific and Technical Reports

Nutrient discharge from rivers to seas for year 2000

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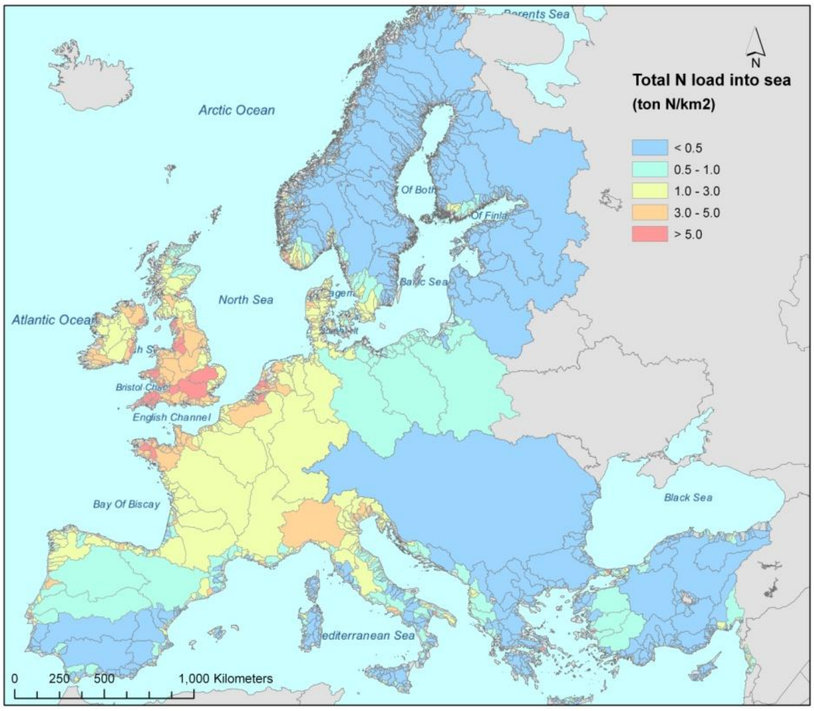

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1. Introduction

The understanding of the fate and impact of pollutants on the functioning of the terrestrial/aquatic interface is a scientific challenge that requires a combination of several disciplines, tools and datasets. In order to support the implementation of the Marine Strategy Framework Directive, DG Environment and the Joint Research Centre joined to develop a study on the expected cumulative impact of existing European Union environmental legislation on the quality of the marine environment, with specific reference to the case of aquatic discharges from inland-based sources (FATE-scenarios). The objective of the study is to perform a long term retrospective and prospective analysis (1985-2020) of land based nutrient loads in European Seas to assess the effectiveness of the EU environmental policies and other management plans adopted by Member States. The focus is not only the nutrient loading to the Sea but also the inland response to various policies.

The project is divided in three phases. The first one focuses on database development and model-based assessment of nutrient loading for the year 2000, which was selected as baseline. The second phase is dedicated to the collection of all relevant data to perform a retrospective assessment, including trend analysis. Finally, the third phase consists in the elaboration and evaluation of scenarios of policies implementation. Given the jeopardised and often scarce availability of information on nutrient loads to European waters, the innovative aspects of the FATE assessment lie in the consistency of data sources and methodology at the scale of study, the continental Europe, and on the spatial resolution of estimates of nutrient pressures.

This report presents the work accomplished in the first phase of the project, concerning database development and model validation for the baseline year (2000). After an introduction to EU legislation dealing with nutrient losses in water bodies (Chapter 2), the report presents first the modelling approach used in the study (Chapter 3), then the data collection and database development (Chapter 4), and finally the estimated nutrients loads to European Seas for the year 2000 (Chapter 5). The analysis is completed by an assessment of nutrient pressures on European waters, including spatial estimates of nutrient source apportionment (Chapter 6).

2. Eutrophication and EU legislative tools

Human activities have enhanced the input of nutrient in terrestrial and aquatic ecosystems. Even though nutrients are necessary to support life, excessive presence of these substances can lead to the deterioration of water quality, causing eutrophication (Nixon, 1995). According to the UWWTP Directive, eutrophication is defined as the excessive enrichment of waters by nutrients leading to water quality deterioration and aquatic ecosystem disturbance. The guidance document on eutrophication developed by the WFD Common Implementation Strategy lays the ground for a common understanding of eutrophication across the various EC Directives. Eutrophication often results in increased primary production, algae blooms, depletion of oxygen, and decrease of the macro benthos. The occurrence of eutrophication has been documented for all European Seas (EEA, 2001). Severe cases of eutrophication have been reported for the Baltic, North Seas and several coastal lagoons along the shore of the Mediterranean Sea (ICES, 2003; EEA, 2001). The spatial extent of eutrophication ranges from local hot spots in enclosed bay to whole seas such as the Baltic.

Even though the EC disposes of a wide arsenal of legislations to combat nutrient emissions in European waters (reinforced by the efforts of MS to reduce nutrient losses in the context of various conventions), their implementation and effectiveness remains yet to be evaluated. Few studies have tempted to perform assessments at large scales. Artioli et al. (2008) have analysed the trend of nutrient budgets for European seas considering the link with the implementation of different EU policies and management plans. No clear trend could be observed throughout Europe, the same policy resulting in different impacts according to the degree of implementation, local conditions, and determinand of interest (nitrogen or phosphorus). For instance, the authors showed that in the Northern Adriatic anthropogenic nitrogen from land based sources, which is the local dominant input, has been increasing steadily since 1950, while for phosphorus the past accumulation in the sediment hinders any improvement in the water column, even though phosphorus loads have been halved during the period 1975-1985,. In the Baltic proper, no significant trend was detected from nutrient loads, despite some drastic reduction in the inland nutrient input (Artioli et al., 2008). The difficulty in detecting changes of nutrient loads into the seas is exacerbated by the climate variability which induces changes in water flow and consequently in nutrient loads. This has been observed for the North Sea (Radach and Patsch, 2007) and in the Danube (van Gils, et al., 2005).

One major problem encountered in studies on nutrients exports to water is the paucity of data on nutrients emission, transformation and flow throughout the river basin. This complexity can be somehow overcome by using a modelling approach, which involves estimation of nutrient sources, pathways and retention.

Nutrient loading into receiving water occurs via two pathways: *point* source and *diffuse* source. Point sources are discharged into water bodies at discrete locations and include various categories of discharges such as municipal and industrial waste water effluents, runoff and leachates from solid waste disposal sites and active mines, runoff from concentrated animal feeding operations, combined sewers overflow (Novotny and Olem, 1994). The industries rejecting large amounts of nutrients include steel, pulp, chemicals, plastics, fertilizers production and oil production and refining (Heathwaite et al. 1996). Diffuse pollution, also called nonpoint pollution, refers to discharge of pollutants via non discrete points and their exact origin is often difficult to determine. Their discharges are highly variable (unlike point source) and are heavily dependent upon climate. Diffuse pollution is often originating from agricultural activities but not only and includes: runoff (surface and groundwater) from agricultural land non linked to concentrated and confined animal operations, return flow from irrigation, atmospheric deposition, scattered dwelling, logging activities, etc. (see Novotny and Olem, 1994, for a more extensive list of various point and nonpoint sources).

There is actually no legislation for controlling directly eutrophication and nutrient loading into coastal and marine waters, it is embedded in several pieces of legislations which are listed and described briefly hereafter.

Protecting European seas is high on the agenda of the European Commission because of their ecological and economical importance. The European Commission has been setting various regulations to control and reduce nutrient load into receiving waters: surface, groundwater and transitional. Two directives were established early in the ‘90ies to control pollution from nitrate from agriculture (diffuse source) and the second to control pollution from urban waste water treatment plants (point sources). In a later effort, the Commission established a Water Framework Directive setting new ecological objectives for all European waters and aiming at more integrated and coherent approach for water protection. Finally in 2008 the European Commission adopted the Marine Strategy Framework Directive to protect the European seas. The following paragraphs briefly describe some legislations and conventions aiming at controlling input of nutrient loads into surface waters

- *Directive 91/676 concerning the protection of waters against pollution caused by nitrates from agricultural sources.* OJ (1991) L375/1 also known as the “Nitrates Directive” aims at reducing pollution from nitrate coming from agriculture and prevents any further pollution. To achieve these objectives, the Directive sets up various steps. Member States (MS) are required to identify waters affected by pollution or potentially affected if no action is taken. Pollution as defined in Annex I of the Directive refers to waters where nitrate concentrations is larger than 50 mg-NO3/L and water bodies affected by Eutrophication or will be affected if no action is taken. The second step of the implementation consists in identifying Nitrate Vulnerable Zones (NVZ) which are the areas draining in the previously identified areas and which contribute to pollution. The following step consists in protecting waters against pollution by requiring MS to establish a Code of Good Agricultural Practices to be implemented on a voluntary basis. The implementation of this code is mandatory on all NVZ in addition to other measures such as manure management which limit the application of organic N at 170kg/ha, etc. The Directive also requires MS for the purpose of designation and revising the designation of the NVZ to set up monitoring programmes.

- *Directive 91/271 concerning urban waste water treatment.* OJ (1991) L271/40 aims at protecting the environment from discharges from urban waste and waste of certain food processing industries. The Directive requires that all agglomerations with 2,000 population equivalent (p.e.) and higher are equipped with collecting systems, and that all waste water discharged be subject to at least secondary treatment. To further protect endangered waters, the Directive requires MS to designate Sensitive Areas which include: freshwater bodies, estuaries and coastal waters which are eutrophic or which may become eutrophic if protective action is not taken; surface freshwaters used for drinking purpose that contains or are likely to contain more than 50 mg/l NO3; and areas where further treatment is necessary to comply with other Council Directives such as the Directives on fish waters, on bathing waters, on shellfish waters, on the conservation of wild birds and natural habitats, etc. The Directive requires that waste water discharged into these sensitive areas must undergo a more stringent treatment than secondary level.
- *Directive 2000/60 Establishing a Framework for Community Action in the Field of Water Policy.* OJ [2000] L327/1 aims at achieving good ecological and chemical status for all waters by 2015. The Water Framework Directive (2000/60/EC, 2000) required MS to perform within the river basin districts an analysis of pressure and impact on the surface and subsurface water resources, where diffuse sources of pollution had to be identified as well as their impacts on the ecological status of surface and subsurface waters. The setting up of monitoring networks had to be achieved by 2006. Then by 2009 MS have to draw and publish river basin management plans and to develop a programme of measures needed to achieve the good status objective.
- *The Common Agricultural Policy (CAP)* reform by decoupling subsidies from production levels and liking them to the protection of the environment is promoting a cleaner agriculture and a more sustainable use of resources. Agricultural subsidies are now linked to application of statutory minimum requirements (SMR) and cross compliance. Farmers willing to go beyond SMR can get additional payments through Rural Development Programs by implementing “Good Farming Practices”. These measures should lead to the decrease in the use of fertilisers.

- The aim of the *Marine Strategy Framework Directive* is to protect the marine environment, prevent its deterioration, or where practicable, restore marine in areas where they have been adversely affected. The implementation will be ecosystem based with four Marine regions to be considered: Baltic, the North East Atlantic Ocean, the Mediterranean Sea, and the Black Sea. Considering the marine regions described previously, each MS shall develop a "Marine Strategy" with the aim of achieving or maintaining Good Environmental Status of their waters within that region by 2020. One major first step in the implementation is, in the context of the initial assessment required for Article 8, the analysis of the "essential characteristics and current environmental status", and an analysis of the predominant pressures and impacts which include among others nutrient enrichment coming from direct discharges from point sources and/or losses from diffuse sources including agriculture and atmospheric deposition.
- The conventions covering the Marine regions discussed previously include *OSPAR, HELCOM, MEDPOL, and the Black Sea Convention*. See EEA (1999) for recommendation by the Marine Conventions to control nutrients from land based activities.

3. Methodology

Modelling has been recognised by the WFD as an essential tool to help achieving its ambitious objectives. Indeed, modelling has the major advantages that it is extremely efficient in evaluating and performing scenario analysis, and can overcome shortage of data. To help evaluate the efficiency of the implementation of the various environmental legislation on nutrient discharge, and to assess alternative scenarios, modelling is the central component of this study, along with the development of a harmonised European data base (whenever possible).

The modelling tool used in this study, the model GREEN, is based on a simplified conceptual approach distinguishing the different pathways in which nutrients reach surface waters. According to this approach, diffuse sources, including fertiliser applications (both mineral and organic forms), scattered dwelling, atmospheric deposition, are first reduced in the soil matrix and then once in the stream they undergo further reduction due to in-stream retention processes, while point sources, which include waste water treatment plants, industrial effluents and runoff from paved areas, reach directly the streams and are thus reduced only by the stream retention process (Figure 1). In the model, the driver behind the nutrient losses is the annual precipitation and the retention in water is linked to the river length (Grizzetti et al., 2005).

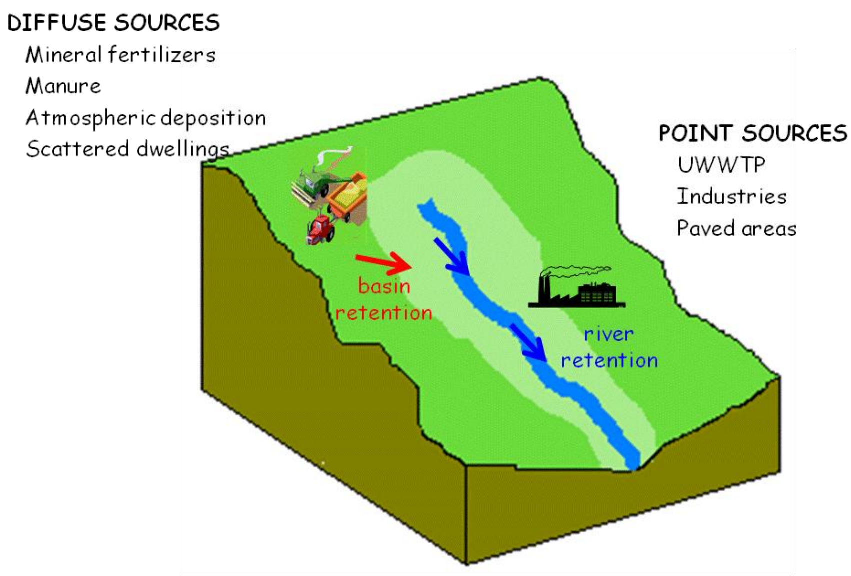


Figure 1. Processes and input accounted for by the GREEN model (red arrow refers to basin retention, blue arrow refers to the stream retention)

The region of study is subdivided into a number of sub-basins according to the monitoring points or according to any predefined scheme. In each sub-basin the nutrient load is related to the sum of the different nitrogen sources reduced by the retention processes occurring in soils and rivers plus all the incoming nutrient from the upstream sub-basins. Indeed, the model considers a routing structure for nutrient load along the watershed, based on the river network (Grizzetti et al., 2005; 2008). During their travel along the channel network, the nutrients are reduced by the retention process. To account for the retention in the lakes, the surface area of the water bodies is also taken into account. The model requires the calibration of only two parameters one related to the annual rainfall driving the basin retention, the second to the river length controlling the stream retention.

The model in any point in the river basin can be formulated as follows:

$$L = [\, DS \cdot \alpha_P \cdot f(R) + (PS + UL)\,] \cdot \alpha_R \cdot f(L, AREA) \qquad \text{Equation 1}$$

where *L* is the annual nutrient load (tons), *DS* is the sum of diffuse source within the basin (tons), *PS* are all the point sources emitted in the basin, *UL* is the upstream loads (tons), *f* is a reduction function which depends on the annual rainfall *R* (mm), for the retention taking place in the basin (including crop uptake, volatilization, denitrification), and on the river length (*L*) and lake area (*AREA*) for the water retention (including nutrient uptake, settling, denitrification), α_P is the basin retention parameter, and α_R is the water retention parameter. The model calibration consists in determining the two parameters α_P and α_R. A robust evaluation of these two parameters requires an extended monitoring dataset. The approach can be used for total nitrogen and total phosphorus or considering dissolved and particulate forms separately. Addition details about the model procedure are found in Grizzetti et al. (2005; 2008).

4. Data collection and database development

4.1 Catchment database

As detailed previously, the modelling approach used in this study relies heavily on monitoring data for the calibration process. An exact positioning of the monitoring stations is also crucial for the discretisation of the large catchments into smaller units. The first step of the data collection consisted in processing a digital elevation model in order to generate a set of uniform catchments, and delineate the basins of interest. Vogt et al. (2007) developed a catchment database for continental Europe (CCM2), using the Shuttle Radar Topography Mission (SRTM) 90m resolution digital elevation model (DEM). However the generated sub-basins were too detailed and heterogeneous in size. Therefore, in order to avoid any interference of the sub-basin size and the river length on the calibration process, it was decided to reprocess all CCM2 layers to generate a set of more size-uniform sub-basins. The data layers were processed using the tools and structure of the ArcHydro data model (Maidment, 2002). ArcHydro is a spatial and temporal data model based on a geodatabase structure and that operates under ArcGis. The flow direction grid used for the processing is that of the CCM2. The flow direction grid was used to calculate for each cell the number of cells draining in it. The grid was then converted into a digital stream map by considering that all cells draining a number of cells larger than a pre-specified threshold are actually part of the hydrographic network. The generated stream network was forced to follow that of the CCM2. In the last step of the DEM processing, the flow direction grid was used to delineate all cells draining into a specific segment of the hydrographic network. The ArcHydro tools were used to define the stream network, and the watershed boundaries. The extent of the area considered in the study is shown in Figure 2. The delineated area includes contribution from 39 different countries.

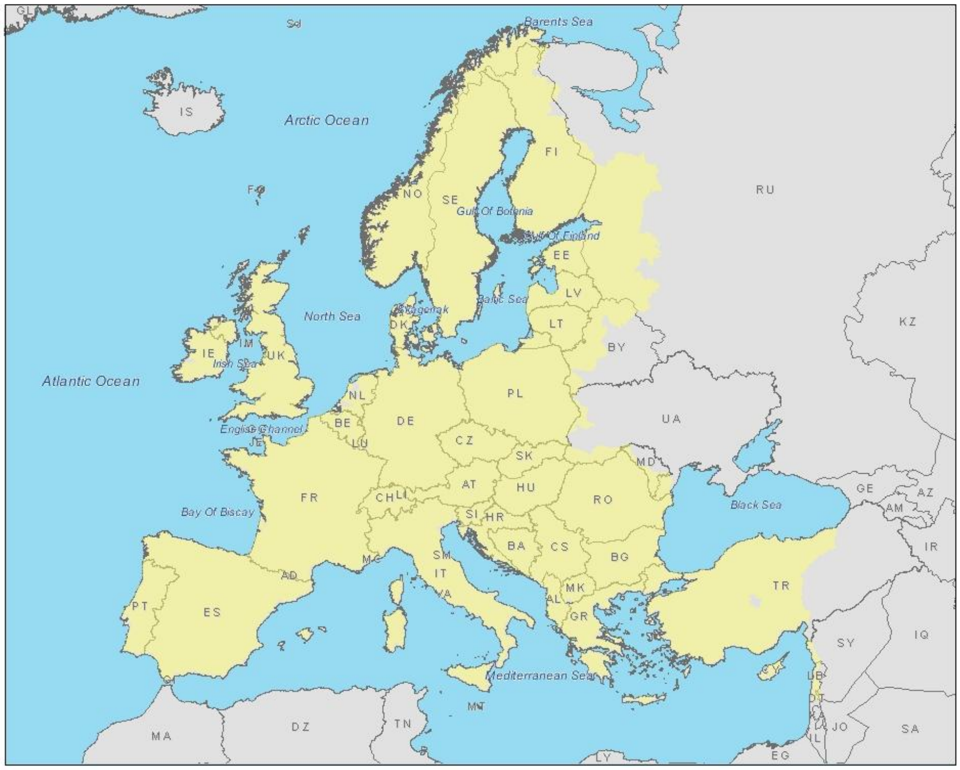


Figure 2. Extent of the area covered in the study

The area of interest covers of surface of 5.9 10^6 km^2 and represent the aggregation of about 2235 river basins (outlet to the sea) divided into 33,000 sub-basins. The average size of each sub-basin is about 180 km^2 (the maximum size is 1700 km^2). All the river basins are shown in Figure 3. Each sub-basin is associated with a river segment, displayed in Figure 3. A layer including all major water holding structure (lakes, dams, etc.) was also added. Each water holding structure is linked to one sub-basin. The database is conceived in a way that each sub-basin is linked to the downstream sub-basins, allowing to follow the flow path throughout the stream network. In addition, it is possible to trace upstream the origin of the flow coming out of any specific sub-basin or water holding structure, and also to determine the links between the water holding structures.

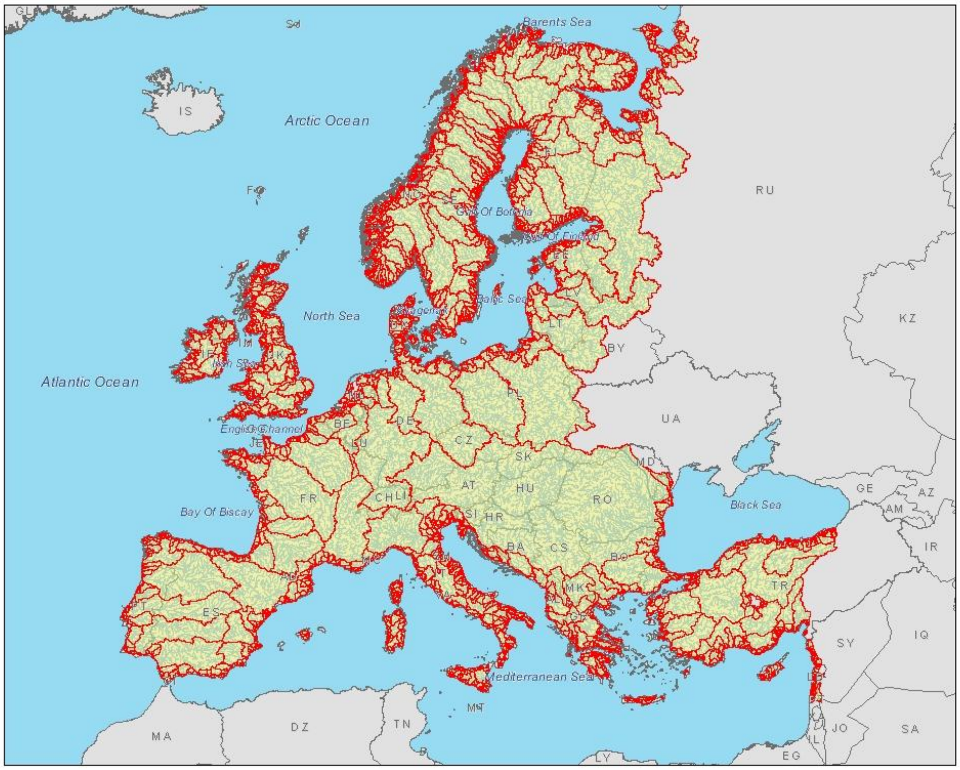


Figure 3. Catchments and river network for the study area

4.2 Monitoring database

At present there is no detailed up to date database including monitoring points for river basins draining in European Seas. The EEA holds the Eurowaternet database that has monitoring points for EU 27. However these data even though covering large spatial extent were not appropriate for this project. Indeed, very often the Eurowaternet database includes long time series for water quality but without the corresponding water flow, making it impossible to calculate time series of nutrient fluxes. It was thus decided to develop a new monitoring database by contacting directly three conventions covering the European seas: HELCOM, OSPAR, and Barcelona conventions.

HELCOM through BNI (Baltic Nest Institute, Stockholm Resilience Institute, Stockholm University, Stockholm, Sweden) provided a database including monitoring data for all catchments draining into the Baltic Sea from year 1980 to 2000. The data included monthly information of water discharge, dissolved inorganic N, total N, dissolved inorganic P and total P. This database included 107 discharge points from which 85 points located at river basin mounts were retained. The other points were not considered as they represented the aggregated discharges from several river basins. All measurement stations provided are located at the watershed outlet (see Figure 4).

During the first year of the project, contact was established with the other two conventions, however, until today no data exchange took place, as the mechanisms of data exchange are still being developed and collaboration scheme still being discussed. To overcome the lack of data and extend the spatial coverage of the monitoring points for model calibration, the database was further populated with data retrieved from the various river commissions and through direct contact with ministries of environment, research institutes. For Greece three stations were obtained from the National Centre for Marine Research (NCMR). The data consisted in monthly water discharge and monthly measurements of NH4, NO3, NO2, PO4, TotP concentrations for the 1980-2000 period.

Concerning Germany, most of the data was provided by IGB (Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany). The data set consisted in 71 stations of water quantity and associated stations of water quality. Most of the data was available on a monthly basis for the period 1990-2002. The data set covered all forms of nitrogen and phosphorus. In addition, for Germany, measurements were also obtained from the Weser River Commission. The dataset consisted in 15 stations with bi-monthly values of water, and NH4, NO3, PO4, TotP and TotN concentrations. The time series retrieved covered the period 1985-2005.

For the German part of the Elbe river basin data were provided by IGB, whereas for the Czech part data were retrieved from the Elbe River Commission. The latter consisted in 4 stations with monthly measurements of NO3, NH4, TotN, PO4 and TotP for the 1990-2002 period.

For France, the data on water discharge were provided by the French Ministry of Environment, while the water quality data were given by IFEN. Initially several thousands of stations were provided, therefore an analysis was performed to keep the stations where both water quantity and quality were available, and spatially homogeneously distributed in the country. The analysis led to the selection of 296 stations, with different time coverage and data availability. Generally, the data consisted in monthly measurements of NO3, NH4, NO2, Tot N, PO4, TotP for the period 1985-2005.

For Spain the data were obtained from the Ebro, Jucar, and Tajo River Commissions. The data consisted of 41 stations with few samples per year of mostly NO3, NO2, NH4 and PO4 (frequency and determinands analyzed vary from one basin to the other).

Data for the Danube was obtained from the Danube River Commission. About 70 stations were available for internet download. The data included all forms of nitrogen and phosphorus, but the availability varied from country to country.

All measurement stations used in the study are shown in Figure 4 and Table 1 provides a summary of the data availability and data source for the monitoring database. Additional data will be added as they come available. It is already planned to extend the time period for the data coming from IGB. Discussions are ongoing for including the data from the Duero river basin (for the Spanish side). Data for all Portugal will also be added. Data availability for Italy is still unknown. No data could be retrieved for the UK.

The present assessment focused only on total nitrogen and phosphorus. The load was calculated using a flow weighted approach. In the first step, monthly values of water flow and concentration of total nitrogen and phosphorus were obtained. Only stations where at least eight months of water flow and water quality were available simultaneously (flow was usually available for all months) were retained for calibration. In these stations the annual flow weighted concentration of total nitrogen and total phosphorus was calculated as follows:

$$\mathbf{C_{an}} = \frac{\sum_{i=1}^{l} \mathbf{C_i\ Q_i}}{\sum_{i=1}^{l} \mathbf{Q_i}} \qquad \text{Equation 2}$$

where C_{an} is the annual flow weighted concentration (mg/L), Q is the monthly flow (m^3/s), and *i* is the number of available month (with *l* varying between 8 and 12). The annual nutrient load was then calculated as the product of the annual flow weighted concentration and the annual flow.

Because of the extent of the database a thorough quality check of the data available was not possible. It was assumed that since the data were obtained from official sources, they had already undergone a systematic quality check. However, some outliers were detected for both flow and water quality data. Some inconsistencies also appeared in transboundary basins, where for the same station located at the country border, the values of concentration for the same parameters varied by a factor three to four. The outliers were then removed and not taken into account in the calculations.

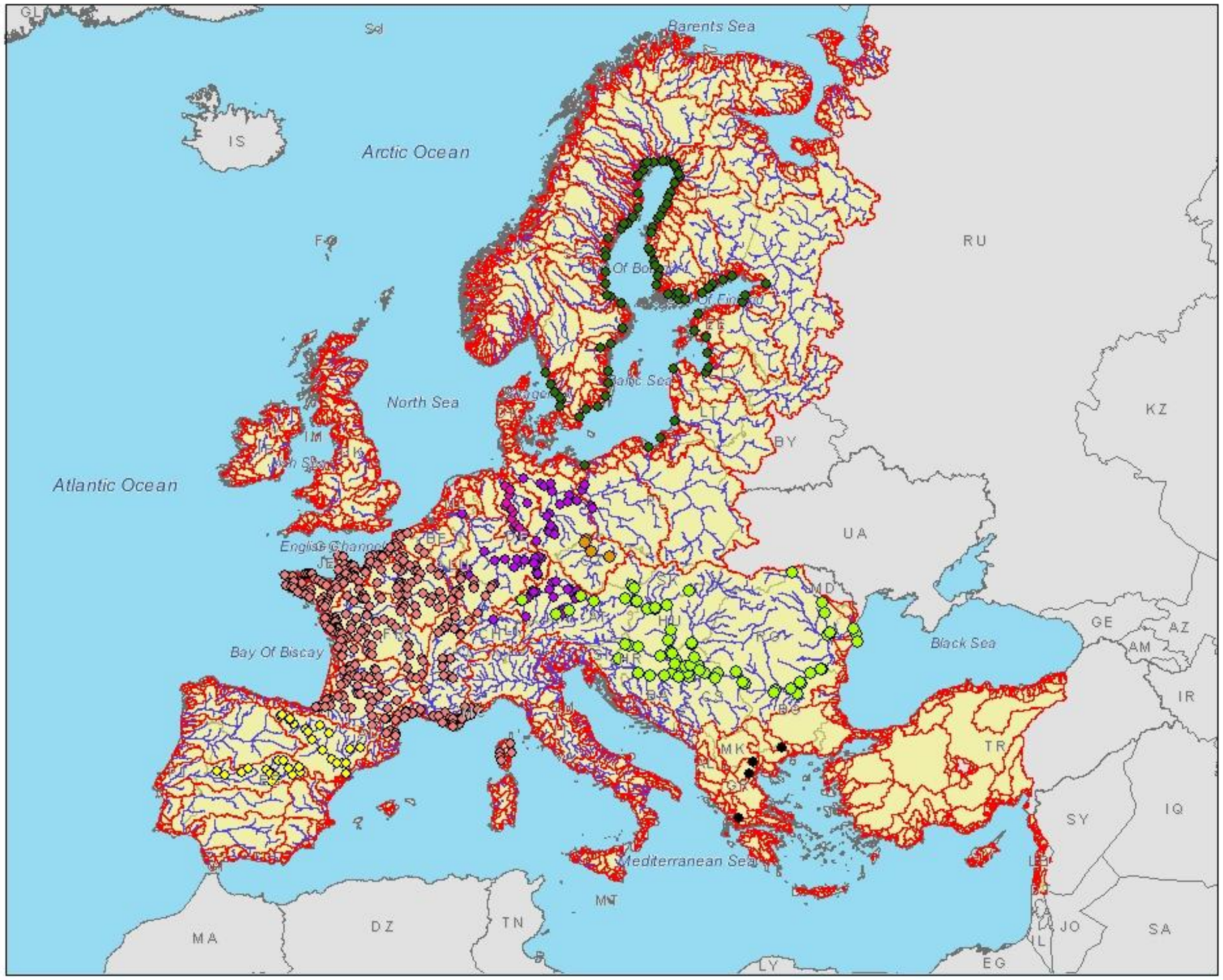


Figure 4. Location of the measurement points available for the study. Colours indicate that data belong to different nation or institution database

Table 1. Data availability and provider for the monitoring stations used in the study

Region	NH4	NO3	NO2	DIN	TOTN	PO4	TOTP	DIP	# stat	Series length	Data provider
Baltic				M	M		M	M	85	1980-2000	Baltic Nest Inst.(HELCOM)
Danube	M	M	M		M	M	M		70	1996-2005	Danube Commission
Greece	M	M	M			M			3	1980-2000	NCMR
Germany	M	M	M	M	M	M	M		71	1990-2002	IGB, Germany
Weser	BM	BM			BM	BM	BM		15	1985-2005	Weser Commission
Elbe (CZ)	M	M			M	M	M		4	1990-2002	Elbe Commission
France	M	M	M		M	M	M		296	1985-2005	French Min. of Environ. / IFEN
Spain	LM	LM	LM			LM			41	1985-2005	Ebro, Tajo, Jucar Commission
Total									**585**		

M refers to monthly measurements, BM refers to bi- monthly frequency and LM refers to less than monthly frequency

4.3 Land use

4.3.1 Global data sources

The nutrient input entering a river basin depends on the activities taking place in the area, such as agriculture, pasture, urban settlement, etc. For this reason, when modelling a river basin, the land cover map is an important data layer to estimate the nutrient input from the different sectors and to identify the spatial distribution of sources, and its accuracy and resolution is highly relevant. Normally, land cover maps are derived from the interpretation of satellite images or aerial photos. These images provide the geographical distribution of the main land covers, such as agricultural land, forest, urban area, water, , but they rarely distinguish between crop types. As agricultural fertilizers represent one of the main nutrient inputs and the fertilization rates may vary deeply according to farm system and crop type, the information on crop spatial distribution needs to be taken into consideration when estimating diffuse nutrient sources. However, in Europe, statistics on crop shares and fertilizer use are available only for administrative regions (country or regional level), which does not fit the river basin dimension. Therefore, methods to estimate the crops share and fertilizer rate within the agricultural areas need to be developed.

In this study, different sources of information were considered to develop a land use map suitable for modelling nutrient fluxes in the European river basins, combining geographical layers covering the whole continental Europe and statistical data available for European administrative regions. The land use map was used later as the basis to distribute the nutrient input through mineral and manure fertilizers and nitrogen biological fixation. The areal extent of the study imposed some simplifications in the scale resolution and in the crop classification. Several global databases were combined: the spatial information on areas occupied by agriculture and pasture was taken from the HYDE 3 database (Klein Goldewijk and Van Drecht, 2006), the geographical location of main land cover types was based on the GLC2000 (Bartholomé and Belward, 2005) and the information on crop shares was derived from the CAPRI database for EU27, Norway and Balkan region (Britz, 2004) and from the SAGE database for the rest of Europe (Monfreda et al., 2008).

The HYDE 3 is grid-based inventory of historical land use (Klein Goldewijk and Van Drecht, 2006). It provides information on global cropland and grassland area per 5 by 5 minute grid cell for 1980, 1990 and 2000. For the allocation of cropland and grassland HYDE 3 used time-dependent weighting maps based on population density, the land suitability for crop production, natural vegetation type and the distance to rivers. The advantage in using these data consists on the spatial resolution of the information, the availability of coherent data for past years and the effort of the HYDE study to provide accurate estimates of crop and grassland areas.

The GLC2000 (Bartholomé and Belward, 2005) is at present the best available land cover map covering the entire area of study and distinguishing between 23 classes. However, GLC2000 was developed only for the year 2000 and does not include information on crop types, required for the present modelling needs.

The information on crop share was taken from the CAPRI database for EU27 countries, Norway and the Balkan region and from the SAGE database for the remaining European countries (Figure 5). CAPRI is a regionalized economic model for agriculture (Britz, 2004), which calculates production statistics per NUTS2 administrative regions in EU27, using data based on official statistics provided by EUROSTAT. CAPRI estimates crop shares and fertilizer applications per administrative regions. The SAGE database describes the geographic distribution of global agricultural lands (Ramankutty et al. 2008) and crop areas, including 175 crops (Monfreda et al. 2008) with a 5 minute resolution in latitude by longitude.

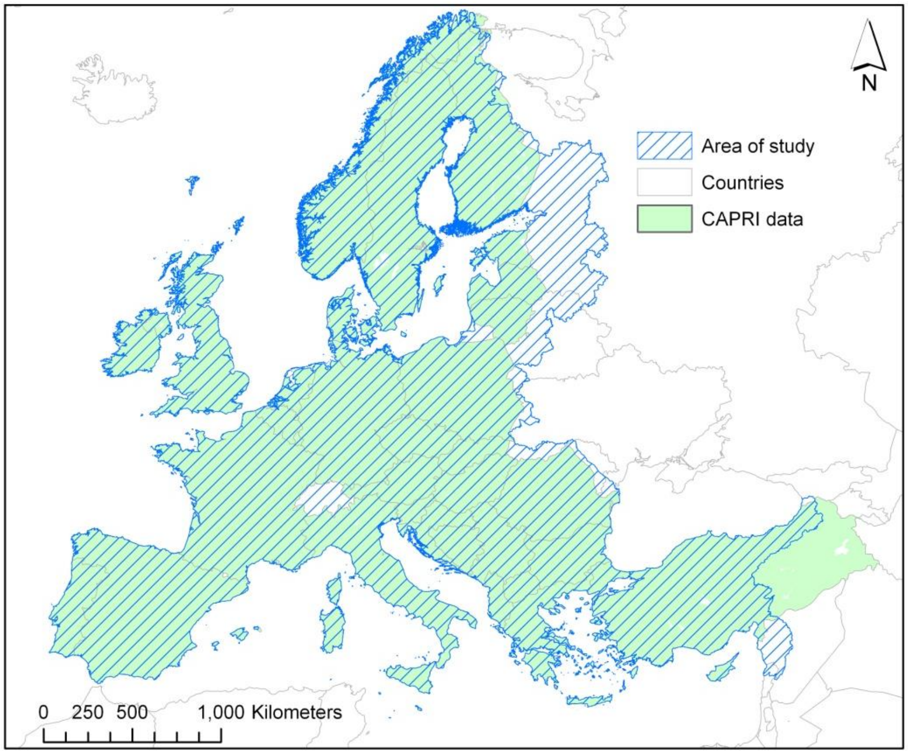
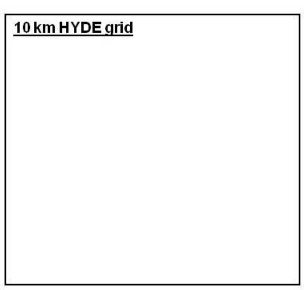


Figure 5. Extent of the area covered by the CAPRI database (data will extend over Turkey in a near future but were not available for this study)

4.3.2 Land use development

1) The global HYDE 3 grid including the information on crop and grassland areas was projected from the 5 minutes resolution to a 10km grid. For each 10km grid the surface occupied by crop (Crpp) and grassland areas (Pasp) was computed (Figure 6). The 10km grid was then used as key unit to develop the land cover map for continental Europe (LC).



	HYDE	
Cropland	30%	
Grassland	20%	
Other	50%	

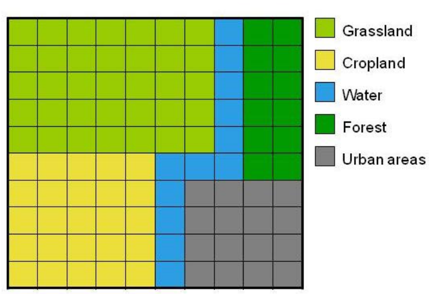
Figure 6. Example of a 10 km grid cell including the crop and grassland share according to HYDE

2) The GLC2000 was reclassified according a simplified scheme (Table 2), which accounts for the main land cover types: Cropland (C), Grassland (G), Shrub (S), Bare areas (B), Forest (F), Urban areas (U) and Waters (W).

Table 2. GLC2000 land cover types in Europe and correspondent simplified classification

GLC value	GLC class name	Simplified classification	Code
1	Tree Cover, broadleaved, evergreen	Forest	F
2	Tree Cover, broadleaved, deciduous, closed	Forest	F
3	Tree Cover, broadleaved, deciduous, open	Forest	F
4	Tree Cover, needle-leaved, evergreen	Forest	F
6	Tree Cover, mixed leaf type	Forest	F
8	Tree Cover, regularly flooded, saline water	Forest	F
9	Mosaic: Tree Cover / Other natural vegetation	Forest	F
11	Shrub Cover, closed-open, evergreen	Shrub	S
12	Shrub Cover, closed-open, deciduous	Shrub	S
13	Herbaceous Cover, closed-open	Grassland	G
14	Sparse herbaceous or sparse shrub cover	Grassland	G
15	Regularly flooded shrub and/or herbaceous cover	Grassland	G
16	Cultivated and managed areas	Cropland	C
17	Mosaic: Cropland / Tree Cover / Other natural vegetation	Grassland	G
18	Mosaic: Cropland / Shrub and/or grass cover	Grassland	G
19	Bare Areas	Bare areas	B
20	Water Bodies	Water	W
21	Snow and Ice	Water	W
22	Artificial surfaces and associated areas	Urban	U
23	Irrigated Agriculture	Cropland	C

3) The HYDE 10Km grid was overlaid with the reclassified GLC2000 1Km grid. The two grids were previously aligned, using the 10km grid as reference (Figure 7). The location and percentage represented by the GLC land cover classes C, G, S, B, F, U and W in each 10km cell were calculated.



	HYDE	GLC2000
Cropland	30%	25%
Grassland	20%	35%
Other	50%	40%

Figure 7. Example of a 10 km cell based on HYDE overlaid with the reclassified GLC2000 1 km grid

4) For each 10Km cell, the difference between HYDE and GLC crop and grassland areas was computed. The location of water and urban areas was considered fixed by the GLC2000, while both crop and grassland areas provided by HYDE were spatially assigned according to the land covers location in the GLC2000 1k grid.

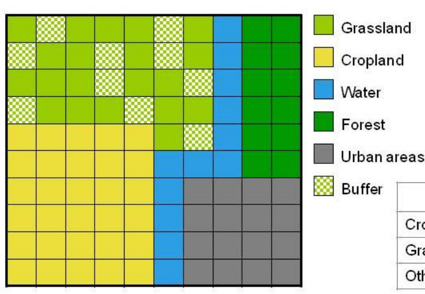
Within each 10km cell:
when HYDE (Crpp) = GLC2000 (C):
no changes were needed

when HYDE (Crpp)> GLC2000 (C):
C was extended on classes G, S, B and F, randomly within each class but respecting the sequential order (G->S->B->F) until all crop area indicated by HYDE in the 10km cell was allocated. In any case, C was never extended on GLC2000 urban and water 1km cells.

when HYDE (Crpp+Pasp)< GLC2000 (C+G):
C was reduced to respect the crop area indicated by HYDE converting randomly the 1km C cells within the 10km cell into agricultural buffer, which was still considered as agricultural land but did not receive any fertilization

The same methodology was applied for matching the grassland area provided by HYDE in each 10km grid. Figure 8 shows the resulting 10km cell after correcting the crop and grassland classes according to HYDE areas.

The fact that area modifications are performed respecting the serial order in changeable classes reduces the error in converting one land cover type into another, as it is more reasonable a conversion from cropland to grassland than one from cropland to shrub land. On the contrary, no convenient assumptions can be made on location of land cover changes within the same land cover type, and at this level the modifications are carried out randomly. However, this does not affect the final results of the changes, since land covers areas are then aggregated again at the 10km grid or the catchment level.

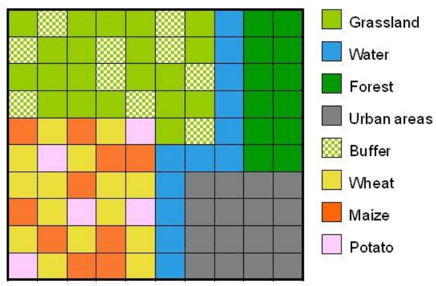


	HYDE	GLC2000	LC
Cropland	30%	25%	30%
Grassland	20%	35%	20%
Other	50%	40%	50%

Figure 8. Example of a 10km cell after correcting the crop and grassland areas according to HYDE shares and respecting as much as possible the GLC2000 location

5) Finally, region specific crop type shares were assigned to each LC 10km cell, based on the information available in the CAPRI and SAGE databases, and the actual crop types were randomly distributed within

the C class (Figure 9). CAPRI provided crop shares at NUTS2 administrative regions for EU27 and Norway, and at country level for the Balkan region. For the rest of continental Europe the information was taken from the global 5 minutes grid map supplied by SAGE. A correspondence was established between the crop classifications of the two databases. The final land cover map for continental Europe is shown in Figure 10.



		LC
Cropland	Wheat	15%
Cropland	Maize	10%
Cropland	Potato	5%
Grassland		20%
Other		50%

Figure 9. Distribution of the crop type in the C class

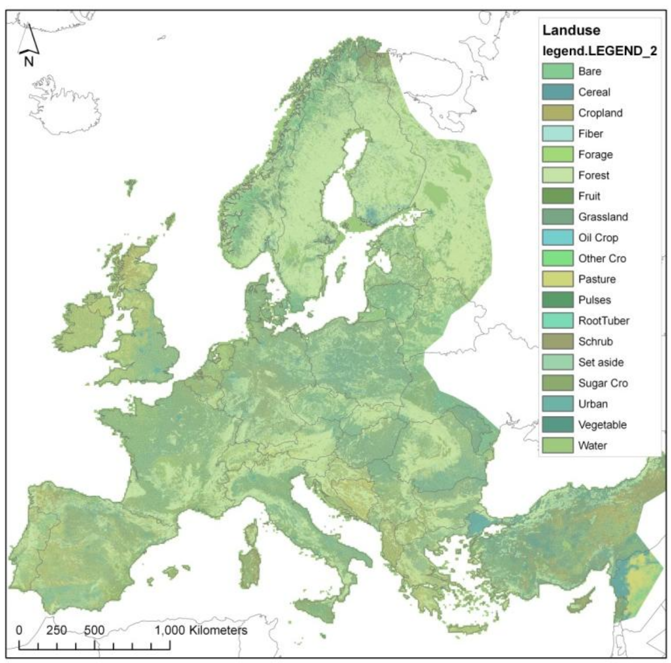


Figure 10. Land cover map for continental Europe

At present, several land cover maps and global agricultural data sets are available for continental Europe; however none of them was developed specifically to assess the nutrients impact on inner and coastal waters at fine resolution. The methodology proposed in this study aimed at developing a land cover/land use map more suitable for modelling nutrient fluxes in the European river basins. In particular, some main objectives underpin the choices made in the land cover development:

1. Set a land cover resolution suitable for detailed spatialised catchment based assessments.
2. Adopt actual crop and grassland areas to avoid significant erroneous estimates of nutrient inputs from agriculture
3. Include as much as possible the available geographic information on land cover distribution to strengthen the link with physical processes
4. Consider regional specific crop share and fertilizer rate based on official European data and robust models.
5. Develop a methodology which could be easily applied for the 1985-2005 period.

According to the present methodology the LC resolution is 10km, although the technical resolution is 1km. This solution is very convenient for studies at catchment scale, as it allows to lump estimations at catchment level with a much higher accuracy than a 10km grid, especially when catchments are small and present peculiar shapes. In addition, the original data resolution is respected when dealing with catchments larger than 100 km^2, which is always the case working at the continental scale.

The extension of agricultural area is fundamental for a correct estimation of the nutrient input from agriculture and precedent studies have shown how discrepancies are present in databases used at European scale (Grizzetti et al., 2007). The agricultural area is show in Figure 11 .

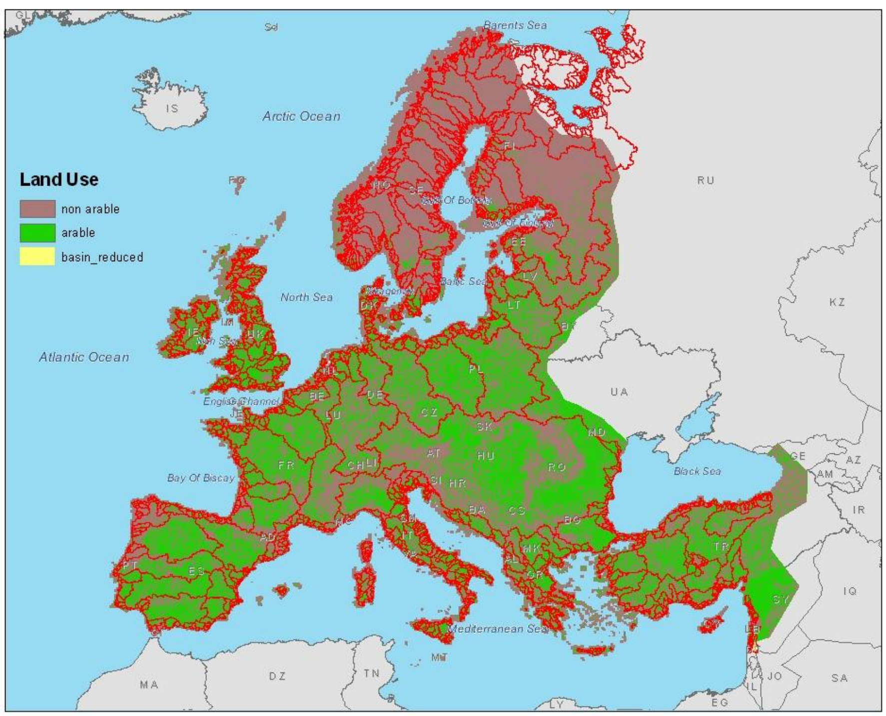


Figure 11. Distribution of arable and non arable land across the study area

The agricultural area estimated by the present land cover map (LC) was compared with other databases for EU15: the FATE land use map (Grizzetti et al., 2007), GLC2000, Corine Land Cover 2000 and CAPRI database. The results are shown in Figure 12, for total utilized agricultural area, cropland and pasture, respectively. In the comparison, the values reported in the FATE land use map can be considered as a reference, because of the specific effort done in that map to be consistent with the agricultural areas provided by the Farm Structure Survey of year 2000 (FSS). The LC developed in the present study fairly agrees with the FATE estimates, similarly happens for the CAPRI database on administrative units, as the LC and the CAPRI model account for the actual reported areas. On the contrary, higher divergences are present for the GLC and Corine maps, which are based on the interpretation of land cover images.

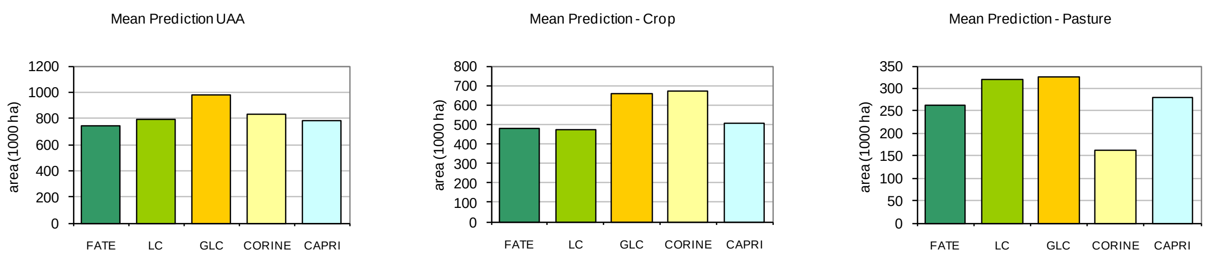


Figure 12. Total utilized agricultural area (UAA = crop+pasture), crop area and pasture area estimated by different maps and datasets for EU15: the present land cover map (LC), the FATE land use map (FATE), GLC2000 (GLC), Corine Land Cover 2000 (CORINE) and CAPRI database (CAPRI)

4.4 Fertilizer application

The fertiliser application rates for EU27, Norway and the Balkan region were obtained from CAPRI (Britz, 2004). For the remaining countries, fertilisation rates were taken from the FAO (2002). The application of fertilizers takes only place on agricultural land (Figure 11). The application rates of mineral and manure nitrogen and phosphorus for some major crops in Europe are shown in Figure 13 .

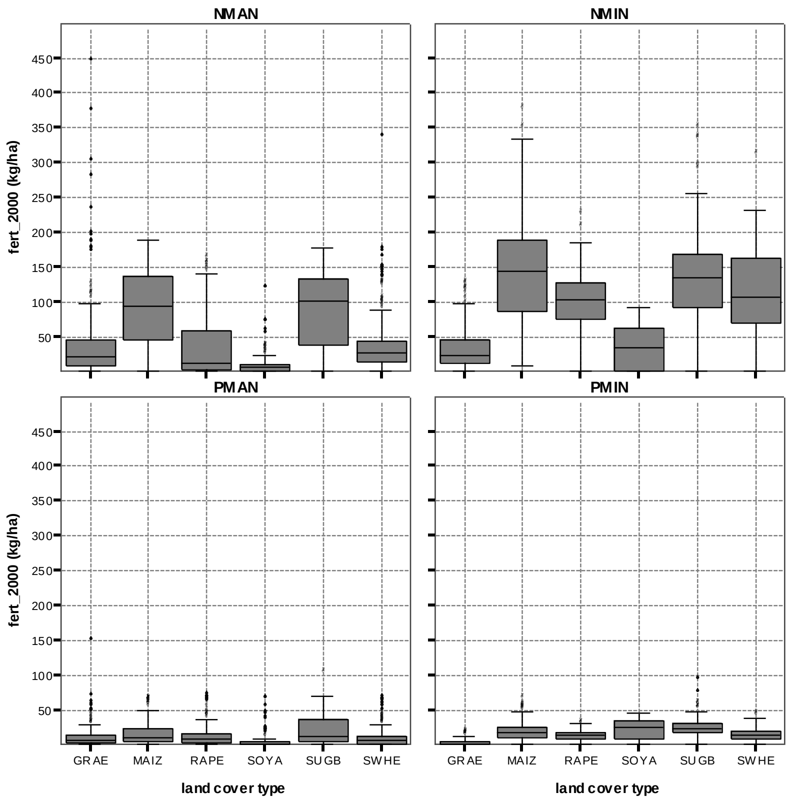


Figure 13. Distribution of mineral nitrogen (NMIN), mineral phosphorus (PMIN), manure nitrogen (NMAN), and manure phosphorus (PMAN) application rates for grassland (GRAE), maize (MIAZ), rapeseed (RAPE), sugar beet (SGBT) and soft wheat (SWHE)

Maps (1km^2 grids) of the application of mineral and manure nitrogen are shown in Figure 14 and Figure 15, respectively. The manure application is obviously mostly concentrated around intensive breeding areas (Brittany, Po valley, Belgium, the Netherlands). The application of mineral nitrogen fertiliser shows less spread than that of manure. The total application of nitrogen is shown in Figure 16.

The applications summarized by basins are displayed in Figure 17. Most of the intensively fertilized river basins are located in Northern France, Northern Italy, Belgium, The Netherlands, Denmark and England. However, this figure hides large variability within the basin itself. The application per sub-basin is shown in Figure 18. Other intensively fertilized regions include Southern Germany and Austria. It is interesting to note that neither the new Member States nor the other non EU 27 countries have an intensively fertilized agriculture, beside the area around Kaliningrad.

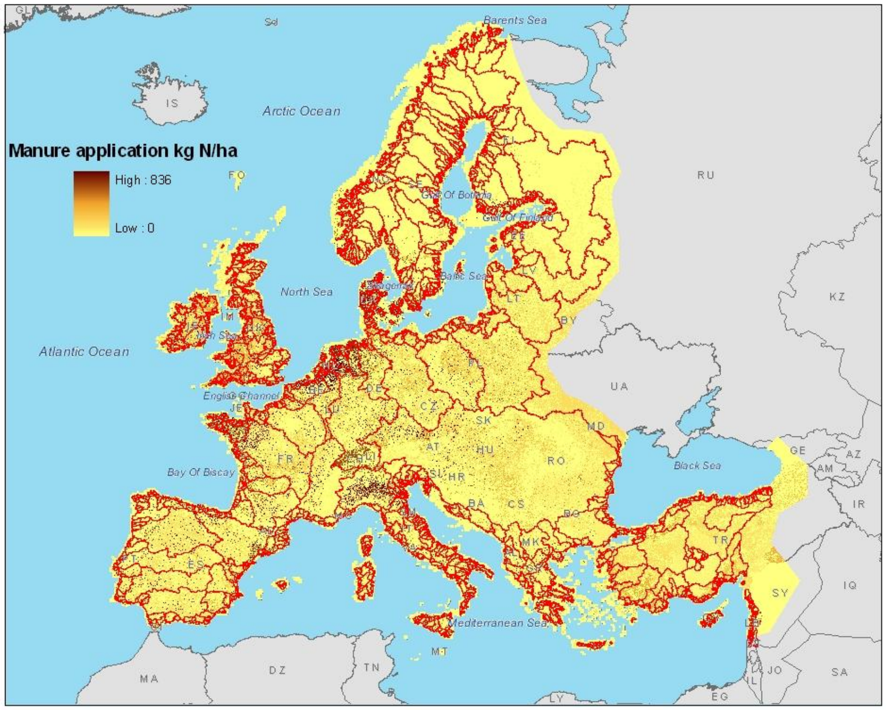


Figure 14. Application of manure N (kg/ha)

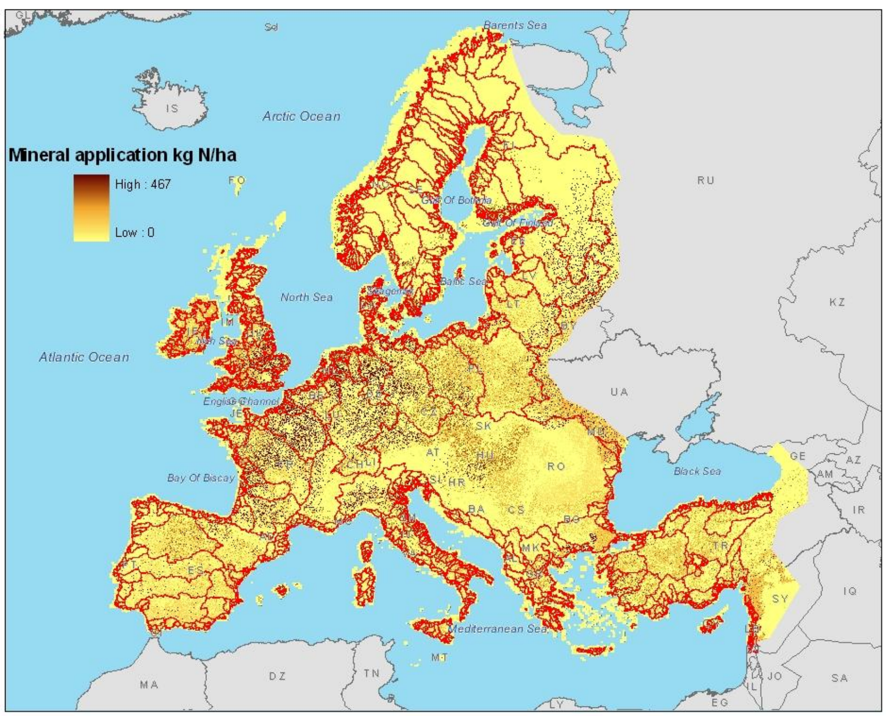


Figure 15. Application of mineral N (kg/ha)

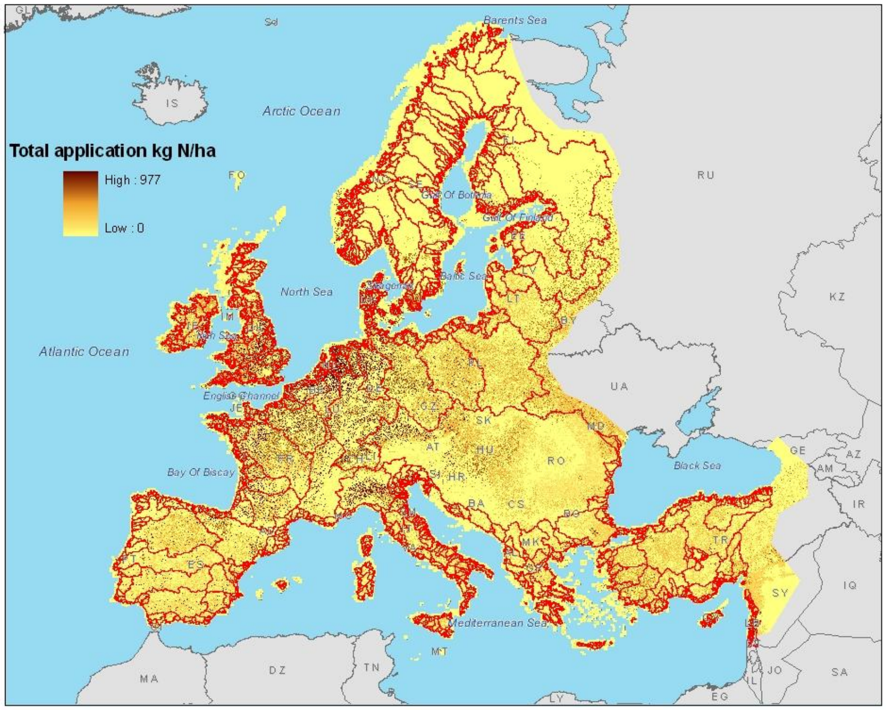


Figure 16. Total N fertilizer application (kg/ha)

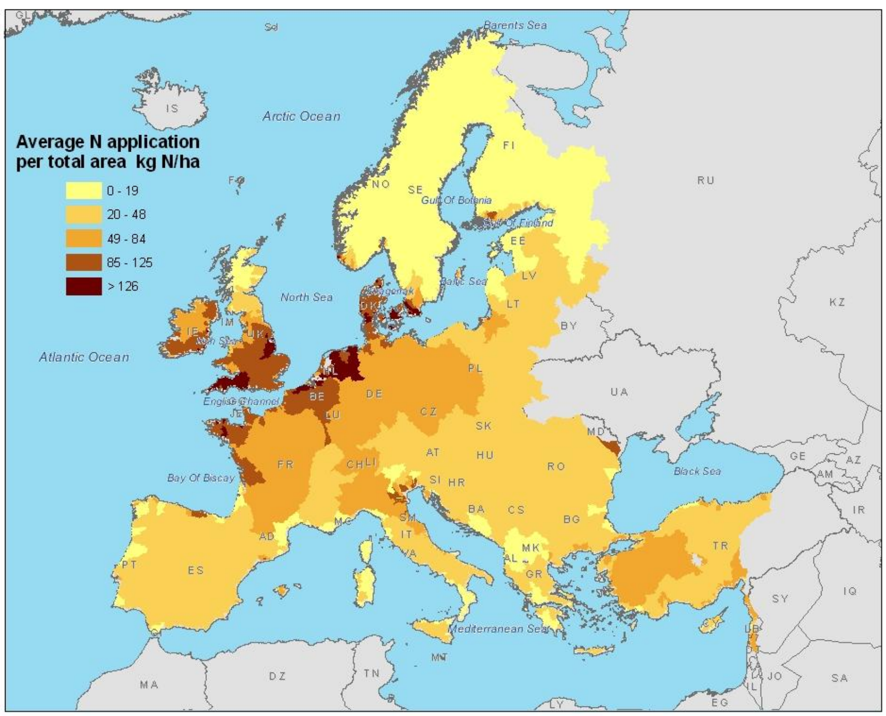


Figure 17. Total application of N (kg/ha) per basin

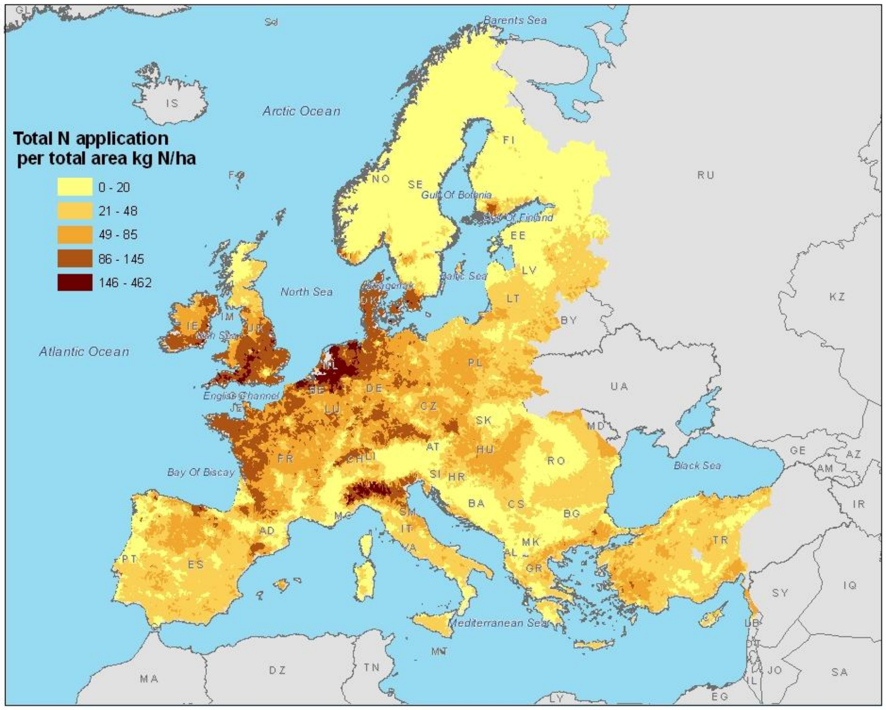


Figure 18. Total application of N (kg/ha) per sub-basin

Figure 19 and Figure 20 show the overlay between the fertilisation maps and the designated and potential Nitrogen Vulnerable Zones (NVZs), respectively. It seems that quite often the NVZs are delineated based on the application rates of nitrogen shown by the good match between the application rates and the designated or potential NVZs. Some zones still appear not to be covered by the NVZs including parts of England, some parts of the Po valley, North-west Greece, Western France, and Northern Spain.

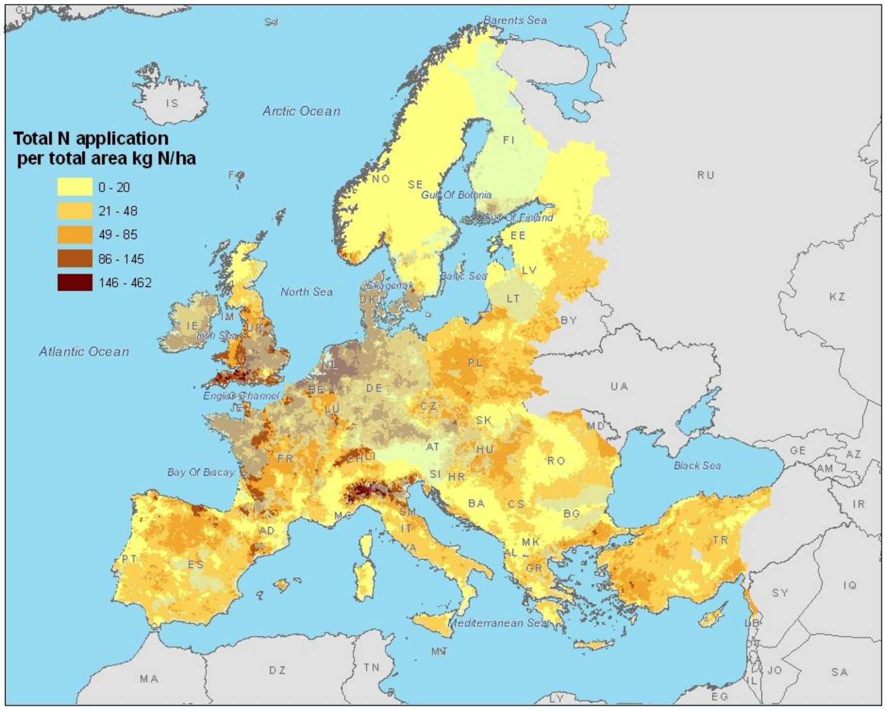


Figure 19. Overlay of designated NVZs (light green) and total application of N (kg/ha) per sub-basin

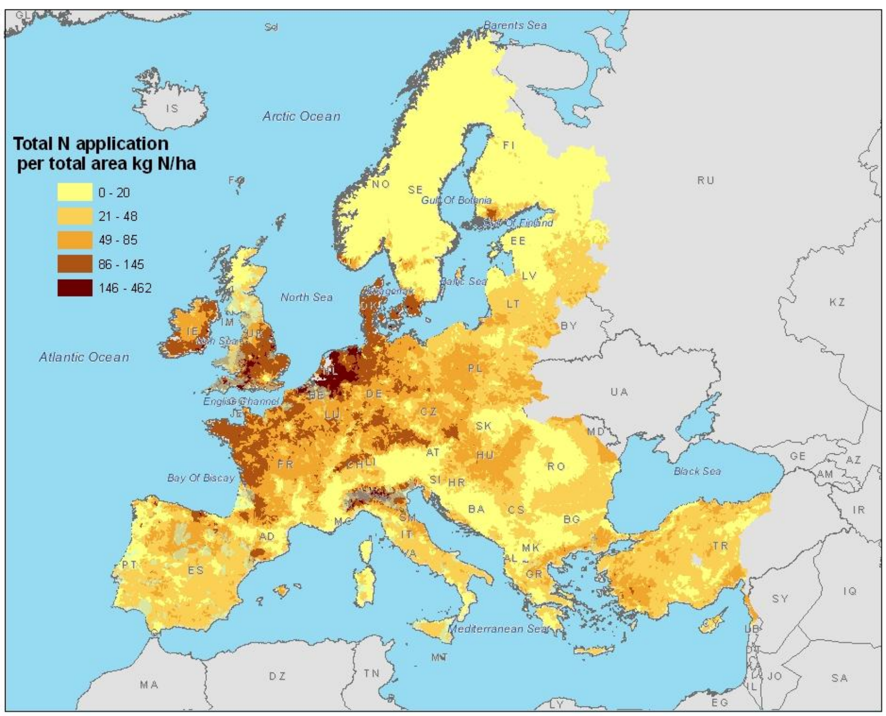


Figure 20. Overlay of potential NVZs (light green) and total application of N (kg/ha) per sub-basin

The maps for phosphorus mineral and manure applications are given from Figure 21 to Figure 25. Again, the most intensive applications of manure take place around breeding areas mainly the Po Valley, Brittany, and The Netherlands. The application of mineral fertiliser shows less concentration than that of manure. It is interesting to see somewhat larger applications of mineral P in Turkey, mostly taking place on the sugar beet, maize and soft wheat cultivation. The total application of phosphorus is shown in Figure 23. The total application of phosphorus per sub-basin is illustrated in Figure 24 and the most intensively fertilized areas are the Po Valley, Belgium, the Netherlands, England, the Atlantic coast of Spain. The average application per basin is shown in Figure 25

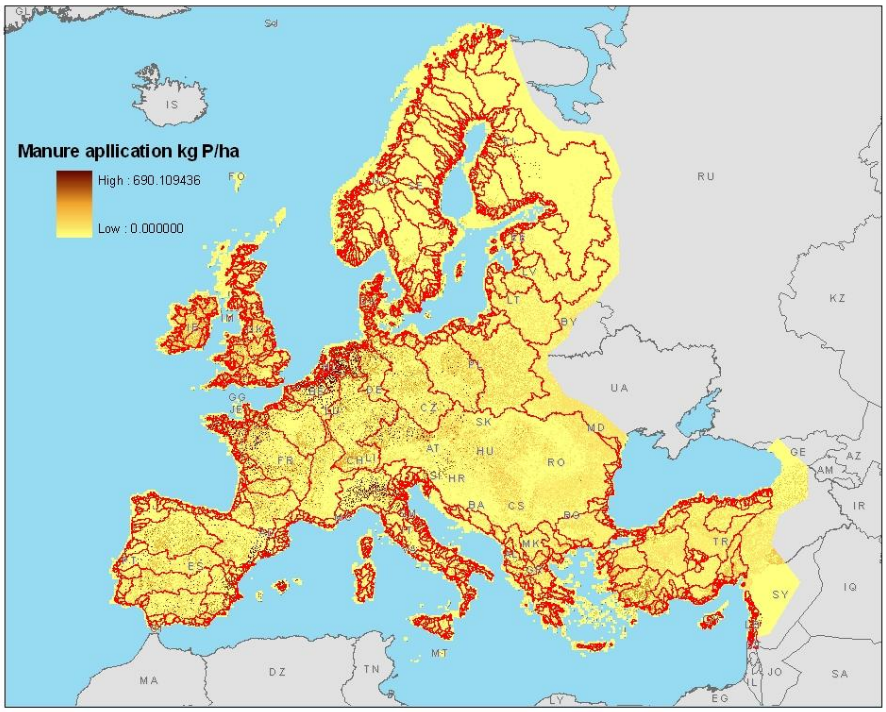


Figure 21. Application of manure P (kg/ha)

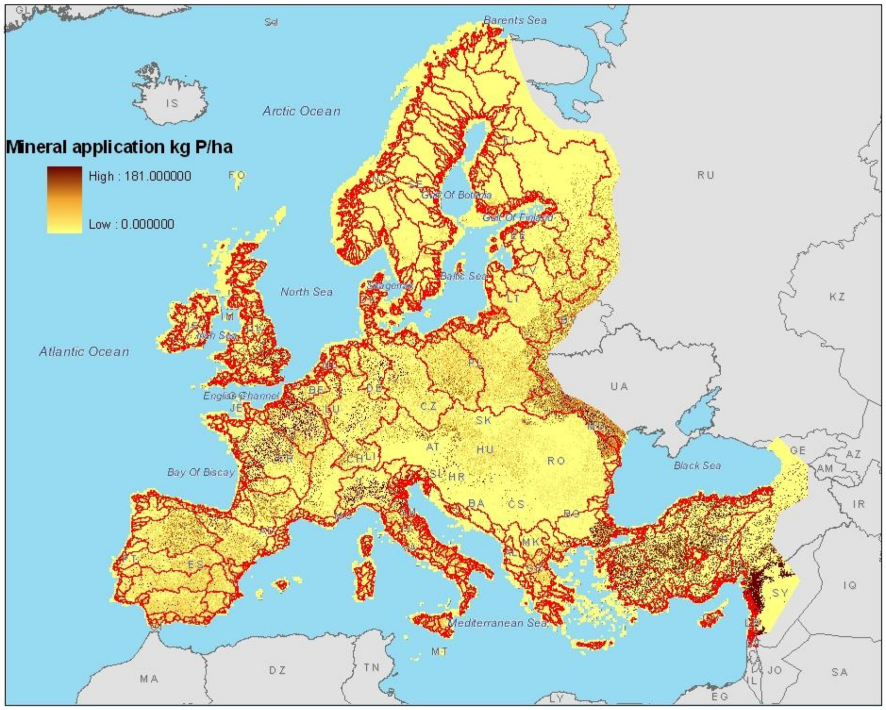


Figure 22. Application of mineral P (kg/ha)

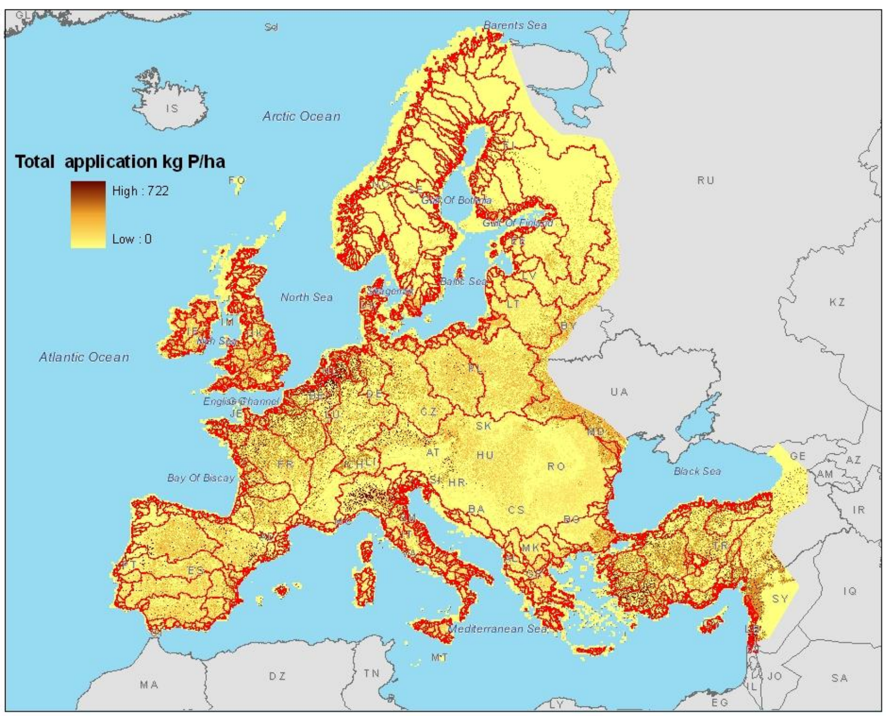


Figure 23. Total P fertilizer application (kg/ha)

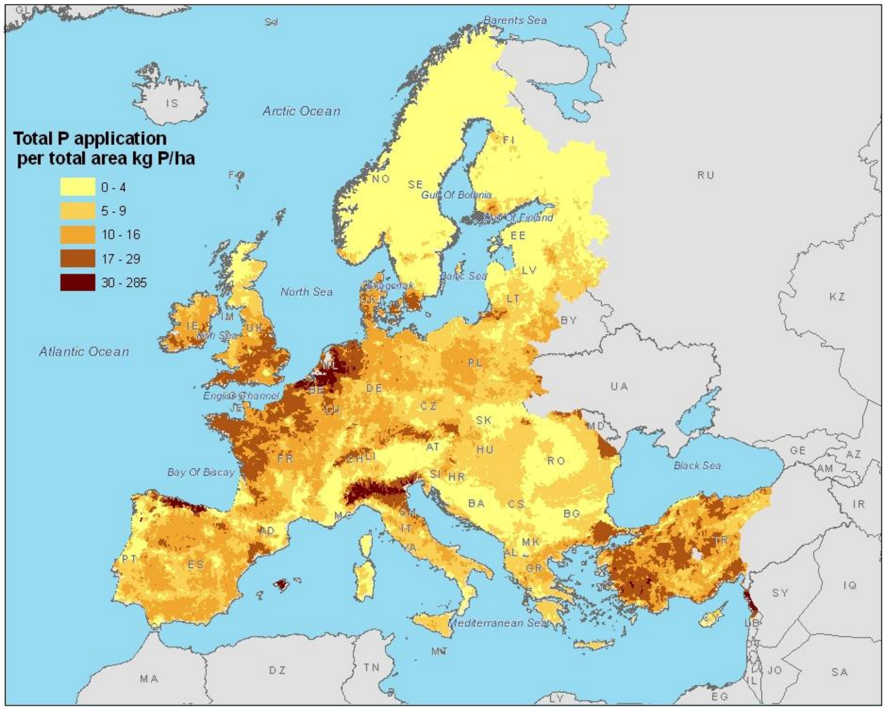


Figure 24. Total P fertilizer application (kg/ha) per sub-basin

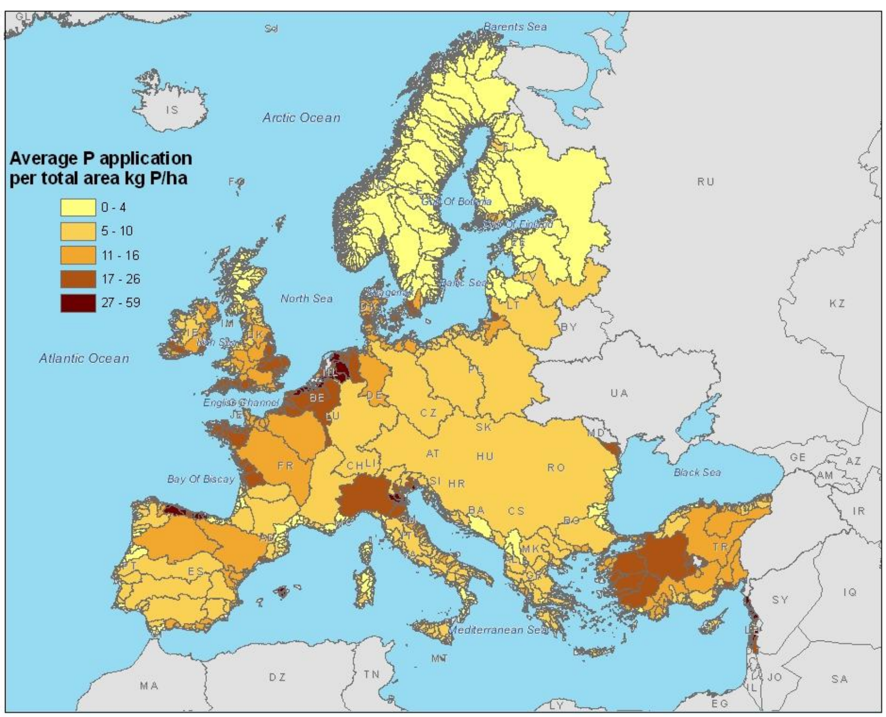


Figure 25. Total application of P (kg/ha) per basin

4.5 Point sources and scattered dwelling emissions

The estimation of nitrogen and phosphorus release from point sources from agglomeration is based on the population density, the percentage of population connected to the sewerage system, the level of treatment, the N and P abatement for each waste water treatment type, and N and P emission factor per person. The population density was obtained from the HYDE database (Klein Goldewijk and Van Drecht, 2006). The HYDE database is a time series of population density and gives an estimate every ten years on a 5 minutes grid. For this study three time slices are considered: 1980, 1990, and 2000. The population density for year 2000 is shown in Figure 26.

The population connected to waste water treatment plant and the level of treatment was retrieved when possible from EUROSTAT. When no data was available data was taken from the World Health Organization. The N emission per capita was calculated as suggested by Van Drecht et al. (2003) who related the human N emissions to the per capita Gross Domestic Product (GDP), using the following equation:

$$N_{em} = 8 + 11(GDP/43639)^{0.5} \qquad \text{Equation 3}$$

where N_{em} is the daily human N emission per capita (g per person per day), *GDP* is the gross domestic product (US dollars per capita per year).

The human emission for phosphorus was computed using the ratio of N to P emission given by OSPAR which is 0.208. The calculated values of N and P emission rates are given in Table 3. The variability among the countries is rather high, with the highest emission rates occurring in Western Europe (19.1 g N/ inh/ day in Luxembourg) and the lowest rate occurring in the Balkan area (9.7 g N/ inh/ day in Albania).

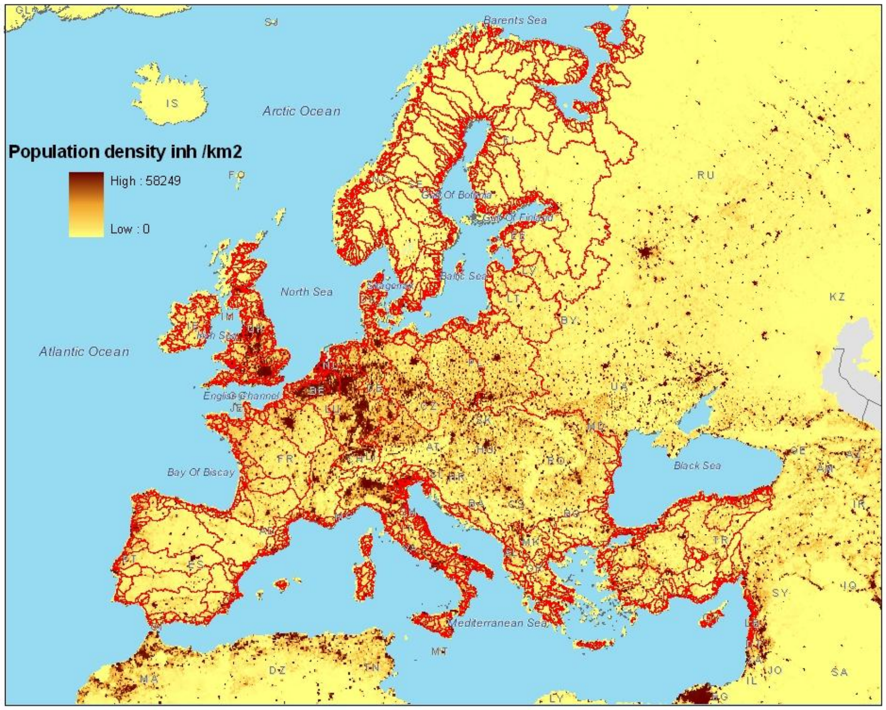


Figure 26. Population density for the year 2000 (inh/km^2). Data from HYDE

Table 3. Population and N and P human emission rates for the countries included in the study

	Population Total (10^3 inh)	Population urban (%)	Population rural (%)	N Emission (g N/inh/day)	P Emission (g P/inh/day)
Albania	3062	42	58	9.7	2.0
Austria	8096	66	34	16.1	3.3
Belarus	10029	70	30	9.9	2.1
Belgium	10304	97	3	16.0	3.3
Bosnia and Herzegovina	3847	43	57	9.9	2.1
Bulgaria	7997	69	31	10.0	2.1
Croatia	4505	58	42	11.4	2.4
Cyprus	786	69	31	13.7	2.9
Czech Republic	10267	74	26	11.7	2.4
Denmark	5340	85	15	17.1	3.5
Estonia	1367	69	31	11.1	2.3
Finland	5177	61	39	16.1	3.3
France	59278	76	24	15.8	3.3
Germany	82344	88	12	16.0	3.3
Greece	10975	60	40	13.4	2.8
Hungary	10226	64	36	11.6	2.4
Ireland	3801	59	41	16.3	3.4
Italy	57715	67	33	15.2	3.2
Latvia	2373	67	33	10.9	2.3
Lithuania	3500	67	33	11.0	2.3
Luxembourg	435	91	9	19.1	4.0
Malta	392	91	9	13.1	2.7
Republic of Moldova	4275	46	54	9.0	1.9
Netherlands	15898	64	36	16.1	3.3
Norway	4502	76	24	18.2	3.8
Poland	38649	62	38	11.5	2.4
Portugal	10225	53	47	13.4	2.8
Romania	22117	55	45	10.1	2.1
Russian Federation	146560	73	27	10.2	2.1
Serbia/Montenegro	10545	52	48	9.7	2.0
Slovakia	5400	57	43	11.2	2.3
Slovenia	1967	51	49	13.1	2.7
Spain	40717	76	24	14.3	3.0
Sweden	8877	83	17	16.6	3.5
Switzerland	7167	68	32	17.6	3.7
TFYR of Macedonia	2010	59	41	10.2	2.1
Turkey	68234	65	35	11.0	2.3
Ukraine	49116	67	33	9.3	1.9
United Kingdom	58670	89	11	16.3	3.4

Concerning the treatment efficiency, it was decided to use the values in the range of that given by Stanners and Bourdeau (1995) and Bouwman et al. (2005). The coefficients used for the various treatment types are given in Table 4.

Table 4. Nitrogen and phosphorus removal in waste water treatment plants according to the level of treatment

Treatment type	% of N reduction	% of P reduction
Primary	15	20
Secondary	30	30
Tertiary	60	90

The resulting nitrogen emissions from point sources are shown in Figure 27. The highest nitrogen emissions occur in the Po Valley, all along the Rhine, across the Netherlands and Belgium, and South-East, West Midlands and London area in the UK. The nitrogen emissions per unit area per basin are shown in Figure 28. The largest emissions per unit area take place in England, the Netherlands and Belgium.

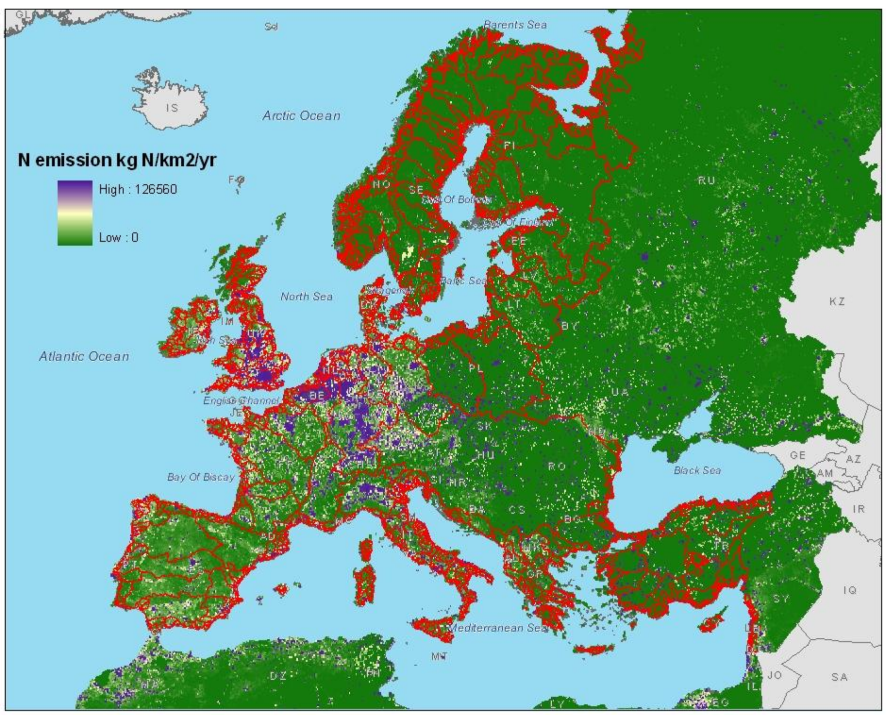


Figure 27. Emission of total nitrogen from point sources (kg N/km^2/yr) for the year 2000

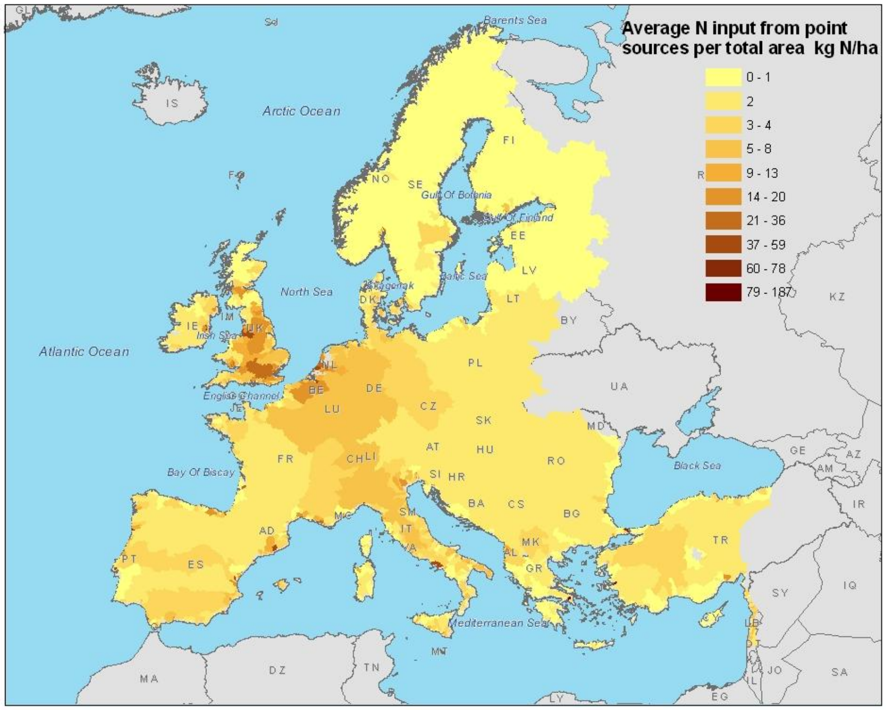


Figure 28. Average input of total N from point sources per basin (kg N/ha) for 2000

The picture in rather similar for phosphorus emissions, however, it seems that emissions are relatively lower for phosphorus in the Rhine river basin (Figure 29). Like for nitrogen, the largest emissions of phosphorus per unit area per basin take place in England, the Netherlands and Belgium.

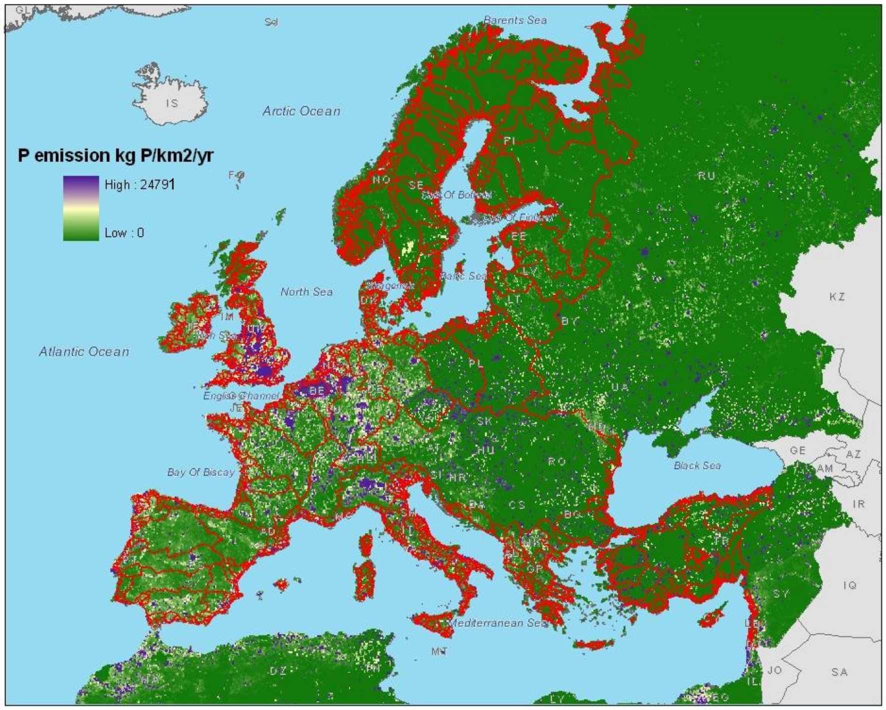


Figure 29. Emission of total phosphorus from point sources (kg P/km^2/yr) for the year 2000

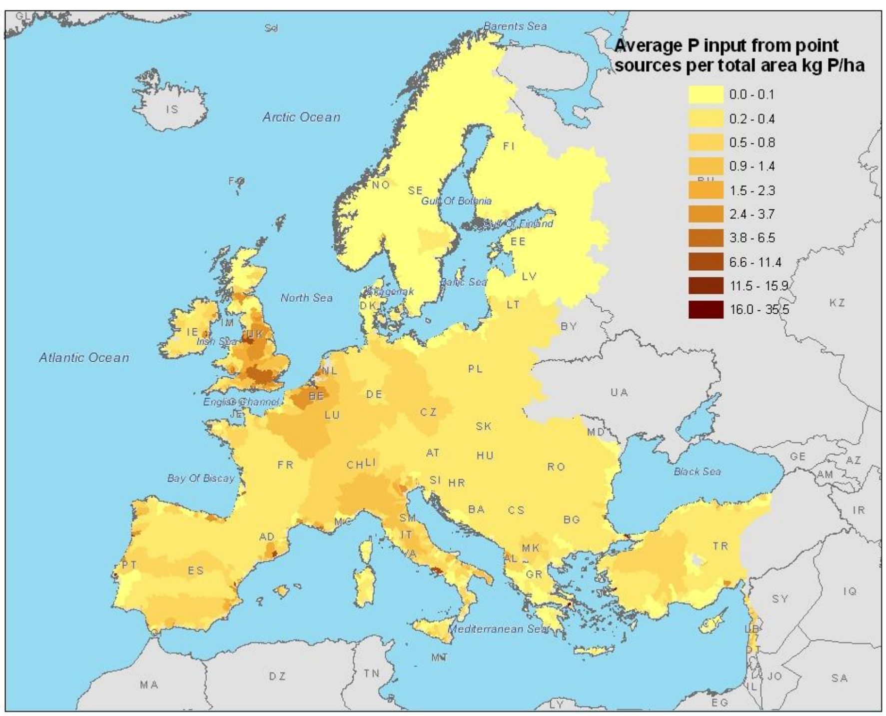
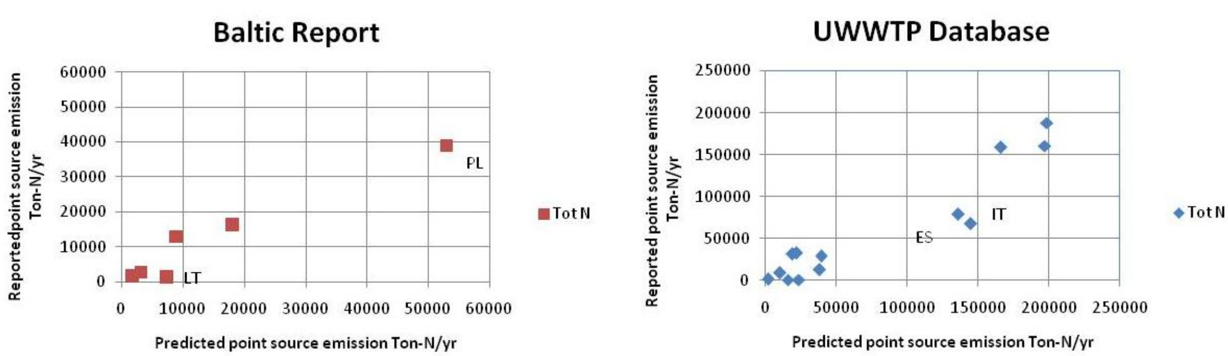


Figure 30. Average input of total P from point sources per basin (kg P/ha) for 2000

The calculated values of point source emissions to water were then compared with those listed in literature. For the Baltic States, the values used for the comparison were taken from the Fourth Baltic Sea Load Compilation (Helsinki Commission, 2004). The reported and predicted values for the Baltic States are shown in Figure 31 (excluding Germany and Denmark as they also discharge in the North Sea). The value calculated for Lithuania using the approach described previously is much higher than the one reported in HELCOM. Further check highlighted that Lithuania did not report the whole load for point source discharge. Indeed, the total nitrogen load reported in the HELCOM report (Helsinki Commission, 2004) is around 1440 tons, while in the State of Environment published by the Lithuanian Ministry of Environment the total nitrogen load for year 2000 is much larger than 3000 tons. Concerning Poland, the reported value of total nitrogen emissions from point sources amounts to 39,000 tons while the estimated value is around 53,000, which however is more in agreement with the value given by Behrendt and Dannowski (2005), who estimated the nitrogen emission for Poland for the Odra River only to be around 40,000 tons for the 1993-1997 period.

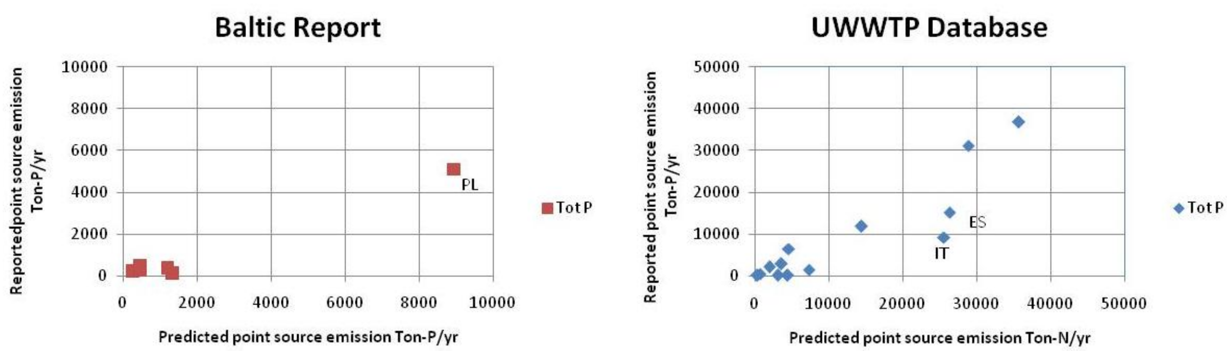
For the EU15 countries, the calculated values were compared with the loads obtained from the Official Urban Waste Water Treatment Plants database. The comparison was performed even though the official database may not include all treatment plants. The analysis showed that the estimated values are in quite close agreement with those reported. Some sources of discrepancies lay in the difficulty in finding accurate values for the level of connection and the level of treatment. Furthermore, as explained previously, it was decided to use the same values of abatement efficiency per level of treatment throughout Europe due to the lack of detailed regional information. Some problems were found for Spain and Italy where the load obtained from the official database is significantly lower than the one estimated.



a) b)

Figure 31. Calculated and reported values for total nitrogen emissions from point sources. Reported data refer to the Fourth Baltic Sea Pollution Load Compilation (a) and the Official European Waste Water Treatment Plants Database (Grizzetti and Bouraoui, 2006)

comparison similar comparison was done for phosphorus (Figure 32). The results are very similar to those obtained for nitrogen. Concerning Poland there is a large overestimation of the calculated load when compared to the reported one (9,000 tons versus 5,000 tons). However again the estimated values are more on line with these obtained by Behrendt and Dannowski (2005) who estimated the phosphorus point source input for the Polish part of the Odra to be around 7,000 tons for the 1993-1997 period. There are also problems for Spain and Italy where the reported load is much lower than the estimated value. This might be explained by the fact that the official data base version used for comparisons, which is that of 2004, was lacking several point sources for many countries. It is important to note that the official database underwent a major update, but due to time constraints, it was not possible to analyse the data for this study. It also important to remember that the date for which connection rate is available does not always correspond exactly to the baseline year, but sometimes refers to the closest year. As for instance, for Germany, the latest connection rate dates from 1998. Another major source of uncertainty in the estimates relates to equation 3.



a) b)

Figure 32. Calculated and reported values for total phosphorus emissions from point sources. Reported data refer to the Fourth Baltic Sea Pollution Load Compilation (a) and the Official European Waste Water Treatment Plants Database (Grizzetti and Bouraoui, 2006)

4.6 Atmospheric deposition

Atmospheric nitrogen deposition data are available within the Cooperative Programme for the Monitoring and Evaluation of the Long- Range Transmission of Air Pollutants in Europe (EMEP). Atmospheric nitrogen deposition data is based on the EMEP Unified Model and the EMEP 50 km x 50 km grid (EMEP, 2001). Data extracted for the FATE project were yearly-accumulated values of total deposition of oxidized and reduced nitrogen (kg N/ha). The atmospheric deposition for nitrogen is shown in Figure 33.

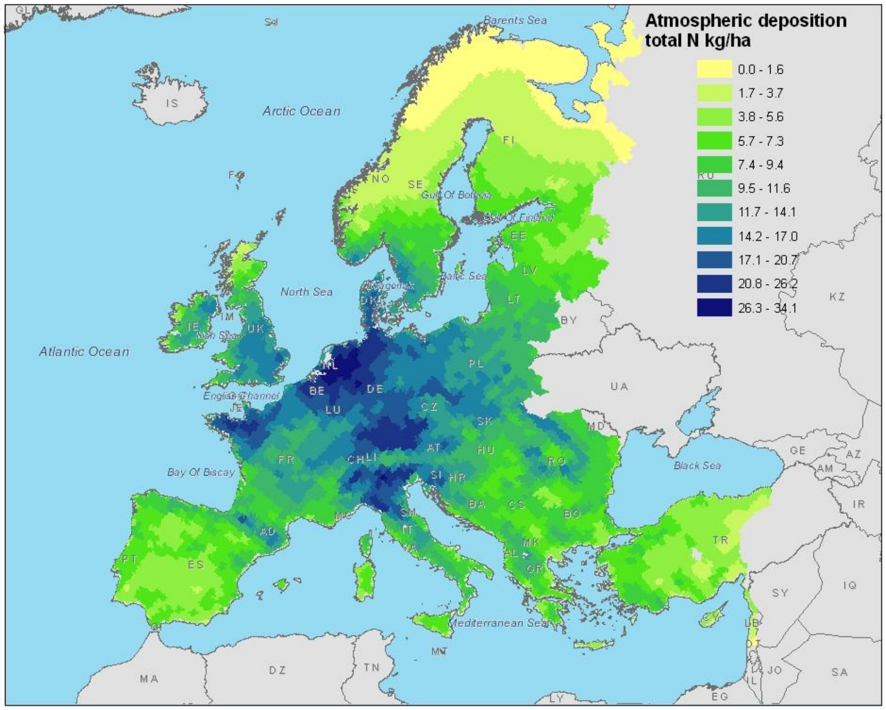


Figure 33. Atmospheric deposition of total N (kg//ha). Data from EMEP

4.7 Climate database

The climate database (Princeton Climate Database) was provided by Sheffield et al. (2006). The datasets were provided as a global grid of 1 degree resolution, for a time period extending from 1948 to 2000. The basic meteorological variables included daily precipitation, shortwave and longwave radiations, surface pressure, specific humidity and wind speed. These datasets were derived by combining the NCEP-NCAR reanalysis (Kistler et al., 2006) and several global observed datasets of precipitation, temperature and radiation (Sheffield et al., 2006). The CRU (2008) long term average precipitation available on a 10 mn grid was used to disaggregate the climatic data from the Princeton Climate Database. The precipitation coming from the Princeton database was downscaled to a 10 mn grid adjusting it by a time invariant spatially changing coefficient. All the CRU grid cells falling within the 1 degree cell from the Princeton database were used to calculate an average CRU rainfall at one degree. Each 10 mn CRU cell was then assigned a correction coefficient equal to its long mean rainfall divided by the 1 degree average. The 10mn Princeton precipitation grid was then obtained multiplying the 1 degree Princeton grid with the 10mn CRU correction coefficient grid. All other climatic variables were not downscaled. The density of the climate station network is shown for Greece (Figure 34). The annual average precipitation (1975-2000) is shown in Figure 35.

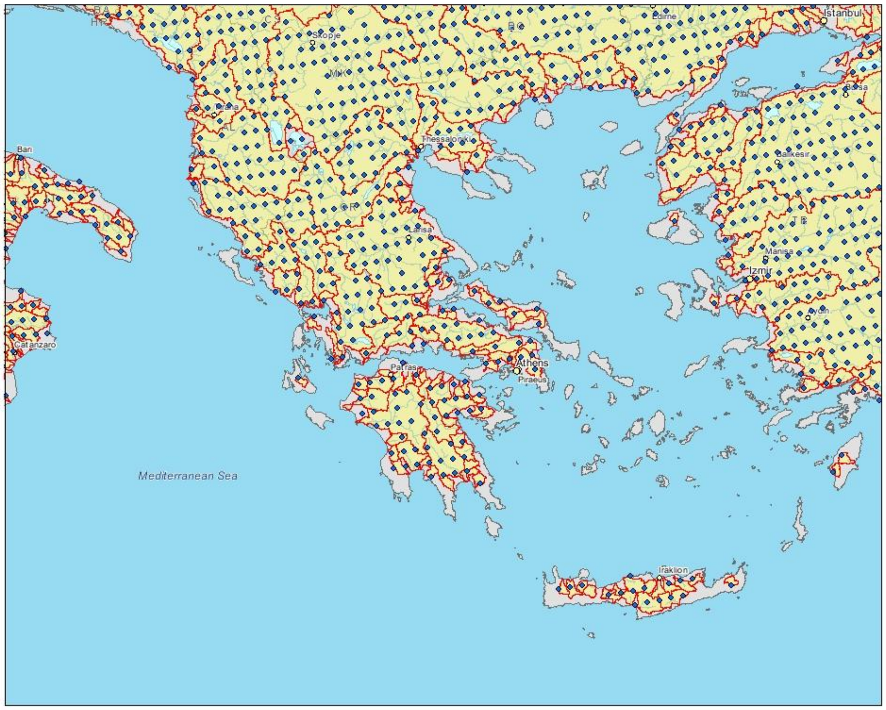


Figure 34. Density of the climate station network (coverage is global)

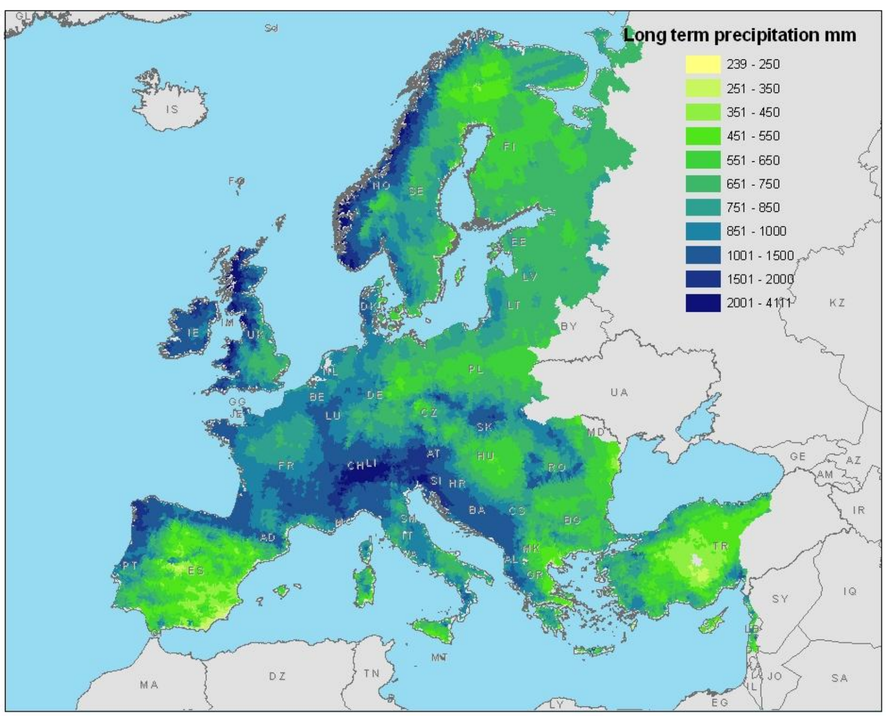


Figure 35. Average long term (1975-2000) precipitation (mm)

5. Nutrient modelling

5.1 Model calibration

The model (see Section 3) was calibrated using measured loads for the year 2000. In total, 235 measurement points were available for nitrogen and 327 for phosphorus. Ideally, a good dataset for model calibration should include a sufficient number of measured points, homogeneously distributed on the region of study and equally representing the range of occurring loads. However, in the reality the available gauging stations, where both water flow and nutrient concentration are available for a targeted year, are limited and not always fulfilling the criteria of spatial and value representativeness. This can affect the results of calibration, especially for statistical models such as GREEN, whose predictions heavily rely on data quality and availability. The dataset available for the present calibration was considered quite satisfactory for the number of stations and the spatial coverage, although a better distribution of measurements between low, medium and high loads would have further contribute to model parameters estimation (Figure 36).

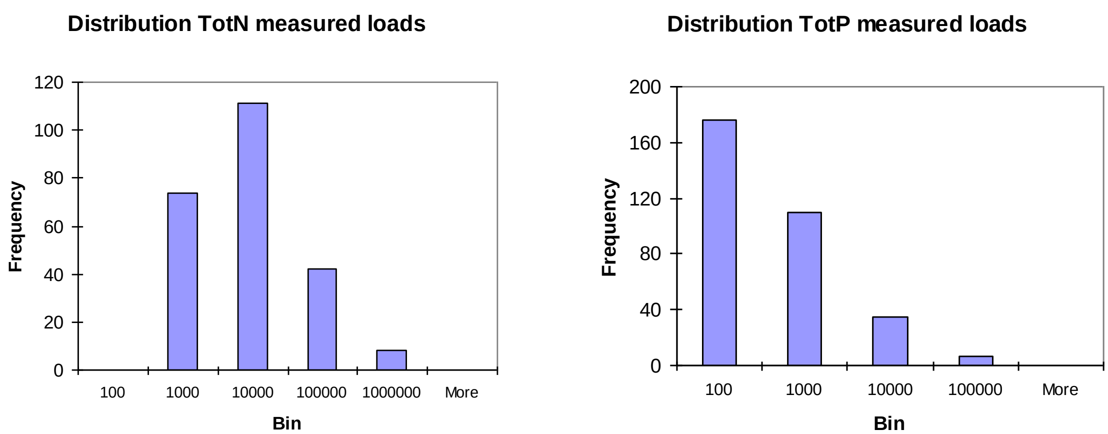


Figure 36. Distribution of measured loads for total nitrogen (tons) (left) and total phosphorus (tons) (right) available for the model calibration

The model parameters, α_P and α_R, for the landscape and river retention, respectively, were calibrated using a quasi-Newton method and a finite-difference gradient. The resulting values are reported in Table 1.

Table 5. Calibrated parameters for the nitrogen and phosphorus models

Model	α_P (relative to landscape retention)	α_R(relative to river retention)
Total nitrogen	9.574	0.015
Total phosphorus	23.000	0.026

Figure 37 and Figure 38 show the calibrated and measured loads according to the total nitrogen and total phosphorus, respectively. In both cases, model estimates are in good agreement with the measured values. Some scattered points appear for low loads.

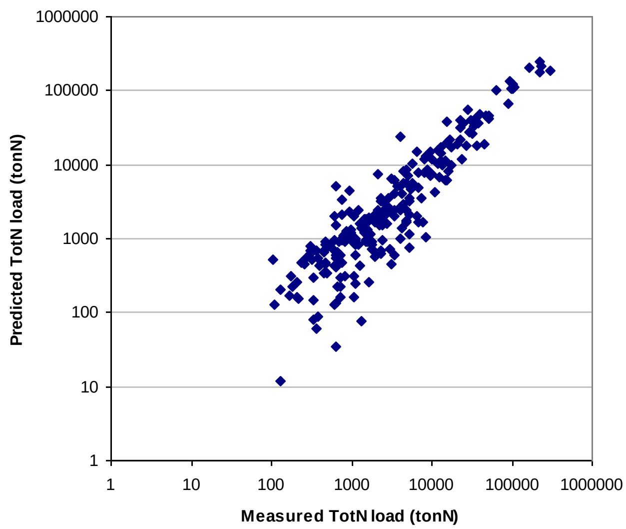


Figure 37. Measured and predicted total nitrogen loads according to model calibration

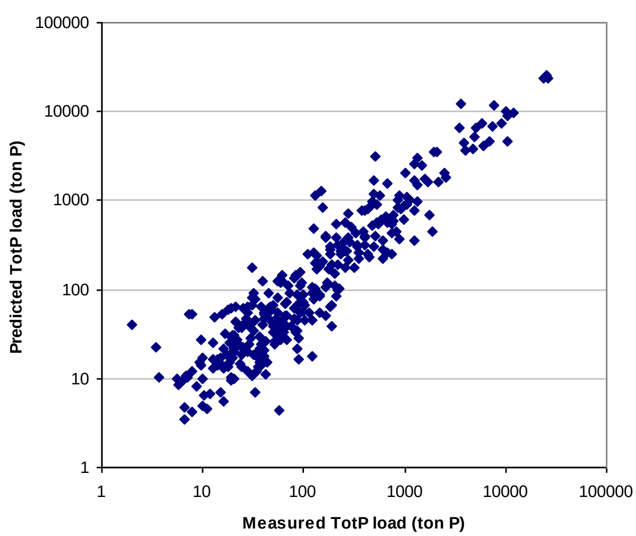


Figure 38. Measured and predicted total phosphorus loads according to model calibration

The statistics on goodness of fitness show a good performance for the nitrogen and phosphorus models, with Nash-Sutcliffe efficiency of 0.92 in both models and very low fraction of systematic error (Table 6).

Table 6. Statistics on model performance for nitrogen and phosphorus models

Statistics	Nitrogen Model	Phosphorus Model
Mean Observations	13295	826
Mean Predictions	13161	859
Stdev Observations	36661	2864
Stdev Predictions	35196	2805
Root Mean Squared Error (RMSE)	10574	792
Average residue	134	-33
Coef det R^2	0.92	0.92
Efficiency E2	0.92	0.92
Efficiency E1	0.78	0.78
RMSE_systemat	2963	171
RMSE_unsystem	10151	773
$(RMSE_S/RMSE)2$	0.08	0.05

5.2 Nutrient loads into European Seas for the baseline: year 2000

The predicted total nitrogen load per basin is shown in Figure 39. The largest losses are coming from the Rhine and the Danube, as they are among the largest catchments in Europe. The estimated total nitrogen losses per unit area are illustrated in Figure 40. The largest losses are then coming from England and the Po River. For phosphorus the highest losses originate from the Danube, the Rhone, and the Rhine (Figure 41). The losses of total phosphorus per unit area are shown in Figure 42. The highest losses concentrate around the large breeding areas.

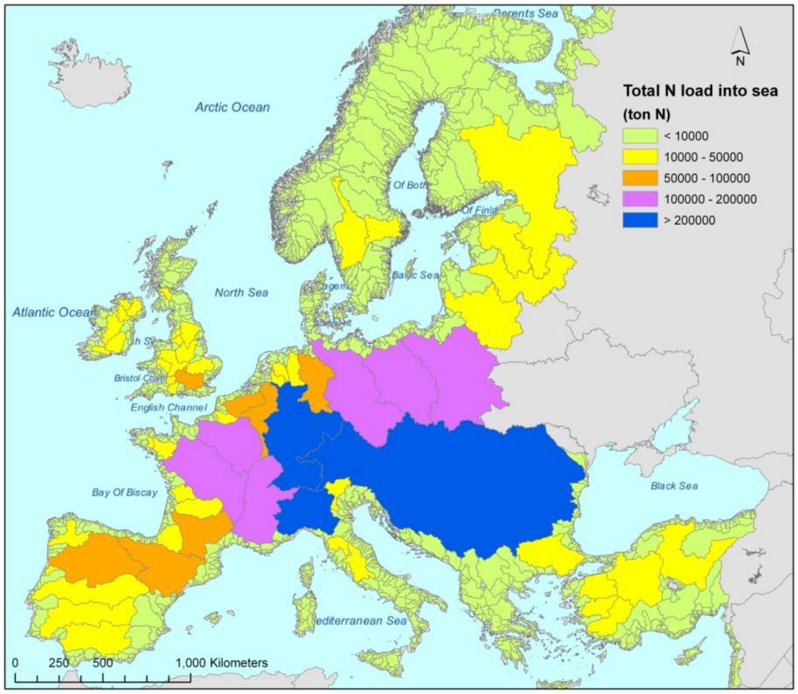


Figure 39. Total nitrogen load per river basin (tons N)

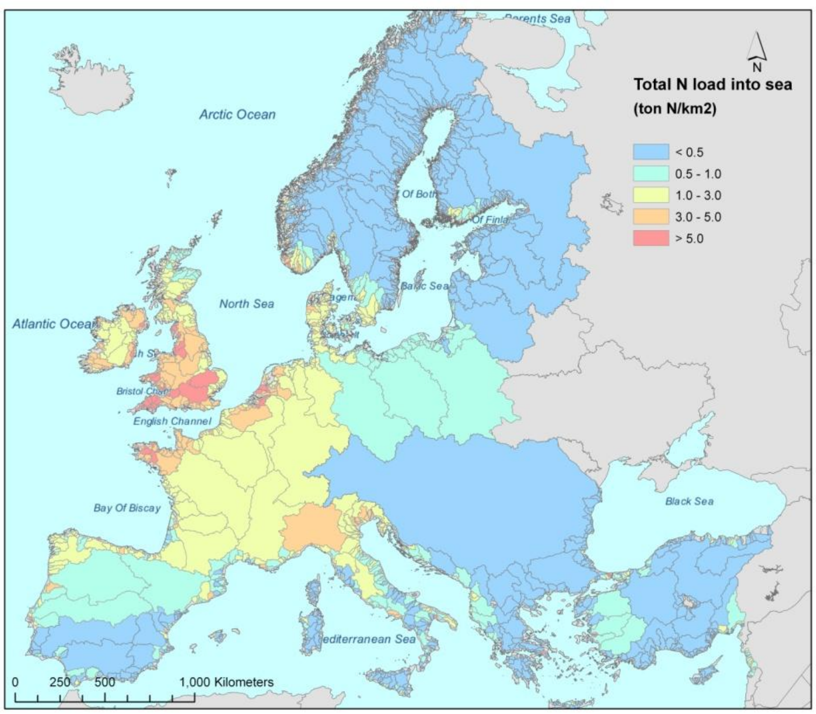


Figure 40. Total nitrogen load per unit area (ton N/km^2)

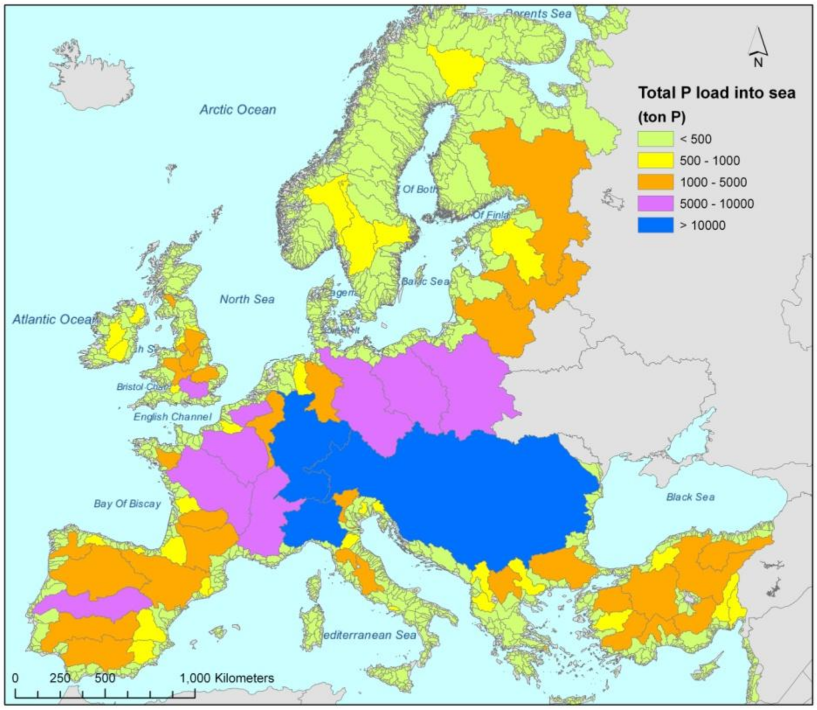


Figure 41. Total phosphorus load per river basin (tons P)

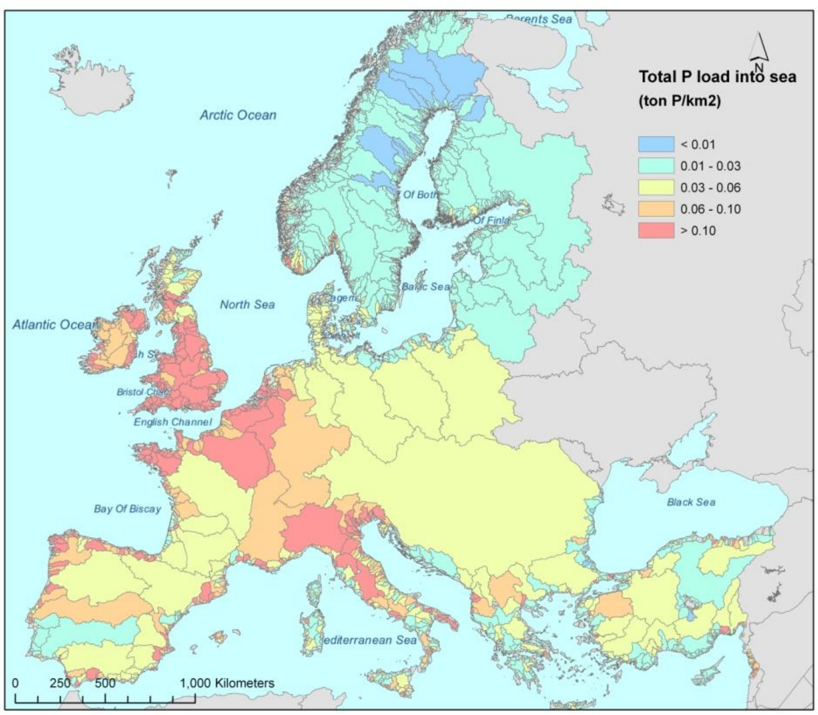


Figure 42. Total phosphorus load per unit area (ton P/km^2)

The nutrient loads per basin were then summarized by sea (Figure 43) and compared with the values reported from different sources (Table 7). UNEP/MAP/WHO (1996) first calculated total nitrogen loads into the Mediterranean Seas under various assumptions and using an export coefficient approach, and estimated the total load of total N discharged into the Sea to range between 786 10^3 and 2,686 10^3 ton of nitrogen. Then, they further estimated the load using river discharge into the Sea and reported a value of total N discharge of 1,100 10^3 tons, with about 25% coming for the Northern African countries, yielding a contribution of about 825 10^3 tons for the rest of the countries (covered by our study). The calculated load of total nitrogen by our study fits well with the values given by the UNEP both using a modelling approach or a monitoring approach. Similarly the calculated total phosphorus load using the export coefficient approach yielded an actual load ranging from 97 10^3 to 270 10^3 ton of phosphorus, and the estimated total P discharge via rivers was calculated to be around 138 10^3 ton of phosphorus (UNEP/MAP/WHO, 1996). We estimated a total load discharged into the sea around 70 10^3 ton in full agreement with the value reported by UNEP/MMAP/WHO (1996).

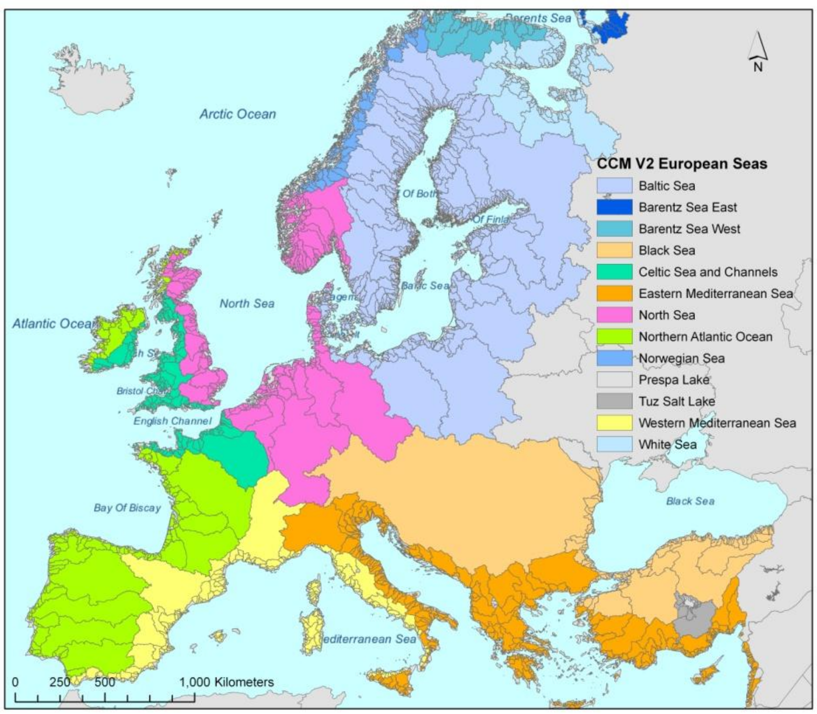


Figure 43. Europeans Seas used to summarize the nutrient loadings

The Helsinki Commission (2003) reports a loss of total nitrogen into the Baltic Sea around 744 10^3 tons which includes 576 10^3 tons from monitored rivers, 130 10^3 tons from non monitored rivers and coastal areas, and 39 10^3 tons from direct point sources input into the Sea. We estimated a loss of total nitrogen about 564 10^3, somewhat lower than the values reported by HELCOM (2003). However, it is important to note that in the catchment delineation approach used in our study, only the basins with a surface area larger than 100 km^2 were considered. This means that some coastal catchments and areas with urban, industrial (in particular aquaculture) and agricultural activities were not considered. Furthermore, the model was developed for agricultural areas, and the estimation of the background losses might also be under evaluated. For phosphorus, our estimate is rather accurate when compared to the values reported by HELOCM (2003). Indeed, the phosphorus load is 27 10^3 tons for monitored rivers, 5 10^3 tons for unmonitored coastal rivers, 3 10^3 tons from direct point sources discharge, for a total load of about 34.5 10^3 tons (Helsinki Commission, 2003), while our estimate is around 35 10^3 tons.

OSPAR reported total nitrogen load of 1267 10^3 and 829 10^3 ton into the North Sea and Atlantic Ocean, respectively. However, these data are incomplete as all the direct input data have not been reported and Ireland for total nitrogen reported only direct input and did not include riverine input. For the North Sea our estimates for both total nitrogen and total phosphorus are on line with those given by OSPAR, while for the Atlantic our predicted value is larger, in particular for total nitrogen.

For the Black Sea data were retrieved both from ICDPR and Bakan and Buyukgungor (2000). Concerning the Danube the last station used is that of Chiciu-Silistra (at the border between Romania and Bulgaria), with the concentration data reported from Bulgaria. It is important to note that for this station, there are large differences in the reported concentrations by Romania and Bulgaria (factor two to three) yielding obviously to large differences in the load estimation. For the Danube, the reported loads are 504 10^3 tons for total nitrogen and 33.2 10^3 tons for total phosphorus. For Turkey no exact value could be retrieved for year 2000. Nutrient loads for the important Turkish rivers along the Black Sea were taken from and Bakan and Buyukgungor (2000), which report losses for total nitrogen and phosphorus of 131 10^3 tons and 5.1 10^3 tons, respectively. However, these refer to year 1990.

Table 7. Total nitrogen and total phosphorus loads into the European Seas reported in other studies and estimated in the present study (further explanations are in the text)

Seas	Measured total N input (10^3 ton)	Predicted total N input (10^3 ton)	Measured total P input (10^3 ton)	Predicted total P input (10^3 ton)
Mediterranean (Europe)	786-2680 [b]	882	97-270 [b]	70
Baltic	745 [a]	564	34 [a]	35
North Sea	1267 [c]	1286	78 [c]	69
Atlantic (France, Spain, Portugal, UK, Ireland)	829 [c]	1502	64 [c]	75
Black Sea (Danube + Turkey)	635 [e d]	485	33.2 [e d]	41

[a] Helsinki Commission (2003), [b] UNEP/MAP/WHO (1996), [c] OSPAR (2002), [d] ICPDR (2000), [e] Bakan and Buyukgungor (2000)

6. Assessment of nutrient pressures on EU waters

6.1 Estimation of total nitrogen concentrations

When evaluating nutrient pressures on inner waters is useful to have available information on both loads and concentrations. The modelling approach used in the present study allows estimating of the nutrient loads. To assess nitrogen and phosphorus concentrations information on runoff is required. In the present study the runoff was estimated by modelling and was then used to convert the nutrient loads into concentrations. The runoff was estimated for each sub-basin as the difference between annual rainfall and actual evapotranspiration. The actual evaporation was computed according to a Budyko type of curve (Pike, 1964) as follows:

$$E = \frac{\mathrm{RAIN}}{\left(1+\left(\frac{\mathrm{RAIN}}{b\ \mathrm{PET}}\right)^{n}\right)^{\frac{1}{n}}} \qquad \text{Equation 4}$$

where *b* and *n* are calibration parameters, E is the annual actual evapotranspiration (mm), RAIN is the annual rainfall (mm) and PET the potential evapotranspiration (mm). PET was estimated according to Turc (1961) formula, where T_{AV} is the annual average temperature (°C):

$$PET = 300 + 25\,T_{AV} + 0.05\,T_{AV}^{\ 3} \qquad \text{Equation 5}$$

All data necessary for the calculations were available at the sub-basin level. The routing scheme used for nutrients was also valid for runoff (see Section 3). Values of measured actual evapotranspiration were calculated for 237 monitoring points as the difference between the measured annual precipitation and the measured annual runoff. The measured points were then used to optimise the two parameters *b* and *n*.

The estimated actual evapotranspiration is shown in Figure 44. The predicted versus the measured runoff is shown in Figure 45 for the 237 stations.

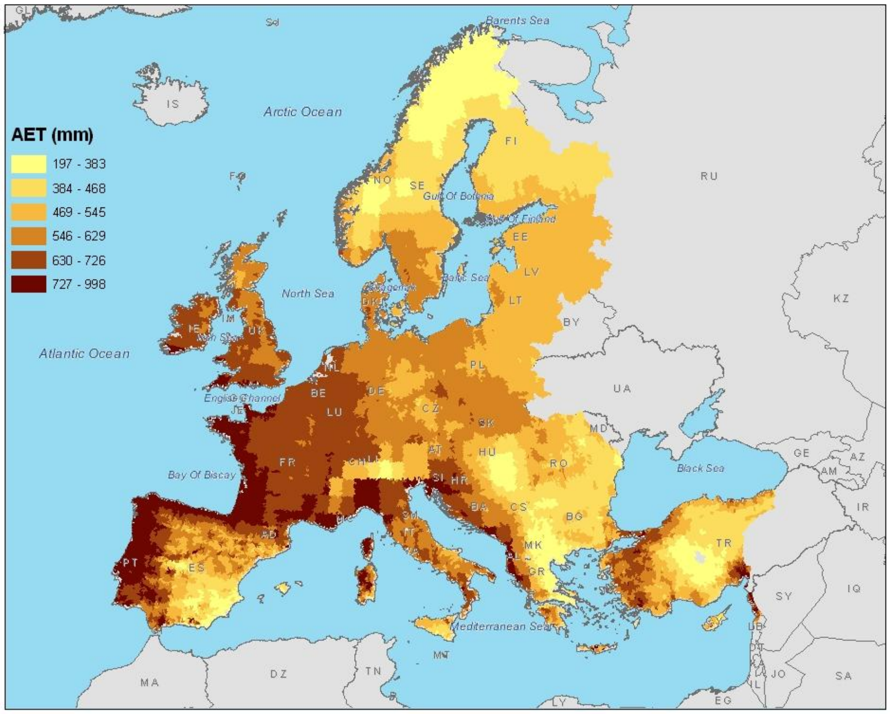


Figure 44. Estimated actual evapotranspiration (mm)

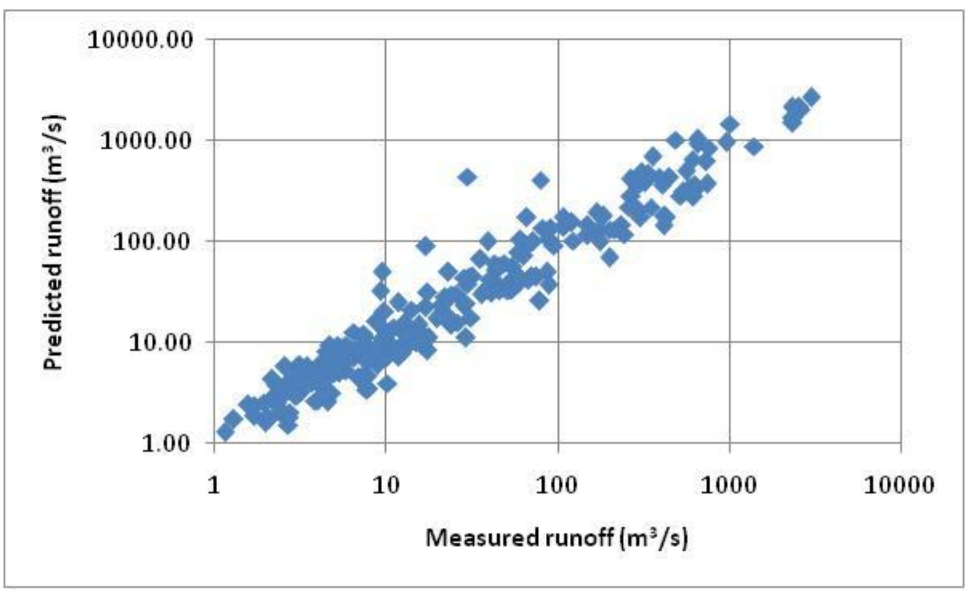


Figure 45. Model predicted versus measured annual runoff for 237 monitoring stations

The optimised coefficients were then used to extrapolate the runoff at all sub-basins. The spatial map of runoff generated within each sub-basin is shown in Figure 46. The actual runoff predicted at each sub-basin outlet is shown in Figure 47. It is clear that the highest runoff in Europe is predicted for the Danube, the Po, the Rhine, the Rhone, the Vistula rivers (Figure 47). However, the regions producing the most runoff per unit area are located in the Alps, Norway, and Western UK (Figure 48).

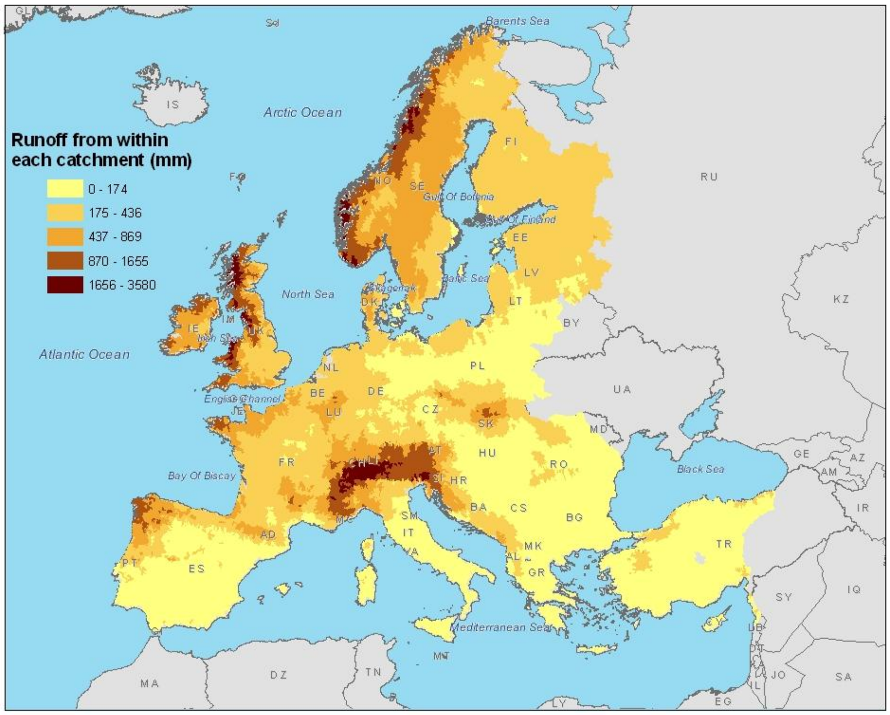


Figure 46. Estimated runoff (mm) generated within each sub-basin

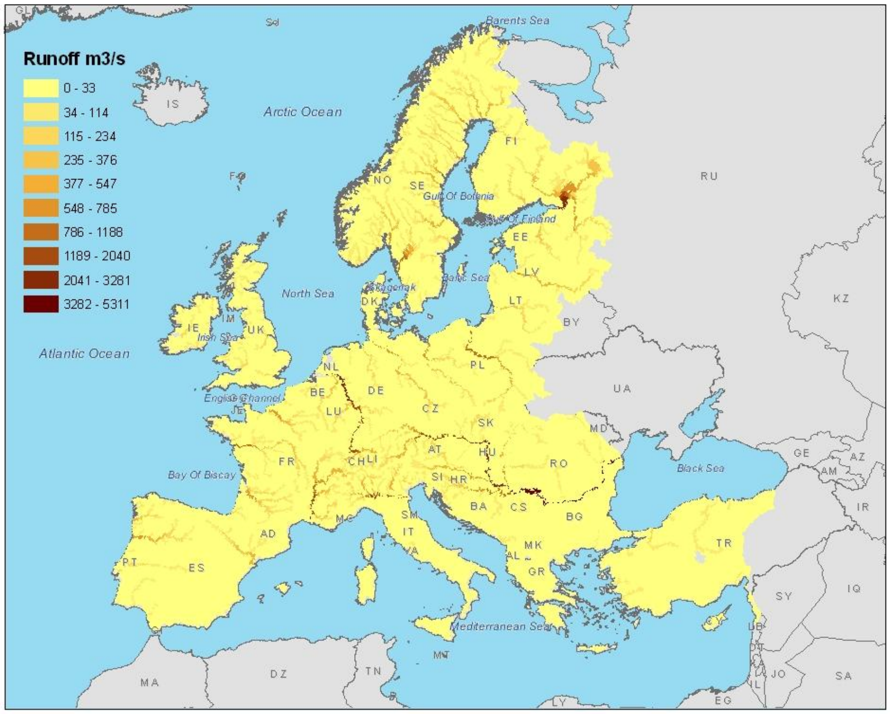


Figure 47. Estimated runoff (m^3/s) at each sub-basin outlet

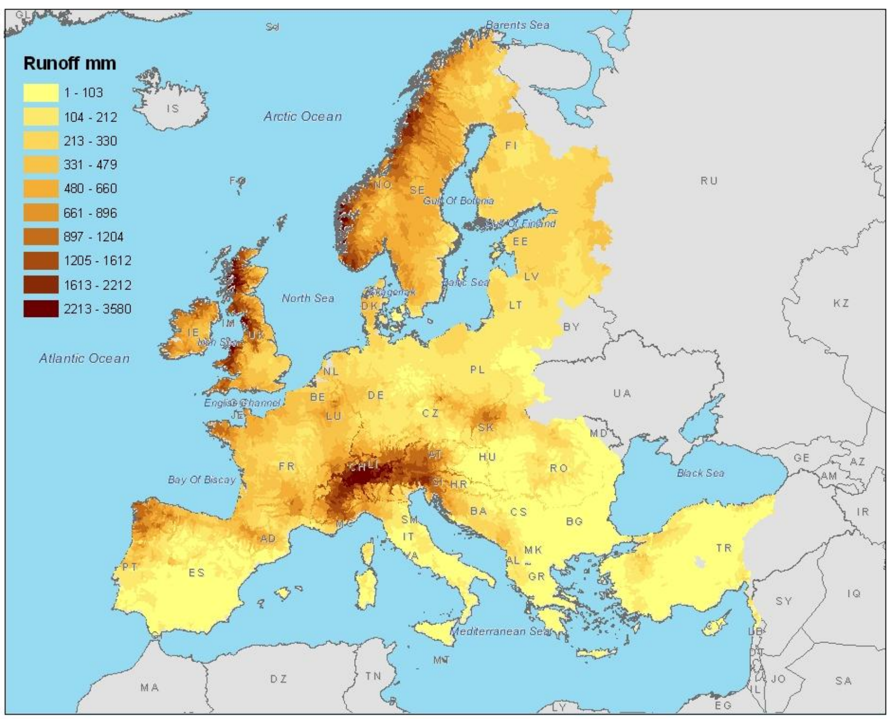


Figure 48. Estimated runoff (mm) at each sub-basin outlet

The calculated concentration of total nitrogen for larger streams is shown in Figure 49. The spatial distribution of high concentration is similar to that reported in the Third Nitrates Report (CEC, 2007).

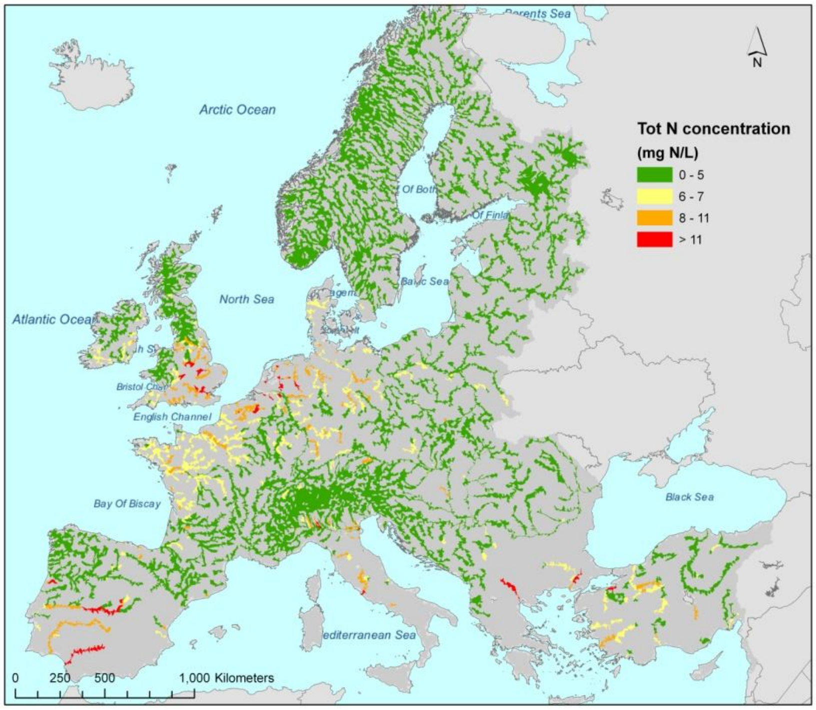


Figure 49. Total nitrogen concentrations in European major streams and rivers

6.2 Sectoral allocation of nutrient losses

The modelling approach used in the study allowed deepening the assessment of nutrient pressures on inland waters. In particular, we estimated the amount of nutrients originated by diffuse sources reaching the surface waters through all possible pathways (diffuse emissions) and the contribution of different sources, point and diffuse, to the total nutrient export (source apportionment). The maps of diffuse emissions provide a picture of the areas characterised by higher nutrient loads, while those on source apportionment allow pinpointing the most contributing nutrient sources. The total nitrogen diffuse emission per sub-basin is shown in Figure 50. The highest losses tend to occur in intensive agricultural areas and also where rainfall is rather high. The diffuse emissions from agriculture are similar to total diffuse emissions, showing that agriculture is the dominant contributor in diffuse losses (Figure 51). The contribution of diffuse sources to total nitrogen load to the sea is illustrated in Figure 52. It is interesting to note that in the south of Europe, diffuse sources contribute less to the total load as in these countries the level of connection to WWTP and the levels of treatment are lower than in Northern Europe. This fact is also shown when performing the source apportionment per sub-basin where the impact of the large cities is clear (Figure 53).

Concerning total phosphorus the picture is rather different than that of nitrogen. The diffuse emissions of total phosphorus are shown in Figure 54. The diffuse emissions are the highest in the regions of intensive breeding. It seems that relatively, diffuse sources contribute less to the total phosphorus load than for nitrogen (Figure 55 and Figure 56).

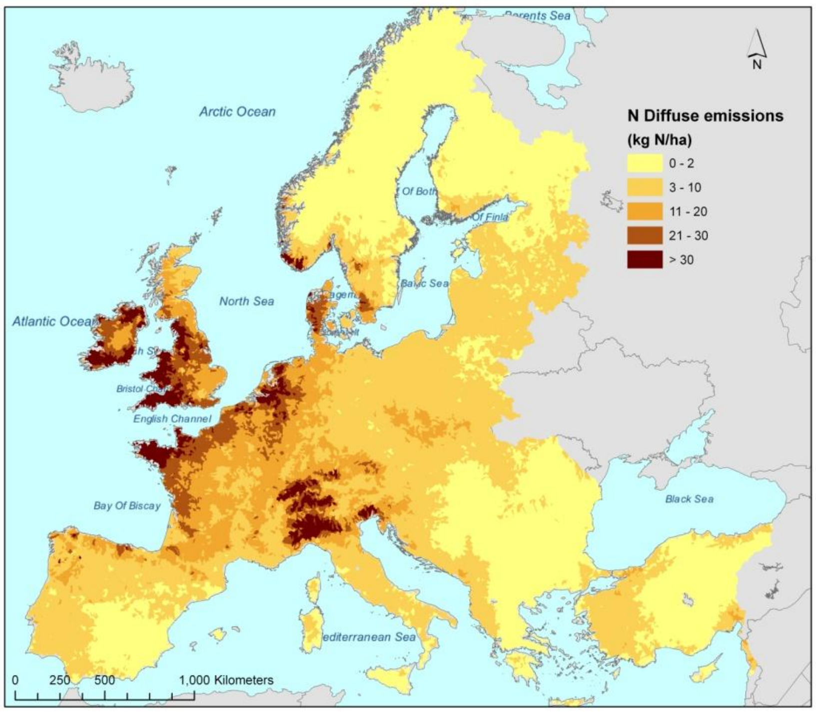


Figure 50. Total nitrogen diffuse emissions per sub-basin

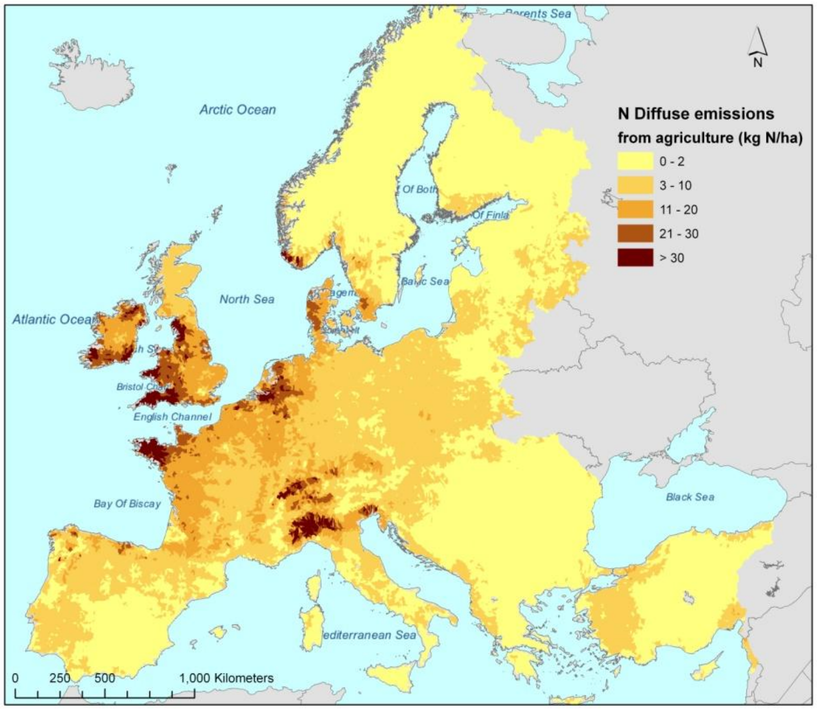


Figure 51. Total nitrogen diffuse emissions from agricultural sources per sub-basin

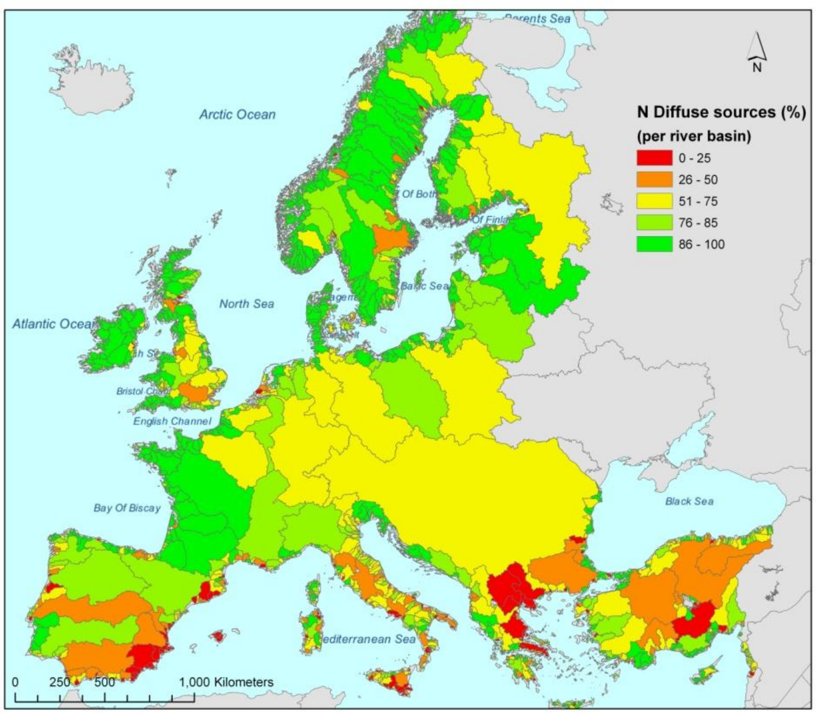


Figure 52. Contribution of diffuse sources to total nitrogen load into the sea per basin. The green colour indicates a predominance of diffuse sources (represented mainly by agriculture), while the red colour signifies a higher contribution from point sources (represented mainly by the waste water discharges)

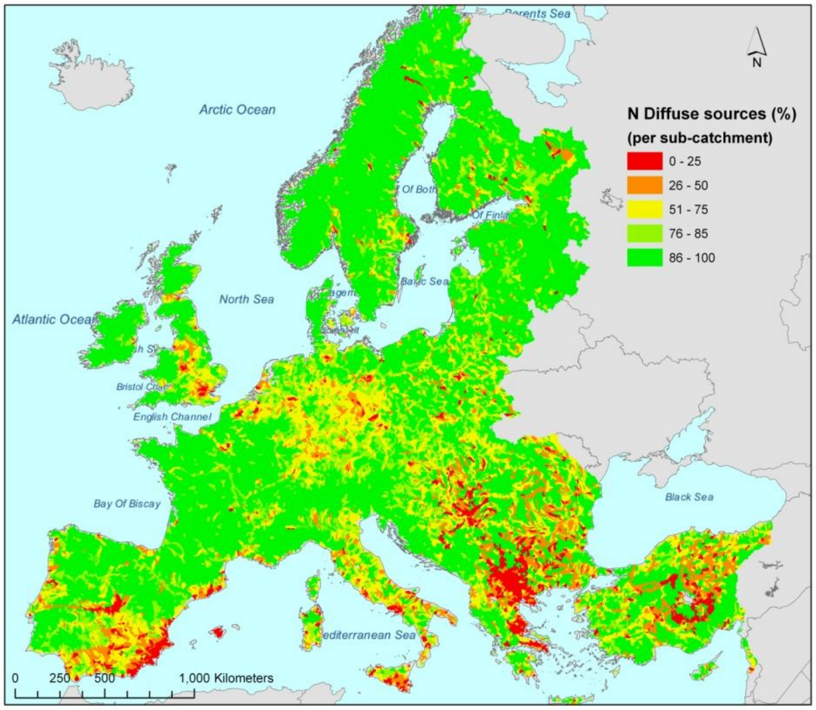


Figure 53. Contribution of diffuse sources to total nitrogen load per sub-basin. The green colour indicates a predominance of diffuse sources (represented mainly by agriculture), while the red colour signifies a higher contribution from point sources (represented mainly by the waste water discharges)

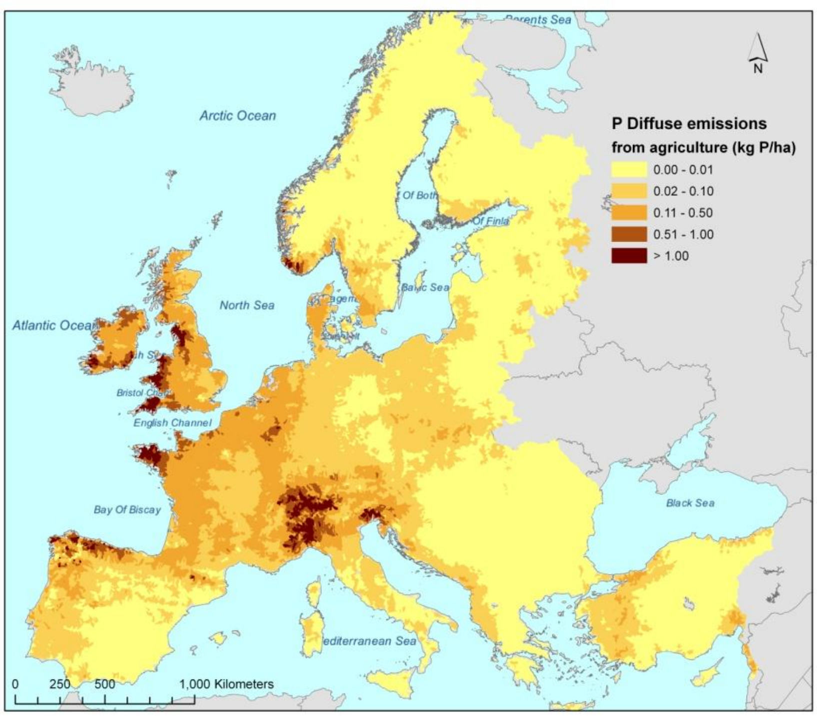


Figure 54. Total Phosphorus diffuse emissions to water from agriculture per sub-basin

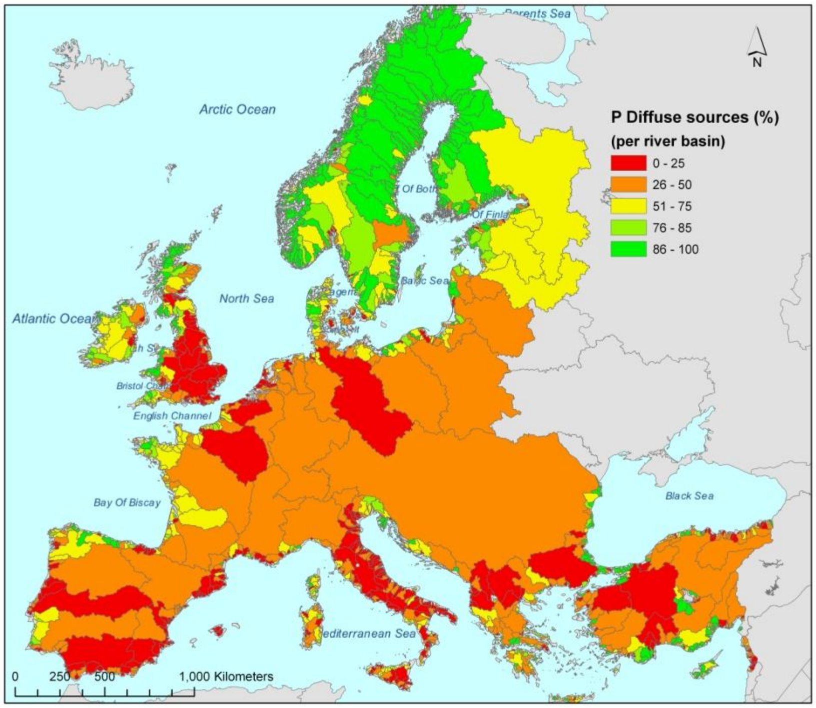


Figure 55. Contribution of diffuse sources to total phosphorus load into the sea per basin. The green colour indicates a predominance of diffuse sources (represented by agriculture), while the red colour signifies a higher contribution from point sources (represented mainly by the waste water discharges)

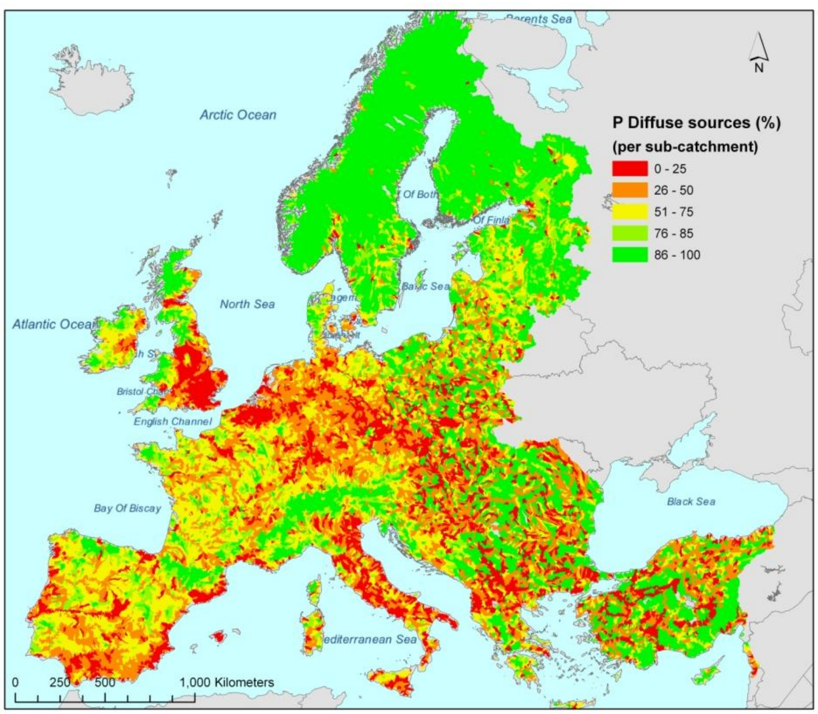


Figure 56. Contribution of diffuse sources to total phosphorus load per sub-basin. The green colour indicates a predominance of diffuse sources (represented by agriculture), while the red colour signifies a higher contribution from point sources (represented mainly by the waste water discharges)

7. Conclusions and recommendations

The first year of the project was dedicated to the development of a European wide harmonized database including all necessary information required to evaluate the load of total nitrogen and total phosphorus from land based activities into European Seas. The task was very time consuming and this was not planned from the beginning All monitoring data, excluding the Baltic, had to be collected from various ministries, river basin authorities and research institutes. However, despite this huge effort, some countries could not be covered by the monitoring data. Furthermore, it appeared that the data needed a thorough quality check, even though it was coming from official sources. For instance, as mentioned in the text, for one monitoring station located at the border between two countries and near the outlet, the concentration for the same determinand could vary by a factor two to three, heavily impacting the calculation of loads. Another problem was also to collect all relevant nutrient sources in particular those from industries. It is important to stress also that the modelling approach do not cover the direct discharge to the sea if not taking place inland. For instance, aquaculture inputs were not considered if taking place outside the river basin. This is not a major issue in this study as the focus was only nutrient coming from land based activities and regulated by the Nitrates Directive, the UWWTP Directive, and the WFD, but clearly the input of direct discharge has to be taken into account when performing nutrient budgeting in the coastal areas. Despite all these unforeseen difficulties, the results are rather promising. Indeed a good evaluation of nutrient loads was performed at the sub-basin, basin and sea level. Clearly, considering the areal extent of the study, the data sources and resolution, some discrepancies were observed. However, the major focus of the study was not to capture all possible details of nutrient losses into European Seas, but rather to provide a continental overview of nutrient loads into European Seas using a uniform approach.

As the model was developed mostly using monitoring data from agricultural areas, the model was more biased in estimating nutrient loads in the Baltic Sea where background losses play an important role. It is the intention to improve the estimation of the loads of nutrient coming from mostly forested areas. It is also envisaged to run the model by region. Indeed, the model was run for Europe as the whole, deriving one unique set of parameters. A trial by splitting Europe in three regions, namely the Baltic, the Mediterranean and Danube, and the rest of Europe will be performed to estimate region specific coefficients. To support this more regional approach, it is also envisaged to extend the monitoring network, including the Baltic where inland monitoring stations will be fetched. An uncertainty analysis to provide a range of nutrient loads into the seas will be performed by repeating the exercise for several years.

A large effort next year will be done on the collaboration with the conventions, and in particular with OSPAR and MEDPOL where good contacts have been made. This is particularly important for the work of the second year where the focus will be on the retrospective analysis. Indeed getting good quality data for the past might prove even more difficult than getting good quality data for the present. An emphasis should be put on point source information about the population connected and the various level of treatment.

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Abstract
The understanding of the fate and impact of pollutants on the functioning of the terrestrial/aquatic interface is a scientific challenge that requires a combination of several disciplines, tools and datasets. In order to support the implementation of the Marine Strategy Framework Directive, DG Environment and the JRC joined to develop a study on the expected cumulative impact of existing European Union environmental legislation on the quality of the marine environment, with specific reference to the case of aquatic discharges from inland-based sources (FATE-scenarios).The main objective of the study is to assess, retrospectively and in forecast mode, changes in environmental pressures due to substances originating from anthropogenic activities and discharged in European marine waters. This document reports on the nutrient discharge from rivers to seas for year 2000 and provides estimates on the contribution of major sectoral activities to the losses of nutrients.

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