Evaluation of total nitrogen concentrations in coastal waters of the Meuse catchment for 2021 and 2027

Deltares

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Summary
The International Meuse Commission (IMC) requested an ex-ante evaluation of the planned measures included in the River Basin Management Plans 2016-2021 of the EU Water Framework Directive to reduce total nitrogen emissions to the North Sea. The study allows more insight into the contributions of the different member states to the total nitrogen concentrations in the Dutch water bodies and the coastal waters of the Meuse catchment. The positive cooperation of all IMC member states characterized this study and supported the process greatly. Member states delivered total nitrogen loads, flow data and expected reductions of total nitrogen loads for 2012, 2021 and 2027 for a selection of the main transboundary rivers in the Meuse catchment. A downstream approach was followed, where output of the upper water body was the input for the next downstream water body. Using the WFD Explorer Model and the ZUNO3D-GEM model (North Sea Model), Deltares calculated concentrations and loads for surface water bodies, including the transitional and coastal waters and the North Sea in close cooperation with the delegations from Germany, Flanders, Wallonia and France.
A reduction in nitrogen load in smaller transboundary rivers of 1-5% in the year 2021 and 2-18% in 2027 is expected compared to the year 2012. For the main stream of the Meuse we expect reduced nitrogen loads by 3% in 2021 and by 6% in 2027.
Compared to 2012, calculations sh.0ow that for individual water bodies total nitrogen concentrations will be reduced by 3-14% in 2021 and 6-17% in 2027. As a result, we expect in 2027 in the Dutch main stream of the Meuse River a total nitrogen concentration of 3.1 – 3.8 mg/l.
Winter DIN concentrations in coastal waters of the Meuse catchment in 2021 and 2027 will be reduced by respectively 0.04 mg/l (4%) and 0.07 mg/l (6%) compared to 2012 and a winter DIN concentration of 1.07 mg/l is calculated for the year 2027.

References
Chrzanowski, C., Cleij, P. Van den Roovaart, J., Thiange, C., Troost, T. 2015. Evaluation of total nitrogen concentrations in coastal waters of the Meuse catchment for 2021 and 2027. Deltares report 1220521-ZSW-0005. Delft.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
5	Nov. 2015	Clara Chrzanowski		Simon Groot		Sacha de Rijk	
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Table of Content

1 Introduction

The International Meuse Commission (IMC) requested an ex-ante evaluation of the planned measures included in the River Basin Management plans 2016-2021 of the EU Water Framework Directive to reduce total nitrogen emissions to the North Sea. The study allows more insight into the contributions of the different member states to the total nitrogen concentrations in the Dutch water bodies and the coastal zone. Member states delivered calculated total nitrogen loads, flows and expected reduction of total nitrogen loads for 2015, 2021 and 2027 for a selection of the main transboundary tributaries in the Meuse catchment. A downstream approach was followed, where output of the upper water body is the input for the next downstream water body. Using the WFD Explorer Model Water Framework Directive Explorer Model) and the ZUNO3D-GEM model (North Sea Model), Deltares calculated total nitrogen concentrations and loads for surface water bodies, including the transitional and coastal waters and the North Sea, in close cooperation with the delegations from Germany, Flanders, Wallonia and France.

2 Conditions of the project

There are several limitations and assumptions in the project that were discussed during bilateral meetings with the delegations. The following list includes the boundary conditions and a brief description.

- **Object of this study is total nitrogen**.

- **Number of transboundary water bodies and locations**
  A limited number of transboundary water bodies is defined in the Dutch schematization of the National Hydrological Model (LHM) which will not be adjusted for additional transboundary water bodies. Relevant water bodies and available data are discussed in bilateral meetings with the delegations.

- **Reference year for calculations**
  It is important to set a reference year for the calculation of the scenarios to allow comparison with a reference situation. Preference goes to the year 2012 since it is also applied in the WFD Explorer Model.

- **Nature of hydrology**
  The WFD Explorer Model makes use of the flows 2005 – 2008. This period represents an average hydrological year in the Netherlands and is used as input for the WFD Explorer Model.

- **Time scale of flow and load**
  Total nitrogen loads (g/s) being used are quarterly mean nitrogen concentrations, averaged for the period 2010 – 2013. The transboundary flows used are quarterly mean flows (m^3/s), averaged for the period 2005 - 2008.

- **Scenarios**
  The effect of planned measures included in the draft 2nd River Basin Management Plans of the WFD for 2021 scenario and 2027 scenario will be calculated for the Dutch part of the Meuse catchment only.

- **Documentation of the results per water body**
  In the study the results of flow and nitrogen loads are documented for the WFD water bodies in the main tributaries of the river Meuse for the Dutch Meuse catchment including coastal waters of the Meuse catchment.

3 Methods

This chapter briefly describes the process of the project activities (Section 3.1), the modelling approach (Section 3.2) and gives a more detailed overview of the Water Framework Directive Explorer (Section 3.3). Section 3.4 describes how the model schematization of the Dutch waters is connected to the model schematization of the transboundary waters of the upstream countries. This includes the bilateral actions related to the data exchange between member states as well as additional information about the effects of nutrient reduction measures which are taken into account for the model calculations. Section 3.5 describes the connection of the WFD Explorer with the North Sea Model, while section 3.6 gives an impression of the Delft3D-GEM/BLOOM Model (North Sea Model).

3.1 Process of the project activities

On the IMC Project Group Chemical (PChem) meeting in Liège on February 26th 2015, Joost van den Roovaart (Deltares) presented the WFD Explorer Model and the approach of this exercise. The flowchart (

Figure 3.1) represents the steps taken by the Dutch delegation. The bilateral actions with the other delegations are briefly described in section 3.4 which also provides a final overview of the data delivered per member state. For more detail of the bilateral meetings the reader is referred to the memo 1220521-000-ZWS-0004 dated 21st August 2015 (Chrzanowski et al., 2015).

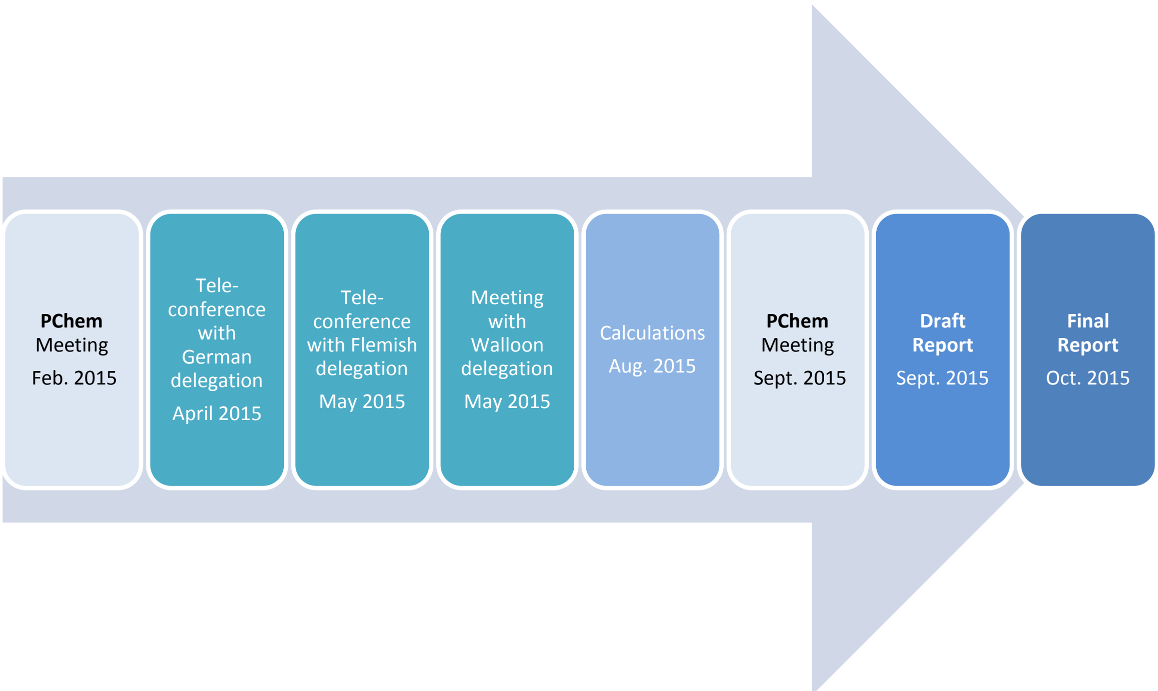


Figure 3.1 Timeline of the actions taken by the Dutch delegation including data collection, (model) calculations and reporting.

3.2 General model infrastructure

It is requested to evaluate the impact of policy measures on manure surplus, nitrate concentrations in groundwater, nutrient load on surface water systems as well as chemical and ecological quality of surface water. In the Netherlands a model chain (Figure 3.2) is used for the assessment of the Fertiliser Act and the Water Framework Directive.

The main models are:

- MAMBO (manure production, manure and fertilizer distribution, manure surplus)
- SWAP/NAGROM (hydrology; unsaturated and saturated zone)
- ANIMO/QUADMOD (ANIMO: soil quality, soil water quality, nitrate concentration groundwater and nutrient loads to groundwater and surface water; QUADMOD: crop response)
- WFD Explorer (surface water quality; chemical and ecological water quality)

In the model chain, the MAMBO model generates the nation-wide manure and fertiliser input for the ANIMO/QUADMOD model over a long-term period. The SWAP model (Van Dam, 2000; Kroes and Van Dam, 2004) is used to generate hydrological input to the ANIMO model (Groenendijk and Kroes, 1999) which simulates the nutrient cycle in soil, crop response (QUADMOD) and the nutrient leaching to groundwater and surface waters. The WFD Explorer calculates the surface water quality.

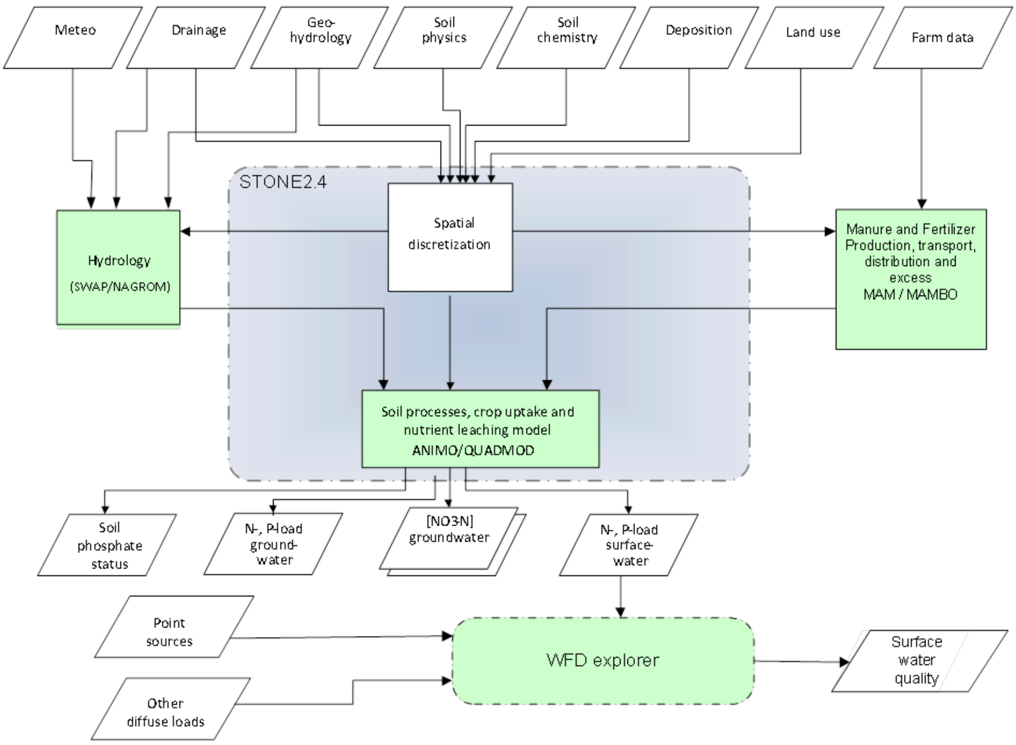


Figure 3.2 General model infrastructure of the Dutch modelling approach to assess water quality

3.3 Surface water quality model

3.3.1 Objective

The WFD Explorer is an analysis tool to calculate the effect of restoration and mitigation measures on the chemical and ecological quality of surface waters. As such, it provides users insight in the effectiveness of programmes of measures in the soil and/or the water system when set against the WFD objectives. A cost module is available to calculate and map the costs of measures.

3.3.2 The Water Framework Directive Explorer 2.0

The Water Framework Directive (WFD) is one of the most important policy directives in Europe for the improvement of water quality and ecology. Deltares worked together with many partners to develop a new software tool to help water managers to assess proposed measures and evaluate results.

The WFD Explorer is an analysis tool to support the implementation of the WFD. The tool enables the calculation of the effect of restoration and mitigation measures on the ecological and chemical quality of surface waters. Users will gain insight into the effectiveness of programmes of measures in relation to WFD objectives. Measures can be defined in relation to both point sources, such as wastewater treatment plants, and diffuse sources, such as agriculture and traffic. Likewise, it is possible to calculate the effectiveness of restoration measures such as stream re-meandering or the construction of near-natural riparian zones. A cost module is available to calculate and map the costs of measures which give insight in the cost-effectiveness of different programmes of measures.

The 2.0 version of the tool is a completely new build instrument and is available free of charge. The WFD Explorer is a flexible tool that allows users to easily import or adjust things like their own schematisation of a river basin, emission data and area specific characteristics. The user-friendly interface makes it easy to set up a model structure, perform an analysis and produce reports in an organized and systematic way which can be used in policy briefings, for the communication with stakeholders and as background documentation for reports to the European Commission.

The WFD Explorer is a lumped, steady state catchment water quality model to quantify catchment nutrient loading after attenuation. It comprises a water balance, a substance balance and an Ecological module which can be applied together or individually. The ecological module focuses on biology, using four biological quality elements (macrophytes, benthic invertebrates, fish and phytoplankton) that together determine the ecological status. In the WFD this ecological status is quantified by the ecological quality ratio (EQR-score), which can be calculated in the WFD Explorer for each water unit. The tool helps to stimulate and structure the development of ecological knowledge.

The WFD Explorer was developed by Deltares, PBL and Alterra by order of the Ministry of Infrastructure and Environment, the Ministry of Transport, Public Works and Water Management, the Foundation for Applied Water Research (STOWA) and “Het Waterschapshuis” (the executive agency on Information and Communication Technology for the 26 regional water authorities in the Netherlands).

3.3.3 Model scheme

The WFD Explorer consists of three main building blocks that can be used either concurrently or as stand-alone modules (Figure 3.3).
The Hydrology module routes the water through the nodal network using the forcing flows from sinks and sources such waste water treatment plants, industry, border crossing streams, etc. as main input. Water quality is subsequently calculated with flow input from the Hydrology module, forcing loads on the nodes, and substance-related retention coefficients. Finally, the

Ecology module provides an ecological score per identified water body usually made up of one or more nodes.

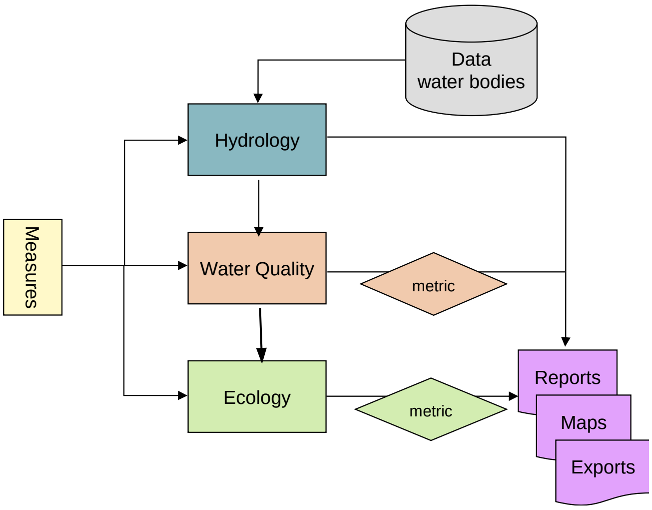


Figure 3.3 Schematic overview of the WFD Explorer

3.3.4 Modelled processes

The Hydrology module routes the water through the nodal network based on a water balance approach without storage terms. For this, the module also needs nodal fractions to correctly divide discharges (bifurcations) and actual flows to meet nodal demands. This information, given in time-averaged values, should be supplied by a precursor hydraulic or water distribution model.

The Water Quality module uses the flows from the Hydrology module and the nodal forcing loads. In its present implementation only the nutrients total nitrogen and total phosphorus are considered, but the versatility of the underlying software also allows for the computation of other substances. Processes are restricted to a simple first-order disappearance approach. Obtained from various literature sources (e.g. De Klein, 2008), on-going research at Alterra, WUR and elsewhere, the applied retention coefficients are generally generic in space and time. At present, coefficients are used for the Pleistocene and the Holocene parts of the Netherlands and split up for the summer and winter half years.

The Ecology module calculates the ecological score for a water body. To do so it uses an Ecological Quality Ratio (EQR) set on a scale between 0 and 1. Scores are based on four so-called biological quality elements represented by macrophytes, benthic invertebrates, fish, and phytoplankton. As such, scores mark the present or predicted condition against the (natural) reference situation, being the unity. Multiple approaches are currently included in this module. First, distinction is made between regional and national water bodies. For the regional scale, relations per water body have been established between certain hydro-morphological characteristics and physico-chemical properties and the EQR by applying regression trees and neural networks on the improved Dutch aquatic-ecological dataset (i.e. Ex-ante KRW (PBL, 2008) and based on the Limnodata Neerlandica www.limnodata.nl).
These relations (or even the trained neural network itself) are subsequently incorporated in the module and are used to predict the effects of measures. The Ecological module is not being used in this project.

3.3.5 Main input en output variables

The WFD Explorer is an instrument which can be applied at multiple scales. This version is hydrological fed by the Netherlands Hydrological Instrument (NHI), a comprehensive instrument covering most of the national territory. From NHI it receives the following inputs:

1. Spatial schematisation:
   a. Local Surface Waters (LSWs) acting as the principal 2-D rainfall-runoff units;
   b. Distribution Model (DM), a 1-D nodal network for the national waters;
   c. District Water (DW) nodes linking the LSWs to the DM nodes;
2. Flow data:
   a. Routing distribution fractions per individual node per unit time for the discharge situation;
   b. Network routed nodal supplies per unit time (mainly for coping with summer droughts, but also to provide uptake points with sufficient water);
3. Hydrological forcing:
   Sink and source flows per node per unit time: drainage, infiltration, water level conservation, industry, agriculture, drinking water, flushing requirements, etc.

To properly represent the local water network and to properly deal with water quality processes (i.e. to prevent excessive numerical dispersion), the WFD Explorer pre-processor converts 2D-LSW data into multiple nodes, one or more for the network and one representing the aggregated water volume within a LSW. Building the network and necessary conversions into WFD Explorer formats are fully supported by a Windows® GUI.

In its national setup water quality data are currently limited to the nutrients total nitrogen) and total phosphorus. These data are derived from the following sources:

1. Load forcing:
   a. Diffuse sources (agriculture) on the LSW aggregation node derived from STONE database (Groenendijk et al., 2005);
   b. Industry and WWTPs on the DM and LSW network nodes which are taken from the national Emission Registration (ER) database (www.emissieregistratie.nl);
   c. Wet and dry airborne depositions of nitrogen on all nodes (www.emissieregistratie.nl) Again, the pre-processor takes care of the conversions and proper formats for the WFD Explorer.
2. Ecological data:
   The natural reference situation of water bodies are derived from the improved Ex-ante KRW dataset (Van Gaalen et al., 2015). Additional data, such as hydromorphological designs, can be collected from databases operated by the Water Boards.
3. Measures:
   Measures or measure packages can be defined and selected by the user. The effects of these pre-defined measures, for instance in load reductions, are included in the WFD Explorer database.

The WFD Explorer provides the user with the following output:

- EQR scores per water body per biological quality element. The User Interface also facilitates EQR comparisons between different measure packages and consequently provides insight in the effectiveness of such packages;
- Nutrient loads and concentrations at different spatial levels of the water system and hence provides insight into the extent of loads passed over from one location to another.

Such functionality is useful for analysing the relations between loads received from neighbouring countries and loads discharged into the North Sea.

3.4 Data exchange

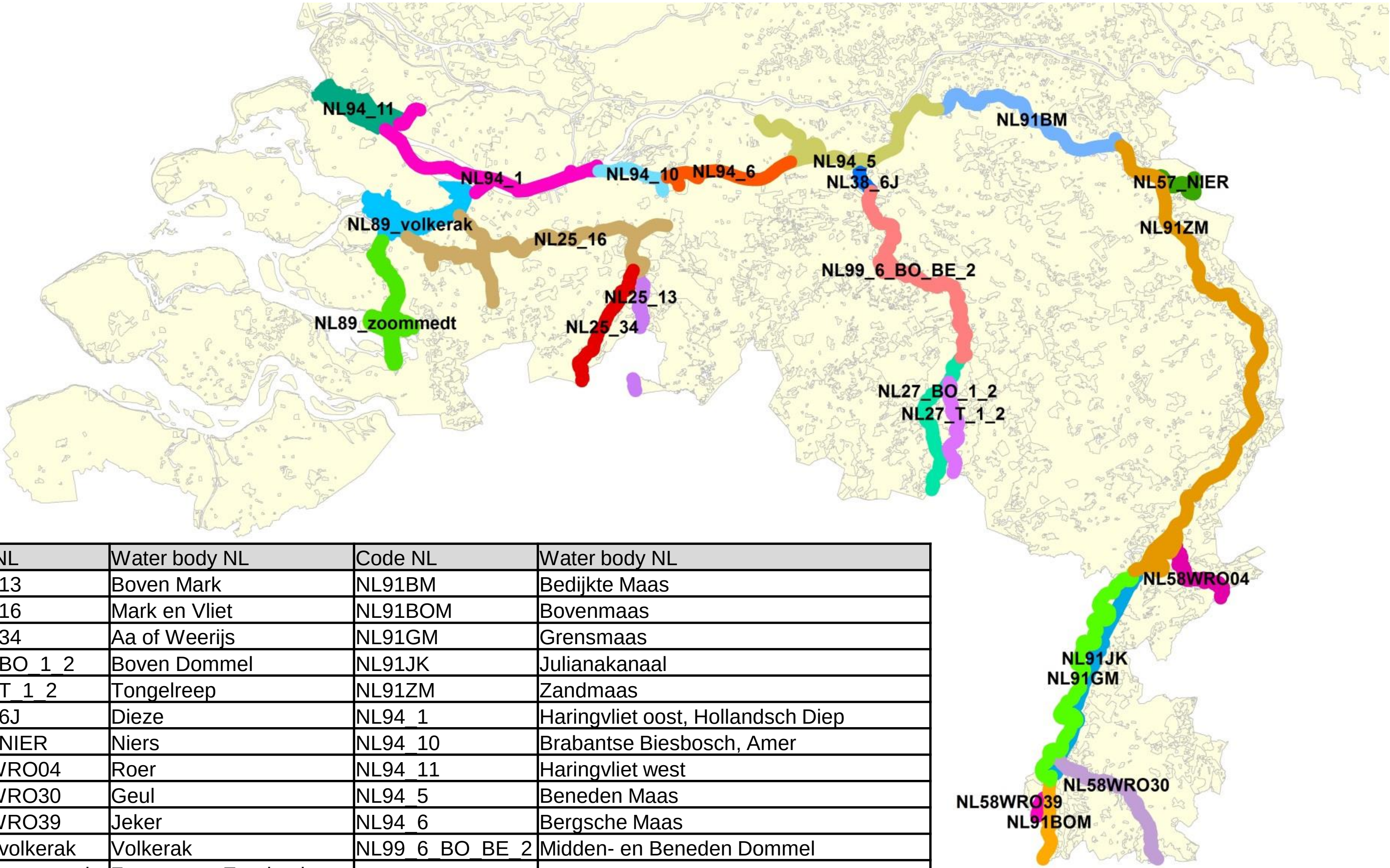
This section describes the exchange of data with the country delegations, in terms of water body schematization (3.4.1) as well as measures and reduction percentages for the scenario years for the individual countries (3.4.2 until 3.4.6).

3.4.1 Transboundary schematization

The Dutch schematization for the National Hydrological Model (LHM) is based on different models of The Netherlands Hydrological Instrument (NHI). The schematization consists of a nationwide presentation of the surface waters on a detailed geographical level, including the individual surface water bodies as designated for the WFD. Several transboundary rivers (see Table 3.1 below) are also included in the national schematization. The flows and loads were replaced with the new data delivered by the member states if not mentioned otherwise. The Flemish water bodies Abeek and Bosbeek are not included in the Dutch schematization but are combined with the loads of the Itterbeek II (Thorner Beek). Figure 3.4 illustrates a selection of the water bodies included in the national schematization.

Table 3.1 Overview of the transboundary water bodies assessed in this project, national codes, available data for flows and loads for each water body and state of the art of scenarios for each country.

	Water body	Name NL	Code Abroad	Code NL	Flows	Concentrations	Scenarios
Flanders	Weerijsbeek	Aa of Weerijs	VL05_148	NL25_34	2005, 2008	2010-2013	No water quality model available. Estimation of total nitrogen reduction is done with online mkm-module. Reduction of total nitrogen load (yearly) is based on measures described in the module. It is not possible to differentiate different quarters.
	Mark	Boven Mark	VL08_145	NL25_13	2005, 2006	2010-2012	
	Dommel	Boven Dommel	VL05_136	NL27_BO_1_2	2005, 2006, 2008	2011-2013	
	Warmbeek	Tongelreep	VL05_147	NL27_T_1_2	2005-2007	2012	
	Lossing	Haelensche Beek	VL05_141	NL57_HAEL	2005, 2006, 2008	2011-2013	
	ItterbeekII	Thorner Beek	VL05_138	NL57_ITT	2005, 2006, 2008	2011-2013	
	Abeek	Thorner Beek	VL11_133	NL57_ITT	2005, 2006, 2008	2011-2013	
	Bosbeek	Thorner Beek	VL05_135	NL57_ITT	2005-2008	2011-2013	
Germany	Niers	Niers	DE_NRW_286_7972	NL57_NIER	2011	2011	Based on MONERIS calculations. It is not possible to differentiate different quarters.
	Rur	Roer	DE_NRW_282_21841	NL58WRO04	2011	2011	
Wallonia	Meuse	Boven Maas	MV35R	NL91BOM	2005-2008 (Deltares)	2010-2013 (Deltares)	Based on Pegase calculations. Differentiated in quarters.
	Geer	Jeker	MV18R	NL58_WRO39	2005-2008	2015	
	Gueule	Geul	MV26R	NL58WRO30	2005-2008	2015	



Code NL	Water body NL	Code NL	Water body NL
NL25_13	Boven Mark	NL91BM	Bedijkte Maas
NL25_16	Mark en Vliet	NL91BOM	Bovenmaas
NL25_34	Aa of Weerijs	NL91GM	Grensmaas
NL27_BO_1_2	Boven Dommel	NL91JK	Julianakanaal
NL27_T_1_2	Tongelreep	NL91ZM	Zandmaas
NL38_6J	Dieze	NL94_1	Haringvliet oost, Hollandsch Diep
NL57_NIER	Niers	NL94_10	Brabantse Biesbosch, Amer
NL58WRO04	Roer	NL94_11	Haringvliet west
NL58WRO30	Geul	NL94_5	Beneden Maas
NL58WRO39	Jeker	NL94_6	Bergsche Maas
NL89_volkerak	Volkerak	NL99_6_BO_BE_2	Midden- en Beneden Dommel
NL89_zoommedt	Zoommeer, Eendracht		

Figure 3.4 Map of the Dutch part of the Meuse catchment with the transboundary flows and Dutch water body codes.

Bilateral actions
The following section describes the approach per member state to prepare the input for the WFD Explorer and the North Sea Model. It was decided to use concentration data from the years 2010 to 2013 and flow data from 2005 to 2008. The reason for this approach was the input for the WFD Explorer Model. The data was not exactly in line with the proposed input; however, we can assume that the data provides enough insight to evaluate the contributions of total nitrogen by every member state. Accordingly, an error margin can be assumed which reflects the individual data situations of the different member states.

3.4.2 Germany

The German delegation provided monthly total nitrogen concentrations and daily discharges for the river Niers and Rur for the year 2011. According to the German delegation the mean discharge of 2011 is representative for the 30-years mean discharge (Table 3.2).

Table 3.2 Quarterly flow-weighted total nitrogen loads and discharge for river Rur and Niers for the year 2011.

Water body	Parameter	Unit	Q1	Q2	Q3	Q4
Rur	Flow	m^3/s	37.9	10.7	9.2	14.4
Rur	Total nitrogen load	g/s	161.9	41.2	28.4	51.8
Niers	Flow	m^3/s	14.2	9.7	5.2	6.9
Niers	Total nitrogen load	g/s	94.3	67.6	30.1	41.5

Calculation
Based on the dataset from LANUV (North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection) for rivers Rur and Niers, quarterly loads for 2011 were calculated according to the flow-weighted concentration method (FWC-method). Since the loads slightly differed the calculations were adjusted as follows:
Per quarter the percentage of total nitrogen load is calculated based on the yearly calculated load (FWC-method) for river Niers and Rur. These quarterly percentages were applied to the estimated yearly loads for Rur and Niers which are also used in the German background document.

Scenarios and measures
The scenarios for 2021 and 2027 are based on the assumption of percentage reduction of inputs from point sources and diffuse sources (e.g. 2.5% or 5%), see Table 3.3. To determine the level of reduction of the total load, the entries of the different pathways of MONERIS are considered. The currently observed loads, based on data of measured concentrations and hydrological flow, are then reduced pro rata to determine the expected loads in 2021 and in 2027 respectively. Using the expected loads and hydrological flows, concentrations are estimated which are then compared with the target values. For the years 2021 and 2027 an estimation of the total nitrogen reduction is provided based on the reference year 2011. The scenarios are based on measures regarding the reduction of point sources and diffuse sources. The reduction of total nitrogen can only be documented as a yearly load. For the scenarios we applied the % of reduction to each quarter.

Table 3.3 Total nitrogen reduction percentages for diffuse and point loads of rivers Rur and Niers for scenarios 2021 and 2027.

	Loads	2021	2027
Rur	Point sources	5%	10%
	Diffuse sources	2.5%	5%
Niers	Point sources	5%	10%
	Diffuse sources	0%	0%

3.4.3 Flanders

Table 3.4 gives an overview of the total nitrogen loads and flows for eight transboundary rivers. The Flemish delegation provided mean quarterly total nitrogen loads averaged for years 2010-2013 or otherwise for the period where data was available. Furthermore, mean quarterly discharges averaged for the period 2005-2008 were received depending on the data available. Refer to Table 3.1 for an overview of the delivered data. No water quality model was available for this part of the Meuse catchment.

Table 3.4 Quarterly flow-weighted total nitrogen loads and discharge for several Flemish water bodies.

Water body	Parameter	Unit	Q1	Q2	Q3	Q4
Weerijsbeek	Flow	m^3/s	2.3	1.0	1.1	1.0
Weerijsbeek	Total nitrogen load	g/s	17.6	4.5	4.0	5.0
Mark	Flow	m^3/s	6.1	3.9	3.9	5.1
Mark	Total nitrogen load	g/s	67.4	28.8	18.4	34.4
Dommel	Flow	m^3/s	1.7	1.4	1.3	1.3
Dommel	Total nitrogen load	g/s	9.1	3.9	3.9	5.8
Warmbeek	Flow	m^3/s	0.4	0.3	0.3	0.3
Warmbeek	Total nitrogen load	g/s	1.8	1.1	0.9	1.4
Lossing	Flow	m^3/s	0.4	0.4	0.4	0.6
Lossing	Total nitrogen load	g/s	2.5	1.6	1.0	1.6
Abeek	Flow	m^3/s	1.1	1.0	1.0	1.6
Abeek	Total nitrogen load	g/s	9.8	4.5	3.5	4.0
Bosbeek	Flow	m^3/s	0.6	0.4	0.4	0.5
Bosbeek	Total nitrogen load	g/s	2.9	1.5	1.7	1.6
ItterbeekII	Flow	m^3/s	0.6	0.6	0.5	0.9
ItterbeekII	Total nitrogen load	g/s	5.3	2.4	2.0	2.0

Calculation
For the Flemish rivers the quarterly flow-weighted concentrations for the years 2010-2013 are calculated by multiplying them by the corresponding quarterly flows for the years 2005-2008 (or the specific years mentioned in Table 3.1).

Scenarios and measures
Scenarios are based on the calculated loads provided by the Vlaamse Milieu Maatschappij (VMM) and the Programmes of Measures of the 2nd River Basin Management Plans for the WFD which are described in an online mkm-module and in Table 3.5. Reduction of total nitrogen can only be documented as a yearly load. For the scenarios we applied the % of reduction to each quarter.

Table 3.5 Description of measures of the Programme of Measures RBMP2 and included in scenarios 2021 and 2027. The measures indicated with an asterisk (*) cannot be quantified in terms of total nitrogen load reduction but contribute to the reduction of nitrate.

Code	Measures
4B_D_097	Anti-erosion measures in protected areas
7B_D_031	Efficient nitrogen fertilization: Adjustment of standards for nitrogen fertilization according to MAP5 (5th Fertilization Action Plan)
8B_A_007*	Increased financial support for machines to prevent soil erosion
8B_A_008*	Expansion of Flemish Knowledge Institute for soil prevention
8B_A_009	Implementing step-wise the tightening of erosion measures
8B_A_011	Anti-erosion measures in unprotected areas
8B_A_025*	Increasing awareness for erosion prevention measures in agriculture and horticulture
8B_A_035*	Development of dynamic list of priority substances in erosion bottlenecks in the Meuse catchment
8B_A_054	Control or execution of solution scenario for erosion bottlenecks in erosion plans at municipal level in the Meuse catchment
8B_A_064*	Stimulation of erosion coordinators and business planners in the Meuse catchment

3.4.4 Wallonia

The Walloon delegation provided information for the three rivers Jeker, Geul and Meuse (Table 3.6). Mean quarterly discharges averaged for the period 2005-2008 for the rivers Geul and Jeker were received. Also, S.P.W. (Service Public de Wallonie) provided mean quarterly total nitrogen loads averaged for the year 2015 for rivers Geul and Jeker. In agreement with the Walloon delegation, quarterly total nitrogen loads and flows of the National Hydrological Model (LHM) are used for the Meuse. The reason for this decision is the remarkable difference between calculated total nitrogen loads in the third quarter of both delegations. Due to the use of different data, an irregularity of about 1% can be assumed for the reduction percentages of the third quarter of the Meuse.

The Walloon delegation provided the following information about the difference between the calculated and measured total nitrogen loads:
“The difference between calculated total nitrogen loads is caused by the use of ecological parameters in PEGASE in which the basket clam C*orbicula sp.* was more limited and phytoplankton was higher and thus N concentrations were lower. The C*orbicula sp.* is an invasive species in the Meuse waters which eats phytoplankton. Because of that, the uptake of N and P by phytoplankton decreases if the C*orbicula sp.* population grows. The animal faeces are also remarkable by their highly concentrated level of nitrate, ammonia nitrogen as well as phosphorus. So, the first result of PEGASE underestimated the nitrogen flux in the 3rd quarter because the ecological parameter of C*orbicula sp.* was more limited. New calculations with adapted ecological parameters could not be performed because of the tight time frame of this study.”

Table 3.6 Quarterly flow-weighted total nitrogen loads and discharge for rivers Meuse, Geul and Jeker.

Water body	Parameter	Unit	Q1	Q2	Q3	Q4
Meuse*	Flow	m^3/s	447.2	193.6	86.2	198.4
Meuse*	Total nitrogen load	g/s	1881.4	700.0	294.2	781.4
Geul	Flow	m^3/s	4.8	2.6	1.4	2.7
Geul	Total nitrogen load	g/s	30.5	11.7	3.3	15.1
Jeker	Flow	m^3/s	2.1	1.2	0.8	1.2
Jeker	Total nitrogen load	g/s	8.9	5.0	3.2	5.6

* Data provided by Deltares

Calculation

The quarterly transboundary flows for the Meuse in the LKM calculations for the current situation (2012) were derived from quarterly flow-weighted concentrations for the years 2010-2013 using measurement data from Waterbase (http://live.waterbase.nl/waterbase_wns.cfm?taal=nl).

These concentrations were then multiplied by the corresponding quarterly flows for the years 2005-2008, derived from the boundary flows of the LSM and averaged for each of the quarters 1 to 4 resulting in four quarterly loads per nutrient (for the year 2012). The boundary flows of the LSM are derived from the (decade-based) LHM boundary flows, which in turn are based on Waterbase flows.

SP Wallonia delivered loads and flows of Jeker and Geul having been calculated using the flow-weighted method. Flows were obtained from the quarterly mean of the period 2005 - 2008. Because 2008 was a leap year, the value of 29th February has been removed. When flow had been missing for a few consecutive days a linear interpolation was performed. The mean total nitrogen concentrations were then multiplied by the corresponding quarterly flows for the years 2005-2008.

Scenarios and measures

The scenarios are calculated with the water quality model PEGASE. The estimated change in total nitrogen load is documented quarterly for the years 2021 and 2027 for rivers Geul, Jeker and Meuse (Eijsden). Table 3.7 describes globally the planned measures regarding the reduction of point sources and diffuse sources for both scenarios.

Table 3.7 Description of measures for urban, industrial and diffuse point loads for scenarios 2021 and 2027 in Wallonia.

Loads	2021	2027
Urban loads	min. 60% connected to sewage system	UWWTP 1500-2000 p.e., new plants connection rate 70%
Industrial loads	Reduction of 5%	Reduction of 10%
Diffuse loads		In 2030 reduction of 15% livestock (compared to 2010); no land use changes

Agri-environmental measures to reduce diffuse loads are based on the scenario called “stratégique” (Van Stappen et al., 2014). Measures of this scenario imply an optimization of the food and non-food uses of Walloon cereals from the environmental, economic and social point of view by 2030.

The scenario is described in more detail by Van Stappen et al. (2014) and includes measures such as a reduction of meat consumption with 20%, focus on renewable energy sources and adjustment of agricultural practices.

3.4.5 France

Using the PEGASE model, Wallonia conducted a transnational modelling with the French agency RHIN MEUSE to perform simulations that incorporate the measures taken for the 2nd River Basin Management Plans for the WFD. France made its simulations according to its own assumptions and produced output files which specify all the characteristics (flows, loads, total nitrogen, total phosphorus, etc.) of the Meuse at transboundary points of French regions. Wallonia used the French exit conditions as input conditions for its own modelling with PEGASE.

3.4.6 The Netherlands

Detailed overviews for the Netherlands are available from the national emission pollutant register (EmissieRegistratie). Figure 3.5 gives an overview of the contribution of the different sources and the contribution of the four international catchments to the release of total nitrogen in the Netherlands for the average of the years 2010-2014. It is shown agriculture is by far the most important source of total nitrogen in the Netherlands.
In the source category “other” a number of smaller sources are summed together. This includes atmospheric deposition to surface water, households not connected to a sewer system and stormwater overflows. Also the contribution of the effluents of the urban waste water treatment plants (UWWTPs) is a significant one.

The Dutch part of the Rhine catchment turns out to be the largest contribution to total nitrogen loads to surface water in the Netherlands, while the Meuse catchment is the second largest with 16% (Figure 3.5, right diagram). In these overviews the input from transboundary rivers is not taken into account.

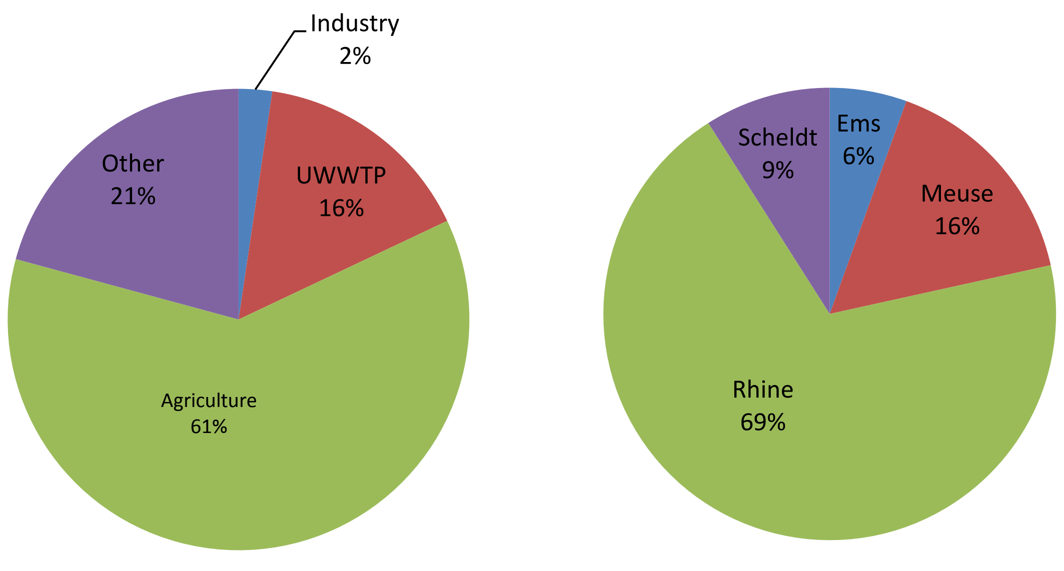


Figure 3.5 Overview of sources of total nitrogen in the Netherlands for the year 2012 (left diagram) and contribution of the (Dutch parts of the) catchments Rhine, Meuse, Scheldt and Ems to the total nitrogen loads in the Netherlands. Input from transboundary rivers in not taken into account.

Table 3.8 shows the releases to surface water from the same four different source categories as used in Figure 3.5 in the base year and the different scenario years. The base year 2012 represents the average of the period 2010-2014. The overall reduction of the total nitrogen emissions in 2027 on a national basis (sum of the four catchments) is estimated to be 7% compared to the base year 2012. For the source categories “industry” and “other” no reductions can be expected. A significant reduction is observed for the UWWTP. For the agriculture, despite a number of measures is included in the River Basin Management Plan, only a limited reduction of total nitrogen is expected.

Table 3.8 Total nitrogen emissions to surface water (million kg) in the Netherlands for four source categories in the base year 2012 and the different scenario years

Source	2012	2021	2027	Reduction % in 2027 compared to 2012
Industry	2.2	2.2	2.2	0
UWWTPs	14.7	11.5	11.1	24
Agriculture	57.4	54.6	54.4	5
Other	19.5	19.5	19.5	0
Total	**93.8**	**87.8**	**87.2**	**7**

Table 3.9 presents the emissions and reduction percentages in the Dutch part of the Meuse district. These data show a significantly higher reduction for both the UWWTPs and the agricultural sources in the Dutch part of the Meuse district compared to the Netherlands as a whole. Also for the sum of all sources, the estimated reduction of total nitrogen in the Meuse district appears to be much higher (19%) than the overall reduction in the Netherlands (7%).

Table 3.9 Total nitrogen emissions to surface water (million kg) in the Dutch part of the Meuse catchment for four source categories in the base year 2012 and the different scenario years

Source	2012	2021	2027	Reduction % in 2027 compared to 2012
Industry	0.5	0.5	0.5	0
UWWTPs	3.6	2.1	1.7	52
Agriculture	9.3	8.3	8.3	11
Other	1.6	1.6	1.6	0
Total	**15.0**	**12.6**	**12.1**	**19**

3.5 Connection with the North Sea Model

The WFD Explorer results are used as input for the Delft3D-GEM model (North Sea Model).In this paragraph the connection of the two models is described.

3.5.1 General coupling concept

Coupling a WFD Explorer model to the North Sea Model involves the following steps:

1. Identify locations where the WFD Explorer domain is discharging into the North Sea Model
2. Distract the computed WFD Explorer loads at these locations
3. Disaggregate and scale the loads

3.5.2 Coupling locations

The schematization of the North Sea Model is called the ZUNO (Southern North Sea Model) domain. Table 3.10 gives an overview of the coupling of the different locations used in both the WFD Explorer domain and in the ZUNO domain. Some of the coupling points correspond to CEFAS locations (Centre for Environment, Fisheries and Aquaculture science). Figure 3.6 illustrates the entire ZUNO domain whereas Figure 3.7 zooms into the Dutch part of the ZUNO domain.

Table 3.10 Coupling locations from WFD Explorer model to coastal domain.

Location	From node	To node	Link ID	CEFAS ID
Oosterschelde	LSM6837	LSM3551	L4190	
Oosterschelde	LSM6842	LSM3551	L4191	
Grevelingen	LSM8500	LSM8501	L4863	
Haringvliet	LSM3433	LSM8406	L2762	Meuse
Haringvliet	LSM9525	LSM9526	L3850	Meuse
Nieuwe Waterweg	LSM6253	LSM1	L793	Rhine
Oude Rijn	LSM4140	LSM7188	L7961	
Noordzeekanaal	LSM8731	LSM4369	L9037	North_Sea_Canal
Den Oever	LSM3333	LSM8319	L501	Lake_IJssel
Kornwerderzand	LSM3331	LSM8318	L491	Lake_IJssel
Friese boezem	LSM4920	LSM1821	L12965	
Lauwersmeer	LSM5217	LSM9040	L15421	
Delfzijl	LSM2826	LSM2827	L21155	
Delfzijl	LSM7903	LSM3210	L28877	
Termunterzijl	LSM5544	LSM2256	L17565	
Nieuwe Statenzijl	LSM2202	LSM5455	L16829	

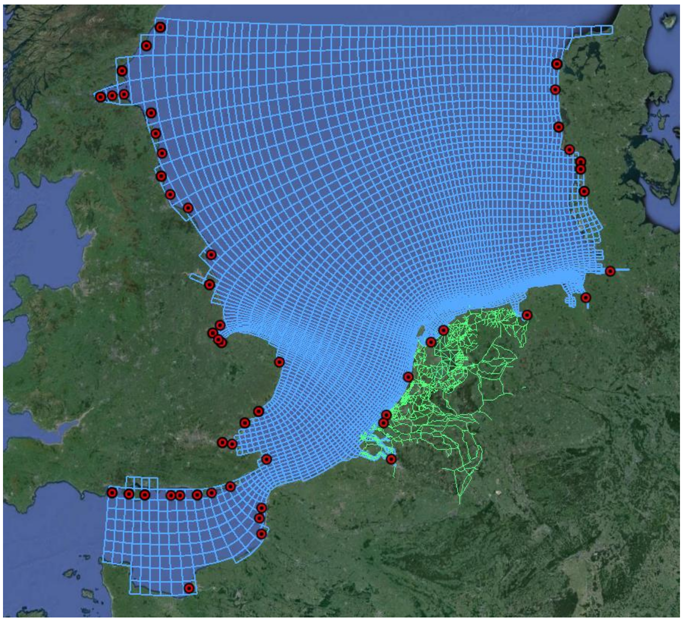


Figure 3.6 Overview of the ZUNO domain. The red dots indicate the discharge points.

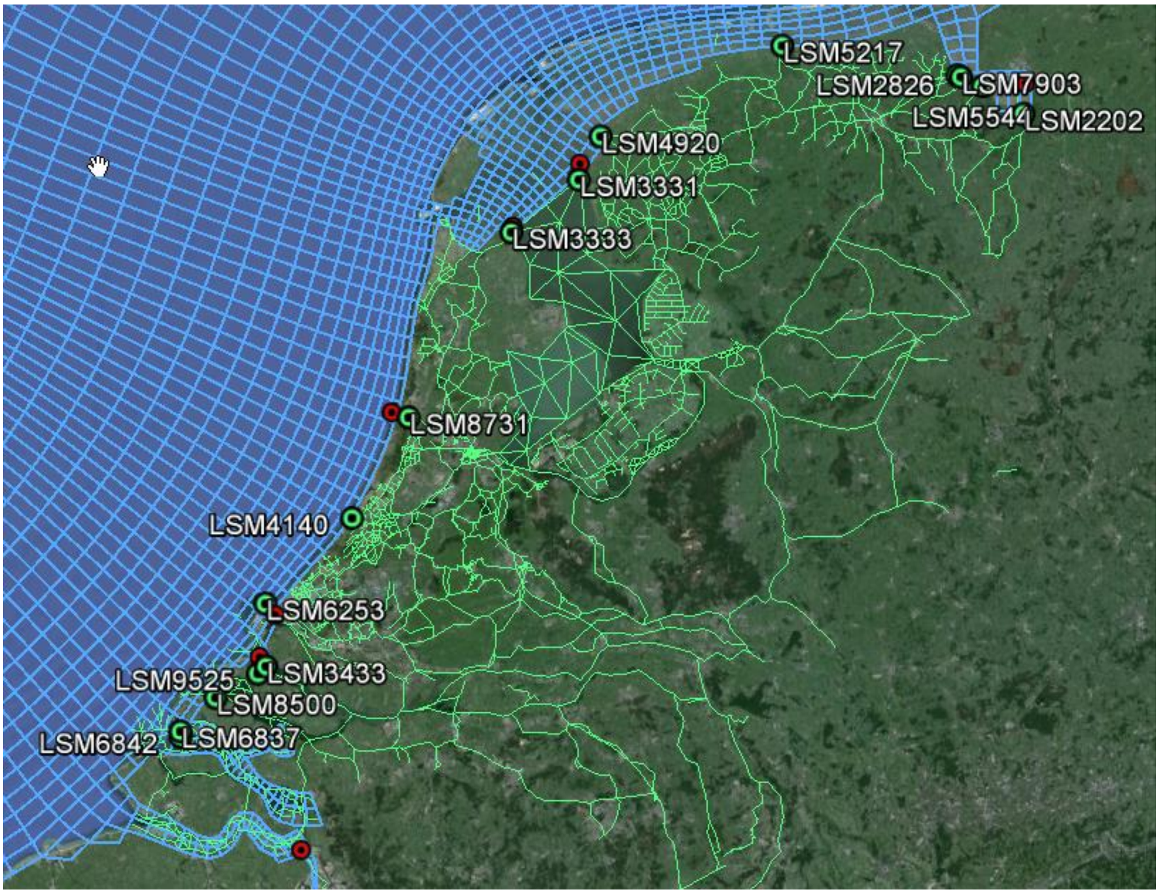


Figure 3.7 Locations of the WFD Explorer domain (green dots) and the discharge points of the ZUNO domain (red dots).

3.5.3 Disaggregation and scaling

WFD Explorer output

The WFD Explorer yields discharges and concentrations. Table 3.11 shows the computed discharges and total nitrogen concentrations for the base year 2012 at each coupling location and for each of the four periods.

Total nitrogen loads can be computed from these results but the coastal model expects series of daily NO_3 and NH_4 loads. The applied method to obtain these values depends on the presence or not of measured data for a given location. The measured loads are provided by CEFAS.

Table 3.11 WFD Explorer computed discharges and total nitrogen concentrations at coupling locations for the base year 2012.

2012	Discharge (m^3/s)				Total N (g/m^3)			
node	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
LSM2826	15.9	2.9	3.3	13.7	3.29	3.42	3.42	2.96
LSM3333	415.7	280.9	264.3	303.1	2.77	1.72	1.27	1.84
LSM3331	268.3	155.3	138.5	204.4	2.64	1.64	1.24	1.75
LSM8500	11.8	8.5	8.3	9.8	0.14	0.08	0.12	0.16
LSM7903	1.2	0.2	0.2	0.4	3.21	3.72	3.89	3.84
LSM8731	77.8	44.0	55.3	78.4	1.37	0.86	0.82	1.26
LSM6837	190.7	175.6	183.3	213.9	0.11	0.06	0.05	0.07
LSM5217	48.5	8.4	13.0	46.6	2.10	0.19	0.28	1.57
LSM4920	8.4	5.7	5.7	6.1	2.86	0.89	0.92	2.50
LSM6253	1836.0	1500.0	1365.0	1468.0	3.15	2.10	1.50	1.95
LSM3433	1030.0	859.9	377.8	335.5	3.49	2.30	1.63	2.24
LSM9525	1.3	2.0	1.4	1.6	6.72	2.30	1.55	6.00
LSM4140	3.5	0.1	0.3	4.8	2.23	1.87	1.49	2.22
LSM6842	196.8	201.7	187.6	230.9	0.12	0.06	0.05	0.08
LSM2202	13.9	3.0	1.9	11.8	3.71	0.74	0.41	3.08
LSM5544	4.8	1.4	1.1	3.8	3.03	1.60	1.42	2.49

CEFAS locations

As can be seen from Table 3.10, some of the coupling points correspond to CEFAS locations. Since CEFAS provides daily loads of total-N, NO_3 and NH_4, these data can be used to disaggregate the WFD Explorer total nitrogen load and convert it to NO_3 and NH_4:

Within one period, the WFD-E load is disaggregated by multiplying the CEFAS series values falling into that period by:

$$\frac{WFDE\ total\ N\ load\ of\ period\ i}{CEFAS\ total\ N\ load\ of\ period\ i}$$

The resulting series of daily loads is then converted to NO_3 and NH_4 values by multiplying it with:

$$\frac{CEFAS\ NO_3\ load\ of\ period\ i}{CEFAS\ total\ N\ load\ of\ period\ i}\ or\ \frac{CEFAS\ NH_4\ load\ of\ period\ i}{CEFAS\ total\ N\ load\ of\ period\ i}$$

Figure 3.8 presents an example of the CEFAS loads and the corresponding disaggregated WFD Explorer loads.

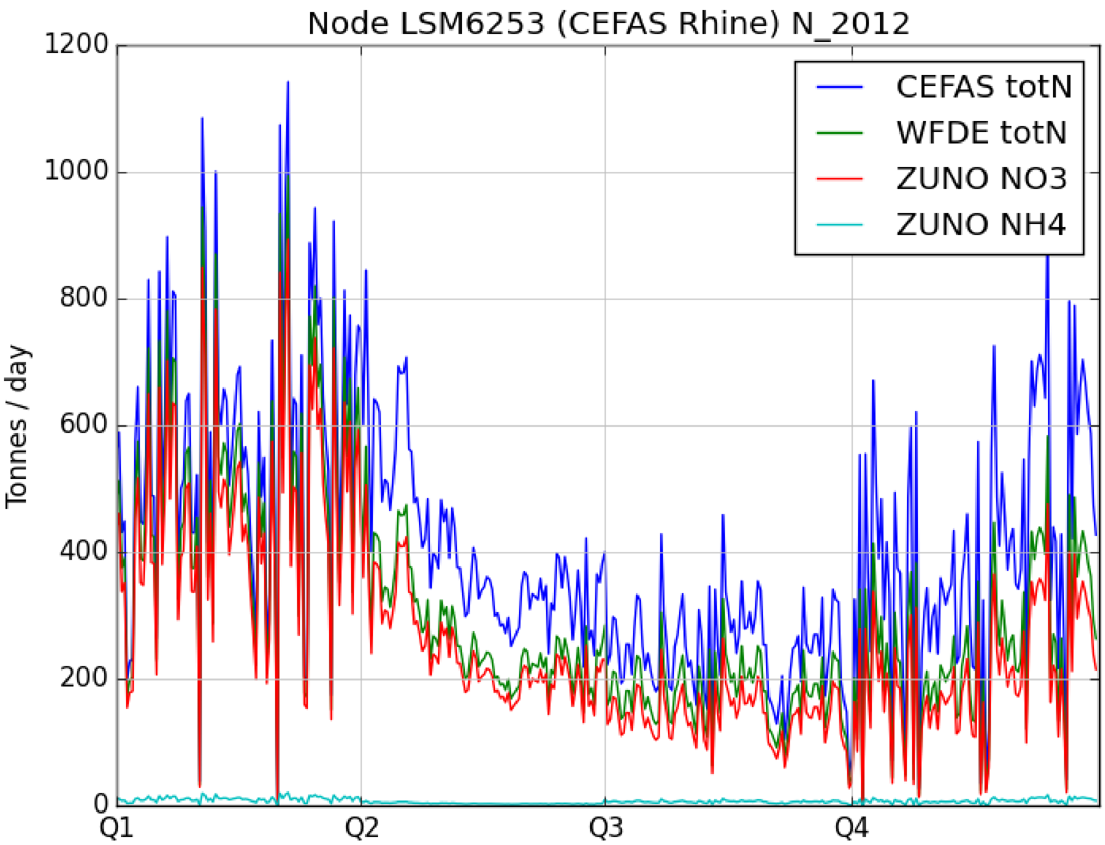


Figure 3.8: 2008 CEFAS loads (measured) for the Rhine and corresponding disaggregated 2012 WFD Explorer loads with derived NO_3 and NH_4 loads for ZUNO model.

Non CEFAS locations
Loads from locations for which no CEFAS data is available are not disaggregated in time. Conversion from total-N to NO_3 and NH_4 is done with following factors:

$$NO_3 = 0.838\ total\ N$$

$$NH_4 = 0.033\ total\ N$$

These values are an average based on the CEFAS data for year 2008 for the Scheldt, Rhine and Meuse.

3.6 North Sea Model

In this paragraph, the North Sea Model is described, focussing on the most relevant aspects of the model for this project.

3.6.1 Considered areas

Figure 3.9 and Figure 3.10 give an overview of the coastal (WFD) and marine (OSPAR) areas that were considered in this study.

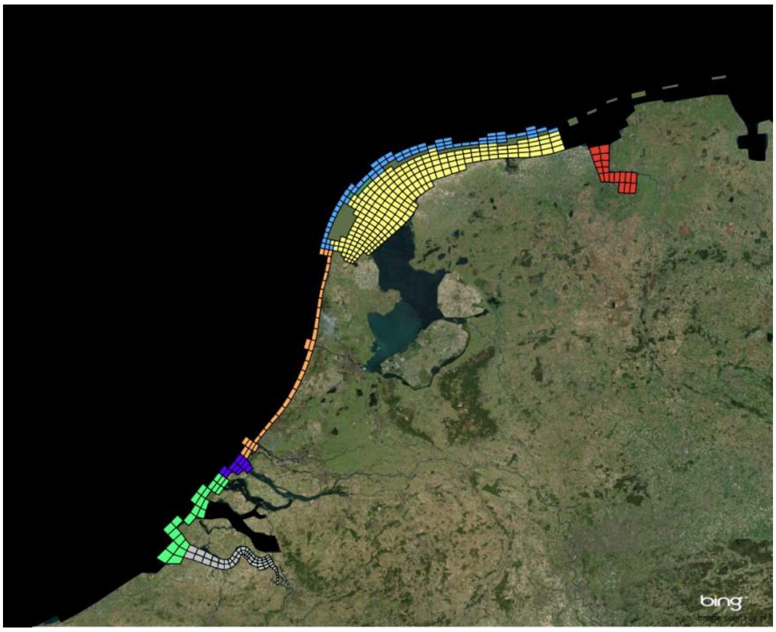


Figure 3.9 WFD areas in the model-schematisation of the Delft3D-GEM for the North Sea. The figure only shows the areas that are considered in this study. Green = Zeeuwse kust; Dark blue = Noordelijke deltakust; Orange= Hollandse kust; Light blue= Wadden kust; Yellow=Wadden Sea; Red = Ems estuary; Light purple=Western Scheldt.

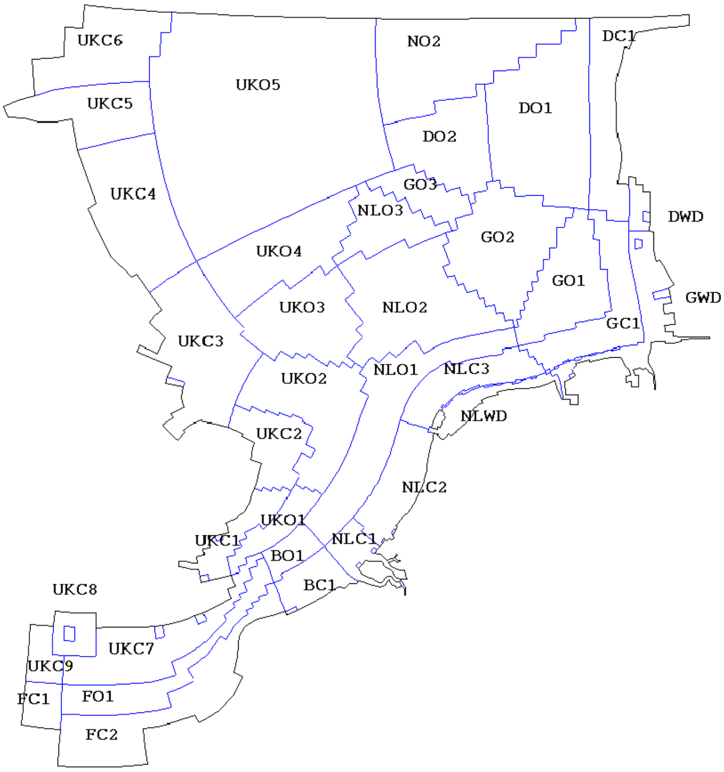


Figure 3.10 OSPAR areas in the model-schematisation of the Delft3D-GEM for the North Sea. Areas considered in this study are the Dutch coastal areas (NLC1, NLC2, NLC3), and the Dutch offshore areas (NLO1, NLO2, NLO3).

3.6.2 Modelled processes

Delft3D-GEM calculates the concentrations of nutrients (nitrate, ammonium, phosphate, silica), dissolved oxygen, salinity, phytoplankton (diatoms, flagellates, dinoflagellates and *Phaeocystis*), and detritus (algae and detritus may have a variable nutrient composition). These substances and the corresponding processes are the key to understanding the impacts of eutrophication in water systems. The model includes the following processes (Figure 3.11):

- uptake of nutrients by phytoplankton and microphytobenthos, resulting in algae growth;
- respiration and mortality of phytoplankton, resulting in the formation of organic matter (with different substances for carbon, total nitrogen, phosphorus and silica);
- decay of suspended organic matter with a decay rate that depends on stoichiometry;
- decay of organic matter in the sediment, releasing inorganic nutrients back to the water column;
- nitrification and denitrification;
- adsorption and desorption of phosphate to suspended solids;
- sedimentation, resuspension, and burial of algae, organic matter, and adsorbed phosphate;
- extinction of light, by suspended solids, organic matter, algae, and humic substances.

These processes are discussed in detail in Blauw *et al.* (20089), Los *et al.* (2008) and WL | Delft Hydraulics (2002, 2003, 2005). In its present set-up for the North Sea, the model does not include grazing and microphytobenthos. Rivers, boundary loads, and meteorology are included as forcing functions based on measurements. Silt concentrations are included as a cosine function based on results of a silt model and short-term wind-dependent variation.

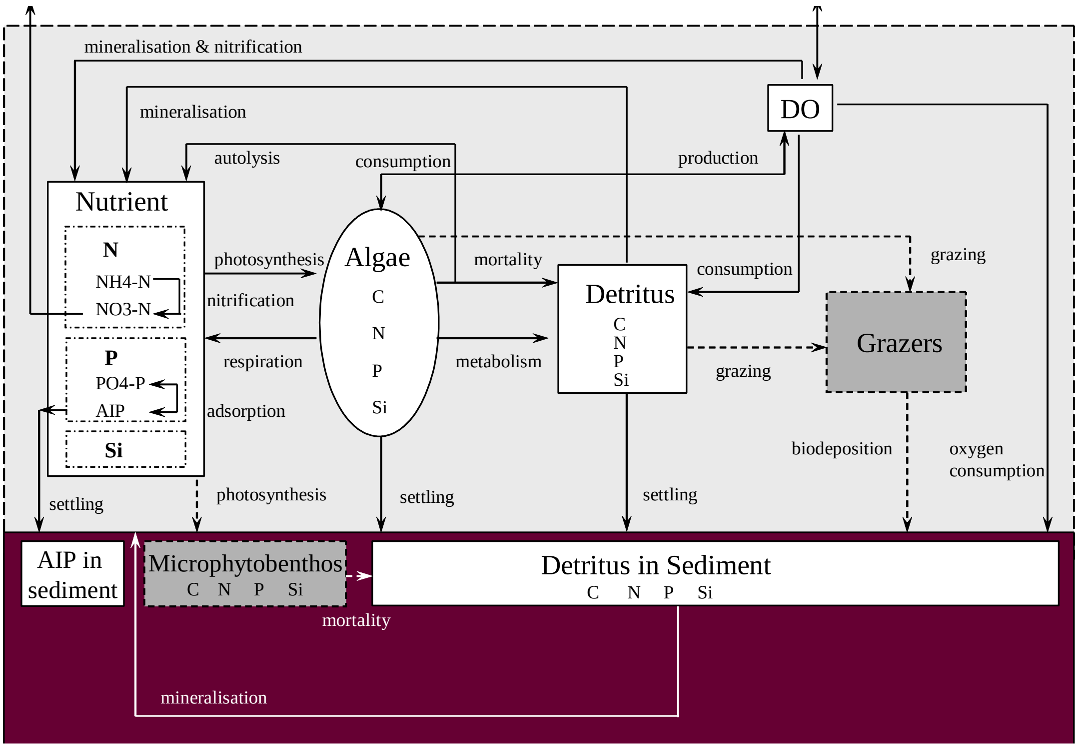


Figure 3.11 Schematic representation of the processes available in GEM. Grey boxes and dotted arrows are not included in the presently used set up for the North Sea.

3.6.3 Hydrodynamics

Hydrodynamic transport underlying GEM is calculated using Delft3D-FLOW. This is a multi-dimensional (2D or 3D) hydrodynamic model, which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or curvilinear boundary fitted grid. Process details and set-up of this program are described in WL | Delft Hydraulics (2006).

3.6.4 Grid

The model grid of Delft3D-GEM/BLOOM for the North Sea is curvi-linear and consists of 4350 horizontal segments (Figure 3.12). The grid has 12 vertical layers (4-11% relative thickness). The grid is variable, with a resolution ranging from 1x1 km at the continental coast to 20x20 km at the North-western boundary.

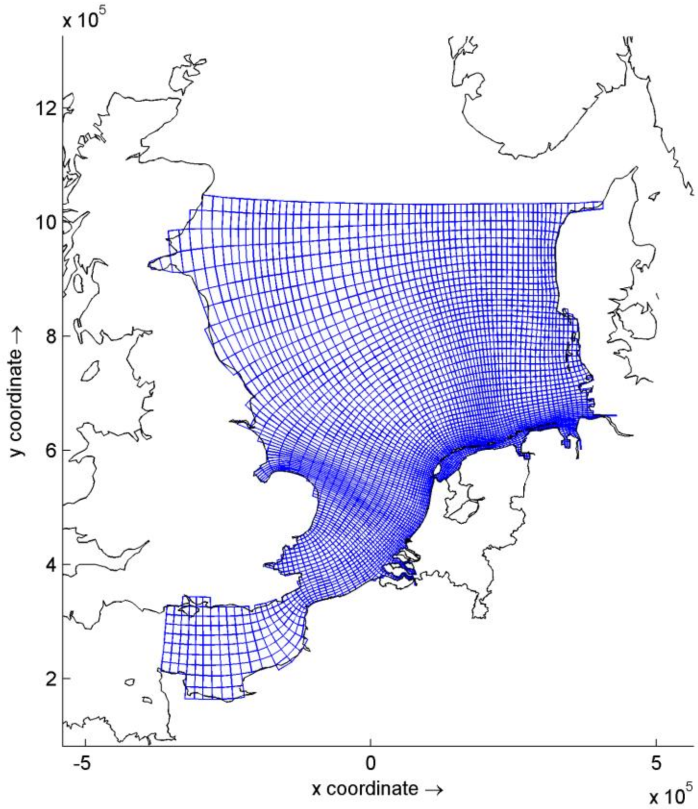


Figure 3.12 Curvi-linear grid of the Southern North Sea.

3.6.5 Nutrient inputs

Nutrients enter the system via 85 rivers, 2 open boundaries (Atlantic and Channel), and via atmospheric deposition.

River loads

In the model, each river discharges into one coastal grid cell in the surface layer. In the default model run, all river discharges and nutrient loads were based on data from national databases. These databases have been harmonized within the OSPAR-ICG EMO group and formatted and archived by Sonja van Leeuwen (CEFAS).

In the reference run and in the scenario runs the same loads were used, apart from the total nitrogen river loads along the Dutch coast which were based on model results from the WFD Explorer (also see section 3.6.6).

Boundary concentrations

The Atlantic boundary consists of all segments located at the Northern model interface, while the Channel boundary consists of all segments at the South-western model interface. Nutrient concentrations at the Channel boundary are based on measurements by Laane *et al.* (1993, 1996); Brion *et al.* (2004); Bot *et al.* (1996); Bentley *et al.* (1999) and Radach *et al.* (1996). Those at the Atlantic boundary were based on measurements by Pätch *et al.* (1997), Bot *et al.* (1996), Brockmann *et al.* (2002), and NERC (1991), Radach *et al.* (1996). For an overview see Meuwese (2007).

Atmospheric deposition

Atmospheric deposition takes place over the entire surface layer, and is included as a spatially and temporally explicit forcing function. Only the atmospheric deposition of total nitrogen compounds is taken into account. The forcing function consists of monthly depositions of total nitrogen (in mg/m^2) in oxidised and reduced forms which add to concentrations of nitrate and ammonium, respectively. These data are derived from atmospheric chemical transport model experiments as reported by Bartnicki and Valiyaveetil (2008); for further details, see Troost *et al.* (2011).

3.6.6 Default run versus reference run

The default run is based on the year 2008. This means that meteorology, hydrodynamics, and nutrient loadings were all based on data from the year 2008. The reference run is based on the year 2008 as well, apart from the total nitrogen loads that are discharged along the Dutch coast. Those total nitrogen loads were based on model results of the WFD Explorer for the base year 2012.

The main reason to choose 2008 as the default year instead of 2012 is to minimize costs: since the previous study on total nitrogen reduction scenarios (Loos et al, 2014) was also based on 2008, many building blocks were ready to use. Since the water quality model that is available at present does not yet include the year 2012, changing to the year 2012 would have required additional budget to update all meteorological data, the hydrodynamic model, river loads data, and validation data, as well as perform a validation on the model results. Also, an update to the year 2012 would have been especially challenging since measured river loads data for 2012 are not yet centrally available through the CEFAS database.

3.6.7 Initial values and spin up

De default model run for 2008 is part of a multi-annual series of model runs (2003 t/m 2008). The initial values of the 2008 model are the result of the model runs of the previous years, which provide a good spin-up. To compare the reference run to the default model run, the same initial values are being used for the reference run.

For the scenario runs also the same initial values are used. However, to make sure that the tested reductions in river loads are allowed sufficient time to be distributed throughout the system, these scenario runs are run twice in a row. This means that in the second, or *restarted*, scenario runs the initial values are replaced by the values at the end of the first run. To make a fair comparison between these restarted scenarios and the reference run, also a restarted run of the reference run is carried out.

3.6.8 Model validation of default run

Over the past few years, Delft3D-GEM for the North Sea has been thoroughly validated, both within the ICG-EMO framework (OSPAR 2008) and outside of it (specifically see Los *et al.*, 2008; Los and Blaas, 2010). Validation has been carried out by comparison of model results with in situ measurements of chlorophyll and nutrient concentrations as well as by graphical inspections of time series, 'goodness of fit' cost functions (Villars et al., 1998) and target diagrams (Jolliff et al., 2009). In general the model captures well the seasonal patterns, as well as the variability in the measurements (e.g. see Los and Wijsman (2007), Los et al. (2008), Los and Blaas (2010), Keetels *et al.*, 2012). Model performance is best along the Dutch coast, but also performs well in other areas where the modelled nutrient levels agree well with the *in situ* data. In addition, in a model inter-comparison it has been shown that the model behaviour is in line with that of other biogeochemical models, both with respect to its behaviour under standard conditions, as with respect to the response to changes (Lenhart et al., 2010).

To give an impression of the goodness of fit, time series are shown comparing modelled and measured nutrient values at four typical stations: **Noordwijk 10** (Figure 3.14, left panel), a station close to the Dutch coast that is largely dominated by river discharges; **Noordwijk 70,** the most offshore located station on the same transect, which is dominated by (boundary) inputs from the Channel (Figure 3.14, right panel); **Terschelling 10** (Figure 3.15, left panel), a coastal station on a more northern transect; and **Terschelling 235**, (Figure 3.15, right panel), an offshore station that is dominated by Atlantic (boundary) inputs. Black curves represent the default model, red curves the reference model. Shown are the modelled concentrations for salinity, chlorophyll, total nitrogen, total phosphorous, silicate, ortho-phosphate, ammonium, nitrate, and dissolved inorganic nitrogen, respectively. Dots represent the *in situ* concentrations measured at the same stations. Figure 3.13 shows the location of the different stations.

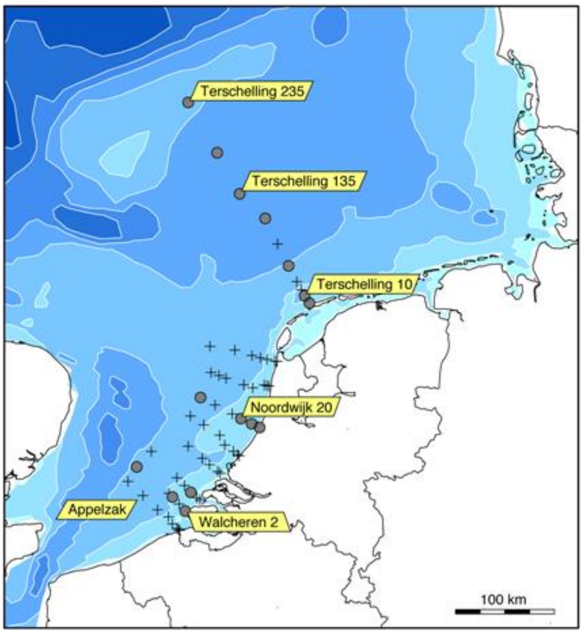


Figure 3.13 Map of the stations for which in situ measurements are available in the Dutch monitoring program (MWTL).

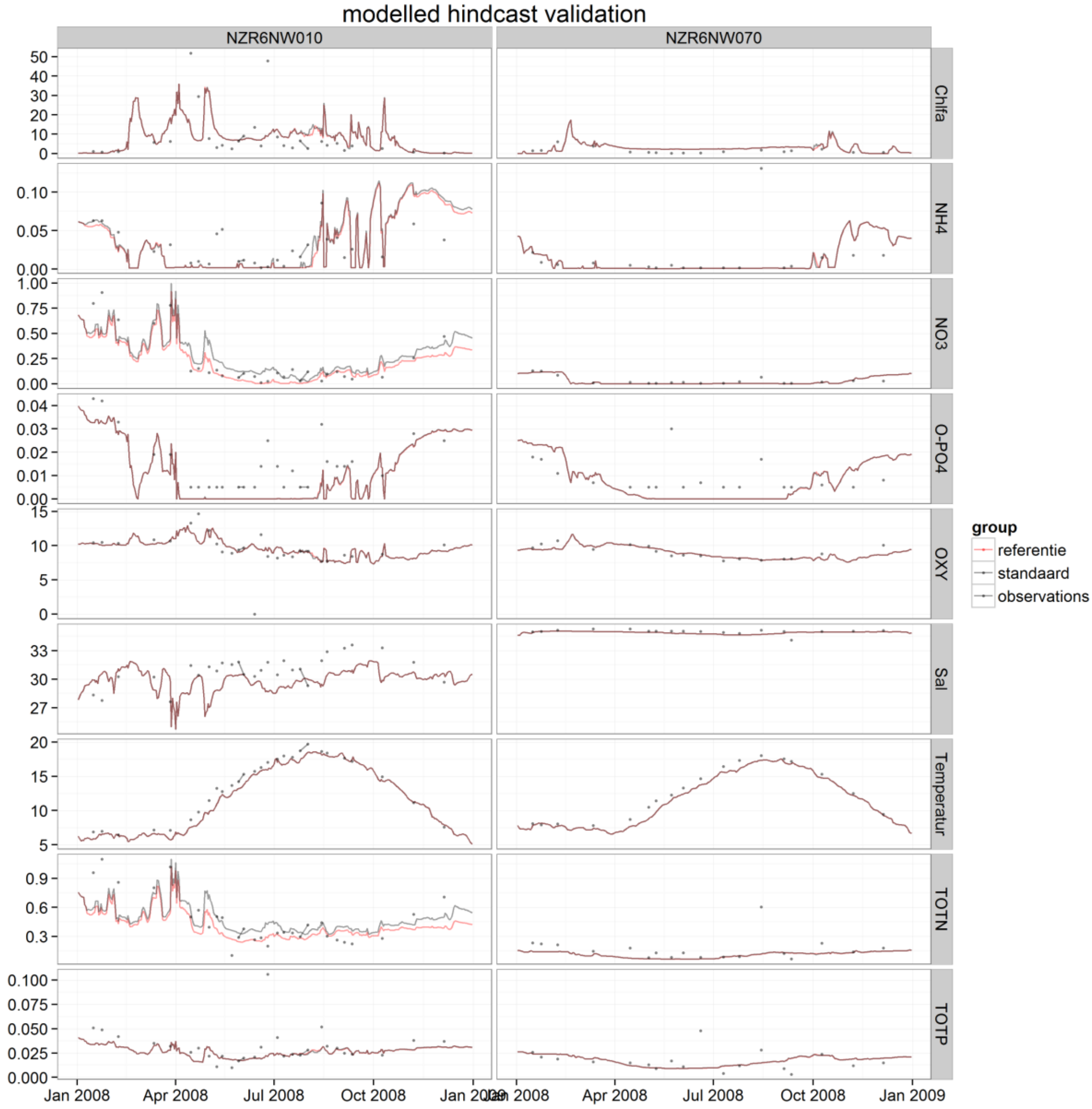


Figure 3.14 Comparison between measured data points (dots) and modelled time series (curves) based on the default run (black curves) and the reference run (red curves) in location Noordwijk 10 (left panel) and Noordwijk 70 (right panel)

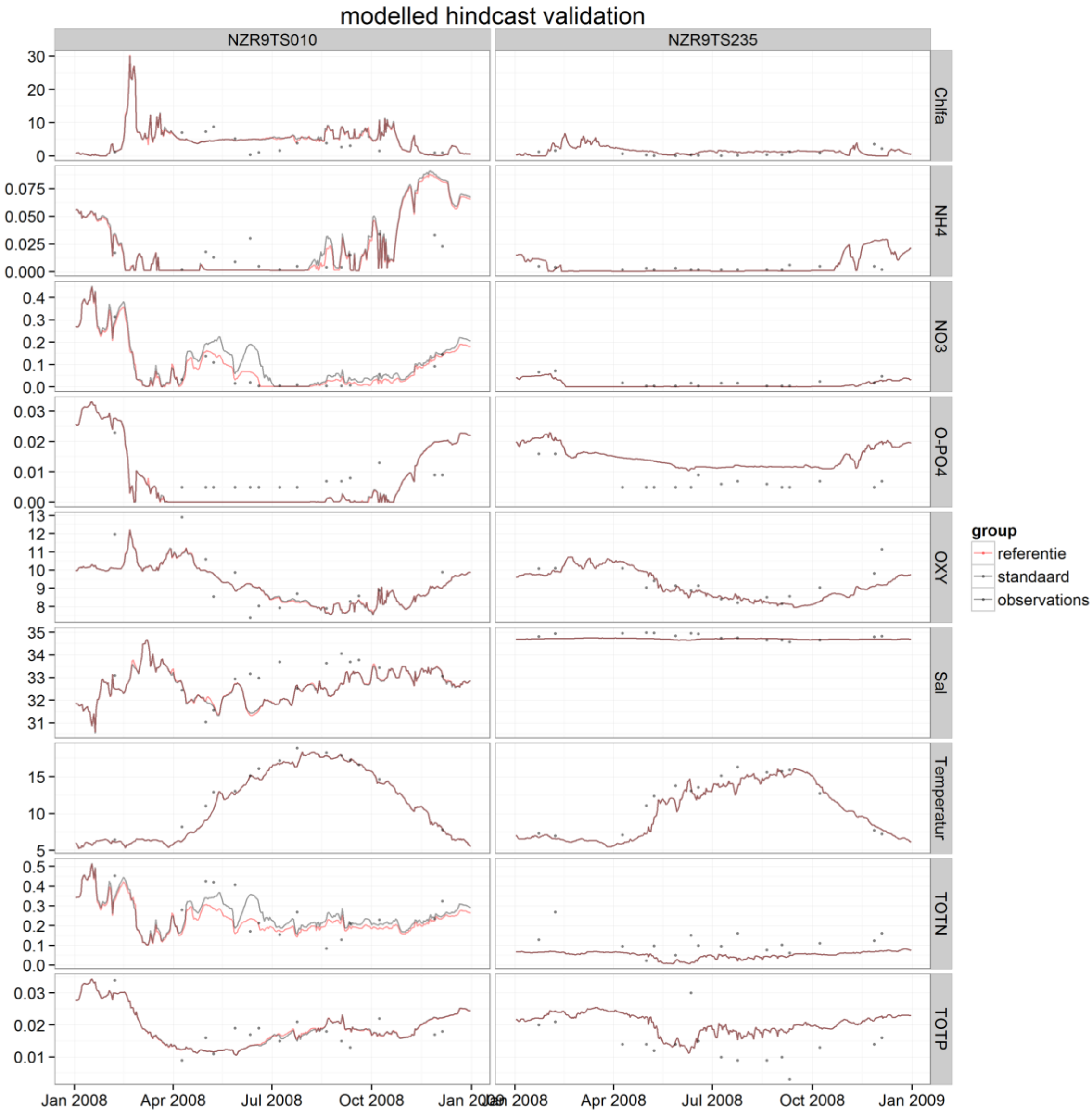


Figure 3.15 Comparison between measured data points (dots) and modelled time series (curves) based on the default run (black curves) and the reference run (red curves) in location Terschelling 10 (left panel) and Terschelling 235 (right panel)

4 Results

This section is divided into two parts, presenting first the freshwater quality calculations performed with the WFD Explorer (section 4.1) and second the coastal water quality calculations performed with the North Sea Model (section 4.2).

4.1 Water quality calculations in freshwater

4.1.1 Load reductions

Table 4.1 provides an overview of all the reduction of total nitrogen loads for the 2021 scenario and the 2027 scenario in comparison to the reference year 2012, as supplied by the IMC delegations. Except for the Jeker, a general reduction of loads is assumed. For the Jeker, an increase of the loads is quantified of 3% in 2021 and 5% in 2027 compared to 2012. For the other transboundary waters a load reduction is assumed of 1-4.9% in 2021 and 2-17.5% in 2027 compared to 2012.

Table 4.1 Modelled total nitrogen loads in the selected transboundary waters for the scenarios 2021 and 2027 given as a percentage of the calculated nitrogen loads in the reference year 2012.

Country	Water body name NL	Water body code NL	Water body name abroad	Water body code abroad	Loads 2021 (% of 2012)	Loads 2027 (% of 2012)
Flanders	Aa of Weerijs	NL25_34	Weerijsbeek	VL05_148	96.6	86.5
	Boven Mark	NL25_13	Mark	VL08_145	98.3	92.4
	Boven Dommel	NL27_BO_1_2	Dommel	VL05_136	98.0	93.5
	Tongelreep	NL27_T_1_2	Warmbeek	VL05_147	95.5	86.2
	Haelensche Beek	NL57_HAEL	Lossing	VL05_141	95.1	87.2
	Thorner Beek	NL57_ITT	ItterbeekII	VL05_138	96.6	91.0
	Thorner Beek	NL57_ITT	Abeek	VL11_133	95.9	87.6
	Thorner Beek	NL57_ITT	Bosbeek	VL05_135	95.2	82.5
Germany	Niers	NL57_NIER	Niers	DE_NRW_286_7972	99.0	98.0
	Roer	NL58WRO04	Rur	DE_NRW_282_21841	97.0	93.9
Wallonia	Boven Maas	NL91BOM	Meuse	MV35R	97.0	94.0
	Jeker	NL58_WRO39	Geer	MV18R	103.0	105.0
	Geul	NL58WRO30	Gueule	MV26R	98.0	97.0

Reduced nitrogen loads for the Meuse River are assumed to be 3% in 2021 and 6% in 2027, determining to a large degree the water quality in the Meuse catchment downstream the Dutch border. These reductions are used as input for the water quality calculations and they are in line with the assumed reductions used in the Ex Ante study (Van Gaalen et al., 2015): a load reduction of 7% in the Netherlands as a whole in 2027 compared to 2012 (see Table 3.8) and a 5% reduction of the loads in the Rhine River (at Lobith) and Meuse River (at Eijsden) as well as the smaller transboundary rivers in the Rhine and Meuse catchment in 2027 compared to 2012.

4.1.2 Water bodies in the Meuse River

Table 4.2 presents the results of the total nitrogen concentrations calculated in this project in comparison to the concentrations calculated in the Ex Ante evaluation (Van Gaalen et al., 2015) which was carried out in the first part of 2015. The table also includes the measured average summer (April – September) concentrations in the water bodies during the year 2012 taken from the Dutch internetsite Water Quality Portal (http://www.waterkwaliteitsportaal.nl/). Figure 3.4 gives an overview of the water body locations presented in Table 4.2.

Table 4.2 Comparison of the summer average total nitrogen concentrations (mg/l) measured in 2012 and calculated for 2012, 2021 and 2027 with the national WFD model for the Ex-ante study (EA) and for this study (IMC) for the main stream of the Meuse River (upper part of the table) and a number of smaller transboundary waters (lower part of the table).

Code NL	Water body NL	2012 measured	2012 EA	2012 IMC	2021 EA	2021 IMC	2027 EA	2027 IMC
NL91GM	Grensmaas	4.1	3.5	3.5	3.3	3.3	3.2	3.2
NL91JK	Julianakanaal	3.4	3.0	3.0	2.9	2.9	2.9	2.8
NL91ZM	Zandmaas	3.7	3.1	3.1	2.9	2.9	2.9	2.8
NL91BM	Bedijkte Maas	3.5	3.0	2.9	2.8	2.8	2.8	2.7
NL94_5	Beneden Maas	3.4	2.1	2.1	2.0	2.0	2.0	1.9
NL94_6	Bergsche Maas	3.7	2.4	2.4	2.2	2.2	2.2	2.1
NL94_10	Brabantse Biesbosch, Amer	3.7	2.2	2.2	1.9	1.9	1.8	1.8
NL94_1	Haringvliet Oost, Hollandsch Diep	2.3	2.2	2.2	2.1	2.1	2.1	2.1
NL94_11	Haringvliet West		2.0	2.0	1.9	1.9	1.9	1.9
NL91BOM	Bovenmaas	3.4	3.5	3.5	3.4	3.4	3.3	3.3
NL58WRO04	Roer	3.0	3.3	3.4	3.2	3.3	3.2	3.2
NL57_NIER	Niers	6.8	7.4	6.0	7.2	5.9	7.0	5.8
NL58WRO30	Geul	6.6	5.0	4.2	1.3	2.9	1.3	2.9
NL58WRO39	Jeker	9.8	2.4	3.4	2.3	3.6	2.4	3.8
NL27_T_1_2	Tongelreep	2.5	3.3	3.7	3.2	3.5	3.1	3.3
NL27_BO_1_2	Boven Dommel	4.7	4.4	2.8	4.3	2.8	4.0	2.5
NL25_13	Boven Mark	5.9	4.8	5.5	4.6	5.3	4.5	5.0
NL25_34	Aa of Weerijs	4.1	3.5	3.2	3.3	3.1	3.3	2.8

The ten water bodies representing the main stream of the Meuse River in the Netherlands are shown in the upper part of Table 4.2.

For these water bodies the concentrations calculated in this project show no difference or slightly lower (0.1 mg/l) concentrations compared to the Ex Ante study. This was expected because the assumed transboundary load reduction of the Meuse River in the Ex Ante study is only slightly higher (2.5% in 2021 and 5% in 2027) compared to this study (3% in 2021 and 6% in 2027). No difference between both studies is observed in the water body that connects to the coastal waters (NL94_11).

For all the water bodies of the Meuse River, the total nitrogen concentrations calculated in this project are lower in 2021 and 2027 compared to the 2012 situation. In 2027, total nitrogen is reduced by 0.1-0.3 mg/l. This conclusion is in line with what can be expected as a result of the load reductions (see 4.1.1).

In the route of the Meuse River from the Dutch-Wallonian border at Eijsden to the coastal waters, there is a general decline of the total nitrogen concentration, both in the measured data and the calculated data (EA and IMC). This lower concentration in the coastal waters is largely the result of the mixture of Meuse water with water from the Rhine River, which has a lower total nitrogen concentration. The calculated concentration in the water body that connects to the coastal waters (NL94_11) meets the Dutch target value according to the Water Framework Directive for this water body (2.3 mg/l).

Comparing the measured concentrations in the Meuse River water bodies with the calculated concentrations in this study, there are no differences observed at the Dutch-Wallonian border at Eijsden and in the water body nearest to the coastal waters. In between these water bodies, the calculated concentrations are significantly lower than the measured concentrations. It is expected that this is a result of missing loads in our calculations (possibly originating from agriculture) and a retention coefficient used in the WFD Explorer which might be too high in these smaller waters. This is an item which has to be elaborated further by Deltares within the upcoming WFD Explorer project activities.

4.1.3 Smaller transboundary waters

In the lower part of Table 4.2, the smaller transboundary waters are shown. For these waters the comparison of the results of the Ex Ante study and this study show large differences per water body. In a number of water bodies, the calculated concentrations in this project are lower compared to the Ex Ante study (Niers, Boven Dommel, Aa of Weerijs), in some higher (Geul, Jeker, Tongelreep, Boven Mark) and one shows (almost) no difference (Roer). The main reason for this are the differences between the input of the Ex Ante study and this study for the situation in the base year. It is expected that the calculated concentrations for the smaller transboundary waters in this study are a better representation of the real situation than the calculations of the Ex Ante study because in this study, the transboundary flow and concentration data have been submitted by the delegations of the upstream countries. Therefore, this study may contribute to an improvement of the Ex Ante study.

For all the smaller transboundary water bodies, there is a reduction of the concentrations calculated in this project, both in 2021 and 2027 compared to the 2012 situation. The range of this reduction is 0.2-1.3 mg/l in 2027. This conclusion is in line with what can be expected as a result of the load reductions (see 4.1.1). For the Jeker, an increase of the calculated concentration of 0.4 mg/l in 2027 compared to 2012 is shown.

4.1.4 Relative reduction method

Due to several reasons, differences are observed between the 2012 measured and 2012 calculated concentrations (IMC).

An important reason for these differences is the range of different hydrological years and years used for measured concentrations (see Table 3.1). Another explanation for differences between measured and modelled concentrations is that not in all Dutch water bodies total nitrogen measurements have been taken: in those cases concentrations are "borrowed" from a connecting water body. To minimize possible bias of the WFD Explorer calculations, a "relative method" was used, in which the calculated concentration reductions in the scenario years compared to the base year, were combined with the measured concentrations in the base year:

$$2021\ \text{Relative} = \frac{2021\ \text{IMC}\ (calculated)}{2012\ \text{IMC}\ (calculated)} \times 2012\ \text{(measured)}$$

$$2027\ \text{Relative} = \frac{2027\ \text{IMC}\ (calculated)}{2012\ \text{IMC}\ (calculated)} \times 2012\ \text{(measured)}$$

The results of the relative method calculation are shown in Table 4.3.

Table 4.3 Comparison of the summer average total nitrogen concentrations (mg/l) measured in 2012 and calculated for 2012, 2021 and 2027 with the WFD model for this study (IMC) for the main stream of the Meuse River (upper part of the table) and a number of smaller transboundary waters (lower part of the table) and relative concentrations for 2021 and 2027.

Code NL	Water body NL	2012 measured	2012 IMC	2021 IMC	2027 IMC	2021 relative	2027 relative
NL91GM	Grensmaas	4.1	3.5	3.3	3.2	3.9	3.8
NL91JK	Julianakanaal	3.4	3.0	2.9	2.8	3.2	3.1
NL91ZM	Zandmaas	3.7	3.1	2.9	2.8	3.5	3.4
NL91BM	Bedijkte Maas	3.5	2.9	2.8	2.7	3.3	3.3
NL94_5	Beneden Maas	3.4	2.1	2.0	1.9	3.2	3.1
NL94_6	Bergsche Maas	3.7	2.4	2.2	2.1	3.4	3.3
NL94_10	Brabantse Biesbosch, Amer	3.7	2.2	1.9	1.8	3.2	3.1
NL94_1	Haringvliet Oost, Hollandsch Diep	2.3	2.2	2.1	2.1	2.2	2.1
NL94_11	Haringvliet West		2.0	1.9	1.9		
NL91BOM	Bovenmaas	3.4	3.5	3.4	3.3	3.2	3.1
NL58WRO04	Roer	3.0	3.4	3.3	3.2	2.9	2.8
NL57_NIER	Niers	6.8	6.0	5.9	5.8	6.6	6.6
NL58WRO30	Geul	6.6	4.2	2.9	2.9	4.5	4.5
NL58WRO39	Jeker	9.8	3.4	3.6	3.8	10.6	11.1
NL27_T_1_2	Tongelreep	2.5	3.7	3.5	3.3	2.3	2.2
NL27_BO_1_2	Boven Dommel	4.7	2.8	2.8	2.5	4.6	4.1
NL25_13	Boven Mark	5.9	5.5	5.3	5.0	5.6	5.3
NL25_34	Aa of Weerijs	4.1	3.2	3.1	2.8	3.9	3.6

The calculations with the relative method show that compared to 2012 for individual water bodies, total nitrogen concentrations will be reduced by 0.1 to 0.5 mg/l in 2021 and by 0.2 to 0.6 mg/l in 2027 which results in a total nitrogen reduction of 3 to 14% (average 6%) in 2021 and 6 to 17% (average 8%) in 2027.

As a result, we expect in 2027 in the Dutch freshwaters and in the main stream of the Meuse catchment a total nitrogen concentration of 3.1 – 3.8 mg/l. For the water body where the Rhine River meets the Meuse River (NL94_1), a total nitrogen concentration of 2.1 mg/l is expected in 2027.

4.2 Water quality calculations in coastal waters

Table 4.4 provides an overview of all modelled winter-DIN concentrations per area (for the location of these areas see Figure 3.9 and Figure 3.10). Results are presented for the default run (which was based on measured loads for 2008), the reference run (which was based on modelled total nitrogen loads for 2012), and for the scenario runs for 2021 and 2027. For each of these runs, both the initial runs and the restarted runs are shown (for an explanation on why and how the runs were restarted, see section 3.6.7).
Please note that the table only shows modelled values and no measured values. This is because only few measurement locations are available per area, which are not representative for the whole area.

4.2.1 Reference run

Figure 4.1 compares the default run and reference run with respect to the DIN concentrations in the WFD-areas and OSPAR-areas. In general, the winter-DIN concentrations from the reference run are somewhat smaller than those from the default run. Differences are most pronounced along the coast. They are a direct effect of the differences in total nitrogen loads that were used as model input for the total nitrogen discharges along the Dutch coast (see section 3.6.6). The largest difference in DIN concentrations occurs in the Wadden Sea, which is in line with the large difference that exists between the default and reference run with respect to the loads from Lake IJssel. In contrast, differences in the Westerschelde and Ems estuary are negligible, which is due to the fact that total nitrogen reductions in the Ems and Scheldt river were not taken into account in this study. Note that the differences in DIN-concentrations between default and reference run do not lead to significant changes in other (non-nitrogen based) variables (see Figure 3.14 and Figure 3.15).

4.2.2 Scenarios

Table 4.4 shows the average winter-DIN concentrations per area and per scenario. Differences are small, but in general the DIN-concentrations are highest in the reference run and a slightly decrease in the different scenarios. The decrease is best visible along the coast, and is negligible in the offshore areas. Also, the table shows that restarting the runs leads to a further decrease in winter-DIN concentrations such that the differences between the runs become more pronounced.
These differences are further visualised in Figure 4.2, which shows time series of the modelled DIN concentrations in the restarted reference run and the two restarted scenario runs in each of the considered areas.

Table 4.4 Modelled winter DIN concentrations (mg/l) in de considered WFD and OSPAR-areas. In the 'default' simulation all river loads are based on measurements, in the 'reference' simulation total nitrogen river loads entering the North Sea in the Netherlands are based on modelled data.

	Default (2008)	Default (2008-rerun)	Reference (2012)	Reference (2012-rerun)	Scenario1 (2021)	Scenario1 (2021-rerun)	Scenario2 (2027)	Scenario2 (2027-rerun)
ZeeuwKst01	0.547	0.539	0.545	0.533	0.541	0.527	0.539	0.523
NDeltKst01	1.061	1.058	1.137	1.136	1.1	1.096	1.077	1.07
HollKust01	0.721	0.701	0.632	0.588	0.611	0.565	0.603	0.555
WaddKust01	0.355	0.305	0.334	0.255	0.327	0.244	0.324	0.24
EemsDollrd	2.526	1.711	2.658	1.914	2.65	1.9	2.649	1.898
Westersch	2.163	2.23	2.162	2.228	2.161	2.225	2.161	2.224
Waddenzee	0.617	0.524	0.484	0.335	0.472	0.318	0.468	0.312
NLO1	0.127	0.13	0.126	0.13	0.126	0.13	0.126	0.13
NLO2	0.088	0.102	0.088	0.102	0.088	0.102	0.088	0.102
NLO3	0.052	0.059	0.052	0.059	0.052	0.059	0.052	0.059
NLC1	0.328	0.327	0.327	0.324	0.325	0.322	0.325	0.321
NLC2	0.254	0.255	0.234	0.227	0.23	0.222	0.228	0.219
NLC3	0.223	0.214	0.214	0.195	0.211	0.191	0.211	0.189

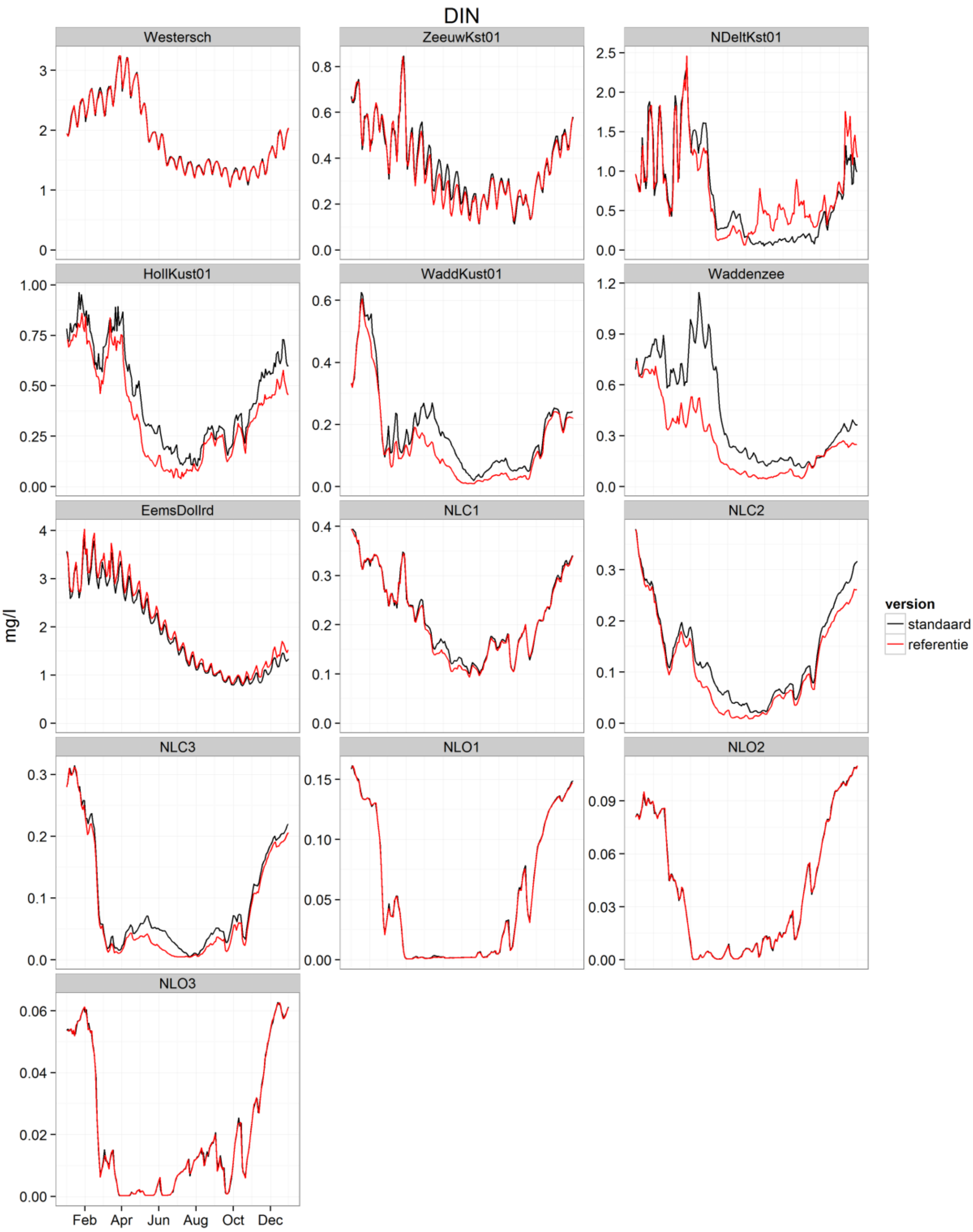


Figure 4.1 Modelled total nitrogen concentrations (DIN) in the OSPAR- and WFD-areas considered in this study, on basis of measured total nitrogen loads (in the default run, black curves) and on basis of modelled total nitrogen loads resulting from the WFD Explorer (reference run, red curves).

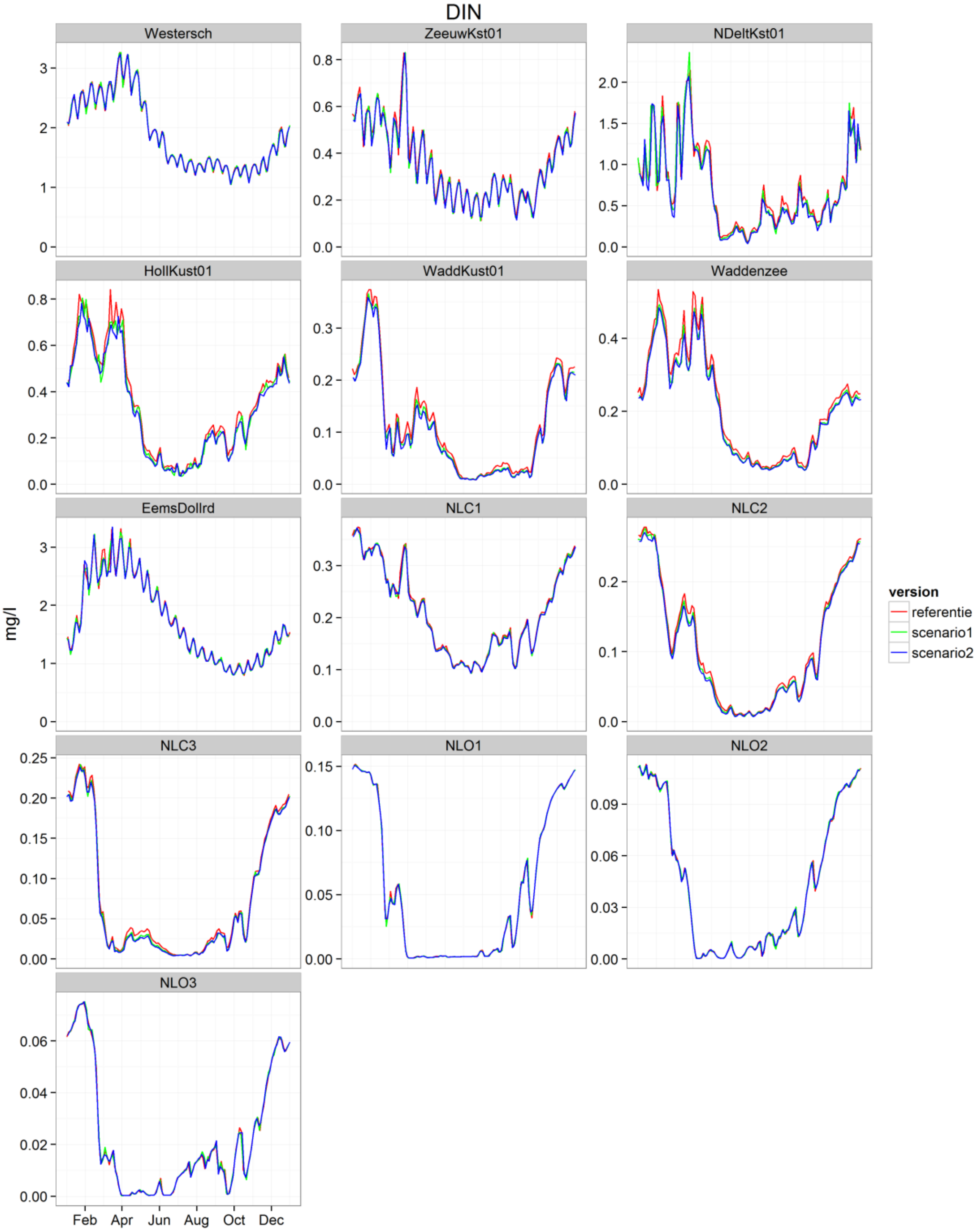


Figure 4.2 Modelled total nitrogen concentrations (DIN) in the WFD-areas and in the OSPAR-areas, based on the restarted reference run (red) and on the restarted scenario runs (2021: green and 2027: blue).

5 Discussion and conclusions

The current study provides more insight in the effects of measures taken in the second River Basin Management cycle regarding the total nitrogen concentrations in the downstream part of the Meuse catchment. The following conclusions can be drawn from this study:

- This study is a result of the positive and active cooperation of all IMC partners and was executed within a short amount of time.
- This catchment wide water quality modeling effort involving all IMC partners has not been performed before in IMC on such a scale.
- For nearly all transboundary water bodies in the Netherlands and the IMC member states, a reduction in nitrogen load is expected compared to the year 2012 ranging from 1% to 5% in the year 2021 and 2% to 18% in 2027. At Eijsden in the Netherlands, located in the main stream of the Meuse river, we expect reduced nitrogen loads by 3% in 2021 and by 6% in 2027.
- Water quality calculations in freshwater and coastal waters located in the Dutch part of the Meuse catchment resulted in reduced total nitrogen concentrations for both scenarios 2021 and 2027. Compared to 2012, calculations show that for individual water bodies total nitrogen concentrations will be reduced by 0.1 to 0.5 mg/l in 2021 and by 0.2 to 0.6 mg/l in 2027 comparable to a total nitrogen reduction of 3 to 14% (average 6%) in 2021 and 6 to 17% (average 8%) in 2027. As a result, we expect in 2027 in the Dutch freshwaters and in the main stream of the Meuse River a total nitrogen concentration of 3.1 – 3.8 mg/l. For the water body where the Rhine River meets the Meuse River (NL94_1), a total nitrogen concentration of 2.1 mg/l is expected in 2027 (Table 5.1*).*
- Compared to 2012, calculations in coastal waters of the Meuse catchment (Noordelijke Deltakust) show lower winter DIN concentrations in 2021 and 2027 which will be reduced by respectively 0.04 mg/l (4%) and 0.07 mg/l (6%). Assuming constant nitrogen contributions from both North Sea Border States and catchments Scheldt and Ems in the scenario years, a winter DIN concentration of 1.07 mg/l is calculated for the year 2027. In these calculations the effects of the measures planned in the second River Basin Management Plan for the river district Rhine are included.

Table 5.1 Total nitrogen summer average concentrations (mg/l) measured for the reference year 2012 and relative calculated concentrations for scenarios 2021 and 2027 as a result of the IMC study for the main stream of the Meuse River, the smaller transboundary waters and the coastal waters of the Meuse catchment. The last two columns present the reduction percentage of total nitrogen load for scenarios 2021 and 2027 compared to the reference year 2012.

Tributary	***Water body code NL***	***Water body name NL***	***2012 mea-sured (mg/l)***	***2021 rela-tive (mg/l)***	***2027 rela-tive (mg/l)***	***Load reduction in 2021 compared to 2012 (%)***	***Load reduction in 2027 compared to 2012 (%)***
Main stream of the Meuse river	NL91BOM	Bovenmaas	3.4	3.2	3.1	3	6
	NL91GM	Grensmaas	4.1	3.9	3.8	4	7
	NL91JK	Julianakanaal	3.4	3.2	3.1	3	6
	NL91ZM	Zandmaas	3.7	3.5	3.4	5	8
	NL91BM	Bedijkte Maas	3.5	3.3	3.3	6	8
	NL94_5	Beneden Maas	3.4	3.2	3.1	6	8
	NL94_6	Bergsche Maas	3.7	3.4	3.3	7	10
	NL94_10	Brabantse Biesbosch, Amer	3.7	3.2	3.1	14	16
	NL94_1	Haringvliet oost, Hollandsch Diep	2.3	2.2	2.1	4	6
		Average	**3.4**			**6**	**8**
Smaller trans-boundary waters	NL58WRO04	Roer	3.0	2.9	2.8	3	6
	NL57_NIER	Niers	6.8	6.6	6.6	2	3
	NL58WRO30	Geul	6.6	4.5	4.5	31	31
	NL58WRO39	Jeker	9.8	10.6	11.1	-9	-14
	NL27_T_1_2	Tongelreep	2.5	2.3	2.2	6	13
	NL27_BO_1_2	Boven Dommel	4.7	4.6	4.1	3	14
	NL25_13	Boven Mark	5.9	5.6	5.3	4	9
	NL25_34	Aa of Weerijs	4.1	3.9	3.6	4	13
		Average	**5.4**			**6**	**9**
Coast*		Noordelijke Deltakust	1.136	1.096	1.07	4	6

* Winter DIN concentrations (mg/l)

6 References

Baretta-Bekker, H., 2014. OSPAR COMMP Assessment “light” of the marine waters, pp. 1–17.

Bartnicki, J., Valiyaveetil, S., 2008. Atmospheric Deposition of nitrogen to OSPAR Convention waters in the period 1995-2006. Summary Report for OSPAR Convention. Norwegian Meteorological Institute, Oslo, Norway.

Blauw, A.N., Los, F.J., Bokhorst M., Erftemeijer, P.L. A., 2009. GEM: a generic ecological model for estuaries and coastal waters. Hydrobiologia 618: 175 – 198. DOI 10.1007/s10750-008-9575-x.

Bot, P.V.M., Van Raaphorst, W., Batten, S., Laane, R., Philippart, K. Radach, G., Frohse, A., Schultz, H., Van den Eynde, D., and Clijn, F. 1996. Comparison of changes in the annual variability of the seasonal cycles of chlorophyll, nutrients and zooplankton at eight locations on the north-west European shelf (1960-1994). Deutsche Hydrografische Zeitschrift 48: 349-363.

Brion, N., Bayens, W., De Galan, S., Elskens, M., Laane, R.W.P.M., 2004. The North Sea: source or sink for nitrogen and phosphorous to the Atlantic Ocean? Biogeochemistry, Springer. 68: 277-296.

Chrzanowski, C., Van den Roovaart, J., Van ‘t Hoff, L., Lebecque, T., 2015. IMC - Evaluation of nutrients in Meuse catchment - Discussion document for chemistry group. Memo 1220521-000-ZWS-0004. 21st August 2015.

De Klein, J.J.M., 2008. From ditch to delta: nutrient retention in running waters. WUR Wageningen UR, dissertation, 194 pp.

Deltares, 2013a. Processes Library Description - Detailed description of Processes. Technical Reference Manual D-Water Quality Version: 5.01.29227 6 September 2013.

Deltares, 2013b. Delft3D-FLOW. Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments - User Manual. Hydro-Morphodynamics Version: 3.15.30059 6 September 2013.

Groenendijk, P., Renaud, L.V., Roelsma, J., 2005. Prediction of Nitrogen and Phosphorus leaching to groundwater and surface waters; Process descriptions of the Animo4.0 model. Wageningen, Alterra–Report 983, 114 pp.

Jolliff, J.K., Kindle, J.C., Shulman, I., Penta, B., Friedrichs, M.A.M., Helber, R., Arnone, R.A., 2009. Summary diagrams for coupled hydrodynamic-ecosystem model skill assessment. Journal of Marine Systems 76: 64 - 82. DOI:10.1016/j.jmarsys.2008.05.014

Laane, R.W.P.M., Groeneveld, G., De Vries, A., Van Bennekom, J., Sydown, S., 1993. Nutrients (P,N,Si) in the Channel and the Dover Strait: Seasonal and year-to-year variation and fluxes to the North Sea. Oceanologica acta 16: 607 – 616, Paris.

Laane, R.W.P.M., Southward, A.J., Slinn, D.J., Allen, J., Groeneveld, G., De Vries, A., 1996a. Changes and causes of variability in salinity and dissolved inorganic phosphate in the Irish Sea, English Channel, and Dutch coastal zone. ICES Journal of Marine Science 53: 933-944.

Laane, R.W.P.M., Svendsen, E., Radach, G., Groeneveld, G., Damm, P., Pätch, J., Danielssen, D., Foeyn, L., Skogen, M., Ostrowski, M., 1996b. Variability in fluxes of nutrients (N,P,Si) into the North Sea from the Atlantic Ocean and Skagerak caused by variability in water flow. Deutsche hydrographische Zeitschrift 48: 401-419, Hamburg.

Lenhart, H., Desmit, X., Grosse F., Mills, D., Lacroix, G., Los, H., Ménesguen, A., Pätsch, J., Troost, T., Van der Molen, J. Van Leeuwen, S., Wakelin, S., 2012. Report on "distance to target" modelling assessment by ICG-EMO, Edited by H. Baretta-Bekker. OSPAR ICG_EMO report.

Loos, S., Troos, T.A., Goorden, N., Thiange, C., Weeber, M., Los, F.J., 2014. Stikstof scenario studie met KRW-Verkenner en koppeling met het Noordzee model. Deltares report 1208815-000.

Los, F.J., Wijsman, J.W.M., 2007. Application of a validated primary production model (BLOOM) as a screening tool for marine, coastal and transitional waters. Journal of Marine Systems 64: 201–215.

Los, F.J., Villars, M.T, Van der Tol, M.W.M., 2008. A 3-dimensional primary production model (BLOOM/GEM) and its applications to the (southern) North Sea (coupled physical–chemical–ecological model). Journal of Marine Systems 74: 259–294.

Los, F.J., Blaas, M., 2010. Complexity, accuracy and practical applicability of different biogeochemical model versions. Journal of Marine Systems 81: 44–74.

Meuwese, H., 2007. Nutrient loads on the North Sea. TUDelft and WL|Delft Hydraulics. MSc Thesis. National Environment Research Council (NERC). 1991. Marine dataset.

Pätch, J., Radach, G., 1997. Long-term simulation of the eutrophication of the North Sea: temporal developments of nutrients, chlorophyll and primary production in comparison to observations. Journal of Sea Research 38: 275-310.

PBL, 2008. Kwaliteit voor Later. Ex ante evaluatie Kaderrichtlijn Water, PBL-publicatienummer 50014001/2008. Planbureau voor de Leefomgeving, Bilthoven. Netherlands. Den Haag/Bilthoven: PBL.

Radach, G., Gekeler, J., Kleinow, O., 1996. NOWESP. http:/www.ifm.uni- hamburg.de/ ~wwwem/res/nowesp.html Hamburg, Institut fuer Meereskunde der Universitaet Hamburg.

Schoumans, O., Groenendijk, P., Smit, R., Kroes, J., De Koeijer, T., Van den Roovaart, J., 2012. Water quality modelling, Dutch approach. Alterra Wageningen UR, LEI Wageningen UR, Deltares.

Troost, T.A., Blaas, M., Los, F.J., 2013. The role of atmospheric deposition in the eutrophication of the North Sea; A model analysis. Journal of Marine Systems 125: 101–112.

Van Dam, J.C., P. Groenendijk, R.F.A. Hendriks, Kroes, J.G., 2008. Advances of modeling water flow in variably saturated soils with SWAP. Vadose Zone Journal 7 (2): 640 – 653.

Kroes, J.G., Van Dam, J.C., Groenendijk, P., Hendriks, R.F.A., Jacobs, C.M.J., 2008. SWAP version 3.2. Theory description and user manual. Alterra-report 1649, 262 pp, Alterra, Research Institute, Wageningen, The Netherlands.

Van Gaalen, F., Tiktak, A., Franken, R., 2015. Waterkwaliteit nu en in de toekomst. Tussentijdse rapportage ex ante evaluatie van de Nederlandse plannen voor de Kaderrichtlijn Water. PBL report 1765.

Van Stappen, F., Delcour, A., Gheysens, S., Decruyenaere, V., Stilmant, D., Burny, P., Rabier, F., Louppe, H., Goffart, JP., 2014. Établissement de scénarios alternatifs de valorisations alimentaires et non alimentaires des ressources céréalières wallonnes à l'horizon 2030. Base [En ligne] 18 (2): 193-208.

Villars, M., De Vries, I., Bokhorst, M., Ferreira, J., Gellers-Barkman, S., Kelly-Gerreyn, B., Lancelot, C., Menesguen, A., Moll, A., Patsch, J., Radach, G., Skogen, M., Soiland, H., Svendsen, E., Vested, H.J., 1998. Report of the ASMO modelling workshop on eutrophication issues, 5–8 November 1996. In: Villars, M., de Vries, I. (Eds.), OSPAR Commission Report. Netherlands Institute for Coastal and Marine Management, RIKZ, The Hague, The Netherlands (The Hague, The Netherlands).

Websites:

Website National Biological Monitoring data: www.limnodata.nl

Website National Emission Registration: www.emissieregistratie.nl

Website SOBEK hydraulic modelling suite:
http://www.deltaressystems.com/hydro/product/108282/sobek-suite

Website WFD Explorer: www.krwverkenner.nl

Database Waterbase (Dutch national water bodies):
http://live.waterbase.nl/waterbase_wns.cfm?taal=nl

Database Water Quality Portal (Dutch regional water bodies):
http://www.waterkwaliteitsportaal.nl/