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Final report

Information System on the Eutrophication of our CoAstal Seas (ISECA)

D3.2 - Eutrophication problems, causes and potential solutions, and exchange of reusable model building components for the integrated simulation of coastal eutrophication.

Final Report, August 2014

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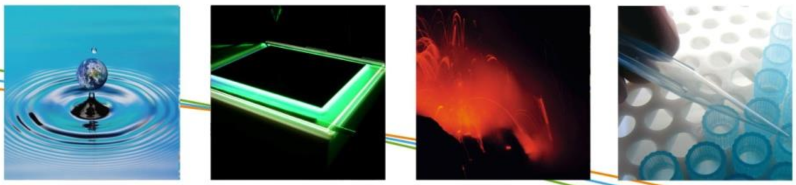

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SUMMARY

The cross-border cooperation project ISECA (Information System on the Eutrophication of our CoAstal Seas), which is supported by the INTERREGIVa 2Seas Program (www.interreg4a-2mers.eu), is a collaboration between Flemish, Dutch, French and British knowledge partners. The objective of the ISECA project is to improve the exchange of data and scientific insights related to the eutrophication of coastal waters in the English Channel and the Southern North Sea (Figure 1), aiming both at knowledge partners and the relevant authorities and general public. The project is coordinated by ADRINORD in France. The ISECA project is to demonstrate the added value of combining three complementary sources of information on eutrophication: earth observation, in-situ measurements and modelling. Action 3 – Modelling - is aimed at designing a web-based platform to demonstrate the integration of model simulations with in-situ observations and earth observation data. This report discusses the currently available models in the context of the EU regulations (WFD, OSPAR, MSFD) and gives an outline of the architecture and functionalities of the prototype web service to be developed (the Web-based Application System or WAS).

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LIST OF ACRONYMS

ASSETS	ASSessment of Estuarine Trophic Status
BCS/Z	Belgian Continental Shelf/Zone
CF	Climate and Forestry
COMPP	(OSPAR) COMPrehensive Procedure
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
ECOOP	European Coastal sea Operational Observing and Forecasting System (www.ecoop.eu)
EEZ	European Exclusive Economic Zone (200 nm limit)
E-MAP	Emission MAPper
EMEP	European Monitoring and Evaluation Programme
EMIS	Environmental Marine Information System; http://emis.jrc.ec.europa.eu/
EQR	Ecological Quality Ratio
ERSEM	European Regional Seas Ecosystem Model
EUTRISK	EUTrophication RISK index
GEOHAB	Global Ecology and Oceanography of Harmful Algal Blooms
GES	Good Environmental Status
GOOS	Global Ocean Observing System
GSR	Global Solar Radiation (in MJm^{-2})
HAB	Harmful Algal Bloom
HEAT	HELCOM Eutrophication Assessment Tool
ICEP	Indicator of Coastal Eutrophication Potential
ICES	International Council for the Exploration of the Sea; www.ices.dk
ICG-EMO	Intersessional Correspondence Group Eutrophication MOdelling
ISECA	Information System on the Eutrophication of our CoAstal seas
LME	Large Marine Ecosystem
LOICZ	Land-Ocean Interactions in the Coastal Zone; www.loicz.org
LPD	Lagrangian Particle Dispersion
MEDPOL	Programme for the Assessment and Control of Pollution in the Mediterranean Region
MERIS	Medium Resolution Imaging Spectrometer
MODIS	MODerate resolution Imaging Spectography
MSFD	Marine Strategic Framework Directive
NAO	North Atlantic Oscillation (dimensionless weather index); http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml; http://www.cgd.ucar.edu/cas/jhurrell/indices.html
NETCDF	Net Common Data Format
NEWS	Nutrient Export from WaterSheds
OSPAR	OSlo-PARis convention; www.ospar.org
PAR	Photosynthetic Active Radiation (in µmol photons m^{-2}s^{-1})
RC	Reference Condition
REPHY	Réseau de Surveillance PHYtoplanktonique
SNAP	Significant New Alternatives Policy
STI	Statistical Trophic Status
WAS	Web-based Application Server
WFD	Water Framework Directive
WFS	Web Features Service

WMS	Web Map Service

CHAPTER 1 INTRODUCTION

The cross-border cooperation project ISECA (Information System on the Eutrophication of our CoAstal Seas), which is supported by the INTERREGIVa 2Seas Program (www.interreg4a-2mers.eu), is a collaboration between Flemish, Dutch, French and British knowledge partners. The objective of the ISECA project is to improve the exchange of data and scientific insights related to the eutrophication of coastal waters in the English Channel and the Southern North Sea (Figure 1), aiming both at knowledge partners and the relevant authorities and general public. The project is coordinated by ADRINORD in France.

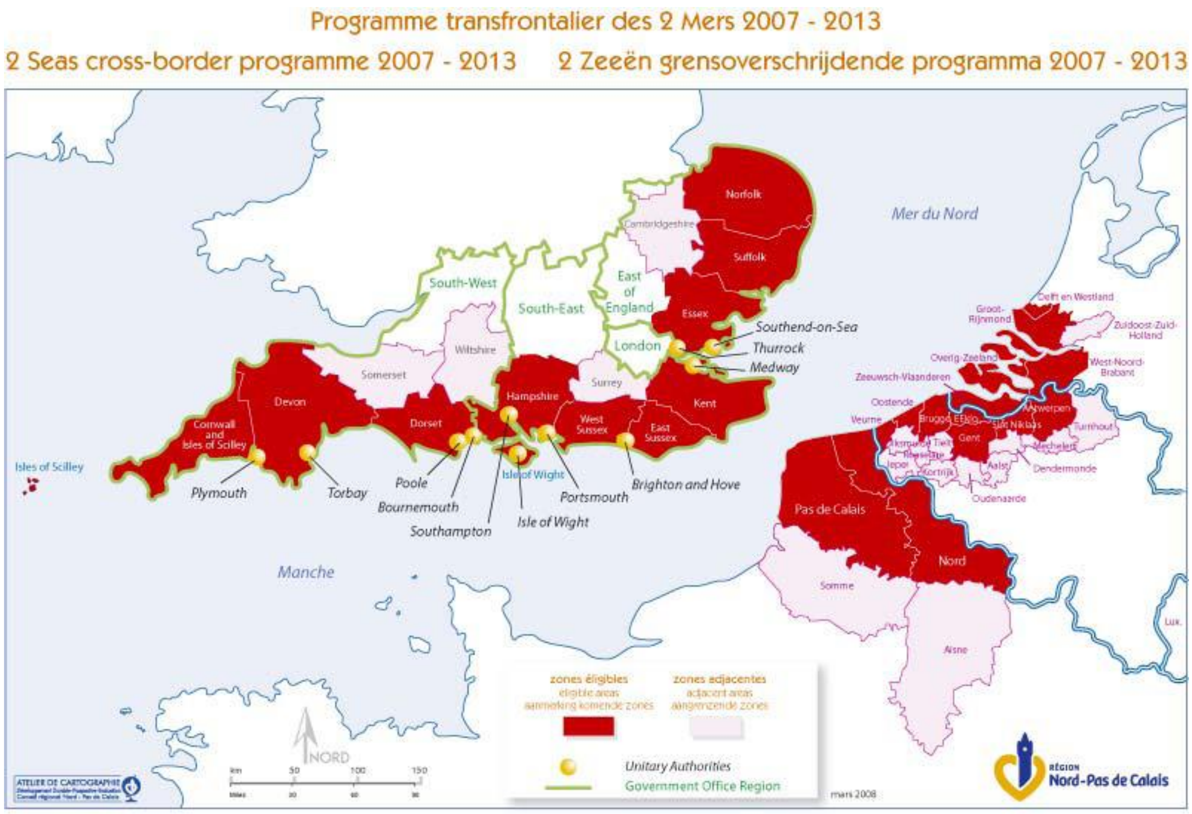

Figure 1-1 The project area for the 2Seas program (www.interreg4a-2mers.eu)

The general objective of the ISECA project is to demonstrate the potential value of the existing knowledge concerning *eutrophication* of the coastal waters in the 2Seas region, with both the scientific community and general public as target audience. Broadly speaking eutrophication is the process of excessive enrichment of waters with nutrients (Ferreira et al., 2010; Ferreira et al., 2011), which in turn may lead to algae growth, Harmful Algal Blooms (HABs) of algae such as *Phaeocystis*, hypoxia, and eventually fish mortality and eventually the production of toxins if the circumstances allow this. Point (industrial and waste water treatment outflows and diffuse sources (mainly atmospheric deposition and agriculture) of nutrients contribute the eutrophication of estuarine and coastal and offshore waters. The potential consequences include a disturbance of the balance of marine ecosystems, and negative impacts on the coastal economy (beach recreation, fisheries and shell farming).

The ISECA project is to demonstrate the added value of combining three complementary sources of information on eutrophication: earth observation, in-situ measurements and modelling. The project activities are organized around three interrelated actions (Figure 1-2) *Action 1 – Inventory* - is to identify the relevant stakeholders and determine the functional requirements for the information portal. The objective of *Action 2 – Earth Observation and in-situ data* - is to make an inventory of the available in-situ and earth observation data, as well as the methods to validate and improve these data. *Action 3 –Modelling* - is aimed at designing a web-based platform for the analysis of eutrophication, including demonstration models and a library of reusable components to model the ecological and economic impacts of eutrophication, using the outcomes of the recently concluded EU 6th Framework Program SPICOSA (www.spicosa.eu).

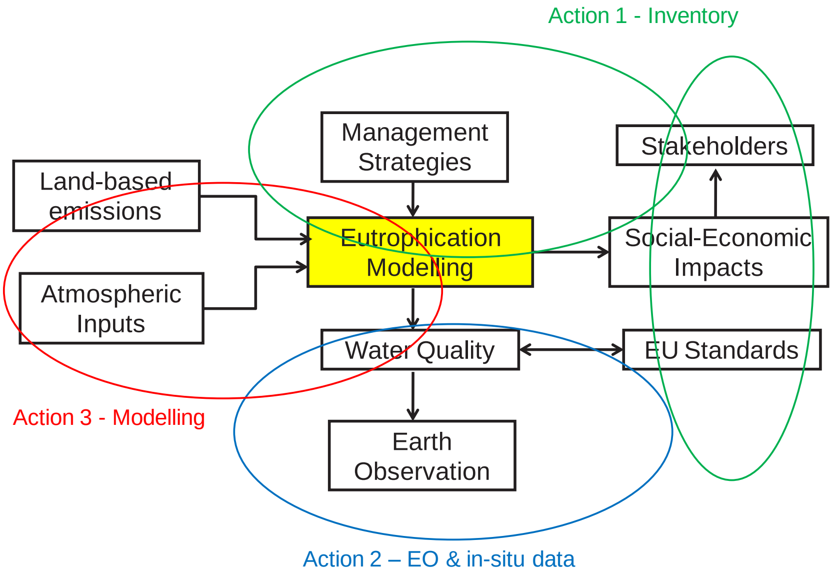

Figure 1-2 Integrated analysis of eutrophication in the ISECA project.

Eutrophication has been an environmental concern in Europe for several decades, which lead to regional conventions addressing the problem including the 1992 Oslo-Paris Convention (www.ospar.org) to protect the North-East Atlantic, the HELCOM Convention for the Baltic Sea and the Barcelona Convention or MEDPOL for the Mediterranean (Ferreira et al., 2011). The two relevant European legislative frameworks are the 2000 EU Water Framework Directive (Directive 2000/60/EC) and the 2008 EU Marine Strategic Framework Directive (Directive 2008/56/EC). Whereas the WFD is limited to the territorial estuarine and coastal waters, stretching 12 nm from the coast the MSFD applies to the marine waters, stretching the 200 nm limit of the Exclusive Economic Zone. The adequate implementation of these legislative agreements depends on a proper definition of the phenomenon as well as measurable and practical indicators. The MSFD is aimed at achieving a Good Environmental Status (GES) by 2020 and addresses the problem of human-induced eutrophication as one of eleven environmental quality descriptors which should be used in combination to assess the environmental status of marine waters (Borja et al., 2010; Cardoso et al., 2010; Ferreira et al., 2011). These descriptors are (Cardoso et al., 2010):

- Biological diversity
- Non-indigenous species
- Commercial fish
- Food webs
- **Eutrophication**
- Sea floor
- Hydrogeographical conditions
- Contaminants and pollution effects
- Contaminants in fish and other seafood
- Litter
- Energy/Noise

International Task Groups were organized to develop practical guidelines for each of the quality descriptors and implementation of the MSFD. Task Group 5, which consisted of selected scientific experts for the Baltic Sea, North-East Atlantic, Mediterranean, and Black Sea, as well as observers to ensure the outcomes of the conventions were properly addressed, addressed the descriptor for coastal and marine eutrophication (Ferreira et al., 2010). This Task Group formulated the following operational definition for eutrophication in the context of the MSFD (Ferreira et. al, 2010; Ferreira et. al., 2011), which takes into consideration the causes of eutrophication, stages of the process, as well as the negative consequences while allowing room for conditions where nutrient enrichment is less problematic:

‘... *a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if the appreciably degrade ecosystem health and/or the sustainable provision of goods and services ...* ‘

Generally, three complementary instruments are available to assess and/or analyze eutrophication: field sampling, earth observation and modelling. Whereas in-situ data can be used to correct the interpretation of earth observation data scientific models are useful tools in this respect because, contrary to EO and in-situ data, these can allow for in-depth the causes and impacts of eutrophication and allow for short- and long-term forecasts.

Action 3 – Modelling - focuses on three tasks specifically: an inventory of eutrophication models, the development of a web-based information system – the Web-Based Application Server or WAS - to demonstrate the integration of EO and in-situ data with model forecasts, and the demonstration of a library of reusable model components. This latter task builds on the outcomes of the EU-FP6 Research Program SPICOSA (www.spicosa.eu), which was aimed at integration of marine science and policy and resulted in a nitrogen source apportionment model for the Scheldt river basin (Vermaat et al., 2012). Modelling coastal and offshore eutrophication is challenging because the phenomenon depends on the complex interaction between physical, biochemical processes which show large regional and seasonal differences. This was demonstrated by a recent model harmonization study in the framework of the OSPAR program (Lenhart et al., 2010). The choice for a particular model will depend on the purpose of the model, data availability and the scientific resources. An inventory of the scientific literature and policy reports on marine eutrophication can be found at the end of this report.

The remainder of this report is organized as follows. In section two we briefly summarize the different indicators used to measure marine eutrophication and the OSPAR Common Procedure for monitoring eutrophication and the effectiveness of nutrient reduction strategies. Section 3 is an inventory of the different biogeochemical models in use for the 2Seas Territory and the Scheldt nitrogen source apportionment model. In Section 4 we present the proposed general architecture for the Web-Based Application Server, and a data-driven eutrophication model based on salinity gradients to test the prototype version of the WAS. The report is concluded with a brief discussion of the envisaged results in the context of the ISECA project and next steps, some useful annexes including a list of selected scientific publication and documents related to marine eutrophication, a list of web links, and a list of sister projects.

CHAPTER 2 EUTROPHICATION ASSESSMENT IN THE EU

2.1. EUTROPHICATION INDICATORS

Different indicators and metrics are in use to measure eutrophication, with chlorophyll-a as the most common descriptor for eutrophication (Ferreira et al., 2011). Chlorophyll-a is a photosynthetic pigment present in photosynthetic plants, absorbing well in the 400-450 nm range of the light spectrum (Wikipedia, accessed 11.01.12). This property makes it particularly useful to detect the planktonic primary production and nutrient enrichment by means of earth observation (Gohin et al., 2008) or in combination with in-situ reflectance measurements (De Cauwer et al., 2004). However, complications occur with earth observation in case of cloud cover and the presence of suspended matter in the water column. This makes a combination with in-situ measurements and correction algorithms important (De Cauwer et al., 2004; Tilstone et al., 2011).

Based on the work of MSFD Task Group Five eleven indicators for human-induced eutrophication were recommended (Ferreira et al., 2010; Ferreira et al., 2011). These are related to the sources of eutrophication as well as the response of the coastal ecosystem. Table 2-1 Selection of recommended eutrophication indicators (after Ferreira et al., 2011).shows a selection of key indicators identified by the task group with the proposed sampling schedule and metric.

-

Indicator	Sampling schedule	Dimension/metric
NUTRIENT LOAD	ANNUAL ESTIMATE	TONS/YR BY SOURCE
CHLOROPHYLL-A	MONTHLY OR MORE FREQUENT	90TH PERCENTILE OR MAXIMUM
PRIMARY PRODUCTION	PERIODICITY OF INCREASE OVER YEAR	CHL-A OR OTHER
NUTRIENT CONCENTRATION	MONTHLY OR MORE FREQUENT	ANNUAL/SEASONAL MEAN OR MAXIMUM
HARMFUL ALGAL BLOOMS	ANNUAL FREQUENCY AND DURATION	
DISSOLVED OXYGEN	MONTHLY OR MORE FREQUENT	ANNUAL/SEASONAL MEAN OR MAXIMUM

Table 2-1 Selection of recommended eutrophication indicators (after Ferreira et al., 2011).

The Task Group proposed to measure the 90th percentile concentration of Chlorophyll-a on at least a monthly basis. Furthermore, the need to include the human-induced loading of nutrients, preferable distinguished by source (agriculture, industrial wastewater, urban wastewater, atmospheric deposition) in the assessment was clearly emphasized (Ferreira et al., 2010; Ferreira et al., 2011). However, even when countries or territories agree on the indicators to measure eutrophication it is necessary to follow some standardized procedure to measure these indicators and ensure the values can be compared.

2.2. THE OSPAR COMMON PROCEDURE

The Common Procedure (OSPAR, 2005) plays a central role in the OSPAR Eutrophication Strategy. The objective is of the procedure to harmonize the monitoring and assessment of the eutrophication status of marine waters of the OSPAR member states in order to support measures to combat the problem. Depending on the eutrophication status estuarine, coastal and marine waters can be classified in one of three categories: problem areas, potential (future) problem areas and non-problem areas (currently and in the future).

The approach consists of a two-step procedure. The *screening procedure* comprises the collection of demographic, hydrodynamic and physical information, observations by air, vessel and remote sensing, as well as nutrient related data (OSPAR, 2005). Furthermore, the member states can decide on the appropriate areas for screening, taking into consideration the local hydrodynamic conditions and proximity of nutrient sources (OSPAR, 2005). The screening is followed by a more detailed *comprehensive procedure* or COMPP of the areas classified as being problem areas or potential problem areas during the screening procedure. This part of the procedure is based on an integrated perspective on marine eutrophication which distinguishes four stages: nutrient enrichment, direct effects such as increased phytoplankton growth, indirect effects such as zooplankton growth and oxygen depletion, and finally other water quality related effects such the production of toxic algae (Figure 2-1) as well as the social-economic impacts.

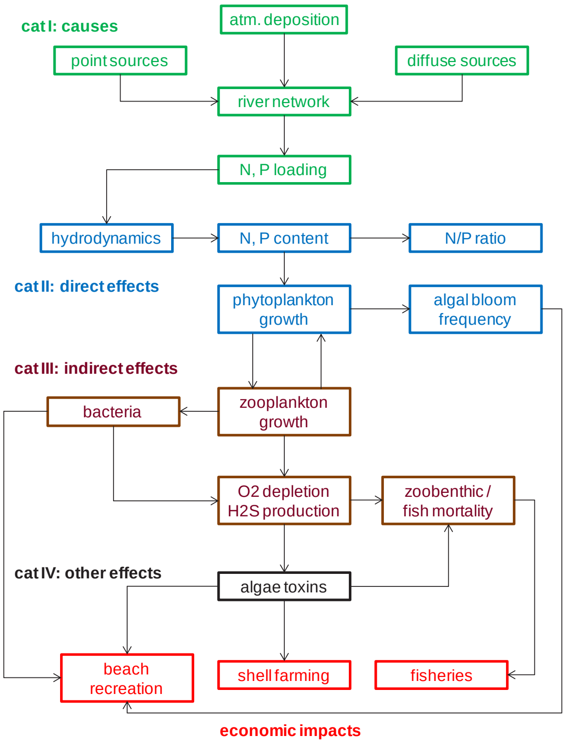

Figure 2-1 Schematization of the causes and consequences of coastal eutrophication following the categories of the OSPAR Common Procedure (adapted after OSPAR, 2005). The economic impacts have been added to the conceptual framework used in the OSPAR Common Procedure.

The comprehensive procedure comprises three steps. First, area-specific parameters for eutrophication assessment are to be determined according to the four stages of the eutrophication process (Table 2-2). Concentrations are assessed based on a background level and a problem threshold level, being 50 % above the background level. The background levels are area specific and salinity dependent.

OSPAR Category	Assessment parameters	Criterion
I. Nutrient enrichment	1. river inputs and discharges	elevated inputs; increased trend N, P
	2. nutrient concentrations	elevated winter DIN and DIP
	3. N/P ratio	elevated winter ratio compared to Redfield value of 16
II. Direct effects	1. chlorophyll-a	elevated max. and mean level
	2. phytoplankton indicator species	elevated level of nuisance/toxic species (duration of algal blooms)
	3. macrophytes including macroalgae	species shifts, elevated biomass or area
III. Indirect effects	1. oxygen deficiency	2-6 mgl^{-1}; lowed % O_2 saturation
	2. zoobenthos and fish	fish kills, species changes
	3. organic carbon/matter	elevated levels related to III.1
IV. Other impacts	1. algal toxins	mussel infections related to II.2

Table 2-2 Summary of eutrophication assessment parameters in the OSPAR comprehensive procedure (OSPAR, 2005).

Next, the scores resulting from the application of the assessment parameters and combined into an initial classification, followed by a final, harmonized assessment using all relevant information for the areas (OSPAR, 2005) in the categories “Problem Area”, “Non-Problem Area” and “Potential Problem Area”. In the WFD the quality of marine waters is classified into one of five categories ranging from Bad, Poor, Moderate and Good to High. The overlap with the OSPAR assessment criteria has been described (OSPAR, 2005). Generally, OSPAR problem areas correspond to the WFD categories Bad, Poor or Moderate, whereas the non-problem areas correspond to the WFD categories Good or High.

2.3. EUTROPHICATION STATUS ASSESSMENT FOR THE 2SEAS TERRITORY MEMBER STATES

Without giving a full report on the current eutrophication status of the marine (coastal and offshore) waters in the 2Seas territory we summarize the findings of the 2008 OSPAR assessment by the member states involved (France, the United Kingdom, Belgium and the Netherlands). This helps clarifying the extent of the eutrophication problem and small differences in the assessment parameters used by the four countries. In 2008 the four countries in the ISECA project area (English Channel and Southern North Sea) reported on the second application of the OSPAR Common Procedure (OSPAR, 2008c-f).

Belgium	time frame	statistic	background	elevated
river input N, P		annual total t/yr		increased trend
winter DIN	2 times per winter (Nov-Feb)	mean	cw 10 / off 8	cw 15 / off 12
winter DIP		mean	0.6	0.8
winter N/P ratio		mean N/ mean P	16	24
chlorophyll-a	growing season (Mar-Oct)	90th percentile	cw 10 / off 5.6	cw 15 / off 8.4
		mean	cw 5 / off 2.8	cw 7.5 / off 4.2
phytoplankton (*Phaeocystis*)		max. nr of cells/l		10^7 cells 30 days
oxygen	growing season	mean (mg/l)		6

deficiency	(Mar-Oct)			

Table 2-3 Key parameters and thresholds of the second application of the OSPAR Common Procedure by Belgium (OSPAR, 2008c). The distinction between coastal waters (cw) and offshore waters (off) is determined by the 34.5 PSU salinity level.

The general conclusion for the Belgian marine waters was that these are still categorized as problem area despite of a 31 % reduction in the N discharge and 62 % reduction in the P discharge during the period 1985-2005 (OSPAR, 2008a). An increasing chlorophyll-a gradient can be noticed in the direction of the Scheldt and Rhine/Meuse plumes. The offshore waters (salinity exceeding 34.5 PSU) are a non-problem area.

The implemented measures are aimed reduction of the nutrient emissions by preventive measures aimed at the agricultural and industrial sectors and sewage. Compared to 1985 the emission of N has been reduced with 45 % in Flanders, and 21 % and 13 % for the Brussels capital region and Walloon region respectively (OSPAR, 2008c), implying a national reduction of 34 %. This value is still below the 50 % reduction target of the PARCOM 89/4 recommendation of the OSPAR agreement (OSPAR, 2003b). The corresponding P emission reduction is 61 %. A new waste water treatment plant for Brussels became operational in 2007 (OSPAR, 2008c).

United Kingdom	time frame	statistic	background	elevated
river input N, P		annual total t/yr		increased trend
winter DIN	Nov-Feb	coastal mean based on PSU 32	13 µM	20 µM
winter DIP		offshore mean based on PSU 34.5	20 µM	30 µM
winter N/P ratio		mean N / mean P	16	24
chlorophyll-a	growing season (Mar-Oct)	90th percentile		cw 15 µgl^{-1} / offshore 10 µgl^{-1}
		mean + max		
phytoplankton (*Phaeocystis*)		new phytoplankton index (OSPAR, 2008f)		10^{6} cells total cells 10^{7}
oxygen deficiency	May-Sep	mean (mg/l)		4

Table 2-4 Key parameters and thresholds of the second application of the OSPAR Common Procedure by the United Kingdom (OSPAR, 2008f).

The general conclusion is that the UK coastal waters are non-problem areas with no sign of undesirable disturbance (OSPAR, 2008a). However, some small harbors, estuaries etc. persist as problem area due to the circulation patterns. For the period 1985-2003 the reduction in N and P emissions was 9 % and 38 % respectively (OSPAR, 2008a). Measures as part of an Action Program to reduce agricultural emissions include limitation of the application of fertilize and manure, and farm records.

Netherlands	time frame	statistic	background	elevated
river input N, P	year round	annual total kt/yr		elevated input, increased trend
winter DIN	2 times per winter (Dec-Feb)	mean in µmol l^{-1}	C 20 / WS 20	C 30 / WS 30
winter DIP			C 0.6 / WS 0.6	C 0.8 / WS 0.8
winter N/P ratio		mean N/ mean P	16	25
chlorophyll-a	growing season	90th percentile	C 10 / WS 6	C 15 / WS 9

	(Mar-Sep) 2 x per month	mean	C 5 / WS 3	C 7.5 / WS 4.5
phytoplankton (*Phaeocystis*)	1-2 x per month	max. nr of cells/l		10^7 cells
oxygen deficiency	growing season (Mar-Oct)	mean (mg/l)		6

Table 2-5 Key parameters and thresholds (C = Coastal; WS = Western Scheldt) of the second application of the OSPAR Common Procedure by the Netherlands (OSPAR, 2008e).

Five out of seven areas in the Dutch marine waters are classified as problem area, despite of a reduction of the river inputs of 45 % for N and 78 % for P during the last three decades (OSPAR, 2008a). The winter nutrient concentrations for offshore waters (PSU > 34.5) showed no enrichment. Measures will remain aimed at a 50 % reduction in the N and P emissions compared to 1985. For nitrogen the reduction was 20-30 % only.

France	time frame	statistic	background	elevated
river input N, P		annual total t/yr		5-7 kT/yr N 0.1-0.2 kT/yr P
winter DIN	Nov-Feb	not used		
winter DIP		not used		
winter N/P ratio		not used	16	24
chlorophyll-a	growing season (Mar-Oct)	90th percentile		Channel 10 µgl^{-1} / North Sea 15 µgl^{-1}
		mean + max		+ 50 %
phytoplankton (*Phaeocystis*)		% samples with >= 1 bloom of small / large type		> 40 %
oxygen deficiency	May-Sep	mean (mg/l)		P10 < 3

Table 2-6 Key parameters and thresholds of the second application of the OSPAR Common Procedure by France (OSPAR, 2008d).

CHAPTER 3 EUTROPHICATION MODELLING

3.1. INTRODUCTION

During the twentieth century ecological modelling developed from simple equations to describe the oxygen balance and predator-prey systems to population dynamics, followed by eutrophication modelling, to even more complex models, including those integrating the ecological and hydrodynamic processes (Jorgensen & Bendoricchio, 2001). Holistic, user-demand driven approaches aimed at developing integrated tools to support environmental managers with their decisions. The current IT technology allows researchers to combine complex ecological models with 3D hydrodynamic models with correspondingly large data requirements and high level of expertise needed to develop, validate and apply these models. The conclusion of a review of the existing biogeochemical modelling approaches (Jørgensen and Bendoricchio, 2001) is that eutrophication modelling itself is complex, with over 50 different modelling approaches in the scientific literature. Fundamentally, one can distinguish between two types of eutrophication models (Jørgensen and Bendoricchio, 2001):

a. Simple eutrophication models predicting the nutrient loading, concentrations or using a simple relationships to translate the nutrient concentration to eutrophication indicators such as the chlorophyll-a content.

b. Complex biogeochemical models which take into consideration the interaction between the physical, ecological and chemical processes governing eutrophication, based on numerical solution of the transport equations.

Models can also be categorized in terms of the objective, for example long-term forecasting of the impact of nutrient reduction scenarios versus short-term alert systems for algal blooms.

An open research need identified as being critical for effective management (IOC, 2008; Ferreira et al., 2010) is the necessity to develop quantified relationships linking the nutrient loading directly to the eutrophication indicators and ecosystem impacts such as algal blooms, serving as practical instruments for coastal managers. Complex biogeochemical models linking the different stages of marine eutrophication to the land-based sources of nutrients can be applied but are usually data demanding and calibrated for specific locations or regions. This makes the application to different study sites a challenge. Generalized empirical relationships capturing the key mechanisms could be used in combination with earth observation data for this purpose.

Models can help understand the causes of eutrophication and forecast the effectiveness of potential measures, thereby complementing monitoring by means of in-situ sampling and earth observation as instruments to support eutrophication assessment. Nevertheless, the design, calibration and validation of marine eutrophication models is not straightforward given the complexity of the biophysical processes involved, spatial and temporal differentiation in the patterns observed, and the dependency on land-based nutrient sources. It is essential that the complexity of the model applied match the purpose (OSPAR, 2008b). In the context of the ISECA project it is useful to distinguish between models aimed at short-term and/or (near)real time prediction of undesirable events such as algal blooms and models which can help assess the long-term future impacts of different mitigation strategies. The latter type of model can address processes at a time scale of several decades, taking into consideration the accelerative potential of climate change on marine eutrophication (Buckley and Dye, 2009). Identification of the existing model applications for the 2Seas Territory and scientific and/or technical limitations is important in view of the technical requirements for the Web-based Application Server, avoid scientific "dead ends" and unnecessary effort spent on data collection and model concepts. One of the key objectives of the ISECA project is to demonstrate the usefulness of modelling approaches of different complexity as tools for eutrophication management. This will be done based on the availability of calibrated models. The approach followed for the design of the Web-based Application Server (see Chapter 4) is to use Type a models to design and test the prototype server in anticipation of the deployment of more complex Type b models such as those compared in the OSPAR model review (Lenhart et al., 2010). During the last decade several literature reviews, reports and workgroups addressed the issue of marine eutrophication modelling, including applications to the North Sea and English Channel (see e.g. Moll and Radach, 2003; OSPAR, 2006; OSPAR, 2008a; Lenhart et al., 2010). We will briefly discuss a number of these models.

3.2. NORTH SEA ECOSYSTEM MODELS

In 2003 Moll and Radach identified eleven ecosystem models for the North Sea, seven of which were reviewed in more detail (Moll and Radach, 2003; OSPAR, 2008b). The emphasis of the review was on three-dimensional biogeochemical models. In chronological order the ecosystem models compared are NORWECOM (1993), GHER (1994), ECOHAM (1995), ERSEM(1995), ELISE(1995), COHERENS (Luyten et al., 1999) and POL3dERSEM (2000), with the year pertaining to the year the first 3D version of the model appeared. The general conclusion was that these models were able to produce consistent spatial-dynamic distributions for the primary production, adding valuable knowledge and complementing (field) observations and the dependency on land-based and atmospheric nutrient inputs. The ERSEM model was the only model considered to be of sufficient complexity for realistic simulation of marine eutrophication.

In 2005 a workshop was organized to obtain an overview of models to forecast marine eutrophication and support the application of the OSPAR Common Procedure (OSPAR, 2006). The purpose of the meeting was to examine the ecological response to a 50 % nutrient reduction for OSPAR problem areas and the required reduction needed to achieve the status of non-problem area for the problem areas for which the 50 % reduction was not sufficient. The models reviewed were MIRO-COHERENS3D for Belgium, Delft3D-GEM for the Netherlands, ECOHAM3 for Germany, ECOMARS3D for France, NORWECOM for Norway, GETM-IOW for the UK and MHID for Portugal. The general performance of the models was considered to be good, demonstrating the usefulness of source apportionment and, for example, the analysis of delayed response to nutrient reduction scenarios. Nevertheless it was concluded that supplementary monitoring was essential for application of the OSPAR Common Procedure (OSPAR, 2006).

An updated overview of the state-of-art models was given in 2008 (OSPAR, 2008b; Lenhart et al., 2010), based on the findings of a workshop held in 2007 by Intersessional Correspondence Group on Eutrophication Modelling (ICG-EMO). Special attention was paid to the required level of model complexity by distinguishing between four stages in marine eutrophication modelling posing an increasing challenge (Lenhart et al., 2010): nutrient inputs leading to increased concentrations, increased phytoplankton growth and primary production, undesirable disturbances and changes in water quality. Whereas the first stage of eutrophication is relatively easy to describe with simple, box-type models for the nutrient balance (see for example, Vermaat et al., 2012) the other stages require biogeochemical modelling to capture the limiting factors for phytoplankton growth. Research issues to be clarified that were identified included a demand for a systematic way to identify the appropriate model complexity for the given purpose, model run times of sufficient length to capture time delays in the response of ecosystems to reduced nutrient loading, model validation, and the availability of historic river input data (OSPAR, 2008b). Recently, the outcomes of the workshop and a number of ecosystem models were discussed in more detail by Lenhart et al. (Lenhart et al., 2010). The six ecosystem models discussed are MIRO-CO3D for Belgium, ECO_MARS3D for France, ECOHAM4 for Germany, Delft3D-GEM for the Netherlands, GETM-BFM and POLCOMS-ERSEM for the United Kingdom. The modelled area includes or partially includes the 2Seas Territory for all six models. What follows is a summarized description of each of the models.

3.2.1. Miro-CO-3d (Belgium)

This model is a coupling of the 3D hydrodynamical model COHERENS (Luyten et al., 1999; Lacroix et al., 2004; Lenhart et al., 2010) and the MIRO ecosystem model (Lancelot et al., 2005; Lenhart et al., 2010; Lancelot et al., 2014) based on 32 state variables. The model works on a spatial resolution of approx. 5 km, a vertical stratification into five layers, and a 15 min time step (Lenhart et al., 2010). The model can be used to examine phytoplankton and zooplankton dynamics in the Southern North Sea, including the dominant Phaeocystis species. The depth-dependent light attenuation coefficient is calculated from the chlorophyll-a concentration, dissolved organic matter absorption and concentration of non-algae particles, the latter of which is obtained from the suspended matter content (Lenhart et al., 2010). For the workshop the SPM was taken from earth observation data. The boundary conditions for the temperature, nutrients and salinity were obtained from the POLCOMS-ERSEM model. Atmospheric deposition was not included.

3.2.2. ECO-MARS3D (FRANCE)

This model is an extension of three-dimensional circulation model MARS3D was developed at IFREMER by Lazure and Dumas (Lazure and Dumas, 2008; Lenhart et al., 2010). Only 19 state variables are used in the ecosystem model, the horizontal resolution is 4 km, the model uses 12 vertical layers and a 400 sec time step (Lenhart et al., 2010). Modelled SPM values replace those obtained from earth observation near the coast and estuaries (Vanhoutte et al., 2009). The model is applied to the English Channel and Southern Bight of the North Sea.

3.2.3. ECOHAM4 (GERMANY)

This model is an extension of the Ecoham3 model (Pätsch and Kühn, 2008) used for the simulation of nutrient reduction and focus on eutrophication. The spatial resolution is 20 km, 24 vertical layers are used, a time step 5 min, and the ecosystem model uses 26 state variables (Lenhart et al., 2010). The modelled area includes the complete North Sea and large parts of the NW European shelf (Lenhart et al., 2010).

3.2.4. DELFT3D-GEM (NETHERLANDS)

This model has been developed by Deltares and is applied to simulate nutrient cycling in the Southern North Sea (Los et al., 2008; Lenhart et al., 2010). A variable horizontal grid with a mesh size in the range 1-20 km is used, with a vertical stratification in 10 layers (Lenhart et al., 2010). The transport model uses a time step of 1 hr, the ecological model a time step of 1 day. The ecosystem model is based on 23 state variables, the SPM is obtained from a mud transport model (Lenhart et al., 2010).

3.2.5. GETM-BFM (UK)

This model couples the GETM transport model with the BFM ecosystem model, which is an application of the ERSEM III model (Blackford et al. , 2004; Lenhart et al., 2010). Both models are open-source software. For the workshop the model was applied to the Channel and the North Sea. The horizontal resolution is 6 nm, a vertical stratification in 25 layers is used, and a 45 sec time step, the ecosystem model is based on 45 state variables (Lenhart et al., 2010).

3.2.6. POLCOMS-ERSEM (UK)

This model couples the POLCOMS 3D hydrodynamic model (Wakelin et al., 2009) with the ERSEM (European Regional Seas Ecosystem Model) model (Blackford et al., 2004). The model was applied to the largest area: the Atlantic Margin and NE Atlantic (Lenhart et al., 2010). The version for the workshop was used to force the boundary conditions for the other models. It uses a horizontal resolution of 12 km, a vertical stratification into 32 layers, and a variable time step in the range 15-1200 secs , and 51 state variables for the ecosystem model (Lenhart et al., 2010).

3.3. ALGAL ALERT SYSTEMS: SHORT-TERM FORECASTING

A key objective of the ISECA project is to demonstrate the feasibility and usefulness of web-based, interactive information services which integrate earth observation and in-situ data with hydro-ecological models. This topic is the subject of a growing interest (Siddorn et al., 2007; Barciela et al, 2009; Blower et al., 2009; Gemmell et al., 2011, Villars, 2011) and the subject of a number of recently concluded and ongoing EU-funded projects such as ECOOP (www.ecoop.eu), COBIOS (www.cobios.eu) and ASIMUTH. The potential applications of a system combining model results and field observations include (Gemmell et al., 2011):

- quality control of in-situ observations allowing error correction
- model validation
- data assimilation of model forcing
- (near) real time decision support

Another type of service could consist of information on the long-term impacts of nutrient reductions scenarios and land-based measures on coastal eutrophication. An example of real-time, short term decision support is AlgaRisk tool for forecasting algal blooms which combines data of the Met Office, earth observations provided by PML and a spreadsheet tool developed by the Environment Agency (Barciela et al., 2009).

The EU-FP7 GMES project COBIOS (www.cobios.eu), which runs from 2011-2013, is aimed at integrating ecological models with earth observation data in an operational algal bloom forecasting tool for EU waters (Villars, 2011). The kick-off meeting of the project was used to compare and discuss a number of (semi)operational tools for the prediction of HABs in the EU:

3.4. MODELLING ATMOSPHERIC INPUTS (CNMPA – UNIVERSITY OF GREENWICH)

The atmospheric inputs of land- and sea-based emission sources such as industry and shipping are significant for eutrophication. For the Greater North Sea the average contribution of atmospheric inputs to the atmospheric depositions for the EMEP model over the years 1990-2004 was estimated to be 33 % (OSPAR, 2007b). However, more detailed information on the emission and transport of substances such as NH3, SOx and NOx is needed to understand the impact on marine eutrophication. Within Action 3 this task is carried out by the partner 4, the Centre of Numerical Modelling and Process Analysis (CNMPA), of the University of Greenwich.

High resolution (7x7 km) emission data were generated by VITO in October 2012 (Maes et al., 2009) were provided to CNMPA and used as input for the Flexpart LPD model to generate deposition data. The high resolution data were prepared for the 11 EMEP SNAP sectors (including combustion plants, agriculture, road transport, production processes etc.) with a range between the 45° and 56° northern latitude and 8° western to 10° eastern longitude, exceeding the 2Seas modelled area. The emission data were provided on an annual basis for the years 1990, 2000 and 2009, and are based on downscaling of geospatial proxy data by means of methodology which is also used by E-MAP (Maes et al., 2009). In addition, time profiles corresponding to the EMEP sectors were delivered to allow for temporal disaggregation at the level of months, days and hours. These data were combined with high resolution weather data to improve the atmospheric modelling.

Three components are needed to achieve detailed modelling of the atmospheric inputs to eutrophication: (a) meteorological data, (b) emissions data and (c) modelling software for atmospheric transport and deposition. Freely downloadable meteorological data records from two different sources were considered: ECMWF Reanalysis data set *ERA Interim* 0.75 degree resolution (http://www.ecmwf.int) and NCEP (U.S.), Final Analysis, 1 degree resolution. The ECMWF was chosen for its slightly higher resolution, excellent compatibility with the LPD tracing software Flexpart (described below) and 'European feel'. The records contain wind velocities, temperature, humidity, pressure, sunshine, precipitation and some other variables needed for the tracing model. Frequency of records is every 6 hours covering from 1979 up to 2 months before real time. For the higher-resolution option, the freely available 'meso-scale' meteorological software package WRF (Weather Research and Forecasting, www.wrf-model.org) was installed and tested at CNMPA. The finer grid (10 km) weather data was carefully examined for consistency in order to verify the software installation and set up. As an example, instantaneous plots of specific humidity (in color contours), horizontal wind velocity (arrows) at the 850 HPa pressure level and sea-level pressure (lines) are shown in Figure 3-1 for 4th April 2009 at noon. The picture on the left is the 0.75 ^{o} data from ECMWF while the picture on the right shows the post-processed result from WRF at 10 km grid spacing. The similarities are obvious, however, the weather front passing from west to east is resolved with greater detail and sharpness in the picture on the right. The same is true for the vertical motions responsible for enhanced dispersion of pollutants in the atmosphere.

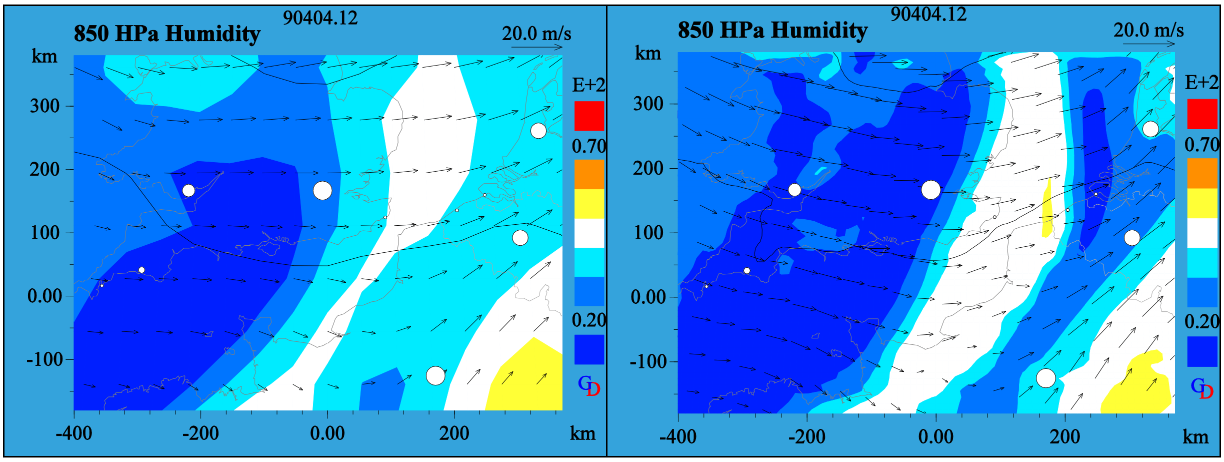

Figure 3-1 Coarse-grid **emissions** (50 km spacing) were obtained directly from EMEP (www.ceip.at) while the fine-grid data were supplied by VITO as described above.

Another open-source software package (Flexpart, http://transport.nilu.no/flexpart) was installed, adjusted and used to carry out the Lagrangian Particle Dispersion (LPD) modelling of the **atmospheric transport** of eutrophicants. It was chosen for its flexibility, compatibility with ECMWF data, extended range of readily implemented physical/chemical relations responsible for pollutant deposition on the sea/land surface, atmospheric boundary layer options and ready library of species behavior (e.g. NO_X, NH_3, SO_2). The LPD method is based on calculating trajectories of air 'parcels' driven by the wind and simultaneously calculating additional dispersion due to air turbulence and sub-grid scale vertical (convective) motions. The sub-grid options can be switched off when using fine-resolution weather data. The Lagrangian method of parcel tracing is 'exact' compared to Eulerian methods which suffer from false, numerical diffusion/dispersion.
The month of April, 2009 was chosen as the test period for the initial runs with both the coarse and the fine emissions/weather options. (April is important because this is when the harmful algal blooms happen in the North Sea and 2009 is one of the years for which fine emissons data are also provided.)

The results of the first simulation runs with the two resolution options are summarized in Figure 3-2 below where the color contours show the total (combined) wet (due to precipitation) and dry (due to other processes) deposition of nitrogen oxides and ammonia in the 2Seas region from sources located in this and the neighboring regions. It can be seen that the coarse and fine results are consistent which gives confidence in the accuracy of the chosen methodology. The fine-mesh results show more nutrients are deposited over the land (correspondingly – less over the sea) than with the coarse set up. It can also be seen from the pictures that the higher deposition rates (colored in red) are retained for the coastal waters of the Netherlands (NO_X) and Belgium (NH_3). Bearing in mind that these waters already receive the highest river input, the atmospheric contribution needs also to be taken into account. The Flexpart software also produces concentration data sets which can be used for direct validation of the model results with in situ measurements (e.g. http://kentair.org.uk).

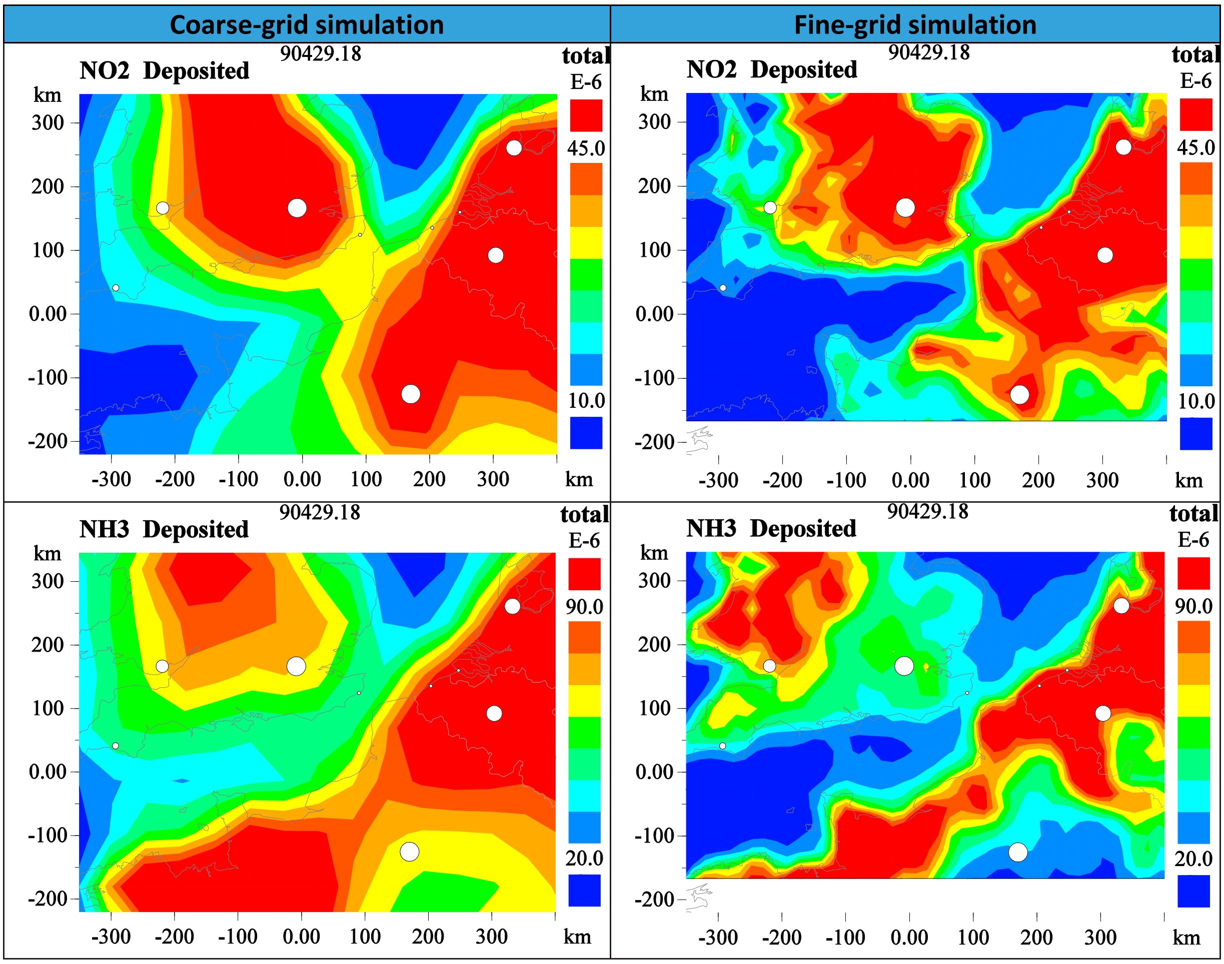

Figure 3-2 Nitrogen oxide and ammonia deposition values for coarse 50x50 km (left) and fine 7x7 km (right) model grid (Maes et al., 2009).

These first results indicate a higher deposition over the land (with the fine-grid calculation compared to the coarse one) which suggests that coarse-grid atmospheric models might over-estimate the quantities deposited directly over the sea by atmospheric processes. Of course, what is deposited on the land will sooner or later find its way to the sea via the rivers, so the atmospheric input directly on the sea surface will be really significant only in the short term – in the weeks immediately preceding algal blooms.

The future steps of the atmospheric transport modelling will include:

- extension of the duration of the periods covered by the high-resolution calculations
- comparison of the high-resolution, low-resolution results with the measurements
- evaluation of the need for high-resolution calculations (which take >24 hours plus about 6 hours of manual preparation for 1 month of real time)

CHAPTER 4 EUTROPHICATION ABATEMENT

The nutrients inputs into the sea include atmospheric deposition, aquaculture and river loading resulting from waste water, industrial and agricultural sources. The latter are due to a combination of the diffuse sources (mainly agriculture but also atmospheric deposition and unconnected households) and point sources (industry, households connected to the waste-water treatment system). The proportional contribution varies from country to country, but agriculture and sewage always dominate the contributions to the river loads. This means nutrient control should first address these sources. The nitrogen reduction between 1985 and 2000 for the Netherlands, Belgium and the UK ranged between 20 – 40 % (OSPAR, 2003b). The PARCOM Recommendation 88/2 prescribed a 50 % reduction in the nutrient inputs during the period 1985-2000 for all contracting parties. By 2003 no country had yet achieved this target (OSPAR, 2003b). The measures to achieve the nutrient reduction target can be found in PARCOM Recommendation 89/4 and include nutrient reduction options related to the optimal spreading and use of manure and fertilizer, optimal establishment of livestock, waste-water treatment plant efficiency and capacity, industrial waste-water treatment technology, control of aquaculture and emission reporting , and new technology to reduce NOx emissions from power plants and private vehicles (PARCOM 89/4).

A nitrogen source apportionment model (Vermaat et al., 2012) was developed for the EU-FP6 project SPICOSA (www.spicosa.eu). This model was used in the ISECA project and further developed to examine and compare the effectiveness of different emission reduction strategies. Figure 4-1 shows the general user interface of the model. Strategies aimed at reducing the nutrient loading include (see De Kok et al., 2014a for details):

a. Gradual decrease of fertilizer use
b. Buffer strips along receiving streams are considered a potentially useful means to achieve nutrient retention (Vermaat et al., 2012).
c. Gradual decrease of cattle stock size
d. Gradual improvement in the efficiency of waste-water treatment plants
e. Gradual reduction in the industrial effluents of nitrogen
f. Gradual reduction in the effluents from households which are not connected to the waste-water treatment system to 0 %
g. A combination of measures a-f.

The model has been implemented in ExtendSim® simulation software, and can be run with the free demo version of the software which is available after registration (https://www.extendsim.com/prods_demo.html). The Scheldt model is available through the SPICOSA model library (http://dataportals.pangaea.de/spicosa/SPICOSA_model_library.html).

In addition to the management options it also possible to select specific scenarios for the annual precipitation and mean temperature, depending on the climate change scenario, or custom-define these two parameters which affect the nitrogen load at the outflow point of the catchment.

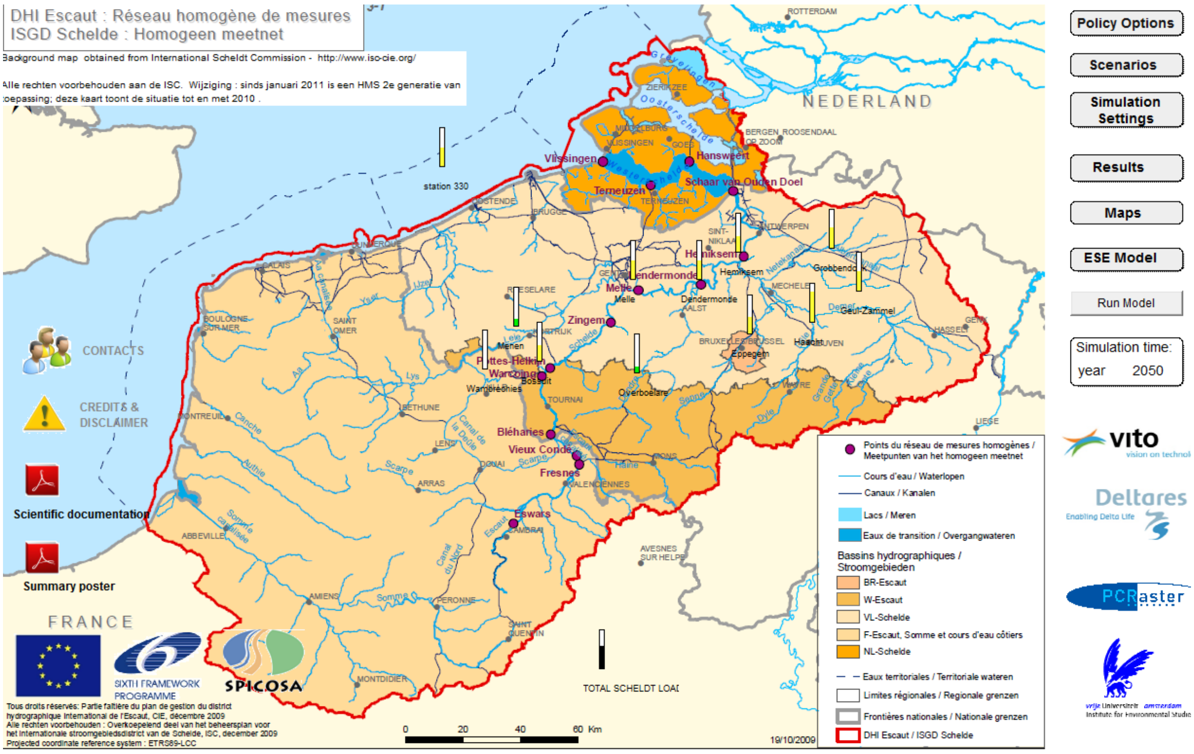

Figure 4-1 General user interface of the nitrogen source apportionment model for the Scheldt basin (Vermaat et al., 2012) with animated indicators for the nitrogen concentration at selected locations.

For the application in the ISECA project the model has been coupled with an empirical model linking the coastal and estuarin salinity with winter level of dissolved inorganic nitrogen and the chlorophyll-a concentrations (OSPAR, 2008a). This model was implemented in MatLab® to generate spatial distributions in NetCdf geo format for use in the ISECA WAS web service (see De Kok et al., 2014a). A more detailed description of the steps can be found in Section 2.4 and Annex E of (De Kok et al., 2014a). The implementation in ExtendSim also includes a compartimentalized 1D transport model for the concentrations of nitrogen in the Scheldt estuary and the Belgian coastal waters, which will be discussed in the next Chapter. Figure 4-2 shows the effectiveness of these management options for reduction of the sectoral nitrogen loads (agriculture, industry, households and other) from the Scheldt basin by 2050 (Vermaat et al., 2012).

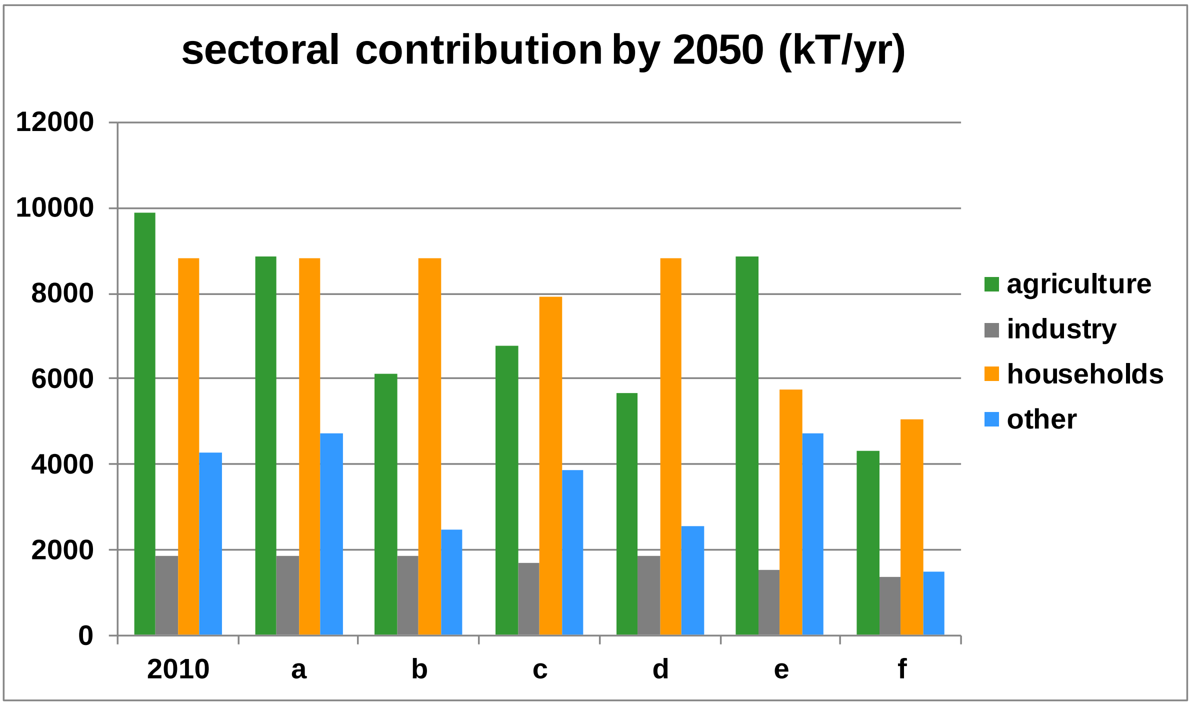

Figure 4-2. Contributions of different sectors to the total yearly nitrogen load for the Scheldt at the Hemiksem effluent point (beginning of estuary) for different scenarios, as compared to the 2010 status (a = business-as-usual; b = 50 % reduction fertilizer use; c = waterway buffer strips; d = 50 % reduction cattle stocks; e = 50 % reduction emissions WWTP; f = b-e combined).

For testing the ISECA WAS server design the land-based source apportionment model is combined with an empirical model for coastal and offshore eutrophication indicators (De Kok et al., 2014a). This demonstration model anticipates later application of scenarios obtained from more sophisticated biogeochemical models, such as those discussed in Section 3.2). Looking at the *total* nitrogen load (Figure 4-3) we notice the most effective strategy (apart from combining measures) is cattle stock reduction, followed by fertilizer reduction.

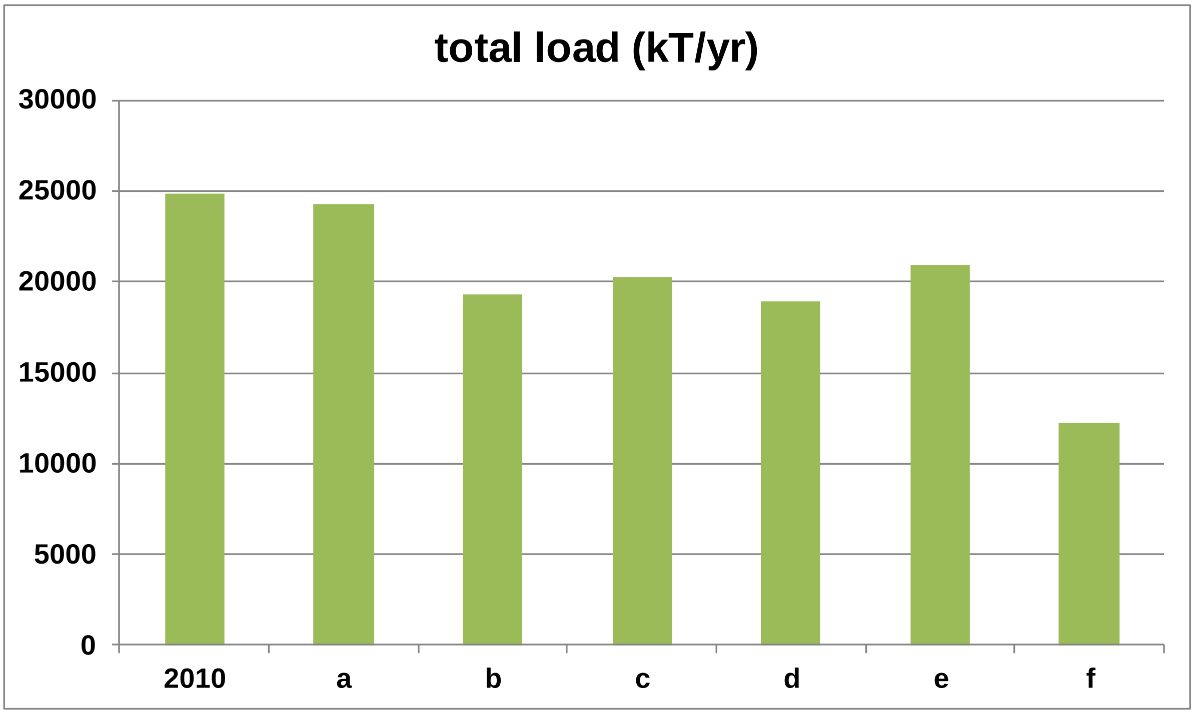

Figure 4-3 Reduction of the total nitrogen load by 2050 for the Scheldt basin for different nitrogen reduction strategies (Vermaat et al., 2012).

It is also interesting to examine the relative contributions of the different sectors under the management strategies (Figure 4-4).

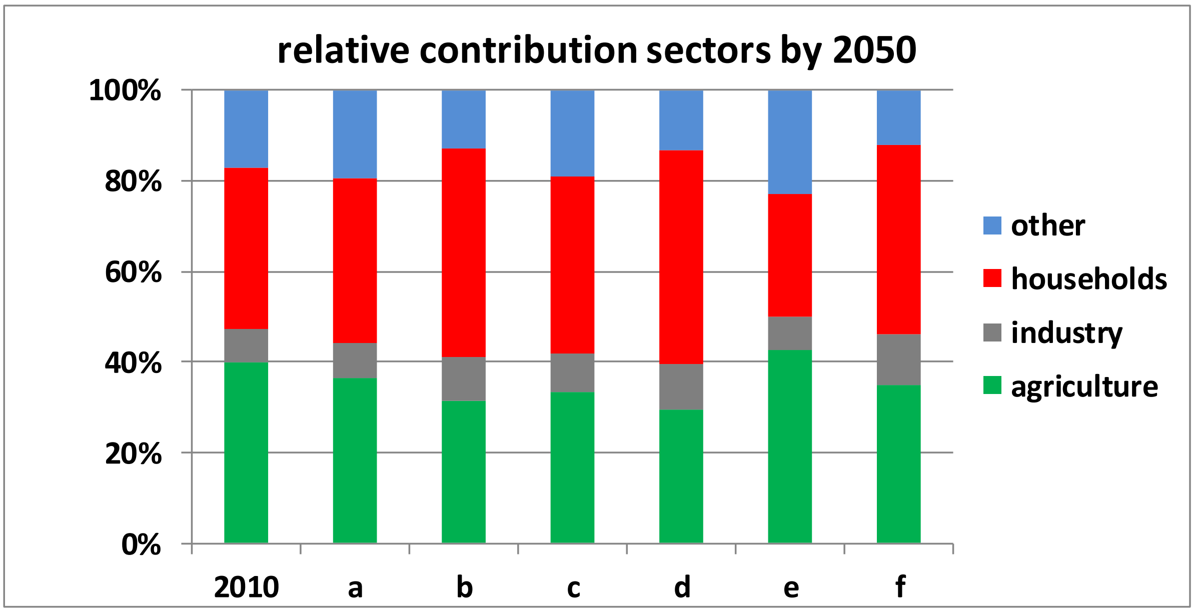

Figure 4-4 Relative sectoral contribution to the total yearly nitrogen load for the Scheldt at the Hemiksem effluent point (beginning of estuary) for different scenarios, as compared to the 2010 status (a = business-as-usual; b = 50 % reduction fertilizer use; c = waterway buffer strips; d = 50 % reduction cattle stocks; e = 50 % reduction emissions WWTP; f = b-e combined).

CHAPTER 5 COMPONENT-BASED MODELLING

The use of plug-and-play components for designing and maintaining models receives growing attention in the integrated modelling literature (Papajorgji, 2005; Donatelli et al., 2007; Verbraeck and Valentin, 2008; Holzworth et al., 2010, De Kok et al., 2010; De Kok et al., 2011). Nevertheless, environmental researchers are less used to design their models based on such components, let alone design these in way allowing reuse by other modellers. Ultimately, the goal should be to develop a generic model library of platform independent, reusable model constructs at the level of state variables (De Kok et al., 2014b). The success of such a model library for supporting the design of new integrated models depends on four conditions: the availability of a sufficiently complete set of model building components with complementary functionalities in the ecological, economic and social domains, open-source access for up- and downloading model components, a procedure for quality control of the contents (Figure 5-1) and the support of the scientific modelling community.

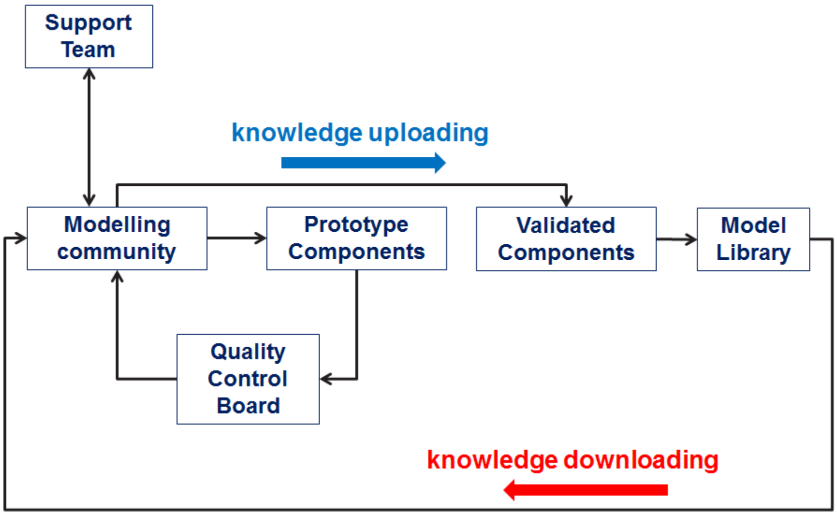

Figure 5-1 Quality control procedure for a generic, open-source model library.

The nitrogen balance model for the Scheldt basin (Vermaat et al., 2012) was one of the models developed in the EU-FP6 program SPICOSA (www.spicosa.eu), which used ExtendSim® as a common modelling platform. Many of the case studies were related to coastal eutrophication problems. A model library of reusable model components, which could be exchanged between the modelling teams, was one of the deliverables of this project. We will first discuss the Scheldt model application, because the study area is in the 2Seas territory. The application of the PolFlow model (De Wit, 2001) to the Scheldt basin (Vermaat et al., 2012) is described somewhat more in detail because it will be used to demonstrate the usefulness of linking models for the land-based emissions to model forecast for marine indicators of eutrophication. This land-ocean integration allows policy makers and researchers to examine the effectiveness of different management strategies to mitigate coastal eutrophication. A good example is the coupled MIRO-RIVERSTRAHLER model (Lancelot et al., 2014). The Polflow model application for the Scheldt river basin (Vermaat et al., 2012) uses a yearly time step and allows linking of different combinations of source control measures such as the reduction of cattle stock size and fertilizer use to the total monthly nitrogen load in the Scheldt estuary. Additional information to visualize are the contributions by sectors which can be obtained with the Scheldt model for each scenario (Vermaat et al., 2012). The Scheldt case study was developed in the framework of the SPICOSA EU-FP6 Research program (www.spicos.eu) and is related to an assessment of the major WFD objective for good ecological quality (total nitrogen content) in the river basin and the coastal zone. The focus of the study was on the spatial-dynamic modeling of the transport of nitrogen, farming economics and feasibility and costs of nitrogen reduction measures concerning agriculture, waste water treatment and industry. A spatially dynamic model was developed to calculate the flow of N from source to river load. The model can assist policy makers to take the most effective measures to reduce the N load in the river. Such a model requires spatial information on emissions and physical characteristics of the entire basin. The system model (Figure 5-2) is based on linkage of a dynamic simulation model using the ExtendSim simulation software (Van Deursen, 1995) and a spatially explicit model in the PCRaster modelling language (www.extendsim.com). The ExtendSim model components are hierarchically organized in a number of modules: (1) a farming economics sub model for Nitrogen generation from diffuse agricultural sources, (2) a near-coast model for the dispersal of the N load into the Scheldt estuary, and (3) a policy response model for the policy response to the N load at Rupelmonde and the coastal concentrations of N. The near-coast model has been completed, the other two Extend model components are currently being tested.

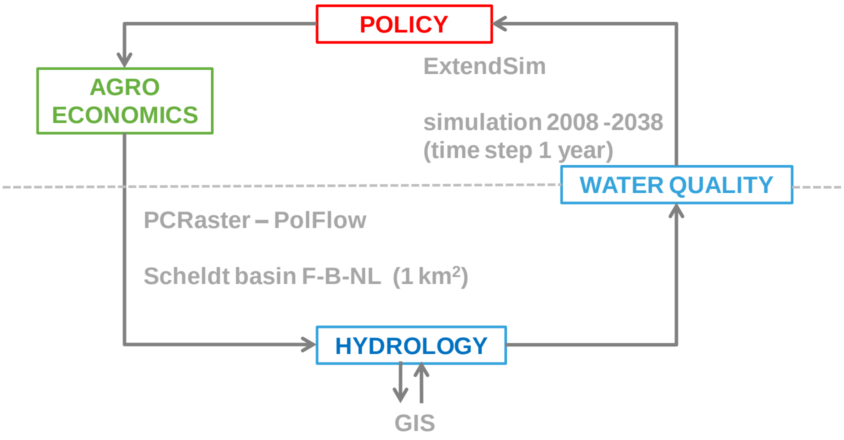

Figure 5-2 General structure of the coupled ESE model in Extend / PCRaster. Economic aspects are in the cost-benefit decisions made by modelled farmers and in the policy and regulations used as external settings for these farmer. Social aspects are grasped presently in the policy part. EXTEND and PCRASTER models are linked (see below).

The farming economics model (Figure 5-3) is based entirely on customized Extend blocks and uses a time step of one year. In principle, it is not spatially explicit, but it differentiates between several EU NUTS3 zones. The near-coast model uses a time step of days , and differentiates between six compartments. The PCRaster model is based on the POLFLOW model (De Wit, 2001) and adaptations by Mourad (2008). POLFLOW has been applied satisfactorily to large river basins, e.g. Rhine, Elbe, Po. It is capable to model N and P fluxes with a temporal resolution ≥ 1 year and a spatial resolution of 1 ha – 1 km^2. In this study the model has been adapted for the Scheldt basin, in order to predict N loads [kg/yr] at Rupelmonde. The model has a spatial resolution of 1 km^2 and a temporal resolution of 1 year.

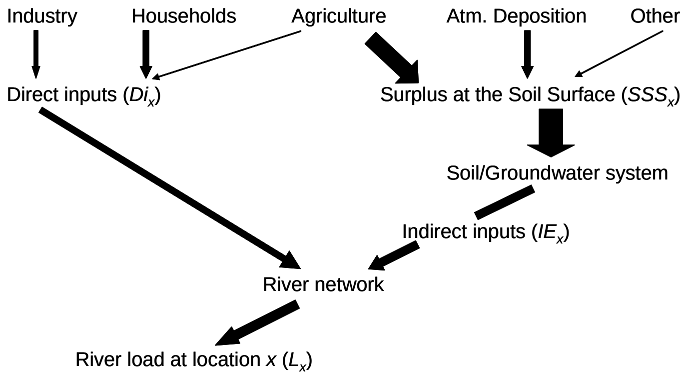

Figure 5-3 Conceptual model of the N fluxes in the Scheldt basin (De Wit, 2001).

The farming economics model (Figure 5-4) is based on a cost benefit approach, taking into account the costs of manure transport and processing in a feedback cycle. The nitrogen deposition norm (Vermaat et al., 2012) is a policy regulator mechanism: every four years the produced nitrogen per unit surface area is compared with the norm. If the norm is not met the norm is lowered a bit and the farms are expected to export and process manure to ensure it is met the next interval.

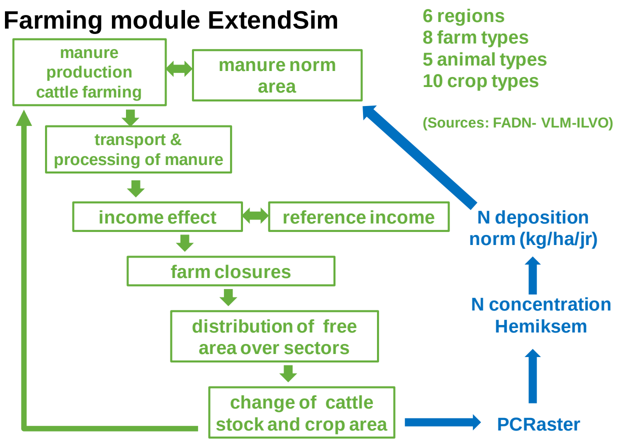

Figure 5-4 The farming module in ExtendSim of the Scheldt model.

The purpose was to develop a model that could reasonably adequate calculate the nitrogen concentrations in the Scheldt estuary and its coastal waters over periods of 5-50 years. A 1-D box model for the water column ignoring the interaction with the sediments was chosen (see Ouboter et al., 1998; Van Gils and Ouboter, 1995; Boderie et al., 1993 and Van Eck and de Rooij, 1990). The first EXTEND version of the model should comprise six boxes for the Westerscheldt estuary and three boxes for the Belgian coastal zone (Figure 5-5). No distinction between water column and sediment is made yet. Only one process is taken into account: N-removal via denitrification.

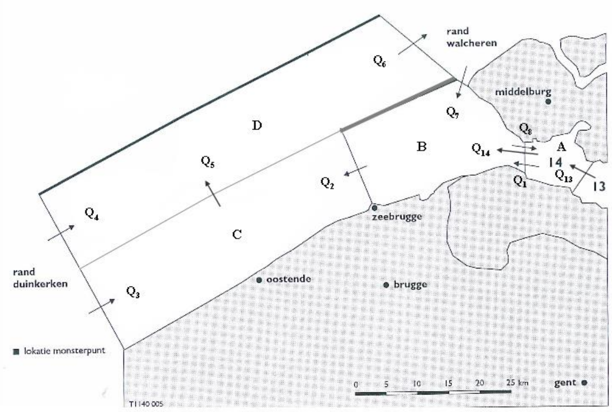

Figure 5-5 Simplified box model structure used for the LIFE model (Van Gils and Ouboter, 1995) in SPICOSA for the coastal receiving part of emissions passing the estuarine Scheldt.

Figure 5-6 shows a typical example of component-based design used in the estuarine module of the Scheldt model application. Here we see how a model component for 1D box transport of nitrogen is reused to describe the transport from one Westerscheldt. compartment to the next.

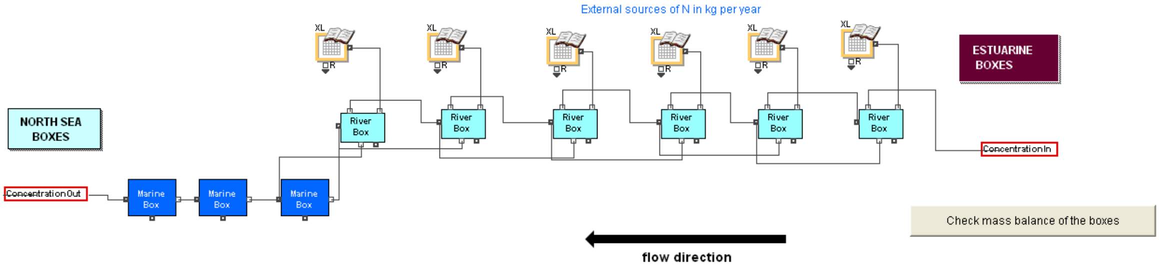

Figure 5-6 Compartimentalized structure of the estuarine section of the SPICOSA nitrogen transport model for the Westerscheldt estuary and Belgian coastal zone (dark blue boxes) with sideway inflow of external nutrient sources.

The PolFlow model (De Wit, 2001; Vermaat et al., 2012) has been developed for the land-based nutrient emissions sources and transport of nutrients. The coupling with the box transport model permits analysis of the coastal and offshore nitrogen concentrations and OSPAR objectives if necessary, but in a schematized way. A different, empirical approach based on the OSPAR reporting (OSPAR, 2008a) is described in Section 2.4 of (De Kok et al., 2014a). Nevertheless, the box transport model can be used to demonstrate the impact of a combination of the measures discussed in the previous Chapter on the nitrogen concentrations beyond the outflow point (Figure 5-5).

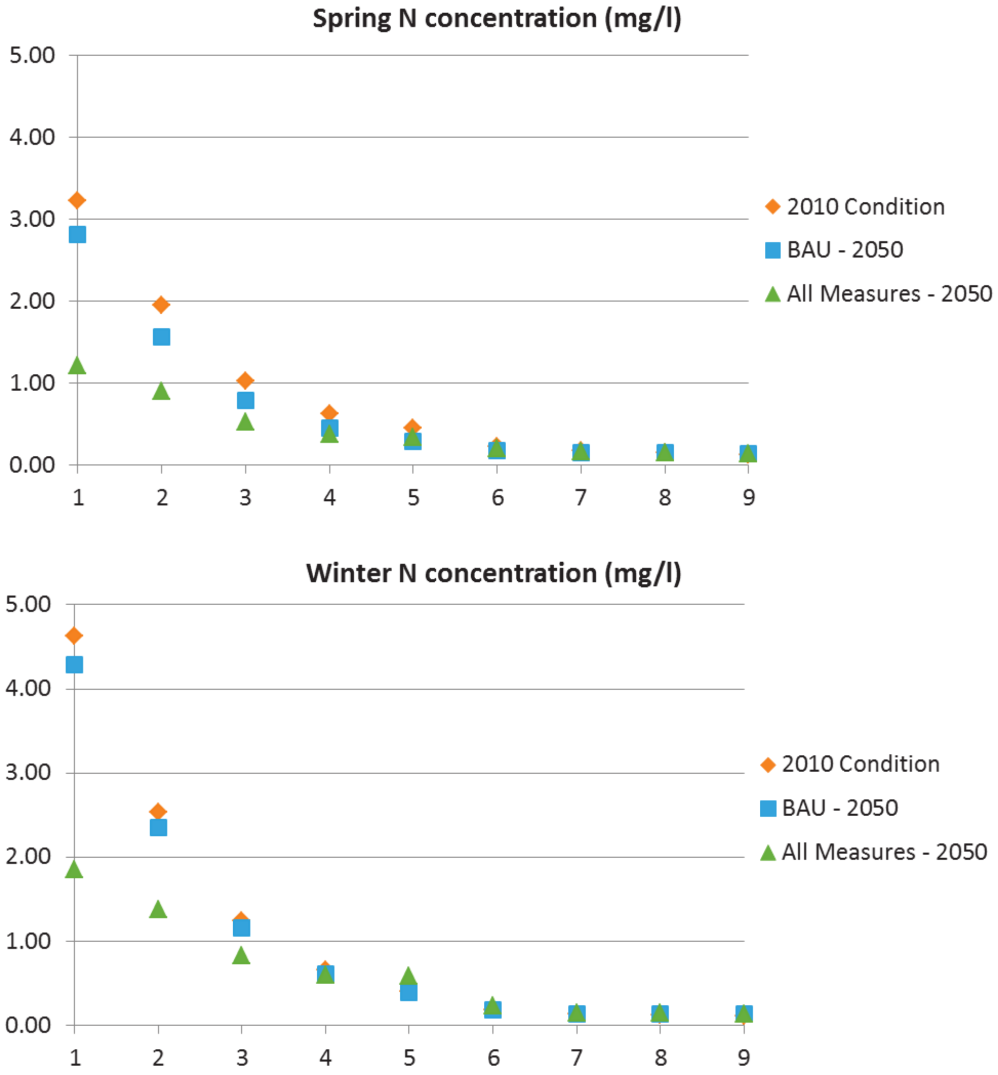

Figure 5-7 Spring (April-June) and winter (November-February) season values of the total nitrogen concentration in the nine estuarine and coastal compartments (numbered seawards from left to right) for the business-as-usual and all measures combined scenario.

The combination of measures has a clear effect on the estuarine water quality, for the coastal and off shore comparments (7 and higher) the simulated differences are not significant. A small long-term improvement of the water quality can be observed for the business as usual scenario as well. Closer examination of the emissions by sector shows a long-term reduction in the agricultural emissions is the reason. It is due to the nitrogen deposition norm (see Figure 5-4). Without this four-yearly intervention this effect does not show up.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

The 3D biogeochemical models examined link up the coastal hydrodynamics with ecosystem processes (categories I-III in Figure 2-1). The general conclusion was that biogeochemical models can be very useful to support the implementation of regulations such as those of the OSPAR Comprehensive Procedure or COMPP (OSPAR, 2003a). The type of model to be deployed depends on its purpose and the stage of eutrophication (see Figure 2-1) to be examined. For OSPAR eutrophication stage I – nutrient enrichment - a simple box-model for the nutrient balance can be sufficient (Lenhart et al., 2010; Vermaat et al., 2012). For stage II – the direct impacts such as an increase in phytoplankton biomass – biogeochemical models are required to simulate the growth of phytoplankton resulting from the increase in nutrients (Lenhart et al., 2010), whereas complex biogeochemical models are needed to simulate stage III impacts such as undesirable Phaeocystis blooms. The dissolved oxygen content can serve as an indicative parameter for stage IV but calls certainly for state-of-art biogeochemical models.

A design of environmental simulations models based on high-quality, peer-reviewed reusable model components is a promising path for the future (Papajorgji, 2005; Donatelli, 2007; Holzworth, 2010; De Kok et al., 2014b; Whelan, 2014). Such models are easier to design and maintain and the components could be exchanged through a web-based model library such as the one developed for the SPICOSA project (http://dataportals.pangea.de/spicosa/SPICOSA_model_library.html). The challenge, however, is to design components which are defined at the proper level of analysis, user-friendly, well documented with proper data handling allowing coupling to other components. The Scheldt model (Vermaat et al., 2012) is not coded in a single script but completely based on components using the ExtendSim® graphical interface, but not all of these components meet these criteria.

The Scheldt model (Vermaat et al., 2012) discussed in CHAPTER 5 is a useful example for testing the integration of model simulations in the Web-Based Application Server or WAS (see De Kok et al., 2014a) and communicating the concept to experts and stakeholders. For integration in the WAS it was decided to convert the spatial distributions for e.g. the chlorophyll-a levels into the NetCDF4 data format, which is CF compliant (http://cfconventions.org/). A limitation of the Scheldt model is that it describes the land-based emissions and transport of nutrients. In the SPICOSA project this problem was solved by coupling the model with an estuarine/coastal box transport model for the mixing of nutrients and temperature-dependent denitrification. For application in the WAS we followed an approach based on the OSPAR 2008 reporting for the Southern North Sea (OSPAR, 2008a); a salinity-dependent mixing function was applied as a generic concept to translate the loads into a spatial distribution for the winter DIN values and other indicators, using Belgian data for the complete 2Seas Territory. A simplifying assumption had to be made, however, implying that the concentrations respond linearly to the load reduction in a restricted “river influence” zone. The validity of this assumption will need to be verified once more sophisticated results of models such as those discussed in CHAPTER 3 become available. A general challenge, recently identified as key marine research issue (EU Seas-ERA Net Forum Brussels, June 2013) is thus to link up the river-basin modelling with the marine modelling. This will help address the eutrophication issue in a more systematic way, following the complete modelling chain from e.g. agricultural measures to the marine impacts.

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ANNEX A. LIST OF PROJECTS

Project Acronym	Title/Hyperlink
AMORE	Advanced MOdeling and Research on Eutrophication; http://www.ulb.ac.be/assoc/esa/comets/AMORE.htm; 1997-2001
AQUAMAR	
ASIMUTH	Applied Simulations and Integrated Modelling for the Understanding of Toxic and Harmful algal blooms; http://www.asimuth.eu
CLAMER	CLimAte change and European Marine Ecosystem Research; www.clamer.eu; 2010-2011
CoastColour	www.coastcolour.org; 2010-2011
CoBIOS	Coastal BIomass Observatory Systems ; www.cobios.eu
DYMPAHY	DYnamic observation system of Marine water quality based on PHYtoplankton analysis by flow cytometry; www.dymaphy.eu; 2010 -2013
ECOOP	European Coastal Operational Oceanography Project; www.ecoop.eu
GMES	Global Monitoring for Environment and Security; www.gmes.info
INPLACE	Integrated Network for Protection and Loss Assessment in Coastal Environment;
ISECA	Information System on the Eutrophication of our CoAstal seas
MARCOAST	MARine and COASTal environmental information services http://esa.gmes-marcoast.info/
MERSEA	Marine Environment and Security for the European Area; 2004-2008
MyOcean	www.myocean.eu; 2009-2012
SPICOSA	Science Policy Integration for COastal Systems Assessment; www.spicosa.eu
WaLTER	Wadden Sea Long Term Ecosystem Research; www.walterproject.nl

ANNEX B. LIST OF ALGAL EARLY WARNING SYSTEMS AND EUTROPHICATION WEB PORTALS

Title	Host	Web link	Contact person
ALGARISK	NEODAAS/ PML	www.npm.ac.uk/rsg/projects/algarisk	Ben Taylor; Peter Miller
Delft3D-BLOOMS Delft-FEWS	Deltares Water Insight	http://geoportal.waterqualitymap.eu; www.waterinsight.nl	Tineke Troost / Arjen Vrielink
ECOOP web portal			AL Gemmell Univ Reading
PREVIMER	IFREMER	http://www.previmer.org	
REMSEM?	MUMM	?? see MARCOAST2 project http://esa.gmes-marcoast.info/	Kevin Ruddick / G. Lacroix
REPHY	IFREMER	??	Alain Ménesguen. Catherine Belin.

ANNEX C. EU REGULATORY FRAMEWORKS

	regulatory framework	year of issue/target year
EU	Water Framework Directive 2000/60/EC	2000/2015
EU	Marine Strategic Framework Directive 2008/56/EC	2008
EU	Urban Waste Water Treatment Directive 1991/271/EC	1991
EU	Nitrate Directive 1991/676/EC	1991
EU	OSlo-PARis treaty (OSPAR)	1998
EU	EC Bathing Waters Directive	2006

ANNEX D. LIST OF MARINE EUTROPHICATION MODELS

Model	**country**	**hor resolution (km)**	**vert resolution (layers)**	**nr state variables**	**time step (min)**	***Phaeocystis***	**remarks**
MIRO-CO3D	B	5	5	32	15	x	
ECOHAM4	D	20	24	26	5	-	
Delft3D-GEM	NL	1-20	10	23	60	x	
ECOMARS3D	F	4	12	19	6-7	x	
POLCOM3D-ERSEM	UK	12	32	51	1-20	?	
GHEM-BFM	UK	10	25	45	1	?	

Key features of 3D coupled biogeochemical models for marine eutrophication after (OSPAR, 2008b; Lenhart et al., 2011).

ANNEX E. SELECTED MODELLING RESEARCH GROUPS

Model	Research Group(s)	Contact person(s)
MIRO - biogeochemical	Université Libres Bruxelles – Ecologie des Systèmes Aquatique (ULB-ESA);	Christiane Lancelot (ULB)
COHERENS - hydrodynamics	Management Unit of the North Sea Mathematical Models (MUMM)	Geneviève Lacroix (MUMM)
ECOHAM4	ZMAW – Institut für Meereskunde – Universität Hamburg (D)	Hermann Lenhart
Delft3D-GEM	Deltares	Hans Los (Deltares) Hanneke Baretta-Bakker (Rijkswaterstaat-Waterdienst)
ECOMARS3D	IFREMER	Valérie Garnier
POLCOM3D-ERSEM	Proudman Oceanographic Laboratory	Jason Holt, Roger Proctor
GHEM-BFM	Centre for Environment Fisheries and Aquaculture Sciences (CEFAS)	David Mills

Key research groups for coupled biogeochemical-hydrodynamic modelling of the Southern North Sea and English Channel (based on Moll and Radach, 2003; OSPAR, 2008; Lenhart et al., 2010).

ANNEX F. MODELLED IMPACT OF N REDUCTION SCENARIOS (OSPAR, 2008).

Subregion	winter DIN		winter DIP		Chl-a		confidence
% N reduction	50	70	50	70	50	70	
Belgian coastal	10-40	17-50	0-2	0-3	0-25	10-36	low
Belgian offshore	10-30	13-36	0-3	0-12	0-16	0-22	low-medium
French coastal	20-40	30-48	0-2	0-5	0-22	7-35	medium
Dutch coastal	35-55	50-65	0-20	2-20	0-12	0-15	medium
UK coastal	15-45	20-55	12-32	16-38	10-22	15-60	low-medium

Modelled impact of 50/70 % N load reduction 1985-2002 for key parameters in 2002 (OSPAR, 2008g).

ANNEX G. USEFUL LINKS

EU Directives
WWW.OSPAR.ORG
http://www.ec-gis.org/inspire/
http://ec.europa.eu/environment/water/water-nitrates/directiv.html
http://ec.europa.eu/environment/water/water-urbanwaste/
http://ec.europa.eu/environment/water/marine/index_en.htm
http://natura2000.eea.europa.eu/#

Eutrophication projects
http://www.thresholds-eu.org/
www.ecoop.eu
www.meece.eu
www.coastcolour.org
http://www.ulb.ac.be/assoc/esa/AMORE/objectives.htm
http://www.asimuth.eu
www.clamer.eu
www.dymaphy.eu
www.spicosa.eu
www.cobios.eu
www.geohab.info
www.ecoop.eu

SPICOSA model library
http://dataportals.pangaea.de/spicosa/SPICOSA_model_library.html

Marine information systems
http://emis.jrc.ec.europa.eu
www.ioc-goos.org
http://www.ioc-unesco.org/hab/
www.npm.ac.uk/rsg/projects/algarisk
http://geoportal.waterqualitymap.eu
http://www.previmer.org
http://www.marcoast.eu/
http://www2.dmu.dk/1_viden/2_miljoe-tilstand/3_vand/4_eutrophication/default.htm
http://www.sea-search.net/
http://www.marineregions.org/

Marine Maps
http://www.vliz.be/vmdcdata/marbound/download.php
http://www.mumm.ac.be/datacentre/Catalogues/datathemelayers.php

Atmospheric data
http://naei.defra.gov.uk/mapping/mapping_2009.php

General GIS data
http://freegisdata.rtwilson.com/#land-and-ocean-boundaries
http://www.eea.europa.eu/themes/landuse/interactive/clc-download

http://spatialreference.org/

Research institutes
http://marine.rutgers.edu/globalnews/mission.htm
http://marine.rutgers.edu/globalnews/links.htm
http://www.cefas.defra.gov.uk/
http://www.mumm.ac.be/

Scientific information
http://www.cefas.co.uk/eutmod
http://www.precisioninfo.com/rivers_org/au/archive/index.php?doc_id=10#3_biogeochem
http://www.encora.corila.it/Events/Conference/session2/markandya_paper2.pdf
http://www.bom.hik.se/ecoharm/deliverables/d3.pdf
http://www.coastalwiki.org/coastalwiki/Eutrophication_in_coastal_environments
http://www.wri.org/project/eutrophication/resources/publications

GLOBAL CHANGE
http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/
www.emep.int

Belgian and Flemish stakeholders and institutional platforms
http://www.coastalatlas.be/en/themes/policy-administration/
http://www.health.belgium.be/eportal/Environment/MarineEnvironment/index.htm?fodnlang=nl
http://www.bnl.gov/eims/main_e.asp
http://www.belgium.be/nl/leefmilieu/biodiversiteit_en_natuur/noordzee/
http://www.health.belgium.be/eportal/Environment/MarineEnvironment/index.htm
www.kustbeheer.be
www.kustatlas.be
http://www.agentschapmdk.be/
http://www.kustatlas.be/nl/themas/beleid-administratie/
http://www.kustatlas.be/nl/downloads/

Various
www.maweb.org
http://www.academiapress.be/science-and-sustainable-management-of-the-north-sea-belgian-case-studies.html
http://www.vliz.be/projects/gaufre/
http://www.mumm.ac.be/datacentre/Catalogues/datathemelayers.php
http://www.mumm.ac.be/datacentre/Tools/Spatial/index.php
http://www.mumm.ac.be/EN/Models/Development/Ecosystem/anim2.php#anim
ftp://ftp.met.no/projects/emep/OpenSource2011/model_results_2008
http://www.seadatanet.org/
http://www.biomecardio.com/matlab/smoothn.html#11
http://www.eos.ubc.ca/~rich/map.html

ANNEX H. WEB MAP SERVICES (EXAMPLES)

http://213.122.160.71/scripts/mapserv.exe?map=D:\Websites\EUSeamap\map\ExternalEUSeamapWMS.map

http://map.ices.dk/geoserver/wms

http://rsg.pml.ac.uk/wms

http://openlayers.org/dev/examples/

http://www.mumm.ac.be/datacentre/Tools/Spatial/index.php#choice

http://www.mumm.ac.be/EN/Models/Development/Ecosystem/anim1.php#anim

http://openlayers.org/dev/examples/getfeature-wfs.html

http://neaforest.vgt.vito.be/

http://rsg.pml.ac.uk/gis/amt/client/?sessid=eba9f495ab97f34d4ac4f4a3a3b9a0a299a28e69

ANNEX I. METADATA STRUCTURE FOR NETCDF4

Global Attributes:
GENERAL ATTRIBUTES = 'GENERAL'
site_name = '2Seas'
project = 'INTERREGIVa 2Seas Project ISECA (www.iseca.org)'
keywords = 'eutrophication,2Seas,OSPAR'
summary = 'model scenario produced with MatLab m_map toolbox using ICES salinity data and OSPAR (2008) mixing functions Belgium'
title = 'test scenario eutrophication 2Seas'
data category = 'model output'
creation_date = '14-Dec-2012'
elapsed time since 01.01.1970 = 1.36e+009
CONTACT INFO ATTRIBUTES = 'CONTACT INFO'
creator_url = 'www.iseca.org'
creator_name = ' Unit Environmental Modelling '
institution = 'Flemish Institute of Technological Research (VITO) Boeretang 200 - 2400 Mol (Belgium)'
contact1 = 'Jean-Luc de Kok'
creator_email = 'jeanluc.dekok@vito.be'
CREDITS & REFERENCE ATTRIBUTES = 'CREDITS'
references = 'to be completed'
citation = 'to be completed'
source = 'ICES databank - OSPAR'
license = 'not applicable'
COORDINATE ATTRIBUTES = 'COORDINATES'
projection = 'Equidistant Cylindrical'
geospatial_lon_min = -6
geospatial_lon_max = 7
geospatial_lat_min = 48
geospatial_lat_max = 54
step_longitude = 0.00899
step_latitude = 0.009
mean cell size x direction in km = 0.629
mean cell size y direction in km = 1
time_coverage_start = -999
time_coverage_end = -999
time_coverage_resolution = -999
time_coverage_duration = -999
NETCDF & CONVENTIONS ATTRIBUTES = 'NETCDF & CONVENTIONS'
metadata_conventions = 'unidata dataset discovery 1.0'
standard_name_vocabulary = 'CF-1.5'
Conventions = 'CF-1.5'
netcdf_library_version = 'MatLab_NETCDF4.1.2'
netcdf_file_type = 'NETCDF3'
cdm_data_type = 'not applicable'
EO ATTRIBUTES = 'EARTH OBSERVATION PARAMETERS'
id = 'not applicable'
naming_authority = 'not applicable'
RSG_sensor = 'not applicable'
RSG_areacode = 'not applicable '
RSG_hash_descriptor = 'not applicable '
processing_level = 'not applicable'
MISCELLANEOUS ATTRIBUTES = 'MISCELLANEOUS'
history = 'not applicable '
2D interpolation method used: = 'inpainting (Errico(2006)) '

Annex i. Metadata structure for netcdf4

```
Dimensions:
 longitude = 1447
 latitude = 668
 levelist = 1
 time = 1
Variables:
 longitude
 Size: 1447x1
 Dimensions: longitude
 Datatype: single
 Attributes:
 standard_name = 'longitude'
 long_name = 'longitude'
 valid_min = -180
 units = 'degrees_east'
 valid_max = 180
 axis = 'X'
 latitude
 Size: 668x1
 Dimensions: latitude
 Datatype: single
 Attributes:
 standard_name = 'latitude'
 long_name = 'latitude'
 valid_min = -90
 units = 'degrees_north'
 valid_max = 90
 axis = 'Y'
 latitude_longitude
 Size: 1x1
 Dimensions:
 Datatype: single
 Attributes:
 grid_mapping_name = 'latitude_longitude'
 levelist
 Size: 1x1
 Dimensions: levelist
 Datatype: int32
 Attributes:
 units = '1'
 long_name = 'model_level_number'
 time
 Size: 1x1
 Dimensions: time
 Datatype: int32
 Attributes:
 time_origin = '1970-01-01 00:00:00'
 long_name = 'time'
 valid_min = 0
 units = 'seconds since 1970-01-01 00:00:00'
 calendar = 'none'
 axis = 'T'
 depth
 Size: 1447x668x1x1
 Dimensions: longitude,latitude,levelist,time
 Datatype: single
```

```
Attributes:
_FillValue = -999
long_name = 'Bathymetric depth 2 minute ETOPO2 data in m source: '
standard_name = 'depth'
grid_mapping_name = 'longitude_latitude'
units = 'm'
chlorophyll_concentration_in_sea_water
Size: 1447x668x1x1
Dimensions: longitude,latitude,levelist,time
Datatype: single
Attributes:
_FillValue = -999
missing_value = -999
long_name = 'chlorophyll'
standard_name = 'chlorophyll_concentration_in_sea_water'
grid_mapping_name = 'latitude_longitude'
units = 'milligram m-3'
```

ANNEX J. GEODATA SOURCES

- Seasonal average salinity Southern North Sea 1970-2005: ICES Data Centre www.ices.dk
- EEZ boundaries UK,NL,B and F: Flanders Marine Institute (2012). Maritime Boundaries Geodatabase, version 6.1. downloaded from http://www.vliz.be/vmdcdata/marbound. Consulted on 2012-08-30
- City coordinates: www.geonames.org
- GSHHS high-resolution coastlines:Global Self-consistent Hierarchical High-Resolution (GSHHS) Coastline source: http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html Gorny, A. J. (1977), World Data Bank II General User GuideRep. PB 271869, 10pp, Central Intelligence Agency, Washington, DC. Soluri, E. A., and V. A. Woodson (1990), World Vector Shoreline, Int. Hydrograph. Rev., LXVII(1), 27-35. Wessel, P., and W. H. F. Smith (1996), A global, self-consistent, hierarchical, high-resolution shoreline database, J. Geophys. Res., 101(B4), 8741-8743.
- ETOPO2 2-minute bathymetric data: http://dss.ucar.edu (not used)