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SPICOSA : Science Policy Interface for Coastal Systems Assessment

EUTROPHICATION IN THE SCHELDT BASIN

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EXTEND MODEL – Status Report

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1 The Scheldt case: linking Extend to PCRaster - use of custom components

1.1 Introduction

Study site 9 – the Scheldt basin – deals with the effects of point- and diffuse sources of nitrogen on eutrophication of the coastal waters. A spatial dynamic model has been 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. The emphasis lies with the contribution of animal and crop farming on the nitrogen load and ultimately nitrogen concentration in the near-coast waters. The model is organized around four modules: farming economics, estuarine dispersal, policy intervention, and spatial dynamics (in PCRaster). This study site is interesting for several reasons. First, the model shows a good balance between the physical, social-economic, and policy aspects of eutrophication and is highly relevant in view of the science-policy interface objective of the SPICOSA project (see DOW – project objective 2.2). Furthermore, this case study has been chosen to design and test the interface between the temporal dynamics of the Extend model and spatial dynamics in PCRaster (see also reports D8.5 and D8.6). The outcomes are expected to be available in the early spring of 2009 and will serve as case example for the other study sites. The economic submodel is entirely based on custom-made model building blocks that were coded in the ModL language. The principles of robust component-based modelling that were outlined in chapters 3 and 4 of this report have been followed as much as possible. Data are imported via the query method that was proposed in section 5.3. Finally, the study area is spread over three different countries and 12 provinces, thereby illustrating the international character of coastal problems and related policy interventions. The following sections provide an outline of the Extend modules, the PCRaster module, and methodology followed to integrate both.

1.2 The Extend model - using custom components

1.2.1 General Structure

The Economic-Social-Ecological (ESE) system model for the Scheldt (Fig. 6a) is based on linkage of a dynamic simulation model in Extend and a spatially explicit model in PCRaster. The Extend model components are (1) a *farming economic* submodel for the N production from diffuse agricultural sources, (2) a *near-coast model* for the dispersal of the N load into the Scheldt estuary, and (3) a *social model* for the policy response to the N load at Rupelmonde and the coastal concentrations of N.

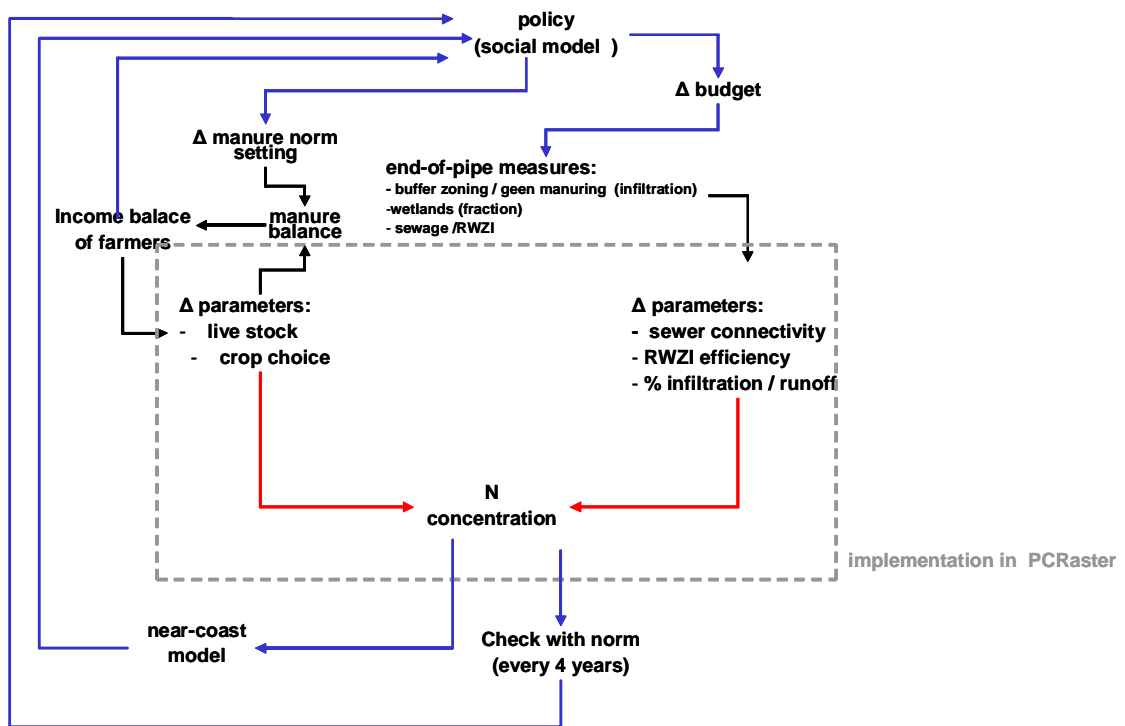


Fig a. General structure of the coupled Extend-PCRaster model for the Scheldt.

1.2.2 Economic model

The farming economic model is based on a cost benefit approach, taking into account the

costs of manure transport and processing. Data and model variables pertain to a categorization on the basis of (in hierarchical order) regions (for example, Flanders), eight farm types (for example dairy farming), five animal types (for example pigs), and ten crop types (for example corn). Animal farming contributes to N production, crop farming to N uptake. The yearly per-farmer income for each farm type is obtained from the gross income of animal and crop farming minus the costs of N transport/processing, and compared to the average regional income. If the income for a certain farm type drops below this value the number of farms declines exponentially in accordance with the farm life time (forty years). A key aspect of the model is the animal specific order in which manure is transported and the remainder processed. The farming economic model takes input from the social model via the N deposition target, which is updated every four years. Figure 6b shows the structure of the economic model, which is based on six generic model building blocks, that have been coded in ModL language. The blocks were designed one-by-one going from left to right in the flow direction. After being designed each block was implemented and then tested by connecting its interface to a data table or block generating random input. The orange post-processing block was designed last and manages the output from Extend to PCRaster. Of course, the blocks could also have been designed as hierarchical Extend blocks (as will be the case for most study sites). The two ways of designing model building blocks, however, do not differ in terms of component architecture as explained in Chapters 3-4.

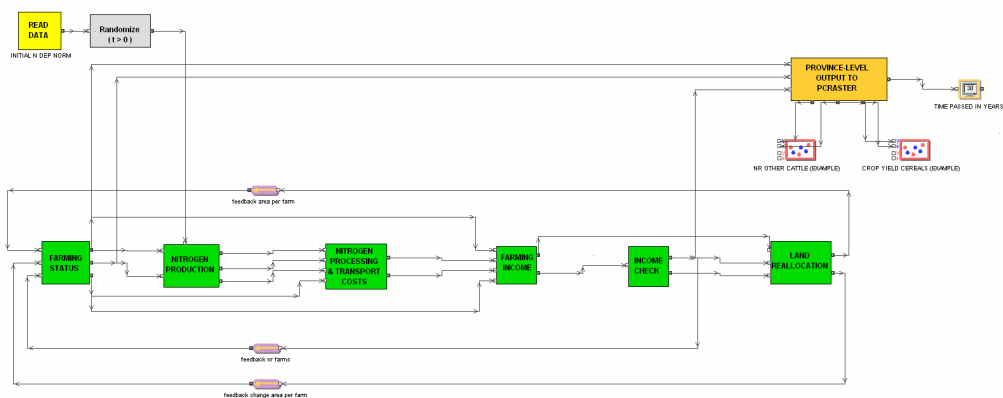


Fig. b. Model building blocks with feedback indicated for the economic subsystem for the Scheldt study site.

The six Model Building Blocks (MBBs) each perform a specific functionality and organized around a specific state variable, or limited set of closely related state variables:

- MBB Farming Status: crop area and animal units per farm type
- MBB Nitrogen Production: N production due to animal manure
- MBB N Processing & Transport Costs: costs per year of transporting and processing manure
- MBB Farming Income: yearly income by farm type
- MBB Income Check: (new) number of farms based on net income
- MBB Land Reallocation: area by farm type

In addition, there is a separate MBB to disaggregate the variables from the regional to the provincial level and pass the results to PCRaster, and a temporary MBB to mimic the policy intervention. This last MBB was needed because the economic model is not yet linked to the policy MBB.

Fig. 6c shows an example of the help documentation provided for each model building block, one of the requirements specified in Section 3.3. The information given includes the creator of the MBB, the last date of modification, the MBB's function, and lists the in- and out-connectors (see guidelines in Chapter 5).

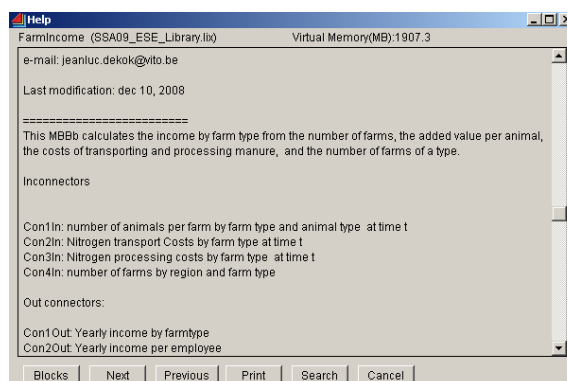


Fig. c. Help documentation for the MBB FarmIncome.

A number of technical problems were encountered during the design of the economic Extend model. It is important to emphasize that the solutions chosen are tentative in nature and still to be discussed. Robustness should be the objective. The problems were:

a. How to im- and export data? The choice was made to store all data in Extend databases (which can be exported to txt files if necessary) via the ModL code. Users can access and change the databases from the Extend Database menu. See Section 5.3 of this report for a more elaborated discussion on how to format the data. Whether this is the most robust solution is a matter for further discussion. It is also possible to place user-defined parameters in the dialog box of the MBBs, as was done for the Policy MBB (see section 6.2.4).

b. The economic model runs with a time step of a year, whereas the estuarine model (see Section 6.2.3) assumes a time step of about 2 days. Extend cannot run with different time steps simultaneously, as this quickly becomes a source of problems. The problem was temporarily solved by choosing the small time step for the complete Extend model and passing the time step explicitly to the economic MBBs that use the yearly time step. This means these are called more often than necessary. Nevertheless, this doesn't affect the computational efficiency, with the exception of the MBB that exports data to a txt file to be read by PCRaster. In this particular MBB a conditional test was included in the dialog box, to allow the user to indicate the time step for writing the data to txt files and plotting intermediate values (Fig. 6d). This speeded up the model considerably.

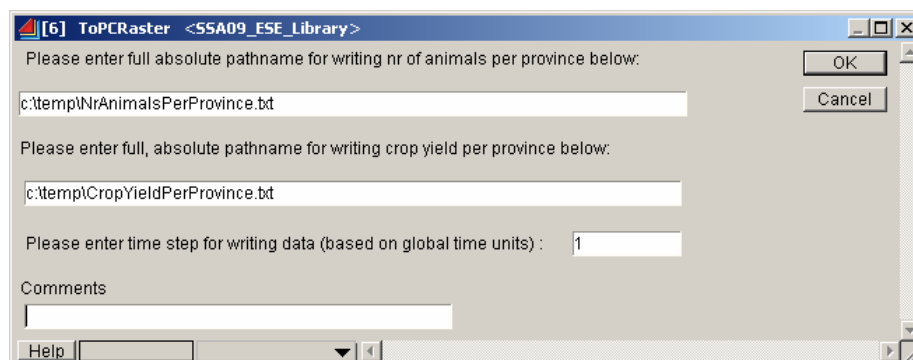


Fig. d. Dialog box for the model block to export data to PCRaster. The user can choose the location of the files and the time step (to avoid unnecessary data exporting) for exporting and plotting results.

c. The complexity of the economic model, which uses multiple categories such as regions and farm types, required to use of two-, and even three-dimensional arrays. The large (> ten) number of categories made it undesirable to model these data in a hierarchical Extend block. In fact, this was the main reason for programming the MBBs in ModL code. The arrays are passed to the MBBs via the connectors.

d. Extend automatically chooses the order of executing the MBBs (following the flow order). It is possible to choose a custom order of block execution, but this was considered to be too risky and not robust. As a result we ran into the problem of blocks requiring input from other MBBs that had not been executed yet. This initialization problem was solved by adding an If ... statement to the code in these block to allow the data to be read from the database with initial parameter values for the first time step. Feedback connectors were used to clarify the structure of the Extend model.

e. Some of the steps in the economic model require or produce the *change* per time step of state variables, in addition to the value of the state variables. Normally Extend deals with the changes in state variables automatically: the variables are updated after each time step according to the structure of the hierarchical block or ModL code of a custom MBB. The problem was dealt with by passing the rate of change per time step via the connectors. For example, the MBB "land reallocation" uses the number of farms and change in this state variable per time step as inconnector, and passes the change in the area per farm as outconnector to the MBB "Farming Status".

f. The linkage between the Extend and PCRaster model raised a number of issues to be decided on. For example, the regional output of the economic module had to be disaggregated to the provincial level (a special building block was designed for this purpose) and, in the opposite direction, a decision had to be taken about how to translate the yearly N load from the PCRaster model to values with a much smaller time step used by the near-coast model (see next Section). The coupling between Extend and PCRaster is discussed in more detail in Section 6.4.

1.2.3 Near-coast model

Given the ESE of the Delta case the purpose is to develop a model that can adequately 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. The first version of the model should comprise six boxes (Figure 6e) for the Scheldt estuary and three boxes for the Belgian coastal zone. No distinction between water column and sediment is made yet. Only one process is taken into account: N-removal via denitrification.

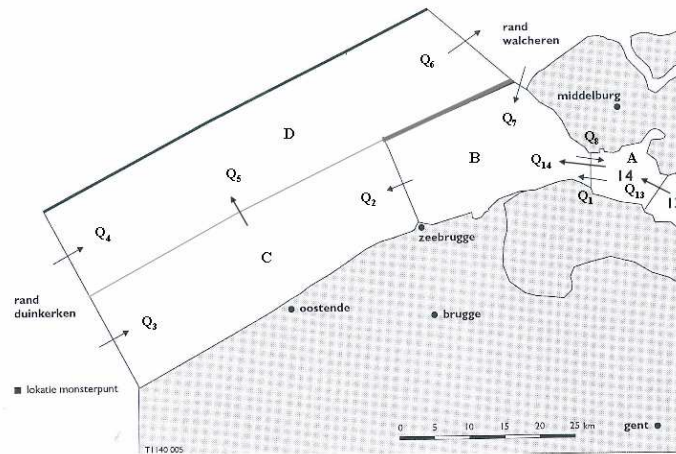


Fig. e. Box model structure of the coastal model in Extend.

In Extend the near-coast model consist of one MBB with a single input-connector for the N load at Rupelmonde (taken from PCRaster) and a single output-connector for the N concentration at sea (last box In Fig. 6e). Figure 6f below shows the internal structure of this hierarchical Extend block.

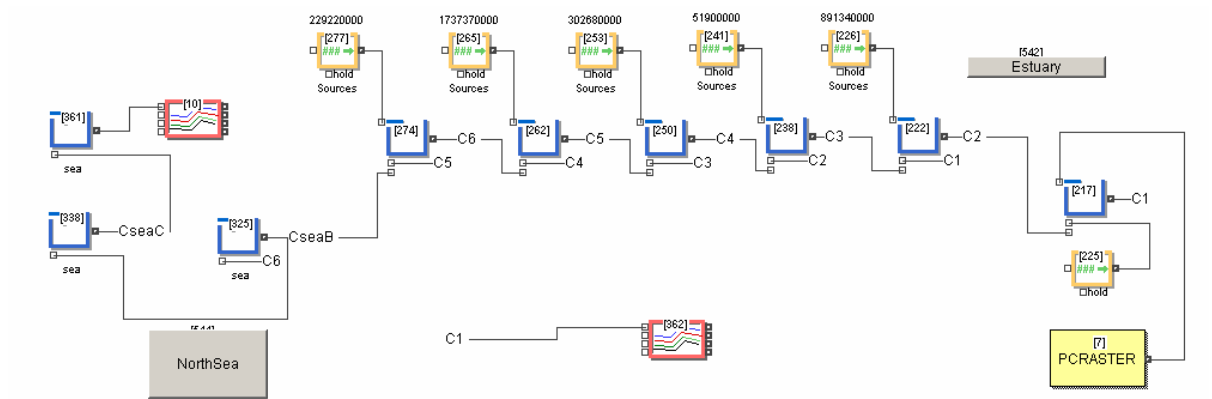


Fig. f. Internal structure of the MBB for the N dispersal in the Scheldt estuary and coastal waters.

1.2.4 Social model

Two key aspects of the social model component are the policy response to changes in the environmental status, as reflected by the near-coast N concentration, and the willingness of farmers to participate to the chosen measures. The user of the ESE model will have the possibility to choose both the time period over which a measure achieves its effect, as the fraction of the target that is reached over this time. For example, whether a 80 % reduction in the N concentration should be reached in 20 % of the time (see Fig. 6g).

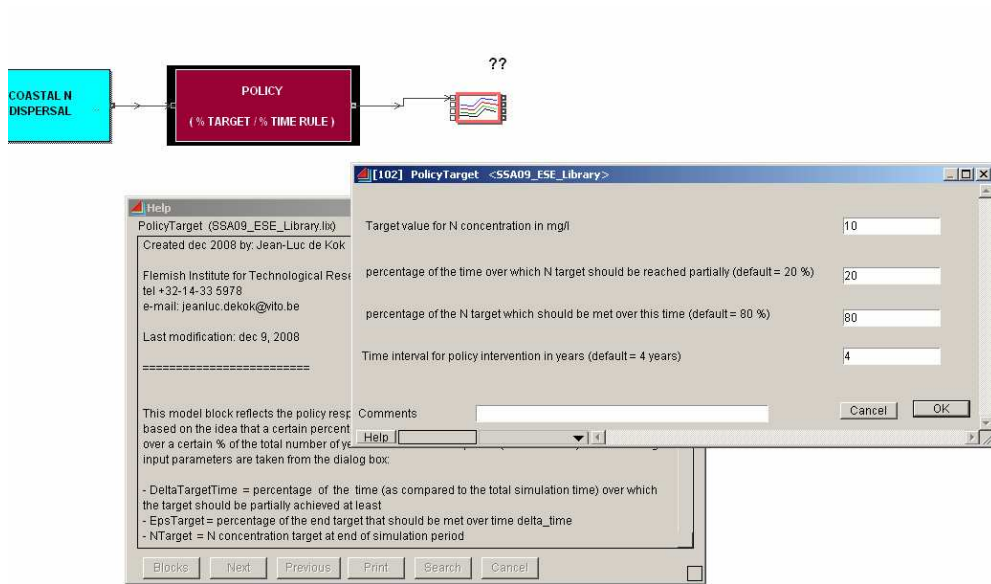


Fig. g. Extend building block for policy response to N concentration with user-defined target setting and time horizon.

This model setup reflects the reality of a delayed effect of policy implementation, and allows for sensitivity analyses. The actual intervention will only occur with a four-year electoral time interval in the model. This means that every four years the modelled concentration is compared with the projected target value and used to adapt the policy, thus leading to feedback from the social model to the economic model. The willingness to participate of farmers will be incorporated in the social model component and passed to the economic model component as a parameter affecting the farming practice. Furthermore, there is a separate social aspect, which will be included in the economic model for technical reasons: a check of the income of farmers with a norm income at the regional level. The outcomes of this check affect the number of farms that will close down in the next time step of the simulation (see Section 6.2.1).

1.3 The PCRaster model

The PCRaster model separates processes on diffuse sources of N and point sources of N.

Calculation of the N load at a point in the catchment is based on:

$$L_x = a \cdot (DI_x + (b \cdot SSS_x))$$

where:

L_x : annual river load of nitrogen [kg/yr] at location x

DI_x : annual emission from point sources [kg/yr], direct input to surface water upstream of x

SSS_x : annual emission from diffuse sources [kg/yr], surplus at soil surface upstream of x

a : factor to account for retention/losses in surface water [-]

b : factor to account for retention/losses in the soil/groundwater system [-]

The model consists of four submodels (Fig. 6h):

1. Emissions: calculates the net input of N in the catchment. This submodel has a separate module for diffuse sources and for point sources
2. Hydrology: calculates the water fluxes and residence times in three compartments: surface runoff, shallow groundwater and deep groundwater
3. Soil and groundwater fluxes: calculates the retention and losses of N in the soil and groundwater system (b)
4. Transport and retention in the river network: calculates the retention and losses of N in the river network (a)

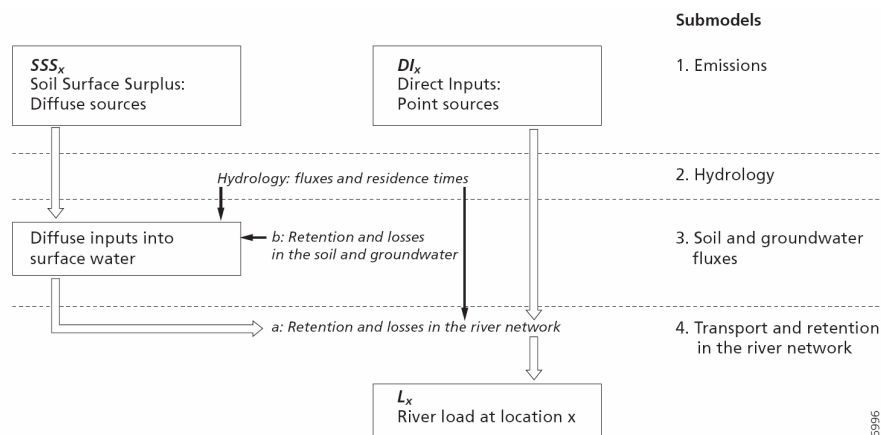


Fig. h. Overview of the modelling approach in the PCRASTER model POLFLOW adopted here (De Wit, 1999).

The PCRASTER model has a spatial resolution of 1 km² and a time step of one year. It uses a range of data, including annual mean temperature, rainfall, population density, industrial point sources, and takes the livestock density and crop yields at the provincial level from the Extend model. Feedback from PCRaster to Extend consist of the N load at Rupelmonde, which is the starting point for the estuarine model. The PCRASTER model links population density, sewage treatment efficiency and point sources into the drainage network, and it has a link between farming profitability, manure regulation and the quantity of N delivered as diffuse contribution. Here socio-economics interface into the ecological part of our models.

1.4 Linking Extend and PCRaster

For technical reasons the decision was made to let the Extend model have the priority in the simulation process. The Extend modules (farming economics, estuarine and coastal dispersal of N, and policy response) will be linked to the spatial PCRaster module in two ways:

- from Extend to PCRaster via the number of animals per farm and crop yield, which are calculated by the economic module at the regional level and then disaggregated to the provincial (NUTS3) level for passing to PCRaster

- from PCRaster to Extend via the N load at Rupelmonde, which is the input for the estuarine module (see Section 6.2.3)

An open issue to be decided on is how to deal with the difference between the yearly time step of the PCRaster model's output on the one hand and the time step of less 0.01 year used for the N dispersal model. Several options are available, for example using an average value throughout the year, a trend, or a seasonally fluctuating N load.