Babovic, V. & L.C. Larsen (eds.), 1998. Hydroinformatics'98. Conference Proceedings.

Ecomorphological Decision Support System for the Western Scheldt

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ABSTRACT: The Ecomorphological Decision Support System for the Western Scheldt area in the Netherlands computes the long term effects of morphological impacts on the functioning of the ecosystem. Changes in the morphology of the estuary caused by dredging are translated into spatial changes of the silt content in the bottom and the altered profiles of tidal flats and channels. This results in a change of available habitat area for benthic organisms, leading to changed potential biomass, affecting the ecological functioning of the system. Evaluation and analysis of morphological, hydrodynamical and ecological results for different dredging scenario's, support decision-makers to optimise the dredging operation with respect to ecological damage.

1. INTRODUCTION

The Western Scheldt estuary forms an important shipping route connecting the North Sea to Antwerp Harbour. Due to the increasing capacity of the ships and the sedimentation in the channels, deepening of the shipping channel is necessary. The dredging operation can have large impacts on the morphology of the estuary and therefore on the ecological functioning.

The Ecomorphological Decision Support System (DSS) is developed as part of the Dutch technology stimulation programme LWI. This DSS computes the morphological development on a long time scale and subsequently calculates the biomass of characteristic benthos species. The results of this study are presented in the report by Wang et al. (1997).

This paper focuses on the methodology and tools that are used to comprise the Ecomorphological DSS. It starts with a description of the structure and tools and subsequently deals with a description of the models that are used.

2. STRUCTURE OF THE ECOMORPHOLOGICAL DSS

This Decision Support System is built with the aid of Delft-Tools, which are modules with different tasks that together form a general framework for Decision Support Systems. The structure of the Delft-DSS system is presented in Figure 1.

The Ecomorphological Decision Support System has three parts in which several of the modules of Delft-DSS are used. The first part consists of the definition of scenarios and measures. The second part consists of the execution of the sequence of models used to determine the ecological effects of morphological changes. The third part consists of the comparison of the computational results for different cases.

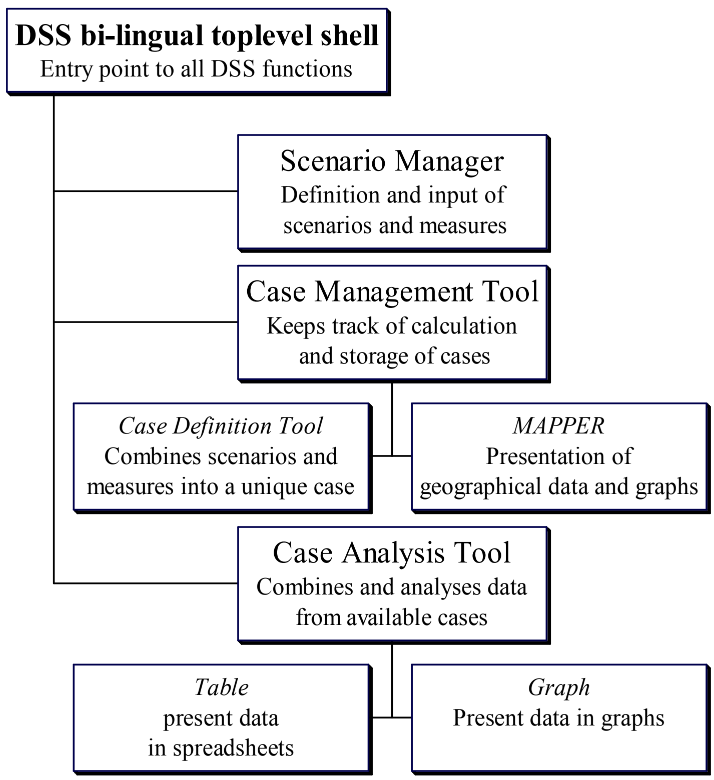

Figure 1. Structure of Delft-DSS.

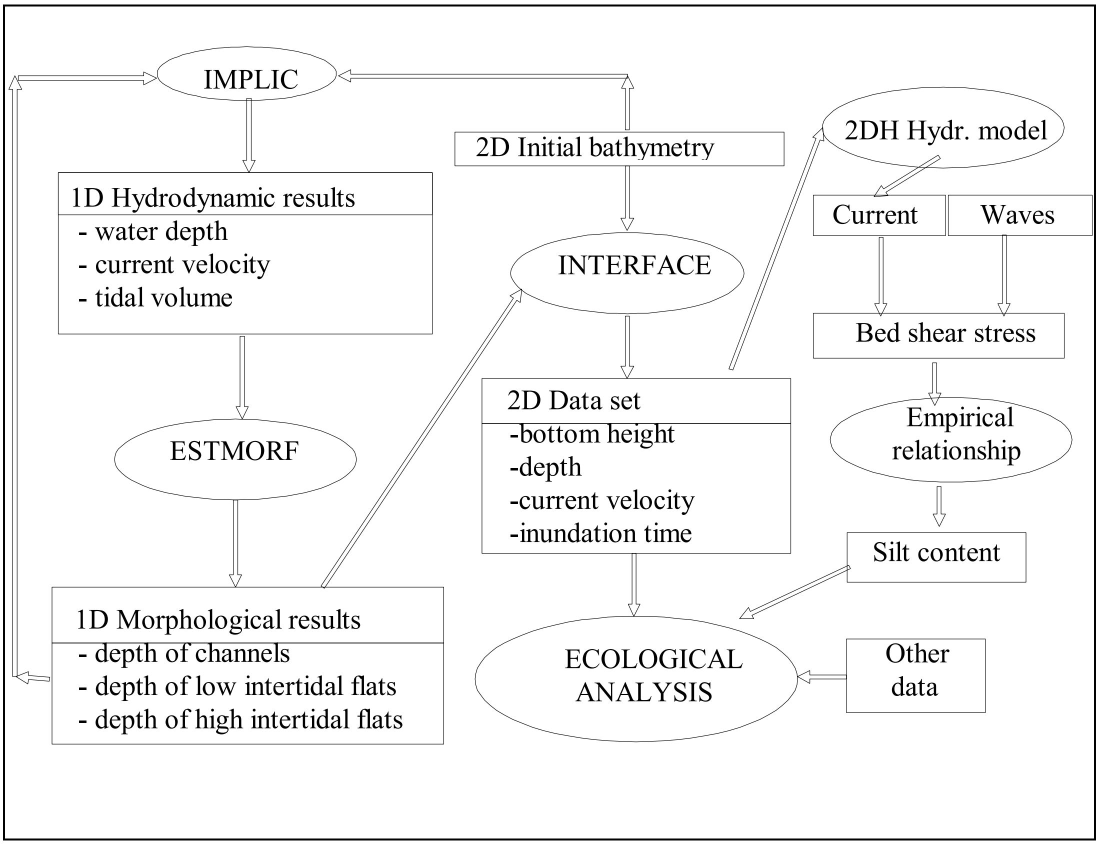

Figure 2. Computations in the Ecomorphological DSS.

2.1 Definition of Scenarios, Measures and Decision Rules

In this part of the DSS, different scenarios, measures and decision rules (Fig. 3) can be defined and/or altered by making use of the Scenario Manager. This tool allows the user to manage and register sets of data that are used to define a specific case later on.

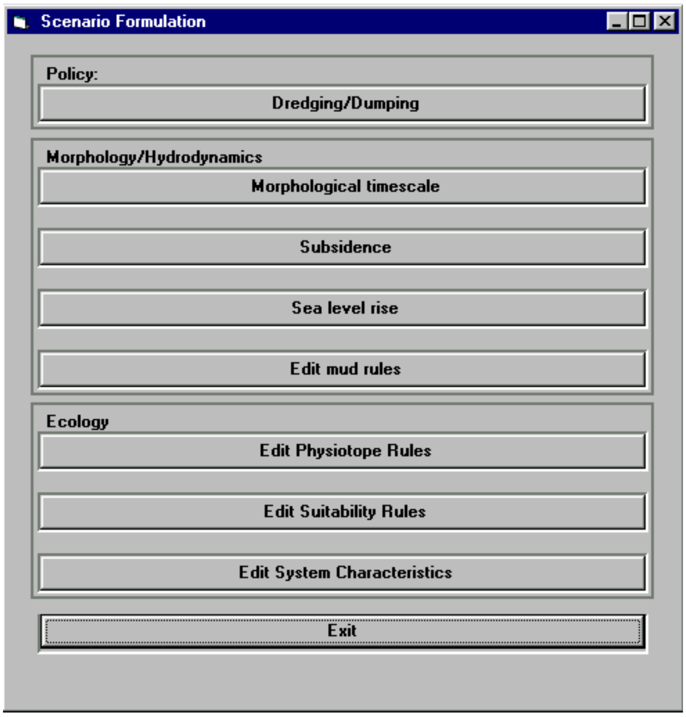

Figure 3. Selection of available scenarios, measurements and decision rules.

The measures that can be edited are the deepening of the shipping channel and subsequent maintenance dredging together with the dumping of dredged material. Editing of these measures takes place in a GIS-environment in which the magnitude of the activities can be changed for each gridcell and for each timestep of the morphological model (Fig. 4).

Scenarios that are important for the morphological development of the estuary are sea-level rise and bottom subsidence. These parameters are included in the morphological modelling and can therefore be defined as well.

Sets of empirical decision rules are used for the computation of the silt content in the bottom, the definition of physiotopes and the definition of habitat suitability rules for macrozoobenthos. Each of these rules can be adjusted by the user of the DSS, for example when new, better empirical knowledge is obtained.

Finally, major system characteristics of the Western Scheldt (salinity, oxygen levels and suspended sediment concentrations) can be modified. These parameters are used to compute the biomass of the modelled species.

2.2 Execution of the Models in the DSS

The second part of the DSS consists of the execution of the sequence of simulation models used to determine the ecological effects of morphological changes. This part makes use of the Case Management Tool.

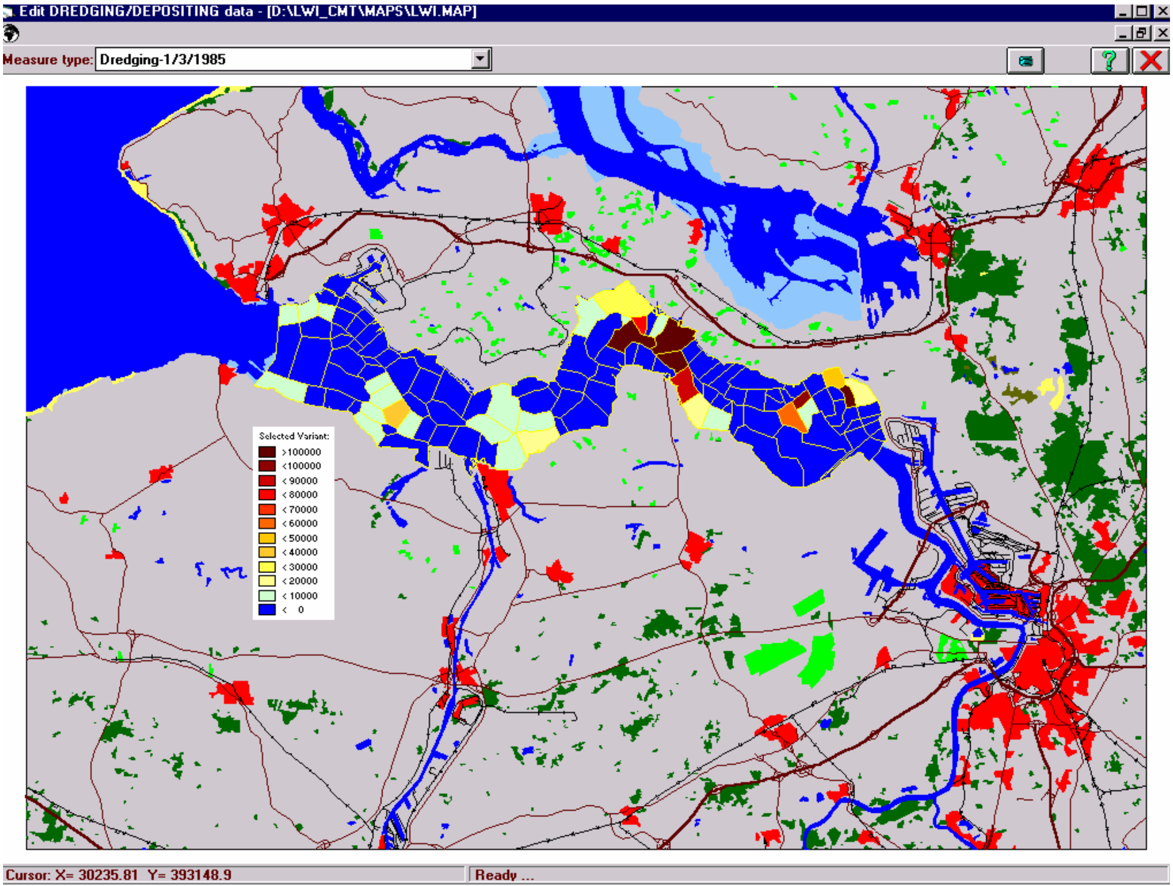

Figure 4. Editing of dredging and dumping measurement in the Western Scheldt.

This tool gives the user the possibility to define new cases, to save computational results of a case and to open existing cases. It keeps track of the execution of the different models, to make sure that the correct order is used (Fig. 6).

The user must start with the definition of a new case or selection of an existing one with the Case Definition Tool. A case is defined as a combination of scenarios and measures. Subsequently the first models in the model sequence can be run; the 1D morphological model ESTMORF, together with the 1D hydrodynamical model IMPLIC and a 1D to 2D post-processing model. This yields the long term (decades) changes in hydrodynamical and morphological parameters on a small spatial scale of 60 × 60 meters, that are used to compute the silt content of the sediment in the next model. Based on this information the spatial distribution of physiotopes and habitats are computed. Finally the biomass of important benthos species for different regions is calculated. After each step, the intermediate results can be presented with the GIS tool MAPPER to get a spatial overview of the effects on the Western Scheldt.

2.3 Comparison of the Computational Results for Different Cases

The third part of the Ecomorphological DSS consists of the Case Analysis Tool to combine and analyse the results for different cases. The Case Analysis Tool can present the results in different ways, with a scorecard, bar chart, a spatial presentation or more. Several statistical methods are ready for use to calculate averages, frequency distributions, extremes, etc., over locations, parameters and timeseries.

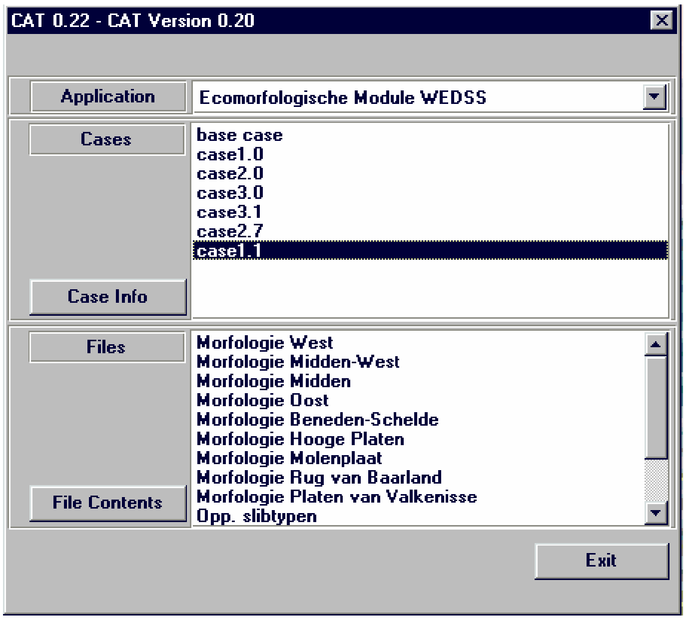

Figure 5. Case Analysis Tool

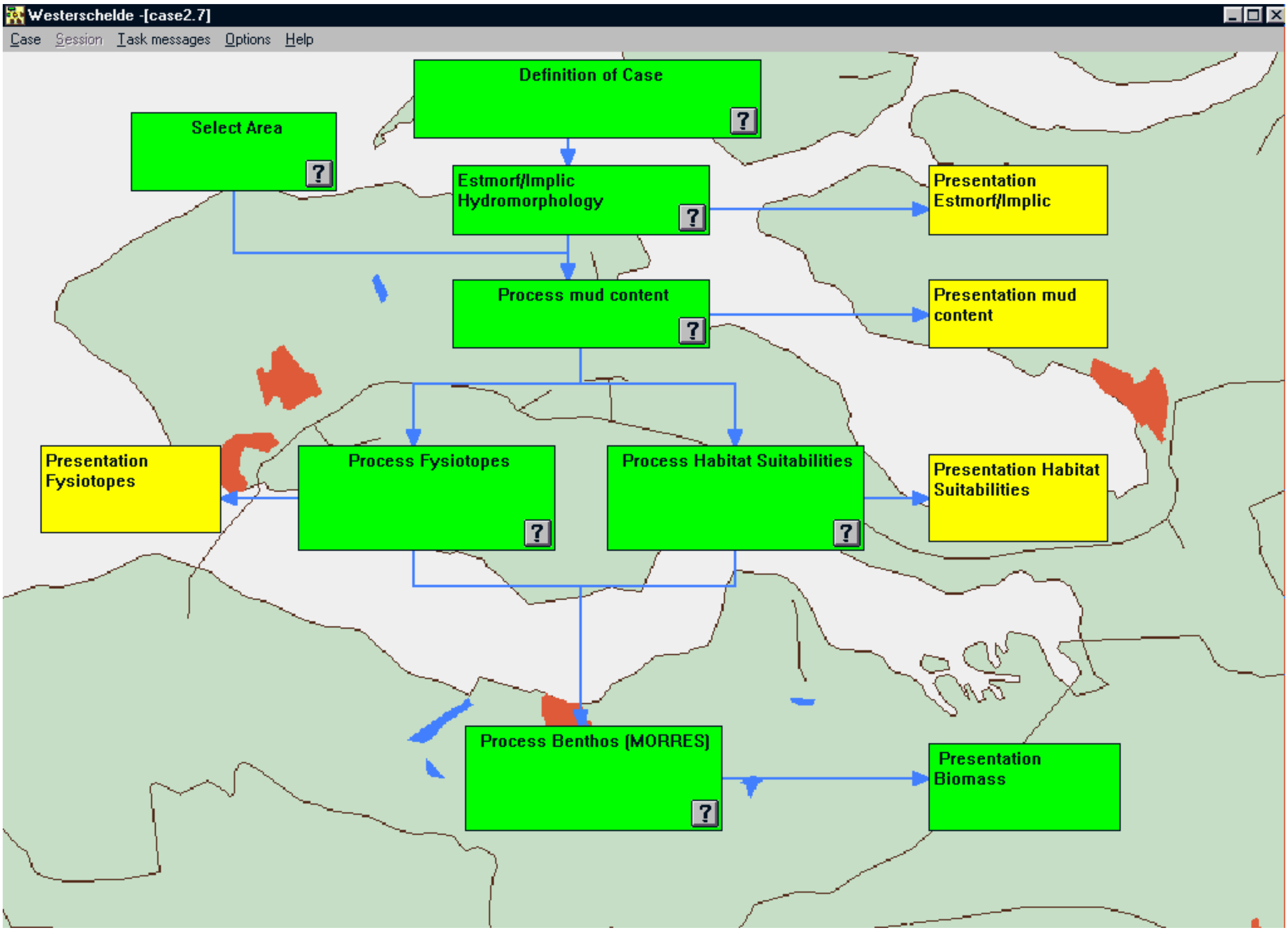

Figure 6. Case Management Tool.

3. MODELS USED

An overview of the models and the way they link together is presented in Figure 2. In the following paragraphs an explanation is given.

3.1 Morphological and hydrodynamical models

For the computation of long-term morphological changes in the Western Scheldt estuary the one-dimensional morphological model ESTMORF is used (Wang et al., 1997). ESTMORF is a model for estuarine morphology. The semi-empirical algorithms in ESTMORF are based on the assumption that after a disturbance in the morphological system the system tends to go to an equilibrium state by sedimentation and erosion. The hydrodynamic data required for defining the morphological equilibrium and for calculating sediment transport and the corresponding morphological changes are calculated with the one-dimensional hydrodynamical model IMPLIC.

The Western Scheldt is schematised as 190 branches, where each branch has a different cross section that is defined by the height of the high tidal flat, the low tidal flat and the gully. The equilibrium cross-sectional area of the gully depends on the tidal volume, the equilibrium heights of the flats depend on the tidal range. Figure 7 shows the cross-section of each branch.

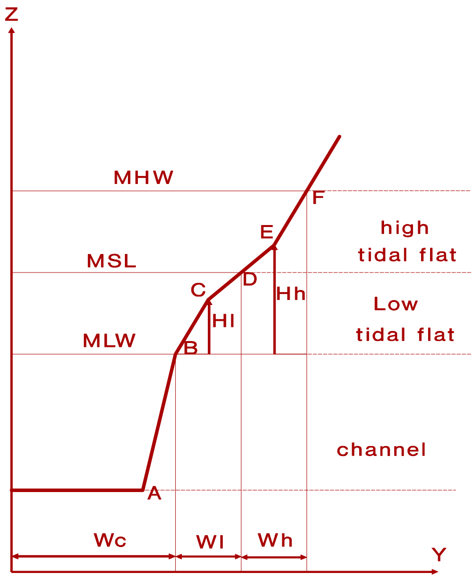

Figure 7. Cross-section through branch of ESTMORF.

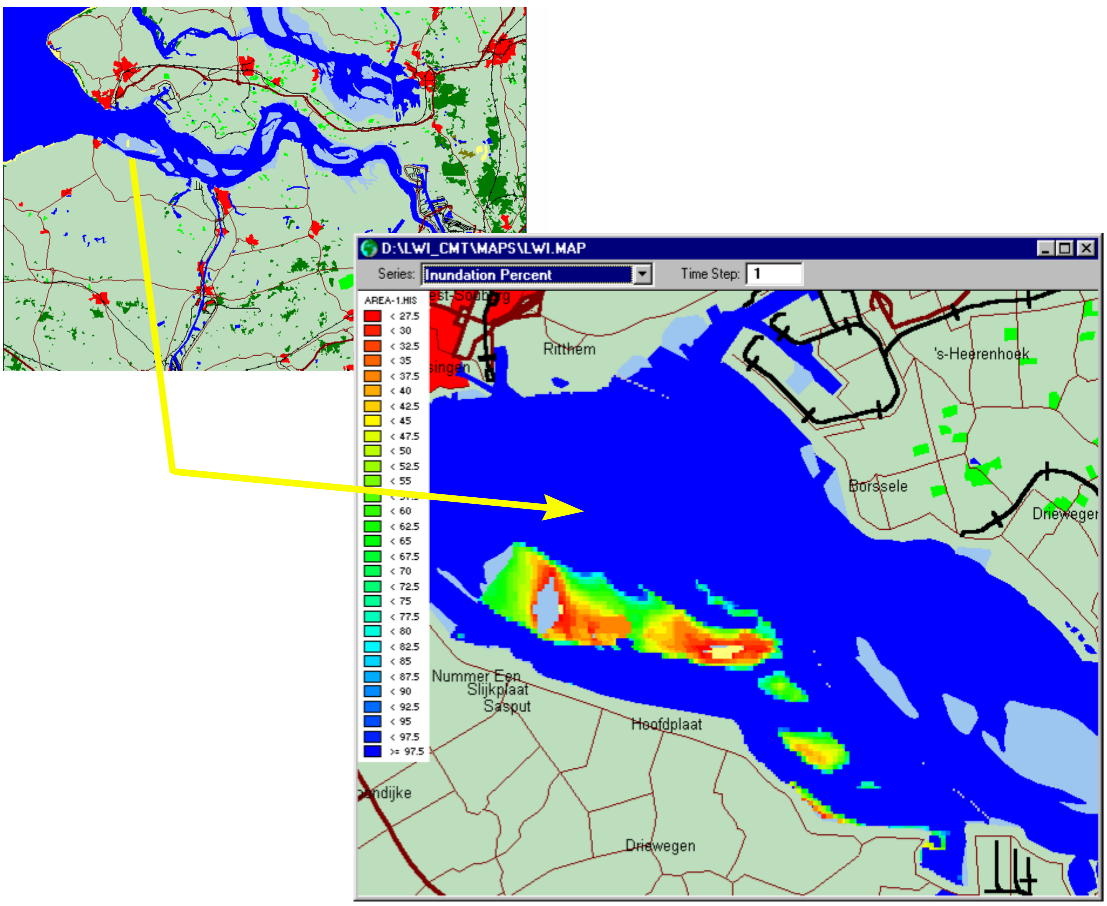

Figure 8. Inundation percentage calculated after hydrodynamic and morphological modelling.

For each timestep of 30 days ESTMORF calculates the sedimentation / erosion in the three parts of each cross section. This information goes back to IMPLIC, which will compute the new water movement and subsequently ESTMORF makes a new computation, based on the morphological equilibrium state and the sediment transport. ESTMORF and IMPLIC are calibrated for the Western Scheldt and are able to represent the historical development from 1968 to today. The morphological changes in the cross sections are used in the 1D to 2D post-processing to determine the changes in bathymetry and hydrodynamic condi-

tion on a 2D grid. To do this a large data set is used which has two-dimensional hydrodynamical results. These results include the bathymetry, current velocities and bed shear stresses for the historical situation of 1968 on a computational grid of 60 by 60 meters. Based on the new bathymetry and the known current pattern a new current field is computed. This allows calculation of the new bed shear stress for each grid cell. The bed shear stress caused by currents as well as wind waves is calculated.
Besides the shear stresses, results of these models are the maximum and minimum water depth, inundation percentage, current velocities and changed bathymetry. These can all be presented spatially with the GIS-mapping tool MAPPER (Fig.8).

3.2 Calculation of the silt content in the bottom

The suitability of the Western Scheldt as a habitat for bottom animals is determined by depth and bottom silt content. Therefore, information about the bottom silt content in the top 10 centimetres of the sediment is necessary.

It is generally believed that the bed composition is closely related to the local hydrodynamic conditions indicated by the magnitude of the bed shear stress. However, a remaining question is how to define a suitable parameter for indicating the bed composition in tidal regions. In an area under influence of tidal flow, the bed shear stress is varying continuously. Hence it is difficult to say what is the characteristic bed shear stress. Furthermore, a possible parameter for indicating the bed composition must also be related to the bed properties characterised by the critical shear stresses for erosion and deposition, the settling velocity of particles and the erosion coefficient. This leads to the idea of defining a comprehensive indicating parameter that takes into account the above parameters and is named the *local hypothetical equilibrium concentration* (Wang, 1996). Since it only depends on local parameters it is relatively easy to evaluate from the data supplied by a hydrodynamic model. This method has been successfully applied for the Nieuwe Merwede (Wang, in press) but is not yet implemented in the Ecomorphological DSS. Instead, an empirical relationship is used, that describes the relationship between the maximum water depth, the bed shear stress by currents and waves and the bottom silt content. To assess this relationship measurements carried out on a tidal flat in the Western Scheldt, the Molenplaat, were used together with detailed hydrodynamical calculations for the same area (Herman et al., 1996; Thoolen & Baptist, 1997). This relationship does not give the absolute silt percentage of the top 10 centimetres, but a classification in one of four classes. Table 1 gives the classes of silt percentage, silt being particles <63µm.

Table 1. Classes of silt percentage.

Class	Description	Silt percentage
S2	Very sandy	Less than 2%
S5	Medium sandy	Between 2% and 5%
S10	Low sandy	Between 5% and 10%
X	Sandy mud	Between 10% and 50%
M	Mud	More than 50%

3.3 Ecological models

To predict the consequences of morphological and hydrodynamical changes on the ecological functioning of the Western Scheldt estuary a habitat evaluation procedure (HEP) is used.

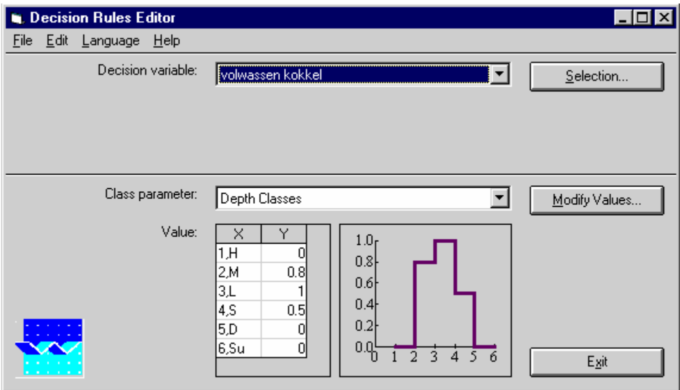

Figure 9. Habitat suitability rule for the adult cockle.

A habitat evaluation procedure (HEP) is a collection of analytical methods and habitat suitability index models for faunal and floral species or communities. This method is developed by the US Fish and Wildlife Service (US Fish and Wildlife Service, 1980). The models are used to predict changes in the suitability, in terms of the carrying capacity, of the faunal and floral habitats in response to changes in environmental factors water depth, substrate type and location, inundation frequency or duration and water quality. The habitat suitability requirements are derived from life history studies, field observations, frequency analyses of environmental factors characterising habitats used by fauna and flora and literature surveys. The overall habitat suitability is determined by the suitability index rating of the environmental factor which limits the carrying capacity. The output of a HEP can be expressed as an overall habitat suitability per species or community, which is a number between 0 (unsuitable) and 1 (optimal), the areal extent of suitable habitat or even as the potential biomass of a species or community.

Based on the results of the morphological and hydrodynamical models the ecomorphological DSS describes ecotopes. Ecotopes are areas with similar physical, chemical or biological conditions. For this application ecotopes are defined on the basis of a water depth classification and the silt content classification depicted in Table 1. The classification of water depths is shown in Table 2. For each gridcell of 60 × 60 meters the combination of depth class and silt class results in a specific ecotope, for example the muddy high intertidal flat.

Table 2. Classes of depth.

Class	Description	Depth
H	High intertidal	Inundation 0% – 33%
M	Medium intertidal	Inundation 33% – 67%
L	Low intertidal	Inundation 67% – 100%
S	Shallow subtidal	0 – 2 m under MLW
D	Deep subtidal	>2 m under MLW

The presence and abundance of marine macrozoobenthos is dependent on the hydrodynamical and morphological conditions. Therefore the species assessed in the ecomorphological DSS are macrozoobenthos species. The habitat requirements with regard to bottom silt content en depth are described for in total thirteen species. These species are representative for the total biomass of benthic species in the Western Scheldt and are presented in Table 3.

Table 3. Macrozoobenthos species.

Cerastoderma edule
Macoma balthica
Mya arenaria
Nereis diversicolor
Arenicola marina
Hydrobia ulvae
Corophium volutator
Nepthys hombergii
Scoloplos armiger
Bathyporeia spp.
Capitella capitata
Haustorius arenaurius
Heteromastus filiformis

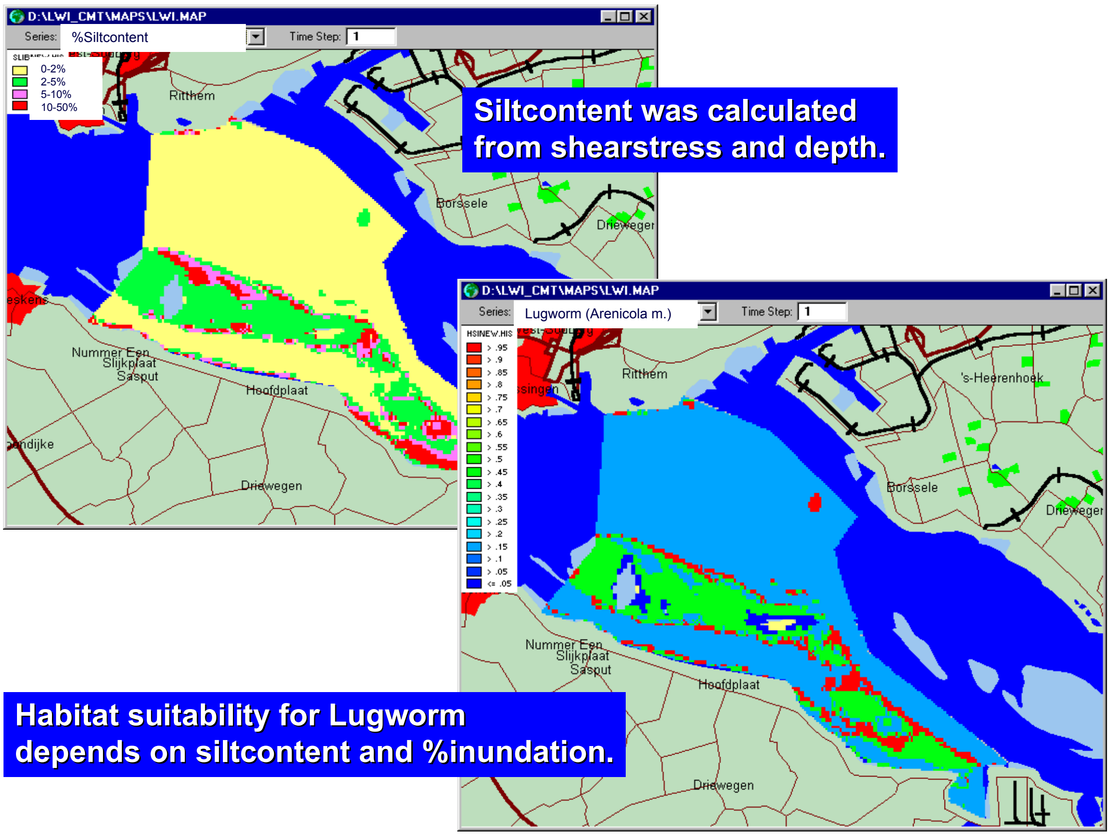

Figure 10. Habitat suitability for the Lugworm.

For each of the silt and depth classes the habitat suitability index is derived from measurements and significant literature (Fig. 9). The ecological analyser evaluates for each gridcell the values for silt class and depth class and applies a minimum rule to define the habitat suitability index for that location. Presentation of these results in a GIS mapping environment is part of the ecomorphological DSS (Fig.10).

The carrying capacity expressed as grams ash free dry weight per square meter for each species is calculated next. This value is dependent on the biomass under optimal conditions, the habitat suitability index for each location and system characteristics such as salinity and dissolved oxygen concentration in summer and winter. The calculation of biomasses is carried out for one of nine pre-defined regions in the estuary. The system characteristics are not significant on the small spatial scale of gridcells, but are known on the larger scale of regions.

The biomass per species for a particular region is calculated by determining the total area of suitable habitat per species multiplied with the optimal biomass that will occur in the most optimal habitat:

$$B = H_{total} \times B_{opt} \quad (1)$$

where B = biomass for a specific species (gAFDW); H_{total} = total area of suitable habitat (m^2), B_{opt} = optimal biomass (gAFDW/m^2).

The total area of suitable habitat is the sum of the suitable ecotope areas for a region multiplied with the species specific sensitivity to system characteristics. The suitable ecotope areas are calculated as the product of the habitat suitability index and the ecotope area for each gridcell:

$$H_{total} = S \times \sum_{i=1}^{j} (H_i \times A_i) \quad (2)$$

where S = species specific reducing factor for system influence; H_i = habitat suitability index for gridcell i, A_i = area for gridcell i (m^2).

4. CONCLUSION AND DISCUSSION

The ecomorphological DSS integrates between human impacts, prediction of physical developments in an estuary and the related ecological consequences. The detailed spatial scale gives a potentially excellent comparison with field measurements and is useful for the future analysis of other (human) activities in the Western Scheldt. This model is calibrated for a specific tidal flat and Delft Hydraulics is working on validation of the modelled results within several other projects.

Limitations to the modelling approach are the (semi-) empirical relationships that are used to derive bottom silt content and habitat suitabilities. Because these relationships and indices are empirical and are subject to discussion, the ecomorphological DSS gives the user the possibility to alter these values according to his own insights.

Delft Hydraulics routinely undertakes biological prediction using a habitat assessment approach as a component of many projects dealing with establishing the effects of engineering or environmental management actions and/or developments. In such projects, the goal is often to provide decision makers with quantified evidence of biological changes and an assessment of the significance of these changes so that full cognisance is taken of the potential ecological effects of decisions. Then trade-offs between beneficial and detrimental consequences can be made. Biological prediction of this form is essential to modern decision making. Ecological effects have to be included in a relevant, understandable and quantifiable manner. The use of habitat evaluation procedures has provided a robust, repeatable and understandable means of doing this.

The ecomorphological DSS is able to make a fast and detailed analysis of the dredging impacts on an ecosystem. Its structure allows the user to define his own policy measures, scenarios and decision rules and to use built-in models to calculate the effects of dredging on the ecological system.

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