The link between morphology and ecology in the Long Term Vision for the Schelde Estuary

A conceptual framework and preliminary results

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Executive summary

The sub-project to establish the links between the morphology and ecology in the Long Term Vision for the Schelde Estuary was initiated in March 2000. At the time of initiation of the project, studies focused on the morphology of the Westerschelde and the development of ecosysterm goals for the Schelde Estuary were already underway. The conceptual bases of these investigations formed stringent boundary conditions for the approach to be adopted in establishing the linkage between morphology and ecology.

The conceptual justification of the selected approach comprises:

- The insight that the most relevant time scale on which to assess the ecosystem response of the estuary is the meso-scale, because the goals of preserving the multi-channel character of the lower Schelde and the meandering character of the upper Schelde proclude extreme human-induced changes on the macro- and mega-scale.

- The logic that the ecosystem develops as a composite response to the hydro-morphological forcing i.e. that if we can describe the abiotic character of the estuary we can then infer the biotic character, provided that no limiting exogenous conditions occur (e.g. deterioration in influent water quality).

A 3-level hybrid approach was developed to support the coupling between morphology and ecology in the process of forming a Long Term Vision for the Schelde Estuary.

The first level uses morphological simulations of bed topography and associated hydrodynamic responses as input data. These simulations are transformed to ecologically relevant indicators such as the extent of characteristic abiotic (salinity) zones and the areal distribution of subtidal, intertidal and supra-tidal physiotopes within these zones. The utility of the output is dependent on the assumptions made in conducting the simulation runs. In the case of this study, use had to be made of simulations runs of only four day duration conducted for the purpose of determining sediment transports. The simulation period and the tidal forcing at the downstream boundary therefore were not appropriate to the prediction of the physiotopes and abiotic zones for biota. However, indicative results were obtained and served to demonstrate clearly the data processing methods necessary to transform hydro-morphological simulation data into ecologically appropriate indices.

The next step in the three-level approach, is separated from the previous step of data translation to ecologically relevant indices. The primary reasons are that data errors or limiting model assumptions need not propogate through the hybrid linked system, and that the separation allows one to proceed based on information or knowledge that may not be able to be simulated by numerical models. Thus Level 2 may be implemented independently of Level 1, or value judgements of the ecologically relevant indicator data generated in Level 1 may be used as input data for Level 2.

In Level 2, the Policy Wizard was used to support the development of a conceptual ecosystem model in a careful stepwise manner. This conceptual ecosystem model consists of seventeen components with a number of system variables to describe them. Inter-relationships between the system variables are described in terms of a seven point qualitative scale which allows their strength and direction to be indicated. This ecosystem model is a means of capturing the system understanding of the experts (in the Nature Working Group) and making it available to other people involved in the LTV process. It is moreover very effective in causing experts to check their own logic, to improve the consistency of ecologically based arguments and assists in focussing discussion on controversial interactions. To enhance its use and acceptance within the LTV, it was necessary that validation of the model occurred with a combined group of ecologists and morphologists and not only separately. This occurred in mid September 2000, resulting in much interactive discussion, clarification of inter-relationships in the model and a general increase in confidence in the approach and its utility.

In Level 3, criteria that allow the attainment of the ecosystem goals to be judged are identified and related to the system variables in a structured way using the Policy Wizard. Lastly, the effects of interventions and relevant exogenous factors are assessed qualitatively by first defining the strength and direction of their effects on individual system variables and then evaluating the results as these effects propogate through the ecosystem. Results are expressed as the range of effects that could possibly occur (from the most negative to the most positive). Most useful at this level of policy evaluation are the insights that can be obtained by comparing interactions to different composite management interventions. Second, third and higher level interactions often cause unexpected effects which can be understood by tracing the logical paths.

Thus the use of the ecosystem model to qualitatively simulate the effects of management interventions and their robustness to exogenous variations (Levels 2 & 3), facilitates policy formulation whether realistic and relevant abiotic simulations can be undertaken or not. However, most satisfying of all is to be able to incorporate an assessment of the change in an ecologically relevant indicator (i.e. a change in areal extent rated on the seven point scale from strong negative through to strong positive), as an effect in the ecosystem model and then be able to evaluate the ecosystem response in terms of its effects on the ecosystem goals. This is to implement fully the 3-level hybrid and in so doing to link morphology and ecology and obtain policy-relevant answers, all be they qualitative in nature.

1 Introduction

1.1 Morphology-Ecology within the Long Term Vision Process

In March 1998, the Technical Schelde Committee (*Technische Schelde Commissie*) commissioned the development of a Long Term Vision for the Schelde Estuary in response to a request from the Dutch Minister of Transport, Public Works and Water Management, issued with the agreement of her Belgian counterpart.

In January 1999, the guiding principal for the Long Term Vision (LTV) was determined as "the development of a healthy and multi-functional estuarine water system that can be utilized sustainably for human needs."

Three central perspectives from which the LTV was to be developed, were identified and associated working groups formed, namely:

- Accessibility (*Toegangkelijkheid*),
- Safety from Flooding (*Veiligheid*), and
- Nature (*Natuurlijkheid*).

Soon thereafter, a research group for Morphology (*Cluster Morfologie*) was formed as the fundamental role of the morphological dynamics of the estuary in determining the potential and the limitations imposed by the natural system on human usage, became evident.

The time frame for the development of the Long Term Vision is two years, commencing January 1999. The working groups have played an active role in the middle period (commencing June 1999) with substantial involvement in attaining consensus on the *Korte Termijn Schets* , a description of the anticipated state of the Schelde Estuary in the short term as a result of agreed policy (RA 1999). The working groups and the Morphology Cluster are the official mechanism whereby the existing information and the results of the research projects launched in support of the LTV process are synthesised and then taken further within the process of vision development.

In February 2000, the morphological research team from WL/Delft Hydraulics presented the conceptual basis of their approach (Winterwerp *et al.* 2000a) to the Working Group for Nature with the aim of achieving agreement on the fundamental hypotheses and promoting an exchange of opinions regarding the potential for linking morphology and ecology. There was considerable discussion (RA 2000a) and it was apparent that the links between morphology and ecology in the Schelde Estuary occur over many different temporal and spatial scales. It is therefore no simple matter to establish a linkage between morphological changes and the ecosystem effects or to define acceptable limits within which these changes may occur, in a robust manner. This discussion provided the first clear indication that specific effort would have to be devoted to the coupling between morphology and ecology within the LTV process.

In the period from December 1999 to February 2000, the research project on the development ofthe goals for the ecosystem of the Schelde Estuary was initiated. This was undertaken by Prof P Meire and Mr E de Deckere of the Universitaire Instelling Antwerpen (UIA) and involved an initial phase in which the conceptual basis for the approach was scientifically tested by means of discussions with acknowledged experts in both the Netherlands and Belgium. The result of these deliberations was the decision to adopt the ecosystem health approach of Costanza et al. (1997) and to use knowledge of the inherent character of the Schelde ecosystem as it is at present in the establishment of the goals for the ecosystem (de Deckere & Meire 2000).

In late March 2000, the circumstances were that morphological and ecological research projects were underway. Both projects had very clear conceptual bases and preliminary information was available from the morphological research. This provided an indication of the form that the output would take and enabled further discussion on the possibility of establishing links between the predicted morphological behaviour of the estuary in the long term and the potential ecosystem responses. Questions remained as to whether such a linkage was possible and, if so, how it could be implemented. However, there was general consensus that establishing a linkage between morphology and ecology was a desirable development on both a conceptual and practical level.

1.2 Project Objective

An additional supportive role was subsequently defined within the LTV process to promote integration between the activities undertaken within the morphological investigation and the goal formulation from the viewpoint of nature and to establish linkages, where possible. Specific tasks included:

- enhancing communication and the exchange of ideas between the morphologists and ecologists
- linking the morphology and ecology of the Schelde Estuary as explicitly as possible, by defining helpful indicators, utilizing available data and applying existing techniques.

The fact that the success of this sub-project was dependent upon information flow from, and the progress of, the morphological research project and the development of the goals for the natural environment of the Schelde Estuary was clear from the outset.

However, the objective of the sub-project will have been achieved if:

- the predicted morphological changes can be associated with anticipated ecosystem responses, and
- the anticipated ecosystem responses can be tested for acceptability against the goals for the natural environment of the estuary, or
- the reason(s) why such a linkage cannot be made in specific instances can be stated clearly.

1.3 Structure of the Report

The approach adopted in developing the link between the morphology and ecology of the Schelde Estuary is described in this report. The constraints which time, resources and the existing research projects (the organisational boundary conditions) placed on the choice of approach are discussed first (Section 2). The chosen approach is then implemented (Section 3) and the preliminary results analysed (Section 4). The advantages of the approach and the limitations thereof are critically assessed (Section 5). Conclusions regarding the applicability and utility of the approach are then drawn and the recommended actions specified together with priority ratings (Section 6).

2 Method Adopted

2.1 Communication

At the outset of the study, both the morphological study and the ecological study were already underway. Consequently, the communication aspects of the sub-project were addressed through the attendance of meetings of both the ecological research team and the morphological research team. In the case of the former, the role of Dr Slinger was supportive in terms of discussions on the rival merits of potential approaches to the formulation of ecosystem goals. This role was undertaken in association with Drs. Coosen and Dr. de Winder, chairperson and member of the Working Group for Nature (WGN), respectively. The communication with the morphological team was more limited and the role adopted was that of translation of potential ecological questions into hydro-morphological data requests. This had to be undertaken in advance of the final formulation of the goals for Nature because this investigation was still underway and the form that the goals would take was not then evident. Data requests, therefore, were made on the basis of anticipated needs. For the majority of the project, communication with the morphologists mainly revolved around the data processing necessary to obtain ecologically relevant indicators from existing hydrodynamic simulation data. In the later stages of the project, advice was sought on the formulation of the morphological component of a conceptual ecosystem model.

Not all requests to the Rijks Instituut voor Kust en Zee, Middelburg, and WL/Delft Hydraulics for ecologically relevant simulation data (Slinger 2000) could be met. This exerted a constraining effect on the development of the linkage and the processing of existing and available data, because the full extent of the data limitations only became clear in the last stages of the project (beginning of September 2000).

Despite the fact that delays and difficulties in communication made for additional difficulties in developing the coupling within the time constraints of the project, these aspects will not be reported upon specifically. Suffice it to say that the organisational boundary conditions were constraining on the one hand and on the other hand provided the forum of the working group within which valuable deliberations and information exchange on morphological-ecological links could occur. These discussions were very helpful and are referenced in the subsequent text.

2.2 Methodological requirements

The approach to be adopted in this study must satisfy the following requirements, as far as possible:

1. ***Temporal and spatial scales***: The response of the ecosystem to morphological changes occurs over time scales ranging from centuries to hours or minutes and over spatial scales ranging from the whole estuary to individual habitats. The linkage between morphology and ecology cannot occur over all of these scales, instead a pragmatic and conceptually sound decision must be made as to the most relevant temporal and spatial scales for the LTV. The vision itself must be formulated for the year 2030 with intermediate actions and development scenarios till 2010.

2. ***Time and information constraints***: In view of resource limitations and project time constraints, the generation of new information specifically for establishing the link morphology-ecology is not a viable option. This link should not be data-intensive, but should be based on available knowledge and information as far as possible. It has also to be established concurrently with the morphology research project and that of the development of the ecosystem goals.

3 ***Defensibility:*** Firstly, the method used in establishing the linkage morphology-ecology must be well founded conceptually, the information used and its sources must be clear, as must be the assumptions upon which the linkage is based. Subjective value judgements arising from the brief to represent the interests of Nature in the Schelde Estuary must be separated out and clarified as far as possible. The approach must provide the Nature working group with a sound logical basis from which to positively propose improvements, indicate the possible implications of uncertainties and, at the very least, defend the estuarine ecosystem against detrimental human activities.

4 ***Adaptability:*** Because the LTV process is dynamic, involving a continuous development of ideas and opinions, an approach which can be rapidly updated to reflect the latest developments in the process and yet remain scientifically defensible is a prerequisite. The capability to investigate the effects of differences in opinion on the outcome is a desirable quality.

5 ***Bridging Function:*** The method adopted must be coherent with the conceptual bases of the morphological research project and the ecosystem goals project. This bridging function is a pre-requisite and as such the strongest of the scientific boundary conditions imposed on the type of approach that can be applied.

2.3 Conceptual basis: morphology

The following differentiation in temporal and spatial scales is made by the morphological research team (Stive *et al*. 1998):

- ***Mega-scale dynamics***: Changes on the spatial scale of the whole estuary or large components thereof, including the exchanges with the mouth region and adjacent coast. The associated time scales are centuries, while the relevant external forcing (natural and anthropogenic) includes sea level rise and sand mining.

- ***Macro-scale dynamics:*** Changes in primary and secondary channels, such as alterations in the functions of channels from flood to ebb. The associated time scales are decades. The relevant external forcing includes channel deepening, maintenance dredging, dumping, the 18.6 year tidal cycle, extreme events and so on.

- ***Meso-scale dynamics***: Changes such as the formation, migration and disappearance of connecting channels, sediment transport on tidal flats and sediment exchange between tidal flats and the channel. The associated time scales are years. The relevant external forcing includes extreme events, dredging and dumping.

- ***Micro-scale dynamics:*** Changes at the level of bed forms e.g. sand waves. The associated time scales are days. The only relevant direct forcing is entirely natural.

The morphological study focussed on the Schelde Estuary from the mouth region until just upstream of the harbour of Antwerpen - the upper reaches of the estuary were not included in the research brief. The concept that estuarine management should focus on ensuring that the morphological basis of the estuary remained qualitatively the same in the long term, the so-called ‘no regret’ management policy, was established relatively early in the study (Winterwerp *et al*. 2000a). Relevant mega-and macro-scale effects that were considered in the analysis included the possibility of drowning (*verdrinking)* or large scale sedimentation (*verlanding*) of the system and the influence of sand mining and dredging and dumping activities as well as sea level rise. Out of these investigations (Winterwerp *et al*. 2000b), came the principal that the mega- and macro-scale character of the estuary should be preserved i.e. the multi-channel nature of the Westerschelde estuary. Associated with this principal is the idea that changes at the meso-scale could, and should, then still occur. These changes includes the appearance, migration and disappearance of features such as gulleys in the sand flats (*kortsluitgeulen*) or marsh areas (*schorren*).

If one accepts this concept of maintenance of the multi-channel system (‘*handhaven meergeulensysteem*’) and the associated ‘no regret’ management strategy, the logical outcome is that meso-scale changes in the morphology of the estuary are the primary geomorphological effects that would exert influence on the Schelde ecosystem. The need to focus on the meso-scale in attempting to link morphology and ecology for the purposes of the Long Term Vision development is then apparent and forms the conceptual basis for the temporal and spatial scale of the linkages to be established in this sub-project (methodological requirement 1).

2.4 Conceptual basis: ecology

The conceptual basis for the establishment of the ecosystem goals for the Long Term Vision of the Schelde Estuary derives from the ecosystem health literature and the viewpoints that the connections of the estuary with the North Sea and the upstream catchment are of vital importance. This is discussed by De Deckere and Meire (2000) and summarised briefly here.

The concept of ecosystem health relates to the characteristic structure and function of an ecosystem, which may be judged as ‘healthy’ if it possesses sufficient resilience to maintain its characteristic structure and function given a certain measure of stress, or can recover from an external stress within a given time (Costanza & Mageau 1999). Biologically, the structure of the Schelde Estuary is understood as the form and complexity of the food web and function is understood in terms of the nutrient cycle and the degree of primary and secondary production (De Deckere & Meire 2000). The resilience is then understood as the measure of the stress for which recovery is still possible and the time it will take.

Application of the ecosystem health concept therefore requires that one looks at the inherent character of an estuarine system, using historical information as background material, but not as a reference state or condition.

Additionally, the concept that the Schelde Estuary is connected with the North Sea and with the upstream catchment is fundamental to the approach adopted. The principal that these connections should be maintained and that the Schelde Estuary should not act as a hindrance to biological exchange or exercise a detrimental effect on water quality in the North Sea is adopted.

The validity of the ecosystem health approach for determining the ecosystem goals for the Long Term Vision of the Schelde Estuary and the role of the principal of connectedness therein, was discussed with leading experts in Belgium and the Netherlands. The interviews occurred until late in April leaving the form of the results to be expected from the study unclear until early in May 2000. However, the conceptual thinking behind the approach was much discussed within the nature working group allowing this element of the scientific boundary conditions on the coupling morphology-ecology to gradually become clearer.

The bridging function (methodological requirement 5) therefore must be satisfied by:

- linking the meso-scale morphological character of the estuary to the structure and function of the ecosystem, and

- facilitating assessment of this ecological response against goals expressed in terms of the ecosystem goods and services identified by Costanza et al. (1997).

A limitation of an approach confined to the meso-scale is that the resilience of the system cannot truly be established. Only aspects of within meso-scale resilience can be addressed. This is not a problem per se. as long as the limitations this imposes on the validity of the predictions are realised at the outset. For instance, there is then an implicit assumption that no 'flip points' occur in the biology of the system that do not originate either in the morphology or biology at the mega- or macro-scale. This is an implicit assumption of dynamic equilibrium, which may well be valid for the Schelde Estuary but is certainly not valid universally.

2.5 Available information and existing techniques

From discussions between morphologists and ecologists it was clear that the type of predictions that morphological models can make are reasonably accurate for channels but inaccurate for tidal flats and that no meso-scale morphological changes could reasonably or accurately be predicted (RA 2000a).

However, during these discussions it became clear that bottom schematisations would be produced for the different scenarios proposed for evaluation (only three at that stage) and that the Delft3D numerical model (Roelvink & van Banning 1994) would be calibrated and applied for the calculation of sediment transports. Thus information on bed topography and associated hydrodynamics would be available.

Much background ecological information was available and the current knowledge of the system had been summarised by van Damme et al. (1999). However, no predictions of the anticipated future state of the ecosystem in response to altered conditions within the system (e.g. channel deepening) or external to it (e.g. water quality of the Schelde catchment), were available.

Existing ecological prediction techniques for the Schelde Estuary included the Ecomorph model (Wang *et al.*1997), but this focused on predicting macrobenthic species occurrence and biomass on the basis of habitat suitability assessments and had not proved particularly reliable in calibration tests (Baptist 1999). The Habimap software system of RIKZ yields physiotope information, but required the basis simulation data and bottom schematisations in a specific form for ease of processing (D de Jong *pers. comm.*). In contrast, @-Ivis, the data presentation system used for the storage and display of the information supporting the *Korte Termijn Schets* and designed to serve this purpose within the Long Term Vision development process was available (RA 2000b). The decision was thus easily taken to use the @-Ivis shell as the presentation format of any ecologically relevant geographically referenced information. This decision complies with methodological requirements 2 and 5.

Although the system to be used for the presentation of map data was clear, the techniques to be applied in building the link between morphology and ecology were not. To be suitable, techniques had to be able to use and interpret hydrodynamic information, be able to include the expert judgement and the intuition of specialists (because most of their knowledge was not formalised in models) and be strongly goal focussed so that the purpose of the linkage remained central.

These criteria meant that detailed time- and spatially-dependent models were not suitable and also excluded from consideration approaches that are heavily reliant on information. Among the latter are the expert system applications for ecological prediction (e.g. Adams & Bate 1997), which require much species-dependent knowledge. A conceptual modelling approach seemed more suitable. An existing technique developed in the Netherlands specifically to support a conceptual modelling approach in policy development and successfully applied in WADBOS (Reijngoud & van de Ven 2000) came to mind. The technique comprises an associative conceptual modelling system, the Rapid Assessment Methodology, embedded in a software shell, the Policy Wizard (van den Werff ten Bosch *et al.* 2000). The Policy Wizard is built around a stepwise policy development process that is routinely and extensively applied by Resource Analysis (RA 2000c) and that is focused on judging the efficacy of management interventions against goals (expressed in terms of measurable criteria). This system complies with the methodological requirements 2 and 5 and aspects of 3. Moreover, the Policy Wizard can be used to support interactive discussions and explore the effects of differences in opinion or uncertainty on outcomes (methodological requirement 4) (Reijngoud & van de Ven 2000, RIVM

2000). It therefore seemed an obvious choice for use in the linkage between morphology and ecology, not least because of the availability of an existing forum of experts (WGN).

The one caveat in the selection of this as an element in the approach is its relative youth (first developed in 1997) and the fact that extensive documentation on the limitations of the approach is not available. Comparative assessments of the technique have been undertaken (Donkers 1997, RIZA 1999) and a paper with a critical analysis of the approach is in preparation (P Kouwenhoven *pers. comm.*). Other than this, a conference paper (Kouwenhoven 1998), the manual (RA 1998) and the examples of existing applications in the Netherlands (van Eck & Consemulder 1999, Reijngoud & van der Ven 2000) provided background reference material.

2.6 Selected approach

Cleary no single system can meet all the requirements for linking morphology and ecology. Accordingly a hybrid approach was adopted (Figure 1). This involved developing a three-level linked system of:

- translating hydrodynamic simulation data into ecologically relevant indices (Level 1);
- conceptual ecological model (Level 2), and;
- structured association with ecosystem goals (Level 3).

Information from Level 1 is presented using the @-Ivis software system (RA 2000b), the existing means of storing and transferring geographically based information within the process of Long Term Vision development. The information is the result of a series of map overlays and reclassifying procedures using hydrodynamic simulation data and bottom schematisations of past, present and predicted future bed topographic as input data. The relevance of the output is primarily determined by the boundary conditions and assumptions of the hydrodynamic simulations and its level of detail is determined by the choice of reclassification limits.

The output from Level 1, maps providing an indication of the relative changes in extent and position of the abiotic zones and physiotopes, can be used to initiate Level 2 of the approach. Level 2 can also be initiated independently (System entry point in Figure 1) so that the morphology-ecology coupling does not rest only on aspects that can be simulated by numerical models. Information from Level 1 enters Level 2 in the form of an expert assessment of the predicted relative changes in zones and physiotopes. For instance a ten percent reduction in brackish marsh area may be rated as a severe loss, whereas a ten percent loss of estuarine shallows may be considered a moderate loss.

Level 2 and 3 were developed using the Policy Wizard software system, which employs the Rapid Assessment Methodology within a stepwise policy analysis framework (van den Werff ten Bosch *et al.* 2000). An associative ecosystem model was developed and validated within a group setting (the WGN) using the Rapid Assessment Methodology. This was then used to link a system understanding in a qualitative fashion to the ecosystem goals derived by de Deckere and Meire (2000). This is accomplished by defining system variables as criteria (the link between Level 2 and 3).

The output from Level 3 is a range of influence of management interventions and/or exogenous variables on the criteria. The range of response of the ecosystem can be traced at every step and the reasons for the final result traced. No definitive prediction is made. Instead, the possible outcomes, both positive and negative, of management policies affecting the morphology and ecology of the estuary can be explored qualitatively and assessed in terms of their success in meeting ecosystem goals.

This ***3-layer hybrid approach*** thus provides the basis for linking the meso-scale morphology to the ecosystem goals. The implementation of the approach in practice will be described next.

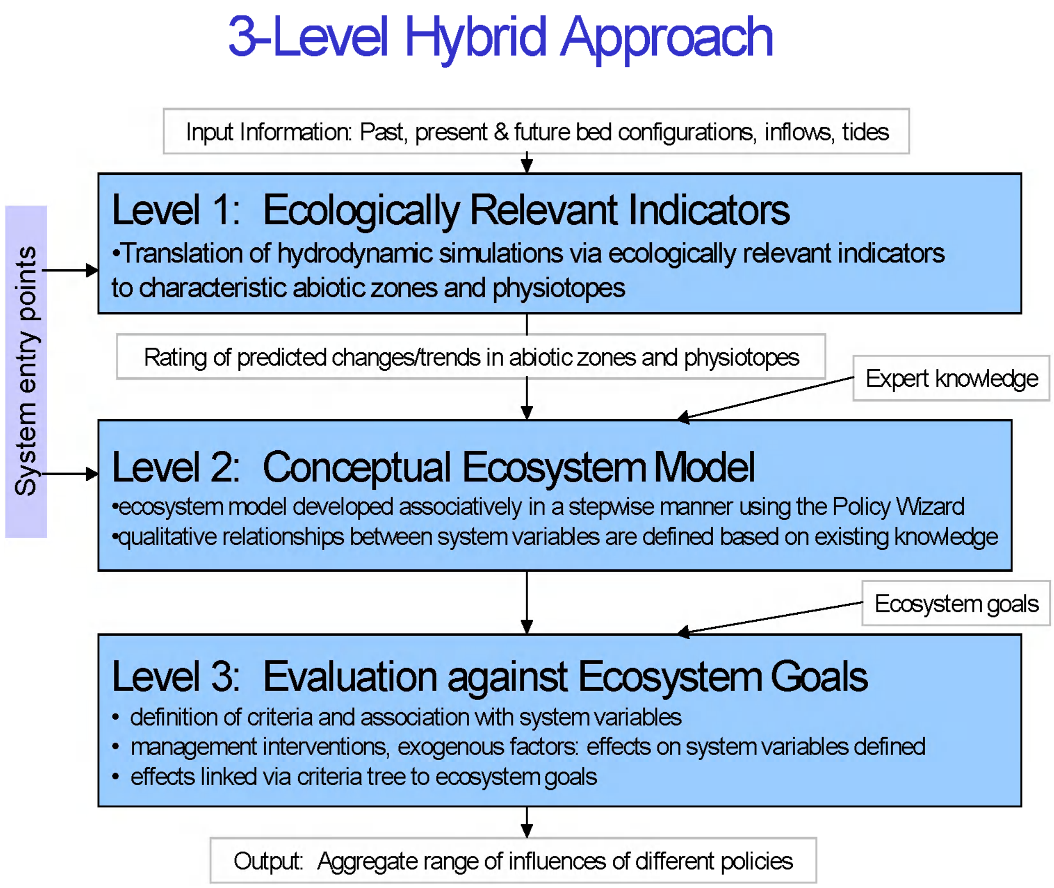

Figure 1 **The 3-level hybrid approach which enables links to be made between the morphological predictions and the ecosystem goals for the Schelde Estuary.**

3 Implementation of the 3-level hybrid approach

3.1 Level one: Ecologically Relevant Indicators

For background material on the natural environment of the Schelde Estuary, the reader is referred to Vroon et al. (1997), van Damme *et al*. (1999) and the Korte Termijn Schets Schelde-estuarium (RA 1999). Suffice it to say here that the Schelde Estuary presently exhibits a range of supratidal, intertidal and subtidal habitats and associated biotic communities along the salinity gradient from the marine waters at the mouth to the freshwater at the head of tidal influence (Gent). It is the presence of these abiotic zones (both the salinity variation along the longitudinal axis and the height variation along the lateral axis of the estuary) and their associated typical biotic assemblages that forms the unique character of the Schelde Estuary.

The 'no regret' management strategy means that the character of the multi-channel system of the lower reaches of the Schelde Estuary (to Antwerpen) and the meandering character of the Boven Zeeschelde will be maintained. However, significant effects on the ecosystem can still occur at the meso-scale, because of alterations in the salinity distributions, local hydrodynamic and sedimentary conditions, inundation times and frequencies, vulnerability to extreme events (e.g. floods) and water quality conditions. These can have considerable biological consequences and it is these consequences that need to be explored more fully.

3.1.1 Data needs, availability and limitations

Based on the methodological analysis (section 2), the decision was taken to characterize the abiotic environment of the estuary at meso-scale in an ecologically relevant way. This involves using as basic input condition, the known and predicted (possible future) bottom configurations of the estuary, available from the morphological research team. The relevant bottom configurations are:

- Reference situation: 1996 bottom schematisation
- Present situation (the 12 m channel deepening): 1999 bottom schematisation
- Possible Future situation: 14 m channel.

From the viewpoint of the natural environment of the Schelde Estuary, it is desirable to have hydrodynamic simulations for each of the bottom configurations and for all of the conditions listed subsequently (Slinger 2000):

- *Upstream boundary:*
  1. High inflow (typical winter flow conditions)
  2. Low inflow (low summer flow, so that the maximum upstream extent of tidal influence is evident)
  3. Very high inflow (so that maximum water levels are attained)
- *Downstream boundary:*
  1. Spring/neap tidal cycle (so that adequate representation of salinity zones can be obtained and the low water levels can be obtained accurately)

2. Sea level rise, 20 cm/century.

In contrast to the simulation requirements for Nature, the only simulation runs available from the morphological research group were those based on a morphological tide with pre-calculated upstream boundary conditions for salinity and inflow (Table 1). Moreover the simulation period was only four days and the model boundaries extended to just upstream of Antwerp.

Table 1 Available hydrodynamic simulation runs

DELFT3D Simulation Runs	Reference condition (1996 bottom)	Present situation (12 m channel, 1999 bottom)	Possible Future (14 m channel)
Upstream salinity and inflow given, morphological tide, simulation period four days	X	X	X

The model runs simulate the hydrodynamic response to altered morphology for the given input and boundary conditions. Aspects which cannot be addressed within this approach include:

- The morphological and hydrodynamic situation of the Zeeschelde above Antwerpen, because this lies outside the defined boundaries of the model applications, and
- The morphological processes which are either not accommodated, or not fully/adequately represented, in models e.g. the dynamics of connecting channels and tidal flat and channel exchanges of sediment.
- The accurate long term salt intrusion for particular inflow conditions, because:
    - The use of the morphological tide as downstream forcing means that year average sediment transports are accurately represented but salt transports not,
    - The simulation period is too short for the salt intrusion to penetrate substantially further upstream in the estuary and for this situation to stabilize (a simulation period of 6 weeks to 3 months may be required), and
    - Only one set of upstream inflow conditions was used.
- Spring-neap tidal variation in maximum and minimum water levels within the estuary, because a spring-neap tidal cycle is not simulated.

Although this is not an optimal situation, these data were translated to ecologically relevant indicators, primarily to illustrate the procedure whereby spatial linkage which can be made between morphology and ecology. This is an area where considerable improvement in the data can, and **MUST,** lead to more relevant predictions in the future.

3.1.2 Defining ecologically relevant indicators

Three ecologically relevant indicators which may be obtained directly from the morpho- and hydrodynamic simulation data are:

- the maximum water levels per grid cell over the simulation period;
- the maximum current speed per grid cell over the simulation period, and

- the maximum bottom shear stress per grid cell over the simulation period.

In determining the longitudinal extent of characteristic abiotic zones (freshwater, brackish, estuarine and marine zones), as well as the distribution within these zones of biologically relevant physiotopes (e.g. supra-tidal marsh areas, intertidal mud- and sandflats, shallow and channel areas), the simulation data from morpho- and hydrodynamic model runs had to be processed as described below.

***Characteristic Abiotic (Salinity) zones*:**

The maximum (volume-averaged) salinity for each grid cell upstream of the mouth over the simulation period was extracted from the data. This information is necessary so that the changes in location of the salinity zones (as defined by McLusky (1981)), owing to differences in bottom configuration, can be determined, namely:

1. freshwater zone (0 - 5 ppt, limnetic and oligohaline);

2. brackish (5 - 18 ppt, mesohaline region characterised by strong gradients);

3. estuarine (greater than 18 ppt, polyhaline and euhaline).

Physiotope distribution:

To obtain an indication of the possible distribution of physiotopes within the estuary, it is necessary to combine the relevant bottom configuration and the maximum water level per grid cell. First the estuary is classified into channel (deeper than – 5 m NAP), shallows (-5 m to –2 m NAP), intertidal (- 2 m to NAP and maximum water level) and high lying area (higher than max water level). The intertidal area is then subdivided into low intertidal and high intertidal, with the division lying halfway between – 2 m NAP and the maximum water level per grid cell.

Highly dynamic/Less dynamic:

Additionally, an indication of the harshness of the tidal environment can be obtained by combining the current speed information and the bed shear stress information. Areas that are exposed to current speeds in excess of 0,6 $m.s^{-1}$ or bottom shear stress in excess of 0,03 $N.m^{-2}$ are deemed highly dynamic. Only those areas where neither of these limits are exceeded are deemed low dynamic. This selection of an exclusion relationship for the division of the intertidal and subtidal areas is based on recent studies of macrobenthic and morphological interactions and subsequent discussions thereover, namely Bell *et al*. (1997), Bult *et al*. (1999), Crosato *et al*. (1999) and Twisk (2000). Should there be extensive debate on the limiting values selected, the values can be altered and the effects of these changes evaluated before a definitive choice is made.

The ecologically relevant indicators to be derived from the available morpho-and hydrodynamic data are summarised in the following table.

Table 2 Ecologically relevant indicators

Ecologically Relevant Indicators	Relationship to Model Data	Comments on Data Limitations
Characteristic abiotic zones, namely: freshwater, brackish and estuarine zones.	Derived from maximum salinities per grid cell over the full simulation period	For realistic prediction, long period simulations for high and low inflow conditions need to be undertaken. Maximum and minimum salinities per grid cell over the last spring-neap cycle of the simulation (i.e. when dynamic equilibrium is achieved) need to be used in determing the extent of these zones.
Potential physiotopes: Channels, shallows, low-intertidal, high-intertidal and high lying areas.	Derived from bottom configurations, and maximum water levels per grid cell over the simulation period	The maximum water levels over the four day simulation period are not necessarily representative of those that would occur over spring tide.
Maximum water levels	Maximum water level per grid cell over the simulation period	The maximum water levels over the four day simulation period are not necessarily representative of those that would occur over spring tide
Maximum current speeds	Maximum current speed per grid cell over the simulation period	The maximum current speeds over the four day simulation period are not necessarily representative of those that would occur over a spring-neap tidal cycle or under high/low inflow conditions.
Highly dynamic and low dynamic areas on the basis of exclusion laws	Derived from maximum current speeds and maximum bottom shear stresses per grid cell over the simulation period	The maximum current speeds and bottom shear stresses over the four day simulation period are not necessarily representative of those that would occur over a spring-neap tidal cycle or under high/low inflow conditions.

The model generated data was supplied in the form of grid cell values. These values had first to be converted into aerial coverages, then classified and grouped appropriately.

By comparing the resultant indicators, the changes in extent and position of the characteristic abiotic zones and physiotopes can be assessed for the different morphological scenarios (past, present and possible future bottom configurations). The information is presented in the form of maps and circulated to those participating in the development of the Long Term Vision using the @-lvis software shell (RA 2000b). The areal extent of the different physiotopes is also calculated so that percentage changes are known.

Because of the data limitations, it is important to appreciate that this information is indicative rather than exact and to use it to establish relative trends only. For instance, as a hypothetical example, to indicate that there is a 10 percent decrease in estuarine shallows when one compares the possible future situation with the 1996 situation (as derived from simulation data).

It is also relevant to note that for the 1996 situation, the comparison can be made between the predicted situation and actual data, whereas that is not possible for a future situation. The procedure for the derivation of the ecologically relevant indices is the same for both past and possible future situations to ensure that comparisons occur on the basis of data of the same level of detail and standard of accuracy. Comparison between reality and the predictions for 1996 can be undertaken through map overlays in the @-Ivis software shell (RA 2000b).

Information on the anticipated distribution of physiotopes and characteristic abiotic zones together with maximum water levels and current speeds is useful as an indication of the changes in hydro-morphological environment that can occur even when a multi-channel and/or meandering system are maintained. The biological responses to these changes (and others which may not be able to be predicted using models or may fall outside the model schematisation) have yet to be assessed.

The values of ecologically relevant indicators based on the input data supplied by the morphological research team (Winterwerp *et al.* 2000b) are discussed in the results section.

3.2 Level two: The Conceptual Ecosystem Model

3.2.1 Structured Process

To facilitate the inclusion in the LTV process of the existing knowledge of biological responses to alterations in abiotic conditions, (some of which cannot be captured effectively in numerical models) and the further outworking of the predicted alterations in the ecologically relevant indicators, a conceptual ecosystem model was developed. This was undertaken using the Policy Wizard (van der Werff ten Bosch *et al.* 1999) a software system which guides the user through a structured stepwise process of policy analysis (RA 2000c) involving:

- problem definition,
- system component identification, and
- model formulation in terms of system variables and qualitative inter-relationships.

The subsequent step of linking ecosystem goals to the conceptual ecosystem model is undertaken through the identification of criteria by which the influence of the interventions and exogenous factors defined subsequently can be judged. These steps of the policy analysis procedure (RA 2000c) are also included in the Policy Wizard, but will be addressed in the section dealing with the relationship to the Ecosystem Goals rather than in this section on the ecosystem model itself.

3.2.2 Model Formulation

The model was formulated using the Rapid Assessment Program of the Policy Wizard. The approach will be described briefly here, but the reader is referred to the discussion in section 2.5 and the following sources for more extensive information and evaluation (Donkers 1997, Kouwenhoven 1998, van Eck en Consemulder 1999, van der Werff ten Bosch 2000, Reijngoud & van de Ven 2000).

The conceptual ecosystem model was first developed based upon discussions with Eric de Deckere from the UIA during the process of formulating the ecosystem goals. Thereafter information and advice was sought from the Morphology research team and modifications were made to the initial formulation. This preliminary formulation was presented to the WGN for comment on 6 July 2000 in Antwerp and the interactive version of the Policy Wizard sent to all members for evaluation. Comments were received in the period late July to August and a final

Validation Workshop was held on 11 September in Middelburg. The workshop was attended by Ir. A Arends, Drs J Coosen, Dr B de Winder and Dr T Ysebaert. Input to the workshop deliberations was also obtained from Drs E de Deckere and Ms B Dauwe. The model described in this document reflects the changes and recommendations proposed in the Validation Workshop.

3.2.3 Identification of Model Components

Model components are broad groupings (building blocks) defined so as to provide a simple and discrete representation of the natural system. Components are selected to assist in maintaining a clear overview of the issues under consideration. In the case of the Conceptual Ecosystem Model for the Schelde Estuary, seventeen descriptors of the general character of the Schelde Estuary were considered fundamental to a description of its past, present and possible future states. These components, are listed subsequently:

1. North Sea
2. Freshwater Supply
3. Hydrodynamics
4. Morphodynamics
5. Permanently Increasing the Storage Capacity
6. Turbidity
7. Water Quality
8. Bed Sediment Quality
9. Abiotic Zones
10. Physiotopes
11. Macrobenthos
12. Fish & Prawns/Shrimps
13. Birds
14. Marine Mammals
15. Primary Production
16. Dredging, Dumping & Sand Mining
17. Ecosystem Indicators

Potential interactions between these component groupings are identified as a means of assisting in the definition of relevant system variables and their interactions. System variables then provide the means of describing the inter-relationships within the system to be modelled.

3.2.4 *System variables and inter-relationships*

System variables were then defined per component and the strength of direct relationships between them were assessed qualitatively. A seven point scale ranging from strongly positive (+++), through normal positive (++), weakly positive (+), no effect (o), weakly negative (-), normal negative (--) to strongly negative (---) is provided in the Policy Wizard (Appendix A). A strongly positive relationship means that an increase in the system variable exerting the influence leads to a strong increase in the affected system variable. A negative response means that an increase in the influencing variable leads to a decrease in the affected variable. In building a conceptual model it is wise to consider each component in turn (and each variable in turn) and systematically assess (qualitatively rate and describe) the direct effects on the other system variables. Only once this has been done in as consistent a manner possible for every component and system variable, can cross-checking of the consistency and the completeness of the model formulation be conducted. The Policy Wizard supports entry of these inter-relationships both graphically or via a table (van den Werff ten Bosch *et al*. 1999). The graphic form is most commonly used, but the tabular form is particularly useful in the consitency checking phase.

The formulation of the conceptual ecosystem model and the assignment of the ratings to the inter-relationships between the system variables is described in detail in Appendix B. Only a general description of the character of the ecosystem model, which forms the central component in the development of a coupling between morphology and ecology for the Schelde Estuary, is given here.

The Conceptual Ecosystem Model for the Schelde Estuary has eighty-six system variables and is a comprehensive reflection of the response of the character of the Schelde ecosystem to changes in the abiotic state at meso-scale. Specific choices were made regarding the level of biological interaction included in the conceptual model. For instance, the effect of predation by higher trophic levels on lower trophic levels was not included, but the necessity for the presence of the lower trophic levels as food supply was included. The focus of the biological component of the model is thus on the potential for the occurrence of each of the components (and their system variables) i.e. whether abiotic conditions and food supplies are favourable or not and in what degree.

The development of this highly complex model caused a lively and satisfactory exchange of opinions on various occasions, most notably at the Validation Workshop on 11 September 2000. It was apparent in the formulation of the conceptual ecosystem model, that knowledge of how changes within one sub-system (freshwater, brackish and estuarine) would influence another was more limited than knowledge about changes within a sub-system itself. Accordingly the structure of the model is such that it reflects a general conceptualisation of the influences of the abiotic environment on biotic components.

It would be interesting to restructure the model to reflect interactions between sub-systems by regrouping variables under different component headings. This would serve to highlight where interlinkage between sub-systems is included and would reveal the weakness in this area in the current model. However, in its present form the system has acted to support the development of a common understanding of the issues of relevance in linking morphology and ecology, particularly within the WGN.

The results obtained when the effects of different combinations of management interventions and exogenous variables are analysed using the Conceptual Ecosystem Model will be described in the results section 4.2.

3.3 Level three: Relationship to the Ecosystem Goals

The primary goal for the WGN was formulated as:

An ecologically healthy, complete and sustainably functioning estuarine ecosystem of guaranteed quality

The findings of the study to scientifically justify this primary goal and detail what it meant in a number of supportive goals, the ecosystem goals, are reported comprehensively in de Deckere and Meire (2000). These ecosystem goals were summarised and structured by the WGN in the manner described below for the purposes of presentation at a Workshop on 24 May 2000 and for ease of inclusion in subsequent LTV documentation (RA 2000d & e).

The inherent value of the system as a whole was deemed significant and the overarching principal of maintaining biodiversity was considered to represent this idea in a societally acceptable and understandable way.

Thereafter two supportive goals were defined:

1. Sufficient **space** for the natural, dynamic physical, chemical and biological **processes**, because these are essential for the morphological and ecological characteristics of the estuary and for maintaining the estuarine gradient

2. maintenance or strengthening of the estuarine ecosystem with **its typical habitats and biological communities** along the gradient from freshwater at the head to the sea at the mouth.

The morphology and water quality are viewed by the WGN as the driving variables and also the means of influencing ecosystem behaviour. All disturbances/interventions at this level affect all other levels and can affect the maintenance of biodiversity.

Based on the work of de Deckere and Meire (2000), the connection of the Schelde Estuary to the North Sea (downstream receptor) and the catchment (upstream influences) is considered important, particularly in terms of the requirements for water quality and quantity that this places on the system (in addition to strictly biological connections).

3.3.1 Association of Ecosystem Goals and System Variables

In order to identify system variables as criteria by which the success or failure of management interventions or intermediate policies in terms of the goals for Nature can be assessed, an association between the ecosystem goals and system variables must first be made.

Because the WGN chose to prioritise goals and thus not include all ecosystem goals explicitly, the first task was to generate a complete list of ecosystem goals. This was compiled from the following documentary sources: de Deckere and Meire (2000), Minutes of the WGN on 17 May 2000 (RA 2000d) and Aanzet tot Streefbeeld Versie 22/05/00 (RA 2000e).

The list appears subsequently with all aspects that relate to supportive goal 1underlined and those relating to supportive goal 2 in italics. Thereafter, the association with system variables is made in Tables 2 and 3 and explained if necessary. The six ecosystem goals that cannot be related fully to system variables are listed after the tables.

Complete List of Ecosystem Goals

- <u>Improve water quality in the Zeeschelde</u> so that *macrobenthic species diversity can increase*.

- Improve water quality to the extent that *higher trophic levels can again be found in the water column of the Zeeschelde.*

- Decrease turbidity in the Westerschelde so that the conditions for filter feeders improve. This may also *increase the biomass of macrobenthos in the Westerschelde-oost*.

- Improvement in water quality to the extent that it *no longer forms a constraint to diadromous fish and estuarine residents.*

- Reduction in turbidity, particularly in the brackish zone so that *diadromous fish can return.*

- Removal of physical barriers to access to the upstream areas by building fish ladders.

- Create favourable conditions for the formation of young marsh areas in the brackish zone.

- Expansion of the estuarine habitat of the Schelde system i.e. expansion of the intertidal area.

- Create sufficient space that morphological processes can occur and so *guarantee a diversity of the various estuarine habitats.*
  - Minimum requirement is that at least the present area of intertidal area and shallows is maintained.
  - Increased marsh area along the Westerschelde is desirable, but not at the expense of the area of mud- and tidal-flats.

- *Rest areas for marine mammals and birds.*

- Limit the fragmentation of habitats by maintaining or creating connections.

- Increased intertidal area in the Westerschelde-oost and the Zeeschelde so that the *biomass of filter feeders in the entire estuary increases and the 'stikstof verwijdering'" increases*.

- Decrease turbidity in the Westerschelde so that *more filter feeders can occur.*

- Reduce the input of nutrients via point and diffuse sources by improving effluent treatment in the case of the former and by building and maintaining river banks of at least 3 m wide for the latter.

- Reduce organic carbon loading by treating effluent.

- Reduce nutrient loading by effluent treatment.

- Reduce the input of nitrate from diffuse sources by building buffer zones.

- Prevention of the further upstream penetration of the flood tide and associated high waters.

- Inclusion of buffer zones in the form of GOG's (Areas for controlled inundation) en GGG's (Areas for controlled tidal effects) along the Zeeschelde for use under high river flow conditions (as a result of heavy rains).

- Improve the quality of the incoming silt so that the water can again be used for irrigation of some agricultural lands, which can then also serve a useful buffer function.

- Reduce the supply of silt so that the rate of sedimentation of the small side channels slows down.

- Sufficient freshwater supply that the characteristic freshwater-marine gradient can be maintained.

- No further reduction of the present buffer capacity of the system. In the Westerschelde this can translate to a stand still situation. For the Zeeschelde, an increase in the area of GOG's en GGG's is desirable.

- A strip of tidal marsh or mudflat of at least 6 m or 12 m wide, respectively along the river banks of the multi-channel part of the estuary. For the single channel part of the estuary, the width of the channel and the expected wave action would have to be taken into account.

- Reduce the silt supply to the estuary by modifying management and use of the Schelde catchment.

- Increase the area were settlement of silt can occur by using GOG's, GGG's and some agricultural land.

- Pre-condition is that the silt is not heavily polluted. If it is, it is better to remove it from the system after dredging rather than dumping further downstream. This can assist in reducing turbidity in the brackish zone (near Antwerp).

- Expansion of intertidal area, particularly the shallows, mud flats, tidal flats and marshes in the estuarine and brackish reaches.

- Maintenance (at the least) of the area of marsh along the Zeeschelde.

- *Mouth region (Vlakte van der Raan) under the European Habitat-and Bird Protection Laws*.

- The presence of a complete and representative food web.

- Presence of a full range of characteristic habitats along the freshwater-marine gradient.

Table 3 The association between the ecosystem goals considered to relate to supportive goal 1 and the system variables of the conceptual ecosystem model

Ecosystem Goals	Associated System Variables	Comments
• Improve water quality in the Zeeschelde • Water quality no longer a constraint to fish • Reduce the input of nutrients via point and diffuse sources • Reduce organic carbon and nutrient loading by treating effluent • Reduce the input of nitrate from diffuse sources by building buffer zones. • Reduce silicon limitation to distom growth in the mouth area	• Freshwater Water Quality • Brackish Water Quality • Freshwater Quality • Silicon Limitation	All reductions in nutrient and organic carbon loadings to the system are deeme dto relate to the quality of the freshwater inflow (which exerts influence on system variables but isn't itself influenced by them). The non-constraining influence on fish is related to the water quality of the brackish and estuarine zones in particular.
• Decrease turbidity in the Westerschelde • Reduction in turbidity, particularly in the brackish zone	• Estuarine Turbidity • Brackish Turbidity	
• Create sufficient space for morphological processes	• Morphological Diversity – Mouth • Morphological Diversity – Westerschelde-west • Morphological Diversity – Westerschelde-oost • Morphological Diversity – Zeeschelde	The issue of space for morphological processes is deemed to be covered by the concept of morphological diversity at the meso-scale.

• Expansion of the intertidal area • At least the present area of intertidal area and shallows is maintained • Increased intertidal area in the Westerschelde-oost and the Zeeschelde • Expansion of intertidal area, particularly the shallows, mud flats, tidal flats and marshes in the estuarine and brackish reaches	• Range of Physiotopes	Each one of the physiotopes could be listed here as relevant, but then the overview is lost. The point here is that all physiotopes occur and in sufficient area – this is captured by the Range of Physiotopes indicator.
• Create favourable conditions for the formation of young marsh areas in the brackish zone • Maintenance (at the least) of the area of marsh along the Zeeschelde • Increased marsh area along the Westerschelde is desirable, but not at the expense of the area of mud- and tidal-flats.	• Freshwater Marsh • Brackish Marsh • Estuarine Marsh • Range of Physiotopes	Special emphasis is placed on marsh areas here, so they are included as well as the Range of Physiotopes.
• Prevention of the further upstream penetration of the flood tide and associated high waters • Sufficient freshwater supply that the characteristic freshwater-marine gradient can be maintained	• Freshwater-Marine Gradient • Freshwater Quantity	The positions of the freshwater-brackish and the brackish-estuarine interface regions are of importance, as well as the tidal variation causing increased high water levels in the upstream reaches. Freshwater quantity influences other system variables but isn't itself influenced by them.
• Inclusion of buffer zones in the form of GOG's en GGG's along the Zeeschelde for use under high river flow conditions (as a result of heavy rains). • No further reduction of the present buffer capacity of the system. In the Westerschelde this can translate to a stand still situation. For the Zeeschelde, an increase in the area of GOG's en GGG's is desirable.	• Permanent Increase in Freshwater Storage Capacity • Permanent Increase in Brackish Storage Capacity	Both of these system variables exert influence on other system variables but aren't themselves influenced by them.
• Improve the quality of the incoming silt so that the water can again be used for irrigation of some agricultural lands, which can then also serve a useful buffer function • Reduce the supply of silt so that the rate of sedimentation of the small side channels slows down • Ensure that the silt is not heavily polluted. If it is, it is better to remove it from the system after dredging rather than dumping further downstream • Increase the area were settlement of silt can occur by using GOG's, GGG's and some agricultural land	• Freshwater Quality • Storten Zeeschelde • Permanent Increase in Freshwater Storage Capacity • Permanent Increase in Brackish Storage Capacity	Silt load is included in the Freshwater Quality variable. A policy of not dumping polluted sediments once they are dredged is reflected by changes in the variable Storten Zeeschelde.

Table 4 The association between the ecosystem goals considered to relate to supportive goal 2 and the system variables of the conceptual ecosystem model

Ecosystem Goals	Associated System Variables	Comments
• Increased macrobenthic species diversity in the Zeeschelde • Increase the biomass of macrobenthos in the Westerschelde-oost • More filter feeders in the Westerschelde • Biomass of filter feeders in the entire estuary increases	• Freshwater Filter Feeders • Brackish Filter Feeders • Estuarine Filter Feeders • Freshwater Deposit Feeders • Brackish Deposit Feeders • Estuarine Deposit Feeders	Primary focus is on increasing the biomass of filetr feeders in the brackish and estuarine zone and the species diversity in the Zeeschelde. The latter effect is not included in the conceptual ecosystem model and so cannot be assessed.
• Higher trophic levels can again be found in the water column of the Zeeschelde	• Estuarine Fish • Diadromous Fish • Complete Food Web	The Fish and Prawns Component is not specified for the abiotic zones, so the general category is used.
• Return of diadromous fish • Water quality no longer forms a constraint to diadromous fish and estuarine residents	• Estuarine Fish • Diadromous Fish	
• Rest area for marine mammals and birds	• Brackish High Intertidal Flats • Estuarine High Intertidal Flats • Freshwater Marsh Vegetation • Brackish Marsh Vegetation • Salt Marsh Vegetation	Rest areas for marine mammals are the high intertidal falts. These serve as rest aresa for some bird species while others utilize the vegetated marsh areas.
• Diversity of estuarine habitats • Presence of a full range of characteristic habitats along the freshhwater-marine gradient	• Full range of Physiotopes • Freshwater-Marine Gradient	Existence of a full range of physiotopes cannot guarrentee their use as a living environment, but is a necessary pre-condition
• The presence of a complete and representative food web	• Complete Food Web	The focus on increasing macrobenthic species diversity and filter feeder numbers and on securing the return of the diadromous fish is an indication that the food web is not representative at this stage.

The ecosystem goals listed subsequently either could not be associated with system variables or could only be associated partially with system variables:

- Removal of physical barriers to access to the upstream areas by building fish ladders: no association.

- Create favourable conditions for the formation of young marsh areas in the brackish zone: partially associated with Brackish Marsh. This variable indicates whether brackish marsh is likely to increase or decrease but not whether it can develop naturally i.e. the formation process is not addressed.

- Limit the fragmentation of habitats by maintaining or creating connections (see van den Bergh et al 1999): no association.

- Ensure that there is a strip of tidal marsh or mudflat of at least 6 m or 12 m wide, respectively along the river banks of the multi-channel part of the estuary. For the single channel part of the estuary, the width of the channel and the expected wave action would have to be taken into account: no association. This goal is expressed in exact spatial dimensions and so cannot be associated directly with variables from the conceptual ecosystem model. The Intertidal Flats variables provide an indication of whether these buffer zones would increase or decrease, but not their size.

- Maintaining river banks of at least 3 m wide: no association. Same reasoning as for the previous goal.

- Mouth region (Vlakte van der Raan) under the European Habitat-and Bird Protection Laws: no association.

3.3.2 *Definition of Criteria*

Each of the ecosystem goals has now been associated with system variables as far as possible. In analysing the list of system variables obtained, four variables can be identified which influence other system variables but are not themselves so influenced. These are:

- Freshwater Quality;
- Freshwater Quantity;
- Permanent Increase in Freshwater Storage Capacity;
- Permanent Increase in Brackish Storage Capacity.

These variables cannot be used as criteria because they only change as a result of policy decisions – they cannot reflect the consequences of internal system dynamics.

From Tables 3 & 4 it is clear that potential abiotic criteria include:

- Freshwater Water Quality;
- Brackish Water Quality;
- Brackish Turbidity;
- Estuarine Turbidity;
- Freshwater-Marine Gradient;
- Morphological Diversity – Mouth, -Westerschelde-west, Westerschelde-oost and – Zeeschelde;
- Full Range of Physiotopes;
- Freshwater, Marine and Brackish Marshes;
- Brackish High Intertidal Flats;
- Estuarine High Intertidal Flats.

From Table 4 it is clear that potential biotic criteria include:

- Estuarine Residents
- Diadromous Fish
- Complete Food Web
- Freshwater, Brackish and Estuarine Filter Feeders
- Freshwater, Brackish and Estuarine Deposit Feeders
- Freshwater, Marine and Brackish Marsh Vegetation

By considering the purpose to which each variable relates, this list can be reduced to the following final list of criteria:

- Freshwater Water Quality
- Brackish Water Quality
- Brackish Turbidity
- Estuarine Turbidity
- Freshwater-Marine Gradient
- Morphological Diversity – Mouth, -Westerschelde-west, Westerschelde-oost and - Zeeschelde
- Full Range of Physiotopes
- Complete Food Web
- Freshwater, Marine and Brackish Marsh Vegetation
- Diadromous Fish

The system variables eliminated from consideration as criteria are those related to the High intertidal physiotopes and the marsh physiotopes, because they are reflected in the full Range of Physiotopes and their function as rest areas for mammals and birds is captured in the Complete Food Web. The importance of the marshes in particular is recognised by including the marsh vegetation specifically. Similarly the high importance placed on diadromous fish is reflected in their choice as criteria. Macrobenthos are implicitly included in the Complete Food

Web variable as well. Strong arguments could be made for only including the variables of the Ecosystem Indicators Component, namely: Freshwater-Marine Gradient, Full Range of Physiotopes, Complete Food Web, as well as Silicon Limitation and Morphological Diversity as the justification for many of the goals was to ensure that these system characteristics were present. This has not been done as the gap between the goals as listed in the literature sources and the criteria is then too large to comprehend easily. Consequently fifteen criteria are selected whereby the effects of management interventions and exogenous influences on the Schelde Estuary will be assessed.

This matching of ecosystem goals with criteria in the form of system variables from the conceptual ecosystem model, provides the connection between Levels 2 and 3 of the 3-level hybrid approach.

3.3.3 Definition of Interventions and Exogenous Factors

By defining management interventions which can occur in the Schelde Estuary and associating them with the affected system variables, the effects of these interventions on the ecosystem can be assessed qualitatively. Similarly, exogenous influences can be investigated by the identification of their effects on system variables. This forms the next stage in the stepwise analysis process of the Policy Wizard.

Accordingly, a number of relevant interventions and exogenous influences from the viewpoint of the natural environment of the Schelde were defined and related to system variables (Table 5 & 6). The majority of these interventions and exogenous influences have been considered extensively in the morphological research effort, but it is relevant to assess the range of response of the ecosystem (including the Zeeschelde) to these interventions and to measure this response against the ecosystem goals as expressed in the identified criteria.

The management interventions to be considered include:

- A conservative dredging, dumping and sand winning policy;
- Ontpoldering of the Zeeschelde independently of, and together with, ontpoldering in the Westerschelde;
- The proposed deepening of the channel to Antwerpen to 14 m;
- Substantial improvements in the water quality of the freshwater inflow to the estuary, with the quantity remaining much the same; and
- Nature compensation in terms of the creation of freshwater and brackish intertidal and marsh physiotopes.

Table 5 Definition of interventions and their effects on system variables

Intervention	System Variables	Effect
Conservative Dumping, Dredging & Sand Mining	Dredging Zeeschelde	Weak +
	Dredging Westerschelde-oost	Weak +
	Dredging Westerschelde-west	Weak +
	Dredging Mouth	Weak +
	Dumping Westerschelde-west	Moderate ++
	Dumping Zeeschelde	Weak +
	Sand Mining	Weak +
Ontpoldering	Permanent Increase in Freshwater Storage Capacity	Strong +++
	Permanent Increase in Brackish Storage Capacity	Strong +++
	Permanent Increase in Estuarine Storage Capacity	Moderate ++
Ontpoldering - Zeeschelde	Permanent Increase in Freshwater Storage Capacity	Strong +++
Channel Deepening (14m)	Channel Depth to Antwerpen	Strong +++
	Dredging Zeeschelde	Moderate to strong +++
	Dredging Westerschelde-oost	Moderate to strong +++
	Dredging Westerschelde-west	Moderate to strong +++
	Dredging Mouth	Moderate to strong +++
	Dumping Mouth	Moderate to strong +++
	Dumping Westerschelde-west	Strong +++
	Dumping Westerschelde-oost	Weak +
	Dumping Zeeschelde	Moderate ++
	Sand Mining	Moderate ++
Nature Compensation	Freshwater Marsh	Moderate ++
	Freshwater Low Intertidal Flat	Moderate ++
	Brackish Marsh	Moderate ++
	Brackish Low Intertidal Flat	Moderate ++
Improved Water Quality	Freshwater Quality	Strong +++

Relevant exogenous factors include:

- Sea level rise; and
- High discharge entering the estuary as a result of heavy rains or flooding in the Schelde catchment area. The quality of such water is usually also problematic.

Table 6 Definition of exogenous factors and their effects on system variables

Exogenous Factor	System Variables	Effect
Sea Level Rise	Mean Sea Level	Moderate ++
River Flood	Freshwater Quantity	Strong +++
	Freshwater Quality	Moderate --

The effects of these and many more combinations of management interventions and exogenous influences on the estuarine ecosystem can be investigated (methodological requirement 3). For the purposes of the LTV only the most relevant of such influences and interventions have been analysed further. These are reported in the Results section.

4 Results

4.1 Level 1: Ecologically relevant indicators

The outputs from the ecologically relevant indicators for each of the morphological scenarios include the following:

1. Maximum salinity intrusion (in response to the morphological tide over 4 days) and classification into the abiotic zones: Freshwater, Brackish and Estuarine. This information is presented in map form in the Prognosis section of @-Ivis as salinity contours and as abiotic zones. The contours facilitate comparison between scenarios while the zones are visually more appealing and comprehensible.

2. Maximum water levels relative to NAP throughout the estuary over the four day period. These are presented in map form in @-Ivis.

3. Maximum current speeds throughout the estuary. These are presented in map form in @-Ivis.

4. Physiotope distributions are derived from a combination of the bed configuration and the maximum water levels. Five categories are distinguished, namely:

   - channel (deeper than – 5 m NAP),
   - shallows (-5 m to –2 m NAP),
   - low intertidal (- 2 m to NAP to 'midway' maximum water level),
   - high intertidal ('midway' maximum water level to the maximum water level), and
   - high lying area (higher than max water level).

   These data are presented as contour maps and areal coverages in @-Ivis. The contours facilitate comparison between scenarios. Additionally, the areal extent of each physiotope for the three scenarios is included as a comment on each map.

5. Highly dynamic and less dynamic areas are distinguished on the basis of bottom shear stress and current speeds. These results are presented as contour maps and areal coverages in @-Ivis.

However, the utility of these data lies not so much in the individual maps which are available per scenario, but in the ability to compare the effects of the different scenarios on the ecologically relevant indicators. Difference maps are therefore of more interest.

4.1.1 Analysis of results

Bottom Topography

The differences in bottom topography between 1996 and the predicted situation following channel deepening are presented in Map 1 (Annexe 1). These are results obtained directly from the Morphology Research Team and are presented here primarily to demonstrate the use that these data are subsequently put to in the translation to ecologically relevant indicators. Most changes in bottom depth are within 1 m of the 1996 value indicating that much of this change will occur outside of the main channel in the shallow, biologically important areas.

Similar information is available for the 1999 situation and is included in @-Ivis as are the results presented in map form in this report. However, for the purposes of illustrating the procedure of translation to ecologically relevant indicators, only the results from 1996 and the possible future situation (channel deepening to 14 m) will be discussed hereafter.

Maximum water levels

The differences between the maximum water levels per grid cell over the full simulation period with the 1996 bottom topography and those following the deepening of the channel to 14 m are depicted in Map 2 (Annexure 1). An increase in water levels of the order of 0.05 to 0.15 m is indicated clearly in the brackish region from Saeftinge to Antwerpen, while a decrease of the order of 0.05 m is indicated in the area near Terneuzen (west-central Westerschelde). Obviously, these values are by no means accurate predictions as they merely represent a comparison over four days under specific tidal conditions (morphological tide), but it would be extremely interesting to be able to compare data from a simulation run using representative spring-neap tidal forcing to see whether the tendency for the maximum tidal water levels to increase in the brackish zone is accurate and to gain a better understanding of the likely magnitude of the increase.

Potential Physiotopes

By combining the bottom topography and the maximum water levels, potential physiotopes are identified (section 3.1.2). The estuary is classified into channel (deeper than – 5 m NAP), shallows (-5 m to –2 m NAP), intertidal (- 2 m to NAP and maximum water level) and high lying area (higher than max water level). The intertidal area is subdivided into low intertidal and high intertidal, with the division lying halfway between – 2 m NAP and the maximum water level per grid cell. This is illustrated for the 1996 situation in Map 3 (Annexure 1). Because of the purely indicative nature of the data (the assumptions for the hydrodynamic model were not appropriate for ecological needs), presentation of the map for the possible future situation was avoided.

Current velocities

The differences in maximum current speeds per grid cell between the 1996 situation and the possible future situation are depicted in Map 4 (Annexure 1). The majority of the differences have magnitudes of less than 0.1 $m.s^{-1}$. This information is of interest because current speeds have a strong influence in determining how dynamic the intertidal environment is and wherenear limiting conditions occur such slight changes can have important biologically consequences.

Characteristic Abiotic (Salinity) Zones

The full upstream extent of salt intrusion and the associated water levels were not simulated within this phase of the Long Term Vision development process. Instead the available data had to be used and the analysis process that should be followed demonstrated. The use of the morphological tide as downstream forcing and the simulation period of only four days mean that only limited upstream penetration of salt can be discerned when the 1996 results are compared with the situation should the channel be deepened to 14m (Map 5, details 2 and 3 in particular (Annexure 1)). Clearly, in reality, there would be a progression of salt upstream and the extent of the estuarine zone and the brackish zone will increase at the expense of the freshwater zone particularly under conditions of low inflow.

The degree to which this would occur in reality is of cardinal importance in assessing the effect on the ecosystem of channel deepening and must be determined.

From the predictions of the anticipated salinity distributions following the 12 m channel deepening using the two-dimensional hydrodynamic SCALDIS400 model (van der Male 1995, Mol 1995), an upstream increase of between 1 and 3 ppt could be expected to occur in the Prosperpolder region (brackish area near Antwerp). The anticipated differences are very dependent on freshwater inflow conditions. However, based on this information and a preliminary rapid assessment using an analytical technique developed by Savenije (1992), it is anticipated that differences in the order of 3 to 5 ppt could occur and that the salt penetration could increase in extent in the order of 5 km or more if the channel is deepened to 14 m (Prof. H. Savenije *pers. comm.*). Confirmation, or at least determination of the range of uncertainty around this issue needs to be obtained as soon as possible.

Highly Dynamic/Less Dynamic

Highly dynamic and less dynamic regions are identified on the basis of the maximum current velocities and bed shear stresses over the simulation period (section 3.1.2). Results indicate that alterations in channel depth do affect maximum current velocities and bed shear stresses. These effects arae minor, but slight shifts in the location of highly dynamic and low dynamic intertidal physiotopes result as shown in Map 6 (Annexure 1). Again, these effects may be more significant if they can be derived from the tidal forcing most relevant to the natural environmental response and they can be considered in combination with differences in the extent of saline intrusion/freshwater influence.

Summary

Quantitative information on the anticipated distribution of physiotopes within the different abiotic zones is useful as an indication of the ecologically relevant changes in hydro-morphological environment that can occur even when a multi-channel and/or meandering system are maintained.

By processing the simulation data as described in section 3.1.2, the trends in the results can easily be identified. For instance, even from this purely indicative data there are indications of an increase in the maximum water levels in the Saeftinge area, an increased penetration of salt and an associated possible increase in both the longitudinal and lateral extent of the brackish zone. The effect of this on the freshwater zone cannot be simulated effectively because the upstream model boundary lies just upstream of Antwerpen. It is advisable to extend the model boundaries or to use a coupled modelling system to undertake the necessary simulations to ensure that the effects on the freshwater interface region are better understood.

Clearly, however, information has to be generated with the purpose for which it will be used in mind (methodological requirements 2 and 4 apply here). A standard processing procedure for some of the the data needed for relevant ecological prediction is a by-product of this study.

The inclusion of the output from Level 1: Ecologically Relevant Indicators as input data for the Conceptual Ecosystem Model will be described hereafter.

4.2 Level 2: Conceptual Ecosystem Model

4.2.1 Input data from Level 1

The type of output produced using the ecologically relevant indicators can always be viewed graphically (using @-lvis), but may also be summarised in the form of the total area of characteristic zones or features. Both the graphical and the tabular form of the output are necessary when an expert is asked to give a value judgement of the changes. This value judgement is undertaken by assigning a rating on a seven point scale (from strong positive through zero to strong negative) to the effects on a system variable in the conceptual ecosystem model. For instance, an overall increase in the depth of the channel to Antwerpen of about 2m would be rated as a strong positive influence on this variable. An increase in the maximum water level in the brackish zone of the order of 10 cm would be rated as a moderate positive influence on the variable ‘Brackish Tidal Variation’ and ‘Brackish Maximum Water Level’.

When these effects have been analysed and assigned ratings, they are entered in the Policy Wizard either as interventions or exogenous effects and then become available for analysis as policy measures (i.e. included in Cases for analysis and evaluation). Given the severe limitations (for ecological purposes) of the data from which the ecologically relevant indicators were derived, this step was not undertaken in this study. It would have meant propogating possibly erroneous findings through the whole study. Instead, the option of initiating Level 2 independently of Level 1 was used.

4.2.2 Assessment of the Ecosystem Response

Relevant combinations of exogenous factors and management interventions, termed cases, are selected and analysed. The choice of cases was made on the basis of concurrence with the morphological scenarios supplied to this sub-project (including channel deepening and effects of sea level rise) and issues known to be under discussion (e.g. ontpoldering, nature compensation and river floods). The cases analysed in this study are presented in the following table.

Table 7 The combinations of interventions and exogenous developments (cases) considered relevant in assessing the response of the natural environment of the Schelde Estuary

Definition of Cases	No exogenous influences considered	River Flood	Sea Level Rise
No management strategies considered		Case 8	Case 9
Ontpoldering (Zeeschelde only)	Case 1		
Ontpoldering (Zeeschelde & Westerschelde)	Case 2		
Conservative dredging, dumping and sand winning strategy	Case 3		
Channel deepening (14 m)	Case 4		Case 10
Channel deepening & Ontpoldering (Zeeschelde only)	Case 5		Case 11
Improved Freshwater Quality	Case 6		
Nature Compensation	Case 7		

The range of variation of the system variables in response to these cases are calculated iteratively using simple calculation rules which assume that weak relations tend to die out over time (Appendix A). The results produced include all the possible states of variation. The results can be evaluated and analysed by stepping through the iterations and examining the chain of events in terms of effects on any of the the system variables. An example of this approach is depicted in Figure 2, where the policy of Ontpoldering (Zeeschelde only) is compared with Ontpoldering (Zeeschelde & Westerschelde) to iteration cycle 7. This type of information is useful in tracing sometimes contradictory looking results to their source.

From the viewpoint of Nature ontpoldering is viewed as a permanent increase in the storage capacity of particular areas of the estuary. Thus ontpoldering in the Zeeschelde is interpreted as affecting the storage capacity of the freshwater reaches only, whereas ontpoldering in the Zeeschelde and in the Westerschelde involves permanently increasing storage capacity in the brackish and estuarine reaches as well. This has the effect of reducing tidal action and the maximum water levels experienced in the brackish region in particular. The consequence is that instead of it only being positive to undertake ontpoldering in the brackish reaches, there is a strong possibility that the brackish intertidal area may decrease overall. Any effect on the height of inundation will work through to the tidal marsh areas which show considerable sensitivity to ontpoldering strategies. The conceptual ecosystem model therefore provides insights into the inter-relationships between system variables and the role that these effects have in determining the potential responses of the ecosystem as a whole.

However, results are generally viewed in terms of their effects on the ecosystem goals as exemplified in the identified criteria i.e. in the summary form provided under the Evaluation button of the Policy Wizard. This means that in practice, the evaluation of results is a function falling under Level 3 of the 3-level hybrid approach, whereas detailed analysis of the causal linkages falls under level 2. The subsequent analyses of the effects of the different cases will be undertaken primarily from the viewpoint of the ecosystem goals (i.e. using the criteria), but clarification will be sought in the effects on specific system variables where necessary i.e. Level 2 will be utilized to elucidate Level 3 results.

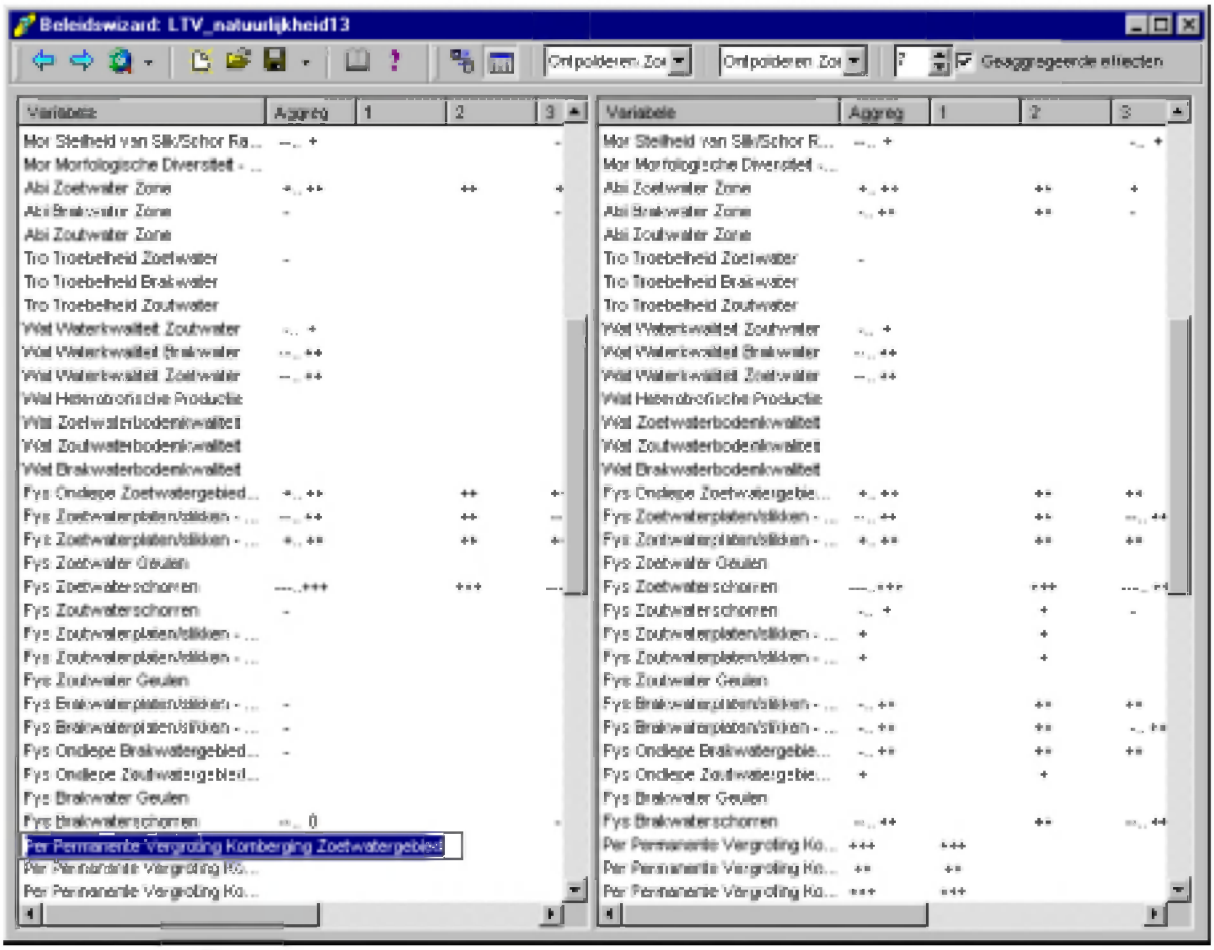

Figure 2 The effects of different policy options, namely: Ontpoldering in the Zeeschelde only (on the left) and Ontpoldering in the Zeeschelde and Westerschelde (on the right) can be analysed by considering the range of variation of the state variables step by step to the seventh iteration (no further changes)

4.3 Level 3: Evaluation against Ecosystem Goals

The response of the Schelde Estuary to the different combinations of management interventions and exogenous influences, as exemplified by the eleven cases, will now be evaluated in terms of their effects on the selected criteria.

A comparison of the effects of case 1 compared with those of case 2 has indicated that differences lie in the response of the brackish and estuarine intertidal reaches and also in the response of the marsh vegetation. For instance, the brackish marsh vegetation varies from moderate negative to moderate positive for case 2, whereas the range is from moderate negative to zero for case 1 (Table 8). Similarly, the effect on salt marsh vegetation ranges from weak negative to weak positive for case 2, compared with a weak negative effect for 1. These effects are to be anticipated, because case 1 does not increase the intertidal area in the brackish or estuarine reaches. There are no other significant differences, so for the purposes of futher evaluation, case 1 will be used as the most likely ontpoldering scenario.

The conservative dredging, dumping and sand mining strategy represents an extrapolation of existing policy in this regard and demonstrates that these activities exercise moderate to weak detrimental effects on morphological diversity at present. The consequences for the ecosystem are also moderate negative, primarily for the vegetation, diadromous fish and also estuarine residents.

In contrast, the effects of deepening of the channel to 14m have a potentially strong negative effect on estuarine marsh vegetation and diadromous (and estuarine) fish. These negative effects originate primarily from the dredging, dumping and sand mining activities associated with the channel deepening. However, the possibility of a moderate positive response of these system variables is also indicated. This arises because of the increased tidal variation and upstream extension of the estuarine and brackish zones. These effects could increase the area available for colonisation by marsh vegetation and the zones favourable to fish. Determination of which of these influences would result is dependent on the expected increase in tidal variation and abiotic zones both of which can be accurately predicted using existing hydrodynamic modelling techniques. However, the implementation of the Conceptual Ecosystem Model allows the potential range of response (and potential positive and negative consequences) to be explored at relatively low cost.

The differences in the range of response to case 4, channel deepening, and case 5, channel deepening and ontpoldering in the Zeeschelde, are indicated by italics in Table 8. Most effects are directly ascribable to the combined influence of the two interventions, namely ontpoldering (cf. Case 1) and channel deepening. Clearly, the effects of channel deepening on the ecosystem are not simply eliminated by providing the estuary with more room. The exact position and extent of the area to be ontpoldered has to be determined with the desired effects on the ecosystem in mind. Issues such the reduction in tidal variation commonly associated with ontpoldering and the anticipated increase in tidal variation as a result of channel deepening must be considered in the final decision making. The possibility of undertaking ontpoldering and channel deepening in such a way as to cause positive influences on the ecosystem to occur is clearly indicated.

Table 8 The aggregated margins of variation within which the criteria vary until the seventh iteration (no further changes occur thereafter) for cases 1, 3, 4 and 5

Criteria	**Case 1** Ontpoldering (Zeeschelde only)	**Case 3** Conservative dredging, dumping and sand mining	**Case 4** Channel deepening to 14m	**Case 5** Channel deepening & Ontpoldering (Zeeschelde only)
Morphological Diversity - Mouth			Strong negative to moderate positive	Strong negative to moderate positive
Morphological Diversity – Westerschelde-west		Moderate negative	Strong negative to moderate positive	Strong negative to moderate positive
Morphological Diversity – Westerschelde-oost		Weak negative	Moderate negative to moderate positive	Moderate negative to moderate positive
Morphological Diversity – Zeeschelde	Weak negative to weak positive		Weak negative to moderate positive	Weak negative to moderate positive
Freshwater Water Quality	Moderate negative to Moderate positive		Weak negative to weak positive	*Moderate negative to moderate positive*
Brackish Water Quality	Moderate negative to moderate positive		Weak negative to weak positive	*Moderate negative to moderate positive*
Brackish Turbidity			Zero to moderate positive	Zero to moderate positive
Estuarine Turbidity			Zero to moderate positive	Zero to moderate positive
Silicon Limitation	Weak negative to weak positive			*Weak negative to weak positive*
Freshwater-Marine Gradient	Weak positive		Zero to weak positive	Zero to weak positive
Full Range of Physiotopes	Moderate negative to moderate positive	Weak negative	Moderate negative to weak positive	*Moderate negative to moderate positive*
Freshwater Marsh Vegetation	Strong negative to strong positive		Moderate negative to moderate positive	Moderate negative to moderate positive
Brackish Marsh Vegetation	Moderate negative to zero		Weak negative to moderate positive	*Moderate negative to moderate positive*
Estuarine Marsh Vegetation	Weak negative	Moderate negative	Strong negative to moderate positive	Strong negative to moderate positive
Diadromous Fish	Moderate negative to moderate positive	Moderate negative	Strong negative to moderate positive	Strong negative to moderate positive
Complete Food Web	Moderate negative to moderate positive	Moderate negative to zero	Moderate negative to weak positive	*Moderate negative to moderate positive*

The effects of improving the quality of the freshwater flowing into the Schelde Estuary, i.e. case 6, are indicated in Table 9. The freshwater and brackish water quality improves with the degree of improvement in the range weak to strong and the brackish water turbidity declines. The degree of improvement is influenced by the water quality of the bed sediment. The silicon limitation in the mouth reaches exhibits a range from zero to moderate negative i.e. there is the potential for improvement in the effects of the Schelde Estuary on the North Sea. The degree of improvement depends primarily on the degree to which the water quality improvements in the upper reaches work through to the lower estuarine reaches. The biological responses as captured in the criteria Diadromous Fish and Complete Food Web range from weak negative to strong or moderately positive, respectively. The negative response arises within the model, because the reduced turbidity means that the nursery function of the estuary for fish cannot be fulfilled as effectively. This also raises a controversial issue that arose during the Validation Workshop as to whether adult fish are affected negatively by turbidity. This viewpoint was taken in the derivation of the ecosystem goals (de Deckere and Meire 2000), but was not included in the review of the model at the Validation Workshop. Clarification on this issue needs to be sought before final conclusions can be drawn from the model output. Should the relationships affecting diadromous fish remain as they are at present in the model, then Case 6, improving the quality of the freshwater supply, will provide a good example of a management measure that exercises a clear, positive effect on the estuary in general yet can still have unexpected slight detrimental consequences to biota e.g. diadromous fish. It is then the task of the biologists to clarify the likelihood of occurrence of this possible negative consequence, its severity relative to the potential positive consequences and to indicate whether measures should be taken concurrently with the actions proposed in the case to ensure that only the beneficial consequences occur.

Table 9 The aggregated margins of variation within which the criteria vary until the seventh iteration (no further changes occur thereafter) for cases 6, 7, 8 and 9

Criteria	**Case 6** Improved Water Quality	**Case 7** Nature Compensation	**Case 8** River Flood	**Case 9** Moderate sea level rise
Morphological Diversity - Mouth				
Morphological Diversity – Westerschelde-west				
Morphological Diversity – Westerschelde-oost			Weak negative to weak positive	
Morphological Diversity – Zeeschelde			Moderate negative to moderate positive	
Freshwater Water Quality	Weak to strong positive	Weak positive	Moderate negative to moderate positive	
Brackish Water Quality	Weak to strong positive	Weak positive	Moderate negative to moderate positive	Weak positive
Brackish Turbidity	Moderate negative		Weak negative to weak positive	
Estuarine Turbidity				
Silicon Limitation	Moderate negative to zero		Weak negative to weak positive	
Freshwater-Marine Gradient			Weak negative to moderate positive	
Full Range of Physiotopes		Weak positive	Moderate negative to moderate positive	Weak positive
Freshwater Marsh Vegetation		Moderate positive	Strong negative to strong positive	Weak negative to weak positive
Brackish Marsh Vegetation		Weak to moderate positive	Moderate negative to moderate positive	Weak to moderate positive
Estuarine Marsh Vegetation			Weak negative to weak positive	Weak to moderate positive
Diadromous Fish	Weak negative to strong positive	Weak positive	Moderate negative to strong positive	Weak positive
Complete Food Web	Weak negative to moderate positive	Zero to weak positive	Moderate negative to moderate positive	Zero to weak positive

Another case beneficial to the natural environment of the estuary in general is that of Nature Compensation (Case 7). This policy involves creating intertidal physiotopes in the brackish and freshwater reaches. The influences on the criteria are in the range weak to moderate positive, apart from the Complete Food Web which ranges from zero to moderate positive. This is an artefact of the weak positive responses of many food web components, which then fade out according to the Rapid Assessment Methodology computational rules.

The effect on the ecosystem of a river flood (an exogenous influence) is considered next (Case 8 in Table 9). The only unaffected criteria are the morphological diversity of the Westerschelde-west and the mouth and the estuarine turbidity. In general, the influence of the flood is equivocal. The increased freshwater supply exercises a favourable effect on the ecosystem, but the higher water levels and stronger currents are not beneficial. Consequently, each of the variables affected exhibits a wide range of variation.

The effect on the Schelde ecosystem of sea level rise is investigated next (Case 9 in Table 9). The only potential negative effect of a moderate sea level rise on the criteria occurred for the Freshwater Marsh Vegetation. However, the effect of a strong sea level rise is very different. Potential weak negative consequences are then indicated for the morphological diversity throughout the estuary and the slope of the tidal flats in the Westerschelde-oost and –west is predicted to possibly increase moderately. The turbidity in the fresh and brackish zones could increase slightly owing to increased water levels and current speeds. The extent of the freshwater zone may decrease weakly and the brackish zone increase moderately. All freshwater physiotopes may decrease in areal extent and the consequences for the freshwater biota are moderate negative. Howvever, the anticipated sea level rise for the Schelde Estuary is moderate and so case 9 was selected for presentation as more representative of reality.

Combinations of exogenous influences and management strategies/interventions were considered next. These include the effects of moderate sea level rise when the channel is deepened to 14 m (Case 10 in Table 10) and the effects of moderate sea level rise, channel deepening and ontpoldering in the freshwater zone (Case 11 in Table 10). The differences in the output for case 11 and case 10 are indicated by italics.

The effects of sea level rise and channel deepening are ambivalent and the margins of variation in the output are wide. The effect on the morphological diversity of the system can be strongly negative to moderately positive, whereas a moderate sea level rise was deemed to have no significant effect on morphological diversity. It is the combination of effects which gives rise to the level of uncertainty indicated in these results. The brackish and estuarine turbidities are likely to increase, but the response of the ecosystem exhibits a wide range of possibilities. In this way, although causal relationships between system variables in the conceptual ecosystem model have been defined, the model is reflecting a high degree of uncertainty in the response to be expected under conditions of channel deepening and sea level rise.

The output from case 11 concurs with that of case 10 except where indicated by italics (Table 10), These effects are easily explained as the influences of ontpoldering by comparing the output with that of Case 5 (channel deepening and obntpoldering). Ontpoldering increases the potential for improving the water quality of the freshwater and brackish reaches and for reducing the negative influence of the Schelde Estuary water quality on the North Sea (reduced silicon limitation), Additionally, ontpoldering acts to increase the freshwater intertidal physiotope which channel deepening and sea level rise tend to reduce. Thus the potential negative effects on freshwater and b\rackish marsh may be able to be compensated for by ontpoldering.

Table 10 The aggregated margins of variation within which the criteria vary until the seventh iteration (no further changes occur thereafter) for cases 9, 10, 11 and 5

Criteria	**Case 9** Moderate sea level rise	**Case 10** Channel deepening & moderate sea level rise	**Case 11** Channel deepening, ontpoldering and sea level rise	**Case 5** Channel deepening & ontpoldering
Morphological Diversity - Mouth		Strong negative to moderate positive	Strong negative to moderate positive	Strong negative to moderate positive
Morphological Diversity – Westerschelde-west		Strong negative to moderate positive	Strong negative to moderate positive	Strong negative to moderate positive
Morphological Diversity – Westerschelde-oost		Moderate negative to moderate positive	Moderate negative to moderate positive	Moderate negative to moderate positive
Morphological Diversity – Zeeschelde		Weak negative to moderate positive	Weak negative to moderate positive	Weak negative to moderate positive
Freshwater Water Quality		Weak negative to weak positive	*Moderate negative to moderate positive*	Moderate negative to moderate positive
Brackish Water Quality	Weak positive	Weak negative to weak positive	*Moderate negative to moderate positive*	Moderate negative to moderate positive
Brackish Turbidity		Zero to moderate positive	Zero to moderate positive	Zero to moderate positive
Estuarine Turbidity		Zero to moderate positive	Zero to moderate positive	Zero to moderate positive
Silicon Limitation			*Weak negative to weak positive*	Weak negative to weak positive
Freshwater-Marine Gradient		Zero to weak positive	Zero to weak positive	Zero to weak positive
Full Range of Physiotopes	Weak positive	Moderate negative to weak positive	*Moderate negative to moderate positive*	Moderate negative to moderate positive
Freshwater Marsh Vegetation	Weak negative to weak positive	Moderate negative to moderate positive	*Strong negative to strong positive*	Moderate negative to moderate positive
Brackish Marsh Vegetation	Weak to moderate positive	Weak negative to moderate positive	*Moderate negative to moderate positive*	Moderate negative to moderate positive
Estuarine Marsh Vegetation	*Weak to moderate positive*	Strong negative to moderate positive	Strong negative to moderate positive	Strong negative to moderate positive
Diadromous Fish	Weak positive	Strong negative to moderate positive	Strong negative to moderate positive	Strong negative to moderate positive
Complete Food Web	Zero to weak positive	Moderate negative to weak positive	*Moderate negative to moderate positive*	Moderate negative to moderate positive

This completes the analysis of the cases selected as relevant for brief discussion in this document. Exhaustive examination of the results for each case can be undertaken and the reasons for the variable ranges can be analysed by stepping through the iterations with the aid of the Policy Wizard. Gaps in knowledge and necessary improvements in the model formulation are easily identified.

Undertaking such an analysis in a group setting can act to stimulate discussions and serve to clarify the important issues and constraints in formulating robust policies. Additionally, new combinations of possible management measures and exogenous influences can be defined and implemented and the results examined. The adaptability of the approach means that it is very suitable for supporting interactive discussions focussed on effective policy formulation or the determination of necessary research to address the identified gaps in knowledge.

5 Discussion and Conclusion

5.1 Three-level hybrid approach: Summary

The conceptual justification of the three-level hybrid approach to linking morphology and ecology for the purpose of the LTV lies in two aspects, namely:

- The insight that the most relevant time scale on which to assess the ecosystem response of the estuary is the meso-scale, because the goals of preserving the multi-channel character of the lower Schelde and the meandering character of the upper Schelde proclude extreme human-induced changes on the macro- and mega-scale.

- The logic that the ecosystem develops as a composite response to the hydro-morphological forcing i.e. that if we can describe the abiotic character of the estuary we can then infer the biotic character, provided that no limiting exogenous conditions occur (e.g. deterioration in influent water quality).

The linkage between morphology and ecology for the LTV is then made on three levels.

The first level is based on morphological simulations of bed topography and associated hydrodynamic responses (the meso-scale). These simulations are processed to yield ecologically relevant indicators in the form of predictions of the longitudinal extent of abiotic (salinity) zones in the estuary and the areal distribution of subtidal, intertidal and supra-tidal physiotopes within these zones. It is necessary to conduct the appropriate simulation runs to generate really useful data. In the case of this study, use had to be made of simulations runs of only four day duration conducted for the purpose of determining sediment transports. The simulation period and the tidal forcing at the downstream boundary therefore were not appropriate to the prediction of the physiotopes and abiotic zones for biota. However, indicative results were obtained and served to demonstrate clearly the data processing methods necessary to transform hydro-morphological simulation data into ecologically appropriate indices.

The next step in the three-level approach, is separated from the previous step of data translation to ecologically relevant indices. The primary reasons are that that data errors or limiting model assumptions need not necessarily propogate through the hybrid linked system, and that the separation allows one to proceed based on information or knowledge that may not be able to be simulated by numerical models. Thus Level 2 may be implemented independently of Level 1, or value judgements of the ecologically relevant indicator data generated in Level 1 may be used as input data for Level 2.

In Level 2, the Policy Wizard was used to support the development of a conceptual ecosystem model in a careful stepwise manner. This conceptual ecosystem model consists of seventeen components with a number of system variables to describe them. Inter-relationships between the system variables are described in terms of a seven point qualitative scale which allows their strength and direction to be indicated. This ecosystem model is a means of capturing the system understanding of the experts (in the WGN) and making it available to other people involved in the LTV process. It is moreover very effective in causing experts to check their own logic, to improve the consistency of ecologically based arguments and assists in focussing discussion on controversial interactions. To enhance its use and acceptance within the LTV, it was necessary that validation of the model occurred with a combined group of ecologists and morphologists and not only separately. Such a validation workshop was undertaken on 11 September 2000, resulting in much interactive discussion, clarification of inter-relationships in the model and a general increase in confidence in the approach and its utility.

In Level 3, criteria that allow the attainment of the ecosystem goals to be judged are identified and related to the system variables in a structured way using the Policy Wizard. Lastly, the effects of interventions and relevant exogenous factors are assessed qualitatively by first defining the strength and direction of their effects on individual system variables and then evaluating the results as these effects propogate through the ecosystem. Results are expressed as the range of effects that could possibly occur (from the most negative to the most positive). Most useful at this level of policy evaluation are the insights that can be obtained by comparing interactions to different composite management interventions. Second, third and higher level interactions often cause unexpected effects which can be understood by tracing the logical paths in reverse.

Thus the use of the ecosystem model to qualitatively simulate the effects of management interventions and their robustness to exogenous variations (Levels 2 & 3), facilitates policy formulation whether realistic and relevant abiotic simulations can be undertaken or not. However, most satisfying of all is to be able to incorporate an assessment of the change in an ecologically relevant indicator (i.e. a change in areal extent rated on the seven point scale from strong negative through to strong positive), as an effect in the ecosystem model and then be able to evaluate the ecosystem response in terms of its effects on the ecosystem goals. This is to implement fully the 3-level hybrid approach and in so doing to link morphology and ecology and obtain policy-relevant answers, all be they qualitative in nature.

5.2 Limitations

Linkage between morphology and ecology cannot occur over all temporal and spatial scales; a choice has to be made in practice. Given the conceptual bases of the morphological and ecological research projects, the focus in linking the morphology and ecology of the Schelde Estuary for the Long Term Vision development process is the meso-scale.

Examples of aspects that consequently are not covered include:

- succession (development and disappearance) of morphological features;
- sediment composition changes and effects;
- explicit causal relationships and changes in the nutrient cycle;
- the effects of extreme events;
- critical periods for species survival and health;
- micro-scale dynamics.

Instead the chosen approach has linked predictions of changes in abiotic conditions, through a dynamic conceptual model to changes in the characteristic state of the estuarine ecosystem and linked that in a structured way to the majority of the ecosystem goals that have been formulated. The predictions from this 3-level hybrid approach are in the form of qualitative trends in ecosystem variables rather than definite numbers or quantities.

The ecosystem goals that either could not be associated with system variables or could only be associated partially with system variables, include:

- removal of physical barriers to access to the upstream areas by building fish ladders: no association;
- create favourable conditions for the formation of young marsh areas in the brackish zone: partial association;

- limit the fragmentation of habitats by maintaining or creating connections (see van den Bergh *et al* (1999): no association;

- ensure that there is a strip of tidal marsh or mudflat of at least 6 m or 12 m wide, respectively along the river banks of the multi-channel part of the estuary. For the single channel part of the estuary, the width of the channel and the expected wave action would have to be taken into account: no association;

- maintaining river banks of at least 3 m wide: no association; and

- mouth region (Vlakte van der Raan) under the European Habitat-and Bird Protection Laws: no association.

Because of the explicit spatial nature of these goals or the fact that they are associated with the successionary development of morphological features they cannot be addressed within the selected approach.

Despite these limitations, it is useful to analyse and discuss the ecosystem response predicted by the Conceptual Ecosystem Model to various policies. The flexibility of the system is such that differences in opinion regarding the strength, direction or relevance of ecosystem interactions can be entered in the Policy Wizard and the conceptual model can be altered. This allows the effects of these different views on the model outcomes to be investigated. This is an advantage as discussion is encouraged and understanding of the reasons for the ecosystem goals develops.

However, there is some concern that this flexibility could lead to mis-interpretation of model results or misuse within the LTV process (RA 2000f). The presentation of the results as aggregated ranges of potential outcomes goes a long way towards addressing this concern. There is no pretence that the coupling morphology-ecology is such that the future state of the estuary can be predicted. Instead the possible range of effects on the ecosystem are indicated as well as the means by which these effectes are brought about. A wide range of variation can be interpreted as an indication of the uncertainty as to the potential outcome. It is more usually used as a means of checking whether policies are robust or whether unexpected negative consequences could occur if they were to be implemented.

Care was also taken when information was presented in map or table form not to give spurious validity to results, but to use categorizations that are representative of the level of accuracy of the results. For instance, for the ecologically relevant indicators this means only five categories of potential physiotopes were distinguished and there are only two categories for the intertidal dynamics. In the case of the conceptual ecosystem model this means verbal descriptions of the outcomes were given so that the degree of uncertainty associated with the ability to couple morphological effects and ecosystem responses remained clear.

An aspect which has seriously influenced the applicability of the ecologically relevant indices component of the approach (Level 1) is the fact that the only simulation data available are not particularly appropriate for prediction of the consequences to the ecosystem of anticipated abiotic changes. The requirements for ecologically relevant prediction were specified in April 2000 (Slinger 2000). Only as late as September 2000, did it become clear that these data would not be able to be produced within this phase of the LTV process. Consequently, recourse has been made to a rapid assessment technique for alluvial estuaries (Savenije 1992) in an attempt to quantify the uncertainties regarding the upstream dispersion of salt and thus the potential change in extent and position of characteristic abiotic zones. The fact that some information on this aspect (surely of cardinal importance to ecology) is only going to be available at such a late stage in the process and that there is no concurrent prediction of water levels, means that Level 1: Ecologically relevant indices, could not be used to its full potential.

5.3 Necessary Research Actions

The present gap in knowledge regarding the extent of upstream dispersion of salt under the possible future situation (channel deepening, 14 m) should be rectified in the short term. At the moment, an estimate of the changes to be anticipated is being undertaken on the basis of analytical techniques (Savenije 1992). Should these indicate an increased upstream dispersion of the order of 5 km or a change in salinity of the order of 3 ppt or more in the brackish/freshwater interface region, then the requisite hydrodynamic simulations should be undertaken because these effects will have consequences for the ecosystem, particularly the biota in the affected areas.

Furthermore, it would be advisable to model the hydrodynamics of the entire estuary and so obtain an improved understanding of possible changes in tidal variation and salt disperison should channel deepening occur. This could be undertaken by a coupling of DELFT3D (Roelvink & van Banning 1994) for the downstream reaches with a one- (or higher) dimensional hydrodynamic model for the upstream reaches (by exchanging boundary conditions at the interface). In the medium term the necessary information on the bed topography, water levels and salinities can be collected so that higher dimensional models can be applied if needed.

In the longer term, research should focus on the processes linking the sub-systems within the Schelde Estuary. It was apparent in the formulation of the conceptual ecosystem model, that knowledge of how changes within one sub-system (freshwater, brackish and estuarine) would influence another was more limited than knowledge about changes within a sub-system itself. Accordingly the structure of the model is such that it reflects a general conceptualisation of the influences of the abotic environment on biotic components. It would be interesting to restructure the model to reflect interactions between sub-systems by regrouping variables under different component headings. This would serve to highlight where interlinkage between sub-systems is included and would reveal the weakness in this area in the current model. Application of the conceptual ecosystem model in this way can assist in the specification of longer term research needs.

An aspect of the linkage between morphology and ecology which could not be addressed within the LTV owing to time constraints, is prediction of the effects on indicator floral and faunal species of the alterations in abiotic zones and physiotope distributions within the estuary. This more detailed and explicit approach is complementary to the conceptual ecosystem model and would act as a check on whether the anticipated general consequences agree with those of the species-specific predictions. Examples of such approaches include Slinger & Breen (1995), Adams & Bate (1997), Quinn (1998) and Peviani *et al.* (1996).

In general, the degree of attention devoted to the lower reaches of the estuary has been disproportionate in relation to the probable effects of channel deepening on the ecosystem. It is the brackish-freshwater interface region which is most likely to experience substantial changes should channel deepening occur.

It is necessary that sufficient attention be paid to the freshwater supply and water quality concerns of the Boven Schelde together with the associated quality of the sediment as these issues will determine ecosystem health in the long term.

5.4 Conclusion

The purpose of this sub-project was to promote integration between the activities undertaken within the morphological investigation and the goal formulation from the viewpoint of nature and to establish linkages, where possible.

From the outset, the project was to be deemed successful if:

1. the predicted morphological changes could either be associated with anticipated ecosystem responses and these responses could be tested for acceptability against the goals for the natural environment of the estuary, or

2. the reason(s) why such linkage could not be made in specific instances can be stated clearly.

The coupling between morphology and ecology for the Long Term Vision of the Schelde Estuary has been developed at the meso-scale using a 3-level hybrid approach (a composite system of software tools such as the Policy Wizard and @-lvis and techniques such as GIS and the Rapid Assessment Methodology). The predicted morphological changes form the basic input data for Level 1 of this system together with DELFT3D hydrodynamic simulation data. These are translated into ecologically relevant indices which facilitate comparison of the effects of the changes in abiotic environment at meso-scale on estuarine biota. The output is in the form of maps of the extent of characteristic abiotic (salinity) zones and physiotopes. By entering this information as an effect on a seven point scale on the system variables of a conceptual ecosystem model (Level 2), the consequences for the ecosystem of changes in the hydro-morphological environment at meso-scale can be assessed. This assessment takes the form of an aggregated possible range of response of each of the system variables. Consequently, success criterion 1 has been met.

Success criterion 2 has also been met in that the data limitations and aspects which could not be addressed within each of the Levels of the 3-layer hybrid approach were reported (sections 3.1.1, 3.1.2, 4.2.1) and discussed extensively in section 5.2. The presentation of the output of the Conceptual Ecosystem Model as an aggregated range of potential responses also assists in indicating the degree of uncertainty associated with any coupling between morphology and ecology. However, the fact that the ranges are based on causal links and that the positive and negative effects can be traced to their origins makes the model useful in supporting policy decision making.

6 Recommendations

To ensure that the potential of the coupling at meso-scale between morphology and ecology is used to support decision making within the process of developing and justifying the Long Term Vision for the Schelde Estuary, it is recommended that:

- quality checks on the existing information base (accessible through @-lvis) occur;
- the rapid assessment analytical method for determining salt intrusion and high water levels in alluvial estuaries is implemented as soon as possible so that the order of magnitude of the anticipated increased upstream penetration of salt and tide can be determined;
- hydrodynamic model simulations appropriate to an assessment of the natural environmental responses and covering the whole estuary (i.e. including the upper reaches) are conducted, the results processed into the ecologically relevant indicators as defined in this sub-project and included in @-lvis;
- the output from the conceptual ecosystem model is evaluated by both ecologists and morphologists and the conceptual model is continuously updated to reflect any new information or additional insights i.e. it remains a flexible tool supporting the LTV process; and
- the model is used to indicate gaps in knowledge and uncertainties in policy outcome relevant to the LTV and so can assist in guiding decisions regarding the research necessary to support policy making in the Schelde Estuary.

In addition, there is a clear indication that research attention needs to focus on developing

- knowledge of the interface regions and processes linking sub-systems within the Schelde Estuary, particularly the brackish-freshwater interface zone;
- techniques for reliably predicting morphological changes in the intertidal areas; and
- the means of effectively integrating this knowledge.

The latter point is particularly relevant, because integration of research results from different disciplines involving different temporal and spatial scales is most effective if planned at the initiation of the research programme.

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Appendix A VAS – Verkennend Analyse Systeem

Rekenregels Achtergrond

Peter Kouwenhoven

Resource Analysis

Delft, 4 juli 2000

A.1 Inleiding

Het VAS (Verkennend Analyse Systeem) kent de volgende elementen:

- componenten
  Een component komt in het VAS overeen met een deel van het "totale systeem" dat beschreven wordt: dit kan betrekking hebben op een fysiek element (water), op een actor (visserij) op een functie (drinkwater) en/of op een kennisdomein of discipline (ecologie). Het is de eerste detaillering van het totale systeem.

- toestandsvariabelen
  Een toestandsvariabele is een grootheid die een bepaalde component karakteriseert. Voor componenten die ruimte "gebruiken" is "area" bv. een goede karakteriserende grootheid. Een toestandsvariabele kan daarnaast nog twee andere functies hebben: 1) als indicator/criterium voor het bepalen van het succes van de te evalueren ingrepen en 2) als grootheid die direct/rechtstreeks verandert als gevolg van een ingreep of als gevolg van (te specificeren) exogene veranderingen

- relaties
  Relaties beschrijven welke toestandsvariabelen direct veranderen agv. het veranderen van een specifieke toestandsgrootheid.

Met het VAS kunnen de gevolgen van veranderingen van specifieke toestandsvariabelen (bv. door beleid) in termen van veranderingen van andere toestandsvariabelen (waaronder indicatoren) berekend worden.

De volgende paragraaf gaat in op de rekenmethode.

A.2 Rekenregels

Een relatie tussen 2 toestandsvariabelen A en B kan de volgende (kwalitatieve) "sterkten" hebben:

+++	een positieve verandering (ie. toename) van toestandsvariabele A heeft een directe, vergelijkbare positieve verandering van toestandsvariabele B tot gevolg
++	een positieve verandering van toestandsvariabele A heeft een directe, positieve verandering van toestandsvariabele B tot gevolg die minder groot is
+	een positieve verandering van toestandsvariabele A heeft een directe, positieve

	verandering van toestandsvariabele B tot gevolg die duidelijk geringer is
0	een verandering van toestandsvariabele A heeft geen (directe) verandering van toestandsvariabele B tot gevolg (er is geen relatie tussen A en B)
-	een positieve verandering van toestandsvariabele A heeft een directe, negatieve verandering (ie. afname) van toestandsvariabele B tot gevolg die duidelijk geringer is
--	een positieve verandering van toestandsvariabele A heeft een directe, negatieve verandering van toestandsvariabele B tot gevolg die minder groot is
---	een positieve verandering van toestandsvariabele A heeft een directe, vergelijkbare negatieve verandering van toestandsvariabele B tot gevolg

Veranderingen van de toestandsvariabelen worden op dezelfde schaal gewaardeerd:

+++	de waarde van de variabele verandert sterk positief, dan wel de verandering van de variabele wordt als sterk positief gewaardeerd
++	de waarde van de variabele verandert normaal positief, dan wel de verandering van de variabele wordt als normaal positief gewaardeerd
+	de waarde van de variabele verandert licht positief, dan wel de verandering van de variabele wordt als licht positief gewaardeerd
0	de variabele verandert niet, dan wel de verandering van de variabele wordt als onbelangrijk gewaardeerd
-	de waarde van de variabele verandert licht negatief, dan wel de verandering van de variabele wordt als licht negatief gewaardeerd
--	de waarde van de variabele verandert normaal negatief, dan wel de verandering van de variabele wordt als normaal negatief gewaardeerd
---	de waarde van de variabele verandert sterk negatief, dan wel de verandering van de variabele wordt als sterk negatief gewaardeerd

Het effect van een bepaalde verandering van toestandsvariabele A via een relatie op toestandsvariabele B wordt bepaald mbv. de volgende rekenregels:

	relatie met B					
verandering in A	+++	++	+	-	--	---
+++	+++	++	+	-	--	---
++	++	+	0	0		--
+	+	0	0	0	0	-
-	-	0	0	0	0	+
--	--	-	0	0	+	++
---	---	--	-	+	++	+++

(in de tabel staat de resulterende verandering in toestandsvariabele B, als gevolg van een verandering in toestandsvariabele A, via de werking van de relatie boven aan de respectievelijke kolommen)

De rekenregels zijn proefondervindelijk vastgesteld met als belangrijkste randvoorwaarde dat er geen versterking op mag treden omdat daardoor divergentie van de werking optreedt (hetgeen een zinvolle analyse verhindert).

De progressie van de veranderingen in het systeem (na introductie van een verandering van een bepaalde toestandsvariabele bv. agv. een ingreep) wordt door het VAS berekend. Omdat veranderingen langs verschillende paden kunnen plaatsvinden, waarbij de mate van veranderingen langs die paden verschillend kunnen uitpakken, houdt het VAS een onder- en bovengrens bij. Het VAS kan ook het geaggregeerde resultaat laten zien waarbij het minimum en maximum over alle mogelijke paden wordt genomen (tot een bepaalde, op te geven diepte).

De rol van relaties in het berekeningsresultaat is een belangrijke en de volgende paragraaf gaat in op een aantal overwegingen tav. het bepalen van de sterke van de relaties.

A.3 Aanwijzingen

De specificatie van de componenten en representatieve grootheden daarin, als weerslag van een te beschrijven "totaal systeem" levert meestal geen problemen op. Ook de duiding van de aanwezigheid van "een" (directe) relatie tussen twee toestandsvariabelen is niet al te moeilijk. In de praktijk blijkt met name het specificeren van de sterkte van de relatie (1 tot 3 plusjes of minnetjes) een lastige kwestie. De volgende aanwijzingen kunnen hierbij helpen:

- de verschillende keuzes kunnen makkelijk in het systeem ingevoerd en uitgeprobeerd worden; zo kunnen gevoeligheden onderzocht worden; een keuze voor een bepaalde sterkte van een relatie is niet definitief

- doordat het VAS de ranges bijhoudt van de grootste negatieve en de grootste positieve verandering, zullen niet alle paden waarlangs de veranderingen plaats vinden in het geaggregeerde eindresultaat meetellen; de discussie over sommige van deze irrelevante paden/relaties hoeft dan niet plaats te vinden

- soms helpt het de veranderingen in het systeem niet direct als veranderingen te beschouwen maar als waarderingen van die veranderingen; de relaties beschrijven dan hoe deze waarderingen van elkaar afhangen; veranderingen die in absolute termen klein zijn kunnen toch als belangrijk gewaardeerd worden alsook het doorwerken op de verandering van de waardering van de gerelateerde toestandsvariabele

- het VAS is vooral bedoeld om de doorwerking van (lokale) veranderingen in het "totale" systeem te laten zien; het blijft aan de gebruiker om de resultaten te accepteren of te verwerpen (op basis van kennis die niet in het VAS ondergebracht kan worden); de gebruiker zoekt daarbij naar onverwachte effecten en analyseert de totstandkoming van de boven/ondergrenzen in de resultaten

- relaties kunnen ook als volgt beschouwd worden:
  +++: een verandering werkt ongefilterd door
  ++ : een verandering werkt licht verzwakt door
  + : een verandering werkt verzwakt door
  - : een verandering werkt verzwakt door in tegengestelde richting
  -- : een verandering werkt licht verzwakt door in tegengestelde richting
  --- : een verandering werkt ongefilterd door in tegengestelde richting

Appendix B

B.1 Formulation of the Conceptual Ecosystem Model

Seventeen descriptors of the general character of the Schelde Estuary were considered fundamental to a description of its past, present and possible future states. These descriptors, which are termed components, are listed subsequently. The convention of always providing the Dutch name in italics after a model component or variable is first defined will be followed throughout this text.

1. North Sea / *Noordzee*
2. Freshwater Supply / *Zoetwatertoevoer*
3. Hydrodynamics / *Hydrodynamiek*
4. Morphodynamics / *Morfodynamiek*
5. Permanently Increasing the Storage Capacity / *Vergroting Permanente Komberging*
6. Turbidity / *Troebelheid*
7. Water Quality / *Waterkwaliteit*
8. Bed Sediment Quality / *Waterbodemkwaliteit*
9. Abiotic Zones / *Abiotische Zones*
10. Physiotopes / *Fysiotopen*
11. Macrobenthos / *Macrobenthos*
12. Fish & Prawns/Shrimps / *Vissen & Garnalen*
13. Birds / *Vogels*
14. Marine Mammals / *Zeezoogdieren*
15. Primary Production / *Primaire Productie*
16. Dredging, Dumping & Sand Mining / *Baggeren, Storten & Zandwinning*
17. Ecosystem Indicators / *Ecosysteem Indicatoren*

The system variables of the conceptual ecosystem model are grouped under the relevant components to make the inter-relationships and linkages between the variables easier to visualise and understand. For each component, these variables will be defined and their degree of influence on other system variables will be assessed in terms of the seven point scale from three minuses (---) to 3 plusses (+++), where the direction of influence is indicated by the positive or negative sign and the strength of the dependence is given by the number of symbols i.e. + indicates weak reinforcement, ++ moderate reinforcement and +++ strong reinforcement (Appendix A).

B.2 North Sea

Biophysical forcing from the adjacent coastal ocean is included in the conceptual model and not treated as completely exogenous, because expert knowledge is needed to enter correctly the interaction with other system variables. If this were not included in the model, but available for testing as a purely exogenous influence, the quality of the model result could be affected by incorrect entry of the influences on the tidal variation in the coastal ocean and the Hydrodynamics and Morphodynamics Components. For the Belgian/Dutch coastal area, a rise in sea level is expected to be accompanied by an increase in tidal variation and maximum tidal water levels (A Arends, *pers. comm.*). These influences will be specified subsequently or when the variables under the components Hydrodynamics and Morphodynamics are defined.

Additionally, the influence of the estuary on the adjacent coastal zone, specifically the chemical influence, is included through the variable Silicon Limitation (*Silicium Limitatie*). Presently, diatom growth in the mouth region is limited by silicon availability, rather than the availability of nitrogen or phosphorus compounds. This is regarded as evidence of the high nutrient loading to the system and provides one of the measures of the success or otherwise of policies aimed at improving the water quality in the estuary. The influence of the water quality of the estuary on the silicon limitation will be described under the Water Quality Component.

System variables include:

- the tidal variation in the nearshore zone (North Sea Tide / *Noordzee Getijslag*),
- the mean sea level (Mean Sea Level / *Zeespiegel*)
- the sand availability (Sand Availability / *Beschikbare Zand*)
- and the silicon limitation (Silicon Limitation / *Silicium Limitatie*).

Table 11 Relationships between variables of the North Sea Component

North Sea Component	North Sea Tide
Mean Sea Level	A rise in sea level will be accompanied by a moderate increase in tidal variation i.e. a rating of ++ is assigned to this relationship.

B.3 Freshwater Supply

Although the freshwater supply to the estuary and its quality are not the fundamental questions to be addressed in the process of building a Long Term Vision for the Schelde Estuary (refer to LTV project description Jill), they are the major driving forces of the abiotic and biotic variation in the upper and middle reaches of the estuary. In addition, the quality of the water in the past has imposed severe constraints on the ecosystem and lead to the present situation of impoverished bottom fauna (only oligochaetes) in some of the highly polluted areas and no diadromous fish in the estuary at all, owing to the low dissolved oxygen levels in the brackish zone.

Consequently, the variables describing the freshwater supply are:

- The quantity of freshwater entering the system, including the flows from tributaries e.g. the Rupel (Freshwater Quantity / *Zoetwaterkwantiteit*)
- The quality of the freshwater inflow, including the quality of the silt load (Freshwater Quality / *Zoetwaterkwaliteit*)

In assigning a rating to the quality of the inflows, four characteristics together with a general assessment of the quality of the silt load (in terms of severely polluted through mildly polluted to unpolluted) are used. These characteristics include: dissolved oxygen levels, nutrient levels, organic carbon loading and heavy metal or organic micropollutant loading. If the quality is rated poorly for any one of these characteristics or that of the silt load, the overall quality is rated poorly. Only if every characteristic is relatively good i.e. not severely limiting to biota, is the water quality rated positively. In this way, the deleterious effect of bad water quality and its potentially limiting influence on the ecosystem can be included without an exact knowledge of the status of each chemical constituent.

At a conceptual level, the Component Freshwater Supply thus reflects the influence of the catchment on the physico-chemistry of the Schelde Estuary. The freshwater quantity and quality variables directly influence other system variables of the Components Hydrodynamics, Morphodynamics, Abiotic Zones, Water Quality, Bed Sediment Quality and Turbidity. These influences will be described subsequently when the affected system variables are defined.

B.4 Permanently Increasing the Storage Capacity (*Komberging*)

In both Belgium and The Netherlands, the issue of permanently increasing the storage capacity of the Schelde Estuary has to be addressed within the process of developing the Long Term Vision. To be of significant value to the ecosystem this ''ontpoldering"' has not just to provide additional storage capacity in time of high riverine discharge, but cause the tidal prism to increase. This ontpoldering has been included as a model component with the variables:

- Permanent Increase in Freshwater Storage Capacity / *Permanente Vergroting Komberging Zoetwatergebied*

- Permanent Increase in Brackish Storage Capacity / *Permanente Vergroting Komberging Brakwatergebied*

- Permanent Increase in Estuarine Storage Capacity / *Permanente Vergroting Komberging Zoutwatergebied*

These variables influence the components Hydrodynamics, Abiotic Zones and Physiotopes. These effects will be specified subsequently when the relevant system variables have been described.

B.5 Dredging, Dumping and Sand Mining

Maintenance dredging of the channels of the Schelde Estuary is an ongoing operation, as is the dumping of dredge spoil. Similarly, the mining of sand in the Westerschelde-west is an ongoing activity. These influences are considered essential to the maintenance of the multi-channel character of the lower estuary (A Arends, *pers. comm.*) and so must form an integral part of the conceptual ecosystem model. The differences in management policies for dredging, dumping and sand mining differ per geomorphological reach of the estuary and these differences are reflected in the model through the use of the categorisations Mouth, Westerschelde-west, Westerschelde-oost and Zeeschelde. The system variables include:

- Dredging of the main channels (Dredging – Zeeschelde, - Westerschelde-Oost, - Westerschelde – West, - Monding / *Baggeren - Zeeschelde, - Westerschelde-Oost, - Westerschelde – West, - Monding*)

- Dumping of dredge spoil away from the main channel (Dumping – Zeeschelde, - Westerschelde-Oost, - Westerschelde – West, - Monding / *Storten - Zeeschelde, - Westerschelde-Oost, - Westerschelde – West, - Monding*)

- Sand mining in the Westerschelde-west area (Sand mining / *Zandwinning*)

The internal relationships between dumping, dredging and sand mining under the maintenance 'no regret'management strategy are described in the following table.

Table 12 Relationships between variables of the Dredging, Dumping and Sand Mining Component

Dredging, Dumping and Sand Mining Component	Dredging	Dumping	Sand Mining
Dredging	No direct influences	Increased dredging in the mouth area weakly increases the spoil dumping in the mouth area (+)	No direct influences
Dumping	No direct influences	No direct influences	No direct influences
Sand Mining	Incresed sand mining moderately reduces the need to dredge in the Westerschelde-west (--)	Increased sand mining weakly reduces the need to dump in the Westerschelde-west and the mouth area (-)	N/a

The maintenance dredging, dumping and sand mining 'no regret' management strategy affects system variables in the North Sea, Morphodynamics, Turbidity and Physiotope Components. The effect on the North Sea is specified in the following table.

Table 13 Influence exerted on the North Sea Component

North Sea Component	Sand Availability
Sand Mining	Increased sand mining moderately reduces the availability of sand (--).

B.6 Hydrodynamics

The system variables describing the hydrodynamics of the estuary are:

- The tidal variation in the fresh, brackish and estuarine regions (Tide – Freshwater Zone / *Getijslag - Zoetwater*, Tide – Brackish Zone / *Getijslag - Brakwater*, Tide – Estuarine Zone / *Getijslag - Zoutwater*)

- The current speeds in the fresh, brackish and estuarine regions (Current Speed - Freshwater Zone / *Stroomsnelheid - Zoetwater*, Current Speed – Brackish Zone / *Stroomsnelheid - Brakwater*, Current Speed – Estuarine Zone / *Stroomsnelheid - Zoutwater*), and

- The maximum water levels in the fresh, brackish and estuarine regions (Maximum Water Level – Freshwater Zone / *Hoogwaterstand - Zoetwater*, Maximum Water Level – Brackish Zone / *Hoogwaterstand - Brakwater*, Maximum Water Level – Estuarine Zone / *Hoogwaterstand - Zoutwater*).

The tidal variation in the mouth region is not specifically included as it is considered to be represented adequately by the North Sea Tidal variation (*Noordzee Getijslag*). The current speeds and the maximum water levels in this area are considered to follow closely those of the Estuarine Zone (*Zoutwater Zone*).

The influences of the North Sea, the freshwater supply and permanently increasing the storage capacity on the variables of the Hydrodynamics Component are described and assigned qualitative ratings in the following table.

Table 14 Influences exerted on the Hydrodynamics Component

Hydrodynamics Component	Tidal Variations	Current Speeds	Maximum Water Levels
North Sea Tide	Most influence in increasing tidal variation in the estuarine and brackish reaches. No direct influence on the upper reaches (estuarine +++, brackish ++)	An increase in tidal variation will increase current speeds in the estuarine and brackish zones by increasing the tidal variation in these zones. Therefore, no direct influence.	An increase in tidal variation will increase maximum water levels in the estuary by increasing the tidal variation per zone. Therefore, no direct influence.
Mean Sea Level	In the same way that the tidal variation in the nearshore region will increase moderately, the increase in the tidal variation in the estuarine and brackish zones will be moderate (++) and in the freshwater zone weak (+).	No direct influence (0)	An increase in sea level will have a strong direct influence on the maximum water levels in the estuarine and brackish water zones (+++) and a moderate influence in the freshwater zone (++).
Sand Availability	No influence (0)	No influence (0)	No influence (0)
Silicon Limitation	No influence (0)	No influence (0)	No influence (0)
Freshwater Quantity	Most influence in damping tidal variation in the freshwater zone (---), decreasing in influence with distance downstream (brackish --) No direct influence on the estuarine reaches. This comes from the adjacent upstream reach.	Strong direct influence on current speeds in the upper reaches and brackish reaches when high volumes (freshwater +++, brackish +, estuarine and mouth 0)	Strong influence on maximum water levels. Very high flows cause very high water levels in the upper reaches, with decreasing influence with distance downstream (freshwater +++, brackish ++, estuarine and mouth 0).
Freshwater Quality	No influence (0)	No influence (0)	No influence (0)
Permanent Increase in Freshwater Storage Capacity	Tidal variation in the freshwater zone deceases moderately (--) and is accompanied by a weak decrease in the brackish zone (-).	Slight increases in current speeds (+) in the freshwater and brackish zones as higher volumes of water are exchanged within the same tidal period.	Maximum water levels decrease strongly in the freshwater reaches (---) and also decline slightly in the brackish reaches (-).
Permanent Increase in Brackish Storage Capacity	Tidal variation in the brackish reaches decreases slightly (-), because of the increased intertidal area.	Slight increase in current speeds (+) as higher volumes of water are exchanged within the same tidal period.	Maximum water levels decease moderately (--), because of the increased storage capacity at lower water levels.
Permanent Increase in Estuarine Storage Capacity	Tidal variation in the estuarine reaches decreases slightly (-), because of the increased intertidal area.	Slight increase in current speeds (+) as higher volumes of water are exchanged within the same tidal period.	Maximum water levels decease moderately (--), because of the increased storage capacity at lower water levels.

In addition to the influences from variables of the components described thus far, there are relationships between the variables grouped under the Hydrodynamics Component. These are described and assigned ratings in the following table.

Table 15 Relationships between variables of the Hydrodynamics Component

Hydrodynamics Component	Tidal Variations	Current Speeds	Maximum Water Levels
Tidal Variations	Tidal variation in the estuarine zone exerts a strong influence on the adjacent brackish zone (+++). The brackish tidal variation strongly influences the freshwater tidal variation (+++), in turn.	Increased tidal variation causes a strong increase in current speeds throughout the estuary (+++)	Increases in the tidal variation cause the maximum water level in the estuarine reaches to increase strongly (+++) and exerts a more moderate influence in the brackish and freshwater reaches (++).
Current Speeds	No influence (0)	No influence (0)	No influence (0)
Maximum Water Levels	No direct effect (0)	No direct effect (0)	Increases in the maximum water level in the estuarine zone have a moderate effect on those in the brackish zone (++). Changes in the brackish zone have a weak influence on the freshwater zone (+). In contrast, high water levels in the freshwater zone moderately influence the brackish (++) and weakly influence the estuarine zone (+).

The Hydrodynamics variables influence the Components Morphodynamics, Abiotic Zones, Physiotopes, Turbidity and Macrobenthos.

B.7 Morphodynamics

The system variables describing the morphodynamics of the estuary were selected to reflect the meso-scale geomorphological response of the estuary to management interventions and external forcing. Consequently, the variables include:

- The channel depth (Channel Depth to Antwerp / *Geul Diepte tot aan Antwerpen*)
- Morphological Diversity – Zeeschelde, - Westerschelde-Oost, - Westerschelde – West, - Monding (*Morfologische Diversiteit - Zeeschelde, - Westerschelde-Oost, - Westerschelde – West, - Monding*)
- Slope of the tidal flats in the multi-channel areas and the slope of the mudflat/marsh area in the Zeeschelde (Slope of the Tidal Flats or Mudflats/Marsh / *Steilheid van Platen of Slik/Schor*)

The first variable is an indication of the freedom of the tidal flats, mudflats and tidal marsh areas to respond dynamically to alterations in forcing at the meso-scale. These alterations in forcing include changes in the tidal variation and current speeds to which they are exposed on a daily basis as well as differences in sand availability from the adjacent coastal area. The types of dynamic feature envisaged in the term morphological diversity are the appearance, migration and possible disappearance of shallow gulleys (*kortsluitgeulen*) within channel/flat complexes (*plaat-geul complexen*) and/or tidal marsh physiotopes (*schorren*) in the fresh upper reaches.

The morphological variables are defined for fixed geomorphological reaches of the estuary and do not vary in extent or location depending on freshwater flow and tidal influence as do the system variables associated with water masses e.g. those of the Hydrodynamics and Abiotic Zone components. A major reason for this decision is the different dredging, dumping and sand mining strategies that apply to different locations in the estuary. The effects of these differences have to be able to be described by the model, because they are considered to exert considerable influence on the morphological character and the maintenance of the morphological cells (Winterwerp *et al.* 2000a & b).

The interaction between the variables morphological diversity and slope of tidal flats is deemed to be very limited (A Arends, *pers. comm.*), so they can be treated as independent variables for practical purposes. However, morphological variables of one location exert influences on adjacent locations (cells) and these influences are specified in the following table.

Table 16 Relationships between variables of the Morphodynamics Component

Morphodynamics Component	Channel Depth to Antwerp	Morphological Diversity	Steepness of the Tidal Flats or Mudflat/Marsh
Channel Depth to Antwerp	N/a	Increasing the channel depth has a weak negative effect on the morphological diversity of the Westerschelde-oost and – west (-).	Increasing the channel depth causes the steepness of the tidal flats to increase slightly in the Westerschelde-oost and -west (-). A similar effect occurs in the lower Zeeschelde (-).
Morphological Diversity	Morphological diversity in the Westerschelde-oost in particular contributes moderately positively to channel depth (++).	The morphological diversity of the mouth positively influences that of the Westerschelde-west (++) and this, in turn, influences positively the Westerschelde-oost (++). The diversity in the W-oost exerts moderate positive effect on the Zeeschelde (++) and a weak positive effect on the seaward adjacent zone the W-west (+)	No influence (0)
Steepness of the Tidal Flats or Mudflat/Marsh	No influence (0)	No influence (0)	An increase in steepness of the sand flats in the Westerschelde-west causes a moderate increase in the Westerschelde-oost (++).

Influences from the components North Sea, Freshwater Supply, Hydrodynamics and Dredging, Dumping and Sand Mining on the morphodynamics are described and assigned rating in the following table.

Table 17 Influences exerted on the Morphodynamics Component

Morphodynamics Component	Channel Depth to Antwerp	Morphological Diversity	Steepness of the Tidal Flats or Mudflat/Marsh
Mean Sea Level	An increase in sea level has a strong positive effect on the channel depth to Antwerpen (+++).	An increase in sea level has a weak positive effect on the morphological diversity of the multi-channel system i.e. in the mouth area and Westerschelde-west and – oost (+). No direct influence on the Zeeschelde, this comes through the effects on the adjacent Westerschelde-oost zone.	No direct influence (0)
	No direct influence (0)	Strongly positively related to the morphological	Increasing the sand supply to the mouth area and the

Sand Availability		diversity in the mouth area (+++), which is sand hungry at present. Moderate positive influence on the nearby Westerschelde-west (++).	nearby Westerschelde-west will cause the slope of the sand flats to decrease moderately (--). When there is too little sand or direct dumping they steepen and pile up.
Freshwater Quantity	No direct influence (0)	Morphological diversity increases with more freshwater, moderately in the Zeeschelde (++) and weakly in the Westerschelde-oost (+).	No direct influence (0). Increased current speeds (Hydrodynamics) will cause the steepness of the mudflats and marshes characterising the upper reaches to increase.
Tidal Variation	Tidal variation in the estuarine and brackish zones exerts a weak positive effect on the channel depth (+).	An increase in tidal variation in the estuarine reaches will increase morphological diversity in the mouth and Westerschelde-west moderately (++) and directly influence the diversity in the next upstream reach, Westerschelde-oost weakly (+). Similarly, an increase in brackish tidal variation will increase diversity in the Westerschelde-oost (++) and exert a weak direct influence on the Zeeschelde (+). Increased variation in the freshwater reach will increase diversity moderately (++).	Increased tidal variation in the freshwater reaches will increase the steepness of the mudflat/marsh interface moderately (++). This detrimental influence does not accompany increased tidal variation in the estuarine and brackish zone. When estuarine tidal variation changes the Westerschelde-west is moderately affected (--) and the Westerschelde-oost and mouth, weakly(-). When brackish tidal variation alters, brackish slopes decline moderately (--) and Zeeschelde slopes weakly (-).
Maximum Water Levels	Increased estuarine and brackish maximum water levels have a weak positive influence on channel depth (+).	No direct influence (0)	No direct influence (0)
Current Speeds	Increased estuarine and brackish current velocities have a weak positive influence on channel depth (+).	When estuarine current velocities increase, the morphological diversity of the Westerschelde-west declines moderately (--) and the Westerschelde-oost and mouth weakly(-). When brackish current velocities increase, brackish diversity declines moderately (--) as does that of the Zeeschelde (-). When Zeeschelde current velocities increase, diversity declines moderately (--).	Increased estuarine current speeds cause the slope in the Westerschelde-west to increase strongly (+++) and those of the Westerschelde-oost and mouth, moderately (++). Increased brackish currents cause slopes in the Westerschelde-oost and the Zeeschelde to increase moderately (++). Increased freshwater current speeds cause the mudflat/marsh slopes in the Zeeschelde to increase strongly (+++).
Dredging	An increase in dredging in the mouth area and the Westerschelde-west and -oost, moderately increases the channel depth (++). This effect is weak for the Zeeschelde (+).	Increased dredging in the mouth area has a weak negative effect on the morphological diversity there (-) because of the sand hunger. In contrast, increased dredging in the Westerschelde-west and –oost and in the Zeeschelde moderately increases diversity in these areas (++).	Dredging in the Westerschelde-west and –oost strongly increases the steepness of the sand flats (+++), whereas this effect is moderate in the mouth area(++). The effect on the mudflat/marsh slope is also moderate in the Zeeschelde (++).
Dumping	No direct influence (0).	Dumping in the mouth, Westerschelde-west and –oost has a strong negative	Increased dumping leads to a moderate increase in slope of the sand flats of

		influence on the morphological diversity in these areas (---). The effect in the Zeeschelde is moderate (--).	the mouth area, Westerschelde-west and -oost (++) and of the mudflat/marsh slope in the Zeeschelde (++).
Sand Mining	No direct influence (0)	Increased sand mining moderately reduces morphological diversity of the Westerschelde-west (--).	Increased sand mining moderately increases the steepness of the sand flats of the Westerschelde-west (++)

The morphodynamics of the Schelde Estuary exerts influence on the Hydrodynamic, Physiotope and Marine Mammal Components. The only direct influences on the Hydrodynamic Component are exerted by the channel depth as listed in the following table. The influences on the Physiotopes and Marine mammals will be discussed later.

Table 18 Influences exerted by the Morphodynamics Component

Morphodynamics Component	Tidal Variations	Current Speeds	Maximum Water Levels
Channel Depth to Antwerp	Increasing the channel depth will cause a moderate increase in the tidal variation in the estuarine and brackish reaches (++) and a weak increase in the freshwater reach (+).	No direct influence (0). This comes through the effect on the tidal variation.	No direct influence (0). This comes through the effect on the tidal variation.

B.8 Abiotic Zones

The characteristic abiotic zones in an estuary with a complete marine-freshwater gradient are described by McLusky (1981). These divisions are used as a basis for the choice of the state variables for the Abiotic Zone component as described below:

- Freshwater zone (limnetic and oligohaline) with characteristic salinities in the range 0 to 5 ppt (Freshwater Zone /*Zoetwatergebied*)
- Brackish water zone (mesohaline with strong gradients) with characteristic salinities in the rage 5 to 18 ppt (Brackish Zone / *Brakwatergebied*)
- Estuarine zone (polyhaline and euhaline) with characteristic salinities exceeding 18 ppt (Estuarine Zone / *Zoutwatergebied*).

The location and extent of the abiotic zones are determined by the freshwater supply to the estuary and the tidal variation. The freshwater acts to extend the freshwater zone downstream and the tide acts to extent the marine influence upstream. The abiotic zones represent the net result of these rival effects over time and there are no internal relationships between the system variables for the different zones.

At present, the estuarine zone extends covers the Mouth area, the Westerschelde-west and extends into the Westerschelde-oost. The brackish area extends from the Westerschelde-oost into the Zeeschelde. The freshwater zone is located in the Zeeschelde.

The system variables of the Abiotic Zone Component are influenced by the Freshwater Supply, Hydrodynamics and Permanent Increase in Storage Capacity Components as described in the following table.

Table 19 Influences exerted on the Abiotic Component

Abiotic Zone Component	Freshwater Zone	Brackish Zone	Estuarine Zone
Freshwater Quantity	Increased freshwater flow exerts a strong positive influence on the freshwater zone (+++)	Increased freshwater flow exerts a moderate positive effect o the brackish water zone, increasing salinity gradients and downstream persistence of freshwater influence (++)	Increased freshwater flow exerts a weak negative influence on the estuarine zone (-).
Tidal Variation	Increased variation in the freshwater zone has a moderate negative effect as upstream dispersion of salt is then possible (--).	Increased tidal variation in the brackish zone acts to increase salt intrusion strongly and so increase its extent strongly (+++).	Increased tidal variation in the estuarine zone acts to promote salt intrusion and extends the estuarine zone moderately (++).
Permanent Increase in Storage Capacity	Increased freshwater storage capacity will increase the freshwater zone moderately (++).	Increased brackish storage capacity will increase the brackish zone moderately (++).	Increased estuarine storage capacity will increase the estuarine zone weakly because it is already vast (+).

The system variables of the Abiotic Zone Component influence those of the Physiotopes, Fish and Prawns and the Ecosystem Indicators. These effects will be specified later when the relevant variables have been described.

B.9 Turbidity

A typical turbidity is associated with each of the abiotic zones. The turbidity is specified separately from the water quality because it is influenced by different system variables and in turn influences the water quality class of the different abiotic zones. The system variables are:

- Freshwater Turbidity (*Troebelheid Zoetwater*)
- Brackish Turbidity (*Troebelheid Brakwater*)
- Estuarine Turbidity (*Troebelheid Zoutwater)*

Influences on turbidity include the quality of the freshwater entering the estuary (Freshwater Supply Component), the current speeds (Hydrodynamics Component), the dredging and dumping of dredge spoil (Dredging, Dumping and sand Mining Components) and autotrophic production (Primary Production). All except the last of these influences are specified in the following table.

Table 20 Influences exerted on the Turbidity Component

Turbidity Component	Freshwater Turbidity	Brackish Turbidity	Estuarine Turbidity
Freshwater Quality	An improvement in the quality of the freshwater inflow will have a strong negative effect on the turbidity in the freshwater zone as the silt loading will decrease (---)	An improvement in freshwater quality will mean a lower silt load and this will have a moderate negative influence on brackish turbidity (--).	No direct influence (0)
Current Speeds	Increased current speeds will increase turbidity in the freshwater moderately (++).	Increased current speeds will increase turbidity in the brackish zone moderately (++).	Increased current speeds in the estuarine zone will increase turbidity weakly as current speeds are already high (+).
Dredging	Dredging in the Zeeschelde increases turbidity moderately (++)	Dredging in the Zeeschelde and in the Westerschelde-oost increase turbidity moderately (++).	Dredging in the Westerschelde-oost and – west increase estuarine turbidity moderately (++). Dredging in the mouth increases estuarine turbidity waekly (+).
Dumping	Dumping in the Zeeschelde increase the turbidity moderately (++)	Dumping in the Zeeschelde and in the Westerschelde-oost increase turbidity moderately (++).	Dumping in the Westerschelde-oost and -west increases the turbidity weakly as current speeds are already high

The system variables of the Turbidity Component influence those of the Water Quality, Primary Production, Macrobenthos and Fish and Prawns Components. These influences will be discussed when the relevant system variables are described.

B.10 Water Quality

Four water quality characteristics are considered in determining the water quality rating for the different abiotic zones. These characteristics include: dissolved oxygen levels, nutrient levels, organic carbon loading and heavy metal or organic micropollutant loading. If the quality is rated poorly for any one of these characteristics, the overall quality is rated poorly. Only if every characteristic is relatively good i.e. not severely limiting to biota, is the water quality rated positively. In this way, as for the quality of the inflowing freshwater, the deleterious effect of bad water quality and its potentially limiting influence on the ecosystem can be included without an exact knowledge of the status of each chemical constituent.

A further aspect included in the Water Quality Component is the heterotrophic production. This reflects the degree of microbial activity in the estuary and provides an indication of the organic waste loading to the system.

The system variables for water quality are:

- Freshwater Water Quality (*Waterkwaliteit Zoetwater*)
- Brackish Water Quality (*Waterkwaliteit Brakwater*)
- Estuarine Water Quality (*Waterkwaliteit Zoutwater)*
- Heterotrophic Production (*Heterotrofische Productie*)

The influences of the water quality system variables upon one another are specified in the table below.

Table 21 Relationships between variables of the Water Quality Component

Water Quality Component	Freshwater Water Quality	Brackish Water Quality	Estuarine Water Quality	Heterotrophic Production
Water Quality per zone	No influence (0)	Strongly positively influenced by the Freshwater Water Quality (+++)	Moderately positively influenced by the Brackish Water Quality (++)	An improvement in the Freshwater Water Quality causes the heterotrophic production to decrease slightly (-)
Heterotrophic Production	An increase in the heterotrophic production impleies an overall moderate decline in water quality (--)	An increase in the heterotrophic production impleies an overall moderate decline in water quality (--)	An increase in the heterotrophic production impleies an overall moderate decline in water quality (--)	N/a

The Water Quality of the Schelde Estuary is influenced by the quality of the freshwater inflow (Freshwater Supply Component), the turbidity per zone (Turbidity Component), the Primary production and the Bed Sediment Quality. The effects of the Freshwater Supply and the Turbidity Components will be specified in the following table and the other effects will be specified when the relevant variables are defined.

Table 22 Influences exerted on the Water Quality Component

Water Quality Component	Freshwater Water Quality	Brackish Water Quality	Estuarine Water Quality	Heterotrophic Production
Freshwater Quality	An improvement in the inflowing water quality exerts a strong positive influence on the water quality of the freshwater zone (+++)	An improvement in the quality of the freshwater inflow exerts a strong positive influence on the brackish water quality (+++)	An improvement in the quality of the freshwater inflow exerts a weak positive influence on the estuarine water quality (+).	An improvement in the freshwater quality decrease heterotrophic production moderately (--).
Turbidity per zone	An increase in the freshwater turbidity is accompanied by a moderate decline in freshwater water quality (--).	An increase in the brackish turbidity is accompanied by a moderate decline in brackish water quality (--).	An increase in the estuarine turbidity is accompanied by a weak decline in estuarine water quality (--).	No influence (0).

The Water Quality Component influences variables of the North Sea, Bed Sediment Quality, Primary Production, Macrobenthos, Fish and Prawns, Birds and Marine Mammals Components. The influence on the North Sea is specified below, the other influences are specified later.

Table 23 Influences exerted by the Water Quality Component

North Sea Component	Silicon Limitation
Water Quality per zone	Improved water quality in the freshwater and brackish zones contributes moderately to reducing the silicon limitation (--). Improvements in the estuarine water quality weakly reduce the silicon limitation (-).

B.11 Bed Sediment Quality

Three state variables are distinguished, namely:

- Freshwater Bed Sediment Quality (*Waterbodemkwaliteit Zoetwater*)
- Brackish Bed Sediment Quality (*Waterbodemkwaliteit Brakwater*)
- Estuarine Bed Sediment Quality (*Waterbodemkwaliteit Zoutwater)*

The quality of the bed sediment is influenced by variables from the components Freshwater Supply and Water Quality. These influences are specified in the following table.

Table 24 Influences exerted on the Bed Sediment Quality Component

Bed Sediment Quality Component	Freshwater Bed Sediment Quality	Brackish Bed Sediment Quality	Estuarine Bed Sediment Quality
Freshwater Quality	An improvement in the quality of the freshwater inflow will have a moderate positive long term effect on bed sediment quality (++)	An improvement in the quality of the freshwater inflow will have a weak positive long term effect on bed sediment quality (+)	No direct influence (0)
Water Quality per zone	Improved water quality in the freshwater zone will improve the bed sediment quality weakly (+).	Improved water quality in the brackish zone will improve the bed sediment quality weakly (+).	Improved water quality in the estuarine zone will improve the bed sediment quality weakly (+).

The Bed Sediment Quality Component in turn influences the Water Quality Component and the Macrobenthos. The former effects are specified below.

Table 25 Influences exerted by the Bed Sediment Quality Component

Bed Sediment Quality Component	Freshwater Water Quality	Brackish Water Quality	Estuarine Water Quality	Heterotrophic Production
Bed Sediment Quality per zone	An improvement in the bed sediment quality exerts a moderate positive influence on the freshwater water quality (++)	An improvement in the bed sediment quality exerts a moderate positive influence on the brackish water quality (++)	An improvement in the bed sediment quality exerts a moderate positive influence on the estuarine water quality (++)	No influence (0).

B.12 Physiotopes

Physiotopes are the physical units in an estuary that may be distinguished on the basis of the salinity zone within which occur and their distribution in relation to water depth. In the case of the Schelde Estuary, channels are defined as areas deeper than –5 m NAP, whereas shallows are defined as areas lying between the –5 m and –2 m NAP contours. Low intertidal (sand/mudflat) is considered to extend from the –2 m NAP contour to + 2 m NAP and high intertidal (sand/mudflat) to be above + 2 m NAP and within the bounds of the estuary. The freshwater, brackish and salt marshes lie above + 2 m NAP (the vegetation of the marshes is considered under the Primary Production Component). These sub-divisions on the basis of abiotic parameters are the basis of the system variables of the Physiotopes Component:

- Freshwater, Brackish and Estuarine Channels (*Zoetwater, Brakwater en Zoutwater Geulen*),
- Freshwater, Brackish and Estuarine Shallows (*Ondiepe Zoet-, Brak- en Zoutwatergebieden*)
- Freshwater, Brackish and Estuarine Low Intertidal-Flats (*Zoet, Brak- en Zoutwaterplaten/slikken – Laag)*
- Freshwater, Brackish and Estuarine High Intertidal-Flats (*Zoet, Brak- en Zoutwaterplaten/slikken – Hoog)*
- Freshwater, Brackish and Estuarine Marshes (*Zoetwater-, Brakwater- en Zoutwaterschorren).*

By definition, the various physiotopes are mutually exclusive and don’t influence one another. The variables of the Physiotopes Component are influenced by variables from the Hydrodynamics, Morphodynamics, Abiotic Zones and Primary Production Components as well as by the Permanent Increase in Storage Capacity and Dredging, Dumping and Sand Mining Components. These influences are described and rated in the following table.

Table 26 Influences exerted on the Physiotopes Component

Physiotope Component	Channels	Shallows	Low Intertidal Flats	High Intertidal Flats	Marshes
Permanent Increase in Storage Capacity	No influence (0)	Moderate positive influence for the zone in which the “ontpoldering” occurs (++)	Moderate positive influence for the zone in which the “ontpoldering” occurs (++)	Moderate positive influence for the zone in which the “ontpoldering” occurs (++)	Strong positive effect of “ontpoldering” in the freshwater zone on the freshwater marshes (+++). Moderate influence for the other zones (++).
Tidal Variation	No influence (0)	Increased tidal variation will result in lower low waters and possible loss of shallow area to low intertidal (-).	Increased tidal variation increases the low intertidal flats weakly at the expense of the shallows area (+). This effect is the same for each zone.	Increased tidal variation increases the high intertidal flats weakly by inundating previously dry areas (+). Only a weak effect because of the containment of the estuary.	Increased tidal variation will result in marshes being inundated more frequently and/or for longer. Moderately beneficial (++).
Maximum Water Levels	No influence (0)	No influence (0)	No influence (0)	An increase in the max. water level in a zone will increase moderately the extent of the high intertidal flats of the zone (++).	An increase in the max. water level in a zone will increase strongly the extent of the marshes (++).
Channel Depth to Antwerp	Increased channel depth causes the extent of the brackish and estuarine channel physiotopes to increase moderately (++)	No influence (0)	No influence (0)	No influence (0)	No influence (0)
Morphological Diversity	Increased diversity in the Westerschelde-west has a moderate positive influence (+) and in the Westerschelde-oost and mouth, a weak positive influence (+) on the estuarine channel physiotope. Weak positive influences on the brackish and freshwater channels (+) are exerted by the	Increased morphological diversity in the mouth and Westerschelde-west influences the estuarine shallows strongly (+++). Increased diversity in the Westerschelde-oost influences the brackish shallows moderately (++) and the estuarine shallows weakly (+). Morphological diversity in the Zeeschelde	Increased diversity in the Westerschelde-west exerts a strong influence on the estuarine low intertidal flats physiotope (+++). Increased diversity in the Westerschelde-oost influences the brackish low intertidal flats moderately (++) and the estuarine low intertidal flats weakly (+). Morphological diversity in the Zeeschelde	Increased diversity in the Westerschelde-west exerts a strong influence on the estuarine high intertidal flats physiotope (+++). Increased diversity in the Westerschelde-oost influences the brackish high intertidal flats moderately (++) and the estuarine high intertidal flats weakly (+). Morphological diversity in the Zeeschelde	Increased diversity in the Westerschelde-west and in the Zeeschelde exerts a strong influence on the salt and freshwater marsh physiotopes, respectively (+++). Increased diversity in the Westerschelde-oost exerts a moderate influence on the brackish marsh physiotope (++), whereas the influence on the

	Westerschelde-oost and the Zeeschelde.	influences the freshwater shallows moderately(++) and the brackish shallows weakly (+).	influences the freshwater low intertidal flats moderately(++) and the brackish low intertidal flats weakly (+).	influences the freshwater high intertidal flats moderately(++) and the brackish high intertidal flats weakly (+).	salt marsh is weak (+). Morphological diversity in the Zeeschelde influences brackish marsh weakly (+).
Slope of the Tidal Flats or Mudflat/Marsh	No influence (0)	Increased slope exerts a moderate negative effect on the freshwater shallows physiotope (--)	Increased slope exerts a moderate negative effect on the freshwater low intertidal flats (--)	Increased slope exerts a moderate negative effect on the freshwater high intertidal flats (--)	Increased slope exerts a strong negative effect on the freshwater marsh physiotope (---)
Freshwater, Brackish and Estuarine Zones	An increase in the extent of a particular zone, weakly increases the channel area in that zone (+).	An increase in the extent of a particular zone, strongly increases the shallows area in that zone (+++).	An increase in the extent of a particular zone, strongly increases the low intertidal flats area in that zone (+++).	An increase in the extent of a particular zone, strongly increases the high intertidal flats area in that zone (+++).	An increase in the extent of a particular zone, strongly increases the area of marsh in that zone (+++).
Dumping	No influence (0)	Weak negative influence on the freshwater, brackish and estuarine shallows (-)	No influence (0)	No influence (0)	No influence (0)

The variables of the Physiotopes Component exert influence on variables from the Components: Primary Production, Macrobenthos, Fish & Prawns, Birds, Marine Mammals and Ecosystem Indicators. These influences will be defined when the variables themselves are defined.

B.13 Primary Production

The system variables of the Primary Production component comprise:

- Autotrophic Production (*Autotrofische Productie*), and
- Freshwater, Brackish and Salt Marsh Vegetation (*Zoet-, Brak- en Zoutschorvegetatie*).

The first variable is a composite for phytoplankton production and microphytobenthic production, whereas the macrophytes of the Schelde Estuary are represented by the marsh vegetation. High turbidity levels in the estuary mean that macroalgae are not present. The system variables within this component do not influence one another.

The variables of the Primary Production Component are influenced by the Turbidity, Water Quality and Physiotopes Components. These effects are described in the following table.

Table 27 Influences exerted on the Primary Production Component

Primary Production Component	Freshwater Marsh Vegetation	Brackish Marsh Vegetation	Estuarine Marsh Vegetation	Autotrophic Production
Turbidity per zone	No influence (0)	No influence (0)	No influence (0)	Increased turbidity causes the autotrophic production to decline moderately (--) in each zone.
Water Quality per zone	No influence (0)	No influence (0)	No influence (0)	Improved water quality causes the autotrophic production to increase moderately (--) in each zone.
Freshwater, Brackish and Salt Marsh Physiotopes	Increased area suitable for freshwater marsh has a strong positive influence on the vegetation (+++).	Increased area suitable for brackish marsh has a strong positive influence on the vegetation (+++).	Increased area suitable for salt marsh has a strong positive influence on the vegetation (+++).	No influence (0)

The variables of the Primary Production Component in their turn influence variables from the Turbidity, Water Quality, Physiotopes, Macrobenthos, Fish and Prawns, Birds and Ecosystem Indicators Components. The influences on the Turbidity, Water Quality and Physiotopes will be specified in the following table.

Table 28 Influences exerted by the Primary Production Component

Primary Production Component	Turbidity per zone	Water Quality per zone	Freshwater, Brackish and Salt Marsh Physiotopes
Freshwater, Brackish and Salt Marsh Vegetation	No direct influence (0)	Filtration effect means that the marsh vegetation acts to improve water quality (diffuse sources) in each zone. This effect is moderate in the freshwater and brackish zones (++) and weak in the estuarine zone (+).	The influence of marsh vegetation in restraining erosion and increasing marsh area by retaining silt is strong for the freshwater (+++), moderate (++) for the brackish and weak (+) for the estuarine physiotopes, respectively.
Autotrophic Production	Increased production causes weakly increased turbidity, because of increasad organic matter in the water column (+)	Increased production causes a weak increase in water quality because of oxygen production and nutrient usage (+)	No influence (0).

B.14 Macrobenthos

The macrobenthos of the Schelde Estuary were categorized by abiotic zone and functional feeding group. There are six variables, each independent of the others, namely:

- Freshwater Filter Feeders (*Zoetwater Filter Feeders*)
- Freshwater Deposit Feeders (*Zoetwater Deposit Feeders)*
- Brackish Filter Feeders (*Brakwater Filter Feeders)*
- Brackish Deposit Feeders (*Brakwater Deposit Feeders)*
- Estuarine Filter Feeders (*Zoutwater Filter Feeders)*

- Estuarine Deposit Feeders (*Zoutwater Deposit Feeders)*

The system variables of the Macrobenthos Component are influenced by the variables of Hydrodynamics, Turbidity, Water Quality, Bed Sediment Quality, Physiotopes and Primary Production Components. These effects are described in the following two tables.

Table 29 Influences exerted on the Macrobenthos Component (1)

Macrobenthos Component	Filter Feeders per zone	Deposit Feeders per zone
Current Speeds per zone	For each zone, increased current speeds have a weak positive influence on the filter feeders because it increases food availability for them (+).	For each zone, increased current speeds have a moderate negative effect (--) on the deposit feeders who may be washed away and who need food to settle out of the water column.
Turbidity per zone	For each zone, a moderate negative influence causes filter feeder numbers to decline (--).	No direct influence (0)
Water Quality per zone	Improved water quality, exerts a strong beneficial effect (+++) on deposit feeders in the freshwater zone. This effect is moderately positive (++) for the brackish zone and weakly positive for the estuarine zone (+).	Improved water quality, exerts a moderate beneficial effect (++) on deposit feeders in the freshwater and brackish zones. This effect is weak positive for the estuarine zone (+).
Bed Sediment Quality per zone	For each zone, improved bed sediment quality exerts a moderate beneficial effect on the filter feeders (++).	For each zone, improved bed sediment quality exerts a strong beneficial effect on the deposit feeders (+++).
Autotrophic Production	For each zone, increased autotrophic production (phytoplankton) means incresaed food and thus a moderate positive influence (++).	For each zone, increased autotrophic production (microphytobenthos) means incresaed food and thus a moderate positive influence (++).

Table 30 Influences exerted on the Macrobenthos Component (2)

Macrobenthos Component	Filter Feeders per zone	Deposit Feeders per zone
Channels per zone	For each zone, increased channel area is weakly positive for filter feeders (+).	For each zone, increased channel area is weakly positive for deposit feeders (+).
Shallows per zone	For each zone, increased area of shallows is strongly positive for filter feeders (+++).	For each zone, increased shallows are moderately positive for deposit feeders (++).
Low Intertidal Flats per zone	For each zone, increased area of low intertidal flats is weakly positive for filter feeders (+).	For each zone, increased area of low intertidal flats is strongly positive for deposit feeders (+++).
High Intertidal Flats per zone	No influence (0)	For each zone, increased area of high intertidal flats is moderately positive for deposit feeders (++).
Freshwater, Brackish and Salt Marsh	No influence (0)	For each zone, increased marshl area is weakly positive for deposit feeders (+).

The variables of the Macrobenthos Component in their turn influence the Fish and Prawns, Birds and Ecosystem Indicator Components. These will be discussed subsequently. It is noteworthy, however, that the effects of predation have not been included in the model, rather the emphasis is on indicating whether the potential for the fish, prawns and birds to inhabit the Schelde Estuary is negatively or positively affected and to identify the causative reason.

B.15 Fish and Prawns

Two categories of fish are distinguished based on their functional use of the estuary. A diadromous fish category represents the fish migrating between the sea and the river ('*doortrekkers*'). The estuarine residents category represents the fish species dependent on the estuarine reaches of the system for some or all life stages. There is an additional category for prawns. The system variables (which do not influence one another) therefore comprise:

- Diadromous Fish (*Diadrome Vissen*)
- Estuarine Residents (*Residente Vissen*)
- Prawns (*Garnalen*)

The variables of the Fish and Prawns Component are influenced by variables from the Turbidity, Water Quality, Abiotic Zones, Physiotopes, Primary Production, Macrobenthos and Marine Mammals Components. All ecept the last of these influences will be described in the following two tables.

Table 31 Influences exerted on the Fish and Prawns Component

Fish and Prawns Component	Diadromous Fish	Estuarine Residents	Prawns
Abiotic Zones	Increased extent of estuarine, brackish and freshwater reaches would be moderately positive for diadromous fish as they utilize all of these zones (++).	Increased extent of estuarine and brackish reaches would be moderately positive for estuarine residents (++). An increased freshwater zone would be weakly detrimental (-).	Increased extent of estuarine and brackish reaches would be moderately positive for prawns (++). An increased freshwater zone would be moderately detrimental (--).
Turbidity per zone	No influence (0).	Incresaed turbidity in the estuarine and brackish zones exerts a moderate positive influence on estuarine residents (++) as it helps to shelter young. In the freshwater zone this effect is weak (+)	Incresaed turbidity in the estuarine and brackish zones exerts a strong positive influence on prawns as it helpd hide them from predators (+++).
Water Quality per zone	Improvements in the freshwater and brackish water quality will exert a strong influence (+++) on diadromous fish. The effect is weak in the estuarine waters (+).	Improvements in the freshwater, brackish and estuarine water quality will exert a strong (+++), moderate (++) and weak (+) influence, respectively, on estuarine residents.	Improved brackish and estuarine water quality will exert a weak positive influence on the prawns (+).
Channels per zone	For each zone, the channel exerts a moderate positive influence on the diadromous fish (++).	For each zone, the channel exerts a weak positive influence on the estuarine residents (+).	The estuarine and brackish channels exert a weak positive influence on prawns (+).
Shallows per zone	For each zone, the shallowsl exert a strong positive influence on the diadromous fish (++).	The estuarine and brackish shallows exert a strong positive influence on estuarine residents (++). This influence is moderate for the freshwater zone (+).	The estuarine and brackish shallows exert a strong positive influence on prawns (+++).
Low Intertidal Flats per zone	No influence (0).	The estuarine and brackish low intertidal flats exert a moderate positive influence on estuarine residents (++). This influence is weak in the freshwater zone (+).	The estuarine and brackish low intertidal flats exert a moderate positive influence on prawns (++).
High Intertidal Flats per zone	No influence (0).	No influence (0).	No influence (0).
Freshwater, Brackish and Salt Marsh	No influence (0).	The estuarine and brackish marshes exert a moderate positive influence on estuarine residents (++). This influence is weak in the freshwater zone (+).	The estuarine and brackish marshes exert a moderate positive influence on prawns (++).
Freshwater, Brackish and Salt Marsh	No influence (0).	Weak influence of estuarine, brackish and freshwater marsh	Weak influence of estuarine and brackish marsh vegetation on

Vegetation		vegetation on estuarine residents (+).	prawns (++).
Autotrophic Production	Weak positive influence on diadromous fish (+).	Moderate positive effect on estuarine fish (++). Source of food.	Moderate positive effect on prawns (++). Source of food.
Filter Feeders per zone	Weak positive influence as potential food for diadromous fish (+).	Weak positive effect on estuarine residents in the estuarine and brackish zones (+).	No influence (0).
Deposit Feeders per zone	Moderate positive influence as potential food source and sediment stabilizers (++).	Moderate positive effect on estuarine residents in the estuarine and brackish zones (++) and weak influence in the freshwater zone (+).	No influence (0).

The variables of the Fish and Prawns Component influence the Birds, Marine Mammals and Ecosystem Indicators Components. These effects will be discussed whe the variables for these components are defined.

B.16 Birds

The birds are sub-divided according to functional use of the estuary, initially into Breeding and Non-Breeding groups. The latter group is then subdivided again on the basis of their food sources. The five system variables for the Birds Component are:

- Breeding Birds (*Broedvogels*)
- Non-Breeding Benthivores *(Niet-broedende Benthivoren)*
- Non-Breeding Herbivores (*Niet-broedende Herbivoren*)
- Non-Breeding Omnivores (*Niet-broedende Omnivoren)*
- Non-breeding Piscivores (*Niet-broedende Piscivoren)*

The variables of the Birds Component are influenced by variables from the Water Quality, Physiotopes, Primary Production, Macrobenthos and Fish and Prawns Components. These effects will be specified in the following table.

Table 32 Influences exerted on the Birds Component

Birds Component	Breeding Birds	Non-Breeding Benthivores	Non-Breeding Herbivores	Non-Breeding Omnivores	Non-Breeding Piscivores
Water Quality per zone	Weak positive influence per zone (+)	Weak positive influence for estuarine and brackish reaches (+).	Weak positive influence for estuarine and brackish reaches (+).	Weak positive influence for brackish and freshwater reaches (+).	Weak positive influence for estuarine and brackish reaches (+).
Shallows per zone	Moderate positive influence for the estuarine shallows (++) as the mouth area is a big breeding area for Stern.	Weak positive influence for estuarine and brackish reaches (+).	No influence (0)	No influence (0)	Strong positive influence for brackish zone (+++) and moderate for estuarine zone (++).
Low Intertidal Flats per zone	No influence (0)	Strong positive influence for estuarine and brackish reaches as this is major	Weak positive influence for estuarine and brackish reaches (+).	Strong positive influence for freshwater and brackish reaches as this is major	Moderate positive influence for estuarine and brackish reaches (++).

		foraging habitat (+++).		foraging habitat (+++).	
High Intertidal Flats per zone	No influence (0)	Strong positive influence for estuarine and brackish reaches as this is major foraging habitat (+++).	Moderate positive influence for estuarine and brackish reaches (++).	Strong positive influence for freshwater and brackish reaches as this is major foraging habitat (+++).	Weak positive influence for estuarine and brackish reaches (+).
Freshwater, Brackish and Salt Marsh	Weak positive influence per zone as thse areas are used as breeding habitat (+).	Weak positive influence for estuarine and brackish reaches (+).	Strong positive influence for estuarine and brackish reaches as provide food (+++).	Weak positive influence for estuarine and brackish reaches (+).	No influence (0)
Freshwater, Brackish and Salt Marsh Vegetation	Strong positive influence per zone as these areas are used for shelter and material when breeding (+++).	Weak positive influence for estuarine and brackish marshes (+).	Strong positive influence for the estuarine and brackish zones (+++), weak for the freshwater zone (+). These areas supply food.	Moderate influence of freshwater marsh on the omnivoren (++). This influence is weak for the brackish marshes (+).	No influence (0)
Autotrophic Production	No influence (0)	No influence (0)	Moderate positive influence (++) as provides food.	No influence (0)	No influence (0)
Filter Feeders per zone	No influence (0)	Moderate positive influence in the estuarine and brackish zones (++). Good source of food.	No influence (0)	Moderate positive effect in the freshwater zone (++) and weak in the brackish zone (+).	No influence (0)
Deposit Feeders per zone	No influence (0)	Strong positive influence in the estuarine and brackish zones (+++). Good food source for birds.	No influence (0)	Moderate positive effect in the freshwater zone (++) and weak in the brackish zone (+).	No influence (0)
Diadromous Fish, Estuarine Residents and Prawns	No influence (0)	No influence (0)	No influence (0)	Weak positive effect (+).	Strong positive effect for estuarine residents (+++), moderate for diadromous fish (++) and weak for prawns (+), representing dietary preferences.

The variables of the Birds Component influence only the Ecosystem Indicators Component as predation and consumption of vegetative matter are not explicitly included in the conceptual model.

B.17 Marine Mammals

The only marine mammals in the Schelde Estuary at present are a colony of seals in the lower Zeeschelde. They are an isolated population which cannot exchange with others along the North Sea coast owing to limitations imposed by the low oxygen conditions in the brackish water zone. They are included in the ecosystem model as representatives of the highest trophic level of the ecosystem. Thus the system variable of the Marine Mammals Component is:

- Marine Mammals (*Zeezoogdieren*).

This variable is influenced by the Morphodynamics, Water Quality and Physiotopes Components as described in the table below and itself exerts an influence upon the Fish and Prawns (described in the table thereafter) and the Ecosystem Indicator Component.

Table 33 Influences exerted on the Marine Mammals Component

Marine Mammals Component	Marine Mammals
Slope of the Tidal Flats or Mudflats/Marsh	Seals require steep banks, so the steeper the slope of the tidal flats and mudflats the better for them. Accordingly the influence of the slope of the tidal flats and the mudflats/marsh is rated as moderately positive for all areas (++) except the mouth where it is weakly positive (+).
Water Quality per zone	An improvement in the water quality of the brackish zone will exert a strong positive influence (+++), whereas the estuarine zone will have a moderate influence (++). It is assumed that water quality could improve to such an extent that the seals are no longer limited to the brackish zone.
Channels per zone	An increase in the extent and depth of the channels of the brackish and estuarine reaches is weakly positive for seals (+).
Shallows per zone	Increases in the area of shallow brackish and estuarine water exert strong and moderately positive influences on seals, respectively (+++ and ++), as this is their primary foraging habitat.
Low Intertidal Flats	Increases in the areal extent of lowlying brackish and estuarine sand and mudflats exert a moderate positive effect on seals (++).
High Intertidal Flats	Increases in the areal extent of high-lying brackish and estuarine sand and mudflats exert a moderate positive effect on seals (++).

Table 34 Influences exerted by the Marine Mammals Component

Marine Mammals Component	Diadromous Fish	Estuarine Residents	Prawns
Marine Mammals	An increase in marine mammals would cause a weak decline in diadromous fish (-).	An increase in the population of marine mammals would deplete estuarine resident fish moderately, as these form the seals primary food source (--).	No influence (0)

B.18 Ecosystem Indicators

A number of indicators were defined to provide a useful means of indicating the state of the ecosystem. The information on which the indicators are based is always available and the reasons for their increase and decrease can be traced at any time. There is therefore no actual information loss in the generation of these indicators – they merely act to summarise information. The indicators themselves arise from the ecosystem goals for the Schelde Estuary (de Deckere & Meire 2000) and are loosely defined in the system variables:

- The presence in the Schelde Estuary of a complete, representative food web (Complete Food Web / *Kompleet Voedselketing*)

- The presence of the full range of physiotopes for the Schelde Estuary with suffiicient areal extent (Full Range of Physiotopes/ *Volledig Range Fysiotopen*)

- The existence of a characteristic longitudinal salinity gradient from freshwater in the upper reaches to marine water in the mouth area (Freshwater-Marine Gradient / *Zoet-Zout Gradient*).

These indicators are formulated in such a way as to be independent of one another. The influence from the system variables of the Components on these indicators is specified in the following three tables.

Table 35 Influences exerted on the Complete Food Web variable of the Ecosystem Indicators Component

Ecosystem Indicators Component	Complete Food Web
Primary Production	Moderate positive contribution to the complete food web indicator (++)
Macrobenthos	Moderate positive contribution to the complete food web indicator (++)
Fish and Prawns	Moderate positive contribution to the complete food web indicator (++)
Birds	Moderate positive contribution to the complete food web indicator (++)
Marine Mammals	Moderate positive contribution to the complete food web indicator (++)

Table 36 Influences exerted on the Full Range of Physiotopes variable of the Ecosystem Indicators Component

Ecosystem Indicators Component	Full Range of Physiotopes
Channels per zone	Weak positive contribution to the physiotope range (+)
Shallows per zone	Moderate positive contribution to the physiotope range (++)
Low Intertidal Flats per zone	Moderate positive contribution to the physiotope range (++)
High Intertidal Flats per zone	Moderate positive contribution to the physiotope range (++)
Freshwater, Brackish and Salt Marsh	Moderate positive contribution to the physiotope range (++)

Table 37 Influences exerted on the Freshwater-Marine Gradient variable of the Ecosystem Indicators Component

Ecosystem Indicators Component	Freshwater-Marine Gradient
Abiotic Zones	Each of the freshwater, brackish and estuarine zones exerts a moderate positive effect on the estuary salinity gradient (++).

This completes the description of the system variables and their inter-relationships for the Conceptual Ecosystem Model describing the coupling between morphology and ecology at the meso-scale for the Schelde Estuary.