Tidal River Development

MONEOS

Integrated Monitoring of the Scheldt Estuary

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Original version: 2008
Translation: 2011

Ecosystem Management Research Group
Universiteit Antwerpen

ECOBE
11-R-147

Project part-financed by the European Union (European Regional Development Fund)

The Interreg IVB North Sea Region Programme

Colophon

Text:
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Commissioned by:
Proses2010

Our thanks go to:
The drafting of this report would not have been possible without the efforts of several people. First and foremost we wish to thank Jos Claessens and Sofie Verheyen of Proses 2010 for their support during the long process which resulted in this report, as well as the MONEOS Project Managers, Frank Mostaert and Richard Jorissen. The input of all the participants during the meetings (see annex 4) was of high value. Next to this we also received several comments on a previous version of this report from Tom Ysebaert, Stanislas Wartel, Bert Van Eck, Marko Schrijver, Wim Dauwe, Erika van den Bergh, Jacco Kromkamp, Tom Pieters, Yves Plancke, Wim Vyverman, Eric Taverniers, Fred Twisk, Peter Meininger, Marc Sas, Peter Herman, Stefan Vandamme, Dick De Jong and several others.

To quote:
Meire, P. & T. Maris. 2008. MONEOS. Geïntegreerde monitoring van het Schelde-estuarium. Rapport - Integrated monitoring of the Schelde Estuary - Report. ECOBE 11-R-147. Universiteit Antwerpen, Antwerp.

Preface

To measure is to know. And although this premise is intrinsically true, a number of conditions need to be fulfilled. Firstly, the right parameters have to be measured in the right way, in the right place and with the right frequency. These data then have to be properly processed before we know something. But we also have to define beforehand what we want to know! So any knowledge based on measurements clearly needs to be properly substantiated.

The Schelde Estuary is a highly complex system, which is subject to continuous change, because of natural factors and due to human intervention. We are obviously trying to know how the Schelde Estuary will evolve in the future and whether all the objectives will be achieved. The present report describes the desired monitoring program for knowing more about developments in the Schelde Estuary as well as identifying cause/effect relationships. This is an essential condition for managing the estuary in a scientifically sound way.

This plan was drawn up based on information about ongoing programs; several measurement programs have already been implemented in the Schelde.

At the same time, the various measurement programs have not yet been properly integrated; a number of important gaps remain, especially with a view to the reporting in the frame of important legislation (such as the EU Water Framework Directive, the Birds and Habitats Directives, etc.) and with a view to understanding cause/effect relationships. Previous versions of this proposal have been discussed during various meetings. In this report we have taken into account all the remarks as much as possible but we were unable to incorporate them all: several proposals pertained more to project and/or research monitoring and as such did not tie in with a basic system monitoring. Other proposals were not retained for financial and/or practical reasons. That is why we consider the present program to be a basic package, which is needed to shape the aforementioned "to measure is to know" premise. The authors take full responsibility for these proposals and any potential shortcomings are their exclusive responsibility, and not that of the many people who were involved in the editing of this report.

Flanders and the Netherlands are facing a major challenge. The planned interventions in the Schelde Estuary are far-reaching. The implementation of the present monitoring program also entails significant costs. And yet this is a unique opportunity to invest in knowledge. We are convinced that a management approach which is founded on the best knowledge can result in significant savings and preserve the managers from unpleasant surprises. On the other hand the active investment in knowledge building, by government as well as the private sector, is a significant economic asset in today's knowledge society. After all, this is the only guarantee for sustainable development and a competitive advantage. The Schelde Estuary already is one of the most studied estuaries worldwide.

The implementation of the below program, coupled with continued investments in research, can provide knowledge institutions, labs and consultancies all over the world with an edge in terms of estuarine research and management. And the respective governments will be able to reap the fruits of this research. That is why we hope that all the financial and practical problems in terms of the implementation of this proposal can be solved in the interest of the sustainable development of the Schelde Estuary and of the entire region which depends on it.

Patrick Meire & Tom Maris

Antwerp, March 2008

Contents

Chapter 1. Introduction

The Schelde Estuary, which covers a surface area of approximately 33,000 hectares, is one of the larger European estuaries and internationally important nature area. It provides a number of essential ecosystem services. These include self-purification of the water, food production (shellfish, fish), serving as a breeding ground for commercially important species, etc. and at the same time it is the gateway to various ports and is a source of other economic activities such as fisheries, sand mining and tourism. On the other hand the Schelde also discharges the water and sediment of the entire Schelde Basin while providing a buffer for the water that flows into the estuary during a storm. Several objectives have thus been formulated in various policy areas for this estuary.

Until a few years ago, various interventions, which were required to achieve the desired goals, were planned at sectoral level after which they were carried out. The measures for deepening the Schelde had not been designed in function of the safety policy, the nature policy and vice versa. As is the case with all estuaries, the Schelde Estuary, however, is a highly dynamic and complex system. This system is continuously changing because of natural processes and because of the strong interaction between hydrodynamics, morphodynamics and ecological functioning. These changes may occur at various time and space scales, resulting in the estuary's natural development.
The many human interventions in the system (dredging, poldering, pollution, etc.) interfere with natural processes and may slow down or even completely overturn certain processes. As a result the measures for one sector may negatively influence the objectives of another sector.

Growing insights in the estuary's complexity and the mutual influence of various measures have ultimately resulted in a more integrated approach. The desired developments in terms of the estuary's naturalness, accessibility and safety were determined based on the Long-Term Vision 2030 for the Schelde Estuary (LTV2030) and the 2010 Development Outline (OS2010) which resulted from it. Next to this, however, there are also other sectors which wish to achieve certain objectives such as tourism. Moreover several Directives and laws apply to this area. The European Water Framework Directive and the European Birds and Habitats Directives constitute the most important legal framework for the physical system and the estuary's naturalness. These Directives contain legally binding provisions about the objectives for a natural system and the manner in which intended interventions or effects need to be monitored. In the Netherlands and in Flanders the Birds and Habitats Directives have been transposed into national nature legislation; the Water Framework Directive has also been implemented in specific legislation and policy in both countries.

The safety standard for preventing floods constitutes another important legal aspect. In the Netherlands this has been enacted in the Flood Defences Act. In

Flanders the policy frame for flood prevention and safety has been incorporated in the updated Sigma Plan.

The 2010 Development Outline contains a number of measures to be implemented in terms of naturalness, safety and accessibility. These include the widening and deepening of the Schelde as well as the consolidation of the estuary's naturalness and even the raising of dikes and the creation of flood plains.

Clearly these far-reaching interventions require an extensive monitoring program that should enable us to assess whether the desired objectives have been reached and whether any unexpected negative developments are occurring. When an objective has not been reached the cause of this should be ascertained. Based on these conclusions new measures can potentially be taken. If external factors (such as climate change, worldwide decrease of a target species, etc.) appear to have caused the discrepancy between the objective and the situation, then this will not give rise to measures (at least not in the area itself). In view of the fact that the entire estuary between Ghent and the mouth of the river constitute one coherent area, Flanders and the Netherlands have agreed to establish and implement a joint monitoring program.

In view of the Schelde's economic relevance it will come as no surprise that several monitoring programs are already ongoing; some observation programs (e.g., the tides) have been in place for more than 100 years. An overview of all ongoing programs can be found in Wijsman et al. (2007) and in Leloup et al. (2007). The MONEOS project was launched in the frame of PROSES 2010 to meet the new challenges which had been laid down in the 2010 Development Outline. The aim was to rationalise monitoring efforts. Donkers et al. (2007) developed a monitoring program to observe the effects of Accessibility measures on the system. Meire & Maris (2008) compiled this vision, together with other ongoing monitoring projects, in one integrated monitoring program. They opted in favour of a system monitoring approach, in which they were able to embed project and research monitoring. Although the incorporation of various ongoing programs in some cases may result in significant rationalisations, the proposal comprises a great number of parameters which have to be measured at various time and space scales. This will require a major financial effort on behalf of Flanders and the Netherlands. Notwithstanding this, the proposal has been reduced to the most essential variables and several scientifically interesting options have not been retained. This greater effort is partly due to new obligations (such as monitoring in the frame of European Directives), partly because a system monitoring approach was chosen meaning a number of variables are essential for a system description. This is necessary with a view to gaining an insight into the reasons/causes of certain trends and/or changes and with a view to tailoring the estuarine management approach to these insights. At the same time, this greater effort is also necessary in order to further develop and optimise the modelling tools that are necessary to underpin the management approach.

This paper starts by briefly referring to the different policy frameworks, after which it elaborates on the philosophy of the proposed monitoring project.

An earlier paper included a critical evaluation of existing programs for the various components, formulating proposals for a consistent program (Meire, 2007). These proposals were discussed in PROSES, in OAP (*Overleg van Adviserende Partijen*, Consultation of the Advisory Parties) and subsequently these were discussed with various specialists during four meetings. The results have been incorporated in this paper. The program proposed here is not an enumeration of all the potential monitoring needs of the various bodies. Instead it constitutes a selection of the parameters required to monitor the system's development. Various proposals have thus not been retained.

Chapter 2. Legal and policy accountability

2.1. Introduction

A great number of laws, regulations and policy frameworks relate to the Schelde Estuary. These have already been extensively summarised in, among others Donkers et al (2007) and the EIA (Environmental Impact Report, Arcadis Technum, 2004) and will not be enumerated below. Based on objectives formulated in the legal frameworks and in various policy documents Donkers et al (2007) have deduced a set of *criteria*. A number of policy frameworks apply to each criterion (see Table 2.1)

Table 2.1: Policy framework for the various criteria relating to Ecology, Morphology and Water. (Taken from Donkers et al, 2007) (BHD: Birds and Habitats Directive, LTV: Long-Term Vision Schelde estuary 2030, OS2010: Development outline 2010, WVO: Dutch Law on Pollution of surface water, Vlarem: Flemish Government Decision on environmental licenses, WFD: Water Framework Directive).

Benchmarking and comparison framework MONEOS-T		**Policy framework**
Ecology	E.1 Habitat diversity	BHD, LTV & OS2010, WVO and Vlarem
	E.2 Species diversity	BHD, LTV & OS2010
	E.3 Ecological functioning	KRW, LTV & OS2010
Morpho-logy	M.1 Morphological diversity of the Westerschelde multichannel system	LTV & OS2010
	M.2 Morphological dynamics	LTV & OS2010
	M.3 Morphological diversity of the Zeeschelde one-channel system	LTV & OS2010
	M.4 Open and natural estuary	LTV & OS2010
Water	W.1 Flood defence	Flood Defence Act, Sigma Plan, LTV & OS2010
	W.2 Quality of the physico-chemical and biological systems	dredging permits
	W.3 General physico-chemical water quality	WFD

Despite the fact that the obligations are very comprehensive, elaborate and far-reaching, the actual monitoring commitments usually have not been specified. A significant exception to this rule is the Water Framework Directive. Mandatory notification of monitoring is an essential component of its implementation. Below we discuss some of the most important legislation, for illustration purposes including the Birds and Habitats Directives, for which no specific monitoring program has been provided, and the Water Framework Directive, with the intended monitoring.

2.2. Birds and Habitats Directives

The European Birds Directive (79/409/EEC) and the European Habitats Directive (92/43/EEC) were adopted in 1979 and 1992 respectively and together they shape the EU's nature conservation policies. In practice, these Directives oblige Member States to designate Special Areas of Conservation, which together form a network of protected areas across Europe: the Natura 2000 network. The designation of these areas of conservation is based on clearly defined criteria, i.e., the presence of certain species and/or natural habitats of Community interest, as specified in the annexes to the Directives. The Member States are obliged to ensure that the habitat types and species for which these areas were designated are maintained and even restored. To this end the Member States have to establish conservation objectives for each area. These conservation objectives include a quantitative designation of what needs to be protected and a proper condition table is drawn up for each habitat type. The table lists a number of abiotic and biotic criteria which the habitats must meet.

These EU Directives do not outline a specific monitoring program; however the Member States are required to regularly (every six years) report on the conservation status of the species and habitat types. The stakeholders agree on the monitoring content and process in management plans. This means that various aspects, including diversity, habitat quality and areas, have to be monitored according to the list of individual conservation objectives.

The monitoring in the frame of the EU Birds and Habitats Directives thus need to include the necessary information in order to be able to evaluate whether the formulated conservation objectives were achieved. At the same time the monitoring shall also include the necessary information relating to the species and habitats listed in the appendices to the Directives (see Donkers et al, 2007 for an overview).

2.3. Water Framework Directive (WFD)

Since autumn 2000, the provisions of the European Water Framework Directive (2000/60/EC) apply to the River Schelde; the aim of this Directive is to improve the general quality of water systems throughout the Schelde Basin. In 2015, all European water bodies need to achieve a "good" ecological quality status at chemical, physico-chemical, hydro-morphological and biological level. The Water Framework Directive requires that a number of parameters, including phytoplankton, macrophytes, macrofauna and fish be monitored in order to evaluate whether the water body meets the Good Ecological Potential criterion.

Article 8 of the WFD requires Member States to establish programs for monitoring water status in order to obtain a coherent and comprehensive overview of the water status within each river basin district.
Pursuant to Article 67, the Flemish and Dutch Governments are required to draw up water status monitoring programs for each of the river basin districts. The programs had to be implemented at the latest by December 22nd, 2006.

As a result a program with the following characteristics (Table 4.2) was proposed. It would have been better if both countries had harmonised their programs.

Table 4.2 Summary of the sampling frequency for Flanders and the Netherlands

	Quality element	**(Annual) measuring frequency**	
		Flanders	**The Netherlands**
		WFD	**WFD**
Biology	Phytoplankton	Monthly (summer semester)	7
	Angiosperms (non-submerged)	1	1
	Macroinvertebrates	1	2
	Fish	2	2
Chemistry	Priority substances that are discharged (Annex X)	12	12
Physicochemical	Relevant Specific Pollutants (Annex VIII)	12	4
	General physico-chemical parameters (*Biol.support)*	12	4
Hydro-morphology	*(Biol.support)*		
	Tidal regime	Continuous	1
	Morphology	1	
	Freshwater flow		1
	Horizontal tide ratio		1
	Wave climate class		1
	Predominant current direction and speed		1
	Hypsometric curve		1
	Soil type		1
	Substrate composition		1
	Intertidal area type		1
	Shore type		1
	Coastal and bank defence		1
	Land use riparian zone		1

Table 4.2: (continued)

	Quality element	(Annual) measuring frequency	
		Flanders	**The Netherlands**
		Act on Integrated Water Policy	
Quantity	Water levels	Continuous	
	Precipitation	Continuous	
Sediment	Sediment concentrations	**Continuous**	

The selection of sample points in the Netherlands and Flanders is determined by the choice of the so-called water bodies. The Schelde Estuary consists of seven water bodies according to the evaluation method of the Research Institute for Nature and Forest (Instituut voor Natuur-en Bosonderzoek/INBO) (see 4.1). Each water body needs to be monitored. In Flanders, however, there is still some debate regarding this division. Naturally this division does not pose a problem for area-wide parameters (e.g., vegetation, habitat diversity, etc.). For discrete samples (physico-chemistry; macrozoobenthos, ecological functioning), the measurement network is sufficiently dense allowing for a representative number of sampling points in each water body.

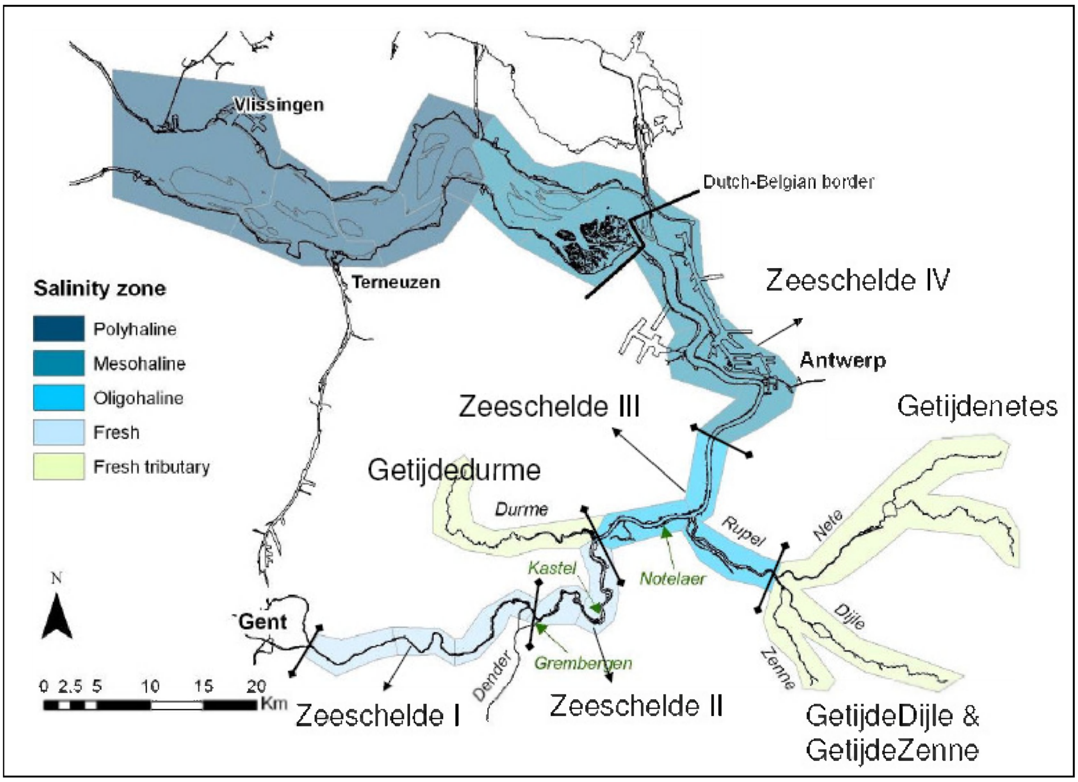

Figure 2.1: Overview of water bodies in the Schelde estuary (from Brys et al, 2005)

2.4. Permits

Various monitoring requirements, such as the monitoring of sediment quality, are imposed in the frame of permits. These obligations have been incorporated in the monitoring proposal and integrated into the whole.

2.5. Conclusion

Although the various policy frameworks require monitoring, few specific and effective monitoring requirements have been incorporated in legislation, except in the WFD. As a result these obligations cannot be considered as a guideline for the monitoring program. Vice versa, we need to be sure that the proposed monitoring program comprises sufficient information to provide the reporting as required by the respective legislation and/or policy frameworks.

The general objectives as formulated in the Long-Term Vision and in the 2010 Development Outline are the most comprehensive but (except for a number of variables, such as channel depth, safety) have not been formulated or quantified in detail. Instead they relate to the conservation of robust nature and a dynamic estuary in which natural processes take place. A number of these concepts have already been elaborated in more concrete parameters and/or indicators. Ecolas (2005), Donkers et al (2007), Kuijper et al (2007) and the EIA (2007) list a large number of parameters for the area's hydrodynamic and morphological development as well as desired trends for these parameters (e.g., conserving a multichannel system, which is obvious from parameters such as the ratio between the water surface at high and low water, r_s, as a characterisation of the intertidal area, combined with the width-depth ratio of a group of bends vis-à-vis the average sea level, β, and/or the depth ratio at high and low water, r_D (Donkers et al, 2007). Ecological functioning criteria were retained in the frame of the Flemish Conservation Objectives (Adriaenssens et al, 2005).

It is worth emphasising, however, that the updated Sigma Plan and the Flemish Government Decision of 20 July 2005 (and 28 April 2006) pertaining to it have also been incorporated in full in this program as the 2010 Development Outline projects and the 2030 LTV have been translated in the updated Sigma plan. Therefore the Sigma Plan not only includes these projects but is much more encompassing. Given that these projects are considered as related in terms of Naturalness and Safety, they have also been included.

An integrated system monitoring is the best guarantee for results in order to meet all the requirements that have been set. After all, the system monitoring includes all the parameters that are required for the various objectives. It is also associated with the modelling tools, which allows for its application and further development.

Chapter 3. Philosophy

3.1. Introduction

We have explained the policy frames in the previous chapter. However this policy frame is insufficient to establish a good monitoring program for the Schelde Estuary. Legal provisions for measuring a parameter thus cannot be the only criterion for including such a parameter in the present program.

After all, objectives follow from policy frames. And the monitoring requirements (Fig. 3.1) are related to these objectives. However, in most cases, the objectives and/or monitoring requirements have not been elaborated in sufficient detail. For example, concentrations are determined in environmental regulations for various substances, but the nutrient ratios have not been included in these regulations. And yet it is precisely these ratios which determine the development of plankton, in combination with these concentrations. Species that should be monitored in the frame of nature conservation regulations are usually a selection of rare species. But the ecological function of the species is rarely taken into account in monitoring requirements. There are a number of species that play a very important role (e.g., system engineers), but these are not necessarily protected and thus there is no monitoring requirement. And yet these are precisely the species that may have a determining effect on the system's development.

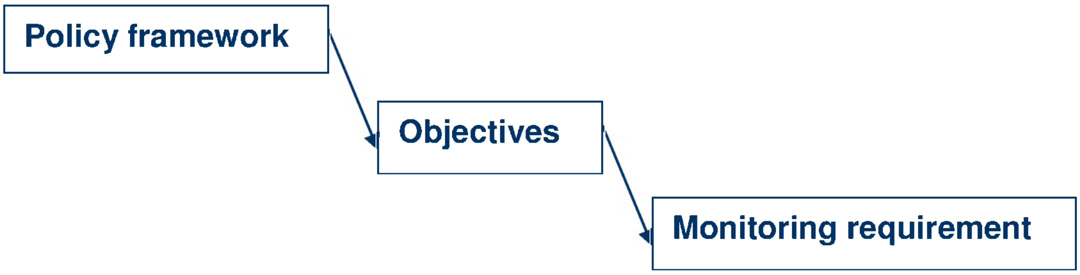

Figure 3.1: deducing monitoring requirements.

On the other hand several parameters are already being monitored, without any real policy frame. There are no legal grounds for conducting an area-wide bathymetry. Measuring discharge, sediment transport or water levels is clearly essential in the frame of the sound management of a waterway in terms of safety, naturalness and accessibility. However, there are no legal provisions as regards the number or frequency of these measurements.

Thus policy frames cannot constitute the only basis for this monitoring plan. The policy frames are an insufficient framework for the monitoring program that needs to be conducted, especially if the aim is to use the obtained results to harmonise the current and future management of the waterway, i.e., to plan measures and implement them with a view to conserving the most important system characteristics, many of which have been enshrined in the policy frameworks.

That is why the challenges for a good monitoring program are:

- Meeting the various legal requirements
- A rational and economic program
- One consistent program which is sufficient as a basis for all the required elements. This means that all data required for:
  - national and international reporting, WFD, EU BD HD, etc.)
  - estimating effects (A, S, N)
  - evaluation tools (models) should be available
- provide an insight into how the system evolves because there is a great chance that unexpected developments may occur requiring flexible and adaptive management. This requires knowledge of the system's functioning.

3.2. Monitoring in the frame of accessibility, safety and naturalness

In order to achieve all the objectives (in terms of accessibility, safety and naturalness) far-reaching interventions are required in the Schelde estuary in the coming years. An extensive monitoring program is also a necessity in this frame. On the one hand the monitoring program needs to be capable of ascertaining whether all the proposed objectives are achieved. These objectives must be tested using a number of (legally determined) indicators. On the other hand, the monitoring program has to check for unexpected negative developments.

If and when certain objectives are not achieved or negative effects occur, it is essential that the cause may be ascertained: which factors have contributed to the failure: certain interventions, natural trends .... Secondly new measures should be potentially implemented, based on the monitoring results. However, if it is proven that external factors (e.g., climate change, worldwide decrease of a target species, etc.) have caused the discrepancy between the objective and the situation, then this will not/should not give rise to measures (at least not in the area itself).

The monitoring program thus must clearly allow researchers to identify causal relationships between the intervention (e.g., the widening of the channel) and the effects (e.g., ecology). In terms of Accessibility the causal relationships mainly relate to the intervention and potentially negative consequences. In terms of Naturalness and Safety, researchers will have to test whether the proposed objectives of several interventions have been reached and what is the relationship between the intervention and the obtained effect. Only then can researchers assert whether certain observed changes may be attributed to a given intervention with a certain probability.

3.3. Monitoring objectives

Monitoring can be conducted for different purposes. The Water Framework Directive distinguishes three different types of monitoring (see insert).

Insert: monitoring for the Water Framework Directive (adapted from Maeckelberghe, 2003)

A. The **Situation and Trend Monitoring** is an intensive monitoring program whereby a great number of parameters is measured for a whole year in a number of relevant measuring points to evaluate and substantiate the evaluation of the effects of the pressure of human activities on the water body but also to ensure that sufficient measurement data are available for evaluating changes in the long term. This measurement program needs to be conducted for one year in the period covered by the water district management plan for each monitoring location for (in principle) all parameters.

B. The **operational monitoring** needs to monitor the effects of the implementation of programs of measures. Particular attention needs to be paid to the water bodies which are at risk of not achieving the proposed objectives as well as to water bodies that are subject to the discharge of priority substances. This measurement program needs to be carried out for the biological and hydromorphological quality elements which are most sensitive to the established burden as well as to all discharged priority substances or other hazardous substances that are discharged in relevant quantities. The Member States need to establish a measuring frequency. As a rule these measurements need to be performed at intervals that are no longer than the intervals indicated in the Directive.

C. Finally the **monitoring for further study** needs to provide the necessary information for drawing up measurement programs in case of exceptions of which the cause is unknown or to determine the extent and impact of accidental pollution.

These types of monitoring, which are primarily intended to test the WFD's objectives, are, however, generic and can be applied for other purposes. Next to the WFD, various other policy areas also rely on monitoring (see above). At first glance the monitoring of populations of given species may not be related to the monitoring of the amount of dredged material deposited in a given location.

The choice was made to establish a monitoring program of the Accessibility (Donkers et al, 2007), Naturalness and Safety aspects in the frame of MONEOS. Additionally, the researchers argued in favour of a distinction between an effect monitoring, aimed at establishing the effects of individual measures on Accessibility (A), Safety (S) and Naturalness (N) and the system monitoring of the effects of all the measures of the 2010 Development Outline, related to the LTV2030 objectives in terms of A, S, and N. The effect monitoring must be able to indicate the impact of individual interventions on (parts of) the system. To this end a paradigm has to be formulated in which the potential effect chains have been defined. The parameters in the paradigm then have to be monitored. The difference between effect monitoring and system monitoring has been summarised in the insert below (based on a memorandum by B. Van Eck).

a. Effect monitoring: monitoring of the effects of individual measures to improve accessibility, naturalness and safety (against floods). This task is assured by MONEOS-T, V and N.

b. System monitoring: monitoring of the full package of measures of the OS2010 in combination with the LTV2030 objectives in terms of safety, naturalness and accessibility. This task is assured by the present report.

The below proposal for an "integrated, joint monitoring program for the OS2010" explicitly starts from this division. Thus a monitoring program will be established for the evaluation of individual measures (a.) and a monitoring for the evaluation of the entire package of measures (b.). The monitoring of a. can be partly embedded in the monitoring of b.

The following example (for the Westerschelde) explains the difference between the two types of monitoring.

The resulting maintenance dredging after the widening of the channel to 13.1 m non-tidal depth can influence the turbidity or the transparency and thus the primary production in the water column in the light-limited Westerschelde or the Westerschelde's productivity. As a result the maintenance dredging activities, the turbidity and the underwater light climate will be monitored as potential direct consequences of this specific intervention.

The "conservation of the Westerschelde's productivity" can be derived from the LTV2030 objectives in terms of naturalness. This can be monitored by measuring primary production in the water column and water bottom (completed where necessary with (productivity) objectives from the fisheries function).

The above example explains the difference between the two types of monitoring. The effect monitoring is aimed at evaluating the expected effects of an OS2010 measure, which often have been predicted in an EIA. The LTV2030 monitoring highlights the effect of all the OS2010 measures and evaluates this effect compared with the LTV2030 objectives. Ideally the evaluation of the effect monitoring should be directly linked to measures to cancel any undesired effects. The evaluation of the LTV2030 monitoring is not linked to such measures. On the one hand because this monitoring highlights all the measures taken and on the other (in the example) because decreased productivity may also be due to other factors than OS2010 measures. The LTV2030 Monitoring thus encompasses much more than the system's functioning as a whole while the effect monitoring tends to focus more on the direct effects of OS2010 measures.

3.4. Limitations of effect monitoring

It is clear that the proposed division is not easy to make. The estuary is a very complex system which is affected by various human activities and natural processes. Hence the effects of an intervention do not in fact always have a local effect (e.g., effect on water level). The effect monitoring should be able to indicate the impact of individual interventions on (parts of) the system. The effect chains in which effects as a result of the 'primary' intervention are expressed in terms of changes in the relevant parameters, possibly through intermediate variables, thus have to be known in order to examine these relationships. Some effects are difficult or even impossible to measure directly. However they can be estimated using models. In addition to the direct measurement of certain variables, the monitoring will then aim to provide adequate input for these models in order to visualise the consequences and intervention-effect relationships.

The effect chains must therefore indicate the potential consequences of a given intervention as well as which matters need to be closely monitored. Figure 3.2 shows such an effect chain. This chain highlights the potential effects of deepening of the fairway on the ecological functioning. It is immediately clear from this chain that widening may result in a whole chain of effects. In order to map the effects on phytoplankton in this example, a whole slew of parameters need to be taken into account. Limiting measurements to Chl a, as a measure of biomass, will not be sufficient to explain the impact of phytoplankton on ecological functioning.

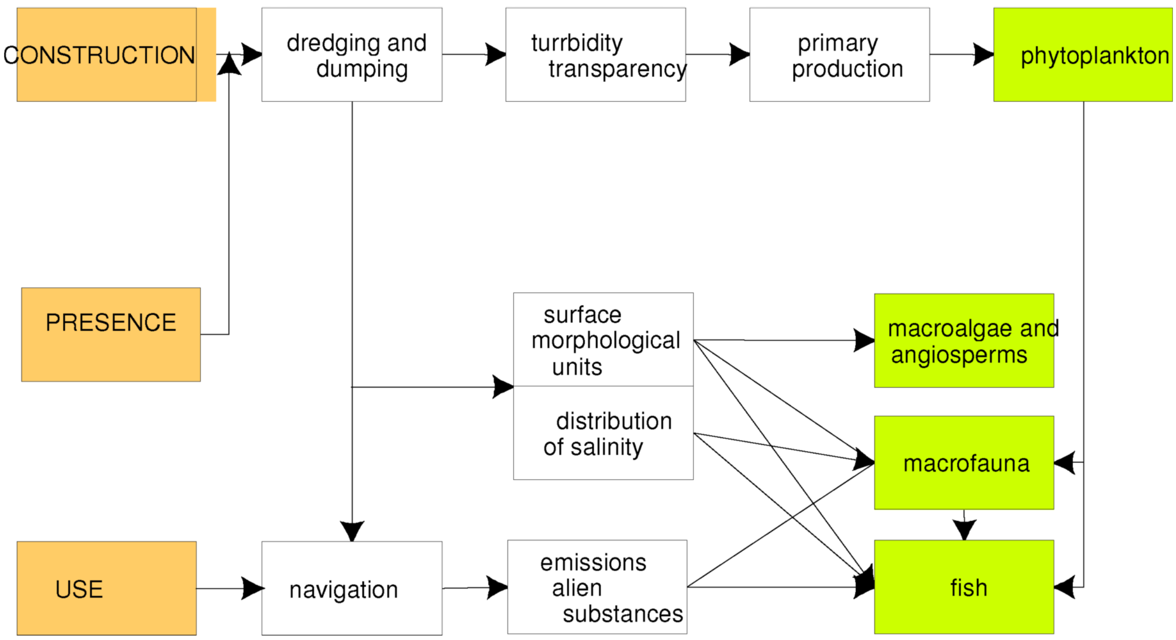

Figure: 3.2 Example of an effect chain: effects of deepening on ecological functioning (taken from Donkers et al 2007, fig 3-3).

Although already very complete, there is always the risk that such a chart underestimates or overlooks an effect chain. By strictly limiting monitoring to the monitoring of the expected effects other potentially important consequences may not be documented. In this example, the potential effects of elevated SPM concentrations on sedimentation on the mud flats have not been included. Changing sedimentation can have a significant impact on the primary production of phytobenthos, and on the secondary production of zoobenthos.

On the other hand the examined intervention is not the only aspect to impact the ecosystem. Changes in all the other system variables will also have to be monitored in order to establish a clear link between cause and effect. Phytoplankton and primary production for example may be influenced by several factors, so it is difficult to assess the effects of deepening the fairway from these factors without having documented the other changed factors. After all, the estuary is a complex ecosystem, which can only be understood through a complex system monitoring. Figure 3.3 shows a model-based representation of the Schelde ecosystem, interactions between the food web, the nutrient cycles and the hydro/morphodynamics. Several factors, i.e., interventions provided for in the LTV but also external factors, can affect this system and result in different effects.

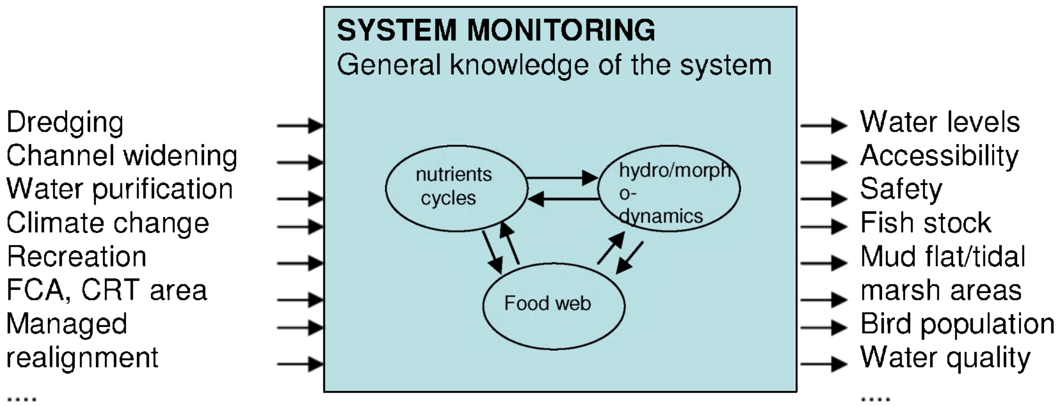

Figure 3.3: system monitoring

Clearly the proposed split between effect monitoring and system monitoring is not an easy one to make. The estuary is a very complex system which is affected by various human activities and natural processes. Hence the effects of an intervention do not in fact always have a local effect (e.g., effect on water level).

3.5. Towards an integrated system monitoring

This MONEOS monitoring proposal is based on a system monitoring approach: the monitoring of those parameters that are required to characterise the entire system. In addition to the system monitoring there also is specific project monitoring. This involves a more detailed follow-up of certain interventions; it can be considered as effect monitoring, as described above. This specific project monitoring is embedded in this system monitoring. In other words: the system monitoring provides the general framework, describes the general status of the entire estuary at all relevant levels. Where necessary, monitoring efforts may be increased, in the frame of (additional) project monitoring but this monitoring is limited in time and space. After all, it is essential that a monitoring program is as cost-efficient as possible. On the other hand such a monitoring program must also allow us to effectively demonstrate trends within a reasonable period within which they occur; likewise it should allow us to establish causal relationships. The latter is essential as a basis for measures that may have to be taken. The figure below illustrates the relationship between project and system monitoring.

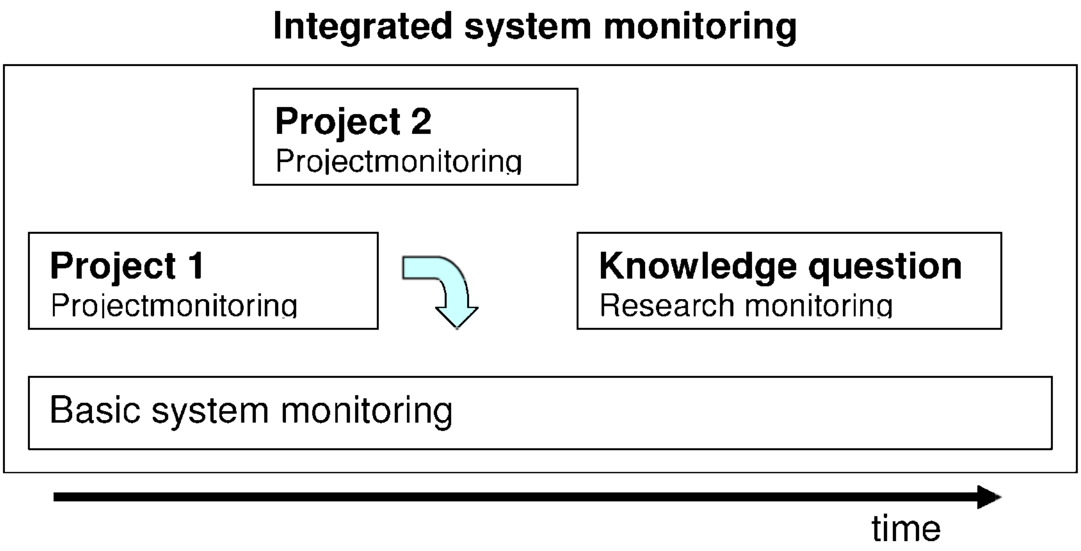

Figure 3.4. Relationship between project and system monitoring

Roughly speaking, project monitoring is a preliminary for the various individual measures, in the form of a limited extension of system monitoring at local level. It is clear that this is the only way of measuring the effect of the different measures, which may have an effect, individually or as a whole, that is not measurable on the scale of the intervention, on the scale of the estuary (or at least part of it) and indirectly also on other parameters.

This monitoring proposal thus does not wish to detract from the logical distinction between effect monitoring and system monitoring. However, in this proposal, the effect monitoring, which is included in the project monitoring, is subordinate to the system monitoring. System monitoring in this proposal not only is designed to monitor global trends; it also has to be able to uncover estuarine processes in order to be able to directly link effects to interventions. However, for the latter, the monitoring activity may have to be extended in order to capture the locally desired effects with a higher resolution. It is therefore recommended to formulate a very clear paradigm for the various elements (effect or project monitoring, system monitoring, etc.) with hypotheses about the potential developments (including effects). Depending on the evaluation that needs to be made, the relevant information can then be derived from the system monitoring, completed with information from project monitoring. The advantage of system monitoring is that it provides the best guarantee for maximum integration and optimisation of the used resources. One of the program's main principles after all should be its integrated character. At present, all too often related parameters are measured at different temporal and spatial scales, meaning that it is not always possible to associate these parameters with one another. We therefore strongly argue in favour of an integrated monitoring of the entire estuary, which may result in optimal synergies. The logic underpinning this assumption is highlighted below.

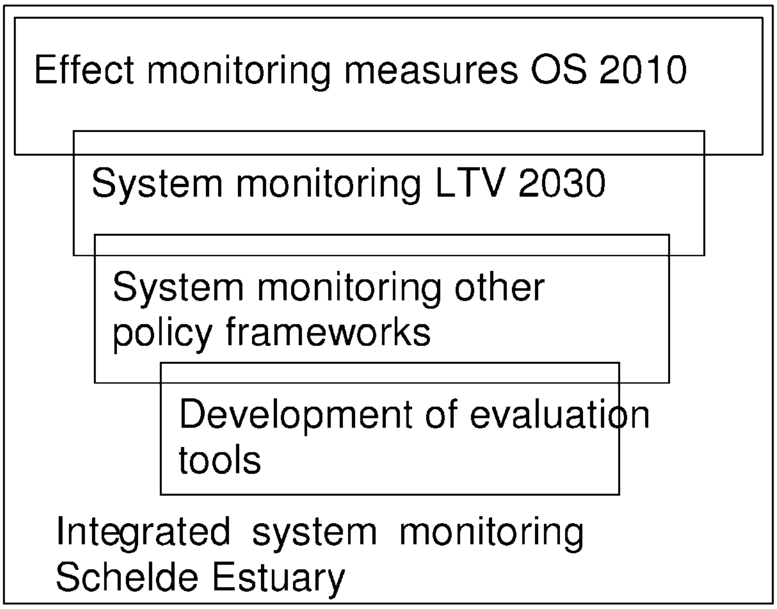

Figure 3.5: Overview of the integrated system monitoring, composed of partly overlapping programs and supplemented with additional parameters for a good, complete description of the system.

The system monitoring (with or without local detail through project monitoring) should then provide an answer to some of the following questions:

- Estuary-wide effects of the widening and of activities and maintenance work related to this widening on the morphology, nature, ecology and water quality of the Schelde Estuary
- Effects of construction work of FCA (Flood Control Area), CRT (Controlled reduced Tide), managed realignment, wetland creation, dike reinforcements on the estuary
- Naturalness measures have to be tested against the desired objectives.
- signals on potential negative effects can be identified in a timely manner; effects that were predicted in the EIA can be verified
- the results can be used in the selection of suitable dumping sites.
- in case of negative effects, flanking measures can be developed based on the results
- in case conservation objectives are not achieved, additional/other measures can be developed using the conclusions of the system monitoring

Next to this it is also very important that the monitoring provides the necessary information for the models. The use of models is after all essential for a proper interpretation of the results. On the other hand models are essential tools for planning new interventions. Both applications require good data, because the quality of the output of the models is directly proportional to the input. During the preparation of the EIA it became clear that there is absolute shortage of good data for the reliable use of some models. The system monitoring should provide such data.

However system monitoring and project monitoring will not be able to solve all the questions. There is a lack of scientific knowledge for several aspects. These gaps should be filled with specific research projects, which often entail research monitoring. This means following up a series of parameters in a given area for a limited period, in order to formulate an answer to a research question. This should lead to new insights, better model formulations, alternative monitoring procedures, etc. This type of monitoring, which is designed to answer scientific questions, is not always categorised as project monitoring because the scientific question does not always directly follow from an intervention in the estuary. Some examples:

- Research monitoring may test a new measurement technique in order to improve the existing monitoring or make it more cost-efficient.
- There is still no full explanation for the strong growth of the algae population in recent years in the Zeeschelde. If this change cannot be explained, then it will become difficult to correctly assess the effects of interventions on the algae population. Research monitoring will be needed to better explain the underlying mechanisms.

This can be summarised as follows:
We advocate one integrated monitoring project for the whole Schelde Estuary made up of a basic system monitoring for which the results from the various relevant policy areas can be used and in which specific project monitoring can be embedded. Above all, a coherent monitoring approach is required for all relevant factors. The emphasis has to be on integrated measurements (measuring the highest possible number of parameters on the same space and time scale and maximum possibilities for the extrapolation of data) as much as possible. This monitoring provides the basic data set that is centrally maintained. A report on this monitoring will be published annually.

3.6. Data management

In addition to designing and implementing a monitoring program it is also essential that the basic data or information are available. In this frame we advocate setting up a system with a central focal point which can also be used as a data node. This node should be responsible for data management as well as for the metadata. It must be a node that provides access to the actual data. All the

(Dutch and Flemish) data need to be collated here. At present many data are dispersed among various bodies, meaning there is no overview of which data are already available. In the frame of long-term analyses all recent data, as well as important long-term data sets will have to be collated in this node.

The Flanders Marine Institute already has built considerable experience on the subject and has also developed an extensive "data policy", which regulates data use. Moreover, the Flanders Marine Institute has already been designated as data system carrier in the LTV, because of the ScheldeMonitor (ScheldeMonitor) at the request of the Flemish and Dutch waterway authorities.

3.7. Analysis, evaluation and reporting

At the same time basic data should also be reported and made available very regularly. For instance, the bathymetric data for the entire estuary should be made available as GIS layers (e.g., through the Flanders Marine Institute). This however requires that the raw data need to be processed to some extent. We therefore advocate in favour of the publication of annual reports on all the parameters that have been measured, which provide a clear summary (e.g., graphic representation of the water levels measures in all tidal stations during that year, overview of bird surveys, etc.). We recommend checking whether such a report should be based on indicators, as is currently the case in the frame of the MIRA (Environment Report) and NARA (Nature report) reports. These indicators could then be updated annually with the measurement data of the last year and be made digitally available. These reports (in the form of printed reports or in digital form) will be mainly used to ensure that data are available and for interpretation purposes (e.g., problems in a sampling station, exceptional circumstances, etc.). These reports will not provide an analysis or an evaluation. Such evaluations or analyses can be found in special reports in which data are analysed in a specific time frame. We thus advocate a complete evaluation of the system, every six years, whereby all the components of the monitoring are summarised and analysed. This should also include a synthesis at the level of the effects of the individual measures and at system level. The six-year period is consistent with the requirements of the Water Framework Directive. The six-year period implies that several ongoing programs that are based on a five-year cycle will have to be redefined, based on a six-year period.

An essential condition for a good monitoring program is a protocol for continuous quality control, intercalibration, standards and protocols, etc. It is only worth collating data from various bodies if standard measuring techniques are used. This report aims to harmonise the various ongoing monitoring activities, including in terms of methodology and quality. Although proposals are formulated for various points, this report by no means aims to expound on the techniques and quality procedures used. These will have to be reviewed on a case by case basis.

A distinction is made between different evaluations for the evaluation. For each evaluation (e.g., the effects of individual projects, system effects, evaluation with respect to the WFD, EU BD and EU HD, ...) a clear paradigm should be drawn up in which the potential effect chains are described and hypotheses are formulated. This may also lead to specific analysis techniques, using models in some cases. The necessary data are extracted from the database for the evaluation.

The available data sets should first and foremost be analysed using the available statistical methods, but models are indispensable tools for analysing data sets, calculating certain parameters (e.g., primary production, nutrient loads, etc.) and for discriminating between various influencing factors. The use of models also requires a consistent data set and the quality of the model outcome is directly proportional to the quality of the input data. Thus high-resolution models require high-resolution input data.

Chapter 4. Elaboration of the monitoring program

4.1. Introduction

There are already several ongoing monitoring projects in the Schelde. We have based the present proposal on the MONEOS-T Monitoring Report (Donkers et al 2007) and its translation into the MONEOS-T Flanders program (obtained from Yves Plancke) and Netherlands program (obtained from Marco Schrijver). The two inventory reports (Leloup et al, 2007 and Wiseman et al 2007) and the Schelde Monitor (http://www.scheldemonitor.be/home.php) were also important sources of information. For MONEOS-N we received significant input from Erika Van den Bergh (Research Institute for Nature and Forest) on the Flemish side and we consulted extensively with Peter Herman, Jacco Kromkamp, Vincent Escaravage, Tom Ysebaert (all NIOO-CEME) and Johan Craeymeersch (IMARES). The MONEOS-V Flanders section was developed in consultation with Marc Sas (IMDC) (incorporated in Chapter 11).

These various monitoring programs each were created in function of their own objective and background. If we examine all these efforts then it is obvious that there is some overlap between the various programs on the one hand and that there are clear gaps on the other hand. The starting point for an integrated system monitoring should therefore be a reduction of the number of measuring points if there is an overlap or if measuring points are unnecessary. A homogenous distribution of measuring points across the entire estuary should be pursued aimed at measuring:

- Spatial variation
- Depth variation if relevant
- Temporal variation
- Gather as many parameters simultaneously in the same place in order to facilitate the integration of parameters.

4.2. Program strategy

The monitoring program mainly consists of a combination of two important approaches. First there is the area-wide information which should describe spatial (and depth) variations (Fig. 4.1). The aim is to produce various map layers here, which facilitate the monitoring of the area’s long-term morphological development. This includes the development of areas of specific habitats/ecotopes as well as volume changes and the spatial patterns of habitat/ecotopes.

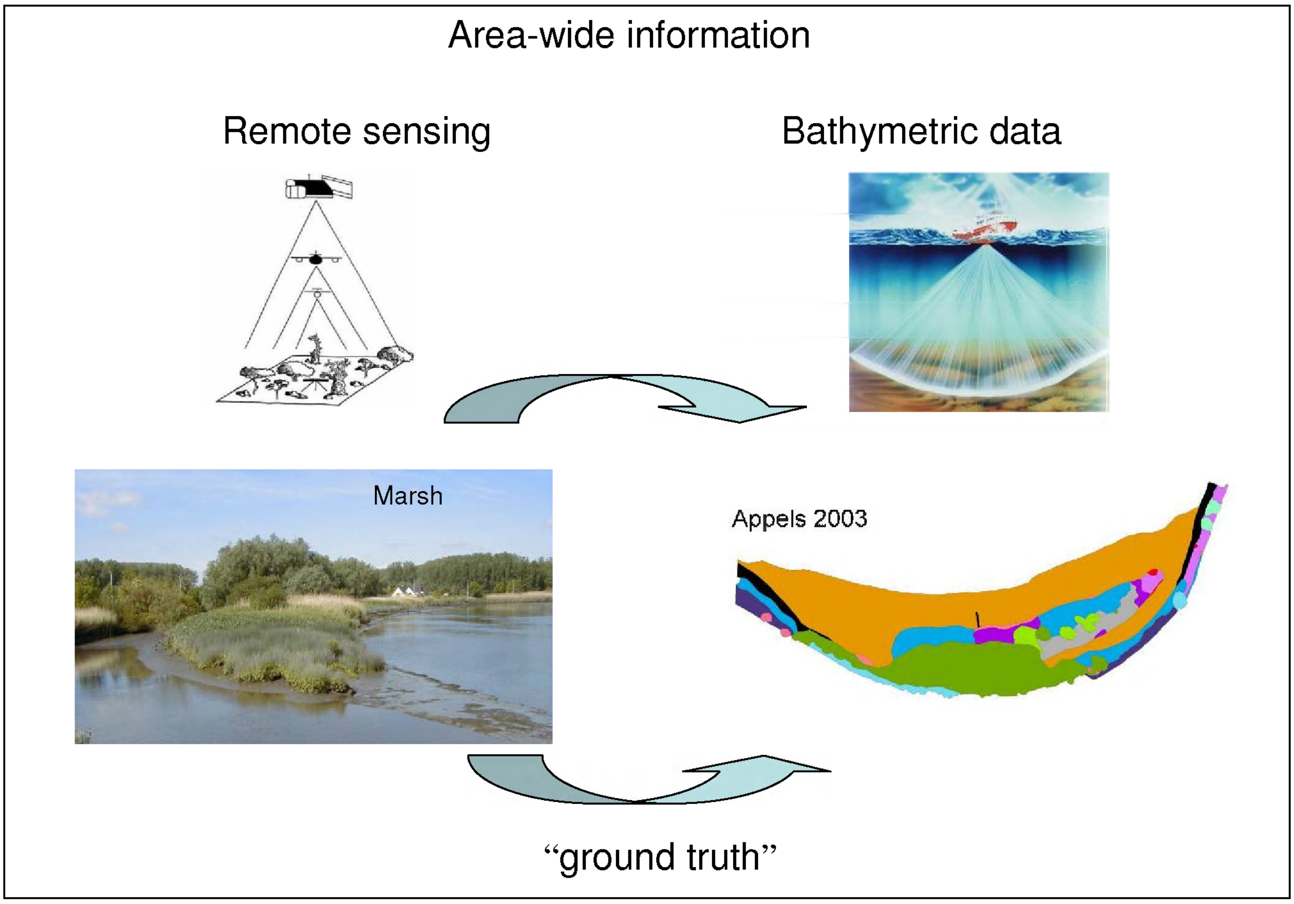

Figure 4.1. Area-wide information is gathered thanks to a combination of remote sensing, bathymetric data and ground truth measurements.

Various measurements, however, also require measurements of the "ground truth" in order to calibrate the information obtained from remote sensing or bathymetric data (e.g., recorded vegetation, soil samples etc.). This immediately establishes a link with the second part which consists of discrete measurements in given points and/or sections (Fig. 4.2). Individual parameters are measured directly in the field and/or samples taken for lab analysis. These samples are often very labour-intensive. As a result, but even more because of the possibility to collate the data that were collected at one given time in the same location, the sampling for the various disciplines should be combined as much as possible. In the measure that it is possible these data should also be used as a "ground truth" for area-wide information.

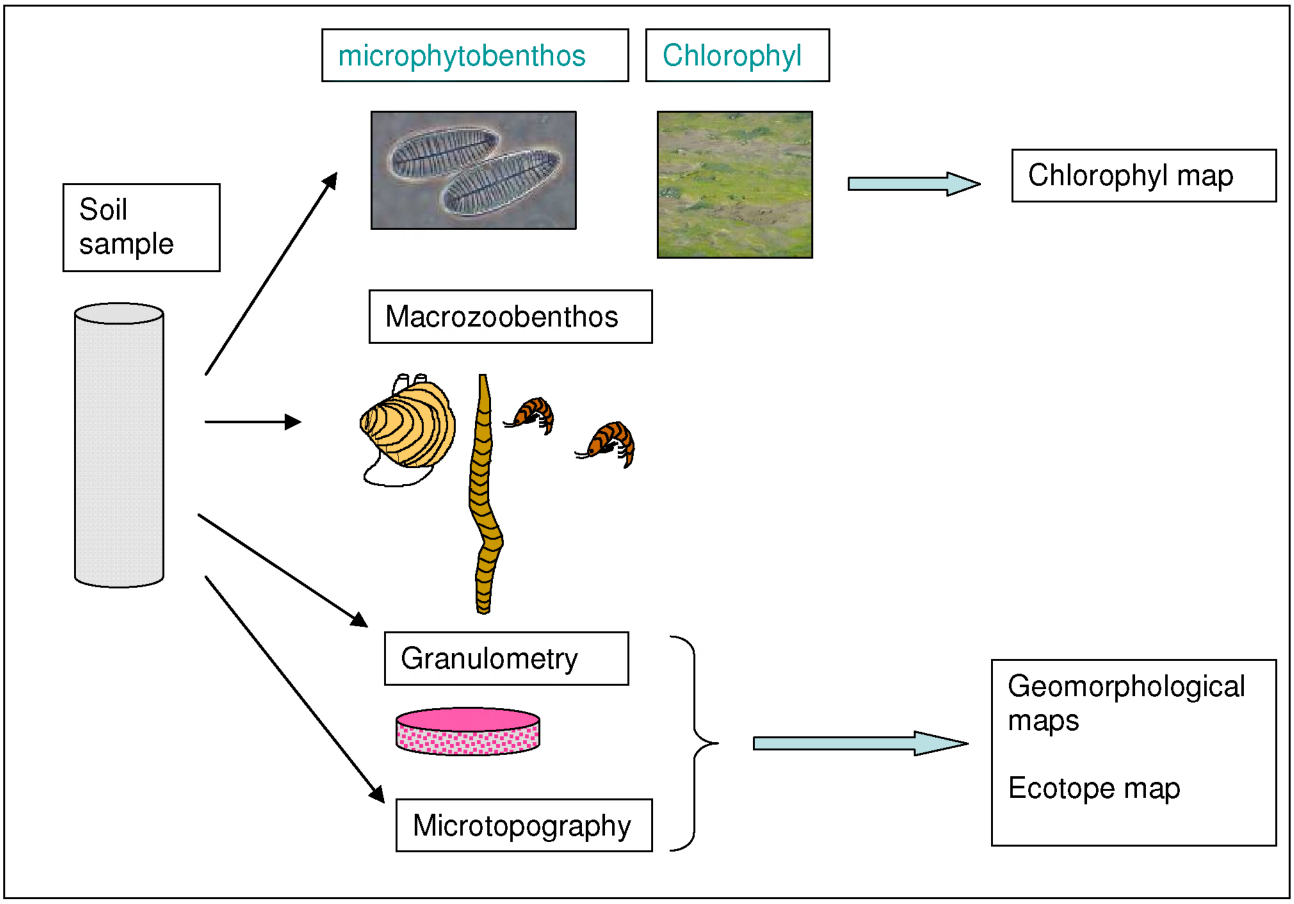

Figure 4.2 Overview of the integration of point measurements and link with area-wide information.

4.3. Strategy for resolution in space and time

Both, the spatial resolution of the monitoring points and the sampling frequency in time have to be harmonised with the spatial scales and with the frequency of occurrence of certain phenomena in the estuary. In other words, the network of monitoring points should be close enough to be able to properly map all the important spatial phenomena, and the frequency high enough so that no important phenomena (such as a peaking algae population) are overlooked. Naturally the frequency does not have to be as high in all locations. The result is a monitoring program with a large spatial spread of points that are monitored on a regular basis, ranging from biweekly to every six years. A limited number of locations across the different zones in the estuary will be sampled more intensely, in order to identify any important short-term fluctuations. This should be done through continuous measurements. This monitoring network provides the data needed for scaling the parameters in space and time by linking the information to area maps (Fig. 4.3) or to generate area-wide information (Fig 4.3).

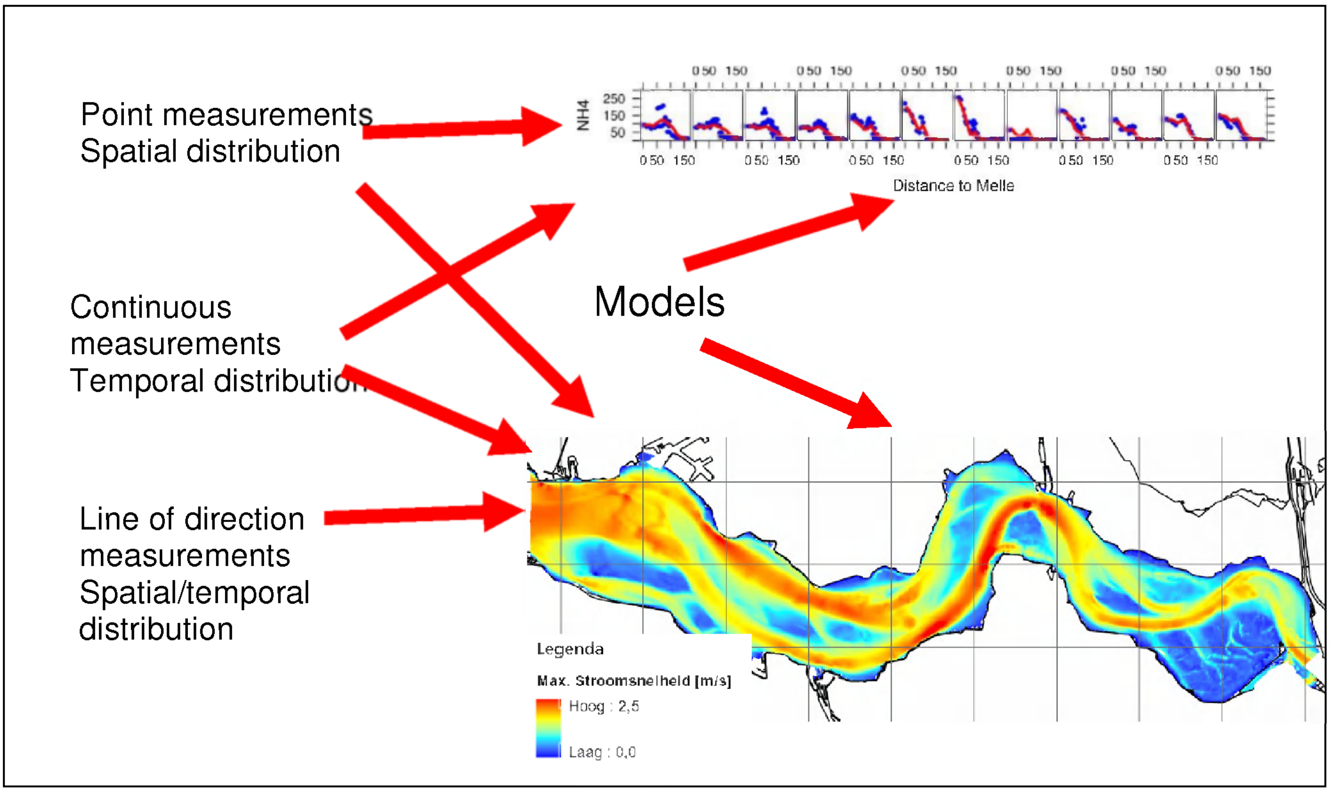

Figure 4.3 Overview of spatial and temporal scaling based on discrete measurements.

The estuary's boundary conditions are crucial to properly understand the entire system and to be able to properly model it. Up until now these have not been given sufficient attention. The model output's resolution and quality can however not be better than the resolution and quality of the boundary measurements. That is why these points have to be sampled with the necessary attention.

4.4. Study area

The study area is defined upstream by tidal boundary or the Sigma plan. As a consequence it covers the entire estuary from salt, to brackish to freshwater, including the tidal tributaries and rivers on which work is carried out in the frame of the Sigma plan work and for which conservation objectives (Adriaensen et al 2005) were drawn up in this frame. These boundaries are broader than the estuary's boundaries as applied within ProSes. We have included this study area based on the premise of the integration of measurements and Waterways & Sea Canal's wish to implement a consistent program for Flanders. This only has consequences for the location of the measuring points; no additional parameters have to be measured.

Figure 4.4 and 4.5 provide a schematic representation of the Schelde Estuary. The Dutch section of the Schelde is called *Westerschelde*. The Flemish section, the *Zeeschelde*, can be divided into the Beneden (Lower) Zeeschelde and the Boven (Upper) Zeeschelde. On the Flemish side several tidal tributaries have also been included in the estuary. The Rupel is considered a branch of the estuary and is subject to the same approach as the Boven Zeeschelde. Other tidal tributaries, which are simply labelled as tributaries elsewhere in the report, are often considered separately. They usually do not require the same monitoring effort as the Zeeschelde and the Rupel. These tidal tributaries are: the Durme, the Dijle (until Haacht), the Kleine Nete (until Grobbendonk), the Grote Nete (until Itegem) and the Zenne (until Eppegem).

The lateral boundary is formed by the landward heel of the dike or ring dike. It thus comprises all flood control areas, where applicable with controlled reduced tide. In Flanders this also includes all non-tidal wetlands which are being developed in the frame of the Sigma Plan or which are included in the conservation objectives for the estuary.

For example, when monitoring general water quality the entire estuary is not sampled with the same intensity. Intensive sampling of pelagic divisions in the estuary here, on the Flemish side, is limited to the Beneden Zeeschelde, the Boven Zeeschelde and the Rupel Basin until the Dijle, Nete and Zenne tributaries. The Durme, the Dijle, the Zenne and the Nete are considered as boundary conditions. The boundaries of the estuary are then considered to be the so-called boundary conditions and will be sampled as points; they constitute the input in the estuarine system and are therefore essential. Boundary points may thus include tidal tributaries, such as the Dijle or Durme, non-tidal tributaries such as the River Dender and the Bovenschelde, but also artificial water bodies, which may have a significant impact on the system in terms of flow or load (e.g., the Antwerp port, the Spuikanaal in Bath). In previous monitoring programs the Rupel was often wrongly considered as a boundary point. In terms of discharge flows and loads the Rupel regularly exceeds the Boven Zeeschelde. A boundary only provides input in the system. There is a clear interaction and mutual influence between Rupel and Zeeschelde. That is why the Rupel has been included in this monitoring program as a full branch of the estuary. It will also be sampled, like the Boven Zeeschelde. The boundary of the Schelde estuary thus is not situated near the mouth of the Rupel, but on the Dijle, Zenne and Nete tributaries (Fig. 4.4)

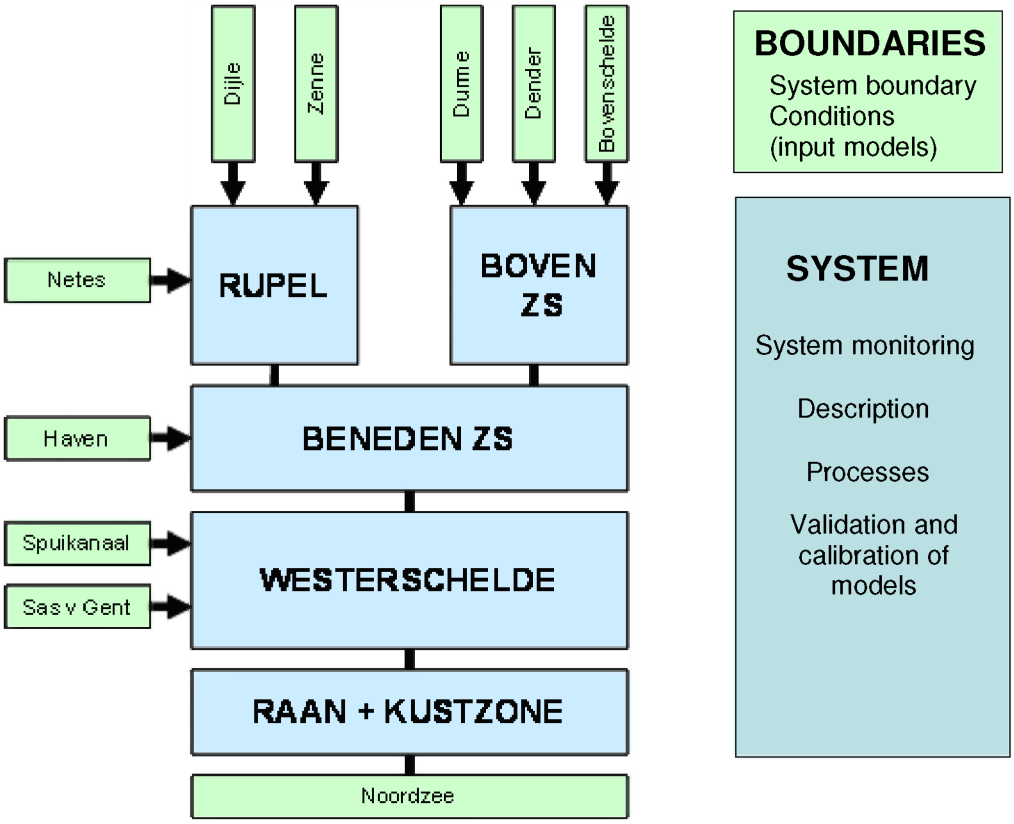

Figure 4.4: Schematic representation of the estuary and its boundaries. Note that the Rupel has been incorporated as an integral part of the estuary.

The downstream boundary of the estuary is formed by the line connecting Zeebrugge with Westkapelle, including the Vlakte van de Raan. This area is still an integral part of the estuary, especially in terms of hydrodynamics and morphodynamics. On the Flemish side the inclusion of this area has given rise to a number of problems in terms of competences, because the Flemish Region's competence only extends to the low low-waterline and to the maintenance of the channels. Naturally this is an administrative boundary, not a substantive boundary. Therefore we advocate in favour of including the part of the Belgian continental shelf that is a part of the estuary. Consultation with the BMM (Management Unit of the North Sea and Schelde Estuary Mathematical Models, a department of the federal Royal Belgian Institute for Natural Sciences) is a requirement. The boundary is formed by the North Sea. For the latter boundary no specific monitoring programs will be drawn up in the frame of the integrated monitoring program.

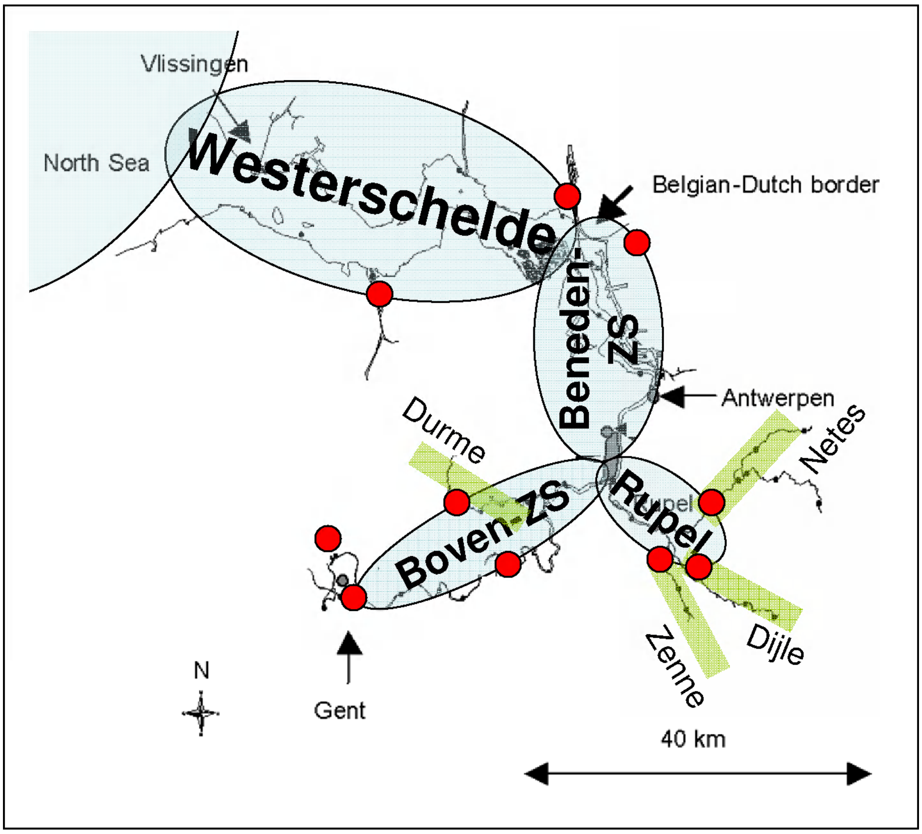

Figure 4.5: Schematic representation of the various compartments (Westerschelde, Beneden Zeeschelde, Boven Zeeschelde and Rupel) in the estuary. Downstream the Raan Plain and the coastal zone constitute the last compartment). The boundary points are situated where there is significant lateral input in the system (red dots). The tidal tributaries (Durme, Zenne, Dijle and Netes) have been highlighted in green.

Intermezzo freshwater estuary

The estuary splits into two branches at Rupelmonde: Rupel and Boven Zeeschelde. Both branches are macrotidal: the highest tides in the Schelde are measures here in these parts of the estuary.

The Rupel and Boven Zeeschelde are fresh waters, which is why some researchers have catalogued them as rivers, albeit tidal rivers. The estuary thus extends to Rupelmonde (or Temse in some studies). This definition is based on the old definition of the estuaries by Pritchard (1967), who stated that tides and salt intrusion were the main conditions for an estuary. This excludes all freshwater sections.

In more recent definitions of an estuary, including that by Fairbridge (1980), freshwater tidal areas may be considered as estuarine areas. Fairbridge states that an estuary is 'an inlet of the sea which extends into a river valley as far as the tide can propagate into this valley'.

Thus Pritchard suggests that the estuary's boundary is situated at the highest point where salt has been detected. This limit is difficult to draw geographically: salt intrusion is strongly related to flow and tidal conditions. In the Schelde the salt border can shift up to 20 km depending on whether it is winter or summer. In extreme conditions (very low flow during spring tide) a salinity 10 has already been observed at Kruibeke; in wintertime this may drop to 0 if the flow is high. This does not facilitate a geographical definition of the estuary based on salinity.

It is much simpler to define the estuary based on tides: the penetration of the tide is less dependent on weather conditions (McLusky, 1993). He suggests that the estuary be defined based on tides in the margin of the 21st Symposium of the Estuarine and Coastal Sciences Association). The following division can then be distinguished:

Division	tidal	salinity	venice system
river	non-tidal	<0.5	Limnetic
head	highest point to which tides reach		
tidal fresh	tidal	<0.5	Limnetic
upper	tidal	0.5 - 5	Oligohaline
inner	tidal	5 - 18	Mesohaline
middle	tidal	18 - 25	Polyhaline
lower	tidal	25 - 30	Polyhaline
mouth	tidal	>30	Euhaline

The freshwater tidal area has been included in the estuaries for purposes of simplicity. At the same time, and from a scientific perspective, these zones have more in common with the estuary than with the rivers in the upper basin.

The chemical and physical processes in freshwater tidal areas differ greatly from those in rivers. The plant and animal communities in rivers live in conditions marked by a unilateral downstream water movement, with relatively constant water quality. By contrast, the dominant processes in estuaries are determined by sediment transport and turbidity, coupled with a wide range of chemical changes. As a result of the tidal flow large gradients in the physico-chemical make-up of water are created (McLucky, 1993), which, in turn, results in communities in the freshwater estuary that are quite different from the river communities. There is no real continuum from river to estuary, especially in most European estuaries, like that of the Schelde, where a lock system abruptly stops the tidal effect. These locks constitute the estuary's hard boundaries.

The Schelde Estuary consists of the Zeeschelde and of the tidal parts of its tributaries, the Durme, the Rupel, the Dijle, the Zenne, the Grote Nete and the Kleine Nete. In the frame of the WFD seven transitional water bodies have been identified in the Schelde Estuary, which are all defined as macrotidal lowland estuary. The two Zeeschelde water bodies that are the closest to the Schelde estuary are brackish (mesohaline and oligohaline respectively); the other five bodies are fresh waters.

4.5. Summary of parameters to be measured

The monitoring program is divided into several parts: hydrodynamics, morphodynamics, habitat diversity, physical chemistry, ecological functioning and safety. This division is mainly pragmatic, since the various components are strongly linked and therefore cannot be considered separately (Fig. 4.6).

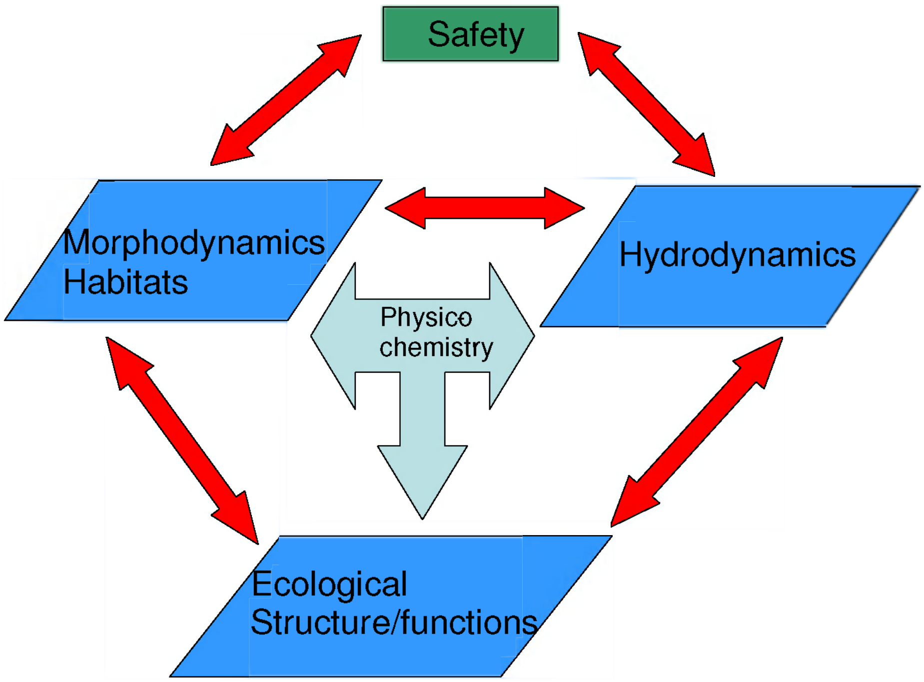

Figure 4.6 Overview of the interdependence of the monitoring program's various components.

Table 4.1 gives an overview of the parameters that have been incorporated in the proposed system monitoring. Donkers et al (2007) have distinguished between criteria, parameters, indicators and/or measurement units. We have chosen not to follow this line of reasoning. We distinguish between parameters (e.g., tide) which then may possibly be divided into a number of subparameters (e.g., water levels, flow rates ,..). The variables which need to be measured are then listed for these parameters or subparameters. The variables that need to be measuredmake up the core of the monitoring program. The variables to be measured can be valuable per se or may be required to calculate derived variables. A review of the table reveals that for hydro-and morphodynamics relatively few variables are measured on the basis of which a large number of derived variables are calculated. The opposite applies in terms of species diversity, physico-chemical properties and ecological functioning. Most variables have to be measured directly in the field (lab) and relatively fewer derived variables are thus calculated.

We have also included references to other reports such as Donkers et al (2007) in the table for purposes of comparability and we have also indicated the policy frames for which the parameters/variables have to be measured. We have also referred to ongoing programs. After all, most measurements are already performed in the area.

Table 4.1 Summary of parameters to be measured. For measuring locations the below table often refers to separate tables (Tables 1 through 9). These are included in Annex 1.

Overview of parameters to be measured: system monitoring

legislative framework/ scientific need*	Parameter	subparameter	Variables to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs*** existing	new	Remarks
scientific need is marked			variabels in *italics* are discussed elsewhere		** codes refer to paragraphs of Moneos-T			*** codes refer to existing projects as described in Wijsman et al., 2007		

Hydrodynamics

legislative framework/ scientific need*	Parameter	subparameter	Variables to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs*** existing	new	Remarks
	tide	Water levels (vertical tide)	Water levels tide gauges estuary		W.1, M.3			B.1.18, C.1.1, C.1.2, C.1.3, WL		
Embankment act				Mean high water	W.1.1	continuously		WS: existing locations	ZS: new location	
Sigmaplan				Mean low water		(registration every 10 minutes)		ZS: mostly existing locations		
Long Term Vision 2030 & Development Outline 2010				Mean tidal amplitude						
WFD: at least 1 per water body				Tidal asymmetry						
				Celerity						
IID: needed for delineating ecotopes				extreme water levels						
				return periods water levels						
				Retention time						
Sigmaplan: area objectives			Water levels CRT (controlled reduced tide)	Mean high water		continuously (every 10 minutes)	FCA Water levels (mostly)	Lippenbroek		CRT: measurement for ecological purposes most CRT are FCA: measurements coincide/overlap
LTV & DO2010				Mean low water						
contribution of CRT to ecosystem				Mean tidal amplitude						
				Tidal asymmetry						
				extreme water levels						
				return periods water levels						
Sigmaplan			water levels FCA (Flood control area)	Degree of filling FCA	W.1.1			Lippenbroek		FCA: measurement for safety also serve ecology
				Duration of emptying						

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement -programs*** existing	new	Remarks
		Discharge (horizontal tide)	Velocity profiles	Ebb volume Flood volume Tidal volume Distribution of tidal volumes over ebb- and flood channel		every three years (to measure within a short time of a few months)		C.1.1, WL		profiles need water levels en topography of cross-sections
Habitat Directive: for delineation of ecotopes		Current velocity (horizontal tide)	velocity profiles	Max ebb velocity Max flood velocity Residual velocity	E.1.2	continuously semicontinuously	potentially tidal gauges			
interpretation of samples related to tide			point velocities	Max ebb velocity Max flood velocity Residual velocity	E.1.2	monthly	surveys physico-chemistry	OMES		In ZS: already existing In WS new
	Wave action		wave height					B.1.18, C.1.1		
				wave period wave energy		continuously	to combine with tidal gauge in ZS			
Sigmaplan, WFD	Fresh water discharge									
ecosystem-functioning input for ecological models			Velocity profiles	fresh water discharge		continuously (daily values)	permanent stations at boundaries			
Sigmaplan	groundwater levels		groundwater level			daily (piezometric)		all wetlands to create within Sigma. Use of existing piezometers is possible		

Morphodynamics										
legislative framework/ scientific need*	**Parameter**	**subparameter**	**Variabels to be measured**	**Derived variabels**	**justification (reference to report)****	**frequency**	**Measurement can be executed together with:**	**Locations of measurement - programs*****		**Remarks**
								existing	**new**	
LTV & DO2010	Morphological structures								ZS: enlargement and increase in frequency in Boven-Zeeschelde and Rupel	
WFD										
		topography						B.2.1, B.2.2, C.2		
			Depth	Mean depth	M.1, M.2, M.3, M.4	Voordelta (2x/j)		area covering surveys		
					W.1	WS en Beneden ZS (yearly)				
					E.1	Boven ZS etc. (once every 3 years)				
				Area per depth class						
			Height area covering	Mean height	M.1, M.2, M.3, M.4, E.1	once every 3 years	vegetation aerial photography, multispectral images	area covering surveys		
				Area per height class						
LTV & DO2010				**Dynamics on macro scale**	M.1 en M.3					
				Channel stability						
				Storage capacity channels						
				Volume changes in channels						
				Width-depth ratio channels						
LTV & DO2010				**Dynamics on meso scale**	M.1 en M.3					
				Prescence of connecting channels						
LTV & DO2010			Depths on cross sections	**Dynamics on micro scale**	M.2	seasonally		30 cross sections WS	20 cross sections ZS	
			Heights on cross sections			tidal flats: seasonally, salt marshes: once every 2 years	vascular plants, position salt marsh border			
				Sedimentation/erosion patterns						
			Position salt marsh border	Dynamics salt marsh border		once every 2 years				
			Heights dikes/salt marshes	**Safety**	W.1.1					
				Height and width of dikes						
				Stability						

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
		fysiotopes						B.2.3		
LTV & DO2010			contours	Area of fysiotopes	M.2 en M.4					
		sediment composition			E.1	WS and ZS: once every 3 years tributaries: 1 every 6 years	Depth?	area covering scan		
			Granulometry	Median grain size Silt content Organic matter	E.1.2	cfr. Benthos	benthos	Associated with each benthos sample + extra locations in channel		
	Sediment transport							existing meetnet + cfr cross sections ebb- and flood volume		
		Sand transport				yearly by survey, every 3 years on cross sections		44 survey-areas	1 location at each cross section	direct measurements of transport necessary
			Sand concentrations, *ebb- and flood volumes*	sand balance		monthly	fysicochemistry, silt concentraties	ZS: OMES	WS: same as ZS	
		silt transport								
			Silt concentrations *ebb- and flood volumes, turbidity*	Silt balance		monthly	fysicochemistry, sand concentrations	ZS: OMES	WS: same as ZS	direct measurements of transport necessary
				silt input		(semi)continuously	current velocity, turbidity	autosamplers, datasonde at boundaries	permanent station in estuary	to discuss with RWS
	Information about human actions							collect all existing information		
		Dredged volume						Dredging information system		
			Volumes in dredgers Dredging location Volume of dredged material relocated							

Diversity of habitats										
legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
BHD	Ecotopes				E.1					
LTV & DO2010										
WVO										
VLAREM										
WFD										
			water levels	ecotope areas	E.1		These measurements are already executed	area covering		
			Topography	Changes in areas						
			Current velocities							
			Geomorfological units							
			Salinity							
			vegetation types							
	vegetation types				E.3.2			B.1.9, INBO		
			Contours vegetation types (aerial pictures)	Areas vegetation types			Lidar surveys		ZS: new methodology	
			Species diversity and abundance	Changes in areas			diversity species			

General fysicochemistry of water and soil										
legislative framework/ scientific need*	**Parameter**	**subparameter**	**Variabels to be measured**	**Derived variabels**	**justification (reference to report)****	**frequency**	**Measurement can be executed together with:**	**Locations of measurement - programs*****		**Remarks**
								existing	**new**	
WFD, HD, BD	Water quality				W.2 en W.3					
WFD		Physical parameters temperature and conductivity						B.1.18, WL, OMES		ZS: overlap exists in current monitoring programs
			temperature		W.3.1	continuously (every 10 minutes)	permanent stations + boundaries	permanent stations +boundaries		
					W.2.2, W.3.1	1 tot 2/month	surveys physico-chemistry			
			Conductivity		E.1.2	continuously (every 10 minutes)	permanent stations + boundaries	permanent stations +boundaries		
					W.2.2, W.3.1, E.1.2	1 tot 2/month	surveys physico-chemistry			
WFD, HD		Suspended matter								ZS: overlap exists in current monitoring programs
			Turbidity		W.2.1, W.3.1, E.1.2	continuously (every 10 minutes)	permanent stations + boundaries	permanent stations +boundaries		
				turbidity, depth profiles		1 tot 2/month	surveys + boundaries, current velocity profiles			depth profiles: calculation of loads, relation with current velocity
			Mass of suspended matter		W.2.1	1 tot 2/month	surveys + boundaries			
			Composition suspended matter (% organic material)			1 tot 2/month	surveys + boundaries			
system: light climate			Coloured Dissolved Organic Matter			1 tot 2/month	surveys + boundaries			

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
WFD		Acidity			W.3.1					
			pH			continuously (every 10 minutes)	permanent stations + boundaries	permanent stations +boundaries		
						1 tot 2/month	surveys + boundaries			
WFD		Oxygen			W.3.1					
			Oxygen concentration			continuously (elke 10 minuten)	permanent stations + boundaries	permanent stations +boundaries		ZS: overlap in existing programs
system functioning			Oxygen saturation			1 tot 2/month	surveys + boundaries			
			Biological Oxygen Demand 5			1 tot 2/month	surveys + boundaries			
			Chemical Oxygen Demand							
WFD		Nitrogen			W.3.1					ZS: overlap in existing programs
			Nitrate-N Nitrite-N Ammonium-N Kjeldall-N	Total-N, oxygen demand for nitrification		1 tot 2/month	surveys + boundaries	B.1.14, OMES, VMM		
ecosystem		Silicium								
recommended in WFD			Dissolved Si			1 tot 2/month	surveys + boundaries	B.1.14, OMES		
ecosystem			Biogenic Si					ZS: OMES	WS: new	
WFD		Phosphate			W.3.1					
			Orthophosphate			1 tot 2/month	surveys + boundaries	B.1.14, OMES, VMM		
			Total P							
ecosystem				N/P/Si ratio						
		Carbon								
			Dissolved Organic Carbon			1 tot 2/month	surveys + boundaries	B.1.14, OMES		
			Particular Organic Carbon							
			Dissolved Inorganic Carbon							
			Total C							
			Isotope ratio (C13/C12)							

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
WFD		Heavy metals			W.3.2					
			Cd, Cu, Fe, Ni, Pb, Zn, in water phase			monthly	surveys + boundaries			
			Cd, Cu, Fe, Ni, Pb, Zn in suspended material							
WFD		Organic micro-contamination			W.3.2					
			PCB's, PAK's,			following WFD richtlijnen	surveys + boundaries	following WFD richtlijnen		
			Annex X compounds WFD							
VLAREA, VLAREBO, VLAREM	Watersoil quality					yearly		triade monitoring network 9 locations in ZS	ZS: none	new decree is expected in Flanders
		Soil parameters								
			Dry matter granulometry			yearly		triade monitoring network	ZS: none	
		Heavy metals								
			Cd, Cu, Fe, Ni, Pb, Zn,			yearly		triade monitoring network	ZS: none	
		Organic micro contamination								
			Mineral oil EOX PCB's PAK's organochlorine pesticides			yearly		triade monitoring network	ZS: none	

Diversity of species										
legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
BD, HD LTV& DO2010 Decree Nature conservation Fauna & flora act										
WFD	Vascular plants				E.3.2			ZS: new method		
			vegetation types Amount of species Coverage of species (both per vegetation type)			every six years	heights on cross sections, position tidal marsh	random plots area covering (about 300 plots in NL, 300 in Vl)		
HD, WFD	Macrobenthos				E.3.3			B.1.1		
			Amount of species	Species diversity		see ecological functioning	macrobenthos production	see ecological functioning		
	Hyperbenthos									
			Amount of species	Species diversity		cfr. Fish (nursery function)	fish: nursery function	cfr. Fish (nursery function)		
WFD	Fish				E.3.4, E.2.1			B.1.16, INBO		
			Amount of species	Species diversity		see ecological functioning	partim hyperbenthos	see ecological functioning		
HD	Amphibia									
			Amount of species	Species diversity		every six years	MWTL + cfr. NARA	inundation areas, to be specified		
BD, HD	Breeding birds				E.2					
		coastal breeding birds			E.2.5					
			Amount of breeding couples		Meininger et al., 2006	yearly	Breading success	B.1.6 area covering counting	None	
HR		appendix I species								
			Amount of breeding couples		Adriaensen et al. 2005	every six years	Local management	area covering counting, NL and Vl together		

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
		Conservation objectives species/ meadow birds								
			Amount of breeding couples		Adriaensen et al. 2005	every six years	Local management	area covering counting, to be specified		
BD	None breeding birds				E.2.4					
		Water birds								
			Amount of birds per species	Bird-days	Ysebaert et al. 1998, Meininger et al., 1998	monthly		B.1.12, INBO area covering counting	none	
	Mammals									
HD		Seals			E.2.6, Witte, 1998			B.1.13		
			number of individuals			monthly, tweewekelijks tussen juli en september		habitats-dekkende vlucht	none	surveys within 1 tidal cycle
			Amount of young seals							
HD		Conservation objectives species/annex species	Amount of species		Adriaensen et al., 2005					
			Amount of species			3 times per year every six years	eventually combined with rat extermination		max 50 transects	Otter: method to be defined
			Abundance of species							Beaver: weekly trace check, if abundant

Ecological functioning										
legislative framework/ scientific need*	**Parameter**	**subparameter**	**Variabels to be measured**	**Derived variabels**	**justification (reference to report)****	**frequency**	**Measurement can be executed together with:**	**Locations of measurement - programs*****		**Remarks**
								existing	**new**	
WFD LTV & OS 2010 system	Pelagic Primary production									
		phytoplankton			E.3.1			B.1.5, OMES		
			Densities of different species	Ratio algae/diatoms Biomass of algae		1 to 2/month	surveys physico-chemistry boundaries	idem fysico-chemistry, all stations of OMES; Chl a on many VMM stations; CEME and RWS measure most pigments		
WFD system			Pigments: Chlorofyl a Other phytopigments	Indirect ratio biomass Ratio of differtent groups of species						
		Determining factors PP								
			Light extinction *nutrients*		W.3.1	1 to 2/month	surveys physico-chemistry	idem fysico-chemistry		
		production measurements								
			C14 incorporation	Bruto and netto primary production		1 to 2/month	surveys physico-chemistry	during surveys physico-chemisrtry, on selected stations		C14 incorporation can be reduced when PAM of FRRF measurements are operational
system	Benthic primary production									
		biomass						B.1.8		
			Pigments: Chlorofyl a			monthly March-October	macrozoobenthos	intertidal macrozoobenthos locations		1): if NDVI camera available
		Direct measuremetns of production								
			C14 incorporation	Bruto and netto primary production		monthly March-October		5-6 (to be specified)		

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
	Benthic secundary production				E.3.3					
		macrozoobenthos					benthic Chlorofyl a, granulometry,	B.1.1, B.1.7		
			Densities and biomass of species		Van Hoey et al. 2007	2 times/yr (spring and autumn)	benthic Chlorofyl a, granulometry,	280 in WS	analoog in ZS, af te stemmen op ecotopen	
		shellfish stocks						B.1.3 (kokkel)		
			Densities and biomass of species		Craeymeersch & Wijsman, 2006	yearly		see surveys existing WOT-monitoring		8 week survey time planned, 6 ISIS and 2 cockles
	Pelagic secundary production				E.3.3					
		Zooplankton								
			Densities and biomass of species	Species diversity Grazing intensity						
WFD		Fish			E.2.1, E.3.4					
			Densities and biomass of species			every six years		To be defined in a specific assignment		with different fish techniques that contain together the complete variety in species
		nursery function			E.2.2					
			Densities and biomass of relevant species: shrimps, juvenile commercial fish			To be further specified	hyperbenthos	To be further specified: at least 1 per water body		

legislative framework/ scientific need*	Parameter	subparameter	Variabels to be measured	Derived variabels	justification (reference to report)**	frequency	Measurement can be executed together with:	Locations of measurement - programs***		Remarks
								existing	new	
		migrating fish	LTV O&M research on migrating fish	LTV O&M research on migrating fish	E.2.3	LTV O&M research on migrating fish		LTV O&M research on migrating fish		
	Fish diseases							B.1.11		
			Polluents in tissue Eel and Flounder			yearly	partim: fish densities and biomass	existing network and further to be specified		
			Presence of fish disease							
	Breeding succes of coastal breeding birds							B.1.2		
			Amount of eggs	Reproductive succes	Meininger et al., 2006	yearly	diversity of breeding birds	colony of Terneuzen'		
			Breeding succes							
			fledging success							

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