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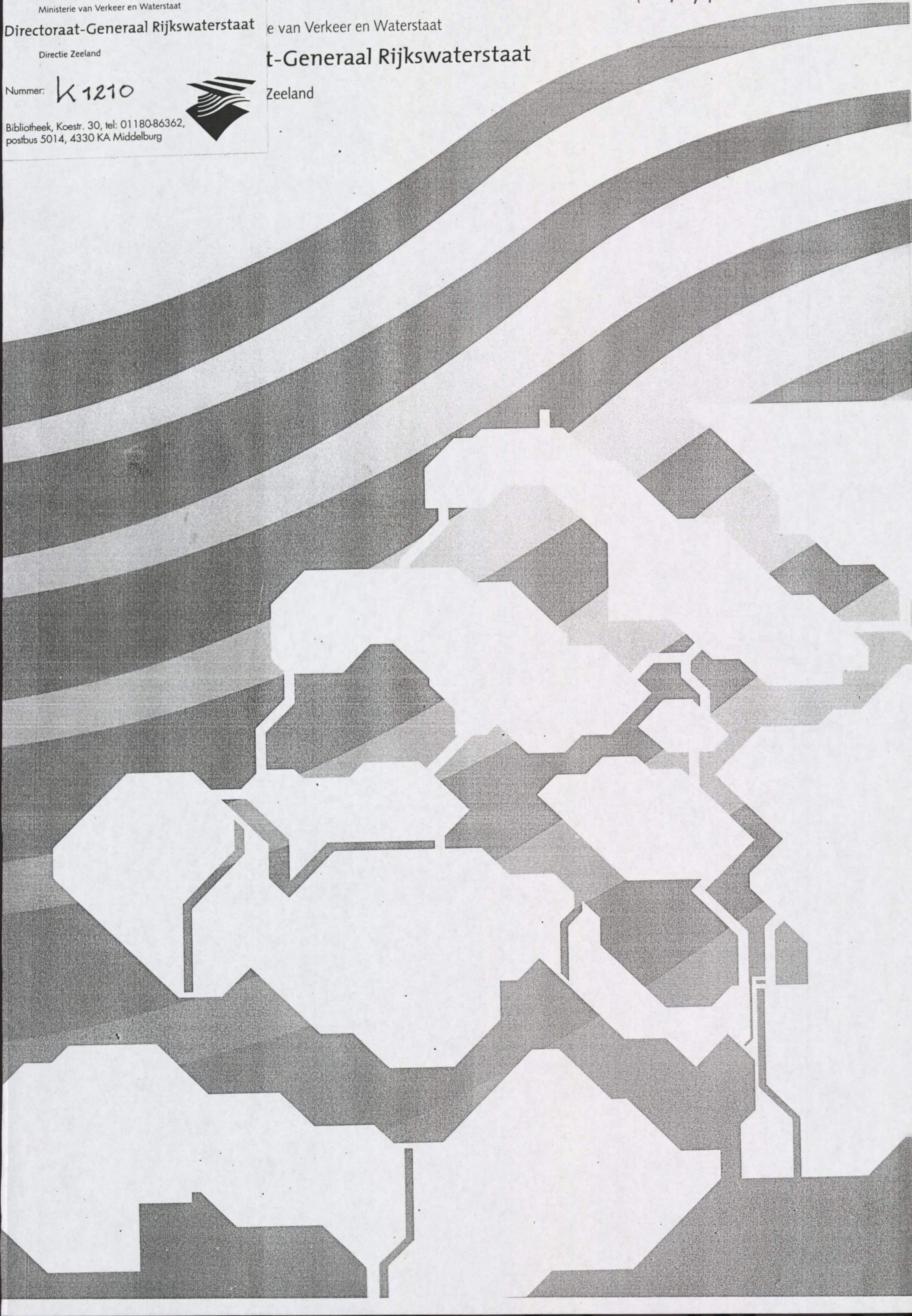

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MANAGEMENT OF THE SCHELDT BASIN AS A FUNCTIONAL ENTITY

Offprint of the Scheldt papers of the RBA-symposium, May 18-22 1992

Ministry of Transport & Public Works
Directorate-General Rijkswaterstaat
Division Zeeland
Middelburg, September 1, 1992

Introduction

This report contains three papers written for the presentation at the international symposium "Transboundary River Basin Administration and Sustainable Development"organized by the Center for Comparative Studies on River Basin Administration from May 18-22 1992 in Delft and Rotterdam, The Netherlands. The papers forms a triptych about managing the Scheldt basin as a functional entity.

In the first paper Miss B.P.S.A Ovaa deals with the legal, administrative and organizational aspects of the transboundary river Scheldt basin management.

In the next paper Mr. F. de Bruijckere discuss the chemical conditions of surface water and sediment of the Scheldt basin and the required emission reductions the obtain a sound and sustainable development of the river basin.

In the last paper Mr. T. Pieters e.a. deal the restoration and fortification of the characteristic morphological elements of the river and estuary Scheldt and the development of an integrated dredging-extraction-dumping strategy.

A more integrated approach and an stronger international co-operation are necessary to succeed in a sustainable management of the Scheldt basin is the collective conclusion of the authors.

F.L.G. de Bruijckere

Middelburg, September 1, 1992

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AS A FUNCTIONAL ENTITY

MANAGEMENT OF THE SCHELDT BASIN
AS A FUNCTIONAL ENTITY
Part 1. In search of a balance between natural substratum and societal claims

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Abstract

The pressure of societal claims on the ecological potentials of the Scheldt basin has risen far beyond the limits of sustainability. In order to reach the objective of sustainable development within a sound river basin, well-considered choices have to be made at the level of societal system. At the same time, a clear notion of the potentials, objectives and priorities at the level of river system and water system has to be formed.

1. Introduction

The river Scheldt takes its rise in the French Ridge of Artesia near St.Quentin, passes through Belgium and reaches the North Sea in the south of the Netherlands near Flushing (Figure 1). In comparison with its neighbour Rhine, the Scheldt is a river of modest size: its catchment area covers just about 20.000 km^2. The river basin can be characterized by three basic aspects: the Scheldt and all of its tributaries are rainfed rivers, the area is marked by low relief, and especially the estuarine part is very rich in natural gradiënts (hydrodynamical, chemical and morphological gradiënts).

The Scheldt area, with its fertile plains and natural transport routes is an attractive place for people to settle. Over the centuries the basin has grown to a densely populated (about 10 million inhabitants) and highly industrialized area, with an important economic production. The low relief has permitted a considerable adaptation of the natural basin into a functional river system. This is shown in Figure 1 by numerous digged canals, forming internal connections within the river system and external connections with surrounding basins. However, as a consequence of the various claims by society on the potentials of the Scheldt basin, this river system is getting more and more subject to severe ecological degradation. The pressure on the river system has risen far beyond the limits of sustainability.

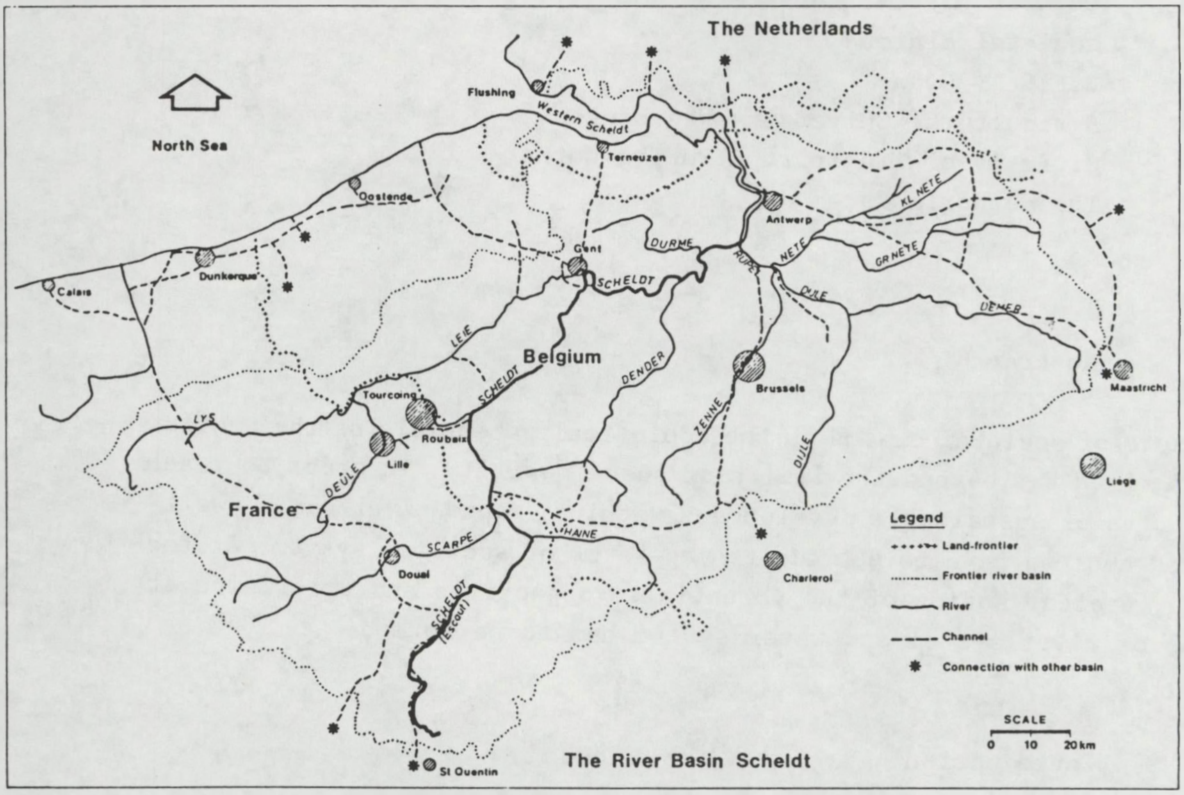

Figure 1. Today's river system of the Scheldt, consisting of natural and artificial elements.

In the consciousness of the urgent need to restore the ecological potentials, being a prerequisite to economic production, a number of studies are being carried out. In this context Mr. F.L.G. de Bruyckere (Part 2) will present an overview of the situation and necessary reduction of pollution of water and sediments and subsequently Mr. L. Bijlsma and Mr. T. Pieters (Part 3) will go into the subject of morphological restoration of the estuarine part of the river system. In the first contribution concerning the Scheldt, presented here, an attempt will be made to outline a comprehensive strategy for the implementation of the concept of sustainable development in the transboundary river basin management.

2. Theoretical framework and elaboration

Sustainable development[1] of a river system like the Scheldt will never be reached by a mere drawing up of scientifically supported technical regulations. The filling up of today's norm values does not mean we are

operating within the safe boundaries of 'exploitable space', but within the risky boundaries of our knowledge. Moreover, the aim (WCED, 1987) not to compromise the ability of future generations to meet their own needs, implicates a necessity of making normative choices prior to technical decisions. Sustainability therefore requires a much more comprehensive conceptualization.
In striving for sustainable development of the Scheldt area the following chain of objectives can be distinguished (Ovaa, 1991) at hierarchically ordered integrative levels:

sustainable development	level A: societal system
sound river system	level B: river system
sound water system	level C: water system

Level A: The societal system [M] can be considered as consisting of three interacting subsystems: an Economic subsystem, a Political subsystem and a Cultural subsystem (Figure 2). In the Economic subsystem the material production and distribution is taking place. The Cultural subsystem stands for the mutual agreement on ethical values, which forms the basis of legitimization with respect to all societal actions. In an ideal situation, the central purpose of [M], i.e. maintenance of the system, can be fulfilled by these two interacting subsystems. In practice however, a third subsystem performing a regulatory task: the Political subsystem, is needed.

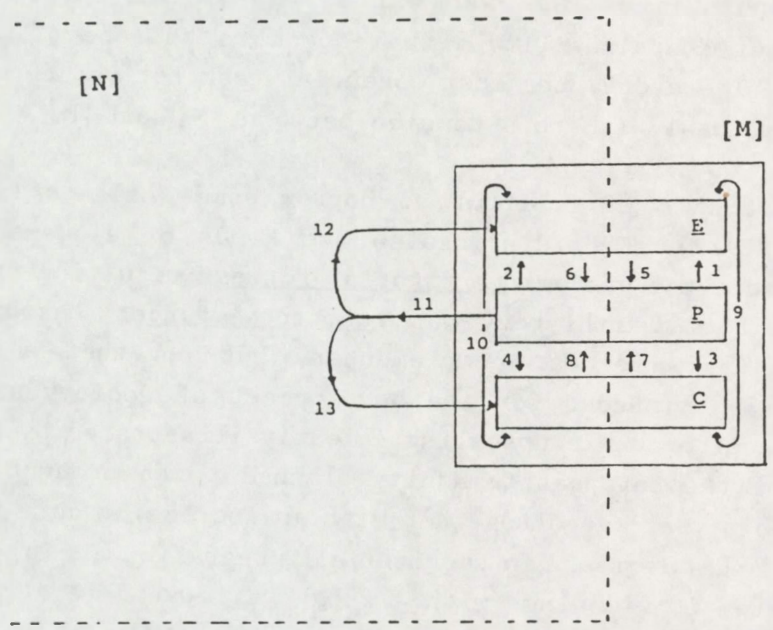

Figure 2. The functioning of the societal system [M] in relation to the natural substratum [N]

The natural environment [N] forms the necessary substratum for the functioning of the societal system [M]. The arrows in Figure 2 refer to the possible interactions between the three subsystems. While the right part of [M] contains mere societal interactions (arrow 1 e.g. may indicate monetary measures), the left part covers the various interactions in which the natural environment [N] is involved (arrow 2 may indicate the digging of canals, arrow 12 the protection of the environment in favour of economic production).

In modern times, the market (E) has become the leading principle of the western society. Beside it, the public authorities (P) have got a double task: on the one hand the creation of the prior conditions for this leading principle and on the other the correction of its negative side-effects. This results in a continuing pursuit of economic growth and social improvement. Together with the belief that society can be known, shaped and directed, the choice of this principle of organization has three important effects (Kleefmann, 1984):

- growing system dynamics
- upscaling
- growing role of science in the Political subsystem

These three effects are strongly interrelated. In order to guarantee a maximum manoeuvring room to the leading principle (market), a high degree of system dynamics is needed: over and over again existing linkages have to be disconnected and new strategies have to be found. However, the tendency to growing dynamics of the societal system [M] is in sharp conflict with the aim of sustainability with respect to the use of the natural substratum [N]! Therefore, the most essential task for the future is to find a strategy to deal with this tension between [M] and [N].

In this respect, it seems to be fruitful to borrow some insights from Friedmann and Weaver (1979). They distinguish two kinds of elementary forces, active in the societal system: territorial forces, resulting from the common social bonds formed in history, and functional forces, based on mutual self-interest. These forces, complementary but nonetheless in constant struggle, are both needed for the development of society. The above mentioned process of economic upscaling (clearly illustrated by the economic integration of the European Community planned to be brought to political completion this year) goes together with an increasing care for functional integration and a decrease in territorial integration. In Figure 2: the Economic subsystem is widening (with a great variety of level and direction) beyond the boundaries of its native territorial [M], and while P tries to find a way to keep pace, C cannot. This results in a considerable overcharge of the carrying capacity of the territorial [N], which exceeds the correcting capacity of the (territorially organized) P. Meanwhile, it is no longer possible for C to make weighed decisions and legitimize the actions of $\underline{E}$ and $\underline{P}^2$. It must be clear, that the dominance of functional forces over territorial forces is apt to lead to the degradation of the ecological potentials. Sustainability needs a certain degree of territorial motivation.

The above observations and conclusions, noted at the level of societal system cannot be ignored at the following levels of river system and water system.

<u>Level B:</u> In practice, most negotiations of riparian states concerning the shared river basin are being motivated by mutual self-interest. In the Scheldt basin so far they mainly relate to the minimum acceptable level of transboundary pollution and the necessary draught for transboundary shipping (for example to the port of Antwerp; Figure 1). For the present, it is not to be expected that functional forces will stop growing. However, a closer look at current management questions (e.g. hydraulic regime at the Flemish nodal point of Ghent / management of the French transversal Canal à Grand Gabarit ; Ovaa, 1991) and the far-reaching consequences of management decisions at these points, shows that a strategy for sustainable use can only be based on a thorough understanding of the whole river system.

The riparian states France, Belgium (consisting of the relatively independent regions Flanders, Wallonia and Brussels) and The Netherlands will have to form a joint notion of the future development of the whole Scheldt system. In fact, here sustainable use requires a joint territorial decision. As regards content, an ecological theory like Cummins' river continuum concept (Figure 3) might be useful as a starting-point. Subsequently, after having built up a reference, agreements can be made upon the adaptations in favour of the necessary economic functions within this framework.

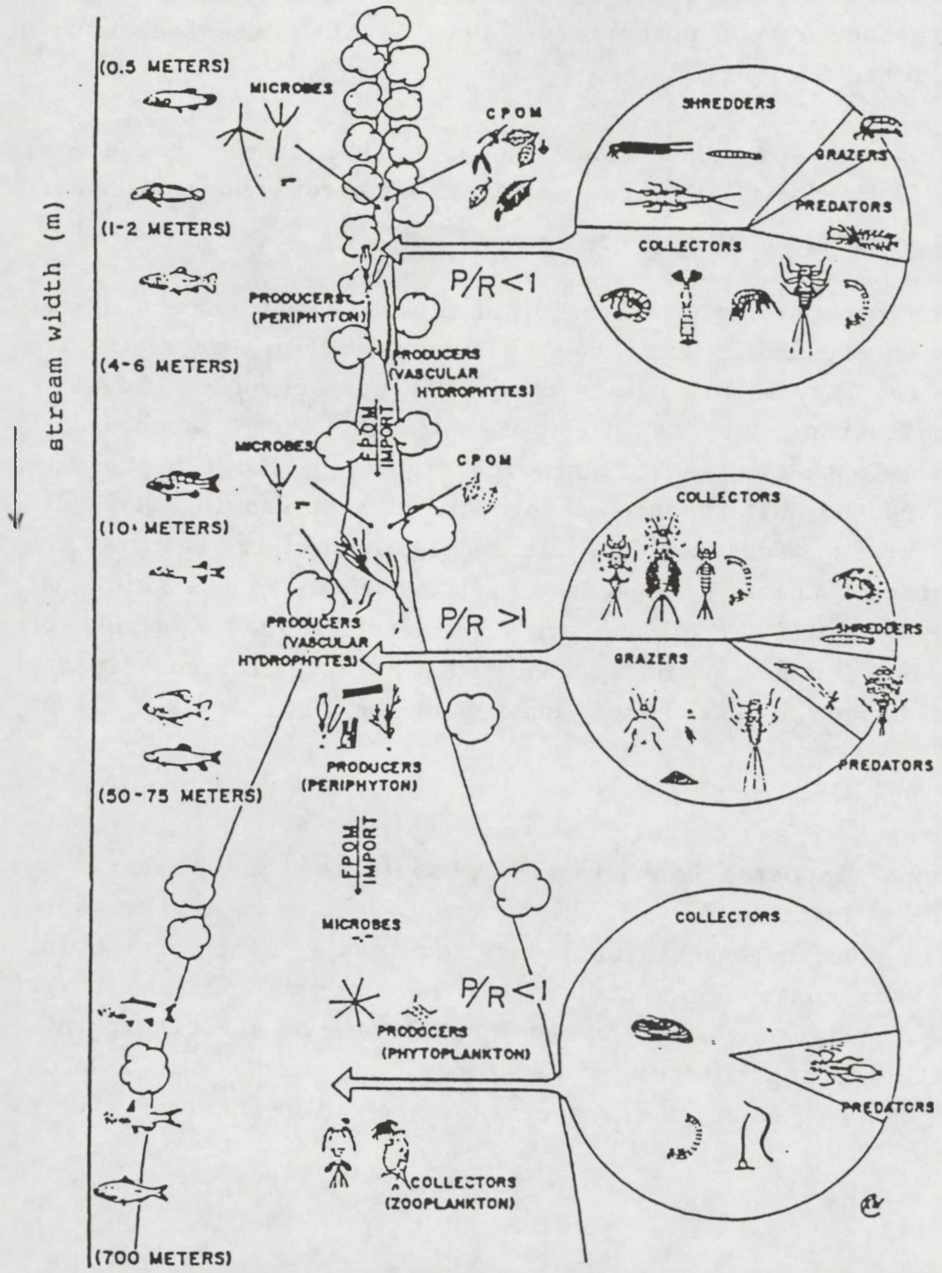

Figure 3. Diagram showing the changes in undisturbed biological communities over the main axis of a hypothetical river according to the river continuum concept of Cummins. (P/R: ratio of primary production to consumption).
Source: Stanford, J.A. and J.V. Ward (eds.) 1979. The ecology of regulated streams. Plenum Press, New York.

Level C: A water system can be considered as a segment of a river system. In Figure 4 the thinking-model is schematically presented. A water system is made up of physical, chemical and biological components with regard to water, waterbed and banks.

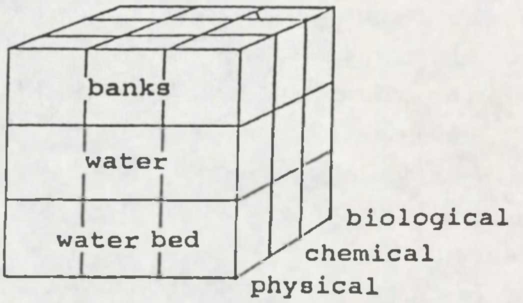

Figure 4. Schematic simplification of a water system

A first problem consists of the choice of criteria with respect to the demarcation of the water system for the sake of operational water management. In this case, demarcation by ecological characteristics, often as well visible in the landscape, appears most appropriate (Ovaa, 1991). Dependent on local characteristics, and in connection with the insights in the potentials of the specific water systems within the framework of the river system, territory-differentiated ecological objectives can be derived.

In managing the water system, care should be taken to include internal relationships (interactions between water quantity and water quality) and external relationships (interactions between water management and adjacent questions concerning town and country planning, environmental consequences, etc.). Subsequently, the adaptations of the water system, carried out in order to meet the societal claims, must fit as close as possible to the natural hydrological and ecological patterns and processes.
Especially at the level of water system, territorial forces can have a positive and stabilizing impact on the establishment and maintenance of a sustainable management of the water system. Within the management program, attention must be paid to the stimulation of local awareness and participation. Sustainability needs the explicit legitimization of the Cultural subsystem.

3. The Scheldt system; some conclusions

In theory, the Scheldt basin is covering three countries: France, Belgium and The Netherlands. Since the revision of the constitution in Belgium in 1980 however, more and more national competencies have been delegated to the federal states Flanders, Wallonia and Brussels. As a consequence, in questions concerning water management, the Scheldt basin has to be considered as administrated by five riparian "states".
In this split up river basin there is no question of one homogeneous societal system [M]. On the one hand, this can be traced back to cultural and economic differences in history; on the other hand, it is based on each of the partner's present interests. Consequently, the way in which the political subsystems of the five respective states will fill in their tasks: the creation of prior conditions and the correction of negative side effects, will be considerably different.
For the present, neither the establishment of one uniform river system management, nor the set up of one official river system authority is to be expected. This however does not rule out the possibility of co-operation. The set up of an international Scheldt Committee could be a start to the exchange of information on measuring data and norm values, the coördination of measuring programs etc., while joint bilateral projects can give some valuable practice.

In the former paragraph a strategy has been outlined aiming at a sustainable development of the Scheldt area, via the objectives of a sound river system and sound water systems. As for the Scheldt basin, there is still a long way to go. However, within the different riparian states, promising developments are taking place. The French 'Politique de Contrat de Rivière' for example contains several components that fit quite well into the ideas outlined in paragraph 2. The contract bears upon a demarcated 'water system', often the basin of a small tributary, and the objective is a comprehensive restoration of the river basin. The negotiations take place in the midst of a broad, local 'Comité de Rivière' of representatives of public authorities and interest groups, while the enlargement of the awareness of the inhabitants of their natural patrimony is explicitly part of the policy. Another promising initiative that should be mentioned is the Flemish study after a typology of the ecologically valuable water-courses (Bervoets et al., 1989). The objective is to set up an ecological reference framework and to define the necessary priorities with respect to river restoration.

These initiatives could be a good starting-point for a territory-differentiated approach of water management within the context of a sound transboundary river system management.

Notes

1. The definition of 'sustainable development' as given by the WCED (1987): 'an approach to progress which meets the needs for the present without compromising the ability of future generations to meet there own needs' forms the main point of departure of the study underlying this article.

2. It might even be put, that to a high degree the legitimizing role in society has left C and is being carried out by E.

Acknowledgements

The author wishes to thank Mr. J.H.G. Verhagen (Agr. Univ. Wageningen, Department of Hydrology), Mr. R. Jongman (Agr. Univ. Wageningen, Department of Country Planning) and Mr. F. de Bruyckere (Ministry of Transport and Public Works) for their stimulating remarks during the research period.

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MANAGEMENT OF THE SCHELDT BASIN AS A FUNCTIONAL ENTITY

Part 2

The Scheldt Basin under chemical pressure.

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the Netherlands.

1 Introduction

The poor condition in which we find the Scheldt today is largely a result of one-sided management of river functions, the main ones being :

- shipping,
- drainage of agricultural and urban land,
- flood defence.

The deterioration of the river is now virtually complete. There are two main causes of the deterioration:

- excessive loading with all kinds of environmentally damaging substances
- changes in the morphology of the river made to improve navigation and flood defence.

I should deal with the first of these, looking at the following aspects:

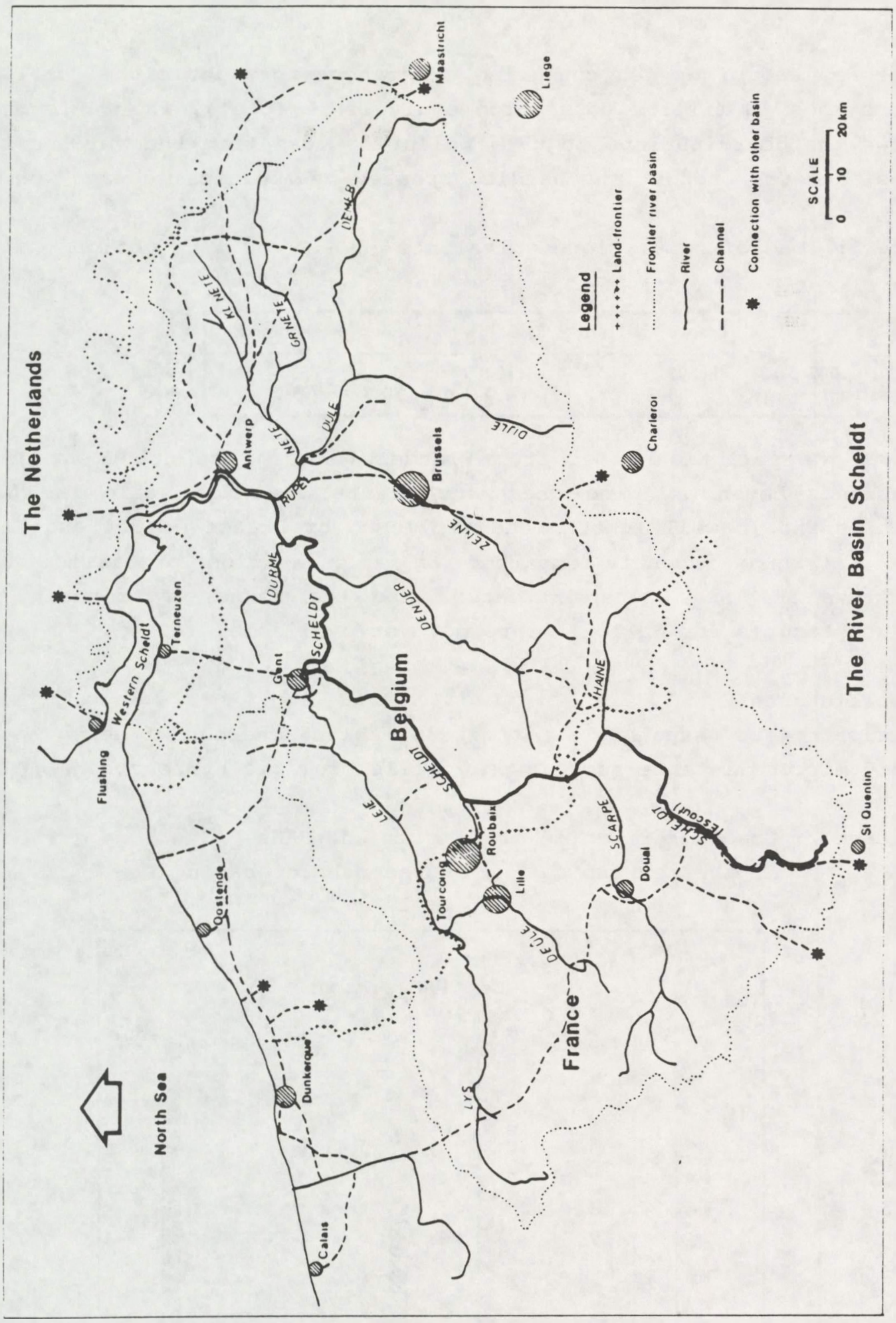
- current loads of oxygen-consuming and hazardous substances.
- the effects of these on the water system
- results of some scenario calculations over freight reductions
- recommendations for complete restoration.

Mr Peters will give a similar account from the morphology angle in these triptych about managing the Scheldt basin (Pieters et al, 1992)

2 Hydrological divisions

From its source in northern France the Scheldt is a freshwater river as far downstream as the Flemish city of Gent; below Gent, the river is tidal, a marine estuary to the North Sea. The estuary is known as the "Sea Scheldt" below the mouth of the Rupel (Rupelmonde), and from the Dutch-Belgian border until the confluence with the North Sea it is called the Western Scheldt.

Hydrographically, the Scheldt basin can be divided into 10 sub-basins: the catchment areas of five tributaries; the Leie, the Dender, the Zenne, the Dijle + the Demer and the Nete; the Scheldt from source till the confluence with the Leie, the Scheldt between the Leie and the Rupel, the Sea Scheldt, the Western Scheldt and the channel between Gent and Terneuzen. See the map of the Scheldt basin on page 2.



Map of the River Scheldt Basin

3 Emissions

Oxygen
The gross load of oxygen consuming substances throughout the Scheldt basin is more than 10 million population equivalents (p.e.). The table on figure 1 shows the contributions to this pollution load from the various riparian states, and the proportions handled treated by municipal sewage works.

Figure 1: Load of population-equivalents (p.e.) and % reduction

	France	Wallonia	Brussels	Flanders	Netherlands
load (*1.000 p.e.)	2.500	450	1.300	5.300	750
% treatment	50 %	n.a.	0 %	30 %	95 %

Most of the pollution comes from Flanders. As far as treatment goes, the Netherlands began building treatment plants on large scale in the early seventies and is well in the lead, followed by France on 50% and Flanders, which has only recently embarked on a sanitation programme. Brussels discharges all its waste untreated into the Zenne, a tributary of the Scheldt. Figures for Wallonia were not yet available.

Micropollutants
The industry are responsible for most of the discharges of heavy metals and organic micropollutants such as polycyclic aromatic hydrocarbons (PAHs).

Figure 2: Load distribution of cadmium and PAHs
in the ten sub-basins of the Scheldt basin.

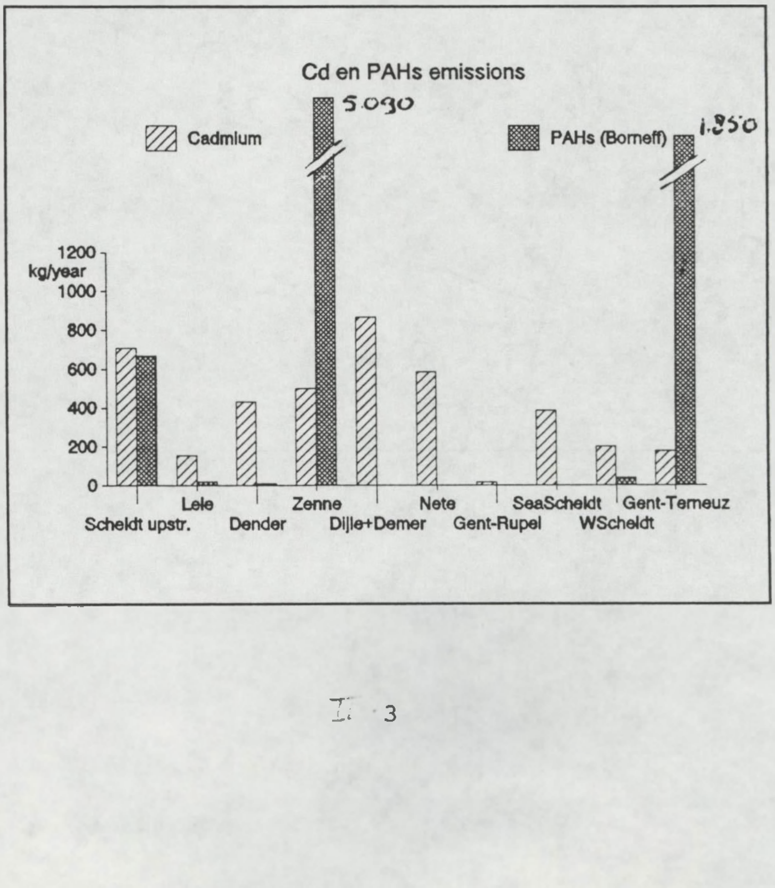


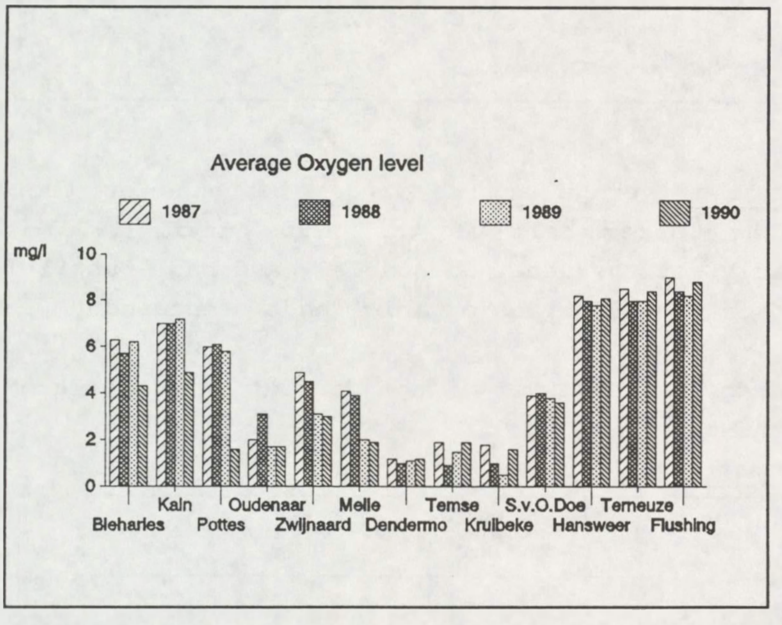
Figure 2 shows the load distributions of the heavy metal Cadmium and PAHs in the ten sub-basins of the Scheldt basin. Cadmium is widely distributed in all the sub-basins, while emission of PAHs is quite clearly concentrated in the Zenne (Brussels) and the channel between Gent and Terneuzen.

4 Effects

4.1 Oxygen levels in the river

According to estimates made by the Flemish Environment Agency, more than 70% of the oxygen demand from the pollution load is met within the river basin. As a result, dissolved oxygen concentration in the Scheldt is well below the 5mg/l minimum acceptable level, as figure 3 shows

Figure 3: The average oxygen level in the Scheldt basin
(Heip & Klap, 1991)



Oxygen contents are especially low in the summer, when biological activity is at its height and river discharge at its lowest. Figure 4 shows the oxygen concentration in the reach between Rupelmonde and Flushing. In the summer, there is no oxygen left at Rupelmonde. Elevated oxygen concentrations in the marine reaches are the result of plankton blooms.

Figure 4: Oxygen level in winter and summer in 1987
between Rupelmonde and Flushing (van Eck, 1991)

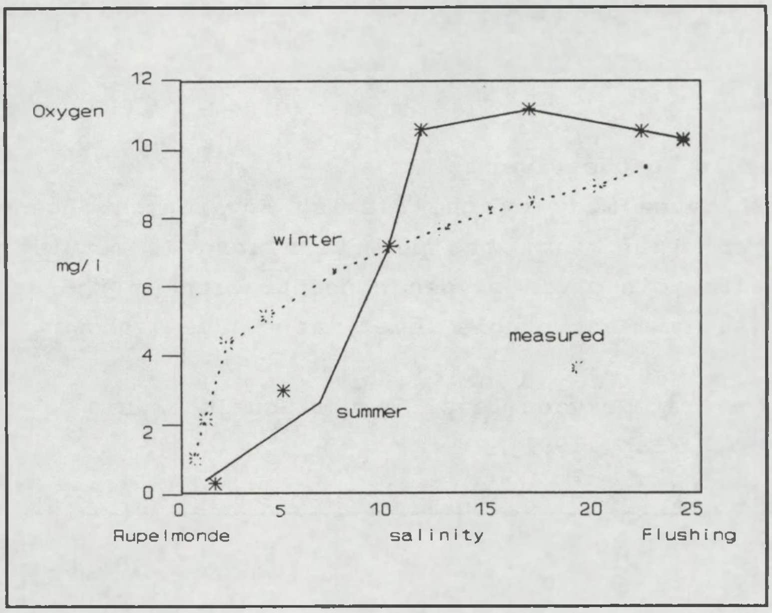
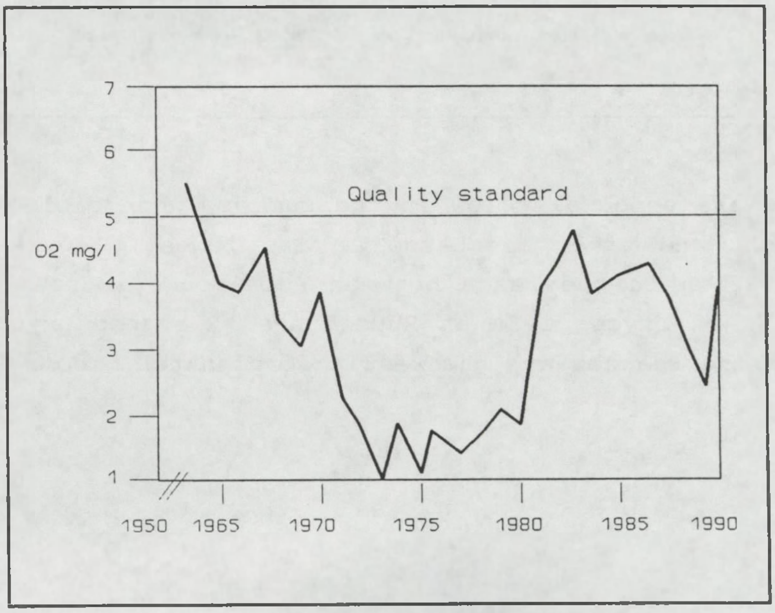


Figure 5 shows the average annual oxygen contents at the Dutch-Belgian border. From the latter half of the 1950s until 1970, the situation deteriorated badly. It the remained stable - and bad - until 1980. Things improved in the 1980s, as organic loads decreased.

Figure 5: Average oxygen level of the Scheldt on the Belgium/Dutch border
(Van Eck, 1991)



But in 1988 and 1989, the situation deteriorated again. The reduction in dissolved oxygen in these years cannot be blamed entirely on higher pollution loads. Mild winters played an important role, by raising water temperatures. This reduces the solubility of oxygen and accelerates mineralisation processes.

4.2 Micropollutants in sediments and organisms

Contents in suspended matter

Heavy metals and most organic micropollutants are only slightly soluble in water; these substances usually adhere to sedimentary particles. The heavier particles are deposited on the river bed, while the lighter fraction is transported seawards by the river.

Figure 6 shows the concentrations of a number heavy metals found in suspended solids in the Scheldt and other rivers. The Scheldt is used as the index river, with its heavy metal content expressed as 100%. Reference values for an average river are shown at the bottom. Heavy metal concentrations in the Scheldt are similar to those in the Weser and the Elbe.Concentrations in the Rhine are significantly lower.

Figure 6: Heavy metals in suspended solids of European rivers.

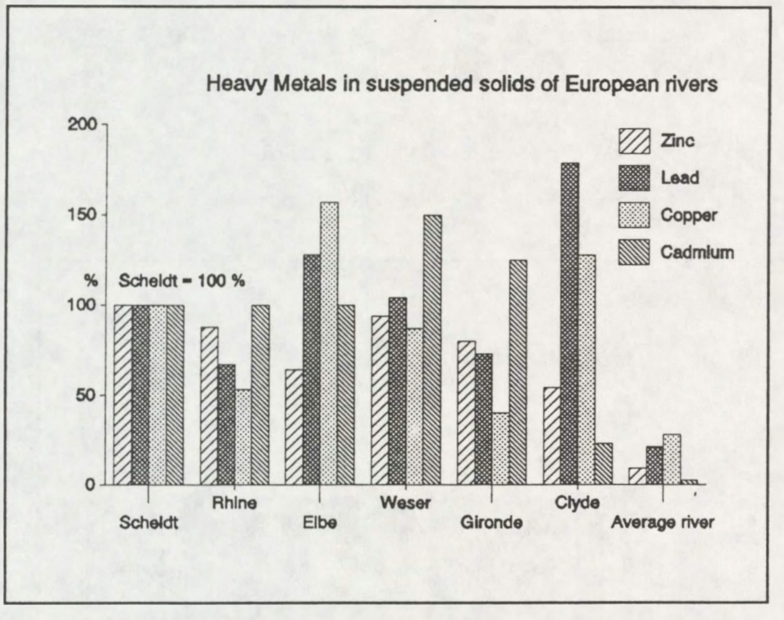
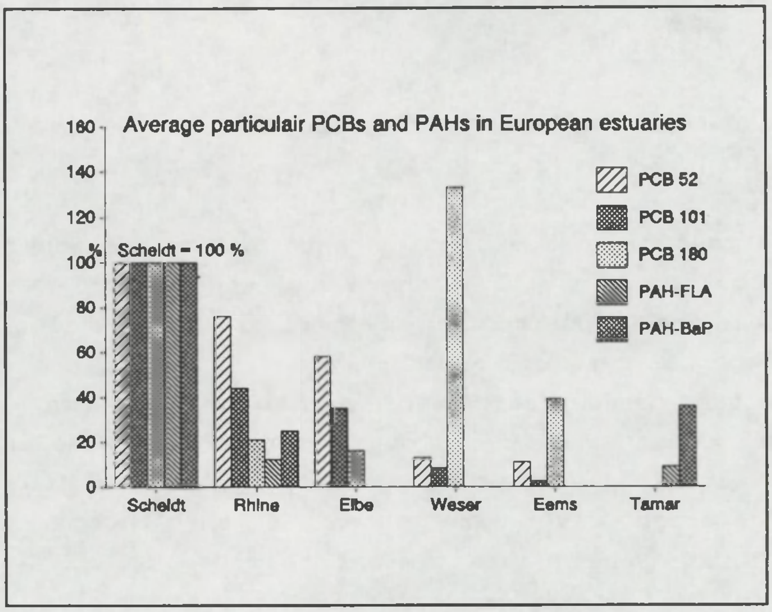


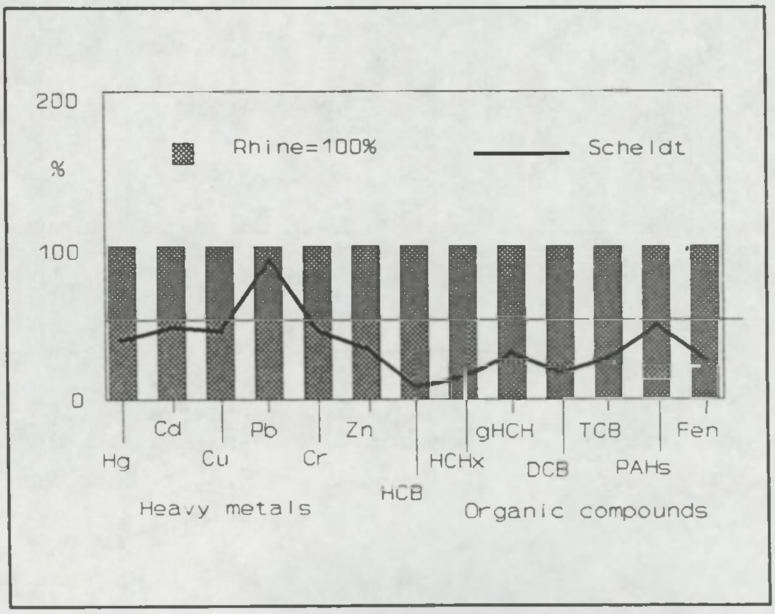
Figure 7 shows concentrations of a number of organic micropollutants in the Scheldt and other European rivers. Concentrations in the Scheldt are the highest by far.

Figure 7: Particulair PCBs and PAHs in suspended solids of European rivers.



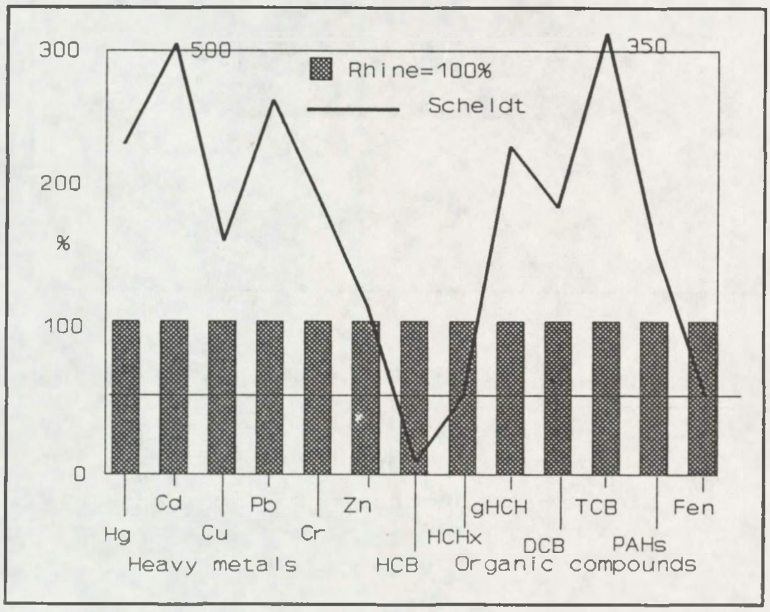
Closer comparison of analyses of suspended solids in the Scheldt and the Rhine over the last fifteen years shows clearly that the Rhine has improved significantly - a reduction of 60% on average. The Scheldt, however, is lagging way behind, as the next two figures show.

Figure 8: Micropollutants in Scheldt and Rhine on the Dutch border in 1971-1973



The diagram on figure 8 shows that initially - between 1971 and 1973 - concentrations in the Scheldt were much lower than those in the Rhine.
Here the Rhine is the index, represented as 100%. The data come from measuring points on the Dutch border. The second diagram (figure 9) compares concentrations fifteen years later; clearly, concentrations in the Scheldt are now higher. True, pollution in the Scheldt has diminished over the period, but not to the same extent as in the Rhine.

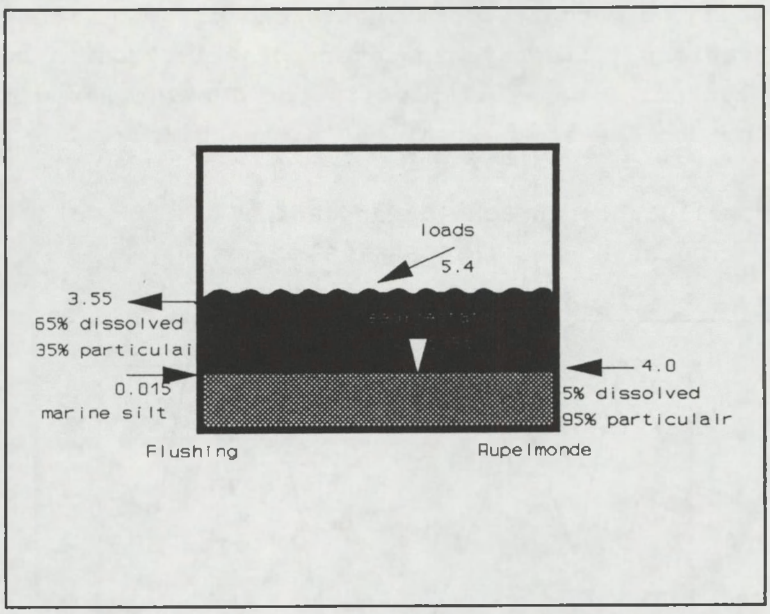
Figure 9: Micropollutants in Scheldt and Rhine on the Dutch border in 1986-1988



River bed concentrations

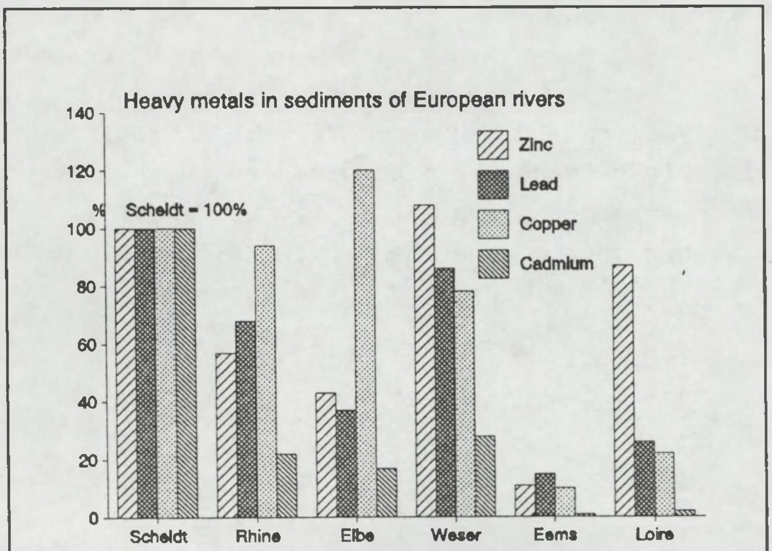
More than half the pollution transported by the river settles out in sedimentation zones such as the ecologically important salt marsh at Saeftinghe in the Western Scheldt. As figure 10 shows 60% of Cadmium carried by the river is retained by areas such as these. Retention of other heavy metals is also around the 60% mark, give or take 10%.
Organic micropollutants on the other hand such as polychlorinated biphenyls (PCBs) remain in the bed of the estuary for almost 90%.

Figure 10: Cadmium balance (in tonnes) of the Scheldt basin (Van Eck, 1991)



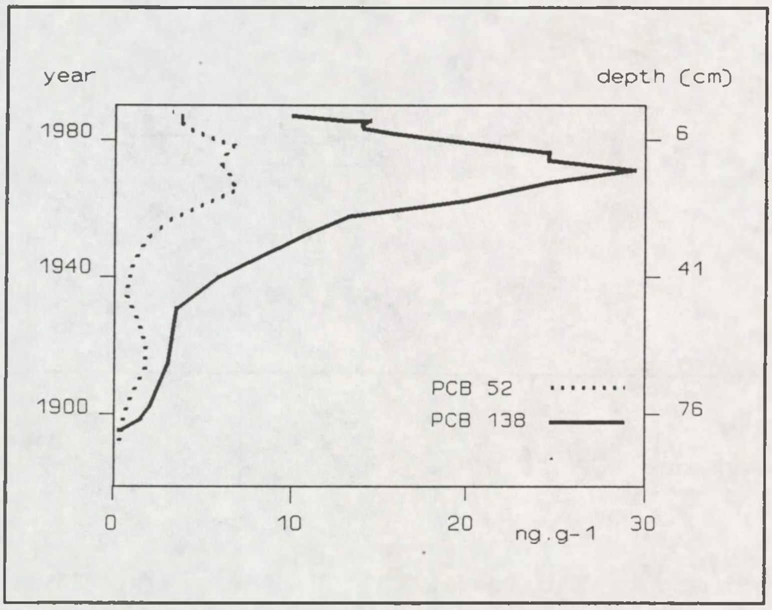
Sediment quality in these areas reflects discharge conditions in the past. The following table on figure 11 gives metal concentrations in bottom sediments of the Scheldt compared with other western European estuaries. The Scheldt has the highest concentrations of virtually all the heavy metals.

Figure 11: Micropollutants in sediments of European rivers.



Age determinations on sediments from areas as Saeftinghe illustrate the long history of contamination in the estuary. Metal concentrations were highest in the 1950s, and readings for most metals only fall in the 1980s. Concentrations of PCBs were three times higher in the 1960s than now as illustrated in figure 12.

Figure 12: PCBs in sediment-cores of estuarine sedimentation zones of the Western Scheldt (Van Eck, 1991).

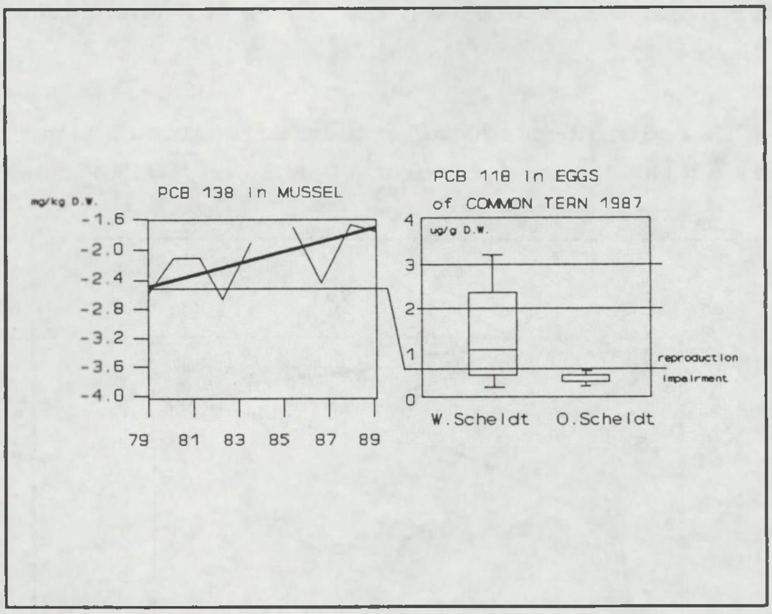


Concentrations in organisms

Organic toxic compounds accumulate readily in fat-rich tissues. PCBs have been found in mussels (PCB-138) and Common Tern eggs (PCB-118) at levels which suggest that their main predators will be reproductively impaired (Figure 13).

Concentrations in eggs from the Western Scheldt clearly exceed non-toxic levels; concentrations in eggs found on the Eastern Scheldt are shown on the right of figure 13 for comparison.

Figure 13: PCBs in mussels and in eggs of Common Tern in Western and Eastern Scheldt

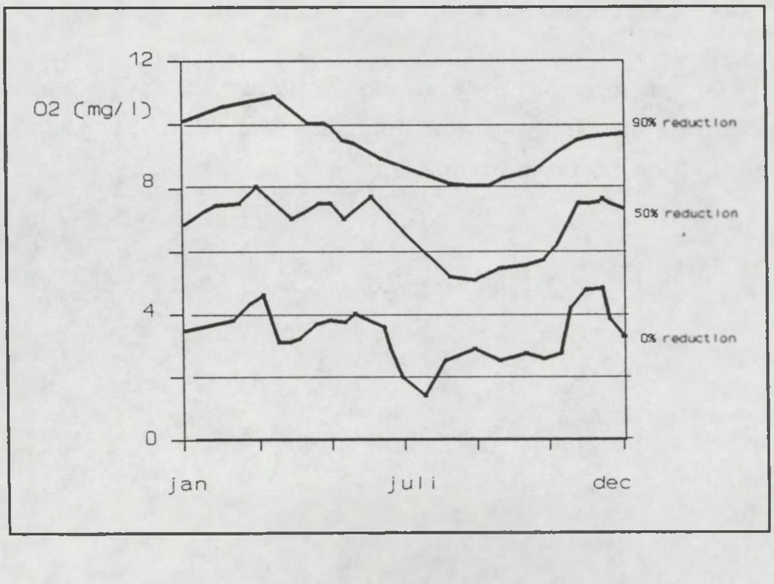


5 Desirable reductions

Oxygen

The water and sediment quality model called SAWES (System Analyses Western Scheldt) has been used to study different pollution reduction scenarios.

Figure 14: Development of oxygen on the Dutch/Belgium border at several reduction levels.



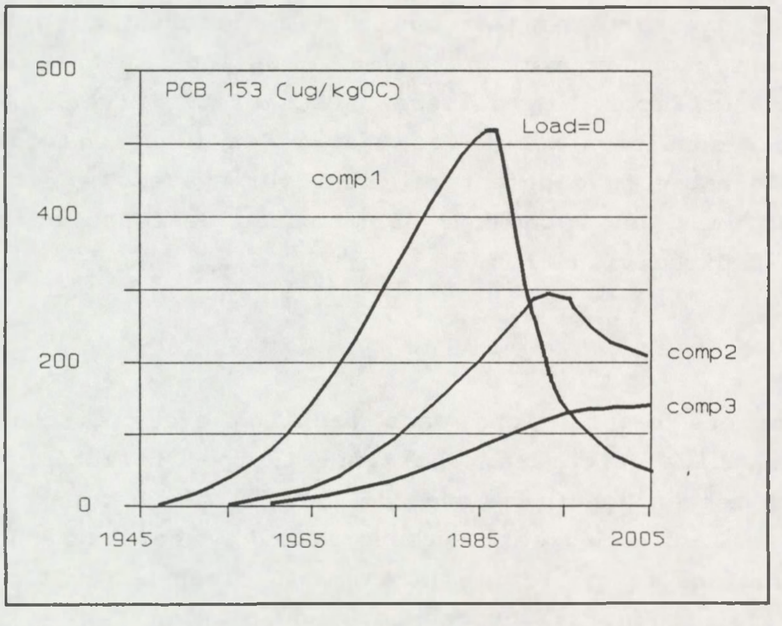
The model predicts that the remaining pollution load would have to be halved to achieve the minimum acceptable dissolved oxygen content of 5mg/l. A 90% reduction would be needed to reach oxygen saturation in the whole Scheldt basin (figure 14).

Micropollutants

Concentrations of pollutants in suspended solids and bottom sediments will gradually decrease once contaminant loads have been reduced. If waste discharges were to cease completely, it would be several decades before any change would be detectable.

The model SAWES has been used to predict the effects over the next 20 years of stopping PCB discharges in 1985. The diagram on figure 15 shows the results. As contaminated sediment is displaced downstream, downstream concentrations exceed upstream concentrations after a given time.
The model also predicts that the reduction target of 90 % is not enough to achieve in the short-term the maximum acceptable PCB and PAH contents. Reduction at source has to be combined with a clean up of the contaminated sediments.

Figure 15: Development of PCB 153 in the sedimentation zones of the Western Scheldt.



6 Current state of affairs

France, Belgium and the Netherlands are taking action to meet the reduction targets agreed at the Third Ministerial Conference on the North Sea.
The Netherlands and Flanders have since embodied this action in policy plans. At the national level, negotiations are continuing between Belgium and the Netherlands on a Water Convention. The main aim is to reach agreement on water quality in the Scheldt and Meuse where they cross the border.
In all the riparian states meanwhile - France, Belgium and the Netherlands - the conviction is growing that much more international cooperation will be needed in the short-term if the Scheldt is to be cleaned up.

7 Follow-up approach

An technical working party has recently been established to coordinate approaches among the five districts in the Scheldt catchment. Its main aim is to develop sustainable conditions in the basin, with all use of the river being subject to its ecological capacity.
The working party envisages the following approach.
First on the agenda is an inventory of current conditions in the whole Scheldt basin.
The next step is to agree a desirable condition, expressed as water quality targets. At the moment there are still differences in chemical standards used to define basic surface water quality in different riparian states.
In setting quality targets for the basin, a balance must be struck between the various demands imposed by different uses of the river.
An important pre-condition should be that river functions do not stand in the way of sustainable development of the river system.
The next step should be a package of measures designed to move from the current to the desired situation.

8 Recommendations

Of course, complete restoration means tackling every discharge at source throughout the entire catchment. The "end-of-pipe" pollution controls that predominate are not enough to remove all harmful discharges.
To achieve a realistic degree of restoration we have to think in combinations - reductions of pollution at source, clean-up of the contaminated sediments, cleaner industrial processes, and so on.
The cure has to embody a more integrated, preventive approach.
Long-term programmes of ecological improvement need to be developed, and these must involve engineers, ecologists and policy-makers.
And better international cooperation is essential, because water does not stop at frontiers. The Scheldt urgently needs an international authority - like the Rhine - with its powers backed up by governments.

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MANAGEMENT OF THE SCHELDT BASIN AS A FUNCTIONAL ENTITY

Part 3
In search for sustainable solutions against threats of the physical structure[1]

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Abstract

The physical structure of the Scheldt estuary has deteriorated badly as a result of man's many interventions. The development of a sustainable and ecologically sound estuary has been hampered by extensive reclamations in the past, resulting in a shortage of natural flood plains, and exacerbated by intensive dredging in the present. A sustainable management of the physical system includes a) a development of an integrated dredging-extraction-dumping strategy b) the restoration and creation of flood plain areas and c) selected measures to enlarge rare habitat type such as saline marsh-lands and freshwater tidal areas.

1 Introduction

The estuaries of large rivers originally harboured unique and highly productive ecosystems, from which many people traditionally could harvest without alternating the system too much. Today, however, most estuaries are threatened by an intensive use by man. In the year 2000 70% of the world population will live within 50 km from the coastline and be concentrated in coastal zones round river-mouths and estuaries. Its fertile soils are increasingly used for agriculture and have therefore been cut-off the estuarine system; the dense population, industrial development and agriculture cause water and sediment pollution; many estuaries are used as a shipping route, which needs to be safe and deep enough for the sea vessels with an ever increasing tonnage. In short, estuaries are threatened by both pollution and physical destruction. In the past decades water management in Western Europe has mainly

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concentrated on solving the problem of water pollution. As a result, the water-quality of several large rivers (e.g. the Rhine and Thames) has improved considerably since the early seventies. Untill present, the problem of physical destruction has deserved much less attention but is becoming a water management issue more and more.
Man started to build dykes and reclaim land, as soon as he was technically capable, to survive and feed himself. In the Scheldt estuary, land reclamation in super- and intertidal areas started in the middle ages. Notwithstanding the benefits, it meant a loss of unique habitats and the deminishing of several essential ecological functions of the estuary, like the reproduction of several (commercial) fish species and crustaceans. The influence of channel normalisation and deepening on the remaining estuary has thusfar been given less attention, since the effects are perhaps less conspicious on the short term. On the long term however, the consequences may be even more dramatical than the former, and involve also the safety of the surrounding regions against floodings. A proper analysis of this process and the magnitude of the effects requires some insight into the long term estuarine processes.

Most natural and man-induced processes cause a reduction of the estuary volume either by sedimentation of fluvial and/or marine sediments (natural processes) or by the direct or indirect effects of embanking, dredging and dumping of sediment and regulation (human activities). Only exceptionally happening catatrophal storm events might cause an enlargement of the estuary, but in fact, this process has been stopped in Western Europe for human safety purposes. Figure 1 illustrates that human activities tend to accelerate the rate of reduction of the estuary volume.

Figure 1. Schematic representation of the most common influences of natural processes and human activities on the estuary volume

In this paper the nature of physical threats in the Scheldt estuary is analyzed, to formulate sustainable solutions, and finally adress to the question whether or not an intensive use of estuaries by man can be combined with the conservation and restoration of the Scheldt estuary.

2 The Scheldt estuary

2.1 Physical characteristics

The Scheldt estuary is the downstream part of a rainfed river basin, which has a chatchment area of 20.000 km^2. The total freshwater discharge to the estuary amounts on average 120 $m^3.s^{-1}$ or 5 million m^3 per tidal cycle. The total amount of water, entering and leaving the estuary every tidal cycle -the tidal flood volume or tidal prism- amounts 1.1 billion m^3 at Vlissingen, 500 million m^3 at Hansweert, 200 million m^3 at Bath and 80 million m^3 at Antwerpen. Mean tidal range amounts 3.85 m at Vlissingen, 5.15 m at Antwerpen, and to 1.90m near Gent (Figure 1). Although the fresh water discharged by the river is only a fraction of the volume of the tide water, it is important for the characteristics and functioning as an estuary.

Mean chloride concentration decreases from 18 g/l in the North Sea to 11 g/l at Hansweert, 4 g/l at Antwerpen and < 0.5 g/l at Gent.

Figure 2. The position of the Scheldt estuary in Belgium and the Netherlands

2.2 Estuary evolution theory - to expand or contract?

The magnitude of the tidal prism is determined by the tidal range at the sea, the deformation of the tidal wave entering the estuary and the surface of the estuary. The tidal prism is a very important variable, which determines the long term development of the estuary -whether it expands or contracts (Figure 1). The volume available between the high and low water marks is defined as the tide storage.
The channels transport the water to and from the tide storage areas and their crossectional profile is a function of the amount of water transported. Any change in the upstream tidal volume will result in an adaptation of the crossectional surface of the channel.
An increase in the tide storage surface area, when a dyke is breached for example, increases the flood tide volume. Since more water now flows in and out of the estuary every tide, flow channels become broader and deeper. Reducing the tide storage by, say, reclaiming salt pastures, leads to a reduction of the tidal prism, and the channels become narrower. An estuary, which becomes drier also shows an increase in tidal asymmetry, the phenomenon whereby flow rates are higher on flood tides than on ebb tides. If other processes are at work in the same direction the result can be a significant landward transport of sediment. In this way the silting process becomes self-reinforcing.

2.3 History and human interventions

The Scheldt set into its present course through the Western Scheldt at the end of the middle ages. From then until the seventeenth century, tide storage volume continued to expand, helped indirectly by man's activities. Floods became more frequent, caused partly by draining of polders and the cutting of peat, and partly by a rise in sea level. From the 17^{th} century tide storage surface area began to decrease, a trend which has continued to the present day. Land reclamations and embankments have conquered the flood. But poldering the shallows has also deprived the Western Scheldt of some 35% of its surface since 1800 (Figure 3).

Figure 3. The surface of flood plain areas in the Western Scheldt from 1800 to 1980

According to the available data, these extensive reclamations, preceded by sedimentation in these areas of about 100 million m^3 beweeen 1880 and 1950, did not result in an immediate reduction of the tidal channels, as might be expected from the theory. However, between 1930 and 1970, while land reclamations were still going on, a strong import of sand from the sea into the estuary was observed.

A very far-reaching milestone in the sequence of human interventions was the deepening of the main channel in the early seventies. The bars between the consequtive bends, which formed the bottle-necks for navigation, were from then on maintained on a greater depth. As a consequence the entire channel deepens. This process, which is still going on with decreasing celerity, will come to an end in the next decade, when the remaining sections of the main channel are adjusted to the greater depths of the bars.
In the eastern section the volume of the main channel increased up till now with some 50 million m^3, an average rate of 2.7 million m^3 per year. The dredging amounts, however, raised from 5 million m^3 per year before the deepening to 10 million m^3 per year. The difference shows the efficiency of the dredging and dumping strategy. The dredged sediments are mainly disposed within the eastern section and return to the dredging sites rapidly. The celerity of deepening of the entire main channel depends on the rate of extraction, from the active system in the eastern section, of the sediments that are liberated by the deepening process. This extraction takes place by the net result of dumping in the middle section, by sand mining from the eastern section and by sedimentation above MLW-level within the eastern section. Figure 4 illustrates the process of "sediment cycling".

Figure 4. Estuary volume changes and sediment fluxes over the period 1975-1990 in the Western Scheldt. Note, that the amounts extracted equal or exceed the natural fluxes.

The deepening and dumping strategy meant the following for the physical processes in the estuary:
- a definite fixing of the main channel was reached, which means a definite fixing of the natural macrodynamics of the estuary in the eastern section,
- the sand import of the estuary came to an end,
- sedimentation and microdynamics (=rate of sediment movement) increased in the intertidal zones like 'Saeftinge',
- the tidal wave penetration in the estuary increased, and raised among others the water levels in Antwerpen.
- the amount of valuable ecological areas decreased by raising of shoals, steepening of shoal-channel transitions and lateral erosion of mudflats.

3 Analysis of the present functioning

Judging the physical state of a watersystem may be more complicated than the chemical state. Chemical pollution is unnatural and generally accepted as undesirable. The natural physical state of the Scheldt estuary is less easily described, and deviations are less obvious for the society and therefore not always recognized as a problem.
Here, we consider the present functions of the estuary and its relation to human activities with emphasis on the physical system.

3.1 The nature function.

3.1.1. *Habitat diversity*

A sound estuarine ecosystem contains a variety of habitats in natural proportions along the gradient from fresh to saline water and from occasionally inundated wetlands and intertidal mud- and sandflats to the channel. Table 1 shows that there is an underrepresentation of freshwater- and saline wetlands, and an overrepresentation of highly dynamic sand flats. These latter flats harbour very low biomasses of benthic invertebrates, a food source for waders.

Table 1. Occurrence of habitat structures in the Scheldt Estuary

	wetlands	mud flats	sand flats		shallow water	
			H	L	H	L
Marine zone Vlissingen - Hansweert	-	0	0	0	0	-
Brackish water zone Hansweert - Antwerpen	+	0	+	-	+	-
Freshwater zone Antwerpen - Gent	-	-	-	-	?	-

H: Highly dynamic; L: Low dynamic

The brackish tidal area 'Saeftinge' is filling up rapidly. Tidal prism decreased from 68 million m^3 in 1880 to 8 million m^3 in 1990 (Figure 5). This process of filling up is natural (see Figure 1) but should slow down as the tidal prism approaches zero. The elevated sedimentation rate is attributed to the dumping of dredged sediments from the channel right at the entrance of the area.

Figure 5. The tidal prism (volume between mean high and low water level) of the brackish water tidal area "Verdronken land van Saeftinge" between 1880 and 1990. The dashed line represents the expected flattening of the path when only natural processes would be involved

3.1.2 *Function for birds*

The number of birds is an important parameter, determining the importance of an area as an international wetland. During the last years 20 species exceeded the 1% standard according to the Ramsar Convention (REF), which means that more than 1% of the West European population of these species was frequently observed in the Western Scheldt. The relative importance of the Scheldt estuary for migratory waders has increased after the completion of the Delta works, as a result of which large intertidal areas have disappeared. The numbers of waders in the intertidal areas of the brackish water zone is much lower than could be expected considering the surface. This is probably attributable to the low biomasses of the macrozoobenthos (Ysebaert et al. 1991).

3.1.3 *Nursery function*

Estuaries are of vital importance for the reproduction and growth of many marine animals. The vitality of the North sea ecosystem is closely linked to that of the surrounding estuaries. In the past many migratory fish species, such as Sturgeon (Acipenser sturio), Salmon (Salmo salar), Shad (Alosa) and Twaite (A. finta), used the Scheldt to reproduce and/or grow up. The decrease in catches of migratory fish and shrimps already took place in the first part of this century because of water pollution and land reclamations in tidal areas (shrimps); spawning areas of the migratory fish species in the upstream part of the rivers became unreachable because of the construction of of barriers and dykes. Today, the nursery function for migratory fish is nearly lost. However, small specimens of Twaite shad are still caught in the brackish water zone. Soles (Solea solea) and shrimps still use the estuary to grow up and their numbers are remarkably stable over the last decades.

3.2 Navigation

The Scheldt estuary forms the entrance to the harbours of Antwerpen, where in 1987 more than 91 million tons was treated with a total added economic value of more than 4 billion US dollars. The harbour requires a sufficiently deep navigation channel to assure the entrance of most types of sea vessels. To this end, the minimum channel depth has been increased from 11.8 m - N.A.P. (= reference level in the Netherlands) in 1970 to 14.5 m -N.A.P. in 1989 (Pieters et al, 1991). Continuous dredging is necessary to maintain the channel depth. In the period 1975-1989 about 10 million m^3 was annually dredged in the Eastern part of the Western Scheldt, with an average annual expense ranging between 25 and 50 million US dollars. A further deepening of the channel with about 1.5 m, which is currently discussed, is of vital economic importance for the harbour. However, dredging amounts and maintainance costs will increase enormously, if the present dredge and storage strategy is maintained. At present, the dredged sediment is stored in eroding outside bends and in side channels. Comparison of depth profiles has learnt that a considerable part of this sediment disappears from the dumping sites and soon sedimentates again on the bars. The disposal sites in the eastern section, used up till now, are almostly filled up. New disposal sites or other ways of depth maintainance should be found.

3.3 Human safety

The inhabitants of the Scheldt basin wish to live with an acceptable risk of inundations. As a consequence of the channel deepening and land reclamations downstream, however, high water levels have increased in Antwerpen with 1.3 m since 1790 and with 0.5 m in the last century. The storage capacity to cope with extreme high waters has decreased as well. At present the so called 'Sigma plan' is executed in Belgium to diminish the risks of inundations. It includes an elevation and fortification of the dykes and the creation of controlled flooding areas, that are flooded only during extreme high water levels. A further deepening of the Western Scheldt will cause a further increase in water levels and so in safety risks in the Scheldt estuary.

4 Outline solutions

It is necessary, possible and fruitful to consider different aspects of the estuary and any plans for it in relation to each other. The following long term solutions would considerably contribute to safequard and even enrich the ecological diversity, and simultaneously quarantee that the necessary human functions will be fulfilled.

4.1 Increase of flood plain areas

The creation of new flood plains has several advantages:
- tidal volume and current velocities will increase, because of which the amount of sediment to be dredged will decrease,
- both normal and extreme high water levels will be lowered, which increases the safety of the inhabitants. Under normal circumstances 450 additional hectares of tidal storage area between Antwerpen and the mouth of the river Rupel would lower the high water levels in this Scheldt section with about 25 cm (Figure 6),

Figure 6. The influence of the creation of additional tidal storage areas near Antwerpen on mean high water levels in the Scheldt estuary.

- ecologically very valuable areas are created. The creation of floodplains is most useful in the brackish and freshwater zone and freshwater tidal areas have become a unique habitat type,
- the silt concentrations in the water and sedimentation rates of the present floodplains (like Saeftinge) will decrease,

There are very good possibilities for flood plain restoration in the fresh water zone. The selected controlled flooding areas could be joint with the estuary permanently in stead of temporarily.

4.2 Adaptation of dredging and dumping strategy

Sediments should, once removed from the bars, be dumped at locations, from where they are not easily transported back to the bars. Dumping in the Western part of the Western Scheldt would at least extend the transport route and so diminish the amount to be dredged. Removal of the 'liberated' sand from the present and possible future deepening by selective and controlled sand extraction will also contribute to this. When care is taken that a minor surplus is created and maintained in the Western part, the sand extractions in the Eastern part will not lead to a significant sand import from the North Sea, and the sandy sea defences in the mouth area (dunes) will not be threatened.

4.3 Restoration of endangered habitat types

Table 1 shows that in the marine zone, the saline marsh lands are underrepresented. Old land reclamation methods, that use willow shoot dams are presently under study. These could be used on a small scale to speed up locally the sedimentation process. The saline marsh lands cannot be built by directly dumping dredged sediments, but the dumping strategy can certainly be adjusted to stimulate accretion of salt marshes. In the brackish zone the low dynamical flats and shallow waters are scarce. An adaptation of the dredging-dumping strategy and selective and controlled sand extractions are adequate means to change highly dynamical areas into lower dynamical ones.

5 Conclusions

The present analysis has demonstrated, that long term estuarine processes are a fruitful starting point, in order to formulate sustainable solutions for physical threats.

The present management of the physical system is far from optimal and can be improved considerably by a) developing an integrated dredging-extraction-dumping strategy b) the restoration and creation of flood plain areas and c) selected measures to enlarge rare habitat type such as saline and freshwater marsh-lands d) improving the physical boundary conditions of existing habitats (lowering the dynamics of the shallow water habitats).

Water authorities should develop an integrated sediment management program, in order to put the sustainable solutions into practice.

A thourough knowledge of the physical system and collaboration between the parties involved are necessary to succeed in a sustainable management of the Scheldt estuary.

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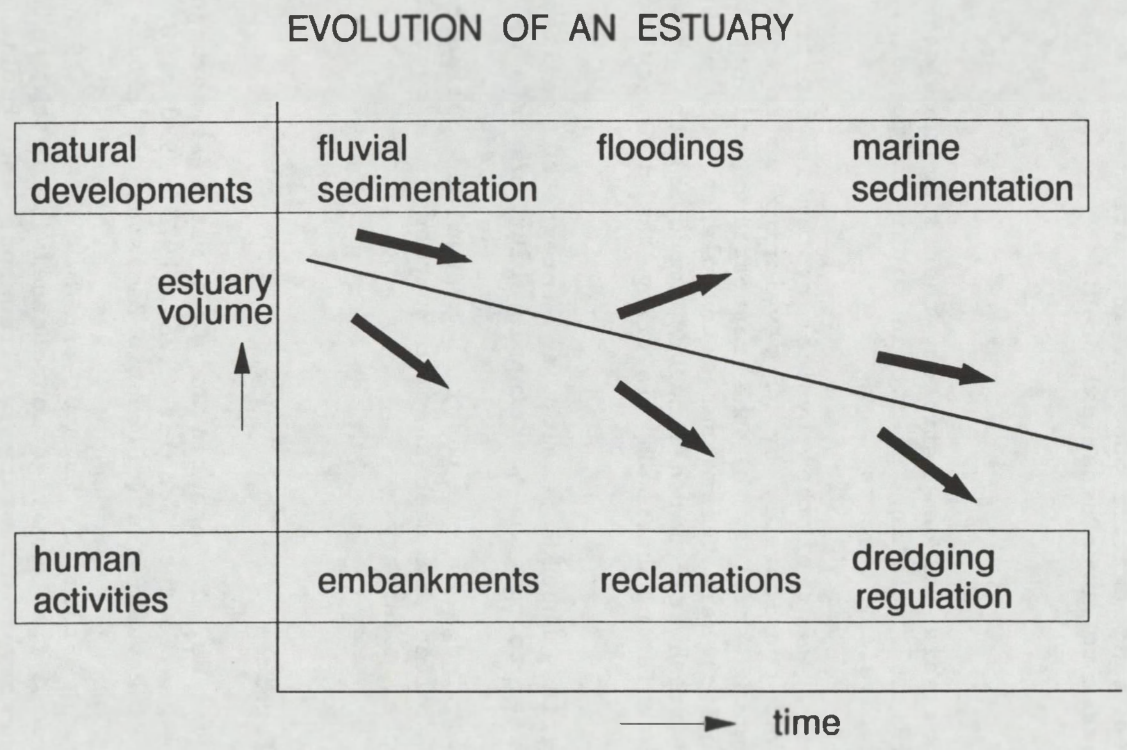

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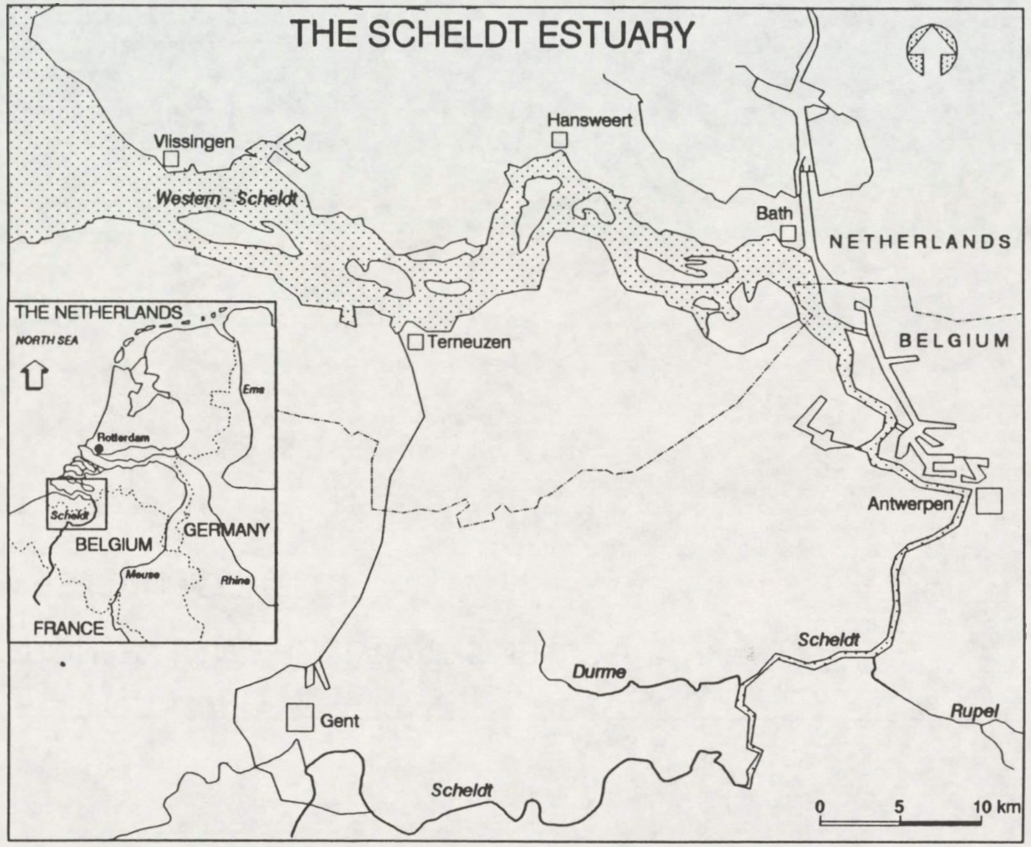

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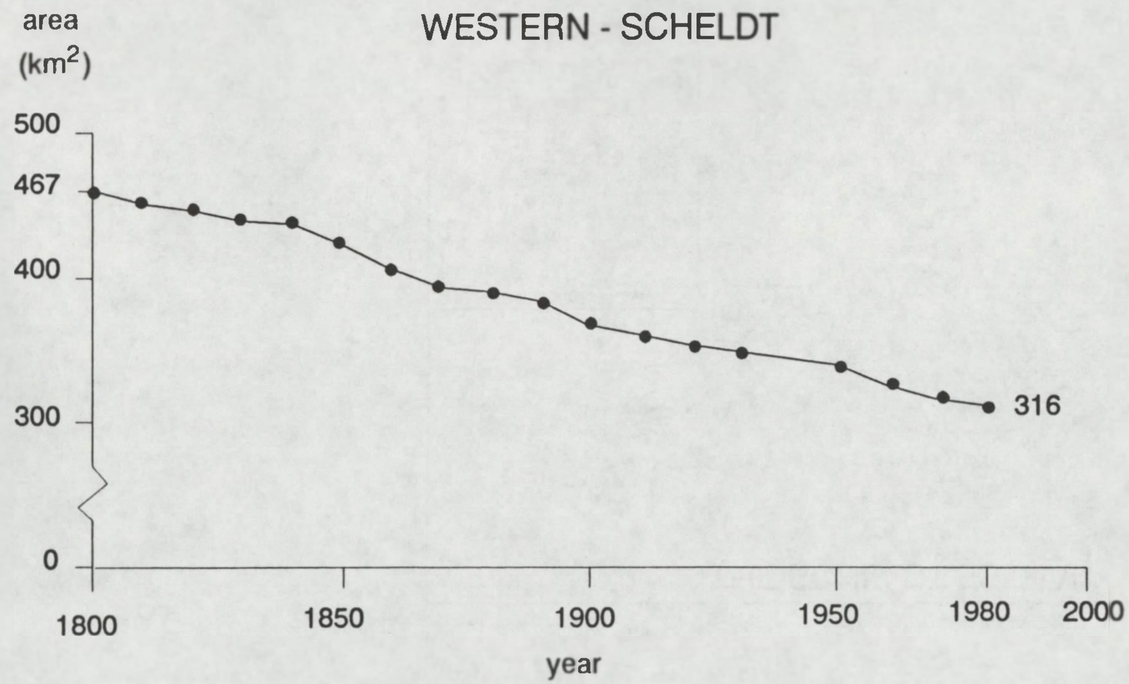
AREA REDUCTION BY LAND RECLAMATIONS

WESTERN - SCHELDT



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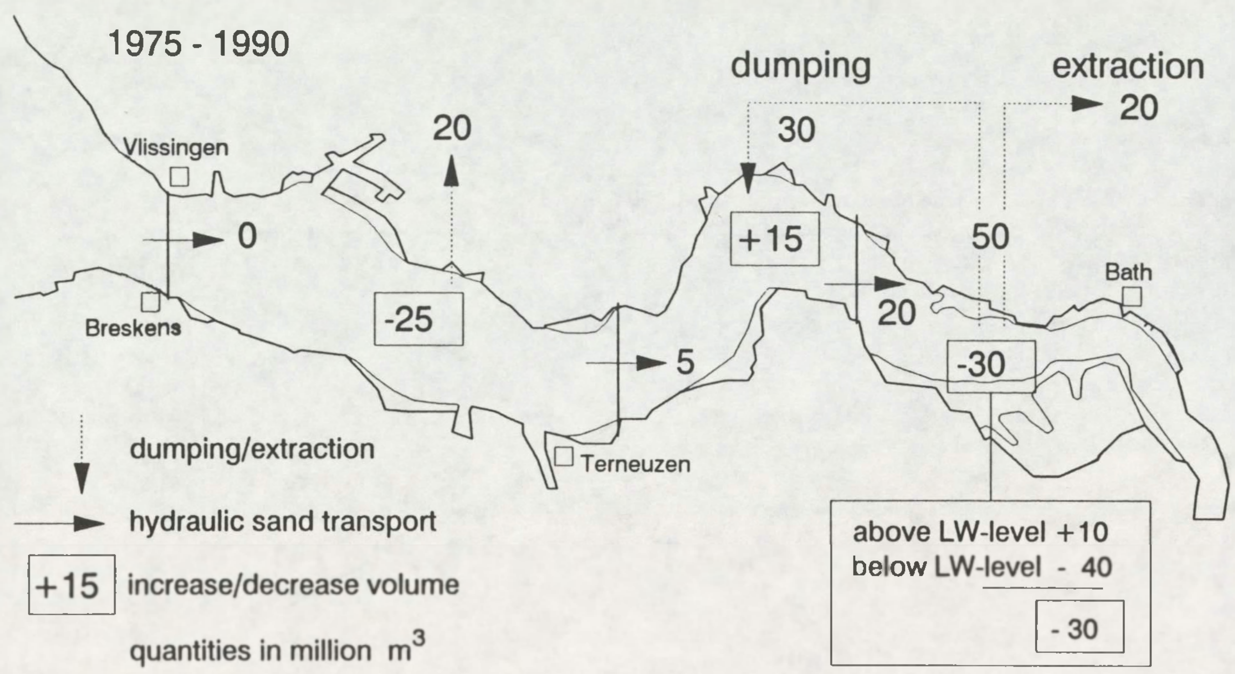

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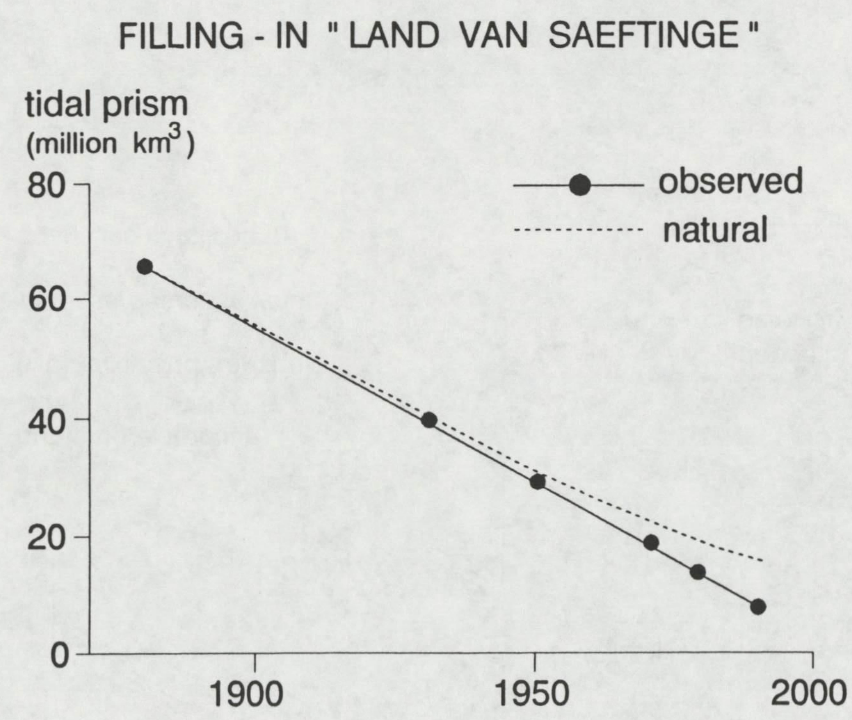
Figure 4



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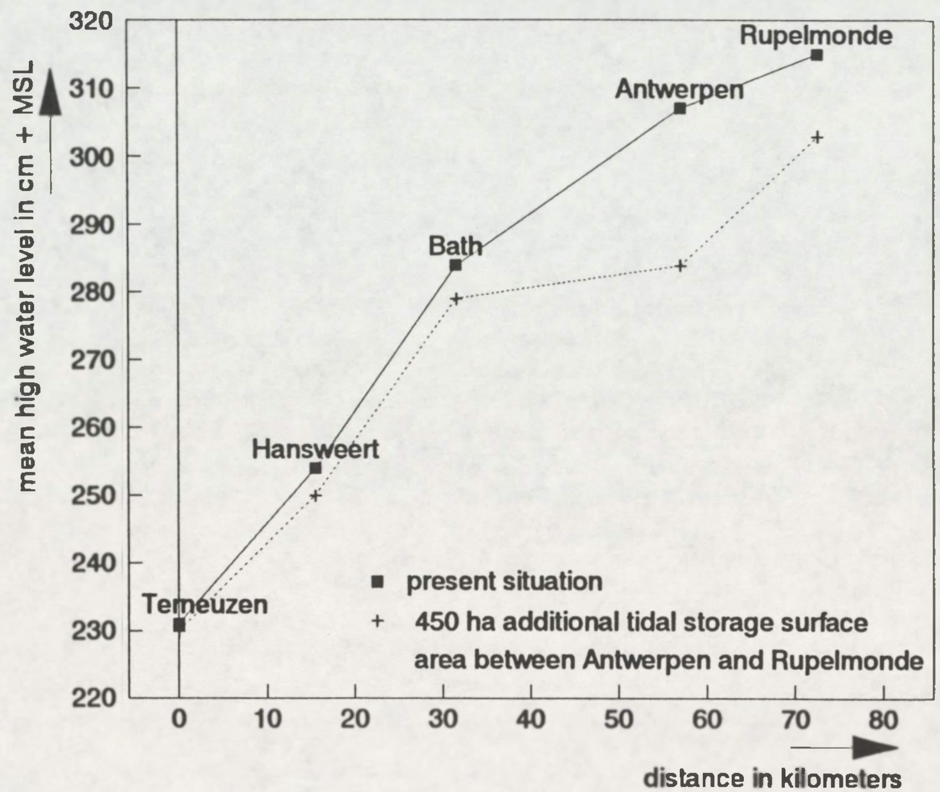

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