

Flood Risk Analysis for the River Scheldt Estuary

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SUMMARY

This report gives an overview of the history of flood risk management along the Scheldt estuary. The purpose of this overview is twofold. It documents the results obtained in the first activity of the Task 25 Pilot, being focused on flood risk analysis, both in historical perspective and with regard to current policies. Secondly, it provides an introduction to the Scheldt estuary for other partners in the FLOODsite project which will use the Scheldt Pilot for their own tasks and activities.

The Scheldt estuary is a clear example where integrated water management is required. Integrated means in this case: meeting the objectives for 3 major basic functions and values of the estuary: safety, accessibility (navigation) and ecology. Recently finalised and ongoing projects, such as *Proses* and the SIGMA plan show a highly multidisciplinary approach in order to fulfil these objectives.

From the perspective of flood risk management we see a significant difference in approach between Belgium and the Netherlands. The Belgian New Sigma Plan has used an approach that is strikingly similar to the FLOODsite methodology, i.e. going through the three phases Risk Analysis, Risk Assessment and Flood Management Strategy formulation. In contrast, the Dutch flood risk management was developed over a long historical period, with the Delta Plan as the final apotheosis. In the time the Delta Plan was formulated, there was hardly any attention and technology available to determine flood probability and flood damage.

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1. Introduction

1.1 This Report

This report gives an overview of the history of flood risk management along the Scheldt estuary. The purpose of this overview is twofold. It documents the results obtained in the first activity of the Task 25 Pilot, being focused on flood risk analysis, both in historical perspective and with regard to current policies. Secondly, it provides an introduction to the Scheldt estuary for other partners in the FLOODsite project which will use the Scheldt Pilot for their own tasks and activities.

By its nature the FLOODsite project does not entail the execution of a complete risk analysis for the Scheldt area. Instead, past and existing flood risk studies are being reviewed and evaluated against modern theoretical concepts and insights. As many different flood management measures are already identified by others, the innovation aspect of the pilot itself does not emerge from designing new ones, but from contributing to the evaluation of the alternative measures, both from a technical and a social perspective. In addition comparison of approaches between the two riparian countries could lead to interesting observations.

This report concludes the first activity of the Pilot Scheldt. It identifies the critical issues regarding flood risk in the region and as such provides the necessary background information for the next two activities, namely the evaluation of flood management options for the Scheldt and the study of transition management needed for implementation of preferred options.

1.2 Short introduction to the river Scheldt estuary and its surroundings

The trans-national Scheldt estuary (Figure 1) extends from the upper reaches near Gent in Belgium to the lower reaches and the mouth at Flushing in The Netherlands. In its Dutch part, called “Westerschelde”, the estuary is a meandering multiple channel system, with intertidal islands and intertidal areas at the inner side of channel bends. In its Belgian part, called “Zeeschelde”, the estuary is a single meandering channel, with intertidal areas at the inner part of bends, but without intertidal islands. The upper parts of the intertidal areas along the shores of the estuary host fauna and flora-rich salt marshes. The lower intertidal areas are important feeding grounds for birds and resting areas for the increasing population of seals.

The estuary is of economic importance as a major shipping artery, hosting the harbour of Antwerp, as well as providing an access route to the harbour of Rotterdam via the Rhine-Scheldt canal. The total population of the Schelde catchment numbers over 10 million (ICBS). The study area includes a total population of around 300,000 people in the Netherlands and less than 1 million people in Belgium (Zeeschelde area). This includes the city of Antwerp with a population of around 450,000 (2003).

A disastrous flood occurred in the region in 1953 and cost the life to more than 1800 persons. This disaster gave birth to the Dutch Delta Project. By strengthening and raising the dykes, by closing some tidal inlets and by constructing the storm surge barriers at the opening of the Eastern Scheldt (1986) and in the Nieuwe Waterweg (1997), the Delta works assured safety from floods to the inhabitants of Delta Region. In the Belgian part its counterpart, the Sigma Plan was initiated after a flood in 1976 (Chapter 2).

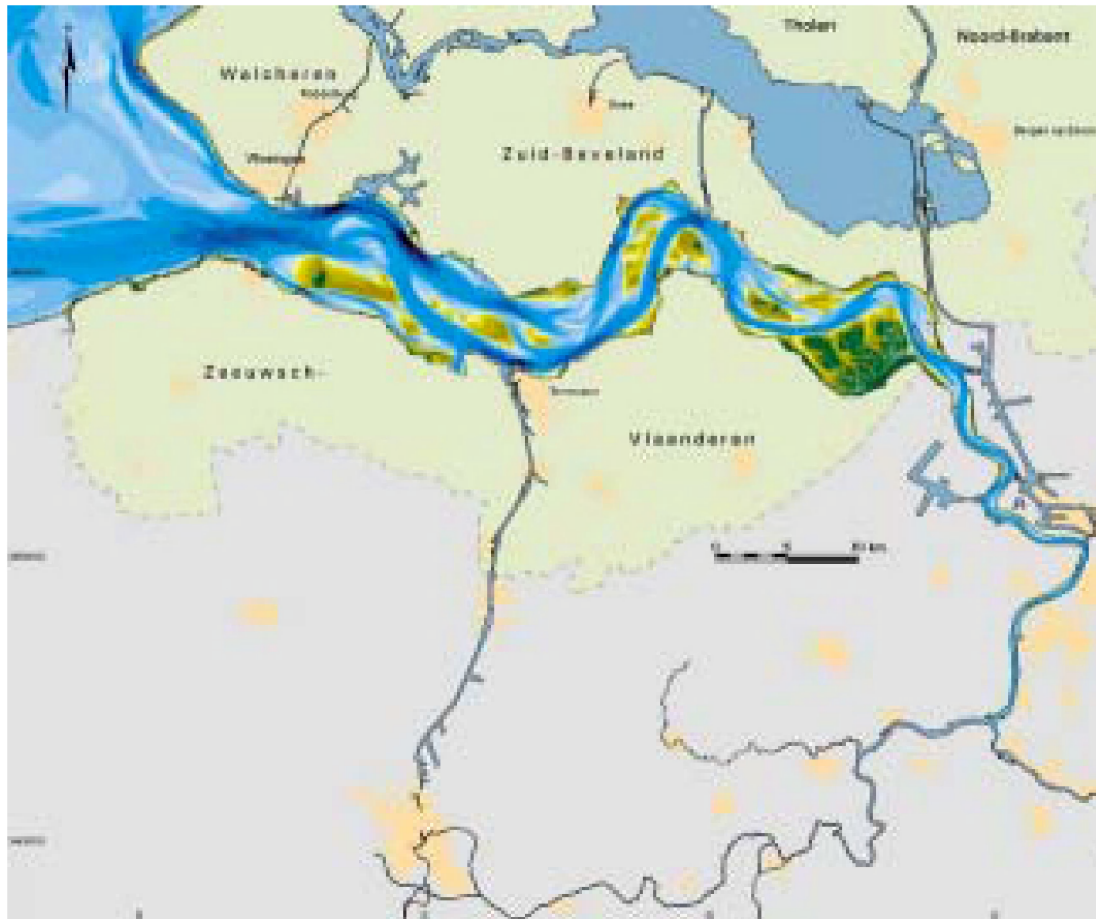


Figure 1: The Scheldt estuary (from <http://www.scheldenet.nl>).

In recent years much discussion and studies have been going on both in the Netherlands and in Belgium with respect to the perceived risk of flooding, especially in view of the changing external conditions (such as sea level rise) and increasing assets under threat (expansion of urban and industrial areas for instance). The tragic events in New Orleans have made this discussion even more important: people are asking whether or not this could happen here too. Both the Dutch and Belgian governments have been working on an improved understanding of the risk through a number of studies. In Zeeuws Vlaanderen a pilot study was undertaken under the VNK (Veiligheid Nederland in Kaart) project of Rijkswaterstaat. And in Belgium the updated *Sigmaplan* has just been ratified by the Parliament. Simultaneously, the *Proses* –project is studying the opportunities and consequences of increased navigability of the Westerschelde, with due attention for the safety and nature compensation aspects. Options such as managed dyke realignment are being currently discussed as a potential flood risk management measure in Belgium and could be explored for the Dutch part of the estuary as well (see Chapter 3).

2. Historical overview of the Scheldt estuary

2.1 Changes in the morphological character

The Eastern Scheldt used to be the main mouth of the river Scheldt until the Middle Ages. In the 14th century it lost this function to the Honte (Figure 2), a tidal channel which formed a vast marsh area since the early Middle Ages. The Honte became connected to the Scheldt river north of Antwerp and evolved into the current river mouth.

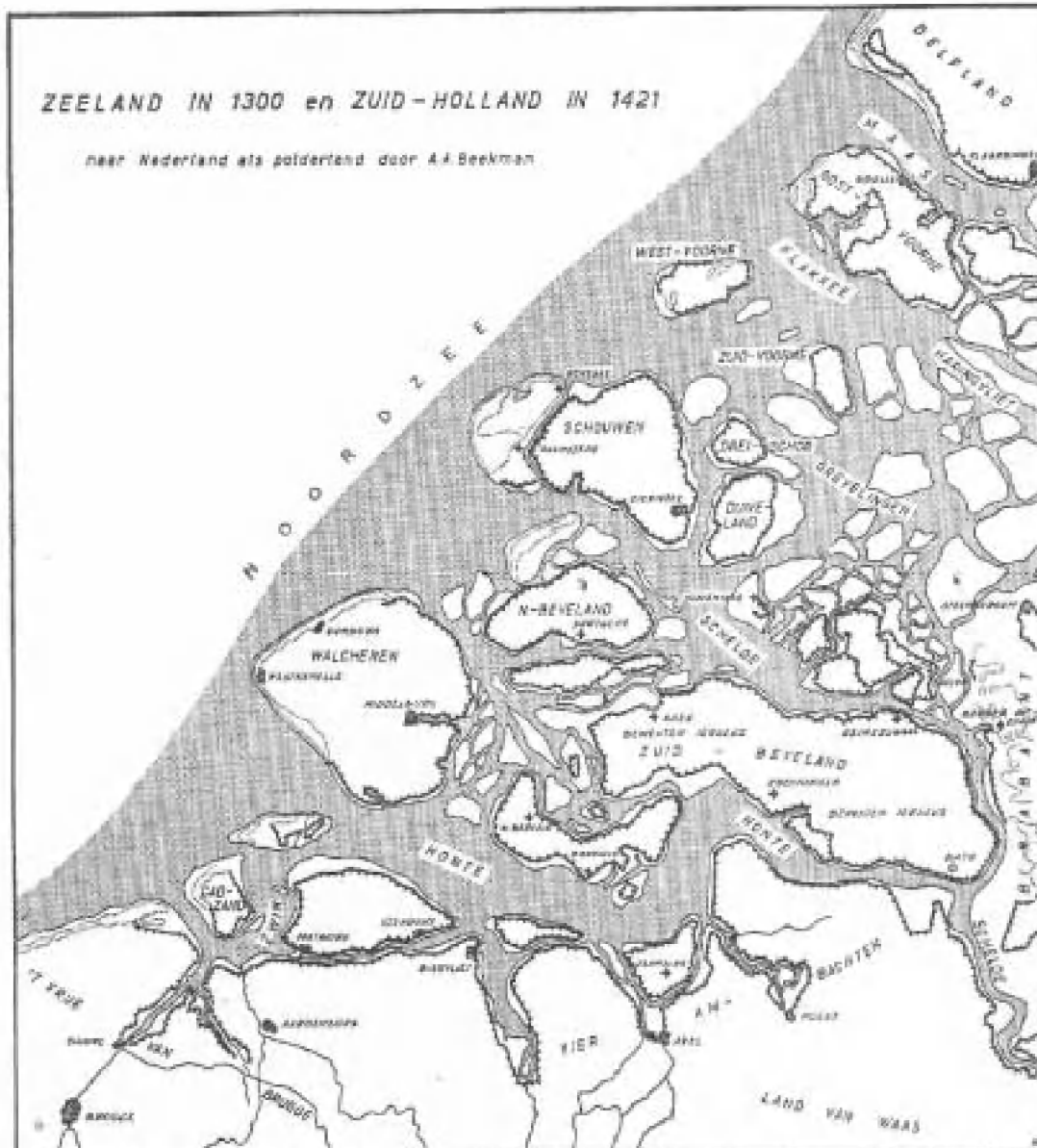


Figure 2: Zeeland in 1300 and South-Holland in 1421 (Verburg, 1955).

In the 17th century the Scheldt estuary was highly branched with extensive intertidal flats and marsh areas having large storage capacity. Since then the system gradually developed into the funnel-shaped estuary of the present days. In the 17th century the Western Scheldt was connected to the Eastern Scheldt by the channels Sloe and Kreekrak. This was basically a very extensive intertidal area on the other side of the Verdrongen Land of Saeftinghe. The latter is the only vast salt marsh area which has remained at the present times. In 1867 the closing of the Kreekrak channel definitely separated the

Easter Scheldt from the river Scheldt and in 1969 the Volkerakdam deprived the Eastern Scheldt also of the fresh water from the Rhine. At present the input of fresh water is negligible, the eastern Scheldt has become a tidal basin.

Both morphology and tidal characteristics have changed with time (van der Spek, 1994). Coen (1988) reconstructed the tidal ranges and the propagation of high water along the estuary from nautical almanacs. He discovered that near Antwerp the tidal range increased considerably: from about 3.2 meters in 1650 to 5.2 meters in present days. The celerity (speed) of the tidal wave also increased: in 1650, the distance Flushing-Antwerp was covered by the wave crest in about 4.5 hours, at present it is covered in about 2 hours. The extensive storage areas present in the 17th century delayed the tidal wave. Another factor which has influenced the changing of the estuary characteristics is the rise of the sea level. Since 1650 the mean sea level has become 0.5-1.0 m higher and it continues to rise.

The present Scheldt catchment has an area of 21,860 km² and has a quite gentle topography. The river Scheldt has its source at an altitude of only about 100 metres above the present sea level. Gates in Gentbrugge, at some 160 km upstream of Vlissingen halt the propagation of the tide. The freshwater drained from the catchment only partly enters the tidal reach, the rest is diverted through canals directly to the sea and to Terneuzen, situated close to the mouth. Gravity flow in the river is significant only down to the confluence of the Rupel, at about 90 Km from Vlissingen (Peters et al., 2000)

2.2 A history of floods

2.2.1 Early floods

In the past ages the Dutch coast has been hit by many storms. A brief account of the most severe storm surges and flooding shows that the Province of Zeeland was most of the time included in the list¹, which made it one of the most vulnerable places to live.

<i>26 December 838:</i>	The oldest trustworthiness account of a large storm surge along the Dutch coast is that of a French Bishop who recorded that almost the entire region of 'Frisia', i.e. the dutch coastal area, was inundated.
<i>19 November 1404:</i>	First Sint Elisabethsflood. Large parts of Vlaanderen and Zeeland were inundated.
<i>18 November 1420:</i>	Second Sint Elisabethsflood in Holland, Zeeland and Vlaanderen. Formation of the Biesbosch in the southern part of Holland (tidal marshes).
<i>5 November 1530:</i>	'Sint Felix Quade Saterdach'. Severe storm surge. The islands of Noord-Beveland and Sint Philipsland disappear.
<i>1 November 1570:</i>	Allerheiligenvloed (All Saints Flood) Notorious storm surge that wreaked havoc on all islands of Zeeland.
<i>31 July and 4 August 1574:</i>	Storm surge. Breaking of the Schielandse high sea dike on 16 locations..
<i>26 January 1682:</i>	Spring tide concurring with a northwester storm. In Zeeland 161 polders were flooded. The first storm surge for which many data is available.
<i>15 January 1808:</i>	Storm surge in Zeeland and Vlaanderen. This triggered a large scale dike enforcement and heightening.
<i>12 March 1906:</i>	Storm surge. In Zeeland 25 polders were inundated. Again a large scale dike heightening followed.
<i>1 February 1953:</i>	Flooding disaster. This triggered the Delta works.

¹ Source: www.ZeeuwsArchief.nl

2.2.2 The 1953 disaster

In 1953 a violent storm breached the dykes in many places in Zeeland and in Vlaanderen and caused a disastrous flooding (Figure 3). The number of casualties was more than 1800. Approximately 72,000 inhabitants from the area had to be evacuated for a long period of time. More than 47,000 head of cattle and 140,000 poultry drowned. Three thousand houses and 300 farms were destroyed and more than 40,000 houses and 3000 farms were damaged. Almost 200,000 hectares of land were inundated. The total material damage is estimated to have been 1 ½ billion Dutch guilders. (eq. 3.1 billion € taken into account the inflation rate over 50 years).



Figure 3: Overview of inundated areas after the 1953 storm surge

In total around 100 breaches were counted after the storm. The lower and less well-maintained dikes on the south side of the polders were the first to go. At Stavenisse (Tholen), the force of the waves gouged out an 1800 m wide breach. And even in Noord-Brabant, near Willemstad, Heijningen and Fijnaart, the dikes could not withstand the storm. It was the same story in the Hoekse Waard of Zuid-Holland at 's-Gravendeel, Strijen and Numansdorp.

Most of Schouwen-Duiveland was flooded. Only the dunes at the head of Schouwen and a few polders near Zonnemaire stayed dry. Except for the land on the lee side of the dunes and a few polders near Melissant and Dirksland, the whole of Goeree-Overflakkee was covered with water. Houses collapsed and were destroyed by the current. The rising waters even caused the total destruction of some small villages. The hamlets of Schuring near Numansdorp and Capelle near Ouwerkerk were obliterated by the water. Not a single house was left standing. Other places were more fortunate. At Colijnsplaat, where men had been trying for some time to keep the flashboards from breaking, a barge suddenly broke loose from its moorings, ended up in front of the cut and worked as a breakwater, sparing the town.

Most of the flood defence structures (dykes) that failed were just too low for the water level and waves at the time (figure 4). The overtopping of the water caused first of all damage to the inner slope of the dyke. Sliding and erosion of the inner slope subsequently led to a complete breach of the dyke.



Figure 4 Dike breach during 1953 disaster

2.2.3 Flooding along the Westerschelde estuary in 1953.

With the mathematical model Delft1D2D the 1953 flood event has been simulated, using the same breaches as actually occurred and the observed water levels (Asselman, 1003). Around 20 % of the total area of Zuid Beveland has been inundated, i.e. 7500 ha. (Rijkswaterstaat & KNMI, 1961). Nearly all breaches occurred along the southern sea dike (bordering the Westerschelde) (see figure 5).

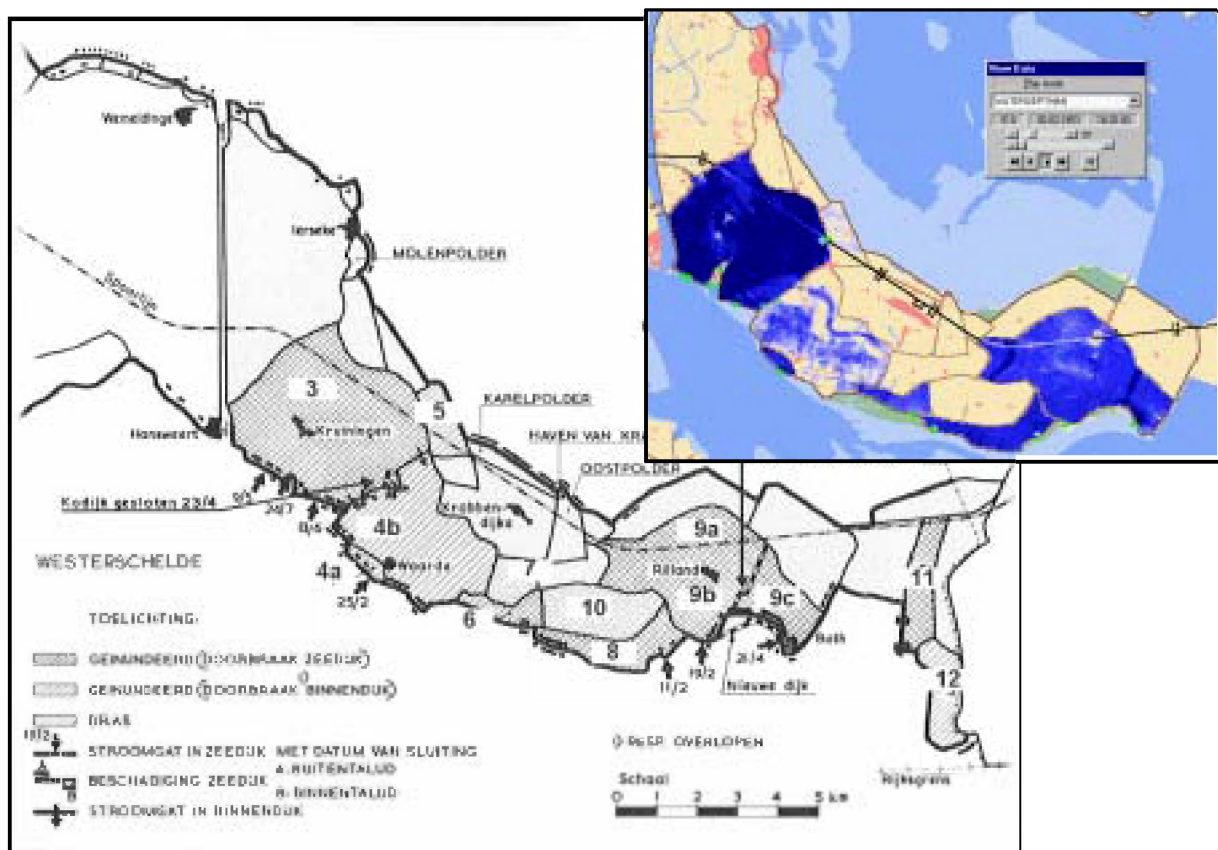
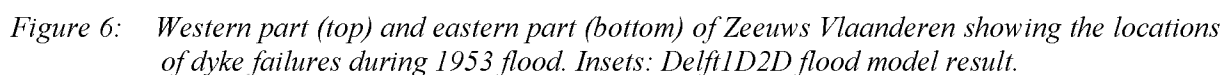


Figure 5: Eastern Zuid-Beveland showing the locations of dike failures during 1953 flood. Inset: Delft1D2D flood model result.

The total area that was inundated in Zeeuws Vlaanderen was around 2880 ha and was least hit compared to other parts of the Delta. Figure 6 shows the locations of dike breaches.



Due to a northwestern storm water was pushed into the Scheldt river leading to dike breaches at several locations along the river. More than 800 ha of the Zeeschelde corridor were inundated. In Antwerp a water level of 7,31 TAW² was recorded. Especially the municipality of Ruisbroek was heavily affected (900 houses under water). This prompted the Flemish government to adopt the Sigma-plan (see section 3.2.2).

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3. Present situation on flood risk management

3.1 Present safety levels in the Netherlands and Flanders

3.1.1 Safety against flood in the Dutch Delta area

After the 1953 storm the Dutch Government decided to undertake a major new flood management strategy. A special Commission (the Delta Commission) started its work and in 1960 they presented the so-called Deltaplan. Next to proposals for extensive protection works they suggested another safety approach. The protection level was not any longer defined as the highest flood level plus 1 meter, but as design water levels based on recurrence times. The Commission also recognised that flood risk was the right basis for a proper determination of the safety level, but at that time they were lacking information and the methodology to determine the flooding probability and the flooding damage. Where possible they carried out an economic optimisation for damage and investments in flood protection for the most important dike ring in the Netherlands: Central Holland. They indicated a safety level based on design water levels for this dike ring with a recurrence period of 10,000 years. Based on the ideas of the Delta Commission the safety levels for all dike rings in the Netherlands were determined (Parment, 2003). As can be seen in Figure 7 the Delta area has a safety standard of 1:4,000 per year.



Figure 7: Dike rings and their protection level in the Netherlands

The Deltaplan arranged for all tidal inlets to be closed by dams with the exception of the Westerschelde and of the Nieuwe Waterweg (being the navigation routes to the harbours of Antwerp and Rotterdam, respectively). The safety of the land had to be assured by proper dykes. Following the Delta Project the Haringvliet and the Grevelingen tidal basins were transformed into lakes with the construction of several dams: the Grevelingendam (1964), the Volkerakdam (1969), the Haringvlietdam (1970), the Brouwersdam (1971). Two secondary dams were built to separate Lake

Veere as well. For the Oosterschelde, however, the Government decided to construct a storm-surge barrier ,after long debates to safeguard its ecological values. Instead of the planned closure dam, which would isolate the Oosterschelde from the sea the barrier is closed during dangerous storm conditions. The construction of the storm-surge barrier ended in 1986 (Figure 8).

Another change to the plan was brought later. A second storm-surge barrier was built across the Nieuwe Waterweg of Rotterdam in 1996. This was the best alternative to raising and strengthening of 700 km of dykes that had been originally planned.

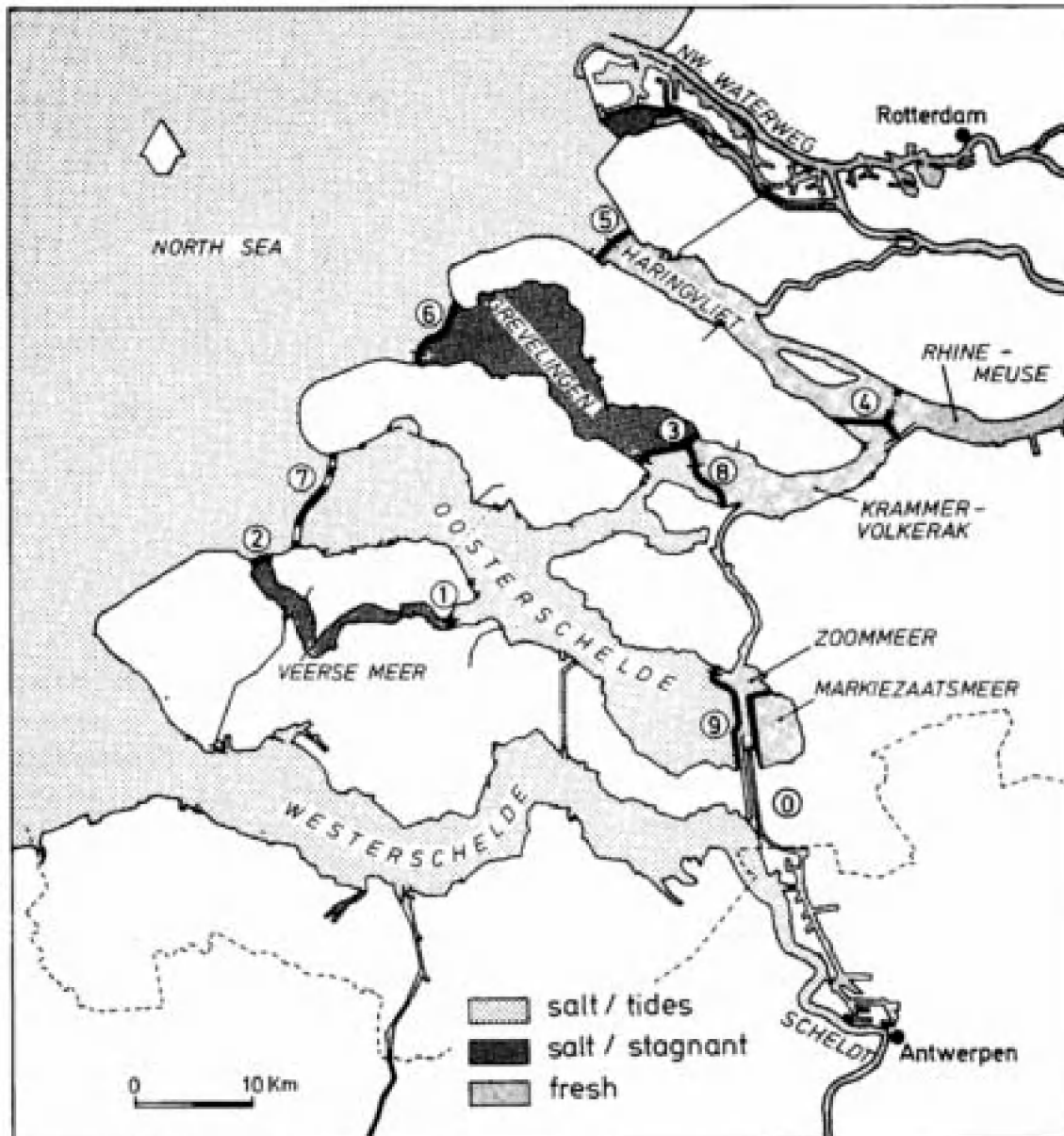


Figure 8: Interventions according to the original Delta Project.

In this map the storm surge barrier built in 1996 in the Nieuwe Waterweg is not drawn.

Legend: 0 = Kreekrakdam (constructed in 1867); this dam separating the Westerschelde from the Oosterschelde already existed before the Delta works, 1 = Zandkreekdijk (1960), 2 = Veersegatdam (1961), 3 = Grevelingendam (1964), 4 = Volkerakdam (1969), 5 = Haringvlietdam (1970), 6 = Brouwersdam (1971), 7 = Storm-surge barrier (1986), 8 = Philipsdam (1987), 9 = Oosterdam (1986). The Markiezaatsmeer has been separated from the Zoommeer in 1983.

3.1.2 Safety levels along the Belgian Zeeschelde and its branches

The 1976 flood in Flanders triggered the Belgian Sigma Project, which used the same design level of 1:10,000 each year as that of the Dutch Delta Project. In order to achieve that the Sigma Project included three main points:

1. The strengthening and raising of 512 km of dykes along the Zeeschelde and its tidal branches (height of the dykes between 8 and 11 m T.A.W.);
2. The creation of 13 controlled flooding areas where flood waters can be stored in a controlled way with negligible damage (gecontroleerde overstromingsgebieden, GOG's);
3. The construction of a storm surge barrier near Oosterweel to protect the city of Antwerp.

Flooding incidents during 1993-1994 prompted an emergency plan for flood management that initially called for an accelerated execution of the ongoing Sigma-Plan. But soon it became clear that the original set-up of the Sigma-Plan could not meet the multiple objectives of integrated watermanagement that became the new paradigm. This prompted the initiation of a long-term study programme (OMES: Onderzoek naar de Milieueffecten van het Sigmaplan). Concern regarding climate change and subsequent accelerated sea level rise added to the idea that the original and partly realised Sigmaplan needed significant adaptation.

One of the innovative elements used in designing the New Sigmaplan was the explicit risk approach using risk maps. This resulted in a downscaling of the safety standard to a much lower level varying between 1:1,000 to 1: 2,500. And based on a Cost Benefit Analysis, it was also concluded that a storm surge barrier at Oosterweel would be much too expensive in relation to the avoided damage (Vito, 2004). On July 22nd 2005, the Flemish government approved the New Sigma Plan, of which the total costs until finishing in 2030 is estimated at 830 million euros, plus 49 million euros for possible accompanying measures.

3.2 Water management policies in Belgium and in the Netherlands

3.2.1 Differences in flood management strategies between the two countries

Flood risk along the Scheldt in Belgium is considered essentially different from the Dutch part. Although a tidal surge could penetrate deep into the Belgian parts of the Scheldt, the potential impact in terms of damage and casualties is entirely different. In case of a similar flood disaster casualties are of the highest concern in the Netherlands. If a dyke breach occurs, the polder behind the dyke floods almost immediately, leading to high water levels within a short time span. Evacuation plans are difficult to realise. On the other hand, Belgium would face considerable economic damage, whereas there is less chance of a high number of casualties. Higher grounds are always nearby.

Table 1 summarises some essential differences between the two countries. These differences in risk characteristics have given rise to a fundamentally different flood risk policy between the two countries. The 1953 disaster created such a trauma in the Netherlands that very high safety standards were adopted (Delta Law) and implemented through the Deltaworks. The flood strategy of the Deltaworks was exclusively based on traditional measures of flood control: dyke enforcements, closure of estuaries and a storm surge barrier. Flood control measures were constructed using design standards based on exceedance frequency of water levels. However, more recently the Dutch government embarked on a process analysing the entire safety chain, including the probability of dyke failure, but excluding the human behaviour (VNK, 2005). But this has not resulted in a new safety policy yet. Also new flood control concepts are investigated, such as the 'Brede Waterkering' (Broad dyke), that allows more overtopping than traditional dykes.

Table 1: differences in flood risk characteristics between the Netherlands and Belgium.

	NL	B
Risk characteristics:		
potential economic damage	low - medium	high
potential number of casualties	high	low
'safety standard'	1:4,000 year	1:70 up to 1:2,500 year
Differences in physical and socio-economic characteristics:		
inundation process	immediately after a breach a polder floods and water depths quickly reach high levels	gradual rising of waters
evacuation opportunities	higher grounds are far away	higher grounds are nearby
land use	predominantly agricultural	highly industrialised around Antwerp
main historic flood event and response	1953 disaster → Deltaworks	1976 flood → Sigma Plan

With the adoption of the New Sigma Plan the Belgium Government has made a great step towards a real flood risk approach. Another difference with the Netherlands is that for the Sigma Plan a wide array of potential measures has been evaluated (storm surge barrier, flood by-passing, managed realignment, dyke enforcements etc.). Furthermore, in the bilateral project *Proses*, an explicit multi-functional planning approach was adopted, combining navigation requirements and nature development objectives with safety.

3.2.2 Proses: integration of flood management with water uses and nature.

In 1999 both the Dutch and Belgium governments decided to formulate a common management policy for the entire Scheldt estuary, based on three important objectives: safety against flooding, accessibility of ports and naturalness of the estuary (veiligheid, toegankelijkheid en natuurlijkheid). For this policy a long-term vision was defined, which consists of three parts: a sketch of the short-term situation (2005), an image of the situation in 2030 and development scenarios for the year 2010. The vision had to take in account the European Bird and Habitat directive. Based on the defined long-term view all interventions in the estuary are to be evaluated in terms of their consequences for naturalness, safety and accessibility (and interactions).

In 2001 this long term vision for the Scheldt estuary was adopted by the authorities. In order to successfully implement the long term vision a special council was initiated with stakeholders and delegates from both countries (OAP: Overleg Adviserende Partijen). Participation in this council includes delegates of port authorities, water boards, municipalities, provinces, environment and nature conservation societies and agricultural stakeholders. Although there was much internal opposition in the OAP, a common Development Outline (Ontwikkelingsschets) has been agreed in 2005.

The need to maintain an up-to-date shipping channel through the Westernscheldt towards Antwerp is considered as one of the dominant factors that furthered cooperation between the Netherlands and Belgium towards integrated management. Economic considerations as well as an old statutory obligation were decisive to agree on the so-called 3rd deepening of the navigation channel from the present depth of 11.6m to 13.1m. But international external legislation, (EU Directives) also proved important. Without the existence of the EU Habitat and Bird Directives the objective of naturalness

would have been much more difficult to materialise. Also the EU Water Framework Directive provides some pressure on decision makers, since some measures have to be implemented prior to 2008 (Workshop Lillo, 2005).

Public participation, another key element of modern integrated water management, was mainly limited to secondary stakeholders. The role of local stakeholders is still not very clear. In the OAP representatives of main stakeholders were present, but it can be expected that in the actual implementation of the new policy local interest groups will still have an important role. Recent press releases already show malcontent with some decisions (cf.: 'Terneuzens raadslid C. Freeke (LCF) vindt het onderwerp ontpoldering of getijdennatuur een typisch geval van achterkamertjespolitiek' Provinciale Zeeuwse Courant, 6 December 2005). Hence, in the implementation phase of both the Sigma Plan and Proses, intensive deliberations / resistance with local stakeholders can still be expected.

4. Future scenarios

4.1 Current trends in boundary conditions

Based on historical evidence the following trends with respect to both sea and river hydraulic boundary conditions are observed:

4.1.1 Sea level rise

During the 20th century a relative sea level rise has been observed between 10 to 15 cm per century, both along the Dutch and Belgian coast. During this period no acceleration of SLR has been observed, but according to Jelgersma (1992) the rate of SLR during the 20th century seems to be higher than during previous centuries, which could be attributed to global warming. Other sources disagree with this conclusion and propose other reasons, such as a delayed effect of the ‘small ice age’ or the human interventions along the Dutch coast (Deltaworks, harbour development etc.)(RLG, 1998; Van Malde, 1992).

4.1.2 Tidal characteristics

Tidal characteristics in the Schelde have changed markedly in the 100 years up to 1990. The tide propagates more rapidly than it did in 1888, the high water levels are higher and the range is greater. In the period 1888 to 1990, within the Scheldt upstream of Vlissingen, the height of the maximum high water level in the Westerschelde has increased by approximately 0.7m (see figure 9) and its position moved upstream by 33 Km. The tidal range has increased by almost one metre and the position of maximum range has moved upstream by 44 Km. The speed of propagation of the tide has increased by 18% from 6.55 m per second to 8 m per second. These observed changes in tidal characteristics are entirely consistent with what is expected when the morphological development of the system is constrained and the intertidal volume reduced by land reclamation (Peters et al., 2000).

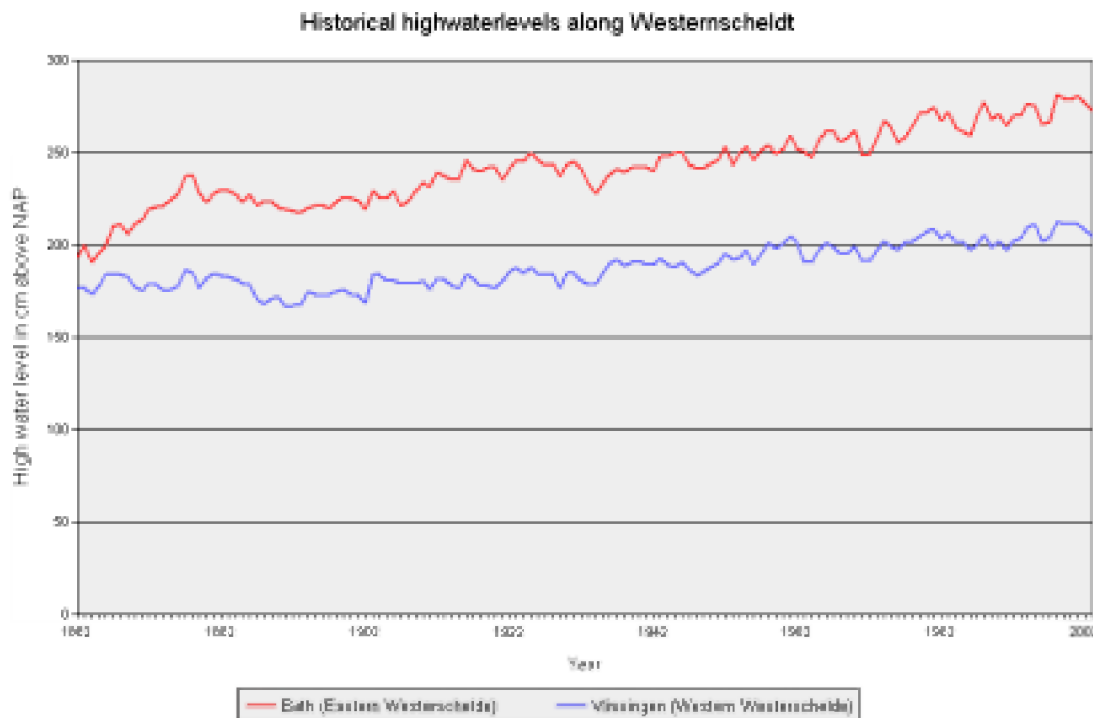


Figure 9: Historical water levels at Vlissingen (western part) and Bath (eastern part of estuary) (Source: RWS online database)

4.1.3 River discharges

The Schelde river is rainfed and this explains the high variability in the discharges (Van Eck, 1999). The mean annual flow for the period 1949-1998 is 107 m³/s. The annual discharge values show an increasing trend (figure 10), that could be attributed to the higher level of urbanisation in the catchment area (WL Borgerhout, 2000). This is especially conspicuous in the Leie and Bovenschelde rivers.

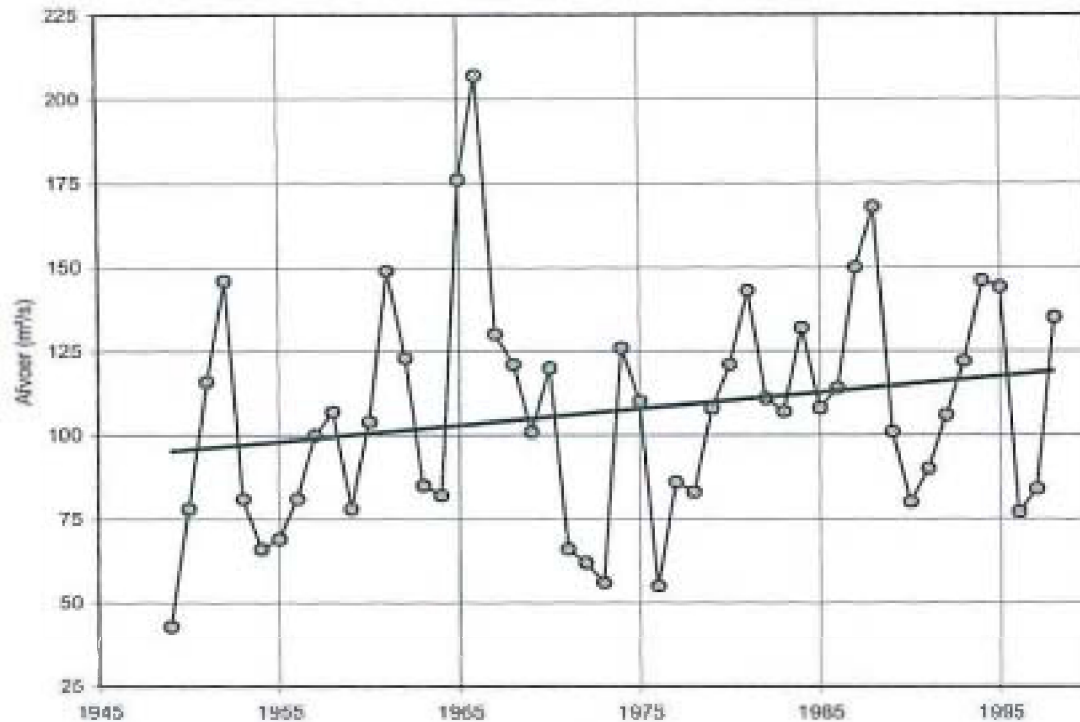


Figure 10: Mean annual discharge of the River Scheldt at Schelle (Source: WL Borgerhout 2000)

4.2 Future flood risk

The following factors are of relevance for future flood risk:

- changes in the exogenous conditions through climate change (sea level rise, river discharges), influencing the hazard (probability)
- changes in the estuarine hydraulic conditions (morphology), also influencing the hazard.
- changes in land use, population densities, urbanisation etc., influencing the possible flooding impact.

4.2.1 Climate changes in the next century

The climate seems to slowly change. In 2100 Flanders and Zeeland are expected to experience the following climatic changes (Können, 2001):

- a rise in the sea level between 20 and 110 cm;
- increase of winter precipitation by 3 - 13% in Belgium (Beersma, 2004);
- an increase in the rivers peak discharges
- an increase of number and intensity of rain showers (increase by 10-40%);
- an increase of number and intensity of storms (wind speed and wave height);
- increase of temperatures;
- drier summer seasons (increase of evaporation higher than increase summer precipitation).

Anticipating on the expected accelerated sea level rise, both the Dutch and Flemish management authorities are currently taking into account a 60 cm increase in 100 years when calculating design standards for coastal flood defence structures.

With respect to the river discharges of the Scheldt, no accurate predictions are available yet. Preliminary simulations based on a range of climate change scenarios show an increase in winter discharge in 2050 between 4 and 28% (WL Borgerhout, 2000).

4.2.2 Changes in estuarine hydraulics and morphology

The Scheldt Estuary is sensitive to changes of geometry (for example due to deepening of the navigation channel or reclamation activities) and of sea level (WL Borgerhout, 2000). Recent studies (Winterwerp & Jeuken, 2004) have been carried out to assess the vulnerability of the estuarine system to the deepening of the navigation channel using different mathematical models (ESTMORF, SOBEK and Delft3D). Morphological simulations for the period 2000-2030 were carried out to compare the autonomous development of the estuary to the development following different deepening scenarios. Several aspects of the estuarine morphology were analysed: the sediment balance, the multiple channel system, the intertidal areas and the shallow areas.

Historical data show that in the period 1970-2000 the estuary lost approximately 60 millions m³ of sediment (sand); the multiple channel system experienced important changes in the relation between ebb and flood channels; the surface of intertidal islands after 10 years of oscillating stability slightly decreased (since 1980), while the shallow areas progressively decreased (trend that started in 1955).

The autonomous development (that includes the present activities, such as dredging, dumping and sand extraction) computed for the period 2000-2030 show that the estuary shall continue to export sediment at a rate of approximately one million m³/year and shall loose extra sediment by dredging and sand extraction activities, which confirms the trend that is present since 1990. The morphological changes will be locally dominated by the dredging-dumping activities and sand extraction. The turn over of ebb and flood channels in the middle reach of the Dutch part of the estuary (Westerschelde) will potentially be a threat to the preservation of the multiple channel system. The surface of intertidal areas will be subject to negligible changes in the western reach, but in the middle reach the changes will be governed by dredging and dumping of sediment in the adjacent channels. The surface of intertidal areas will clearly decrease in the eastern reach, near Belgium, which is due to the dredging activities, but with reduced rate with respect to present. Similar trends are forecasted also for the shallow areas.

The simulations of different deepening scenarios, with a navigation channel 13.1 m deep (against a present depth of 11.9 m), show that deepening will have the following consequences: stronger erosion in the eastern reach of the estuary, sedimentation in the western reach and increased sediment export to the sea with respect to the autonomous development; stronger loss of intertidal and shallow area. The stability of the multiple channel system will be more at risk. But if the deepening will be accompanied by optimized dredging-dumping and sand extraction strategies the effects of deepening will be minimal and the morphological changes similar to those of the autonomous development.

Assuming that the optimized management strategy will be the one adopted, we can assume that the morphological developments of the Scheldt estuary in the next 30 years will be comparable to those predicted for the autonomous development.

With respect to the future changes of the hydraulics characteristics, these have been recently studied by Arcadis, Technum & Alkyon (2004) for the period 2000-2010. The autonomous development shows that the maximum increase of water level, 11 cm, will occur at Bath (eastern reach of the Westerschelde), which is due to both sea level rise and increase of tidal range. Extra effects of deepening in combination with optimized management of dredging-dumping and sand extraction activities will be negligible. The time necessary for the tidal wave to reach Antwerp will be subject to negligible changes (order of minutes). Sea level rise will have no effects on the tidal asymmetry,

which will be mostly affected by the morphological changes of the estuary (autonomous development, deepening, and managed realignment).

4.2.3 Changes in land use

An important factor that can influence the land use development along the Scheldt is the proposed establishment of the 'Schelde – Landschapspark'. This consists of 5 different areas (table 2), each with its own character and dynamics.

Table 2 Components of the Schelde Landschapspark (Antrop, 2004)

area	characteristics
1. Durme-Schelde + Old Schelde	many traditional villages, large areas of unspoilt landscapes
2. Doorbraakdal van de Schelde	many traditional villages, isolated elements of unspoilt landscapes
3. Antwerp waterfront	very high population density, many historical monuments
4. Harbours on left- and rightbank	hardly any inhabitants, highly dynamic industrial areas, landscape and historical relicts
5. Scheldt estuary	no inhabitants, highly dynamic natural area

The formulation of scenarios for land use requires an understanding of the dynamic nature of the Scheldt landscape and its likely behaviour with regard to external influences. Hence, its future development is a combination of internal processes and external factors. Below a list of both internal and external factors are presented that could form the basis for a number of realistic scenarios. These scenarios have to be worked out in cooperation with FLOODsite Task 14 (Strategy and scenario definition).

Table 3. Factors influencing future land use development in the Scheldt area

factors	description	land use consequences
population increase		housing requirements
aging population	more people having free time, demands for recreation	green space, landscape parks
deepening of navigation channel	13,10 m in 2008 demands from transport sector for further deepening are likely	industrial expansion
reduced EU agricultural subsidies	loss of economically viable farms, exodus of farmers	potentially highly significant land use conversion from agriculture to urbanisation and / or nature / recreation area
regional / international cooperation	increased cooperation between Rotterdam and Antwerp, stimulation of smaller industrial centres (Terneuzen, Sloegebied etc.)	stable or reduced growth of Antwerp harbour, decentralised industrial development
regional / international competition	increased competition between Rotterdam and Antwerp	increased growth of Antwerp
upcoming Asian markets (China)	slow down of economic growth, loss of jobs	industries in decline, overcapacity

5. Conclusions

The Scheldt estuary is a clear example where integrated water management is required. Integrated means in this case: meeting the objectives for 3 major basic functions and values of the estuary: safety, accessibility (navigation) and ecology. Recently finalised and ongoing projects, such as *Proses* and the SIGMA plan show a highly multidisciplinary approach in order to fulfil these objectives.

From the perspective of flood risk management we see a significant difference in approach between Belgium and the Netherlands. The Belgian New Sigma Plan has used an approach that is strikingly similar to the FLOODsite methodology, i.e. going through the three phases Risk Analysis, Risk Assessment and Flood Management Strategy formulation. In contrast, the Dutch flood risk management was developed over a long historical period, with the Delta Plan as the final apotheosis. In the time the Delta Plan was formulated, there was hardly any attention and technology available to prepare risk maps. Although the developers of the Delta Plan did recognise that flood risk was the right basis for a proper determination of the safety level, at that time they were lacking information and the methodology to determine the flooding probability and the flooding damage. The assessment of the level of safety (risk assessment) was therefore only rudimentary based on a cost-benefit analysis.

In order to explain the differences in flood risk management between the two countries, besides the historical perspective also the differences in physical characteristics leading to a different type of flood risk should be taken into account. In case of a similar flood disaster, casualties are of the highest concern in the Netherlands. If a dyke breach occurs, the polder behind the dyke floods almost immediately, leading to high water levels within a short time span. Evacuation plans are therefore difficult to realise. On the other hand, Belgium would face considerable economic damage, whereas there is less chance of a high number of casualties. Higher grounds are always nearby.

Another reason could be due to the Law of the Retarding Lead³ which refers to the fact that those who adopt a new technique tend to institutionalize it so that as others later improve upon the idea, the originators find it difficult to change and keep pace. In the context of flood risk management this refers to the Belgian Sigma Plan that started in a reaction to the Dutch Delta Plan, but that has been able to improve on it by adopting new ideas. It also hypothesises the relative inability for keeping pace by the Dutch water managers with innovations because of the already institutionalised flood management system. As this hypothesis cannot be proven or rejected by the current knowledge assembled in this report, it is worthwhile to explore this hypothesis further.

³ Originally formulated by the Dutch historian Jan Romeijn, the Law of the Retarding Lead is when the most successful societies have problems in changing and retaining their lead in a period of transition.

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