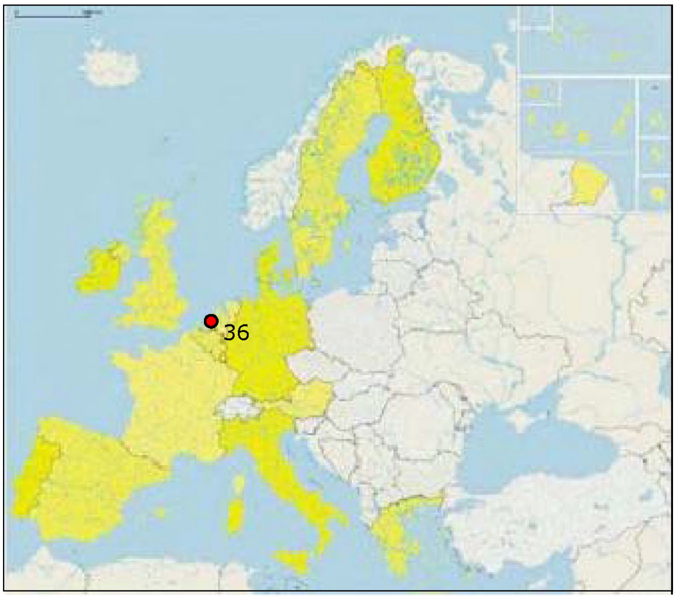
WESTERN SCHELDT ESTUARY
(THE NETHERLANDS)



Contact:

Paul SISTERMANS
Odelinde NIEUWENHUIS

DHV group

Laan 1914 nr.35, 3818 EX Amersfoort
PO Box 219 3800 AE Amersfoort
The Netherlands

Tel: +31 (0)33 468 37 00
Fax: +31 (0)33 468 37 48

e-mail: paul.sistermans@dhv.nl
odelinde.nieuwenhuis@dhv.nl

1. GENERAL DESCRIPTION OF THE AREA

1.1 Physical process level

1.1.1 Classification

The Western Scheldt is located in the Netherlands (see Figure 1). The coastline of the Netherlands is part of the low sandy shore bordering the southwestern part of the North Sea between the French-Belgian border and the north of Denmark. The total length of the Dutch coastline is slightly more than 400 km. Three units can be distinguished; the Wadden islands (with the Wadden sea, a large tidal flat area, between these island and the Dutch mainland) in the northern part of the country, the more continuos sandy coastline in the central part and the Rhine, Meuse and Scheldt estuary (Delta in Figure 1) in the southwestern part of the Netherlands. The Western Scheldt is the seaward marine section (60 km) of the tide-dominated Scheldt estuary, which has a length of 200 km and stretches up to Gent in Belgium.

Fig. 1: Location of case area.

The classification conform the scoping study is:
3a. Tide-dominated sediment. Plains.
Atlantic & North sea estuaries.

1.1.2 Geology

Reconstructions of the Holocene evolution of the province of Zeeland (the Southwestern part of the Netherland) show that this area had been part of the North Sea, but silted up almost completely by 3100 BC. The area changed into a large coastal peat bog that was dissected by the river Scheldt. From about 200 AD onwards this peat bog deteriorated, and finally large estuaries and tidal basins were formed. In the following centuries, land reclamation and land loss during storm surges shaped the landscape. It is this landscape that can still be recognized in present-day Zeeland (Van Veen, 1950).

Relatively fine sediment is found in the estuary. In general the D_{50} of the bed varies between about 150 μm and 300 μm in the channels and the deeper parts of the shoals. At the higher parts of the shoals, as well as at the salt marshes, the sediment size is in general smaller than 200 μm. Additionally, a significant percentage of silt (>10%) can be found at the intertidal areas. In the main channels, the percentage of silt is smaller than 10%.

1.1.3 Morphology

The Western Scheldt exhibits a well-developed system of channels and shoals (see Figure 2). It has a funnel-shaped geometry and covers an area of about 370 km^2. Its cross-sectional area decreases exponentially from the estuary mouth at Vlissingen to the estuary head near Gent. The width averaged depth decreases from about 15 m at Vlissingen to only

3 m near Gent. The width of the estuary reduces from 6 km via about 2-3 km near Bath to less than 100 m near Gent.

The estuary can be characterized as a multiple channel system, separated by elongated tidal flats. The large channels form a more or less continuous meandering channel, constrained by fixed points along the estuary (dikes, harbour moles). Due to the meandering of the channels shallow areas are formed (so-called sills, positioned at transitions between channel bends). Regular dredging at these sills is required in order to secure safe navigation to the port of Antwerp. Presently, ships with a draught of about 14 m can reach the port of Antwerp from Vlissingen within one tidal cycle.

Along the main land, salt marshes are present at several locations. The 'Verdronken Land van Saeftinghe', near the Belgian border, is one of the largest brackish water salt marshes in Europe (about 3500 ha.).

Fig. 2: Overview of the Western Scheldt.

1.1.4 Physical processes

Tide

The main driving force of the system is the tide. The tidal prism at the mouth is about 1 billion m^3. The mean range of the semi-diurnal tide varies from about 3.8 m at Vlissingen (at the mouth) to about 5.2 m at Antwerp (78 km upstream). Therefore, the major part of the estuary is meso-tidal. Current velocities for an average tide range up to 1-2 m/s in the main channels. Due to a combination of sea level rise and changing morphology in the estuary, the propagation of the tidal wave is enhanced and the high water levels have increased.

River discharge

The river Scheldt discharges into the Western Scheldt. The yearly-averaged discharge is about 120 m^3/s and is negligible, compared to the tidal volume.

Sea level rise and land subsidence

Sea level rise at the Dutch coast is estimated at 6 mm / year for the coming century. This is a clear increase compared to 2 mm / year for the past century. This increase is caused by climate change.

Land subsidence in the Netherlands is caused by groundwater pumping. In the last century one quarter of the relative sea level rise can be attributed to land subsidence.

Waves

The waves coming in from the North Sea loose their energy by dissipation in the smaller depths of the mouth of the Western Scheldt. Therefore, the wave heights in the estuary are small, maximum values of 2-3 meters can occur during severe storms.

1.1.5 Erosion

Both natural and human factors have determined the present configuration of the Western Scheldt. In general, the surface area of the estuary has decreased, mainly by land reclamation. Since 1800 about 15.000 ha. of intertidal area has been reclaimed (RIKZ, 1996). Between 1960 and 1990 the area of shallow water zones and intertidal salt marshes and mud flats has decreased with about 3200 ha, partly due to land reclamation and dike reinforcement, but also due to erosion caused by sea level rise, climate change and tidal cycles. Another type of human interference that is of great importance in the Scheldt estuary is dredging. In the beginning of the 1970's and also in the end of the 1990's, the Flemish government deepened and widened the navigation channel to Antwerp. As a result, the yearly amount of maintenance dredging has increased from 4 Mm^3 (1970) via 8-10 Mm^3 (1995) to an expected amount of 14 Mm^3 in 2002. Most of the dredging was done in the eastern part of the estuary (east of Hansweert, see Figure 2).

A dredging strategy was chosen such that dredged material from the main channels was dumped into the side channels. In this way, dredging and dumping threathens the existence of the multiple channel system and can lead to a decrease in intertidal area and shallow water zones, which provide a habitat for various valuable species. Apart from these dredging activities, causing a redistribution of sediment, sand excavation takes place from the Western Scheldt estuary. Since 1955 about 90 Mm^3 of sediment has been excavated.

Table 1 gives the surface areas in ha in 1960 and 1990 and shows the decrease in the shallow water zones and intertidal areas. By the year 2020 a further decrease of almost 500 ha. is expected, due to a combination of natural erosion and human interference. The surface area of the channels and higher located shoals is expected to increase with about 500 ha (RIKZ, 1996).

Table 1: Surface areas (ha.) in 1960, 1990 in Western Scheldt.

	1960	1990	Change
1. intertidal salt marshes	3520	2540	-980
2. intertidal mud flats	4260	3330	-930
3.shallow water	4450	3170	-1280
(1 + 2 + 3)	12230	9040	-3190
4. shoals	4480	4930	+480
5. channels	16160	16960	+800
Total	32870	30930	

In the future, sea level rise can cause extra loss of intertidal areas. Furthermore, it will cause relatively higher water levels in the inner estuary.

Locally, meandering of channels causes erosion of salt marshes in the order of several meters per year. At several locations, the meandering of channels causes critical situations as channels have migrated towards sea dikes and further migration would cause damages to the dikes.

1.2 Socio-economic aspects

1.2.1 Population rate

The average population rate in the Dutch part of the catchment area of the Western Scheldt is about 460 per km^2, with concentrations in the towns Middelburg, Vlissingen and Terneuzen, having respectively 45.000, 44.000 and 35.000 inhabitants (www.cbs.nl). Figure 3 shows the distribution of the population density in the Scheldt area, including the estuary.

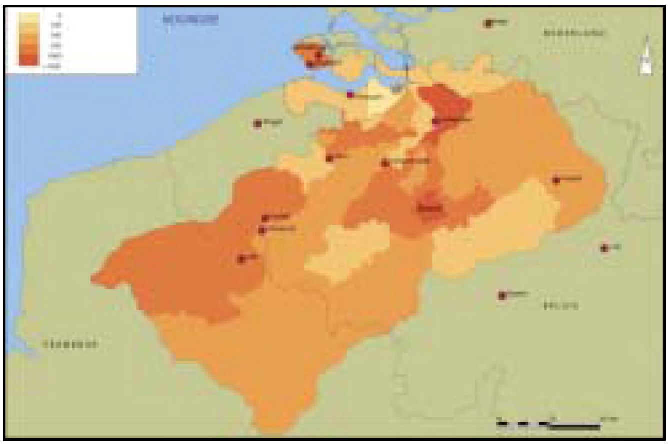


Fig. 3: Population density (persons/km2) in the Scheldt area and the Scheldt estuary.

1.2.2 Major functions of the coastal zone

- **Industry, transport and energy:** The Dutch ports of Vlissingen and Terneuzen are situated along the Western Scheldt. They contribute to a large extent to the economy of the region. About 10% of the working population in Zeeland depends on port-related activities. The transshipment in the ports of Zeeland is about 45 million tons a year (2001).

  In Belgium, the port of Antwerpen is of major importance and the port of Gent is of minor importance. Most shipping traffic takes place in the mouth of the estuary (about 51.000 ship motions in 1995). In the direction of Antwerpen this number reduces to about 32.000 (1995). The transshipment in Antwerpen is about 100 million tons a year (2002), of which about 40% is container shipping.

- **Tourism and recreation:** Although the policy concerning recreational shipping traffic is conservative, there is still a considerable amount of recreational shipping, in 1994 about 6.000 and 23.000 yachts passed Hansweert and Vlissingen, respectively.

  The beaches near Vlissingen and Cadzand, in the mouth of estuary, are extensively used in summer. In July and August of 1991 and 1992 about 150.000 people visited the beaches on an average summer day (Rijkswaterstaat, 1998). Additionally, about 3000-4000 persons recreate around the dikes and shores of the Western Scheldt.

- **Fisheries and aquaculture:** At various sites, commercial fishermen are active (mostly shrimp, sole and cockles). The shallow water zones in the estuary provide good breeding grounds for fish.

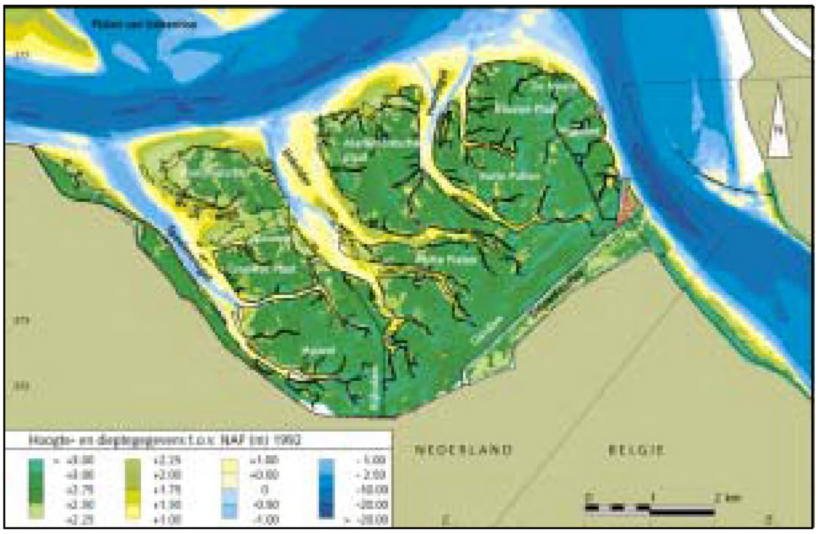


Fig. 4: The 'Verdronken Land van Saeftinghe', near the Belgian border. Depths are given with respect to N.A.P. (Dutch Ordnance Level, approximately equal to the mean water level).

- **Nature conservation:** The Western Scheldt comprises a number of internationally recognized nature reserves, which are important for birds. One of them is the 'Verdronken Land van Saeftinghe', near the Belgian border (see Figure 4), one of the largest brackish water salt marshes in Europe (about 3500 ha.), which has been a Ramsar-site since 1995 (www.ramsar.org). Yearly, about 400-500 seals are counted.

  Other designated nature reserves are the 'Schor van Waarde' (100 ha), near Hansweert, and the Verdronken Zwarte Polder (73ha) in the mouth of the estuary.

- **Agriculture and forestry:** Around the Western Scheldt a lot of farmland is present. Forestry is not present at any noticeable scale.

1.2.3 Land use

The primary land use around the Westerschelde is agricultural. The main urban areas are Vlissingen and Terneuzen, and the industrial areas consist of the sea harbours at Vlissingen and Terneuzen. Furthermore, at the mouth of the estuary sand dunes and recreational beaches are present.

1.2.4 Assessment of capital at risk

According to Bryant *et al.* (1995), the coast of the Western Scheldt is at high risk.

High risk:	city or major port or > 150 persons/km^2 or >150 m road/km^2 or > 10 m pipeline/km^2
Moderate risk:	150 < persons/km^2 > 75 and 150 < m road/km^2 > 100 and 10 < m pipeline/km^2 > 0
Low risk:	persons/km^2 < 75 and m road/km^2 < 100 and no pipelines

2. PROBLEM DESCRIPTION

2.1 Eroding sites

The locations at which the natural meandering of the channels may cause critical situations by causing damage to the dikes are indicated in Figure 5 and 6. The red lines in the figure indicate a fixation of the main channel by dikes.

Fig. 5: Natural migration of channels has come to an end at certain places.

The 'Zuidgors' salt marsh eroded with a rate of about 5.4 m per year due to wave attack. The increased wave attack was the result of channel migration, having a shallower foreshore as a result.

2.2 Impacts

An increase in surface area of channels and shoals at the cost of the surface area of intertidal marshes andshallow water zones is observed. Thus, valuable habitats are lost (1, 2 and 3, see Table 1). Further erosion of these habitats is undesirable and impermissable in case international recognized nature reservations are involved.

Fig. 6: Local erosion in intertidal area.

Due to the increased propagation of the tidal wave, high water levels have increased, having a direct negative effect on the safety of the hinterland.

Damage to dikes by meandering channels threatens the hinterland.

3. SOLUTIONS/MEASURES

3.1 Policy options

No further retreat of the coastline near sea-dikes can be accepted (see Figure 5). The policy option is to hold the line at these locations.

At other locations, an attempt is made for the rehabilitation of intertidal salt marshes. Here, plans have been developed for the construction of small piers, with the purpose of creating protected areas where sedimentation of fine sediment is stimulated. Here, a 'move seaward' strategy is adopted (see Figure 7).

3.2 Strategy

Fig. 7: dike at Western Scheldt

At present a different dredging and dumping strategy is proposed to prevent a further reduction of valuable habitats Formally, this is arranged in licenses by setting maximum quantities for dumping sediment in the eastern part of the estuary.

At locations, where a further migration of the channels may cause undesired effects, such as erosion of dike toes or intertidal salt marshes, revetments are constructed. Since migrating channels are characteristic for the natural dynamical behaviour of an estuary, it can be argued that these revetments cause a less 'natural' behaviour of the estuary.

The increased propagation of the tidal wave has led to increased high water levels. The dikes are raised to ensure the safety of the hinterland.

Summarising, the strategy consists preferable of soft measures. Locally, hard measures are adopted, if required.

3.3 Technical measures

3.3.1 Historic measures

In the Western Scheldt historic measures mainly consist of dikes (against flooding) and groynes (against erosion). Channel revetments is also a common measure against erosion. Dredging and dumping of sediments is a measure to ensure sufficient depth in the navigation channel.

3.3.2 Type

Basically, three types of measures are taken to cope with the erosion problem in the Western Scheldt.

1. Firstly, soft solutions are adopted to influence the large-scale morphology of the estuary and to counteract the undesired changes in the large-scale morphology.

The quantities of dredged material before and after the deepening of the navigation channel are given in Table 2.

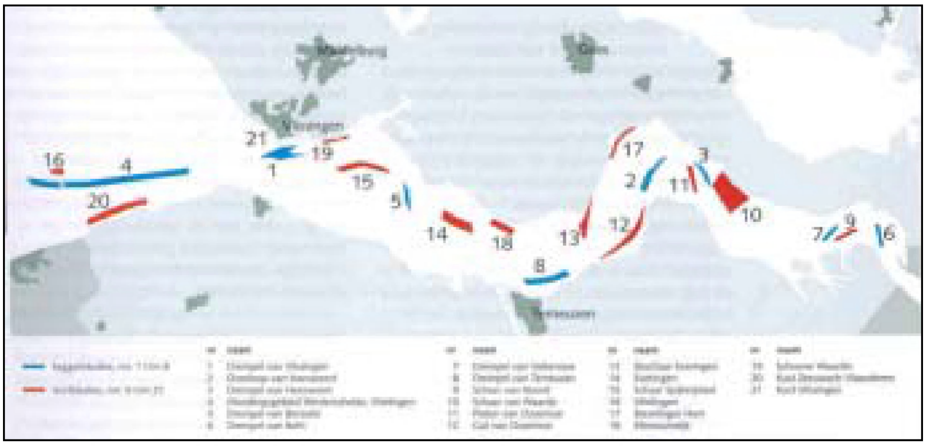


Fig. 8: Dredging (1-8) and dumping (9-21) locations in Western Scheldt.

Table 2: Dredging quantities before ('86- '96) and after (estimated) deepening of the navigation channel in Mm^3. The translation of 'drempel' is 'sill'.

	before	after
1. Drempel van Vlissingen	-	-
2. Overloop van Hansweert	0.8	1.2
3. Drempel van Hansweert	2.6	4.2
4. Wielingen	-	-
5. Drempel van Borssele	0.7	1.2
6. Drempel van Bath	1.4	2.2
7. Drempel van Valkenisse	1.4	2.2
8. Drempel van Terneuzen	0.1	0.2
other locations	1.7	2.8
Total	8.7	14

2. Secondly, the eroded sites are protected by constructing channel revetments at various sites.

As a result of the deepening of the navigation channel, the current velocities in these channels are expected to increase. In order to prevent further migration of the channels and possible erosion of intertidal salt marshes, the embankment of the channels is protected by stone revetments at several locations.

At the start of the deepening of the sills (June 1997), a revetment near the 'Nauw van Bath' was constructed (2 km).

In 1998 a 3 km revetment at the 'Zuidergat' was constructed as well as a revetment of 600 m near Ossenisse. In 1999, a revetment at the southern part of the Platen van Hulst was constructed. In 2000, the eastern side of the 'Verdronken land van Saeftinghe' and in 2001 the 'Overloop van Valkenisse' were protected by revetments.

3. Thirdly, intertidal salt marshes are rehabilitated by constructing small piers (pile rows or stones) with the purpose of creating protected areas where sedimentation of fine sediment is stimulated (see Figure 9).

Recently, a project was defined for the protection of the intertidal salt marsh (about 100 ha.) near Waarde (see Figure 10).

Fig. 9: Protection of eroding salt marsh near Waarde.

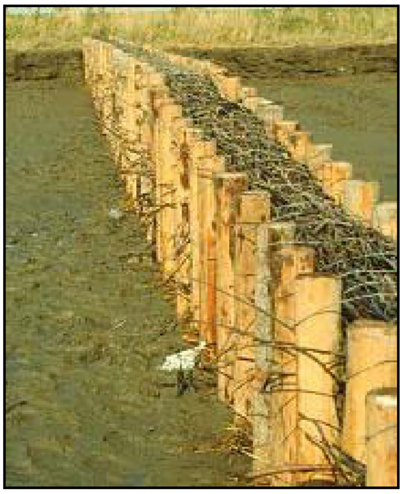


Fig. 10: Pier protection of tidal area.

3.3.3 Costs

The costs of the maintenance dredging are estimated to be in the order of 90 M€ (14 Mm^3 x 5€/m^3).

The costs of the revetments are estimated to be in the order of 65 M€ (IMDC, 2000).

The costs of these protection works are estimated at € 2 M (NRC Handelsblad, 02.01.2003).

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

A recent evaluation (RIKZ, 2001) indicates that the present strategy of dumping more dredged sediment in the western part of the estuary does not seem to significantly alter the trends observed during the last decade. Whether or not the present strategy works, will have to be further evaluated in the future.

Some of the rehabilitation works for the intertidal salt marshes have been evaluated (Van Oevelen *et al.*, 2000). One of these projects was the protection of the 'Zuidgors' salt marsh by groins Further erosion was prevented and sedimentation was stimulatedThe protection works were finished in 1992. An evaluation (1997) showed that sedimentation took place between the groins and the erosion rate reduced from 5.4 m/year to 2.2 m per year.

The effects of the revetment near the 'Nauw van Bath' were monitored in 1997 and 1998, showing the channel did not further migrate inland. At the west side of the revetment an inland migration did not come to an end.

4.2 Effects related to socio-economic aspects

he dredging is carried out with the purpose of maintaining a navigable depth in the ebb channels, in order to ensure the connection with the port of Antwerpen. From an economic point of view, this connection is of major importance for Belgium.

Erosion has negatively affected the area of available intertidal areas, which provide a habitat for many different birds and plants.

In order to reduce the increased water levels in the estuary, the option 'managed realignment' was considered locally. However, the public opinion strongly rejected this option. This strong rejection is related to the flooding that occurred in 1953. In that year, 1836 people died. Since then, a large number of measures (storm surge barrier, dike raising) have been taken to reduce the risk against flooding and 'giving back land to the sea' is out of discussion.

4.3 Effects in neighbouring regions

The enhanced propagation of the tidal wave has caused higher water levels along the Scheldt estuary, up to Belgium. In Belgium, measures are being taken for the protection against the increased water levels. These measures consist of raising seadikes and possibly the construction of a storm surge barrier downstream of Antwerpen.

4.4 Relation with a ICZM

Integrated coastal zone management aspect plays an important role in the Western Scheldt. Although the ecological value of the estuary is acknowledged, it seems that the economical function of the port of Antwerp is leading in the development of the estuary. The dredging and dumping activities, required to maintain the shipping channel, is believed to be one of the reasons for the loss of habitats. According to European regulations, compensation of these negative effects is required.

Summarising, three issues can be distinguished which are of importance. First of all, the safety of the hinterland is a condition that has to be met. Second, the shipping/transport function of the Western Scheldt plays a dominant role in the estuary. Finally, the ecological function is a major issue in the Western Scheldt.

4.5 Conclusions

Effectiveness

Besides the safety of the hinterland, the leading factor in the further development of the Scheldt estuary seems to be the transport function of the estuary towards the port of Antwerp. The ecological value of the area is acknowledged but is minor compared to the transport function. However, the negative effects on ecology like the loss of intertidal habitats due to dredging and dumping do have to be compensated.

Whether or not the proposed strategy of concentrating the dumping of sediment in the western part of the estuary works will have to be evaluated in the future. Some of the rehabilitation works for the intertidal salt marshes have been evaluated. This kind of projects seems to be able to prevent further erosion and sometimes even stimulate sedimentation.

In the future, the effects of the possible deepening of the channel and the effects of relative sea level rise will be the main causes for an increase in erosion.

Possible undesirable effects

Until now, no negative effects of the proposed dredging/dumping strategy are experienced. As a result of the revetments, locally the migration of the channels is stopped, causing a less ‘natural’ behaviour of the estuary.

Gaps in information

The effects of the proposed dumping/dredging strategy require further monitoring of the morphology and hydraulics of the estuary. Furthermore the response of the estuary to relative sea level rise is uncertain.

5. REFERENCES

Bird, E.C.F.; Schwartz, M.L. (1985). *The world's coastline*. Van Nostrand Reinhold Company Inc., ISBN 0-442-21116-3.

International Marine & Dredging Consultants N.V. (2000). *Kostenindicaties bij de langetermijnvisie Schelde-esturarium* (Eindrapport), I/RA/12025/00.055/JSS.

NRC Handelsblad (2003). *Een Zeeuw geeft geen land weg*. January 2/2003

Rijkswaterstaat Directie Zeeland (1998). *Milieu Aspecten Studie Baggerspeciestort Westerschelde.*

Rijksinstituut voor Kust en Zee (1997). *Westerschelde, stram of stuis?,* Rapport RIKZ-97.023.

Rijksinstituut voor Kust en Zee (2001). *Monitoring van de effecten van de verruiming 48'/43'. Beschrijving van de fysische toestand van de Westerschelde t/m 2000*, Rapport 5, Rapport RIKZ/2001.023.

Rijksinstituut voor Kust en Zee (2001). *Monitoring van de effecten van de verruiming 48'/43'. Samenvatting van de ontwikkelingen in de Westerschelde (tussenstand 2000),* Rapport 6, Rapport RIKZ/2001.025.

Van Oevelen, D.; Van den Bergh, E.; Ysebaert, T.; Meire, P. (2000). *Literatuuronderzoek naar estuariene herstelmaatregelen*, Rapport IN.R. 2000.4, Instituut Voor Natuurbehoud, Ministerie van de Vlaamse Gemeenschap/Universtitaire Instelling Antwerpen, Departement Biologie.

Van Veen, J. (1950). *Eb- en Vloedschaar Systemen in de Nederlandse Getijwateren*, Tijdschrift Koninklijk Aardrijkskundig Genootschap, Vol. 67, pp. 303-325.

Internet:

http://www.scheldenet.nl
http://www.scheldenet.nl/uploaded_files/325_kostenindicatiesltvcpl.pdf
http://www.scheldenet.nl/uploaded_files/324_kostenindicatiesltv.pdf
http://www.scheldenet.nl/uploaded_files/325_kostenindicatiesltvcpl.pdf
http://www.scheldenet.nl/uploaded_files/310_natuurherstelmaatregelen.pdf
http://www.ramsar.org/profiles_netherlands.htm
http://www.coastalguide.to
http://www.zeeweringen.nl
http://www.cbs.nl

Figures:

Figure 1: http://www.icm.noaa.gov/country/netherlands.html