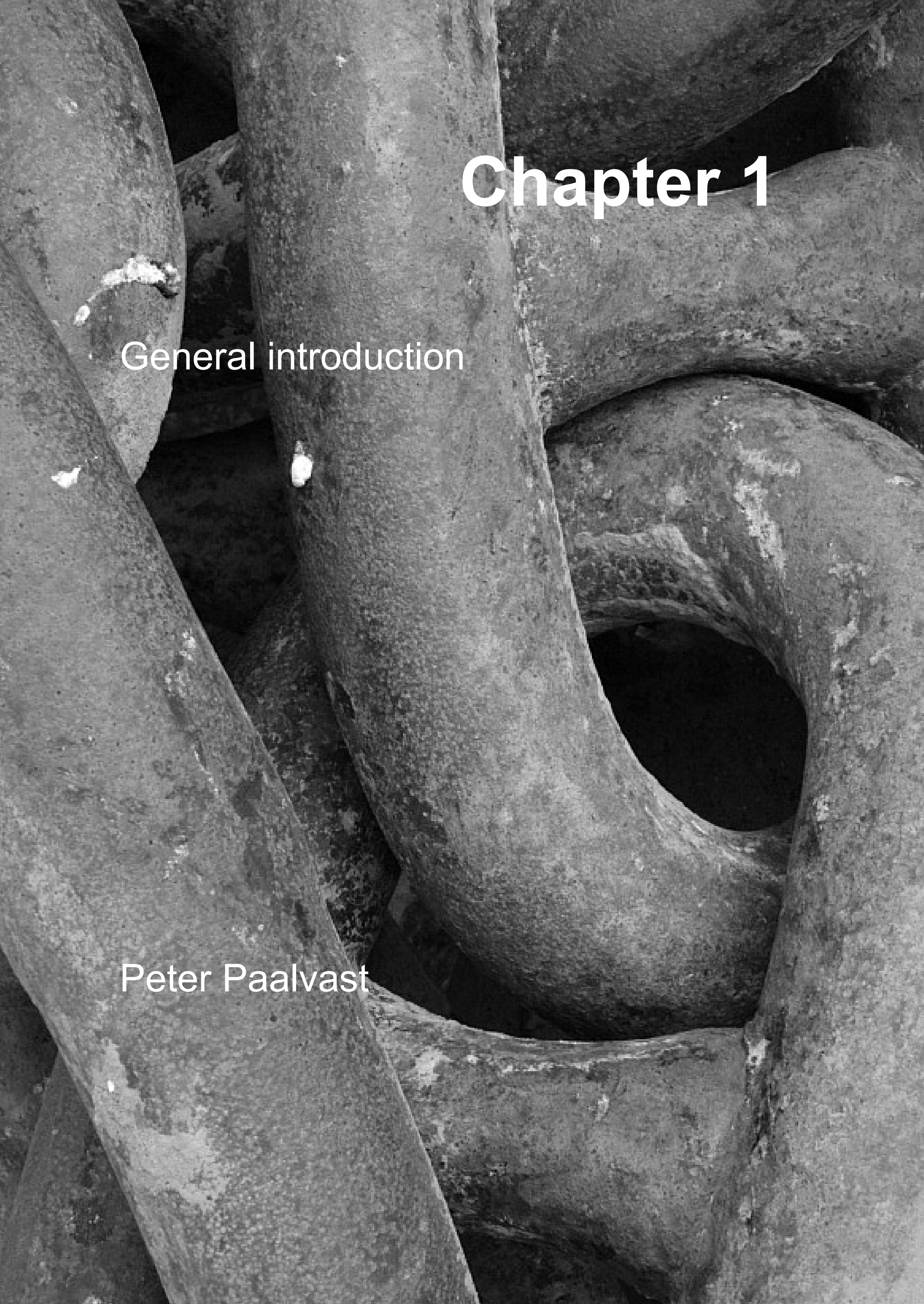

# Chapter 1

## General introduction

Peter Paalvast

The port of Rotterdam is located in the so-called "Noordrand" of the northern delta basin of the Netherlands (Fig. 1). It comprises the Nieuwe Maas and Nieuwe Waterweg (including Scheur) with adjacent harbour systems and a part of the Oude Maas.
Rotterdam received its city rights from Count William IV on June 7, 1340. In the beginning of the second half of the 14th century, newly constructed canals (Coolse and Goudse vest) that served as a defence line around the city came in use as harbours (Brolsma, 2006). Well into the 17th century Rotterdam was mainly a herring port leading to related economic activities to conserve the herring for trade. The Rhine hinterland was a major customer, but also Rouen in northern France was an important destination for herring products. On the return trip a range of goods was carried and Rotterdam developed itself more and more as a transhipment port. The growth of the port kept pace with the economic development of Holland and from the mid-19th century with that in the German Rhine and Ruhr area.

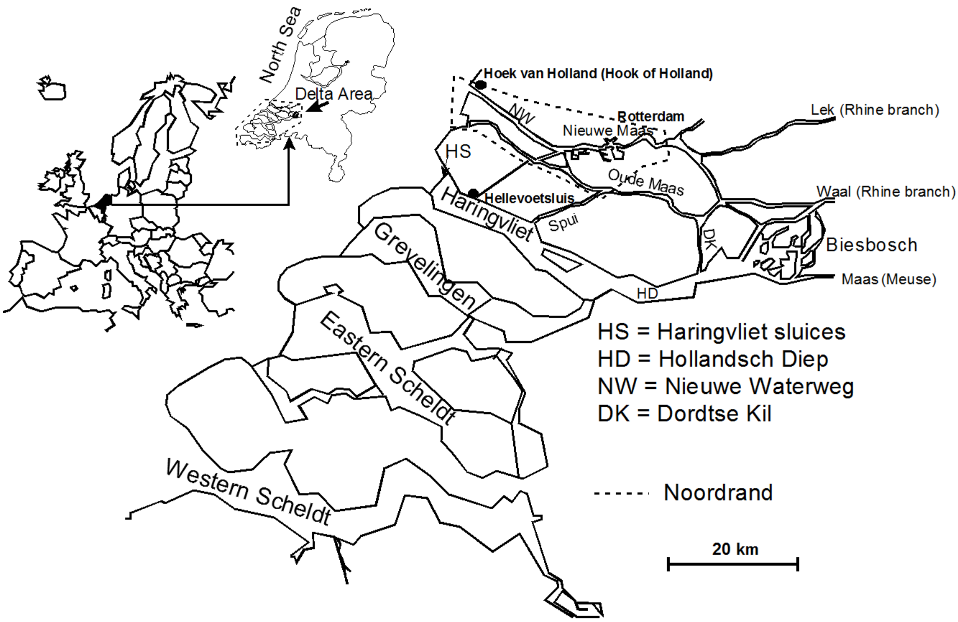


**Figure 1** The location of the port of Rotterdam area at the Noordrand in the northern part of the Delta Area in the Netherlands.

Large harbour expansions took place in particular in three periods: a) so-called Golden Age of the Netherlands (1600-1700), b) the industrial revolution in the mid 19$^{th}$ century and c) after the second World War (WWII) (1945-nowadays) in particular. In the period 1962-2004, the port of Rotterdam in terms of cargo handling could call itself the largest port of the world. Nowadays, Rotterdam is the fifth largest port in the world behind ports such as Shanghai (China) and Singapore, but by far the largest of Western Europe.

## Hydrology and salinity

Human interference in the area by land reclamation and port development have had an enormous impact on the hydrology of the area (see Table 1), which is reflected in changes in the average yearly tidal range (difference between low and high water level), water velocities, sediment transport and salt intrusion. But also the global sea level rise of about 21 cm between 1880 and 2009 (Church and White, 2011) must have had an important influence on the hydrology. At Hoek van Holland the sea level rise between 1890 and 2008 was even higher, viz. 30 cm (Fig. 2)(Dilling et al., 2012).

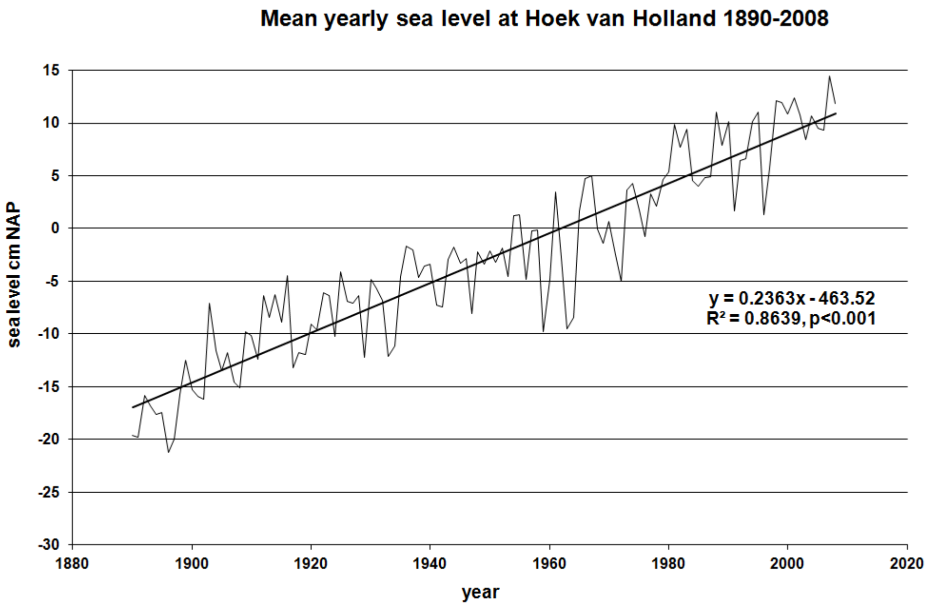


**Figure 2** Changes in mean yearly sea level at Hoek van Holland (Hook of Holland) between 1890 and 2008 (redrawn after data from Dilling et al., 2012). NAP=Amsterdam Ordnance Datum.

Water levels in the area were first recorded at Brielle (Fig. 3) at 1815 and were continued (with missing data from 1818, 1820 and 1822) till the closure of the Brielsche Maas in 1950 (data till 1949). Between 1830 and 1870 based on 10 year averages there is a decrease in tidal range from 163 cm till 140 cm (Fig. 4). The cause of it was the natural silting up of the mouth of the Brielsche Maas.

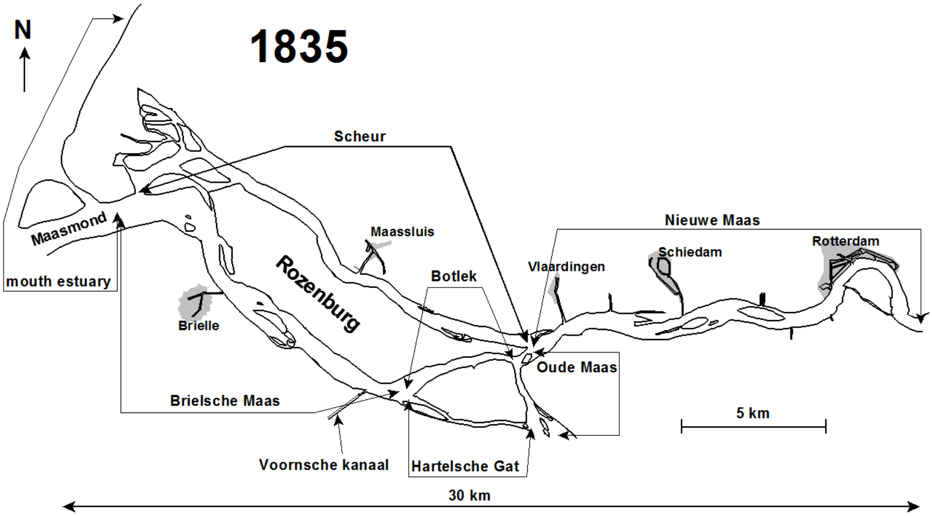


**Figure 3** Topography of the “Noordrand” in 1835. Drawn after old river maps.

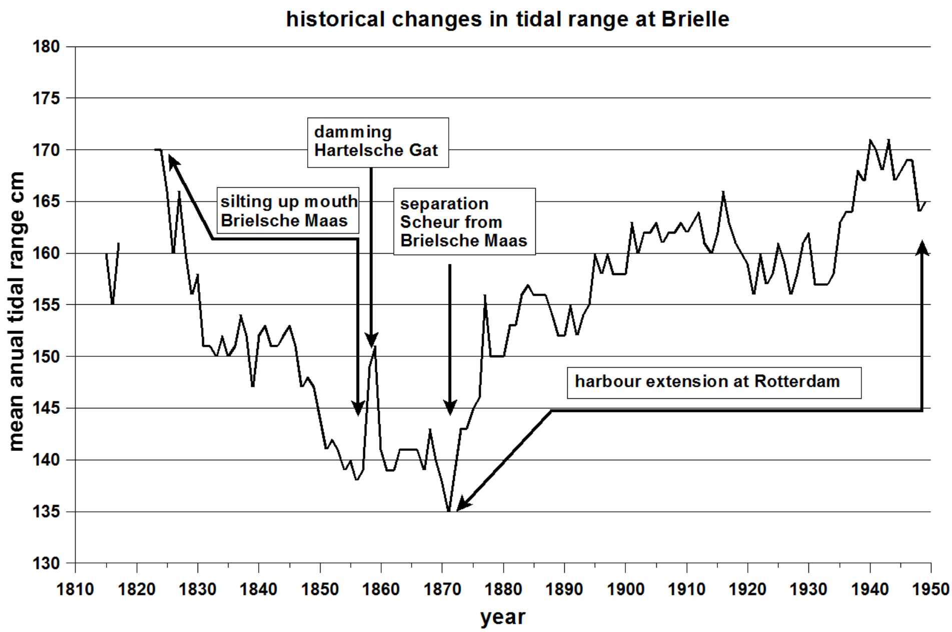


**Figure 4** Historical changes in tidal range at Brielle at the Brielsche Maas between 1815 and 1950 (after data provided by Rijkswaterstaat).

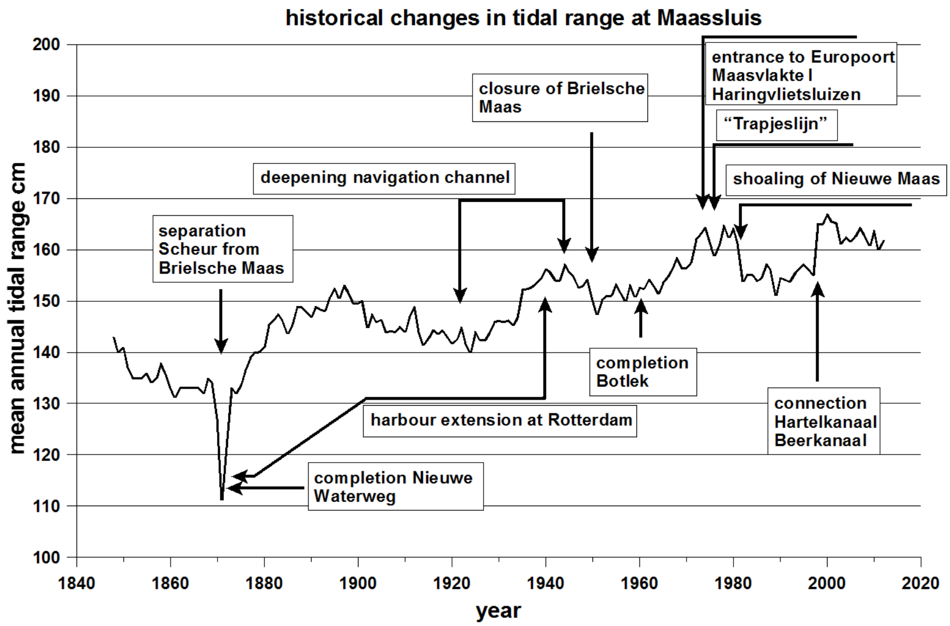


**Figure 5** Historical changes in tidal range at Maassluis at the Scheur between 1850 and 2010 (after data provided by Rijkswaterstaat).

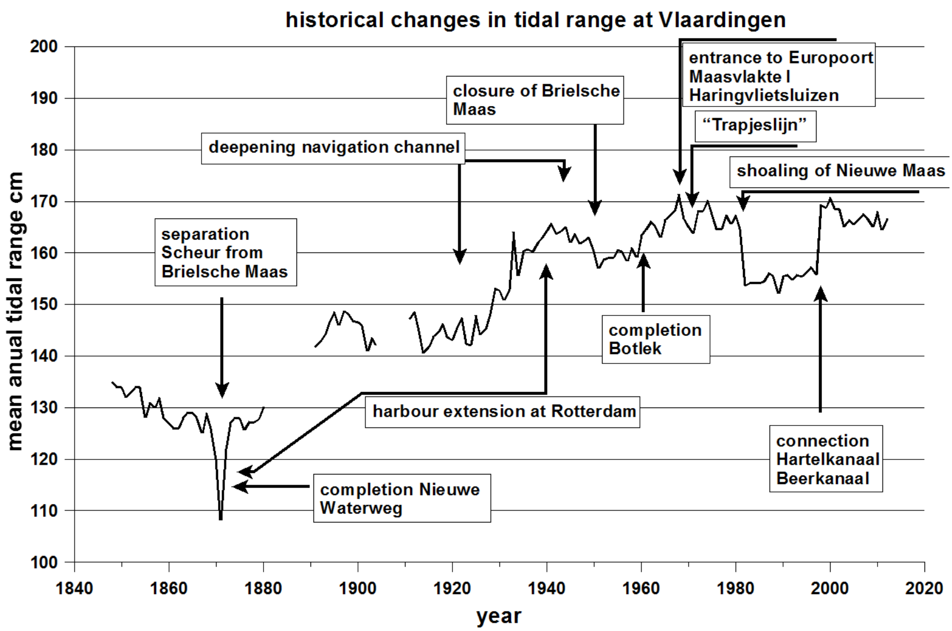


**Figure 6** Historical changes in tidal range at Vlaardingen at the Scheur between 1850 and 2010 (after data provided by Rijkswaterstaat).

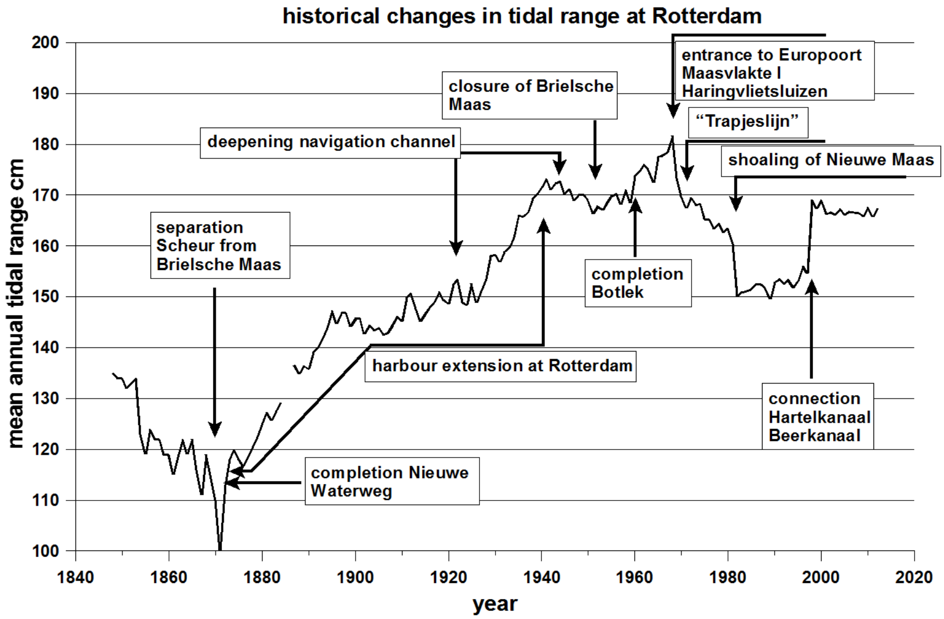


**Figure 7** Historical changes in tidal range at Rotterdam at the Nieuwe Maas between 1850 and 2010 (after data provided by Rijkswaterstaat).

The cause of the increase in the average yearly tidal range at Brielle in 1858 and 1859 seems unclear but might be the effect of the damming of the Hartelsche Gat in 1857 (Fig. 4).

The recording of the water levels at Maassluis, Vlaardingen and Rotterdam started all around 1850. The graphs in figure 5, 6 and 7 all show a decrease in tidal range due to sedimentation in both Scheur and Nieuwe Maas before 1868. In 1868 the excavation of the Nieuwe Waterweg through the dunes of Hoek van Holland started and the canal was opened in 1872. The connection between the Brielsche Maas and the Scheur became closed in 1872. To separate the Scheur from the Brielsche Maas first the banks were reinforced and in 1871 a low water dam was constructed. The effect of this low water dam is clearly shown in figures 5, 6 and 7 by a decrease in the average yearly tidal range of 1871 for Maassluis, Vlaardingen and Rotterdam compared with 1870 of 16 cm, 12 cm and 10 cm, respectively. At Brielle this was less clear as this difference in tidal range between 1871 and 1870 was only – 3 cm.

After the completion of the Nieuwe Waterweg the port water surface quadrupled from 50 to 200 ha between 1872 and 1900 (see chapter 2). Also the average wet cross section of the river increased by dredging for greater depth and widening of the mouth of the Nieuwe Waterweg (Table 1). These interventions led to a considerable increase in channel detention of this part of the estuary and resulted in a rise in tidal range of 20 cm at Maassluis and Vlaardingen and

**Table 1** Historical morphological and hydrological changes in the Nieuwe Waterweg and Scheur (after Van Os, 1993).

| year | 1874 | 1908 | 1956 | 1963 | 1971 |
|---|---|---|---|---|---|
| average width m | 141 | 375 | 375 | 410 | 410 |
| average depth m | 7.7 | 7 | 10.8 | 11.8 | 15.8 |
| wet cross section $m^2$ | 1089 | 2626 | 4048 | 4846 | 6478 |
| river discharge $m^3\ s^{-1}$ | 358 | 649 | 738 | 895 | 1550 |
| flood volume $10^6\ m^3$ | 25 | 47 | 69 | 83 | 94 |
| maximum ebb velocity $m\ s^{-1}$ | 1.61 | 1.24 | 1.2 | 1.21 | 1.02 |

about 30 cm at Rotterdam (Fig. 5 to 7). The period 1897 till 1909 is considered as the first period in which sedimentation and erosion of the Nieuwe Waterweg were in equilibrium with each other (Haring, 1977) and no significant increase in tidal range occurred. Within the period of 1910 till 1923 many harbours were constructed or under construction, for example the Waalhaven (261 ha), by which the flood volume strongly increased and by dredging and possible erosion of the Brielsche Maas, Scheur and Nieuwe Waterweg the tidal range as a consequence of this further increased. Between 1924 and 1944 from the mouth of the Nieuwe Waterweg to 1 km upstream Rotterdam the whole river was deepened increasing the flood volume and tidal range stream upwards again. On the contrary the tidal range at Hoek van Holland probably due to sedimentation near the mouth dropped between 1910 and 1950 about 10 cm. In 1950 the Brielsche Maas was dammed leading to an approximately 20% increase in river water discharge via the Nieuwe Waterweg (Haring, 1977), a situation that remained unchanged until the closure of the Haringvliet in 1970 as part of the Delta Project (see chapter 2). With the closure of the Haringvliet and the management of the Haringvliet sluices the discharge of river water via the Nieuwe Waterweg at an average river discharge of 2200 $m^3/s$ at the Dutch German border increased from 950 $m^3/s$ to 1700 $m^3/s$ (Paalvast et al., 1998). Also the construction of weirs that close at low river discharges in the Lek (and Nederrijn) as part of the Rhine channelization programme affected the tidal range. The period 1950-1958 is considered as the second equilibrium of sedimentation and erosion and no change in tidal range took place. Between 1958 and 1964 many improvement works for shipping such as dredging for greater depth for the new harbour systems Botlek and Europoort were carried out leading to an increase of 10 cm in tidal range at Rotterdam. The decline in tidal range at Rotterdam and rise of tidal range in particular at Hoek van Holland in 1971 (Fig. 6) were the result of the enormous increase of the channel detention by opening of the Beer- and Calandkanaal harbour system. The construction of the large harbour systems and the deepening of the navigation channel had a great impact on the salt intrusion upstream and consequences for both the intake of drinking water and the supply of water for agriculture. To reduce this salt intrusion the water depth of the Nieuwe Waterweg (and Scheur) and Nieuwe Maas was managed by either dredging from or supplementation of sediment (Nieuwe Maas and parts of the Nieuwe Waterweg) on the river bottom in a stepwise way from mouth to upstream as far as Rkm 955 from respectively -22.5 metres relative to NAP and -8.0 metres relative to NAP (Fig. 8). This stepwise intervention in the river bottom is called “Trapjeslijn” in Dutch and the works started in 1968 and were finished in 1972 reducing the tidal range by a few cm’s. In fact the “Trapjeslijn” is a compromise between the need to reduce the salt intrusion, which requires a water depth reduction, and the need of greater depth for navigation. In the first years the “Trapjeslijn” was well maintained, but later on shipping prevailed and in particular the depth of the Nieuwe Waterweg and the route to the Waalhaven at the Nieuwe Maas

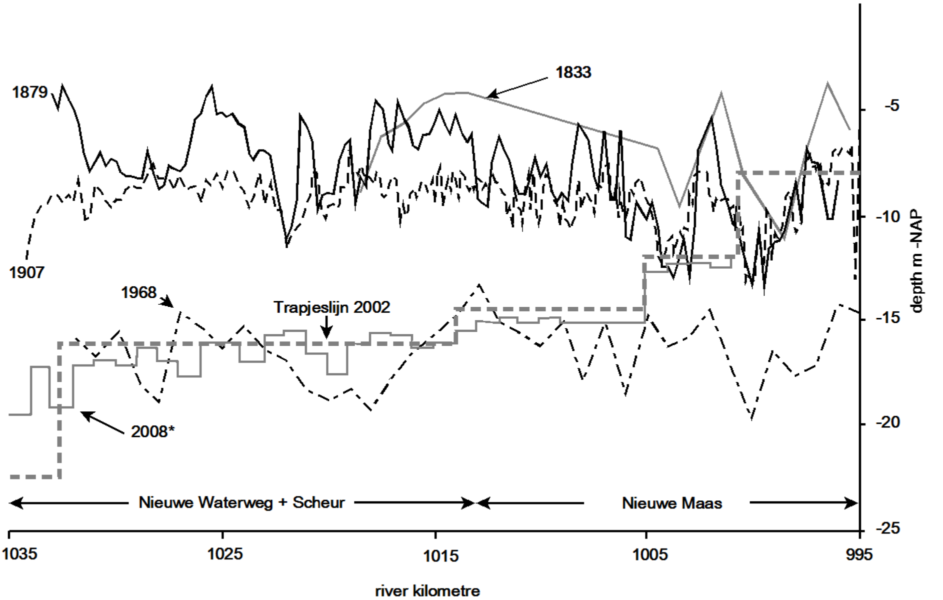


**Figure 8** Historical changes in the depth of the navigation channel of Nieuwe Waterweg, Scheur and Nieuwe Maas. The depths of 1833, 1879 and 1907 were retrieved from old river maps, those of 1968 from data of Deltares. Trapjeslijn 2002 = design of river bed elevation 2002. 2008 = average depth of the navigation channel per river kilometre (redrawn from Kuijper and Kaaij, 2009). NAP= Amsterdam Ordnance Datum.

increased again (Rijkswaterstaat, 2004). The deliberate shoaling of the Nieuwe Maas in 1984 decreased the tidal range at Rotterdam by another 10 cm (Fig. 7). In December 1997 the Beerkanaal was connected with the Hartelkanaal (see Fig. 11) which led to a new rise in tidal range at Maassluis, Vlaardingen and Rotterdam of 10 cm, 13 cm and 14 cm, respectively. Since then the tidal range remained similar.

The historical change in tidal range along the Nieuwe Maas, Nieuwe Waterweg and Brielsche Maas is significantly correlated with the increase of the port water surface or harbour extension (in fact all the deepening and widening of the waterways to the harbours).This is clearly shown in the graphs for Brielle (Fig. 9) and Rotterdam (Fig. 10). The weaker correlation for Brielle (Fig. 9), Maassluis ($Y=3.86\ln(X)+125.12$, $R^2=0.48$, $p<0.001$) and Vlaardingen ($Y=10.71\ln(X)+86.75$, $R^2=0.86$, $p<0.001$) compared with Rotterdam (Fig. 10) is related to their shorter distance from the sea. If the extension of the port surface by the creation of Europoort and Maasvlakte 1, that led to an increase of the channel detention at the mouth, is disregarded then correlation between harbour extension and increase in tidal range at Rotterdam is even stronger ($R^2=0.913$ vs $R^2=0.906$, figures not round off).

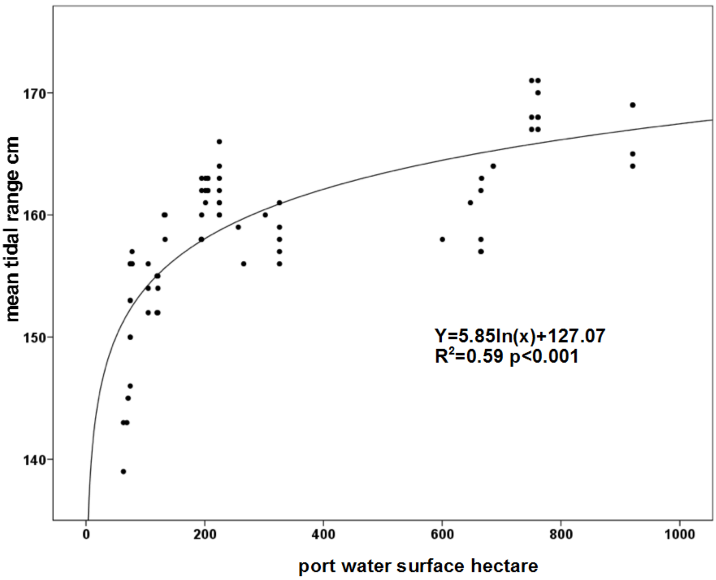


**Figure 9** Relation between harbour extension along the Nieuwe Maas near Rotterdam and the mean tidal range at Brielle between 1872 and 1949.

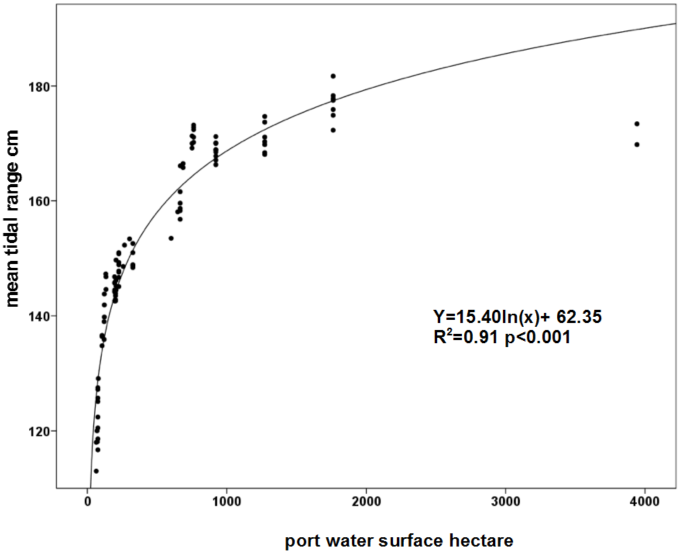


**Figure 10** Relation between harbour extension along the Nieuwe Maas near Rotterdam and the mean tidal range at Rotterdam between 1872 and 1970.

There are not many historical salinity data of the Rotterdam port area as monitoring started in the 1970s when the Haringvlietsluizen came into operation. In the months of September 1907 and July 1908 however salinity measurements were carried out in the northern part of the Dutch delta area by Rijkswaterstaat. On the basis of the minimum and maximum values that were acquired isohalines for the average river flow in those months were derived (Fig. 11). Peelen (1967) calculated the isohalines of the Delta area for the period (1960-1970) before the closure of the Haringvliet, Grevelingen and Oosterschelde. The underlying data were used by Wolff (1973) to calculate the salinity at the bottom of the rivers and the sea floor (Fig. 12). They clearly show the effect of deepening of the navigation channel on salt intrusion, which was more stream upwards in the period 1960-1970 than it was in 1907 and 1908 (Fig. 12). Around 1970 Beer- and Calandkanaal were connected to the sea and the Nieuwe Waterweg and in this way a large polyhaline area was formed. In that same year the management scheme of the Haringvliet sluices was implemented and extra river water from then on is forced through the Noordrand to reduce salt intrusion. The reduction of salt intrusion by means of the management of the Haringvliet sluices and the "Trapjeslijn" becomes clear by comparing the isohalines of around the year 2000 (Fig. 13A) and those of the period 1960-1970 (Fig. 12A).

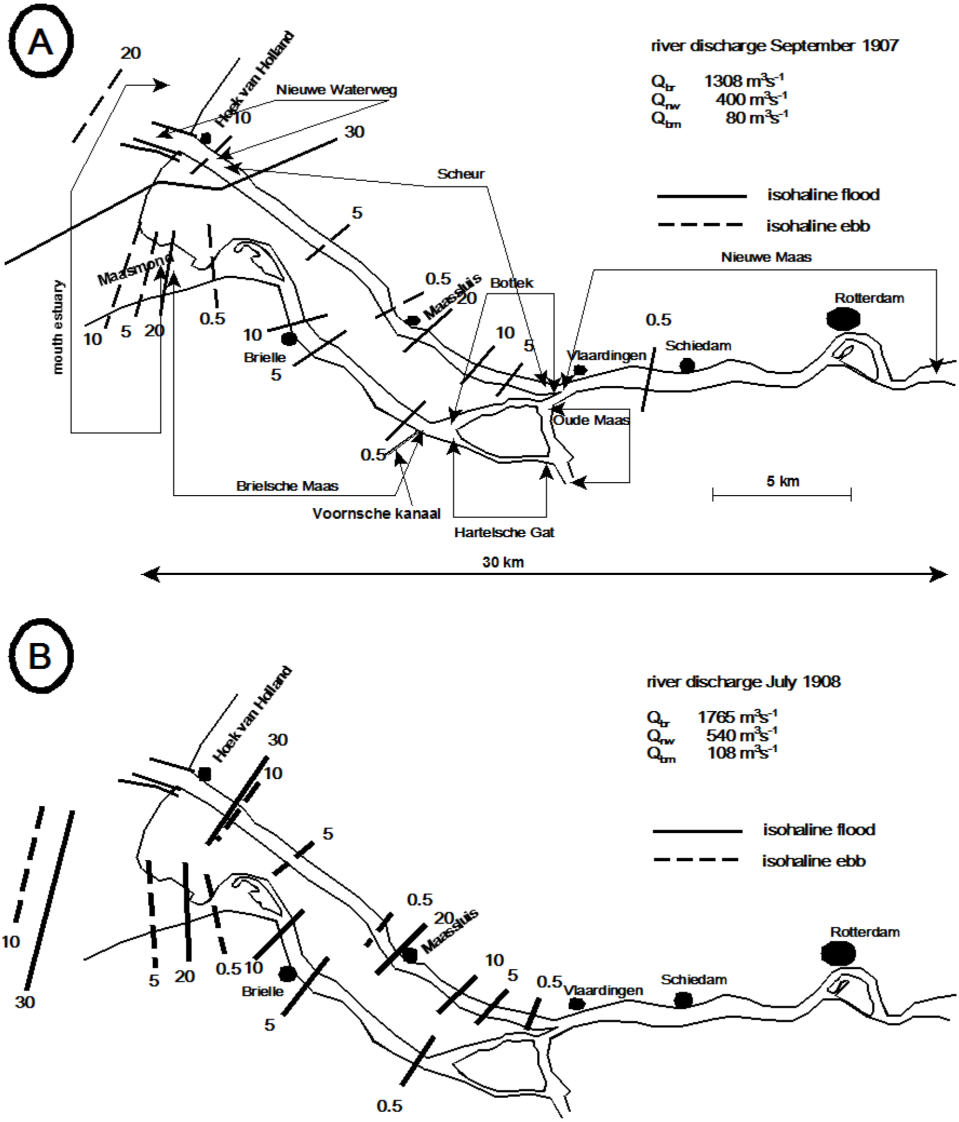


**Figure 11** Isohalines (S) at the bottom in the Noordrand in September 1907 (A) and July 1908 (B) (after data from Anonymus, 1911).$Q_{br}$ = monthly average discharge at the Dutch-German border, $Q_{nw}$= monthly average discharge Nieuwe Waterweg, $Q_{bm}$= monthly average discharge Brielsche Maas.

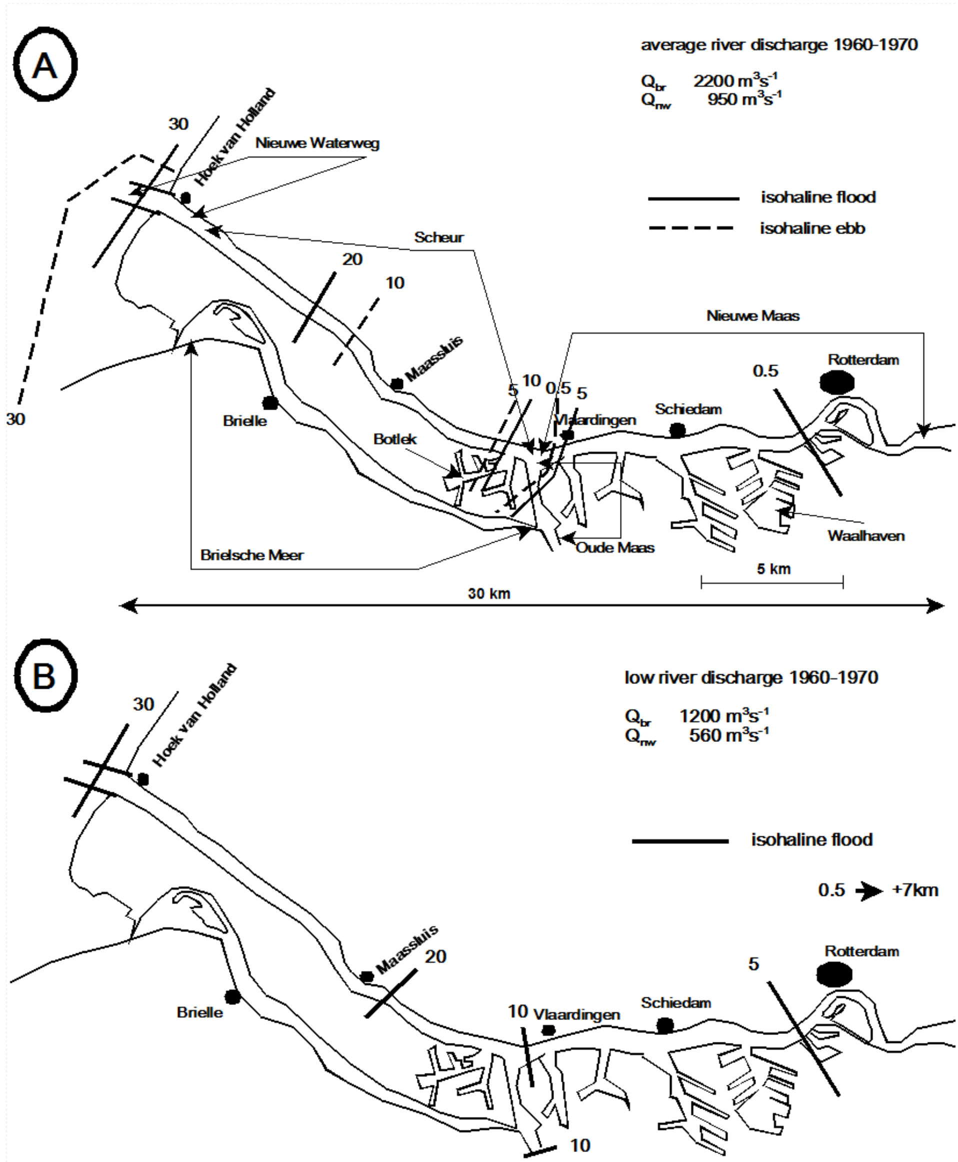


**Figure 12** Isohalines (S) at the bottom in the Noordrand in between 1960 and 1970 (redrawn after Wolff, 1973). A. at average discharge at the Dutch German border. B. at low discharge at the Dutch German border. $Q_{br}$ = discharge at the Dutch-German border, $Q_{nw}$= discharge Nieuwe Waterweg.

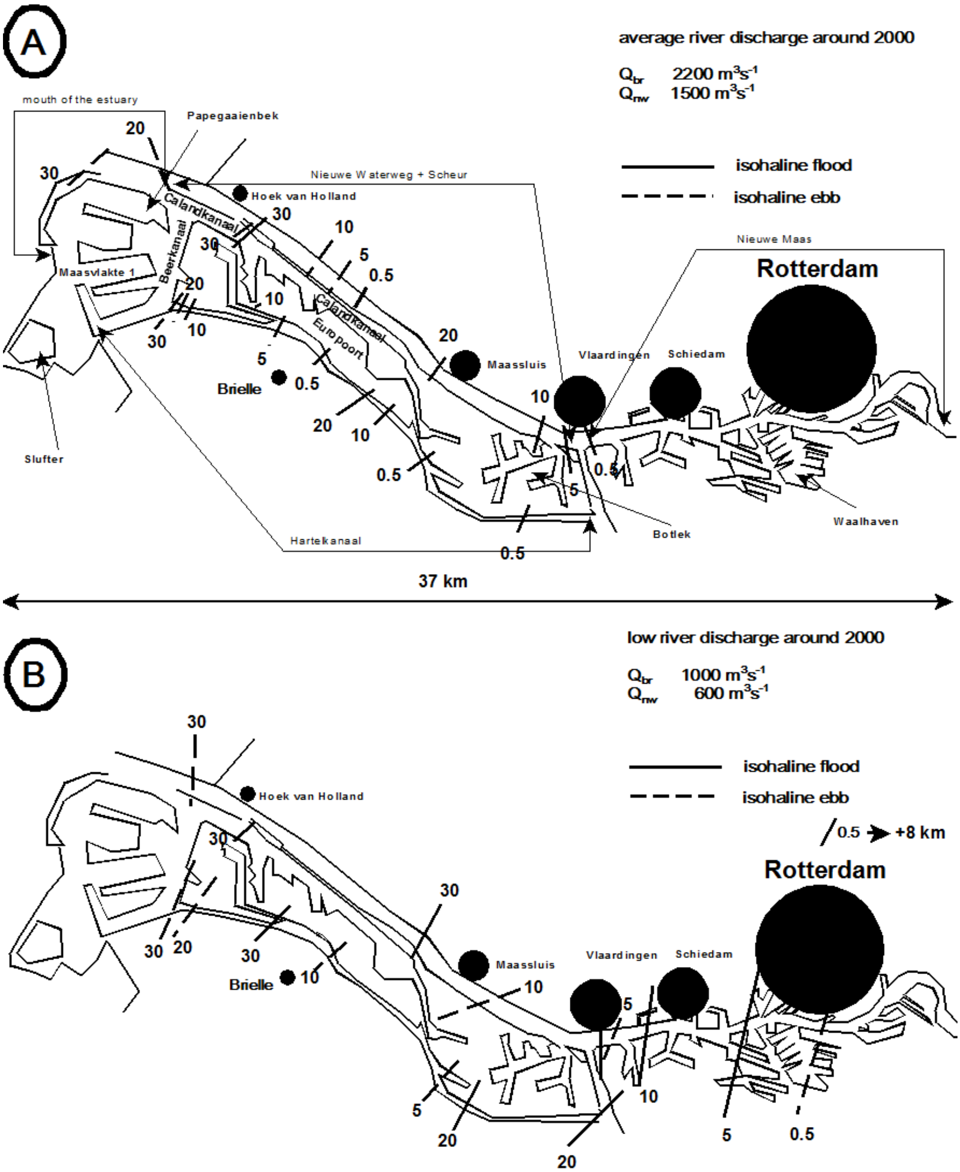


**Figure 13** Isohalines (S) at the bottom in the Noordrand in around 2000 calculated with the model RIJMAMO 3D (Bol and Kraak, 1998). A. at average discharge at the Dutch German border. B. at low discharge at the Dutch German border. $Q_{br}$ = discharge at the Dutch-German border, $Q_{nw}$= discharge Nieuwe Waterweg.

## Ecological monitoring

The pollution of water and soil in the period after WWII, especially in the 1960s and 1970s was the major reason for the neglectance of ecological studies in the Noordrand (Den Hartog, 1963a, Wolff, 1973, Heerebout, 1974). During that period the port of Rotterdam area was considered as almost biologically dead. There are a few exceptions. For example before and after the closure of the inlets of the delta region inventories of higher plants along the banks have been taken place by members of the KNNV (the Royal Dutch Society for Natural History) and employees of the DIHO (Delta Institute for Hydrobiological Research). The data gathered are included in the Atlas of the Dutch Flora (FLORON, 2012). Den Hartog (1959) and Nienhuis (1974) have paid attention to the algae of the littoral zone of the area. Further Den Hartog (1963b, 1964) investigated the amphipods in the Delta region and found the talitrid amphipods *Orchestia cavimana* and *O. gammarella* along the Nieuwe Waterweg and Nieuwe Maas but no gammarid amphipods. Gammarids were only found on the piers in the mouth of the Nieuwe Waterweg. Further fauna records are anecdotal for example the first observation of the Chinese mitten crab (*Eriocheir sinensis*) in the harbours Rotterdam and the mouth of the Nieuwe Waterweg in 1931 (Kamps, 1937), the Brackish water mussel *Mytilopsis leucophaeata* (syn. *Congeria cochleata*) in the harbour of Maassluis in 1946 (pers. comm. Wim Kuijper) or the Dog whelk (*Nucella lapillus*) on the northern pier at Hoek van Holland (Smits, 1954). No studies were carried out in the Nieuwe Waterweg, Scheur or Nieuwe Maas. Only on a few occasions the hard substrate of the pier of Hoek van Holland at the mouth of the Nieuwe Waterweg was investigated (Wolff, 1968). In the years after the large inlets (Oosterschelde, Grevelingen and Haringvliet) as part of the Delta project were closed more floristic and faunistic research in the Noordrand has been conducted in particular in the context of the monitoring of the chemical and ecological condition of the Dutch water bodies (MWTL) (Boogaart-Scholte et al., 2012). Within the Noordrand there are a small number of measuring points but the harbours were excluded, in spite of the fact that they comprise the major part of the water surface of the area. Platvoet and Pinkster (1995) studied the distribution of various amphipod species in the Delta region in 1992 and found several talitrid and gammarid amphipod species along the Nieuwe Waterweg and adjacent harbours and the Nieuwe Maas. Ecological investigations have taken place within the harbours along the salinity gradient only on an ad hoc basis, for example the investigation of the flora and fauna of the littoral zone in Beer-, Caland- and Hartelkanaal and Nieuwe Waterweg by Paalvast (1998). This has led to some insight into the functioning of the harbours as an estuarine ecosystem, but due to the lack of consistency no deeper insight could be derived.

**Outline of this thesis (Fig. 14)**

Land reclamation, urbanisation, industrialisation and harbour development have radically changed the Noordrand as part of the Rhine-Meuse estuary from a soft to a hard substrate environment made of asphalt, stone, concrete, wood and steel. This environmental change from soft to hard is the underlying theme of this thesis.

From the middle of the 14th century to the construction of Maasvlakte 1 in the 1960s there was only awareness of the demands for shipping, port, industrial and urban development. Until the middle of the 19th century this had no serious consequences for estuarine nature, but with the industrial revolution this changed rapidly. In about one century, the ever changing dynamic estuary with its typical flora and fauna has been transformed into a massive hardened environment.
How and how quickly have these changes taken place? What characteristics of the estuary have been lost and what has come in its place? In **chapter 2**, the historical demise of the estuary using the disappearance of the estuary distinctive soft substrate ecotopes and the rise of hard substrate ecotopes related to port development, industrialization and urbanization is described.

The policy of the port of Rotterdam, international collaboration and a stricter environmental legislation drastically reduced the pollution of water and sediment. In particular the ban on the aggressive biocide TBT (tributyltin) from 1 January 2003 following the decision taken by the International Maritime Organisation has created possibilities for estuarine nature to recover. As water and sediment quality improved in the port area over the last decades, many plant and animal species have settled on the new hard substrates. The shipworm *Teredo navalis*, a wood boring bivalve mollusc is a threat to wooden structures in the port area, in particular fir and oak wood where many quays of the old harbours are build upon. The question is, is the shipworm still present in the port of Rotterdam area since its first appearance in the Dutch coastal waters in 1730 (Vrolik et al., 1860)? In **chapter 3** the distribution of this species in the port area and the growth of first year individuals in various types of wood are described.

The shipworm, *T. navalis*, drills in wood and depending on the type of wood may reach a length of 60 cm during its three year lifespan (Sordyl et al., 1998, Hoppe, 2002). But why it needs wood? Does it pierces in timber to use it as food or only to protect itself from predators. A stable isotope approach is used in **chapter 4** to answer to this question.

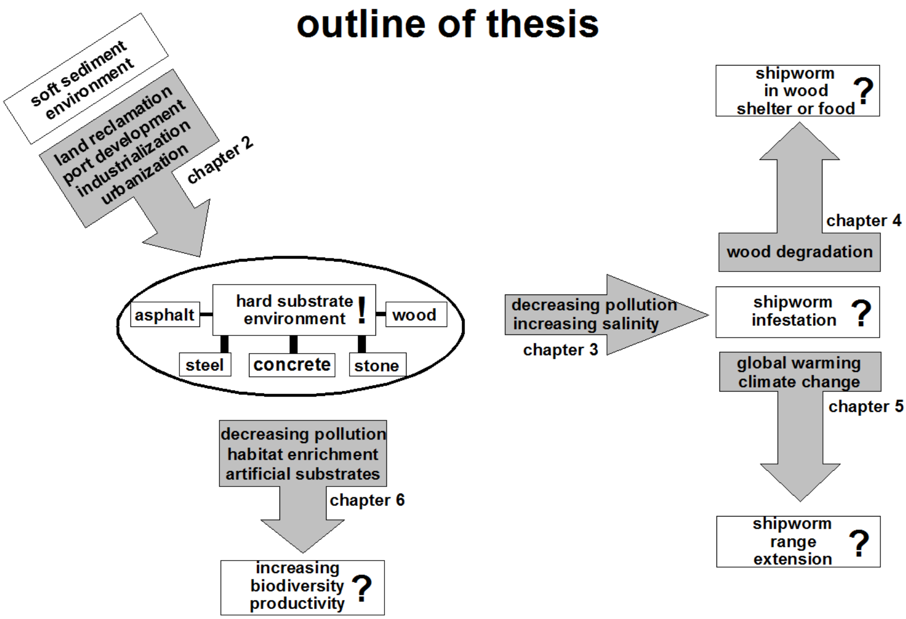


**Figure 14** Schematic outline of the thesis.

Dredging for greater depth for shipping as mentioned above has led to a further penetration of the salt wedge stream upwards. At low river discharge brackish water penetrates the old harbours of the eastern part of the port of Rotterdam where quay walls are built on fir and oak piles. This might create conditions favourable for the shipworm to settle and grow. Climate change by global warming could result in long-term low to very low river discharges in summer. This may cause the shipworm to become a real threat to the stability of quay walls, but also for other structures made of wood, such as sluice gates and mooring poles. The sea level rise, also a consequence of climate change may exacerbate this.
But how serious will be the threat of the shipworm *T. navalis* to wooden structures in the harbours of the port of Rotterdam at global warming? In **chapter 5**, a risk analysis is made for damage caused by the shipworm in the

old harbours of the city of Rotterdam based on the KNMI (Royal Netherlands Meteorological Institute) climate change scenarios (Van den Hurk et al., 2007).

The harbours of the port of Rotterdam are designed exclusively for the berthing of ships and the transhipment of goods. No structural provisions are made neither intertidal nor subtidal for aquatic flora and fauna. A development of a stable soft bottom fauna by the ever continuing disturbance of the sea floor by dredging and boat propellers is impossible. However, with relatively simple means in sheltered environments, for example under jetties and pontoons, structure-rich habitats can be created, that might strengthen the biodiversity and productivity of the estuarine ecosystem of the port, now pollution is no longer limiting. One of the remedies could be rope structures around mooring poles and under pontoons and piers. The results of a pilot study described in **chapter 6** could bring clarity if habitat enrichment with this kind of structures really has an positive influence on biodiversity and -productivity in harbour systems.

In **chapter 7,** the outcome of the study is discussed in a broader perspective and compared with developments elsewhere.
Further improvements of the harbour environment by structural habitat enrichment are delineated that could make the port of Rotterdam a haven for estuarine nature.

## References

Anonymous, 1911. Nota's betreffende het zoutgehalte der Nederlandsche benedenrivieren van Rijkswege waargenomen in 1907 en 1908. Met 31 bijlagen. Uitgegeven door het Departement van Waterstaat.

Bogaart-Scholte, M.W.M.,Van der Weijden, M.H., Naber, A., Wetsteijn, L.P.M.J., Roos, M., 2012. MWTL Meetplan 2012. Monitoring Waterstaatkundige Toestand des Lands. Milieumeetnet rijkswateren. Water, Wegen, Werken, Rijkswaterstaat.

Bol, R., Kraak, A., 1998. MER Beheer Haringvlietsluizen. Over de grens van zout en zoet. Deelrapport Water- en Zoutbeweging. ISBN: 903694871. RWS, notanummer: apv 98/093. 212 pp.

Brolsma, J.U., 2006 "Havens, kranen, dokken en veren." De Gemeentelijke Handelsinrichtingen en het Havenbedrijf der gemeente Rotterdam, 1882-2004. PhD-Thesis, University of Leiden, the Netherlands.

Den Hartog, C., 1959. The epilithic algal communities along the coast of the Netherlands. Wentia, 1: 1-241.

Den Hartog, C., 1963a. The amphipods of the deltaic region of the rivers Rhine, Meuse and Scheldt in relation to the hydrography of the area part I. Introduction and hydrography. Netherlands Journal of Sea Research, 2: 29-39.

Den Hartog, C., 1963b. The amphipods of the deltaic region of the rivers Rhine, Meuse and Scheldt in relation to the hydrography of the area part II. The Talitridae. Netherlands Journal of Sea Research, 2: 40-67.

Den Hartog, C., 1964. The amphipods of the deltaic region of the rivers Rhine, Meuse and Scheldt in relation to the hydrography of the area: Part III. The Gammaridae. Netherlands Journal of Sea Research, 2: 407-457.

Dillingh, D., Baart, F., De Ronde, J., 2012. Is er al versnelde zeespiegelstijging? H2O, 45: 37-41.

Floron, 2012. Nieuwe atlas van de Nederlandse flora. Floron, Nijmegen. ISBN 9789050114134.

Heerebout, G.R., 1974. Distribution and ecology of the Decapoda Natantia of the estuarine region of the rivers Rhine, Meuse and Scheldt. Netherlands Journal of Sea Research, 8: 73-93.

Hoppe, K., 2002. *Teredo navalis* – The cryptogenic shipworm. In: Invasive aquatic species of Europe. Distribution, impacts and management. Leppäkoski, E., Gollasch, S., Olenin, S. (eds.). Kluwer Academic Publishers, The Netherlands, 116-119.

Kamps, L.F., 1937. De Chineesche wolhandkrab in Nederland. PhD-thesis, University of Groningen.

Kuijper, C., Van der Kaaij, T., 2009. Herstel van de "trapjeslijn" in de Nieuwe Waterweg en de Nieuwe Maas. Fase 1: Voorstudie naar de effecten op de zoutindringing. Deltares, Delft.

Nienhuis, P.H., 1975. Biosystematics and ecology of *Rhizoclonium riparium* (Roth) Harv. (Chlorophyceaea: Cladophorales) in the estuarine area of the rivers Rhine, Meuse and Scheldt. PhD-thesis, University of Groningen, the Netherlands.

Paalvast, P., 1998. Ecologische waardering van de oevers in het Rotterdamse havengebied. Calandkanaal, Beerkanaal, Hartelkanaal en Nieuwe Waterweg. Ecoconsult. In opdracht van het Rijksinstituut voor Kust en Zee, Middelburg. Rijkswaterstaat, directie Zuid-Holland.

Platvoet, D., Pinkster, S., 1995. Changes in the amphipod fauna (Crustacea) of the Rhine, Meuse and Scheldt estuary due to the 'Delta Plan' coastal engineering works. Netherlands Journal of Aquatic Ecology, 29: 5-30.

Rijkswaterstaat, 2004. Huidige situatie en autonome ontwikkeling Rijn-Maasmonding. Beschrijving hydraulische, morfologische en scheep-vaartkundige aspecten in het kader van 'ruimte voor de rivier'. Rijks-waterstaat, Directie Zuid-Holland. Hoofdgroep Planvorming Water AP. Notanummer AP/2004/15.

Smits, H., 1954. Purperslakken aan de mond van de Nieuwe Waterweg. Het Zeepaard 14: 33-34.

Sordyl, H., Bönsch, R., Gercken, J., Gosselck, F., Kreuzberg, M., Schulze, H., 1998. Dispersal and reproduction of the shipworm *Teredo navalis* L. in coastal waters of Mecklenburg-Western Pomerania. Deutsche Gewässer-kundliche Mitteilungen, 42: 142-149.

Van den Hurk, B., Klein Tank, A., Lenderink, G., Van Ulden, A., Van Oldenborgh, G.J., Katsman, C., Van den Brink, H., Keller, F., Bessembinder, J., Burgers, G., Komen, G., Hazeleger, W., Drijfhout, S., 2007. New climate change scenarios for the Netherlands. Water Science & Technology, 56: 27-33.

Van Os, A.G., 1993. Density currents and salt intrusion. Delft Hydraulics.

Vrolik, W., Harting, P., Storm Buysing, D.J., Van Oordt, J.W.L., Von Baumhauer E.H., 1860. Verslag over den Paalworm, uitgegeven door de Natuurkundige Afdeeling der Koninklijke Nederlandsche Akademie van Wetenschappen, Amsterdam, 153 pp.

Wolff, W.J., 1968. The Echinodermata of the estuarine region of the rivers Rhine, Meuse, and Scheldt, with a list of species occurring in the coastal waters of the Netherlands. Netherlands Journal of Sea Research, 4: 59-85.

Wolff, W.J., 1973. The estuary as a habitat. An analysis of data on the soft-bottom macrofauna of the estuarine area of the rivers Rhine, Meuse and Scheldt. Zoölogische Verhandelingen, 126: 1-242. Brill, Leiden.