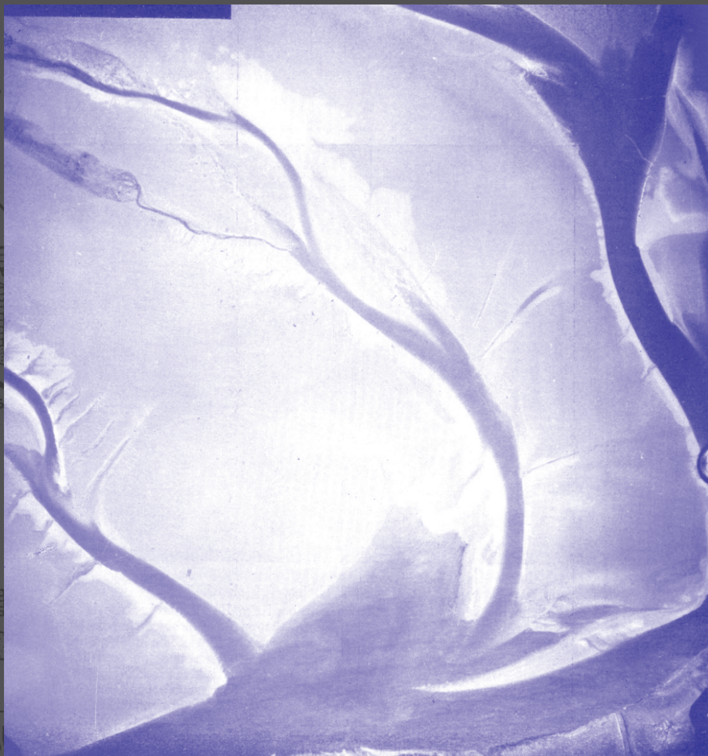
Johan van Veen

Ebb and Flood Channel Systems in the Netherlands Tidal Waters



ENGLISH TRANSLATION OF THE ORIGINAL DUTCH TEXT WITH ANNOTATIONS

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Introduction

Johan van Veen was a man of wide interests. Although he was trained as a civil engineer, he took interest in and published on a variety of subjects, such as historical geography, geology, land reclamation, climate, land subsidence, sampling equipment, etc. He worked with Rijkswaterstaat, the national water-management authority of The Netherlands, for most of his career. Van Veen was an unorthodox scientist with enormous energy. We compiled a reference list of almost 50 papers. Moreover, Van Veen laid the basis for the development of several instruments, e.g. the Van Veen grab sampler, automatically registering current meters, and the electrical Analogon (a computer for tidal calculations that used the principles of electric currents). Van Veen was also one of the first scientists to recognize the importance and possibilities of the echo sounder. His suggestions in the early 1930s contributed to the development of this instrument. Van Veen's character can be described as resourceful, untiring, persistent and even headstrong. His strongly developed sense of responsibility, in combination with little patience with officialdom, led to conflicts with his superiors at Rijkswaterstaat. These conflicts have overshadowed his great contributions to the disciplines of coastal dynamics and coastal engineering.

Van Veen started out investigating the tidal motion, sediment transport and changes in chlorine content in the Dutch estuaries and tidal inlets, and along the adjacent coast, making use of extensive measurements of discharges, sand motion and density profiles. The purpose of this research was getting to know the natural dynamics in the estuaries, in order to understand the system and to be able to improve the conditions for navigation (Van Veen, 1956). A major issue discussed by van Veen was sediment supply to the Netherlands coast. A first synopsis of his knowledge is given in his thesis "Onderzoekingen in de Hoofden in verband met de gesteldheid der Nederlandse kust" (Research in the Dover Straits in relation to the condition of the Netherlands coast), which he defended in Leiden in 1936. Van Veen was awarded the gold medal of the "Bataafsch Genootschap voor proefondervindelijke Wijsbegeerte" (Batavian Society for empirical Philosophy) for his thesis. The influence of his supervisor, the geologist G.B. Escher, is reflected in his interdisciplinary research approach. Van Veen combined disciplines such as field study, laboratory experiments, historical studies, etc., to get an overview as wide as possible and to be able to find practical solutions to various water-management problems. The experts in those fields did not always appreciate his concern with disciplines other than his own. There are many examples of debates, discussions and replies in the literature.

The present paper, "Eb- en vloedschaarsystemen in de Nederlandse getijwateren" (Ebb- and flood-channel systems in the Dutch tidal waters), which was published in 1950, should be considered as Van Veen's most important publication since his thesis. It summarizes the results of 20 years of intensive study of estuarine and tidal-basin morphodynamics in The Netherlands. The paper is testimony to Van Veen's keen observational and artistic skills. His approach is nearly "Da Vincian" in the sense that he is not only a fascinated but also sharp observer of nature and tries to capture the essentials of the dynamic behavior of complex coastal systems in apparently simple sketches. Many of the natural systems that

Van Veen studied have been regulated since; thus, this paper contains a set of irreplaceable, high-quality observations on the natural dynamics of tidal systems. Along with Robinson's (1960) paper on ebb-flood channel systems, it forms an excellent introduction to the study of channel dynamics in estuaries, tidal inlets, and tidal basins.

Unfortunately, Van Veen's paper was published in Dutch, with only a brief summary in English. Luckily, the figure captions were given in both Dutch and English, allowing international researchers coming across the paper to read it as a kind of 'cartoon'. Understandably though, the paper has received very limited recognition in the international literature. So far, we have traced only 8 publications in which reference is made to this paper (see the reference list on page 53). The majority of these publications have Dutch-speaking (co-)authors. Geyl, one of these authors, gives an extensive summary of van Veen's results in his 1976 paper, conscious of the obscurity of the original paper. Ludwick (1972) refers to an English translation of Van Veen's paper that we have not been able to trace. Usually, reference is made to Van Veen's paper to define ebb- and flood channels in estuaries and tidal inlets. However, his paper contains much more information that should be available to the international research community. Translation of this paper has been the subject of several discussions between Graham Evans, formerly of Imperial College, London, and one of us (AvdS). Until recently, a translation was not undertaken, however.

The present publication is a tribute to Professor Kees d'Angremond, who retired on November 28, 2001, from the chair of Coastal Engineering (Faculty of Civil Engineering and Geosciences) at Delft University of

[A1] Van Veen's mission in this article is clearly to display his ideas on ebb and flood channel dynamics. As an introduction he sketches his view on the Netherlands Holocene evolution, which does not coincide with our present views. We have to realize that in 1950 there was little insight into Holocene sea-level rise and the Holocene evolution of The Netherlands' coastal system. Systematic investigations into sea-level rise didn't start until the mid-1950's. We note that Van Veen initiated the investigations on Holocene sea-level rise in The Netherlands by Jelgersma as part of the Delta Works and well-thought

Technology. We have seized this occasion to publish an English version of Van Veen's paper. The translation is annotated in order to put it in the perspective of our present-day ideas on coastal dynamics. It contains contributions by several researchers involved in tidal-basin research, notably Hans Bonekamp, Edwin Elias, Anneke Hibma, Co van de Kreeke, Mattijs van Ledden, Dano Roelvink, Henk Schuttelaars, Huib de Vriend and Zheng-Bin Wang, edited by Ad van der Spek, Marcel Stive and Tjerk Zitman.

Delft, September 2002

Ad van der Spek
Marcel Stive
Tjerk Zitman.

geological reconstructions based on field data started in the early 1960's. The statement of Van Veen that our coast was in principle a lagoon-type coast is not untrue, but as it appeared the various coastal sections had this lagoon mode at different stages. Obviously, his interpretation was based on the present Netherlands' topography, assuming that sea transgression took place over this topography.

In the present-day view on the Holocene evolution of the Netherlands coast, tidal basins were formed in the low-lying valleys of the late-glacial landscape due to the fast rise in sea level. The high areas between these basins acted as 'headlands' which were slowly eroded away. Most of the basins silted up after a strong reduction in the rate of sea-level rise around 6000 years before present (BP). In a later stage new transgressions, caused by the slowly but continuously rising relative sea level (relative sea-level rise is the product of absolute sea-level rise and land subsidence) took place. For an overview of the holocene evolution of the Dutch coast, see Beets and Van der Spek

[A2] Van Veen suggests that the secondary barrier was formed by wave action. This is not correct. The "secondary wadden" originally were not seperated from the present-day Wadden Sea. They were filled in with sediment by tidal action and evolved into salt marshes. These salt marshes were predominantly sandy at their sea-ward margin, whereas the landward parts were predominatly clayey. Differential compaction of these deposits resulted in a higher elevation at the seaward side of these salt marshes. These high-lying parts are Van Veen's 'secondary barrier'. These sandy parts were gradually reworked by waves, resulting in the formation of sand ridges and sand spits (see below).

[A3] Van Veen uses the word 'alluvial' to give an age to these zones. The name Alluvium was used in contrast to Dilluvium. The first period was younger than the second. Nowadays, we would refer to these periods as Holocene and Pleistocene.

[A4] Legend: 'zeeopp.' = seasurface; 'duineiland' = dunebarrier; 'wad (zout)' = lagoon (salt); 'kleigordel' = clay ridge; 'veen (zoet)' = peat (freshwater).

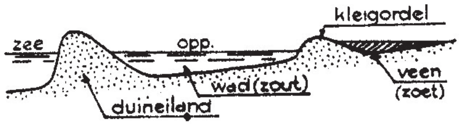


Figure 1 Sketch of the 4 alluvial [A3] zones: dunes, wadden, silt, peat (fresh water) [A4].

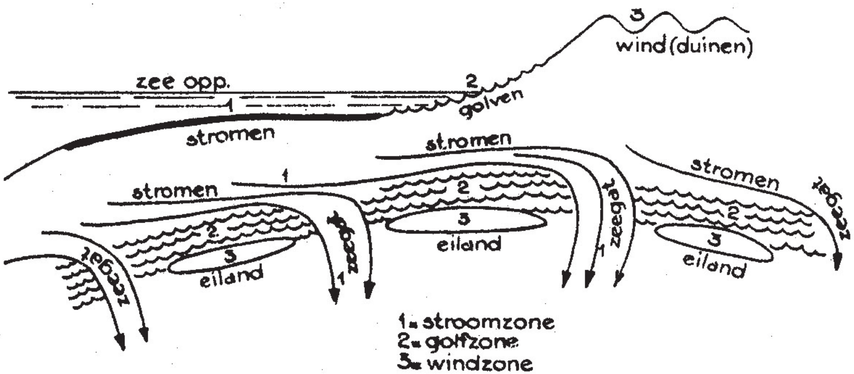


Figure 2 Sketch of the 3 vertical regions in an offshore bar: those of the currents (1), the waves (2) and the wind (3).

[A5] NAP (Dutch ordnance level), which is approximately Mean Sea Level. At the Dutch tidal coast stations deviations are 7 cm at the most.

Ebb and Flood Channel Systems in the Netherlands Tidal Waters

In principle our coast is a lagoon-type coast (Figure 3) **[A1]**. The initially whimsically formed sandy coast, with its very gently sloping profile - too gentle to be sustained along a sea with tidal and wave actions - was given a string of barrier islands by the action of the North Sea waves and tides, separated by inlets. Behind these was the wad, a secondary sea (lagoon), which - itself also having wave action - created a low, wide secondary barrier **[A2]** that we now refer to as the clay ridge. The "secondary wadden" behind this ridge could be filled with peat, as salt water could no longer penetrate this area (Figure 1).

As a result we have 4 zones: 1, the dune barrier, 2, the wadden zone, 3, the clay ridge, 4, the peat zone. The dune and the clay ridge are congenerous in that they are repeatedly breached embankments. Near breaches one can distinguish 3 regions in the vertical plane: 1, the current-dominated region, 2, the wave-dominated region, 3, the wind-dominated region (Figure 2).

The transitions are at approximately 2.5 m - and 2.5 m + NAP **[A5]**, i.e. approximately at the seaward boundary of the surf zone and at the foot of the dune. Obviously the transitions are rather vague since the zones merge smoothly. In region 1 we observe ebb and flood channel systems, which are discussed below. In region 2 the forces of wave turbulence and oscillatory wave motions are active, seeking to form a beach-barrier. In region

3 the Aeolian forces work to form dunes. Wave action promotes the development of a continuous smooth barrier while tidal currents obstruct this. The compromise is an interrupted barrier, which constitutes the well-known string of barrier islands.

Along the secondary clay barrier one does encounter regions 1 and 2, but the wind-action region is absent. The wave-action region, in as far as it concerns the lee-side of a basin, is observed in the form of rather low shore ridges. At the weather-side one can expect east-west oriented spits or ridges. An example of this is the silted Fivelbay, where - to my opinion – subsequently two 'head' (or leeward) ridges and three spits **[A6]** have been formed (Figure 4). Their common name is levees, although this term is rather more associated with the levee of a river.

Figure 3 The chain of sand-dune islands (or wadden-islands) along the Lowland coast in Roman (?) times. The fillings of the tidal flats (wadden) with peat and silt, are omitted.

In the South (Flanders) the original lagoon area was small (Figure 3). It disappeared in historical times as a result of sedimentation and peat formation. Along Zeeland (Zwin to Helinium) a mix of land and lagoonal area remained until present **[A7]**. The main part of the mouth of the Rhine (Rijn) silted up and just north of Monster an unusually fresh water area existed in recent geological times due to the presence of water from the Rhine. In this fresh water area - protected by a wide and solid dune ridge[4] - a peat landscape could be maintained **[A8]**. This centrally located wadden area

[A6] Van Veen uses the name 'tail ridges' for the three ridges formed by spit growth due to alongshore sand transport

[A7] Reconstructions of the Holocene evolution of Zeeland show that this area had silted up almost completely by 3100 BC (before Christ). The area changed into a large coastal peat bog that was dissected by the river Scheldt. From

c. 200 AD on 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 recognised in present-day Zeeland.

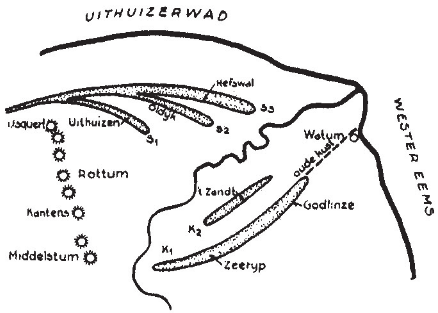


Figure 4 Shore Ridges, due to wave-effect, in the now silted-up mouth of the Fivel in the silt-zone of the province of Groningen. Left "tails", right "heads"[3].

[A8] After silting of the wadden in Central Holland, a totally different peat landscape was formed. Originally, a coastal peat bog with formation of eutrofic peat existed here. This peat bog was depending on the groundwater level and the changes in it. Subsequently, this peat bog was replaced by forest peat along the rivers and a moor in the areas inbetween. The first depends on the supply of river water, the latter on rainfall.

[A9] This is a very important statement! It forms the basis of the present-day reconstruction of the Holocen evolution of the Netherlands coast.

[A10] Von Freitag Drabbe was a cartographer who was interested in histori-

[3] The mounds (in a row) are "wierden", built on an ancient coast. "Hef" is oldfashioned Dutch for sea; "rijp" for "high bank", and "wal" is equivalent to "wall".

[4] Also this long "island" has been breached in fairly recent times (Von Frijtag Drabbe) [A10].

was so strongly influenced by the Rhine that it acquired an unusually thick peat filling. Only at Alkmaar does the clay ridge emerge. It extends far to the east and it has been breached at many locations. This clay ridge, or secondary shore ridge, could be inhabited by means of dwelling mounds. The peat region – which includes the presently so important Holland region between Alkmaar and Rotterdam-Delft - was not developed until after the invasions of the Vikings.

East of the Vlie the dune coast appears never to have been closed sufficiently to allow for peat formation directly behind the dunes.

Breaches have not so much been due to active marine forces, but rather the result of the passive (Pleistocene inherited) presence of low-lying basins behind the clay or shore ridge. As soon as the tides gained access to such a basin, a channel was scoured in a matter of decades. Not the tidal channels, but rather the tidal prisms are of primary importance **[A9]**.

The general appearance of a sea breach is therefore a broad, sometimes virtually round basin in a peat area (Zuiderzee, Biesbosch at its largest extension, Dollard, Jade basin) and a relatively narrow neck (channel) in the scour-) resistant clay ridge. The (discharge capacity of a tidal channel depends on the size and shape of the basin and also on the magnitude of the tidal range.

It is, however, not entirely correct to assume that the tidal range itself is the determining factor, since the tidal prism is determined by the elevation difference between the water levels at times of slack water. In deltas and coastal inlets, flow reversal occurs approximately one hour after high tide and one hour after low tide, implying that generally the famous cos $\varphi = 0.9$ needs to be applied, which is also familiar in the field

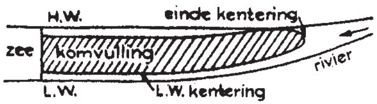


Figure 5 Tidal fill of an estuary is usually not the contents of the tidal basin between high tide and low tide but that between the levels of slack water.

of electricity **[A11]**. The flow is indeed caused by the surface slope but cannot follow it directly and lags. Consequently the slack water levels are closer to each other than the water levels at high tide and low tide (Figure 5).

One should be aware that the volume of water, stored upstream of some cross-section, is determined by the volume displacement through this cross-section between the moments of the local flow reversal. Therefore the water levels at slack water rather than the water levels at high tide and low tide determine the filling and emptying of the basin (Figure 6). In tidal basins without freshwater discharge, slack water at the boundaries occurs everywhere during high tide and low tide. However in basins with a discharge, the factor of approximately 0.9 again usually applies instead of the complete basin content **[A12]**.

Figure 6 The lines of slack water are generally at a distance of 0.9 x tidal amplitude; in deep, wide estuaries less, in seas the distance is zero.

cal maps. He published for instance on the accuracy of (a medieval copy) of the Peutinger map, a map of the important travel routes in the northwestern Roman empire. Unfortunately, we have not been able to find a publication that fits this reference.

[A11] The volume of water that flows through a cross-section into an estuary or out again with the movement of the tide, excluding any freshwater, is referred to as the tidal prism of that cross-section.

$$P = \int_{LWS}^{HWS} Q dt \qquad (1)$$

in which LWS refers to time of low Water Slack and HWS refers to time of high Water Slack. *Q* is the discharge at the mouth.

Van Veen suggests that the tidal prism *P* as defined by Eq. (1) is approximately a factor cos $\varphi = 0.9$ smaller than the volume, *V*, between the water levels at times of local High Water and Low Water. For the mouth the relationship between *V* and the water levels translates into

$$V = \int_0^L (A_{HW}(x) - A_{LW}(x))dx \qquad (2)$$

in which L = length of estuary; A_{HW} = cross-sectional area at time of local High Water; A_{LW} = cross-sectional area at time of local Low Water.

That $P < V$ follows from the relationship between *P* and the cross-sectional areas of the basin at time of slack water at the mouth:

$$P = \int_0^L (A_{HWS}(x) - A_{LWS}(x))dx - \int_{LWS}^{HWS} Q dt \qquad (3)$$

in which A_{HWS} = cross-sectional area at time of High Water Slack at the mouth, A_{LWS} is the cross-sectional area at time of Low Water Slack at the mouth and Q_r is the river discharge. The right hand of Eq.(3) is smaller than the right hand side of Eq.(2) because $A_{HWS} \leq A_{HW}$ and $A_{LWS} \geq A_{LW}$. Therefore $P < V$.

Values of the ratios *P/V* for the mouths of the estuaries/tidal lagoons Western Scheldt, Humber, Eyerlandse Gat and Amelander Zeegat, calculated from 1D network tidal flow models, are respectively, 0.86, 0.88, 0.98

and 0.95. Values that are close to the value of 0.9 but do show variations from one estuary to the other.

An interesting point is that van Veen relates the constant 0.9 to "the renowned cos φ used in the electricity". At the time that numerical hydrodynamic models did not exist Van Veen was a strong proponent of using electric circuits to simulate tidal flow (see Van Veen, 1946). Most likely refers to the phase difference between the current and the emf of an electric circuit consisting of an inductance, resistance and a capacitance forced by an *emf* $E = E_0 \sin \omega t$.

[A12] Complete basin content stands for the volume between HW and LW behind the cross-section considered, which as explained in annotation [A11] differs from the tidal prism based on ebb- and flood discharge volume.

[A13] A flood depression may simply be considered the result of a narrow neck channel decreasing the outside forcing surface amplitude in a backbarrier basin with relatively large intertidal area. This mechanism is probably the reason for rapid transgressions in coastal areas. It can be illustrated by the expansion of tidal basins and the drowning of settlements in Zeeland between 600 BC and 300 AD due to scouring of the tidal inlets (see Vos and van Heeringen, 1997).

[A14] Based on our current insights in the geological reconstruction of the Holocene evolution of the Dutch coast we can state that the importance of the wind direction in the morphological lay-out of the Zeeland and Wadden basins is much less than Van Veen claims. The current geometry is very much so a result of human intervention. Originally, all tidal basins were orientated more or less shore-normal. In the Wadden area, reclamation of the salt marshes which had been formed at the landward ends of the tidal basins finally resulted in a more or less continuous west-east running sea dike (the now dammed Lauwerszee was still open then). In the Delta area, silting of the landward parts of the tidal basins and estuaries did not take place, partly due to the influence of the rivers

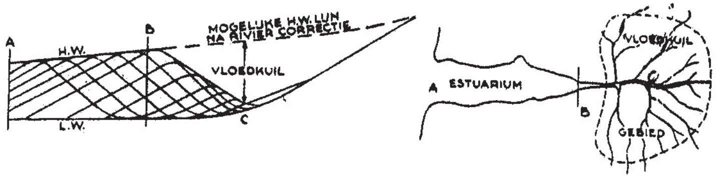


Figure 7 A "flood depression" occurs in those areas where the tide (or stormtide) cannot enter fully, due to some bottle-neck. The floods become higher there, when dredging is done in the bottle-neck, or when the tidal fill of the area above the bottle-neck is diminished by reclamation works.

If the neck of the flood basin (the basin inlet channel) is rather narrow, which is often the case since the clay ridge has not been completely eroded, a so-called flood depression occurs in the peat region of the flood basin.

A flood depression **[A13]** is a supra-tidal or an inter-tidal area where the high tide or the storm surge does not reach the water levels as experienced seaward. Especially during storm surges the neck may be too narrow relative to the basin dimension to be filled completely (Figure 7).

In our environment flood depressions occur (or have occurred) in the river Scheldt to the south of Antwerp, in the Biesbosch estuary, in the former Zuiderzee, in the Ems at Leer, et cetera. During a storm surge, the water depth in a flood depression may reach up to 1 to 2 m. Flood depressions are comparatively unsafe areas. Whenever dredging or scouring enlarges the neck or when reclamation reduces the tidal prism, local storm surge levels increase.

The tidal basins that still exist in our country display a different form in the North than they do in the South. A tidal basin is bordered by the mainland coast and by the tidal divides of the Wadden isles. In the North the mainland coast is often located not far from the barrier islands, while in the South this distance is larger. Also, due to the larger tidal range, the tidal prisms are large in the South and as a result the tidal channels became wide and deep. Schematically the differences between North and South are illustrated in Figures 8 and 9 **[A14]**.

The fact that, in contrast to the North, land has accreted along the tidal divides of Zeeland should largely be explained by the orientation of the tidal divides relative to the dominant wind direction. The dune barriers in the South functioned as a shelter to the dominant westerly storms, while those in the North did not. Also the strength of the wind (proportional to the wind velocity squared) will have played a role, since the wind in Zeeland has approximately half the strength it has in the North (the wind velocity itself is about 1.4 times as low). In the North even the remainder of the island of Griend nearly disappeared **[A16]**; the stretched barchan-shaped island has now been split in two. Stimulated by human action, accretion has taken place continuously around the tidal divides in Zeeland. On the other hand, meandering **[A17]** and breaching have caused substantial erosion. Transverse channels cut right through the accumulations around the tidal divides in Zeeland. They sustain the necessary compensatory flows caused by the Northwise decreasing tidal amplitudes and the differing flow resistances in the coastal inlets (Kreekrak, Sloe, Zijpe, Slaak, Hellegat).

The channel systems formed in the tidal basins display tree-type shapes that are reminiscent of slim poplars in Zeeland (Figure 8) or of scrubland. In the North they are reminiscent of low apple trees (Figure 9) **[A18]**. If one considers the 'tree' as being the Western Scheldt, then the trunk is a wide channel that meanders from the left to the right bank, with branches stretching along the banks. Such branches are called flood channels.

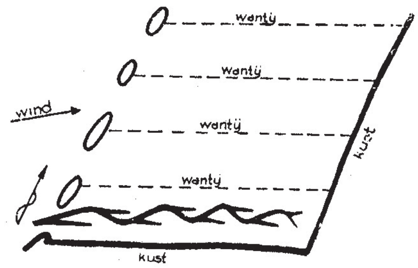


*Figure 8 Sketch of the tidal basins in Zeeland. short dune-islands, long flood basins parallel to the prevailing wind (poplar-shaped channel system) **[A15]**.*

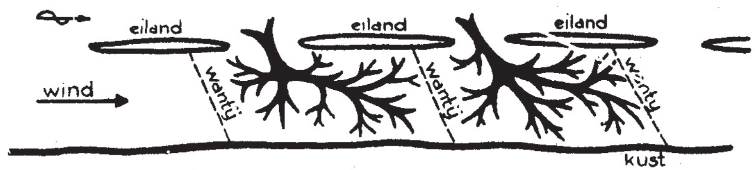


Figure 9 Sketch of the Frisian tidal basins; short basins, perpendicular to the prevailing wind (apple-tree shaped channel system).

Rhine, Meuse and Scheldt. Here, sedimentation and subsequent reclamation predominantly took place in the tidal divide areas between the basins.

[A15] Reference is made to annotation [A32].

[A16] The island of Griend has since been maintained by human intervention, such as dune enforcement and groins.

[A17] Within the morphological context meant by Van Veen, the term 'meandering' refers to the natural phenomenon that curved channels expand continuously away from their centre as a result of centripetal sand transport induced by the spiral-type flow in these channels. In his english captions to the figures, Van Veen calls it 'bend action'.

[A18] The observed similarity by Van Veen between apple trees and the channel systems in the North is recently confirmed by means of a fractal analysis for the Dutch Wadden Sea (Cleveringa and Oost, 1999). The basic hypothesis behind a fractal analysis is the (statistical) scale invariance of the geometrical properties of a complex pattern. Patterns found in nature (e.g. trees, mountains, mud flocs) may seem unstructured at first sight, but they appear to be described quite well by fractals. Cleveringa and Oost (1999) showed that also "channel systems can be regarded as 'statistical self-similar fractal' networks, considering the natural variability in branch lengths and channel positions" (cit.).

[A19] In our translation, we follow Van Veen and use flood channel for "vloedschaar" and ebb channel for "ebschaar" (as he did in his English captions to the figures), although the word branch is probably a more appropriate translation of "schaar" (literally: scissors) than channel.

[A20] Basically, Van Veen has used the foregoing text as an introduction to what should be considered the core of this article, the dynamics of ebb- and flood channels in tidal basins and estuaries.

[A21] Legend: 'drempel is delta ebschaar in delta vloedschaar' = sill is ebb-channel delta in flood-channel delta.

[A22] Legend: 'drempel' = sill.

[A23] Note that the gross sediment circulation in such cells is an order-of-magnitude larger than the residual sediment transport along the estuary lateral axis.

[A24] After Van Veen's description of the estuarine ebb and flood channel systems he now pays attention to the seaward side of the inlet systems. His obvious interest into the suitability of tidal basins for navigation seems to be central here.

Definition: A "vloedschaar" (flood channel **[A29]**) is a tidal channel that is open to the flood current and that exhibits a sill at the upstream end. An "ebschaar" (ebb channel **[A19]**) is a tidal channel that is primarily open to the ebb current and that exhibits a sill at the seaward end.

Therefore, the word 'schaar' refers to a channel that shallows in one direction, but it might be originally derived from the gradual process of an outer bend erosion. One may speak of the "vloedschaar" (=flood channel) and of the "ebschaar" (= ebb channel). Besides ebb and flood channels, there are also 'continuous main channels'. To simplify matters, I have maintained the dual and not the tripartite division. All channels I have designated either as a flood channel or an ebb channel. For example, the main channels were ebb channels on the left and flood channels on the right. I have sketched the transition approximately in the middle.

An eye-catching feature of flood and ebb channels is that they seem to evade one another **[A20]**.

In some cases an ebb or flood channel splits into two branches embracing the oncoming channel (Figure 10). In other cases the two opposing channels move sideways and approach each other in a sort of flank attack (Figure 11). One reason for this is opposing sand transport; another is meandering (see Figure 24).

Most probably a flood driven sand flux dominates in an ordinary flood channel, while this is the case for an ebb-driven sand flux in an ordinary ebb channel. Where the ebb and flood channel meet the opposing sand fluxes form a sill. One could refer to this as the 'battle of the deltas'.

Most probably a flood driven sand flux dominates in an ordinary flood channel, while this is the case for an ebb-driven sand flux in an ordinary ebb channel. Where the ebb and flood channel meet the opposing sand fluxes form a sill. One could refer to this as the 'battle of the deltas'.

Of course the sand transport pattern is more complicated than the brief description above. The tidal motion oscillates the sand as on a sieving grid. A so-called residual transport or drift results. Near ebb and flood channels sand eddies usually occur, with the sand moving upstream in a flood channel and downstream in an ebb channel. A sand eddy is a circulating sand motion in the sense that it is an oscillating sieving motion, not necessarily circular in shape, but such that the same grain may return eventually to the same location (Figure 12). The real motion is closer to what Figure 13 shows.

Hydraulically a sill is a difficult problem. The flow of sand does not cease there and thus continues. Where the sand goes must be determined case by case. In some cases the sand is feeding the flats, in other cases it returns along the sides of the ebb and flood channels and other channels. This abundant sand transport indicates an excess of tidal energy, or rather a waste of this energy, since it is not used to create navigational depth.

At times it is rather difficult to recognize whether a channel is an ebb or a flood channel. Sometimes a channel has a sill at both ends. Such a channel is cut-off from the system, as it were, and may silt up eventually or play a secondary role in the system. Some subjectivity in schematizing the system of ebb and flood channels is inevitable. It is however a very instructive exercise. Especially if a series of bathymetric maps over a period of, for example, a century is available, one may learn much about the nature of the channel systems **[A24]**.

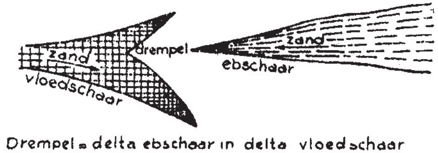


Figure 10 Sketch of the mutual "evasion" of flood and ebb channels by means of a forked tongue ***[A21]****.*

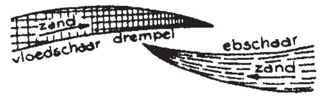


Figure 11 Sketch of mutual "evasion" with flank attack of flood and ebb channels ***[A22]****.*

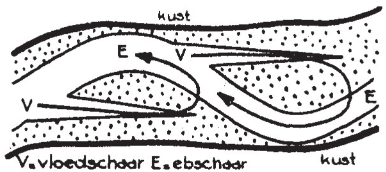


Figure 12 Sketch of so-called circulating sand currents, the sand moving up-stream in flood channel, down-stream in ebb channel ***[A23]****.*

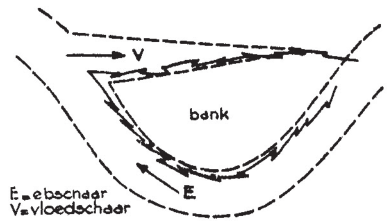


Figure 13 Sketch of the true up- and downstream movement of the sand in so-called circulating sand currents. A grain of sand may come back to its original place; dredging may be of small avail.

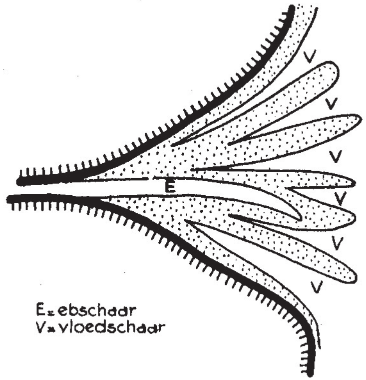


Figure 14 Sketch of ebb and flood channels in a wide estuary (Thames or Wash). Meander action may bring the ebb channel in connection with any of the flood channels.

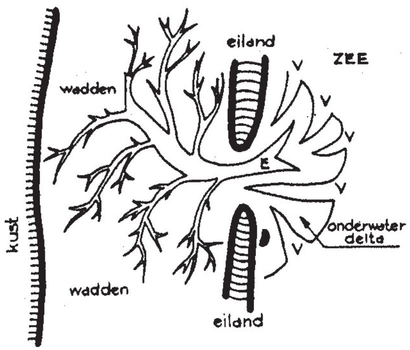


Figure 15 Sketch of ebb and flood channels in a typical submarine delta of the Dutch coast. Bottle-neck between dune-islands, several flood channels coming in; tendency of E to turn to the left due to the tide coming from the left ***[A27]***.

[A25] Van Veen refers to the Dutch Wadden coast.

[A26] Whereas in international literature these deltas are often named ebb-tidal deltas, the link with the ebb tide as the forming force is not made by Van Veen, or by many others in the Netherlands. In Dutch literature it is now common to refer to the ebb-tidal delta as outer delta. However, it is should be stated that either ebb-tidal delta (looking at the forming force) or following Van Veen shield delta (cf. the terminology list schilddelta), looking at its most prominent morphological role in the system, would be preferable.

[A27] In Sha and Van den Berg (1993) another explanation for the channel orientation is given. Along the Dutch Wadden coast the tidal wave has the character of a standing wave. The longshore tidal currents reach their maximum at about mid-tide water level. At mid-tide the tidal currents in the gorge also reach their maximum, filling or emptying the basin. This implicates that there is no phase difference between the tidal currents at open sea and in the gorge.

From the sea, a number of large flood channels try to penetrate the inlet, especially from the direction of the tidal wave. Initially the flood carries little sand and only starts entraining sand as it propagates shoreward. For a broad estuary like the Thames, one may expect therefore a configuration as indicated schematically in Figure 14. Mariners zealously search for the lowest sill between one of the flood channels and the ebb channel that exists in the estuary. At the subtidal deltas along our coast **[A25]**, also called 'shield deltas', one often encounters a form as indicated in Figure 15 **[A26]**.

Only occasionally do ships find a truly good connection between a seaborne flood channel and the main ebb channel. One such case is present in the Western Scheldt. The Eastern Scheldt, which has almost the same capacity **[A28]** as the Western Scheldt, already possesses a high sill between the main flood and main ebb channel at the tip of the dune of North-Beveland, called the Onrust **[A29]**.

Whenever the main ebb channel, or 'stem' **[A30]** splits into a flood and an ebb channel that start to flow alongside, two parallel channels develop with a new, obstructing sill in-between (see Figure 27). This splitting of the main ebb channel is a consequence of the excessive local width of the estuary, or in other words of insufficient guidance of the channel by the banks. Every natural channel of notable length will split, unless one is able to prevent this by training works or dredging. It is difficult to force an ebb channel and a flood channel into a one-channel system.

Where the width between the fixed banks is not too large, i.e. 3 to 5 times larger than the width of the main ebb channel, an attractive meandering main ebb channel will develop, which in the bends rests against the resistant banks. The flats in each inner bend will develop a flood channel. In the Western Scheldt this pattern repeats itself (up to Antwerp) some 10 times (Figure 16) and a couple of times in the Hollands Deep. Also, in the Wester-Ems this preferred system is observed (Figure 17), although the Northern bank at Emshorn was not protected.
It is the Ems which rebelled in the 19th century. When the Germans designated the straightly aligned flood channels as a future shipping lane, the Sill at Knock was dredged substantially. As a result, the bend at Watum developed into a secondary channel with sills on both ends. Dredging alone is already a powerful way of manipulating nature **[A31]**. It may be possible to create a ‘poplar’ with a straight trunk and curved branches, as indicated in Figure 18. However, this is unnatural since a straight ‘trunk’ receives insufficient support

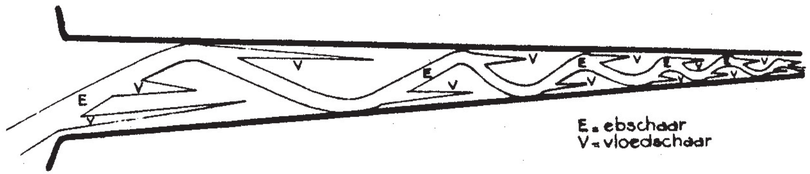


Figure 16 Sketch of an ideal system of ebb and flood channels (Scheldt estuary). sineshaped main (ebb) channel, flood channels starting in each bend. The latter have a double function; viz.: 1. filling the tidal sand-flat in the inner bend of the main channel; 2. serving the cut-off currents of the bend. Notwithstanding considerable scour the depths of the bars at the upper end of the flood channels are not permanently increased ***[A32]***.

The longshore ebb-current is directed from east to west. Meanwhile the basin is being emptied through the main ebb-channel in the gorge. Due to the combination of these currents, the outflow bends to the west. During maximum flood-current alongshore, the inflow is also concentrated at the west side of the inlet, as the longshore flood-current is from west to east.
[A28] With capacity Van Veen refers to the tidal prism. We note that since 1950 the tidal prism has been reduced due to the open barrier.
[A29] An impression of this sill and the surrounding channels can be obtained from Figure 29.

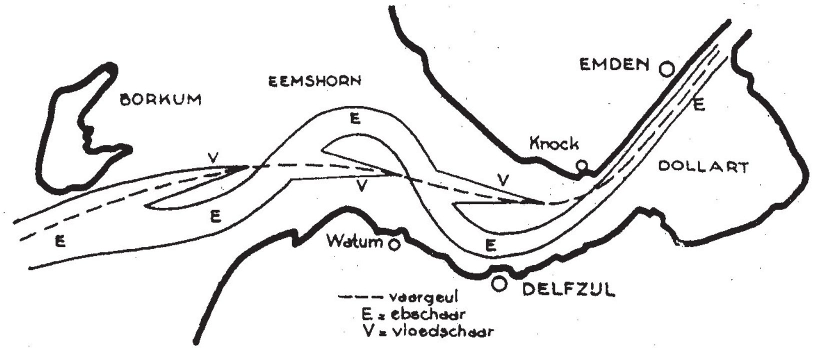


Figure 17 Sketch of the natural flood and ebb channels in the Eems-outfall. The Emshorn-bend is not stable, because it has no defended shore to lean against.

[A30] See his earlier comparison of tidal basin channel systems with tree-shapes. In the following paragraph, Van Veen considers the behaviour of the tidal channels to be governed only by the motion of water and sediment. However, the initial channel pattern usually is inherited from earlier phases in the evolution of an estuary. This is illustrated (unfortunately not very clear) in the evolution of the Westerschelde, see e.g. the channel ‘Schaar langs de Hoofdplaat’ in the figs. 26-28. This channel used to feed the Braakman, a large sidebranch of the Westerschelde. With the infilling of this sidebranch

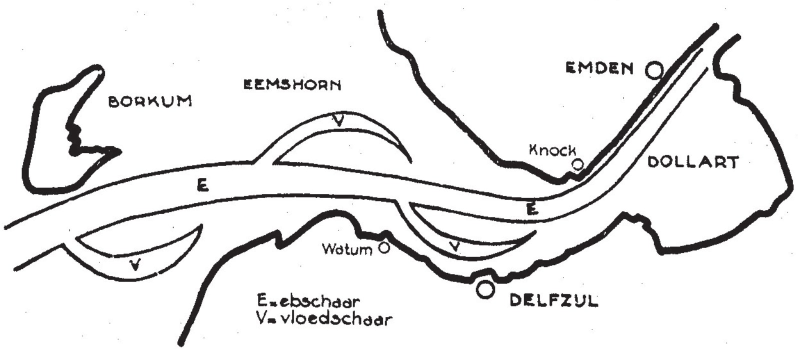


*Figure 18 What might be achieved in the Ems-outfall by dredging **[A33] [A34]**.*

and the subsequent damming of the remaining channel after 1950, this channel lost its discharge. This channel is now flood dominated and fits in Van Veen's sketch of an ideal system (see Figure 16).

[A31] 'Dredging alone is already a powerful way of manipulating nature.' This is typical for the approach of those days. Nowadays, compensation of nature values is an important issue in management studies of estuaries.

[A32] In Hibma et al. (2001) the formation of the channel and shoal pattern in a highly schematic estuary is investigated using a 2-D depth-averaged numerical model based on the description of the elementary flow and sediment transport processes. The emerging pattern shows a striking resemblance with this sketch of Van Veen. The model results suggest that, after the initial growth of certain perturbations in a relatively simple and regular pattern, a self-organisation process yields the much more complex channel/shoal patterns found in nature.

[A33] Translated literally, the Dutch caption says "Sketch of an artificial main channel with a straight stem and curved branches".

[A34] The current channel bathymetry of the Ems is very close to Figure 18.

[A35] 'Te loevert' is old Dutch for windward, in this case the upwind shore is meant.

[A36] In the following sections Van Veen first pays ample attention to the phenom-

from the curved banks.

One can only understand a system of tidal channels by keeping in mind the 3 main factors. These are: tidal prism (being the primary factor), meandering, sand transport. In addition, wind direction (wave action at the upwind side) and near-bank turbulence should be mentioned **[A36]**.

Meandering explains many of the changes that occur in a tidal channel system. Often large channels become stable only once they encounter a stone-protected bank. However, sometimes a meander may be cut off by natural processes on a tidal flat. In the absence of a bank or training wall that hampers formation of meanders, a bend may become so large that a cut-off occurs. One might have expected a cut-off much sooner because the flood channel is already present at the cut-off location, but a layman could easily be mistaken. The sill of a flood channel does not breach easily. Yet, as in the case of the former Hellegat (Figure 19), it is possible for the flood channel and an embryonal ebb channel to be temporarily aligned, thus forming the connecting channel E1-V without the presence of a sill. However, they separate again due to meandering of the ebb channel. At the Hellegat (Willemstad), the resulting repetitive cycle lasted for about 25 years, i.e. until a training wall was constructed that hindered meandering permanently **[A37]**.

In a tidal basin or in an estuary it is very rare for meanders to be cut off, i.e. a flood channel is seldom breached and when this does occur, it is of short duration and incomplete. The interesting feature is that the sill upstream of a flood channel maintains

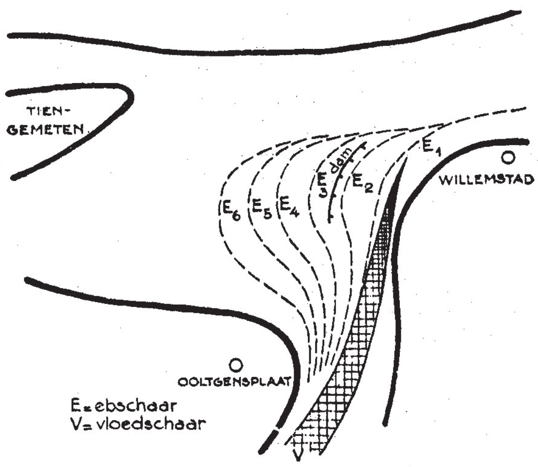


Figure 19 Sketch showing bend action in the Hellegat near Willemstad (N.-Brabant) before a training wall (or dam) was built in 1931. Once in about 25 years the bend was cut off and the cycle started anew. The training wall ended this meander-action.

its elevation. This occurs notwithstanding the fact that the flood channel is located exactly where the cut-off must be expected and that on the sill itself fairly large currents and large water-level gradients usually occur. Large sand transports on a sill are the probable cause.

Another example of a temporary cut-off and its demise, as occurs frequently in the Scheldt, is given in Figure 20. Imagine that at a certain instance a breach E_1 through the sill occurs causing a large ebb discharge onto the flood channel. Shallow-draught ships will follow this route, but due to meandering during ebb, E_1 will have shifted after a while to E_2, and subsequently to E_3 etc.

Ebb-flow related meandering shifts the ebb channel E_1, E_2, E_3, E_4, downstream, causing the water to follow an increasingly sharper bend. Gradually the angle with the main channel increases to approximately 90° and the ebb channel, which seemed so promising for navigation, disappears. However, when E_1 occurs again, the cycle (which

enon of meander action. Tidal prism is of course the primary driving force, but meandering is the phenomenon which determines the channel orientation and its evolution. Subsequently, the importance of the secondary mechanisms are treated.

It is certain (see furtheron) that Van Veen beside centrifugal forcing of meanders also was aware of the importance of Coriolis for larger bends, say with a radius in the order of 10 km. In his below description for tidal basins he explains bend orientation rather from the location of the tidal prism, which implies he sees centrifugal forcing as dominant. This is also clear in the Terminology Annex where bochtwerking ('Bend-action') is translated as centrifugal action and/or meander-action.

[A37] Van Veen was the engineer who proposed the construction of this training wall. It proved to be very successful.

[A38] This cycle of downstream migration of ebb channels is also found in other settings, e.g. in tidal inlets. In the Amelander Gat, the inlet between the Wadden islands of Terschelling and Ameland, the ebb channel that drains the western part of this tidal basin in one phase discharges in the main

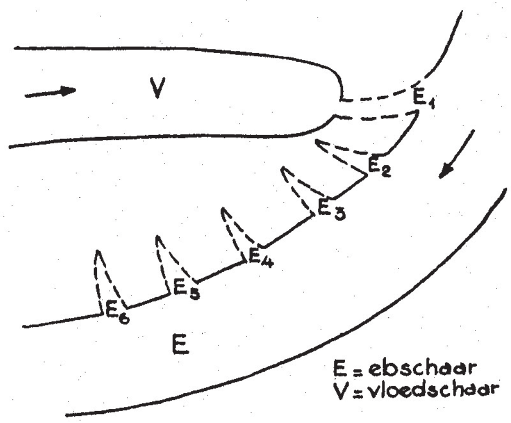


Figure 20 Sketch of a wandering ebb channel, starting in the bar of a flood channel. It is bend-action or meander-action again.

Figure 21 The coast is supposed straight. The direction of the tidal wave is W.-E.; therefore the wan-tides shifted to the East, so that the Eastern part of the basin and its tidal fill is larger than the Western, effecting a main ebb current from the East. Bend-action causes erosion of the "tail" A of the wadden-island.

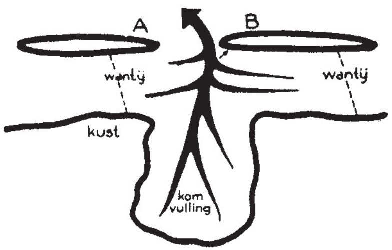


Figure 22 Here the coast is bent inward. In this case the Western part of the total basin is largest, so that the main ebb current comes from the West. Bend-action causes erosion of the "head" B of a wadden-island ***[A39]****.*

channel Borndiep. This ebb channel migrates downstream to form a second channel in the inlet. Subsequently this channel silts up and a new channel, discharging in the Boorndiep, takes over the discharge. After that, the inlet has only one main channel.

[A39] This situation existed in the past in the Friesche Zeegat, that was connected to the Lauwerszee, and in the Amelander Zeegat, when it was connected to the medieval Middelzee, a part of the Wadden Sea that has been reclaimed. Information on the bend-action described by Van Veen is not available, however.

[A40] With 'in our environment', Van Veen refers to the Dutch coast.

[A41] This seems to be an over-simplification. In the present-day situation the western side of Ameland is eroding. This is probably caused by the east-ward migration of the tidal divide south of Ameland. The erosion of the east side of Terschelling, the western island bounding this inlet, is caused by the cyclic downstream (= seaward) migration of ebb channels that has been discussed above.

[A42] There is no information available on this kind of evolution of small islands. It

can take some to many years) starts all over again **[A38]**.

Other examples of meandering are given in Figure 21 and Figure 22. Whenever a barrier island is aligned along a straight coast the tidal divide is located in our environment **[A40]** far to the east behind the island because the tide arrives from the West. In this case the eastern prism is larger than the western prism. During ebb, a channel with its bend in western direction develops at the inlet. However, if the western prism is larger, due to an indented back barrier coast or otherwise, a main channel will develop with a bend oriented eastward. Together with the wind from the West, this channel development threatens the 'head' of the eastern barrier island **[A41]**. A threat to the 'head' of a barrier island (Western side) is always more dangerous than that to its 'tail' (Eastern side), since the latter is usually new land and consequently not inhabited.

Whenever a short barrier island is located between two larger ones, the prism distribution may be such that the small island can be made to disappear due to meandering (Figure 23) **[A42]**.

Effect of the wind. The fact that wind may cause the migration of a tidal channel becomes clear when considering a water like the Hollandse IJssel **[A43]**. Even

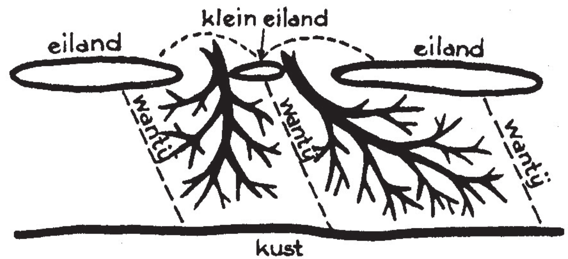


Figure 23 Small wadden islands may disappear when larger ones are its neighbours.

in this river with its comparatively firm, vegetated banks, all meanders migrated in north-easterly direction until they were stopped by the dikes. In this respect it is assumed that the dikes were originally constructed at some distance from the river bed.

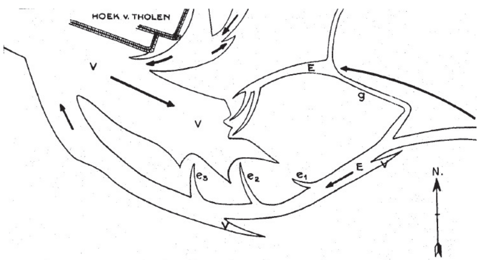
Near-bank turbulence. Yet another factor promoting channel migration is the defence of a bank by mattresses and groins. This generates turbulence that attracts the channels towards the banks as it were. The general tendency in the estuaries of Zeeland is therefore a deepening near the banks, which causes bank collapse and similar phenomena **[A44]**. It is like a vicious circle: bank protection causes turbulence, which in turn increases the need for protection. Evidently, the only effective measure is to tackle the primary cause, which is to reduce the tidal prism of the inlet in order to reduce the currents **[A45]**.

could only happen if both eroding processes were linear and not cyclic. Van Veen's implicit statement is that the evolution of barrier islands is governed by the evolution of the channels separating them. For the long-term perspective this is an important observation.

[A43] The Hollandse IJssel is a tidal river.

[A44] There is also an important geological component in the occurrence and frequency of bank collapses: they seem to be related to young, sandy channel infills that are exposed in the channel banks. Channel banks consisting of clayey and peat deposits appear to be more stable.

[A45] Reduction of tidal prisms is the general concept of the Delta Plan.



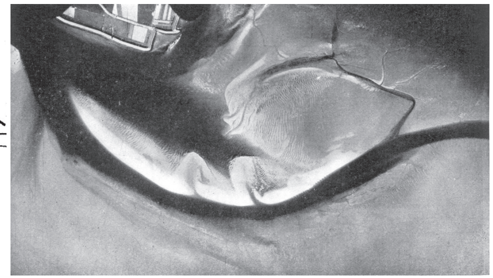


Photo 1. S.E.-corner of Tholen. (cf. sketch).

A flood channel V shoots by the South mouth of the Eendracht because it is too strong to take the sharp bend. In front of the end and besides the end it throws up the sand bar, which shows sharply white on the photo. The ebb channel E does not run directly into the flood-channel, but has to go round the sand bar and only joins the flood channel much lower down in its flank. This ebb channel has the bend-shape but apparently no caving, as there is no steep bank on the hollow side of the bend (tendency at the ebb towards the flood channel). Another ebb way runs via the small channel g along and through the North side of the sand bar. Three little secondary ebb channels, e1, e2, e3 run direct from the ebb channel into the flood channel through the sand bar; of these e1 is recently formed, e2 has properly developed (with a caving bend), and e3 is dying away. The secondary ebb channels flowing through the sand bar make little deltas along the terminus of the flood channel.

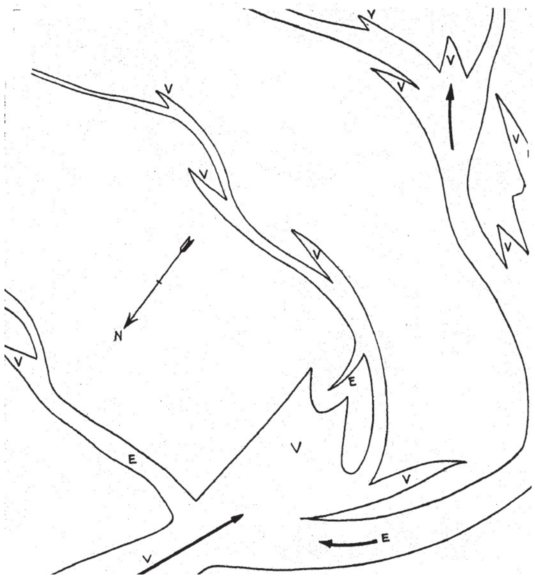


Photo 2. Wadden-channels (between the Westpolder [Groningen] and the East point of Schiermonnikoog). (cf. sketch).

The middle channel has the reguIar system by which flood channels come out of the bends of the ebb channel. The left-hand channel has also just such flood channel in a bend. From the lower left comes water at high tide which wants to flow straight on. The greatest right-hand ebb channel again bends round outside this flood channel and reaches it in the flank. The mouth of the middle ebb channel shows this inclination and does not take the shortest way. this ebb channel caused a fairly large delta and so gave the flood channel a forked shape. In the right-hand top corner the flood flows in at the point of confluence of two ebb channels and tries to alter this. Owing to insufficient sand being carried during flood this has not yet taken place. still the flood has caused erosion, but, as yet, no change of place of the mouth of the ebb channels.

Using these factors one may explain the complicated mechanism of tidal waters with sand transport from a more functional perspective.

For example, when a channel exhibits a simple S curve (Figure 24), the flood flow attacks the banks at AA and the ebb flow does so at BB. As

a result the channel soon splits into an ebb channel and a flood channel (Figure 11). When both channels are still curved, as most likely is the case, the bends could expand until certain functions are fulfilled, for instance related to the most efficient way of filling and emptying tidal flats or serving and establishing so-called compensatory flows and short-cut flows.
Therefore, in untrained bends where sand transport and bank erosion occurs, ebb and flood currents cannot coincide or maintain their individual positions: the cause is meandering or centrifugal effects.
The fact that sand transport amplifies the tendency to split is often a secondary but may sometimes be a primary effect. Secondary since sand transport is always caused by the presence of currents; primary since sand accumulates to form sills that affect the currents **[A47]**. Where two sand transporting tidal channels meet (or split) a sill develops in the least active channel. Flood channel deltas might be a better name for very prominent sills, like the ones that occur in the upstream end of flood channels. Sills and deltas are effects and also secondary causes.
While studying the ensemble of tide and sand one observes a round dance of cause and effect. I have not yet mentioned the causing factors: tide-induced variations in water level that cause the water to flow over the flats during flood and much less or not at all during ebb, the tendency of bends to cut off, which is always present even in the absence of an actual cut-off, the increase of erosion with depth, the compensatory currents due to transversal water level gradients, the Coriolis effect, etc. These phenomena all have effects: currents, channels, sand displacements and the like, and all these have effects again. 'Wer wagt es Rittersmann oder Knapp, zu tauchen in diesen Schlund?' (Schiller) **[A48]**. For those who dare it is best

[A46] These spliced channels can form a stable feature in estuaries. A contemporary of Van Veen, Ahnert (1960) described a chain of these cells in the Chesapeake Bay Area, which are also reproduced in simulations Hibma et al. (2001). All authors agree on the scheme of ebb- and flood-channels. Among the mechanisms behind this phenomenon, Ahnert described three dimensional density currents and historical causes, which cannot be subscribed by the work of Hibma et al.
[A47] Van Veen's struggle here (primary or secondary role of sand transport) refers to uncertainty about cause and effect. Is there a feedback mechanism or is it simply hydrodynamic forcing?
[A48] The German quote of Schiller translates: "Who dares, Rittersmann or Knapp, to dive into these muzzles?", indicating that Van Veen warns that it is not trivial to assess the cause-effect chain.
It is important to interprete the above statement against the spirit of the times of the 1950's. Taming the dynamics of nature applying hard engineering interventions was a common policy following centuries of collective action against flooding and navigation hazards.

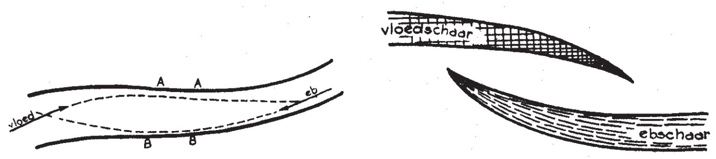


*Figure 24 Bend-action explains to a large extent splicing of a channel, or the birth of ebb and flood channels **[A46]**.*

[A49] This three-dimensional mechanism is proven not to be essential for this feature to exist, as in the patterns found by Hibma et al. (2001), identical bars in flood-channels occur, using a 2D depth-averaged model.
[A50] Van Veen refers to the Western Scheldt estuary.

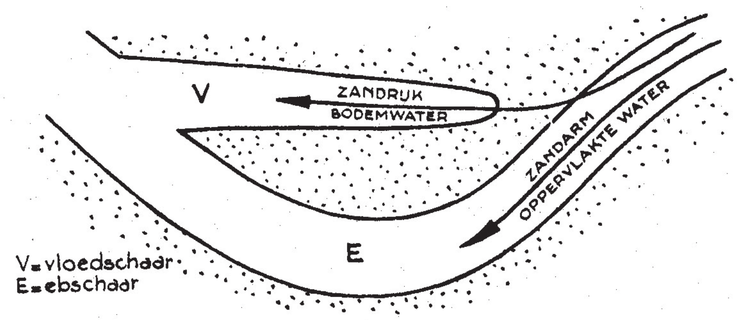


*Figure 25 The slow-moving heavy-laden bottom ebb currents can be "sucked off" into the flood channels more easily than the quick-moving sand-free top currents. This may be one of the reasons for the existence of bars in flood channels **[A49]**.*

to continuously ask oneself questions such as: Why is this channel stable or why isn't it? And to try to find answers to these questions, remembering that a why without a reason does not exist. As an example consider the afore-mentioned simple question: A flood channel is often an embryonal cut-off, but why doesn't it breach (Figure 25)? One may point out that the fast-flowing, sand-deprived surface water cannot follow the bend towards location V, while the slow sand-laden groundwater can. However there are more factors. We are still far from claiming that we have fathomed all the "secrets of the depths".

The goal of hydraulic engineers is to stabilize main channels as economically as possible. In natural estuaries meandering mobilizes much sand and channels lack time to deepen. Meandering is the major drawback of natural estuaries. Fixation of bends directs the tidal energy to the bed.

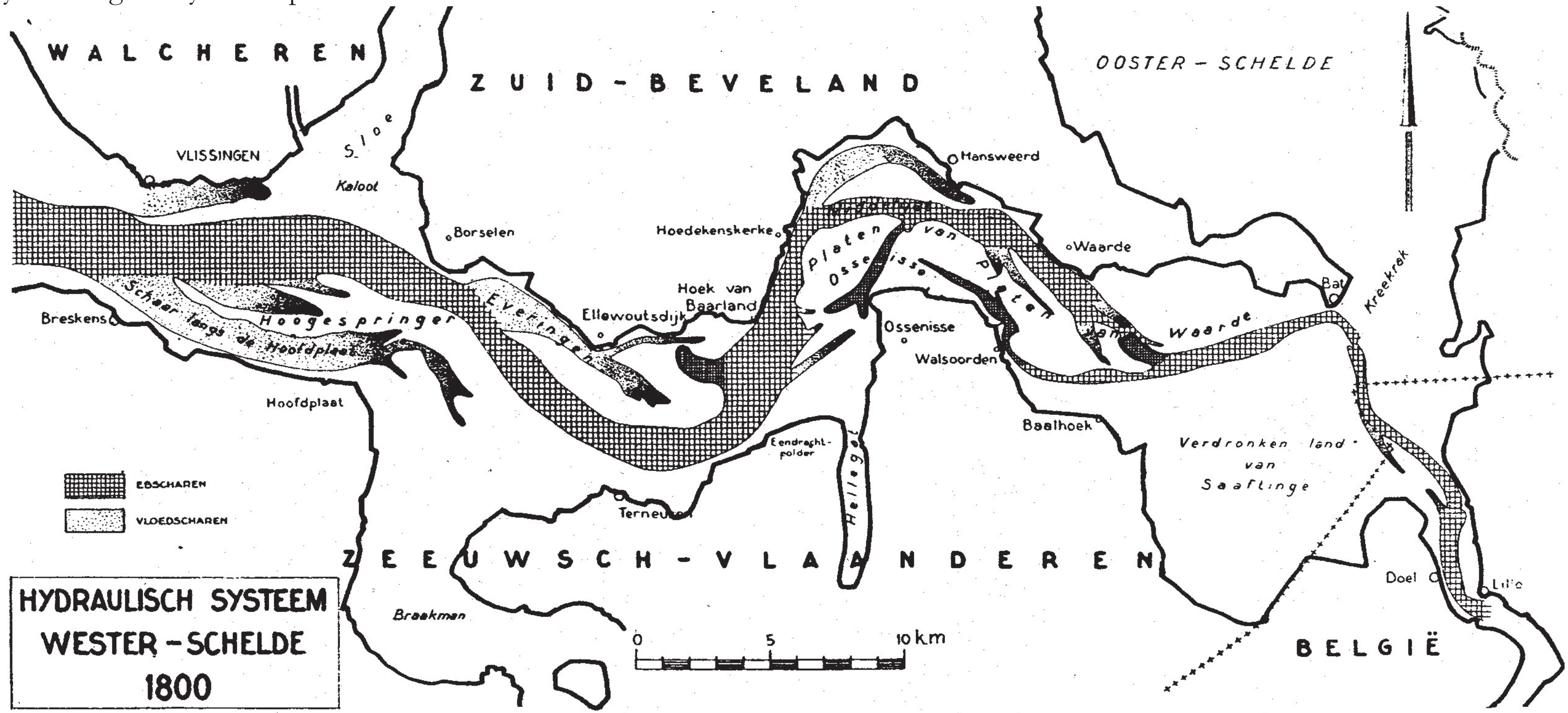
Whenever the banks exert no influence or inappropriate influence on the system of ebb and flood channels, the bends do not stabilize. In other words, the banks are situated such that the continuous ebb channel cannot develop.

The Scheldt estuary **[A50]** proves that a broad estuary can be regulated quite economically by simply stabilizing the main bends; the main channel's winding behaviour and the associated left and right emanating flood channels display a beautiful regularity reminiscent of the regular meandering between the banks of normally regulated rivers which discharge sediments. A good example is the river Rhine in Switzerland. The main channel and the sand banks are analogous, but obviously there are no flood channels through the sand banks.

Figures 26, 27 and 28 show sketches of the systems of ebb and flood channels of the Western-Scheldt in the years 1800, 1862 and 1938. Clearly such sketches are somewhat subjective, primarily since the elevations of the sills are absent. These sketches are intended to be of an instructive nature only.

Initially, in 1800, the system was rather 'wild', with the main channel not yet resting firmly on the protected banks and at some locations such banks

Figure 26 System of ebb and flood channels in the West Scheldt in 1800. Badly developed part between Hoedekenskerke and Baalhoek.



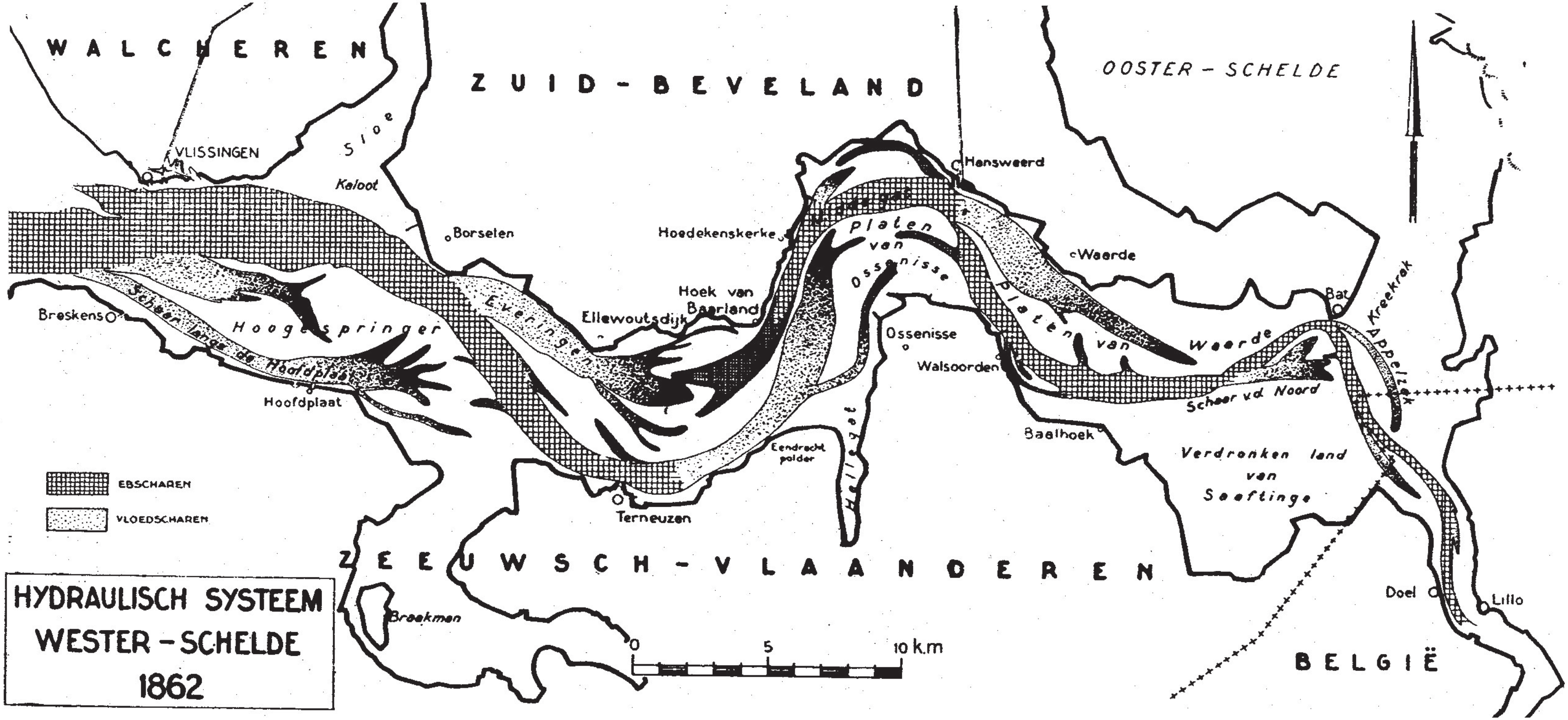


Figure 27 System of ebb and flood channels in the West Scheldt in 1862. Broken main channel near Baarland, badly developed channels near Hansweerd.

were even absent. In 1862 the main channel was interrupted due to the width of the river upstream of Terneuzen, but in 1890 this was restored by natural processes. In 1938 the general condition was far better than it was in 1800 or 1862. The Eastern Scheldt may serve as a counter example (Figure 29). There the regularity was largely absent; due to its more dynamic character the navigation hindering sills between ebb and

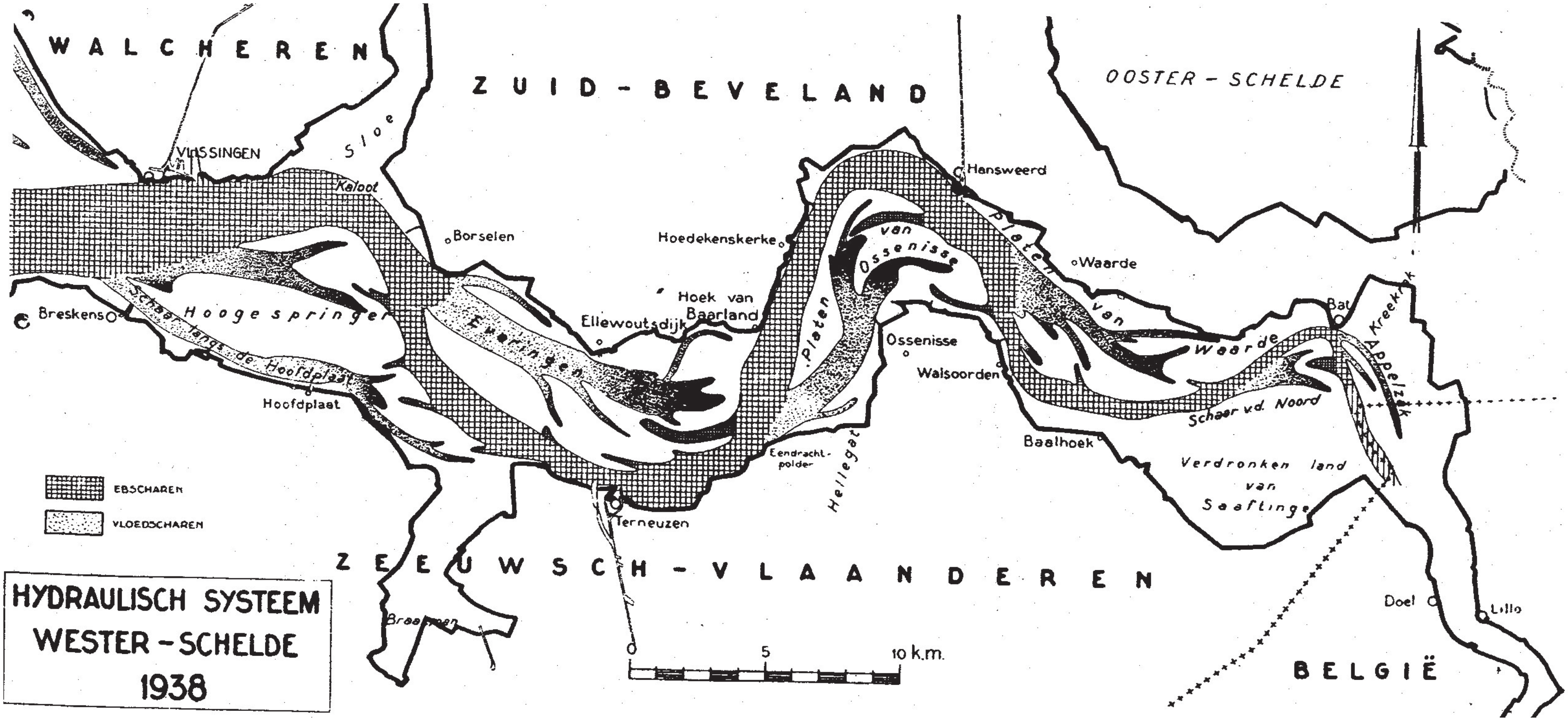


Figure 28 System of ebb and flood channels in the West Scheldt in 1938. Well developed system at last.

flood channels were often high. Maintaining the bend near Schouwen was unsuccessful at the time.

Protruding old groins or harbour moles (Walsoorden, Zierikzee, Middelharnis, etc.) are powerful obstructions, attracting currents. They force channels to merge, forming kinds of interchanges, the antipodes of the streamline principle. An example of this may be observed in Figure

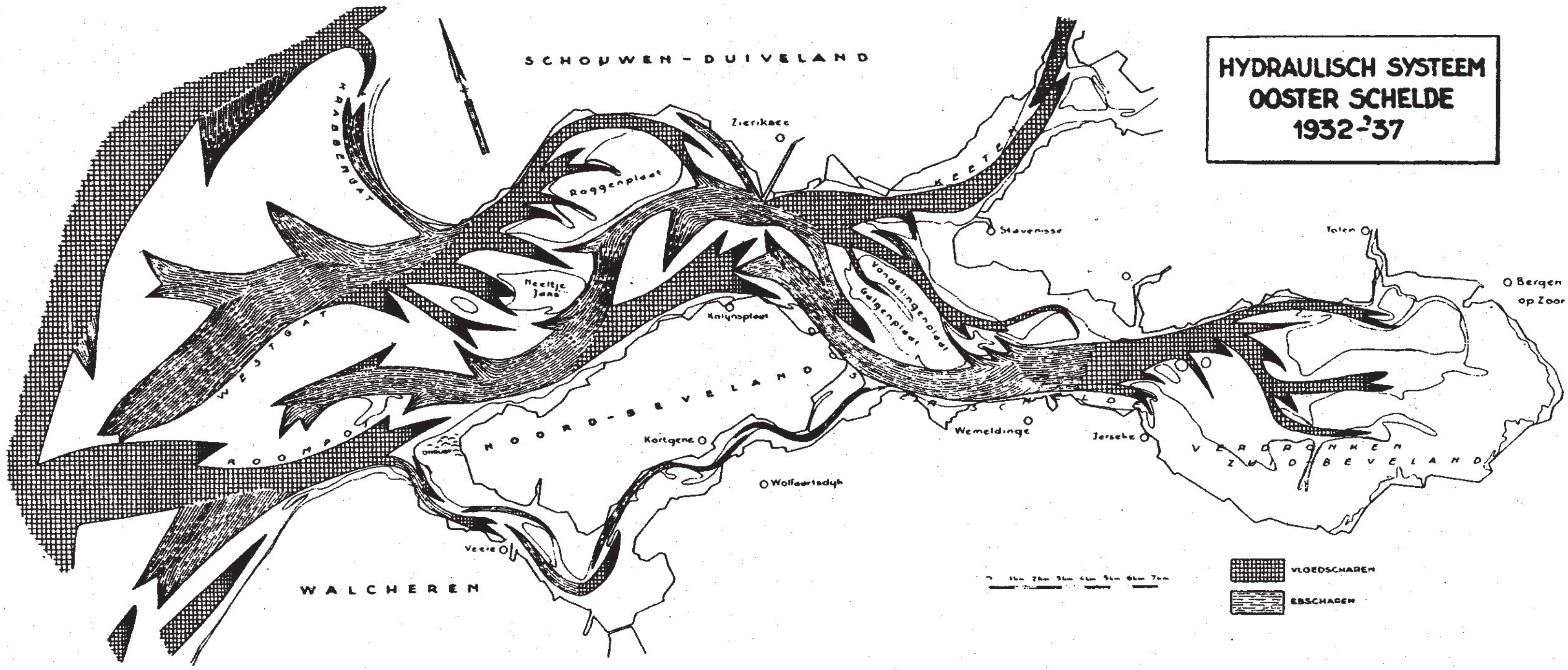


Figure 29 System of ebb and flood channels in the East Scheldt in 1937. Confused system, high bars near Onrust and Kolijnsplaat; shore-seeking channels.

29 at the harbour of Zierikzee. These interchanges were not intended as obstacles, but they were initially located on the shoreflats aiming at providing access to the harbour or to keep away a deep, outwardly curving channel. The latter almost always failed as a single long obstacle causes intensive turbulence.

SUMMARY [A51]

[A51] The summary and the terminology review are the original summary and terminology review added by Van Veen.

Ebb and flood channel systems in the Netherlands tidaI waters

The Dutch coast is considered as a Wadden coast. The Wadden (tidal flats, tidal sands) between Blanc Nez and the Elbe have been partly filled up with silt and peat (the latter grown in fresh or brackish water, of course), especialIy so in the region South of Amsterdam. In the North there are 5 zones: dunes, wadden, silt, peat, sand, of which the 1st and 3rd have a related origin. All tidal channels are divided into flood channels and ebb channels and different systems of these are treated. Their main characteristic is that flood channels seem to avoid ebb channels and vice, versa. This is partIy due to the opposed direction of the sand-streams in those different channels, which deposit their sand on the bar between them, partly it is the different meander action of ebb and flood.

TERMINOLOGY

Wadden: tidal flats, covered at high tide, Iargely dry at Iow tide; compare Engl. "to wade".
Wantij : meeting place of tidal waves behind an island; i.e. irreguIar, 'sickIy', tidal currents and a regular vertical movement of the water level. Compare Engl. wan = sickly, Skand, vanskabt, Dutch wanstaltig, etc.. Therefore wantij = wan-tide.
Kentering or kanteling: slack water or turnover. Compare 'to cant' in the meaning of turn over.
Komvulling or komberging: flood fill of a tidal basin between the high and low levels of slack water. (Fill of basin, Dutch "kom", has primary function in shaping a tidal channel).
Schoorwal: Off-shore bar, literally shore-wall; here a series of sand-islands forming a chain.
Vloedschaar: flood channel, open to the flood, a bar at its upper end.
Ebschaar: ebb channel, open to the ebb stream, bar at the lower end. Compare 'to scour'?
Schilddelta: Semi-circular submarine delta in front of each inlet or river mouth.
Bochtwerking: centrifugal action, meander-action.
Neer or maalstroom: slow maelstrom, maximum velocity at the outer side.
Wervel = vortex: maximum velocity in centre.
Zandstroom: intermittent, or non-intermittent stream of sand; in tidal waters an alternating movement with a "drift' or rest-stream towards the interior or towards the sea.
Zandneer: Circulating sand-stream, i.e. movement of the sand up in a flood channel, down in an ebb channel ; therefore not a gyratory or circular movement but a slow, intermittent movement where a sand grain after many weeks may return to the same place where it was before.
Drempel: literally sill, i.e. bar; often meeting-place of the two opposite sandstreams.
Vloedkuil: flood depression, or area where the high tides or storm-floods do not reach the heights they attain closer to the sea.

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Colofon

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Netherlands Centre for Coastal Research
In 1992 the coastal research groups of Delft University of Technology (TUD), Utrecht University (UU), WL | Delft Hydraulics and Rijkswaterstaat (RIKZ) engaged in a strategic co-operation programme, NCK (Netherlands Centre for Coastal Research). Some time later the Netherlands Institute of Applied Geoscience TNO (TNO-NITG) and the University Twente (UT) joined NCK, recently followed by the Netherlands Institute for Sea Research (NIOZ) and the Netherlands Institute for Ecology-Centre for Estuarine and Marine Ecology (NIOO-CEMO).
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Five Delft knowledge institutes, active in the field of civil- and hydraulic engineering, have combined forces to form Delft Cluster. Collaboration is in the form of an open network, whose aim is to develop and distribute knowledge in the field of sustainable development of densely populated delta areas. The core of Delft Cluster consists of GeoDelft, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE), Netherlands Organisation for Applied Scientific Research (TNO), Delft University of Technology (TUD), WL | Delft Hydraulics.
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