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Data on Temperature, Oxygen, Sediment and Transparancy of the Water in the Northern Part of the Delta Area of the Netherlands between 1961 and 1972

by

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ABSTRACT

A description is given of changes in temperature, oxygen content, suspended matter and transparancy of light in the waters of the northern part of the Delta area of the South-West Netherlands, during various phases in the realization of the Delta Plan between 1961 and 1972.

In the open estuaries a temperature gradient was established between the highly fluctuating rivers and the more stable sea. Temperatures in the closed, stagnant or semi-stagnant basins are almost equal throughout the length of the basin, but vertical stratification developed in the deeper parts.

In the original situation the concentration of suspended matter was very high in the water, not only owing to natural causes but also owing to dredging of sand and construction of dams. After the closures sedimentation of suspended matter took place. Accordingly Secchi-disc values increased after the closures in the stagnant basins. Transparancy of the water – measured with a radiation meter – was seen to increase as well.

INTRODUCTION

Two rivers, Rhine and Meuse, flow through the northern part of the Delta Area of the Netherlands (Fig. 1). The Rhine is fed by glaciers and by rainwater whereas the Meuse is exclusively a rainwater river. The discharge of the Rhine fluctuates relatively less through the seasons than the discharge of the Meuse. At every magnitude of the total discharge, 40% of the Rhine-water flows through the Nieuwe Merwede and mingles with the Meuse-water in the form of the total discharge of the Amer. In the long term the Nieuwe Merwede discharge fluctuates between 620 m^3/sec. and 1120

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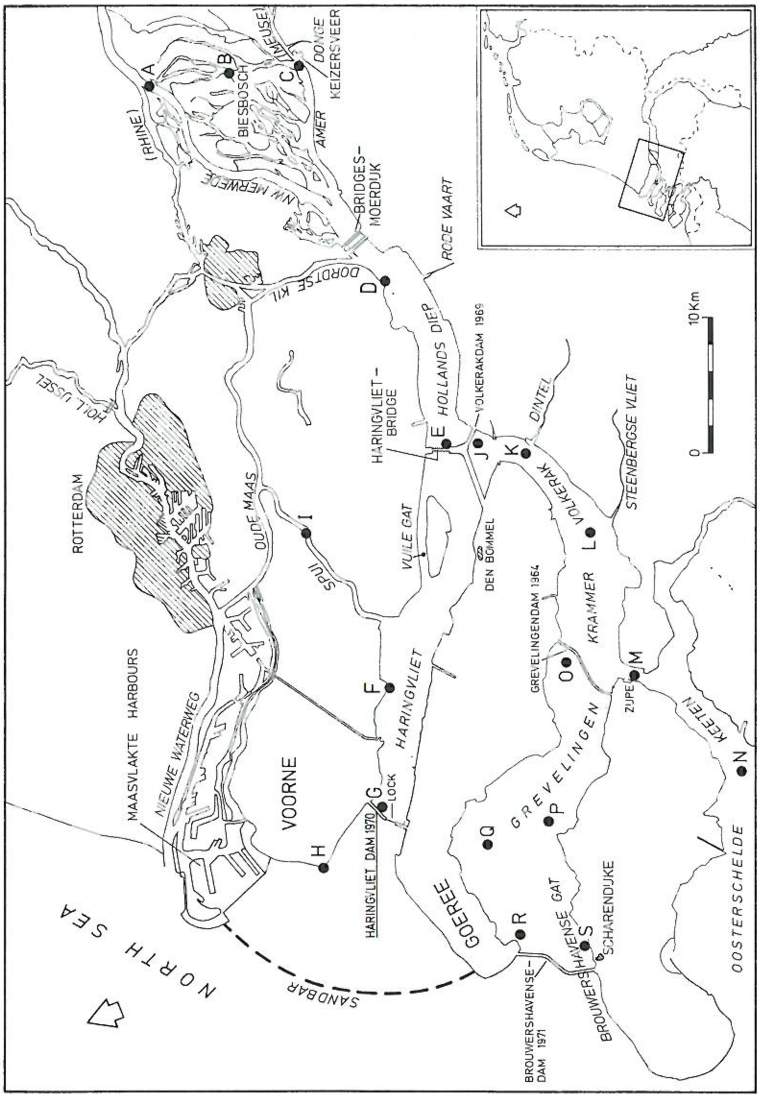


Fig. 1. Survey of the northern Delta area with new dams.

m³/sec, with an average of 880 m³/sec. For the river Amer these figures are 150, 600 and 330 m³/sec; respectively. (Rijkswaterstaat 1964). Thus the Rhine may show fluctuations from 2/3 to 4/3 of its average discharge and the Meuse from ½ to double. The Hollands Diep, receiving its water from Nieuwe Merwede and Amer, will thus fluctuate between 830 and 1720, with an average of 1210 m³/sec. (Fig. 2). The total discharge of Spui and Dordtse Kil (Fig. 1.) is irratic and does not exceed 6% of the Rhine-discharge.

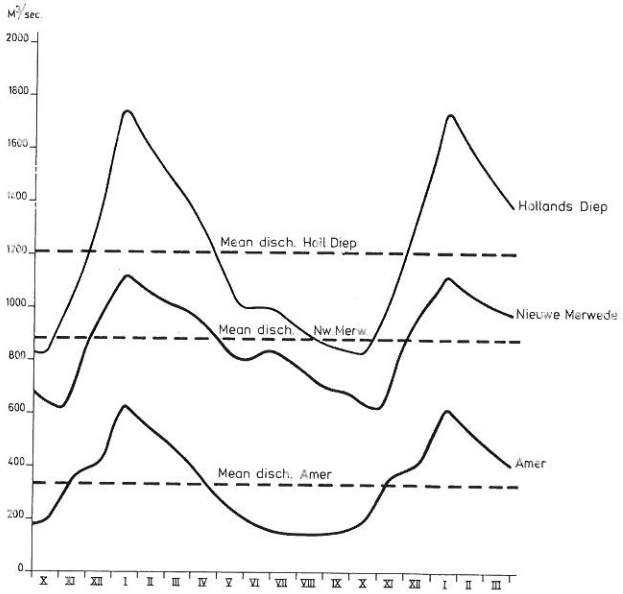


Fig. 2. Long term average of the discharge of Nieuwe Merwede (Rhine) and Amer (Meuse). Together these rivers form the Hollands Diep.

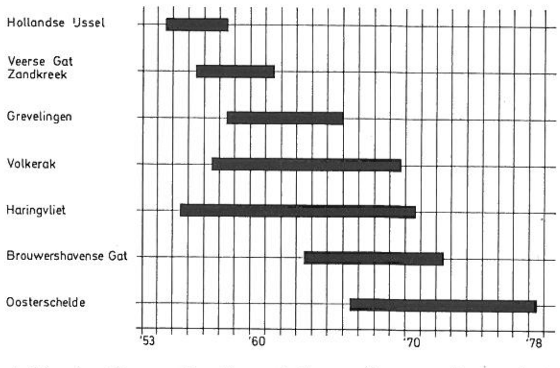


Fig. 3. Time-table for the realization of the various projects of the Delta Plan.

The drainage area of Rhine and Meuse is characterized by a dense population and large industrialized areas, and thus carries a good deal of sewage. Agricultural regions along the border add fertilizers to the river. River pollution will be diluted in winter and spring and concentrated in summer and autumn. The North Sea exerts its influence on the river from the other direction, mainly during periods of low discharge (PEELEN, 1967).

In the Delta area of The Netherlands various closures are being realized to protect the hinterland from the sea (Fig. 3.). First a storm flood barrage was built in the Hollandse IJssel, a branch of the Rhine. Veerse Gat and Zandkreek in the Southern Delta area were closed and the Veerse Meer was formed. The Grevelingen was separated from the Krammer. The Volkerak and Haringvliet were closed. During ebb the locks drain off fresh water from the latter basin, when the discharge of the Rhine exceeds 1500 m^3/sec. at Lobith, the place where the river enters The Netherlands. The Haringvliet still shows a small tidal movement of some decimeters and a weak current. The Brouwershavense Gat has been separated from the sea and a stagnant marine lake formed. Construction of the Oosterschelde dam in the Southern Delta area is in progress.

In two previous papers a survey was given of the changes in salinity during the subsequent phases in the realization of the Delta Plan (PEELEN, 1967, 1970).

The present paper gives a description of changes in temperature, oxygen content, sediment and transparancy for light in the rivers, the estuaries and the coastal water of the northern part of the Delta area of the South-West Netherlands during the following four phases in the realization of the Delta Plan.

1. From 1961 until closure of the secundary Grevelingendam in December 1964. The dam was built in the region of a tidal divide. The influence of its construction on conditions in the adjacent waters is slight.
2. From December 1964 until closure of the Volkerak on 28 April 1969. The northern waters Haringvliet and Hollands Diep became more fresh, while the southern waters Volkerak, Krammer and Keeten became more marine.
3. From closure of the Volkerak until closure of the Haringvliet on 2 November 1970. As within this period the Grevelingen was separated from the sea by the Brouwershavense Gatdam in 3 May 1971, the situation in this waterbody will be discussed firstly during the period April 1969—May 1970.
4. From closure of the Haringvliet until January 1972, except the Grevelingen. This basin will be discussed from the closure of the Brouwershavense Gat till January 1972, when our measurements were terminated.

After the complete realization of the Delta Plan the former estuarine area of the rivers Rhine and Meuse in the South-West Netherlands will be transformed into a stagnant southern part including Oosterschelde, Keeten-Krammer-Volkerak and Grevelingen, connected by the locks in the Volkerak-dam with a northern part consisting of Haringvliet, Hollands Diep and Biesbosch, at its eastern end in open connection with the river and at its western end separated from the sea by the locks in the Haringvlietdam. When the Rhine discharge at Lobith exceeds 1500 m^3/sec the locks will be opened at the ebb-phase of the sea. At those periods a weak current will flow through these waters, but when the locks are closed the water is stagnant, because all river discharge is directed towards the Nieuwe Waterweg.

TEMPERATURE

During short periods in winter, surface temperatures in the rivers may drop to about 0°C. Some ice is usually formed in these periods, mainly along the borders where the currents are weaker. Occasionally the whole river will be frozen (Rijkswaterstaat, IJsverslagen 1941—1970). During mild winters the minimum temperature will be about 2°. During moderate summers, surface temperatures will rise to 20° and in hot summers, such as the one in 1957, to 23°.

In an estuarine area large sandflats emerge during every low tide. In winter these areas lose heat by convection and radiation and ice will often be formed here. In summer these flats will absorb heat and lose some of it to the overflowing water on later emersion. In this way a temporary difference in temperature can be built up between the water flowing over the sandflats and the water in the deeper gullies. In spring and autumn, when the average water temperature is about 10°, this difference amounts to 2° utmost and in summer and winter to + 1° or — 1°, respectively.

An estuarine area is a transition zone between the sea and the river further inland. Owing to its larger mass of water, the sea fluctuates less in temperature than the river. In summer the monthly average surface temperature of the coastal waters is 17.7° and in winter 4.2°. The long-term average monthly temperatures of the river Rhine at Gorichem and of the coastal seawater at the lightship "Schouwenbank" are depected in Fig. 4. (VERPLOEG, 1956; VISSER & WIGGERS, 1969).

The various closures influence this pattern of temperatures in different ways.

The secondary Grevelingen dam was finished in 1964 and created a situation where the eastern part of the Grevelingen was cut off from the rest of the estuary and no longer felt the influence of the river. For this reason the surface temperature in the eastern part, near the dam, dropped to —0.8° in January 1970. In the mouth, the temperature amounted to about 2°. In summer, the mouth of the Grevelingen is about 2° lower in temperature than the eastern end near the dam. After the mouth had been cut off from the sea, owing

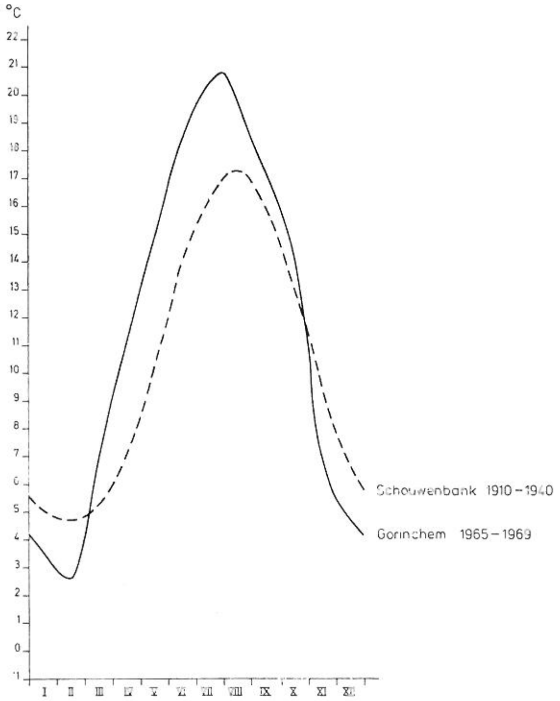


Fig. 4. Monthly average temperature of the Rhine water near Gorichnem and the coastal sea water near the Light vessel "Schouwenbank". (after VERPLOEGH, 1956).

to the construction of the Brouwershavense Gat dam in May 1971, the influence of the sea was eliminated and in July 1971 the surface temperature was 21° throughout. However, owing to the absence of tidal currents, a vertical thermostratification developed in this entirely closed area, with a temperature of e.g. 20.9° at the surface and 16.0° at a depth of 40 m in July 1971 (Station S, Fig. 1.).

After the construction of the dam across the Volkerak in 1969, the horizontal flow of the water was blocked in the Volkerak region and only vertical tidal oscillations could take place. In August 1971 the maximum surface temperature did not exceed 20°. Further inland near Gorinchem the river temperature amounted to 24° in the same period, and to 30° in the Amer owing to the influence of the cooling water from a power station.

In the Hollands Diep-Haringvliet area also a levelling of surface temperatures took place after the closure of the Haringvliet in 1970. In summer, surface temperatures were 21° throughout, whereas in previous years those in the eastern part of the region had been higher.

OXYGEN

The oxygen concentration was determined by the modified Winkler method, using Na-azide to counteract the influence of nitrites. Surface samples were scooped up, samples from greater depth were collected with a Ruttner-bottle.

In winter and spring, when water temperature is low and the activity of mineralizing bacteria therefore limited, oxygen consumption is low. In this period, river discharge is high and the sewage load is diluted. According to data collected by the International Rhine Commission, the maximal value for dissolved oxygen in the surface of the Rhine, measured from 1953 on, was about 12 mg/l or 85% saturation in 1956. Owing to increased pollution this maximum dropped to a value of 9 mg/l or 64% saturation in 1969 and to 8.2 mg/l or 58% in 1971. Minimal values are found in summer and autumn when surface temperatures and bacterial activity are high. Discharge is low at that time and dilution of sewage limited, so oxygen consumption is bound to rise. For the Rhine, minimum values of 4.5 mg/l (50% saturation) were measured from 1953 on; later, in 1967, this value dropped to 3 mg/l (33% saturation) (Internationale Kommission 1953—1968). In September 1971 1.4 mg/l (15% saturation) was measured by the State Institute for Purification of Sewage (RIZA) at a river discharge of 912 m^3/sec only. (Oral communication RIZA).

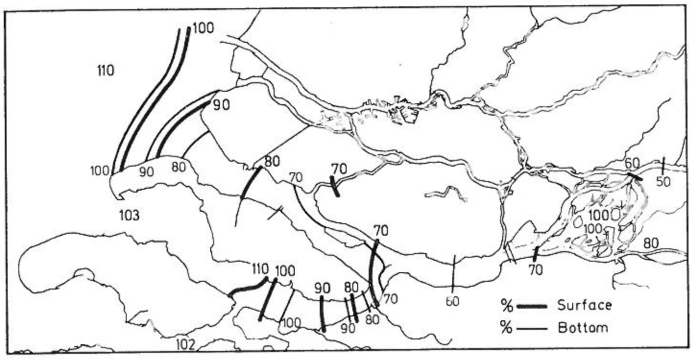
For the Meuse the situation is slightly more favourable, because there are many barrages in this river aerating the overflowing water. In the Meuse this aeration effect amounts to an increase of about 1 mg/l of oxygen (WIBAUT-ISEBREE MOENS, 1955). As the retention time of the water is also increased algae have more opportunity to participate in the production of oxygen in the water. In winter maximal values of 12—13 mg/l (90—96% saturation) were measured between 1960 and 1968. In later years these values decreased to 10 mg/l or 80%. Summer values fluctuated around 8 mg/l (80%) from 1960—1967, and dropped to 4.2 mg/l (about 50%) in 1971.

In the freshwater tidal area of the Biesbosch the river water is purified to a certain degree. Here values of 11—12 mg/l or 90—100% saturation are found in winter, but, owing to the action of the sewage from sugar refineries discharging the effluents in the Amer, these values are somewhat reduced in autumn during the period the sugar-beets are processed (9 mg/l = 80% saturation). The rich phytoplankton of the Biesbosch causes the oxygen values of the surface to rise to values of 11 mg/l in summer, equivalent to a supersaturation of about 130%.

A generalized picture of the situation between December 1964 and 28 April 1969, the date of closure of the Volkerak, is given in Fig. 5. The increase in dissolved oxygen, caused by the more higher oxygenated, more saline water from Krammer-Volkerak mixing with the riverwater is yearly seen in many deeper places in the Haringvliet (PEELEN, 1970). The water of the Grevelingen is supersaturated throughout because hardly any sewage comes in.

After the Volkerak was closed no saline water entered the Hollands Diep. As could be expected the oxygenation of the Krammer-Volkerak increased. (Stations J, K and L). The surface layers are influenced by the water from the locks, as well as by the discharge from two small rivers Dintel and Steenbergse Vliet. This closure did not cause any changes in the Grevelingen (Stations 0 through S).

The closure of the Haringvliet affected the whole of the Haring-



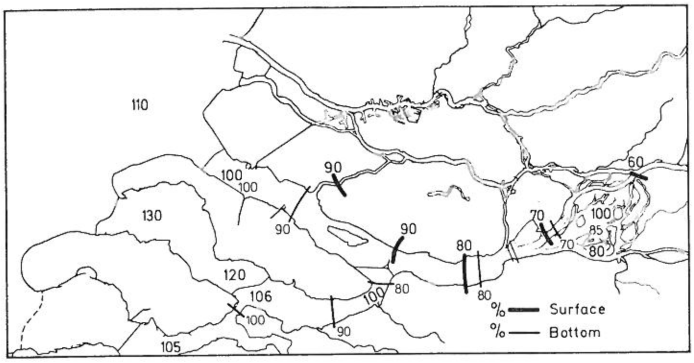


Fig. 5. Average oxygen content of the water on the surface and near the bottom between 1964 and 1969.

Fig. 6. Average oxygen content of the water on the surface and near the bottom. Haringvliet-Hollands Diep after closure. Keeten-Kramerm-Volkerak after closure Volkerak. Grevelingen after closure Brouwershavense Gat.

vliet-Hollands Diep-Biesbosch Amer area and the Nieuwe Merwede the latter area to a smaller extent however. A sedimentation of silt took place, increasing the transparancy of the water for light. The increase in oxygenation can be seen in Fig. 6.

Before the closure turbid, silt-laden riverwater of low oxygen content entered the Haringvliet from the Spui. After the closure the less turbid and better oxygenated water of the Haringvliet flowed out in a north-eastern direction through the Spui towards the Oude Maas. (Compare Fig. 5 and 6). The average oxygen content of the Biesbosch increased. As tidal amplitude was greatly reduced, far less riverwater enters the area now and, because discharge of any kind is unimportant here, selfpurification proceeds to a further degree. After the closure the Keeten-Krammer-Volkerak area became completely filled with water from the Oosterschelde, but for a slight interference with water from the locks and from the small rivers Dintel and Steenbergse Vliet. Thus the water is saturated c.q. supersaturated with oxygen (Stations J through N).

On 3 May 1971 the Brouwershavense Gat was closed and the Grevelingen was severed from the sea. As in many years before the closure, the surface water remained heavily supersaturated but now values as high as 190% saturation were reached. This situation lasted until August, when slight undersaturation was observed, coinciding with the decline of the planktonic bloom. During the autumn bloom oxygen figures rose again. Near the bottom the water was slightly supersaturated at the time of the closure, except on Station O. In the four Stations O, R. P and S a fall in oxygen content is seen, followed by an increase beginning in August at the Stations O, R and S and in June at Station P (Fig. 7). Later on the water layers were mixed by wind action. When a sea-arm is closed those organisms dependent on current and tidal movement are bound to die and, after sedimentation, to withdraw oxygen in the water layers near the bottom.

SUSPENDED MATTER

Suspended matter was measured by filtering 1 l of water and drying the filter to constant weight at 105°C. It should be mentioned that maximal amounts of sediment will be found during stormy weather, when sampling could not be carried out. For this reason our average sediment data will be too low.

Some data on the amount of suspended matter in various waters have been published. In the freshwater tidal area of the river Lek (Rhine) DE LINT (1917) found an average of 19 mg/l. According to

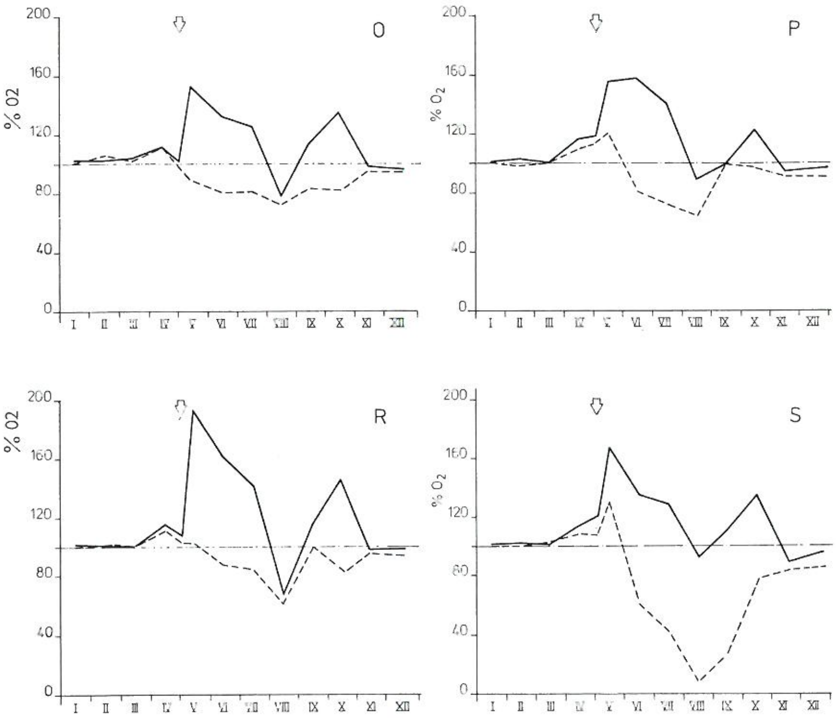


Fig. 7. Oxygen content of the Stations O, P, R and S during 1971, on the surface and near the bottom. Arrow is the moment of the closure Brouwershavense Gat 3-5-1971. Surface: solid line. Bottom: broken line.

Lucht (1964) sediment in the Elbe amounted to 25 mg/l in 1957 and 31 mg/l in 1958. In 1954—1955 the Rhine at Gorichem contained 31 mg/l of sediment (Wibaut-Isebree Moens, 1956). For the same location 37 mg/l was found in 1965/1968 (measurements carried out by the State Institute for Purification of Sewage, RIZA). In the Amer near our Station C the same agency measured 36 mg/l in the corresponding years. As decribed by various authors (Kühl & Mann, 1961, Postma, 1967) an estuary is characterized by a turbidity zone, where the amount of sediment is about 3 to 4 times that in the river, depending on the discharge. Our coastal North Sea water carries sediments amounting to 12 mg/l (Ploix, 1876).

Not only have discharges of agricultural, industrial and urban sewage increased rapidly in recent years, but in our area the sucking of sand for building purposes and also for various constructions in connection with the realization of the Deltaplan, has been on the up grade (Fig. 8). The dredger sucks up a mixture of water, silt and sand from the bottom and deposits it in a barge. The sand settles out in the barge and the heavily silt-laden water flows out into the surface layers. Annually an amount of 17—20 x $10^6 m^3$ sand is sucked up in this way. The percentage of silt mixed with the sand varies with its origin. Near the sea it amounts to 10% of material with a grain size less than 100μ. This percentage increases landwards, till values between 40 an 50% of the total amount of suspended matter in the Hollands Diep-Biesbosch area are found on sandflats. In the gullies the percentage is lower (oral comm. M. C. DAANE). Tidal movements holds the silt in suspension over long distances. Usually a relationship can be found between river discharge and the extension of the zone of turbidity and the amount of suspended matter per volume of water. (TERWINDT, 1967). However the large amounts of silt introduced artificially in our estuaries make the determination of such a relationship impossible.

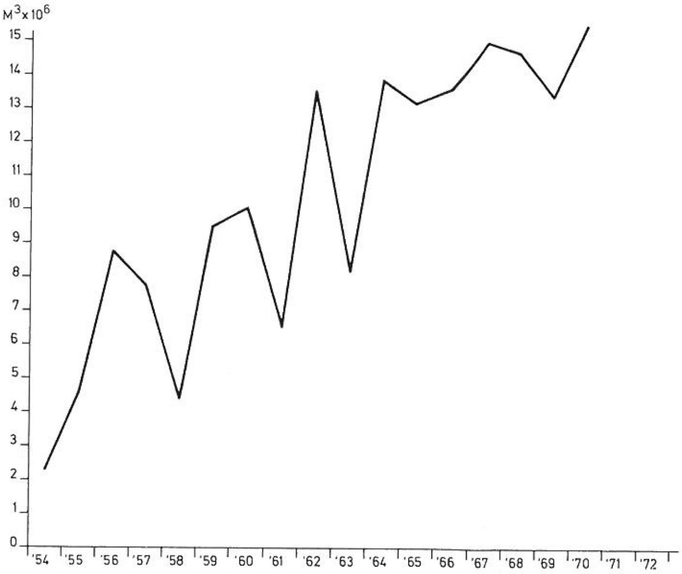


Fig. 8. Amounts of sucked sand for building puposes in the Delta region between 1954 and 1971 in m^3 x 10^6. The annual amount for the Delta constructions is between 3 and 6 x 10^6 m^3.

For these reasons average values over 8 years are shown in Fig. 9. Maximal values over 100 mg/l were found in deep gullies with heavy currents, e.g. Station F and G near the locks in the Haringvliet, Stations J and K in the Volkerak area, and Stations R and S in the mouth of the Grevelingen. Where the current is less, turbidity is lower because more sedimentation takes place. In the freshwater tidal area of the Biesbosch (Station B) and in the marine area of the eastern basin of the Grevelingen (Station O) values between 15 and 20 mg/l were found in the surface layers.

After the closure of the Volkerak the water in the Keeten-Krammer-Volkerak system is pushed by the flood against the dam and flows back again during the ebb-tide. Average values between 8 and 20 mg/l of sediment were found at the surface of the Stations J through M and between 9 and 38 mg/l near the bottom. The amount of suspended matter at the Station N, situated at the beginning of the Keeten, remained unchanged. In the Haringvliet-Hollands Diep region hardly any change took place.

When the Haringvliet was closed sediment values increased slightly in the Nieuwe Merwede (Station A), but dropped markedly in the area of Haringvliet-Hollands Diep-Biesbosch and Amer, reaching values between 9 and 23 mg/l at the surface and 13 and 26 mg/l near the bottom.

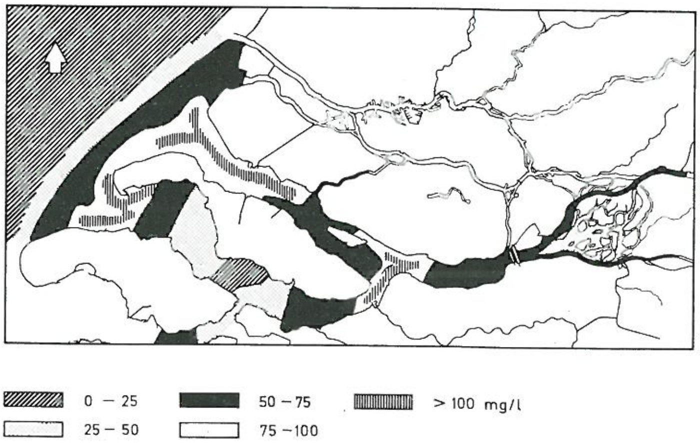
The Grevelingen, unaffected by both previous closures, changed drastically when the dam through the Brouwershavense Gat was finished. At the moment the average amount of suspended matter is between 6 and 9 mg/l at the surface and between 9 and 14 mg/l near the bottom. (Sations O through S, Fig. 10).

TRANSPARANCY OF THE WATER MEASURED WITH THE SECCHI-DISK

Amounts of suspended matter cannot directly be correlated with transparancy values measured with the Secchi-disc. Near the sea the water will contain more fine sand grains and bigger plankton organisms, towards the river finer silt and smaller plankters. In Fig. 11 transparancy is seen to increase from Nieuwe Merwede via Biesbosch to Amer. The Nieuwe Merwede contains Rhine water, with a good deal of silt and hardly any plankton. The Amer --a continuation of the Meuse- contains less silt and more plankton. In the Biesbosch the silt of the Amer precipitates and plankton develops strongly. In the Hollands Diep region sand-dredging was very frequent along the north banks and thus transparency along the south banks is higher. The silt-laden water flows on through the Vuile Gat (Fig. 1), and joints the water from the Spui. In the Haringvliet transparancies are higher, but near the locks turbidity is higher owing to the works carried out. A similar high turbidity is seen in the mouth of the Haringvliet as far as Station H. In the Grevelingen transparancy decreases gradually from the basin (Station O) towards the mouth (Stations P through S). in the Volkerak Secchi-disc values are low in the eastern part and increase gradually towards the Oosterschelde (Stations J through M).

After the closure of the Volkerak transparancy in this waterbody increased. Secchi-values of 1½ m were found near the dam. Near the locks of the river Dintel outflowing water decreased the transparancy till values between 1 and 1½ m. In the Haringvliet-Hollands Diep-Biesbosch region Secchi-disc values were seen to drop. (Sations D, E and F). The area is filled with river water until the dam (PEELEN, 1970). Dredging operations lowered the transparancy in the Biesbosch (Station B). In the Grevelingen (Stations O through S) no changes took place.

When the Haringvliet was closed, sedimentation of silt took place and Secchi values of about 1 m were observed. In Biesbosch and Amer transparancy increased as well. As dredging operations were stopped after the dam was finished, transparancy rose in the Keeten-Krammer-Volkerak region too.



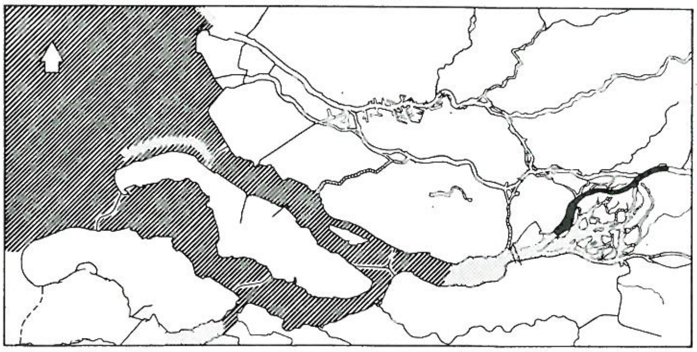
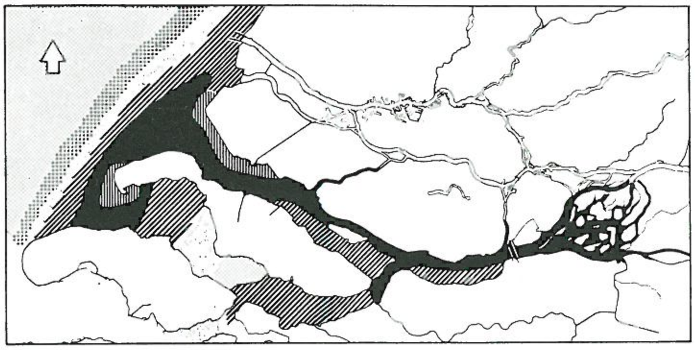


Fig. 9. Amounts of suspended matter in the water near the bottom before closure of the Volkerak 1969.

Fig. 10. Amounts of suspended matter in the water near the bottom after closure of the Brouwershavense Gat dam 1971.

When the Brouwershavense Gat was closed Secchi values rose from 75 cm to about 2 m in the western part and from $2\frac{1}{2}$ m to $3\frac{1}{2}$ m in the basin (Stations R, S, O, P, Q, Fig. 12).



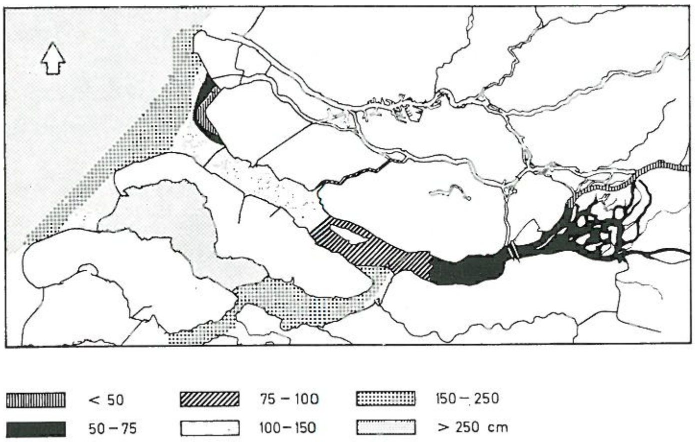


Fig. 11. Transparancy of the water measured with the Secchi-disc before closure of the Volkerak 1969.

Fig. 12. Transparancy of the water measured with the Secchi-disc after closure of the Brouwershavense Gat dam 1971.

In the coastal water at a distance of 20 km from the shore, the average content of suspended matter amounts to 20 mg/l, with a Secchi value of $4\frac{1}{2}$ m.

TRANSPARANCY OF THE WATER MEASURED WITH A RADIATION METER

A spherical radiation meter, constructed as indicated by WASSINK & VAN DER SCHEER (1951), was used. This instrument measures the energy of light absorbed by one cm^2 of the spherical surface of two semi-circular lenses in contact with a selenium cell. The meter was checked against a thermo-couple and its threshold is 100 erg/sec. It operates within a range from 350 to 700 mμ. No spectral shift in the composition of the sunlight was found to take place in the shallow waters measured in the present study. The values measured by the radiation meter can be converted into calories with the following formula: 1 cal/cm^2 = 4.19 x 10^7 erg/cm^2.

In the open Haringvliet-Hollands Diep estuary the depth at which light of 100 erg/sec. could be determined, fluctuated between 1 and 4 m in April and between 4 and 8 m in June-July, decreasing to values between 1 and 3 m in October and the rest of the year. In the Biesbosch transparancy was larger, as was also found using the Secchi-disc. More light than 100 erg/sec always reached the shallow bottom here.

On 22 and 23 April 1968 light was measured from sunrise to sunset in the Haringvliet near Den Bommel. Transparancy -down to a minimum of 100 erg/sec- fluctuated between $\frac{1}{2}$ and 3 m, while Secchi values between 70 and 85 cm were found. During the period of the measurement the current fluctuated between 70 cm/sec during the ebb-tide to 130 cm/sec. during the flood. Transparancy was seen to rise slightly during the high water period (Fig. 13). The total energy of sunlight measured on 22-4-1968 was 280 cal/cm^2 and on 23-4-1968: 172 cal/cm^2, as measured by the Royal Meteorological Station at Vlissingen. For this reason there is a discrepancy between the values of the two days.

In the Keeten-Krammer-Volkerak area light is already absorbed in the first two meters of water in winter. In April-May light can penetrate till a depth of 5–7 m and in June—July till 9—12 m. In October values of 3—4 m were measured and 2—3 m in December.

In the Grevelingen a difference exists between the basin, where the amounts of suspended matter were low and the Secchi-disc values correspondingly high, and the mouth where a good deal of silt was brought in suspension by the inflowing water from the Haringvliet as well as by the construction of the dam through the Brouwershavense Gat. In the Basin 100 erg/sec. of light could be measured on the bottom at a depth of 10 m and in June—July 2000 erg/cm^2.

On 24—25 April 1968 measurements were carried out from sunrise to sunset. The total energy measured at Vlissingen on 24-4-1968 was 401 cal/cm^2 and on 23-4-1968: 463 cal/cm^2. It is clearly seen that the lines of the various depths are on the same level at 17.30 h. (Fig 14). Secchi-disc values between 175 and 250 cm were found. During the measurements the current of the surface water fluctuated between 0 till 25 cm/sec. mostly in the direction S-SSW.

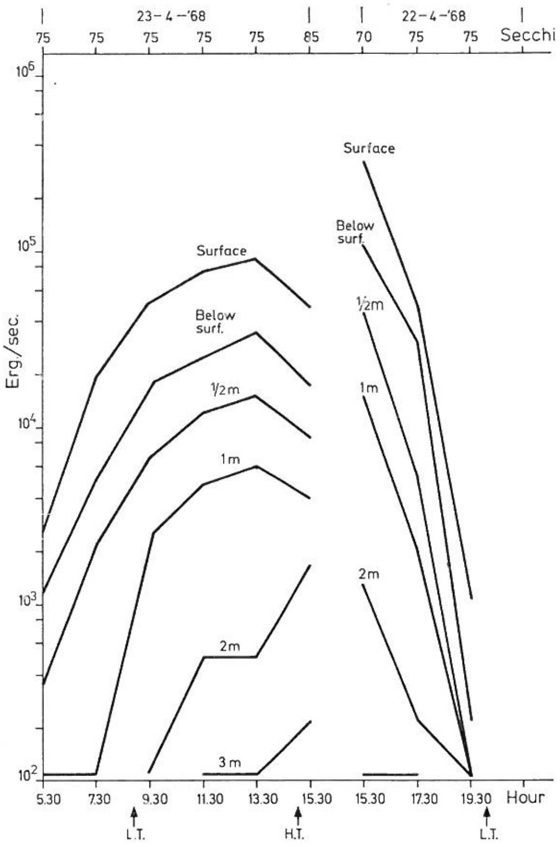


Fig. 13. Transparancy of the water of the Haringvliet near den Bommel measured with the radiation meter on 22 and 23-4-1968.

In the Figures 13 and 14 the amount of light is plotted on a logarithmic scale against the time of the day. The upper graph depicts light registrated just over the surface, the second one just under it, the others registrate the changing light at ½ meter and meter intervals. Maximal values are found at noon. Secchi data, measured throughout the day, do not fluctuate to such an extent, because the human eye adapts automatically to changing light conditions.

Along the axis of the Grevelingen light transparancy was seen to decrease from the basin towards the mouth. There is a difference here between the south- and the north side. On the north side minimal quantities of light of 100 erg/sec. were found in winter at a depth of 2 m and in summer at 3 m. On the south side values between 1 and 7 m were measured in winter and between 7 and 12 m in summer.

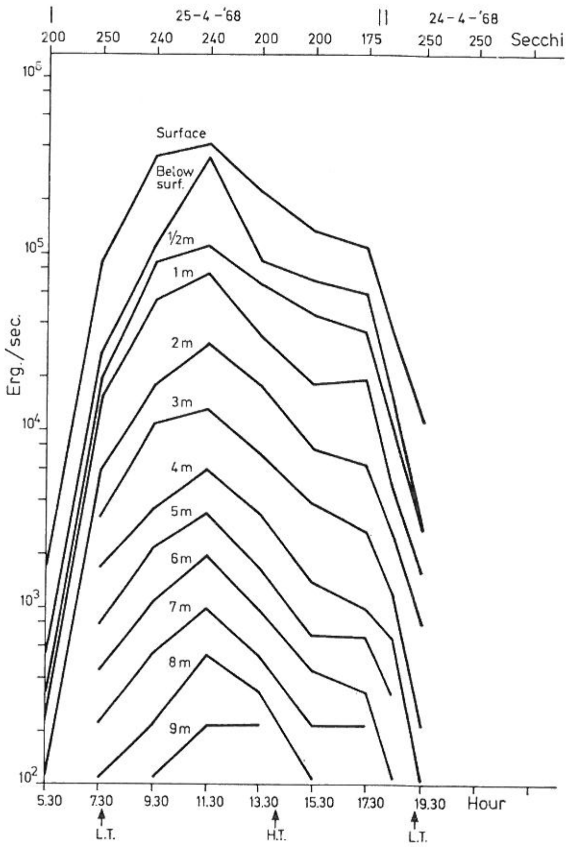


Fig. 14. Transparancy of the water of the Grevelingen bassin measured with the radiation meter on 24 and 25-4-1968.

After the closure of the Volkerak on April 1969, transparancy in the Volkerak increased towards the dam. Minimum light could be detected here at a depth of 11—15 m. At that time the Haringvliet-Hollands Diep formed a riverine area where the water of Rhine and Meuse could still flow out at sea through a gap in the unfinished dam. Light did not penetrate further than 2 m. After the closure of the Haringvliet sedimentation of silt took place and light penetrated till 5—6 m. After the closure of the Grevelingen in May 1971 light transparancy increased strongly, notably in the mouth. The process of sedimentation was greatly furthered by the fair weather in summer. In gullies values till 20 m were found and in the mouth light penetrated to 17 m.

DISCUSSION

In the whole area oxygen concentrations in the water were found to have increased after the various closures, because selfpurification could proceed to a further degree in the stagnant water. However, in small tributaries of former tidal waters, such as the Donge and the Roode Vaart (Fig. 1), pollution became far more severe.

Because the percentage of sand in the suspended matter is higher on the sea-side of the estuaries than on the river-side, Secchi-disc values measured at the western end of our estuaries will be higher than those measured at the eastern end at equal amounts of sediment (compare Station A = 32,8 mg/l sediment and 55.5 cm Secchi-disc with Station N, 31,3 mg/l sediment and 129.6 cm Secchi-disc).

Comparison between our values and those of TYLER (1968) and HOLMES (1970) is not feasible as our Secchi values are too small. On 22 February 1968 even a value of 5 cm was measured at Station H.

Roughly the relationship between Secchi values and the threshold value of the lightmeter — 100 erg/sec. —, was as follows: 4 x depth-of Secchi disc = depth of treshold value at noon.

PERL (1935) gave a minimum energy value of 55 cal/cm²/day and a maximum value of 595 cal/cm²/day on 50° Northern Latitude. At the Meteorological Station in Vlissingen these values are 40 cal/cm²day, in moderate summers 430 cal/cm²/day and in hot summers 530 cal/cm²/day. The total energy during a whole year amounts to 116.340 cal/cm² when the values of PERL are used and using the Vlissingen data of 1966—1971, to 86.070 cal/cm². This station has the most sun-hours of our country and lies 60 km S.W. of the basins. So the total energy for a whole year will be about 85.000 cal/cm² in the water of the basins studied.

The changes in environmental factors, such as temperature, oxygen, suspended matter and transparancy for light, caused by the closures of the sea-arms and estuaries, together with the changes in salinity and in vertical as well as horizontal tidal movement are so radical, that drastic changes in the flora and fauna are taking place and will continue for years before a new biological equilibrium is reached.

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