DRAFT REPORT

A direct measurement of the transport of organic matter in the Eastern Scheldt.

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Contents

1. INTRODUCTION

The pelagic and benthic biota of the Eastern Scheldt are sustained by a food base of dissolved, suspended and deposited organic matter. This food base represents the energy input into the ecosystem, including solar energy trapped in organic molecules by in situ photosynthesis, and energy contained in organic matter that is imported into the ecosystem from outside.
In 1985, the construction of a storm-surge barrier across the mouth of the Eastern Scheldt will be finished. This barrier can be closed at times of dangerously high water in the southern North Sea. At other times, the gates will be open to permit water to flow between the Eastern Scheldt and the North Sea. The area through which water will flow, however, will be so small that it will reduce the tide and thus possibly alter the circulation pattern within the Eastern Scheldt. This altered circulation may modify the exchange of organic matter with the North Sea, which may, in turn, affect the estuarine biota that depend on this exchange for food (Bigelow et al., 1977 and Elgershuizen, 1981).

Estuarine transport of organic matter is at present poorly understood. Generally accepted principles or procedures (i.e. relating to topography, currents, depth, concentrations and sorts of organic matter and different ecological processes like primary production etc.), by which we can estimate organic matter transport, are to be developed on the basis of present knowledge of sedimentology and ecology (Odum et al., 1979). The transport process of organic matter is a very complex one. Organic matter encompasses dissolved, colloïdal and particulate materials that may be quantified by organic carbon determination. From a practical point of view organic matter in the present study is divided into two fractions: "Particulate" organic carbon (POC), which refers to organic matter that is left on a filter with an initial pore size of 1 µm by filtration of a water sample, and "dissolved" organic matter (DOC), which refers to organic matter that passes through such a filter.
Different ecological processes and factors influence the transport of organic matter and also a part of the whole suspended matter (seston) between two compartments of an estuary.

While water flows from one compartment into another there may be primary production which adds new organic matter to the water mass. Consumption and mineralisation may cause a decrease in the concentrations of the organic matter. Sedimentation and entrainment processes add or subtract suspended matter to or from the flowing water mass. Furthermore, the hydraulics of an area (tides etc.), the weather (sun, wind, etc.), the morphology and other characteristics of the matter itself (e.g. sorts of plankton), the interaction between matter (e.g. flocculation) may cause a reduction or increase of the organic matter in time, space and quality, resulting in an accelaration, retardation, division, pulsation etc. of the organic matter transport. This may ultimately form observable patchiness in time and space (e.g. plankton patches) and changes (e.g. one sort of plankton may be displaced by another one) in the transported matter. A more detailed description of the transport phenomenon can be found in Darnell & Somiat (1979).
In a first approach, the transport of organic matter in the Eastern Scheldt was studied by a measurement of the transport of organic matter through a cross-section* between two assumed compartments during one mean tidal cycle. The effect of the primary producers was determined by a measurement of the primary production and analysis of the plankton. In order to find a significant contribution of organic matter due to primary production the measurement was done in the spring bloom of 1979. Consumption and mineralisation were not taken into account at that time.
This report shows the results of that transport measurement. A more detailed evaluation of the methods used and an analysis of correlation between the different components measured are to be found in Elgershuizen & Stortelder (1980)**. A more complete survey of the measurement of the primary production that was made is given in Elgershuizen & Stortelder (1981)**.

Acknowledgement
The measurement of the transport of organic matter in the Eastern Scheldt was carried out as a joint effort of the Delta Institute for Hydrobiological Research of the Royal Academy of Sciences in the

* transect=cross-section=cross sectional area=transect surface area
** report in Dutch

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MATERIAL AND METHODS

2.1. The study area

The Eastern Scheldt is a totally mixed estuary surrounded by dikes and the North Sea (fig. 1). Its water surface at mean high water covers an area of 393.5 km^2 and at mean low water 245.5 km^2. The mean tidal amplitude varies between 2.91 m in the mouth and 3.84 m at Bergen op Zoom. The average depth is 8 m and the bottom consists mainly of fine sand and only at a few places along its edges can muddy sand be found. The water temperature is 18 - 20°C in summer and 3 - 5°C in winter. The salinity is usually between 28 and 33 o/oo. On an average the fresh water run-off is very small (< 50 m^3/sec) and nearly constant.Suspended matter varies between 10 and 30 mg/l but, under storm conditions, concentration up to 150 mg/l can be measured at the water surface. Secchi disc visibility fluctuates between 0.5 and 5 m. POC concentration are usually between 1 and 2.5 mg/l and DOC between 1.8 and 3 mg/l. More information on the aquatic ecology of the Eastern Scheldt can be found in Wolff (1973), Bakker & Vegter (1979) and Bigelow et al (1977).

2.2. The measurement

During one tidal cycle, eleven ships were involved in a measurement of the organic matter transport in the Eastern Scheldt through a transect between Zuid-Beveland and Tholen (ZB 62 - T 33) close to Wemeldinge (fig. 1). The profile of the transect and the positions of the ships are shown in fig. 2. The profile of the transect shows two main channels of about 21 m and 18 m depth respectively separated by a shallow bar at about 12 m depth. The width of the transect is about 2500 m. The complete measurement took place on the 20th April 1979 between 2.00 and 16.00 h MET (Mid-European Time).

A perpendicular system of co-ordination was defined as follows: The crosspoint of the x-, y- and z-ax was at ZB 62, the x direction was perpendicular to the transect and positive to the East, the y direction was the horizontal transectline ZB 62 - T 33 positive to T 33 and the z direction was positively the depth and zero at NAP-level. All times are in MET unless it is stated otherwise.

At Wemeldinge harbour, tidal elevation in cm was measured relative to New Amsterdam Standard Water level (NAP) by use of an electronic water level meter. It was also measured by echo-sounding at the sampling stations to correct for local deviations.
The actual surface area, through which the water flowed, was computed from an echo-sounded recorded profile reckoning with the actual surface elevation.

2.2.1. Water sampling, transport and storage

Water samples for analysis of POC (Particulate Organic Carbon), DOC (Dissolved Organic Carbon), seston (total suspended matter) and chlorophyll-a (a green photo-active pigment in phytoplankton) were collected at y = 1206 and 2225 m at z = 1, 2.5, 5, 10, 15 m and at 1 m from the bottom (b + 1 m) each 3/4 hour and, at y = 700 and 1750 m, at the same depths each 1 1/2 hour. Water samples for measurements of the rate of primary production were taken from y = 1206 and 2225 m, the same depths as described above, each 1 1/2 hour. Plankton analysis was done on fixated water samples from y = 1206 and 2225 m, from the water surface, mean water depth and b + 1 m at 5.30, 8.30, 11.30 and 14.30 hour. Fixation was done with 2 ml lugol/l. Moreover, for POC-, DOC-, seston- and chlorophyll-a analysis, 10 duplicate water samples were taken at random in time and depth.
If the vertical tide caused that two sampling depths to be closer than 1 m, then only the deepest one was applied.
At y = 1206 and 2225 m, a hydrobios 5 l-water sampler and at y = 700 and 1750 m, a water-pumping system (50 l/min) was used to sample some volume of water depending on the forward analysis. In POC- and seston analysis, in chlorophyll-a analysis, in plankton analysis and, in measurement of the rate of primary production, 1 l water samples were needed but in DOC analysis only a 200 ml water sample was required. Thus, at a certain moment, a maximum of 4 x 1 l and 200 ml was taken from a sampling depth. Usually polyethylene flasks were used but glassware had to be used in the plankton samples, because of the adverse effects of lugol on (plastics) polyethylene.
The samples were carried to the lab by ship and car on average within 3/4 hour. Whilst awaiting analysis, they were stored in the dark at 4°C.

2.2.2. Current velocity measurement

OTT current velocity meters, Elmar current direction meters, electronic integrators and printers were used to measure vertical profiles of current velocity and direction each quarter of an hour at 7 stations (y = 350, 510, 800, 1100, 1535, 2060 and 2365 m) comprising 5-10 measurement points depending on total depth and stressing the underhalf of the water column.

At y = 1206 and 2225 m, current velocity was measured only at half depth.

2.2.3. Temperature and salinity measurements

At y = 700 and 1750 m, temperature and salinity at the sampling depths were automatically and continuously registered on the basis of electric conductivity measurements.

2.3. <u>Analysis</u>

2.3.1. POC and seston

At the lab 1 l water samples were filtered over a glass-fibre filter (Schleicher & Schüll nr. 6, initial poresize ca. 1 µm) at an underpressure of ca. 0.5 atm maximally and were flushed with demi afterwards. The pre-weighed filters with seston were dried at 70°C during at least 2 hours and reweighed which resulted in data to calculate seston dry weight and actual seston concentration. Using a Coleman C-H-analyser, the filter with seston was incinerated at ca. 640°C (to prevent interference with anorganic carbonates). By weighing and reweighing the CO_2-absorption column, the POC-concentration in the seston could be determined. The working of the Coleman C-H-analyser used was daily verified with anthracene (94,25% C) or acetanilide (71.09%).

2.3.2. DOC

The determination of DOC-concentration was done by use of an automatic colometric method encompassing U.V. destruction (Schreurs, 1978).

2.3.3. Chlorophyll-a

The determination of chlorophyll-a concentration was according to the method described by Strickland & Parsons (1968) and calibrated by means of chlorophyll-a of spinach.(Sigma, St. Louis, MO, USA)

2.3.4. Plankton

Allowing the extra 1 l lugol-fixated water samples to stand for a few days resulted in concentration of the plankton. After decantation of the super fluid, this plankton was determined and counted under an inverted microscope.

2.3.5. Primary production

Measurements of the rate of potential primary production were done according to the ^{14}C method of Steeman Nielsen (1952), as detailed by Strickland and Parsons (1968) and, in an incubator as described by Fee (1973 a, b). The incubator used and built by B.H.H. de Bree and P.R.M. de Visscher (Delta Institute, Yerseke, Netherlands) comprised eleven compartments each with 18 places for Duran-50 glass tubes (inner diameter: 2.5 cm, volume: 54 ml). An air cooled system of 39 parallelly placed Philips TL-33 white fluorescent light tubes produced an initially available Photosynthetic Active Radiation (PAR) of about 9.0 10^2 µE/cm^2/sec. The actual PAR in the sample tubes was measured with a MACAM Fotometrics light cell. Per sampling point, two PPP-measurements were made in duplicate with sub-samples at different constant irradiation close to the average light situation at the sampling point. One dark-measurement was added. The length of one measurement in the incubator was 5 hours.

The $Na_2{}^{14}CO_3$-solution was made on a basis of 16.5 °/oo NaCl solution according to the chlorinity at the sampling points. It was adjusted to pH 10 by NaOH to which 5 mCl $Na_2{}^{14}CO_3$ per liter was added. To establish the CO_2-concentration before and after incubation, pH was measured (Strickland and Parson, 1968). After incubation, filtration was done over a 0.45 µm Sartorius cellulose-nitrate membranefilter with 80-100 mm Hg underpressure. Within half an hour HCl-fumes, in an excicator were supposed to remove the remaining CO_2 and $^{14}CO_2$. The filter was put in counting fluid (on toluene basis, 0.5% PPO, 0.05% POPOP mixed with methoxy-ethanol at 62.5 to 37.5%) in a standard counting bottle.

Scintillation counting was done in a Nuclear Chicago Mark I liquid scintillation counter. Quench correction per ampoule was done by the Channel Ratio method.

Blanks, i.e. ampoules with 10 ml Lumagel in a xylene solution mixed with 1 ml demiwater and 100 µl phenetylamine and 20 µl of the Na_2-$^{14}CO_3$-solution, offered the opportunity to acquire data of the actual added radio-active carbon.
A PPP of a water sample was calculated by using the formula

$$PPP = \frac{(R_s - R_b) \times C \times 1.06}{E \times A}$$

R_s = radioactivity (dpm) of the water sample after having been in a light situation
R_b = radio-activity (dpm) of the water sample after having been in the dark
C = available C in a water sample for primary production (mg C/l)
E = counting efficiency of the liquid scintillation counter
A = added ^{14}C (dpm/ml)
1.06 = discrimination factor of ^{14}C for C.

E varied between 30 and 60%. Uptake of CO_2 and $^{14}CO_2$ was assumed to be linear in time.
A Kipp & Zoonen CM 3 Solarimeter, in combination with a Kipp integrator CC 2, was used to establish total irradiation per hour above the watersurface at the sampling sites. The solarimeter was verified for PAR by a Xenonlamp and a standard light cell. Underwater irradation could then be calculated by using light (PAR) transmission curves measured with a Kahlsico light cell at the sampling stations during sampling time. The light transmission curves and the actual irradiation defined the position in the incubator.
The duplicates were averaged and two PPP values per sampling point could be calculated. A PPP/I curve and the data of the light situation in the water column for the following five hours were used to determine the PPP/depth curves. Integrated PPP values for each water layer were computed by the trapezium method. Daily primary production was estimated by dividing PPP values by 5 and integrating over time and depth.

2.4. Calculations

2.4.1. Transport of water

Tidal water transport was computed in four different ways:

Method I (rough estimation)

In preliminary investigations, the transport of water was roughly estimated after dividing the transect surface area into six parts: horizontally at y = 1400 m and vertically at z = 6 m and 12 m.
Vertically averaged current velocities were calculated from measurements at y = 800 m for the 3 transect parts in the southern channel and from measurements at y = 2060 m for the three transect parts in the northern channel. Drawing a fluid line by hand through the points in a current velocity versus time graph yielded 1/2 hour values for each transect part, i.e. v_{it} (i = I. ..VI, t = 1....26). Using the formula

$$W_{it} = v_{it} \cdot A_{it}$$

in which A_{it} is the surface of a transect part at moment t, the transport speed of water (discharge) could be calculated.
Integration in time resulted in transports of water during flood and ebb phase. The net transports over the total tidal cycle were determined by substraction:

$$W_{i\ net} = \int_{flood} W_{it}\, dt - \int_{ebb} W_{it}\, dt$$

A positive W_{net} means an import of water to the eastern part of the Eastern Scheldt; a negative one an export.

Method II (Public Works Department standard method)

The quarter of an hour measurements of current velocity and direction were vertically averaged for the stations: y = 350, 510, 800, 1100, 1535, 2060 and 2365 m. Synchronous 1/2 hour values of each station were determined by drawing a fluid line through the points in a graph of speed and direction versus time. Averaged 1/2 hour values of current velocity perpendicular to the transect were calculated by multi-

plying the current velocity values by the sine of the angle between the transect line and the 1/2 hour averaged direction. These last values were drawn graphically as a function of y.
By graphical interpolation, averaged 1/2 hour current velocities v_{it} (t = 1.....26) were calculated for each width Δy_i (Δy_i = 100 m, i = 1....30). Multiplication of the average depth $\bar{z}_{it}$ by corresponding Δy_i and $\bar{v}_{it}$ yielded tidal discharges (m^3/sec) at each 1/2 hour for each Δy_i. Integration over y = 200 to 1400 m (i = 3 t/m 14) and from 1400 to 2500 m (i = 15 t/m 25) for each time step t (t = 1....26) gave discharges through the southern and northern transect part respectively for each 1/2 hour.
Integration in time gave the transported volumes through the transect or part of it during flood and ebb phases and the total tidal period.

Method III (trend surface method)
1/2 hour current velocity values at eight relative depths at seven stations were first established by correcting the original data for the direction by multiplication with sine and secondly, by a cubicinterpolation (parabolic blending)per station of eight relative depth 1/4 hour values in time.
These last values were used to establish third degree trend surfaces by a least square method (Davis, 1973) after a nondimensionalisation of the transect in depth and width (Kjerve, 1975). To get real values, these relative trend surfaces were transformed back again into actual y and z co-ordinates thus forming current velocity (v) distributions. The data from 1/2 hour v-distributions were used for integration over time and over the transect area (or part of it) to calculate water transports.
The goodness-of-fit of each trend surface was tested by using an F-test (Davis, 1973. pag. 337): the variance due to regression or trend was compared to the variance due to deviations from the trend.

Method IV (method based on water level differences)
Total water transports were also calculated from a volume-depth relationship of the eastern part of the Eastern Scheldt and the measured tidal water level course at Wemeldinge harbour.

2.4.2. Mass transport of organic matter and seston

The measured POC-, DOC- and seston data were dealt with in the same way as current velocity values by method III. For each 1/2 hour value, second degree POC-, DOC- and seston trend surfaces were established. These led to corresponding c-distributions in the transect based on five relative depth values at four sample stations. The goodness-of-fitt of the trend surfaces was tested also using an F-test (Davis, 1973, pag. 337). A multiplication of the trend surfaces of current velocity and a component i.e. POC, DOC and seston respectively resulted in transport speed (v. c) values (fluxes) for the components and their distribution over the transect.

Integration in time and over the transect surface (or a part of it) led to mass transport of a component for the flood and ebb phases and the total tidal cycle.

Plankton analysis resulted in cell counts of the different plankton-species. By Hagemeier's list (Biologische Anstalt Helgoland F.R.G.). These cell counts could be converted into phytoplankton-POC data, which were correlated with actual measured chlorophyll-a concentrations (see also Gieskes & Kraay, 1977). Thus, all chlorophyll-a concentration data could be converted into phytoplankton-POC data. These data were used to establish second degree trend surfaces as for total POC. Concentrations of total POC, minus corresponding estimated concentrations of phytoplankton-POC, gave data of (detritus+zooplankton)--POC concentrations. Because zooplankton could be ignored these data (see 3.3.5. and 3.4.) could be used to calculate trend surfaces of detritus concentrations. Multiplication of these specified POC-trend surfaces with trend surfaces of current velocity gave the fluxes of phytoplankton-POC and detritus-POC. Integration over the cross-section (or part of it) and in time resulted in mass transports through the cross-section of a tidal phase and of the total tidal cycle.

2.4.3. Contribution of primary production to the transport of organic matter

The water-mass that returned, at any given time, through the transect might have experienced some addition of organic matter (POC and DOC) subsided by its suspended primary producers during its residence beyond the transect.

From knowledge of the potential of these primary producers, the actual light climate (irradiation) and the water mass involved, that addition might be calculated.
From a practical point of view, the water samples to be used in the measurements of the rate of primary production had to be taken in the transect. Therefore, the next assumptions were made:

1. the vertical distribution of the primary producers, i.e. their concentrations and composition, and their physiology beyond the transect were the same as measured in the transect when the water passed.
2. the light climate in the transect also remained the same beyond the transect.
3. the profile of the transect also remained the same beyond the transect.
4. the residence time of the water with its suspended producing components, that flowed at any given time t through the transect, was on the average five hours ($\Delta T = 5$ h) east or west beyond the transect.

It was assumed that the addition would return with the producing living matter and it was estimated using the formula:

$$POC_{tz} = \bar{v}_t \cdot A_{tz} \cdot PPP_{tz}$$

POC_{tz} = added POC during some time ΔT to the water layer z flowing through the transect surface at moment t (g/sec)

$\bar{v}_t$ = depth-averaged current velocity in x direction at moment t (m/sec)

A_{tz} = actual transect surface area through which water layer z flows at moment t (m^2)

PPP_{tz} = potential primary production in water layer z that flows at moment t through A_{tz} in the next time ΔT (g/m^3)

t (moment 1.....26), t = 1/2 hour

z (waterlayer 1.....12), z = 1 m

(At z = 12 the actual PAR was always < 1% of the PAR at z = 1).

Integration of POC_{tz} in time and depth gave an estimation of total potentially added POC to the water mass during the flood phase, ebb phase and total tidal cycle respectively.

3. RESULTS

3.1. Accuracy

3.1.1. Measured variables

- Co-ordinates

  Y co-ordinates deviated 25 m maximally from the stated ones because of ships moving at their anchorage. Z co-ordinates deviated 0.5 m maximally from the stated ones because of vertical movements of ships on the waves and because of the sampling method.

- Current velocity

  The accuracy of the current velocity measurements were less than 2 cm/sec at current velocities $\geqslant$ 5 cm/sec. Direction measurements were accurate within $\leqslant$ 5 degrees.

- Temperature and salinity

  Temperature was measured to an accuracy of at least 0.1°C and salinity of at least 0.01 °/oo S.

- POC and seston

  The standard deviation based on nine samples in duplicate was on an average 3.6 mg/l for seston and 0.1 mg/l for POC. The reproducibility of the seston sampling differed vertically: i.e., the standard deviation close to the bottom was twice the standard deviation at the water surface. However, the standard deviation of POC did not differ vertically. Actually, heavier bottom material (sand) adds much in seston weight but less in POC weight because it contains only about 2% organic matter (see Wolff, 1973). It is therefore obvious, that sampling of the heavier seston fraction close to the bottom ($<$ 2 m) caused the large standard deviation.

  On 1 July 1980, a special sampling programm during which 25 water samples were taken from 60% of the water depth within 10 min, while the ship was floating, revealed that seston and POC had a relative standard deviation of 10%. From analysis of anthracene samples, the error in the lab analysis was estimated at 2%.

- DOC

  The standard deviation of DOC caused by sampling and analysing procedure was estimated at 5%. The lab analysis alone accounts for about 2% (Schreurs, 1978). This applied at least to concentrations between 1.5 and 3.5 mg/l.

- Chlorophyll-a

  Chlorophyll-a was measured to an accuracy of 0.9 µg/l. The relative standard deviation was estimated on average at 7%.

- Phytoplankton-POC and detritus-POC

  The accuracy of phytoplankton-POC and detritus-POC could not be calculated because the accuracy of the plankton counts was not estimated. They were assumed to have an accuracy at least of the same magnitude of total POC, because of the highly significant correlation that could be established between calculated phytoplankton-POC and chlorophyll-a data.

3 1.2. Concentrations and current velocities in the transect

The advantage of using trend surface analysis is to obtain information on the main trends in the distribution of the components in the cross section at any given time. Applying this method, random variations due to errors in sampling and analysis and any occuring small scale patchiness are smoothed out to a certain extent, depending in part on the applied degree of polynomial funtion.

It can be shown that at any given time t holds

$$TSS = \sum x^2 + \sum(x_i - \bar{x})^2 = \sum \bar{x}^2 + \sum(x_f - \bar{x})^2 + \sum(x_i - x_f)^2$$

in abbreviations:

$$TSS = M^2 + TMS = M^2 + FSS + RSS$$

in which

x_i = measured value

$\bar{x}$ = mean of measured values

x_f = fitted value

TSS= total sum of squares

M^2 = sum of squares of the mean

TMS= total sum of squares of deviations from the mean

RSS= total sum of squares of differences between measured and fitted values (residuals)

FSS= total sum of squares of deviations of fitted values from the mean

all at any given time t in the cross-section.

From this it was calculated $M\% = 100 * M^2/TSS$

$$Fit\% = 100 * (TMS-RSS)/TSS$$

$$R\% = 100 * (RSS/TSS)$$

while M% + Fit% + R% = T% = 100%. So, at any given time t, it could be evaluated to which part i.e., the mean, the added fit part due to trend analysis and the residue, made up the measured values.
These M%, Fit% and R% are shown for seston, DOC, total POC, phytoplankton-POC and detritus-POC as a function of time in fig. 4.
The well-known F-statistic, i.e. FSS/RSS, tests the significance of the trends and is shown for the different parameters in fig. 5.
In DOC, the M% is relatively more close to 100% than in other components. Obviously, its dissolved status caused a distribution with no observable trends at the second degree level. However, the particulate components showed observable trends and the fitted values were better to calculate fluxes than mean values at any given time, because these fitted values differed less from the actual measured ones.
A comparison of the fitted values shown in the c-distributions with the actual measured ones, revealed that generally the first ones differed from the last ones less than 5% in DOC, less than 8% in POC and less than 12% in seston.
The v-distributions show fitted current velocities that on an average differed less than 10% from the measured ones, if the mean current velocity in the transect at some time was more than 0.40 m/sec. However, at and around slackwater time the differences were usually much larger, sometimes more than 50%.

3.1.3. Transports of water, organic matter and seston

The accuracy of the transports through a cross section can be roughly estimated by the following calculation.

Notations:

Q = water transport during time T through A (m^3)

M_D = dispersive mass transport during time T through A (g)

v = measured current velocity (m/sec)

c = measured concentration (g/m^3)

T = tidal period

A = cross-sectional area

Δw = space time grid

i = integer counter of a part of the assumed space time grid

δ = inaccuracy of the measured value due to errors in measurement and interpolation

$\overline{\quad}$ = averaged over A and T

In the present measurement, the well known advective term in the transport could be ignored because it was relatively very small (< 2% of the flood transport). Therefore, only the dispersive term is analysed, i.e. $M_D = T\overline{Av\ (c-\bar{c})}$

Assume that the measured values v_i and c_i at position x_i, y_i, z_i at moment t are representative for the real transport v,c in a space time grid Δw_i. Then, the error δc_i can be splitted up in a part that is due to actual variations in Δw_i ($\delta c_{i\ stoch}$) and a part caused by systematic errors ($\delta c_{i syst}$):

$$\delta c_i = \delta c_{i\ stoch} + \delta c_{i\ syst}$$

In this analysis $c_{i\ syst}$ is ignored

By definition:

$$\sum_{i=1}^{N} w_i = \int_0^T dt \iint_A dydz = AT$$

It is postulated that

$$M_D = \sum_{i=1}^{N} \Delta w_i v_i (c_i - \bar{c})$$

Consider v_i and c_i stochastic and uncorrelated, then

$$M_D = \left\{ \sum_{i=1}^{N} (\Delta w_i)^2 \left[v_i (c_i - \bar{c}) \right]^2 \right\}^{1/2} =$$

$$= \left\{ \sum_{i=1}^{N} (\Delta w_i)^2 \left[(v_i\ \delta c_i)^2 + (c_i - \bar{c})^2 (\delta v_i)^2 \right] \right\}^{1/2}$$

Assume $v_i \leqslant v_{max}$, $c_i \leqslant c_{max}$, $\delta c_i \leqslant \delta c_{max}$ and $\delta v_i \leqslant \delta v_{max}$, then

$$\delta M_D \leq \left\{ \sum_{i=1}^{N} (\Delta w_i)^2 \left[v^2{}_{max} \; \delta c^2{}_{max} + (c_{max} - \bar{c})^2 \; \delta v^2{}_{max} \right] \right\}^{1/2}$$

Assume that the measurements are equally distant in space and time:

$$\Delta w_i \equiv \Delta w \text{ and } \Delta w = \frac{AT}{N}$$

then

$$\delta M_D \leq \frac{AT}{\sqrt{N}} \left[v^2{}_{max} \; \delta c^2{}_{max} + (c_{max} - \bar{c})^2 \, \delta v^2{}_{max} \right]^{1/2}$$

As can be seen from fig. 4 and table III, it can be roughly assumed that

POC : $(c_{max} - \bar{c}) \approx 1$ mg/l and $\delta c_{max} \approx 1$ mg/l

while: $v_{max} \approx 1$ m/sec and $\delta v_{max} \approx 0.1$ m/sec

This means that the second term between the brackets is roughly 100 times smaller than the first term.

This also aplies to the other components studied in this report.

Therefore $\delta M \leq \frac{AT \; v_{max} \;\; c_{max}}{\sqrt{N}}$

For POC using T = 46000 sec, A = 34000 m^2, v_{max}= 1.2 m/sec, δc_{max}= 0.2 g/m^3 and N = 100 this formula yielded

$\delta M_{POC} \leq 38$ tons

For seston, but applying $\delta c_{max} = 3 \; g/m^3$ resulted in

$\delta M_{seston} \leq 570$ tons

Phytoplankton and detritus-POC transport are supposed to have at least the same error as total POC, because they are calculated using the data for total POC.

For DOC, δc_{max}= 0.1 g/m^3 and thus

$$\delta M_{DOC} \leqslant 19 \text{ tons}$$

The accuracy of the transports of water (δQ) could be roughly estimated using the same formula for δM, but substituting δv_{max} for δc_{max} and omitting v_{max}.
Applying T = 46000 sec, A = 34000 m^2, v_{max}= 0.1 m/sec and N =2200 resulted in

$$\delta Q \leqslant 3.10^6 \text{ m}^3$$

Once again, it is stressed that the accuracies imply only stochastic errors. Systematic errors are unknown.

3.2. Transport of water

3.2.1. Current velocities in the transect

The way the water flowed through the transect is shown by the 1 hour distributions of the current velocity (v-distributions), that are calculated by use of the trend surface method (fig. 6). Actually, for each moment of the tidal cycle, such a v-distribution could be computed by interpolation in time of the measured values. In the pictures shown here positive and negative values are not marked differently. Thus, it is relevant to know that the pictures at t = 180 through 480 min show the flood phase and the ones at t = 600 min through 840 min the ebb phase, while at t = 540 min the high water slack occured. These pictures made it clear that the flooding water mainly used the southern channel and the ebbing water the northern channel. Furthermore the changing water level should be noted!
The F-values, resulted from a test on the goodness-of-fit of the calculated trend surfaces, are shown in fig. 5a. At all times, a significant trend ($P < 0,05$) was present and, at some times (e.g. t = 220 min and 600 min), an even more pronounced one ($P < 0,001$).
A comparison of fig. 6 and fig. 5a might help to evaluate the trends. The highest trends were at the onset of the tidal phases, when the

current velocities just increased and a strong vertical gradient existed. At the same time, there was also a remarkable difference in magnitude of the current velocities between the most northern and southern parts of the transect. The current velocities increased to about 1.1 m/sec, although some higher current velocities (e.g. 1.4 m/sec) were actually measured, but those higher velocities were levelled off by the trend surface analysing procedure.
The mean values of the current velocity during the flood and ebb phases were in the southern channel 0.59 m/sec and 0.49 m/sec respectively and, in the northern channel 0.42 m/sec and 0.56 m/sec respectively. These were calculated from the water transport values (method III) dividing them by the length of the ebb and flood phases in the channels (see under 3.2.2.) and the mean wet surface area of the transect.

3.2.2. Transports of water through the transect

The actual tidal water level curve measured at Wemeldinge harbour (fig. 3) was used to establish the actual wet surface area of the transect. The actual water level went from - 175 cm NAP at 140 min to + 176 cm NAP at 530 min and down to - 143 cm at 900 min.
The course of the water level did not differ very much from the mean water level course measured at Wemeldinge harbour. High and low water levels are on an average respectively + 171 cm and -165 cm NAP (year 1971).
The wet surface area of the transect below NAP was estimated at 34005 m^2 divided into 16372 m^2 of the northern channel and 17634 m^2 of the southern channel. The vertical tide caused a difference of approximately 12% in the wet surface area that was below the NAP zero level.
Water transport through a small northern channel, called the Dortsman, was ignored because, on average, only 3% of the total water transport goes through it.
The water discharge as a function of time is shown in fig. 10a. Fig. 11a shows the cumulative water transport. Once again these figures made the character of the channels clear: the southern channel is a flood channel, and northern one is an ebb channel.
Moreover, figure 10 reveals the exact endurances of flood and ebb in the channels. In the southern channel, the flood fase was 397 min and the ebb fase 350 min; in the northern channel 389 min and 382 min respectively.

Integration in time of the curve shown in fig. 10a resulted in total transports of water during flood and ebb time for each channel (tabel II, trend surface method): in the northern channel $164.10^6 m^3$ water and in the southern channel $236.10^6 m^3$ water flooded resulting in a total of $400.10^6 m^3$ inflowing water. The flow of ebbing water was in total $383.10^6 m^3$, of which $213.10^6 m^3$ flowed through the northern channel and $170.10^6 m^3$ through the southern channel. A net outflow was estimated at $66.10^6 m^3$ through the southern channel and at $49.10^6 m^3$ through the northern channel. Thus, $17.10^6 m^3$ water was imported over the total tidal cycle and the whole transect.

3.2.3. Comparison of different methods to calculate water transports

All methods showed (see Table II) a comparable result: a higher flood volume than ebb volume resulting in a flood surplus. They all showed that the southern channel is a flood channel and the northern one an ebb channel. Historically, the Netherlands Department of Public Works uses method II if the measured current velocities do not vary very much vertically. This resulted in a flood volume of $398.10^6 m^3$, an ebb volume of $382.10^6 m^3$ and a net inflow of $16.10^6 m^3$. In method III main vertical trends are more accounted for than in method II and the volumes were $400.10^6 m^3$, $383.10^6 m^3$ and $17.10^6 m^3$ respectively.
The close results of methods II and III confirmed the justification of the averaging process in current velocity profiles by the Hydraulic Department. Obviously, in this case, vertical profiles were rightly substituted by vertically averaged values to calculate discharges.
Methods I and IV were supposed to be less accurate but gave at least an indication of the discharges. Using data of one station in a main channel (method I) led easily to an overestimation of about 20% in the transported water volumes resulting in a 3 times higher total net transport than was calculated by the standard method II.
Method IV revealed that the net transport of water could also be roughly estimated from water level measurements, using a known function of the volume-depth relationship of the Eastern Scheldt beyond the transect (in eastern direction). From this method, a flood volume of $402.10^6 m^3$ and a total ebb volume of $377.10^6 m^3$ were calculated. These values differed only about 1% from the standard method values.

However, the total net volume was estimated at $25.10^6 m^3$ and that was about 50% higher than the value from methods II and III. Obviously, subtraction of almost equal large values yielded a net value with a larger relative error.

3.3. Mass transport of organic matter and seston

3.3.1. Concentrations in the transect

Total POC, chlorophyll-a, DOC and seston were the components that were directly measured.
The chlorophyll-a data were converted to phytoplankton-POC data (see 3.3.5.). Subtraction from corresponding total POC values yielded (detritus + zooplankton) -POC values. Plankton analysis revealed that less than 1% of the total POC was zooplankton (see 3.3.5). Zooplankton-POC was therefore ignored and the resulting data were considered to be detritus-POC values.
The data of total POC, phytoplankton-POC, detritus-POC, DOC and seston were applied in the trend surface analysis to establish distributions of concentrations of such a component in the transect ("c-distributions"). These c-distributions (except for DOC, see under) are shown in fig. 7 for every one hour of the measured tidal cycle.
An F-test on the goodness-of-fit of the 1/2 hour trend surfaces of each component resulted in F-values that are shown in figs. 5b and c. These values gave some information about the reliability of the pictures shown in fig. 7 and they indicated the occurence of significant trends. Where trends allready existed, they had to be accounted for in the calculations of transports of the component; i.e. no integration over time of mean values for the transect, but integration over time of distributions of concentration times current velocity ("v.c-distributions", see further 3.3.2.).
The pictures in fig. 7 of t = 180 through 480 min apply to the flood phase, those of t = 540 min for high water slack time and the rest for the ebb phase. It is most instructive to compare these pictures with those of the v-distribution in fig. 6 which gave some insight into what actually happened.

The pictures of seston, total POC, phytoplankton-POC and detritus-POC show some common characteristics. The particulate components were whirled up at t = 180 through 240 min (the current velocity remained nearly constant for a while at t = 270 min - not shown here) and were whirled up later on at t = 360 min through 480 min (while current velocities increased and highest values were reached at about t= 420 min). Then, at t = 540 min and 600 min (at and beyond high water slack time),sedimentation dominated. At t = 700 min through 840 min, upwhirling of the particulate components caused by the current once more, followed by another sedimentation period around low water slack time.
Where a strong concentration gradient existed, high F-values (figs. 4b and c) were calculated. Thus, e.g. when some particulate components sedimented (in total POC and detritus-POC at t = 210 and 540 min and in seston at t = 210 and about 600 min), or was whirled up to a large extent (in total POC, detritus-POC and seston at t = 420 and 750 min) the high vertical gradients possibly resulted in a more pronounced F-value. At highest current velocities (t = 360 through 480 min), vertical gradients of POC tended to disappear while those of seston became more pronounced, possibly due to bottom erosion that adds sand to the seston load but only a small amount of POC (bottom comprises ca. 2% organic matter while the seston on an average 10%).
In DOC, no obvious trends could be established (fig. 5b). Thus, the calculated fits did not give more information about the cross-sectional distribution than mean concentrations over the channels. The fits of DOC are therefore not shown.
From fig. 5c, it was deduced that in phytoplankton-POC significant trends were only present around low water slack time, i.e. in the second stage of the ebb phase (t = 750 - 870 min) and at the beginning of the flood phase (t = 180 - 270 min) caused by a stronger vertical gradient in the southern channel possibly due to falling down of this material. The time around high water slack might be too short to settle effectively. This might indicate that phytoplankton was lighter than the detritus.
In the southern channel the upwhirling was more pronounced than in the northern channel both during the flood phase and during the ebb phase. Maximal current velocities close to the bottom were almost the same in both channels during the ebb (see in fig. 6 at t = 660 and 720 min). Thus, a higher load of material might have been present for entrainment and transport in the southern channel.

The difference in concentrations between the northern and southern channels (y-direction) and the upwhirling alone (z-direction) might have influenced the computed F-values.

Above the shallower middle part of the transect the entrainment caused higher concentrations at the surface. This phenomenon was both clear visually and by use of a turbidity meter in the surface waters. These last qualitative observations reconfirmed the reliability of the calculated "c-distributions".
The concentrations calculated at the southern and northern edges of the transect (above the sandplates), that are inundated by the flooding water, were unreliable. Therefore all transport calculations were based on data from y = 250 to 2500 m.

The applied trend analysis yielded fitted concentrations implying some dominating trends, in which extremes in concentrations due to small patchy "behaviour" of the particulate components and sampling errors, were levelled off. As a consequence, a correlation analysis of POC-versus corresponding current velocity-data (see pag.27) showed that fitted values of POC correlated more positively with actually measured current velocities than did the actual measured values of POC.

In addition to the pictures, table III summarises some information about the measured concentrations. It gives the mean concentrations weighed on water discharge ($\bar{c}^Q$), the means of the actually measured concentrations ($\bar{c}$) and their standard deviation(s), the number of involved measurements (n), and the lowest and highest concentrations measured (resp. l and h) of DOC, POC and seston for the tidal phases and the two channels. During the flood, the mean concentrations of DOC over half an hour were often rather lower than during the ebb, but means calculated over the whole flood phase or ebb phase did not differ significantly, as can be deduced from the calculated standard deviations. However, the lowest and highest concentrations measured confirm this fact e.g. 1.96 mg/l was measured during flood and 3.00 mg/l during ebb.
Moreover, mean concentrations weighed on water discharge ($\bar{c}^Q$ in table III) also indicated that the water mass that flooded had a lower concentration of DOC than that ebbed (2.35 mg/l and 2.60 mg/l resp.).

However, if an accuracy in the transport of water and DOC of 2% and 5% respectively is assumed, then the calculated mean concentration of DOC weighed on water transport might have an accuracy of about 5%. The water in the southern channel had a $\bar{c}^Q$ = 2.31 mg/l during flood and the water in the northern channel had a $\bar{c}^Q$ = 2.60 mg/l during ebb. The first value had an estimated standard deviation of 0.12 mg/l and the second one of 0.13 mg/l. Therefore, these values were significantly different (at the 50% level). Thus, it may be assumed that the flood water in the southern channel had a lower $\bar{c}^Q$ than that of the ebb water in the northern channel.

Because the flood current caused e.g. rather more upwhirling of the particulate components (see in fig. 7 at t = 420 and 480 min), the mean concentration ($\bar{c}$) calculated for the flood water might be rather higher than that for the ebb water. Actually, e.g. in the southern channel $\bar{c}$ of POC was 1.41 mg/l in the flood phase and 1.25 mg/l in the ebb phase. However, great variations in time and depth caused a large standard deviation of these values 0.65 mg/l and 0.53 mg/l respectively. Also, highest values were measured during flood and lowest ones during ebb. Assuming an accuracy in the transport of water and POC of resp. 2% and 10% respectively the accuracy of $\bar{c}^Q$ might be estimated at about 10%. The $\bar{c}^Q$ of POC of the flood water in the southern channel (1.49 mg/l) was significantly higher than of the ebb water in the northern channel (1.17 mg/l).
Because the values of seston indicated the same differences between flood and ebb water in both channels as in POC, the $\bar{c}^Q$ of POC and seston were assumed to be accurate enough to be used in further calculations (see 3.3.4.: Tentative transport schemes).

Mean values weighed on water transport tended to be higher than the arithmetic means in POC and seston (table III).
This might be explained by the fact that POC and seston are whirled up by the higher currents. As a consequence of this process, higher currents are synchronised to some extent by higher concentrations causing higher transports of these particulates. Such upwhirling does not occur in DOC and therefore the means of DOC weighed on water transport are generally not higher than the arithmetic means of DOC.

Regression analysis POC versus seston

A linear regression analysis of POC on seston showed that there was always a highly significant positive correlation between POC and seston (P always < 0.001, see table V). This applied to all data together or grouped to channel or to depth. All regression lines had a significant intercept on the ordinate (b). In the southern channel this intercept varied between 0.67 and 0.84 mg/l but in the northern channel this variance was between 0.43 and 0.55 mg/l. This can be interpreted as an occurence of an other relation between POC and seston at the lowest values or only a fraction of POC correlated with seston. In fact, this might indicate a basic fraction or background of POC that was present all the time. At a POC concentration between 1 and 2 mg/l, this background was between 30% and 80% of the total measured POC. After subtraction of this background seston contained 3 to 7% POC.
From an F-test on parallelism and distance of the regression lines of POC on seston, based on data from the northern channel grouped to ebb and flood period and total tidal cycle, it was proved (table VI) that the slopes (a) differed significantly and this was due to data from the southern channel and the flood phase. During the flood phase relatively more POC was whirled up with the seston in the southern channel than in the northern channel, thus causing a higher slope value there (0.07 instead of 0.04). Moreover, the "background POC",indicated by the intercept value on the ordinate was higher in the northern channel (0.67 mg/l) than in the southern one (0.45 mg/l). Obviously, the inflowing organic matter might have been on average heavier than the outflowing organic matter. The slope values tended also to increase with greater depth in both channels (see table V). At greater depth this was due to a similar phenomenon: the heavier organic matter added relatively more in weight when it was whirled up.
The mean POC- and seston concentrations in the northern channel tended to be lower than in the southern channel (table III and VII), but the differences at the water surface were insignificant because of the standard deviations involved.
In table V it can also be seen that a correlation between POC and seston increased from surface water to deep water (surface water is 0 - 1/3, mean depth 1/3 - 2/3 and deep water is 2/3 - 1 times the total water column at any given moment): the shown correlation coefficients increase from 0.680 to about 0.779 in the northern channel and from

0.750 to 0.892 in the southern channel. This is largely explained by more variation in the seston concentrations, which is also confirmed by the calculated standard deviations in table VII.

Seston contained 9.7 to 13% POC, depending on channel and depth (table VII). A lower percentage was found at the bottom and the lowest in the southern channel (9.7%) possibly due to the heavier seston at the bottom that added more in weight but less in organic matter.

Regression analysis: POC versus current velocity

It was shown from data of the southern channel that the means of concentrations of POC at moment t_1 (POC_{t1}) positively and significantly ($P \ll 0.001$) correlated with the means of the currentvelocities of a given moment t_2 (v_{t2}) if $t_1 - t_2 \leq$ 45 min (table VIII). At $t_1 - t_2 >$ 45 min, the correlation was worse or did not exist at all. The best correlation was found at $t_1 - t_2 =$ 15 min but did not differ much from $t_1 = t_2$. The established regression formulae are also given in table VIII. These formulae indicated that in the southern channel a "background" concentration of POC existed of about 1 mg/l. They confirmed that some organic matter was not whirled up but in suspension all the time (and was not correlated with v). By using fitted data from the trend surfaces analysis a higher correlation between POC and current velocities could be established, because the trend surfaces were mostly deprived of inaccuracies of measurements (incl. sampling technics) and patchy behaviour of variables.

From regression analysis of seston versus v, the same conclusions could be drawn as for POC versus v. From regression analysis of DOC versus v, it was proved that between these parameters there was no relation at all.

3.3.2. Fluxes in the transect

Multiplication of the trend surfaces of the components (c) with the corresponding trend surfaces of the current velocity (v) yielded "c.v trend surfaces". Only the 1 hour flux-distributions of seston, total POC, phytoplankton-POC and detritus-POC are shown here in a series of pictures (fig. 8); The pictures of flux-distribution of DOC are almost similar to those of v (fig. 6): the values indicated of v need only to be multiplied by about 2.5. Therefore, they are not shown.

To analyse these pictures, it is important to compare them with the corresponding pictures of c and v (figs. 6 and 7). All series of flux distributions of the different particulate components appear roughly the same. At t = 180 through 360 min, a vertical gradient in the fluxes dominated, due to strong vertical gradients in c especially in the southern channel. At t = 920 and 480 min, the v was so large in the upper half of the transect that it caused the fluxes to be almost constant vertically. There was only a horizontal gradient of c.v and this indicated higher values in the southern channel and lower ones in the northern channel. At and around slack time (t = 540 min) v values were almost zero and the values of c.v also. While, upstreaming still occured in the southern channel, already downstreaming started in the northern channel (compare figs. 6 and 8 at t = 540 min.).

At t = 600 through 840 min, vertical c gradients reappeared more clearly in the southern channel than in the northern one. On the contrary, higher v values were measured in the northern one. The result was an area with higher flux values in the middle of the transect.

A look through all the series of pictures of flux distributions made it clear that the highest fluxes were measured in the southern channel at t = 420 min. Moreover, it appeared that the transports of the particulate components differed mostly in the horizontal cross direction because, at times of highest fluxes (t = 420, 480, 720 and 780 min), c.v was vertically constant to a large extent.

In addition, no obvious differences could be found in the distribution of the fluxes of total POC and detritus-POC. However, there were some differences between seston and POC. As can be seen from the pictures at t = 360 through 480 min, fluxes were more constant vertically in POC than in seston, possibly due to erosion of the bottom that caused a higher suspended seston load immediately above the bottom. At these times, POC itself is vertically almost homogeneously mixed (see especially the c-distribution of POC at t = 480). This indicates that, at higher current velocities, when bottom erosion occurs, seston flux may become more bulky than POC flux, if material from the bottom has a lower POC-content than the average suspended matter.

The current velocity is the dominating factor in the distribution of the fluxes of DOC and a mean concentration in the water discharges involved already determined the actual transport.

3.3.3. Mass transports through the transect

Integration of the fluxes (c.v-values) over the southern channel, the northern channel and the whole transect yielded total fluxes (tons/sec). These total fluxes are shown as a function of time in figs. 10b through f for DOC, seston, total POC, phytoplankton-POC and detritus-POC respectively. The cumulative transports are shown in fig. 11, from which at about t = 900 can be derived what the net transports were over the total tidal cycle. The integrated values over the flood phase, ebb phase, and total tidal period i.e. the mass transports are summarised in table II.

As has already mentioned, the transport of DOC followed to a large extent the pattern, that was shown by the transport of water (see 3.3, fig. 10a and b, figs. 11 a and b).

546 tons DOC were imported through the southern channel and 356 tons DOC through the northern channel. The exports through these channels were 436 and 554 tons DOC respectively. The flood water therefore imported 110 tons DOC through the southern channel and the ebbing water exported 168 tons DOC through the northern channel resulting in 57 tons DOC export. The export was due to higher concentrations of DOC in the ebb water than in flood water (table III).

352 tons POC were imported, through the southern channel and 215 tons POC through the northern one. The export through these channels was 236 and 249 tons POC respectively. Thus, the southern channel had an importing function of 116 tons POC net and the northern one an exporting function of 34 tons POC net. Thus 82 tons POC were brought into the eastern part of the Eastern Scheldt during the tidal cycle of 20th April 1979.

The rough estimation of the transport, based on data from one station per main channel led to transports that were on average overestimated by 20%. But net transports differed less and e.g. the total net transport of POC was only 15 tons higher than was calculated by the trend surface method.

At first sight the pattern of flow of seston, phytoplankton-POC and detritus-POC was almost the same as that held for POC except that the figures differed.

Generally, the figures of transports of seston were ten times those of POC. Transport of phytoplankton-POC and detritus-POC were generally

25% and 75% respectively of the transport of POC. However, the net transport of phytoplankton-POC (8 tons) was only 10% of the total net transport of total POC (82 tons). Detritus-POC made up the rest of the net transport of POC.

The net transport of seston appeared to have only 6.5% POC.

These figures might indicate that relatively more seston remained in the eastern part of the Eastern Scheldt than the total POC. Moreover, more detritus-POC was also brought into that part than phytoplankton-POC. This can be explained by the fact that phytoplankton is lighter than detritus and that organic matter as measured by POC is itself lighter than total seston on average. The inorganic seston usually has a density higher than 2.5 g/cm^3, total POC and detritus more than 1.2 g/cm^3 and phytoplankton-POC less than 1.4 g/cm^3 (see e.g. de Jonge, 1979). Thus, relatively more heavier matters were imported than lighter ones. That more seston was relatively transported with the higher current velocities than POC is also shown by the transport curves in fig. 10. For example at t = 450 min the total flux of seston is about three times that of t = 300 min, while in POC it was only twice the amount.

The net values of mass transport over the whole transect and the total tidal cycle were 1253 tons seston, 82 tons POC and 57 tons DOC. These values were higher than the ones that indicated a rough level of accuracy, i.e. 570 tons seston, 38 tons POC and 19 tons DOC (see under 3.1.2.). Therefore, it was concluded that they were significant. Applying a similar level of accuracy of 38 tons POC to the net transports of phytoplankton-POC (8 tons) and detritus-POC (74 tons) it was concluded that only the last figure was significant.

3.3.4. Tentative schemes of net transports

A tentative scheme of water transport was made using data from method II in table II and is shown in fig. 9a. In this scheme, exchange between flood water and water beyond the transect present at low waterslack is ignored. The flood and the ebb water in the southern and northern channels respectively was assumed to return through the the same channels (resp. $170.10^6 m^3$ and $164.10^6 m^3$), leaving $49.10^6 m^3$ of water for horizontal circulation after subtraction of $17.10^6 m^3$ of

water that remained beyond the transect. Thus, it was assumed in this scheme that the channels had their own water masses that moved around in them. The horizontal water-circulation, i.e. the roundstream from the southern to the northern channel, was supposed to be a direct one, although some of that water might have stayed over more tidal cycles beyond the transect. This tentative scheme revealed the importance that horizontal water circulation might have in the exchange of water in the area of the transect: it made up 20% of the flood water through the southern channel and 22% of the ebb water through the northern channel. A flood surplus also occurred and this would have extra repercussions on the mass transport of the components. Using data of the means weighed on water transport for the different components ($\bar{c}^Q$ in table III) and the scheme of water transports (fig. 9a), the net transports of DOC, POC and seston could be further analysed.
Table IV summarizes the applied concentration or concentration difference of POC (Δc) and applied watervolumes (Q_w), from which net POC-transports ($\Delta c \cdot Q_w$) were calculated. The difference between the $\bar{c}^Q$ of the flood and of the ebb phase in the northern channel, multiplied by the water volume that moved around in that channel, yielded a net transport of a component due to that water mass. The net transport, due to the moving around of the water mass in the southern channel was calculated in a similar way. The flood surplus times the $\bar{c}^Q$ in the flood water of the southern channel resulted in an estimation of the net transport that was due to the water that remained behind in the eastern part of the Eastern Scheldt during that particular tidal cycle. The difference between $\bar{c}^Q$ of the flood water in the southern channel and that of the ebb water in the northern channel multiplied by the estimated water volume that moved from the southern to the northern channel yielded an estimation of the net transport due to horizontal water circulation. A comparison of figs. 9a and 9b made it clear that water that moved about in both channels (resp. 164.10^6 and $170.10^6 m^3$ indicated almost the same net transport of POC (23 and 17 tons). An assumed water circulation of $49.10^6 m^3$ resulted in a net import of 16 tons POC and the flood surplus of both channels of $17.10^6 m^3$ resulted in an import of 25 tons POC. The total resulting resulting import of POC through both channels was estimated at 82 tons and occured through both channels.

The scheme of net seston-transport (fig. 9d) revealed the same as for net POC-transport; only the estimated values are roughly ten to twenty times higher.
The scheme of net DOC transports (fig. 9c) revealed that 39 and 43 tons DOC were exported by the moving around of water in respectively the southern and northern channels respectively. The local horizontal water circulation in that area might have resulted in an addition of 14 tons to the net export of DOC. Another 39 tons DOC net were exported and this occured in the opposite direction for the particulate components.

Although the values in these schemes are rough estimates it was concluded that relatively small amounts of water (horizontal circulating water, water surplus due to changes in the tide from one tidal cycle to another, or from springtide to neap tide) might change the net mass transports through the transect during one tidal cycle to a large extent: in this study alone the water surplus might have already added some 30% to the net transport of POC through the transect (table V). Horizontal water circulation accounted for another 20% of the net transport of POC.

3.3.5. Transport of plankton

Plankton counts gave three different results which are shown in figs. 12a, b and c. In these graphs, counts at 330 and 510 min can be interpreted as flood counts and counts at 690 and 870 min as ebb counts. The counts are averaged values of surface, half depth and bottom + 1 m samples because there were only slight differences vertically.
In Katodinium rotundatum (fig. 12a), higher concentrations were established in the northern channel and during ebb. In Rhizosolenia delicatula (fig. 12b), there were no differences between the concentrations estimated in the northern and southern channels during flood- and ebb phases respectively. In Ditylum brightwelli (fig. 12c), higher counts in the flood phase in the southern channel especially could be established. Other counted species gave similar results to these three examples. Obviously, µ-flagellates gave a similar picture as Katodinium rotundatum. It can be hypothesized that Katodinium rotundatum had a transport direction from East to West and Ditylum brightwellii from West to East, while Rhizosolenia did not have a pronounced transport direction. Obviously, some smaller species that grew more in the eas-

tern part of the Eastern Scheldt (like the μ-flagellates) spreaded from East to West in the estuary and others (possibly heavier marine species) were taken by the tide further up the estuary while, however, the bulk was spread in equal numbers in both directions. These data confirmed the fact that phytoplankton-POC was relatively light and only a small net amount was imported (see 3.3.2).

If specific parts of the phytoplankton were concentrated upon - e.g. species - the calculation of transports would be much more complex with uncertain results.

Therefore, it was decided to deal with phytoplankton as a whole.

Phytoplankton-POC could be calculated from estimated plankton concentrations, using Hagemeier's formulae that gave POC-plankton volume ratio's for many different phytoplankton species (Biologische Anstalt Helgoland, F.R.G. see Gieskes & Kraaij, 1977). The results revealed that the phytoplankton-POC varied from 0.1 - 0.5 g/m^3 and that about 10-50% of the total POC was phytoplankton. Chlorophyll-a concentrations varied between 5 and 25 μg/l and were on average 14.2 μg/l. Zooplankton was less than 1 mg C/m^3, i.e. 1% of the total POC. Therefore, even in a plankton bloom in the Eastern Scheldt, that usually occurs in the period April-May (Drinkwaard 1958, 1959, 1960), most of the POC in the water column is detritus.

A regression analysis of the phytoplankton-POC data on chlorophyll-a concentration data resulted in the following regression formula:

(phytoplankton-POC)= 24.913 (chl.a) - 0.649 (r = 0.862, n = 24, concentrations in μg/l).

This relation was used to transform all measured chlorophyll-a concentrations into phytoplankton-POC concentrations. The latter were used to establish trend surfaces of phytoplankton-POC. Because zooplankton--POC was less than 1 mg/m^3, the rest op the POC that was measured was assumed to be almost completely detritus. Therefore, concentrations obtained from subtraction-total POC minus phytoplankton-POC were used to establish trend surfaces of detritus-POC (see 3.3.12.).

As was done for total POC, transports could be calculated of phytoplankton-POC and detritus-POC (fig. 10e, f and 11e, f and see 3.3.2. and 3.3.3.). The linear regression function of total POC on chlorophyll-a and total POC was:

(total POC) = 95.529 (chl.a) - 0.3709 (r = 0.661, n = 24, concentrations in μg/l)

This already indicated that the calculated trend surfaces of phytoplankton-POC and detritus-POC should be almost similar to those of POC and seston and differed only in concentration levels.

3.4. Primary production and organic matter transport

Maximal additions of POC to the different hypothetical 1 m thick water layers were estimated by measurements of potential primary production (PPP). It was assumed that the water remained modally for 5 hours beyond the transect. Fig. 13 shows these PPP-values as a function of time for most of the water layers of the euphotic zone.

It can be seen that, somewhat later than at 10 hours, the PPP-values decreased quickly, possibly due to the lower concentrations of POC, seston and phytoplankton-POC (fig. 7 t = 600 and 720 min).

Some later than at 13 hours the flowing water through the transect contained some more productive components because of the resuspension process which led to a reviving of the PPP. (The available PAR in the following five hours was almost the same).

With certain assumptions (see 2.7.3.), multiplication of the PPP-values with the water transport speeds of the different water layers resulted in values of a function f (z,t), that described in depth and time the potential addition of POC in the following five hours to the water mass that passed the transect at any given time (fig. 14). Integration of f(z,t) over time gave the total potential additions of POC by PPP. The addition of POC appeared to be the highest in the uppermost layer (2.3 tons) and turned out to be almost half of the total euphotic zone (ca. 5 ton) during residence of the water in the eastern part of the Eastern Scheldt. Thus, some POC was added to the water that flowed during flood phase through the transect.

In the water that passed the transect during the ebb phase, the addition of POC was estimated at 9 tons for the uppermost water layer and at 34 ton for the total water mass.

So the difference between in and outgoing POC-mass, if calculated only from direct POC measurements at the transect, would be 5 tons higher if there had been no primary production. The 34 tons POC, potentially provided by algae in the water that flowed from East to West during the residence of the water mass west of the transect, could pass the transect in the next flood phase (consumption, mineralisation etc. leaving at that).

Daily primary production was estimated at some 2000 mg C/m^2/day at y = 2225 m and 1700 mg C/m^2/day at y = 1206 m resp. with a peak around 14 hours of 319 mg C/m^2/h and 232 mg C/m^2/h in the euphotic zone. The available PAR that day was 297,45 J/cm^2, the water temperature was 13.6 - 14.4°C and salinity was 15.5 - 16.0 o/oo Cl^-.

Although systematically the chlorophyll-a concentrations were somewhat higher at y = 1206 m than at y = 2225 m (fig. 6: phytoplankton-POC), the primary production per square meter was the opposite, possibly due to the higher turbidity at y = 1206 m caused by a heavier load of seston there (fig. 7: seston).

4. Discussion

Postma (1954) and Wolff (1977) used data from the phosphorus balance to estimate organic matter transport in an estuary. They assumed that this balance in an estuary is in equilibrium, which assumption is highly questionable (Postma & Rommets, 1970). Moreover,the P/C ratio of 1/100 they used may vary (Bigelow, 1977). A 1-dimensional longitudinal dispersive transport model can only be applied when the variable is distributed homogeneously in horizontal and vertical cross-directions. From the present study, it became clear that this is not true for seston nor for totally suspended organic matter. Gradient methods, based on averaged data of a year or longer,are not to be recommended for modelling suspended organic matter transport, because they ignore short time variations that might have induced high transports. Moreover, water transport weighed values, instead of mean values of a component, should be used to draw conclusions with respect to mass transports. Only Bigelow et al. (1977) estimated the transport of organic matter in such a way that main ecological processes were directly reckoned with. They calculated the transport of organic matter in time periods of a year by means of an overall carbon balance equation for the Eastern Scheldt. All components of their balance were rough estimates and the virtual deviations were summarized in the transport component. "Rough"is used here because the estimates were based on data from other estuaries and on balancing terms in an ecological model, based on the optimalisation of a function that was very similar to Gibbs' function in thermodynamics. However, they calculated the yearly requirements of the ecological system, the Eastern Scheldt as a whole, and not the actual transport figures of the physical transport phenomenon.

The present study investigates, whether a direct measurement of the transport of organic matter through a transect in the Eastern Scheldt, could be carried out; i.e. calculations from the data collected on the 20th april 1979 would result in significant net transports of organic matter for one tidal cycle.
A net import of 82 tons POC and a net export of 57 tons DOC was calculated by use of the trend surface method. With respect to the accuracy criteria, it should be said that, according to Kjerve (1981), all

relevant bathymetric regimes involved were sampled. Because, in well mixed estuaries, detailed knowledge of the cross-sectional velocity structure is more important than the same detailed knowledge of the concentration of some component (Kjerve & Proehl, 1979), the current velocity measurements were more stressed than the measurements of the components. Moreover, the latter were restricted because of the possible number of samples that could be analysed in the labs. A rough significance level was estimated at 38 tons POC and 19 tons DOC, which indicated that the net import of POC and the net export of DOC could be assumed to be real.

Primary production added some 5-10 tons to the water mass during its residence in the Eastern part beyond the transect. So, not 82 tons but 90 tons approximately were "actually" imported during that tidal cycle. However, $17.10^6 m^3$ water did not return through the transect. This meant that about 25 tons (see also table IV) was transported by the flood surplus. Therefore, a corrected net transport was estimated at some 65 tons POC. This meant a net import of ca. 125 tons particulate organic matter (using of a conversion factor of 1.9) or 0.9 g/m^2 per tidal period. This was about 11% of the total import during the flood phase. More measurements of this kind are needed to reveal the significance of these values over a longer period.

The organic matter produced by the process of primary production, caused an extra export of ca. 15 tons particulate organic matter, which meant less than 3% of the total export that day.

Bigelow et al (1977) estimated on basis of a trophic balance an import of 700 tons/day for the whole Eastern Scheldt i.e. on average 0.8 g/m^2 per tidal period. This value might have a large standard deviation, owing to the applied calculation method, so the value from this measurement of the 20th April 1979 might not be contradictory.

Terwindt (1967) calculated an import of 0.1 - 0.3 10^6 tons of mud per year to the eastern part of the Eastern Scheldt. Assuming POC weight as 10% of seston weight, a net import of ca. 40 tons POC per tidal cycle might occur. This value is almost similar to the one calculated in this study.

There are some remarks to be made as a result of using the trend surface method. To deal with the collected data in a straightforward and consistent manner, a simple mathematical method had to be applied. Its first aim was to draw isopleths of concentrations of matter in the transect. The most simple way to do so was to fit the data in the transect with some polynomal surface function by the least squares method and calculate lines of equal concentration. Such a method has already been described for e.g. geographical data (see Davis, 1973). Mountains and valleys in an area might hide some overall trend(s) in altitude. These trends could be established by this method and even the goodness-of-fit could be tested. The higher the degree of polynomal function that is applied, the more of the actual morphology is re--created. A prerequisite is that the distribution of measurement points are sufficiently dense. This trend surface method also helps to find trends in a transect that comprises data of some component or even current velocity. From the present data of the components (seston, total POC, phytoplankton-POC, detritus-POC and DOC), a second degree polynomal function was calculated for each 1/2 hour situation. This second degree level had to be sufficiently accurate; otherwise, constraints with respect to the bottom, for example, would have to be made. A higher degree polynomal function turned out to overweigh extreme values which were caused by random errors of sampling, analysis, or by extra-ordinary micro-variations in the water. This might result in unreliably fitted surfaces and inaccurate transport. From a rough field survey in the horizontal cross-direction, i.e. visual observations and turbidity measurements at some 5 m depth, it appeared once more that the present fit could be considered to be reliable.

The much higher density of current velocity data in the transect (about 60) facilitated the use of a much higher degree polynomal function. However, lack of time made it necessary to accept a third degree level. Actually, a first or second degree fit vertically should be sufficient because vertically mean values are to be used in the standard method and that one gave to the experiences of the of the State department of Public Works reliable discharge values in the Eastern Scheldt.

A higher degree polynomal function might be applied to the data in horizontal cross-direction, in order to get more accurate distributions of the current velocity in the transect. To calculate water transports the applied third degree level was sufficient: the trend surface method resulted in discharge values, that did not differ much from those calculated by the standard method (see table II and under

3.2.3.). As was expected, such lower degree trend surfaces also levelled off extreme local variations of concentrations. Remarkably, the fitted concentrations of POC had a better correlation with occuring vertically averaged fitted current velocities than the actual measured ones (see 3.3.1.). Obviously, the main trends in concentrations of this particulate component in the transect were induced by the current velocityregime. Small patches of higher and lower concentrations in time and space were possibly due to the particulate components themselves, small scale turbulences or insufficient sampling techniques or analysis. From the c-distributions in fig. 7, it could still be deduced that the measured particulate components might have had significant correlations with each other and, actually, they did have (see e.g. for POC and seston 3.3.4.1., and POC and phytoplankton-POC 3.3.5.).

An increase in the extent of correlation from surface water to bottom that was shown for POC on seston (table V), might mainly be due to the much larger variation of concentrations of POC and seston that occurred at greater depths (see standard deviations of the means of these components for different depths in table VI).

Actually, a net mass transport might have occurred due to three factors:

1. a net water transport that held matter
2. water exchange processes whereby water with some concentration was exchanged with water with a different concentration of matter
3. processes that changed the concentrations e.g. sedimentation, resuspensions, primary production, consumption etc.

<u>ad. 1.</u>

In the present tidal cycle, a flood surplus of some $17.10^6 m^3$ of water caused a transport of about 25 tons POC net import. The flood and ebb water surplus through the transect at Wemeldinge might be up to ± $90.10^6 m^3$. Assuming an average POC-concentration of 1 g/m^3 such a surplus transport might imply 90 tons POC within one tidal cycle. Therefore, the water surplus in transport calculations of suspended organic matter per tidal cycle in the Eastern Scheldt must be considered because of its magnitude.

Moreover, these surplusses may have been loaded or unloaded with or from organic matter beyond the transect due to different processes. If the result is a lower mean concentration in the flood or the ebb surplus, a net transport might have occured in some direction. Although, the water surplus are net zero over a long period, it is unknown to what extent these surplusses contribute to the net transport of some components on a year-long basis.

In addition to these surplusses there is also an advective transport due to freshwater run-off implying net flow of water to the North Sea. This run-off into the Eastern part ($<10^3$/sec. $< 0.5.10^6 m^3$/tidal cycle) is small in comparison with the total tidal volume, that moved around each tidal cycle, through the transect (about $400.10^6 m^3$), and is therefore ignored in calculations in the present study.

ad. 2.

It was already known that the tidal exchange of water through the transect was less than 1% of the flood volume ($< 4.10^6 m^3$). If a difference in mean concentration of POC in the exchanging water masses was assumed to be 0.34 mg/l (table V), a net transport of POC due to exchange of water masses was estimated at about 1 ton. This transport could be ignored in view of the other transports involved, which were a magnitude larger.

The same held for the other components.

ad. 3.

Ignoring water exchange processes between tidal prism and the water below low water level beyond the transect, four ways of water transport through the transect were considered:

1. a moving around of water in the flood channel
2. a moving around of water in the ebb channel
3. a horizontal water circulation in cross direction
4. a tidal water surplus

Because these water masses all together move, it is very tentative to split up mass net transports of water and the components.

However, from a tentative schematic approach, it appeared that, (see 3.3.4.) although the transport of water differed in magnitude (the first and the second one were almost similar, but were about four times the third one and about 10 times the fourth one), they explained similar parts of the net transport of POC. Thus, processes in the water were acting in such a way that small amounts of extra water trans-

port caused already relatively large amounts of extra mass transport through the transect.
The main physical processes that act on suspended matter are sedimentation and erosion. Postma (1954, 1961) and van Straaten & Kuenen (1957) developed a qualitative model, by which they could explain a transport of suspended matter up an estuary, resulting in a continuous gradient along the axis of the estuary with the highest concentrations on the landwardside.
They described a "jump type" transport, due to critical erosion and sedimentation current velocities in combination with a decrease in maximal current velocities, along the axis of the estuary. Actually, the net transport was then effected by an asymmetry in the alternating tidal current (see also Groen, 1967) or an asymmetry in the depth-width ratio along the axis of the estuary.
A tentative application of a similar model as the one that was published by Groen (1967) to simplified Eastern Scheldt data resulted, however, in a nearly zero mass transport of POC (personal communication J. Dronkers, DDWT-the Hague). Another approach is to be made using the second effecting mechanism.
From Drinkwaard's data (1958), it could be deduced that in a bloom period of phytoplankton (diatoms), about 80% of total POC at the water surface would not sink within 2 hours over a distance of 30 cm and beyond these periods about 60%. Data from the southern channel indicated about 0.7 g/m^3 (for e.g. at y = 1206m, half depth, see table IX and fig. 7) and a correlation analysis of POC on seston showed a background of about 0.5 g/m^3 (table V). Thus 40-80% of the total POC in the Eastern Scheldt was continuously in suspension and did not take part in sedimentation-resuspension processes: its transport could have been described by a longitudinal dispersive model.
Plankton analysis showed transports of different POC-components in different directions. A bloom of some species, somewhere along the axis of the estuary, might have caused an extra transport in some direction based on exchange processes (gradient type transport) or in a way that is caused by e.g. differences in falling down and upwhirling (non-gradient type transport).

It was shown that, within one tidal cycle the primary production process was a source of new organic matter equivalent at least to the net transport of suspended organic matter through a cross section of an estuary. The addition to the transport of DOC was estimated to be less than 1 ton DOC and was therefore ignored.

Evaluating the part that the primary production process took in calculations of POC-transports, it should be mentioned that there were some assumptions in calculations of primary production values as follows:

1. The hydrodynamical (channel type) situation and the irradiation at other places where the water flowed were the same as in the transect.
2. The vertical distribution of the primary producers, their quantities, composition and physiology were the same as in the transect.
3. The residence time of the water with its components that flowed at any given moment through the transect, was modally five hours east or west of the transect.

Referring to assumption 1., it must be pointed out that this type of transport profile is roughly similar only for a few kilometers in western and eastern direction. The water that flowed through the transect went much further i.e. some 15 km west and east. So the irradiance situation had already altered by spreading out of the water over a larger area, which meant more light energy was available for the primary production process. It spread roughly over 1.5 - 2 times the area concerned in the calculations. The composition, quantities and physiology must have changed a little during the tidal cycle. For instance, from the plankton counts of the two channels, it became apparent that there were differences in the plankton composition of the flood and ebb water. The resultant change in primary production was admitted to be very small.

Referring to assumption 3 it should be noted that a "first-in last out" principle could also have been applied to the water that flowed vice-versa through the cross-section. However, lack of knowledge of the actual manner of horizontal water circulation and tidal water surplus also implied that it was not known which part of the water actually went in first or out last, or remained behind till the next tidal cycle(s).

Therefore, it had to be concluded that the calculated potential additions, by the primary production process, were only indicative for the magnitude of the share that the primary production process takes in

transport calculations. A reasonable estimate was that the primary production process added some 5 - 10 tons POC to the water that flowed in and out of the eastern part of the Eastern Scheldt through the transect during the tidal cycle being studied on 20th April 1979.
However, during the spring bloom, that addition might have varied roughly from 0 to about 75 tons, both during residence of the water west and east of the transect. Because the water spread much more in the eastern direction, the addition might have been higher there if integration over the whole spring bloom time had taken place. Better estimates could have been made by measuring primary production at some stations beyond the transect, i.e. west or east of the transect depending on which additions were to be calculated. Furthermore, a synchronisation of the highest primary production, with the largest water transports through the transect, might have caused the highest potential additions. So, on some days, a suitable synchronisation between the tides and primary production could have implied an extra import and, on other days, an extra export. At the moment, the ultimate result for a one year long period is only a matter of conjecture.
Once more, it must be pointed out that consumption and mineralisation were ignored. Consumption in particular, might have explained the net import of POC to some extent, as has already been shown for Lake Grevelingen (Wolff et al., 1976) and indicated for some parts of the Waddensea (Postma & Rommets, 1970). The net export of DOC was largely be due to benthic loss or bottom seepage because exchange processes and loss from pelagic primary production could only explain a net transport that is a magnitude smaller. Therefore, a future study of the transport of organic matter should also include a look at the share of the consumptive components in the Eastern Scheldt.

If, after 1985, the current velocities are reduced to the same extent as the tidal volumes, i.e. about 20%, part of the POC will no longer be transported. In particular, this applies to those parts which are whirled up by the higher current velocities. Assuming that the current velocities at the transect were reduced to a level below 0.8 m/sec then at least for five half hours (flood: 3, ebb: 2) the concentrations would not have been higher than 1.4 g/m^3, whereas on 20th April 1979 they increased to about 1.7 g/m^3. Over the total tidal cycle, the net transport of POC would have been reduced as a result of the lower transports at least during these five half hours. A rough estimate is that this meant about 18 tons net POC transport (using v = 1.0 m/sec, c = 0.39 g/m^3, A = 34,000 m^2) i.e. about 20% of total net transport of POC. If a tidal cycle like the one measured on 20th April 1979 is representative for the average situation, this is a substantial reduction. In addition, a small reduction will also occur when there is a decreased exchange of water within the eastern part. It is not yet known, however, how great this reduction will be nor its possible effects. Further investigations should be made to clarify this.

Because only a few such laborious and costly flux measurements as the one of 20th April 1979 can be carried out, it is very important to know what the differences are between these flux measurements and their cause. It should be known to what extent they differ in the kind of material transported, occuring concentrations etc. For this, a reference point is badly needed.

5. CONCLUSIONS

The present study resulted in the following conclusions:

(a) direct conclusions

(b) deduced tentative conclusions

1 (a) The net transport of organic matter through the transect ZB 62 - T 33 at Wemeldinge in the Eastern Scheldt, measured as a result of one tidal cycle on 20th April 1979, was estimated at 82 tons POC import and 57 tons DOC export using a trend surface method. These values were well above the calculated level of significance i.e. 38 tons POC and 19 tons DOC respectively.

(b) The net transport of organic matter through a transect in the Eastern Scheldt can be measured by a direct flux measurement during one or more tidal cycles.

2 (a) The transport of particulate organic matter through the transect ZB 62 - T 33 at Wemeldinge in the Eastern Scheldt measured during one tidal cycle on 20th April 1979 occured inhomogeneously i.e. through some parts of the transect more organic matter was transported than through others. There were often trends in horizontal and vertical cross directions. These trends extended to some 0,2 g POC/sec vertically and 1 g POC/sec horizontally during the highest mass transports of POC. In the present measurement, 5 points were applied vertically for the first gradient and 4 points for the second. The sampling points of POC should have been distributed so that the horizontal gradient was more stressed.

(b) In the Eastern Scheldt, which has a depth-width ratio of some 1/100 or more (here 1/300), the measurements of POC transport in the horizontal cross direction are relatively more relevant than the ones in vertical cross direction. Future measurements should account for this.

3 (a) DOC transport occurred in the transect inhomogeneously mainly due to differences in water transport vertically and horizontally.

Actually, one sampling point of DOC per channel would have been sufficient to calculate DOC net transports through the transect.

(b) To calculate net transports of DOC through a transect in the Eastern Scheldt, only one sampling point per main channel is needed.

4 (a) The transport of particulate organic matter appeared to follow to a large extent the same rules and ways with respect to sedimentation and resuspension as the other seston particles. POC distribution in time and depth could generally have been derived mainly from seston distribution by a regression analysis.

(b) Transport studies of seston in the Eastern Scheldt might give a lot of information about the transport of POC there.

5 (a) Primary production in the water contributed significantly to the transport of organic matter through a transect in the Eastern Scheldt during one tidal cycle in the springbloom of 1979. In the water mass, that flowed through the transect, an addition of 8 tons POC occurred during the flood phase and 34 tons POC during the ebb phase.

(b) To explain the transport of organic matter, biological processes like primary production, consumption and mineralisation should be accounted for.

6 (a) The net transport of particulate organic matter through the transect of Wemeldinge on 20th April 1979 would have been reduced by about 20% if current velocities that will occur after 1985 had been applied.

(b) The net transport of particulate organic matter might change after 1985, when the construction of a storm surge barrier is completed, due to a decrease in occurring current velocities and a consequent decrease in transports of particulate organic matter.

6. LITERATURE

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Tables

Table I Abbreviations frequently used in text and figures.

Table II Calculated transports; for abbreviations see table I.

Table III Mean concentration weighed on water transports ($\bar{c}^Q$) and mean of actually measured concentrations ($\bar{c}$), standard deviation (s), number of measurements (n), lowest and highest concentration measured (resp. l and h) of DOC, POC and seston; for abbreviations see table I.

Table IV Estimated net transport of POC through N, S and T and their cause; for abbreviations see table I.

Table V Results of regression analysis of POC (y in g/m^3) on seston (x in g/m^3) according to the model y = ax + b. All correlations are highly significant ($P < 0.001$). Abbreviations: s = surface water, m = mid depth, d = deep water, t = total water column; for other abbreviations see table I.

Table VI Results from a F-test on parallelism and distance of regression lines of POC on seston (see table VI) ($P < 0.001$ indicates high significance, $P < 0.05$ low significance and P 0.05 no significance); for abbreviations see table I.

Table VII Mean POC ($\bar{y}$) and seston ($\bar{x}$) concentrations and their standard deviations ($s_{\bar{y}}$ and $s_{\bar{x}}$) grouped according to channel and depth; for other abbreviations see table I.

Table VIII Results of regression analysis of POC_{t_1} (g/m^3) on v_{t_2} (m/sec) ($P < 0.001$ indicates high significance); for abbreviations see table I.

Table IX Results of regression analysis of POC (g/m^3) on v (m/sec) measured (index m) or fitted (index f, by method III) of y = 1206 m at half depth ($P < 0.001$ indicates high significance); for abbreviations see table I.

Table I

Abbreviations frequently used in text and figures

N : northern channel

S : southern channel

T : total transect

F : flood phase

E : ebb phase

Tc: total tidal cycle

c : concentration of a component g/m^3

$\bar{c}$: mean concentration (g/m^3)

$\bar{c}^Q$: mean concentration weighed on water transport (g/m^3)

v : current velocity (m/sec)

Table II.

Calculated transports; for abbreviations see table I.

	FLOOD			EBB			TOTAL TIDAL CYCLE			
	S	N	T	S	N	T	S	N	T	
WATER (rough estimation)	282	198	480	- 170	- 257	- 427	112	- 59	53	$10^6 m^3$
(standard method)	233	165	398	- 170	- 212	- 382	63	- 47	16	$10^6 m^3$
(trend surface method)	236	164	400	- 170	- 213	- 383	66	- 49	17	$10^6 m^3$
(tidal prism method)			402			- 377			25	$10^6 m^3$
TOTAL POC (rough estimation)	405	217	622	- 241	- 285	- 505	164	- 67	97	tons
(t.s. method)	352	215	567	- 236	- 249	- 485	116	- 34	82	tons
PHYTOPLANKTON-POC	71	59	130	- 52	- 70	- 122	19	- 11	8	tons
DETRITUS-POC	278	160	438	- 184	- 180	- 364	94	- 20	74	tons
DOC	546	386	940	436	554	997	110	-168	-57	tons
SESTON	3517	2217	5734	-2170	-2311	-4481	1347	- 94	1253	tons

Table III.

Mean concentration weighed on water transport ($\bar{c}^Q$) and mean of actually measured concentrations ($\bar{c}$), standard deviation (s), number of measurements (n), lowest and highest concentration measured (resp. l and h) of DOC, POC and seston; for other abbreviations, see table I (all concentrations in mg/l).

	DOC						POC						SESTON					
	$\bar{c}^Q$	$\bar{c}$	s	l	h	n	$\bar{c}^Q$	$\bar{c}$	s	l	h	n	$\bar{c}^Q$	$\bar{c}$	s	l	h	n
N,F	2.35	2.40	0.28	1.96	2.64	65	1.31	1.12	0.38	0.50	2.35	65	13.52	9.57	7.40	1.52	29.5	65
N,E	2.60	2.52	0.27	2.00	2.84	71	1.17	1.11	0.36	0.22	2.35	80	10.85	9.38	4.72	1.09	24.4	80
N,TC		2.46	0.28	1.96	2.84	136		1.11	0.37	0.22	2.35	145		9.47	6.05	1.09	29.5	145
S,F	2.31	2.43	0.24	2.10	2.70	75	1.49	1.41	0.65	0.52	4.15	85	14.90	13.10	8.71	1.68	48.2	98
S,E	2.56	2.59	0.26	2.18	3.00	69	1.31	1.25	0.53	0.27	3.55	98	13.52	11.98	6.96	2.60	40.0	98
S,TC		2.50	0.26	2.10	3.00	144		1.32	0.59	0.27	4.15	183		12.50	7.82	1.68	48.2	183

Table IV.
Estimation of net transports of POC through N, S and T due to different water transports; for abbreviations, see table I.

part of transect:	$\Delta c (g/m^3)$	$Q_w (10^6 m^3)$	POC-transport $\Delta c.Q_w$ (in tons)	Watertransport:
N	$c_{NF}^Q - c_{NE}^Q = 0.14$	$Q_{NF} = 164$	23	moving around of water in N
S	$c_{SF}^Q - c_{SE}^Q = 0.10$	$Q_{SE} = 170$	17	moving around of water in S
T	$c_{SF}^Q - c_{NE}^Q = 0.32$	$Q_{NE} - Q_{NF} = 49$	16	water circulation from S to N
T	$c_{SF} = 1.49$	$Q_{TF} - Q_{TE} = 17$	25	flood surplus of N + S
			82	

Table V
Results of regression analysis of POC (y in g/m^3) on seston (x in g/m^3) according to the model y = ax + b. All correlations are highly significant ($P < 0.001$).
Abbr.: s = surface water, m = mid depth, d = deep water, t = total water column; for other abbreviations see table I.

tidal period	depth	N a	N b	N r	N n	S a	S b	S r	S n
F	t	0.038	0.75	0.752	65	0.070	0.49	0.941	85
E	t	0.064	0.84	0.838	80	0.068	0.43	0.889	98
TC	t	0.046	0.67	0.763	145	0.070	0.45	0.917	183
TC	s	0.039	0.67	0.680	52	0.058	0.54	0.750	53
TC	m	0.043	0.71	0.703	54	0.064	0.49	0.911	54
TC	d	0.047	0.73	0.779	39	0.069	0.55	0.892	30

Table VI.
Results from a F-test on parallellism and distance of regression lines of POC on seston (see table V) ($P < 0.001$ indicates high significance, $P < 0.05$ low significance and $P > 0,05$ no significance); for abbreviations see table

F-test on		N-S	N_E-S_E	N_F-S_F	N_E-N_F	S_E-S_F	N_E-S_F
Parallellism	F	34.96	0.42	41.52	15.09	0.03	0.42
	P	<0.001	>0.05	<0.001	<0.001	>0.05	>0.05
Distance	F		1.08			6.12	1.08
	P		<0.05			<0.05	<0.05

Table VII

Mean POC- ($\bar{y}$) and seston ($\bar{x}$) concentrations and their standard deviations ($s_{\bar{y}}$ and $s_{\bar{x}}$) grouped according to channel and depth; for abbreviations see table I.

channel	depth	$\bar{y} \pm s_{\bar{y}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{y}/\bar{x}$.100%
N	s	0.96 ± 0.04	7.3 ± 0.7	13.0%
	m	1.09 ± 0.04	8.8 ± 0.7	12.6%
	d	1.35 ± 0.06	13.1 ± 1.0	12.3%
S	s	1.00 ± 0.05	8.2 ± 0.7	12.3%
	m	1.26 ± 0.06	12.0 ± 0.9	10.4%
	d	1.90 ± 0.13	19.6 ± 1.7	9.7%

Table VIII.

Results of regression analysis for POC_{t_1} (g/m^3) on v_{t_2}(m/sec) ($P < 0,001$ indicates high significance)

t_1-t_2(min)	regression function	r	n	P
0	$POC_{t1} = 0.921\ e^{0.648 v_{t_2}}$	0.711	25	<0.001
15	$POC_{t1} = 0.955\ e^{0.596 v_{t_2}}$	0.760	25	<0.001
30	$POC_{t1} = 0.890\ e^{0.693 v_{t_2}}$	0.693	25	<0.001
45	$POC_{t1} = 1.019\ e^{0.487 v_{t_2}}$	0.656	25	<0.001
60	$POC_{t1} = 1.014\ e^{0.469 v_{t_2}}$	0.499	25	<0.01

Table IX.

Result of regression analysis of POC (g/m^3) on v (m/sec) measured (index m) or fitted (index f) of y = 1206 m at half depth ($P < 0.001$ indicates high significance).

Regression function	r	n	P
$POC_m = 0.626\ e^{1.079 v_m}$	0.767	25	<0.001
$POC_f = 0.725\ e^{0.849 v_m}$	0.826	25	<0.001
$POC_m = 0.663\ e^{1.010 v_f}$	0.680	25	<0.001
$POC_f = 0.739\ e^{0.900 v_f}$	0.859	25	<0.001

Figures

Fig. 1. Site of the transect in the Eastern Scheldt (S.W. Netherlands).

Fig. 2. Profile of the transect and positions of the ships (^=water sampling site, v=flow measurements site). Abscissa indicates distance from ZB 62 and ordinate depth from NAP (both in meters)

Fig. 3. Actual tidal water level curve measured at Wemeldinge harbour.

Fig. 4. Calculated M%, Fit% and R% as a function of time for seston, DOC, total POC, phytoplankton-POC and detritus-POC.

Fig. 5. F-values of the test on goodness-of-fit of the calculated 1/2h MET trend surfaces of (a) current velocity, (b) DOC and seston, (c) total POC, phytoplankton-POC and detritus-POC.

Fig. 6. 1 h MET trend surface determination of current velocity in the transect for the flood phase (t = 180-480 min) and ebb phase (t= 600-840 min).

Fig. 7. 1h MET trend surface determination of seston, total POC, phytoplankton-POC and detritus-POC in the transect.

Fig. 8. 1h MET "trend surface" determination of seston x v, total POC x v, phytoplankton x v and detritus-POC x v in the transect.

Fig. 9. (a) Scheme of transports of water (in $10^6 m^3$) through the transect. Scheme of nett transports of (b) DOC, (c) POC and (d) seston (all in tons) through the transect.

Fig. 10. Integrated transport speeds of (a) water, (b) DOC, (c) seston, (d) total POC, (e) phytoplankton-POC and (f) detritus-POC over N, S and T as a function of time.

Fig. 11. Cumulative transports of (a) water, (b) DOC, (c) seston (d) total POC, (e) phytoplankton-POC and (f) detritus-POC over N, S and T as a function of time.

Fig. 12. Vertically averaged concentrations of (a) Katodinium rotundatum, (b) Rhizosolenia delicatula and (c) Ditylum brightwelli at two moments in the flood phase (330 and 510 min) and in the ebb phase (690 and 870 min).

Fig. 13. PPP (mg $C/m^3/5h$) of nine 1 m thick water layers at the transect as a function of time.

Fig. 14. Potential additions of POC (g C/sec) by PPP beyond the transect to the water flowing through the transect at a given time.