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A Detailed 2DH-Hydrodynamic Model For the Nieuwe Merwede

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A Detailed 2DH-Hydrodynamic Model For the Nieuwe Merwede

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1 Introduction

This report describes the set-up of and the simulations with a 2DH-hydrodynamic model for the Nieuwe Merwede. The model is developed within the framework of the study "Natural Sand-Mud Bed" carried out for the Institute for Inland Water Management and Waste Water Treatment of the Ministry of Transport, Public Works and Water Management of The Netherlands (Rijkswaterstaat / RIZA) under contract number RI-2055.

The objective of the study is to build a model for the determination of the bed composition in the Noordelijk Deltabekken. The hydrodynamic model described here will be used to provide data required by the model for the bed composition.

The model set up is based on the Delft3D-flow system, but the model can be run under the WAQUA system of Rijkswaterstaat as well.

The study is carried out by ing. R. Bruinsma and dr.ir.Z.B. Wang of DELFT HYDRAULICS under guidance of drs.E.J Houwing of RIZA. This report was drawn up by Z.B. Wang and R. Bruinsma.

2 Set-up of the model

2.1 Model area and computational grid

The model covers the whole Nieuwe Merwede branch of the Noordelijk Deltabekken (Fig.1). The upstream boundary of the model is located at Werkendam (Km.961.000) and the downstream boundary at Anna Jacominaplaat (Km.979.650). This river section has a length of 18.65 km and a width of about 500 m.

The model is based on a curvilinear grid, which is much more efficient than the rectangular grid for modelling such a river section. The computational grid as shown in Fig.2 has in total 178 (in the longitudinal direction) by 42 (in the lateral direction) grid points. The grid size in the longitudinal direction is about 100 m and in the lateral direction about 25 m. During the design of the grid the following considerations were made:

- The resolution of the grid should be such that the smallest relevant features in the area, such as the groynes along the river banks, can be represented in the model.
- The grid size in the lateral direction should be much smaller than that in the longitudinal direction in order to give the correct representation of the bathymetric variation in the area.
- The variation of the bathymetry in the lateral direction changes from cross-section to cross-section (due to e.g. changing curvature along the river section). Therefore a more or less equidistant grid in the lateral direction is most efficient.

The groynes along the river banks are defined as “thin dams” in the model (see Fig.1).

2.2 Bathymetry

The bed level in the model is based on the bathymetrical data collected in 1993. Two data sets are available: one is the original sounding data measured in the cross-sections and the other is data on a 10 m by 10 m grid. The first data set is used as much as possible whereas the second data set is only used for those grid points at which the bed level cannot be determined from the first data set. This is done because the second set contains processed data from the first one with some interpolation procedure.

2.3 Boundary conditions

The boundary conditions required by the model were determined by RIZA using the ZWENDL model for the Noordelijk Deltabekken. The ZWENDL model is a one-dimensional network model. For a defined flow scenario (determined by the upstream river discharge and the tide at the down stream boundary Hoek van Holland) the ZWENDL model is run to determine the required data for the boundary condition of the present model.

The upstream boundary is located at Werkendam. Here the discharge is prescribed as boundary condition. Note that the ZWENDL model only provides the total discharge through the whole boundary (ZWENDL station 104.1) whereas the 2DH-model requires the discharge through each grid cell at the boundary. For the distribution of the discharge over the cells it is assumed that the energy gradient normal to the boundary is constant over the whole boundary and that the Manning coefficient in all the cells are the same. The discharge at each cell is then

$$Q_i = \frac{B_i a_i^{5/3}}{\sum\limits_{all\,cells} B_j a_j^{5/3}} Q_{tot}$$

Herein

Q_i = discharge through grid cell i,
B = width of the grid cell (grid size in the lateral direction),
a = water depth at the grid cell,
i, j = cell number,
Q_{tot} = Total discharge through the whole boundary.

The downstream boundary is located at the Anna Jacominaplaat. Here the water level calculated by ZWENDL at station 100.2 is prescribed across the whole boundary.

It is further assumed that there is no water input or water withdraw along the banks. The two river banks are thus closed boundaries.

2.4 Physical parameters

For determining the physical parameters in the model reference is made to the existing Noordelijk Deltabekken WAQUA model (WAQUA-NDB) at RIZA. Since WAQUA-NDB is an operational calibrated model it is expected that the values of the physical parameters used in that model for the Nieuwe Merwede area are sufficiently accurate.

The most important physical parameter for the model is the bed roughness coefficient. In the WAQUA-NDB model the Manning coefficient is used. In the Nieuwe Merwede area the value of the Manning coefficient is constant and equal to 0.023. However, a number of test runs have shown that a Manning coefficient of 0.024 in the present model gives better results concerning agreement between the discharges computed from ZWENDL-model and the present model. Therefore this value is applied in the present model.

Another physical parameter is the eddy viscosity. In the WAQUA-NDB model this parameter is set to 1 m^2/s in the whole model area. It is noted that this parameter is in a certain sense dependent on the grid size. It should be smaller as the grid size becomes smaller. Further the model results are not very sensitive to this parameter. Since the present model has a much finer grid the (horizontal) eddy viscosity is set to 0.2 m^2/s in the whole model area.

For the other physical parameters such as the density of water, acceleration of gravity, etc. the normal values from the WAQUA-NDB model is taken over.

2.5 Numerical parameters

The numerical parameters should be chosen such that sufficient numerical accuracy is guaranteed and that the computation is as efficient as possible.

The most important numerical parameter in the model is the time step. It is chosen by trial and error. In a number of test runs different time steps are used. The largest time step at which decreasing of the time step does not influence the computation results significantly is chosen for the model. For the present model 2.5 minute appears to be the optimal time step. In Fig.3 and Fig.4 the computational results from the runs with 1 min and 2.5 min as time step are shown. It is clear that the difference between the results from the two runs is very small. Further it is noted that the tidal period to be used in the present study is 12 hour and 25 min. A time step of 2.5 min is convenient for defining the various time intervals. For this time step the Courant number is about 10 in the longitudinal direction.

3 Verification and model results

3.1 Definition of the cases

The boundary conditions of the model is determined with the ZWENDL Noordelijk Deltabekken model. A run with the present model can thus be characterised by two factors, viz. the tide at the downstream boundaries (Hoek van Holland and Stellendam) of the ZWENDL model and the river discharge at the upstream boundary of the ZWENDL model.

For sediment transport and morphological development the representative tide is usually a tide between the spring tide and the averaged tide. Therefore a standard tide is defined in the present study by taking the average of the spring tide and the averaged tide. This is done for Hoek van Holland as well as for Stellendam. The tides at the downstream boundaries are thus the same in all the runs. It is periodic with a tidal period of 12 hours and 25 minutes.

In all the runs a constant discharge is prescribed at the upstream boundary of the ZWENDL model. Each run can thus be characterised by the value of this discharge. At present four runs have been defined with the following discharges (representing the four characteristic seasons).

Run Number	Discharge at the upstream boundary of the ZWENDL model
120	1200 m^3/s
200	2000 m^3/s
220	2200 m^3/s
300	3000 m^3/s

3.2 Verification of the model

The present model has not been calibrated extensively since the important physical parameters are based on an existing operational model covering the present model area. However, the results from all the four runs have been checked by comparing the water level and the total discharge with the results of the ZWENDL model at the following cross-sections, see Fig.4 through Fig.7.

ZWENDL station	KM.	Location
104.1	961.000	Werkendam (upstream boundary)
104.2	962.300	
103.2	966.015	
102.2	970.820	
101.2	977.000	
100.2	979.650	Anna Jacominaplaat (downstream boundary)

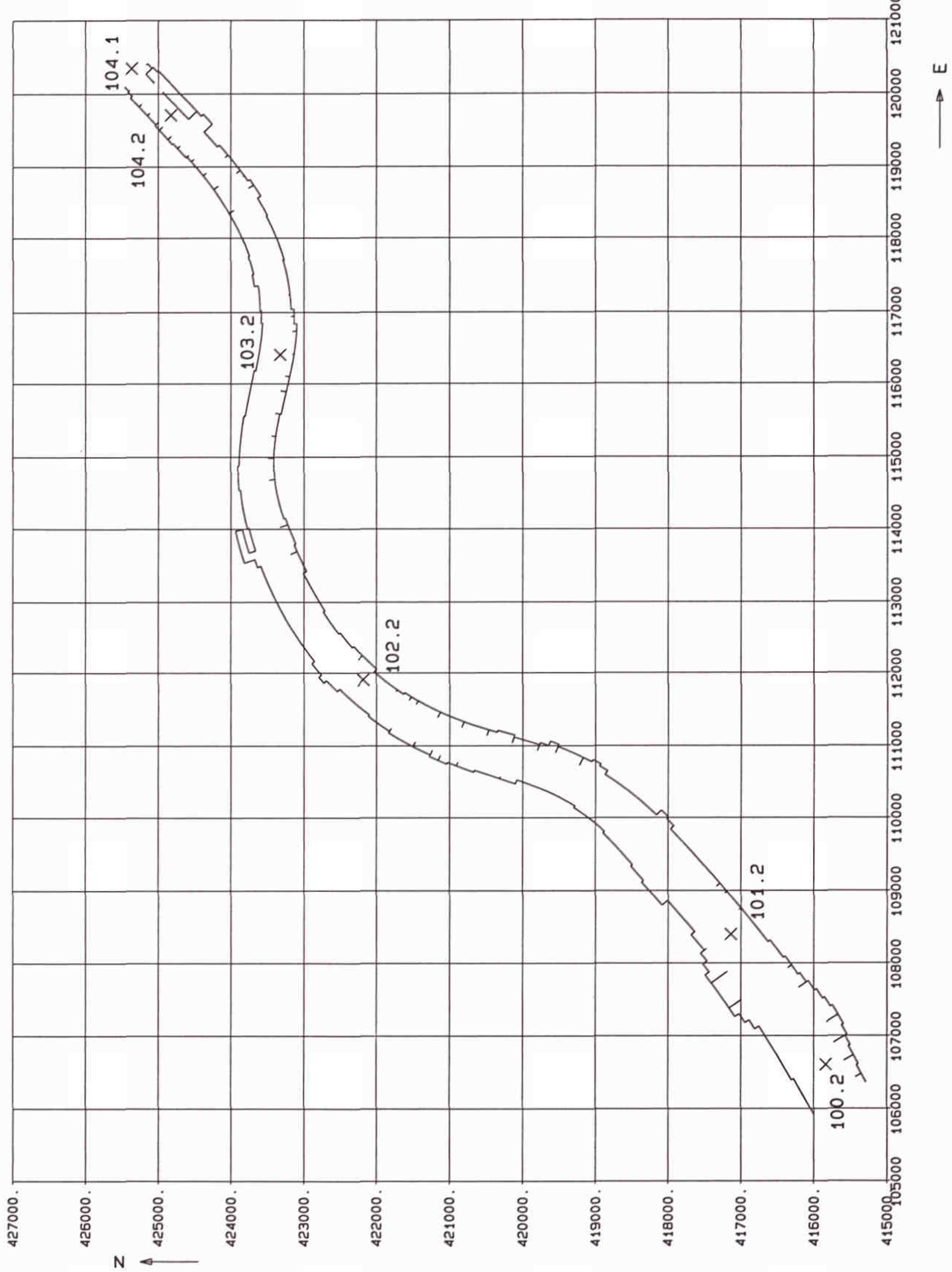
Note that the discharge at the first cross-section and the water level at the last cross-section are used as boundary condition in the model. The figures show that the agreement between the results from the ZWENDL model and those from the present model is good. Only at the most downstream cross-sections some difference can be observed in the computed discharges. It should be noted though that the present model has a totally different schematisation than the ZWENDL model. The present model can therefore be considered to represent the flow in the Nieuwe Merwede properly.

3.3 Model results

The computated flow velocity fields at rising tide and falling tide for all four runs are presented in Fig.8 through Fig.15. The following observations are made from these figures:

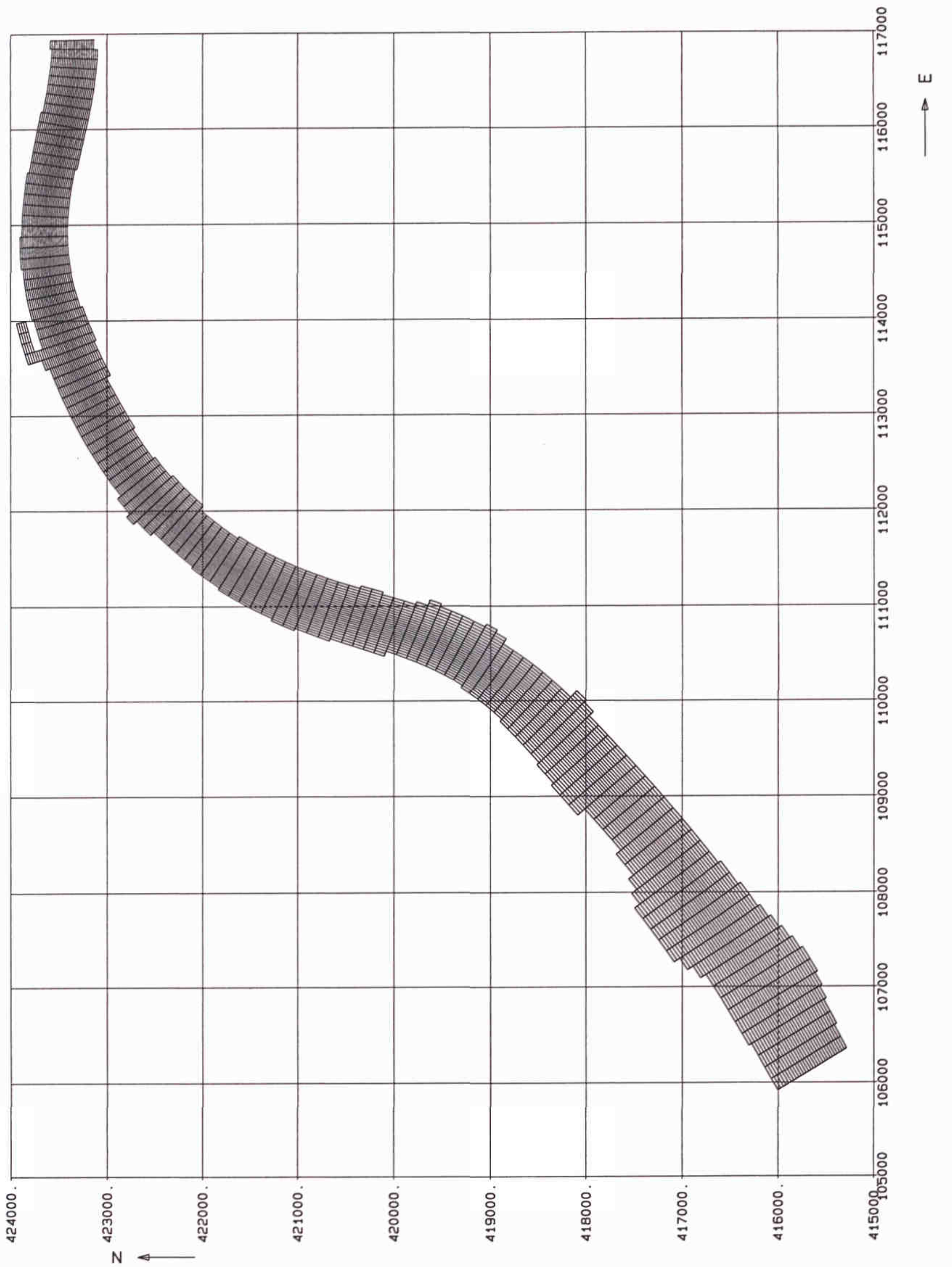
- In all the figures the flow patterns show a typical river-bend flow structure. At the entrance of a bend the flow is more concentrated at the inner bend, and further downstream in the bend the flow gradually shift tot the outer bend.
- In all the four runs no significant difference between the flow pattern at minimum discharge and that at maximum discharge is present. Only the magnitude of the flow velocity is clearly different as can be expected. The difference between the velocity magnitude at maximum discharge and that at minimum discharge becomes smaller as the averaged discharge increases.
- The flow patterns from the four runs with different averaged discharge do not differ significantly form each other. Only the velocity magnitudes are different.
- The groynes have clear influence on the flow pattern. The magnitude of the flow velocity between two nearby groynes is significantly decreased due to the groynes.
- The tidal influence on the flow pattern is very limited for the model area. Even at the most downstream part of the model area, where two channels can be distinguished which probably used to be an ebb- and flood-channel system before the construction of the Haringvliet sluice, no tidal circulation can be observed.

The results will further be applied in the model for predicting the bed composition. Finally it is remarked that the present model can also be applied for providing hydrodynamic data for other purposes than predicting bottom composition.

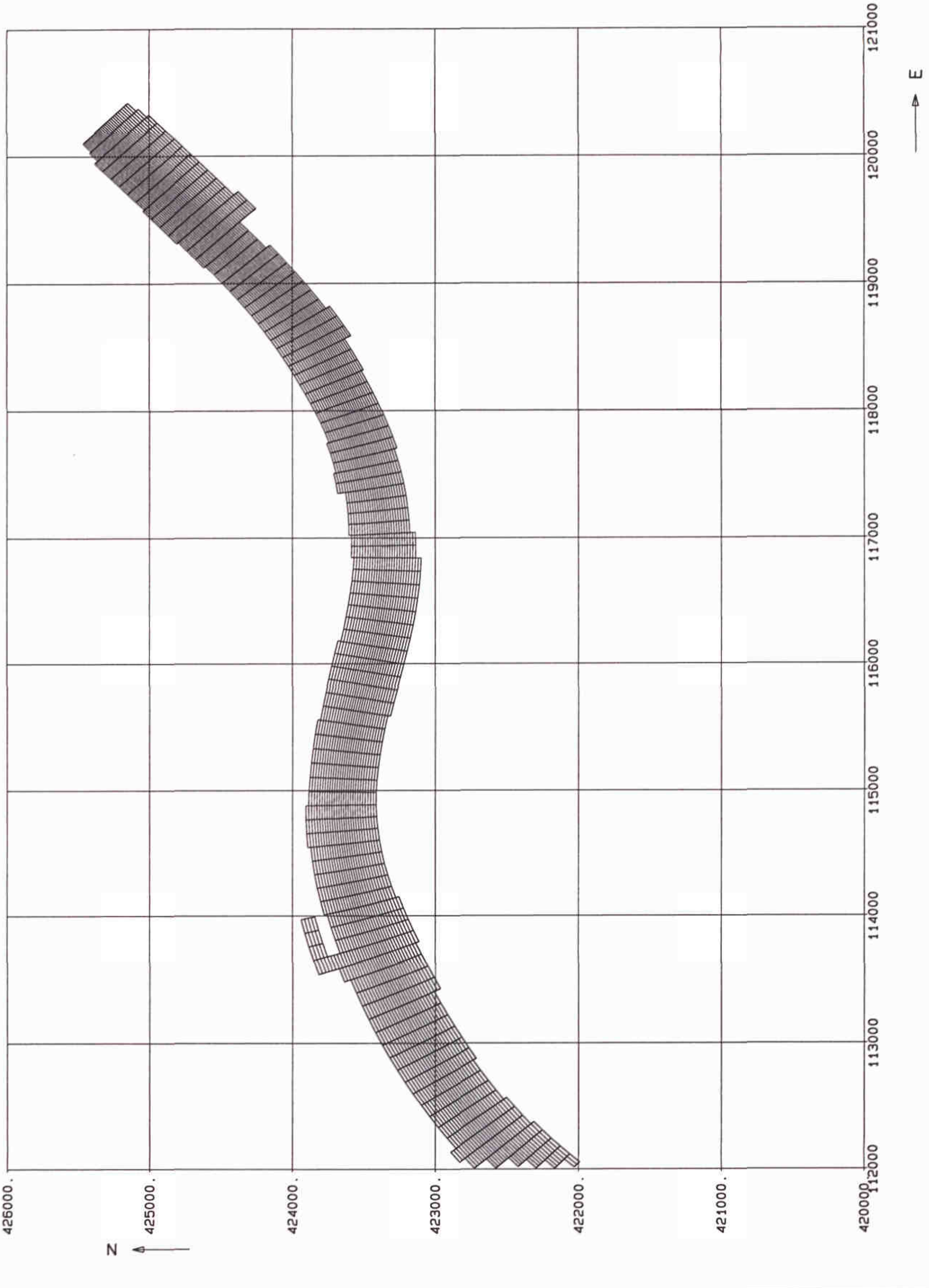


Model layout Nieuwe Merwede
X = check point

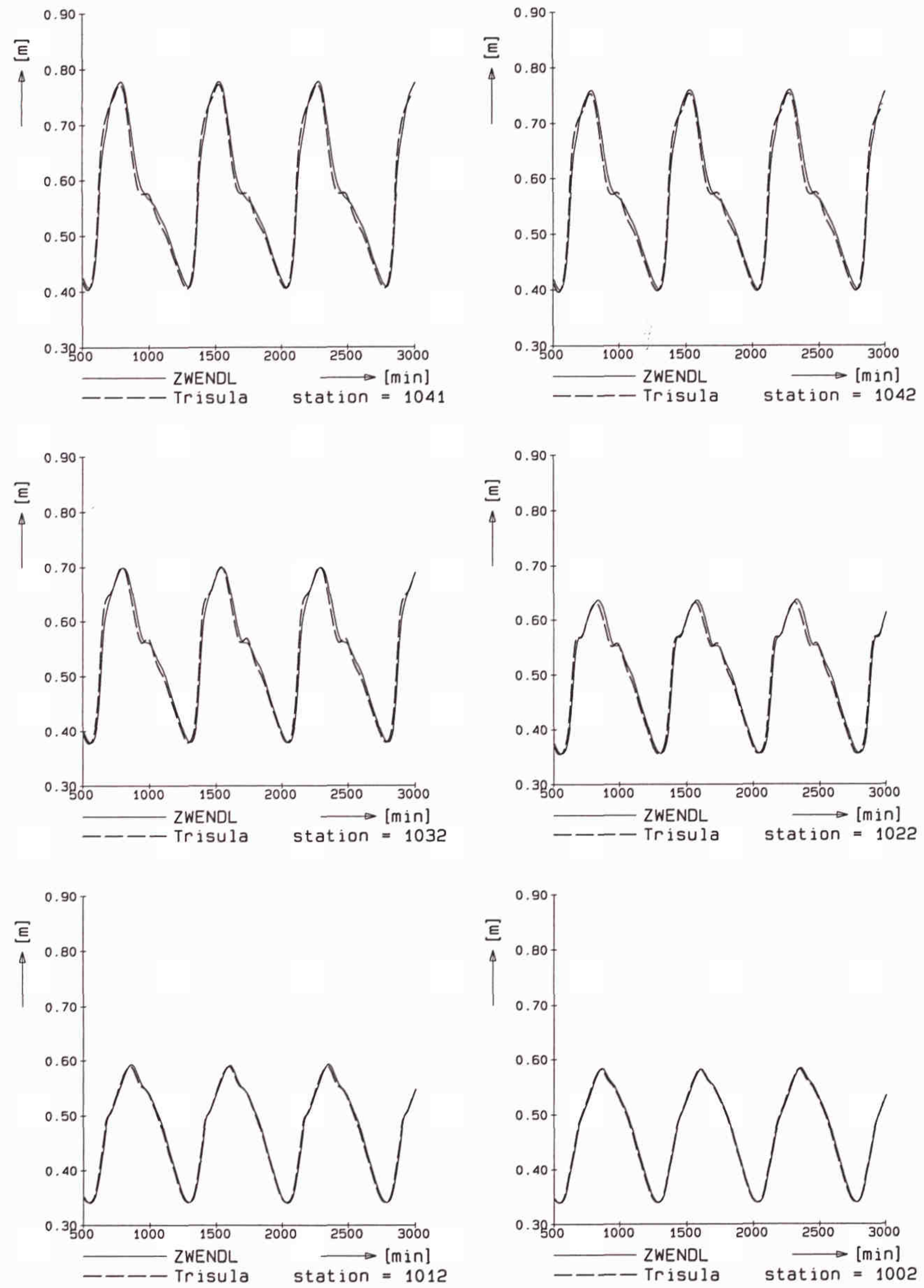
Zand-Slib	
DELFT HYDRAULICS	
Z-2192	Fig 1



Lower part of model grid		
	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 2a



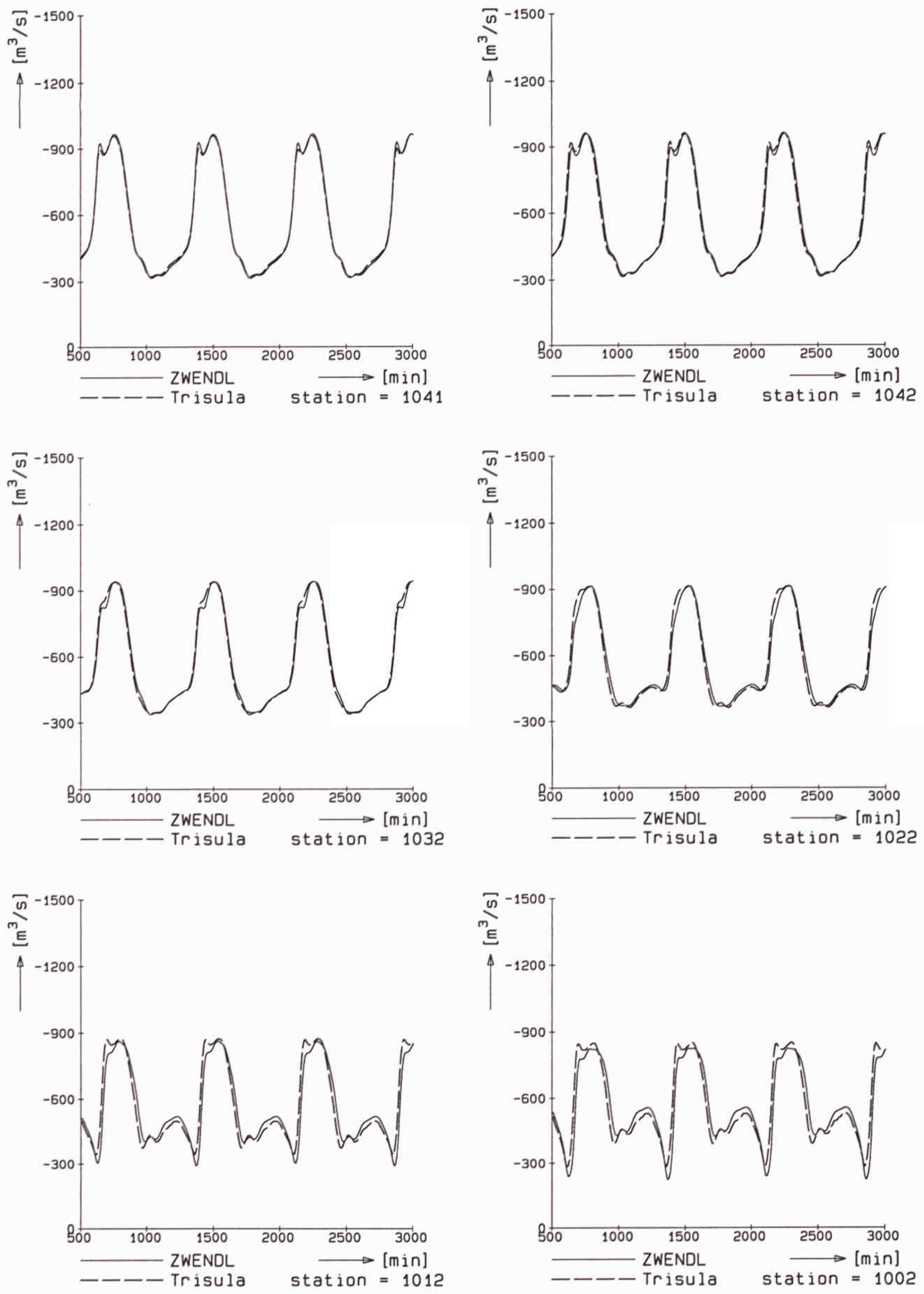
Upper part of model grid		
	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 2b



Water levels run = 120
Time step = 1 minute

Zand-Slib	
Z-2192	Fig 3a

DELFT HYDRAULICS



Discharges run = 120
Time step = 1 minute

Zand-Slib

DELFT HYDRAULICS

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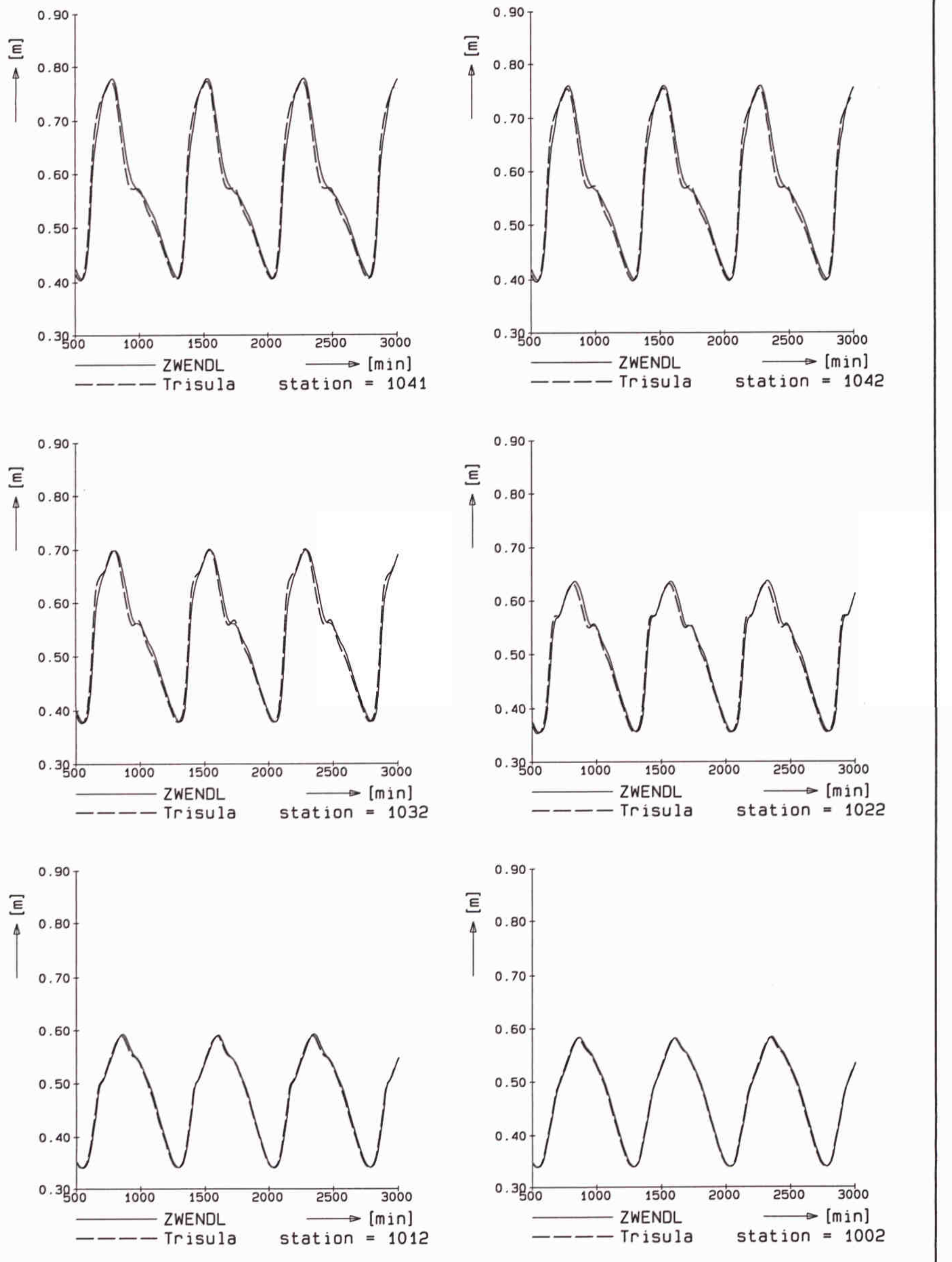
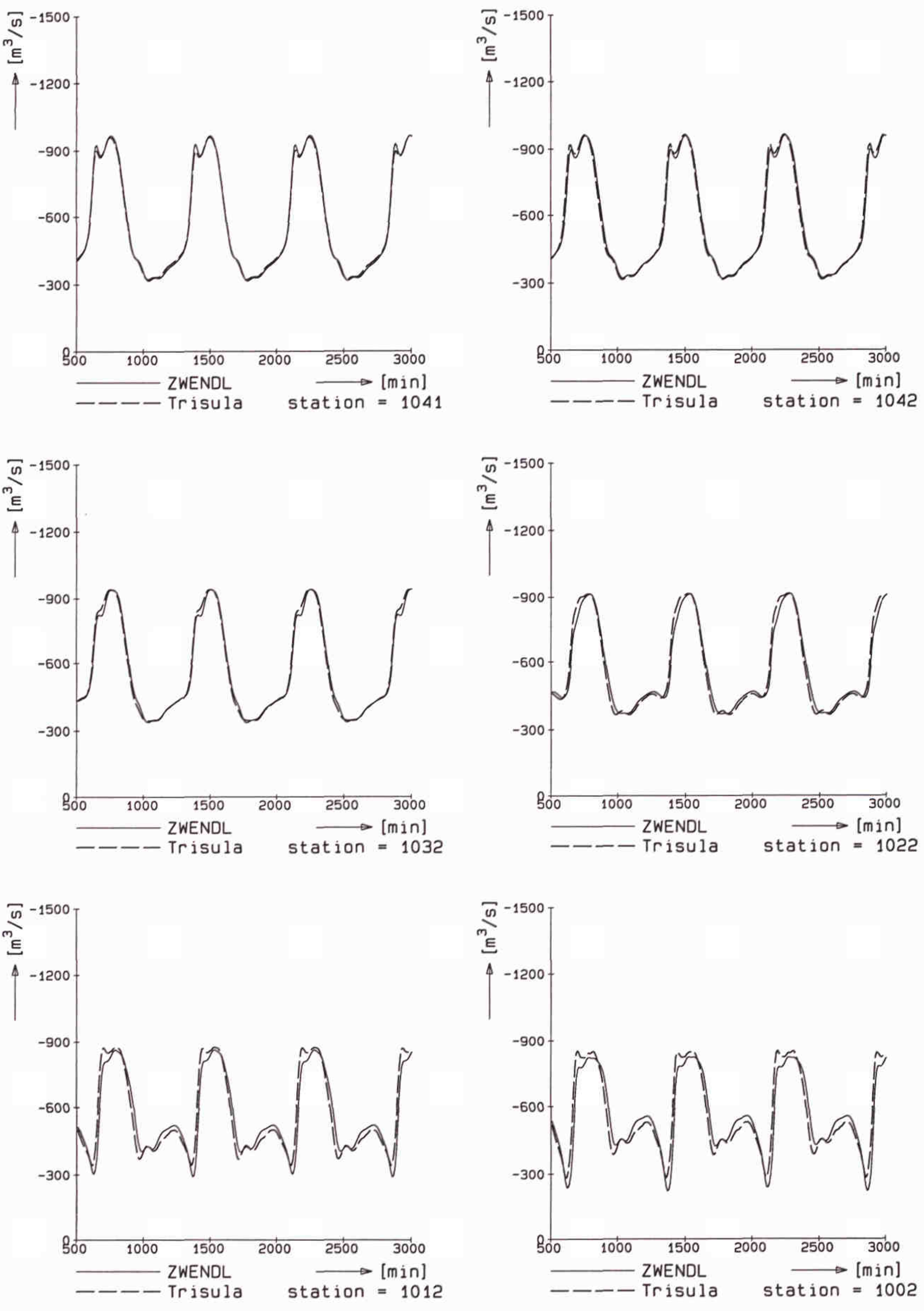
Fig 3b



Water levels run = 120 Time Step = 2.5 minutes		
	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 4a



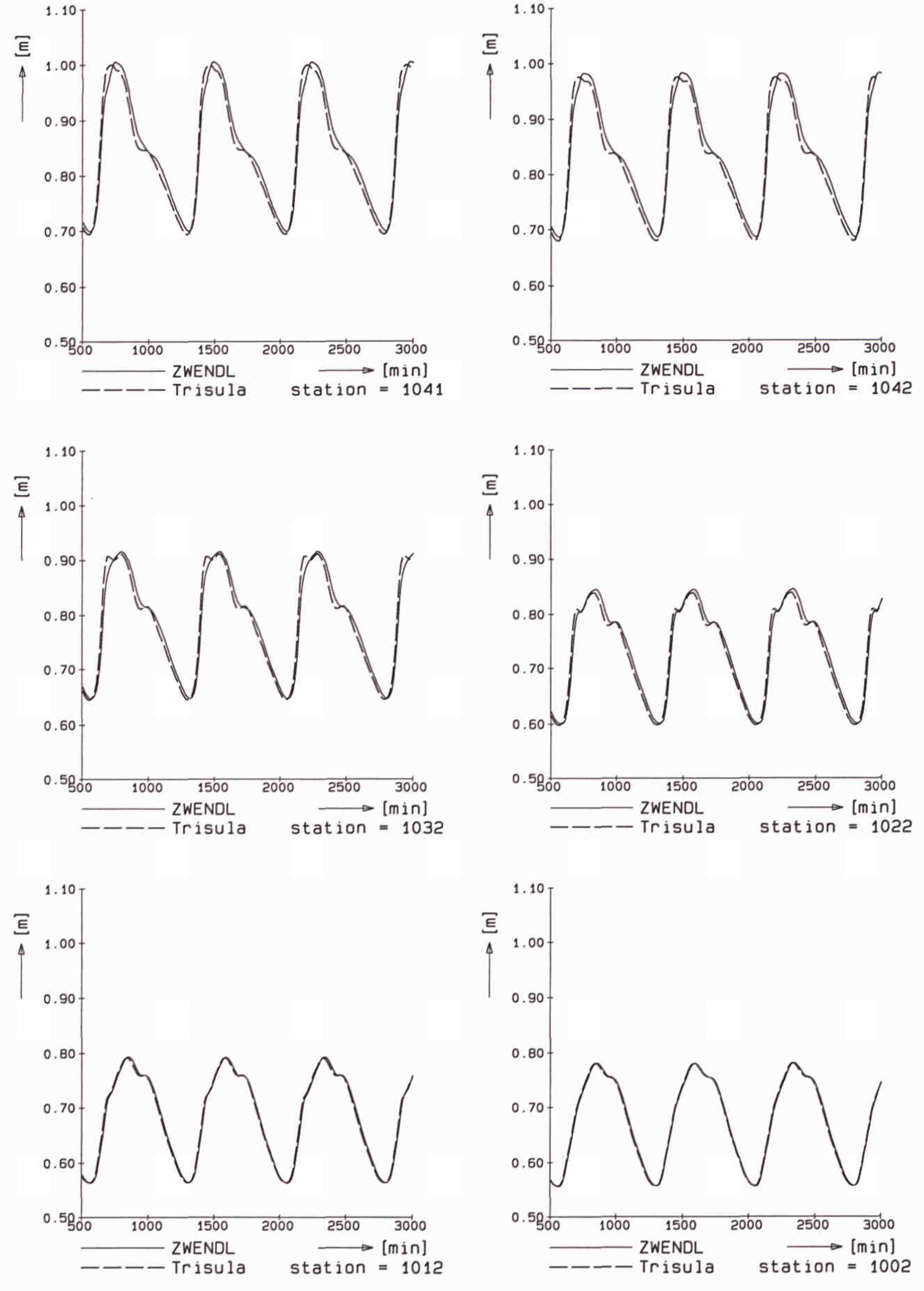
Discharges run = 120
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS

Z-2192

Fig 4b



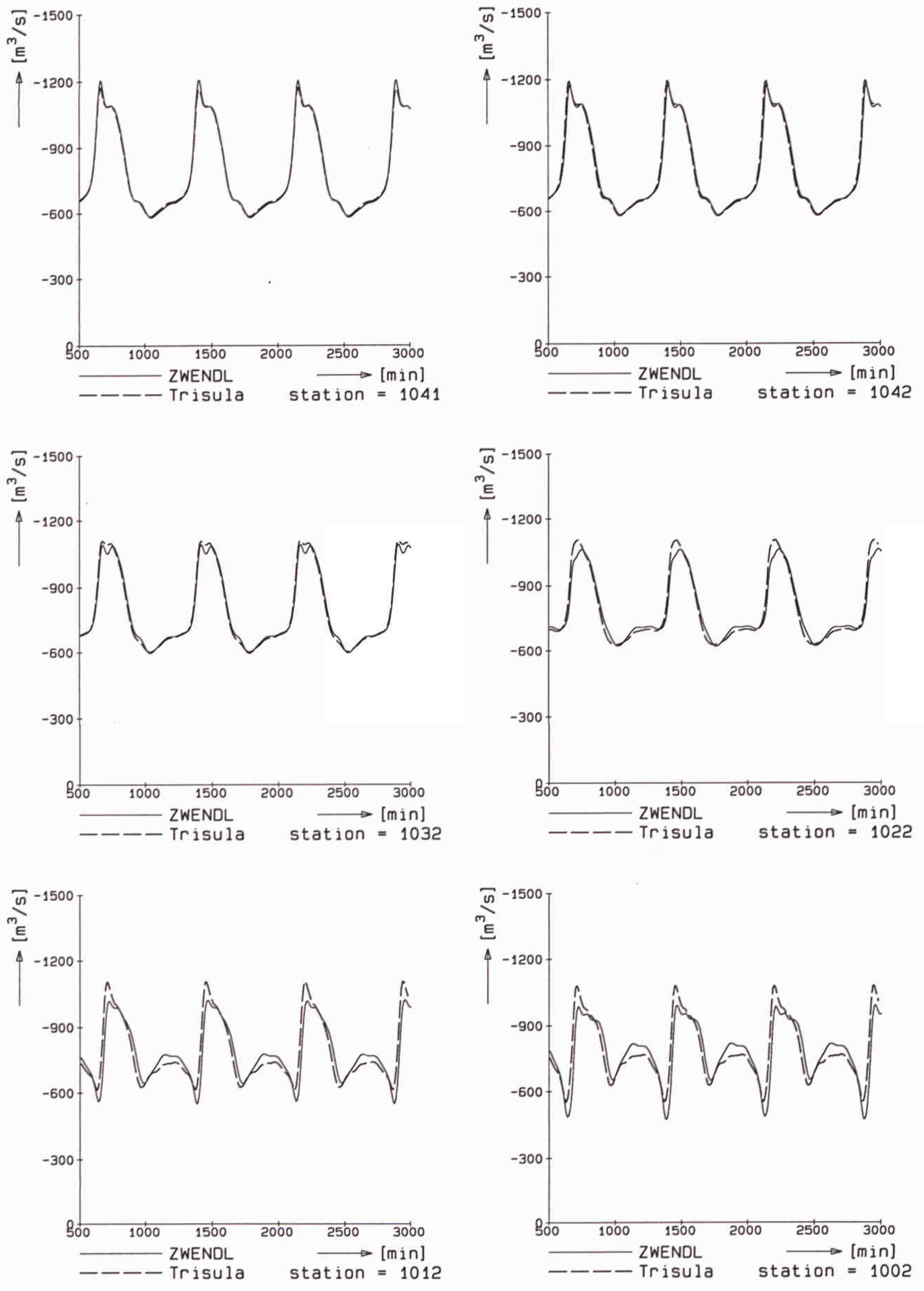
Water levels run = 200
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS

Z-2192

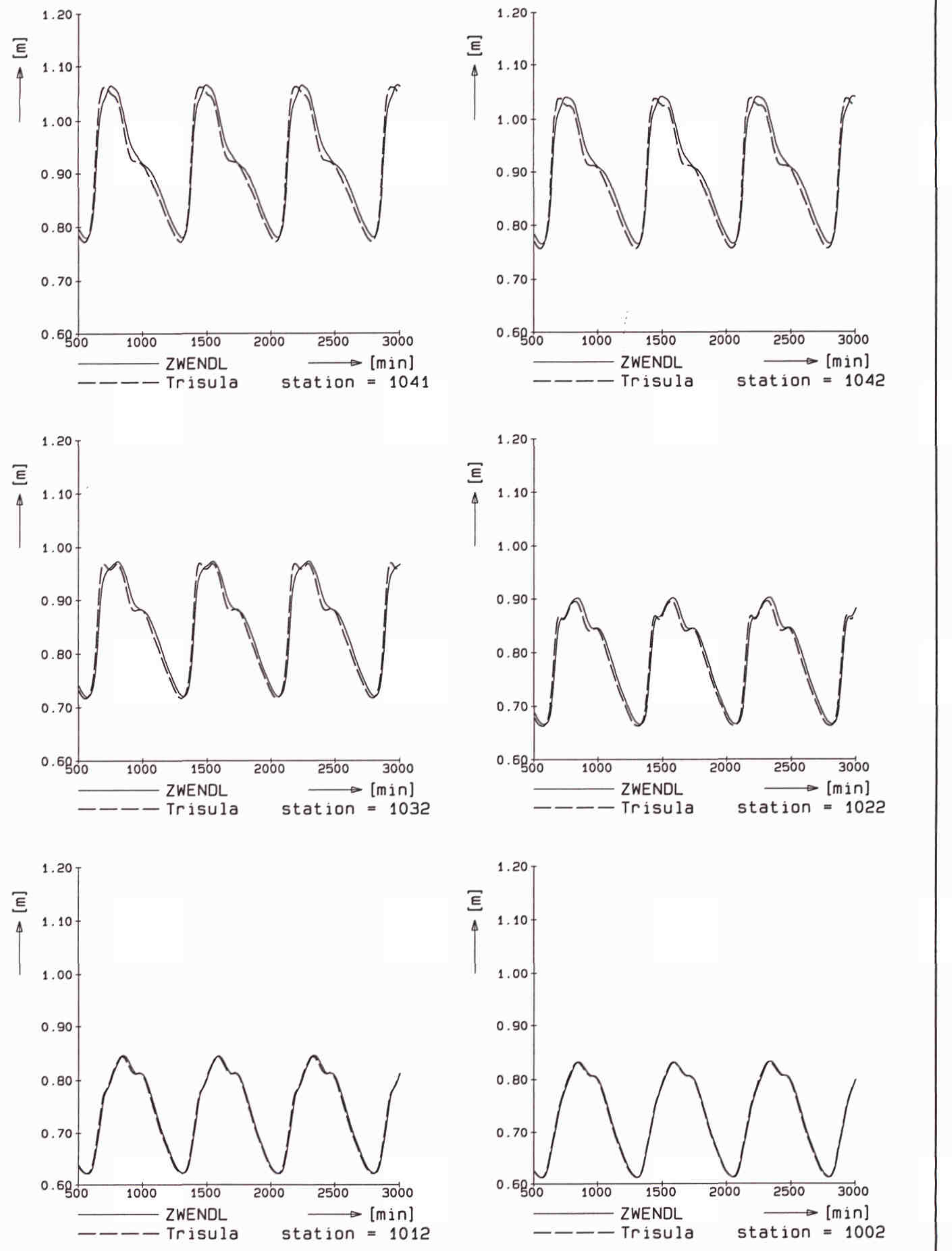
Fig 5a



Discharges run = 200
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS | Z-2192 | Fig 5b



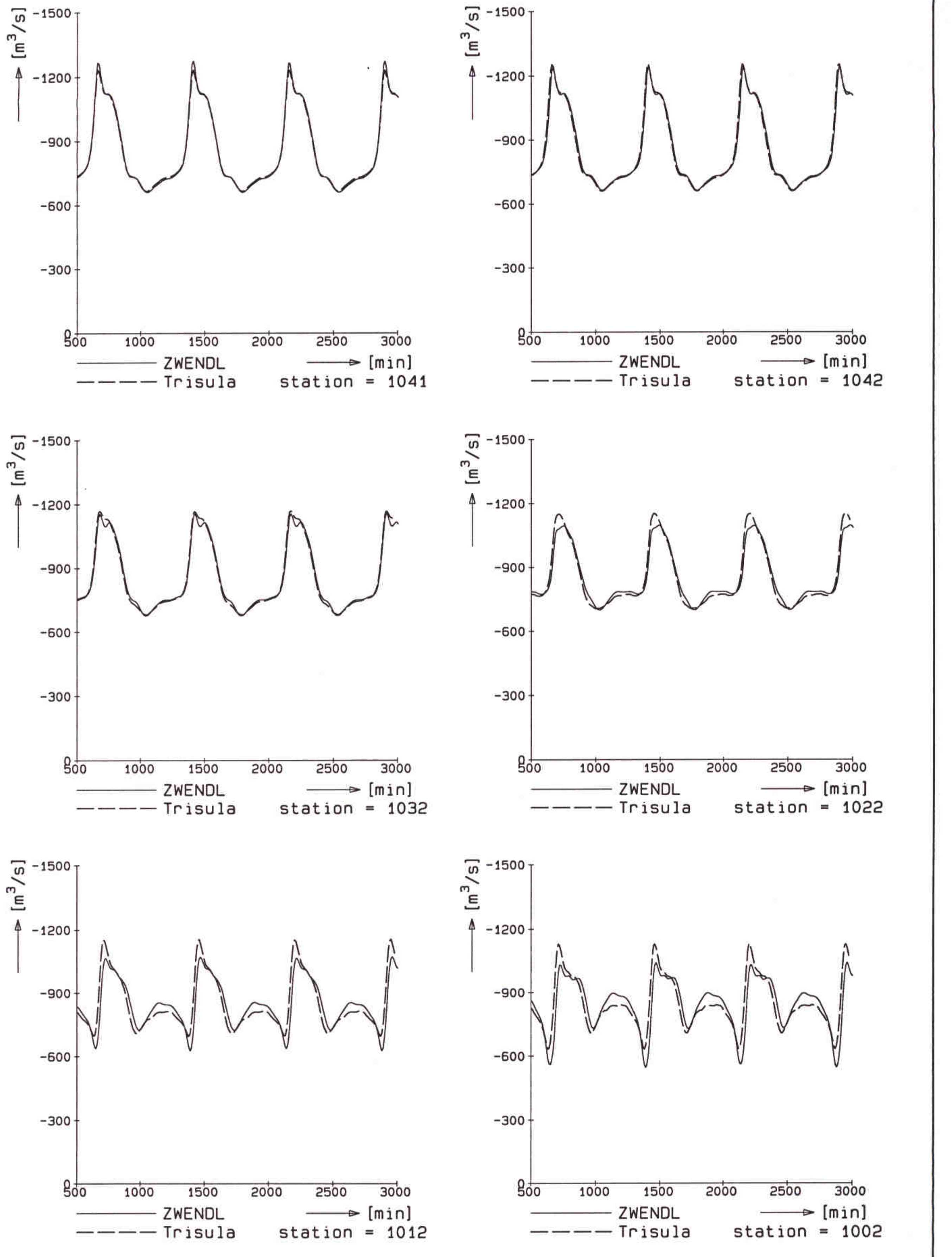
Water levels run = 220
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS

Z-2192

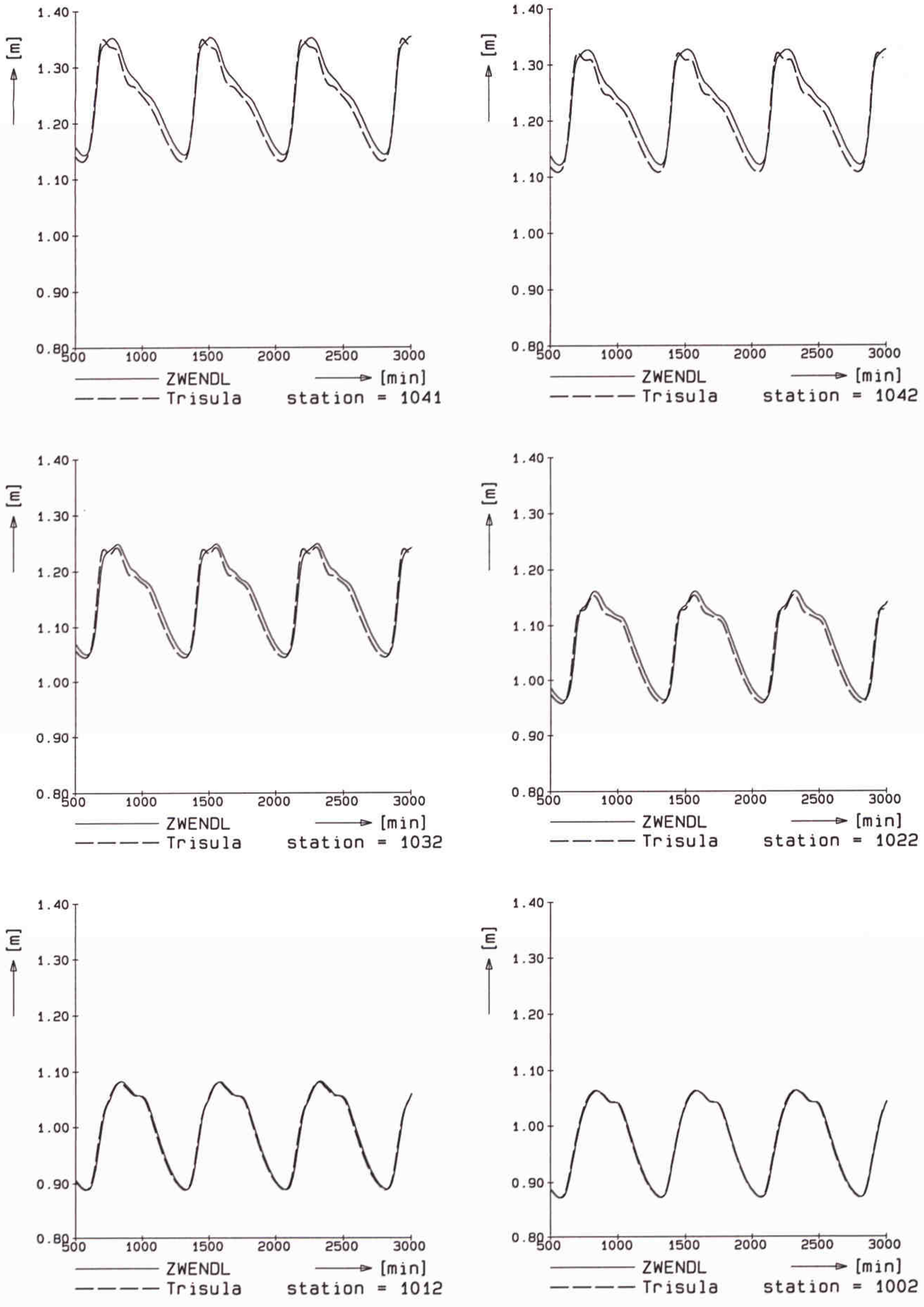
Fig 6a



Discharges run = 220
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS | Z-2192 | Fig 6b



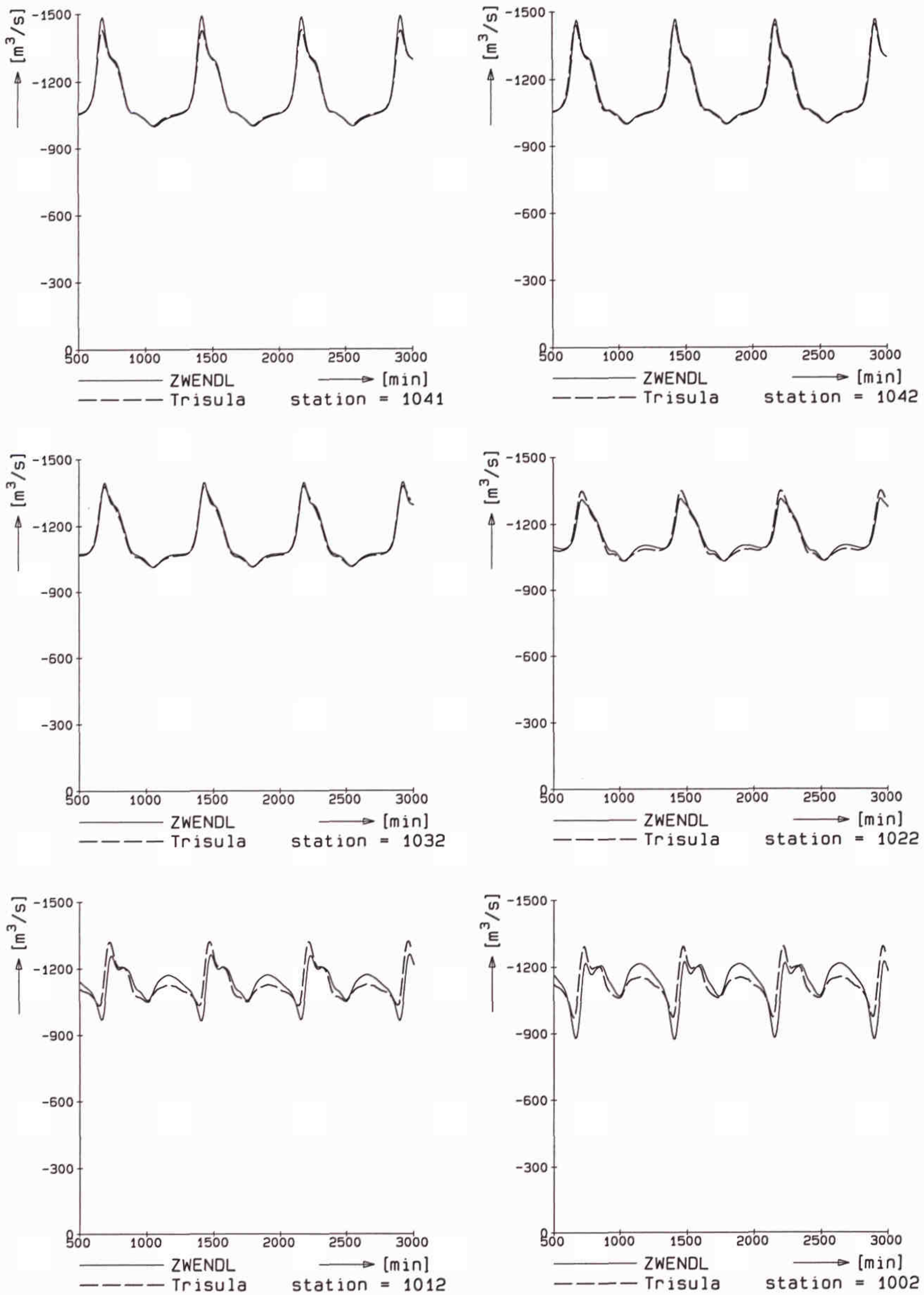
Water levels run = 300
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS

Z-2192

Fig 7a



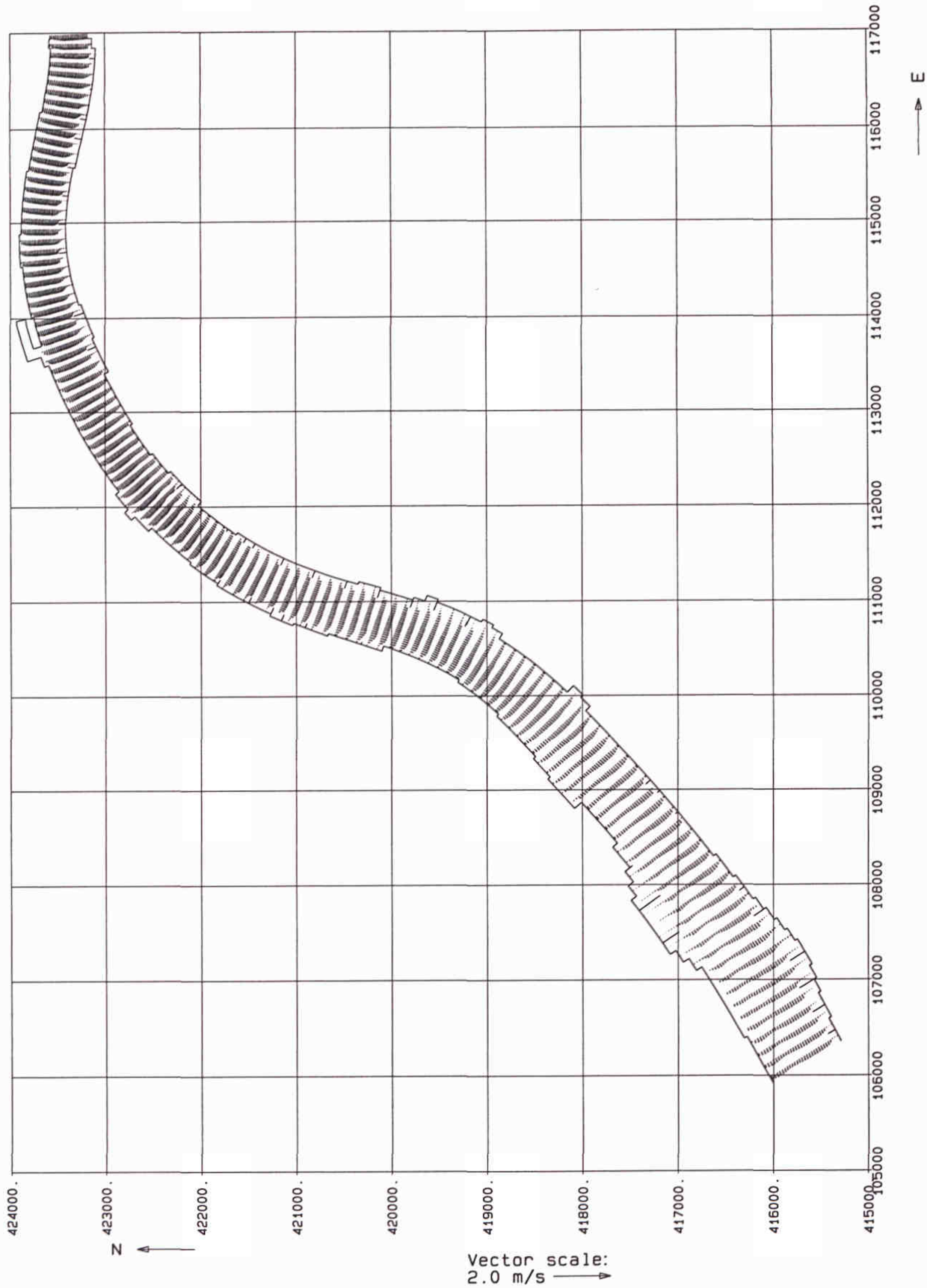
Discharges run = 300
Time Step = 2.5 minutes

Zand-Slib

DELFT HYDRAULICS

Z-2192

Fig 7b



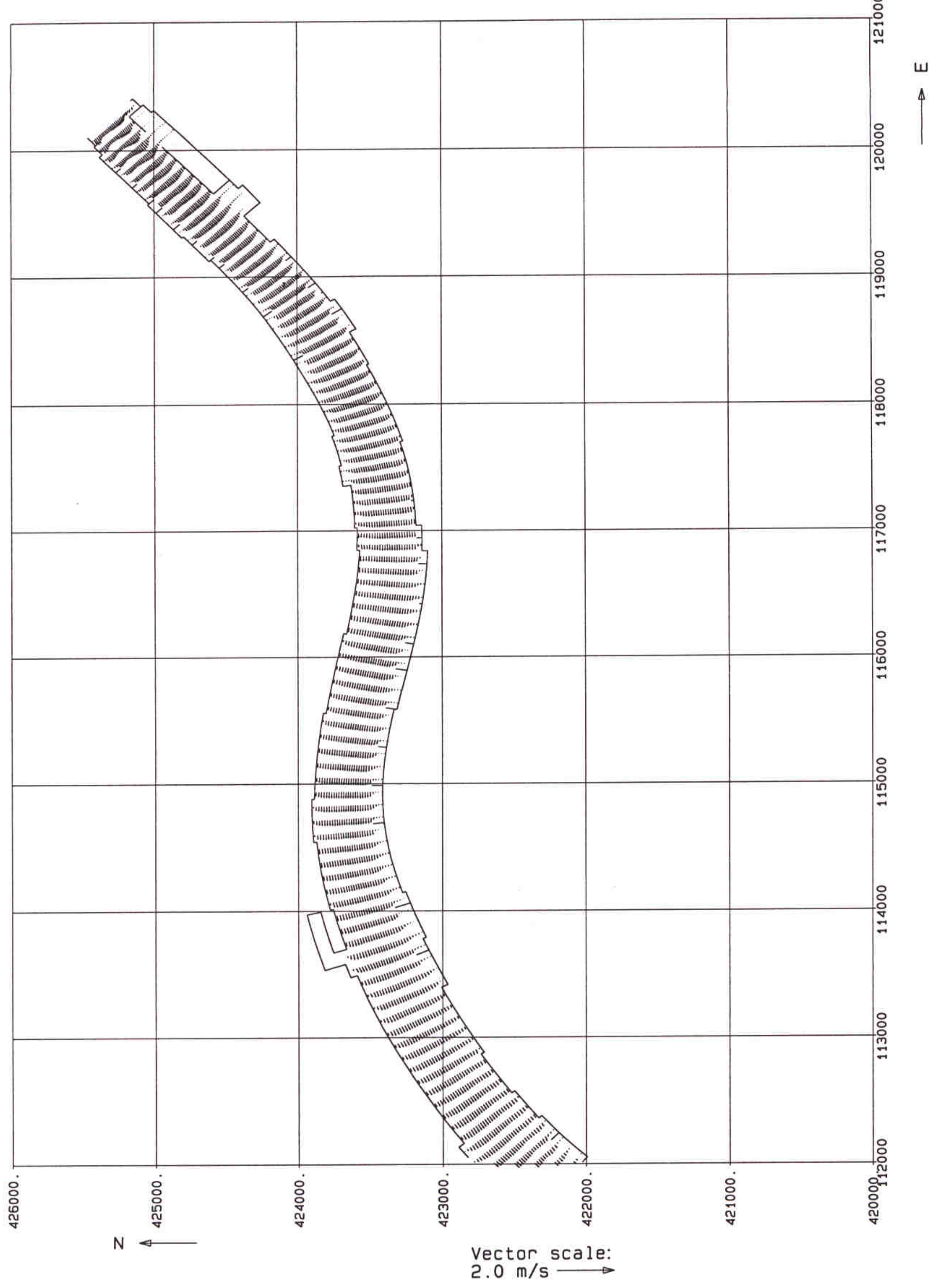
Lower part of model grid
Current vectors run = 120
Time : at minimum discharge

Zand-Slib

DELFT HYDRAULICS

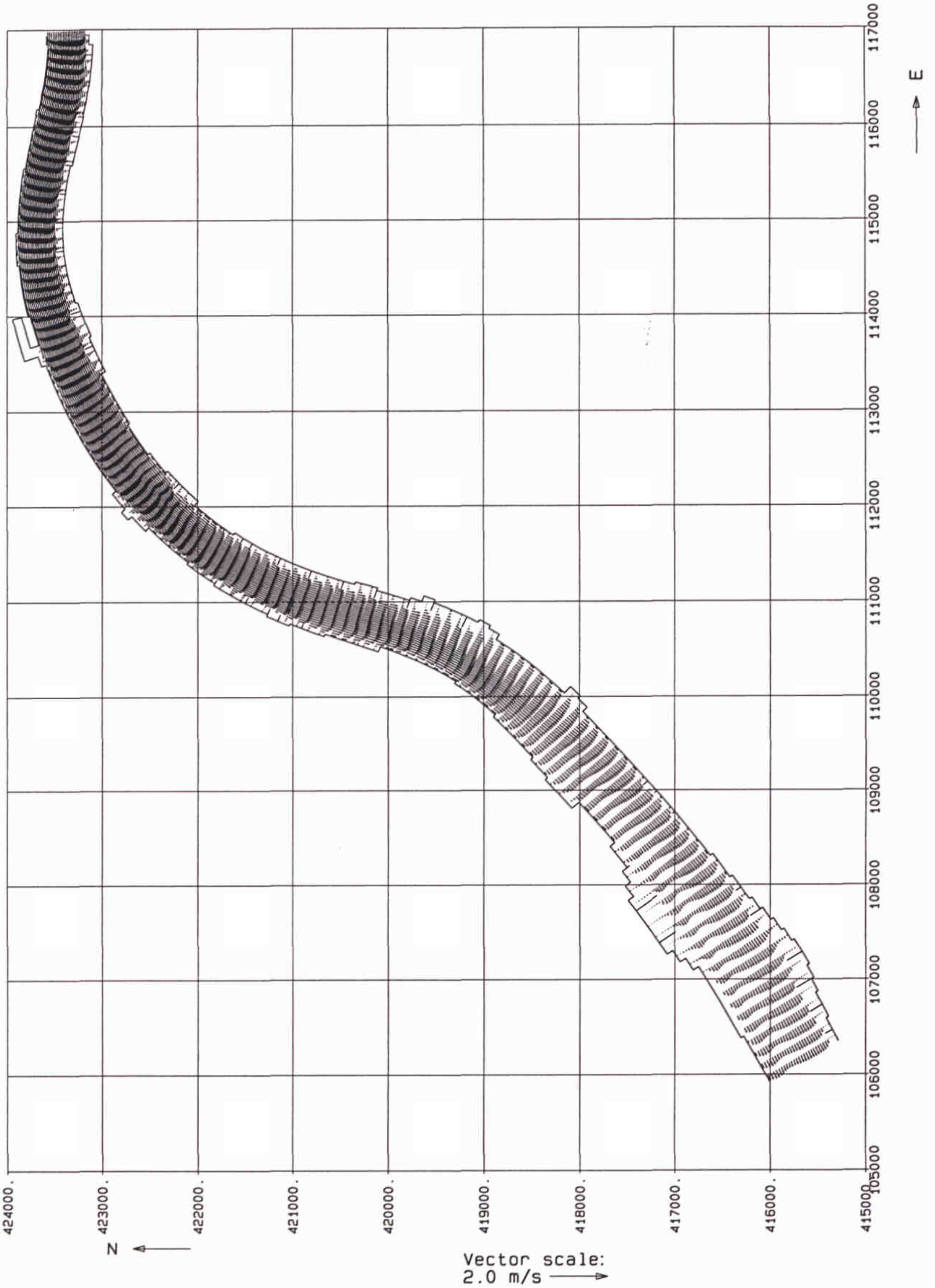
Z-2192

Fig 8a

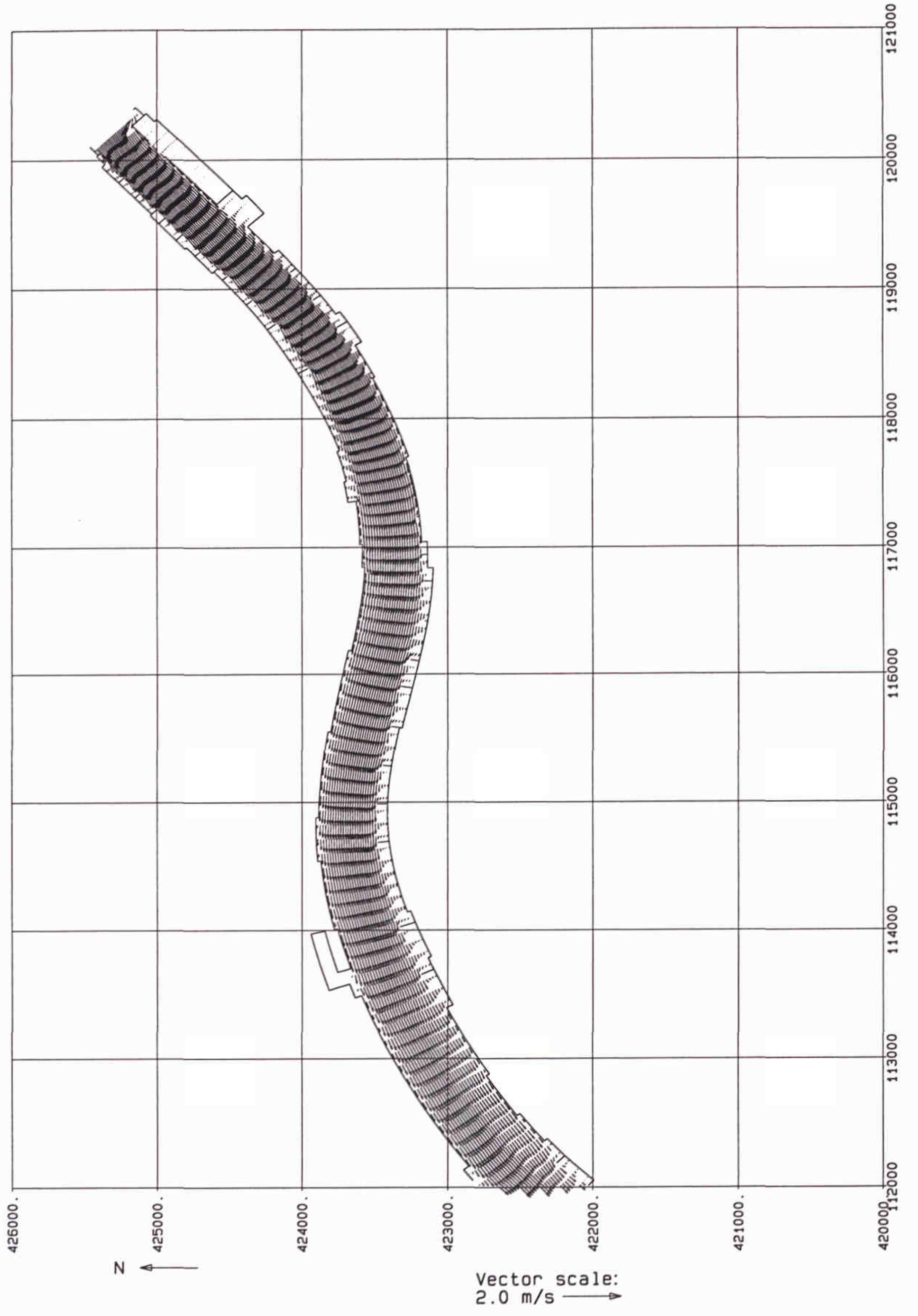


Upper part of model grid
Current vectors run = 120
Time : at minimum discharge

	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 8b

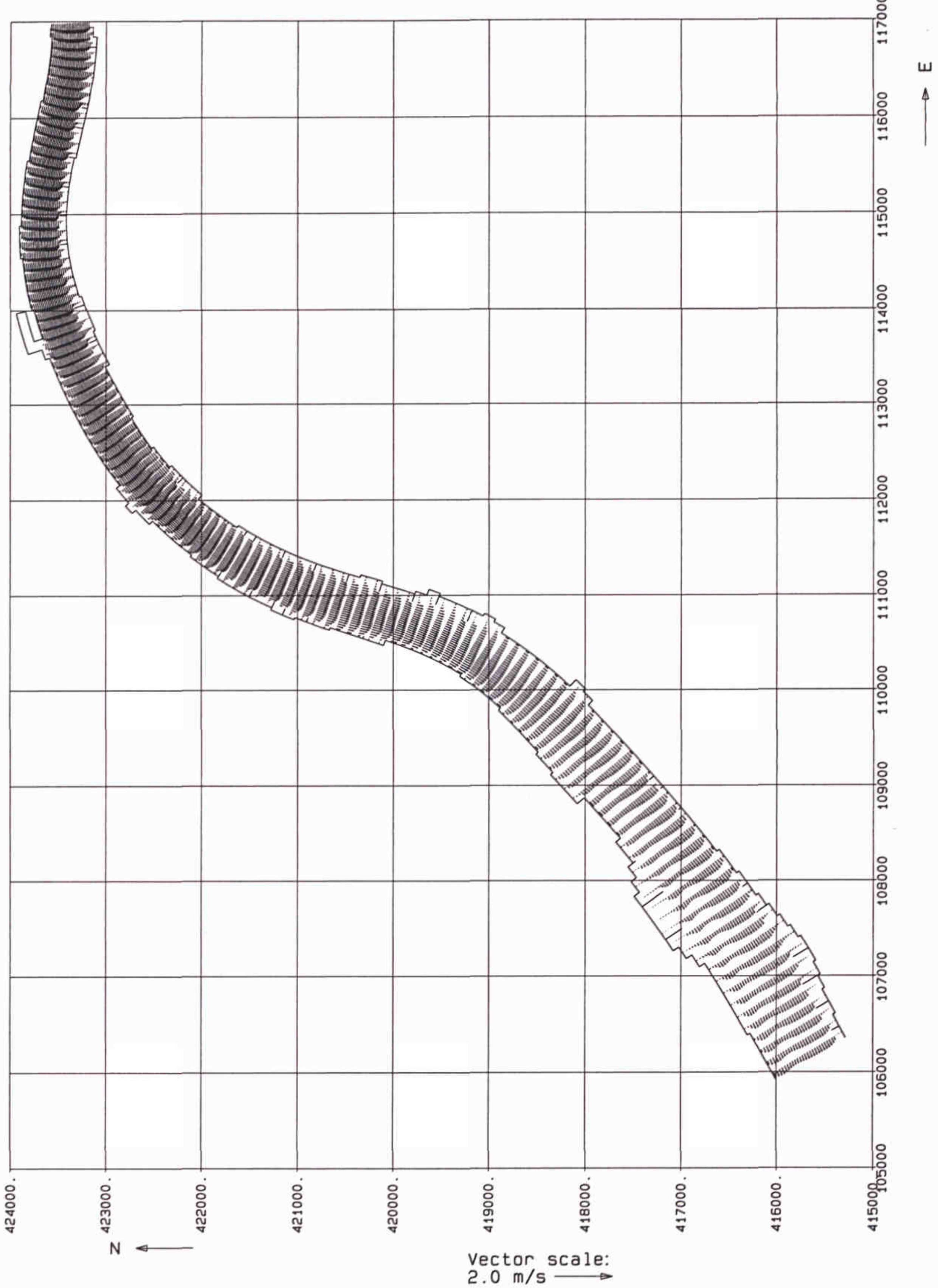


Lower part of model grid Current vectors run = 120 Time : at maximum discharge	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 9a



Upper part of model grid
Current vectors run = 120
Time : at maximum discharge

DELFT HYDRAULICS	Zand-Slib
	Z-2192	Fig 9b

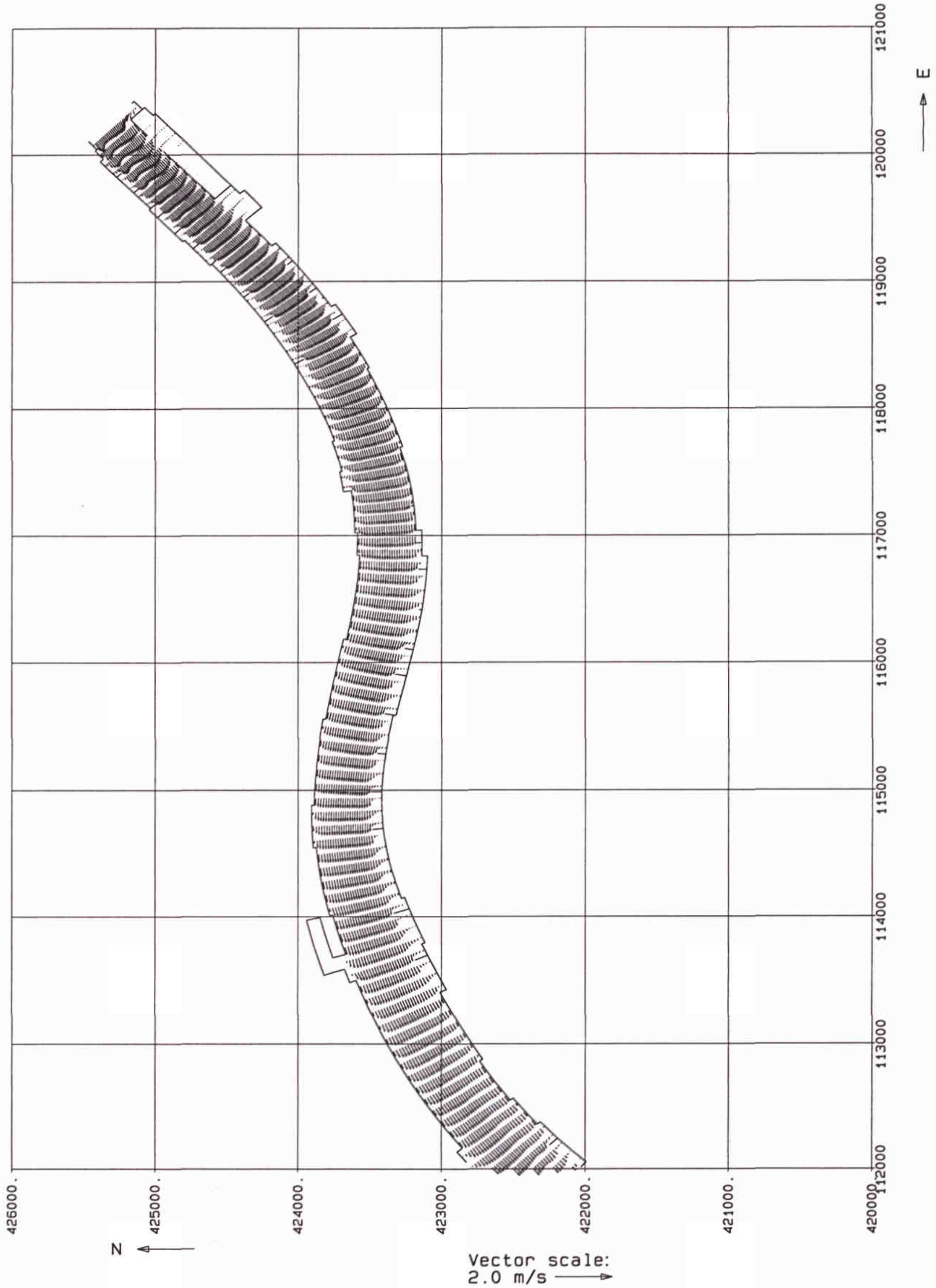


Lower part of model grid
Current vectors run = 200
Time : at minimum discharge

Zand-Slib

DELFT HYDRAULICS

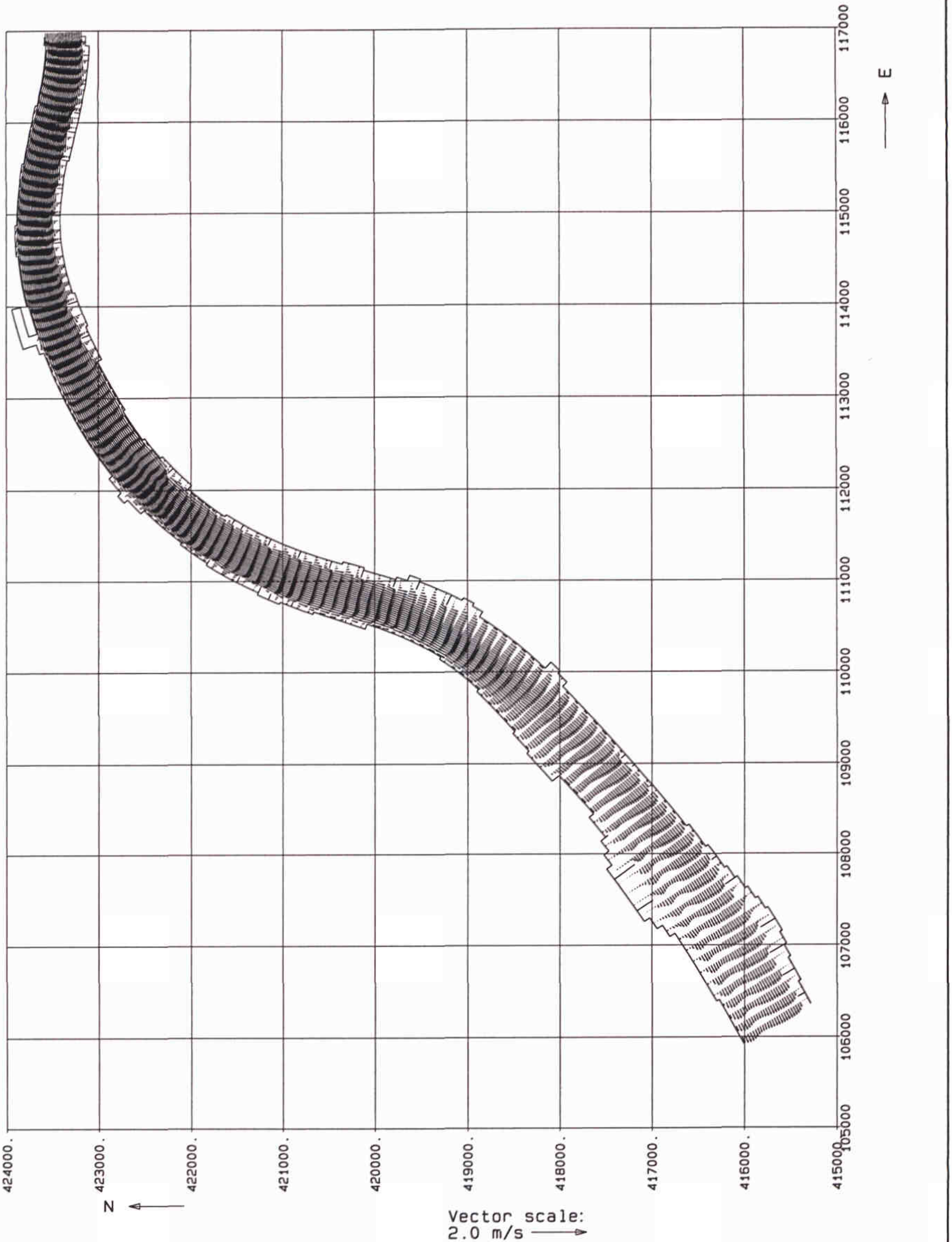
Z-2192 | Fig 10a



Upper part of model grid
Current vectors run = 200
Time : at minimum discharge

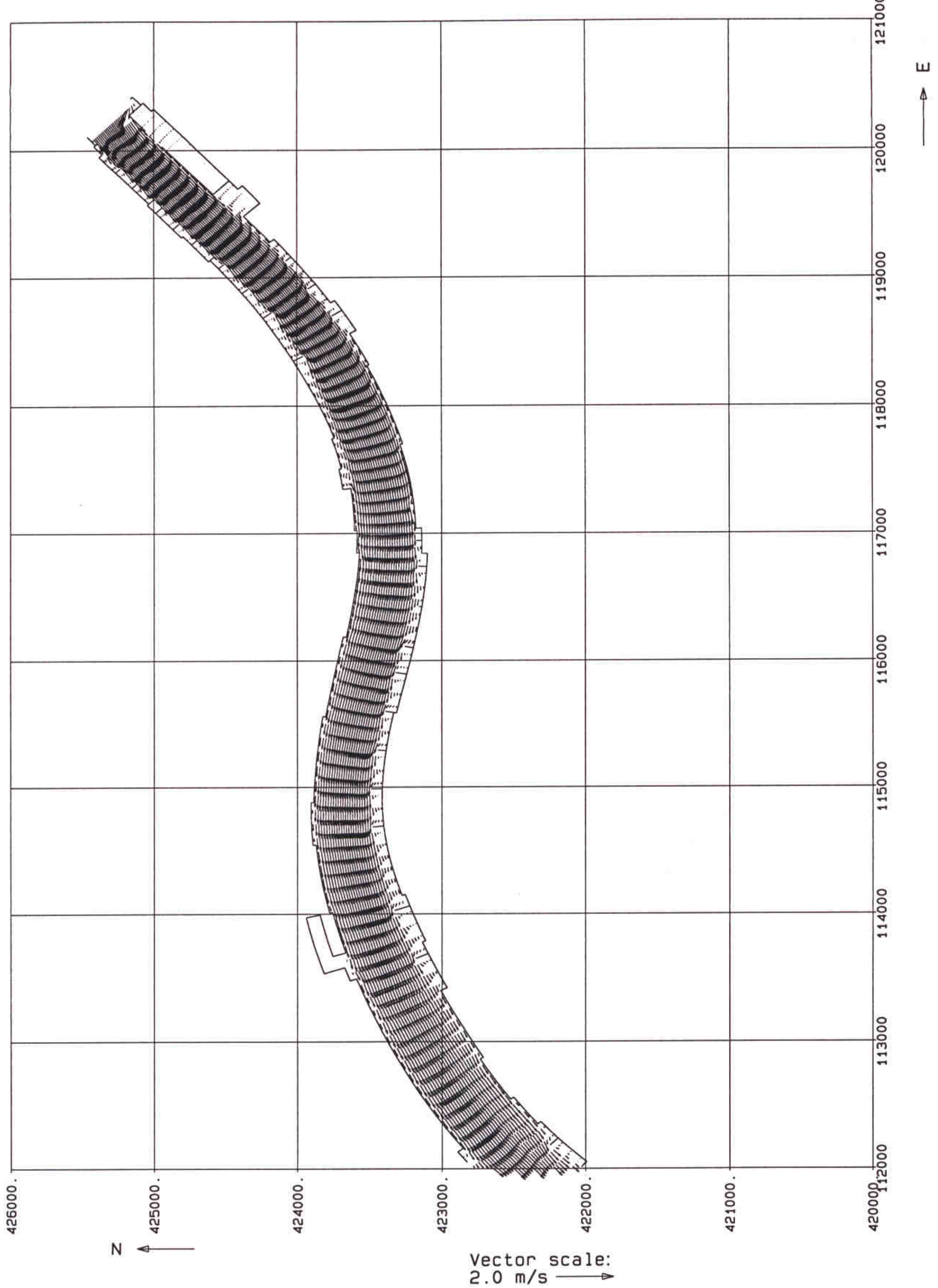
Zand-Slib	
Z-2192	Fig 10b

DELFT HYDRAULICS



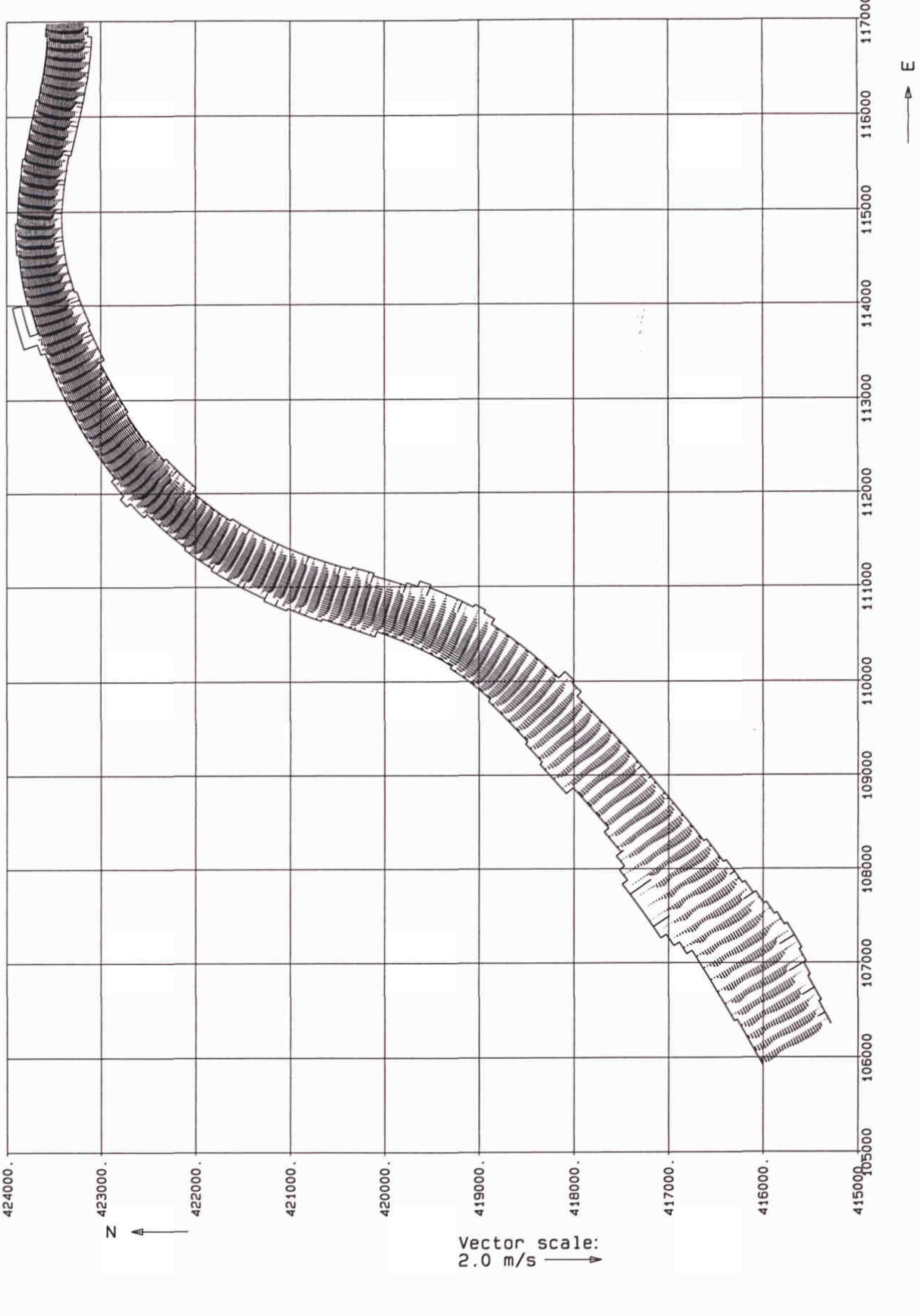
Lower part of model grid
Current vectors run = 200
Time : at maximum discharge

Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 11a



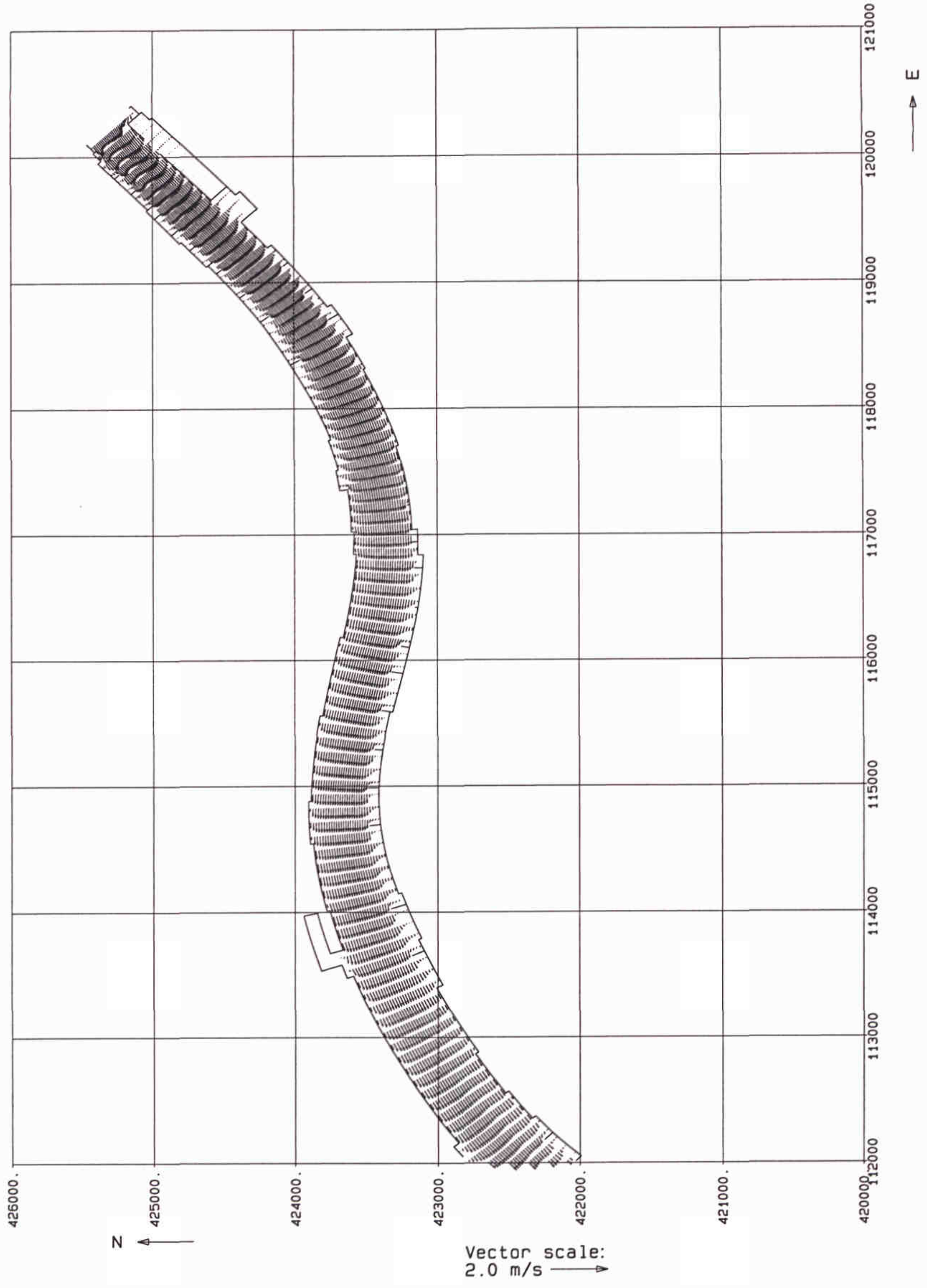
Upper part of model grid
Current vectors run = 200
Time : at maximum discharge

Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 11b

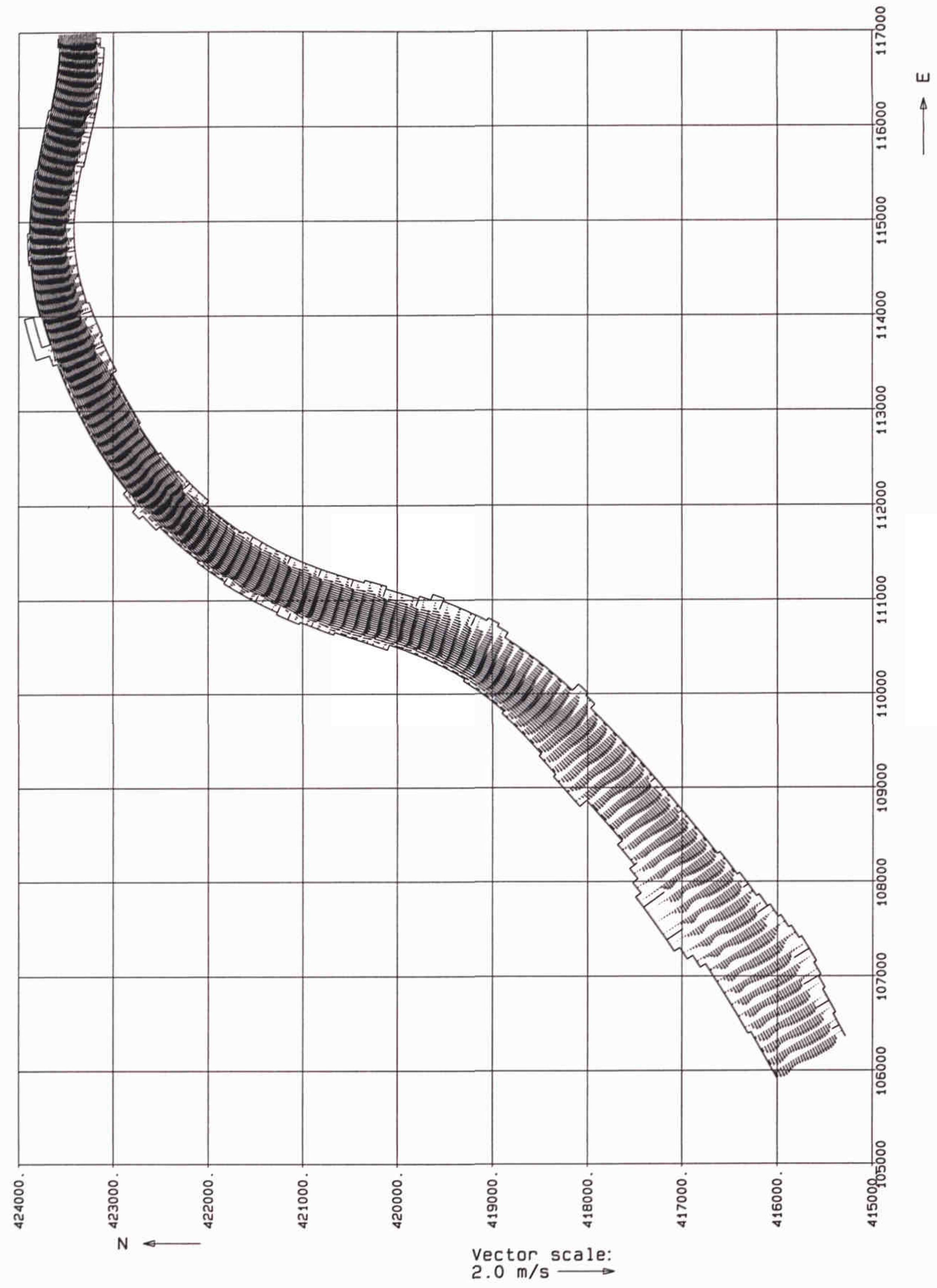


Lower part of model grid
Current vectors run = 220
Time : at minimum discharge

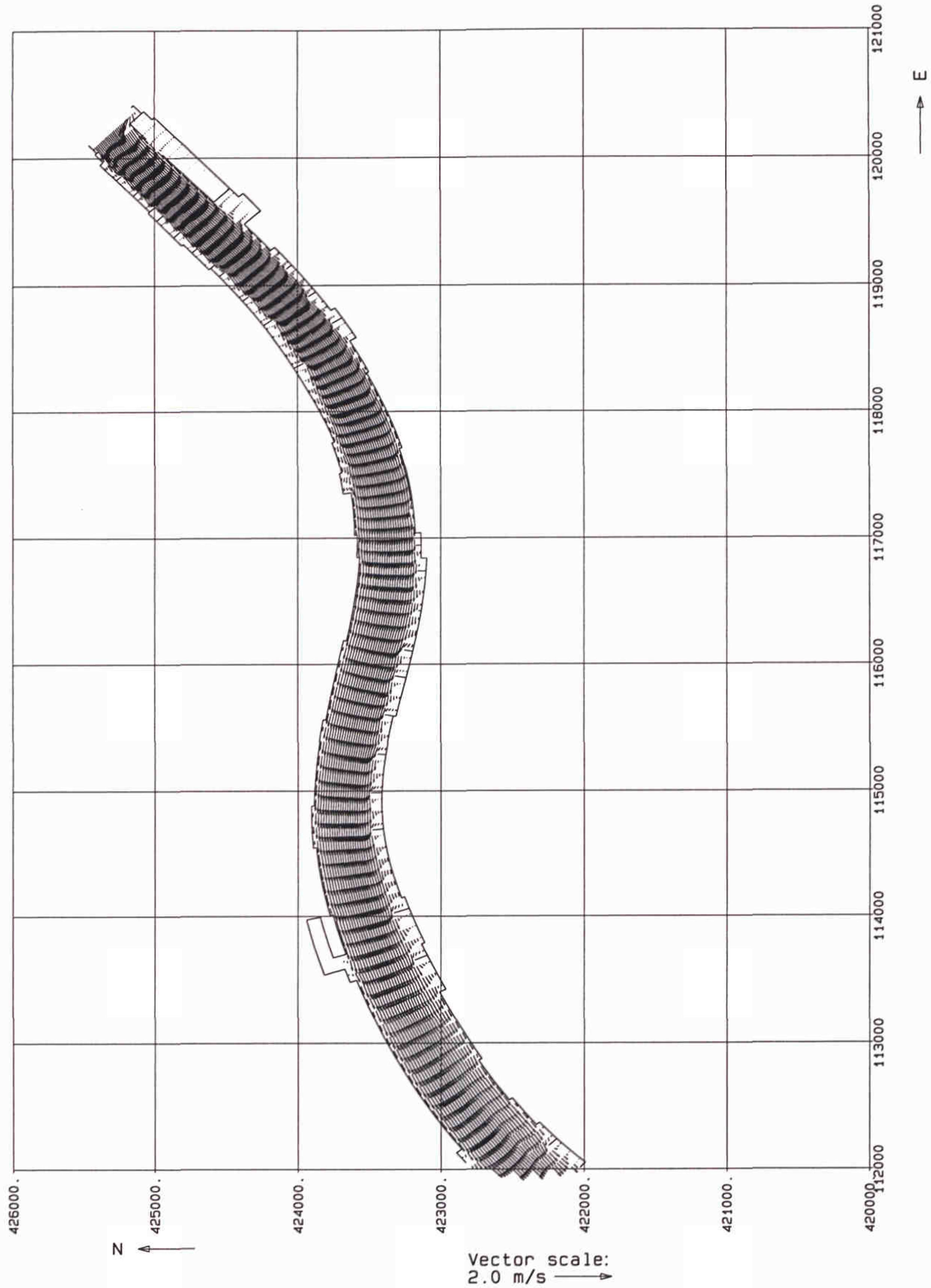
DELFT HYDRAULICS	Zand-Slib
	Z-2192
	Fig 12a



Upper part of model grid Current vectors run = 220 Time : at minimum discharge	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 12b



Lower part of model grid Current vectors run = 220 Time : at maximum discharge	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 13a



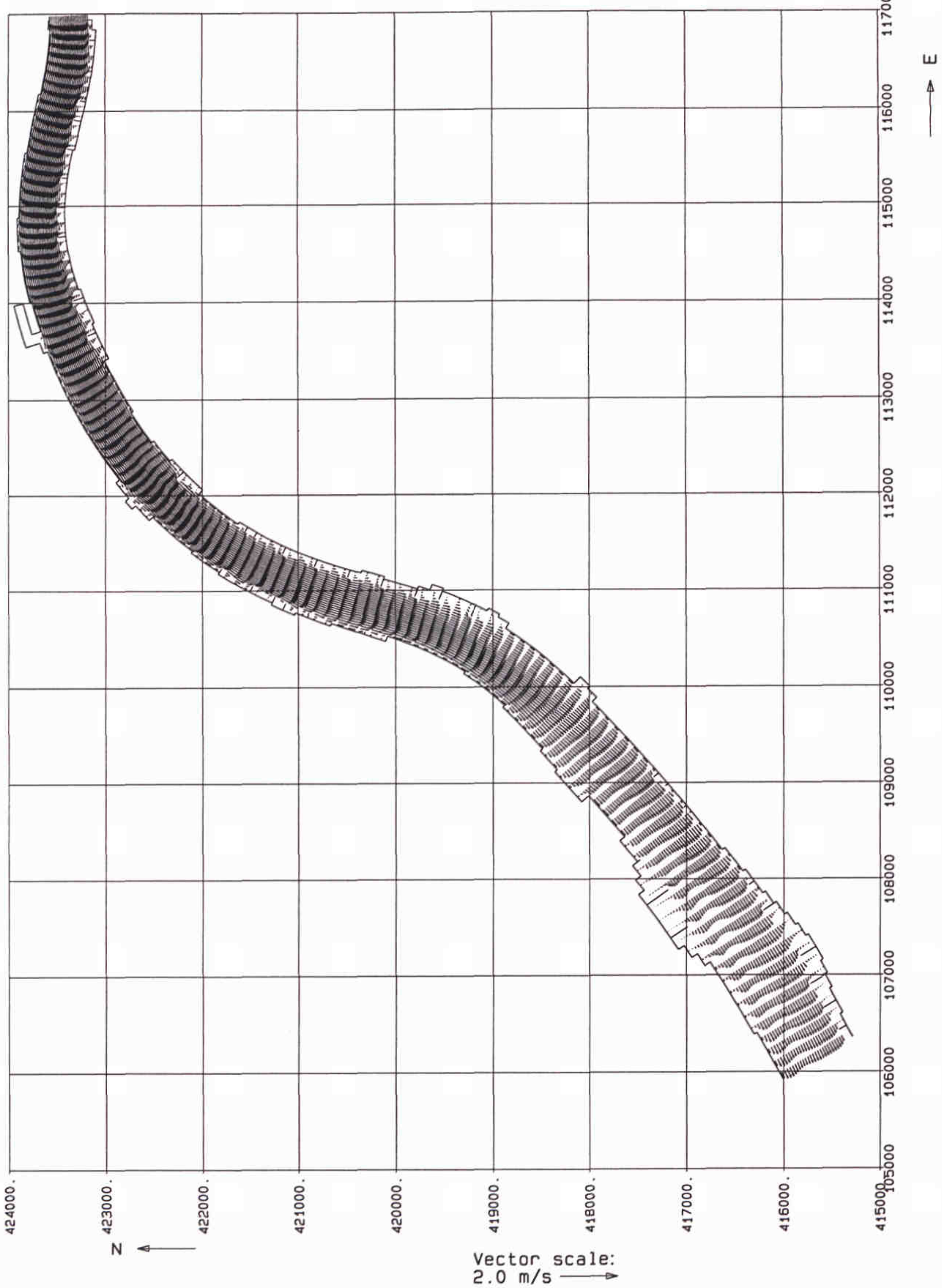
Upper part of model grid
Current vectors run = 220
Time : at maximum discharge

Zand-Slib

DELFT HYDRAULICS

Z-2192

Fig 13b



Lower part of model grid
Current vectors run = 300
Time : at minimum discharge

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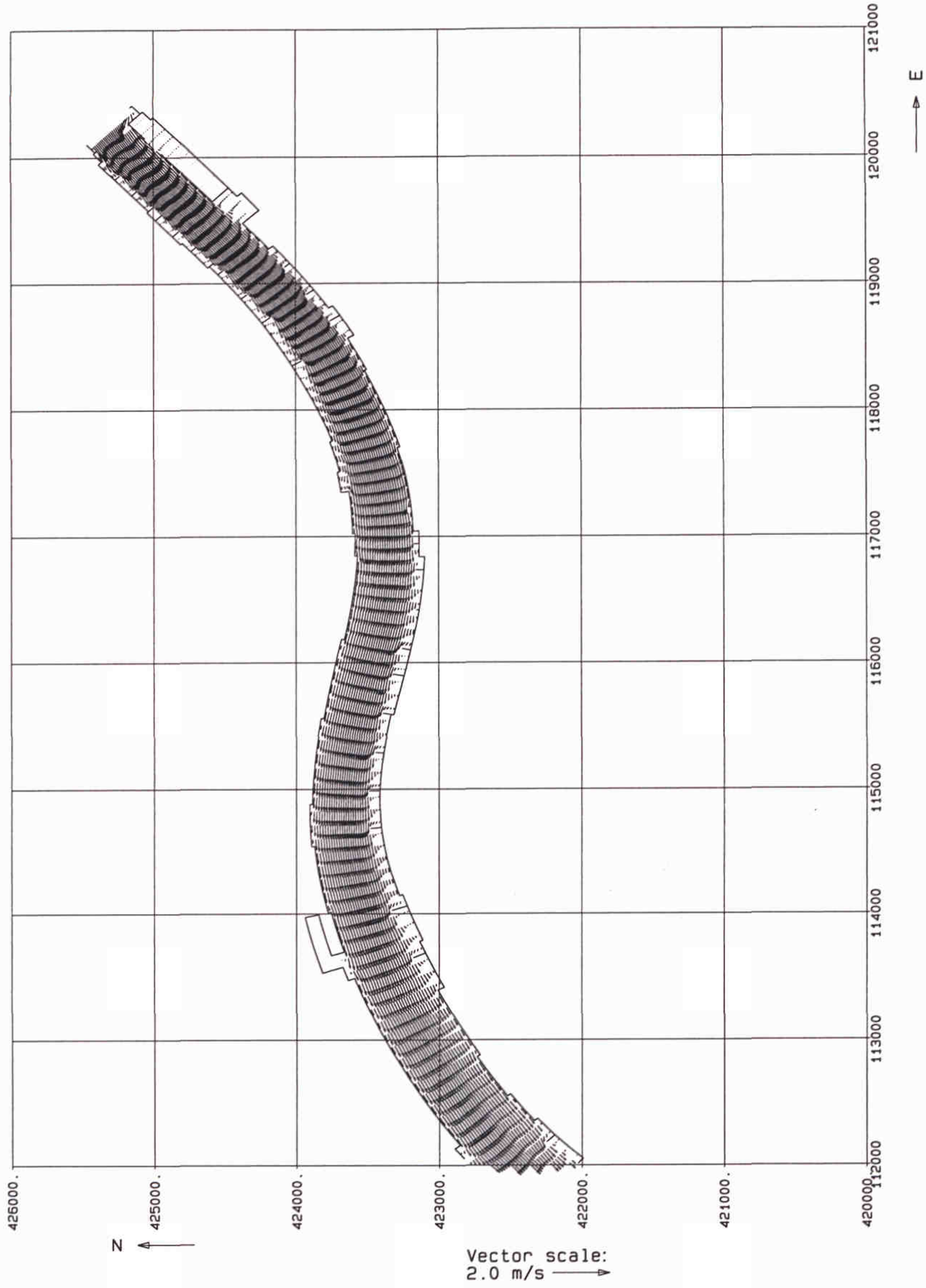
Fig 14a



Upper part of model grid
Current vectors run = 300
Time : at minimum discharge

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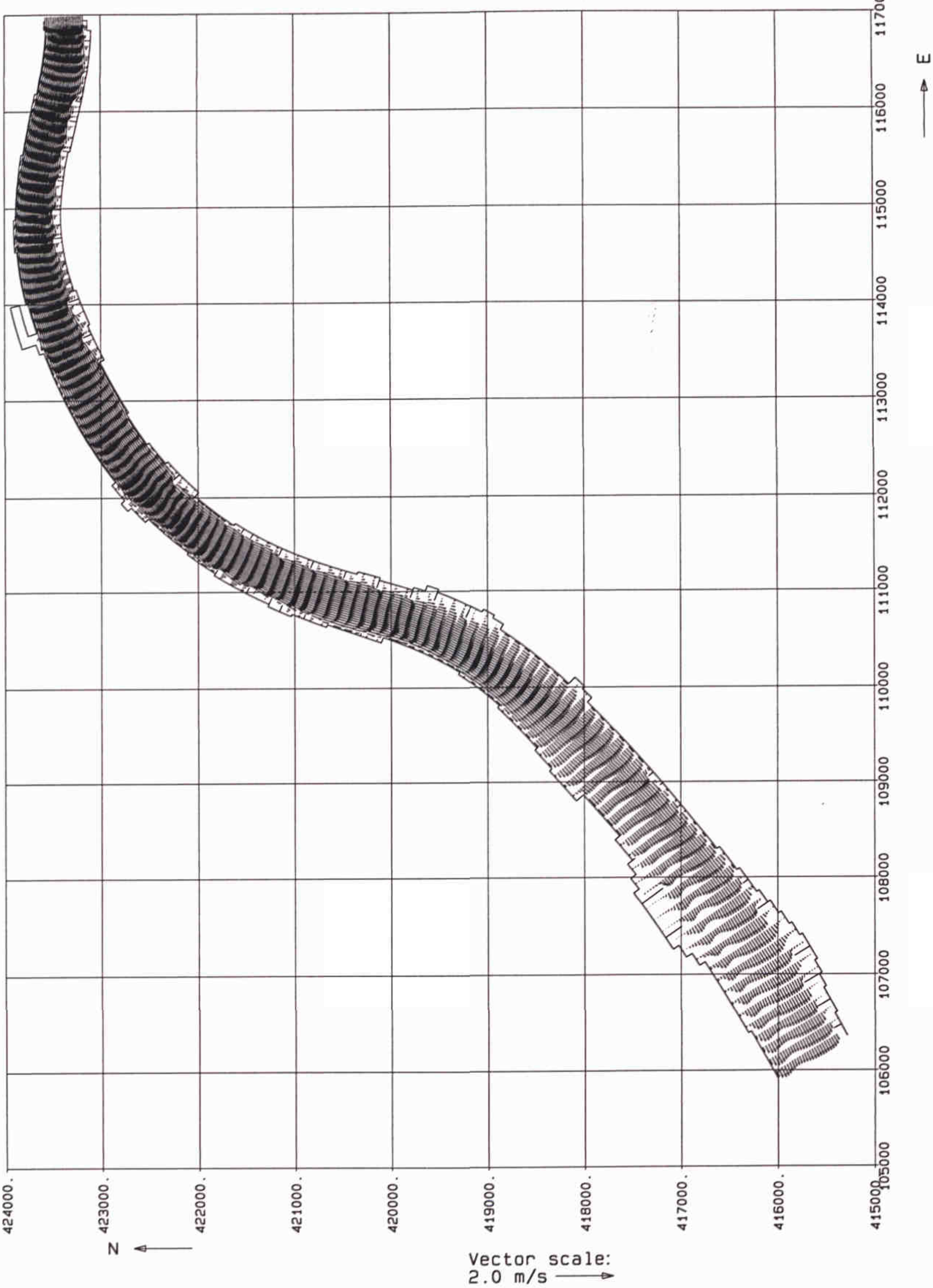
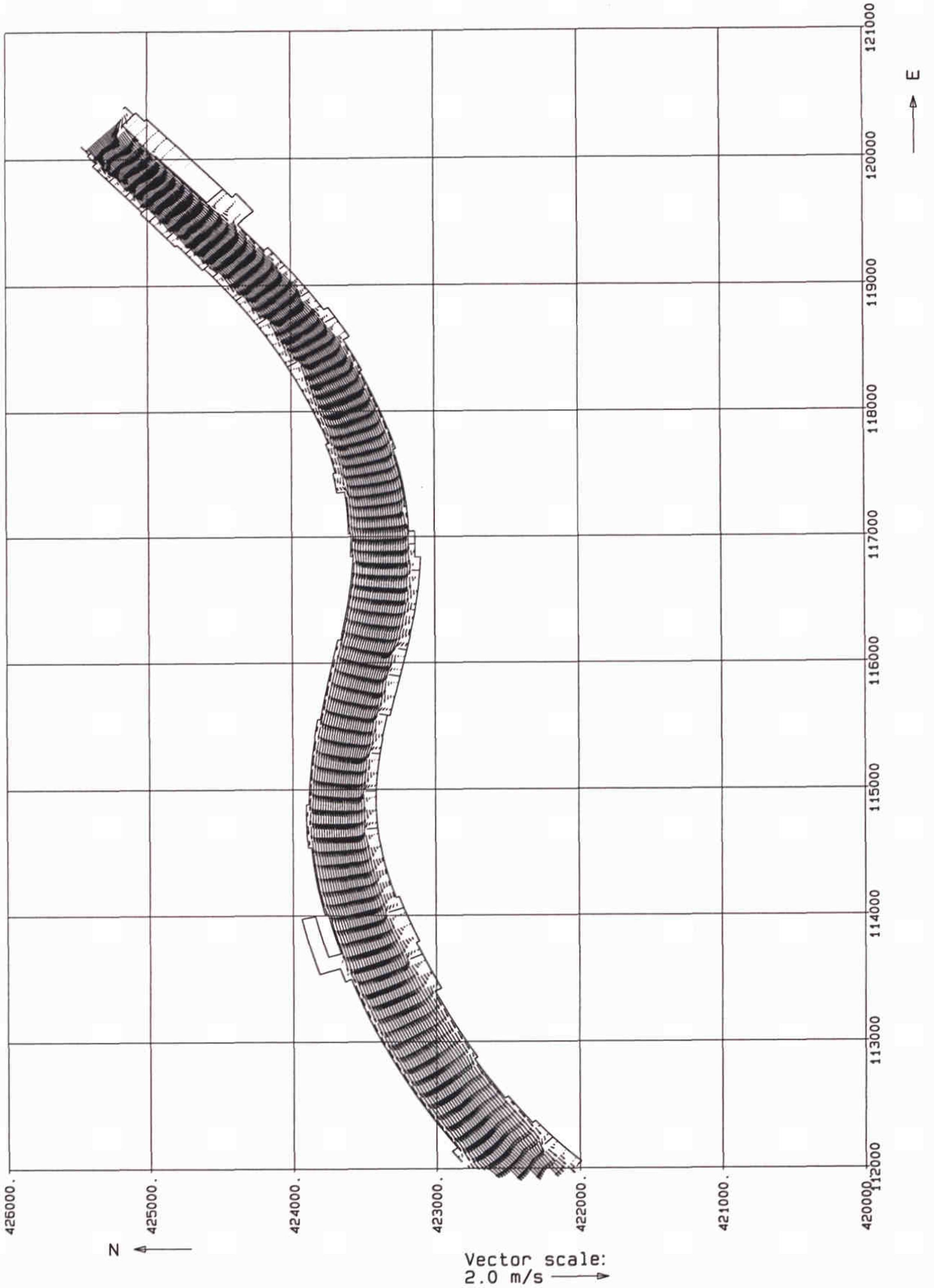
Fig 14b



Lower part of model grid Current vectors run = 300 Time : at maximum discharge	Zand-Slib	
DELFT HYDRAULICS	Z-2192	Fig 15a



Upper part of model grid
Current vectors run = 300
Time : at maximum discharge

Zand-Slib

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Fig 15b

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