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Calibration of the profile model UNIBEST-TC

Report on model investigation

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Calibration of the profile model UNIBEST-TC

J.A. Roelvink and Th.J.G.P. Meijer

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Contents

List of figures

1 Introduction

In the autumn of 1993, a nearshore nourishment of approx. 2 Million m^3 was placed about 800 m from the coast of the Dutch Wadden island of Terschelling. This nourishment, aimed at stabilising the retreating coastline, was part of a EU-funded project, "NOURTEC", which comprises nourishment projects in Denmark, Germany and the Netherlands. Part of the NOURTEC project is an extensive measurement and monitoring campaign at all three sites. The comparative analysis of the behaviour of the three nourishments must yield an improved insight in how to design optimum nourishment strategies in different environments.

During the first two years of NOURTEC, a vast amount of data has been produced at all three sites, and particularly at the Terschelling site. Several analyses have already been carried out to reduce the data in different ways, in order to improve our understanding of the dominant processes.

One of the tools which can be applied in this respect is the process-based profile model UNIBEST-TC. This model is used first in a "diagnostic" mode. Here the purposes are:

- to explain the relation between different point measurements;
- to understand the behaviour of disturbed and undisturbed profiles under various conditions, and
- to relate the nourishment behaviour at Terschelling to the behaviour of other nourishments.

Given that the model results can explain the observed behaviour reasonably well, we can then apply it in "predictive" mode, to forecast the effect of the nourishment on the nearshore zone over a 10-year period. This will be done by analysing differences between predictions with and without a nourishment, which will tell more about the effects of the supply than just the straightforward prediction. The latter is hampered by many uncertainties in model and boundary conditions.

In order to establish whether or not the model can be used at all in both diagnostic and predictive modes, we have to check if the behaviour measured so far can be represented well enough by the model. The uncertainties in some parts of the model can be reduced by calibration against hydrodynamic and profile data. In this report, we present an outline of this calibration phase. After a brief description of the model in Chapter 2, we discuss the data relevant to this study in Chapter 3. The schematisation of inputs and numerical aspects are treated in Chapter 4. Results are analysed in Chapter 5 and finally some moderately positive conclusions are drawn in Chapter 6.

2 Model description

A complete description of the updated version of the UNIBEST-TC model is given in DELFT HYDRAULICS (1995). In Walstra et al. (1995), the validation of this model against an extensive data set of large-scale wave flume data is discussed. Here we give a brief overview of the physics included in the model, and explain a new feature in the description of the breaking process.

The basic assumption in the model is that the coast is nearly uniform in longshore direction. A wave energy balance based on Battjes and Janssen (1978) can then be used to provide the cross-shore distribution of wave heights, dissipation and set-up. These parameters in turn drive local models for the longshore and cross-shore velocity profiles, where also wind and tidal influences are included. Combined with models for the near-bed orbital velocity this information is used in the prediction of longshore and cross-shore sediment transport rates.

The cross-shore distribution of the cross-shore transport determines the changes in the profile depth; these changes are fed back into the profile and the process is repeated over a number of morphological timesteps, using a robust, fully implicit numerical scheme.

The model requires an initial profile, grain sizes and offshore boundary conditions for waves, water level, tidal velocity and wind velocity. These boundary conditions usually vary in time. The morphological time step must be small enough to represent the natural fluctuations.

The model version described in DELFT HYDRAULICS (1995) differs from the previous version in the following respects:

- a consistent treatment of the cross-shore and longshore velocity vertical, using parametric viscosity distributions;
- inclusion of wind effects;
- a new sediment transport formulation, according to Van Rijn et al. (1995). In this formulation, bed load and suspended load transports are treated in fundamentally different ways.

The updated transport formula is a fundamental improvement in the Terschelling case. In the Bailard formula, used in previous versions, bed load and suspended load were assumed to react instantaneously to velocity fluctuations. This is probably correct for bed load, but certainly not for suspended load. In the present model, suspended transport is approximated by the product of mean current and mean concentration verticals.

It is now possible that bed load transport and suspended load transport are in opposite directions. Computations for the present case show that this indeed happens (see Chapter 6): bed load is generally directed onshore, and suspended load offshore. In previous versions of the model, the suspended load transport was mainly directed onshore, which led to unrealistic accretion of the upper profile.

A modification implemented in the present study concerns the wave energy decay model. It has often been noticed, and most recently during the validation of UNIBEST-TC against Delta Flume data, that the process of wave breaking is not described accurately by the Battjes and

Janssen model in the case of rather strong bottom variations. The sub-model which predicts the fraction of breaking waves reacts only to the local water depth, and disregards the fact that waves need a distance in the order of a wave length to actually start or stop breaking. In the Delta flume tests (Arcilla et al., 1994) this was especially apparent in one test, where almost no wave broke at the bar crest, and almost all waves broke in the trough behind it.

This feature has been taken into account in the following manner. In the sub-model which computes the fraction of breaking waves, the local water depth has been replaced by the water depth weighted over a certain distance seaward of the point in question:

$$h_b(x) = \frac{\int_{x-X}^{x} W(x-x')\, h(x')\, dx'}{\int_{x-X}^{x} W(x-x')\, dx'} \tag{1}$$

where h is the water depth, h_b is the weighted water depth used in the computation of the fraction of breaking waves, X is the integration distance and W is the weighting function. A triangular weighting function was used:

$$W(\xi) = X-\xi \tag{2}$$

The integration distance X was taken proportional to the local peak wave length L_p:

$$X = \lambda L_p \tag{3}$$

where λ is a coefficient of order one. The effect of varying the value of λ on wave properties and on the morphologial behaviour will be treated in Chapter 6.

3 Data description

3.1 Surveys

Data from six consecutive surveys were made available by Rijkswaterstaat. The survey files concerned values already interpolated onto a regular 20 m by 20 m grid, oriented East-North. The survey dates and codes are given in Table 3.1 below.

Code	Date	Remarks
n1905	19-05-93	pre-nourishment
n1711	17-11-93	post-nourishment
n0294	20-04-94	150 days after nourishment
n0394	14-06-94	
n0494	24-11-94	
n0195	13-01-95	

Table 3.1 Overview of survey data

To facilitate further analyses, we converted this grid to one in longshore - cross-shore direction, with grid sizes 60 m in longshore direction and 20 m cross-shore. Given the typical scales of the bathymetry, this does not lead to much loss of information.

Based on this grid it is quite easy to perform averaging of profiles over a certain length of coast, or to average longshore profiles over some cross-shore distance. In this way, we can select "typical" profiles, which exhibit the behaviour of individual profiles without irregularities and accidental errors.

An example of this is shown in Figure 3.1, where the bathymetry 150 days after the nourishment is shown, together with the development up till then of averaged longshore and cross-shore profiles situated over the nourishment.

The development of an averaged profile over the nourishment (between RSP km. 14.7 and 17.1) is shown in Figure 3.2. The nourishment between 19-05-93 and 17-11-93 is clear to see, as well as the strong response of the profile in the period following 17-11-93, after which the response slows down considerably. Almost half of the nourished sediment appears to have moved shoreward of the –5 m depth contour line. This does not explain in full the accretion of the upper part of the profile; the total profile area is not conserved, which indicates either a longshore transport gradient or sand inputs from the dune area, which is not included in these analyses.

The development of the undisturbed profile East of the nourishment (averaged between RSP km. 18.24 and 20.1) over the same period is shown in Figure 3.3. The outer bar and second bar move onshore during the nourishment period, and move substantially offshore in the period following the nourishment. It is worth noting that the outer bar is dominated by offshore transport during the period after the nourishment, in contrast with the behaviour of the nourished area.

To show that the averaged profiles are indeed representative of the behaviour of individual profiles, the undisturbed profile was split up into three separate profiles. In Figure 3.4, the movement of these profiles in the period after the nourishment is shown. Although the profiles vary slightly in shape and location, their characteristics and behaviour are the same.

Figure 3.5 shows averaged longshore profiles over the area indicated by the lines in Figure 3.1, which covers most of the nearshore area. Of course the nourishment is clearly visible; what is also evident is, that the eastern edge of the nourishment has moved East by some 300 m in the period following the nourishment. Apart from smaller fluctuations, some of which may be due to measurement errors, another striking feature is the accretion of a large part of the profile after the nourishment.

In order to get a first indication of the sediment budget of the area, differences in average bed level were computed over control sections of 200 m cross-shore by 10,000 m longshore, for each consecutive survey. The results are shown in table 3.2 below. It must be stressed that these are uncorrected survey data; work is in progress at Rijkswaterstaat to analyse the (many) sources of systematic errors that severely influence these numbers.

	1540-1740	1340-1540	1140-1340	940-1140	740-940	540-740	340-540	140-340	total
Average level 19-05-93	-7.81	-7.16	-5.91	-5.98	-6.52	-4.04	-3.62	-1.22	
19-05-93 to 17-11-93	-.08	-.08	-.13	**.35**	**.59**	-.05	.04	.01	0.65
17-11-93 to 20-04-94	.05	.10	.06	-.07	-.02	**.41**	.10	.05	0.68
20-04-94 to 14-06-94	-.10	-.10	-.10	-.06	-.06	-.09	.02	.06	-0.43
14-06-94 to 24-11-94	-.08	-.06	-.05	-.06	-.09	-.07	-.02	.05	-0.38
24-11-94 to 13-01-95	.22	.19	.16	.16	.22	.01	.11	-.01	1.06
	0.01	0.05	-0.06	0.32	0.64	0.21	0.25	0.16	1.58

Table 3.2 Differences in bed level averaged over 200 by 10,000 m^2 areas

Just to show the implications of the errors apparent in the data, the differences in bed level were corrected per survey in such a way that the changes in deep water were minimal. This produces a rather different picture, as shown in Table 3.3.

	1540-1740	1340-1540	1140-1340	940-1140	740-940	540-740	340-540	140-340	total
Average level 19-05-93	-7.81	-7.16	-5.91	-5.98	-6.52	-4.04	-3.62	-1.22	
19-05-93 to 17-11-93	-.00	-.00	-.05	**.43**	**.67**	.03	.12	.09	1.29
17-11-93 to 20-04-94	-.02	.03	-.01	-.14	-.09	**.34**	.03	-.02	0.12
20-04-94 to 14-06-94	.00	.00	.00	.04	.04	.01	.12	.16	0.37
14-06-94 to 24-11-94	-.01	.01	.02	.01	.02	.00	.05	.12	0.22
24-11-94 to 13-01-95	.01	-.02	-.05	-.05	.01	-.20	-.10	-.22	-0.62
	-0.02	0.02	-0.09	0.29	0.65	0.18	0.22	0.13	1.38

Table 3.3 Differences in bed level averaged over 200 by 10,000 m^2 areas. Corrected to minimum changes in deep water

The implications of the errors in the survey data are severe: depending on which analysis one believes, the nourished volume is in the order of 1.9 Mm^3 or 2.2 Mm^3 if one considers just the nourished area; if we consider the balance of the whole area before and after the nourishment, the difference is 1.3 Mm^3 or 2.4 Mm^3. Of these numbers, the latter seems the more realistic. Still, the overall budget is far from closed. If we consider for instance the 0.12 m difference (corrected) between surveys 17-11-93 and 20-04-94, which is equivalent to 240,000 m^3, this may be due to dune erosion in the order of 24 m^3/m' or a difference in longshore transport over the area of 240,000 m^3 in 150 days. The first explanation is in accordance with observations of dune erosion during the January '94 storm. The sediment budget for the period following the nourishment thus seems to be reasonably in order. For the other periods, however, the total differences between surveys are much larger than can be ascribed to either longshore transport gradients or cross-shore losses or gains; no sensible budgets can be gained from these data at this stage.

These analyses again show the importance of

- reducing systematic errors between surveys to a level of cm's or less, and
- including the dry beach and dune in the analyses.

For the present study, we focus on the period between 17-11-93 and 20-04-94, where we will accept the overall sediment budget of Table 3.3 as the "best guess".

For the purpose of the calibration, two typical profiles were selected: an "undisturbed" profile, East of the nourishment (averaged between km 18.240 and 20.100), and a "disturbed" profile (averaged between km. 14.700 and 17.100).

3.2 Wave and water level data

It has been shown from the data that significant changes in the profiles mostly took place in the 150 days following the nourishment. Therefore this period was selected for the present analyses. Wave data from the WAVEC buoy at 15 m water depth were used as input, as well as water level data from a nearby tide gauge. In the present phase, tidal and wind-induced currents were not considered, as the emphasis was first on cross-shore processes.

The wave data from the WAVEC buoy suffered from a large gap in the month of January 1994. At first, the data during this month were just replaced by small values, as the bnuoy indicated very low wave heights or error values. The thus obtained time series of water levels, wave heights, wave periods and wave directions are shown in Figure 3.6. Most computations were carried out based on these boundary conditions.

At a later stage, a further analysis showed that the missing period contained a short but severe storm, with H1/3 values of 6.5 m and water levels of 2.40 m +NAP. As this might have a significant impact on the results, the final computations were redone with the boundary conditions shown in Figure 3.7, where the large gap has been filled with values from the nearby station of Schiermonnikoog Noord (SON). Results are discussed in Chapter 5.

3.3 Sedimentological data

In several surveys a dense sampling of surface sediment hase been carried out (Hoekstra and Juillen, 1955). The surveys show some very systematic behaviour of the sediment characteristics; there appears to be a strong dependence of the sediment size on the water depth; the adaptation time of this spatial sorting to morphological changes apparently is quite short, given the fact that the impact of the nourishment on the sediment distribution has quickly disappeared.

We can use the fact that the sediment sorting adapts quickly in our modelling, by taking into account a unique relation between water depth and sediment size. This relation is shown in Figure 3.8. Of course this is just a first step towards taking sediment sorting into account; in the near future, attempts will be made to predict the behaviour of individual sediment fractions, and hence the spatial sorting effects.

4 Schematisations and numerical aspects

The coordinate system was chosen with the x-axis increasing shoreward, and x = 0 at y = 2000 m in the coordinate system shown in Figure 3.1.

In the course of a number of initial runs, a grid size of 10 m in the nearshore area was found to be accurate enough, and still reasonably efficient. The grid sizes chosen in most computations were distributed as shown in Table 4.1 below.

From (m)	To (m)	Number of cells	Grid size (m)
-2800	-1000	9	200
-1000	0	10	100
0	400	8	50
400	600	8	25
600	2200	160	10

Table 4.1 Grid size distribution

A morphological time step of 6 hours was chosen to represent the variation in boundary conditions. This leads to an aliasing effect in the tidal water level variation, which has no significant effects over longer periods.

This time step poses no problems to the stability of the numerical solution, and does not lead to significant inaccuracies.

5 Results

5.1 Initial runs

Initially, a number of sensitivity tests were carried out in order to establish that the model produced sensible results for the range of conditions present in these tests, and to determine necessary grid sizes and time step. The grid size distribution which resulted from this is given in Table 4.1. Here just a few examples are shown of the results of these tests.

In Figure 5.1 the effect of the wave height on the cross-shore transport is shown. For low wave heights, bed load transport is dominant. In these cases the onshore transport due to wave asymmetry and streaming leads to onshore movement of sand bars. For the higher waves, suspended transport becomes more important, and the transport direction on bar crests turns seaward due to the undertow under breaking waves. In the troughs, bed load transport may still dominate.

In Figure 5.2, the distributions of bottom transport, suspended transport and total transport are shown for normally incident waves with a wave height of H_{rms} = 3.5 m. The result is rather typical for the behaviour of the new transport model: bottom transport is generally shoreward and suspended transport seaward. The resulting total transport shows large fluctuations about zero transport. Under these conditions, moving bars are possible without introducing much long-term erosion or accretion.

5.2 Long runs

After the initial sensitivity tests approximately twenty runs were carried out which covered the entire 150-day period. The most important parameters determining the cross-shore morphological behaviour turned out to be:

- the adaptation length of the wave breaking process, represented by the parameter λ (see Chapter 2).
- the bottom slope effect. At present, a rather crude formulation is implemented, awaiting results of ongoing research in MAST-G8M. The parameter "$\tan\phi$" indicates the tangent of the natural angle of repose, which is quite uncertain in the present conditions.
- the breaking parameter γ in the Battjes and Janssen model. Measurements indicate that the usual parameterisation by Battjes and Stive (1985) is not very useful here, and that rather a value in the order of 0.65 must be chosen.
- the grain diameter. In the standard UNIBEST-TC version, this value is constant over the profile. Measurements indicate however a systematic dependence of the water depth. This dependence (see Chapter 3.3) has been taken into account in some runs, with a significant influence.

Table 5.1 below gives a summary of all the long runs which were carried out. In the following, relevant results will be shown and discussed.

Run no.	undisturbed/ disturbed	λ	γ	$\tan\phi$	D_{50} variable	Wave climate corrected
101	u	1	0.65	0.6	no	no
102	u	2	0.65	0.6	no	no
103	u	0	0.65	0.6	no	no
104	u	0	0.65	0.6	no	no
105	u	2	auto	0.6	no	no
106	u	2	0.65	0.1	no	no
202	d	2	0.65	0.1	no	no
107	u	2	0.65	0.3	no	no
203	d	2	0.65	0.3	no	no
108	u	2	0.70	0.1	no	no
204	d	2	0.70	0.1	no	no
109	u	3	0.65	0.1	no	no
205	d	3	0.65	0.1	no	no
110	u	2	0.65	0.15	no	no
111	u	2	0.60	0.1	no	no
206	d	2	0.60	0.1	no	no
112	u	2	0.60	0.1	yes	no
207	d	2	0.60	0.1	yes	no
120	u	2	0.60	0.1	yes	yes
220	d	2	0.60	0.1	yes	yes

In Figure 5.3, the effect of the breaking delay parameter λ is shown for the undisturbed profile. The top graph shows the development with the original formulations; the bottom graph shows the effect of including the breaking delay, with a λ-value of 2. Clearly, the effect is positive: the unrealistic small disturbance seaward of each bar disappears. However, the seaward slope of the bars is much too steep, and the seaward bar does not damp out.

A reason for the steep slopes and the lack of damping may be in the modelling of the gravitational effect. The present formulation includes a bed slope term in the bed load transport; the main parameter determining the effect is the ratio between bed slope and the angle of repose. The latter is not well defined in an environment such as this; it's value may be an order of magnitude smaller than the stationary value of 0.6.

The effect of reducing the angle of repose to 0.3 and 0.1 respectively is shown in Figure 5.4. The results improve dramatically for the outer bar and the seaward slope of the second bar. Howevert, the height of the second bar becomes too small, and there is little movement in the deep trough between the outer and the second bar.

The breaker parameter γ determines for a given bathymetry the depth at which waves tend to break; inversely it is likely to influence the depth of bar crests for a given wave climate. In Figure 5.5 the effect of varying γ within a reasonable range of between 0.7 and 0.6 is shown. The effect on the outer bar is very limited; on the inner bar, a value of 0.6 leads to a larger amplitude, which is more in keeping with the data. Another effect is that the nearshore profile is much more stable with a γ of 0.6; this value was chosen for further computations.

In Figure 5.6, the depth-dependence of the grain diameter as shown in Figure 3.8 has been taken into account. Although the agreement for the outer bar is now somewhat less than in the previous case, the second bar is now much better represented; the seaward slope and the inner trough are now closer to the measurements.

For the time being, this model setting has been selected as the best compromise; it produces a quite acceptable representation of the actual development.

In the same Figure 5.6, the computed and measured development of the disturbed profile is shown. The model is apparently capable of predicting the erosion of the nourishment due to transport in onshore direction. The spectacular growth of the inner bar is not represented well yet: the accretion in the model takes place too far landward.

In Figure 5.7, both computations have been repeated with the corrected wave climate as discussed in Section 3.2, which includes a short but severe January storm. The results are practically the same: apparently, the longer storms both at the beginning and nd of the simulation dominate the outcome.

A point for further study is the effect of dune erosion on the profile development on this scale. There has been some dune erosion in the order of 25 m^3/m' during the January '94 storm, which is not well accounted for in the model.

6 Conclusions

These analyses show that the present version of UNIBEST-TC can be calibrated to reproduce important changes in the bathymetry, both for undisturbed and disturbed profiles, using a realistic parameter setting. The landward bar does not grow enough in the disturbed case. This aspect needs to be looked into further, as well as the overall sediment balance after the nourishment.

The dominant agents which determine the balance between onshore and offshore transport are wave asymmetry and undertow.

Major processes which influence the shape and behaviour of bars are the wave breaking process, the gravitional effect and sediment sorting.

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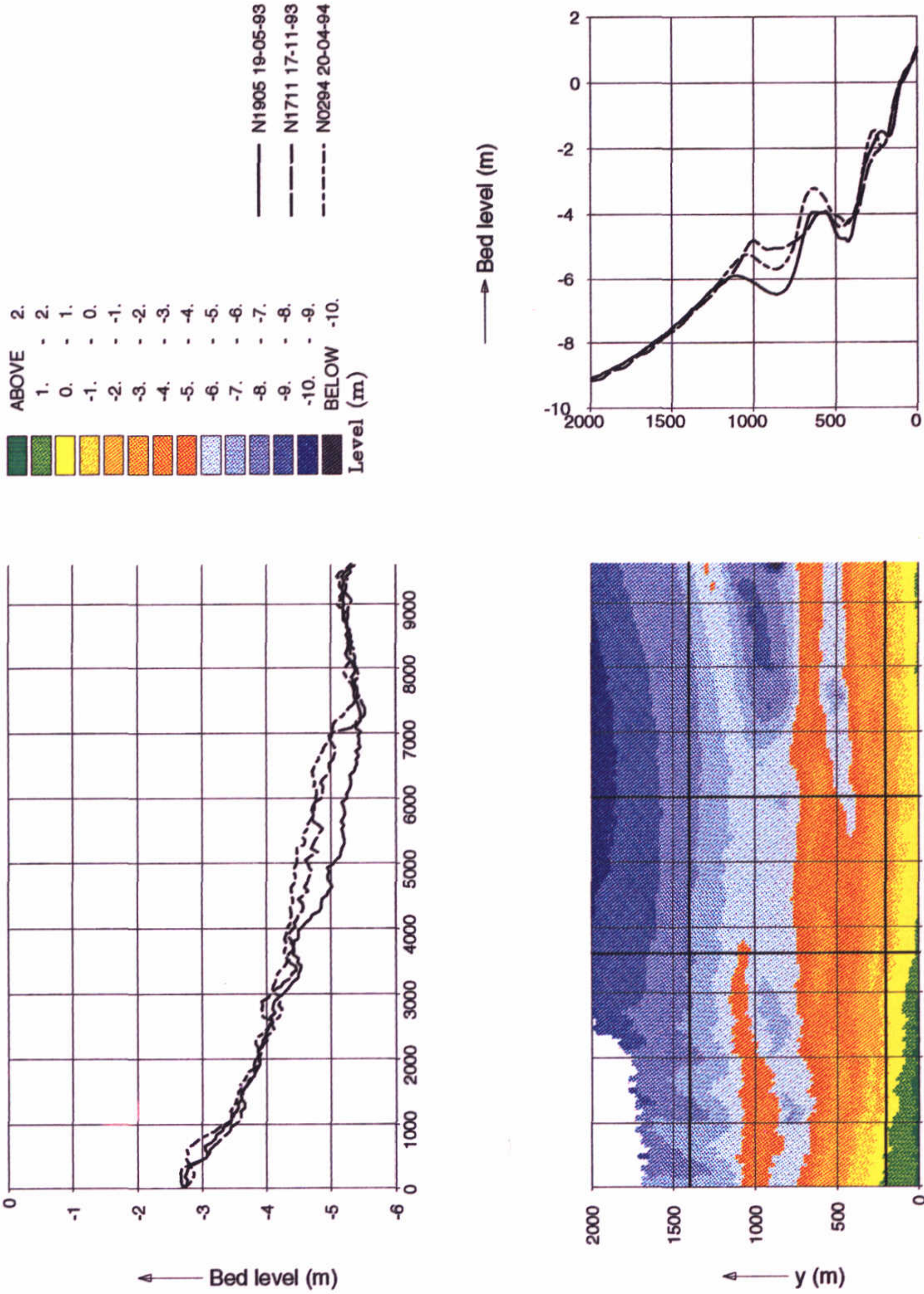
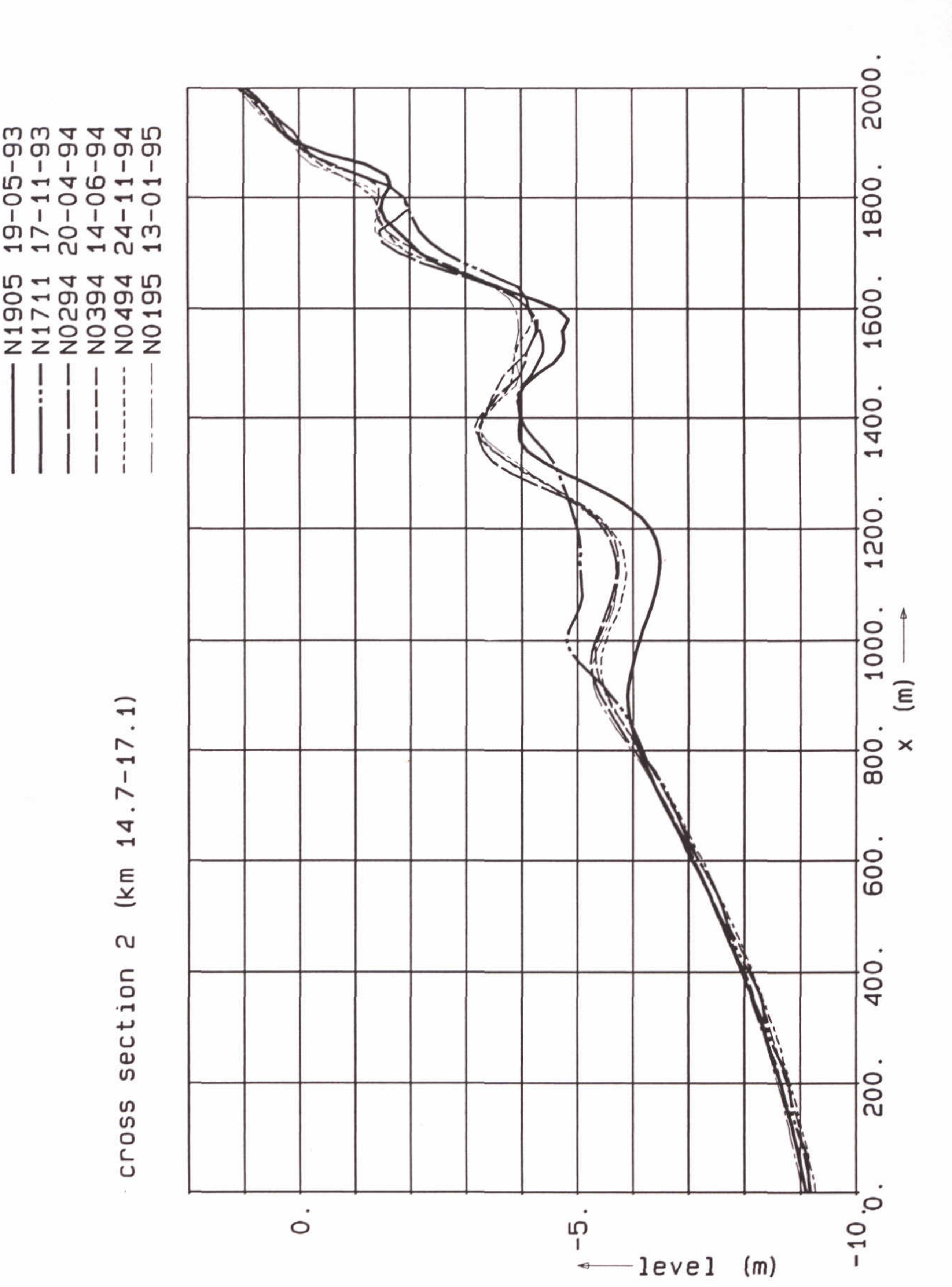
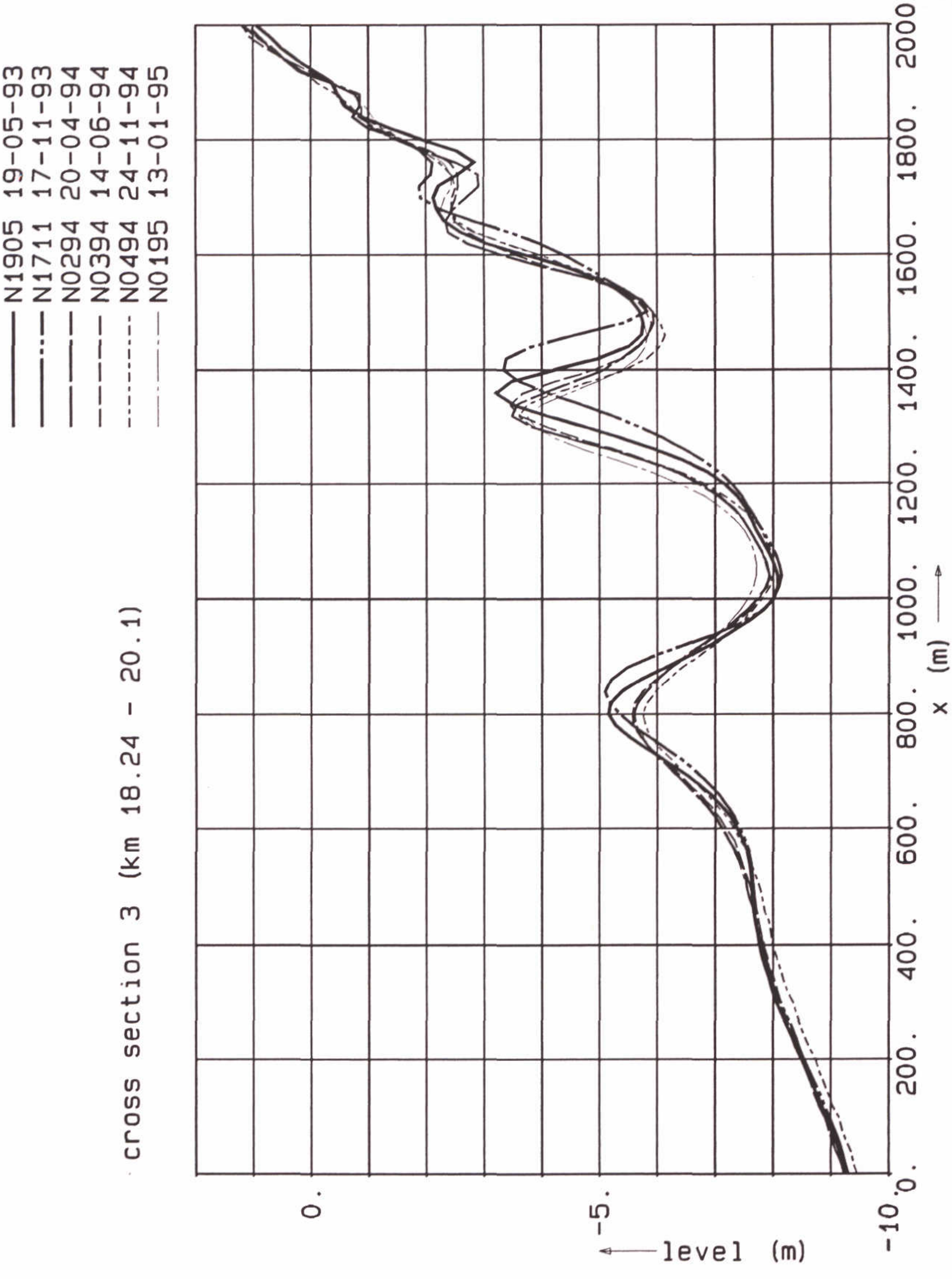


Bathymetry 150 days after nourishment and development of averaged longshore and cross-shore profiles	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.1



Development in time of averaged profile km. 14.7 - 17.1 nourishment area	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.2



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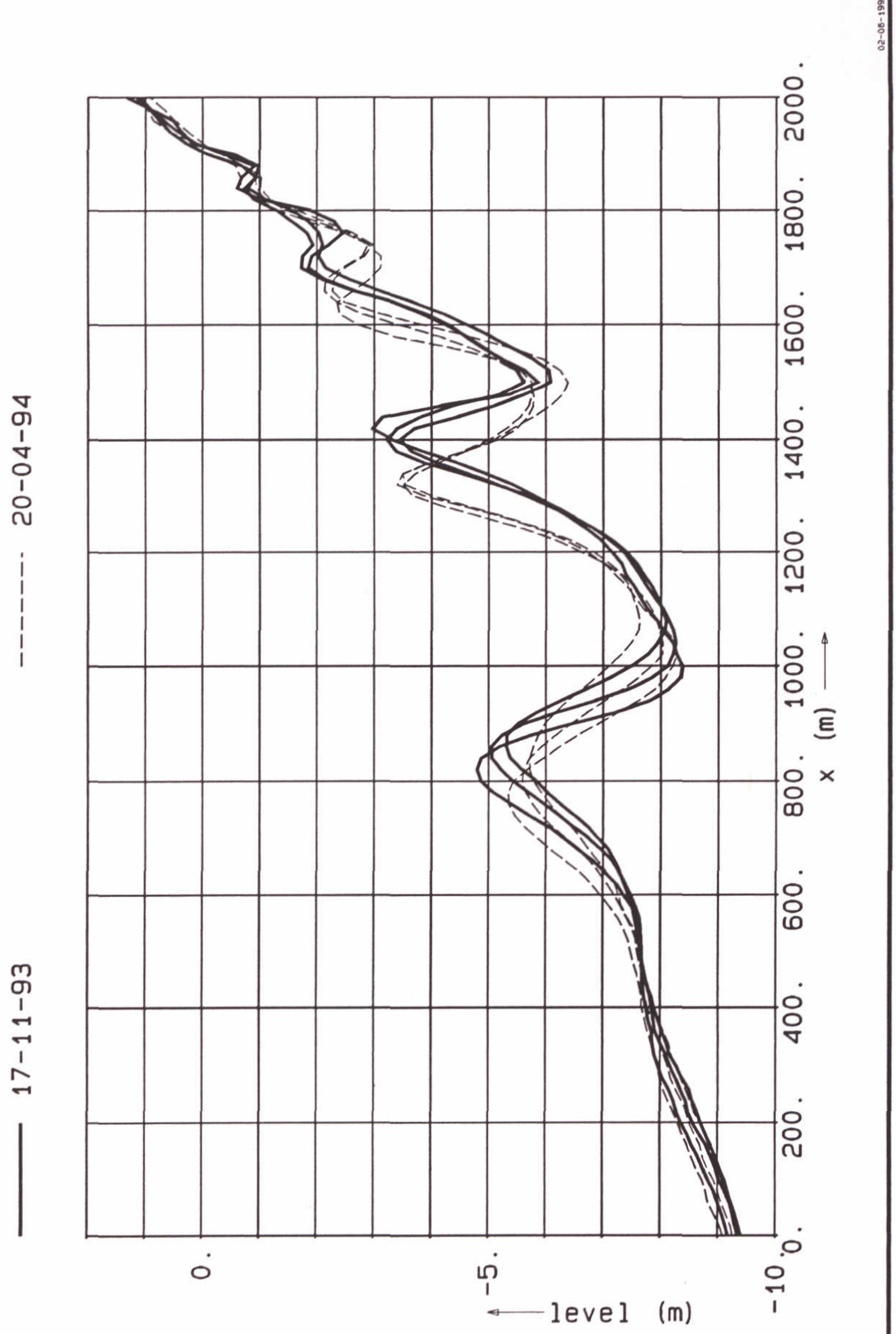
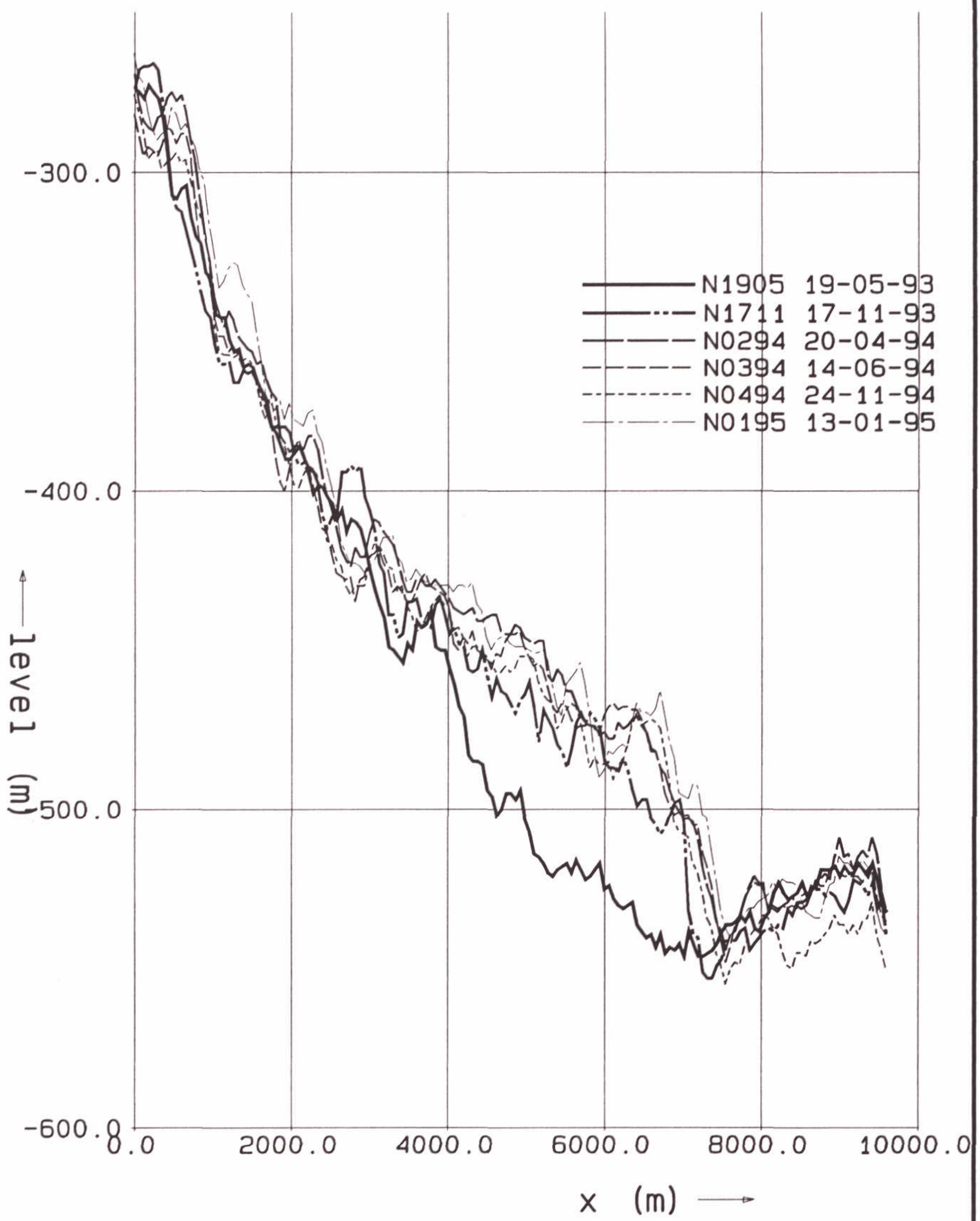
Development in time of averaged profile km. 18.24 - 20.1 undisturbed area	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.3



Development after nourishment
three separate sections
undisturbed area

DELFT HYDRAULICS	NOURTEC	
	H 1698	Fig. 3.4



Development in time of averaged longshore profile 200 - 1400 m from reference line	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.5

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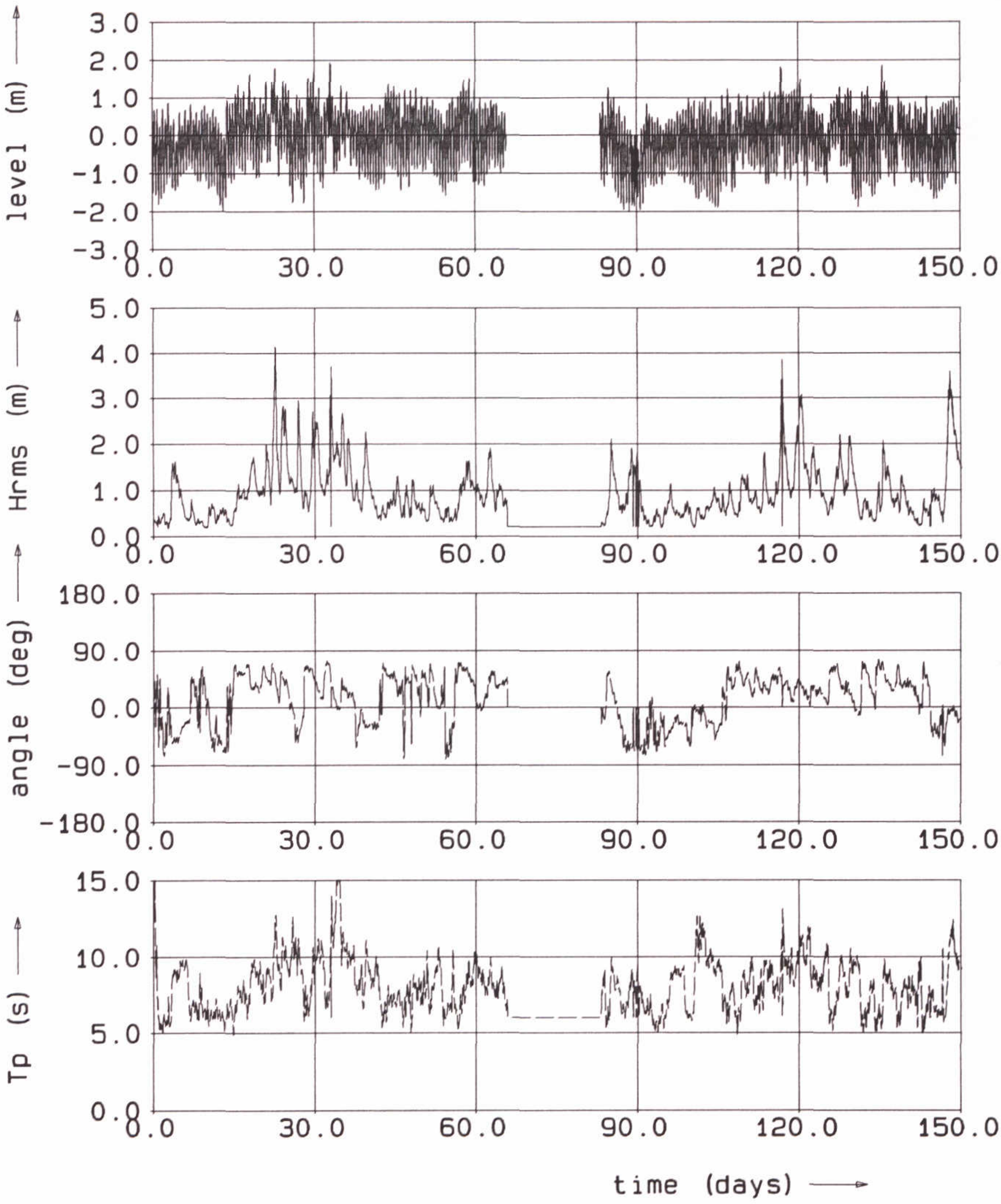
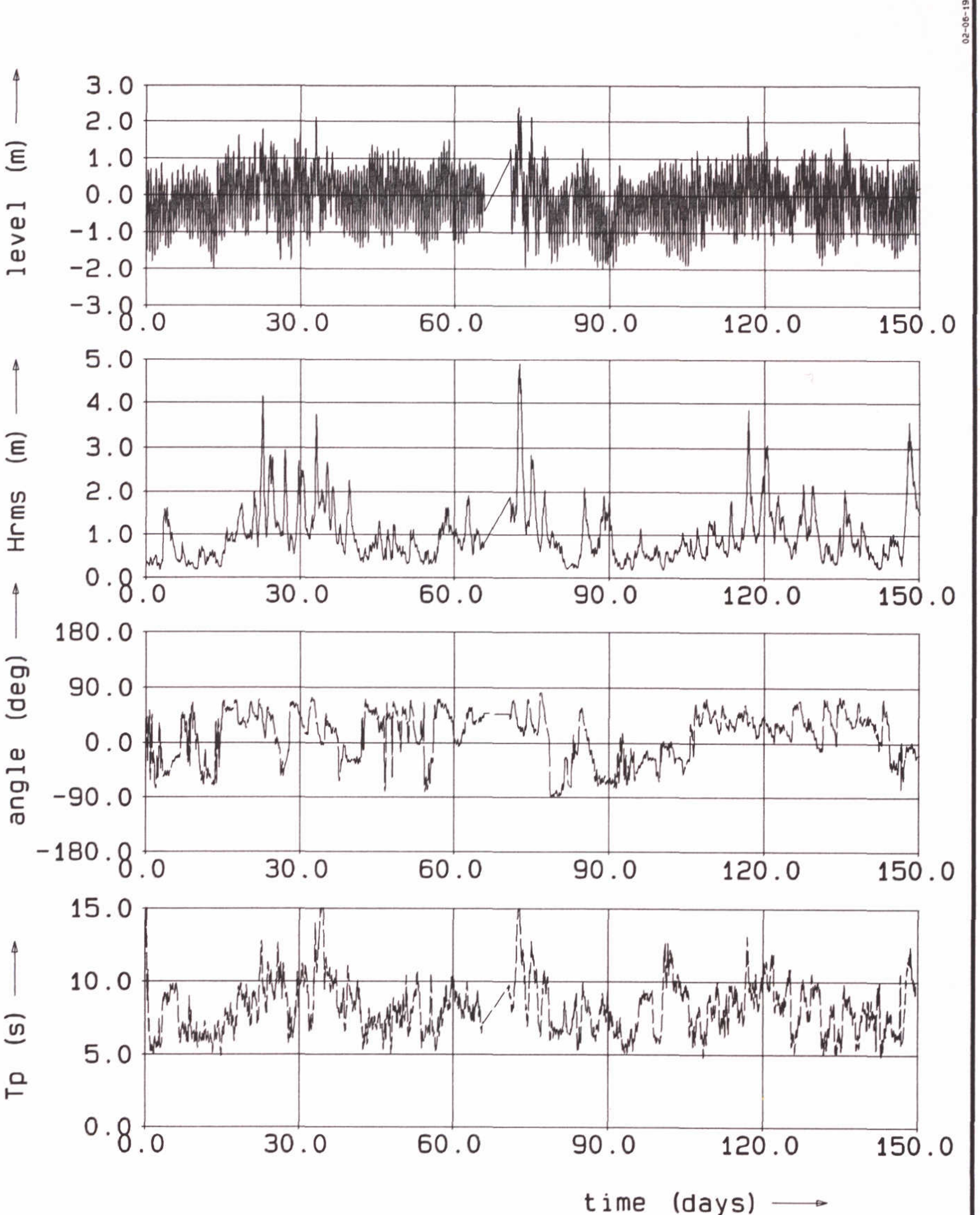
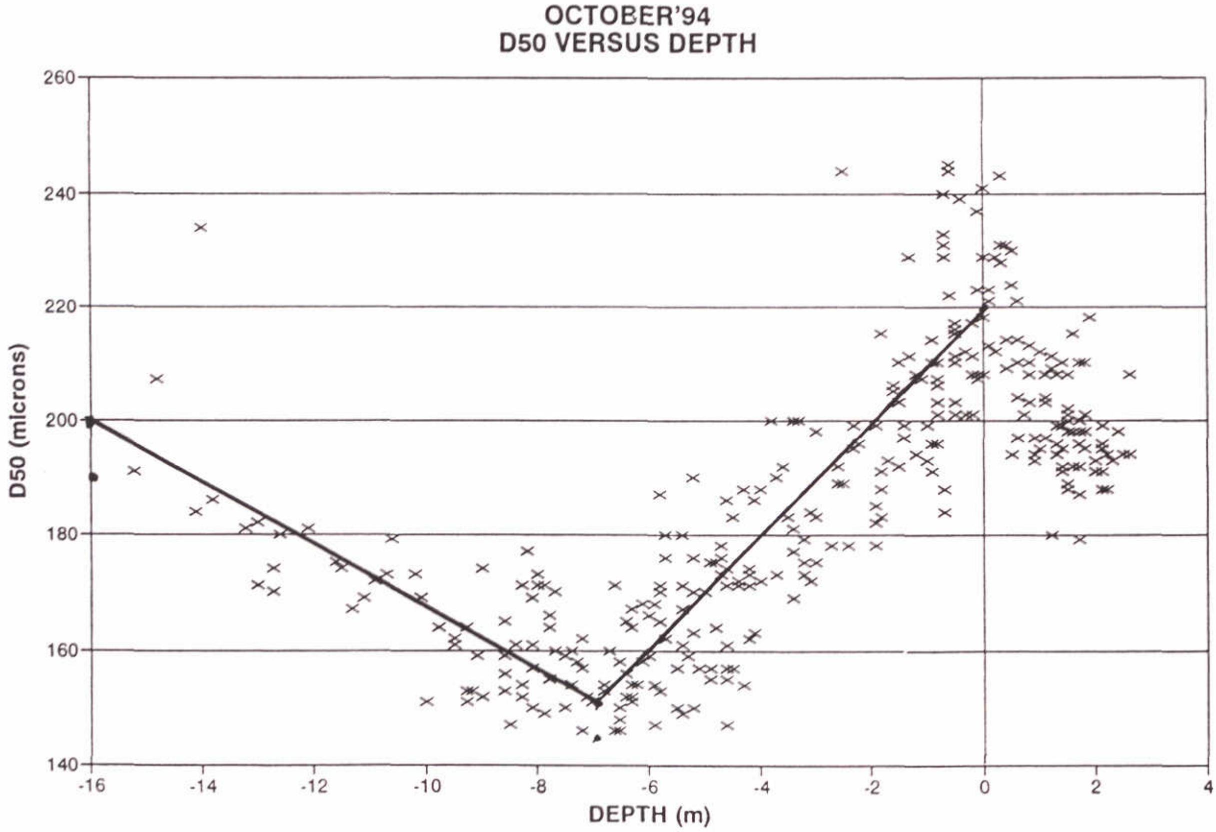


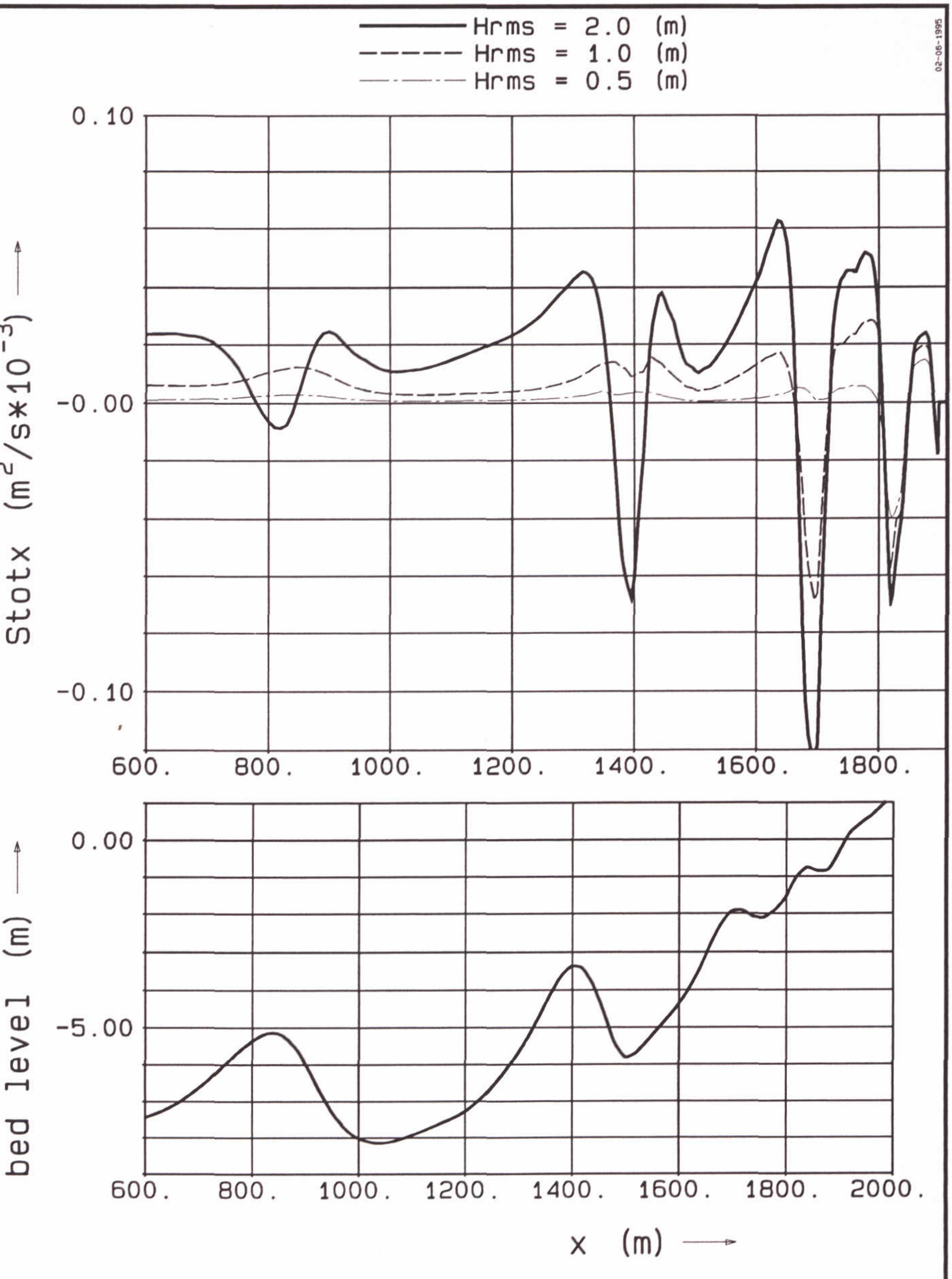
Variation in time of water level, wave height, wave angle and wave period Wavec and tide gauge, after nourishment	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.6



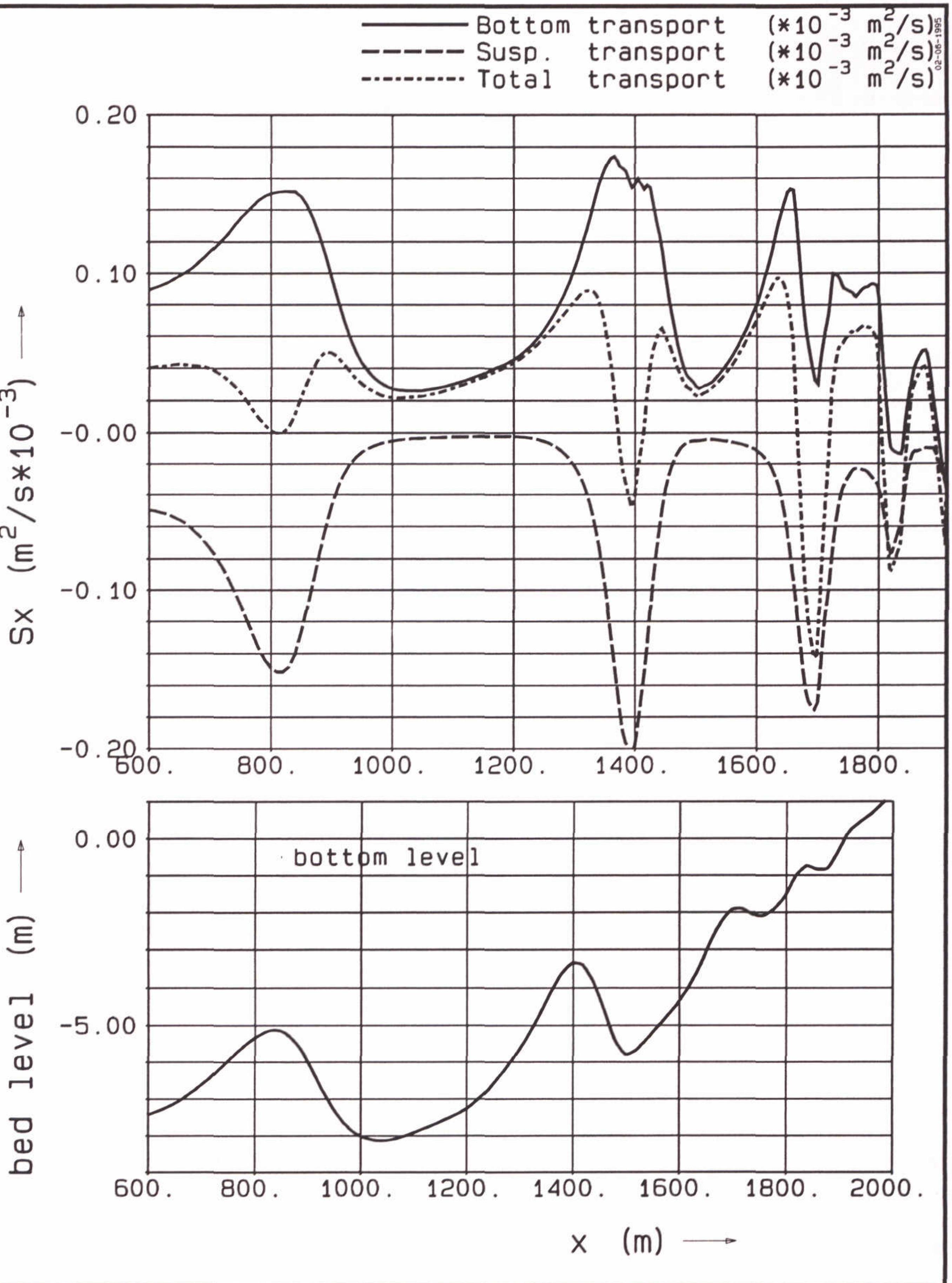
Variation in time of water level, wave height, wave angle and wave period Wavec and tide gauge, SON data included	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.7



Grain size dependence on water depth measured and schematised	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 3.8

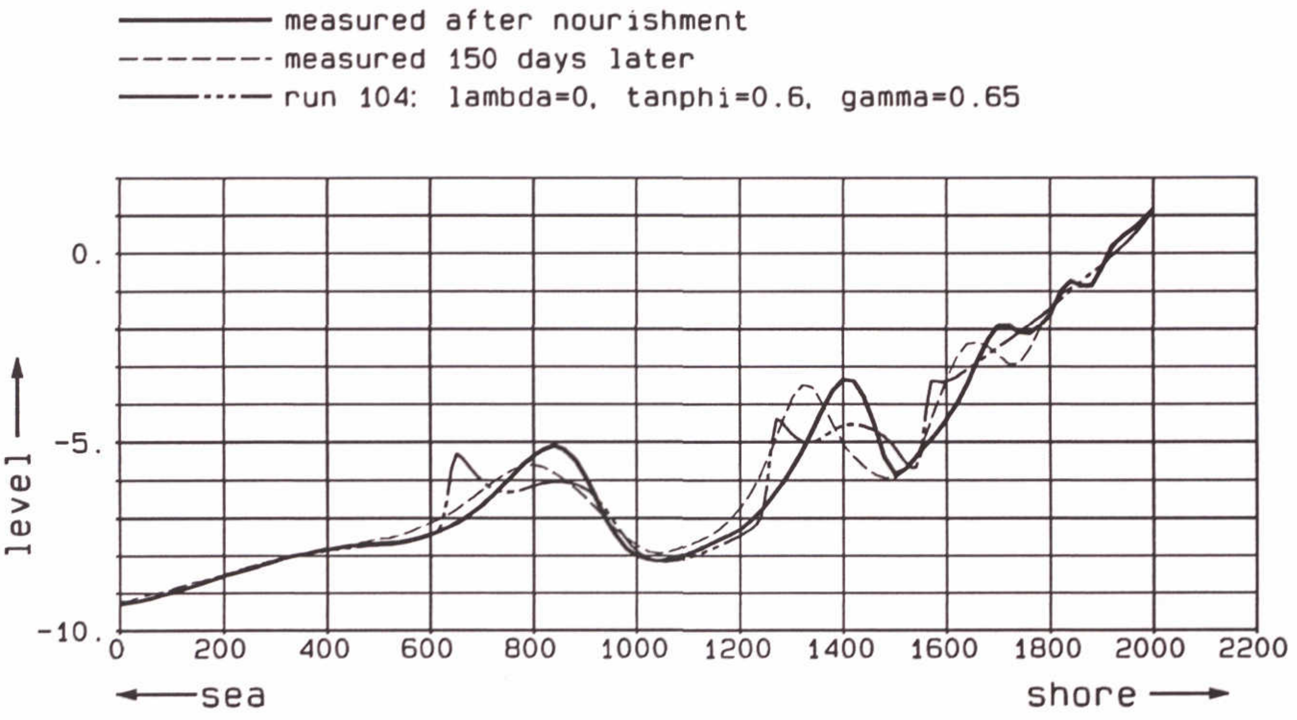


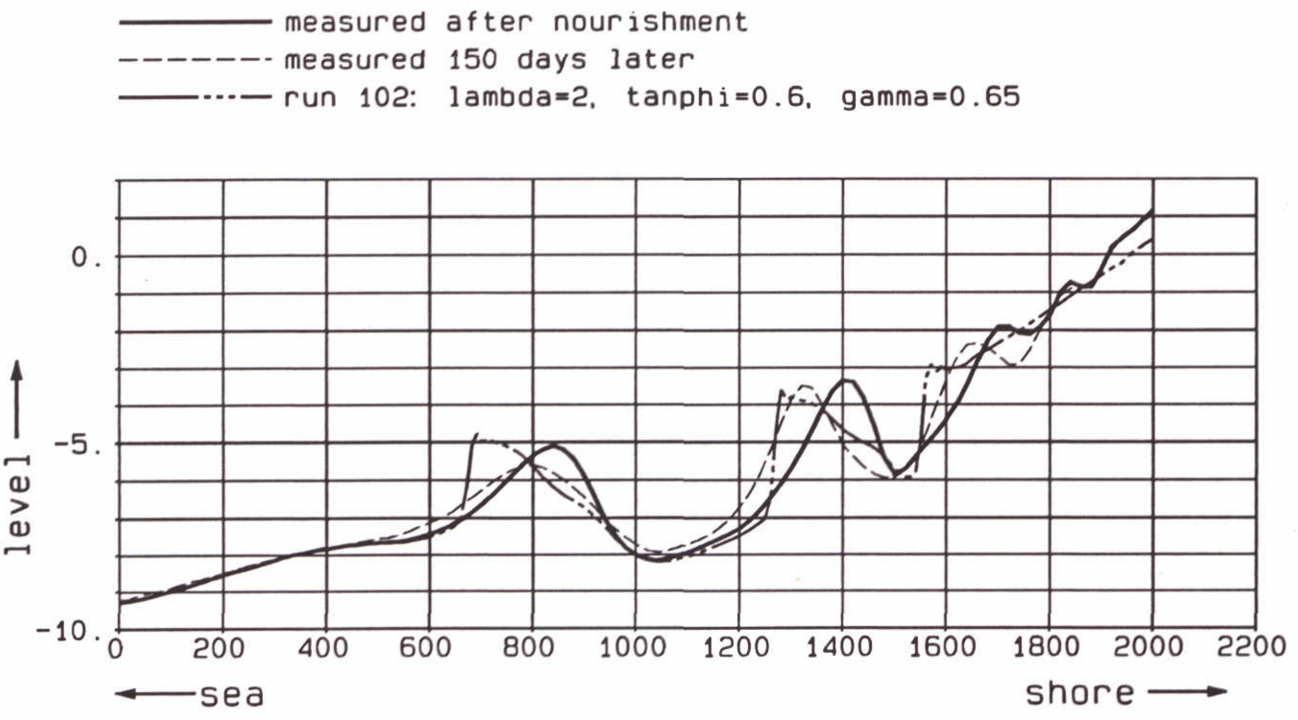
Influence of wave height on total transport	NOURTEC
DELFT HYDRAULICS	H 1698 — Fig. 5.1



Suspended transport + bottom transport = total transport	NOURTEC	
DELFT HYDRAULICS	H 1698	Fig. 5.2

09-06-1995





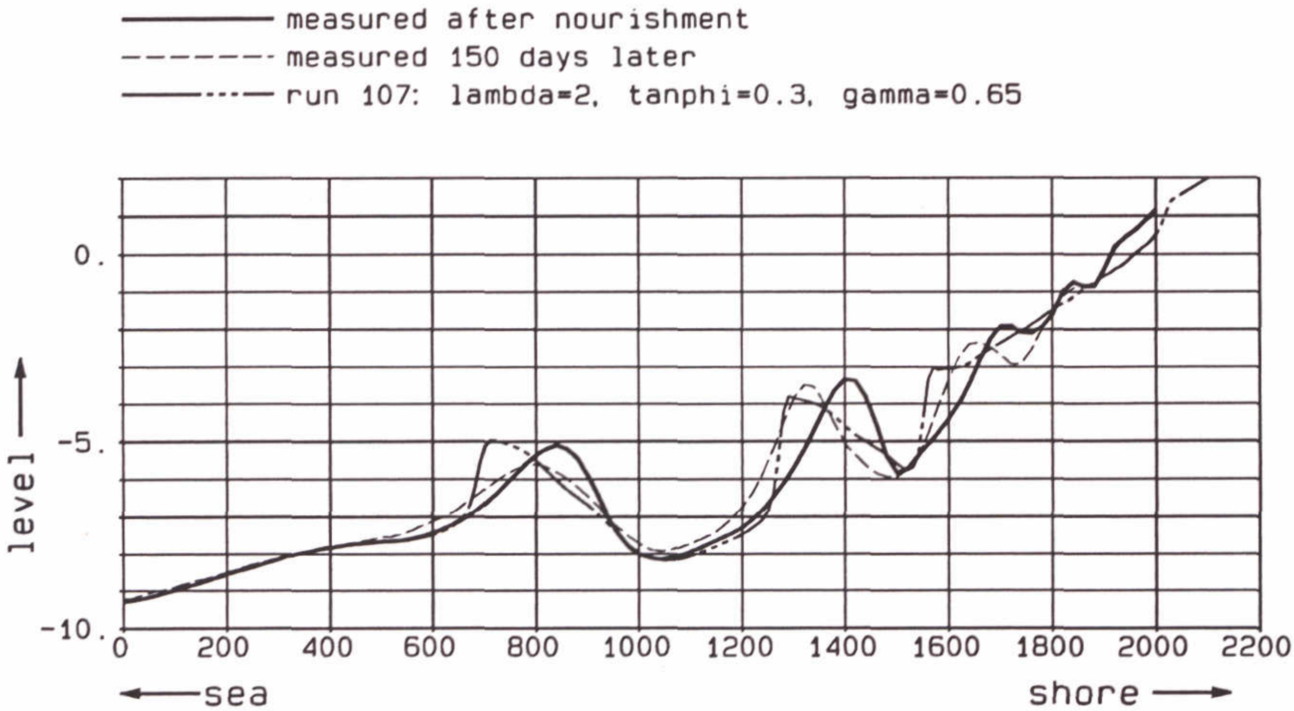
Measured and computed development
Effect of breaking delay lambda
undisturbed profile

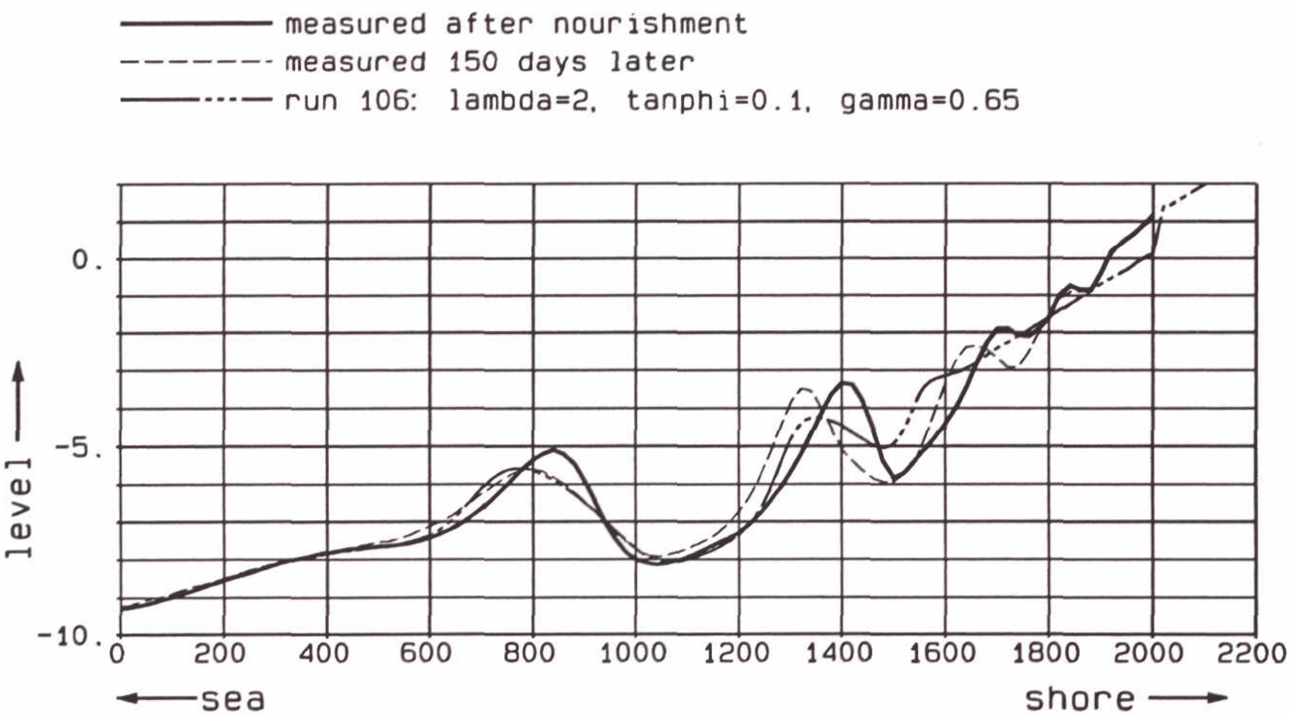
NOURTEC

DELFT HYDRAULICS

H 1698

Fig.5.3

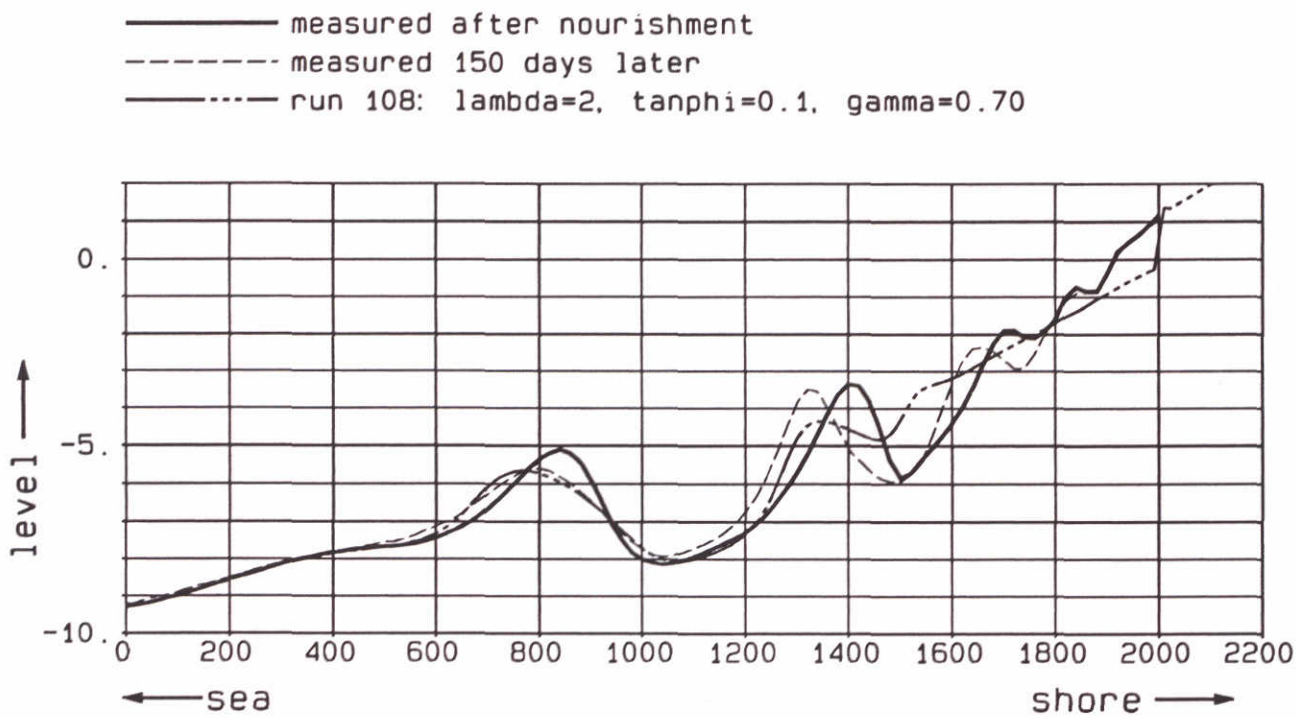


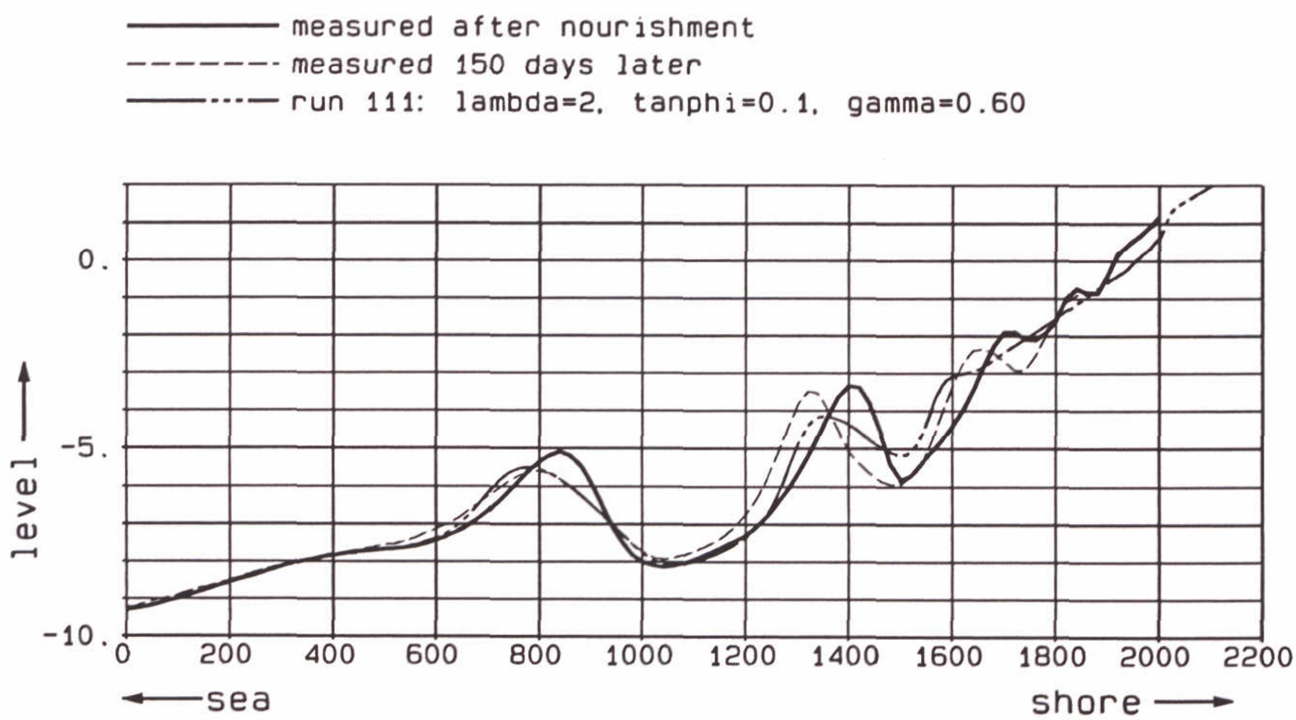


Measured and computed development
Effect of bed slope term
undisturbed profile

DELFT HYDRAULICS	NOURTEC	
	H 1698	Fig.5.4

09-06-1995





Measured and computed development
Effect of breaker parameter gamma
undisturbed profile

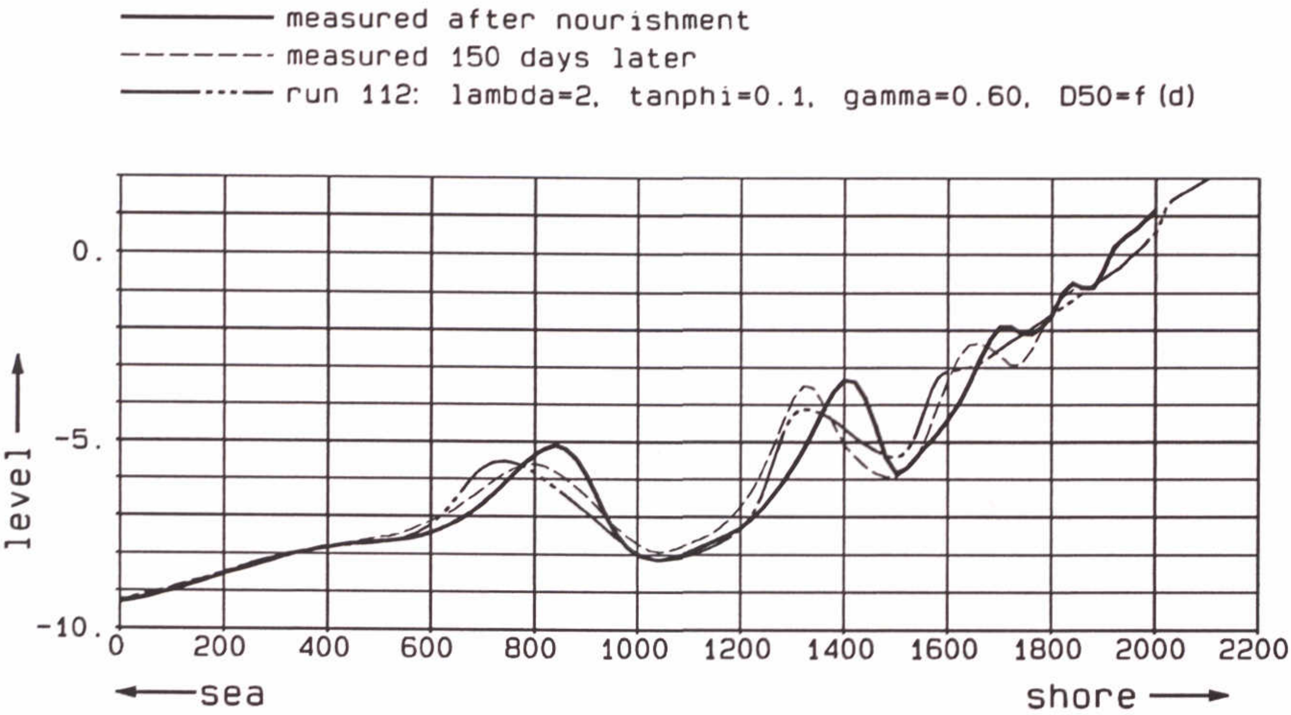
NOURTEC

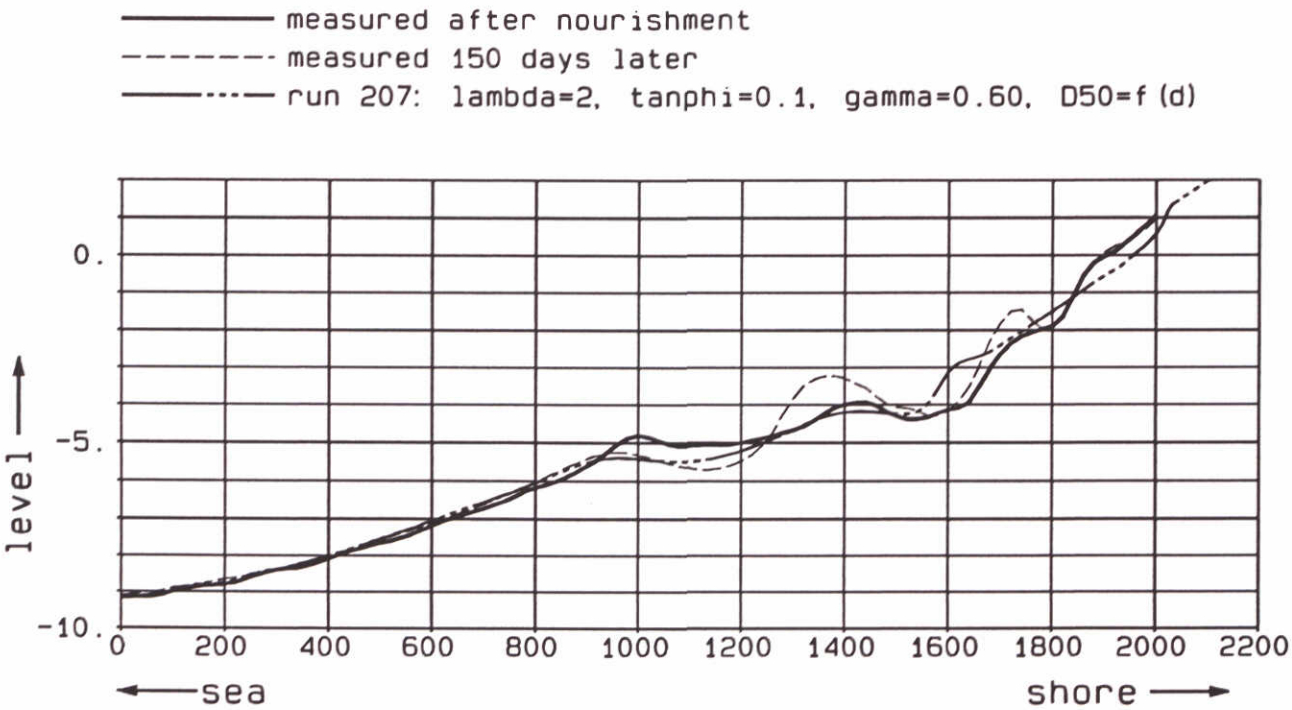
DELFT HYDRAULICS

H 1698

Fig.5.5

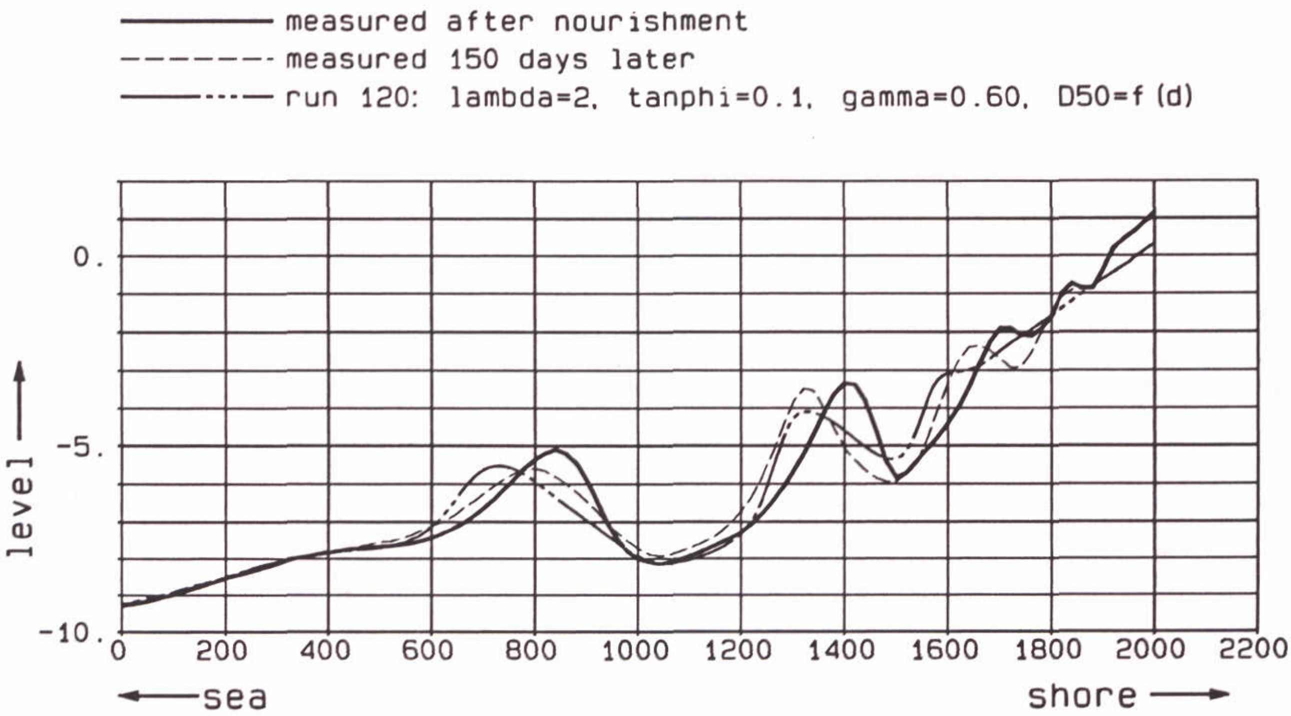
09-08-1995

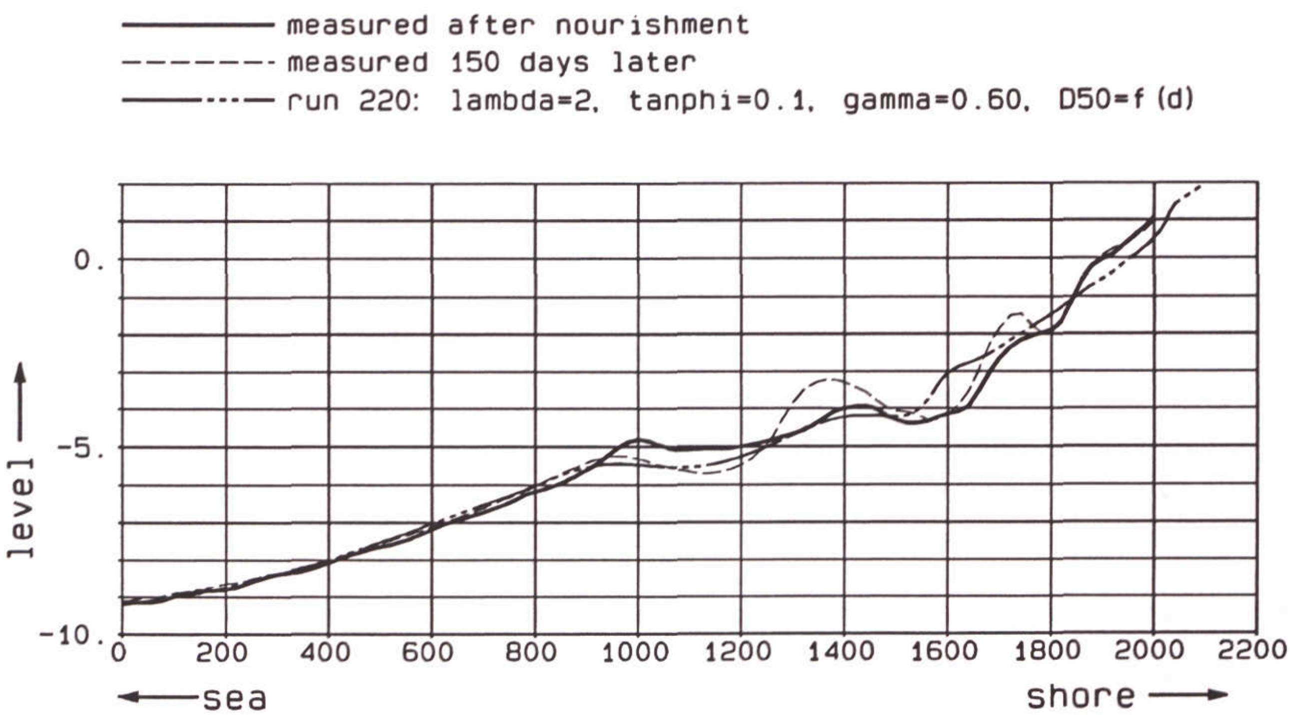




Measured and computed development D50-variation included undisturbed and disturbed profile	NOURTEC
DELFT HYDRAULICS	H 1698 · Fig.5.6

09-06-1995





Measured and computed development
Corrected wave climate
undisturbed and disturbed profile

NOURTEC

DELFT HYDRAULICS

H 1698

Fig.5.7

main office
Rotterdamseweg 185
p.o. box 177
2600 MH Delft
The Netherlands
telephone (31) 15 - 56 93 53
telefax (31) 15 - 61 96 74
telex 38176 hydel-nl

location 'De Voorst'
Voorsterweg 28, Marknesse
p.o. box 152
8300 AD Emmeloord
The Netherlands
telephone (31) 5274 - 29 22
telefax (31) 5274 - 35 73
telex 42290 hylvo-nl