MODELLING OF SEDIMENTATION OF DREDGED TRENCHES AND CHANNELS UNDER THE COMBINED ACTION OF TIDAL CURRENTS AND WAVES

D.J.R. Walstra[1], L.C. Van Rijn[1], S.E. Hoogewoning[2], S.G.J. Aarninkhof[1]

Abstract: The central theme in the study was the knowledge and modelling of sand transport processes on the lower shoreface (seaward of -20 m depth contour) of the Dutch coast with the aim of predicting the morphological behaviour of large-scale sand mining pits using the SUTRENCH-model. The performance of the upgraded SUTRENCH-model was first evaluated against laboratory data. It was found that the model showed good agreement with measurements. Next, a model was set up of the Euro-Maas channel (the approach channel to Rotterdam Harbour) to study the effects of various large-scale sand mining pits. With this calibrated model the morphological development of various trench geometries was investigated over a period of 50 years. It was found that, if the stability (minimum migration rate) is considered as the main criterion, narrow relatively deep pits are preferable over wide relatively shallow pits. Furthermore it was shown that the water depth at which a pit is located can have a dramatic impact on the stability of a trench.

INTRODUCTION

Within the framework of the Dutch Rijkswaterstaat research-programme COAST*2000, which runs between 1995 and 2000, morphologic knowledge of the Dutch Coast is used to generate advises to the several Directorates of Rijkswaterstaat. Central question to be answered is:

What will be the morphologic effects (on the long term) of large scale sand mining on the lower shoreface of the Dutch Coast?

1. WL | Delft Hydraulics, PO Box 177, 2600 MH Delft, The Netherlands. Fax +31 15 2858710. Email: DirkJan.Walstra@WLDelft.nl, Leo.VanRijn@WLDelft.nl and Stefan.Aarninkhof@WLDelft.nl
2. National Institute for Coastal Zone Management (RIKZ), PO Box 20907, 2500 EX The Hague, The Netherlands. Fax +31 70 3114321. Email: S.E.Hoogewoning@rikz.rws.minvenw.nl

For both the “natural” morphologic development of the lower shoreface and large scale extraction sand mining areas, information about the (yearly averaged) sediment transports at the lower shoreface in front of the Dutch coast (around 20 m below Dutch Ordnance Level = NAP) is necessary. Therefore, research on sediment transports at the lower shoreface takes a central place within the research programme COAST*2000.

To address short term environmental and policy issues it is thought that primarily process based models will have to be applied. However, deployment of process based models is hampered by the fact that, especially in deeper water, present knowledge of bedload transport and suspended sediment transport is still very limited. This is illustrated by the fact that the direction and magnitude of the (residual) sediment transports at deep water in front of the Dutch coast are not well known (Van Rijn, 1997). Also to address long term environmental and policy issues, knowledge of the (residual) transports and the associated morphological behaviour of large-scale sand mining pits at deeper water are necessary. It is clear that expansion of the knowledge of the occurring transport processes in deeper water are imperative to the improvement of existing theories.

The central theme in the study was the knowledge and modelling of sand transport processes on the lower shoreface (seaward of -20 m depth contour) of the Dutch coast with the aim of predicting the morphological behaviour of large-scale sand mining pits using the SUTRENCH-model. The work presented in this paper is described in more detail in Walstra et al. (1998).

DESCRIPTION OF SUTRENCH

The SUTRENCH-model (Van Rijn, 1986a, 1986b and Van Rossum et al., 1990) is a two-dimensional vertical (2DV) mathematical model for the simulation of bed-load and suspended load transport under conditions of combined quasi-steady currents and wind-induced waves over a sediment bed. All processes (parameters) in the direction normal to the computation direction are assumed to be constant. This can impose limitations to the applicability of SUTRENCH if 2DH or 3D effects play a dominant role. SUTRENCH should be applied at a space-scale of 1 to 10 km and at a time scale of 1 to 100 years (imposed by computation time and available computer memory). Practical application requires detailed knowledge of the sediment composition along the bed and the incoming sediment transport (at inlet boundary x=0). It is applicable in regions outside the surfzone where wave breaking is limited.

Basic processes taken into account:

Hydrodynamic

- modification of velocity profile and associated bed-shear stress due to presence of waves,
- modification of velocity and associated bed-shear stress due to the presence of non-uniform sloping bottom (only for case without waves),

Sediment transport

- advection by horizontal and vertical mean current,
- vertical mixing (diffusion) by current and waves,
- settling by gravity,

- entrainment of sediment from bed due to wave- and current-induced stirring,
- bed-load transport due to combined current and wave velocities (instantaneous intra-wave approach),
- slope-related transport components (bed load),
- effect of mud on initiation of motion of sand,
- non-erosive bottom layers.

Basic simplifications are:
Hydrodynamic
- logarithmic velocity profiles and associated bed-shear stress in conditions with waves (steep-sided trenches and channels can not be modelled),
- shoaling and refraction of wind waves is not implicitly modelled,
- current refraction (veering) is not implicitly modelled,

Sediment transport
- steady state sediment mass conservation integrated over the width of the flow (stream tube approach),
- no longitudinal mixing (diffusion),
- no wave-related suspended sediment transport (no oscillatory transport components),
- uniform grain size (no mixtures),

Numerical
- forward-marching numerical scheme (transport due to near-bed return currents can not be modelled),
- explicit Lax-Wendorf numerical scheme for bed level changes (smoothing effects may occur).

Boundary conditions to be specified, are:
- water depth, flow width (stream tube width, discharge is constant) and bed level along computation domain,
- wave heights along computation domain,
- equilibrium or non-equilibrium sediment concentrations at inlet (x= 0); model has option to generate equilibrium concentrations,
- bed concentration or bed concentration gradient is prescribed as function of bed-shear stress and sediment parameters,
- sediment, settling velocity, and bed roughness.

VALIDATION OF SUTRENCH

SUTRENCH was validated against a laboratory experiment carried out in wave-current basin (Havinga, 1992). A channel with a sediment bed consisting of fine sand (d_{50} = 100 µm, d_{90} = 130 µm) was present at the end of the basin. The movable bed surface was at the same level as the cement floor of the surrounding basin. Irregular waves were generated by a directional wave generator. The wave spectrum (JONSWAP form) was single-topped with a peak frequency of 0.4 Hz. The water depth was about 0.4 m in all tests. Three different wave conditions were used with significant wave heights of 0.07, 0.1 and 0.14 m for each wave direction. In all, three wave directions were considered 60°, 90° and 120° (angle between wave orthogonal and current direction). A pump system was used to generate a current in the channel. Guiding boards were used to confine the current in the movable-bed channel (width = 4 m) . The guiding boards were placed normal to the wave crests in all experiments to allow free passage of the waves. Three different current velocities (0.1, 0.2 and 0.3 m/s) were generated by varying the pump discharge. The velocity distribution across the channel was found to be almost uniform (current alone). The vertical distribution of the velocity in the middle of the channel was perfectly logarithmic in all tests (current alone).

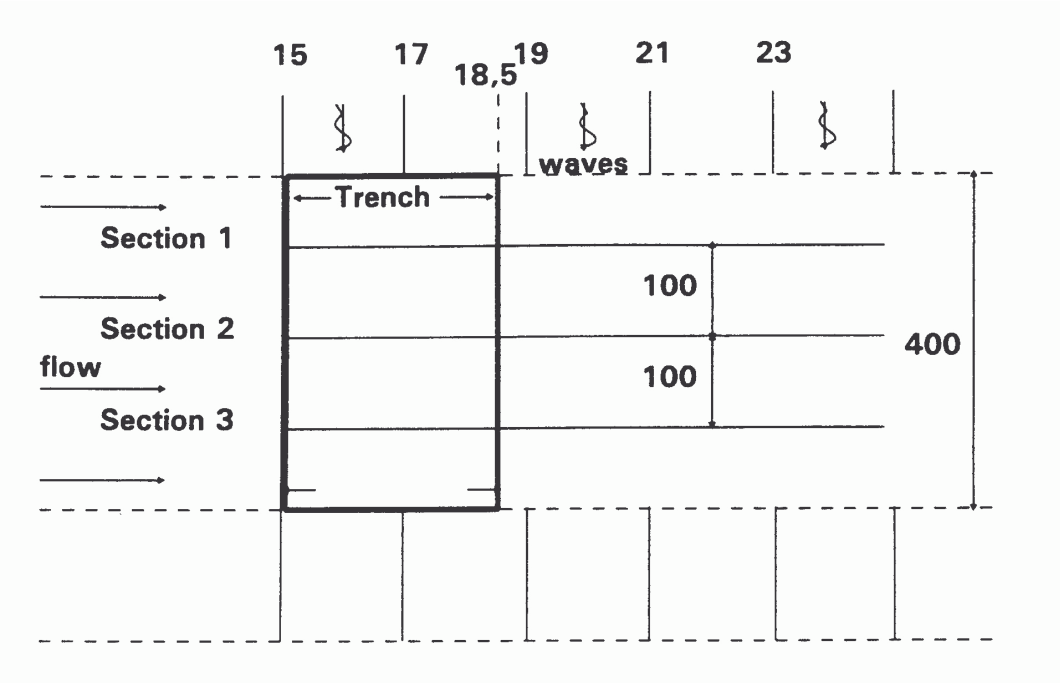

Figure 1 *Experimental set up of test T10.20.90*

SUTRENCH was compared with the test during which the wave approach angle was normal to the current direction. In the concerned test (T10.20.90; wave height of about 0.1 m, current velocity of about 0.2 m/s and wave approach angle of 90°, normal to channel) a trench was present in the movable-bed channel. The trench (longest axis) was situated normal to the current and parallel to the wave propagation direction (see Figure 1). The sedimentation in the trench was recorded by performing regular soundings (over about 25 hours) in three sections. The results of Section 2 are shown in Figure 2. The dimensions of the initial trench profile are: depth of about 0.2 m, bottom width of about 0.5 m, side slopes of about 1 to 8.

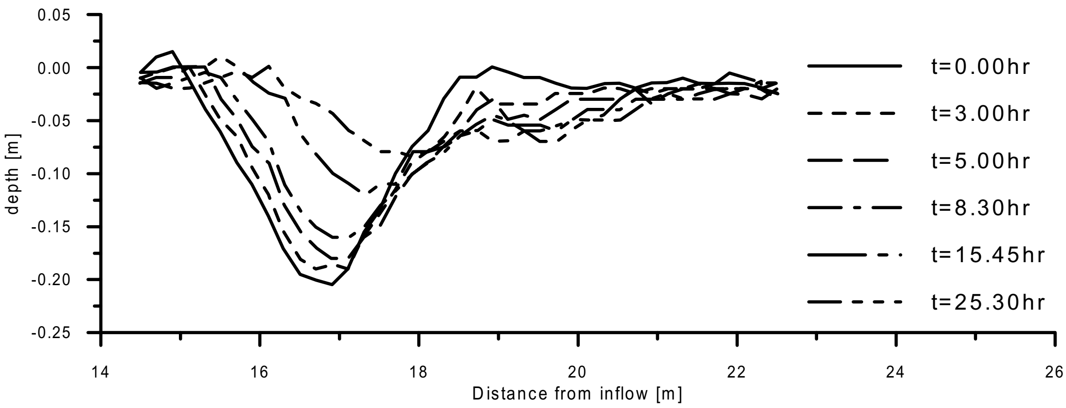

Figure 2 *Morphological development of trench (Section 2)*

The basic data upstream of the trench are listed in Table 1 below:

Table 1 *Measured data upstream of the trench*

Parameter	Value
water depth	0.42 m
significant wave height	0.105 m
peak wave period	2.2 s
depth-mean velocity	0.245 m/s
angle between current and waves	90^{o}
median particle size of bed	0.0001 m
fall velocity of suspended sediment	0.006 m/s
suspended sand transport	0.018 to 0.024 kg/s/m
ripple height	0.007 m
ripple length	0.084 m

Model Settings

The computational domain of the SUTRENCH simulations starts at x=13.0 m and ends at x=26.0 m (see also Figure 3). The computational resolution (*dx*) was set to 0.1 m. This leads to 131 grid points in the computational domain. In the vertical 20 layers were defined. The model width was taken as 1 m. A timestep of 15 min was applied. To prevent numerical instabilities at the upstream boundary (x=13.0 m), the first two computational points were defined as a non-erodable layer. This is done because SUTRENCH may develop an erosive area just inside the computational domain, if there are strong gradients in the suspended sediment close to the inlet. The hydrodynamic boundary conditions and the sediment characteristics were obtained from the measurements.

In some preliminary runs the model was calibrated by adjusting the bed concentration to give the measured suspended transport rate at the inlet (x=0). The correction factor for the bed concentration (c_a) was set to 2.2. The main input parameters are listed in Table 2. The reference level of the bed concentration was set at the level of the ripple crest. The effective bed roughness values were estimated to be equal to 2 times the observed ripple height.

Table 2 *Summary model settings for laboratory experiment of Havinga (1992)*

Model dimensions	
Length	13.0 to 26.0 [m]
Grid resolution (horizontal)	0.1 [m]
Number of layers (vertical)	20 [-]
Hydrodynamic boundary conditions	
Discharge, Q	0.1082 [m^3/s]
Wave height, H_s	0.105 [m]
Wave period, T_z	2.16 [s]
Wave direction, *Dir*	90° (normal to current direction)
Sediment characteristics	
Median grain size, d_{50}	0.000100 [m]
90% grain size, d_{90}	0.000130 [m]
Sediment fall velocity, w_s	0.006 [m/s]
Reference level, z_a	0.004 [m]
Wave related roughness height, r_w	0.01 [m]
Current related roughness height, r_c	0.01 [m]

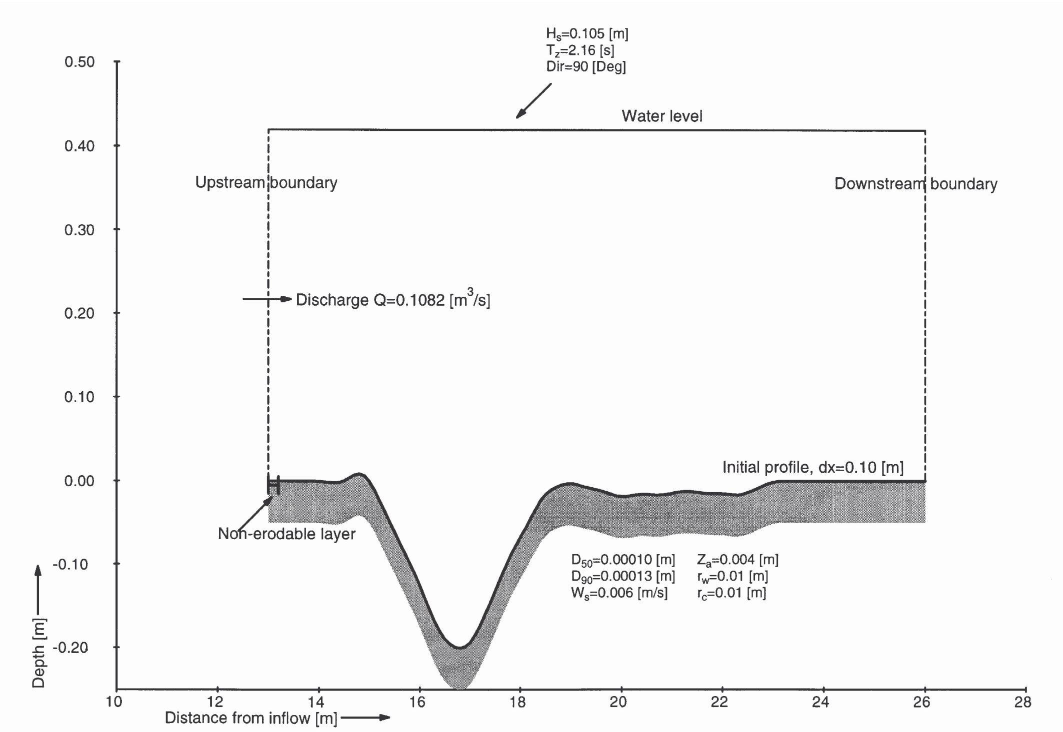

Figure 3 *Model set up of SUTRENCH for laboratory experiment of Havinga (1992)*

In Figure 4 the velocity and concentration verticals are compared to the measurements. The velocities in the upper half of the water column are slightly over-estimated. The concentrations are well predicted in the upper half of the water column, near the bed however an under-estimation can be observed. In general it can be concluded that there is good agreement with the measurements.

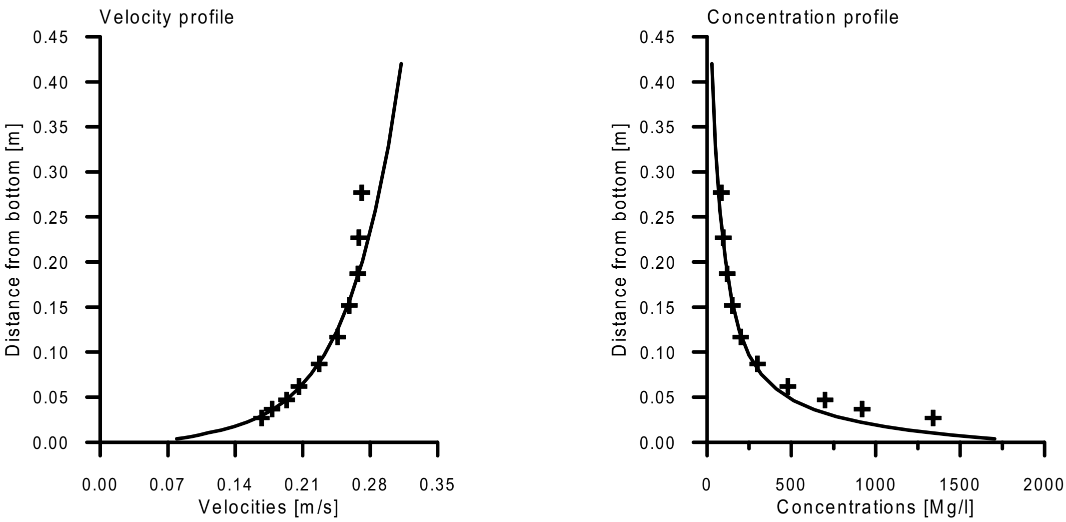

Figure 4 *Comparison of velocity and concentration profiles upstream of trench*

In Figure 5 the resulting trench after 25hr30min is compared. The erosion of the downstream slope and the adjacent section is underestimated. The upstream slope of the trench is calculated somewhat too steep. The downstream erosion is however underestimated whereas the upstream slope of the trench is too steep. This is caused by the fact that the influence of the acceleration of the water at the downstream trench slope on the vertical velocity distribution is not taken into account in SUTRENCH. This results in an underestimation of the near bed velocities and as a consequence also of the picking up of sediment, resulting in an underestimation of the erosion on the downstream slope. The overall migration and sedimentation of the trench is simulated accurately by the model. In general it can be concluded that SUTRENCH is able to give a good representation of the morphological development of the trench.

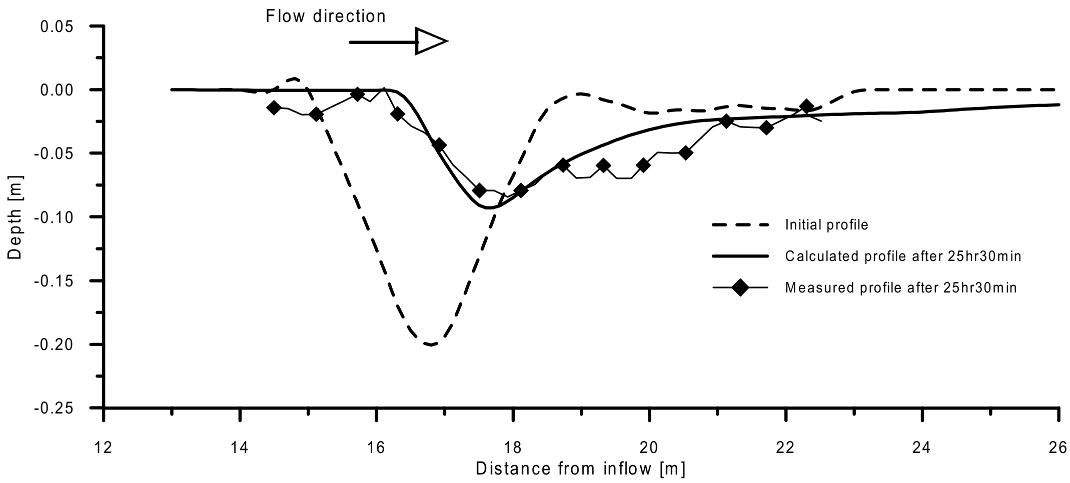

Figure 5 *Comparison of measured and calculated trench after 25hr30min*

MODELLING OF EURO-MAAS CHANNEL; REFERENCE CASE

In Walstra et al. (1997) a SUTRENCH model was set up to investigate the sedimentation and migration (in longshore direction; parallel to coastline) of the Euro-Maas channel (the approach channel to Rotterdam Harbour). A representative tidal schematisation was derived from a tidal area model. Furthermore the wave climate was reduced to one representative wave condition. The model was calibrated to give a northward residual transport of 50 m^3/m/year in line with measured and computed values (Van Rijn, 1997 and Walstra et al., 1997). In the present study this case was used as a reference to investigate the morphological development of various trench geometries for constant input conditions. To that end a schematised bottom profile was used which has the approximate same dimensions as the trench of the Euro-Maas channel. To enable objective comparison between the investigated geometries it was decided to construct a symmetrical trench. The measured upstream slope was used in the schematised trench (see Figure 6). The tidal forcing, wave conditions and model settings were constant in all computations. In the present study morphodynamic simulations over a period of 50 years were made.

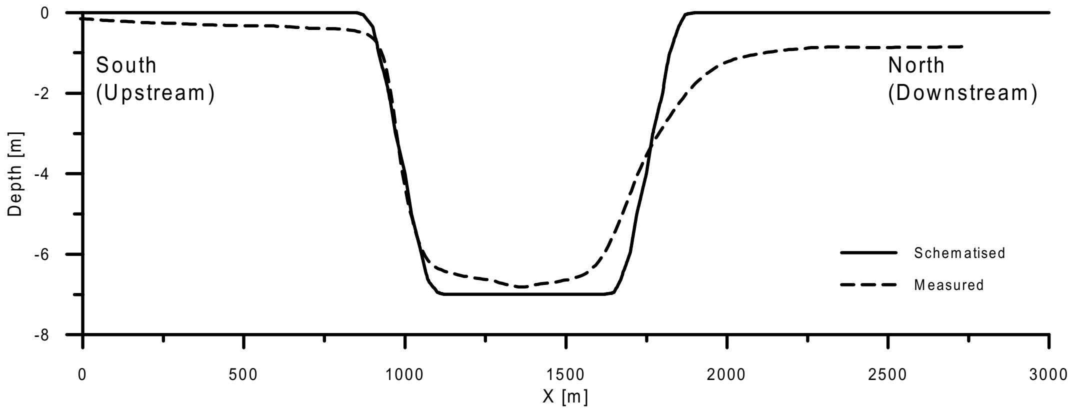

Figure 6 *Schematised and measured trench of Euro-Maas Channel*

In Table 4 below a summary is given of the model settings as used in Walstra et al. (1997):

Table 4 *Model settings of reference run*

Model parameter / Boundary Condition	*Value*
Water Depth [m]	20.0
Representative wave height, H_{sig} (m)	2.25
Wave period, T_{sig} (s)	6.6
Wave direction (degrees, relative to north)	315
Wave related roughness, R_w (m)	0.01
Current related roughness, R_c (m)	0.05
Reference level, Z_a (m)	0.05
Median grain size, d_{50} (μm)	210
90 % Grain size, d_{90} (μm)	310
Sediment fall velocity, w_s (m/s)	0.0275
Computational step size, dx (m)	10
Number of computational points in vertical	15
Number of time steps per tide	19
Coefficient pseudo viscosity, α_{max}	0.0005
Correction factor for c_a	0.7

In Figure 7 the initial and resulting profile after 50 years are shown. It can be seen that the complete trench has experienced considerable sedimentation. Since the residual transports are northward directed, the accreted sediment in the trench is mainly originating from the area South of the trench. This implies that if the toe of the northern slope is accreting, there is a "morphological interaction" between the northern and southern slope. The morphological development of one slope is influenced by the development of the other. The trench volume has decreased by approximately 25%. The horizontal longshore displacement of the centre of gravity is 430 m northward.

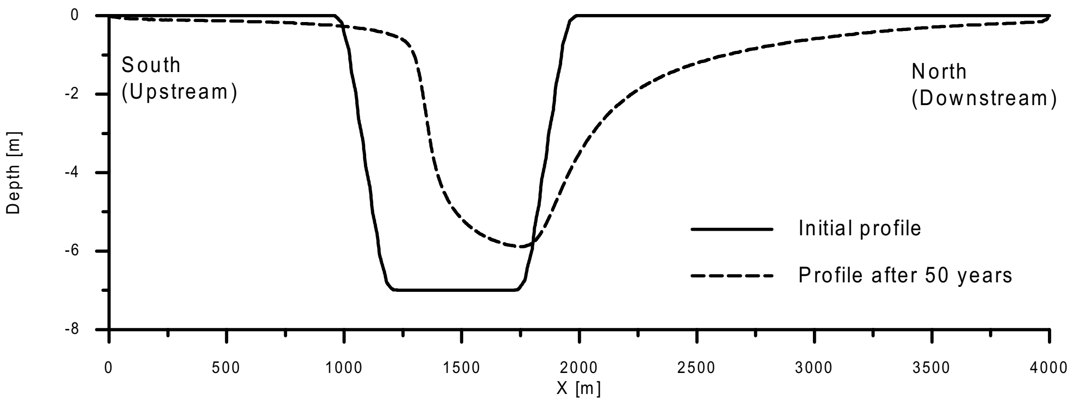

Figure 7 *Results of Reference simulation after 50 years*

This simulation is used as a reference case against which the other geometries are compared and evaluated. To enable an objective comparison between the investigated trench geometries it is necessary to formulate some characteristic features (e.g. trench dimension, volumes, slopes, etc.). This is described in the following section.

DEFINITION OF TRENCH CHARACTERISTICS

Objective comparison of various trench geometries requires the definition of some trench characteristics. This is especially important after a trench has experienced considerable sedimentation and flattening of the downstream slope. In this section a definition method is described which will be applied on the resulting bottom profiles and sediment transports. The method defines the outer dimensions of the trench, some characteristic locations for determining: the trapping efficiency, the trench volume, width and averaged depth.

Definition of Trench Dimensions

The angle of the trench slopes is here defined by the inflection points of the first derivative of the trench bottom profile (i.e. horizontal bottom gradient). Based on the derived trench slope angles a logarithmic approximation of the trench slopes can be made. The lower inflection points, defining the transition between the trench bottom and slopes of the trench (see Figure 8, Points *P2* and *P3*), are used as starting points of the logarithmic approximation. Below the applied logarithmic function is described.

$$h(x) = h_e\left(1 - e^{\left(\frac{-x}{x_{tau}}\right)}\right) \quad (1)$$

where h is the resulting slope profile as a function a horizontal coordinate x, h_e is the reference level which acts as a asymptotic limit and x_{tau} is a horizontal length scale.

This function starts from the lower inflection point (points *P2* and *P3* in Figure 8). It is assumed that the trench slope is a good representative of the gradient of the function at the starting point (the line through Points *P3* and *P4* and Points *P1* and *P2*). With this assumption the logarithmic function has been defined as the crossing of the line through the inflection points with the reference line, giving x_{tau}. The h_e factor is equal to the vertical distance from the reference line to the bottom inflection point (*P2* and *P3*). An advantage of this method is that the validity of the applied approximation can easily be checked by also plotting Eq. 1 in the same graph (it is shown in Figure 8 as a dashed line). It can be seen that the approximation is in good agreement with the calculated profile. The outer dimensions of the trench are now defined by the vertical line from this zero-crossing to the bottom profile (Points *P5* and *P6* in Figure 8).

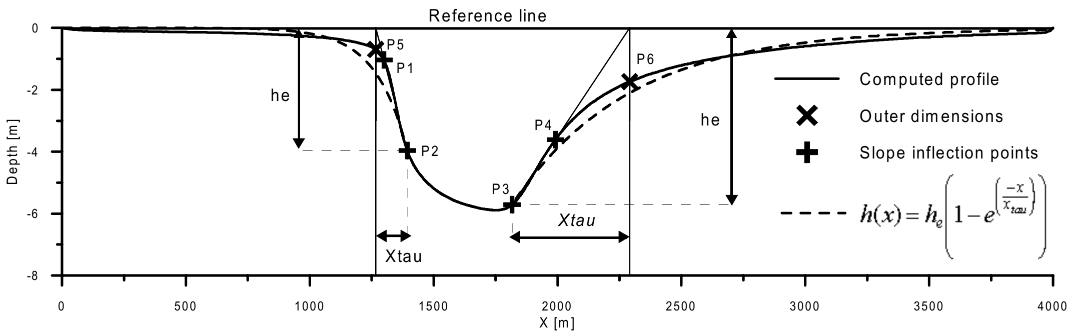

Figure 8 *Definition of trench characteristics*

The four points: P2, P3, P5 and P6 are used to define characteristic transport locations, trench volume, width etc. and some characteristic regions of the trench or pit. The next sub-section will be devoted to these definitions.

Transport properties

The transports at the characteristic trench points P3 and P5 will be considered to study the trapping of sediment in the trench. The trapping of sediment in a trench (so-called trapping efficiency) is mainly related to the area where sedimentation occurs (upstream slope and trench bottom) and which is a good indication of the sediment to be dredged, in case a constant depth has to be maintained. This trapping efficiency (TE_{dredge}) is written in terms of transport rates (S) as:

$$TE_{dredge} = \frac{S(p5) - S(p3)}{S(p5)} \quad (2)$$

The relative sedimentation of the total trench, indicated by *SER,* (i.e. volume change) is calculated by determining the ratio of the trench area between the two outer trench points at the beginning and end of the simulation.

COMPARISON OF VARIOUS TRENCH GEOMETRIES

In total 12 geometries were considered. In each simulation over a period of 50 years only one geometrical feature was modified (viz. width, depth, slope and water depth). In Table 5 an overview is given of the investigated geometries.

Table 5 *Overview investigated trench geometries.*

Run ID	*Comment*	*Width [m]*	*Trench Depth [m]*	*Slope Angles [%]*	*Water Depth [m]*
Ref	Reference run	600	7	4	20
W24	Width 400%	2400	7	4	20
W12	Width 200%	1200	7	4	20
W03	Width 50%	300	7	4	20
TD100	Depth 140%	600	10	4	20
TD140	Depth 200%	600	14	4	20
TD035	Depth 50%	600	3.5	4	20
TD020	Depth 30%	600	2.0	4	20
S8	Slope angles 200%	600	7	8	20
S2	Slope angles 50%	600	7	2	20
WD15	Water Depth 75%	600	7	4	15
WD25	Water Depth 125%	600	7	4	25

Variation Of Trench Width

The results for trenches with a width of 2400 m, 1200 m and 300 m after 50 years of morphodynamic simulation are shown in Figure 9 (the reference simulation is also included). It can be seen that in case of the 2400 m wide trench there is no morphological interaction of the slopes. On the bottom of the trench there is a relative large area where no sedimentation has occurred. This implies that, because the morphological development of the two slopes is independent, the development of both trench slopes can be considered as autonomic behaviour. Because of the northern directed residual transports, the southern slope experiences considerable sedimentation. Both the top of the slope and the toe show a considerable northward migration. The trench slope, however, remains more or less constant. The transition between the trench slope and bottom is much more gradual. This is due to the gradual settling of sediment in this region. The northern slope shows a relative small migration, the region around the toe of the slope does not accrete and the location of the toe remains more or less constant. The shape of the northern slope does, however, change considerably. The trench slope is flattening and the transition between the slope and the original sea floor is much more gradual. The morphological development of the northern slope is mainly governed by the positive gradient of the (residual) sediment transports over the slope. The erosion north of the trench is caused by the small gradient in the residual transports in this area, which is caused by the lag in picking up the sediment.

If the results for the various trench widths are compared, an increased morphological interaction between the two slopes is clearly visible if the trench width decreases. The wide trenches (*W12* and *W24*) show a very similar behaviour. The narrow trench (*W03*) and the reference case (*Ref.*) show an increasing sedimentation and flattening of the downstream slope.

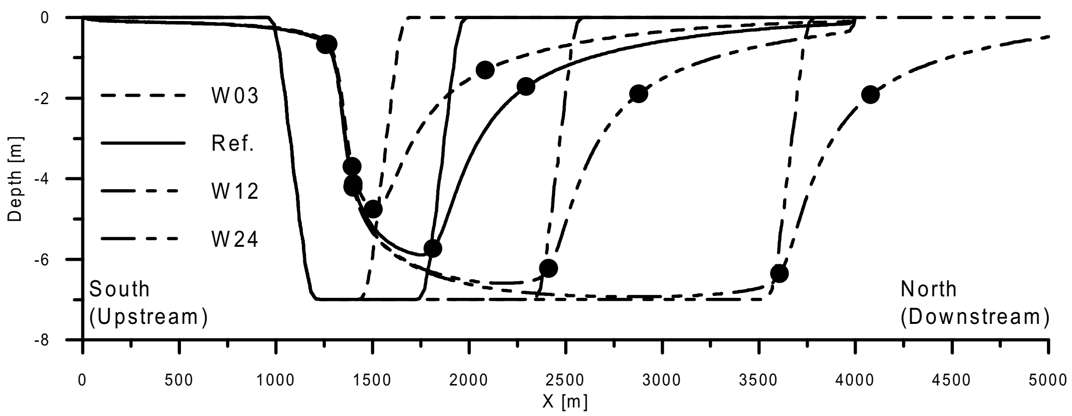

Figure 9 *Influence of a varying trench width*

Variation Of Trench Depth

In total four geometries have been used; two with increased trench depths (14; *TD14* and 10 m; *TD10*) and two with decreased trench depths (3.5; *TD35* and 2 m; *TD25*). The results of the four simulations are shown in the Figure 10. The sedimentation-erosion on the slopes of the 14 m alternative are, similar to the simulation with a trench width of 2400 m (and to some extent the 1200 m alternative) more or less independent. On the considered time scale the morphological developments mainly take place on the trench slopes. The settling of sediment occurs mainly on the upstream (southern) slope. The toe of the downstream slope only shows a minor shift. In case of a 10 m deep trench the same effects can be observed but to a lesser extent. If the other alternatives (trench depths of 3.5 m and 2 m, respectively) are compared it can be seen that the toe of the downstream slope shows a gradually accretion and horizontal shift if the depth is decreasing.

The morphological development of the upstream slope also changes in case of a decreasing trench depth. The 14 and 10 m alternatives mainly show a migration and steepening of the upstream slope. In the shallow trenches (3.5 and 2 m) the upstream slopes also show an increased migration. In contrast to the deeper trenches, however, the slopes have flattened considerably. This is an indication of the increasing morphological interaction between the upstream and downstream slopes with a decreasing trench depth.

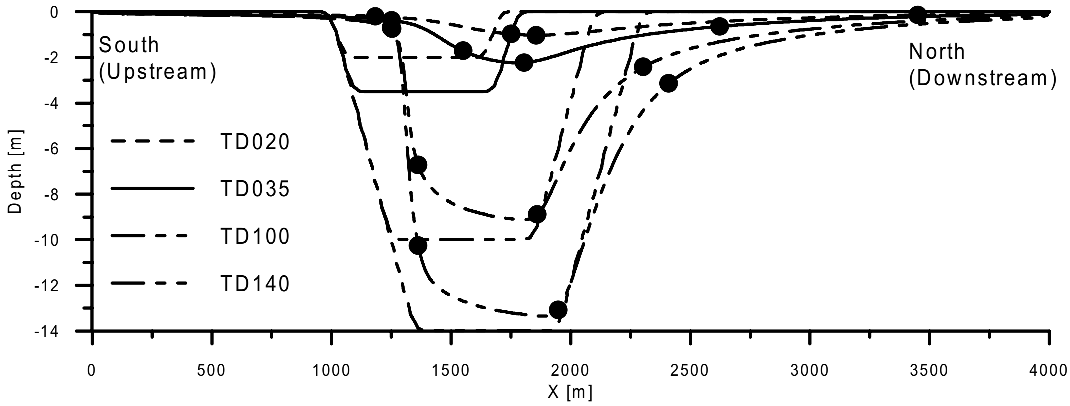

Figure 10 *Influence of a varying trench depth*

Variation Of Trench Slopes

Two alternatives have been investigated in which the trench slopes angles were increased (slopes 8%) and decreased (slopes 2%), respectively (slope angles of reference run are 4%). The results of the simulations are shown in Figure 11. It can be seen that in case of steep slopes more interaction between the two slopes is present. This is mainly due to the fact that the total width of the trench has decreased in case of the steep slopes which results in significant sedimentation of both the trench bottom and the toe of the downstream (northern) slope.

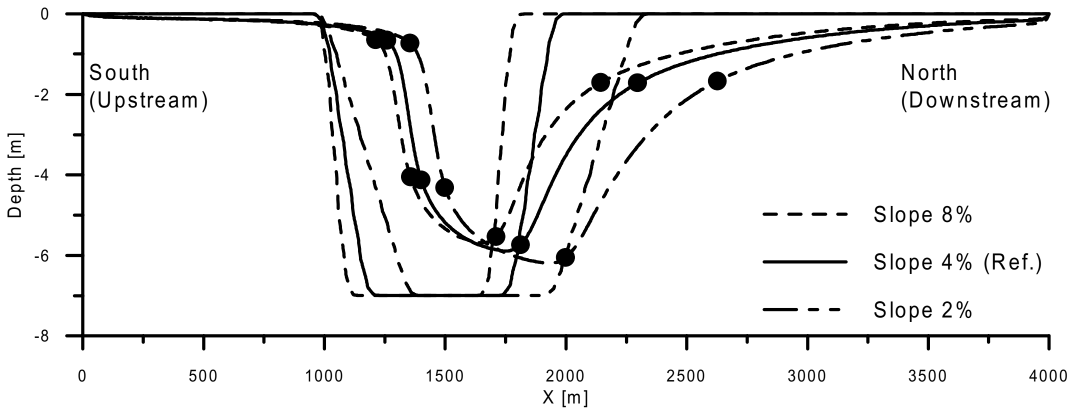

Figure 11 *Influence of varying the trench slopes*

Variation Of Water Depth

To investigate the variation of the water depth, two alternatives have been defined in which the water depth was increased and decreased with 5 m respectively. The tidal velocities were identical to the velocities applied in the reference run, the wave condition was also kept the same. The calculated northward directed residual transports were: 80, 50 and 40 m^3/m/year for water depths of 15, 20 and 25 m respectively. As the tidal velocities were kept constant in the simulation the resulting transports are largely dependent on the stirring of sediment due to waves.

In case of a decreased water depth it can be seen that the resulting trench has experienced considerable sedimentation. In case of an increased water depth the trench shows, compared to the base run, reduced sedimentation. It can be concluded that due to the relative large influence of the water depth on the residual transports the morphological development of the trench is also relatively sensitive to variations of the water depth.

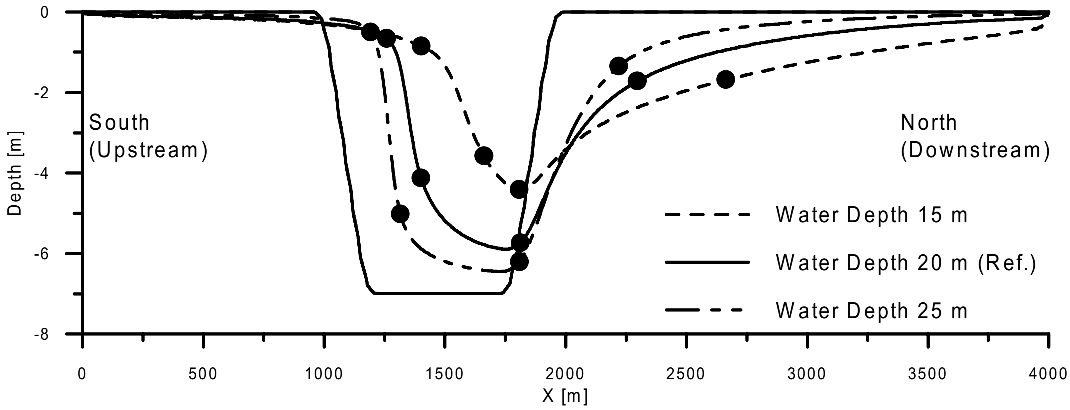

***Figure 12** Influence of varying the water depth*

INTERCOMPARISON OF INVESTIGATED GEOMETRIES

Volume

In Figure 13 the relative sedimentation after 50 years is shown, the relative sedimentation is determined dividing the initial and final trench area. The relative sedimentation of the shallow (*TD020*) and wide trench (*W24*) is relatively small. However for the shallow trench this is influenced by the applied trench definition. In general it can be concluded that because of the fact that most sediment is trapped during the considered period of 50 years, the relative sedimentation is directly related to the initial volume of the trench.

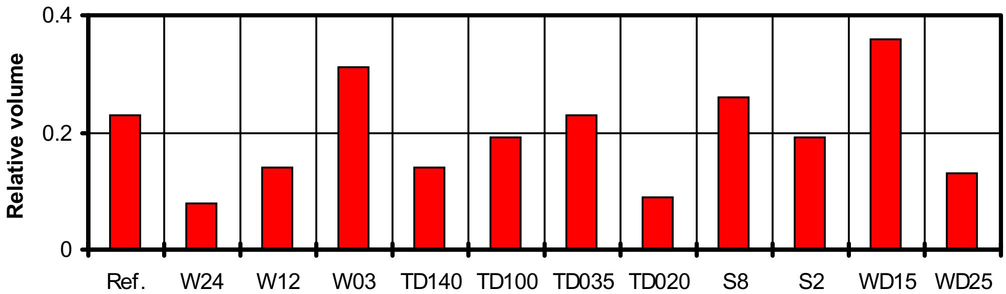

***Figure 13** Relative sedimentation (SER) after 50 years*

Migration

In Figure 14 the migration of the trenches (i.e. the displacement of the centre of gravity) are compared. It can be seen that all alternatives with a decreased width or depth show an (expected) increased migration rate.

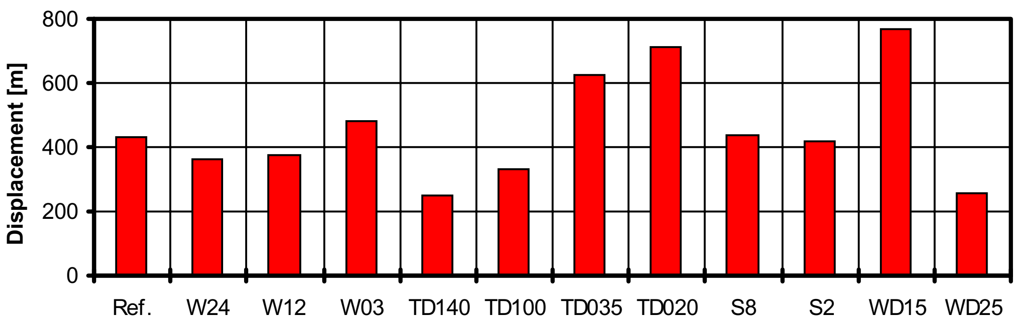

***Figure 14** Migration of centre of gravity of trenches*

Shape

In Figure 15 the relative width and depth changes after 50 years are shown, the relative changes are determined by dividing the initial and final width or depth. As can be seen in Figure 15 the relative width is not significantly affected by variations in trench width. A decrease of the trench depth however results in a significant increase of the width and decrease of the depth. The deeper trenches do not significantly affect the relative shape changes of the trench after 50 years.

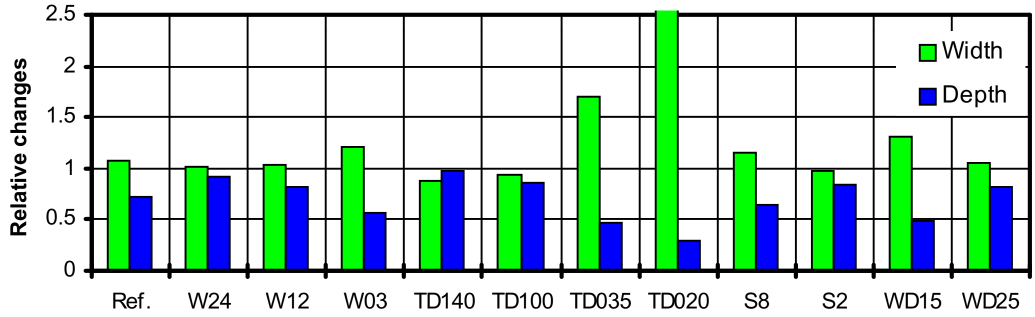

Figure 15 *Relative changes of trench width and depth after 50 years*

Trapping efficiency

In Figure 16 the trapping efficiencies after 0 and 50 years are compared. The first and second bar represent the trapping efficiency at the start and end (50 years) of the simulation, respectively. It can be seen that the TE_{dredge} is not significantly affected if the trench width is increased, a decreased width results in a significant reduction of the trapping efficiency. For the shallow trenches TE_{dredge} reduces significantly. At t=0 the trapping efficiency increases if the water level is decreased and vice versa. The trapping efficiency decreases after 50 years in all cases. The alternatives with reduced width and depth show a relative large decrease in TE_{dredge} which indicates that the morphological time scales of these geometries are significantly shorter than the alternatives with an increased depth or width. It can be seen that the trapping efficiency shows a significant reduction after 50 years if the water level is reduced with 5 m (*WD15*). In case of an increased water level of 5 m (*WD25*) a relative small decrease of the dredging trapping efficiency can be observed.

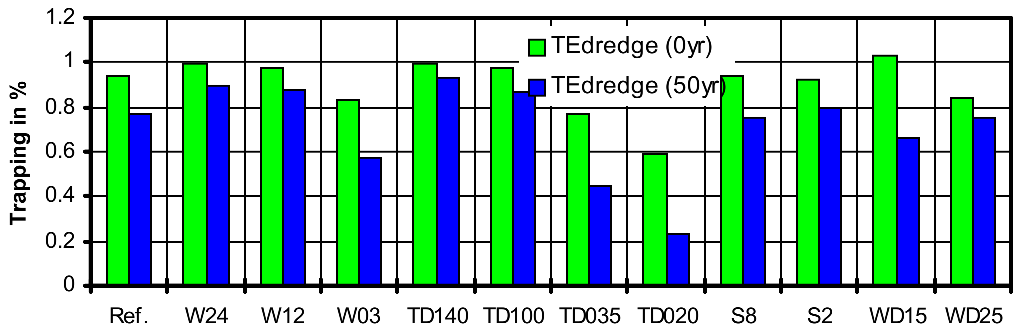

Figure 16 *Comparison of initial and final trapping efficiencies*

Morphological Time Scale

For the derivation of the morphological time scales it is suggested here, to use the trapping efficiency. An extrapolation from the developments in time of this output parameter to zero, seems to be a sensible method to estimate the morphological time scale. In Table 6 the resulting morphological time scales are listed.

Table 6 First order estimate of morphological time scales

Run-ID	*Time scale [yr.]*	*Run-ID*	*Time scale [yr.]*
Reference run	275	depth = 3.5 m	125
width=2400 m	550	depth = 2 m	75
width=1200 m	500	slope = 8 %	250
width = 300 m	150	slope = 2 %	400
depth = 14 m	825	water depth = 15 m	150
depth = 10 m	450	water depth = 25 m	450

From the table above it can be seen that the morphological time scales are in the order of centuries (complete filling of trench). The alternative with a trench depth of 14 m has the largest time scale. According to this definition of the morphological time scale it can be concluded that deep trenches have relative long time scales. Time scales of wide trenches are relatively shorter. If the total volume of the trench is also taken into account it can be concluded that wide trenches are favourable to deep trenches if a minimum time scale is the main criterion. It has to be noted that the listed time scales should be considered as a lower limit as the backfilling rate will probably decrease in time when the trench accretes.

CONCLUSIONS

The morphological development of all the investigated geometries is mainly influenced by the lag of the settling and picking up of the suspended sediment. If most of the sediment has settled on the trench bottom before the toe of the upstream slope, both slopes will develop almost independently from each other. This so-called morphological interaction between the trench slopes mainly occurs for the relatively narrow and shallow trenches. A reduced width or depth leads to an increasing interaction between both slopes which results in an increasing sedimentation at the toe of the downstream slope. This is clearly illustrated when the five simulations with modified trench depths are compared. An increased sedimentation at the toe of the downstream slope results in considerable flattening of that slope.

The suggested definition of the morphological time scale seems to give reliable results. From these time scales it can be concluded that wide trenches are preferable over deep trenches if the morphological time scale is an important criterion. A deep trench of 14 m (twice as deep as base run) has a time scale of 800 years whereas a wide trench of 2400 m (four times as wide as base run) only has a time scale of about 500 to 600 years. It has to be noted however that these are first order estimates of the morphological time scales. For a more reliable prediction simulations in the order of 500 years have to be made. This was outside the scope of the present study.

It can be concluded that wide trenches have a relative short morphological time scale whereas deep trenches have relatively long morphological time scales but also have relatively small migration rates. It is thought that a minimum migration rate is one of the most important parameters as it determines to a large extent the area in which the effects of sand mining can be distinguished. Especially, to limit the effects on the coast, a low migration rate in cross-shore direction is important.

Cross-shore Versus Longshore

The presented results have been derived for the longshore case. Cross-shore tidal currents are of a smaller order. The transport capacity of waves however increases if the water depth decreases. This was illustrated by performing two simulations in which the water depth was increased (h = 25m) and decreased with 5 m (h=15m). It could be seen that the results after 50 years of simulation are seriously affected by these variations. A decrease of 25 % in water depth results in an increase of the migration rate with almost a factor 2. The morphological time scale is also halved. It illustrates that the dynamic behaviour of a trench or a mined area changes dramatically if it is located or migrates to shallower waters. The results that have been presented in this study cannot directly be translated to the cross-shore direction. Additional research is needed to give a reliable indication of the dynamic development in cross-shore directions. In Van Rijn et al. (1997) both cross-shore and longshore residual transport rates have been predicted. The ratio between longshore and cross-shore transports along the Dutch coast vary between 5 and 20. As a first estimate this ratio could be applied to the presented results.

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