LITPACK Toolbox

User Guide

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CONTENTS

SCATTER DIAGRAMS

DFS0SCAT is a tool for analysing time series data.

1 DFS0SCAT - Scatter Diagrams

The following describes the LITPACK Tool for Scatter Analysis of time series data.

It is organised logically following the appearance on the dialog pages.

1.1 Input time series file

On this page you select you input file and which items in the file that you want to use for the analysis.
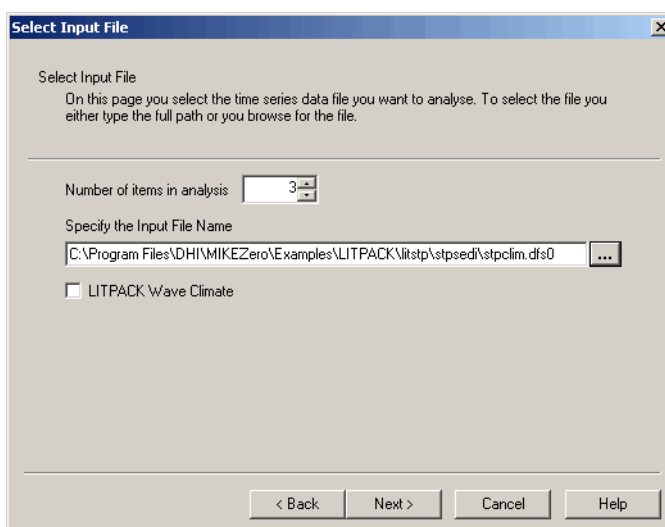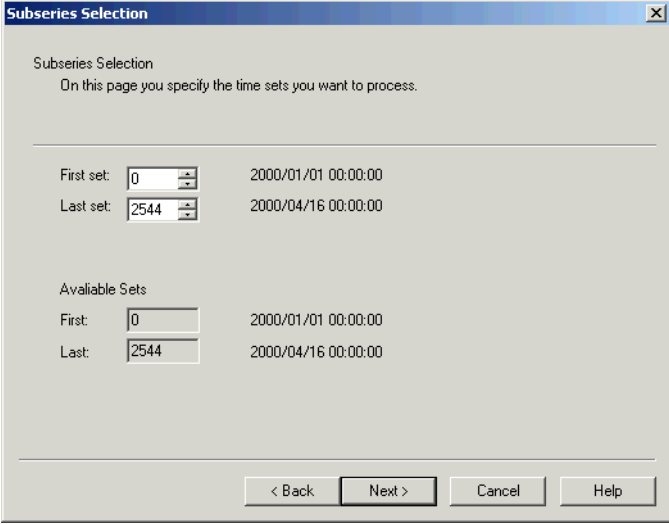
Figure 1.1   Definition of input data time series file

You have the option to specify the time series as an old LITPACK wave climate (with Data type 102). In this case it is assumed that the duration of each wave event (% of year) is defined in item 1 of the file. The analysis will then consider the duration of each event in the analysis. And the resulting number of events for each class is then reflecting the number of seconds the class properties is taking place instead of the number of timesteps in the input file.

1.2 Subseries Selection

This page allows you to select a specific temporal subset of the input data you want to include in your analysis. The analyses are calculated over time, so selecting the subseries will influence the results.

Typically you probably want to process the whole period.

Figure 1.2   Selection of subseries

1.3   Class Delimiters

On this page you define the dimension of the classes that the time series data is to be sorted into.

Figure 1.3   Definition of class properties

Minimum Value
The minimum value defines the start of each class table.

Interval

The interval defines the step by which each dimension is divided.

No. Interval

The number of intervals defines the range of the classes.

Note:

All values below the minimum value will be sorted into the first class and all values above the maximum value will be sorted into the last class.
For example, if you select to sort wave directions between 90 degrees and 270 degrees at 10 degrees intervals, then all directions in the input time series that are between 0 degrees and 89 degrees will be assigned 90 degrees and directions that are between 270 degrees and 360 degrees will be assigned 270 degrees.

1.4 Output Data Description

On this page you specify the name(s) of the simulation output files you want to generate.

The default output file is an ascii file containing the resulting scatter diagrams from the analysis.

As an option you can choose to create an additional list of valid events classes, each defined by the class delimiters and the number of events.

Figure 1.4   Definition of output data files

1.5   Overview

The overview page presents you a summary of all the input parameters you have specified. You should inspect that the parameters are correct and if not go back and change them.

From the page you can either *Finish* the setup which will transfer your setup definition to the current toolbox file or execute the setup.
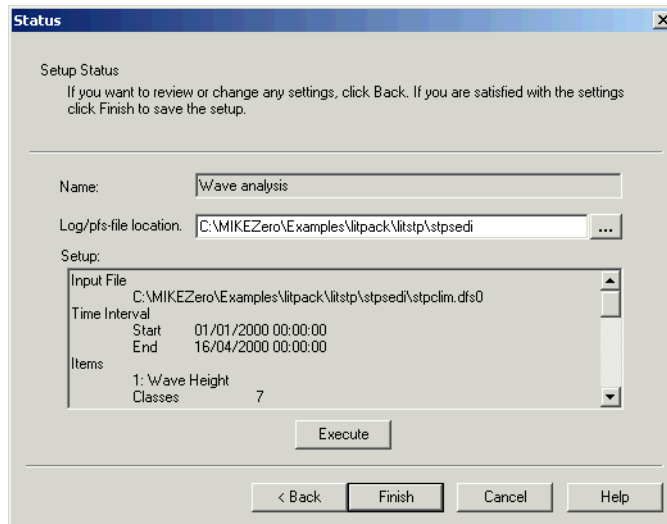
Figure 1.5   Overview dialog

PROFILE EVOLUTION TOOLS

2 Introduction to Profile Evolution Tools

The Profile Evolution tool simulates the storm profile response and the response of beach nourishment to storm conditions.

The model behind the Profile Evolution tool describes the cross-shore profile changes based on a time series of wave events. The model is based on the assumption that longshore gradients in hydrodynamic- and sediment conditions are negligible and that the depth contours are parallel to the coastline. Thus the coastal morphology is solely described by the cross-shore profile.

Through successive calls to a sediment transport program the Table Generator tool calculates and tabulates transport rates for an envelope of the hydrodynamic conditions.

At the offshore boundary time varying wave conditions are specified in terms of wave height, mean wave period and mean wave direction.
Wave transformation across the profile is calculated including the effects of shoaling, refraction, bed friction and wave breaking.

In case of oblique wave attach, the longshore current is calculated from the wave induced radiation stress gradients. The vertical variation of turbulence, shear stress and mean flow is calculated taken into account the effects of assymetry of the wave orbital motion, mass flux in progressive waves, surface rollers and the wave setup.

The assumption of uniform conditions along the shore imply a mean zero cross-shore discharge.

Sediment transport is calculated from an intra-wave hydrodynamic model where the time evolution of the bed boundary layer is resolved.

The bed level change is described by the continuity equation for the sediment:

$$\frac{\partial z}{\partial t} = -\frac{1}{1-n}\frac{\partial q_s}{\partial x} \qquad (2.1)$$

where z is the bed level, q_s is the cross-shore transport and n is the porosity of the bed material.

3 Table Generator

3.1 Short Description

The Profile Evolution tool determines the net sediment transport and the bed level change across the profile for a given wave height and water level.

To reduce the time for simulating profile evolution the value of the local sediment transport rate, q_s (α_0, H, H/D, T, dD/dY, Diss, V) is tabulated for an envelope of hydrodynamic conditions:

α_0	Deep water wave angle
H	Wave height
H/D	Wave height - water depth ratio
T	Wave period
dD/dY	Bed slope
Diss	Dissipation rate
V	Longshore current

During profile evolution calculations, the transport rates are then found by interpolation in the tables established beforehand by the Table Generator rather than calculating the sediment transport for each grid point each time.

The tables are generated by successive calls to the basic sediment transport program, STPQ3D, and input includes the usual input to calculating sand transport in a point.

The definition of the coordinate system orientation causes the input bed slopes to be mainly positive (the bed slope is defined as positive uphill towards the shore), see Figure 3.1.
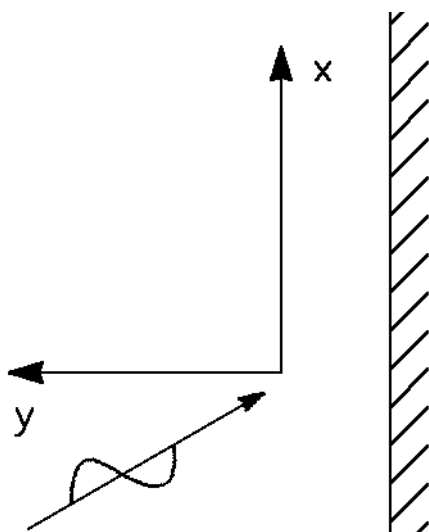
Figure 3.1   Definition of coordinate system in Table Generator

The generated tables are automatically oriented as the Profile Evolution tool demands, i.e. with the x-axis pointing towards the shore.

Since the calculations involved in the process of creating the tables may take several minutes, or even hours, the tables corresponding to the examples are provided with the installation. However, it is a good idea that you follow the instructions below in order to become familiar with the procedure required to create the sediment transport tables for the Profile Evolution Tool. When doing so, please note that the Table Generator does not overwrite existing tables, so you will have to rename those provided with the installation, or move them to another directory.

3.2 Overall Calculation Parameter
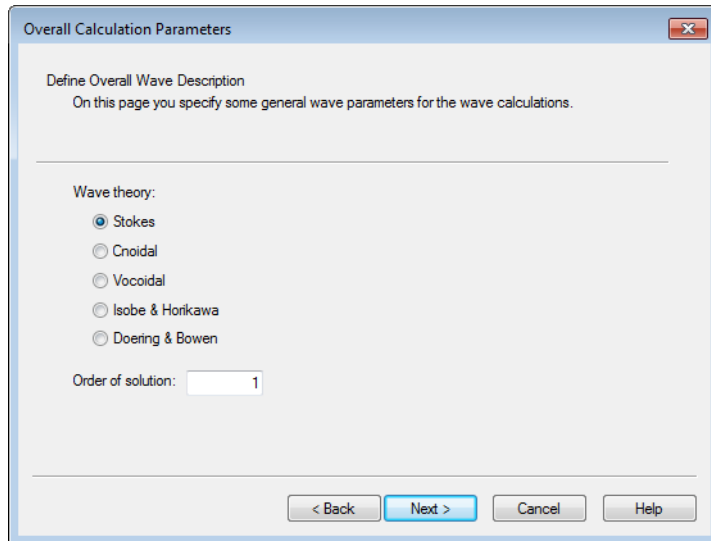
Figure 3.2 Specifying wave theory

First you specify which wave theory to use in the sediment transport calculations. You have several options to describe the wave:

- Stokes Theory, 1st-5th Order

- Cnoidal Theory, 1st-5th Order

- Vocoidal Wave Theory

- Isobe & Horikawa

- Doering & Bowen

The program will internally check if the wave theory is valid for the given conditions and if not, choose an alternative theory.

3.3 Specifying Dimension of Tables

Figure 3.3   Specifying dimension of transport tables

You must specify the dimensions of the table. For each parameter you define the number of values and the minimum and maximum value. Select the values to cover the given hydrodynamic conditions that you may have to use during the simulation of the profile evolution.

Note: The table only describes half the waves as the model assumes the table to be symmetric around 0 degrees.
- Deep water wave angle = 0: waves are perpendicular to the shoreline
- Deep water wave angle = 90: waves are parallel to the shoreline

3.4 Sediment Transport Conditions

This dialog contains information about the grain characteristics, the ripple characteristics and some basic sediment transport parameters.

Figure 3.4   Specifying sediment transport conditions

3.4.1   Sediment Description

The sediment drift calculation may be carried out and based on either a "uniform" grain description or a "graded" grain description.

Uniform sediment
By the uniform sediment description the sediment drift calculations will be based on the mean grain diameter d_{50} and mean fall velocity.

Graded sediment
By the graded sediment description the sediment drift calculations will be based on the size of the grains that actually have the possibility to come into suspension.

The grains will be divided into **a number of fractions**, each described by a representative grain diameter. The calculation of these are based on a log-normal grain curve characterized by the mean grain diameter d_{50} and the sediment spreading. The fall velocity for each of the representative grain diameters is calculated based on the **water temperature**.

Ripples
The effect of ripples on the bed on the bed shear stresses may be included. The four constants C1, C2, C3 and C4 are for assessing the dimensions and the effect of wave ripples, if any. It is normally not recommended to change the default values.

3.4.2   Additional Sediment Parameters

On this dialog you define some basic calculation parameters for the simulation.
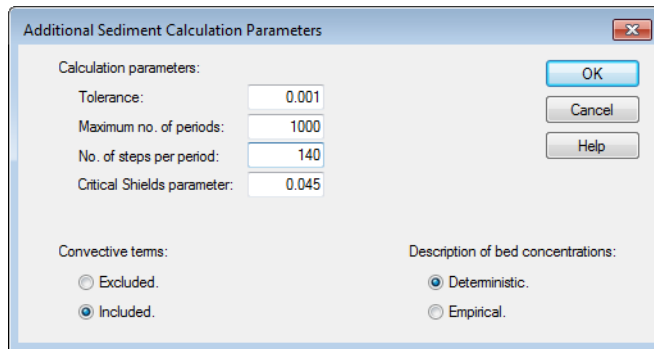
Figure 3.5   Definition of calculation parameters

Critical Shields Parameter
The critical dimensionless Shields Parameter is normally found in the range 0.04-0.06. The default value is 0.045.

Calculation Parameters
The calculation parameters reflects the accuracy of the calculation. The tolerance and maximum no. of periods are used for the iterative calculation of the sediment transport profile. The number of steps per period reflects the deterministic inter period approach.

Convective Terms
The effect of convective terms may be included.

Bed Concentration
The bed concentration may be determined by a deterministic approach or by an empirical formula. Please see the Littoral Processes FM Scientific Documentation for further description.

3.5   Output Specifications

Figure 3.6   Specifying output sediment transport tables

The resulting sediment transport table is divided in two parts, so the cross-shore and longshore sediment transport capacity is saved in separate tables.

The output tables contains the sediment transport capacity (solid volume rate) for each combination of the parameters in the table.

You have to specify a name for the table. The file will have a default extension of '.dat', but other extensions will work.

You may also specify a title to describe the contents in the table.

3.6   Overview and Simulation

Overview
A summary of the input parameters for the model is listed in the grayed window. You can use the vertical scroll-bar to review the input and check it for logical errors.

Execute
This button activates the actual simulation of the model setup. If the input parameters have been changed, an input file name is asked for beforehand.

Table Generation
When the execution is finished, you should inspect the file just created (it is a normal ASCII file) for verification.

Note that transport rates equal to 0.0 for high values of both wave height and ratio height/depth may indicate that the particular event cannot be calculated because of the combination of input parameters being outside a realistic range.

Having created the sediment transport table, you are now ready to use the Profile Evolution tool.

4 Profile Evolution

4.1 Profile Selection
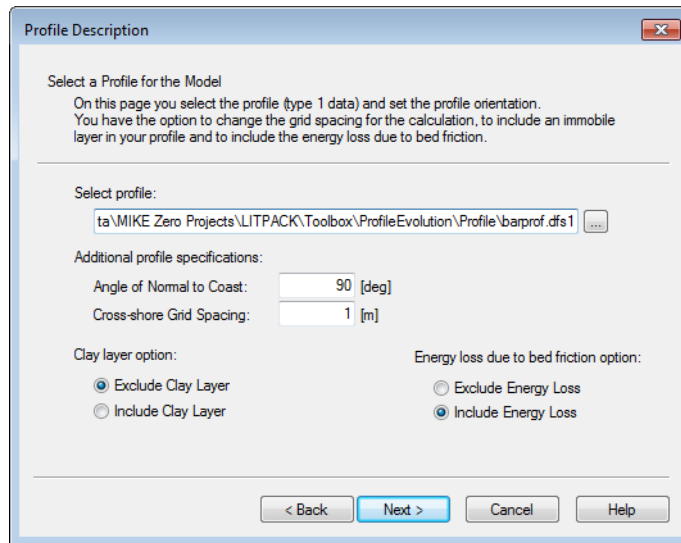
Figure 4.1   Selection of cross-shore profile

First you have to select the cross-shore profile and profile specific parameters.

The cross-shore profile is described by a line series file with 5 items for historic reasons. Only the first only the first two (or three) items are necessary to specify.

A description of the file representing the cross-shore profile can be found in Section 4.1.1, Cross-shore profile.

Optional the bathymetry of a clay layer may be inserted in item 3, replacing the mean grain diameter (see Non-erodible layer).

Orientation
Having selected the profile, the orientation of the profile is given. It is possible to change the angle for quick sensitivity tests, but not advisable.

Cross-shore grid spacing
The grid spacing of the cross-shore profile may be refined in the calculations. Per default the grid spacing given for the input profile is used in the calculations, but it is possible to define a different grid spacing to be used for the calculations.

Non-erodible layer

It is possible to define a non-erodible layer in the profile. If such a layer is included, its level is obtained from item 3 in the cross-shore profile file.

Energy loss due to bed friction

In cases of long and shallow beach profiles the energy loss due to bed friction and its effect on the wave propagation is not negligible.

The energy loss due to the bed friction is calculated from the bottom boundary layer model where the bed roughness and hydrodynamic conditions are used as input.

4.1.1   Cross-shore profile

This file describes the shape and properties of a cross-shore profile.

The profile origin is positioned at a chosen water depth, approaching the shoreline along an axis which is perpendicular to the depth contours. The cross-shore profile is described by a line series data file with 5 items:

1. Bathymetry (m)
2. Bed roughness (m)
3. Non-erodible bed (m)
4. Mean grain diameter, d_{50} (mm)
5. Geom. Spreading ($\sqrt{(d_{84}/d_{16})}$)

Data Type parameter = 101

This type of file is obligatory input for the profile evolution tool. The file format can be created from the profile series template 'Cross-shore Profile'.

NOTE: The orientation of the profile, α_0 (deg.N), is saved in custom block 1 in the file when the data file is created in the profile editor using the Cross-shore profile template. See Figure 4.2 for description of the profile orientation.
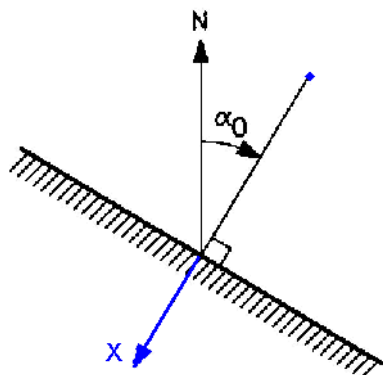
Figure 4.2   Definition of profile orientation

4.2   Climatic Description
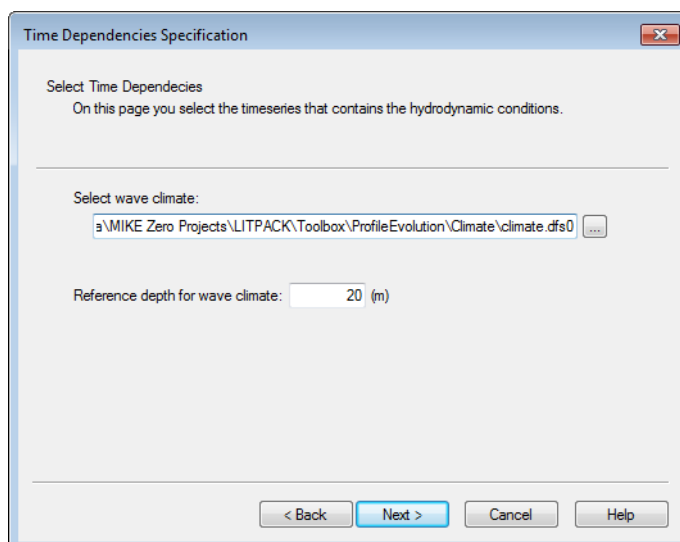
Figure 4.3   Selection of wave climate

You have to specify the hydrodynamic conditions at a certain reference depth. The wave climate for the Profile Evolution tool is described in a time series data file that contains 5 items.

The reference depth describes the condition where the wave conditions are valid. The depth may be larger than is present in the cross-shore profile, but it is not advisable to have a smaller depth than the one defined in the first grid point of the profile.

A description of the file representing the wave climate is given in the following section.

4.2.1 Profile Evolution Hydrodynamics

This file describes the wave- and water level conditions during a period of time.

The climate is described by a time series data file with 6 items:

1. Time (hours)
2. Wave height, Hrms (m)
3. Wave direction (deg. N)
4. Wave period, Tz (s)
5. Spreading factor n or DSD
6. Mean water level (m)

Data type parameter = 107

This type of file is obligatory input for the profile evolution tool. The file format can be created from the profile series template 'Profile Evolution Hydrodynamics.

NOTE: Item 1 contains the time increment in hours for the wave climate. I.e. the value for the first time step must be 0 and the following time steps increasing in order.

NOTE: Item 5 contains either the directional spreading index, n, or the directional standard deviation, DSD (deg). The type is defined as an input parameter.

4.3   Simulation Period

You have to specify the simulation period and some runtime parameters.

Start time/End time
This is the start time and end time for the simulation of profile development.

The conditions at start time and end time have to be described by the time series file for the wave climate.

Maximum morphological time step
This value expresses the maximum time interval between the update of the bathymetry.

The model calculates the morphological time step automatically. If you wish, you can define an upper limit of this time step.

Maximum angle of bed slope
This is the maximum angle of the bed slope can have the bathymetry is modified due to slope failure. The recommended value is 20 to 30 degrees.

Scale parameter
The scale parameter α_{scale} is a calibration factor which reflects the cross-shore exchange of momentum and is proportional to a characteristic length scale over which the transport is smoothed. It will to some degree affect the shape of the developing bars. The higher value, the longer bars.

There is a large degree of uncertainty connected with this parameter.

4.4 Global Wave Conditions

Figure 4.5 Specifying global wave conditions

You have to specify how the waves are to be described in the model.

The model is applicable with both regular waves and irregular waves. See section below for further description.

Roller coefficient factor Beta
This coefficient describes the relation between the energy dissipation rate and the surface roller area, see Dally & Brown (1995)/5/. Here the default value of Beta is generally set to 0.15, also for irregular waves although the value in the latter case usually is much smaller.

Directional spreading parameter
The directional spreading parameter is given as item 5 in the wave climate file. It is here you specify how to interpret the value.

4.4.1 Spectral description of waves

Regular waves
In case of regular waves, the propagation of waves is calculated according to linear shoaling outside the breakpoint, which is given by the height/depth ratio of 0.8. Inside the surfzone the wave height variation is calculated according to an empirical model for wave decay:

- Type 1 refers to the theory of Andersen & Fredsøe /1/
- Type 2 refers to the theory of Dally et. al /6/

The wave breaking parameters Gamma1 and Gamma2 is set implicitly by the program.

Irregular waves

In case of irregular waves, the model of Battjes & Janssen (1978)/2/ is used. The wave breaking parameters, Gamma1 and Gamma2, must be specified. The recommended values are 0.88 and 0.8, for Gamma1 and Gamma2 respectively.

If Gamma2 is set to 0, the model will automatically calculate the value according to Battjes & Stive (1984)/3/.

4.5   Sediment Transport Tables

Figure 4.6   Defining the tables containing sediment transport capacities.

In this dialog you specify parameters and file names regarding the sediment transport.

Morhological Feedback Option

You have the possibility to disable the update of the profile bathymetry, so the simulations of the sediment transport rates are carried out on the same cross-shore profile. The time step is taken equal to the time step in the climate file.

Transport Mode

You have the possibility to specify which transport directions you want to include in the calculations. In case you enable profile evolution the cross-shore transport must be enabled.

Transport Table Name

This is the name of the file containing the sediment transport table in the cross-shore direction and longshore direction, respectively.

Sediment porosity

The sediment porosity is included in the calculations of the sediment transport rates as the transport capacities in the sediment transport tables are given in solid volumes. The recommended value is 0.4.

4.6   Structures
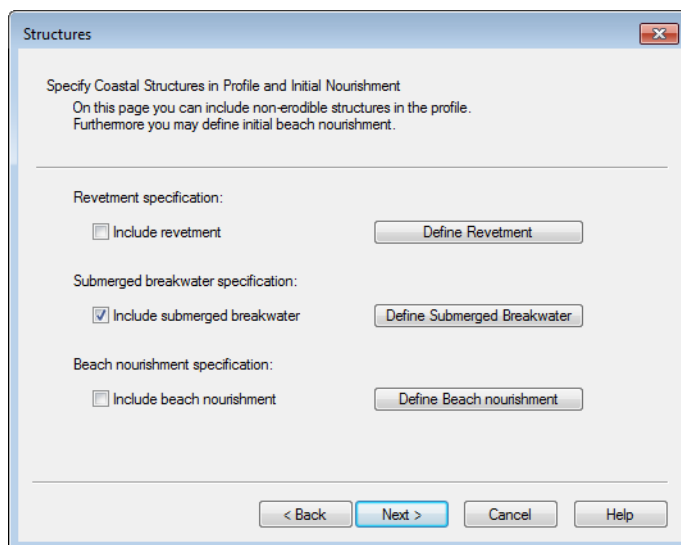
Figure 4.7   Definition of modifications to the natural profile

In this dialog you have the possibility to define non-erodible structures like a revetment and/or a submerged breakwater. Furthermore you can include the description of beach nourishment, where the cross-shore profile bathymetry is altered initially.

Note that the location of a structure is defined as the distance (in meters) from the grid point 0 in the cross-shore profile.

4.6.1 Revetment Specification

Figure 4.8   Definition of revetment

A revetment is defined by the starting grid position from where the bed is assumed to be non-erodible, to the end of the profile.

4.6.2 Submerged Breakwater Specification

Figure 4.9   Definition of submerged breakwater

A submerged breakwater is defined by the location of the breakwater crest centre, the depth of the breakwater crest (below MSL) and the width of the breakwater crest. Furthermore the seaward and landward slope of the breakwater must be specified.

4.6.3   Initial Beach Nourishment

Figure 4.10   Definition of initial beach nourishment

This option allows you to quickly assess the behaviour of beach nourishment on an existing beach profile. The nourishment can be defined either by volume per m beach length or by initial extended beach width.

The initial profile of the nourished beach is defined by the height of the nourishment above MWL and the initial submerged beach slope.

4.7   Output Data Description

Figure 4.11   Description of output data

Output Data

The output data file is described by the file name. The title description is written in written in the result file. A more detailed description of the items in teh file is given in the following section.

Output Frequency

The output frequency defines the number of simulation hours between output.

The output interval must not be larger than the simulation period.

4.7.1   Output file description

The line series file (dfs1) describes the simulated cross-shore profile, hydrodynamic conditions and sediment transport rates across the profile in time.

1. Bathymetry (m)
2. Longshore Velocity (m/s)
3. H_{rms} wave height (m)
4. Water level (m)
5. Cross-shore transport rate (m^3/s/m)
6. Longshore transport rate (m^3/s/m)
7. Integrated cross-shore transport rate (m^3/m)
8. Integrated longshore transport rate (m^3/m)

DATA TYPE Parameter = 120

4.8   Overview and Simulation

Overview

A summary of the input parameters for the model is listed in the window. You can use the vertical scroll-bar to review the input and check it for logical errors.

Execute

This button activates the actual simulation of the model setup. If the input parameters have been changed, an input file name is asked for beforehand.

5   Profile Evolution Examples

One of the best ways of learning how to use a numerical model is through practice. Therefore we have included some applications which you can go through yourself and which you can modify in order to see what happens if this or that parameters is changed.

The first section in this chapter describes a simple application in order to get you started. The "what key to press" procedure for going through this example is given in great detail (what to select in the different menus).

The following section contains a series of simple examples to illustrate the behaviour of the model with respect to changes in parameter settings.

The specification data files for the examples as well as the setups are included with the installation.

5.1   A Simple Example: Development of a Bar on a Straight Profile

5.1.1   Purpose

This first example has been chosen to introduce you to the Table Generator tool and Profile Evolution tool.

In this example the development of a bar on a straight profile during a period of uniform wave conditions is simulated. No structures are present.

The test conditions are:

- The cross-shore profile (see Figure 5.1) has a uniform slope with a gradient of 0.05, defined from the depth of 6.5 m up to 1 m above mean water level. The orientation of the beach normal is 90 deg. N.

- The grain material in the area is assumed uniform with a mean grain diameter d_{50}= 0.2 mm and corresponding fall velocity of 0.022 m/s.

- At 20 m depth the wave conditions are uniform for a period of 24 hours. The wave height is 1 m, the wave is propagating from 90 deg. N, the wave period being 6 s. The waves are irregular.

Additional information required by the model is:

- The grid spacing for the initial profile is selected to be 1 meter.

- The wave theory is chosen as Stokes 1st order theory

- Bed concentration is described by deterministic theory and ripples are not included
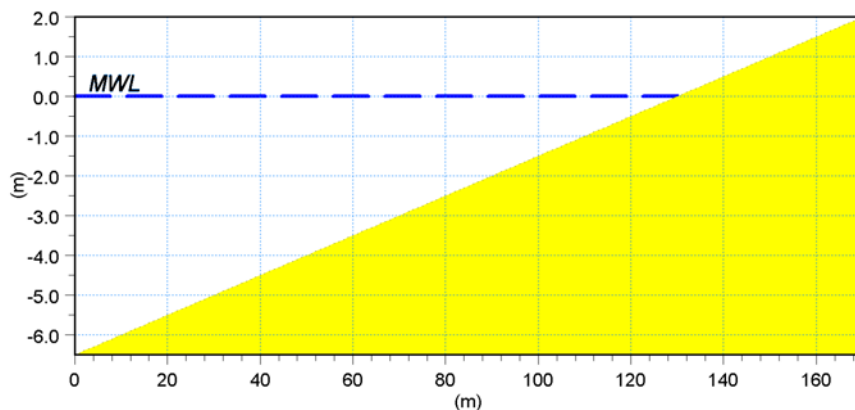
Figure 5.1   Initial cross-shore profile

5.1.2   Generating the transport tables

Before simulating the evolution of the profile, it is necessary to generate a transport table to use as input. The Table Generator tool is applied for this.

You start the Table Generator tool by opening the LITPACK Toolbox editor from the MIKE Zero shell and select the Profile Evolution tool 'Table Generator'.

- Press New and specify a name for the setup. Press Next.
- Set the wave theory to Stokes 1st order. Press Next.
- The dimension of the transport table is defined as shown in Figure 5.2, covering the given wave condition in the example. Press Next.
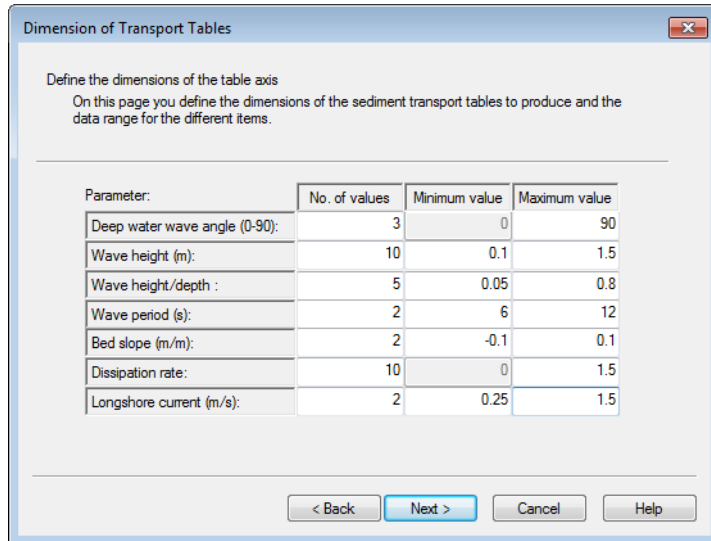
Figure 5.2   Dimension of small sediment transport table.

- Define the sediment description as 'Single' and use the default values, 0.2 mm and 0.022 m/s as mean grain diameter and fall velocitiy, respectively. Exclude ripples. Press Next.

- Specify the names of the transport tables to **cross.dat** and **long.dat**, for the cross-shore and longshore transport direction, respectively. Press Next.

- The overview page allows you to use the vertical scroll-bar to review the input and check it for logical errors. You can save the model setup by pressing **Finish** and then save the LITPACK Toolbox setup. You may also press **Execute** to create the transport table.

- Press Execute to generate the sediment transport tables for the present example

- Once the tables have been generated, save the Toolbox file.

5.1.3   Setting up Profile Evolution simulation

You start the Profile Evolution tool by opening the LITPACK Toolbox editor. Select the Profile Evolution tool 'Profile Evolution'.

Press New and specify a name for the setup.

First you select your **cross-shore profile**, see Figure 5.3.
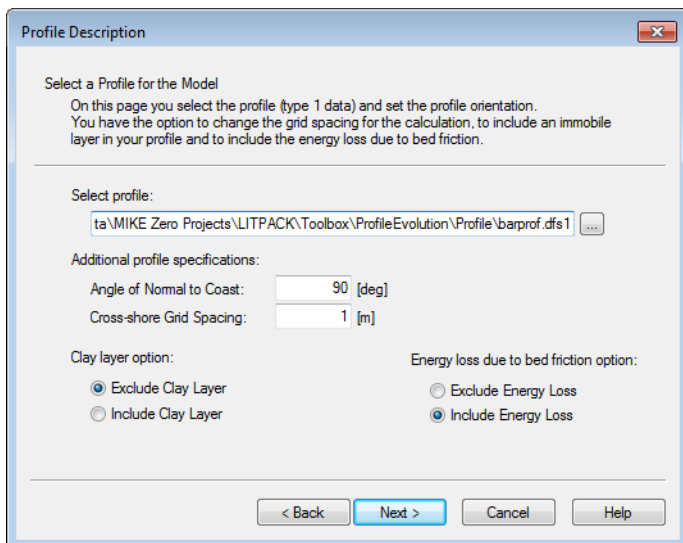
Figure 5.3   Profile selection

Here you select the **profile** data file '**barprof.dfs1**', which is situated in the directory containing the example. The profile orientation (**Angle of Normal to coast**) is set by default as the orientation set in the profile data file, here as 90 deg.N. The **Cross-shore Grid Spacing** is set to 1.0 m. Press **Next** to accept the values and continue.

The wave climate (hydrodynamic parameters) is specified in the *Time Dependencies Specification Dialog*, see Figure 5.4.
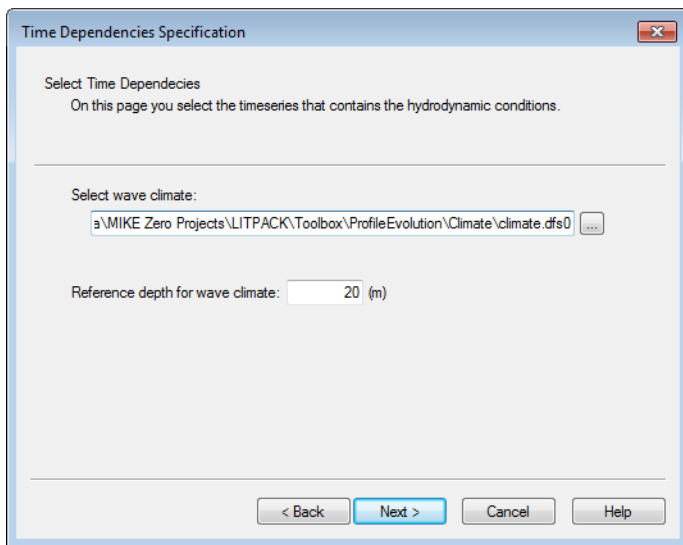
Figure 5.4   Specifying the hydrodynamic conditions

Select the **wave climate to 'climate.dfs0'**. Press next to accept the input and continue to the dialog defining the simulation period and runtime parameters, see Figure 5.5.

Figure 5.5   Specification of simulation period and runtime parameters

The wave condition will be simulated for 24 hours from a starting date of **1990/01/01 00:00:00** to **1990/01/02 00:00:00**

The runtime parameters, **Maximum Morphological Timestep**, **Maximum Angle of Bed Slope and Scale Parameter** is set to the default values, 1800 s, 30 deg and 1, respectively.

On the next dialog, *Specify Global Wave Conditions*, the waves are chosen as irregular and the default values are chosen.

In the dialog *Sediment transport Description* you have to specify the name of the transport tables. Select **Only cross-shore transport** and type **cross.dat** for the cross-shore sediment transport table to specify the table previously generated. Also specify the name of the longshore transport table, even if it is not to be used.

No structures or sediment nourishment is to be included, you proceed to the *Output Data Specification* Dialog.

For the line series file containing the results you specify the name '**.\bar.dfs1**'. As the *title* of the output you may type **Profile Development**. Specify an **Output Interval** of 6.0 hrs. Press **Next** at the bottom of the dialog to accept the input.

5.1.4 Checking the model input

As you have now specified the model setup, a summary of the whole model setup are listed on the *Overview Page*, see Figure 5.6.
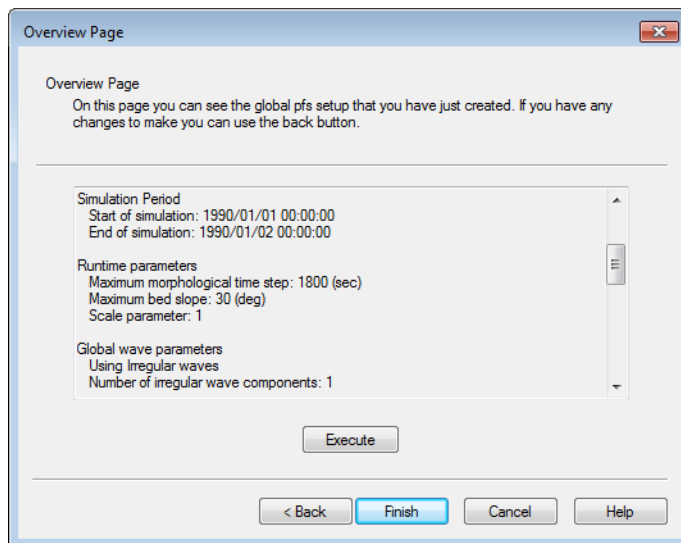
Figure 5.6　　Overview of input and execution

You can use the vertical scroll-bar to review the input and check it for logical errors.

5.1.5 Doing the actual simulation

When you are satisfied with the model setup, you can start the actual simulation by pressing the **Execute** button.

When the job has finished (the time required will depend on your computer) press **OK** and **Finish**. Save the Toolbox file. You should check the log file. This file contain the relevant input parameters and the output data file statistic information.

5.1.6 Plotting results

You can use the MIKE Zero Plot Composer to plot the results from the simulation.

In the present example you may e.g. plot the initial profile and the resulting bathymetry as shown in Figure 5.7.
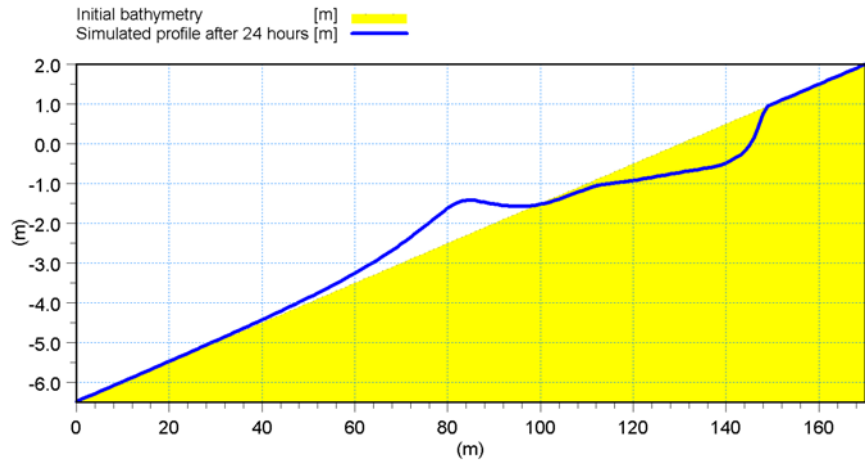
Figure 5.7   Morphological evolution during 24 hours

The plot shows the resulting morphology after 24 hours. A bar with a crest depth around 1.4 m, 55 m from shore has emerged. The position of the bar corresponds to where the most waves are breaking.

5.1.7   List of data and specification files

The pre-generated setups 'Transport Table' and 'Bar' from the specification file 'Tool_ProfileEvolution.lpkt' were used for running the simulations.

The following data files are supplied with the installation:

- File: barprof.dfs1 (cross-shore trench profile data)
- File: climate.dfs0 (wave and current conditions)

The following transport table files are supplied with the installation:

- File: cross.dat (cross-shore sediment transport)
- File: long.dat (longshore sediment transport)

Please note that in order not to over write the specification file, you should copy it over to your own data directory.

5.2   More Examples

5.2.1   Influence of submerged breakwater

Purpose of the example

The purpose of this example is to determine the influence of the presence of a submerged breakwater on the profile development.

The model setup resembles the one in the previous example, apart from the inclusion of a submerged breakwater.

The breakwater is defined at gridpoint no. 100, the width of the crest is 20 m and the top of the crest is 1 m below the water surface. The seaward slope and landward slope of the breakwater are 1.5 and -0.5, respectively.

Profile evolution

The resulting cross-shore profile after 24 hours of development is shown in Figure 5.8.
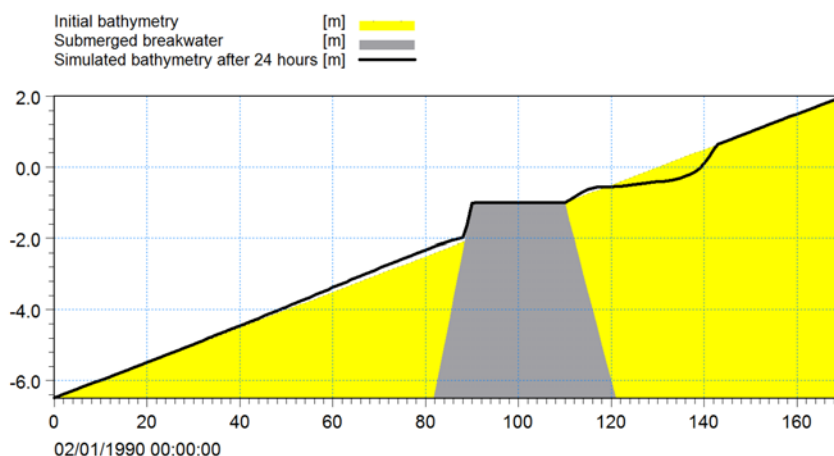
Figure 5.8   Cross-shore profile with submerged breakwater. Initial and resulting profile after 24 hours.

The profile after 24 hours is seen to differ from the situation without a submerged breakwater. In this specific case, the breakwater has somewhat dampened the evolution of the profile.

List of data and specification files

The pre-generated setup 'Submerge' from the specification file 'Tool_ProfileEvolution.lpkt' was used for running the simulation.

The applied data files and transport table files are the same as the ones in the previous example.

5.2.2   Influence of angle of approach

Purpose of example

The purpose of this exercise is to illustrate the effect of waves approaching the coastline with a different angle. An angle of 30 deg. to the coast-normal is chosen in this example - all other parameters but the wave angle are the

same as in the first example **A Simple Example: Development of a Bar on a Straight Profile**.

Profile evolution

The profile after 24 hours with coast-normal waves and with oblique waves are compared in Figure 5.9.
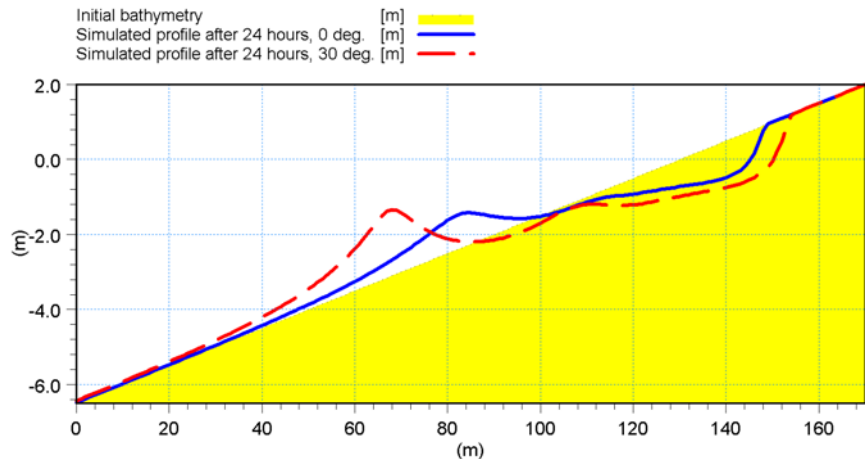
Figure 5.9   Cross-shore profile after 24 hours in the case of oblique and coast-normal wave incidence.

The oblique waves induce a bar which is located further offshore. This is mainly due to the effect of shoaling and refraction. In general the bar will be furthest away from the coast for wave angles close to 45 degrees to shore normal.

List of data and specification files

The pre-generated setup 'Angle' from the specification file 'Tool_ProfileEvolution.lpkt' was used for running the simulation.

The applied data files and transport table files are the same as the ones in the previous example apart from the climate file.

The following wave climate data file was used:

● File: climate_30deg.dfs0 (wave climate)

5.2.3   Influence of cross-shore exchange parameter

Purpose of example

The purpose of this exercise is to illustrate the effect of the choice of the horizontal cross-shore exchange parameter ALFA. Apart from the ALFA parameter all other parameters are the same as in the first example **A Simple Example: Development of a Bar on a Straight Profile**.

Profile evolution

In Figure 5.10, profiles after 24 hours is shown for different settings of the exchange parameter ALFA = 0.3, 0.6, 1.0 and 1.5. It is seen that the higher value, the longer and lower crested the bars will get.
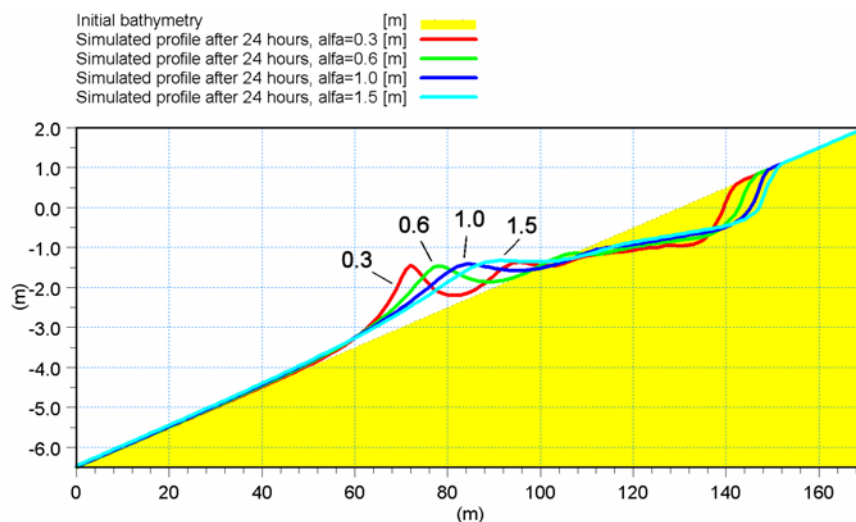
Figure 5.10   Cross-shore profile after 24 hours for different settings of the cross-shore exchange parameter.

List of data and specification files

The pre-generated setups 'Scale-0_3', 'Scale-0_6' and 'Scale-1_5' from the specification file 'Tool_ProfileEvolution.lpkt' were used for running the simulation.

5.2.4   Influence of initial slope

Purpose of example

The purpose of this exercise is to illustrate the effect beach slope. Two simulations are compared: beach slopes of 1/40 and 1/80, respectively.

Profile evolution

In Figure 5.11, profiles after 7 days are shown for different initial slopes. It is seen that the milder slope the slower the morphological processes are. This is reasonable as the development of the profile is related to the local gradients in wave height and hence sediment transport.
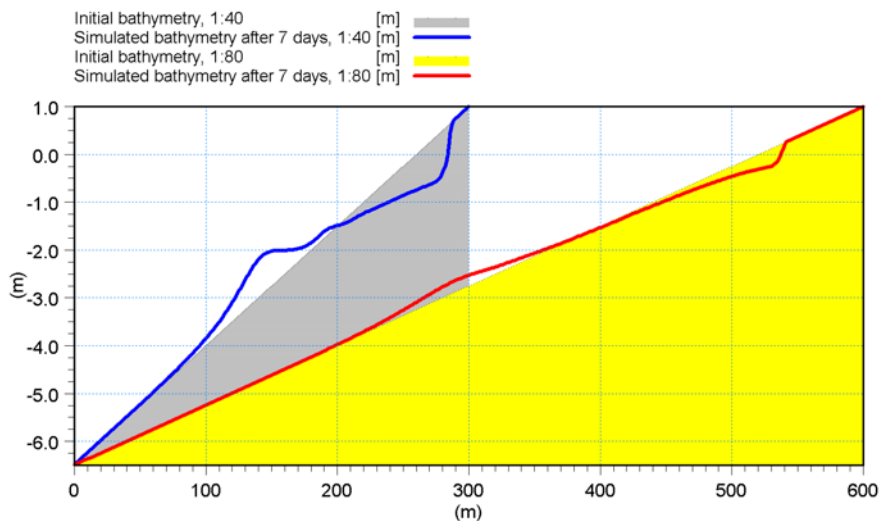
Figure 5.11   Cross-shore profile after 7 days for two different slopes.

List of data and specification files

The pre-generated setups 'Slope-40' and 'Slope-80' from the specification file 'Tool_ProfileEvolution.lpkt' were used for running the simulation.

The following bathymetry files were applied:

- File: barprof_40.dfs1 (initial condition)
- File: barprof_80.dfs1 (initial condition)

All other settings are as in A Simple Example: Development of a Bar on a Straight Profile.

6 Scientific Background

6.1 Introduction

The aim of this scientific background is to provide the user with a more detailed description of the theory and methods used in the Profile Evolution tool than is supplied in other sections of the manual. To enable an improved understanding, a few terms which are used in the documentation will be briefly described.

The Profile Evolution calculations are based on a coordinate system in which the x-axis is a line running normal to the coastline along the cross-shore profile, while the y-axis runs parallel to the primary coastline orientation, see Figure 6.1.
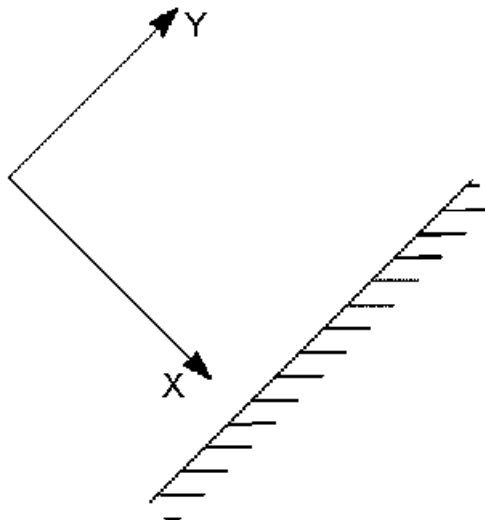
Figure 6.1   Definition of coordinate system

During the last decades, much effort has been put in the description of sediment transport due to currents and waves in the nearshore zone. A review of the most important developments is given by Fredsøe & Deigaard in /21/. In this model the cross-shore profile evolution is simulated by a deterministic description of the sediment transport by including the effects of oblique wave attack and the interaction of the motion with currents in any direction on the time varying hydrodynamic forces, the turbulence, the mean flow properties and the resulting sediment transport.

The net cross shore transport is a result of two opposing meachanisms. Firstly, the non-linearity of the wave motion in shallow water gives rise to higher values of the bed shear stress under the wave crest than under the

wave trough in case of pure wave motion. This results in a net onshore sediment transport. Secondly, the time averaged current near the bed is usually directed offshore (undertow). Further away from the bed the mean flow gradually changes from off shore near the bed to onshore near the water surface. Due to the higher sediment concentrations near the bed, this results in a net offshore sediment transport due to the mean current.

6.2 Hydrodynamic Model

In these calculation it is assumed that the conditions along the shore are uniform. The vertical variation of shear stress, turbulence, flow and sediment transport is calculated from the quasi-3D model as explained in section 6.3. The results of the hydrodynamic model are used as input to the sediment transport model. The hydrodynamic model is outlined in this section.

6.2.1 Wave transformation and breaking.

Waves entering the nearshore zone are subject to transformation processes such as refraction, shoaling, breaking and energy loss due to bed friction. In the Profile Evolution tool, the cross-shore variation of the wave height is calculated from the wave energy equation, which reads:

$$\frac{\mathrm{d}}{\mathrm{d}x}(E_f \cos\alpha) = D_{br} + D_{bf} \qquad (6.1)$$

Here, E_f = wave energy flux, α = angle of wave incidence, x = cross-shore coordinate. D_{br} = dissipation due to wave breaking, and D_{bf} = energy dissipation due to bed friction.

The wave energy flux is calculated using linear wave theory:

$$E_f = \frac{1}{16}\rho g H_{rms}^2 c\left(1 + \frac{2kh}{\sinh(2kh)}\right) \qquad (6.2)$$

Where ρ = density of water, g = gravitational acceleration, H_{rms} = root mean square wave height, c = celerity, k = wave number and h = water depth.

NOTE: the wave conditions at point 0 in the profile should be such that only insignificant wave breaking will take place.

Irregular waves
For irregular waves the energy dissipation due to wave breaking is calculated according to Battjes and Janssen (1978)/2/:

$$Diss = \frac{\rho g Q_b H_m^3}{4Th} \qquad (6.3)$$

Here Q_b = fraction of breaking waves, H_m = max wave height and T = mean wave period.

The efficiency factor used in the original work of Battjes and Janssen (1978) was always taken equal to 1 and is omitted in eq. 2.3. The fraction of breaking waves, Q_b, is calculated from:

$$\frac{1 - Q_b}{\ln Q_b} = -\left(\frac{H_{rms}}{H_m}\right)^2 \tag{6.4}$$

where H_m is defined as:

$$H_m = \frac{\gamma_1}{k} \tanh\left(\frac{\gamma_2}{\gamma_1} kh\right) \tag{6.5}$$

The coefficients γ_1 and γ_2 are specified at input level and are typically 0.88 and 0.8 respectively.

If $Q_b > 0.001$ at the beginning of the profile, $H_{rms}(0)$ is modified.

Regular waves

If a regular wave description is used, the wave height outside the breaking zone is calculated from eq. (6.1), where the energy loss due to breaking is zero. When the ratio H/h exceeds a certain critical ratio, approximately 0.8, the wave breaking is initiated. The wave height variation inside the breaker zone is calculated from either Andersen and Fredsøe (1983)/1/ or from Dally et al (1984)/6/. The model of Andersen and Fredsøe reads:

$$\frac{H}{D} = 0.5 + 0.3 \cdot e^{-0.11 \frac{\Delta X}{h_{br}}} \tag{6.6}$$

where Δx = cross-shore distance to the breaking point and h_{br} = water depth in the breaking point.

The model of Dally et al (1984)/6/ reads:

$$\frac{\mathrm{d}}{\mathrm{d}x}(H^2\sqrt{h}) = -\frac{K_1}{h} \cdot (H^2\sqrt{h} - K_2^2 h^2 \sqrt{h}) \tag{6.7}$$

Here, K_1 and K_2 are constants in the order of 0.4 and 0.15 respectively

The energy dissipation due to bed friction, using linear wave theory, can be written as, Fredsøe and Deigaard (1992)/21/:

$$Diss_b = \frac{2}{3\pi}\rho f_w U_{1m}^3 \tag{6.8}$$

U_m = orbital velocity amplitude and f_w = wave friction factor, calculated as, Fredsøe and Deigaard (1992)/21/:

$$f_w = 0{,}04\left(\frac{a}{k_n}\right)^{-1/4}$$

(6.9)

Here, k_N = sand roughness defined as 2.5 times the median sediment grain size, a = amplitude of wave orbital motion.

If H_{rms} > 0.8D at the beginning of the profile, then Hrms(0) = 0.5D.

6.2.2 Surface roller

In the surf zone, energy is extracted from the organized wave motion and transformed into turbulence through the development and decay of surface rollers. Surface rollers are important for cross-shore morphodynamics, mainly because of the production of turbulence and net mass-flux.
Another important effect of surface rollers is that they cause a space lag between the location of maximal change in organized wave motion, i.e. the right hand side of eq. (6.1), and the maximal production of turbulence, which is important for the strength of the undertow.

The growth or decay of an initial perturbation of the seabed i.e., the initial development of a breaker bar is determined by the local gradients in sediment transport, which are affected by the effect of surface rollers. In the present model the roller description of Dally and Brown (1995)/5/ is used. If oblique incident waves are considered, their roller description yields:

$$\frac{\mathrm{d}}{\mathrm{d}x}(E_f\cos\alpha) + \frac{\mathrm{d}}{\mathrm{d}x}\left(\frac{1}{2}\rho_r c^2\frac{A}{T}\cos\alpha\right) = \rho_r g\beta_d\frac{A}{T}$$

(6.10)

Here ρ_r = density of roller, including air bubbles, A = surface roller area and β_d = empirical constant.

Dally and Brown (1995)/5/ determined the coefficient β_d to be in the order 0.1 to 0.2, based on laboratory experiments with regular waves. If the same values are used for irregular waves, the predicted roller areas will be too small. The value of β_d for irregular waves has not been validated through experiments. A comparison with laboratory experiments of Roelvink and Stive (1989) indicates a value of β_d in the order of 0.005, which is considerably smaller than the recommended value for regular waves. However, further validation will be required.

When estimating the value of β_d it can be helpful to realise that the length scale by which the roller is adapting the decrease in the organized motion is given by

$$\text{Adaptation of roller} = h/\beta_d \tag{6.11}$$

Thus, a β_d-value of say 0.1 would correspond to an adaptation length 10 times the local water depth. Putting β_d to a high value 'turns off' the effect of gradual adaptation of the roller (i.e. instantaneous growth).

6.2.3 Longshore current

The depth – and time-averaged momentum equation along an infinitely long uniform beach, exposed to long-crested oblique incident waves, can be written as:

$$-\frac{dS_{xy}}{dx} - \tau_b + \frac{d}{dx}\left(\rho E h \frac{dV}{dx}\right) = 0 \tag{6.12}$$

Here, S_{xy} = longshore momentum flux, τ_b = bed shear stress, E = cross-shore momentum exchange factor, and V = longshore current velocity.

In the present model, the longshore momentum flux consists of a contribution of the organized wave motion and from the surface rollers:

$$\frac{dS_{xy}}{dx} = \frac{d}{dx}\left(\frac{1}{c}E_f \sin\alpha\right) + \frac{1}{T}\frac{d}{dx}(\rho_r A c \sin\alpha \cos\alpha) \tag{6.13}$$

The exchange factor E is calculated according to Fredsøe and Deigaard (1992)/21/:

$$E = h\sqrt{gh}\frac{(H_{rms}/h)^3}{4\alpha_0^2\sqrt{gT^2/h}} \tag{6.14}$$

Here α_0 = the slope of the interface between the roller and the organized wave motion and is approximately tan(10°).

6.2.4 Directional Distribution

Given the wave parameters, the directional distribution of the wave energy is given by

$$E(\theta_i) = E_1 D(\theta_i) \qquad i = 1, \text{ndir} \tag{6.15}$$

where ndir is the number of discrete directions. Here this number is per default set to 20.
$E_1 = H_{m0}^2/16$ is the total energy of the discrete energy spectrum and the directional distribution function D is defined by

$$D(\theta_i) = \begin{cases} \beta \cos^n(\theta_m - \theta_i) & \text{for} & |\theta_m - \theta_i| \le \theta_d \\ 0 & \text{for} & |\theta_m - \theta_i| > \theta_d \end{cases} \tag{6.16}$$

where β is a normalization factor and θ_m is the maximum wave angle. θ_m is defined as 90 degrees in the Profile Evolution tool.

The directional distribution factor and $D(\theta)$ for selected values of the directional spreading index is shown in Figure 6.2.
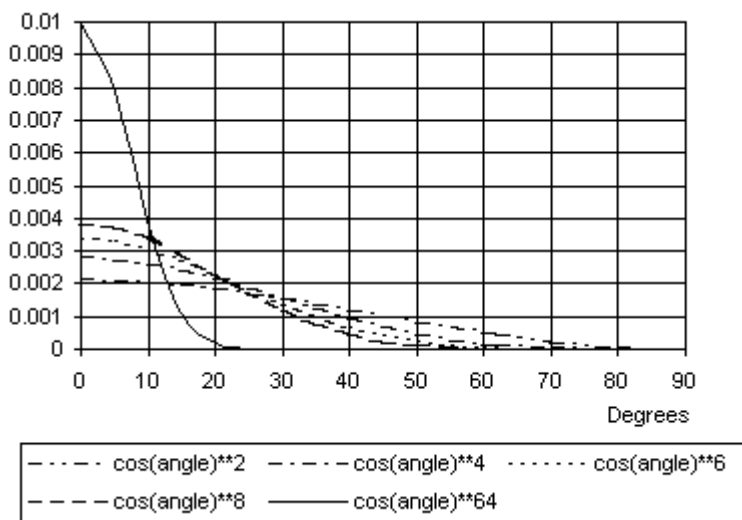
Figure 6.2   Directional spreading function $D(\theta)$ for n=2,4,6,8 and 64, with n=64 giving the narrowest directional distribution of the five shown.

6.2.5   Wave set-up and set-down

The wave set-up and set-down are calculated form the time averaged cross-shore momentum equation included in the calculation of the wave height variation across the shore. The wave height decay and the resulting water level variations are found by iteration.

Figure 6.3 shows an example of the present hydrodynamic model applied on a single-barred beach. The deep-water wave height H_{rms} was taken as 1m with a mean period of 6 s. The deep-water wave angle was 30 deg. compared to the profile orientation (coast normal). The figure shows the cross-

shore variation of the wave height, roller area, dissipation and longshore current.

Figure 6.3   Present hydrodynamic model on a single-barred beach
Bottom: Beach profile, wave height and wave set-up
Lower middle: Mass flux in roller
Upper middle: Energy dissipation including rollers
Top: Longshore current velocity

6.3 Quasi 3D Sediment Transport Model

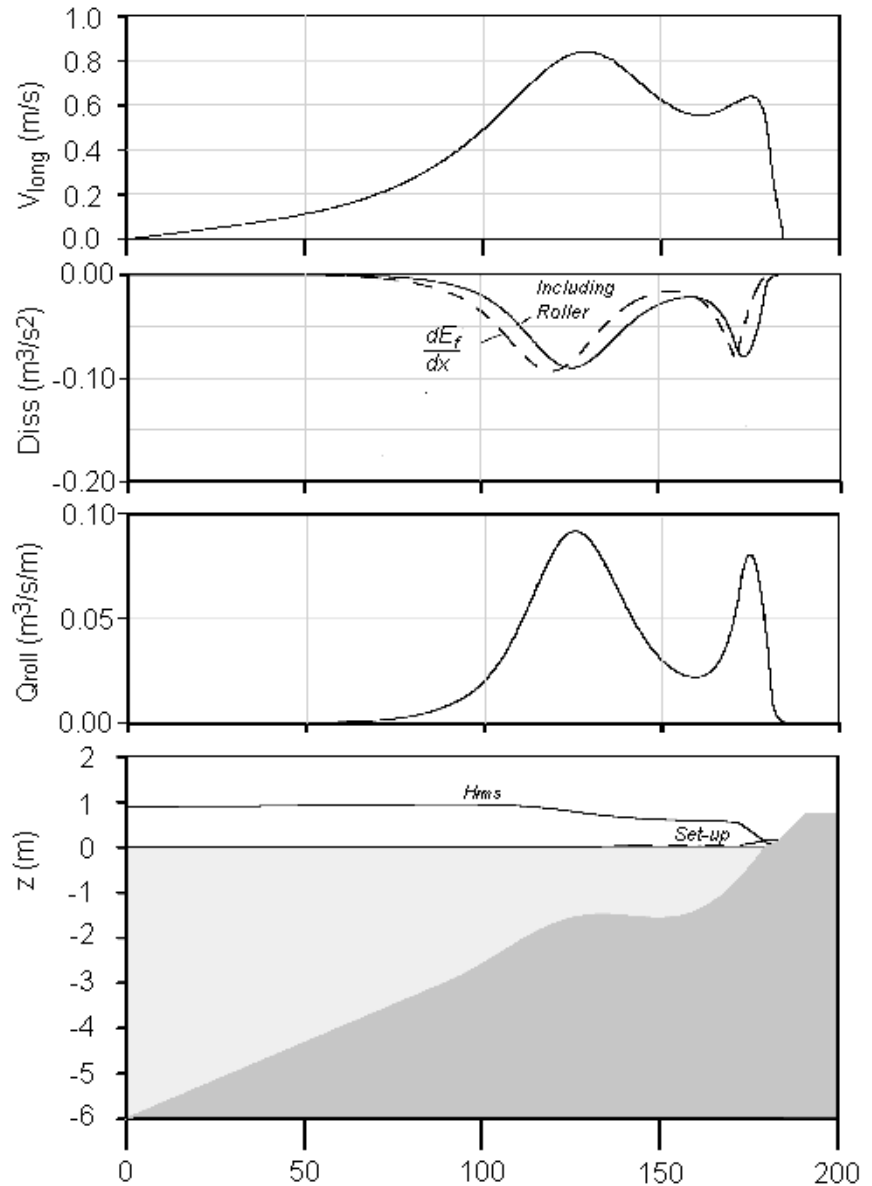The output from the cross-shore wave and current model is used to calculate the variation of cross-shore and longshore sediment transport across the profile. The STPQ3D model, which is the core of the sand transport calculation models in combined waves and currents, is applied to calculate the vertical variation of shear stress, turbulence, flow, and sediment transport. For a more detailed description of the scientific background for the sediment transport computations, please refer to the Scientific Documentation for Littoral Processes FM.

6.3.1 Time-averaged shear stress distribution

In the cross-shore direction, time mean onshore-directed forces, originating from the asymmetric wave orbital motion (skewness), streaming in the wave boundary layer and wave breaking, act upon the water column. The waves induce an onshore mass flux, wave drift, that must be compensated for by a return current driven by a gradient in the water level (set-up).

In the longshore direction, the net force originating from the gradient in the longshore momentum flux must be balanced by a mean bed shear stress from a longshore current.

The different forces acting on the water column are not constant over the water depth. The forces, related to the wave orbital motion (asymmetric wave orbital motion and streaming), are confined to the bottom boundary layer, whereas the forces originating from wave breaking and the cross-shore water level gradient vary linearly over the entire water column. A detailed description of the shear stress distribution is given in Deigaard and Fredsøe (1989)/9/ and Deigaard (1993)/10/.

The vertical variation of the time-averaged shear stress (neglecting convective terms) reads:

$$\overline{\tau}_{c,z} = -\left[\frac{1}{c}\frac{\partial E_f}{\partial x} + \frac{\partial}{\partial x}\left(\frac{\rho_r A c \cos\alpha}{T}\right)\right]\cos\alpha - \rho g S_x(h-z) \qquad (6.17)$$

$$\overline{\tau}_{l,z} = -\left[\frac{1}{c}\frac{\partial E_f}{\partial x} + \frac{\partial}{\partial x}\left(\frac{\rho_r A c \cos\alpha}{T}\right)\right]\sin\alpha - \rho g S_y(h-z) \qquad (6.18)$$

Here S_x and S_y are the cross-shore and longshore gradient in mean water level respectively and z = elevation above the bed.

The values of S correspond to the water level gradient that gives a predefined mean discharge and is found by iteration.

6.3.2   Eddy viscosity

The eddy viscosity consists of contributions from the wave boundary layer, the mean flow and from wave breaking at the water surface. The total instantaneous eddy viscosity, $v_{t,tot}$, is calculated by adding the three contributions at the energy level:

$$v_{t,tot}^2 = v_{t,bl}^2 + v_{t,c}^2 + v_{t,br}^2 \tag{6.19}$$

The eddy viscosity in the boundary layer, $v_{t,bl}$, is assumed to vary parabolic across the boundary layer and is calculated as:

$$v_{t,bl} = \kappa U_f(t) z \left(1 - \frac{z}{\delta(t)}\right) \tag{6.20}$$

Here $U_f(t)$ = Instantaneous shear velocity and $\delta(t)$ = instantaneous boundary layer thickness.

The eddy viscosity originating from the mean flow, $v_{t,c}$, is calculated from a mixing length formulation:

$$v_{t,c} = l^2 \frac{d\overline{U}}{dz} \tag{6.21}$$

Here U = mean flow velocity and l = mixing length defined here as $l=\kappa z(1-z/h)$.

The contribution from wave breaking at the water surface is calculated from a one –equation model for the transport of turbulent kinetic energy, Deigaard et al (1986)/7/:

$$\frac{\partial k}{\partial t} = -\frac{\partial}{\partial z}\left(\frac{l\sqrt{k}}{\sigma_k}\frac{\partial k}{\partial z}\right) + \frac{1}{\rho}PROD - C_l \frac{k\sqrt{k}}{l} \tag{6.22}$$

Here k = turbulent kinetic energy

The eddy viscosity is related to the turbulent kinetic energy as $v_{t,br}=lk^{1/2}$. Standard values for σ_o = 1 and C_l = 0.08 have been used. The production term PROD is obtained from the total energy dissipation as calculated from the wave model. The production of turbulent kinetic energy was assumed to be parabolic in time and space, see Deigaard et al (1986)/7/ for a detailed description.

6.3.3 Flow velocity profile

The time averaged flow velocity profile is calculated from:

$$\frac{\mathrm{d}}{\mathrm{d}z}\overline{U} = \frac{\overline{\tau}}{\rho v_{t,tot}}$$

(6.23)

The no-slip condition at the bed is used as boundary condition. The instantaneous flow velocity profiles are calculated from the model for the turbulent boundary layer for combined wave-current motion, Fredsøe (1984)/19/. Inside the wave boundary layer, the flow velocities are assumed logarithmic. Outside the boundary layer the instantaneous flow velocity profiles are obtained by adding the wave orbital motion to the time averaged flow velocity.

6.3.4 Wave-orbital motion

The wave orbital motion can be calculated from the model of Isobe and Horikawa (1982)/22/, that was adjusted with regard to the velocity skewness. Elfrink et al (1999)/15/ analyzed the effect on velocity skewness and found that its effect on cross-shore sediment transport is of equal importance as other cross-shore mechanisms such as the undertow. Doering and Bowen (1995)/12/ derived a parameterized expression for velocity skewness as a function of the Ursell parameter. Doering et al. (2000)/14/ extended this work and included the effect of the bed slope on the velocity skewness. In the present model, velocity skewness is derived from general wave parameters (height, period) and morphological parameters (water depth, bed slope) using the expression of Doering et al (2000).

6.3.5 Sediment transport

Bed-load transport is calculated from the instantaneous bed shear stress, using the model of Engelund and Fredsøe (1976)/18/. The effect of the bed slope on the critical Shields parameter is included. Suspended sediment concentrations are calculated from the diffusion equation for suspended sediment, Fredsøe et al. (1985)/20/, where the sediment diffusivity is taken equal to the eddy viscosity as calculated from eq. (6.19).

6.4 The cross-shore exchange factor

Processes associated with momentum and sediment exchange in the horizontal direction will add a horizontal diffusion effect to the resulting transport. A clear example of this is the effect around a break point for a regular wave, where the flow and sediment transport will be smoothly distributed around the break point although the wave forcing is rather abrupt. Diffusive effects will also be present in the case of irregular waves and should be included in the general case.

Diffusive effects are taken into account using a redistribution concept to smooth out large gradients in the transport field. The resulting diffusive effect of the horizontal exchange processes is associated with a characteristic length scale over which the transport is smoothed. In the Profile Evolution tool, the length scale is assumed to be proportional to the local wave length, with a cross-shore exchange factor α_{scale} (the Scale parameter).

$$\text{Length scale of cross-shore mixing } = \alpha_{scale} \cdot \frac{2\pi}{k} \tag{6.24}$$

The exchange factor α_{scale} is a calibration factor which to some degree will affect the shape of the developing bars. The higher value, the longer bars. The horizontal exchange process furthermore has a positive influence on the numerical solution, smoothing out high frequent false oscillations without adding numerical diffusivity to the solution.

There is a large degree of uncertainty connected with this parameter.

6.5 Morphological Model

The continuity equation for the seabed reads:

$$\frac{\partial z_b}{\partial t} = -\frac{1}{1-n} \cdot \frac{\partial q_{s,x}}{\partial x} \tag{6.25}$$

Here, z_b = bed level, n = porosity and $q_{s,x}$ = cross-shore transport rate.

A forward in time - central in space (FTCS) scheme is applied to solve this equation. The scheme was proven to work satisfactory for realistic setting of parameters. The scheme is explicitly stepping forward in time, meaning that the size of the time step relative to the spatial discretisation is limited by the migration speed of the bed (Courant-Fredriechs stability criterion). Although the time step is checked - and reduced internally if necessary - numerical instabilities may in rare cases emerge if the time step becomes too large. If such instabilities occur, the time step should be decreased until a stable solution is obtained.

6.6 Influence of model parameters

To render the validity of the Profile Evolution model different aspects of the processes involved in profile development is given here.

6.6.1 Influence of slope

On the gentle slope, energy dissipation due to breaking is weak, which results in a weak undertow. Onshore sediment transport mechanisms such

as streaming and non-linear wave orbital motion are dominant.
On a steeper slope, the offshore-directed transport, induced by the undertow becomes more important, resulting in erosion in the nearshore zone and the development of a breaker bar.

For a given grain size, the direction of the cross-shore transport is mainly a function of the Irribarren number or surf similarity parameter x, defined as the ratio of the beach slope and the square root of the wave steepness.
For low values, during storms generally offshore transport occurs resulting in beach erosion.
For high values of x, corresponding to the beach recovery phase after a storm, the transport is directed onshore, resulting in beach accretion.

6.6.2 Influence of offshore angle of wave incidence

The cross-shore energy flux is lower for oblique waves than for normally inci-dent waves. This is due to the effect of shoaling and refraction, i.e. normally the larger wave angle the closer to shore the breaking point will appear, and thus the position of a bar.

Even though the cross-shore energy flux is lower for oblique waves than for normally incident waves, the offshore sediment transport can become higher due to the interaction between the longshore current and the undertow. The co-existence of a longshore current and the undertow will cause higher levels of turbulence near the bed, compared to a situation without longshore cur-rent. This has two opposing effects for cross-shore sediment transport.

Firstly, the vertical gradients of the horizontal flow velocity are lower due to the increased eddy viscosity. This leads to lower flow velocities near the bed and slightly higher velocities higher in the water column.
Secondly, due to the increased turbulence near the bed, the suspended sedi-ment concentrations are higher in the combined undertow-longshore current motion than for the undertow alone.

6.6.3 Influence of natural wave conditions

As an example a Profile Evolution simulation was carried out for a natural beach, located approximately 40 km North of the city of Esbjerg along the western coast of Jutland, Denmark. A period of one month was simulated. The time history of the wave height and direction are shown in Figure 6.4.
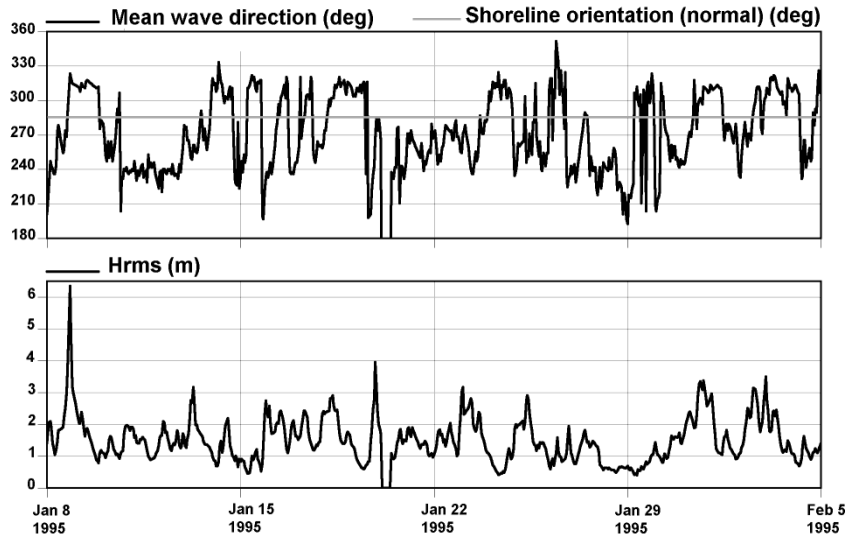
Figure 6.4   Measured offshore wave conditions. Period Jan. 8 1995-Feb 8 1995.

The mean wave height (H_{rms}) was approximately 1.5 m. Several storm events occurred during this period where H_{rms} exceeded 3m. Unfortunately no field data was available to validate the model's ability to predict profile changes in time. However, its results can be evaluated in a qualitative way.

The simulated profile and the corresponding transport rates are shown in Figure 6.5 and Figure 6.6, respectively.

The model simulation shows that the outer bar is not significantly affected by the stormy conditions. It is questionable whether this bar is formed by wave-generated transport alone or if other phenomena, such as tides are important as well.

The middle bar is considerably more affected by wave generated sediment transport. The crest level is more or less unchanged but the inshore trough has been eroded with approximately 1m. It has migrated slightly offshore during the simulation period.

Erosion in the order of maximal 1.5 m was simulated close to the shoreline. A new inshore bar has formed at approximately 100 m from the shoreline.
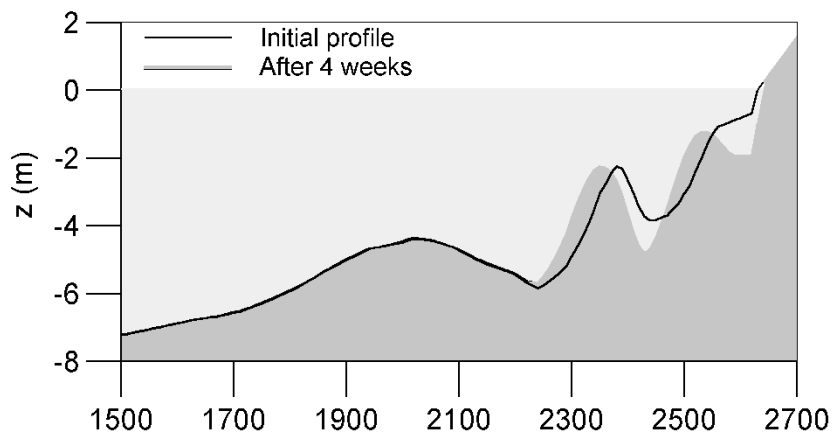
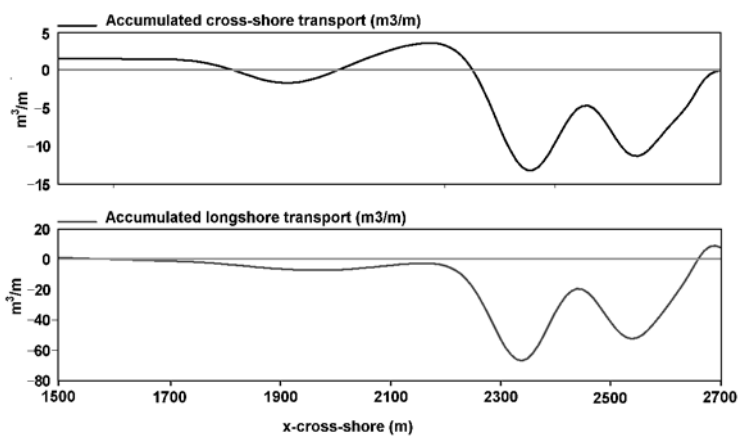Figure 6.5   Simulated cross-shore profile, SW Jutland Denmark after 31 days.

Figure 6.6   Simulated accumulated cross-shore and longshore transport rates over a period of 31 days.

7 Literature References

/1/ Andersen, O.H., and Fredsøe, J.(1983): *Transport of Suspended Sediment along the Coast*. Progress Report No. 59, ISVA, Technical University of Denmark.

/2/ Battjes, J.A., and J.P.F.M. Janssen (1978) *Energy Loss and Set-Up due to Breaking of Random Waves*. Proc. of the 16th Int. Conf. on Coastal Eng. pp. 569-587, Hamburg.

/3/ Battjes, J.A., and Stive, M.F. (1985) *Calibration and Vertification of a Dissipative Model for Random Breaking Waves*. J. of Geophys. Res., 90:9159-67, September.

/4/ Brøker, I., Deigaard, R., and Fredsøe, J. (1991). *In/offshore sediment transport and morphological modelling of coastal profiles.* Proc. ASCE Specialty Conf. Coastal Sediments' 91, Seattle, WA, pp. 643-657.

/5/ Dally, W.R. and Brown, C.A. (1995) *A modeling investigation of the breaking wave roller with application to cross-shore currents.* J. of Geophys. Researc, Vol. 100, No. C12, pp. 24.873-24.883.

/6/ Dally & Dalrymple (1984) (Wave decay)

/7/ Deigaard, R., Fredsøe, J., and Hedegaard, I.B. (1986) *Suspended sediment in the surf zone*, Jour. of Waterway, Port, Coast. and Ocean Eng., ASCE, Vol. 112, No. 1, pp. 115-128.

/8/ Deigaard, R., Fredsøe, J., and Hedegaard, I.B. (1986) *Mathematical model for littoral drift*, Jour. of Waterway, Port, Coast. and Ocean Eng., ASCE, Vol. 112, No. 3, pp. 351-369.

/9/ Deigaard, R. and Fredsøe, J. (1989) *Shear stress distribution in dissipative water waves*. Coastal Engineering, ASCE, vol. 13, pp. 357-378.

/10/ Deigaard, R. (1993) *A note on the 3-dimensional shear stress distribution in a surf zone*. Coastal Engineering, ASCE, vol. 20, pp. 157-171.

/11/ Dette, H., Uliczka (1986) 'Seegangserzeugte Wechselwirkung zwichen Vorland und Vortrand sowie Küstenschutzbauwerk'. Technischer Bericht Nr. 3, SBF 205/TP A6. Universität Hannover.

/12/ Doering, J.C. and Bowen, A.J. (1995) *Parametrization of orbital velocity asymmetries of shoaling and breaking waves using bispectral analysis*, Coastal Engineering (26)1-2, pp. 15-33.

/13/ Doering, J.C., Elfrink, B., Hanes, D.M. and Ruessink, G. (2000)

Parameterization of velocity skewness under waves and its effect on cross shore sediment transport. Proc. 27th Int. Conf. on Coastal Engineering, ASCE, Sydney.

/14/ Elfrink, B., Brøker, I., Deigaard, R., Hansen, E.A. and Justesen, P. (1996) *Modelling of 3D Sediment Transport in the Surf Zone,* Conf. of Coastal Engineering 1996, Proceedings.

/15/ Elfrink, B. , Rakha, K.A., Deigaard, R. and Brøker, I. (1999) *Effect of near-bed velocity skewness on cross shore sediment transport*. Proc. Coastal Sediments '99, pp. 33-47. Long Island - NY, USA.

/16/ Elfrink, B., Brøker, I. and Deigaard, R. (2000) *Beach profile evolution due to oblique wave attack.* Proc. 27th Int. Conf. on Coastal Engineering, ASCE, Sydney.

/17/ Elfrink, B. and Baldock, T. (2002) *Hydrodynamics and sediment transport in the swash zone: a review and perspectives*. Coastal Engineering (45) pp. 149-167.

/18/ Engelund, F. and Fredsøe, J. (1976) *A sediment transport model for straight alluvial channels*, Nordic Hydrology, **7**, pp. 296-306.

/19/ Fredsøe, J. (1984) *The turbulent boundary layer in combined wave-current motion*, Journal of Hydr. Eng., ASCE, Vol. 110, No. HY8, pp. 1103-1120.

/20/ Fredsøe, J., Andersen, O.H., and Silberg, S. (1985) *Distribution of Suspended Sediment in Large Waves*. Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, Vol. III, No. 6, pp. 1041-1059.

/21/ Fredsøe, J. and Deigaard, R. (1992) *Mechanics of Coastal Sediment Transport*. Advanced Series on Ocean Engineering, Vol. 3, World Scientific.

/22/ Isobe and Horikawa (1982) *Study on water particle velocities of shoaling and breaking waves,* Coast. Eng. in Japan, Vol.25, pp.109-123.

/23/ J. Buhr Hansen: *Air Entrainment in surf zone waves,* 3rd Int. Conf. on Coastal and Port ing. in Developing Countries, Mombasa, Sept 1991.

/24/ M.B. Abbott: *Computational Hydraulics*, Pitmann Publ. Lim., 1979.

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