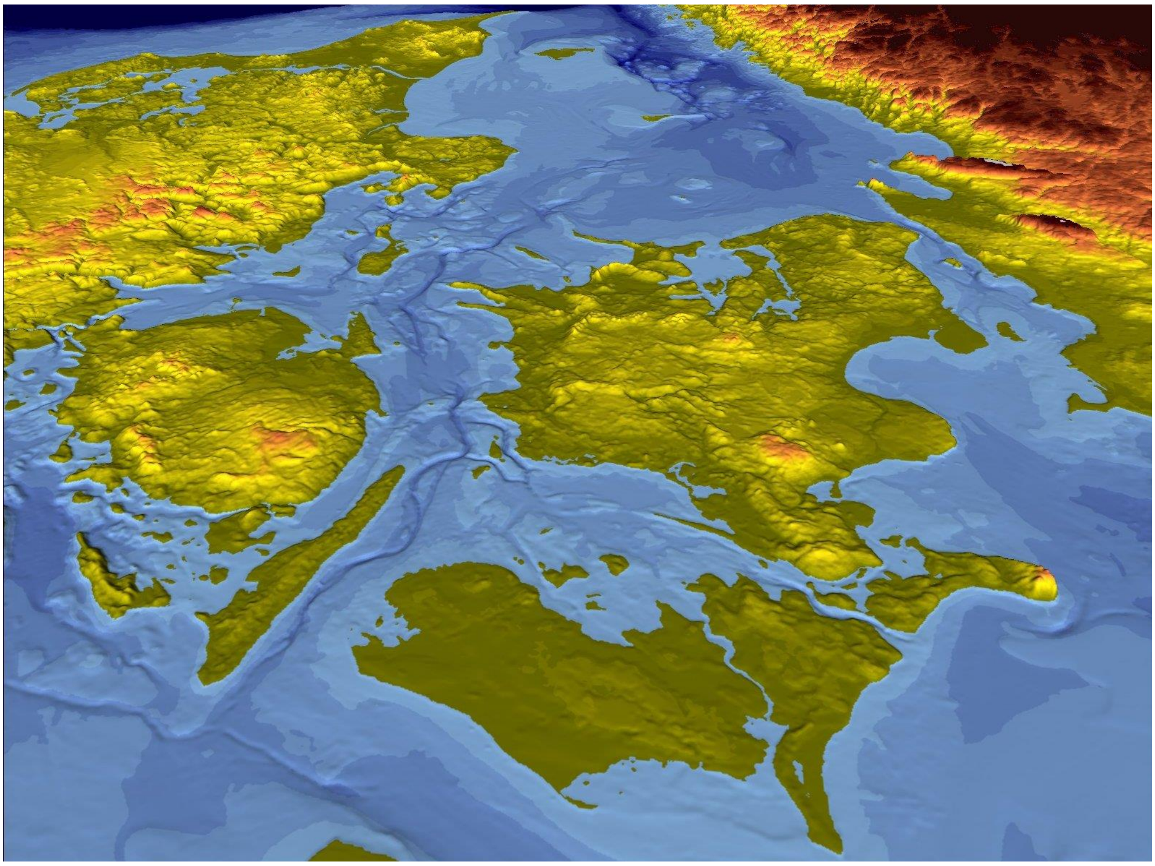

MIKE 21

Hydrodynamic Module

Step-by-step training guide

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CONTENTS

MIKE 21
Hydrodynamic Module
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1 Introduction

This training example relates to the fixed link across the Sound (Øresund) between Denmark and Sweden.

Figure 1.1 The Sound (Øresund), Denmark

1.1 Background

In 1994 the construction of a fixed link between Copenhagen (Denmark) and Malmö (Sweden) as a combined tunnel, bridge and reclamation project commenced. Severe environmental constraints were enforced to ensure that the environment of the Baltic Sea remains unaffected by the link. These constraints implied that the blocking of the uncompensated design of the link should be down to 0.5 %, and similarly, maximum spillage and dredging volumes had been enforced. To meet the environmental constraints and to monitor the construction work, a major monitoring programme was set up. The monitoring programme included more than 40 hydrographic stations collecting water level, salinity, temperature and current data. In addition, intensive field campaigns were conducted to supplement the fixed stations with ship-based ADCP measurements and CTD profiles. The baseline-monitoring programme was launched in 1992 and continued into this century.

By virtue of the natural hydrographic variability in Øresund, the blocking of the link can only be assessed by means of a numerical model. Furthermore, the hydrography of Øresund calls for a three-dimensional model. Hence, DHI's three-dimensional model, MIKE 3, was set up for the entire Øresund in a nested mode with a horizontal resolution ranging from 100 m in the vicinity of the link to 900 m in the remote parts of Øresund, and with a vertical resolution of 1 m. MIKE 3 was subsequently calibrated and validated based upon the intensive field campaign periods.

Amongst the comprehensive data sets from the monitoring programme, which form a unique basis for modelling, a three-month period was selected as 'design period' such that it reflected the natural variability of Øresund. The design period was used in the detailed planning and optimisation of the link, and to define the compensation dredging volumes, which were required to reach a so-called zero-solution.

1.2 Objective of Training Example

The objective of this training example is to set up a simplified MIKE 21 Flow Model for Øresund from scratch and to calibrate the model to a satisfactory level.

The exercise has been made as realistic as possible, although some short cuts have been made with respect to the data input. This mainly relates to quality assurance and pre-processing of raw data to bring it into a format readily accepted by the MIKE Zero software. Depending on the amount and quality of the data sets this can be a tedious, time consuming but indispensable process. For this example the 'raw' data has been provided as standard ASCII text files.

The files used in this Step-by-step training guide are a part of the installation. You can install the examples from the MIKE Zero start page.

Please note that all future references made in this Step-by-step guide to files in the examples are made relative to the main folders holding the examples.

User Guides and Manuals can be accessed via the MIKE Zero Documentation Index in the start menu.

If you are already familiar with importing data into MIKE Zero format files, you do not have to generate all the MIKE Zero input parameters yourself from the included raw data. All the MIKE Zero input parameter files needed to run the example are included and the simulation can start immediately if you want.

1.3 Tasks to be completed to form a Complete Hydrodynamic Setup

Bathymetry setup

- Set up of Bathymetry by importing geographical data with soundings based on a survey or digitised from nautical chart

Creation of boundary conditions

- Set up water levels at the boundaries
- Set up of Wind condition

For the model verification of the hydrodynamic model we need simultaneous measurements of water levels and current speed inside the model area.

Creation of verification data

- Create data set with current speed and direction
- Create data set with water levels

2 Creating the Bathymetry

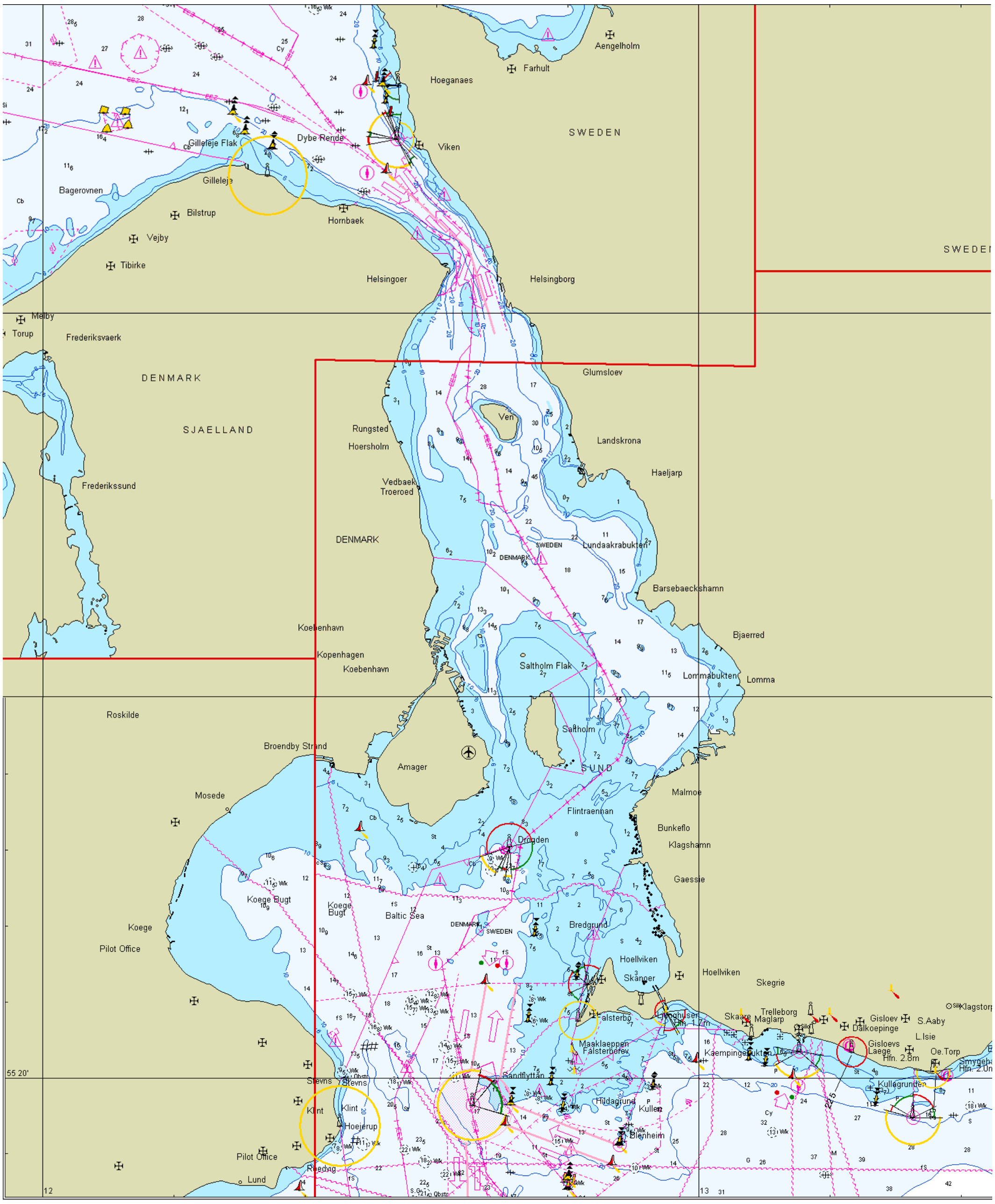


Figure 2.1 Chart covering the area of interest

Based on the sea chart we define our working area in the Bathymetry Editor

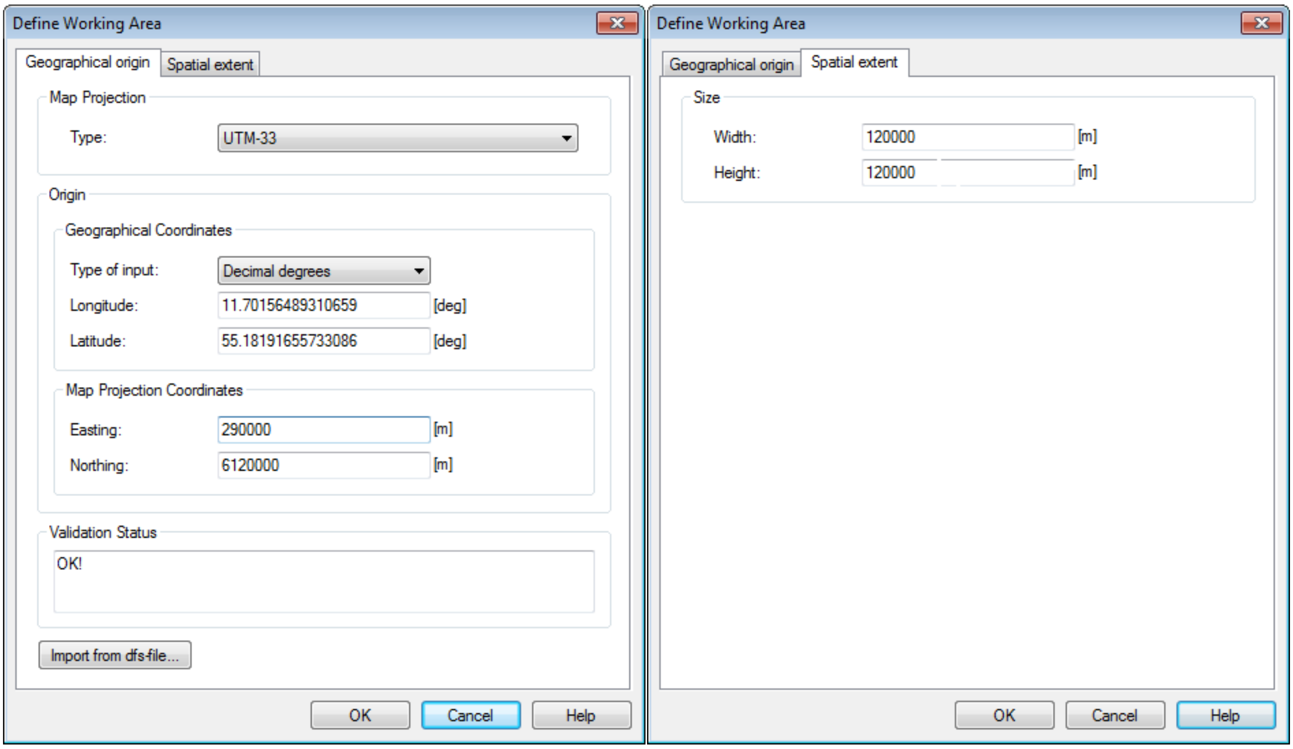
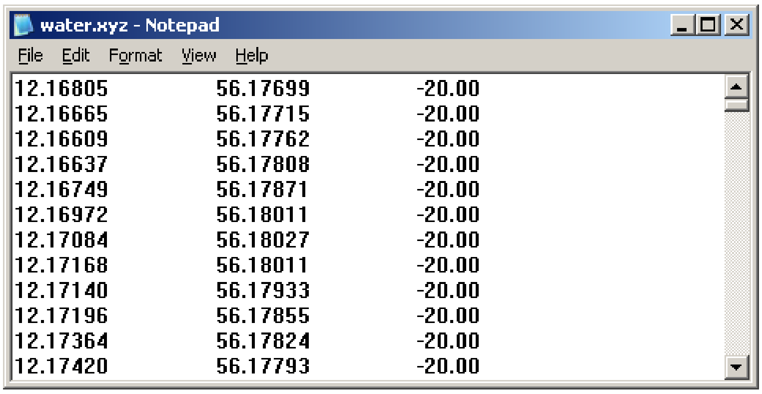


Figure 2.2 Defining the Working Area

Define the Working Area (UTM Zone 33) with origin at Easting 290000 and Northing 6120000 and with a width of 120000 m and a height of 120000 m. (See Figure 2.2) The resulting Working Area is show in Figure 2.4.

Import digitised shoreline data (land.xyz) and digitised water data (water.xyz) from ASCII files (see example in Figure 2.5). Remember to convert from geographical co-ordinates (WorkArea → Background Management → Import). See Figure 2.6.



12.16805	56.17699	-20.00
12.16665	56.17715	-20.00
12.16609	56.17762	-20.00
12.16637	56.17808	-20.00
12.16749	56.17871	-20.00
12.16972	56.18011	-20.00
12.17084	56.18027	-20.00
12.17168	56.18011	-20.00
12.17140	56.17933	-20.00
12.17196	56.17855	-20.00
12.17364	56.17824	-20.00
12.17420	56.17793	-20.00

Figure 2.3 ASCII file describing the depth at specified geographical locations (Longitude, Latitude and Depth)

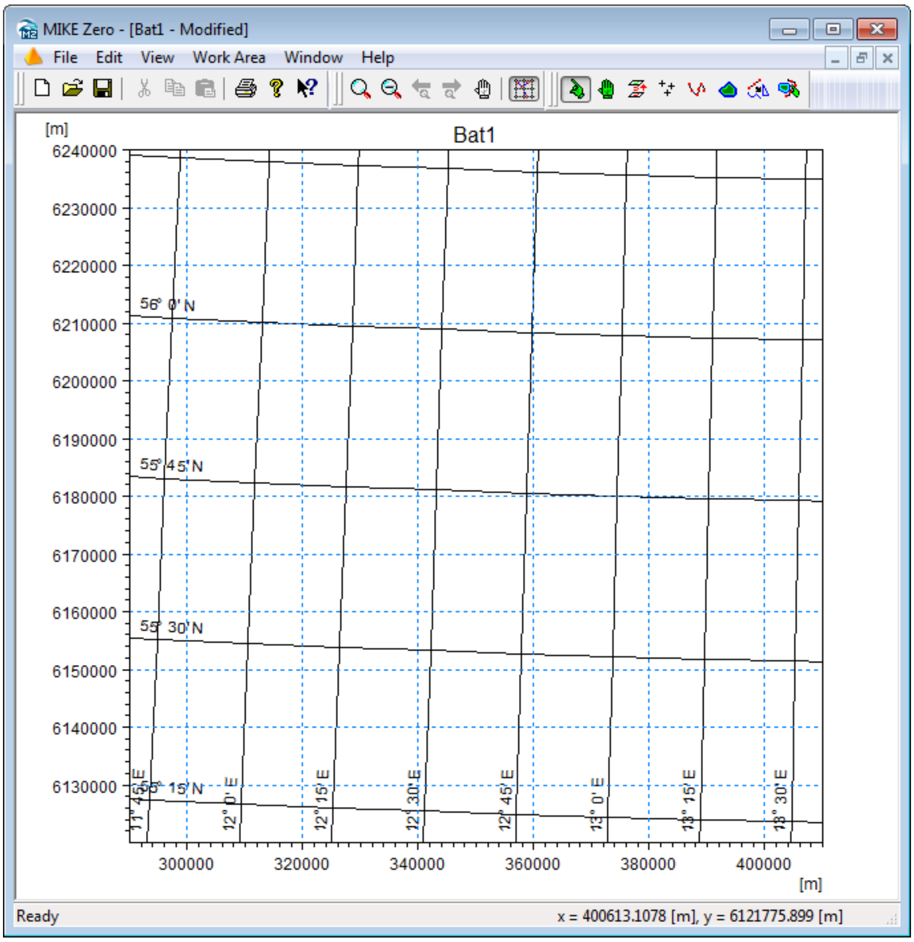


Figure 2.4 Working Area

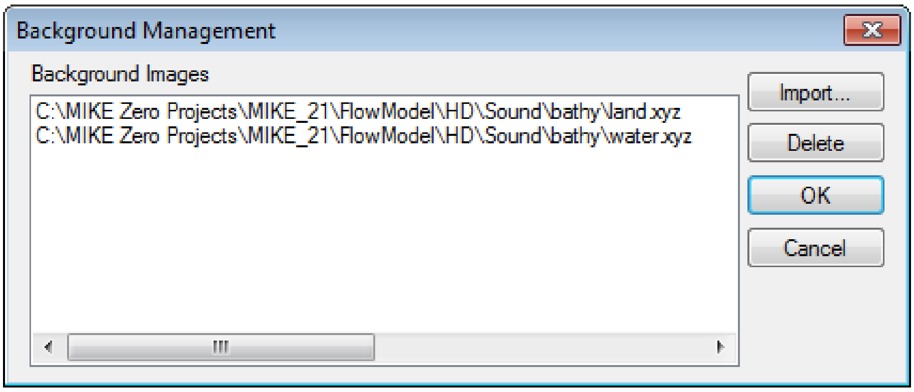


Figure 2.5 Background Management

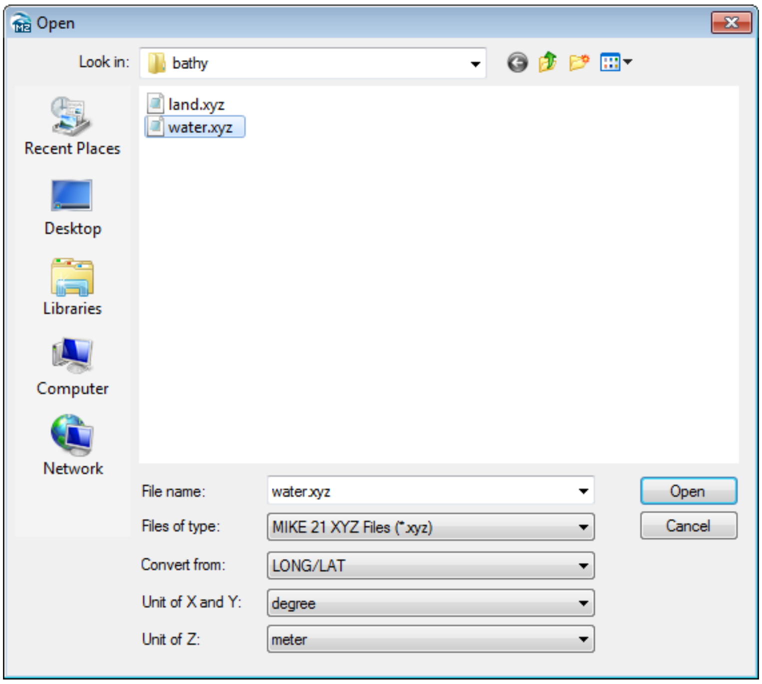


Figure 2.6 Import digitised Shoreline and Water Depth from ASCII files

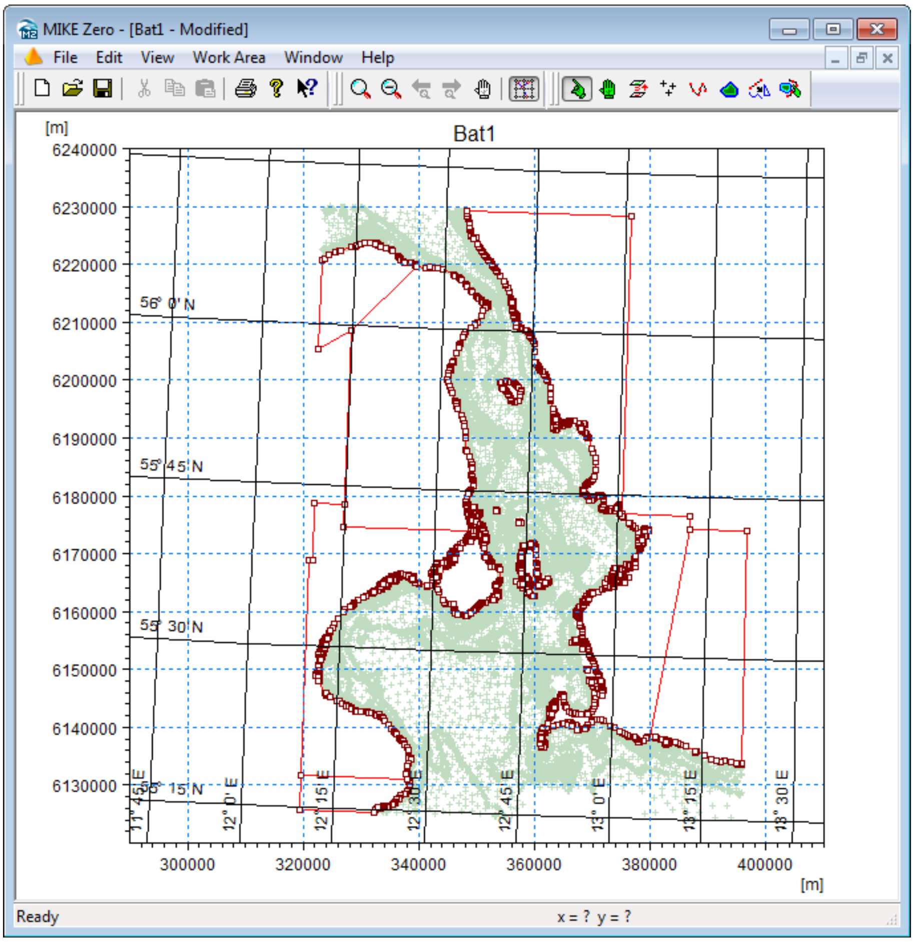


Figure 2.7 Working Area after import of land and water data

Next define the Bathymetry (WorkArea → Grid Bathymetry Management → New)

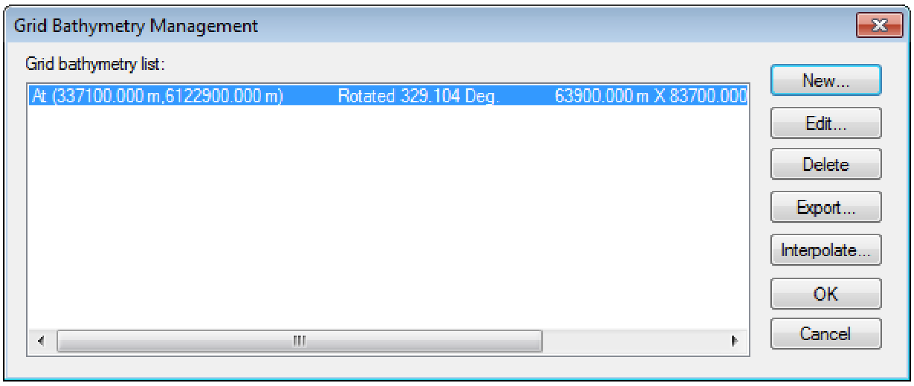


Figure 2.8 Grid Bathymetry Management

Specify the Bathymetry as follows:

- Grid spacing 900 m
- Origin in 337100 m East and 6122900 m North
- Orientation 327 degrees.
- Grid size 72 in x-direction and 94 in y-direction.

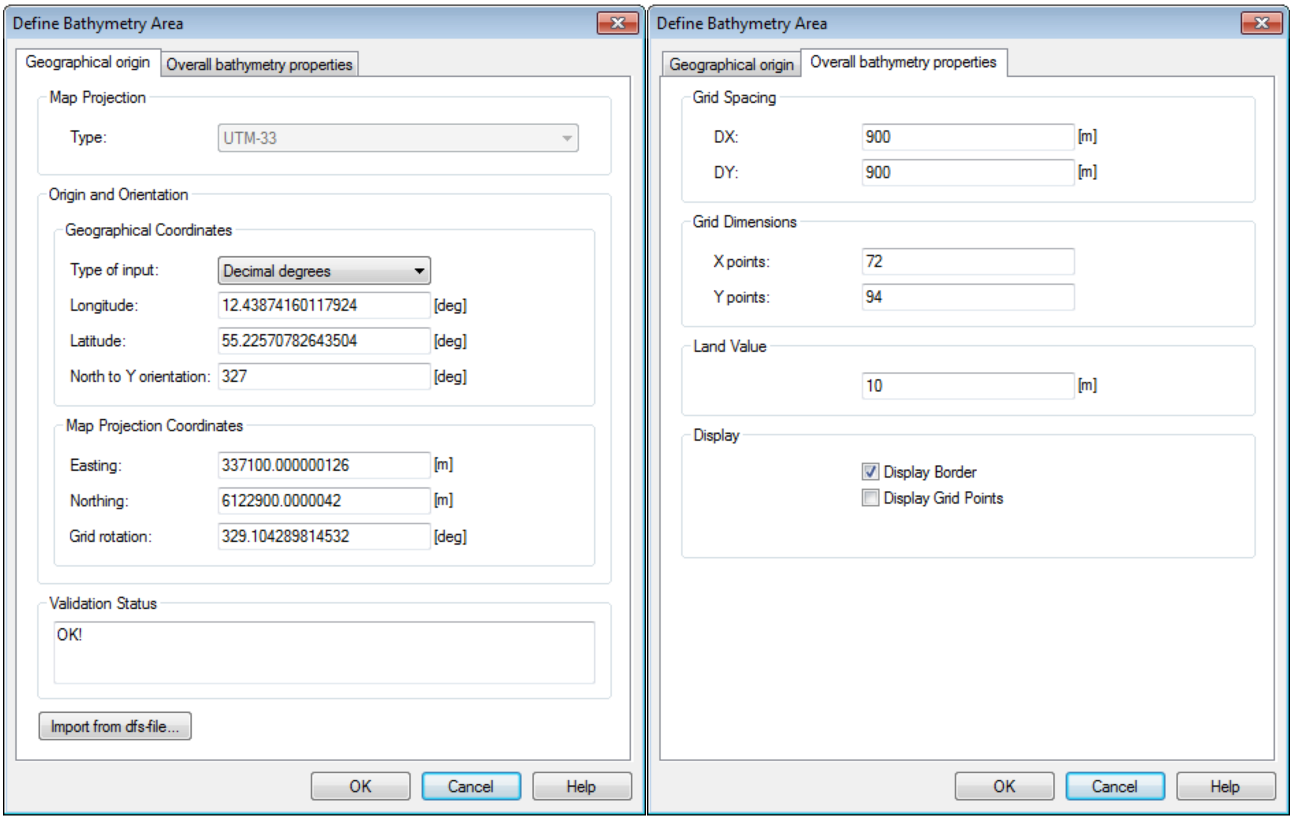


Figure 2.9 Defining the bathymetry

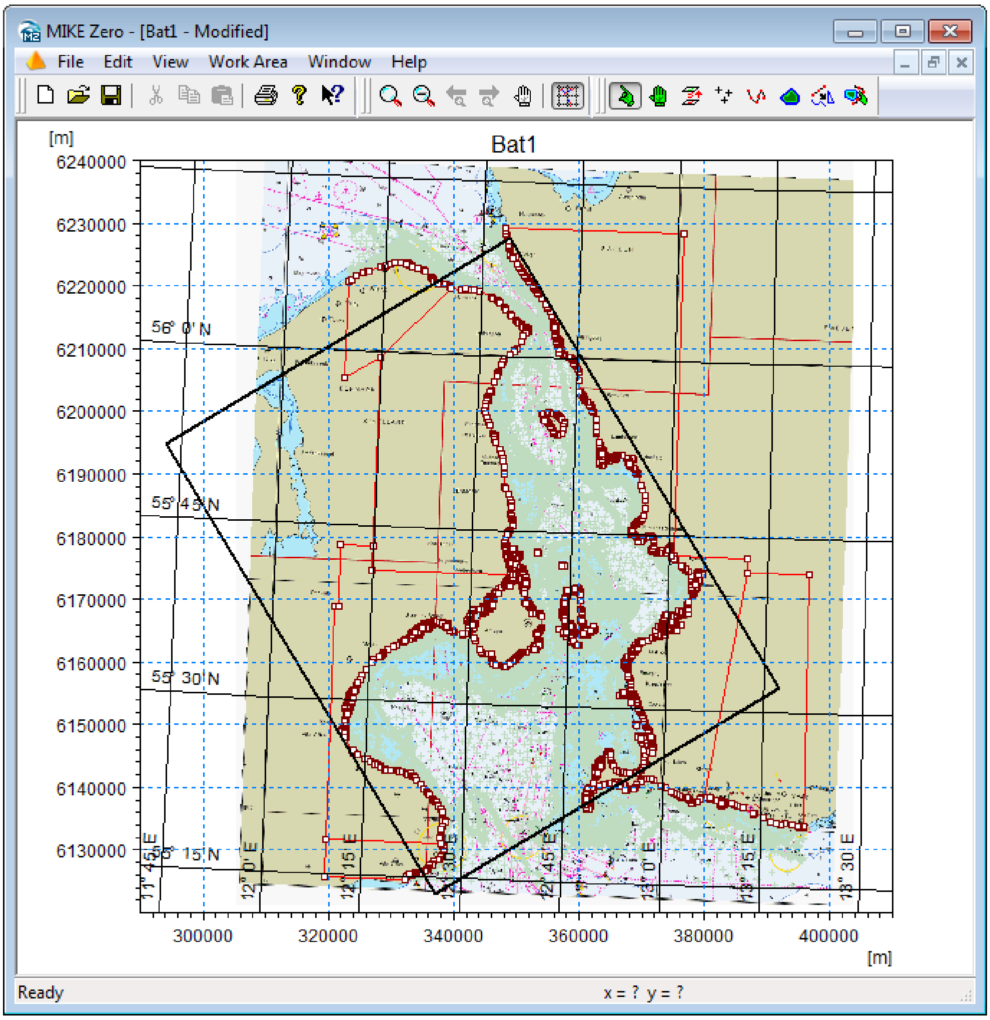


Figure 2.10 Working Area with imported depth values and defined bathymetry (the black rectangle)

The Working Area will now look like the one illustrated in Figure 2.10, where a bitmap actually has been included as a background image (map.gif). The image can be used for manual digitising or adjusting some areas using some of the tools on the menu bar.

Now import data from background (click on 'Import from Background' and drag mouse over points of interest, selected points are now changing colour, finally click on 'Import from Background' once more). Now we are ready for interpolation of the xyz data to grid points (WorkArea → Bathymetry Management → Interpolate). Save the bathymetry specification file and load the generated dfs2 file into the Grid Editor, for example.

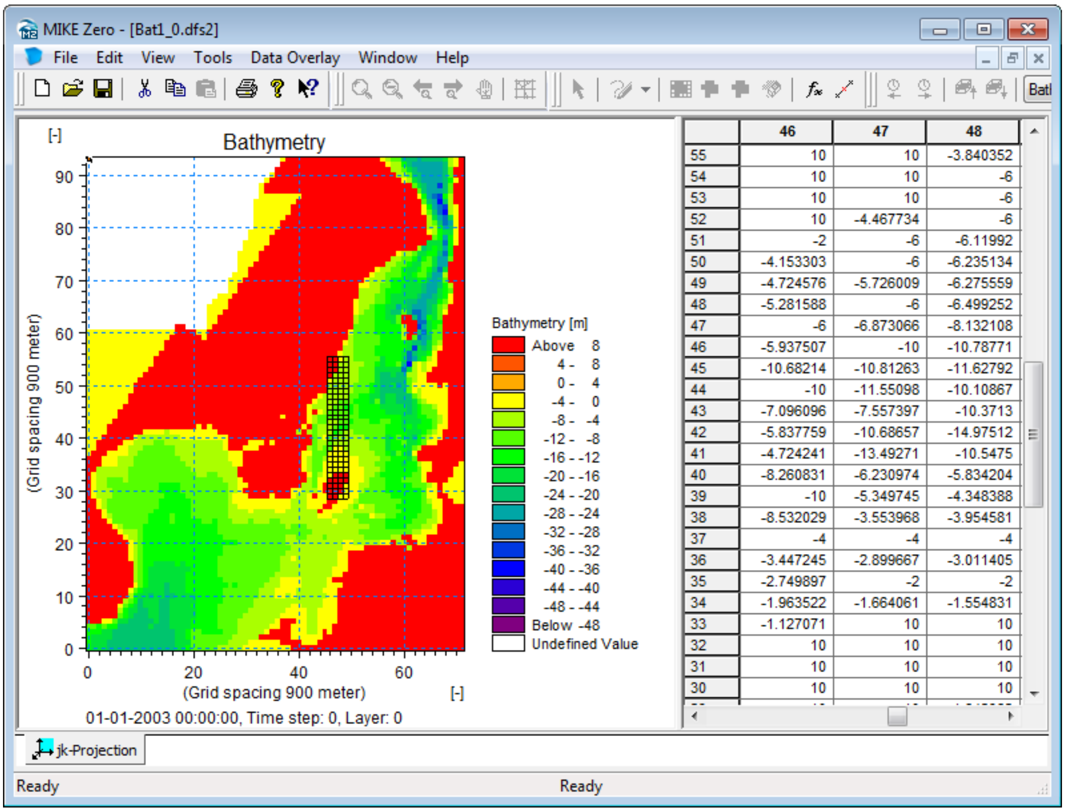


Figure 2.11 Grid Editor showing the interpolated bathymetry

Make some adjustment in order to obtain only two boundaries, namely the northern and southern boundary. Close the eastern boundary by assigning land at the southern part of the eastern boundary and fill up the small lakes around in the bathymetry and inspect the land water boundary carefully. Furthermore, inspect the bathymetry close to the boundaries avoiding areas with deeper water just inside the boundaries. Adjust the north boundary so it is open from 60 to 69 along line 93. Adjust the south boundary so it is open from 1 to 30 along line 0. Use land values to fill the areas close to the boundaries as shown in Figure 2.11.

The Grid Plot control in Plot Composer can now be used to make a plot of the bathymetry. Select File → New → Plot Composer. From the menu bar select Plot → Insert New Plot Object. Select Grid Plot. Right-click on the Plot Area, select properties and select the Master file.

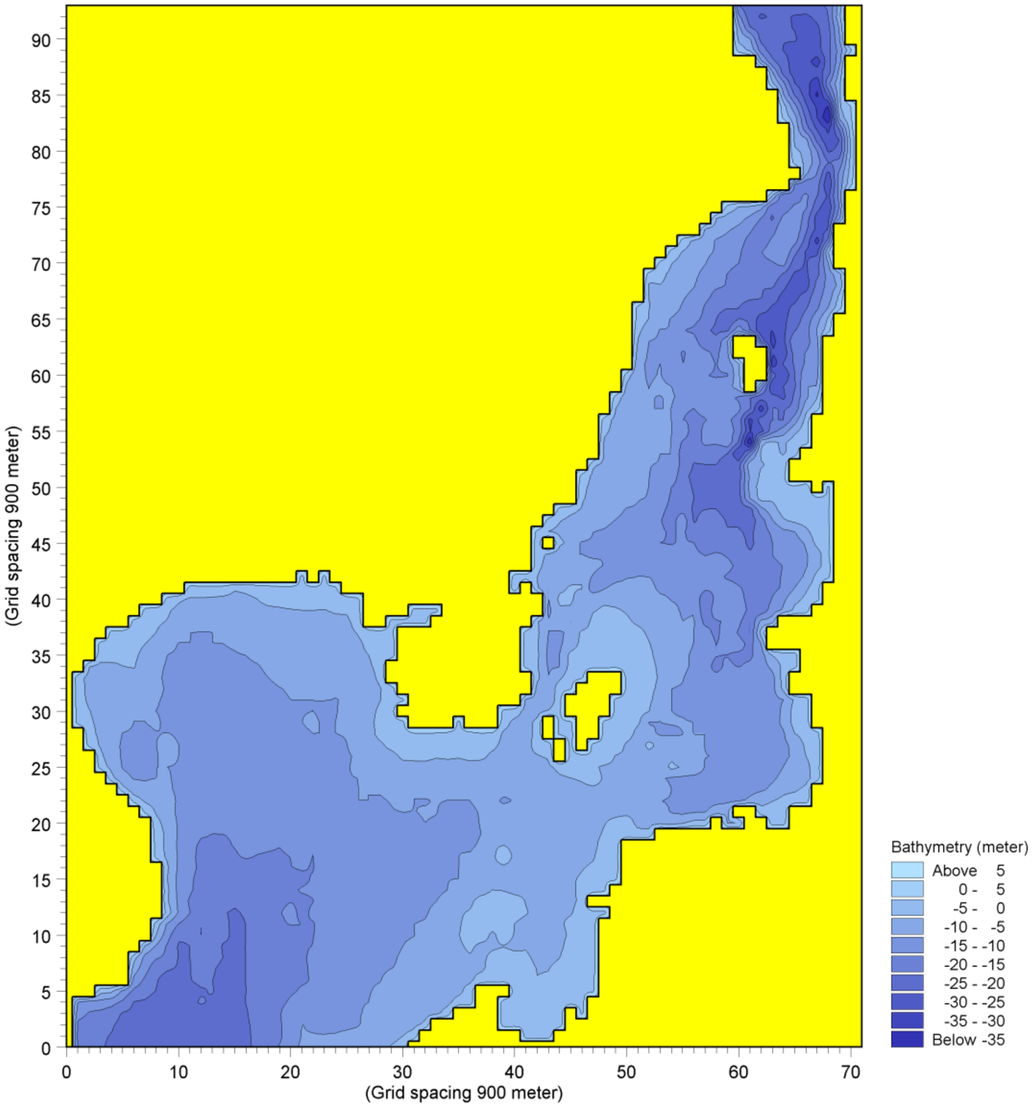


Figure 2.12 Plot of the adjusted Bathymetry

3 Creating the Input Parameters

3.1 Generate Water Level Boundary Conditions

Measured water level recordings from four stations located near the open model boundaries force the Øresund model. Due to strong currents and because the influence of the Coriolis effect is significant, water level recordings at each end of the open boundary are required.

The objective of this example is based on measured recordings from four stations to create two line series with water level variations. The locations of the four stations are listed in Table 3.1.

Table 3.1 Measured water level data

Station	Data File	Position	
		Easting (m)	Northing (m)
WL1	WL1.txt	385929	6243197
WL2	WL2.txt	338957	6220549
WL3	WL3.txt	348310	6225949
WL4	WL4.txt	362880	6137713

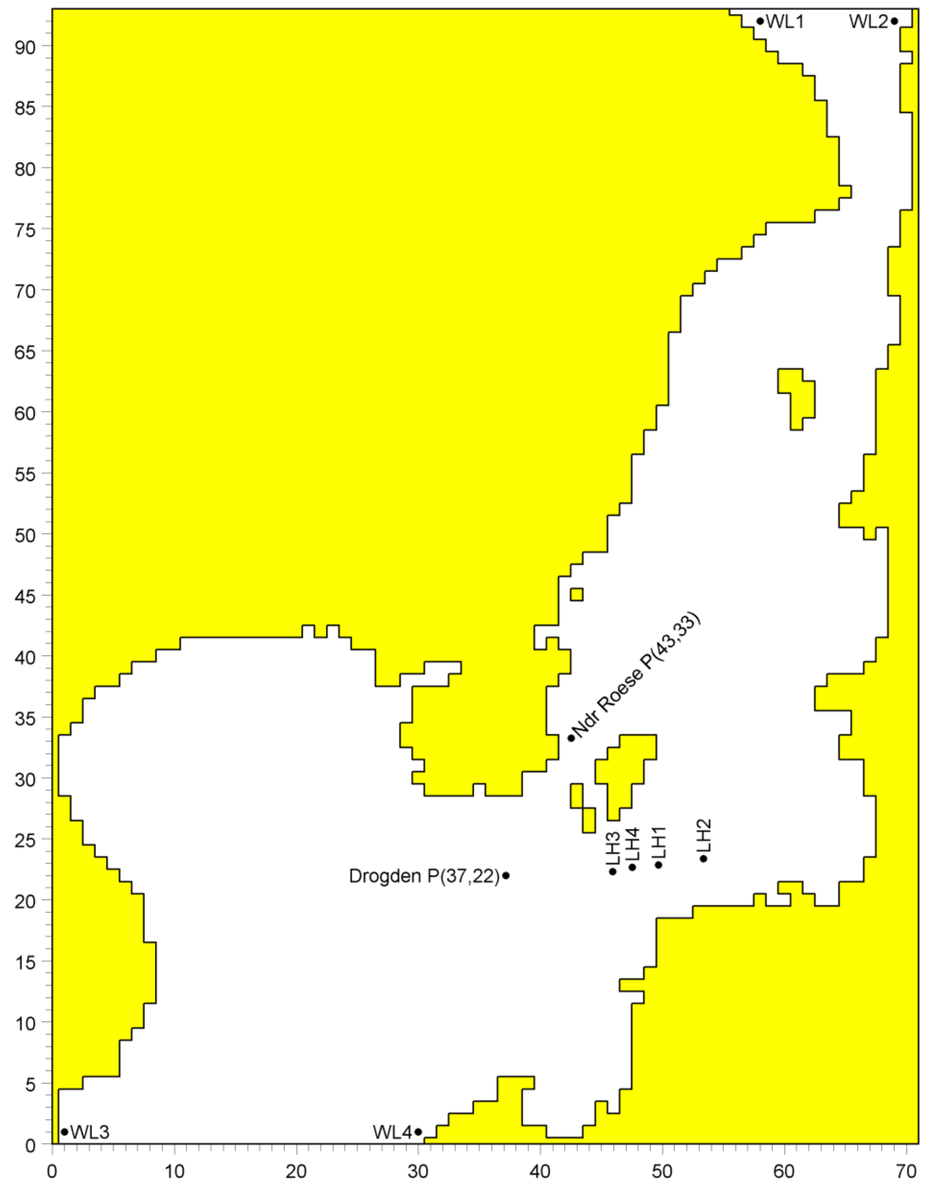


Figure 3.1 Map showing the individual stations (LH = Light House)

3.1.1 Importing measured water levels to time series file

Open the Time Series Editor. Select the ASCII template. Open the text file WL1.txt. Change the time description to 'Equidistant Calendar Axis' and click OK. Then right-click on the generated data and select properties change the type to 'Water Level'. Save the data in wl1.dfs0. Repeat these steps for the remaining 3 stations.

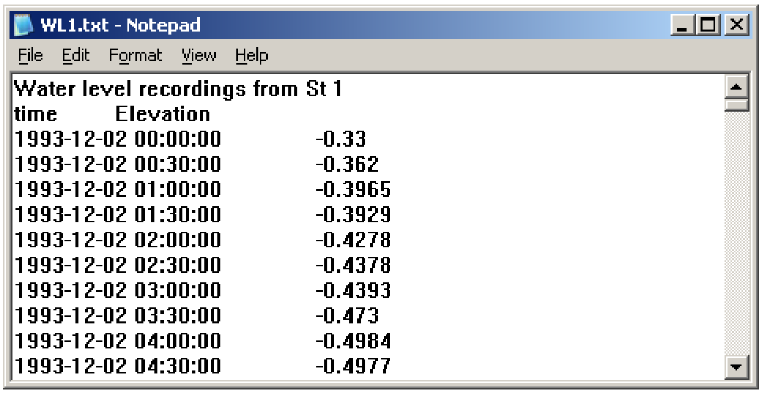


Figure 3.2 ASCII file with water level recordings from Station 1

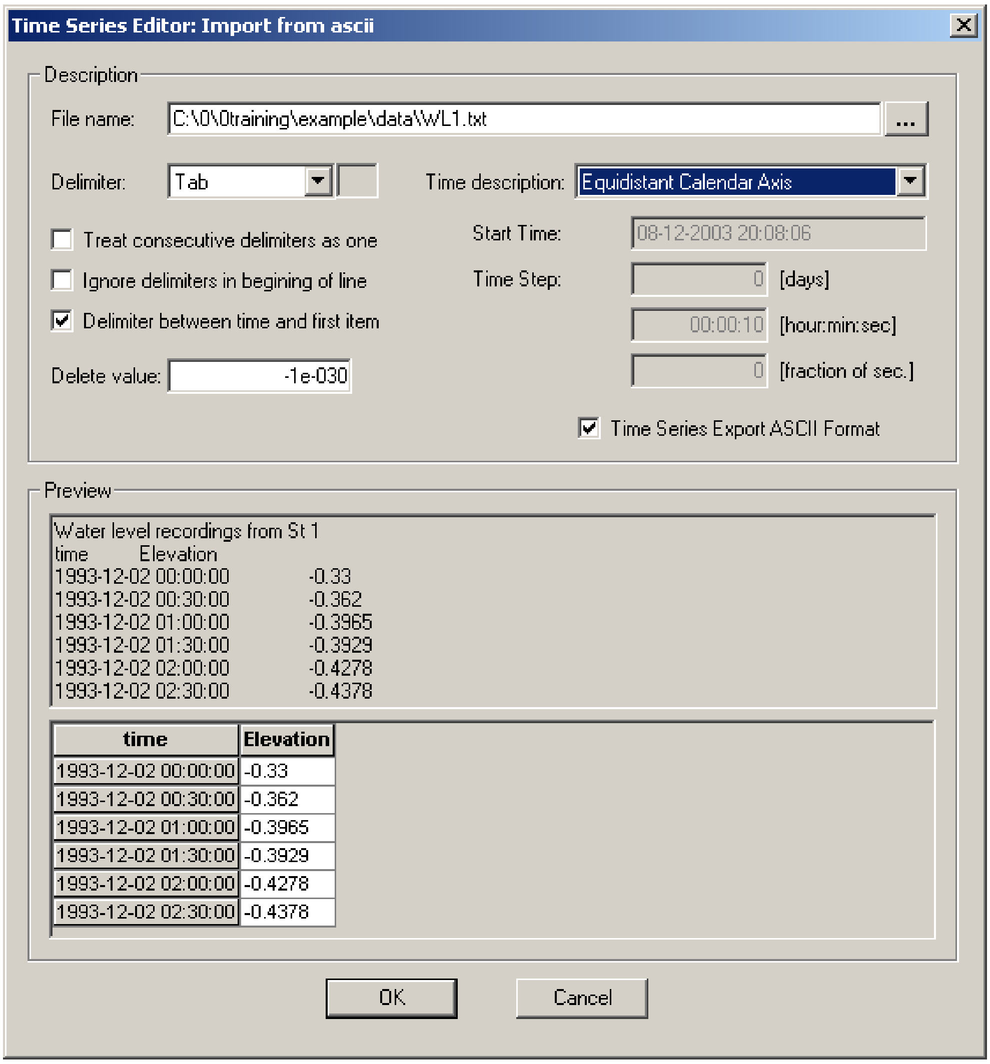


Figure 3.3 Time Series Editor Import template

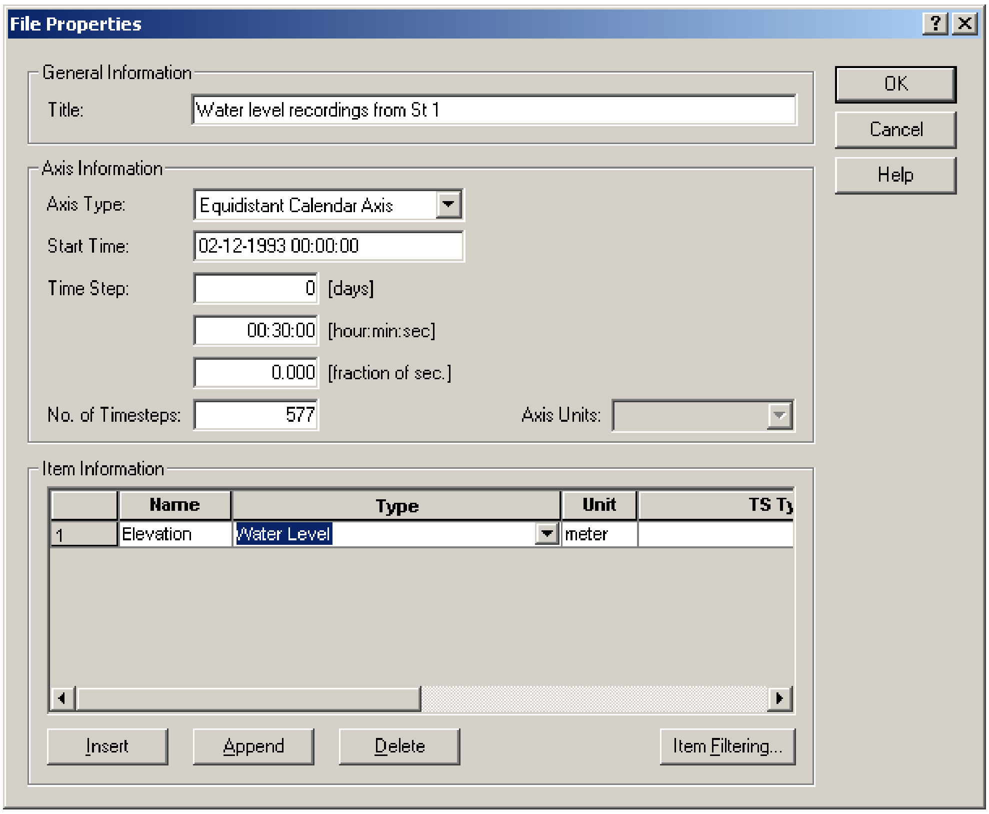


Figure 3.4 Time Series Properties

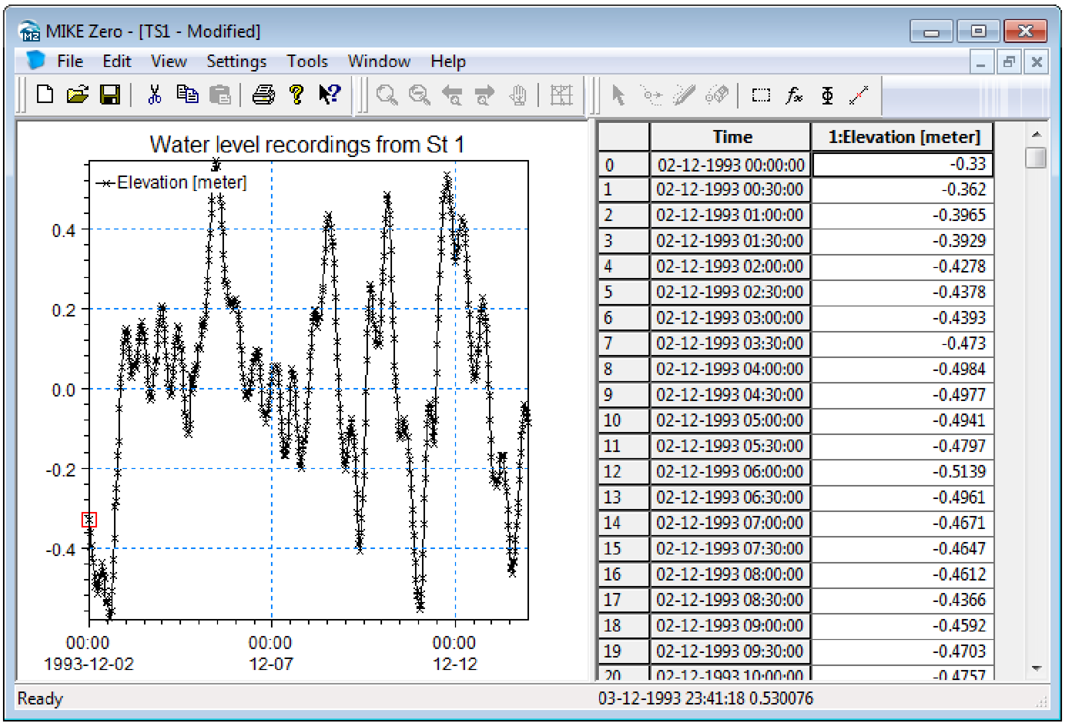


Figure 3.5 Time Series Editor with imported Water Levels from Station 1

To make a plot of the water level time series, open the plot composer select 'plot' → 'insert a new plot object' and select 'Time Series Plot' (see Figure 3.6). Right-click on the plot area and select properties. Then find the actual time series file and change some of the properties for the plot, if any (see Figure 3.8).

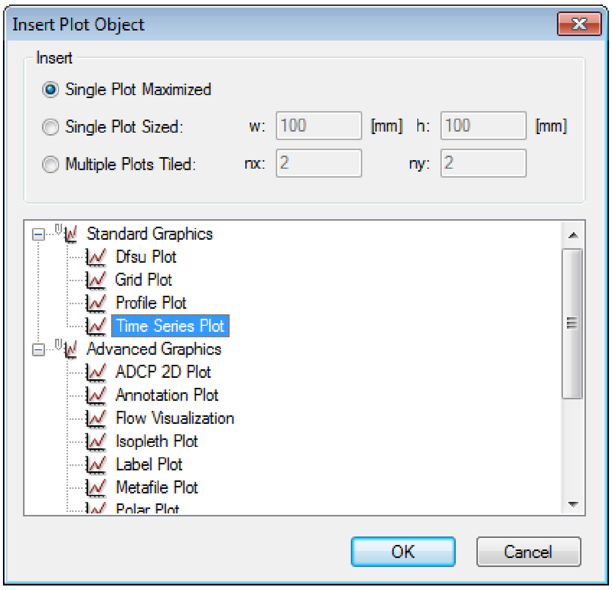


Figure 3.6 Plot Composer inserted a new Plot Object as Time Series

If several time series files are to be plottet in the same plot, right-click on the plot area and select new item (see Figure 3.7).

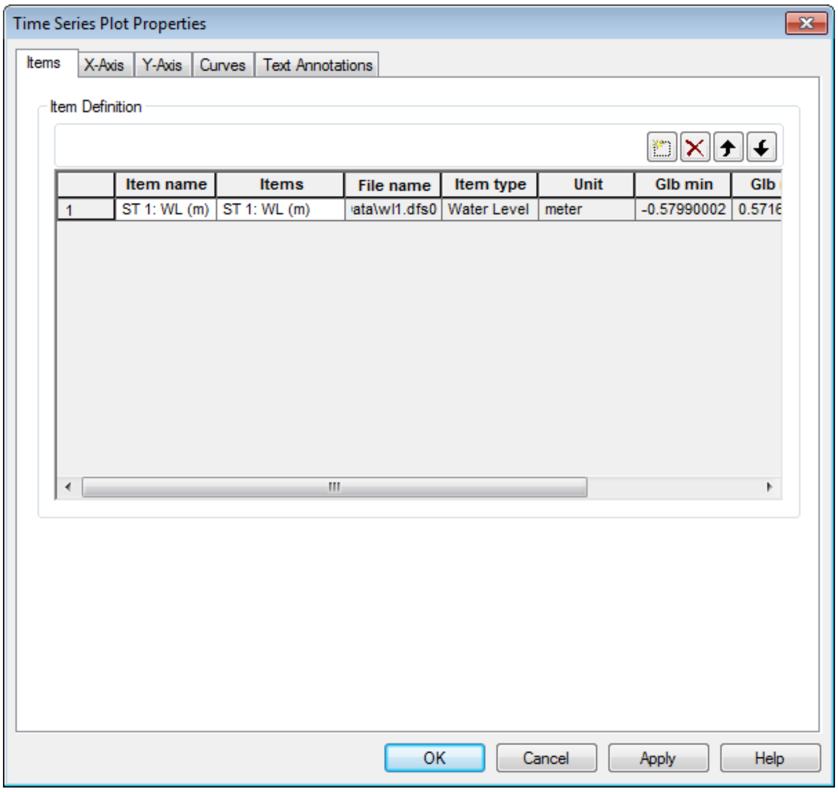


Figure 3.7 Plot Composer Time Series Plot Properties select new item

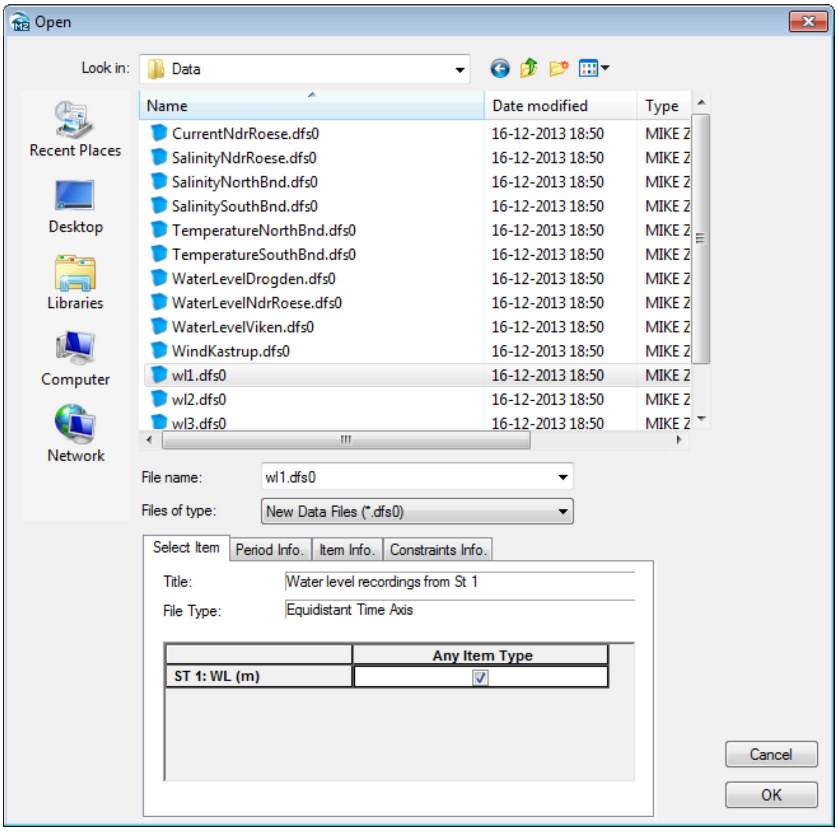


Figure 3.8 Plot Composer properties select time series to plot

Figure 3.9 and Figure 3.10 show the measured water levels at the two boundaries.

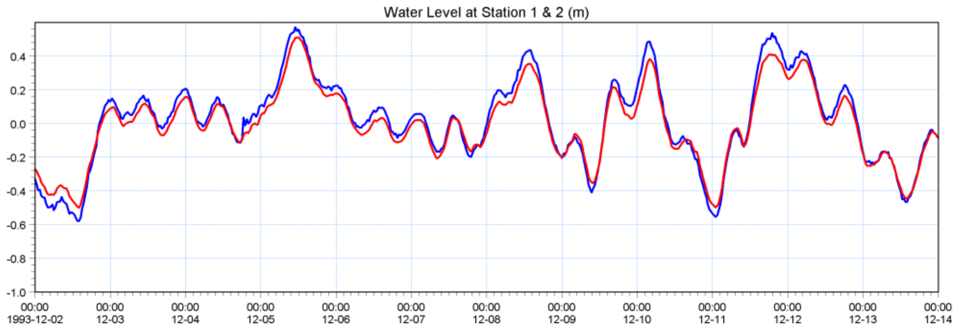


Figure 3.9 Combined Time Series at the North Boundary Station 1 and 2

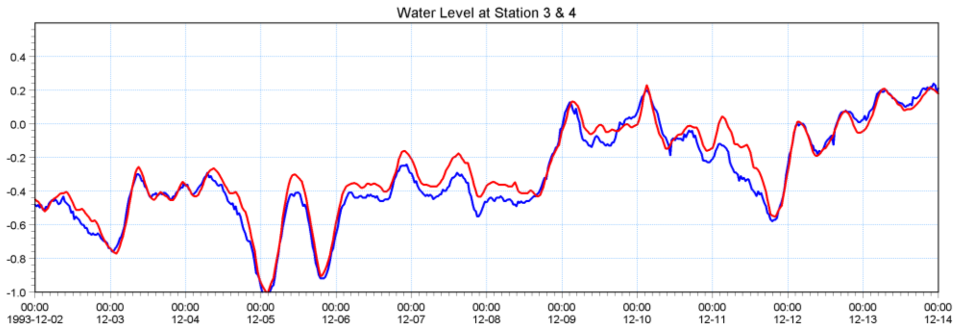


Figure 3.10 Combined Time Series at the North Boundary Station 3 and 4

3.1.2 Creating boundary conditions

Now you must define the boundary in a shape that correlates to the bathymetry.

Determine the width of the two boundaries (use for instance Grid Editor). Load Profile Series and select 'Blank ...'. Fill in the required information:

North boundary

- Start date 1993-12-02 00:00:00
- Time step: 1800s
- No. of time steps: 577
- No. of grid points: 10 (60 – 69 line 93)
- Grid Step: 900m

Load Station 1 (WL1.dfs0) and copy and paste the water levels to the profile Series Editor at point 0. Next load Station 2 (WL2.dfs0) and copy and paste the levels into point 9 (see Figure 3.12). Then select tools and interpolate the profile series. Save the profile series as WLN.dfs1 (see Figure 3.13).

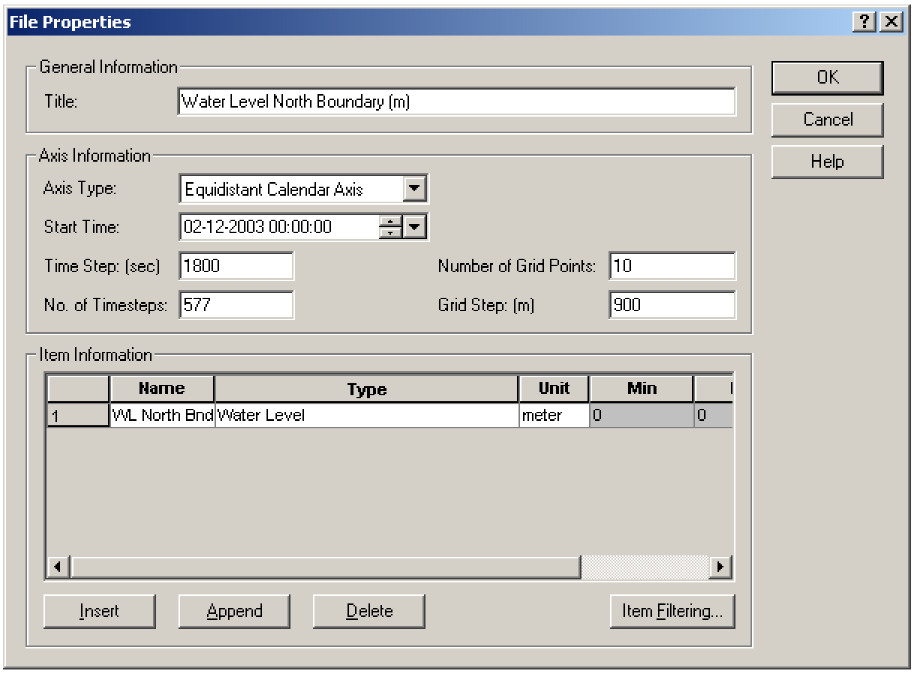


Figure 3.11 Profile Series Properties

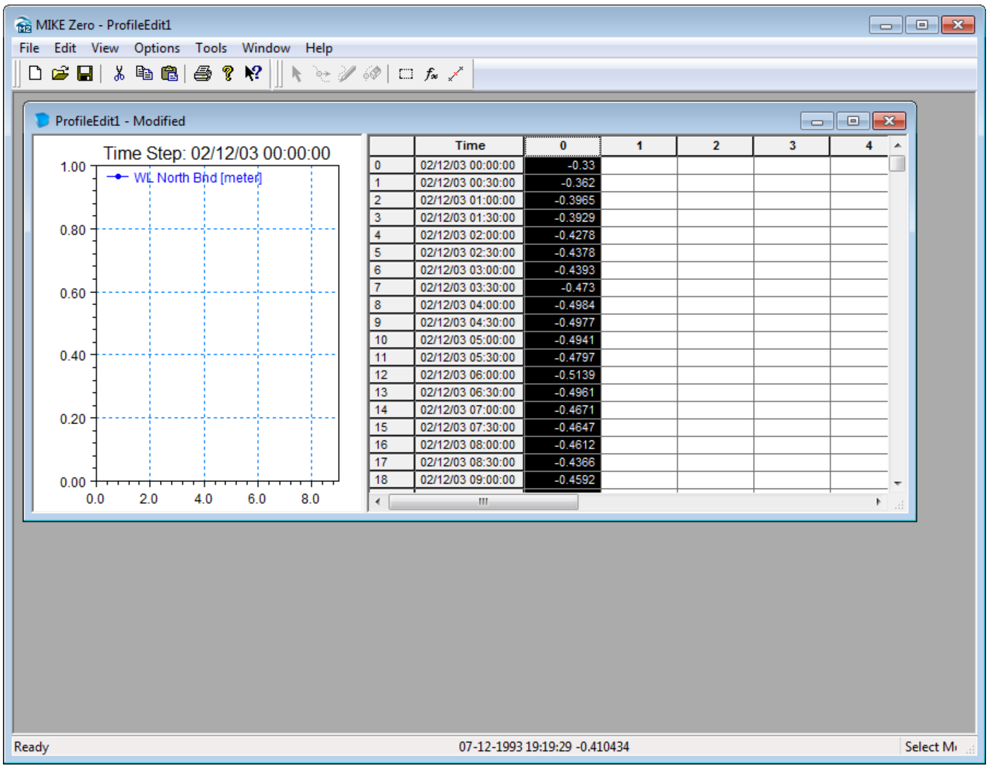


Figure 3.12 Copying WL1 and WL2 into Profile Series Editor

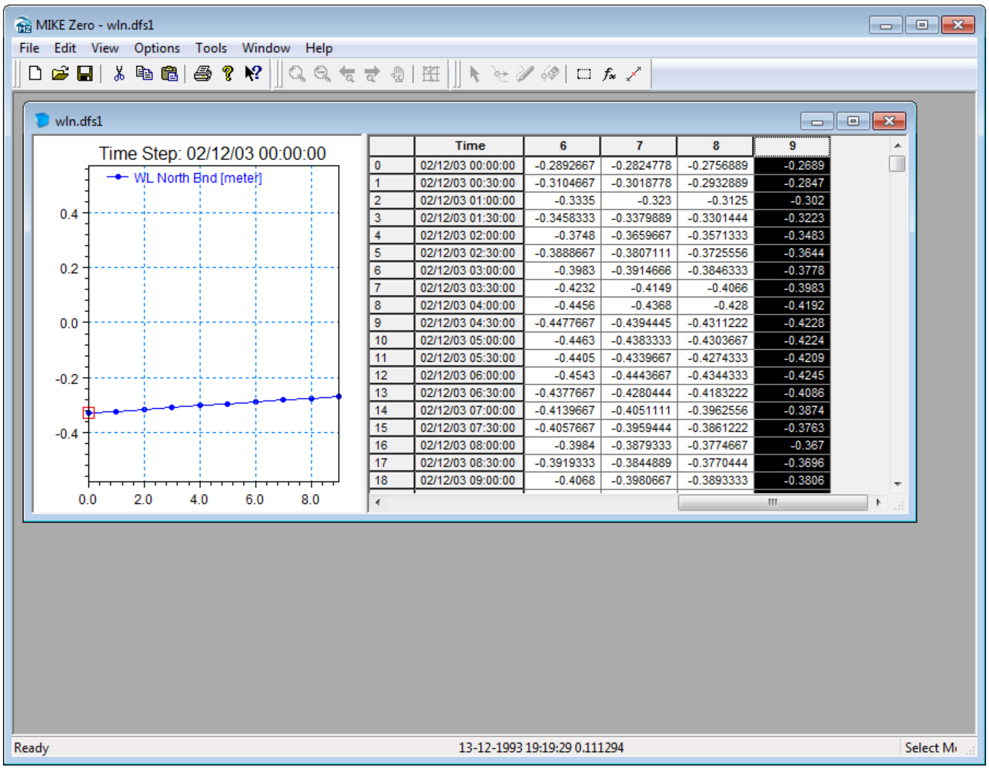


Figure 3.13 Interpolated Water Level at the North boundary

Repeat the same steps with the southern boundary with the similar information except the number of grid points and using the recorded water levels at station 3 (WL3.dfs0) and 4 (WL4.dfs0) and save the resulting file as WLS.dfs1.

South boundary

- Start date 1993-12-02 00:00:00
- Time step: 1800s
- No. of time steps: 577
- No. of grid points: 30 (1 – 30 line 0)
- Grid Step: 900m

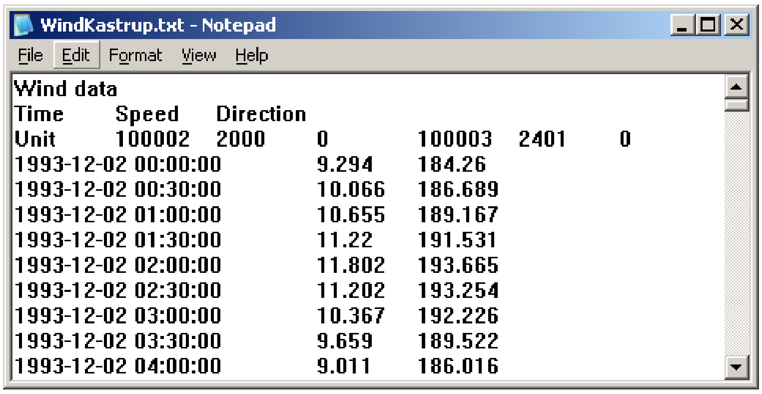
3.2 Initial Surface Level

The initial surface level is calculated as a mean level between the northern and the southern boundary at the beginning of the simulation. Load the two boundary files and approximate a mean level at the start of the simulation. We will use –0.38m.

3.3 Wind Conditions

Wind recordings from Kastrup Airport will form the wind condition as time series constant in space. Load the time series editor and import the ASCII file ‘WindKastrup.txt’ as equidistant calendar axis. Save the file in ‘WindKastrup.dfs0’. Time series of the wind speed and direction is shown in Figure 3.14, Figure 3.15 and Figure 3.16.

A more descriptive presentation of the wind can be given as a wind speed diagram. Start the ‘Plot composer’ insert a new plot object select ‘Wind/Current Rose Plot’ and then select properties and select the newly created file ‘WindKastrup.dfs0’ and change properties to your need. The result is shown in Figure 3.17.



WindKastrup.txt - Notepad

File Edit Format View Help

```
Wind data
Time        Speed     Direction
Unit        100002    2000      0         100003    2401      0
1993-12-02 00:00:00             9.294     184.26
1993-12-02 00:30:00             10.066    186.689
1993-12-02 01:00:00             10.655    189.167
1993-12-02 01:30:00             11.22     191.531
1993-12-02 02:00:00             11.802    193.665
1993-12-02 02:30:00             11.202    193.254
1993-12-02 03:00:00             10.367    192.226
1993-12-02 03:30:00             9.659     189.522
1993-12-02 04:00:00             9.011     186.016
```

Figure 3.14 ASCII file with Wind speed and direction from Kastrup Airport

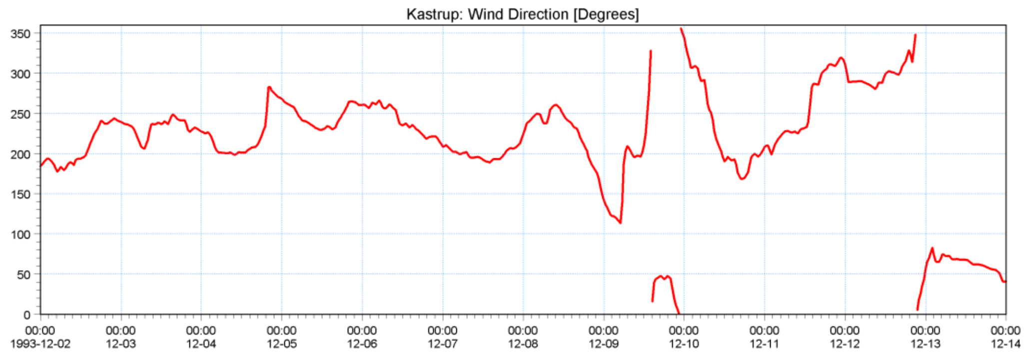


Figure 3.15 Measured wind direction at Kastrup Airport

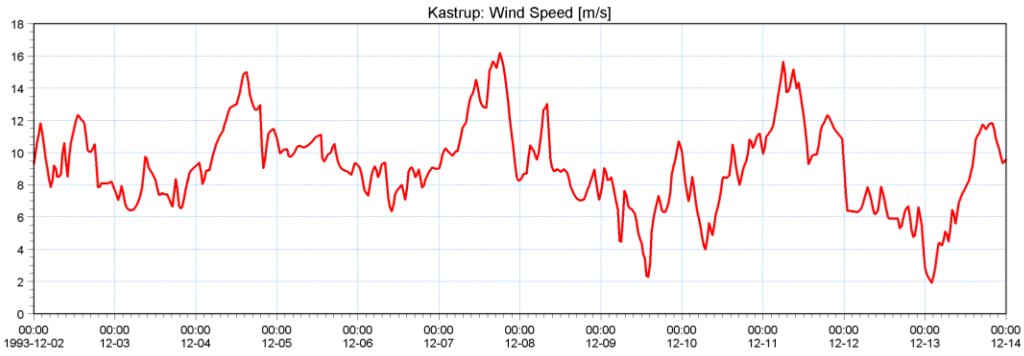


Figure 3.16 Measured wind speed at Kastrup Airport

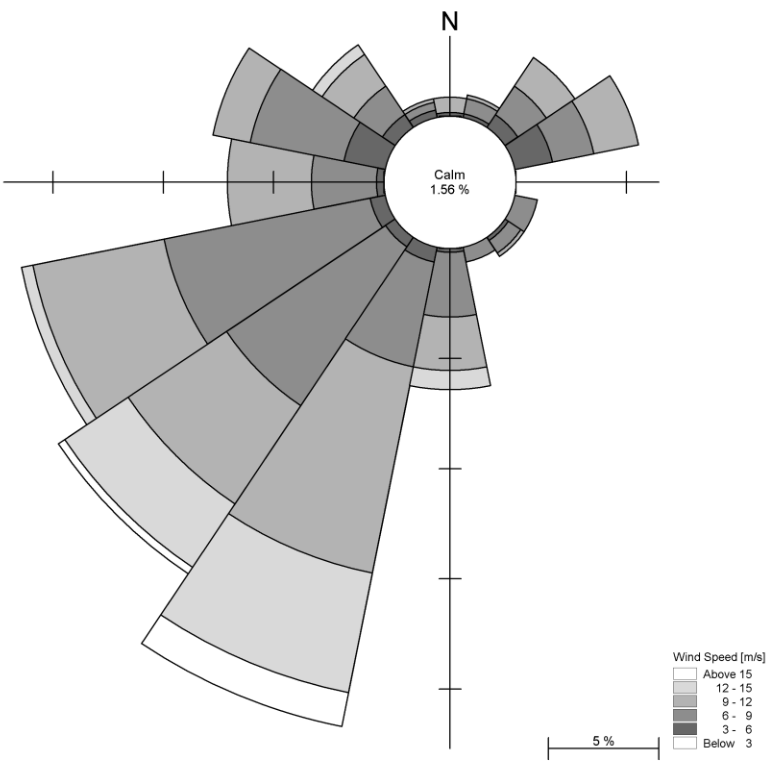
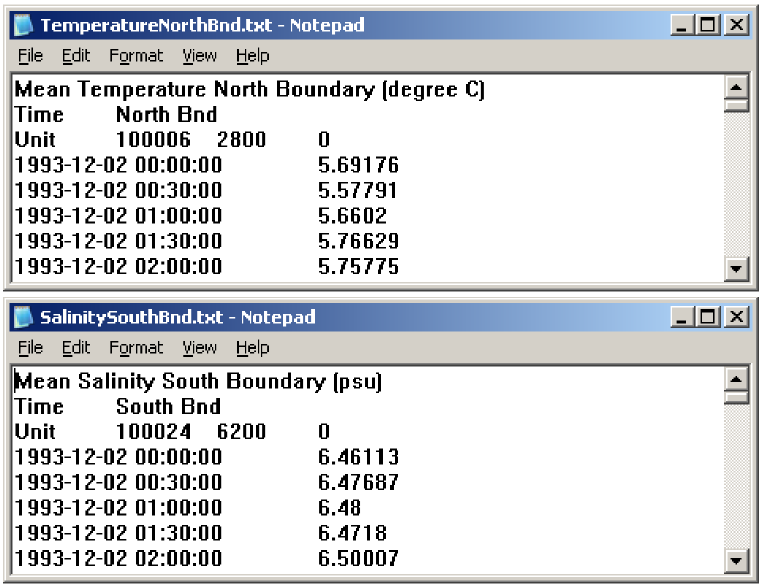


Figure 3.17 Wind Rose from Kastrup Airport

3.4 Density Variation at the Boundary

As the area of interest is dominated with outflow of fresh water from the Baltic Sea and high saline water intruding from the Ocean measurement of salinity and temperature has taken place at the boundaries. Depth average values of these measurements are given as ASCII files named: SalinityNorthBnd.txt, SalinitySouthBnd.txt, TemperaturNorthBnd.txt and TemperaturSouthBnd.txt. Examples are shown in Figure 3.18. Import these ASCII files with the time series editor and save the files with the same name but with extension dfs0. Remember to change the time description to ‘equidistant calendar axis’.


TemperatureNorthBnd.txt - Notepad
File Edit Format View Help

```
Mean Temperature North Boundary (degree C)
Time       North Bnd
Unit       100006   2800     0
1993-12-02 00:00:00          5.69176
1993-12-02 00:30:00          5.57791
1993-12-02 01:00:00          5.6602
1993-12-02 01:30:00          5.76629
1993-12-02 02:00:00          5.75775
```

A

SalinitySouthBnd.txt - Notepad
File Edit Format View Help

```
Mean Salinity South Boundary (psu)
Time       South Bnd
Unit       100024   6200     0
1993-12-02 00:00:00          6.46113
1993-12-02 00:30:00          6.47687
1993-12-02 01:00:00          6.48
1993-12-02 01:30:00          6.4718
1993-12-02 02:00:00          6.50007
```

B

Figure 3.18 ASCII files with average temperature at the North boundary (A) and average salinity at the South boundary (B)

A plot of the measured data is shown in Figure 3.19 and Figure 3.20.

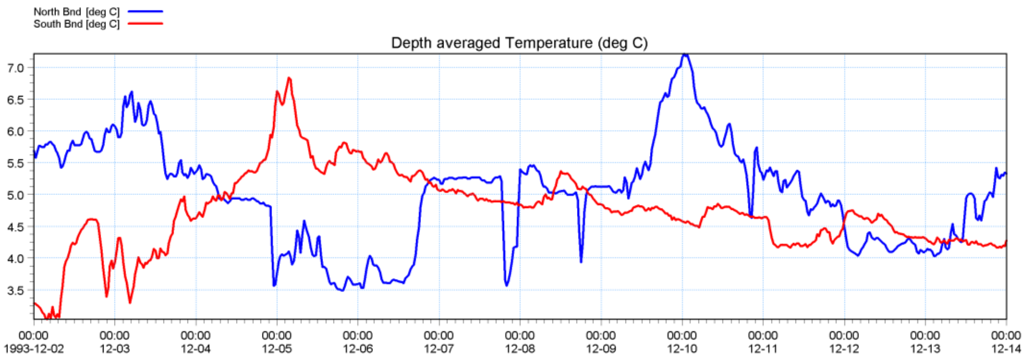


Figure 3.19 Measured average temperature at North and South boundary

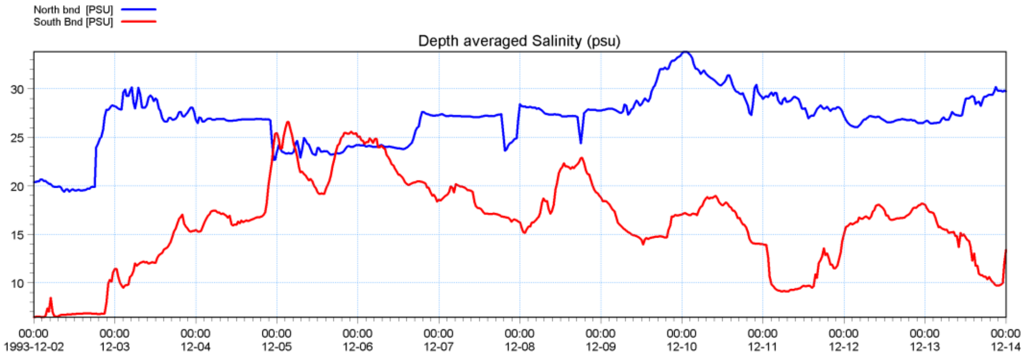


Figure 3.20 Measured average salinity at the North and South boundary

4 Model Setup

4.1 Flow Model

We are now ready to set up the model using the above boundary conditions and forcing. Initially we will use the default parameters and not take into account the effect of the density variation at the boundaries. The setup consists of the following parameters:

Parameter	Value
Module	Hydrodynamics only
Bathymetry	Bathy900
Simulation Period	1993-12-02 00:00 – 1993-12-14 00:00
Time step	300s
No. of Time steps	3456
Enable Flood and Dry	Drying depth 0.2 Flooding depth 0.3
Initial surface level	0.38
North Boundary	(60 – 69) along line 93
North Boundary	Type 1 data: WLN.dfs1
South Boundary	(1 – 30) along line 0
South Boundary	Type 1 data: WLS.dfs1
Eddy Viscosity	Smagorinsky formulation, velocity based. Constant 0.5
Resistance	Manning number. Coefficient 32
Result file	HD01.dfs2

In the following, screen dumps of the individual input pages are shown and a short explanation is provided.

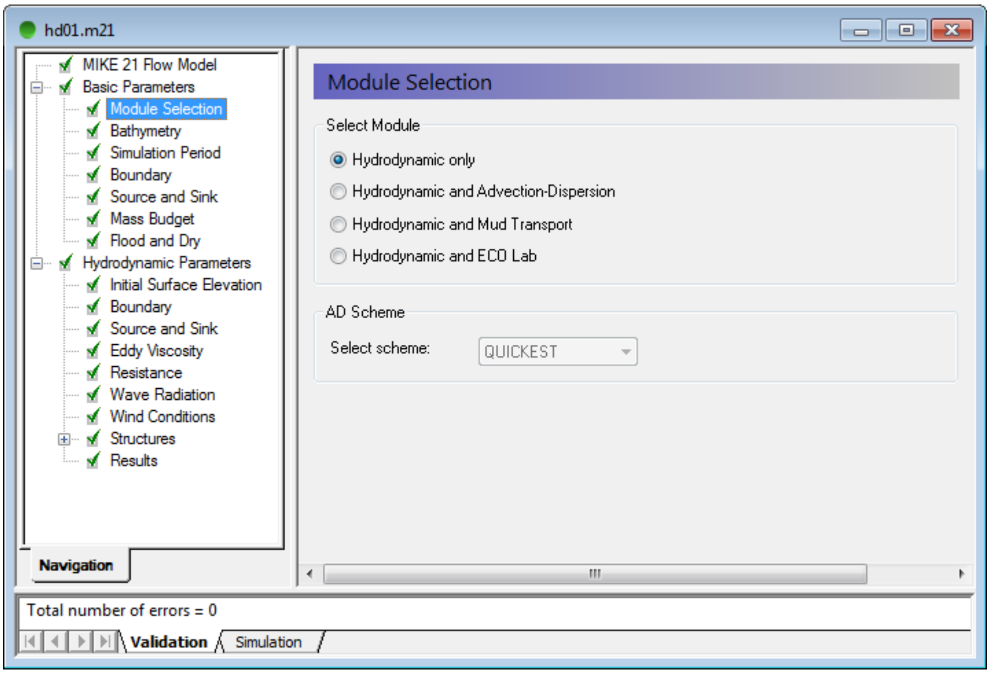


Figure 4.1 Flow Model: Module Selection

Specify Hydrodynamics only

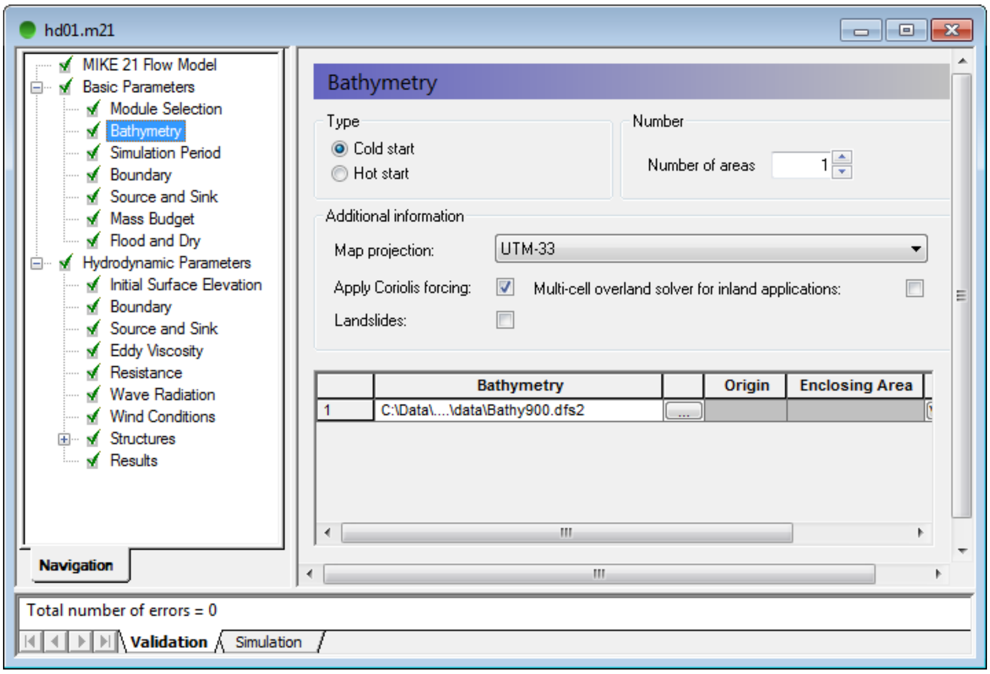


Figure 4.2 Flow Model: Bathymetry

Specify the bathymetry Bathy900.dfs2. The projection zone will be defined as UTM-33 automatically.

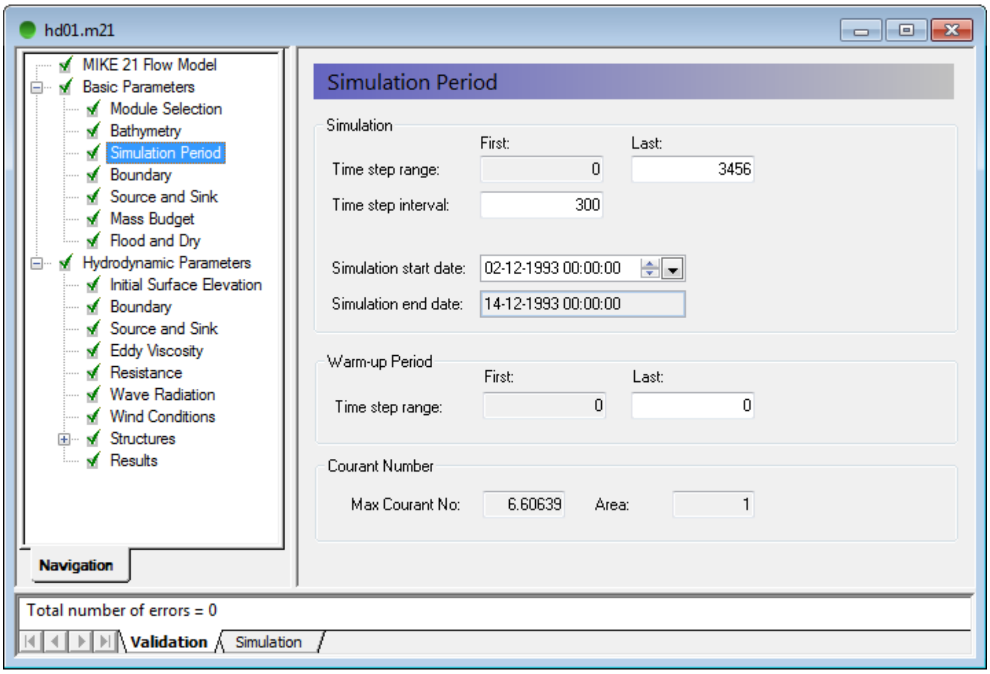


Figure 4.3 Flow Model: Simulation period

Specify a time step, which will result in a Courant between 1 and 7. Start with a time step of 300s. The time step range must be specified to 3456 time steps in order to simulate a total period of 12 days.

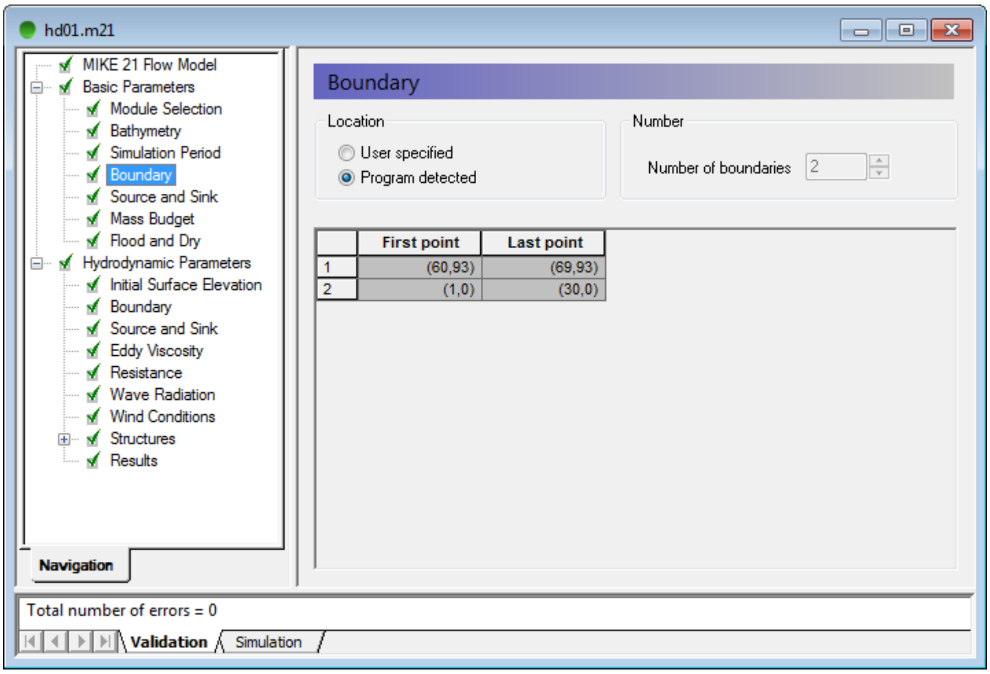


Figure 4.4 Flow Model: Boundary

Select Program detected boundary conditions. If you have more than two boundaries, you must inspect you bathymetry again.

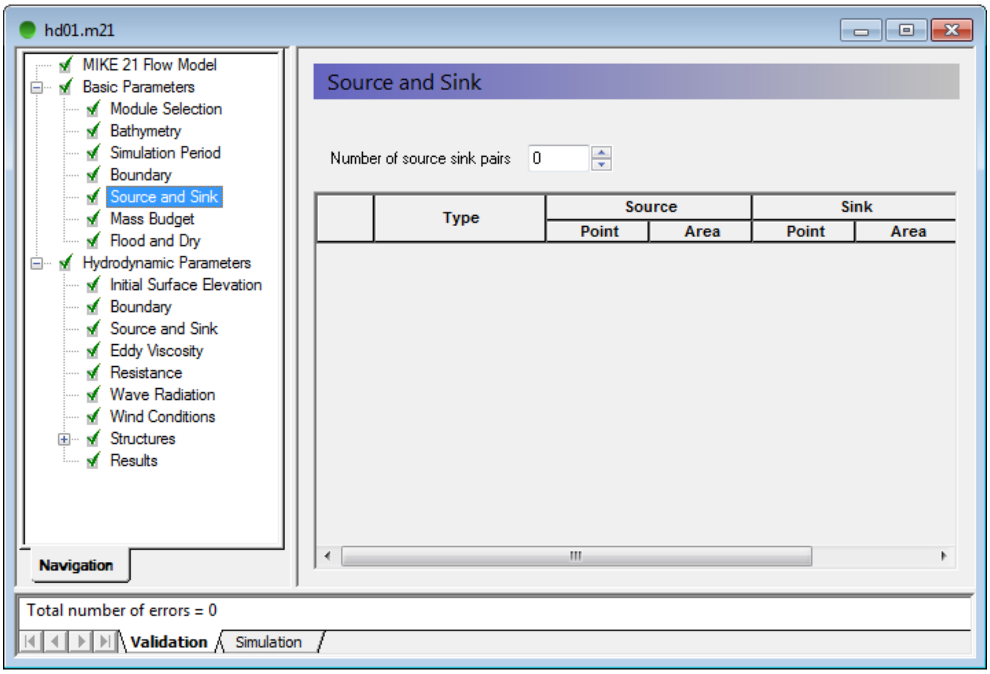


Figure 4.5 Flow Model: Source and Sink

If you have any sources or sinks these have to be specified. Here in our case we do not have any.

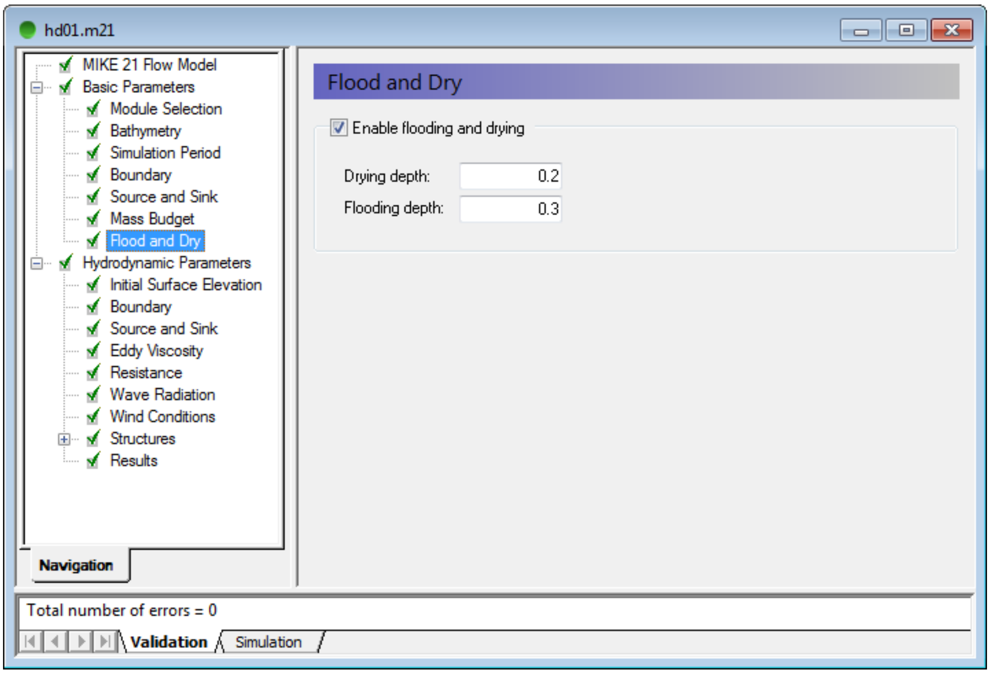


Figure 4.6 Flow Model: Flood and Dry

Specify Flooding and Drying depth. In our case, select the default values.

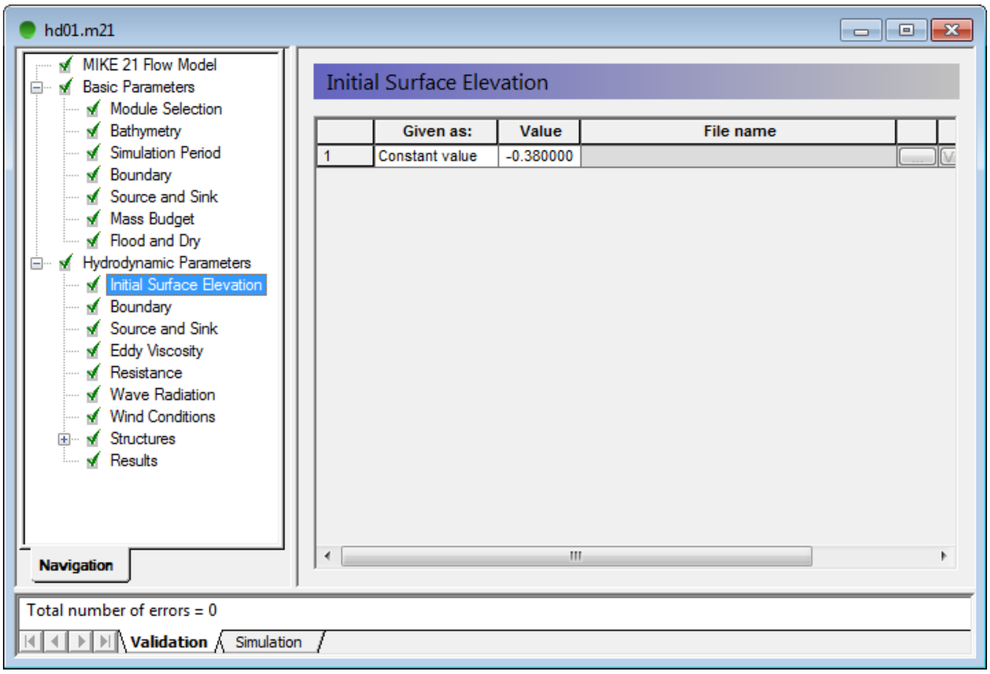


Figure 4.7 Flow Model: Initial Surface Level

After inspection of the boundary condition at the simulation start time decide the initial surface level, or if the variation is large decide for an initial surface level map. In this case we will use a constant level of -0.38m, which is the average between our north and south boundary at the start of the simulation.

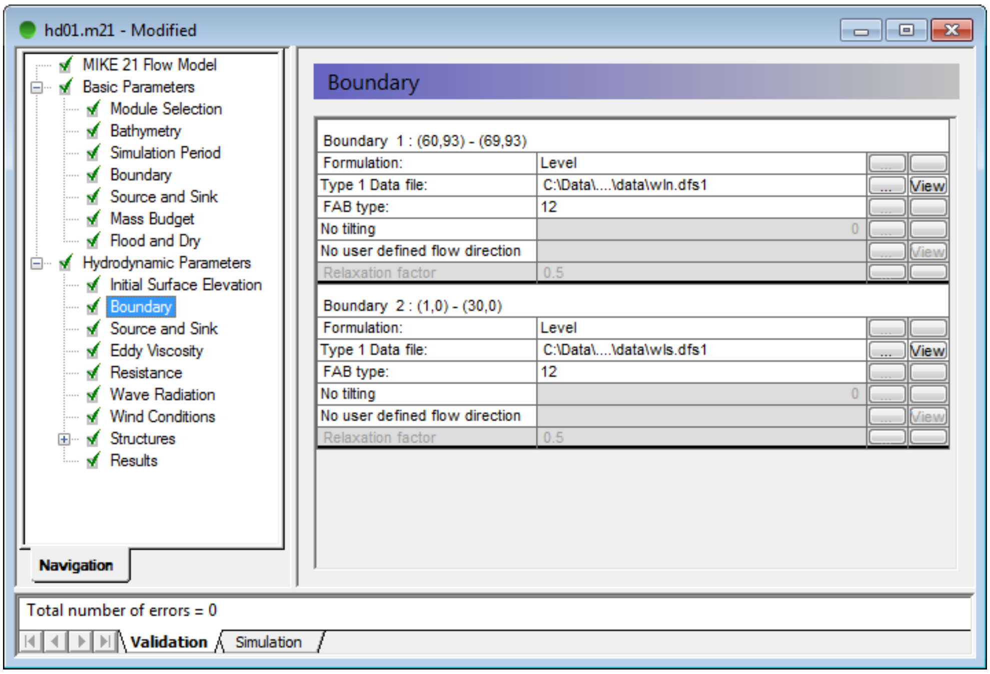


Figure 4.8 Flow Model: Boundary

Specify the type of boundary as a type 1 profile time series and select wln.dfs1 at the northern and wls.dfs1 at the southern boundary.

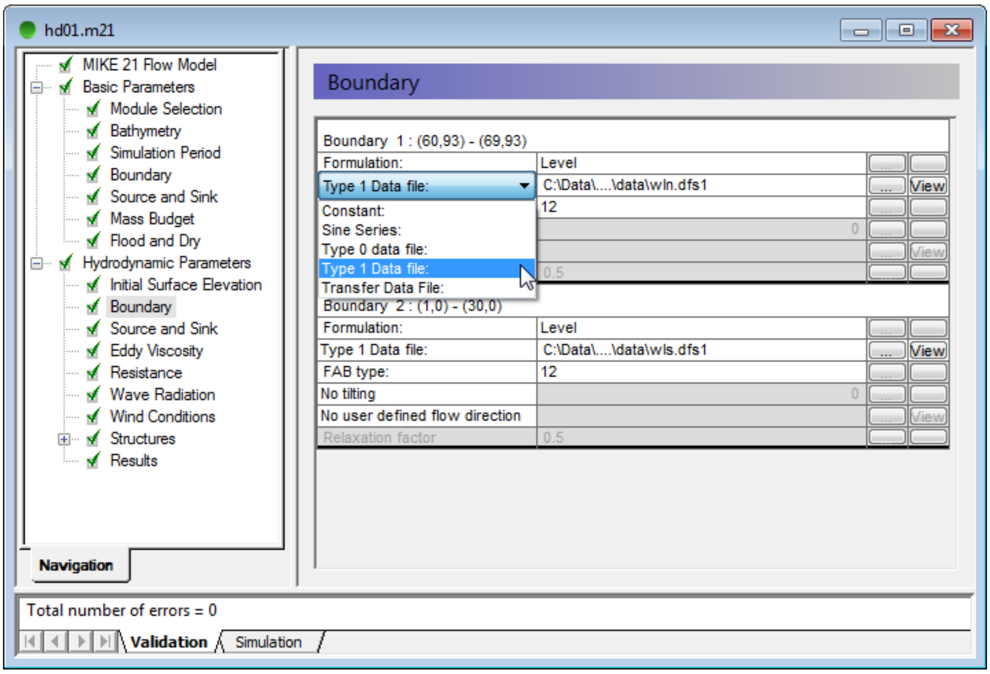


Figure 4.9 Flow Model: Boundary Type

To select the boundary type, move the cursor to the type field and click on this then select Type 1 Data file.

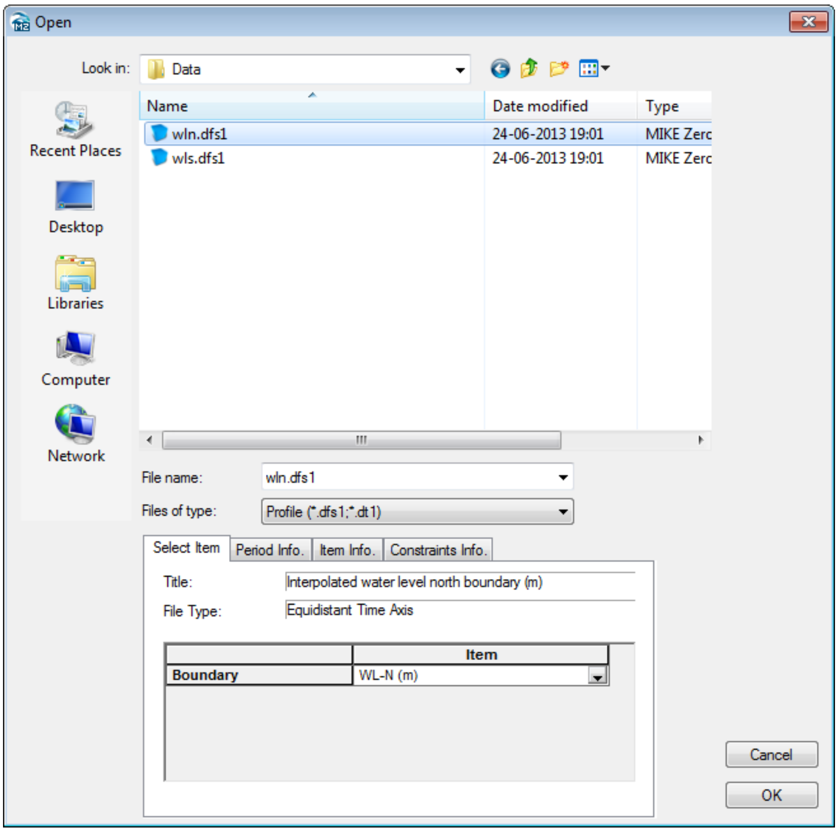


Figure 4.10 Flow Model: Boundary Select File

Next, locate the appropriate data file in the file box to the right.

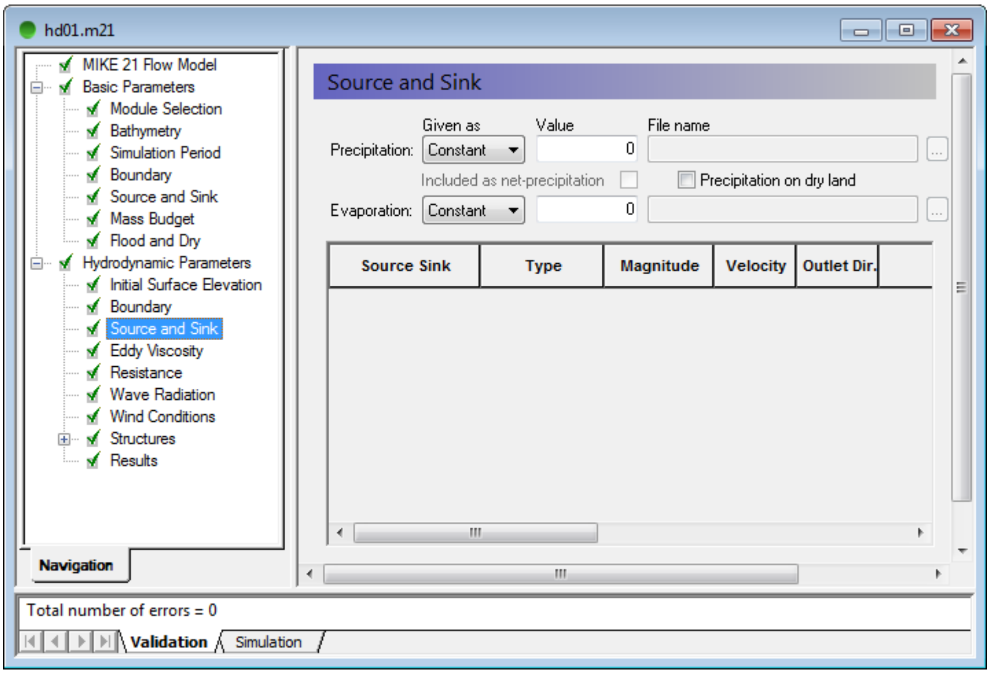


Figure 4.11 Flow Model: Source and Sink

The discharge magnitude and velocity for each source and sink is given here. But, since we do not have any sources, leave it blank.

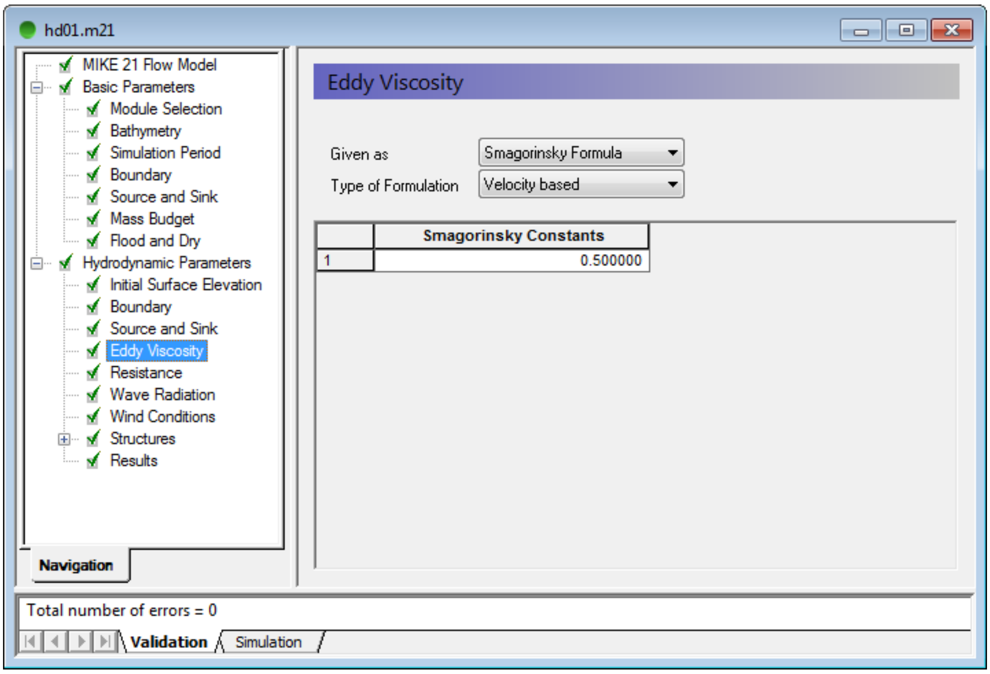


Figure 4.12 Flow Model: Eddy Viscosity

Change the default Eddy viscosity to Smagorinsky formulation with a coefficient of 0.5.

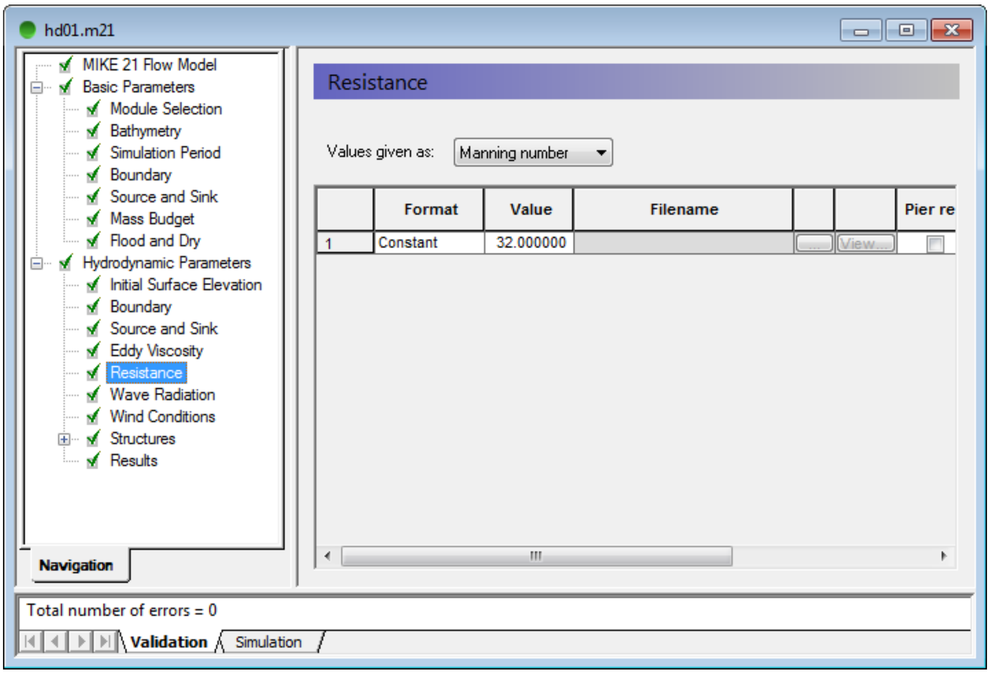


Figure 4.13 Flow Model: Bed Resistance

We will start the default Bed Resistance with a value given as a Manning number at $m^{1/3}/s$. Later on we will use this value for calibration purposes.

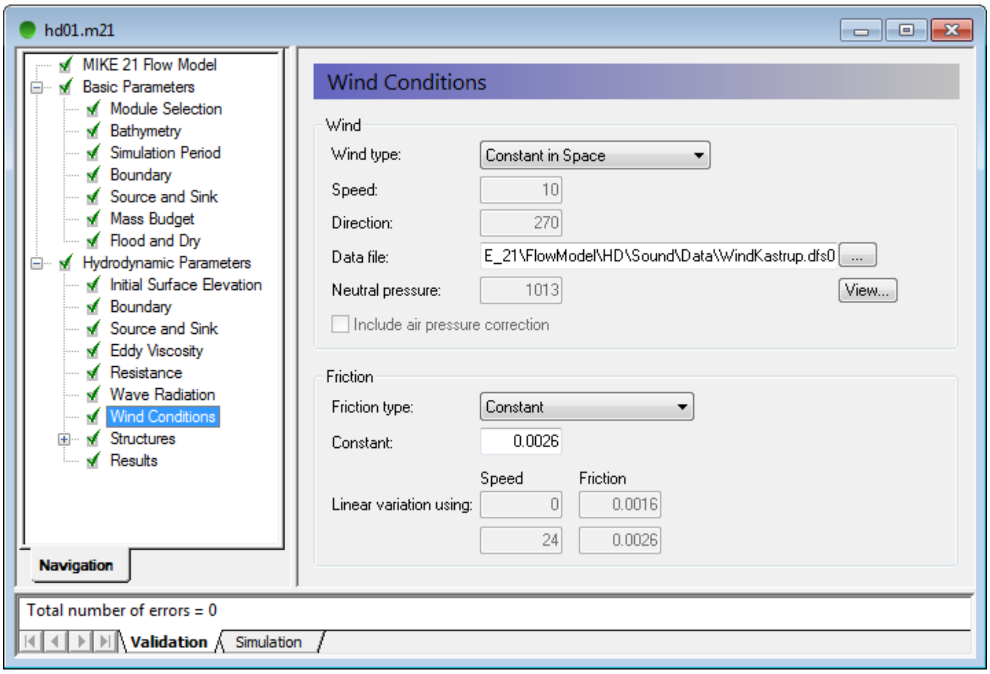


Figure 4.14 Flow Model: Wind Conditions

To use the generated wind time series, we specify ‘Constant in Space’ and locate the time series WindKastrup.dfs0. Use the default value for the friction.

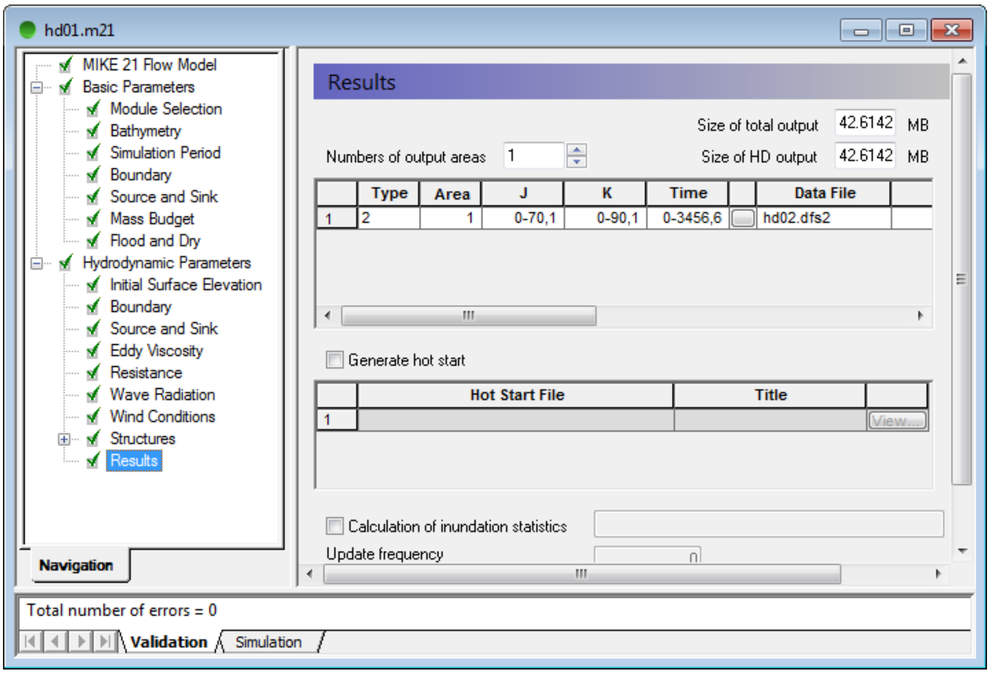


Figure 4.15 Flow Model: Result

Specify one output area and specify the resulting output file name. The actual output size is calculated on beforehand. Make sure the required disk space is available on the hard disk.

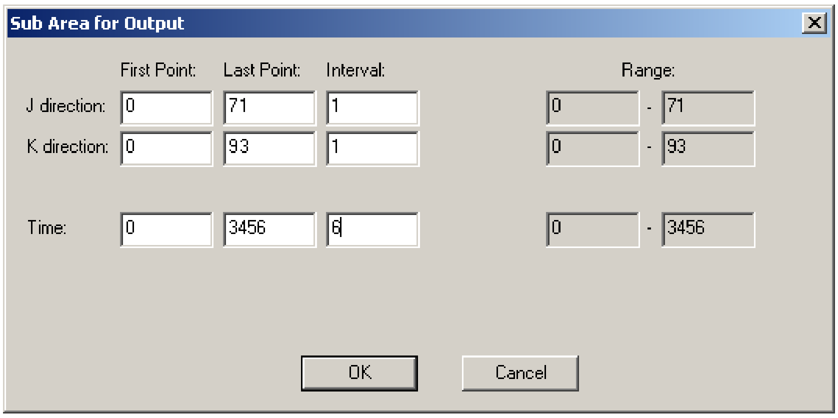


Figure 4.16 Flow Model: Result Output Area

Reduce the output size to a reasonably amount by selecting an output frequency of 1800s which is a reasonably output frequency for a tidal simulation. As our time step is 300s then the specified output frequency is 1800/300 = 6. Area-wise, select the full area.

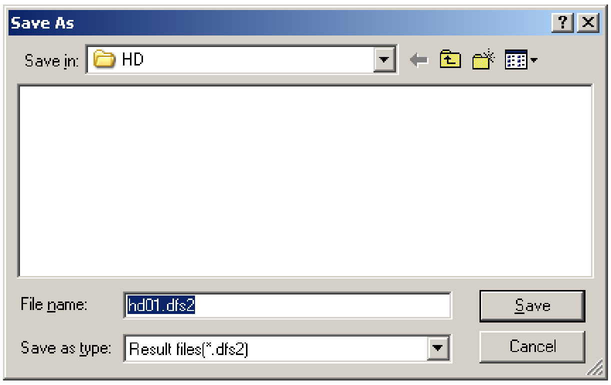


Figure 4.17 Flow Model: Result Output File Name

Specify the file name HD01.dfs2 for our first simulation.

Now we are ready to run the MIKE 21 Flow model.

After the simulation use the Plot Composer (or Grid Editor, Data Viewer) to inspect and present the result. Two plots are shown below; one with current towards North (Figure 4.18) and one with current towards South (Figure 4.19).

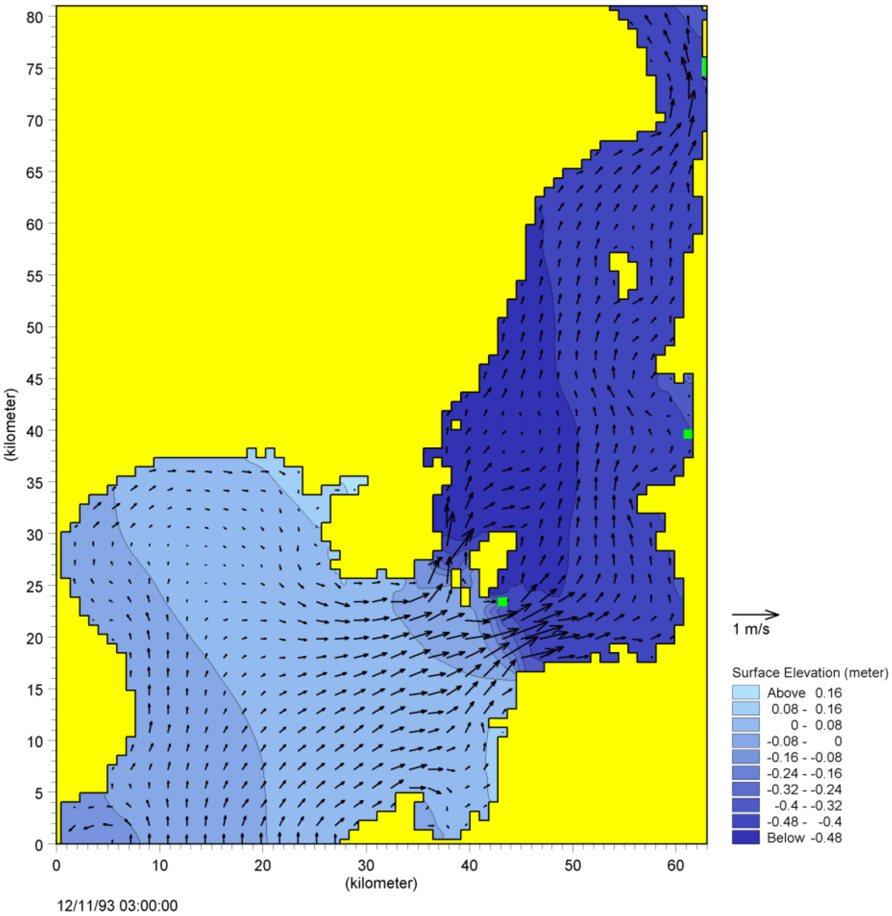


Figure 4.18 Current Speed and Water Level during current towards North

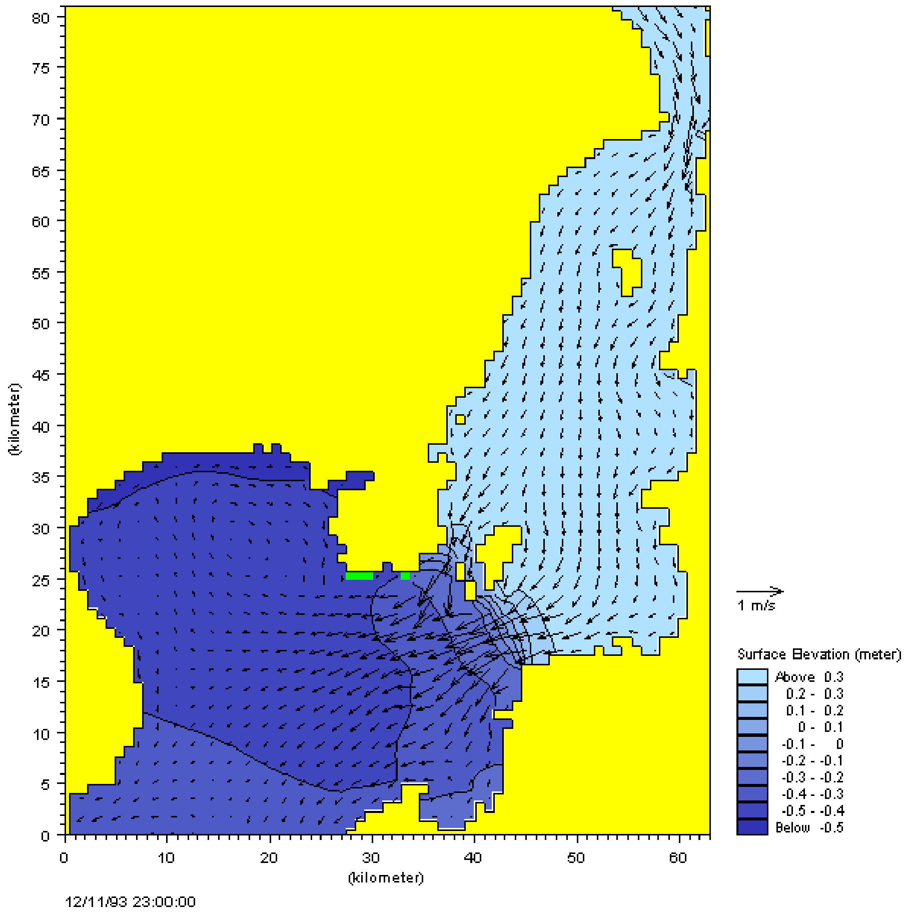


Figure 4.19 Current Speed and Water Level during current towards South

4.2 Model Calibration

In order to calibrate the model we need some measurements inside the model domain. Measurements of water level and current velocities are available.

4.2.1 Measured water levels

Measurements of water level are given at station Drogden (WaterLevelDrogden.txt) and Ndr. Roese (WaterLevelNdrRoese.txt) import these ASCII files using the Time Series Editor, cf. Figure 4.20 and Figure 4.21.

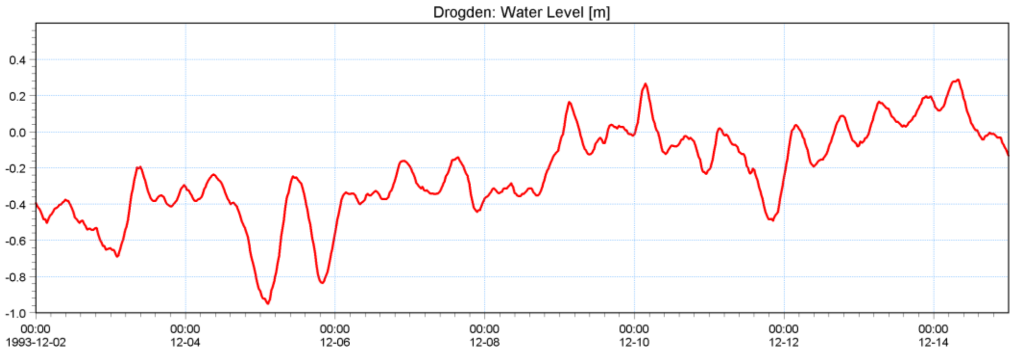


Figure 4.20 Drogden: Measured Water Level

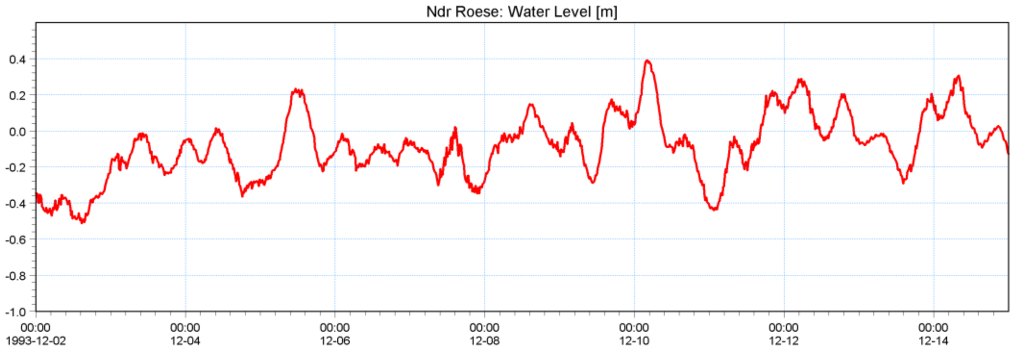


Figure 4.21 Ndr. Roese Measured Water Level

4.2.2 Measured current velocity

To calibrate the current velocity, measured current is given at station Ndr. Roese (CurrentNdrRose.txt) Import this file with the Time series Editor. Plots of current velocity and current speed and direction are shown in Figure 4.22, Figure 4.23 and Figure 4.24.

Furthermore, a Speed/Direction diagram of the measured current is shown in Figure 4.25.

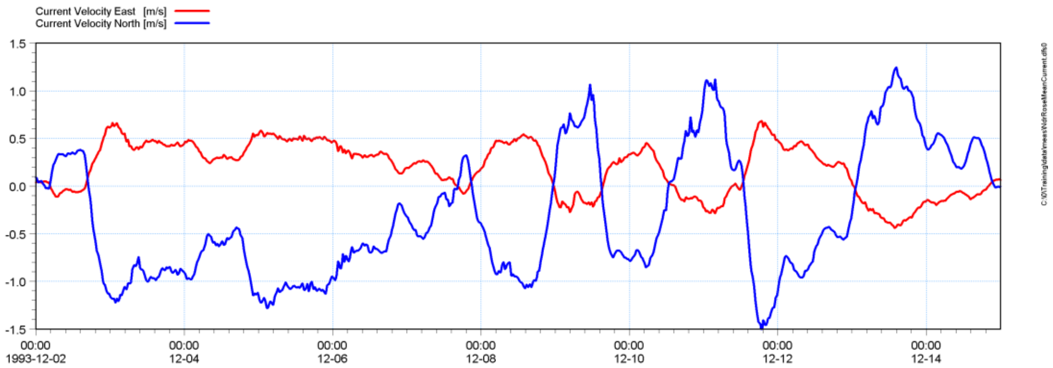


Figure 4.22 Ndr. Roese Measured Current Velocity East and North Component

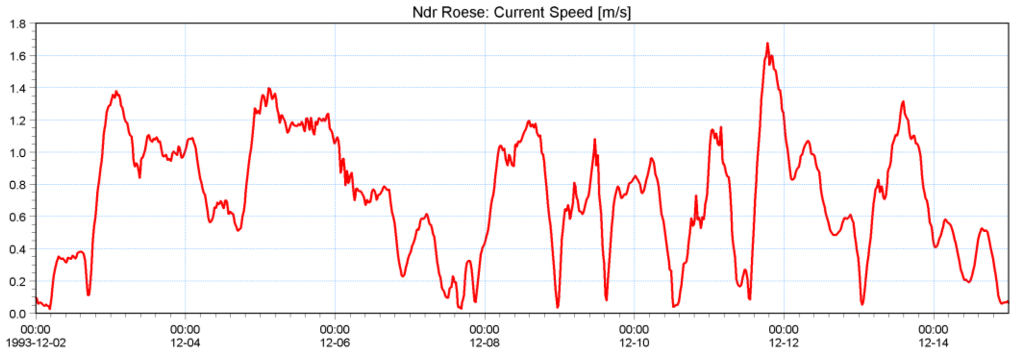


Figure 4.23 Ndr. Roese Measured Current Speed

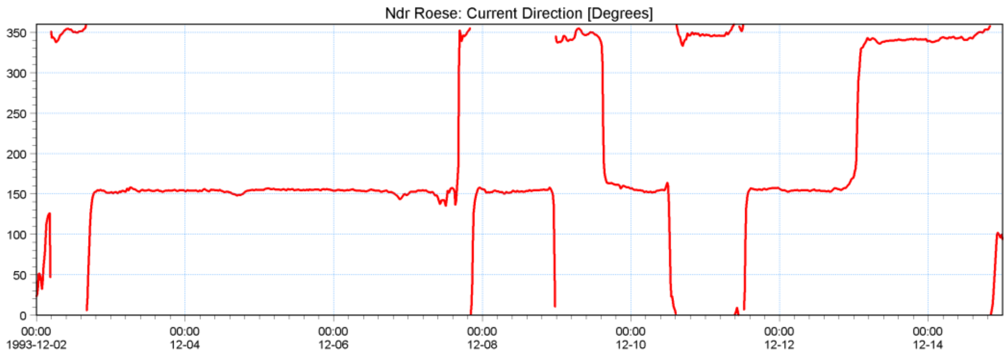


Figure 4.24 Ndr. Roese Measured Current Direction

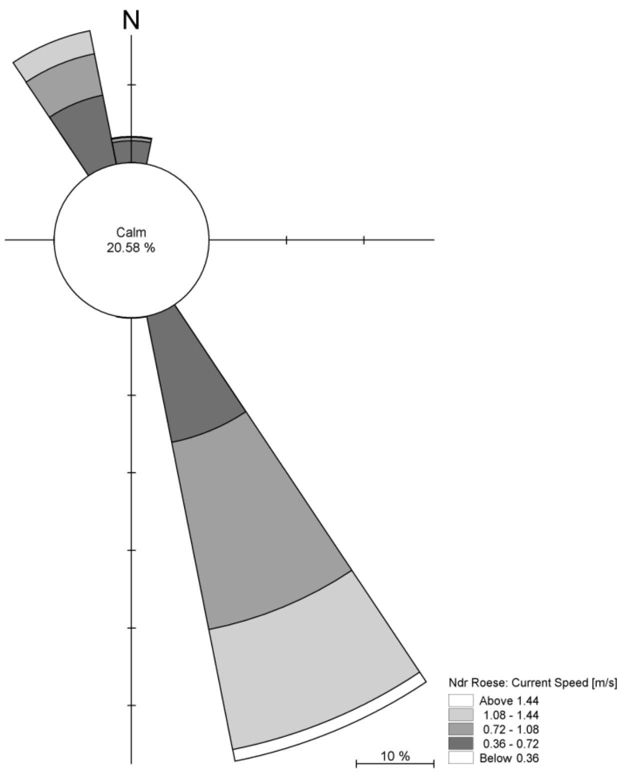


Figure 4.25 Ndr. Roese Current Rose

4.2.3 Model extraction

Now we are ready to extract water level and current speed from the simulation at the points corresponding to Ndr. Roese: Point (43,33) and Drogden Point (37,22). Start the ‘MikeZero Toolbox’ then click on the + sign in front of Extraction and select ‘Time Series from 2D files’. Figure 4.28 to Figure 4.34 show the corresponding dialogue pages for extracting the results.

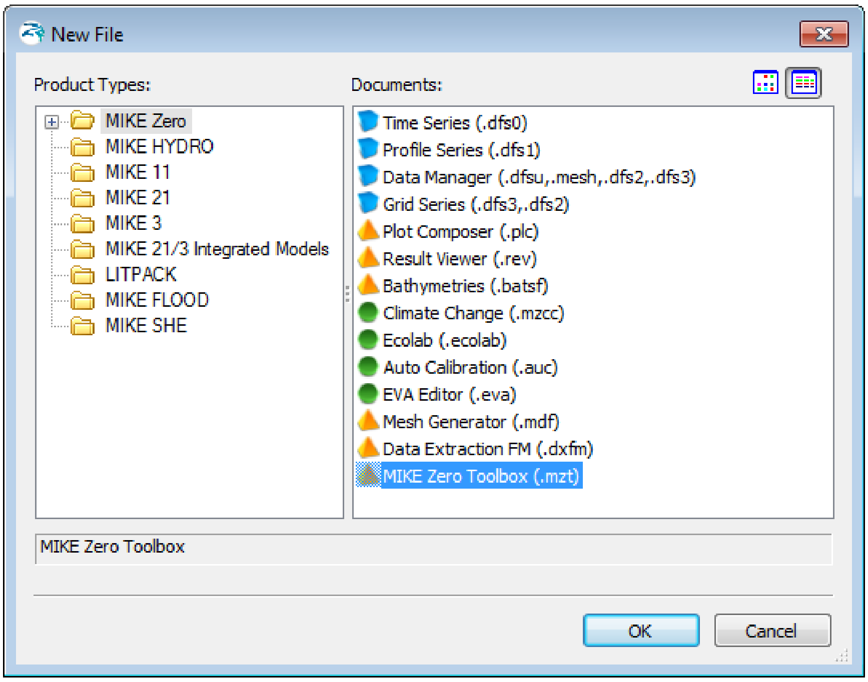


Figure 4.26 Select MIKE Zero Toolbox

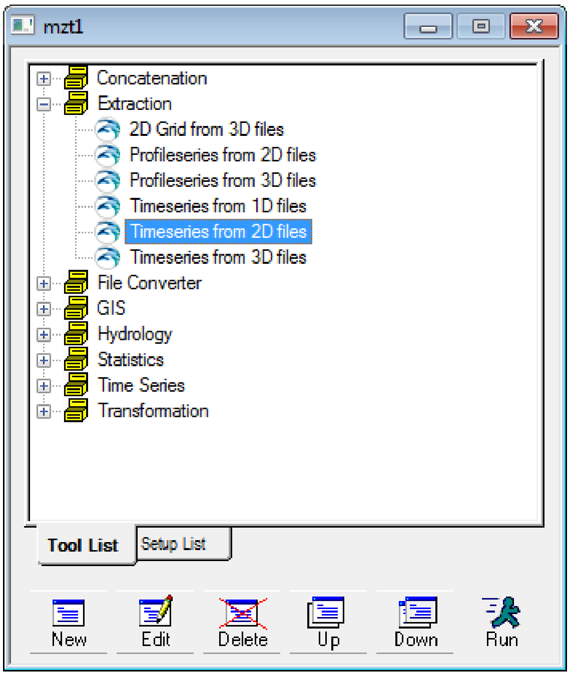


Figure 4.27 Select Time Series from 2D files

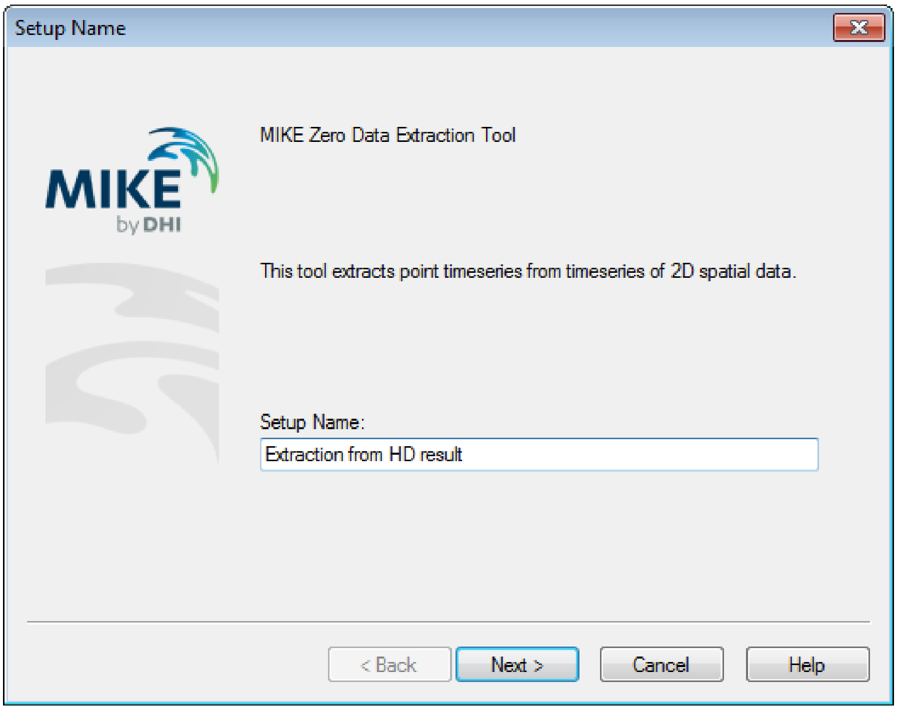


Figure 4.28 Name of the Time Series Extraction

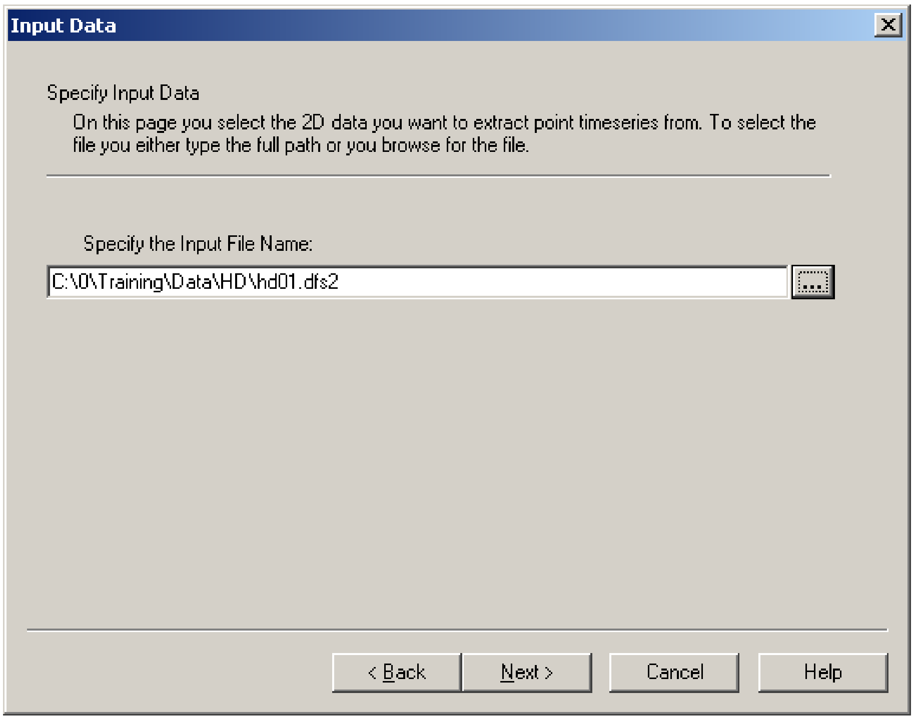


Figure 4.29 Specify the Hydrodynamic Result file

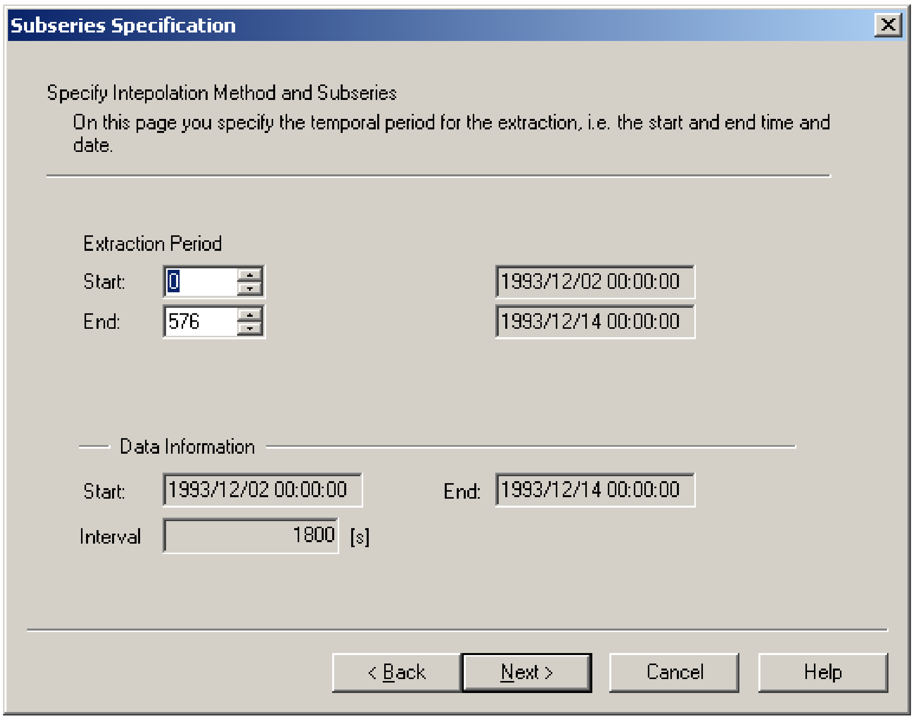


Figure 4.30 Specify the Extraction Period

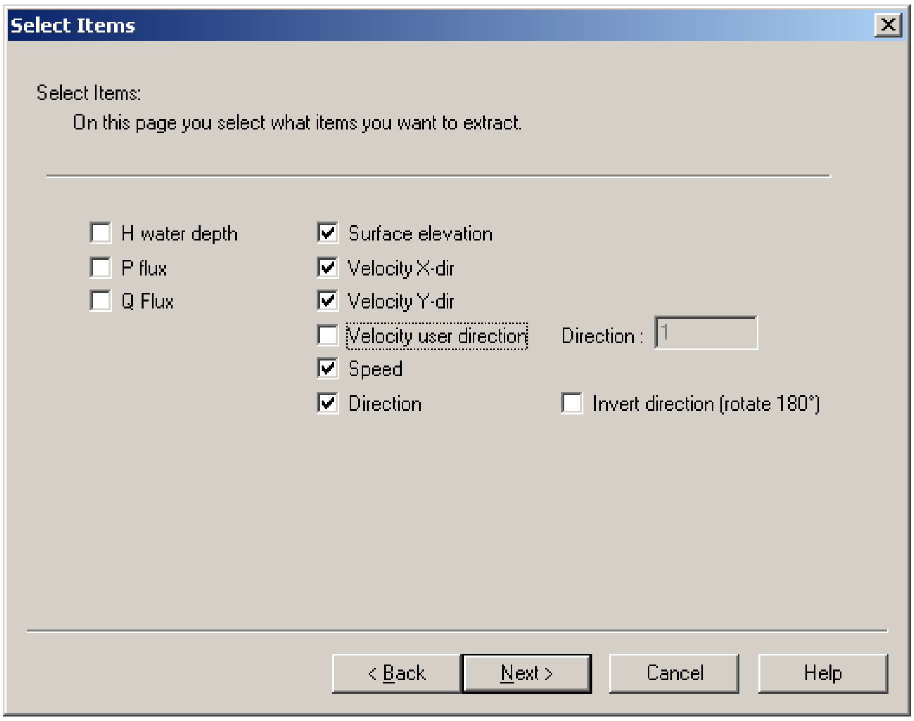


Figure 4.31 Specify the items to extract

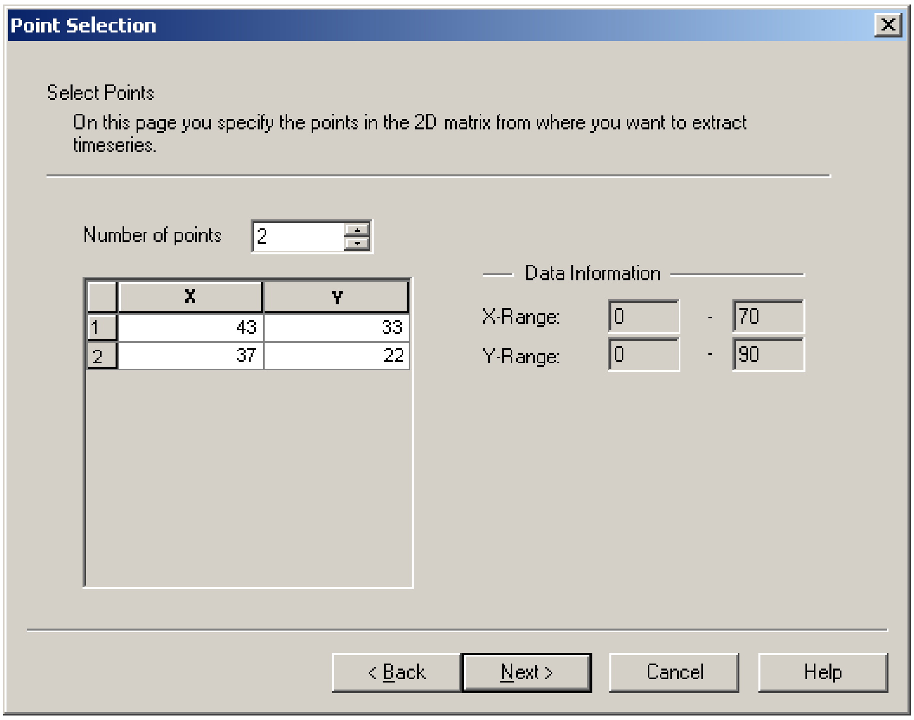


Figure 4.32 Specify the extraction points

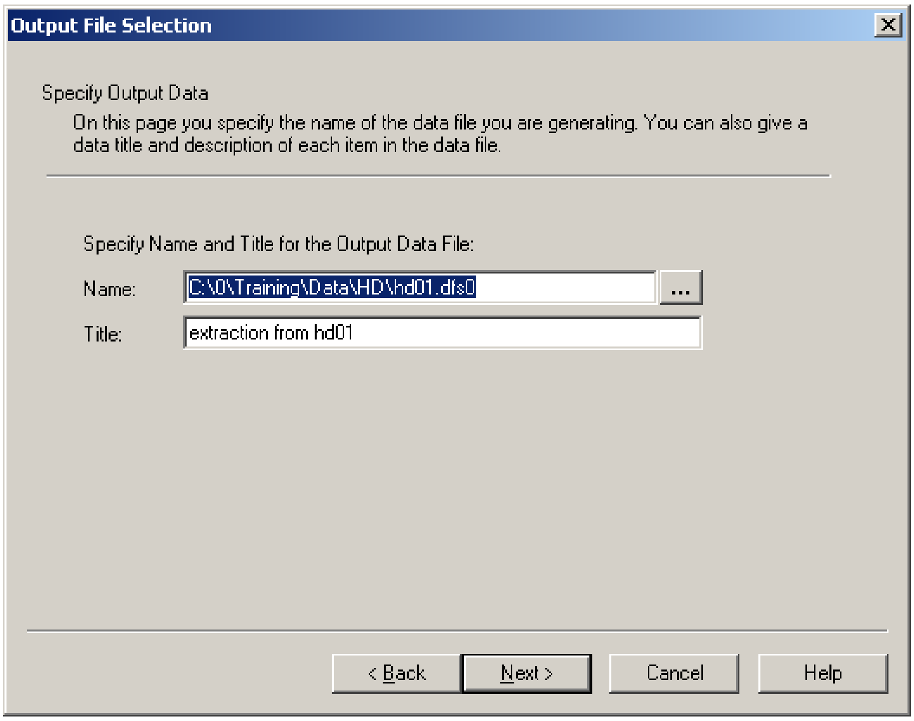


Figure 4.33 Specify the Time Series Output file

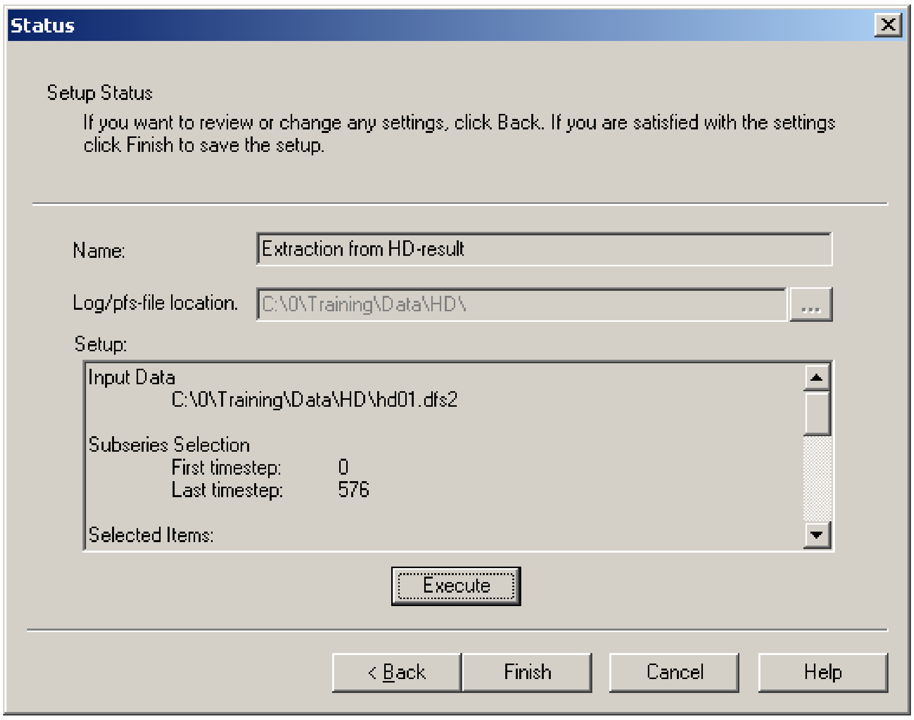


Figure 4.34 Click Execute to extract the selected data

4.2.4 Compare model results and measured values

Compare the extracted values with measured values. Use the Plot Composer to plot the simulated and measured water level and current.

The comparison is shown in Figure 4.35 for water level at Drogden and for Water Level at Ndr. Roese on Figure 4.36. Current comparison for Ndr. Roese is shown in Figure 4.37.

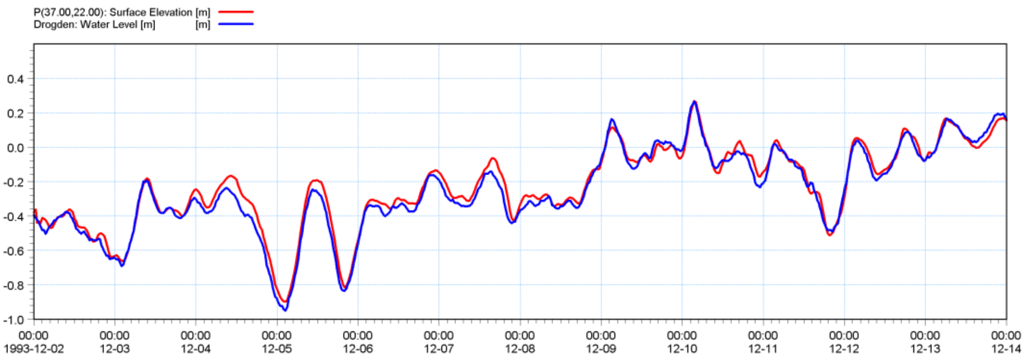


Figure 4.35 Water Level comparison at Drogden

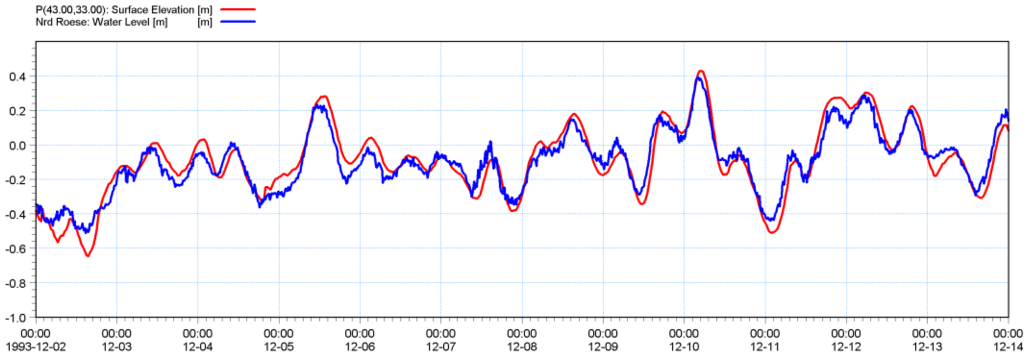


Figure 4.36 Water Level comparison at Ndr. Roese

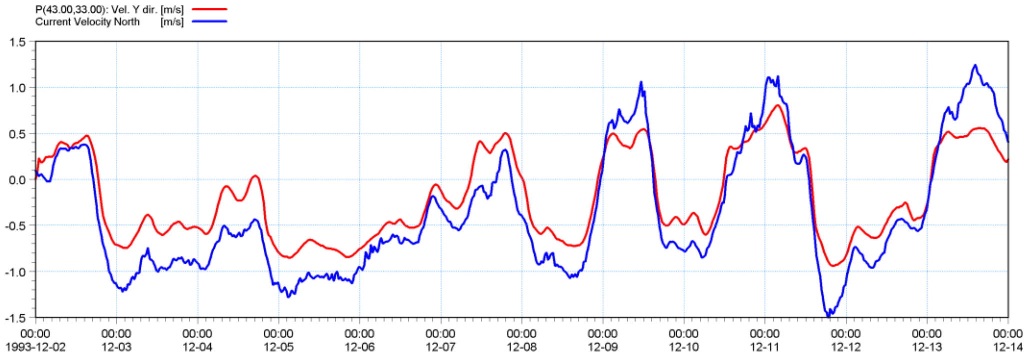


Figure 4.37 Comparison of Current Velocity North at Ndr. Roese. Simulated with a Manning number of 32 $m^{1/3}/s$.

The comparison between measured and calculated water level shows a reasonable agreement. But the current velocity shows that the calculated speed is too low. To adjust this we make a new calibration with a new Manning number of 44 $m^{1/3}/s$ to decrease resistance to the flow. Load the former simulation specification HD01.M21 and change the Manning number to 44 $m^{1/3}/s$. Change the output file name to HD02.dfs2. Save the specification as HD02.M21 and run the simulation with the new specification.

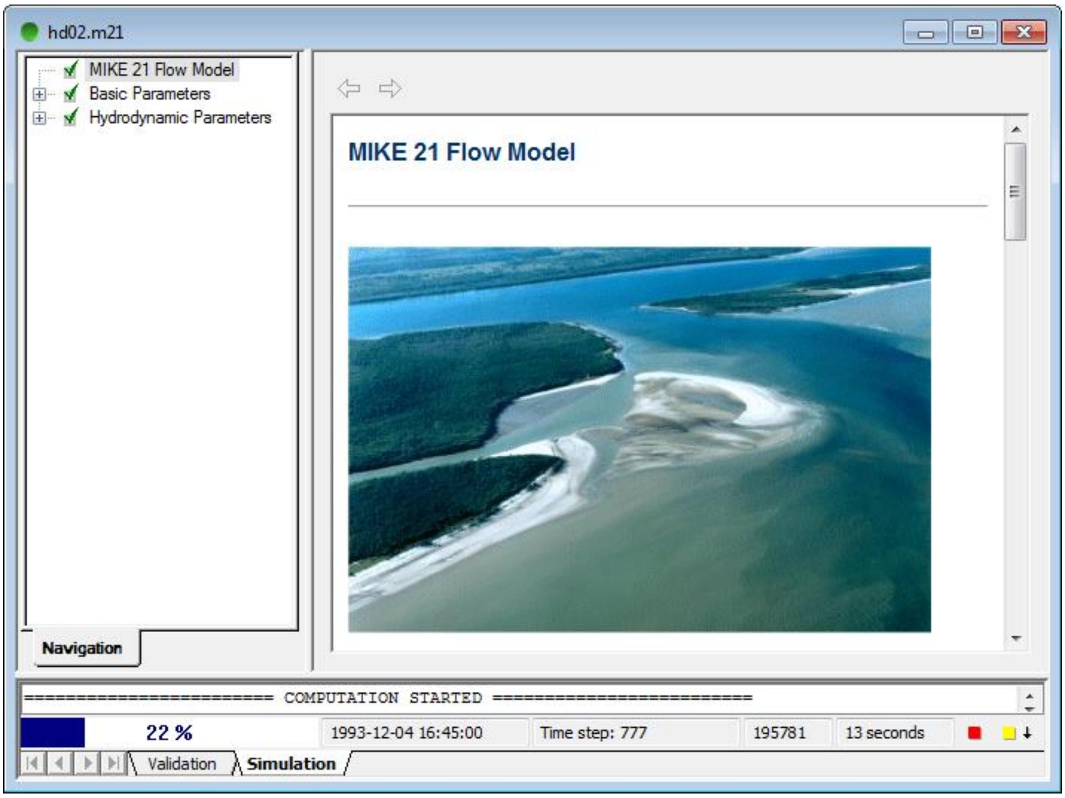


Figure 4.38 Status window for execution of HD model

Extract the new time series similar to the former one and make a new plot of the comparison. The result is shown in Figure 4.39.

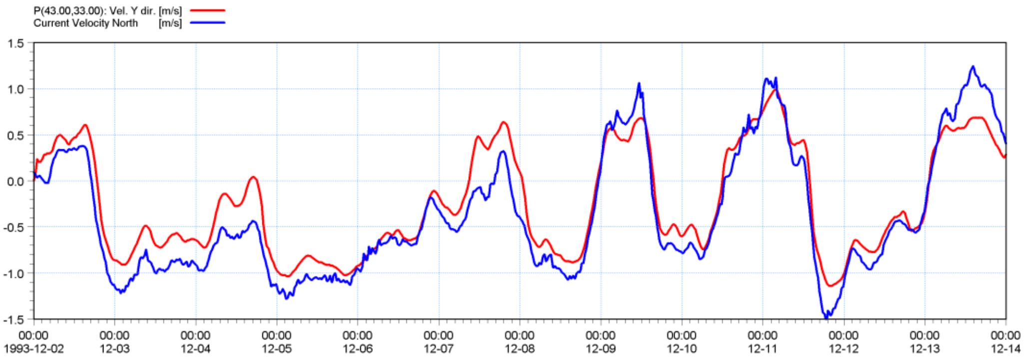


Figure 4.39 Comparison of Current Velocity North at Ndr. Roese with a Manning number of 44 $m^{1/3}$/s.

The calculated current speed is closer to the measured, but still we need a little more calibration. Including the density variation at the boundary will also improve the calibration. Try to make the calibration by increasing the Manning number and reducing the Eddy coefficient. For each calibration only change a single parameter and track the changes in a log.

A major improvement in the calibration process could be obtained by using variable wind friction.