SeCoTide

version 0.9A

User's Guide

Agnieszka Herman

Institute of Oceanography
University of Gdańsk, Poland

March 31, 2010

Contents

Chapter 1

Introduction

Numerical modelling of water circulation in tidal basins can be performed either by means of lumped-parameter models, where the basins and inlets are reduced to objects characterized by a few geometric parameters, or by means of advanced hydrodynamics models taking into account full three-dimensional geometry of the analyzed area. The model presented in this document, called SeCoTide (Semi-Connected Tidal Inlets), belongs to the first group. It is designed for simulating water circulation in a system of neighbouring basins that can be approximated in a way shown schematically in Fig. 1.1. The basins are treated as water reservoirs with uniformly varying water level. The inlets connecting the basins to the open sea are parameterized as one-dimensional channels described by their length, cross-sectional area and mean water depth. The watersheds (or tidal divides or 'transition areas') connecting the neighbouring basins are treated in the same way. The flow through the inlets and watersheds is driven by water-level differences at both ends and damped by friction. Thus, for N basins the model solves a system of $3N-1$ ordinary differential equations (see section 2.3): N continuity equations for the basins, N momentum equations for the inlets and $N-1$ momentum equations for the watersheds.

The model has been successfully applied to the analysis of various aspects of water circulation within the basins of the East Frisian Wadden Sea (Germany) and of the Magdalen Islands (Gulf of Saint-Lawrence, Canada), see Herman (2007); Urbański and Herman (2009); Herman (2010) and the example on the SeCoTide home page.

1.1 Features of SeCoTide

The most important features of SeCoTide are:

- The model can be run for any number of basins N.
- The basin surface areas can be described by any nondecreasing function of z, $A_b(z)$. Similarly, the cross-sectional areas and mean depths of the inlets and of the watersheds depend on water level: $A_c(z)$, $A_w(z)$, and $h_c(z)$, $h_w(z)$, respectively. Thus the drying and flooding of tidal flats, leading to the nonlinear behaviour of the tidal basins, can be taken into account.
- The user can provide the input parameters for the model either in a dimensional form or in terms of parameters analogous e.g to the Helmholtz frequency defined traditionally for single tidal inlets (see further chapters for details).

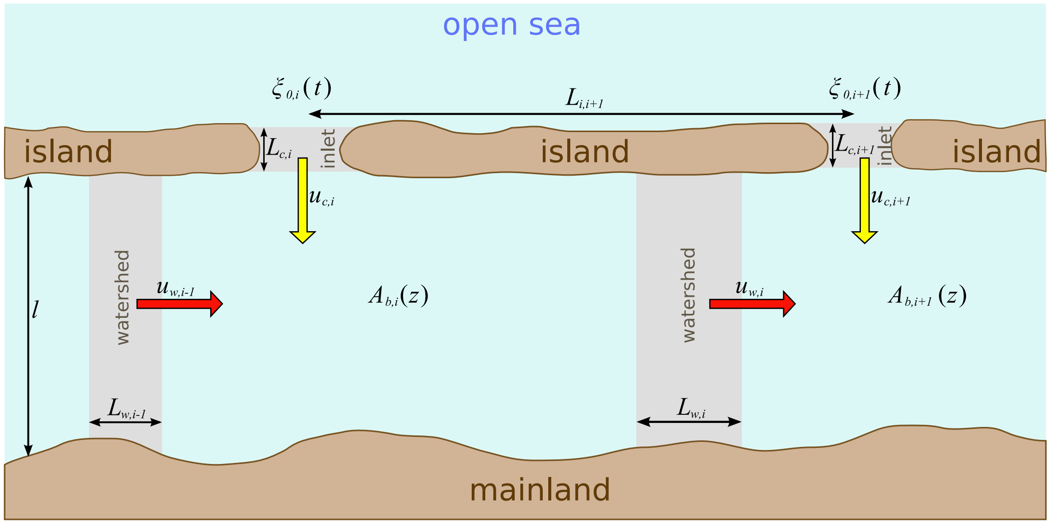


Figure 1.1: Sketch of a system of N semi-connected tidal inlets. See section 2.1 for the definitions of the symbols and for detailed description.

- Based on time series of sea-surface elevation at the entrance to each inlet the model calculates time series of sea levels in each basin and of the current velocities through the inlets and watersheds.
- The model equations are written in a matrix form and solved by means of variable-order multi-step ODE solver available in MATLAB.
- SeCoTide can be run via a simple, easy-to-use Graphical User's Interface (GUI) with help in HTML describing all technical details of its usage. The computational part of the programme (MATLAB m-file) is freely available as well.

1.2 Downloading and installing SeCoTide

SeCoTide is freely available. The SeCoTide stand-alone programme can be downloaded from the web site:
`http://www.ocean.univ.gda.pl/~herman/SeCoTide.htm`
as a single zipped file `SeCoTide.zip`. The programme doesn't require installation: the zip-file can be simply unpacked (preserving the internal directory structure) into a chosen folder. The `SeCoTide.exe` executable opens the GUI. All functionalities of the GUI are described in the HTML help and in this manual.
To run SeCoTide you need either MATLAB release 2008a or the MATLAB Compiler Runtime (MCR), a stand-alone set of shared libraries that enable the execution of m-files. If you do not have MATLAB or if you use another MATLAB version, please send me an email (`oceagah@univ.gda.pl`) and I'll provide you with the proper MCR installation programme.
Apart from the stand-alone programme, the computational module of SeCoTide is available as a MATLAB script (`SeCoTideCalc.m`) that can be integrated into other tools and functions. After downloading `SeCoTideCalc.m`, place the file in a chosen directory, add this directory to the MATLAB path and in the MATLAB command prompt type:
```
help SeCoTideCalc
```

for instructions on how to use this function.

1.3 SeCoTide directory structure

The SeCoTide directory structure is:

- `SeCoTide.exe` – the main executable (opens the GUI)
- `SeCoTide_ug.pdf` – this manual
- `SeCoTide.fnc` – function definitions file (see 4.4)
- `help` – folder with the HTML help of the programme
- `sample` – folder with example configuration and boundary condition files
- `private` – folder with some internal stuff required by the GUI.

Preserving this original directory structure is essential for the proper functioning of the programme.

1.4 Updates, modifications and bug-fixes

The present (17.09.2008) SeCoTide version is 0.9A. The modifications relative to the previous version 0.9 are:

- The values of the head-loss damping coefficients in the inlets and watersheds can now be different for the flood and ebb conditions, which enables to take into account possible asymmetries in the channels' geometry by in- and outflow conditions.
- Some small bugs have been fixed.

Chapter 2

Theory

This chapter discusses the theoretical background of the model of semi-connected tidal inlets, the main assumptions underlying the model equations and their numerical implementation.
The dimensional version of the equations derived in section 2.2 was first formulated (in a slightly different form) by Herman (2007), who demonstrated the applicability of the model to the analysis of circulation in the chosen basins of the East Frisian Wadden Sea, Germany. The transformed (scaled) equations are formulated and discussed in Urbański and Herman (2009); Herman (2010), where some aspects of the stability of a system of tidal basins is investigated numerically, analogously to the recent analysis of Brouwer (2006) and van de Kreeke et al. (2008).

2.1 Theoretical background

A starting point for SeCoTide is a one-dimensional momentum equation for the flow velocity u, governed by the along-channel (direction x) gradient of the water level ξ and the friction within the channel, described by a quadratic law:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = g\frac{\partial \xi}{\partial x} - \tilde{\gamma}|u|u, \tag{2.1}$$

where t denotes time, g is the acceleration due to gravity and $\tilde{\gamma}$ is the friction coefficient. This basic form of the momentum equation is assumed to describe the flow between each pair of the neighbouring basins constituting the analyzed system, as well as the flow through the channels connecting the basins with the open sea. In other words, both channels and watersheds are modelled in the same way, although of course they may have—and usually do have—very different depths, cross-sectional areas and so on.
To simplify (2.1) further, we follow the common practice and combine the advective acceleration term (the second term on the left-hand side) with the quadratic friction term (the second term on the right-hand side), as e.g. in Maas (1997). Also, the slope of the water surface in the channels is assumed to be uniform. Thus, the system can be described by a set of $3N-1$ nonlinear ordinary differential equations (ODEs):

$$u'_{c,i} = \frac{g}{L_{c,i}}(\xi_{0,i} - \xi_i) - \gamma_{c,i}|u_{c,i}|u_{c,i}, \qquad i = 1,\dots,N, \tag{2.2a}$$

$$u'_{w,i} = \frac{g}{L_{w,i}}(\xi_i - \xi_{i+1}) - \gamma_{w,i}|u_{w,i}|u_{w,i}, \qquad i = 1,\dots,N-1, \tag{2.2b}$$

$$V'_i = A_{c,i}u_{c,i} + A_{w,i-1}u_{w,i-1} - A_{w,i}u_{w,i}, \quad i = 1,\dots,N, \tag{2.2c}$$

with primes denoting differentiation with respect to time. $u_{c,i}$ and $u_{w,i}$ denote the flow velocities through the channels and watersheds, respectively. Positive $u_{c,i}$ means water flowing from the open sea to the i-th basin; positive $u_{w,i}$ means flow from basin i to basin $i+1$ (with $u_{w,0} = u_{w,N} = 0$). The water elevation at the entrance to the i-th channel is given by a prescribed function of time $\xi_{0,i} = \xi_{0,i}(t)$. The water level within each basin, ξ_i, is assumed to be spatially uniform.
The coefficients $\gamma_{c,i}$ and $\gamma_{w,i}$ in the last terms of (2.2a) and (2.2b), respectively, describe the joint effect of friction and advection and are given by:

$$\gamma_{c,i} = \tilde{\gamma}_{c,i} + \delta_{c,i} = gn^2 h_{c,i}^{-4/3} + \delta_{c,i}, \tag{2.3a}$$

$$\gamma_{w,i} = \tilde{\gamma}_{w,i} + \delta_{w,i} = gn^2 h_{w,i}^{-4/3} + \delta_{w,i}, \tag{2.3b}$$

where n denotes the Manning's friction factor (in $\mathrm{m}^{-1/3}\mathrm{s}$) and $h_{c,i}$, $h_{w,i}$ denote the mean water depth at $z = 0$ of the channels and watersheds, respectively. As the formulae (2.3) suggest, it is assumed that the hydraulic radius, defined as a ratio of the inlet cross-sectional area to its wetted perimeter, can be approximated by the inlet mean depth, which is a reasonable approximation for wide and shallow inlets and—especially—watersheds e.g. those at the Dutch and German Wadden Sea coast (if the user of SeCoTide finds it appropriate, he may adjust the value of n and provide e.g. the square roots of the inlet cross-sectional areas for h_c and h_w). The last terms in (2.3), $\delta_{c,i}$ and $\delta_{w,i}$, are quadratic head-loss damping coefficients. In the present version of SeCoTide it is possible to set different values of those coefficients for positive and negative flow velocities, thus taking into account different effective inlet lengths for flood/ebb conditions, resulting from specific geometry of the inlets and watersheds. At many tidal inlets it is crucial for properly reproducing the tidal asymmetries.
It is assumed that the lengths of the channels $L_{c,i}$ and the watersheds $L_{w,i}$ are constant and do not depend on water level. The other parameters describing the geometry of the channels (cross-sectional area $A_{c,i}$ and mean water depth $h_{c,i}$), basins (surface area $A_{b,i}$) and watersheds (cross-sectional area $A_{w,i}$ and water depth $h_{w,i}$) vary with the water level according to:

$$\begin{aligned}
A_{b,i} &= \bar{A}_{b,i}\alpha_{A_b,i}(\xi_i), \\
A_{c,i} &= \bar{A}_{c,i}\alpha_{A_c,i}(\xi_i), \\
h_{c,i} &= \bar{h}_{c,i}\alpha_{h_c,i}(\xi_i), \\
A_{w,i} &= \bar{A}_{w,i}\alpha_{A_{w,i}}(\xi_i) \\
h_{w,i} &= \bar{h}_{w,i}\alpha_{h_{w,i}}(\xi_i),
\end{aligned}$$

where bars denote values of the respective parameters at $z = 0$ and $\alpha_{A_b,i}$, $\alpha_{A_c,i}$, $\alpha_{h_c,i}$, $\alpha_{A_{w,i}}$ and $\alpha_{h_{w,i}}$ are positive, nondecreasing functions of z, all equal 1 for $z = 0$. The excess volumes of the basins, occurring in the continuity equations (2.2c), are given by:

$$V_i = \int_0^{\xi_i} A_{b,i}(z)\mathrm{d}z = \bar{A}_{b,i}\int_0^{\xi_i} \alpha_{A_b,i}(z)\mathrm{d}z$$

for $i = 1, \ldots, N$, so that:

$$V_i' = \bar{A}_{b,i}\alpha_{A_b,i}(\xi_i)\xi_i'. \tag{2.4}$$

For the purpose of the further analysis let us introduce the following variables:

$$v_{c,i} = u_{c,i}A_{c,i}/A_{b,i}, \tag{2.5a}$$

$$\hat{v}_{w,i} = u_{w,i}A_{w,i}/A_{b,i}, \tag{2.5b}$$

$$\check{v}_{w,i} = u_{w,i-1}A_{w,i-1}/A_{b,i} \tag{2.5c}$$

and the set of parameters:

$$\sigma_{c,i}^2 = \frac{g\bar{A}_{c,i}}{L_{c,i}\bar{A}_{b,i}}, \quad \alpha_{c,i} = \frac{\alpha_{A_{c,i}}}{\alpha_{A_{b,i}}}, \quad \beta_{c,i} = \frac{\gamma_{c,i}\bar{A}_{b,i}}{\bar{A}_{c,i}}, \tag{2.6a}$$

$$\hat{\sigma}_{w,i}^2 = \frac{g\bar{A}_{w,i}}{L_{w,i}\bar{A}_{b,i}}, \quad \hat{\alpha}_{w,i} = \frac{\alpha_{A_{w,i}}}{\alpha_{A_{b,i}}}, \quad \hat{\beta}_{w,i} = \frac{\gamma_{w,i}\bar{A}_{b,i}}{\bar{A}_{w,i}}. \tag{2.6b}$$

2.2 Model equations

The final set of the model equations follows from (2.2)–(2.6):

$$\begin{aligned} \upsilon_{c,i}' &= \sigma_{c,i}^2\alpha_{c,i}(\xi_{0,i} - \xi_i) - \frac{\beta_{c,i}}{\alpha_{c,i}}|\upsilon_{c,i}|\upsilon_{c,i} \\ &\quad + \frac{1}{\alpha_{c,i}}\frac{\mathrm{d}\alpha_{c,i}}{\mathrm{d}\xi}\upsilon_{c,i}\left[\upsilon_{c,i} + \frac{A_{b,i-1}}{A_{b,i}}\hat{\upsilon}_{w,i-1} - \hat{\upsilon}_{w,i}\right], \end{aligned} \tag{2.7a}$$

$$\xi_i' = \upsilon_{c,i} + \frac{A_{b,i-1}}{A_{b,i}}\hat{\upsilon}_{w,i-1} - \hat{\upsilon}_{w,i}, \tag{2.7b}$$

$$\begin{aligned} \hat{\upsilon}_{w,i}' &= \hat{\sigma}_{w,i}^2\hat{\alpha}_{w,i}(\xi_i - \xi_{i+1}) - \frac{\hat{\beta}_{w,i}}{\hat{\alpha}_{w,i}}|\hat{\upsilon}_{w,i}|\hat{\upsilon}_{w,i} \\ &\quad + \frac{1}{2\hat{\alpha}_{w,i}}\frac{\mathrm{d}\hat{\alpha}_{w,i}}{\mathrm{d}\xi}\hat{\upsilon}_{w,i}\left[\upsilon_{c,i} + \upsilon_{c,i+1} + \frac{A_{b,i-1}}{A_{b,i}}\hat{\upsilon}_{w,i-1} + \left(\frac{A_{b,i}}{A_{b,i+1}} - 1\right)\hat{\upsilon}_{w,i} - \hat{\upsilon}_{w,i+1}\right]. \end{aligned} \tag{2.7c}$$

2.3 Numerical implementation of the model

The set of the model equations (2.7) is written in a matrix form as:

$$\mathbf{y}'(t) = \mathbf{f}(t, \mathbf{y}(t)), \tag{2.8}$$

where:

$$\mathbf{y} = [\upsilon_{c,1}, \ldots, \upsilon_{c,N}, \xi_1, \ldots, \xi_N, \hat{\upsilon}_{w,1}, \ldots, \hat{\upsilon}_{w,N-1}]^T = [\mathbf{y}_c, \mathbf{y}_\xi, \mathbf{y}_w]^T$$

is a solution vector (^{T} denotes transposition) and:

$$\mathbf{f} = [f_{c,1}, \ldots, f_{c,N}, f_{\xi,1}, \ldots, f_{\xi,N}, f_{w,1}, \ldots, f_{w,N-1}]^T = [\mathbf{f}_c, \mathbf{f}_\xi, \mathbf{f}_w]^T$$

with:

$$\begin{aligned} f_{c,i} &= \sigma_{c,i}^2\alpha_{c,i}(\xi_{0,i} - \xi_i) - \frac{\beta_{c,i}}{\alpha_{c,i}}|\upsilon_{c,i}|\upsilon_{c,i} \\ &\quad + \frac{1}{\alpha_{c,i}}\frac{\mathrm{d}\alpha_{c,i}}{\mathrm{d}\xi}\upsilon_{c,i}\left[\upsilon_{c,i} + \frac{A_{b,i-1}}{A_{b,i}}\hat{\upsilon}_{w,i-1} - \hat{\upsilon}_{w,i}\right], \qquad i = 1, \ldots, N, \end{aligned} \tag{2.9a}$$

$$f_{\xi,i} = \upsilon_{c,i} + \frac{A_{b,i-1}}{A_{b,i}}\hat{\upsilon}_{w,i-1} - \hat{\upsilon}_{w,i}, \qquad i = 1, \ldots, N, \tag{2.9b}$$

$$\begin{aligned} f_{w,i} &= \hat{\sigma}_{w,i}^2\hat{\alpha}_{w,i}(\xi_i - \xi_{i+1}) - \frac{\hat{\beta}_{w,i}}{\hat{\alpha}_{w,i}}|\hat{\upsilon}_{w,i}|\hat{\upsilon}_{w,i} \\ &\quad + \frac{1}{2\hat{\alpha}_{w,i}}\frac{\mathrm{d}\hat{\alpha}_{w,i}}{\mathrm{d}\xi}\hat{\upsilon}_{w,i}\left[\upsilon_{c,i} + \upsilon_{c,i+1} + \frac{A_{b,i-1}}{A_{b,i}}\hat{\upsilon}_{w,i-1}\right. \\ &\qquad\qquad \left. + \left(\frac{A_{b,i}}{A_{b,i+1}} - 1\right)\hat{\upsilon}_{w,i} - \hat{\upsilon}_{w,i+1}\right], \qquad i = 1, \ldots, N-1. \end{aligned} \tag{2.9c}$$

It is convenient to write the Jacobian matrix $\mathbf{J}$ of the system (2.8) as:

$$\mathbf{J} = \begin{bmatrix} \frac{\partial \mathbf{f}_c}{\partial \mathbf{y}_c} & \frac{\partial \mathbf{f}_c}{\partial \mathbf{y}_\xi} & \frac{\partial \mathbf{f}_c}{\partial \mathbf{y}_w} \\ \frac{\partial \mathbf{f}_\xi}{\partial \mathbf{y}_c} & \frac{\partial \mathbf{f}_\xi}{\partial \mathbf{y}_\xi} & \frac{\partial \mathbf{f}_\xi}{\partial \mathbf{y}_w} \\ \frac{\partial \mathbf{f}_w}{\partial \mathbf{y}_c} & \frac{\partial \mathbf{f}_w}{\partial \mathbf{y}_\xi} & \frac{\partial \mathbf{f}_w}{\partial \mathbf{y}_w} \end{bmatrix} = \begin{bmatrix} \mathbf{J}_{cc} & \mathbf{J}_{c\xi} & \mathbf{J}_{cw} \\ \mathbf{J}_{\xi c} & \mathbf{J}_{\xi\xi} & \mathbf{J}_{\xi w} \\ \mathbf{J}_{wc} & \mathbf{J}_{w\xi} & \mathbf{J}_{ww} \end{bmatrix}. \tag{2.10}$$

The exact form of the elements of the nine sub-matrices follows directly from (2.9). From a point of view of solving the system (2.8) numerically, an important feature of these sub-matrices is that they have non-zero elements along at most three diagonals.

In SeCoTide the set of explicit ODEs (2.8) is solved by means of one of the two variable-order multistep solvers available in Matlab (Shampine and Reichelt, 1997): 'ode45' or 'ode15s'. The difference between them concerns the method of calculation of the terms of the Jacobian matrix. Whereas 'ode15s' uses the analytical formulae for $\mathbf{J}$ as given by equation (2.10), 'ode45' approximates the entries of $\mathbf{J}$ numerically, which is faster, but less accurate.

Chapter 3

Graphical User's Interface

This chapter describes the options and functionalities of the SeCoTide Graphical User's Interface (GUI). The main programme window that appears after running SeCoTide.exe is shown in Fig. 3.1. It has three groups of tools that allow to configure the model, perform the calculations and generate simple plots of the results.

3.1 Menu bar and toolbar

The options available through the SeCoTide menu bar are grouped into four thematical categories with subcategories:

1. File
    - New config file

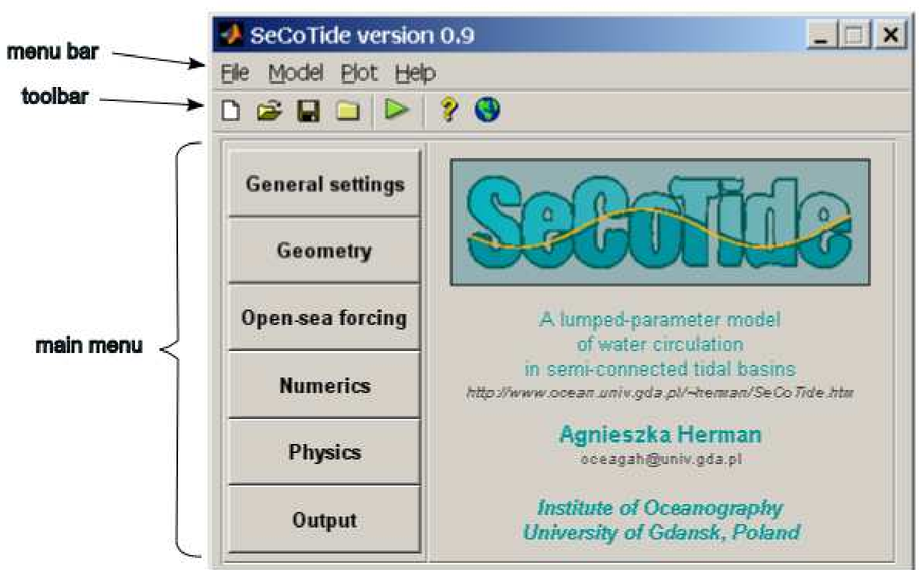


Figure 3.1: The main panel of the SeCoTide GUI.

  - Open config file
  - Save config file
  - Set working directory
  - Exit SeCoTide

2. Model

  - Run the model

3. Plot

  - current results
  - from file

4. Help

  - Help
  - SeCoTideweb site
  - About SeCoTide

3.1.1 Menu File

New config file

This operation is equivalent to restoring the default settings for all model parameters. All options are set to their default values, the same as those assigned to them at start-up. After choosing this option a dialog box with a warning is displayed (Fig. 3.2).

The 'new config file' operation can be accessed by pressing the Toolbar button .

Open config file

This menu item opens a dialog box for reading an existing SeCoTide configuration file. Only files with *.in extension are accepted. The file must contain all information necessary to run the model. The format and structure of the SeCoTideconfiguration files is described in detail in section 4.1. The entries in the *.in file may be provided in any order; however, it is advisable

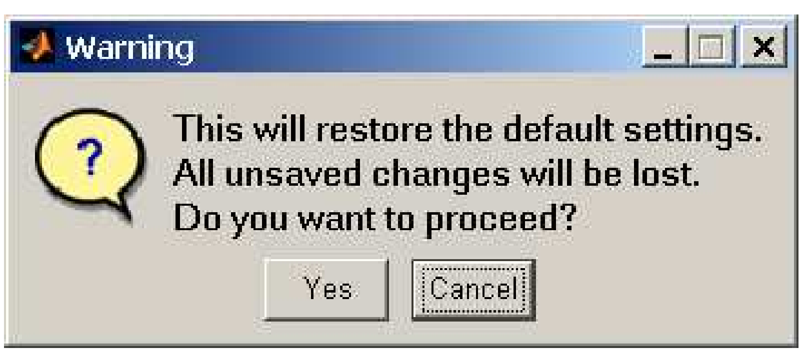


Figure 3.2: Dialog box with a warning showing up after the user chooses the 'new config file' option.

to keep an analogous file structure as in the sample files provided with the model (and in the *.in files saved by the user with the 'save config file' option, see below), especially while the present model version does not perform a full check of the input file content. A good practice is to prepare new config files by modifying existing ones.

The 'open config file' operation can be also accessed by pressing the Toolbar button .

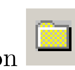
Save config file

This menu item open a dialog box for saving the current model configuration into a chosen *.in file.

The 'save config file' operation can be also accessed by pressing the Toolbar button .

Set working directory

By setting the working directory the user specifies the location from where the configuration files (and other input data, e.g. the time series with boundary conditions) will be loaded and where the result files will be saved. If no working directory is specified, the SeCoTide home directory is the default.

The 'set working directory' operation can be also accessed by pressing the Toolbar button .

Exit SeCoTide

This option closes SeCoTide *without asking if the configuration/results should be saved before.*

3.1.2 Menu Model

Run the model

This menu item starts the computational module of SeCoTide. A waitbar showing the calculation progress is shown in a separate window (Fig. 3.3a) and the operation of the SeCoTide GUI is blocked until the computation completes. After a successful computation the results are saved to file(s) in format(s) specified by the user (see section 4.3 for available output file formats). The end of the computation is reported in a message box shown in Fig. 3.3b).

3.1.3 Menu Plot

The GUI provides a simple plotting functionality to graphically present the modelling results. It has rather limited possibilities and is meant for a quick inspection of the results rather than for producing attractive graphical output. The tool produces two windows with the time series of water levels in the basins (and possibly at the entrances to the inlets) and the time series of current velocities through the inlets and watersheds, respectively. The plotting tool can be used in two versions:

current results

... creates time series plots for the results of the last calculation, currently stored in the operational memory. Obviously, this option is available only after a successful calculation performed in the present SeCoTide session.

(a)

(b)

Figure 3.3: Waitbar showing the progress of the simulation (a) and a message window informing of a successful computation.

from file

... opens a dialog box for reading of a *.mat or *.dat result file and generates plots for the data contained in those files.
The plotting tool is meant for reading files produced with SeCoTide, i.e. the file structure as described in the section 4.3 is assumed.
The plot figures allow to print the figure contents and/or to save them in a MATLAB *.fig format and/or as graphic files (gif, tif, png, pdf etc.). The user may also zoom selected plot area and adjust the plot legend.

3.1.4 Menu Help

Help

This menu item opens an external web browser with the html documentation.

The html help can be also accessed by pressing the Toolbar button .

SeCoTide web site

This menu items opens the SeCoTide home page in an external web browser. The home page contains a lot of additional useful information concerning the model, including some case studies, references, bug fixes and links to other sites concerning hydrodynamic modelling of tidal inlets.

This option can be also accessed by pressing the Toolbar button .

About SeCoTide

This menu item returns the SeCoTide main window to its initial form, containing the basic information about the model.

3.2 Menu GENERAL SETTINGS

The uppermost button on the left-hand side of the SeCoTide GUI opens a panel with the most important parameters governing the model configuration. It is advisable to begin the work on a new model set-up with assigning proper values to those parameters, as they influence and/or decide upon the remaining ones. Fig. 3.4 shows how the 'General settings' panel looks like.

The most basic issue is the number of basins N considered. By default $N = 2$, and an edit field with a slider enables to modify this value.

Importantly, the change will take effect only after the user presses the 'update' button to the right of the edit field. This—at the first sight superfluous—operation should prevent an undesired change to the number of basins, which intervenes with the overall model configuration; it is particularly important by decreasing the value of N, which is associated with removing from the memory of all information concerning the geometry of the basins, inlets and watersheds being deleted.

The present GUI version can handle up to $N = 10$ basins, which is enough for most applications. However, the computational module can be run for an arbitrary number of basins. If $N > 10$, the panels 'Geometry' and 'Open sea forcing' are disabled and the model set-up must be loaded from a manually-prepared configuration file, as stated in the message window in Fig 3.5.

The second sub-panel allows to define the range (in selected units: seconds, minutes or hours) of the computation period.

Finally, the user has a choice between the 'scaled' (default) and 'dimensional' version of the model. This choice influences exclusively the kind of information—the set of parameters describing the geometry of the objects being modelled—that should be provided to the model at the configuration stage. It has no influence whatsoever on the calculation itself, which in both

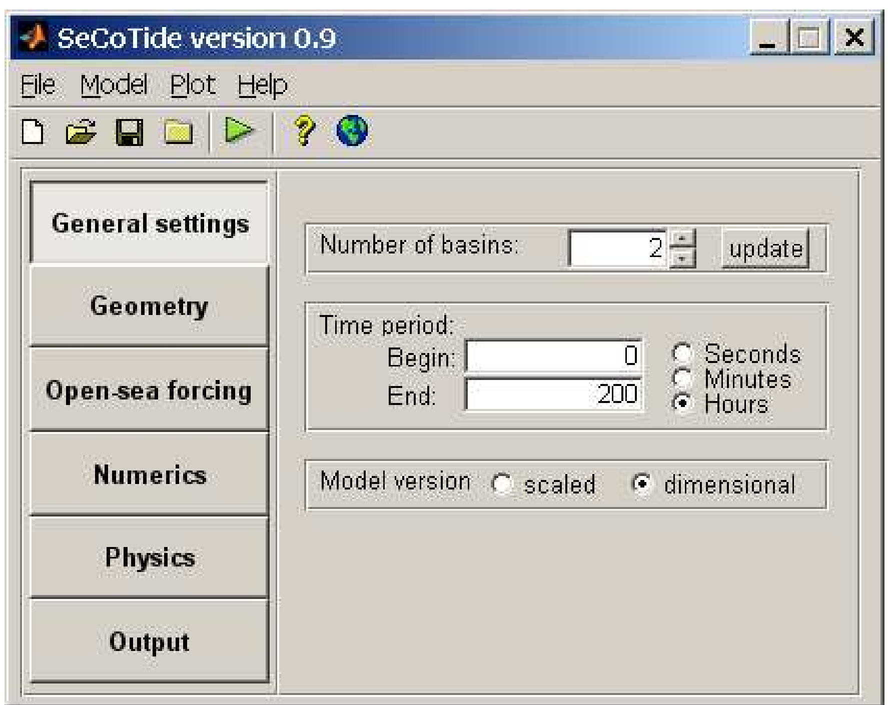


Figure 3.4: The 'General Settings' panel of SeCoTide.

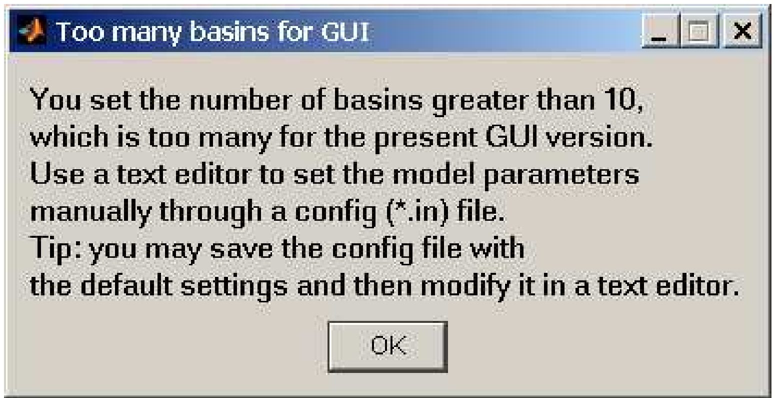


Figure 3.5: Message window displayed when the user chooses the number of basins $N > 10$.

cases is done on the scaled equations.
The list of parameters required to set up the 'dimensional' and 'scaled' model version is provided in the next section.

3.3 Menu GEOMETRY

The second button of the SeCoTide menu enables to configure the geometry of the objects—basins, inlets and watersheds—constituting the model set-up. The panel contains N push buttons corresponding to the basins and their respective inlets and $N-1$ push buttons corresponding to the watersheds connecting those basins. An example for $N = 3$ is shown in Fig. 3.6.
If N is modified—either in GUI in the 'General settings' panel or by loading an external configuration file—the number of push buttons in the 'Geometry' panel will be adjusted automatically. If the new N value is lower than the old one, all data describing the geometry of the deleted basins is removed from memory. In the opposite case, if N increases, an appropriate number of 'new' basins and watersheds is created with default parameters that may then be adjusted either in GUI—as described in this section—or by saving the configuration file and modifying it manually in an external text editor.
Each push button in the 'Geometry' panel opens a separate window with a list of parameters describing the respective basin/inlet pair or the watershed. The list of parameters—and thus the content of the window—depends on the choice of the 'scaled' or 'dimensional' model version, selected under 'General settings'.
If the model version is 'dimensional', the windows look like those in Fig 3.7.
The required parameters for a basin/inlet pair are: the basin surface area at the mean water level $(z = 0)$ $A_{b,0}$, the channel cross-sectional area at the mean water level $A_{c,0}$, the channel length L_c and mean water depth h_c, a function $\alpha_c(\xi, a)$ describing the dependence of A_c/A_b on the water level and the head-loss damping coefficients $\delta_{c,fld}$ and $\delta_{c,ebb}$, corresponding to $u_c > 0$ (flood) and $u_c < 0$ (ebb), respectively.. If $\alpha_c(\xi, a)$ is concerned, the user has to choose one from a list of available predefined functions. The function definitions are loaded at the initialization stage of the programme from a function-definition file called `SeCoTide.fnc`—its format is described in detail in section 4.4. Thus, the user can easily extend the built-in function library with an arbitrary number of new functions, provided that two conditions are met. Firstly, the functions have to be second-order differentiable with respect to z and the derivatives definitions have to be included in the `SeCoTide.fnc` file together with the functions themselves (see also menu

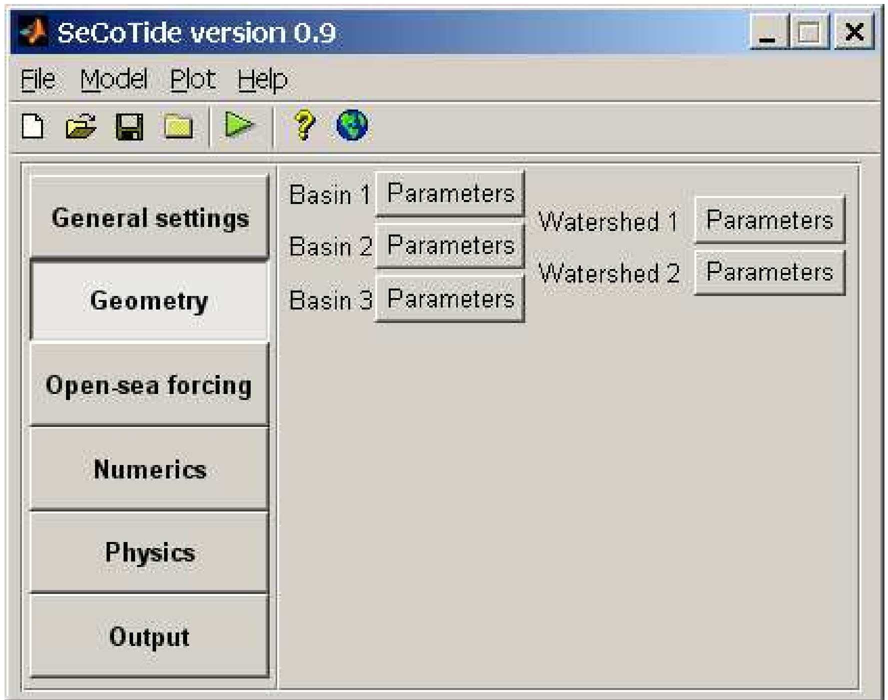


Figure 3.6: The ‘Geometry’ panel of SeCoTide.

‘Numerics’). And secondly, in the present GUI version only two parameters (scalar constants) are allowed in a function argument list. These constants are grouped into a two-element vector a. Their values in any particular case can be set either in GUI (third and fourth position in the ‘Basins’ window) or equivalently in the configuration file.

In the present version of SeCoTide a linear dependence of h_c on z is assumed: $h_c(z) = h_{c,0}+\alpha_{hc}\xi$. The push button ‘Calculate parameters’ displays quantities—calculated based on the dimensional variables entered by the user—that are actually used as an input for the computational module: σ_c (defined in equation 2.6a), $T_H = 1/\sigma_c$ and the ratio $A_{b,0}/A_{c,0}$.

Important: the calculation of these parameters does not depend on whether the user presses the ‘Calculate parameters’ button or not.

As Fig. 3.7b demonstrates, the windows for the watersheds have a similar structure to those for the basins, with the required parameters being: the watershed cross-sectional area at $z = 0$ $A_{w,0}$, its length L_w and mean depth $h_{w,0}$, a function $\hat{\alpha}_w(\xi, a)$, analogous to α_c and describing the ratio $(A_w/A_b)(z)$ with A_b being the surface area of this one of the two basins connected by the analyzed watershed, which has a *lower* index (i.e. the left basin if the basins are number from left to right), and, finally, the head-loss damping coefficients $\delta_{w,+}$ and $\delta_{w,-}$, corresponding to positive and negative values of u_w, respectively.

If SeCoTide is to be run in the ‘scaled’ mode, the basins/inlet and the watershed windows have less elements (Fig. 3.8).

The notation is the same as in the ‘dimensional’ version.

Tip: it is possible—and quite useful—to open many basin and/or watershed windows at the same time, to keep an overview of all or most of the objects constituting the modelled system. In more complicated configurations it is also helpful to view the summary of the model settings, which is a functionality available through the GUI toolbar or the menu bar.

(a) (b)

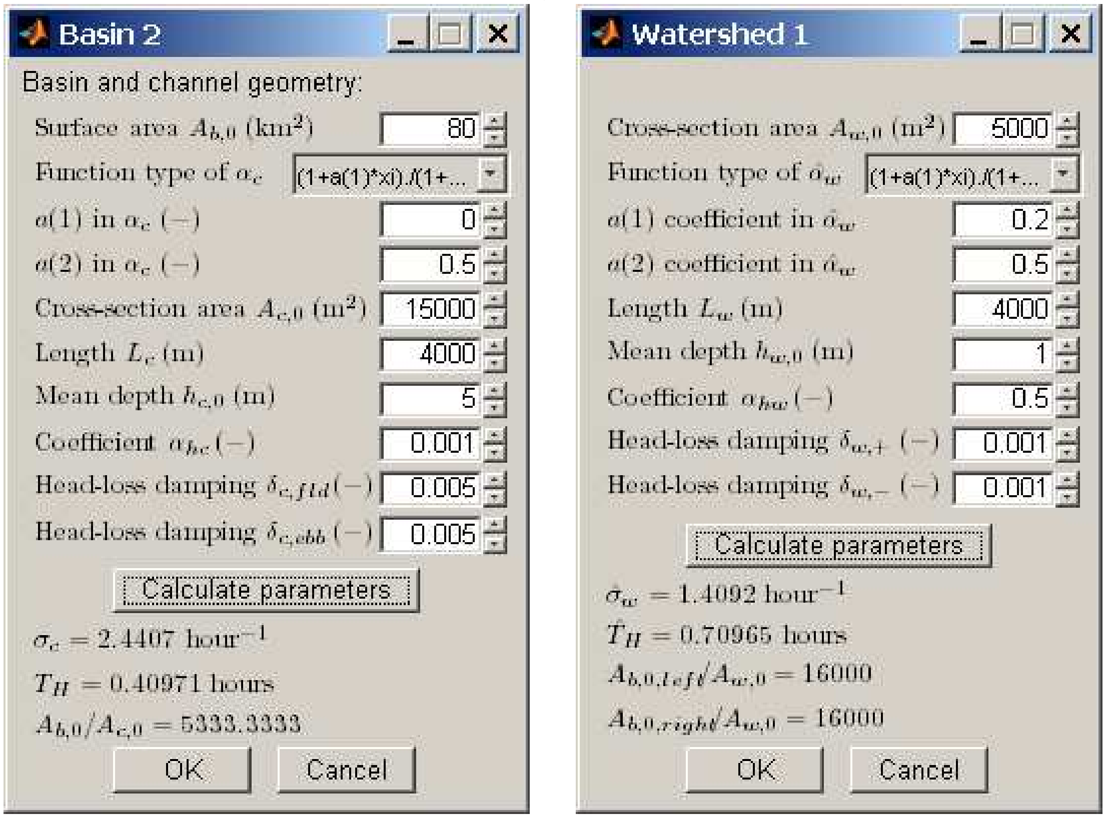


Figure 3.7: Dialog windows for setting the geometrical parameters of the basins (a) and watersheds (b) in the 'dimensional' model version.

3.4 Menu OPEN SEA FORCING

For the computations the model requires time series of water levels at the entrance to each one of the N inlets connecting the basins to the open sea. In SeCoTide there are two ways to define the open boundary conditions: either as simple cosine functions $a_i \cos[2\pi t/T_i + \phi_i]$ (where a_i, T_i and ϕ_i denote amplitude, period and phase, respectively, for $i = 1, \ldots, N$) or as arbitrary time series $\xi_{0,i}(t)$ read from an external file. The radio buttons in the upper part of the 'Open sea forcing' panel enable to choose between those two types of boundary conditions.

If the 'cosine functions' option is selected (which is the default), a set of three edit fields appears for each inlet, as in the example in Fig. 3.9a.

By default, $a_i = 0.5$ m, $T_i = 12.4167$ hours (which corresponds to the period of the M2 tide) and $\phi_i = 0$ radians.

After selecting the 'time series from file' option, a push button appears that enables to browse for an input file containing the boundary conditions time series (Fig. 3.9b). The text field above this button is 'inactive', i.e. it shows the name and path of the currently chosen file, but it does not allow for editing.

In the present version SeCoTide accepts only ASCII boundary condition files, with an extension *.txt or *.dat. The acceptable formats are described in detail in section 4.2. If an inappropriate file is chosen, a question dialog box is shown with two alternatives to choose from: the user may

(a) (b)

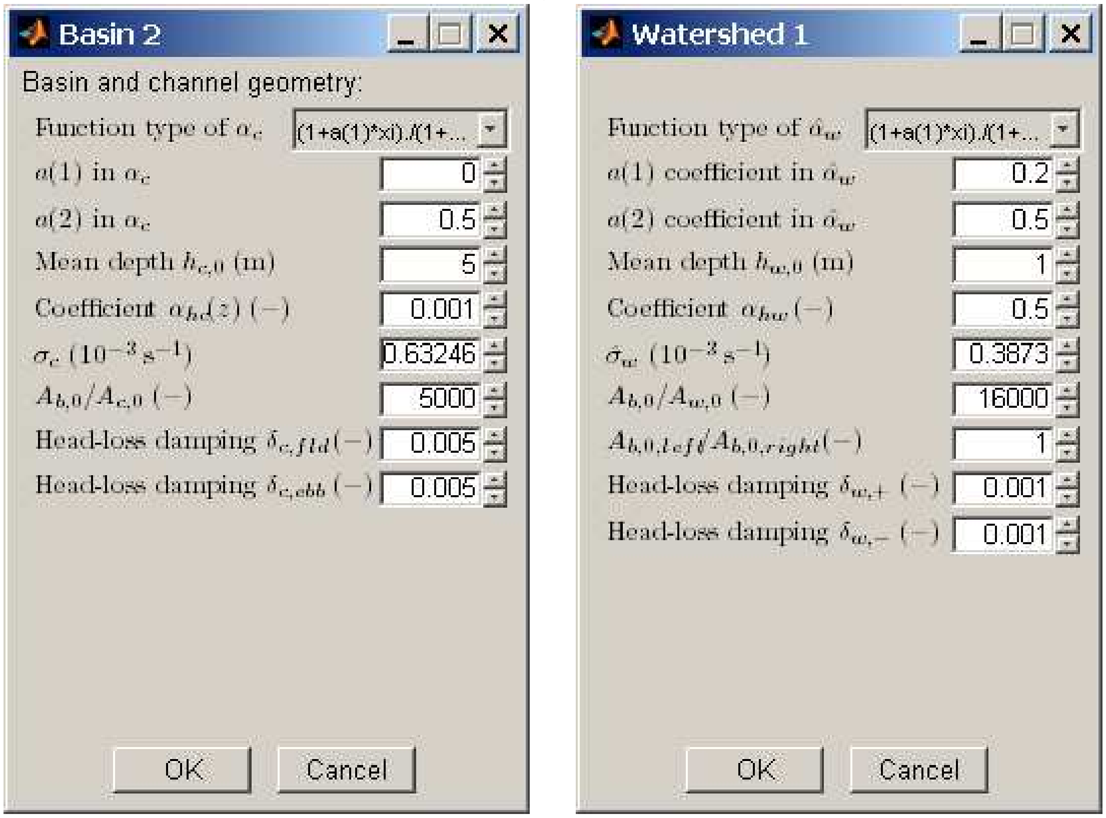


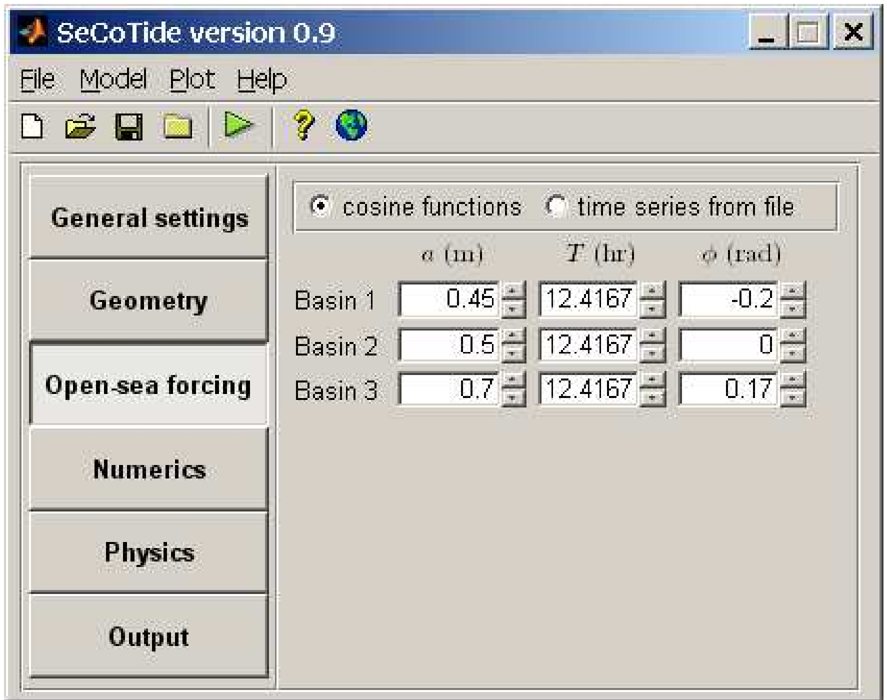
Figure 3.8: Dialog windows for setting the geometrical parameters of the basins (a) and watersheds (b) in the 'scaled' model version.

want to provide another input file name or to return to the default 'cosine functions' boundary conditions formulation.
Similarly, if the time range of the data in the file does not fully cover the chosen calculation time period $t_{\text{begin}} - t_{\text{end}}$ declared in the 'General settings' panel (first time input later than t_{begin} and/or last time input earlier than t_{end}), a question dialog box enables either to provide another input file or to adjust t_{begin} and/or t_{end} to the boundary conditions data.
The time units in the boundary conditions file do not have to be the same as the time units specified in the 'General settings' panel.
During the computations, the boundary conditions data read from file are interpolated linearly onto the model time steps.

3.5 Menu NUMERICS

The 'Numerics' panel (Fig. 3.10) groups the options and parameters important for the computational module of SeCoTide.
The radio buttons in the upper part of this panel enable to select one of the two ordinary differential equations (ODE) solvers available in SeCoTide. Their names are—following the nomenclature of MATLAB—'ode45' and 'ode15s'. Both are variable-order multi-step ODE

(a)



(b)

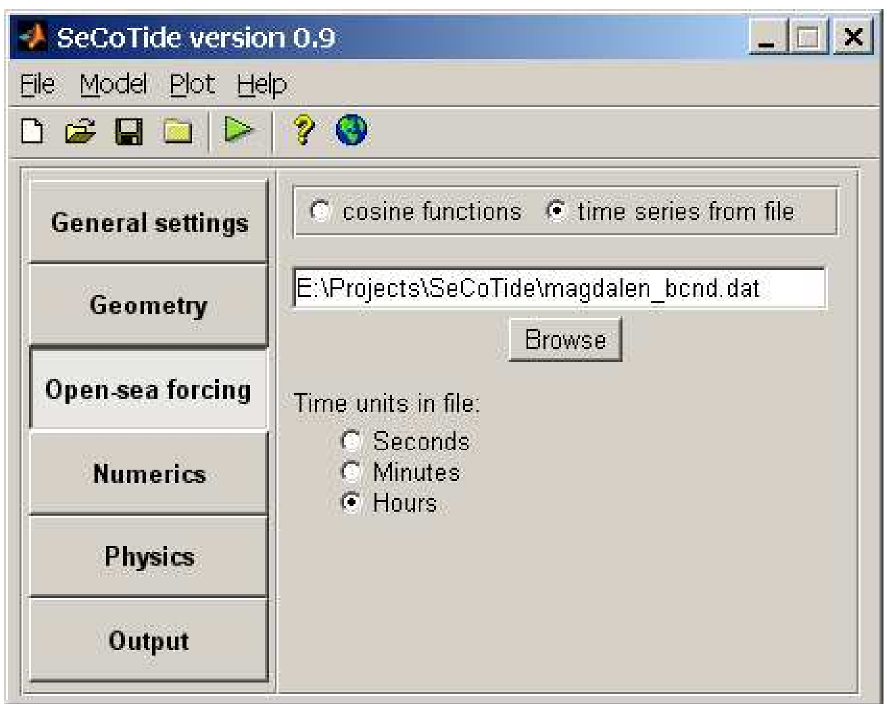


Figure 3.9: The 'Open Sea Forcing' panel of SeCoTide for two types of boundary conditions formulation: as cosine functions (a) and as arbitrary time series (b).

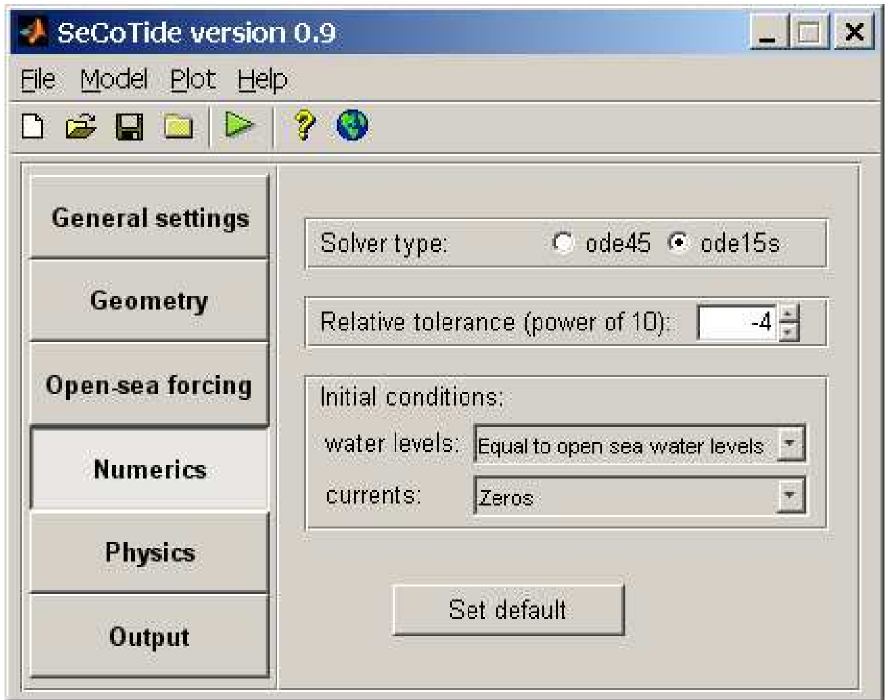


Figure 3.10: The ‘Numerics’ panel of SeCoTide.

solvers; the main difference between them concerns the way in which the entries of the Jacobian matrix of the system are calculated (see section 2.3 and Shampine and Reichelt, 1997). In the case of ‘ode15s’ those entries are calculated analytically (this is what the derivatives of the functions describing the geometry of the basins/channels and watersheds, provided in the `SeCoTide.fcn` file, are for; see also the ‘Geometry’ section). In the case of ‘ode45’ they are approximated numerically by means of a finite difference method. Needless to say, ‘ode15s’ is more exact; ‘ode45’ is faster. Our experience with SeCoTide shows that in most realistic cases both solvers produce very similar results, but testing both methods and comparing their performance is advisable in any new configuration of the model.

Another issue concerning the numerics is the desired accuracy of the computations, i.e. the criterion which has to be fulfilled so that the solver moves on to the next time step. By default it is set to 10^{-4}, defined as a relative difference between the results of two subsequent iterations, which is sufficiently accurate in most cases. Increasing this parameter will speed up the calculations, but the results may be inaccurate (which may manifest itself in too low amplitudes of the tidal fluctuations, both in terms of the water level variations and the current speeds). Decreasing the tolerance parameter slows the calculations; decreasing it too much may produce convergence problems if the solver is not able to reach the too rigorously set termination criteria.

Finally, in the ‘Numerics’ panel the type of initial conditions for water levels in the basins and for currents can be set. In the present model version the current velocities are always set to zero at the start of the computation (‘Zeros’ is the only option on the list). In the case of water levels, two options are available: zero values or (and this is the default) values equal to water levels at the entrances to the respective inlets. In most situations this choice does not have any influence on the model stability. However, the spurious oscillations present in the model solution during the initial phase of the computation usually have smaller amplitude and decline faster if the second option is selected.

Generally, it is advisable to begin the work with the model with the default settings for the numerics and then to modify them if needed, e.g. if computational problems are encountered. The default settings can be quickly restored by pressing the 'Set default' button at the bottom of the 'Numerics' panel.

3.6 Menu PHYSICS

The options grouped in the 'Physics' panel (Fig. 3.11) concern primarily the treatment of friction in the model. In the present SeCoTide version the range of possibilities concerning the friction formulation are quite limited; however, a number of extensions are planned in the subsequent versions.

At present, only the quadratic friction formulation is implemented (the 'linear' option is inactive). The user can provide a value of the Manning's friction factor n (the same for all inlets and watersheds). Another choice concerns the usage of the head-loss damping terms in the inlets and in the watersheds (the watersheds option is active only if the number of basins $N > 1$). The values of the damping coefficients δ_c and δ_w may be adjusted individually to the geometry of the inlets and watersheds (see menu 'Geometry' above).

The default settings ($n = 0.02$ m$^{-1/3}$s; head-loss damping with $\delta = 0.005$ m^{-1} in the inlets and watersheds) can be restored by pressing the 'Set default' button.

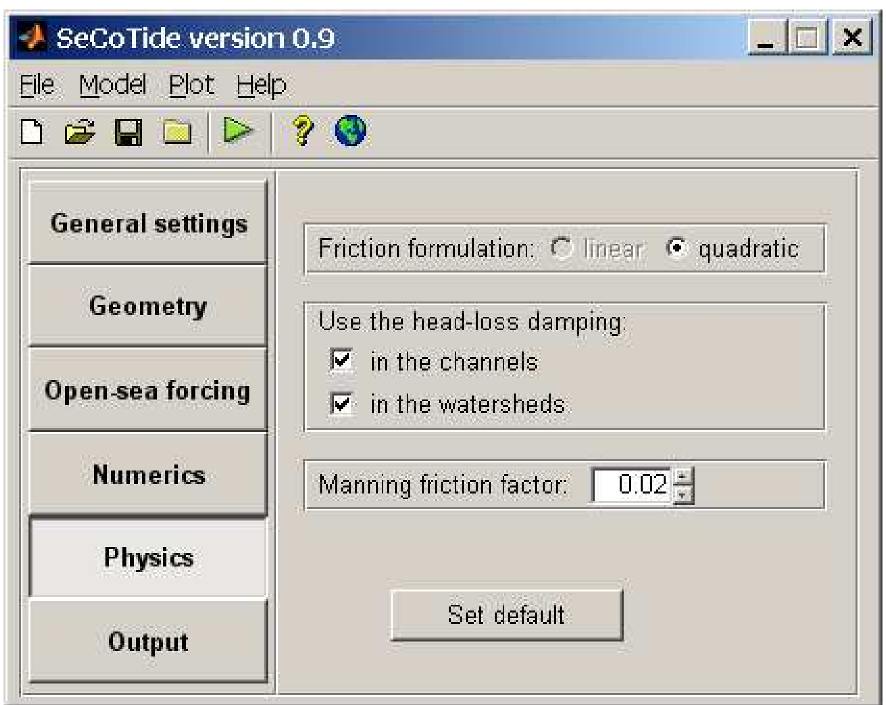


Figure 3.11: The 'Physics' panel of SeCoTide.

Figure 3.12: The 'Output' panel of SeCoTide.

3.7 Menu OUTPUT

The 'Output' panel (Fig. 3.12) groups the parameters controlling the output of the model. The first of those parameters is the output time step Δt (in seconds), i.e. the time step with which the results will be written to the output file(s). It must be stressed that the value of Δt has no influence on the computation time step, which is set internally by the ODE solver. The results--time series of water levels ξ_i and current velocities through the inlets $u_{c,i}$ and through the watersheds $u_{w,i}$ (for $i = 1, \ldots, N$)--may be stored in two types of output files: in a MATLAB (*.mat) and/or ASCII (*.dat) format. The contents and structure of those files are described in detail in section 4.3. Finally, there is a possibility to store the time series of water levels at the entrances to the inlets $\xi_{0,i}$. The 'Set default' button restores the default settings.

Chapter 4

SeCoTide files

4.1 Configuration file

A SeCoTide configuration file contains all information that is necessary to run the model. It is an ASCII file with a obligatory `*.in` extension.
Each line of a configuration file must be a valid MATLAB expression of the form:
`variable name = value;`
Each time the user loads a `*.in` file, its contents are read line by line in a text mode and then evaluated as a MATLAB expression.
The names of the variables, listed in Table 4.1, are predefined. Their order in the configuration file is unimportant. However, it is strongly advisable to keep a file structure identical to the one provided in the sample configuration files in order to avoid errors. In the present version of SeCoTide only a crude check of the file contents is performed, and consequently only the most 'obvious' errors, mainly those disabling the calculations, are discovered.
The model variables are grouped into three structures: '`mod`', '`b`' and '`w`'.
The structures '`b`' and '`w`' contain information concerning the geometry of the basins/inlets and watersheds, respectively. '`b`' has dimension N and '`w`' has dimension $N-1$. For example '`b(3)`' contains parameters describing the third basin. The structure '`mod`' groups variables describing the overall model settings.
Important: The contents of the configuration file depend on the model version: 'scaled' or 'dimensional'. Table 4.1, listing all variables defined in SeCoTide, provides an information whether a given parameter is valid in the scaled (column 'S') and/or the dimensional (column 'D') mode.
Note: the names of the variables are case-sensitive!
Example input files can be found in the `sample` folder in the SeCoTide home directory.

4.2 Boundary conditions

In the present version SeCoTide accepts only ASCII files as source of the boundary conditions data. The allowed file extensions are *.dat and *.txt.
If the number of basins is N, then the boundary conditions file should contain $N+1$ columns: the first one with time and the remaining ones with time series of water levels at the entrances to the respective inlets. The time unit in the file can be specified in GUI in the menu 'Open sea forcing' or directly in a configuration file (parameter mod.ostunit).

Table 4.1: Variables used in the configuration of SeCoTide

Variable name	Default value	Units	'S'	'D'	Description
					elements of the structure 'mod'
mod.N	2	–	+	+	number of basins
mod.tb	0	hr	+	+	computation start time
mod.te	24	hr	+	+	computation stop time
mod.tunit	3	–	+	+	time unit: 1=sec; 2=min; 3=hr
mod.ver	1	–	+	+	model version: 1=scaled; 2=dimensional
mod.ostype	1	–	+	+	type of open-boundary conditions: 1=cosine functions; 2=time series from file
mod.osfile	"	–	+	+	name of the file with open-boundary conditions time series
mod.ostunit	3	–	+	+	time unit in file: 1=sec; 2=min; 3=hr
mod.g	9.806	ms^{-2}	+	+	acceleration due to gravity
mod.fric	2	–	+	+	friction formulation: 1=linear; 2=quadratic [a]
mod.hlc	1	–	+	+	head-loss damping in the channels: 0=off; 1=on
mod.hlw	1	–	+	+	head-loss damping in the watersheds: 0=off; 1=on
mod.n	0.02	$m^{-1/3}s$	+	+	Manning's friction factor
mod.solver	'ode15s'	–	+	+	ODE solver type
mod.reltol	−4	–	+	+	relative tolerance (power of 10)
mod.init(1)	2	–	+	+	type of initial conditions for water levels
mod.init(2)	1	–	+	+	type of initial conditions for currents
mod.dt	900	s	+	+	output time step
mod.outtype	[1 0]	–	+	+	[Matlab ASCII] output: 0=off; 1=on
mod.outfile	{'test.mat', 'test.dat'}	–	+	+	names of the output files
mod.outos	0	–	+	+	save open-sea water levels: 0=off; 1=on
					elements of the structure 'b' (n=1,...,mod.N is a basin index)
b(n).xi0	[0.5 12.4167 0]	[m hr rad]	+	+	[amplitude period phase] of the tidal signal at the inlet entrance [b]
b(n).afun	1	–	+	+	type of the $\alpha_c(\xi, a)$ function [c]
b(n).a	[0.0 0.5]	–	+	+	coefficient vector a in $\alpha_c(\xi, a)$ [d]
b(n).h	[5.0 0.001]	[m –]	+	+	$[h_{c,0}\ \alpha_{hc}]$, where $h_c(z) = h_{c,0} + \alpha_{hc}\xi$
b(n).delta	[0.005 0.005]	$[m^{-1}\ m^{-1}]$	+	+	head-loss damping coefficients in the channel, for $u_c > 0$ and $u_c < 0$
b(n).sigm2	$4{\cdot}10^{-7}$	s^{-2}	+	–	σ_c^2 (Helmholtz frequency squared)
b(n).Ab2Ac	5000	–	+	–	A_b/A_c
b(n).Ab0	$8{\cdot}10^{7}$	m^2	–	+	surface area at $z = 0$
b(n).Ac0	15000	m^2	–	+	channel cross-sectional area at $z = 0$
b(n).L	4000	m	–	+	channel length

Continued on next page...

Table 4.1 – Continued

Variable name	Default value	Units	'S'	'D'	Description
					elements of the structure 'w' (n=1,...,mod.N-1 is a watershed index)
w(n).afun	1	–	+	+	type of the $\alpha_w(\xi, a)$ function[c]
w(n).a	[0.2 0.5]	–	+	+	coefficient vector a in $\alpha_w(\xi, a)$ [d]
w(n).h	[1.0 0.5]	[m –]	+	+	$[h_{w,0}\ \alpha_{hw}]$, where $h_w(z) = h_{w,0} + \alpha_{hw}\xi$
w(n).delta	[0.001 0.001]	[m^{-1} m^{-1}]	+	+	head-loss damping coefficient in the watershed, for $u_w > 0$ and $u_w < 0$
w(n).sigm2	$1.5{\cdot}10^{-7}$	s^{-2}	+	–	σ_w^2 (analogous to Helmholtz frequency squared)
w(n).Ab2Aw	16000	–	+	–	A_b/A_w
w(n).Abratio	1	–	+	–	$A_{b,\mathrm{left}}/A_{b,\mathrm{right}}$
w(n).Aw0	5000	m^2	–	+	watershed cross-sectional area at $z = 0$
w(n).L	4000	m	–	+	watershed length

[a] The option mod.fric=1 is unavailable in the present model version, see section 3.6

[b] used if mod.ostype=1

[c] from the list of functions defined in the `SeCoTide.fnc` file

[d] the length of this vector can be longer than 2; however, in GUI there is a possibility to enter only two values, see section 3.3

The time unit in file does not have to be the same as the time unit chosen to set up the calculation period (menu 'General').
Example boundary conditions files can be found in the `sample` folder in the SeCoTide home directory.

4.3 Result files

The results of the simulations can be saved in two types of files: in a binary MATLAB format (extension *.mat) and in an ASCII format (extension *.dat). The user may specify the type of the output file(s) and their names in GUI in menu 'Output' or directly in a configuration file (parameters mod.outtype and mod.outfile, respectively).
In the files, positive current speed through the i-th inlet means water flowing from the open sea into the i-th basin; positive current speed through the i-th watershed means water flowing from the basin i into the basin $i+1$.
The MATLAB results file contains a structure called `out` consisting of four or five fields, as summarized in Table 4.2.
The first line of the ASCII results file contains only one value, namely the number of basins N. The modelling results are stored column-wise in the rest of the file. The columns are: time (column 1), water levels in the basins (columns 2N+1), current speeds through the inlets (columns N+22N+1) and through the watersheds (columns 2N+23N) and--if the parameter mod.outos equals 1–open-sea water levels (columns 3N+14N).

4.4 Function definition file

`SeCoTide.fnc` is an ASCII file containing the definitions of the functions used in SeCoTide to describe the dependence of various model parameters on the water level ξ, e.g. α_c and α_w.
The file must be present in the main SeCoTide directory and its content is loaded during the model initialization, i.e. every time `SeCoTide.fnc` is modified, SeCoTide must be closed and opened again so that the list of available functions is updated.
In `SeCoTide.fnc` each line beginning with the '`%`' sign (comment line) is ignored. The remaining lines must form correct MATLAB expressions according to the rules given below.
For each function, the user must provide $f(\xi, a)$ and its first- and second-order derivative with respect to ξ: $\partial f/\partial\xi$ and $\partial^2 f/\partial\xi^2$ (used in the calculation of the Jacobian matrix if the 'ode15s' solver is chosen, see sections 2.3 and 3.5). Thus, a full function definition consists of three subsequent lines, as in the examples below.
Important: the programme does not check whether the functions provided as derivatives really *are* derivatives of the respective functions.
Each function definition must begin with the '`@`' sign followed by the function arguments in brackets: '`(xi,a)`', where '`xi`' denotes water level and '`a`' is a vector of parameters (constants).
Note: in GUI the length of this vector cannot exceed 2 (only two fields are provided to enter the values of `a(1)` and `a(2)` in the 'basins' and 'watersheds' windows, as described in section refmenu:geometry. If the user sets up the model directly in a configuration file, there is no limitation concerning the length of '`a`'.
In the present model version, `SeCoTide.fnc` contains definitions of two functions. Its contents are as follows:

```
% function 1:
\@(xi,a)(1+a(1)*xi)./(1+a(2)*xi)
@(xi,a)(a(1)-a(2))./(1+a(2)*xi).^2
```

Table 4.2: Fields of the `out` structure containing the results of the SeCoTide computation (n_t denotes the number of time steps).

Field name	Size	Description
`t`	$n_t \times 1$	time in seconds
`xi`	$n_t \times N$	water levels in the basins
`uc`	$n_t \times N$	current speeds through the inlets
`uw`	$n_t \times (N-1)$	current speeds through the watersheds
`xi0`	$n_t \times N$	water levels in the open sea, saved only if mod.outos=1

```
@(xi,a)2*a(2)*(a(2)-a(1))./(1+a(2)*xi).^3
% function 2:
@(xi,a)1+max(-a(1)*(x-a(2)).^3,0)
@(xi,a)-3/2*a(1)*((x-a(2))-abs(x-a(2))).*(x-a(2))
@(xi,a)-3*a(1)*((x-a(2))-abs(x-a(2)))
```

The user may extend this set with any number of additional functions. Of course, only positive, nondecreasing functions equal one for $\xi = 0$ are physically meaningful candidates for α_c and α_w.

Bibliography

Brouwer, R. (2006). Equilibrium and stability of a double inlet system. Master's thesis, Department of Civil Engineering, Delft University of Technology. 81 p.

Herman, A. (2007). Numerical modelling of water transport processes in partially-connected tidal basins. *Coastal Engng.*, 54:297–320.

Herman, A. (2010). Secotide – a matlab tool for analysis of water circulation in a system of semi-connected tidal basins. *Computer Aplications in Engineering Education*. submitted.

Maas, L. (1997). On the nonlinear Helmholtz response of almost-enclosed tidal basins with sloping bottoms. *J. Fluid Mechanics*, 349:361–380.

Shampine, L. and Reichelt, M. W. (1997). The MATLAB ODE Suite. *SIAM J. Scientific Computing*, 18:1–22.

Urbański, J. and Herman, A. (2009). Water exchange between the basins of the german wadden sea studied with a coupled matlab-arcgis model. *J. Coastal Res.*, SI 56:1085–1089.

van de Kreeke, J., Brouwer, R., Zitman, T., and Schuttelaars, H. (2008). The effect of a topographic high on the morphological stability of a two-inlet bay system. *Coastal Engng*, 55:319–332.