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BOUSS-2D Wave Model in the SMS: 1. Graphical Interface

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PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to describe the graphical interface for the BOUSS-2D Boussinesq wave model that has been added to the U.S. Army Corps of Engineers (USACE) Surface-water Modeling System (SMS). Nwogu and Demirbilek (2001) give the theoretical background and user's manual for BOUSS-2D and subsequent technical notes in this series on the BOUSS-2D model will describe updates and applications of the model.

BACKGROUND: A reliable estimate of the nearshore waves is required in design, maintenance and operation studies for navigation, channel sedimentation, inlets, harbors, and coastal structures. The propagation of nearshore waves in these applications is strongly affected by seabed topography, tidal currents and coastal structures in the areas of interest. The resulting changes in wave characteristics due to these effects can be estimated using the BOUSS-2D model that employs a time-domain solution of fully nonlinear Boussinesq-type equations. These represent the depth-integrated equations of conservation of mass and momentum for waves propagating in water of variable depth and are uniformly valid from deep to shallow water (Nwogu and Demirbilek 2001). BOUSS-2D is a phase-resolving wave model that includes the following phenomena: shoaling, refraction, diffraction, full/partial reflection and transmission, bottom friction, nonlinear wave-wave interactions, wave breaking and dissipation, wave runup and overtopping of structures, wave-current interaction, and wave-induced currents.

The governing equations in BOUSS-2D are solved in time domain with a finite-difference method where the water-surface elevation and horizontal velocities are calculated at the grid nodes in a staggered manner. The area of interest is discretized as a rectangular grid, and time-histories of the velocities and fluxes corresponding to incident storm conditions are specified along wave generation boundaries. Input wave may be periodic (regular) or nonperiodic (irregular), and both unidirectional or multidirectional sea states may be simulated. Waves propagating out of the computational domain are either absorbed in damping layers placed around the perimeter of the domain or allowed to leave the domain freely. Damping and porosity layers are used to simulate the reflection and transmission characteristics of jetties, breakwaters, and other structures existing in the modeling domain. Details about BOUSS-2D model are provided in the model theory and examples report (Nwogu and Demirbilek 2001). SMS (SMS (2005), and Zundel et al.(1998)) includes an interface for BOUSS-2D to facilitate the generation of computational grids, specification of model parameters, and visualization of model input and output. The focus of this CHETN is the description of the BOUSS-2D interface and guidance on usage of the interface. The BOUSS-2D interface allows users to interactively construct, evaluate, edit, and visualize finite-difference grids for the model. Users can define bathymetric conditions, model control parameters, and current, tidal and wave conditions to be simulated. The interface provides tools for visualizing model results in the form of graphical images, animations, and tabular output that may readily be ported into engineering study reports.

The SI engineering units are used in BOUSS-2D calculations. Although the model input and output (I/O) is in metric units, data in English units may be imported into the SMS interface and converted to metric. For example, bathymetric data in latitude/longitude can be converted in the model interface to Universal Transverse Mercator (UTM) or State Plane coordinates. Likewise, model results can be presented in non-SI units using conversion tools and data calculator features available in SMS.

BOUSS-2D I/O FILES: Two files are required for a BOUSS-2D simulation (Figure 1). These are the model parameters (*.par) and the bathymetry grid (*_bathy.grd). Other input files are optional. The name of a parameter file can be passed to the BOUSS-2D model as a command line argument or the program will prompt the user for this file. The model may be launched from inside of SMS in which case the parameter file name is included in the SMS simulation.

In addition to the parameters file, the model requires spatially varied input for the grid, damping, and porosity files. The names and locations of these files are specified in the .par file along with the names and locations of model output files. Spatially varied model I/O is stored in ASCII grid files for steady-state parameters and binary files for time-dependent output. Time-series output at specific locations are stored in a time series file format. A number of I/O files are involved in a simulation. All the potential input and output files are listed in Figure 1, and a description of each file is given in Table 1. Sample files are listed in Appendix A.

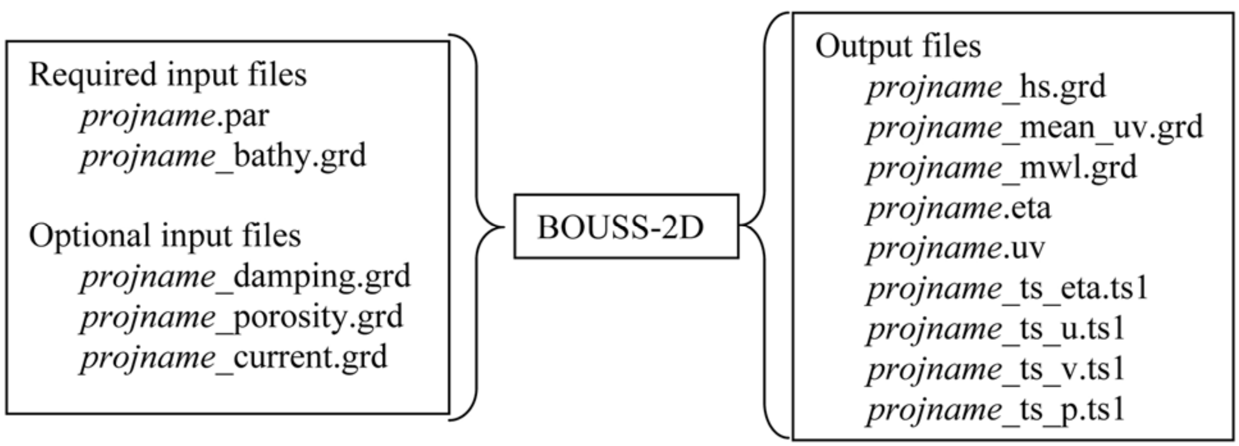


Figure 1. Files involved in a BOUSS-2D simulation

The model includes an option to place all gridded output data (both steady state and and time dependent) into a single binary file. The binary data file uses XMDF (*http://www.wes.army.mil/ITL/XMDF*) and it is written in the standard hdf5 file format to allow for storing large files in compressed form to improve faster processing and viewing. In addition, the binary file ensures the portability of the compressed data across different computing platforms, i.e., a user could run BOUSS-2D model on a high-performance computer, save results in hdf5 format, and perform post-processing on a personal computer (PC). Alternatively, all of these tasks can be performed on a PC.

Table 1.
Files Involved in BOUSS-2D Simulation

File Name	Type	Description
projname.par	Input – required	Parameters, filenames, & boundary conditions
*projname*_bathy.par	Input – required	Elevation value at each node
*projname*_damping.grd	Input – optional	Damping value at each node
*projname*_porosity.grd	Input – optional	Porosity value at each node
*projname*_current.grd	Input – optional	Current vector at each node
*projname*_hs.grd	Output – ASCII grid	Significant wave height at each node
*projname*_mean_uv.grd	Output – ASCII grid	Mean current vector at each node
*projname*_mwl.grd	Output – ASCII grid	Mean water level at each node
projname.eta	Output – Binary grid	Transient water surface at each node
projname.uv	Output – Binary grid	Transient current vector at each node
*projname*_ts_eta.ts1	Output – ASCII time series	Transient water level at probes
*projname*_ts_u.ts1	Output – ASCII time series	Transient u component of current at probes
*projname*_ts_v.ts1	Output – ASCII time series	Transient v component of current at probes
*projname*_ts_p.ts1	Output – ASCII time series	Transient pressure at probes
projname.h5	Output –XMDF (hdf5)	Portable binary output file – all spatial output

BOUSS-2D INTERFACE: Like other finite-difference models in SMS, the BOUSS-2D model is controlled through the 2-D Cartesian grid module. The user should select the *Set Current Model* command in the *Edit* menu and choose BOUSS-2D to activate the model interface. When BOUSS-2D is selected as the current model, the BOUSS-2D menu and tools become available. This document describes the standard components of the BOUSS-2D interface. It is recommended that the user become familiar with other modules of SMS to fully exploit the interface. For example, the BOUSS-2D grid can also be specified in the map module via a BOUSS-2D coverage. In addition, in most simulations the user will use the scatter module to import surveys and digital maps to define bathymetry for a grid.

a. **BOUSS-2D menu:** The BOUSS-2D menu (Figure 2) commands are listed in Table 2 along with a description of each command.

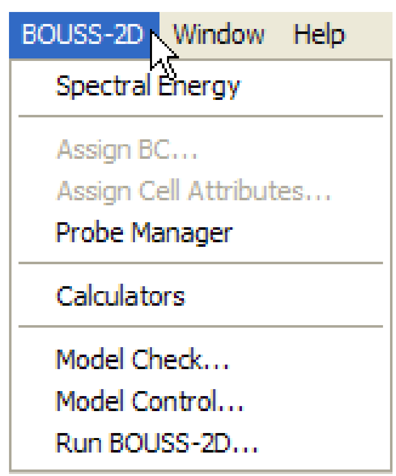
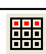
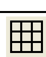


Figure 2. BOUSS-2D menu

Table 2. BOUSS-2D Menu Commands	
Command	**Functionality**
Spectral Energy	Brings up the spectral energy dialog to define/view wave energy spectra. Generally, BOUSS-2D will generate wave conditions internally, but a spectrum may be input. This command also allows the user to visualize wave spectra that are generated inside of the model.
Assign BC	This command is used to assign damping, porosity, or wave maker conditions along a selected cell string or strings.
Assign Cell Attributes	Selected cells can be defined as land or water.
Probe Manager	Brings up the Probe Manager to control time series output from the model.
Calculators	Brings up a popup menu to access the Wave Conditions Calculator (see Appendix A) as well as the Run-up/Overtopping Estimator.
Model Check …	Performs a quality check on the simulation to identify glaring omissions.
Model Control…	Brings up the Model Control dialog to specificy model parameters.
Run BOUSS-2D	Brings up a dialog that allows the user to check what executable of BOUSS-2D should be run and then runs the model with the currently loaded simulation. As the model runs, a dialog monitors progress of the model and gives the user status messages. When the run is complete, the spatial solutions are read in for analysis and visualization.

b. **BOUSS-2D tools:** The BOUSS-2D tools are listed in Table 3 along with their icon and functionality. In SMS, one tool is active at a time. The active tool may be a model specific tool such as those listed in the following table, or it may be a general tool such as *Pan* or *Zoom*. The active tool controls what response the program will make when the user clicks or drags the mouse through the graphics window. Typically there are two types of tools, those that are used to select entities and those that are used to create entities. In the BOUSS-2D interface, the user can create a grid, or a cell-string, and can select cells or cell-strings. Multiple entities can be selected by dragging a box or polygon around more that one entity, or by holding down the **Shift** key while sequentially clicking on entities.

Table 3. BOUSS-2D Tools		
Tool	**Icon**	**Functionality**
Select Cell		Allows the user to select a computation point (cell) by graphically clicking on it. BOUSS-2D works on a "Mesh Centered" grid meaning that its computation points are at the intersection of grid lines. Once selected, the user can adjust the elevation of the cells or assign them to be land or water.
Select Row		Allows the user to select an entire row of cells by clicking on any cell in the row
Select Column		Allows the user to select an entire column of cells by clicking on any cell in the column.
Select Cell String		Allows the user to select defined cell strings to assign boundary conditions to a specific location in the grid.
Create Cell String		Allows the user to define cell strings for the creation of wave makers and other boundary conditions by clicking on the cells. Cell strings are created around the boundaries of the domain automatically when the grid is created.
Create Grid		Allows the user to create a computational grid by clicking three corners of the grid.

c. **Creating a grid:** The process for creating a BOUSS-2D model grid consists of four steps:

(1) Read in bathymetric data. These data can be from one or more surveys, or from a previous numerical model simulation. Data should be brought into SMS as a scattered data set or a digital elevation map (DEM). The most common formats are described as an *.xyz or *.pts file in the SMS documentation. Data for the coastlines and structures in the modeling domain could either be included in the bathymetry (recommended) or brought into SMS separately and merged with the bathymetry data inside SMS.

(2) Select BOUSS-2D as the working model. In the Cartesian grid module, under *Data* menu, find *Switch Current Model* submenu and select BOUSS-2D as the working model.

(3) Define modeling domain. Zoom into the area around the computational domain and select the *create grid tool*. To define the extent of your modeling domain, user must click three times in the graphics window. The first click (Pt 1) is at the location where the lower left corner of the grid will lie. Then the user should move the cursor (a line will appear from the selected corner) to the location where the lower right corner of the grid will be and click again (Pt 2). Finally, the user must move the cursor to the location where the upper right corner of the grid will be and click again (Pt 3). Figure 3 shows a grid being defined.

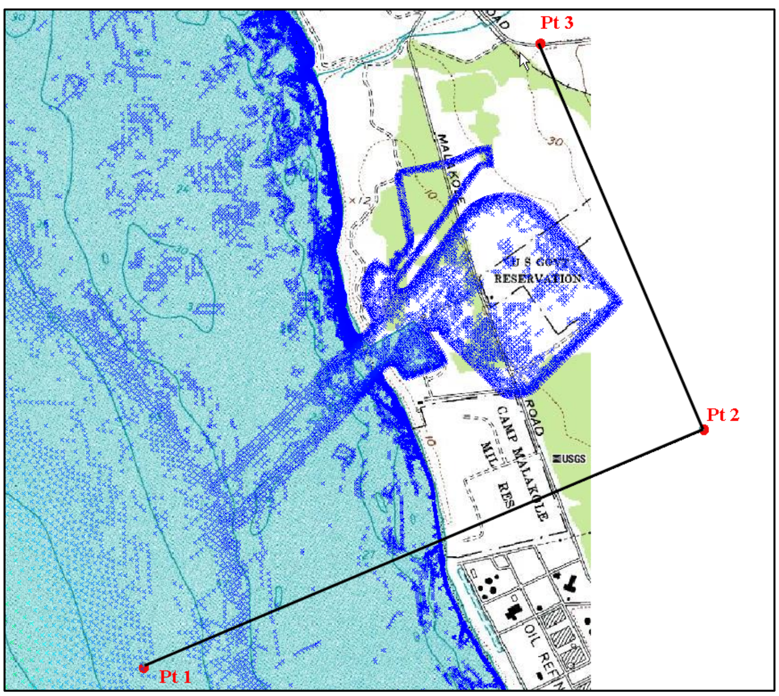


Figure 3. Creating a grid

(4) Create a grid. After defining the Map->2D grid, dialog will appear (Figure 4). This dialog allows the user to modify the size, orientation, position, and cell size for the grid that is being created. If more exact locations are known for the grid position and orientation, the user would enter these in the top section of the dialog. In the center section, the individual cell size is entered. The default values create a grid with 10 x 10 cells, which can be changed by users to any desired values. In the lower section of this dialog, users tell SMS to interpolate the bathymetry values for the grid from the scattered data. Once these data are entered, the user clicks the **OK** button, and a grid will be

created. Bathymetry values for each node of the grid will be interpolated from the scattered bathymetry data at the node locations. Grid cells with a positive bathymetry value will be classified as dry land and excluded in the BOUSS-2D calculation of waves. After the grid is created, the user can also select nodes and modify bathymetry values and cell classifications.

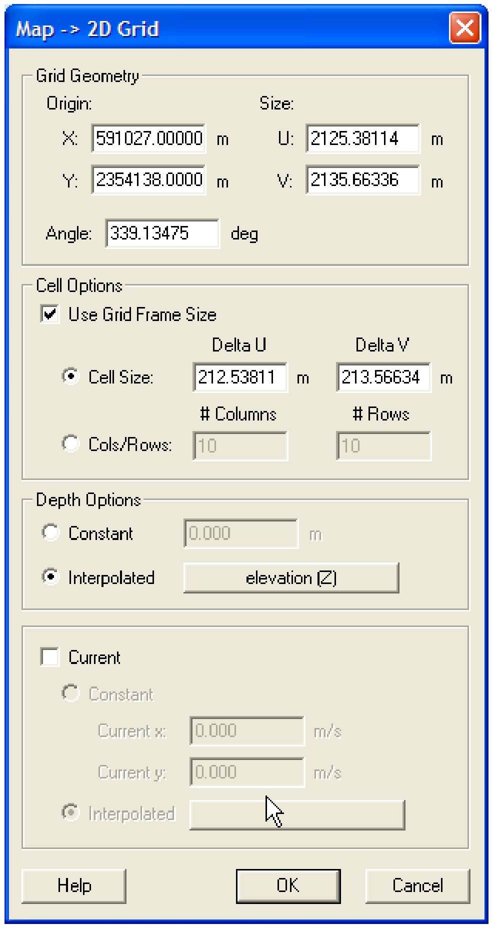


Figure 4. *Map ->2D Grid* dialog

d. **Editing a grid:** The BOUSS-2D grid may be edited, but the grid itself cannot be repositioned. To reposition a grid, a new grid should be created. This is required if the domain needs to be enlarged or reduced, the grid cell size needs to be modified, or the grid orientation needs to be adjusted to align better with principal wave directions. Various operations are permitted for editing a BOUSS-2D grid. These include:

(1) Specification of individual node elevation. Select one or more nodes using the select cell tool , and specify a elevation value in the edit field located at the top of the dialog box. This feature could be used, for example, to evaluate the effects of a dredging operation on the wave field by deepening parts of a navigation channel or describing dredged material mounds in the modeling domain, etc. This feature is useful when some changes to the underlying bathymetry are desired in a small part of the modeling domain where such changes can be made manually to a subarea or selection of cells.

(2) Classification of node point as land or water. This is done by selecting one or more nodes using the select cell tool and specifying the cell attributes using the *Assign Cell Attributes* command in the *BOUSS-2D* menu. This brings up the *BOUSS-2D Cell Attributes* dialog.

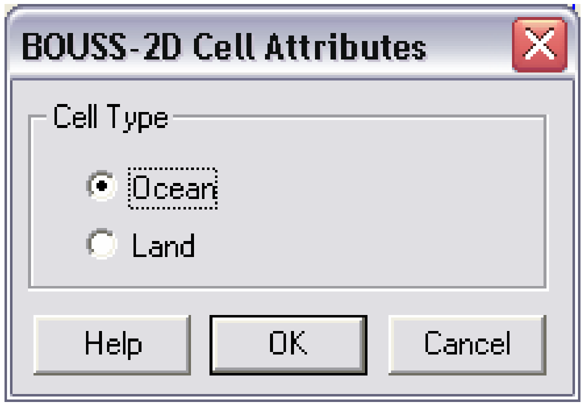


Figure 5. *BOUSS-2D Cell Attributes* dialog

(3) Smoothing bathymetric data in the grid. The Cartesian grid (*CGRID) Smoothing Options* dialog (Figure 6) is available when there is an active grid. To access the dialog, select *Data | Smoothing Options…* from the menu bar. The two choices for the *Filter Size*: (3x3 and 5x5) refer to the subgrid size that the smoothing utility will use. The cell in the center of the subgrid is checked against all the other cells in the subgrid to determine if it needs to be smoothed. The *Number of Iterations* assigns the amount of times the smoothing utility will loop through the cells. The *Maximum Elevation Change* sets the property that the difference in elevation between a cell and any of the cells that surround it (depending on the filter size) will be no larger than the value entered in this field. The *Filter Ratio* ranges from 0.00 to 1.00, and it represents the percentage of filtering. Smoothing bathymetric data may sometimes be necessary, but in general its usage requires careful consideration of the filtering schemes used since the smoothed bathymetry can be substantially different from the original.

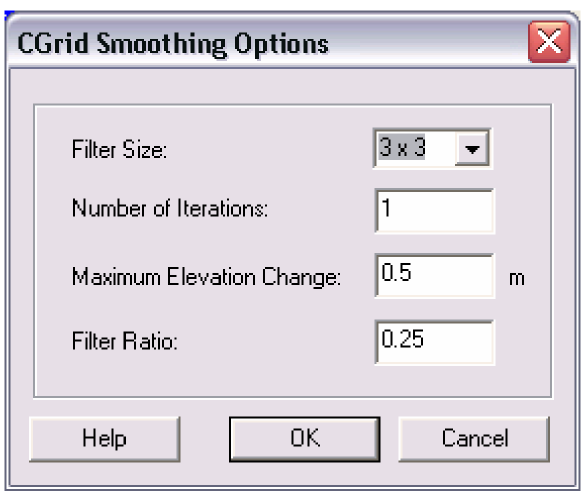


Figure 6. *Smoothing Options* dialog

e. **Assigning boundary conditions:** When the BOUSS-2D grid is created, SMS creates cell strings around the computational boundaries of the domain. A cell string is a list of contiguous node locations in the grid. The left portion of Figure 7 shows a grid with four cell strings that were automatically created. The cell string on the left includes the cells along the open ocean. This one has been assigned to be a wavemaker. The one on the right defines the interface between ocean and land along the coastline, and the top and bottom define the portion of the grid that are open to the ocean on those sides.

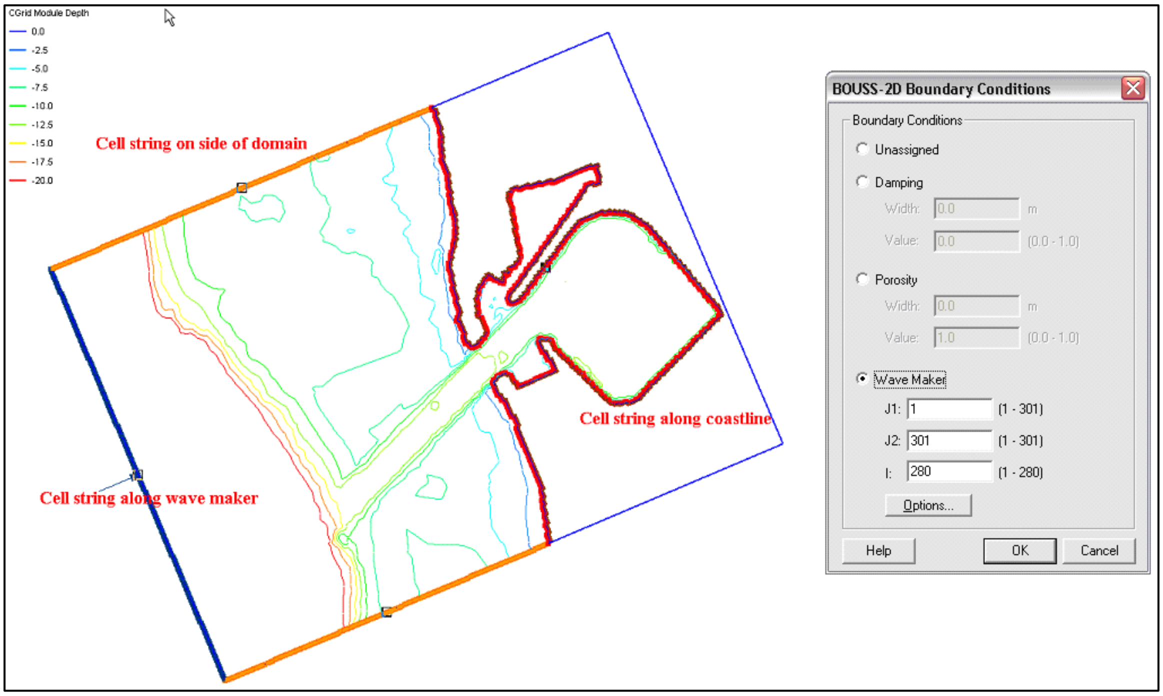
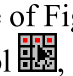


Figure 7. Grid with cell-strings and *Boundary Conditions* dialog

Cell strings can also be created manually to specify the location of structures, wavemakers, and areas where damping and/or porosity layers may be necessary.

Boundary conditions are specified along cell strings in the *BOUSS-2D Boundary Conditions* dialog (shown in the right side of Figure 7), which is accessed by selecting one or more cell strings using the select cell string tool , and then selecting the *BOUSS-2D | Assign BC* menu item. Normally, the user will select a single cell string and assign a boundary condition. If a boundary condition already exists for the selected cell string, the attributes are displayed. The different options for a cell string include:

(1) Unassigned BC. When a cell string is created in BOUSS-2D its default boundary condition type is *Unassigned*. Unassigned cell strings do not influence the model. In fact, unassigned cell strings are not saved as part of the BOUSS-2D input files.

(2) Damping BC. Waves propagating out of the computational domain are absorbed in damping regions (or damping layers) placed around the perimeter of the computational domain. Damping layers can also be used to model the partial reflection from harbor structures inside the computational area. The user must enter a physical width into the "Width" edit field to specify the

size of the damping layer. The damping region extends the width on either side of the cell string. The damping value is a nondimensional damping coefficient that is allowed to vary from 0.0 to 1.0. No damping will occur when a value of 0.0 is used. Waves will be damped when a value of 1.0 is used along the side boundaries. A typical value for shoreline is 0.1. The default damping value is 1.0. SMS will assign the value specified at the cell string and ramp down to 0.0 at a distance of "width" from the cell string.

(3) Porosity BC. Porosity boundary conditions are used to simulate partial wave reflection and transmission through surface-piercing porous structures such as breakwaters. Enter a physical width into the "Width" edit field to specify the size of the porous structure. Like with the damping regions, this width is extended on both sides of the cell string. The porosity value is a nondimensional porosity coefficient that is allowed to vary from 0.0 to 1.0. A value of 0.0 corresponds to an impervious structure, while a value of near 1.0 would correspond to a highly porous structure. Typical porosity for stone type breakwaters is 0.4. The default porosity value is 1.0.

(4) Wavemaker BC. The wavemaker option is only available when a single cell string is selected and that cell string lies in a single column or row (straight line). Legal cell strings can be created using the **SHIFT** key when creating cell strings, using automatically created cell strings along a grid boundary, or by creating short cell strings. The extent and position of the wavemaker can be modified using *I,J* indices in the dialog. BOUSS-2D generates waves emanating from this cell string. The properties of the waves are defined using the *Wave Generator Properties* dialog (described later) that is accessed through the **Options** button. The edit fields are used to position and size the wavemaker in the computational domain. The first two values are the *Start* and *End* cells of the wavemaker along the column or row that is specified by the third value, which is the *Offset* value. The *Start* and *End* values are limited to the number of cells in either the *I*- or *J*-direction, and the *Offset* value is limited to the number of rows or columns.

When the **OK** button is clicked, a check is done to see if the wavemaker cell string is at a constant depth. If the depth varies by more than 20 percent and the wavemaker is on the edge of the grid (not internal), the user is asked whether to force constant depth along the wavemaker cell string or not. If so, the grid is extended to allow the wavemaker to be at the deepest elevation along the string, with a maximum slope of 1:10 from the existing grid to the new wavemaker position. A *Wave Calculator* is provided as part of BOUSS-2D interface in SMS (see Appendix B) to assist users in the preparation of wave input parameters required by the model. Note that the *BOUSS-2D | Assign BC* menu item is disabled any time multiple wavemakers are selected or if a wavemaker and one or more other cell strings are selected.

f. **Runup/overtopping:** To assist the user in the design of coastal structures, the interface includes a one-dimensional (1-D) wave runup and overtopping calculator. This utility runs a 1-D simulation with BOUSS-1D based on user-specified parameters. To access the *1D Runup and Overtopping* calculator (Figure 8) select the *BOUSS2D | Calculators* menu item to bring up the *BOUSS-2D Calculators* dialog. The *1D Runup and Overtopping* calculator is a tab in the *BOUSS-2D Calculators* dialog. The *BOUSS-2D Calculators* dialog is always in the *BOUSS-2D* interface.

Input to the *1D Runup and Overtopping* calculator is organized into a spreadsheet. The first row of the input parameters spreadsheet is fixed and will contain the column titles given in Table 4. The remaining rows contain the input parameters as shown. The names and units columns are read-only. The value column is editable.

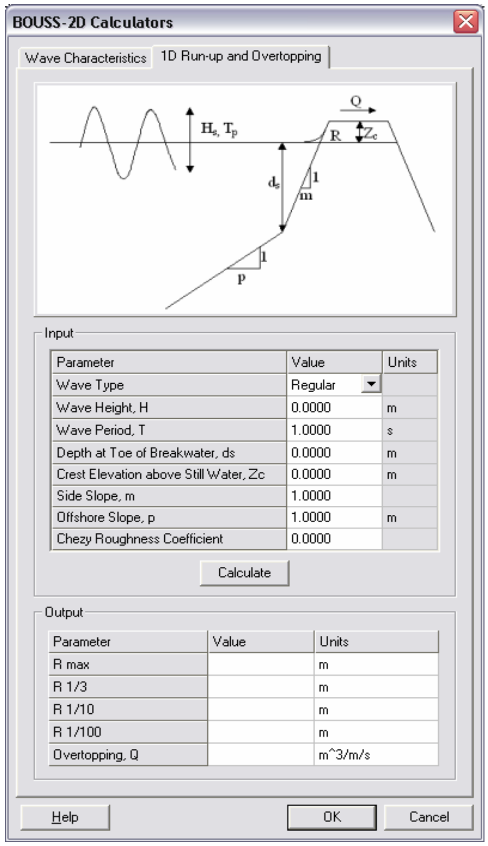


Figure 8. *1D Runup and Overtopping* calculator

Table 4.
Input Parameters for Runup and Overtopping

Parameter	Value	Units
Wave Type	Choose between “Regular” and “Irregular”. Titles of the wave height and period change depending on wave type. Default is “Regular”	-
Wave Height (H) (regular) Significant Wave Height (Hs) (irregular)	User must specify	m
Wave Period (T) (regular) Peak Period (Tp) (irregular)	User must specify	sec
Depth at Toe of Breakwater (ds)	User must specify	m
Crest Elevation above Still Water (Zc)	User must specify	m
Side Slope (m)	User must specify	-
Offshore Slope (p)	User must specify	-
Chezy Roughness Coefficient	User must specify	$m^{1/2}$/sec

Output of the calculator is displayed on the bottom portion of the dialog after the **Calculate** button is clicked. The output is organized into a spreadsheet. When the dialog first comes up, the values in the output parameters spreadsheet are blank. The output parameters calculated are:

(1) Runup, R. This value corresponds to R_{max} for regular waves and $R_{2\%}$ for irregular waves. The units of runup are in meters.

(2) Overtopping, Q**.** A single overtopping value will be computed. The units for overtopping are $(m^3/s)/m$.

g. **Model control parameters:** The *Model Control…* command in the *BOUSS-2D* menu brings up the *Model Control* dialog shown in Figure 9.

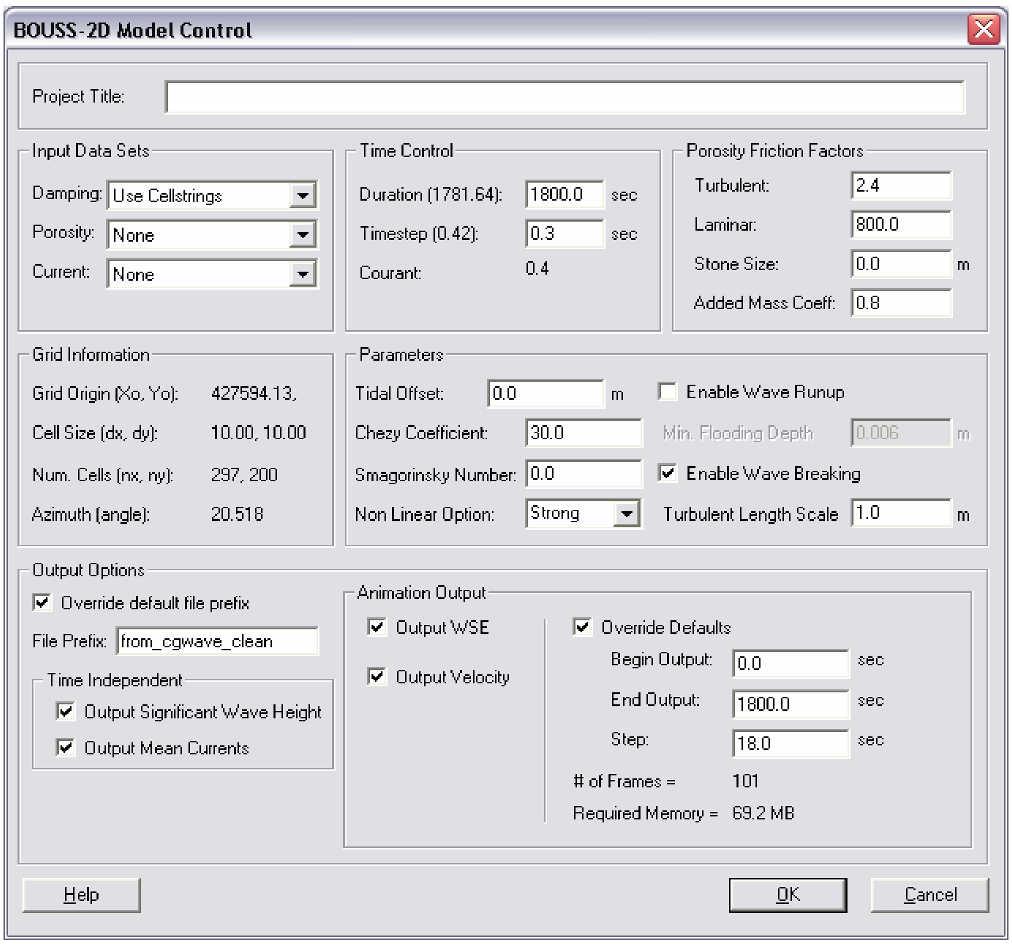


Figure 9. *BOUSS-2D Model Control* dialog

This dialog is divided into sections for different types of parameters which are used by the model as it runs. These include:

(1) Input data sets. These inputs specify spatially varied input parameters for the model. In addition to the bathymetry, *BOUSS-2D* can utilize spatially varied damping, porosity and currents. In this section, the user defines whether these inputs are used (*None* is selected if not), and if so, how

they are defined. The *Damping* and *Porosity* values can be specified using boundary conditions on cell strings or selected from the scalar functions. The *Current* is selected from the available vector functions.

(2) Time control. The interface displays the recommended values for *Duration* and *Time-step* in parentheses. The *Courant number* (Nwogu and Demirbilek 2001) is computed based on the cell size and the specified time-step. A value 0.3 to 0.5 is recommended.

(3) Laminar and turbulent viscous flow coefficients for porosity. The *Turbulent* value ranges from 0.0 to 3.6 with a default value of 2.4. The *Laminar* value ranges from 0 to 1,500 with a default value of 800. *Stone size* represents the characteristic stone size (d_{50}) in meters of the breakwater armor layer and must be greater than zero.

(4) Grid information. This section displays the attributes of the active grid and cannot be edited from within the *Model Control* dialog.

(5) Parameters. The *Tidal Offset* value is the elevation of the water level relative to the still-water level. Check the *Enable Wave Runup* box to enable wave runup calculations. A minimum flooding depth must be specified for runup calculations with a default value of one-hundredth of the wave height. The Chezy coefficient ranges from 0.0 to 1,000.0 (default = 50) and the Smagorinsky coefficient must be between 0.0 and 2.0 (default=0.2). The choice for *Nonlinear Option* is either *Strong* or *Weak*. Check the *Enable Wave Breaking* box to enable simulation of wave breaking and enter a value for the *Turbulent Length Scale* with a default value equal to the wave height.

(6) Spatial output options. BOUSS-2D can output spatial data across the grid. These include the constant functions *Significant Wave Height* and *Mean Currents*, as well as the temporally varied values of *Water Surface Elevation* and *Velocity*. In this section of the dialog, the user defines which files are to be created. The *Override default file prefix* box allows the user to specify a file name for these solution files. The default file prefix is the file name of the .par file. By checking *Output WSE* and/or *Output Velocity* the user tells the model to output the time varying data sets. By default, the model will save data at each time-step. This would result in huge files, so normally the user will select the *Override Default* toggle. This enables the *Begin Output, End Output,* and *Step* controls. The *Begin & End Output* values must be greater than 0.0 and less than the run duration. Also, the begin time must be less than the end time. The *Step* control determines how often the model will save time-varying output. SMS computes the number of frames and an approximate amount of memory required for the resulting data sets.

h. **Defining wave conditions with wavemaker(s):** The principal input boundary condition to the BOUSS-2D model is the wave conditions at wavemaker(s). The BOUSS-2D model requires at least one wavemaker. The properties of a wavemaker are defined in the *BOUSS-2D Wave Generator* dialog (Figure 10). This dialog is accessed selecting a cell string with the *Select Cellstring* tool and choosing the *BOUSS-2D | Assign BC* menu item. In the *BOUSS-2D Boundary Conditions* dialog, the *Wave Maker* option is selected and the *Options* button is clicked. This brings up the *BOUSS-2D Wave Generator* dialog.

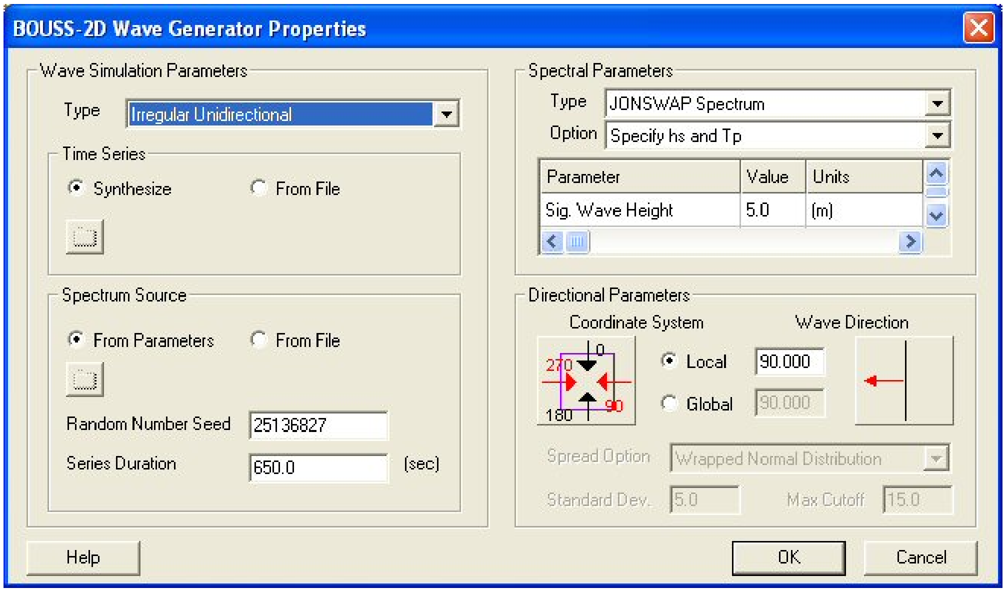


Figure 10. *Wave Generator Properties* dialog

On the left side of the dialog, the user selects the type of wave to be generated. This can be regular, irregular unidirectional, or irregular multidirectional wave type. Then the user specifies whether the time series will be synthesized from wave parameters or read from a file. If synthesized, the parameters (wave height, period, and direction) are entered in the spreadsheet on the right side of the dialog under *Spectral Parameters*.

(1) Regular waves. When generating regular waves the following parameters must also be specified:

- Wave height
- Wave period
- Number of wave cycles
- Wave direction

(2) Irregular unidirectional waves. Irregular unidirectional waves can be generated in the following ways:

- By using an input water-surface elevation time series file (*.ts1). The user specifies which *.ts1 file to use and incident wave direction. The wave direction can either be specified in a shore normal/local coordinate system or a meteorological/global coordinate system.
- By creating a synthetic water-surface elevation time series from an input wave frequency spectrum file (*.spf). The user specifies which *.spf file to use and incident wave direction, time series duration, and random number seed.
- By creating a water-surface elevation time series from a parametric wave spectrum listed in Table 5. The user also has to specify incident wave direction, time series duration, and random seed.

Table 5.
Irregular Unidirectional Wave Spectral Parameters

Method	Required Parameters
TMA spectrum (shallow water)	Significant wave height (H_s) Peak wave period (T_p) Gamma Minimum wave period (T_{min}) Maximum wave period (T_{max}) Whether to rescale the spectrum or not
JONSWAP spectrum	H_s and T_p or wind speed and fetch distance Gamma Minimum wave period (T_{min}) Maximum wave period (T_{max}) Whether to rescale the spectrum or not
Bretschneider (ITTC) spectrum	Significant wave height (H_s) Peak wave period (T_p) Minimum wave period (T_{min}) Maximum wave period (T_{max}) Whether to rescale the spectrum or not
Pierson-Moskowitz spectrum	Wind speed or H_s or T_p Minimum wave period (T_{min}) Maximum wave period (T_{max}) Whether to rescale the spectrum or not
Ochi-Hubble double peak spectrum	H_s for the low frequency H_s for the high frequency T_p for the low frequency T_p for the high frequency Gamma for the low frequency Gamma for the high frequency Minimum wave period (T_{min}) Maximum wave period (T_{max}) Whether to rescale the spectrum or not

(3) Irregular multidirectional waves. Irregular multidirectional waves can be generated in the following ways:

- By using an input water-surface elevation time series file (*.ts1). The user specifies which *.ts1 file to use and the directional distribution function.
- By using an input directional spectrum file (*.dws) either from field measurements or generated in the spectral generator. The user specifies the range of frequencies and generates a spectrum from observed data or from the output of another model such as STWAVE. Spectra may also be generated from parameters for all of the types listed in Table 5. The spectral generator can be used to visualize the spectra as well. Viewing options include both Cartesian and polar projection of the spectral grid and allow selection of individual frequency, direction combinations to view the energy component. The user can also rotate the spectra to examine or better understand the wave conditions in a simulation.
- From a parametric directional wave spectrum by specifying the spectral and directional parameters. The user also has to specify the random number seed and time series duration. This is similar to the unidirectional waves previously described, but adds directional spreading parameters. The spreading parameters determine how the generated wave spectrum is spread directionally. Two spreading options are available for irregular multidirectional waves. These are wrapped normal distribution and cosine power function. With the wrapped normal distribution, the user must specify a standard deviation and a maximum angle cutoff. With the cosine power function, the user must

specify the spreading index and the maximum cutoff angle. Recommended value for the cutoff angle is three times the standard deviation of the directional distribution.

i. **Probes:** The BOUSS-2D model can output the histories of the computed water-surface elevation, velocities, and pressure at every grid point and at every time-step. However, due to the number of data points in the domain, this is usually done at intervals of 15-30 min. In order to provide a more complete temporal representation of the results of the calculation, the model allows the user to specify probes. At a probe location (x,y,z) the user can specify what data should be saved and at what temporal resolutions. The options include water surface, u-velocity, v-velocity and pressure.

(1) The probe manager. The *BOUSS-2D Probe Manager* (Figure 11) manages creating, editing, and deleting probes. This dialog is only accessible when a *BOUSS-2D* grid exists. To access the *BOUSS-2D Probe Manager,* select the *BOUSS-2D* | *Probe Manager* menu item.

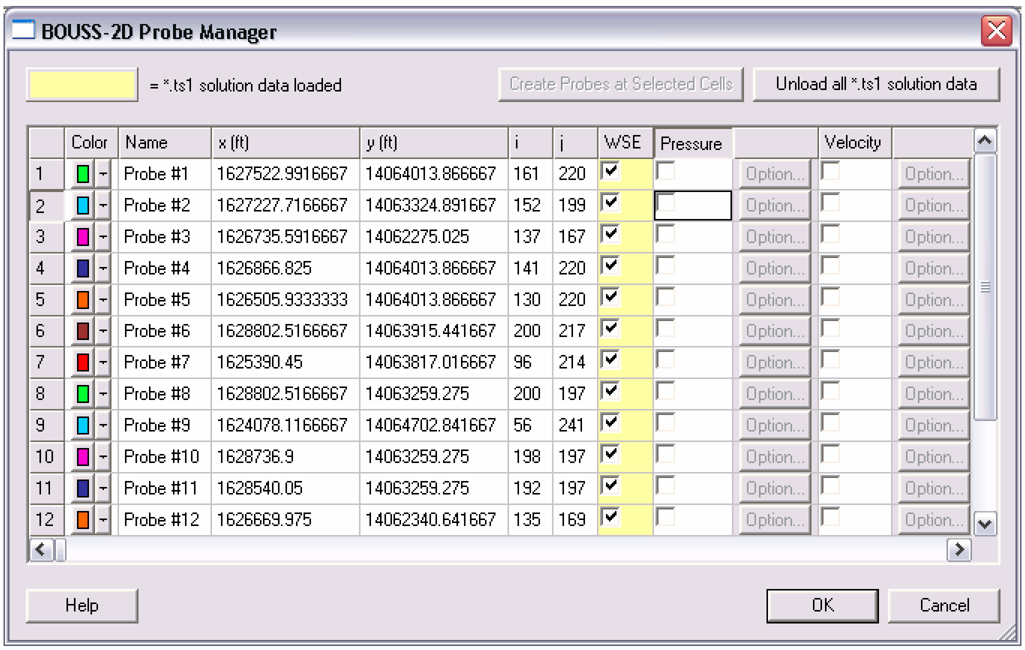


Figure 11. *Probe Manager*

The properties associated with probes are managed in a spreadsheet. These properties are described as follows:

(a) Color. Each probe has a color associated with it. When a probe is created, this color is randomly assigned, but can be changed at any time. A probe is displayed in the main graphics window in the color assigned to it. After a BOUSS-2D simulation has been run, *.ts1 solution data can be loaded. The probe's color is used on the plots of the *.ts1 solution data. This color is also used when plotting the results of the *Spectral Analysis* utility. Currently, the color is not saved to BOUSS-2D input files. When the *.par file is read in, colors are again randomly assigned.

(b) Name. Each probe has a unique name. When a probe is created, a name is assigned by default, but can be changed at any time. The name is used in the legends of the plots of the *.ts1 solution data as well as in the reporting of the results of *the Basic Statistical Analysis*, *Zero-crossing Analysis*, and *Spectral Analysis* utilities. Currently, the name is not saved to BOUSS-2D input files. When the *.par file is read in, default names are again assigned.

(c) Probe locations (x,y) & (i,j). Each probe must have a world location. This world location can be assigned either by entering the (x, y) world location of the probe or by entering the (i, j) grid location. When the (x, y) location is specified, the (i, j) location is updated. When the (i, j) location is specified, the (x, y) location is updated. Only one probe can exist at a given (i, j) grid location. The (x, y) location is saved to the *.par file.

(d) Water-surface elevation, (wse). To gather water-surface elevation (eta) time series data at a probe, the *WSE* toggle box must be checked. A highlighted cell in the *WSE* column means that eta *.ts1 solution data have been loaded for that probe. Turning off the *WSE* toggle box will result in the eta *.ts1 solution data being unloaded for that probe. All *.ts1 solution data can be unloaded by clicking the *Unload all *.ts1 solution data* button. This button is only enabled if *.ts1 solution data has been loaded.

(e) Pressure. To gather pressure time series data at a probe, the *Pressure* toggle box must be checked. When the *Pressure* toggle is checked, the *Options* button in the next column becomes enabled. The *Options* button brings up the *BOUSS-2D Probe Options* dialog (Figure 12) that allows the user to specify at what elevations above the seabed they want the pressure time series data to be collected. At least one elevation above the seabed must be specified. When a cell is highlighted in the *Pressure* column, it means that pressure *.ts1 solution data have been loaded for that probe. Turning off the *Pressure* toggle box or deleting elevations above the seabed will result in the pressure *.ts1 solution data being unloaded for that probe. All *.ts1 solution data can be unloaded by clicking the *Unload all *.ts1 solution data* button. This button is only enabled if *.ts1 solution data have been loaded.

(f) Velocity. To gather velocity (uv) time series data at a probe, the *Velocity* toggle box must be checked. When the *Velocity* toggle is checked, the *Options* button in the next column becomes enabled. The *Options* button brings up the *BOUSS-2D Probe Options* dialog (almost identical to Figure 12) that allows the user to specify at what elevations above the seabed they want uv time series data to be collected. At least one elevation above the seabed must be specified. When a cell is highlighted in the *Velocity* column, it means that uv *.ts1 solution data have been loaded for that probe. Turning off the *Velocity* toggle box or deleting elevations above the seabed will result in the uv *.ts1 solution data being unloaded for that probe. All *.ts1 solution data can be unloaded by clicking the *Unload all *.ts1 solution data* button. This button is only enabled if *.ts1 solution data have been loaded.

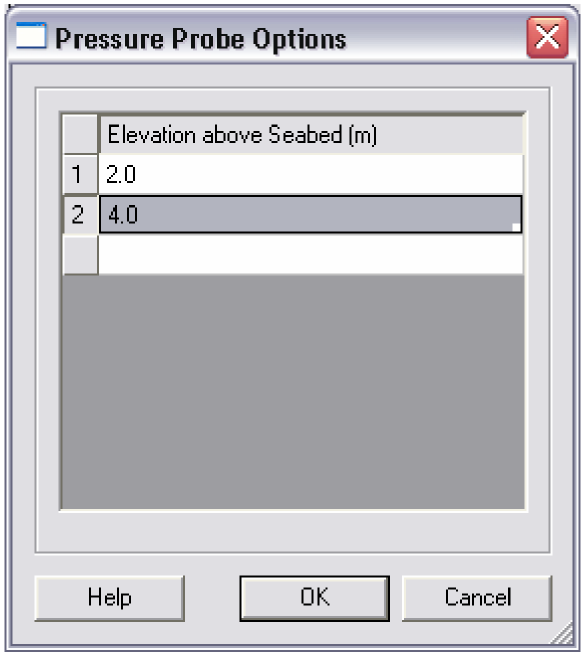


Figure 12. *Pressure/Velocity Probe Options*

(2) Creating probes. The spreadsheet in the *BOUSS-2D Probe Manager* always ends with a blank line. This blank line is for creating a new probe. To create a new probe, assign the new probe a name and either an x, y location or and i, j location. After the name and location of the probe has been specified, the other parameters can be set as desired.

To simplify the creation of probes, the user can click the *Create Probes at Selected Cells* button. This button is only enabled when grid cells have been selected with the *Select Cell* tool prior to opening the *BOUSS-2D Probe Manager*. When this button is clicked, new probes are created at the selected cells and the *Create Probes at Selected Cells* button is disabled.

(3) Editing probes. The properties of probes can be edited at any time.

(4) Deleting probes. A probe is deleted by selecting an entire row of the spreadsheet where probe is defined, and by pushing the **Delete** key on the keyboard. The **Shift** and **Ctrl** keys on the keyboard can be used in combination with the **Delete** key to delete multiple probes.

j. **Time and frequency domain analysis tools / post-processing:** Results from BOUSS-2D can be visualized on the grid or in frequency space as appropriate.

(1) Visualizing spatial results. The grid or XMDF result files from the BOUSS-2D simulation can be displayed inside of SMS. These can be visualized with the general tools in SMS, which allow users to create images and plots of the calculated wave information in the model domain. These include:

(a) Contour plots of wave height and direction for the entire modeling area or a subarea

(b) Vector plots of wave direction and radiation stress for the entire modeling area or a subarea

(c) Tracer animations of wave direction for the entire modeling area or a subarea

(d) Extracted curves of any of the computed values along user-defined transects

(2) Visualizing temporal results. The time series results at the probes can be displayed and analyzed. When SMS opens a ".ts1" file, the symbol for the probe is displayed as a data rich probe. This change of symbol gives immediate feedback to the user about what data are available. The time series data can then be displayed directly as a 2-D plot by right clicking on the probe and asking SMS to create the plot. Figure 13 illustrates the menu that pops up when the user right clicks on the probe. In this example, the probe only contains water-surface (eta*)* series. If other times series data existed, additional menu items would exist in the top section of the menu to allow the user to create plots of these time series.

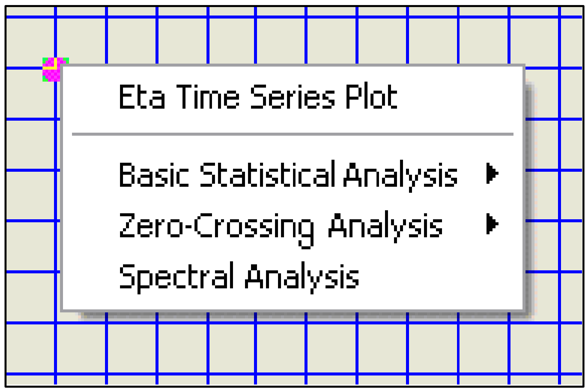
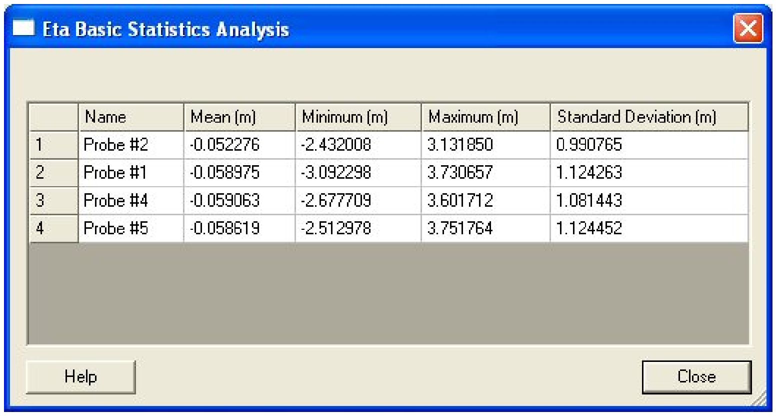


Figure 13. Plot options available when right clicking on a data rich probe

The bottom portion of the menu displays the analysis utilities available for the probe data. When the user selects these menu items, SMS performs the specified analysis and displays a spreadsheet of the results for all selected probes and depths. Analyses that can be performed include basic statistics, zero-crossing and spectral analysis. Plans are in the works to add directional and reflection analysis to the utility.

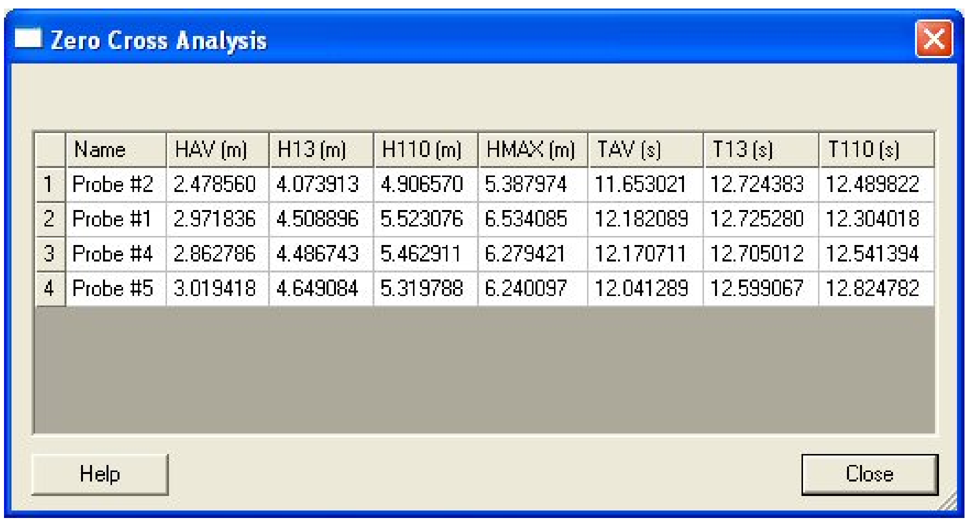
(a) Basic statistical analysis*.* This utility is available for any type of time series data and calculates the mean, minimum, maximum, and standard deviation for the scalar time series data. For pressure, u, and v data, a line of static text appears above the spreadsheet reporting the elevation above the seabed the pressure, u, or v values were collected. All units are in metric.



	Name	Mean (m)	Minimum (m)	Maximum (m)	Standard Deviation (m)
1	Probe #2	-0.052276	-2.432008	3.131850	0.990765
2	Probe #1	-0.058975	-3.092298	3.730657	1.124263
3	Probe #4	-0.059063	-2.677709	3.601712	1.081443
4	Probe #5	-0.058619	-2.512978	3.751764	1.124452

Figure 14. Basic statistics analysis results

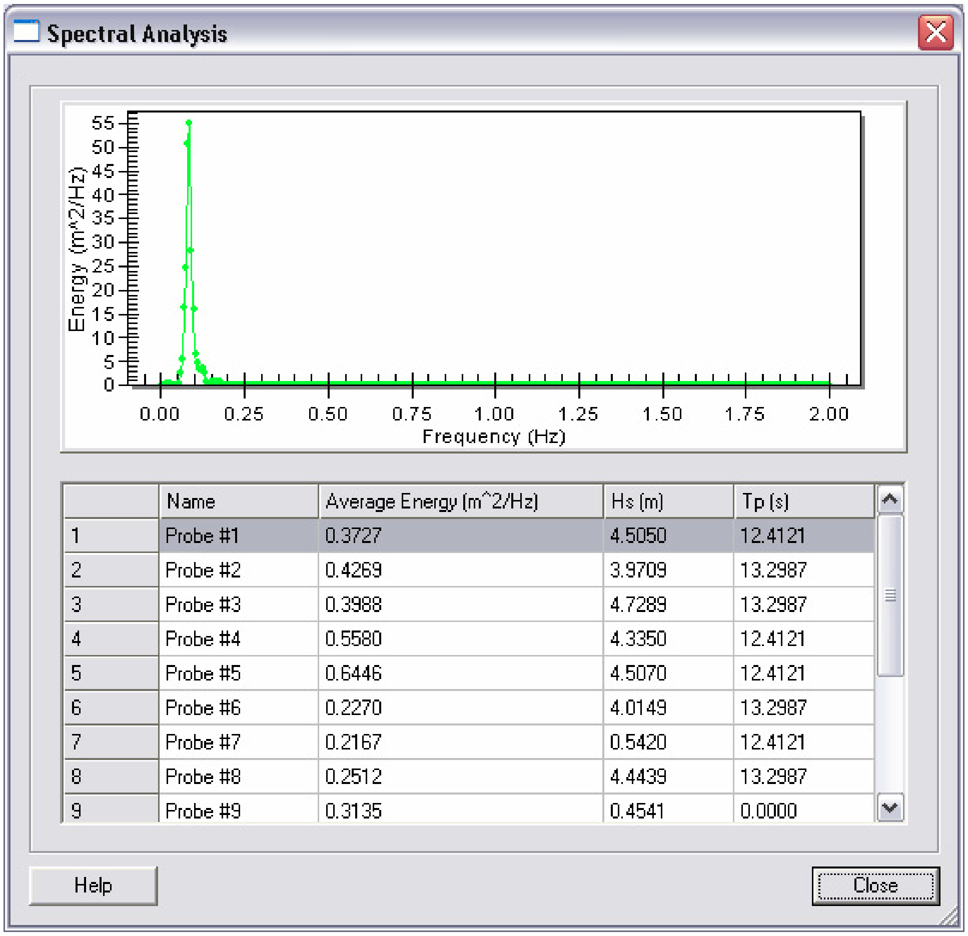
(b) Zero-crossing analysis. This utility is available for only water-surface elevation (eta) time series and calculates the average wave height(H_{ave}), the highest third of all wave heights ($H_{1/3}$), the highest tenth of all wave heights ($H_{1/10}$), the maximum wave height (H_{max}), the average period (T_{ave}), the longest third of all periods ($T_{1/3}$), and the longest tenth of all periods ($T_{1/10}$) for the scalar time series. All units are in metric.



	Name	HAV (m)	H13 (m)	H110 (m)	HMAX (m)	TAV (s)	T13 (s)	T110 (s)
1	Probe #2	2.478560	4.073913	4.906570	5.387974	11.653021	12.724383	12.489822
2	Probe #1	2.971836	4.508896	5.523076	6.534085	12.182089	12.725280	12.304018
3	Probe #4	2.862786	4.486743	5.462911	6.279421	12.170711	12.705012	12.541394
4	Probe #5	3.019418	4.649084	5.319788	6.240097	12.041289	12.599067	12.824782

Figure 15. Zero-crossing analysis results

(c) Spectral analysis. This utility is available for only water-surface elevation (eta) time series. The user specifies the value for the degrees of freedom (DOF) to be used (default=30). The plot displays energy density (m^2/Hz) vs. frequency (Hz) of the selected probe(s) in its/their respective color(s). The spreadsheet displays the average energy density, significant wave height, and peak period for each probe. All units are in metric.



	Name	Average Energy (m^2/Hz)	Hs (m)	Tp (s)
1	Probe #1	0.3727	4.5050	12.4121
2	Probe #2	0.4269	3.9709	13.2987
3	Probe #3	0.3988	4.7289	13.2987
4	Probe #4	0.5580	4.3350	12.4121
5	Probe #5	0.6446	4.5070	12.4121
6	Probe #6	0.2270	4.0149	13.2987
7	Probe #7	0.2167	0.5420	12.4121
8	Probe #8	0.2512	4.4439	13.2987
9	Probe #9	0.3135	0.4541	0.0000

Figure 16. Spectral analysis results

SUMMARY: Various features, tools and analysis capabilities outlined in this document are designed to enhance the ability of engineers to efficiently utilize the BOUSS-2D model in SMS. This CHETN provides specific guidance to users to ensure a comprehensive understanding of the interface necessary for the most efficient usage of the BOUSS-2D model. With the usage of the model in engineering projects by the user community, both the model and its interface are expected to evolve, and the current interface will continue to undergo revisions. Feedback and suggestions from users on the design, implementation, and usage of the present version of the BOUSS-2D interface are welcome. Please direct any comments to the lead author of this CHETN.

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Appendix A
BOUSS-2D File Formats

There are six files formats associated with BOUSS-2D model which include:

1. parameter file (*.par)
2. grid file (*.grd)
3. transient water surface elevation file (*.eta)
4. transient current file (*.uv)
5. time series file (*.ts1)
6. xmdf file (*.h5)

All files but the XMDF file are part of the BOUSS-2D model. They are described in the technical report for the model. Samples of the two most commonly used ASCII files are shown in this appendix. The XMDF file format is based on the HDF5 binary file format and created through the use of an Applied Programmers Interface (API) available through the U.S. Army Engineer Research and Development Center (ERDC) and most other institutes. BOUSS-2D supports the option to output data in the traditional files (i.e., a set of individual standard ASCII files as described in the model's theory report), or have all the spatial data output to a single XMDF binary file. The XMDF file is smaller, faster, and portable across computer platforms, so SMS sets the option in the parameter file to save output into an XMDF file. This can be modified using a text editor.

Parameter file: *.par

```
####################################################################
# BOUSS-2D Run Parameter File: test.par
# Written by:                SMS
# Creation Date:             Tuesday June 22 10:28 2004
####################################################################
#
# Bathymetric Grid Parameters
#
:BATHY_FILE                  test_bathy.grd
:TIDAL_OFFSET                0.000000
#
# Damping Parameters
:DAMPING_FILE                test_damped_end_damping.grd
#
# Wavemaker #1 parameters
#
:START_WAVEMAKER
:  WM_POS_I1                 1
:  WM_POS_J1                 3
:  WM_POS_I2                 1
:  WM_POS_J2                 103
:  WAVE_TYPE                 Regular
:  WAVE_HEIGHT               1.000000
:  WAVE_PERIOD               8.000000
:  WAVE_DIRECTION            270.000000
:  WAVE_CYCLES               20
:END_WAVEMAKER
#
```

```
# Simulation parameters
#
:DURATION                400.000000
:TIME_STEP               0.200000
:CHEZY_COEFF             30.000000
:SMAGORINSKY_CONST       0.000000
:NONLINEAR_OPTION        Strong
:CHECK_WAVE_BREAKING     Yes
:TURB_LENGTH_SCALE       1.000000
:CALC_WAVE_RUNUP         No
#
# Output Parameters
#
:OUTPUT_FILE_PREFIX      test_dampedend
#
# Output File for Significant Wave Height
#
:HS_FILE                 test_dampedend_hs.grd
#
# Output File for Mean Currents
#
:MEAN_UV_FILE            test_dampedend_mean_uv.grd
#
# Surface Elevation Animation File Output Options
#
:SAVE_ETA_ANIMATION
:  ETA_ANIM_FILE         test_dampedend.eta
:  START_TIME            0.000000
:  END_TIME              400.000000
:  SAVE_TIME_STEP        4.000000
:  SAVE_FULL_GRID        Yes
:END_SAVE_ETA_ANIMATION
#
# Velocity Animation File Output Options
#
:SAVE_UV_ANIMATION
:  UV_ANIM_FILE          test_dampedend.uv
:  START_TIME            0.000000
:  END_TIME              400.000000
:  SAVE_TIME_STEP        4.000000
:  SAVE_FULL_GRID        Yes
:END_SAVE_UV_ANIMATION
#
# Output File for XMDF Solution File
#
:SOLUTION_FILE_OPTION    1 # 0 - BOUSS-2D, 1 - XMDF, 2 - Both
:XMDF_SOLUTION_FILE      test_dampedend_sol.h5
```

Grid file: *_bathy.grd

This can be for input or output, and can have one or two values per node.

```
# BOUSS-2D Elevation Grid File
:FileName        test_bathy.grd
:WrittenBy       SMS Version 9.0
:CreationDate    Tuesday June 22 10:28 2004
#
```

```
:N_Arrays          1
:DataDescription(1) Seabed Elevation
:DataUnits(1)      meters
#
:NGrid_X           201
:NGrid_Y           105
:Delta_X          5.000
:Delta_Y          5.000
:X_Origin         0.000
:Y_Origin         -10.000
:Grid_Orientation   0.000
#
:EndHeader
 2 2 2 2 2 2
.
. (values for each node point in the grid)
.
```

Time Series file: *.ts1

This file temporal data at specified locations. The probe locations are listed in the header of the file. The body of the file has one column for time, and one column for each probe.

```
# BOUSS2D Type 2 Time Series File
:WrittenBy      BOUSS-2D Version 1
:CreationDate    Mon Jun 21 18:42:22 2004
#
:NDataSets            3
:DataDescription(1)    Time
:DataUnits(1)          seconds
:DataDescription(2)    Surface Elevation
:DataUnits(2)          meters
:DataDescription(3)    Surface Elevation
:DataUnits(3)          meters
#
:x_probe(1)           428491.84375 # meters
:y_probe(1)           75775.984375 # meters
:z_probe(1)           50          # meters
:x_probe(2)           428701.3125  # meters
:y_probe(2)           75758.289063 # meters
:z_probe(2)           50          # meters
#
:NTimeSteps           6000
#
:EndHeader
   0.000000       0.000000       0.000000
  0.3000000       0.000000       0.000000
    Times       Value @ Probe 1  Value @ Probe 2
     .
     .
   1799.400      0.5389687E-01   0.5170128
   1799.700      0.5273482E-01   0.3926659
```

Appendix B
Wave Parameters Calculator

The BOUSS-2D interface of SMS includes a generic wave attributes calculator to assist the user when defining parameters such as damping widths and cell sizes, which require information about maximum wave height, steepness, wavelength, celerity etc. The *Wave Parameters* calculator provides users a quick estimate of these and other wave parameters. To access the *Wave Characteristics* calculator (Figure B1.) select the *BOUSS2D | Calculators* menu item to bring up the *BOUSS-2D Calculators* dialog. The *Wave Parameters* calculator is a tab in the *BOUSS-2D Calculators* dialog. The *BOUSS-2D Calculators* dialog is always available in the *BOUSS-2D* interface.

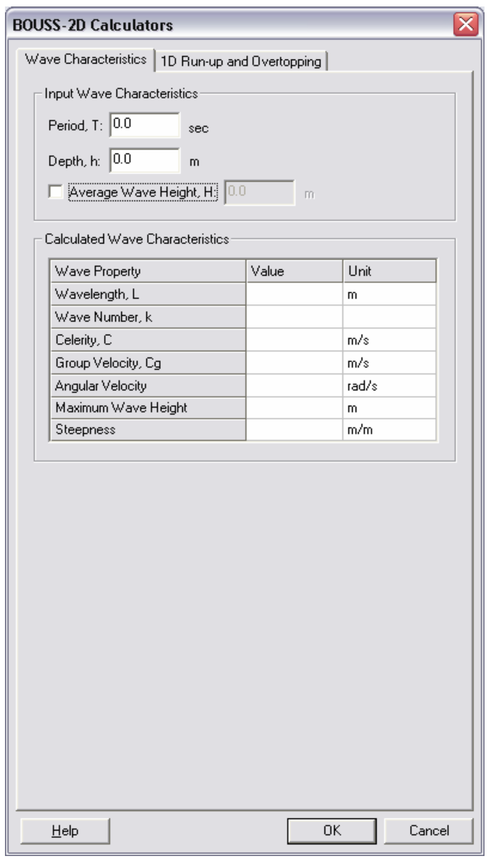

Figure B1. *Wave Parameters* calculator

To use the calculator, the user supplies the following:

(1) Wave period, T. When the dialog opens, the wave period is set to 0.0 by default. The period is forced to be a number greater than or equal to 0.0. When the user changes the period, the calculated wave parameters are updated.

(2) Depth, d. When the dialog opens, the depth is set to 0.0 by default. The depth is forced to be a number greater than or equal to 0.0. When the user changes the depth, the calculated wave parameters are updated.

(3) Average wave height, H. When the dialog opens, the average wave height toggle box is not checked by default. The average wave height itself is set to 0.0 by default. When the average wave height toggle box is off, then the edit field and unit's text are disabled. When it is on, then the edit field and unit's text are enabled. The average wave height is forced to be a number greater than or equal to 0.0. When the average wave height toggle is changed and when the average wave height value is changed, the calculated wave parameters are updated.

Wave parameters computed by the calculator include:

(1) Wavelength, L. The wavelength will be calculated using the transitional wavelength equation. Wavelength has units of meters.

(2) Wave number, k. The wave number is calculated from wave number as $k = 2\pi / L$. If the wavelength is 0.0, the spreadsheet cell for the wave number value is left blank. The wave number has units of 1/m.

(3) Celerity, C. The wave celerity is calculated from wavelength and wave period as $C = L / T$. If the period is 0.0, the spreadsheet cell for the celerity value is left blank. The celerity has units of m/s.

(4) Group velocity, C_g. The group velocity is calculated using the following equation: $C_g = nC$ where $n = \frac{1}{2}\left[1 + \frac{\frac{4\pi h}{L}}{sinh\left(\frac{4\pi h}{L}\right)}\right]$. If the wavelength is 0.0 or if $sinh\left(\frac{4\pi h}{L}\right)$ is 0.0, then the spreadsheet cell for the group velocity is left blank. The group velocity has units of m/s.

(5) Angular velocity, ω. The angular velocity is defined as: $\omega = \frac{2\pi}{T}$. If the period is 0, then the spreadsheet cell for the angular velocity value is left blank. The angular velocity has units of rad/s.

(6) Maximum wave height (or breaking wave height). The maximum wave height is calculated using the following relationship: $H_{max} = 1.86 H_{1/3}$ where $H_{1/3} = 1.416 H_{ave}$. However, the maximum wave height cannot exceed 0.78h. If the maximum wave height exceeds 0.78h, then the breaking wave height is reported as $H_{break} = 0.78h$. The maximum wave height (breaking wave height) is only calculated when the average wave height toggle is on. The maximum wave height (breaking wave height) has units of meters.

(7) Steepness. The steepness is calculated from the relationship: $steepness = H_{max} / L$. If the wavelength is 0, then the spreadsheet cell of the steepness value is left blank. The steepness is only calculated when the average wave height toggle is on. The steepness has no units (m/m).