ASMITA_lite Manual Version 1.0

Summary

This manual provides details of how to use the ASMITA software, guidance on setting-up models and a series of Appendices that detail the theoretical background and some of the current limitations. It is accompanied by some sample models and a number of spreadsheets:

Southampton Water.mat	four element model of Southampton Water
Southampton water 2shore.mat	mix of 2-sided and single bank representation of estuary reaches
ASMITA_lite program structure.xls	details subroutines that make up the model
Blank model parameters.xls	spreadsheet to help define model parameters
SW4e model parameters.xls	worked example for one of the sample models
SW4e_change.xls	sample spreadsheet detailing changes used in Southampton Water model.

Acknowledgements

The concept of an **A**ggregated **S**cale **M**orphological **I**nteraction between **T**idal basin and **A**djacent coast (ASMITA) was first proposed by Marcel Stive and co-workers at TU Delft. The first Matlab version of ASMITA was developed by Tjerk Zitman at TU Delft. Work by Zheng Bing Wang and colleagues also at TU Delft further developed the model and set out the basis of model parameterisation. This version was provided to ABPmer where Ian Townend and Adrian Wright extended the model to include variable area, variable flow conditions and a more extensive user interface. As part of the Estuaries Research Program Phase 2 (ERP2), funded by the Environment Agency and Department for Environment, Food and Rural Affairs (part of project FD2107) this research code was documented, tested and a manual prepared. Version 1.3 was then released as Open Source software available from the Estuary Guide web site (www.estuary-guide.net).

The ASMITA_lite model is a simplified version that models volume changes assuming constant area and is the result of ongoing development and testing at HR Wallingford by Kate Rossington, Ian Townend, Jeremy Spearman, and Michiel Knappen at HR Wallingford.

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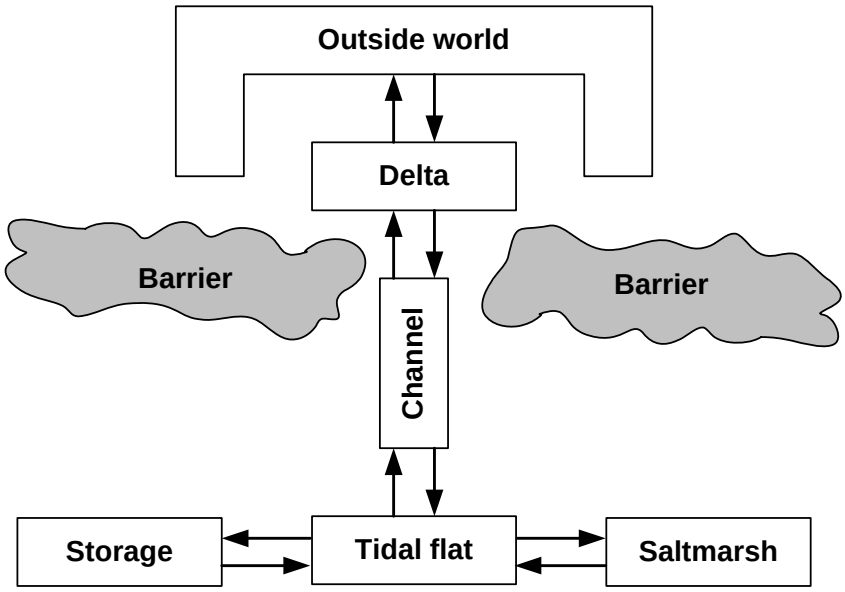
1 INTRODUCTION

Definition: **A**ggregated **S**cale **M**orphological **I**nteraction between a **T**idal inlet and the **A**djacent coast (**ASMITA**).

This manual has been written as a guide to using the Matlab ASMITA model and illustrates the concepts and methodology used in long-term morphological modelling.

Figure 1 Schematisation of an estuary or inlet into a number of elements as used in ASMITA



The idea behind ASMITA is that a tidal basin, or estuary can be sub-dividing into a number of elements (Figure 1). Each element has an equilibrium condition when unperturbed and following some form of perturbation (eg. sea level rise, addition or removal of volume or area) the model seeks a new equilibrium. For example, if under initial conditions the accommodation space is zero (no net change in the transport of sediment), with increased mean sea level the accommodation space becomes positive and sediment may be imported, the opposite is true when sea level falls. The key concepts of the ASMITA model are:

- The estuary is schematized into a number of geomorphologic elements;
- The state of each element is described by its volume and plan area (water or sediment);
- Integrated parameters of hydrodynamics (tidal prism, or tidal range) are used;
- Empirical relationships define the morphological equilibrium for each element;
- Deviation from the morphological equilibrium causes sediment demand; and
- A gradient in sediment demand drives sediment transport, and thereby morphological change.

Appendix A describes the theory and concepts used within the ASMITA model.

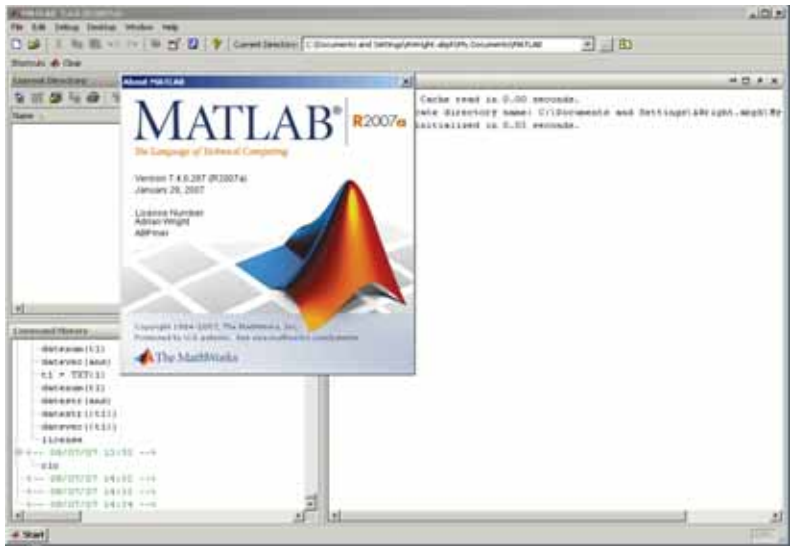
Note to Users:
This manual seeks to explain how to use the ASMITA software. It also provides some guidance on how to set-up a model and how certain aspects of the model work. However, if when using the model you come across issues that are not explained in the manual please either draft a suitable addition to the manual, or send a short note describing the issue to one of the developers (see Acknowledgments).

2 GETTING STARTED

2.1 About ASMITA Software

The ASMITA software has been written using the software language Matlab, version R2007a (Figure 2). The software utilises only the functions present within Matlab and does not require additional toolboxes. Distributed alongside this manual is a document that details the relationships between the various routines that makeup the ASMITA program.

Figure 2. The ASMITA program has been developed using the software Matlab R2007a from Mathworks



2.2 Opening ASMITA

Within Matlab navigate to the folder containing the Matlab ASMITA scripts. From the command line, type **asmuilite;** (Figure 3) this command will invoke the installation and setup of the ASMITA graphical user interface (GUI).

Figure 3. To load and run ASMITA type 'asmuilite;' within the command widow

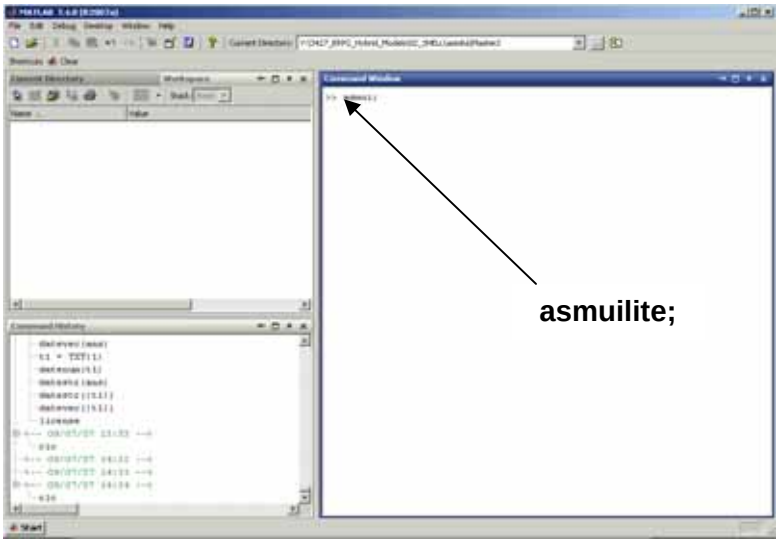
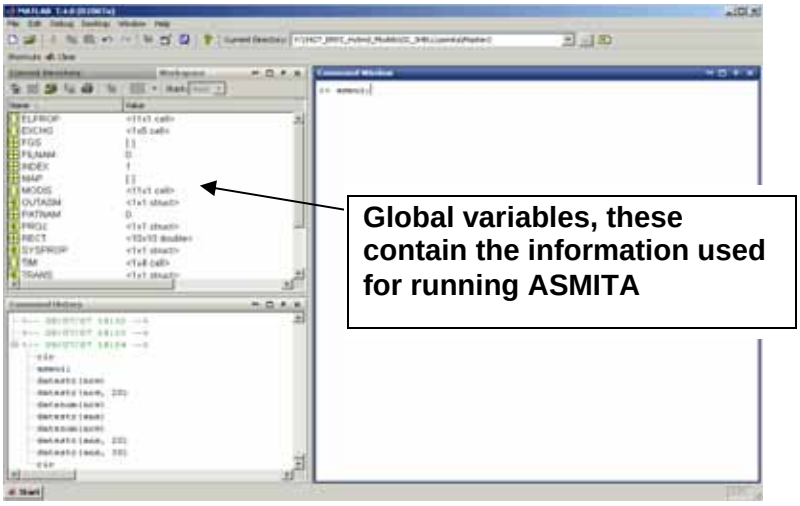


Figure 4. The Matlab environment after calling the ASMITA program



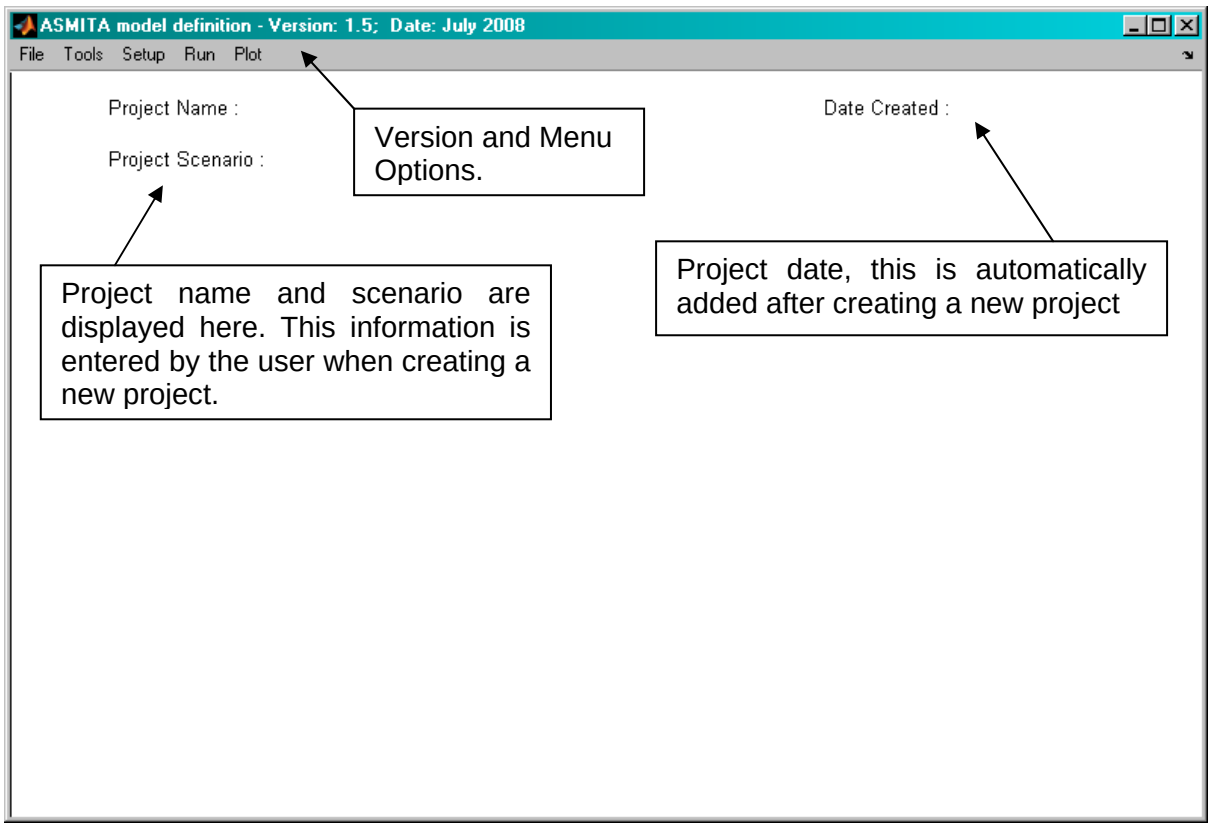
The information entered into the ASMITA model (type, properties, flow, diffusion rates and so on) are contained within global variables stored within the Matlab environment. This information is used throughout the various routines and stored in memory throughout the lifetime of the application. The user can view this information either through the graphical plotting interface provided in the software (Section 7), or from the excel spreadsheet that is generated to record all of the input data and the model results on a series of worksheets. From within Matlab the user can also interrogate both global and local variables from the workspace window (Figure 4).

Note: Within Matlab, information is stored as numbers, cell arrays and structured arrays.

On entering 'asmuilite' the following splash screen appears (Figure 5) for a few seconds before being replaced by the ASMITA interface (Figure 6).

Figure 5. Splash screen acknowledging the project partners who have contributed to the ASMITA program

Figure 6. The ASMITA interface



The user is able to control **all** aspects of the ASMITA model through the ASMITA interface (Figure 6), there is no requirement for the user to access data or commands through the Matlab command window.

Note: Users have full access to the code that will enable them to make fine adjustments to the controlling algorithms. For example, additional driving forces may be needed that are not described in the current setup. Having full access to the software code allows the user to add additional functionality.

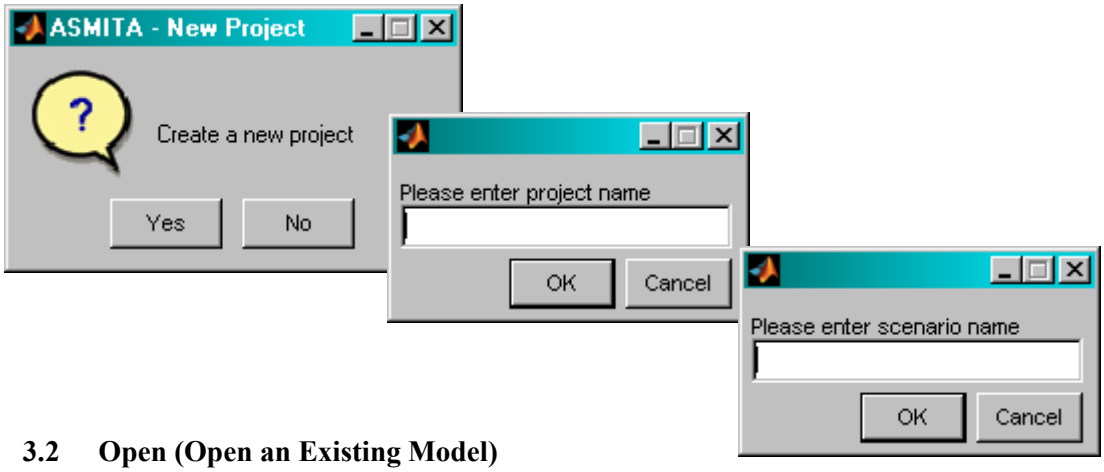
3 FILE MENU

From within the ASMITA interface (Figure 6) there are a number of menu options. The menu item **FILE** allows the user to perform a number of file operations such as open or create a new instance of ASMITA, exit the program or save the current model setup. The following section explains the options available to the user for each of these items under the FILE menu.

3.1 New (Create a New Model Setup)

After selecting **New** from the File menu option a series of popup windows will appear. The user is asked a number of questions regarding the project name and scenario (Figure 7). This information will be displayed in the ASMITA interface (Figure 6).

Figure 7 A series of dialog windows appear after selecting the New menu item



3.2 Open (Open an Existing Model)

Information regarding existing ASMITA models can be stored within a Matlab work file (*.mat). The *.mat file contains the information regarding the complete model setup including element and system defined properties.

Select an existing ASMITA model setup file from the common dialog box. By default the *.mat file extension is visible (Figure 8). An example *.mat project is provided along with the model scripts.

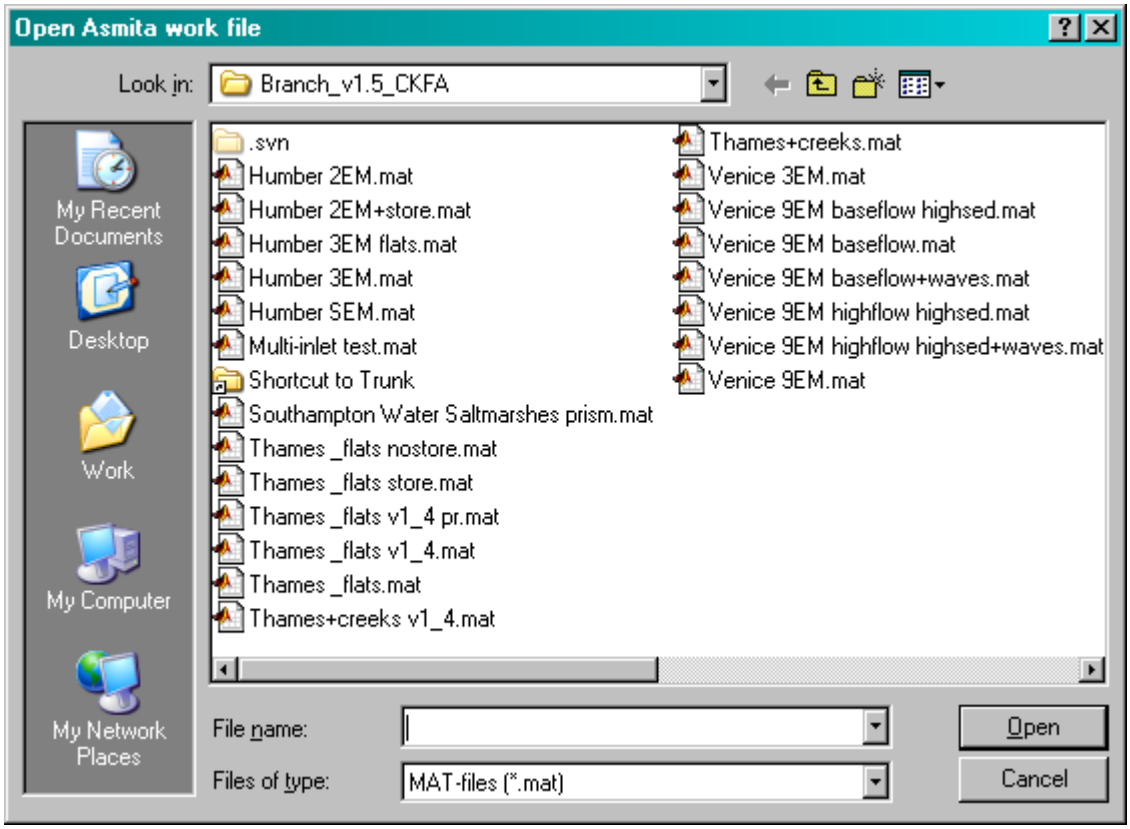
3.3 Save and Save As

The user can save the current setup of the ASMITA model by selecting **Save** or **Save As** from the **File** menu item. If the user selects **Save** without first specifying a name then the program will, by default, request a name from the user.

3.4 Exit

The user can exit the ASMITA program at any point by going to the **Exit** menu item in the **File** drop down list.

Figure 8. Shows the dialog window that appears after selecting the Open menu item. Only *.mat files should be selected



4 TOOLS MENU

Within the ASMITA model software there are a number of tools, designed to assist in the building and visualisation of the model elements. Also included are a number of tools that allow the user to clear unwanted figures or clear the whole ASMITA model setup.

4.1 Load Image

In order to have some context or point of reference of the system being modelled, an image can be loaded as a background map. This can help the user visualise the schematised approach. On selecting **Tools → Load Image** a dialogue box appears allowing an image file to be selected which is then loaded as a background to the user interface as illustrated in Figure 9.

Figure 9. Load Image option from the Tools file menu

The user is able to select from the following image types:

ID Num	File Type
1	JPEG File Interchange Format (*.jpg, *.jpeg)
2	Tag Image File Format (*.tif)
3	Windows Bitmap (*.bmp)
4	Portable Network Graphics (*.png)
5	Hierarchical Data Format (*.hdf)
6	PC Paintbrush (*.pcx)
7	X Window Dump (*.xwd)

4.2 Model Image

To save an image of the model setup containing both any background map or image and the element boxes select **Tools → Model Image.** A Save As dialogue box opens prompting the user to define the folder and file name that the image is to be saved to. The default is to save the image as a JPG file at 600 dpi.

Note: this can be modified by editing the 'print' definition in file cb_fil5.m.

4.3 Refresh

The **Refresh** function updates the screen image, if an image appears incorrectly then use the **Refresh** function to redraw the screen image.

4.4 Clear Model/Figures

The **Tools → Clear → Clear Model** function resets all parameters in ASMITA, allowing the user to start the process of setting up an ASMITA model without the need to close the whole application.

Tools → Clear → Clear Figures function will delete any open plot windows (Under the **Plot** menu, Section 7) the user can plot selected information in numerous windows). To simply close all figure windows click the **Clear Figures** function from the drop down menu list.

5 SETUP MENU

The setup menu comprises forms to define the system properties, the individual element properties and the time step parameters to be used.

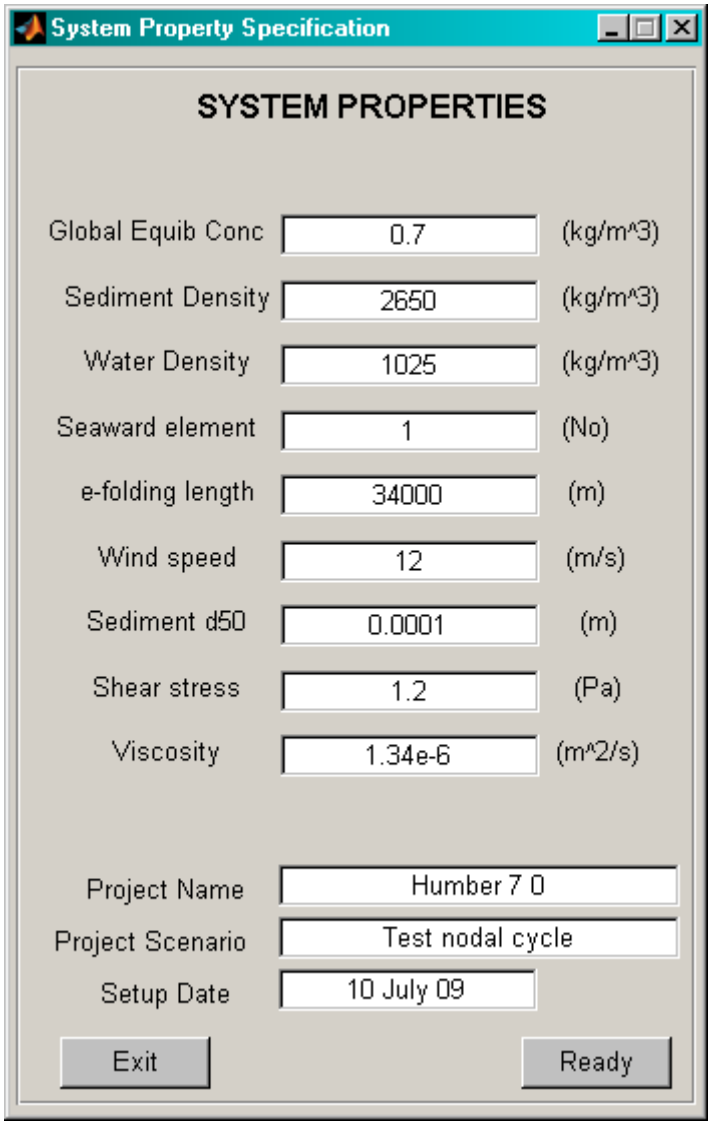
5.1 System

System properties are not element dependent, that is to say the information defined within the system properties represents the whole environment. The System menu includes a number of menu options for general properties, water level information, a definition of user defined changes to the system (ie perturbations over the duration of the model run), saltmarsh properties and the option to update older versions of model files to version 1.5.

5.1.1 System - Properties

The user can access the system properties by selecting **Setup → System → Properties** from the menu drop down list. Tool tips for the System properties provide a brief definition, or advice on default values, and are displayed when the user hovers over a specific entry field.

Figure 10 System Properties data entry



This is the sediment concentration that is the global value of the "external", usually marine, environment.

Sediment and water densities with default values shown.

Index of the most seaward '**channel**' element .

The width e-folding length is used if tidal pumping is included

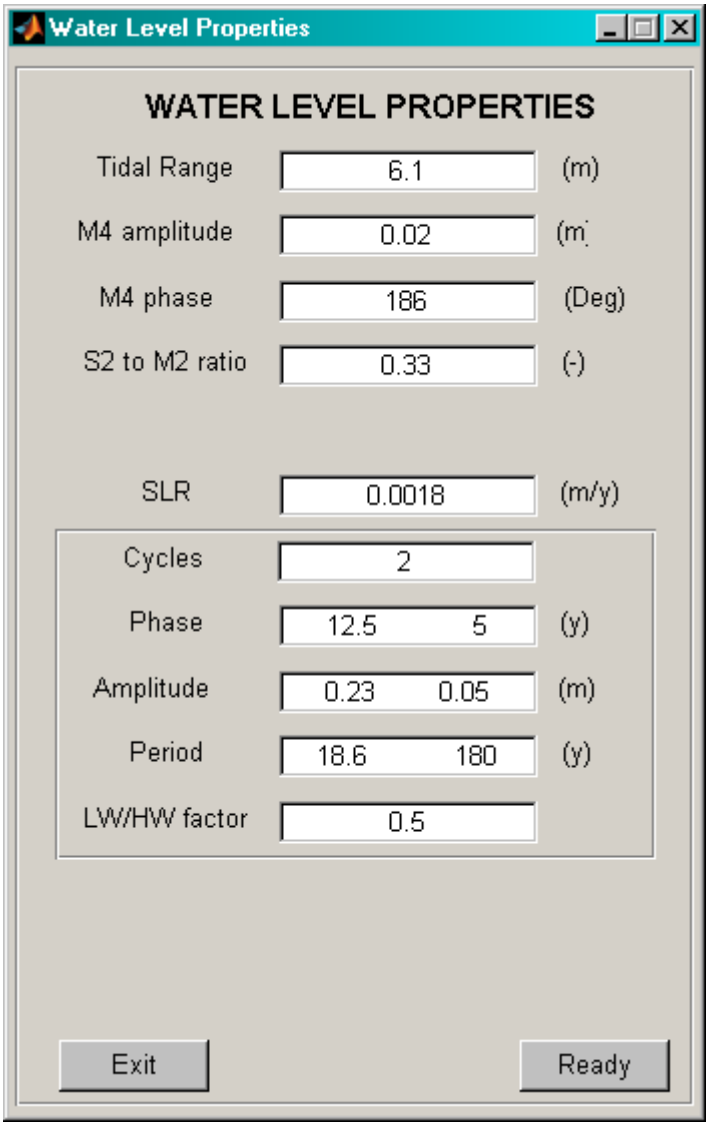
Wind speed, sediment median grain size, critical bed shear stress, and water viscosity are used calculation of erosion of marsh edge and some equilibrium methods. In the current version these properties are specified for the system as a whole rather than on an individual element basis.

Project and scenario titles and set-up data are entered when creating a new project (Figure 7) and can be edited here.

5.1.2 System - Water Level Properties

Additional system properties related to water levels are accessed by selecting **Setup → System → Water levels.** Tool tips for the Water Level properties provide a brief definition, or advice on default values, and are displayed when the user hovers over a specific entry field.

Figure 11 Water Level Properties data entry



The tidal range at the mouth and if element specific values are not defined (see Element Properties) then this value is used for all elements.

M4 constituents and the S2/M2 ratios are used in the tidal pumping calculation and to define the duration of submergence over a spring-neap cycle.

Rate of sea level rise (see note below)

Any number of long-term cycles can be specified and these are used to vary the tidal range over time. The GUI checks that the number of values entered for phase, amplitude and period agree with the number of cycles specified. The values shown here are for a nodal cycle and long-term cycle.

The LW/HW factor adjusts the proportion of change in tidal range apportioned to high and low water. Option included because of observed bias (eg on Humber nodal tidal cycle has an amplitude of 0.23m with a high water amplitude of ~0.14 and low water amplitude of ~0.08 ie factor = 0.08/0.23 = 0.35). The default value is 0.5.

Note: There is an option to include a non-linear rate of sea level rise. This has the format: dslr = -yr0.slr0, where yr0 is the start year for the start of an exponential rate of slr and slr0 is the rate at yr0. The rate of exponential increase is hard coded as 0.011. For yr0=1900, slr0=1mm/yr, and ert=0.011 slr is 1mm/yr in 1900, 3mm/yr in 2000 and 5mm/yr in 2050 and 9mm/yr in 2100.

5.1.3 System – Change

Changes can be defined as one or more adjustments to the volume and/or surface area of individual elements to represent alterations to the system. The user can specify specific periods where a known change in an element may have occurred, for example a capital dredge or some engineering works, or a repeating cycle such as may be needed to represent maintenance dredging.

To specify a change in the element the user should select **Setup → System → Change**. The user is provided with 3 options New, Edit and Load. Each menu item refers to an excel sheet that can be generated from within the ASMITA interface by selecting **New** and then subsequently edited using **Edit**. The **Load** option uploads the linked excel sheet into the model.

*Note: Creating and Editing a file saves the path and file name of the excel worksheet in the model but not the data. This must be loaded using the **Load** option.*

After selecting **New**, an excel sheet will be generated. The default is to crate the file in the current working directory with the file name 'Change.xls'. If the defaults is selected (Figure 12) all previous information stored in the 'Change.xls' file will be lost. A separate sheet will be generated for each element that has been defined by the user. Each worksheet (numbered 1 to n) will have the header information shown in Figure 13.

Figure 12 Messages and prompts when creating a New Change excel spreadsheet

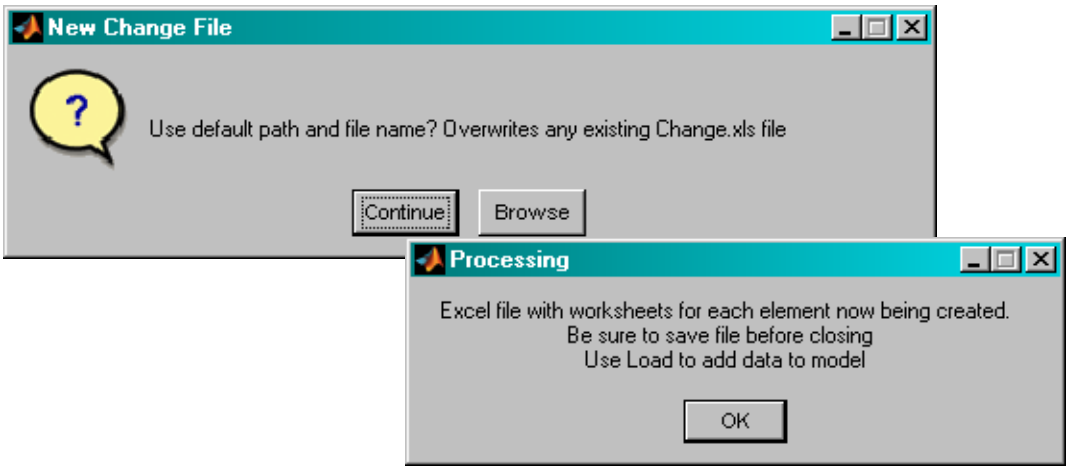
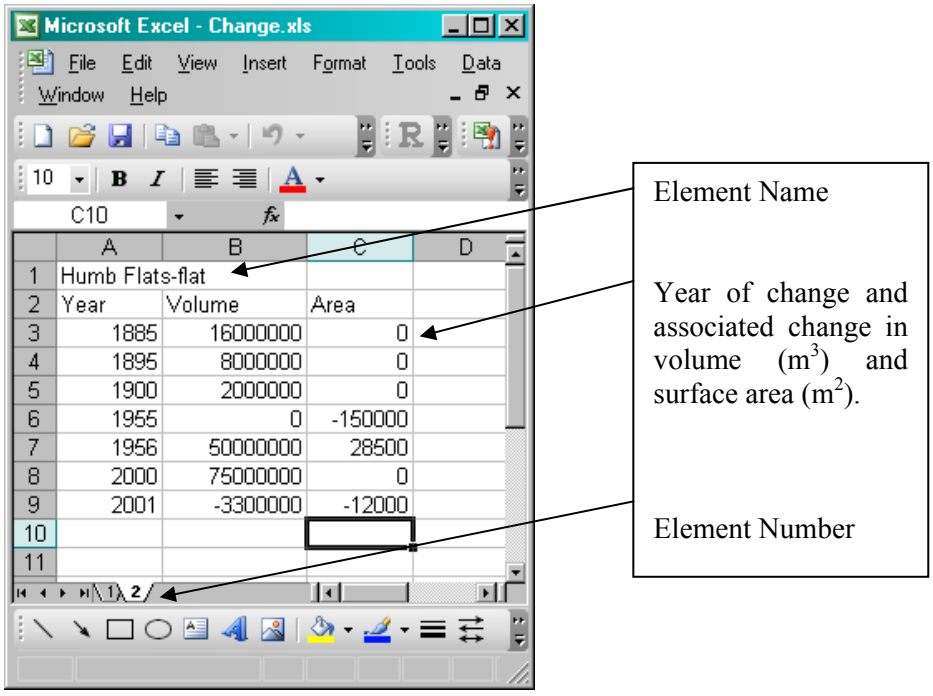


Figure 13 Excel Spreadsheet created to hold Change data



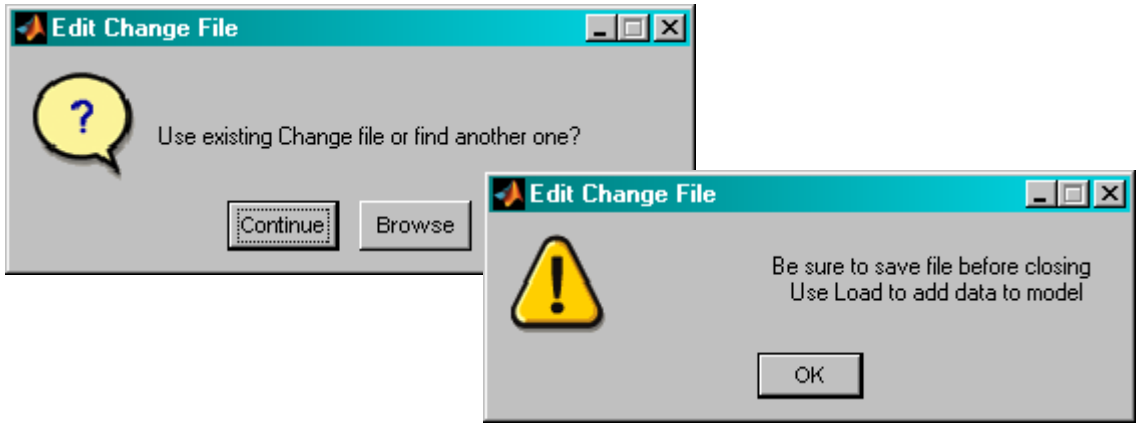
The user then enters years (within the specified simulation period and using decimal values for parts of a year) and the change in area and volume associated with that year. Years of change must be entered in ascending order, ie. 2000, 2004, 2005 and so on. The user can specify the change to either all elements, or to just selected elements.

Note: The change specified is specific to the number of elements and period of the model. The generation of the Change file may take several minutes, depending on the number of elements.

Once a change file has been generated, the user can edit this at any time using the **Setup → System → Change → Edit** option. This opens the previously created change file, or gives the option to select a different change file (Figure 14). The path and file name is stored in the model, replacing any previous file. Once the edits have been made and saved the excel worksheet should be closed before attempting to load the data into the model.

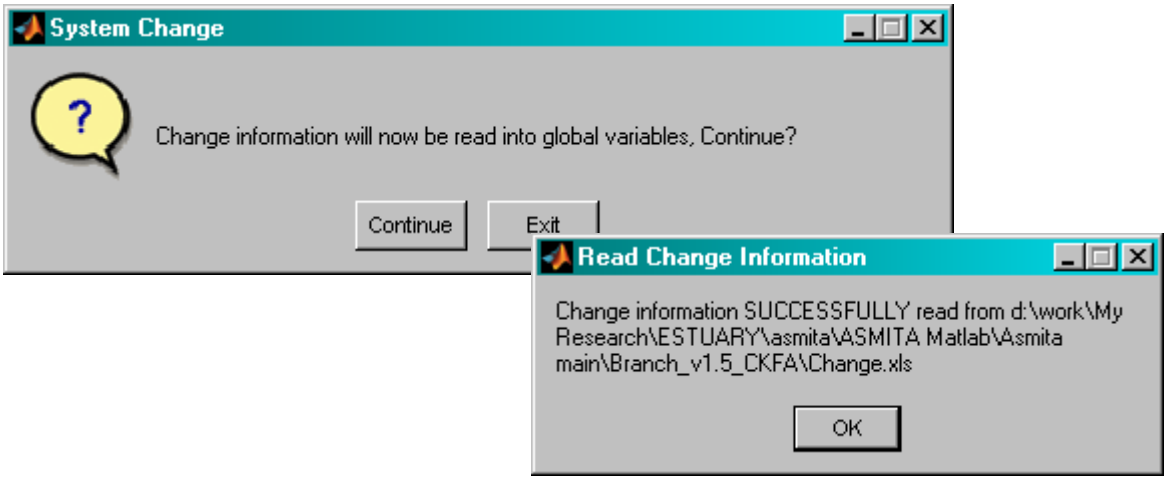
The user can load or edit an existing 'Change.xls' file by selecting /Load. After selecting either Edit or Load the 'Change.xls' file will open and the user will be able to amend this. The user must then close Excel before moving on to other operations within the ASMITA program. Matlab will determine when the 'Change.xls' file has been closed and prompt the user to update the global variables. Selecting yes will update the system change variables within the global defined variables.

Figure 14 Messages and prompts when editing a Change excel spreadsheet



To load new change data or alter the change data that may have already been loaded use the **Setup → System → Change → Load** option. This reads the file that has previously been linked to the model using the **New** or **Edit** options and loads the data into the model (Figure 15).

Figure 15 Messages and prompts when loading data from a Change excel spreadsheet



*Note: Under **Setup → Time Step** there is an option to include the user defined changes in the model run, allowing the model to be run with and without the changes. The change data can therefore be loaded when setting up the model and included when needed. However, only one change data set can be loaded at any one time.*

5.2 Element

Six different types of element can be specified and for each element a number of properties have to be specified. In addition, if the model contains more than one element then the linkages and exchanges between elements has to be specified. This can all be done via the user interface, using either the drop down menu, or, once elements have been created, by right clicking the mouse on the edge of the element box and selecting an option from the pop-up menu.
Note: Selecting elements can be a bit ticklish. Clicking the mouse just inside the top right corner is the most effective.

The process of defining, specifying and deleting is described in the following sections followed by a section explaining the definition of the element properties in more detail.

5.2.1 Define

To define an element the user must select the **Setup → Element → Define** item from the drop down menu item, then use the mouse to draw a rectangle in the ASMITA model window (there is no prompt to do this). To draw (define) the element, select the position of the top right hand corner. Whilst holding down the left mouse button, drag the mouse until you have reached the desired size for the element (rectangle). Figure 16 illustrates this concept.

Note: The size of the rectangle drawn plays no part in the calculation, the rectangle only represents the schematisation of the environment under investigation.

No overlapping of elements is allowed, and no more than 30 elements can be specified in the current version (Version 1.5). It is recommended that the user define at least two elements and that the user allow for a suitable gap between elements, this ensures easier selection of elements.

Note: The order of the elements specified by the user determines the order in which they are stored within the ASMITA model data structures. It is worth planning out the layout and sequence of the model elements before setting-up the model as a well defined order to the elements can make the subsequent definition of linkages easier. However the user can give each element a text name as part of the Element Properties definition.

5.2.2 Specify

To enter element properties or define linkages either select **Setup → Element → Specify** from the main menu, or right clicking on the element. The user can then select options from the pop-up menu for Properties, Flow, Diffusion and Flats.

(i) Properties

Select **Setup → Element → Specify → Properties** from the menu and then left click on the element to be edited, or right click on the element and selecting **Properties** from the pop-up menu. The selected element will be highlighted and the Individual Element Specification window will be opened (Figure 17).

Figure 16 Steps to define a new element

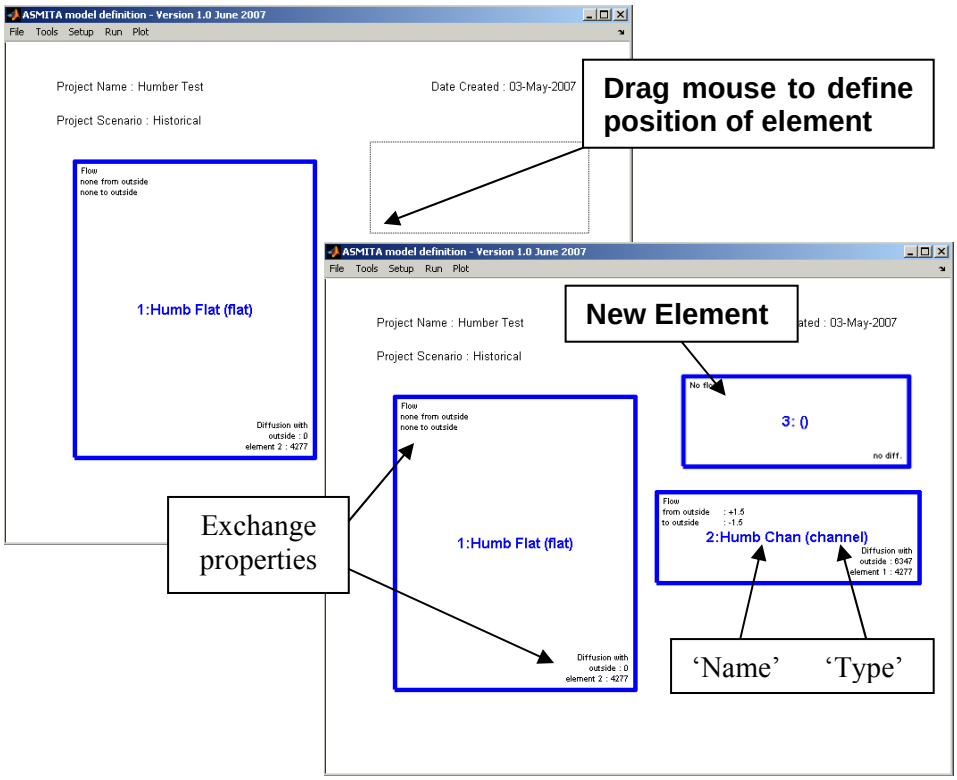
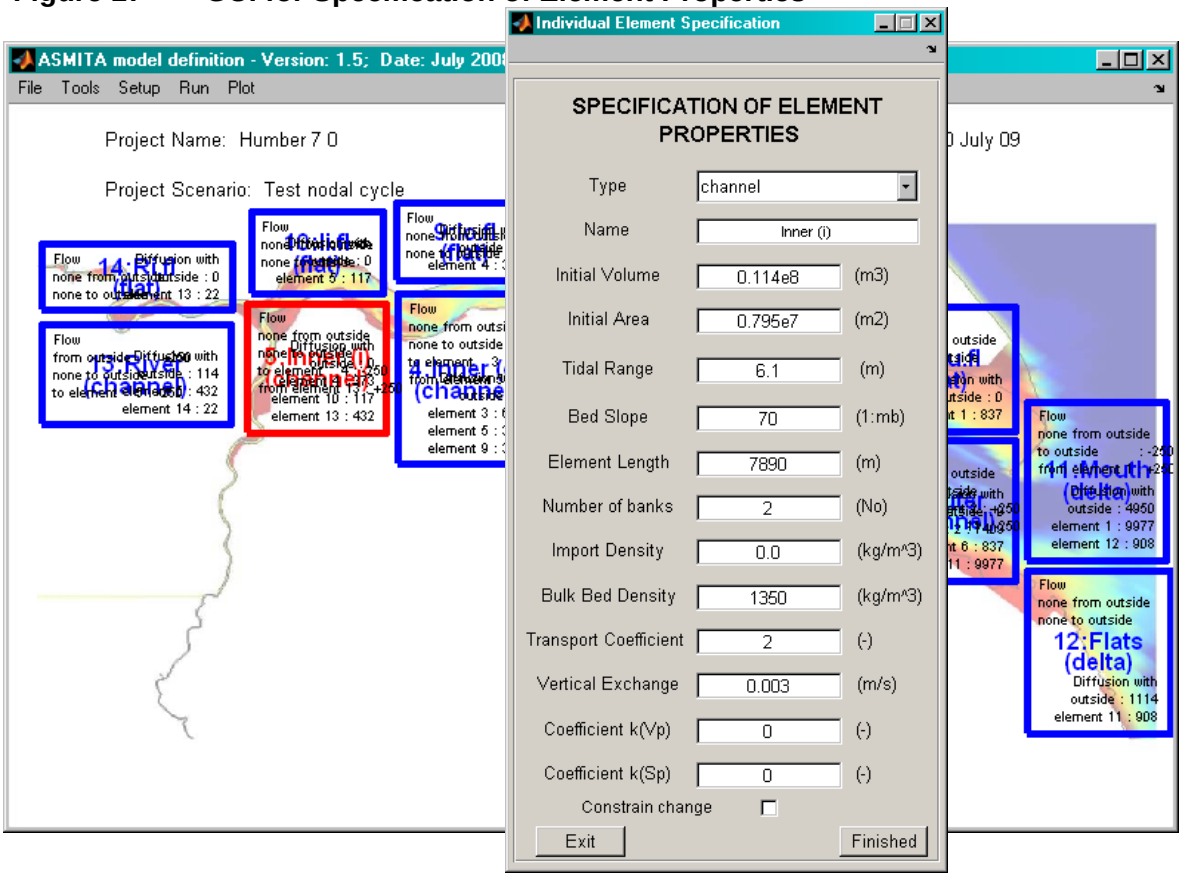


Figure 17 GUI for Specification of Element Properties



(ii) Flow

To establish the dynamic exchange between elements any flows of diffusive exchanges have to be defined. These can either be from one element to another and to or from the element to the surrounding environment. In order to specify a flow, either left click on the element to be edited and then select **Setup → Element → Specify → Flow**, or right click on the element and select **Flow** from the pop-up menu. A pop-up is displayed prompting the user to click on the element that the flow is going into (Figure 18). Once this has been selected the pop-up window details the elements that the flow is from and to and allows the input a flow value in m^3s^{-1} (Figure 19).

Figure 18 Initial pop-up to define flow prompting user to click on destination element

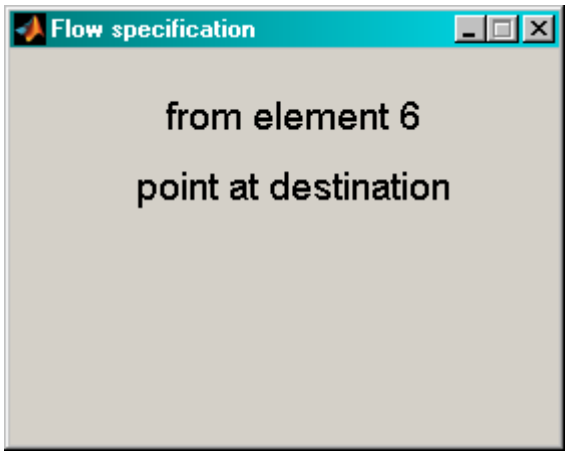
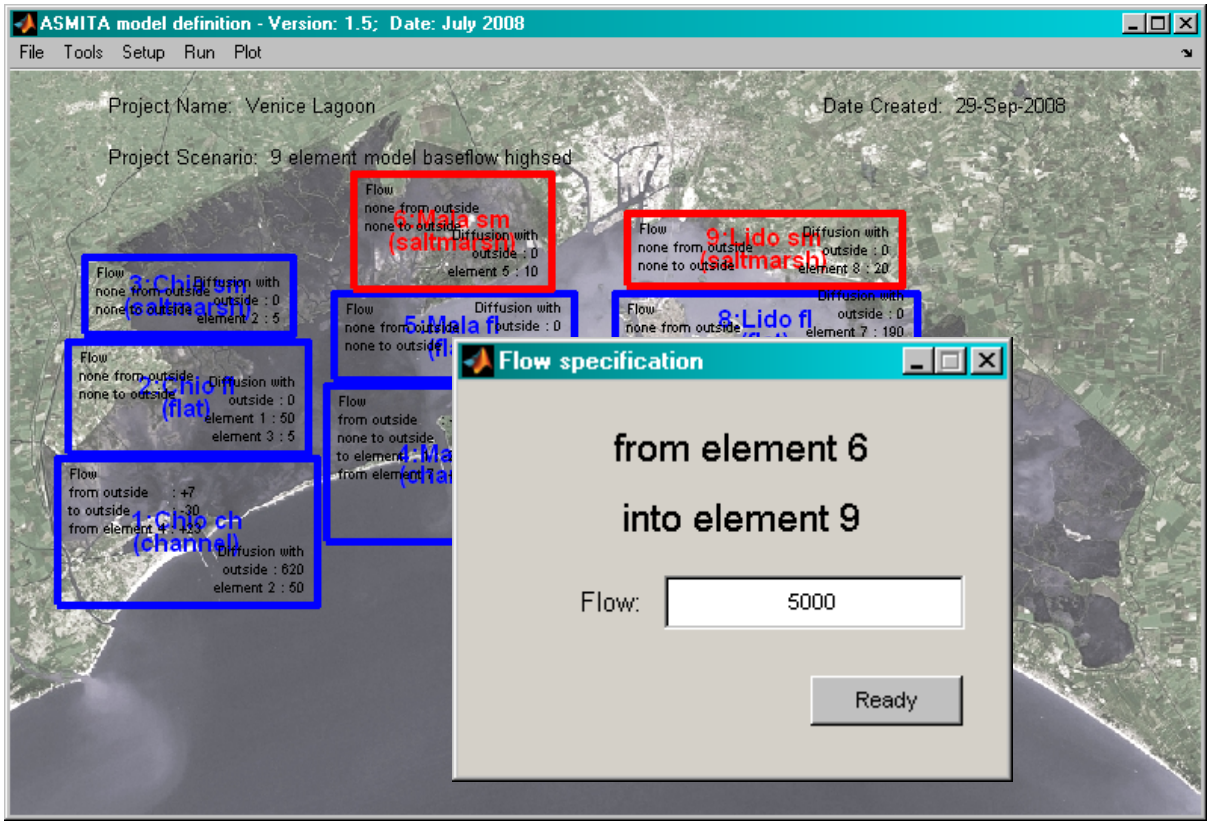


Figure 19 Pop-ups to define flow from one element to another



To specify flow from an **Element to Environment**, the user should follow the method above but rather than selecting a second element, should click outside all of the elements displayed in the ASMITA interface (Outside environment).

To select flow from the **Environment to Element** the user has to access the Flow method from the main menu drop down list. The user should select **Setup → Element → Specify → Flow** and then mouse click on the Outside Environment (outside all elements). The user is then prompted to select the element in which flow will enter from the outside world (pop-up similar to Figure 18).

(iii) Diffusion

The process for defining diffusion between elements is similar to the definition of flows. As with Flow, one can either right click to select an element and select **Diffusion** from the popup window, or left click to select an element and access the same utility using **Setup → Element → Specify → Diffusion**. Popup windows guide the user to select elements and enter diffusion rates. However, diffusion is non-directional and so the order in which elements or the Outside Environment are selected does not matter.

5.2.3 Resize

This option is only available from the pop-up menu that appears when the mouse is used to right click on an element. Having selected **Resize** from the menu the user then uses the mouse to define a new box and the existing element should move to the new location. However, if the new box is too close to any other existing element box in the window, the box is not moved and the user will need to reselect the option by right clicking on the element to be resized or moved.

5.2.4 Delete

To delete an element select **Setup → Element → Delete** from the menu and then left click on the element to be deleted. The selected element will be highlighted and a popup window will appear asking the user to confirm this action. Click yes to permanently delete the selected element. Alternatively, elements can also be deleted by right clicking on the element and selecting **Delete** from the pop-up menu.

5.2.5 Defining Element Properties

A number of properties have to be specified for each element. As explained above (Section 5.2.2(i)), the GUI is accessed using the main menu option **Setup → Element → Specify → Properties** and using the mouse to select an element. Tool tips for the Element properties provide a brief definition, or advice on default values, and are displayed when the user hovers over a specific entry field.

To begin, the 'Type' of element has to be selected from the drop down list. There are six types of element currently available:

Channel	Water volume below MLW and area at MLW. *Can be linked to coast, delta, flat, storage and other channel elements.*
Coast	Dummy element to allow the inclusion of exchanges alongshore. *Can be linked to delta and channel elements.*
Delta	Water volume over delta (where the delta has a volume relative to undisturbed coastal bed). Can also use this element type to represent delta flats. *Can be linked to channel, coast and other delta elements.*
Flat	Water volume between MLW and MHW over flats (ie not including the prism over the channel) and area over flats. Flats on both sides of channel in a given reach can

be included in a single flat element.
Can be linked to channel, saltmarsh and storage elements. Flats can also be linked to adjacent along-channel flat elements for diffusion and advective exchanges but multiple flat elements linked to the same channel element are not allowed.

Storage — Water volume and area of storage unit. Treated as locally independent of system (not dependent on upstream prism) but contributing to downstream prism.
Can be linked to a channel or a flat element.

In addition the user can give a Name to each element. This is used as a label in the output file and for plots and can be used to distinguish different branches or reaches as well as the type of element.

The other properties included in the GUI (Figure 17) are defined in Table 1 and further discussion of how to set some of the sediment properties is provided in Section 8.

Table 1 Definition of Element Properties

Property	Description
Initial Volume (m^3)	The water volume of the element at the start of the simulation
Initial Area (m^2)	The surface area of the element at the start of the simulation
Tidal Range (m)	A tidal range is specified in the System Properties GUI which is used as the 'whole' system value. The value entered here allows the tidal range to be varied for individual reaches of the estuary. This allows tidal amplification and damping to be taken into account. *Notes:* *(i) there is no consistency check to ensure elements in the same reach have the same tidal range. The calculation of the tidal prism and high water volume both use only the values specified for channel elements. However, the 'equilibrium profile' option (see below) uses thevalues specified for the tidal flat elements If saltmarsh elements are included the calculation of concentration over the marsh uses the tidal range specified for the marsh element. It therefore best to ensure that these values are consistent within any given reach.* *(ii) the amplitude of cycles that alter the tidal range (Figure 11) are scaled based on the ratio of the element specific tidal range to the system tidal range.*
Bed Slope (1:mb)	This is the transverse (cross-shore) slope of the element at its upper boundary (low water for a channel element; with water or toe of marsh for flat element and high water for a marsh element). The value mb is the horizontal distance for a 1m vertical change.
Element Length (m)	The along-estuary length of the element. *Note: Although channel, flat and marsh elements in a given reach can have different lengths, a change in area in one element is assumed to give rise to an equivalent change in the adjacent element. So if the channel expands in area, this area is removed from the low water boundary of the tidal flat. Consequently if the elements are of different lengths this can give rise to unrealistic changes.*
Number of banks	In general a reach will have two banks and although only a single flat

Property	Description
	and marsh is associated with each channel this is presumed to represent both banks. Hence the default value is two. However, when using the equilibrium profile option (see below) it is possible to draw the distinction between a symmetric channel (nbk = 2) and a half channel with only one intertidal (nbk = 1). This can be useful where the intertidal has been reclaimed on one side of the channel. It can also be used to divide the estuary in two and represent each bank separately (see case studies).
Import Density ($kg.m^{-3}$)	The density of sediment contained in any advective flow that is an input to the model.
Bulk Bed Density ($kg.m^{-3}$)	The density of the bed is used to take account of the consolidation of sediments on the bed.
Transport Coefficient	This coefficient represents the dominant mode of transport. If over the long-term the model is considered to represent a diffusion process, this would have a value of 2. Where advective transport (such as fluvial import dominates) then a value of 5 based on bed load transport may be more representative or a value of 3 where suspended load transport dominates sediment exchanges.
Vertical Exchange ($m.s^{-1}$)	This is the rate at which sediment is deposited on the bed of the element. As this is a long-term model it is not strictly the sediment settling velocity but this does provide a useful initial estimate of a suitable value.
Coefficient k(Vp)	Equilibrium coefficient for volume: kv = Ve/Vp where Ve is the equilibrium volume and Vp is the tidal prism. See below for options.
Coefficient k(Sp)	Equilibrium coefficient for surface area: ks = Se/Sp where Se is the equilibrium surface area, Sp = Vp/tr, Vp is the tidal prism and tr is the tidal range. See below for options.
Constrain change	Check box to set flag to constrain change so that element only in-fills. Only applies to channel and flat elements. Used to represent hard geology.

Note: See (Wang et al. 2007) for a discussion on model parameter setting and the interdependence of the global equilibrium concentration, horizontal and vertical exchange rates and the transport coefficient.

A unique value of kv and ks between 0 and 0.99 can be specified for each element using the input boxes 'Coefficient k(Vp)' and 'Coefficient k(Sp)'. Consequently different values can be used to represent channel and flat equilibrium conditions. When a delta element is included, the delta equations are also multiplied by kv and ks, so they can be used to re-scale the delta equilibrium equations.

However, the values can also be set to force the model to calculate the equilibrium conditions and there are currently three options available which are enabled by setting 'Coefficient k(Vp)' for ALL elements to a value of 1, 2 or 3 (The values defined for 'Coefficient k(Sp)' are then ignored).

Note: this is most easily changed from the command line of the Matlab interface by using the following command:
>> for i=1:nelmax ELPROP{i}.kVp = 'N'; end where N is the value 1, 2 or 3.

K(Vp)

1 Initial conditions used to calculate ratios of the volume of the element and the tidal prism, and the ratio of the surface area and prism/tidal range.

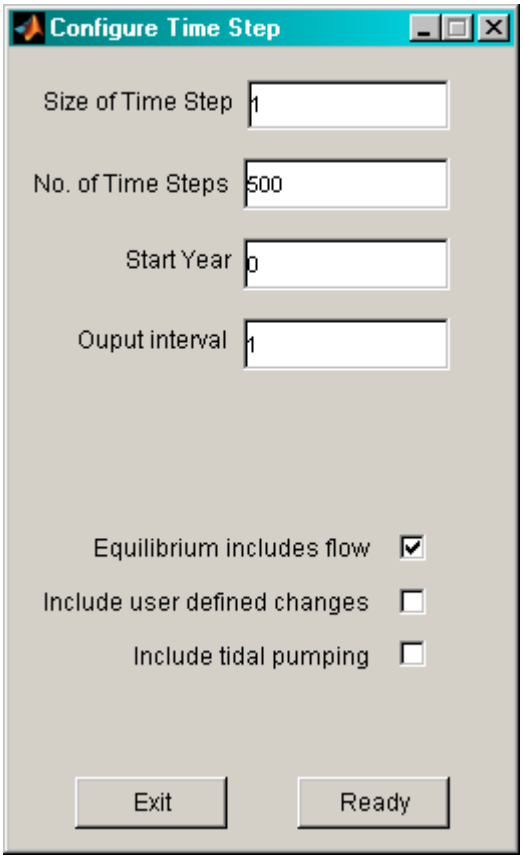
2 Initial conditions used to derive the equilibrium profile of an 'average' cross-section for each reach, from which estimates of volume and surface area are made for the channel, flat and marsh. The default is for these estimates to be scaled to the initial values, to provide a scaling coefficient which is used to 'correct' the equilibrium estimates based on this theoretical model (ie kv =Vo/Veq, etc). By setting 'Coefficient k(Sp)' for all elements to a value of '0', the equilibrium model values are used without scaling.

The models used in each of the two options are described in Appendix IV.

5.3 Time Step

To access the time step configuration window select **Setup → Time Step** from the main menu drop down list. Tool tips for the Time Step properties provide a brief definition, or advice on default values, and are displayed when the user hovers over a specific entry field.

Figure 20 Form to set run-time variables



Sets the calculation interval in years or parts of a year. Some model set ups can be quite sensitive to the time step and if the results suggest some form of instability it is worth trying a smaller time steps. This may be particularly needed if the elements are substantially different in size.

No of time steps x time step determines the duration of the simulation.

The start year provides a point of reference for introducing changes (see Section 5.1.3).

Output interval allows the output to be sub-sampled (eg if running the model with a 0.25 year time step, a value of 4 produces annual output)

Various options can be enabled for inclusion in the run by checking the box alongside each option.

The model run duration is for the no. of Time Steps x the Step Size, starting at the Start Year. So for the values shown in Figure 20, the model will run from 1500 at half yearly intervals until 2060.

Note: When using the model to hindcast historical periods including the influence of sea level rise, it is important to remember that the model has a lag in its response to the initial onset of sea level rise (at the beginning of the model simulation) and it will take some years to reach a steady state response based on the morphological time scale of the system. For small estuaries this may only be a few decades but for large systems can be several centuries.

5.3.1 Options

A number of check boxes are provided on the Configure Time Step form which operate as follows:

Equilibrium includes flow	If all external inputs area assigned the global equilibrium sediment concentration then the basis for computing equilibrium is unaltered. However, it is often desirable to include river inflows with their associated sediment load. This would then be interpreted as a perturbation to the system and the volumes and areas would be adjusted accordingly. However, where initial values are used to define the equilibrium coefficients (see Section 5.2.5 and Appendix IV) it is implicit that the initial condition is being defined as an equilibrium state. This option corrects for this by calculating an offset based on the initial conditions and the defined flow conditions. See Appendix VI for further details of the method used.
Include user defined changes	This option allows the user to include imposed Changes to the system, such as dredging and reclamation. See Section 5.1.3 for details of how to enter this information. The Changes are only included in the model simulation if this option is checked.
Include tidal pumping	For multi-element models representing large systems with relatively low sediment concentrations towards the mouth and a turbidity maxima at some distance up-estuary, a more appropriate representation can be achieved by including the influence of tidal pumping. Checking this option includes tidal pumping. See Appendix VI for further details of the method used.

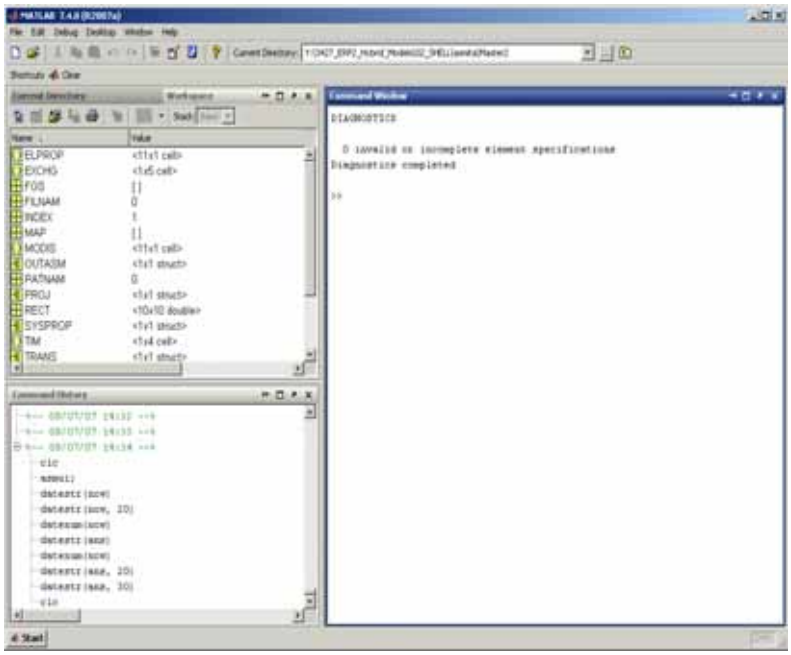
6 RUN MENU

After defining the individual elements and assigning the element and system properties the user has the option to check the input data and run the ASMITA model.

6.1 Check Input

The **Check Input** function checks all data entered to ensure consistency. The diagnostic information is reported back to the Matlab command window (Figure 21), a dialog box will also appear if all values specified with ASMITA are correct. Note the **Check Input** function is called when the user chooses the **Run Model** option. However, it might be more convenient to establish the model setup without actually running ASMITA, in this circumstance the user should select the **Check Input** function. Missing or inconsistent values will be reported to the user who will then be able to address these errors. To access the **Check Input** function the user should select **Run → Check Input** from the main menu drop down items.

Figure 21. The Matlab command window where the diagnostic information is reported back to the user



6.2 Run Model

To run the ASMITA model the user should select **Run → Run Model** from the main menu drop down list. Before the model run is initiated, the user is prompted for a file name with NO extension. As the program runs a progress bar is displayed.

6.3 Model Output

ASMITA produces two output files. One is a text file with the setup information and the second is a Microsoft Excel file. The Excel file contains a full set of model results, as well as a summary of all the information used in the model configuration used for that run. The name of both the text and Excel files are identical, except for the file extension.

The model output includes the following parameters:

Moving Surface Volume (vm)	The volume below a water level that may rise and fall over the simulation period depending on the input parameters e.g. climate change, nodal cycle and so on[1]. The moving surface volume describes the combined morphological and water level change in the element
Equilibrium Volume (ve)	This depends on the formulation used to define the equilibrium condition (see Appendix) but is typically some function of the tidal prism. The equilibrium volume describes the volume that the element will try to adjust towards at any given point in time[1].
Fixed Surface Volume (cf)	The volume below a fixed water level defined by the water level at the start of the simulation[1]. The change in volume represents the morphological change in the element below the level of the fixed surface.
Tidal Prism Volume (vp)	The is the tidal prism assigned to each element at each time step. Where a channel, flat and saltmarsh elements are linked to define a given reach of the system, they will have the same tidal prism.
Tidal Range (tr)	For simulations which only include sea level rise or forced perturbations, this will be constant. Where a variation in tidal range is included (eg nodal tidal cycle) this will show the tidal range used in element (note if element specific values are not specified this will use the value specified at the estuary mouth on the **System → Water Level** properties input form.
Sediment Concentration (cn)	The local equilibrium sediment concentration for each element.

Note: labels in parenthesis (eg. vm) are the worksheet tab names in the Excel spreadsheet output file.

The output parameters from the ASMITA model can be used to inform such things as:

- How elements change over time, responding to perturbations (eg dredging and reclamations) or ongoing changes (eg sea level rise and changes in tidal range).
- The response in a moving frame of reference (moving surface) and fixed frame of reference (fixed surface).
- The morphological phase lag and damping, based on the differences between the moving and equilibrium values.

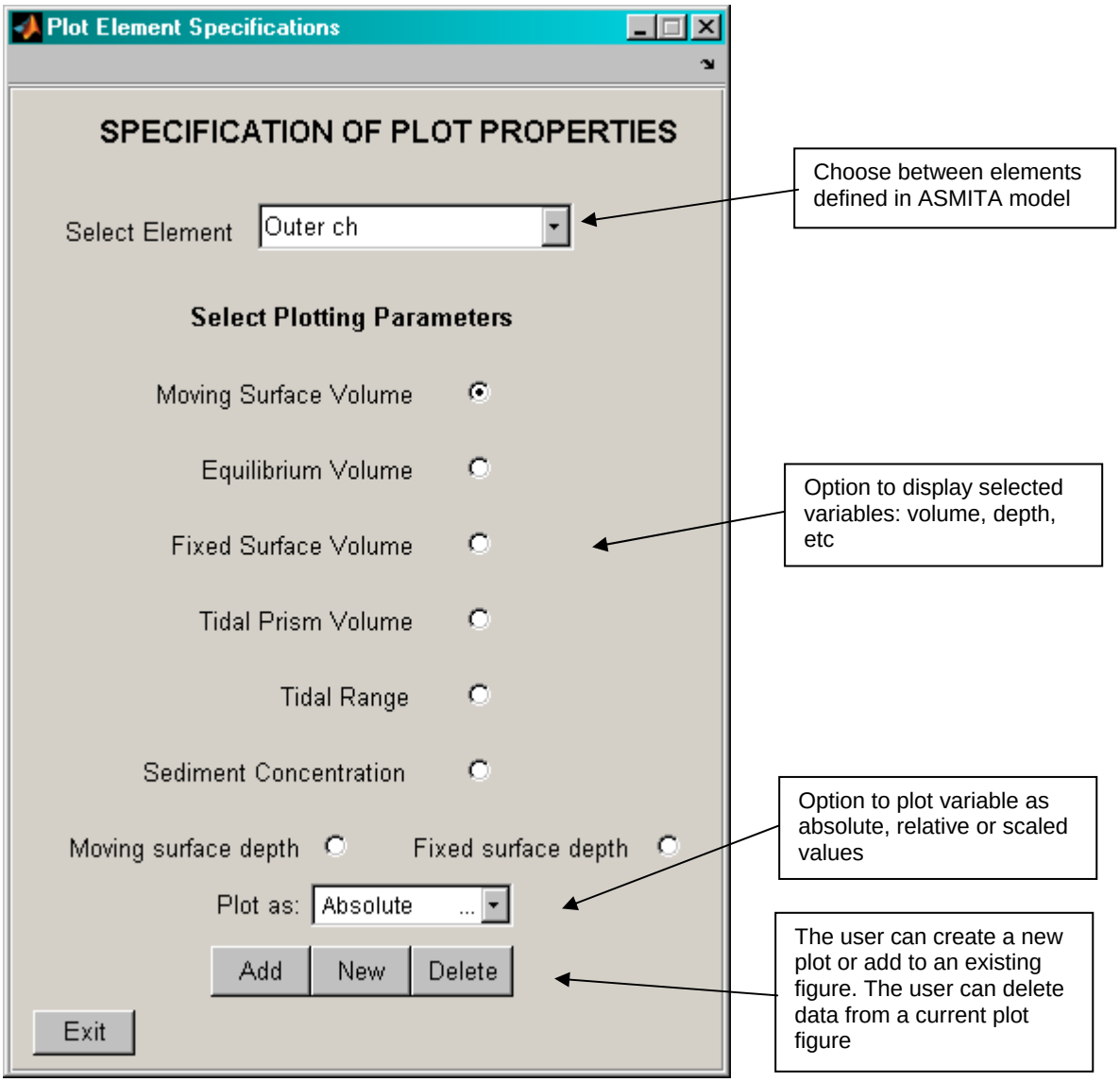
[1] This will be a wet/water volume if the transport coefficient for the element is positive, otherwise it will be a dry/sediment volume

7 PLOT MENU

In order to visualise the results generated by the ASMITA model select **Plot → Plot Results** from the drop down menu. Plot parameters are then selected from the Plot Element Specification interface (Figure 22).

There are no limits as to the number of plot windows, the user can clear individual windows by clicking on the cross in the top right hand corner. The user can select to clear all plot windows by selecting the **Tools → Clear → Clear Model** function on the drop down menu. The plotting routines will not allow identical parameters for the same element to be plotted on the same figure. By design, selected parameters will be added to the current figure.

Figure 22 User interface for the generation of plots of the model results



A typical example of the output from ASMITA is displayed in Figure 23. The user can access this data either from the saved Excel spreadsheet, or through the Matlab environment while the main ASMITA window remains open.

Figure 23 Example of results plot generated using ASMITA

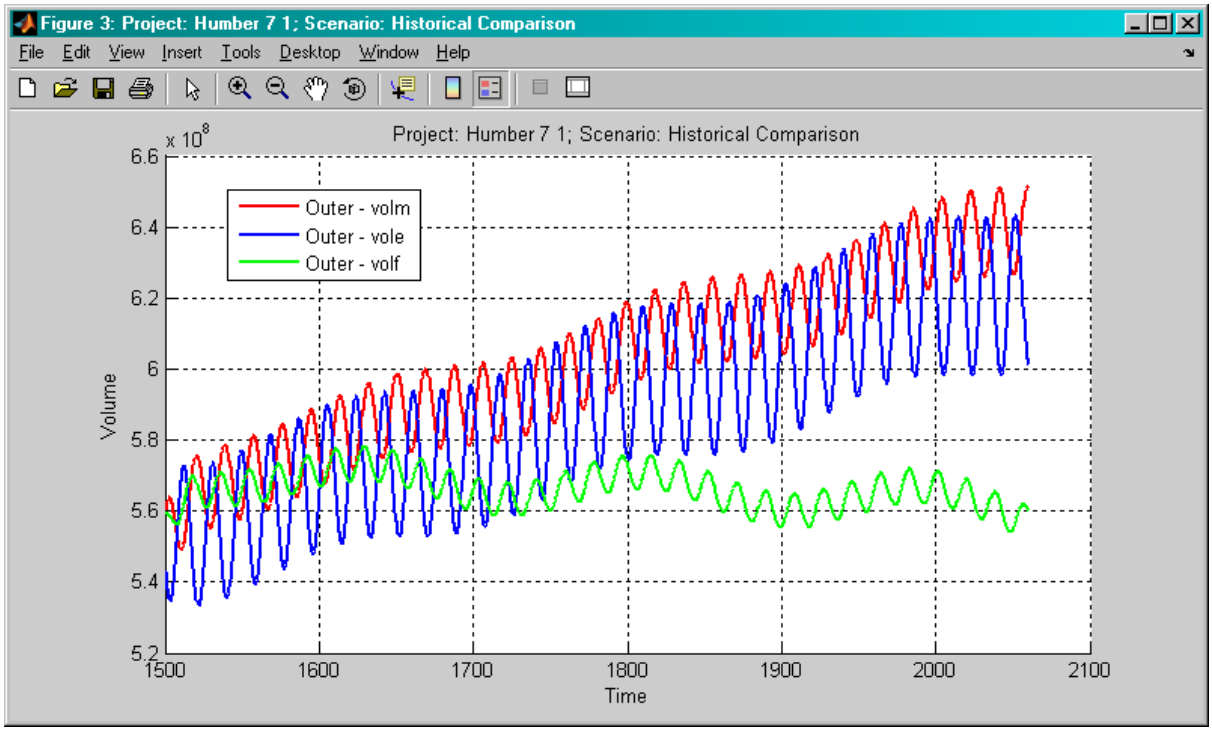
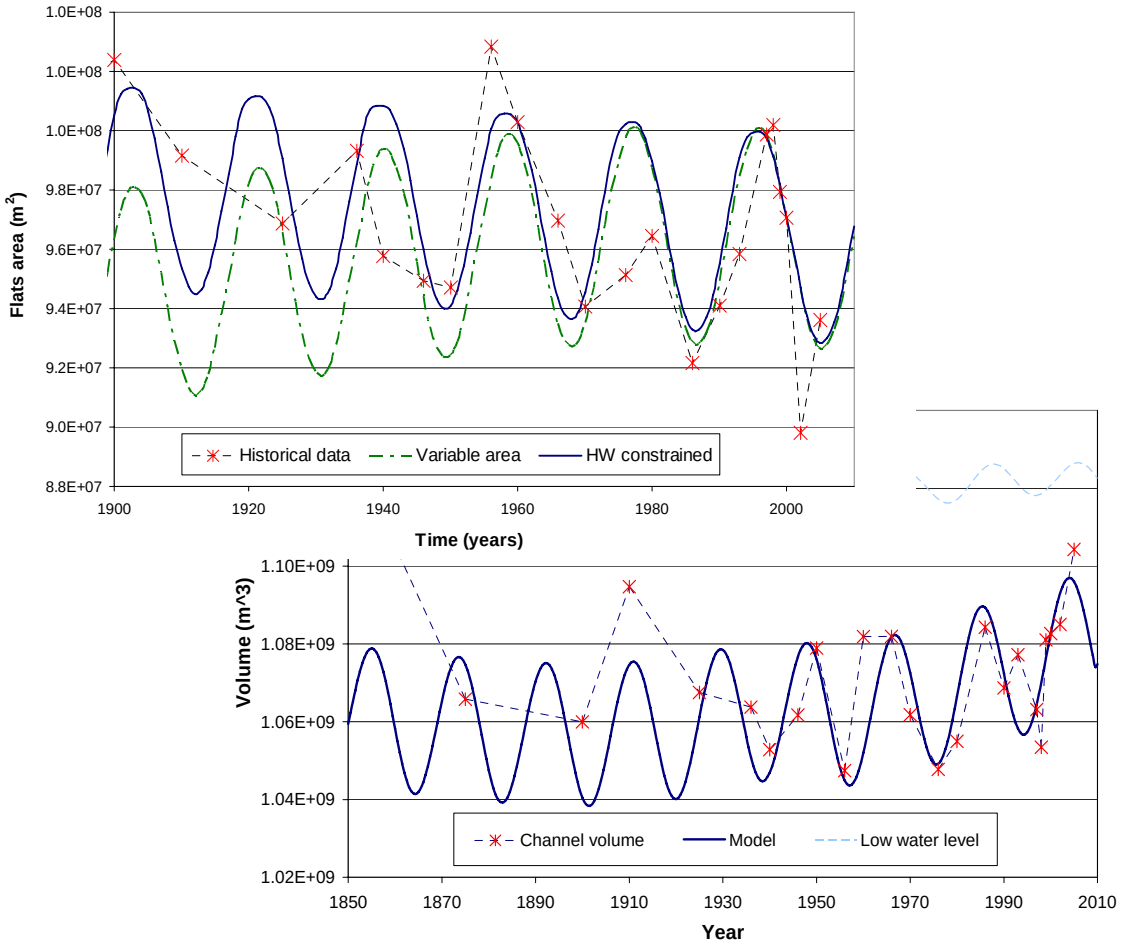


Figure 24 Example of model results taken from output Excel spreadsheet and plotted against historic data



8 MODEL SET-UP

8.1 Element Definition

Decide how the estuary or tidal inlet should be sub-divided. This will usually involve a number of channel elements with associated tidal flat elements. In addition, there may be a need to include a tidal delta and any tidal flats associated with the delta.. As far as possible it is worth trying to examine the constraints on the system (geology, sediment sources, sea walls, etc), as a basis for identifying "reaches" that are likely to have a consistent internal behaviour. It is also better to avoid very large differences in the size of elements (several orders of magnitude), as this can give problems in some of the matrix calculations.

Sometimes it is useful to set up a whole estuary model (comprising just a channel and tidal flats, or delta, channel and tidal flats) to get a feel for the overall behaviour of the system, prior to developing a more detailed representation. However, if river inflows with a sediment load are to be included, it should be noted that the response of a "single" channel element model, will be different to a multi-element model. As a consequence, it is sometimes better to ignore the river inflows for the single channel element case.

A range of different model configurations are described in Section 9, to illustrate some of the possible ways in which different types of element can be combined.

To set up multi element channels

- Define Seaward element in System/Properties as the id of the most seaward channel element. If a delta is included, this value is not used and the program uses the link between delta and channel element to define the most seaward element. Channel elements can branch and the cumulative prism includes all upstream branches of any given channel element.
- Each channel element can have a flat a marsh and multiple storage elements. Storage elements are included in the calculation of tidal prism but not in the area and volumes at high water used to determine constraints (ie storage elements are considered outwith the estuary system).
- Channels and flats can be linked by diffusion and advection.

*To set up multiple tidal inlets***.**

- Define Seaward element as 0 in System/Properties
- Each inlet can have a delta, channel, flat, saltmarsh and multiple storage elements. Storage elements are included in the calculation of tidal prism but not in the area and volumes at high water used to determine constraints (ie storage elements are considered outwith the estuary system).
- Channels and flats can be linked by diffusion and advection

8.2 System Specification

The global equilibrium concentration is one of the main calibration parameters. One option is to use the seasonally averaged mean value of suspended sediment concentration as an initial estimate. (For the Humber this is 720mg.l^{-1}, which as a volume concentration equates to c_E=2.7x10^{-4}, a value not dissimilar to the value proposed by w/|delft for Estmorf of c_E=2.0x10^{-4}). Where tidal pumping is included some experimentation will be needed to define the global equilibrium concentration that generates realistic concentration gradients within the estuary. In theory, this should reflect the long-term average concentrations at the marine boundary but again may need to be adjusted to give realistic values within the estuary.

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8.3 Water level Specification

Define the tidal range for the estuary as a whole (value at mouth). For large systems divided into multiple elements, the tidal range can be defined separately for each element. As a default the system value is used if element specific values are not defined.

The rate of sea level rise, can be specified as a constant linear rate or an exponential function. Details of how to define the rate of sea level rise are given in Section 5.1.2.

The model allows variations to the tidal range to be included. For each cycle included, the amplitude, period and phase need to be specified. The most readily identifiable cycle is the nodal tidal cycle which is given by:

Amplitude = 3.8% of tidal range; period = 18.6 years, phase = 12.2 years.

In work on longer-term changes, a long-term cycle be relevant, such as the one defined based on studies on the Humber (Townend *et al*. 2007) and defined as follows:

Amplitude = 0.05m; period = 180years, phase = 128 years.

This provides an increase in tidal range of ~1mm/year in phase with what was observed over the 20th century.

8.4 Element Specification

Using a suitable DGM the volumes and areas can be calculated in one of two ways:

(i) Define a horizontal plane at high and low water level and calculate the water volumes below the plane and the surface areas on the planes.

(ii) Use the surfaces for high and low water derived from a hydraulic model in conjunction with a DGM to calculate the water volumes below the surface and the surface areas at high and low water. This added complexity is not needed for small or relatively short estuaries but can be important for longer estuaries that are near resonant (Thames, Humber, Severn, etc).

Note: the HTA toolkit, developed in Matlab as part of FD2107, provides the tools to rapidly generate the required volumes and areas, for each element, using either of the above methods.

It is also possible to define elements as sediment volumes rather than wet volumes. If this is preferred, then the sediment transport coefficient, n, should be expressed as a negative value. This was the basis for the original model development which used fixed surface areas (Stive *et al*. 1998; Kragtwijk *et al*. 2004) and works for this form of configuration.

The same DGM can be used to obtain the average cross-shore slope at high and low water within each element.

The tidal range can be specified for each element. This is useful for large systems with significant along estuary variation and can be derived using the output from a hydraulic model by averaging the tidal range over the length of each element. The tidal flat associated with a given channel element is assumed to have the same tidal range (for the internal calculation of tidal prism) but there is no check for this within the code.

The concentration imported by advection is the sediment load associated with any inflows to the element (see Section 8.6 for fuller explanation).

The bulk density of sediment relates to the density of the bed within the element. This is included to take account of the consolidation of sediment that is deposited and is used in the code to adjust the vertical rate of exchange. The default value of 1350kg.m^{-3} is typical for many UK estuaries.

The sediment transport coefficient reflects the nature of the transport process. For simple diffusion a value of 2 can be adopted. Where suspended or bed load transport dominate a value between 3 and 5 may be more appropriate. As this model is considering long-term evolution it can be argued that the process can be treated as essentially diffusive, suggesting a value of 2. Furthermore, it is the product of n and c_E that determines the morphological response time, so that using a set value may simply result in a slightly different value of c_E.

The vertical exchange (although not strictly a sediment fall velocity) should be based on the fall velocity for the sediment type that characterises most of the element. There is an inter-dependence between the fall velocity and the horizontal exchange which is explained further in the Section on Diffusion.

8.5 Diffusion

The spreadsheet '*Blank Model Paramenters.xls*' is available to help define the values to be used for horizontal exchange.

8.5.1 Exchange between channel elements (and channel and delta)

The horizontal diffusion coefficient is related to the vertical exchange by the relationship:

$$\frac{D}{uh} = \varepsilon \frac{u}{w_s} \tag{1}$$

where u is the velocity (at mtl or peak) between two channel elements, h is the hydraulic depth (assumed to be at mtl) and w_s is the vertical exchange. The basis of this equality is explained in Wang *et al.* (2007), where the parameter ε is a coefficient of proportionality, which is suggested as a calibration coefficient of order 0.1. Given the uncertainty in defining the horizontal exchange coefficient, as set out below, the coefficient is taken to be unity and accounted for by simply adjusting the horizontal exchange values directly.

For use within ASMITA, this has to be expressed as a horizontal rate of exchange between elements, given by:

$$\delta = D.A/L_x \tag{2}$$

where A is the cross-sectional area between the elements and L_x is the distance between the two elements. However, this is rather dependent on how the elements happen to be defined and a better way of determining L_x is to use the tidal excursion distance given by:

$$L_x = u_p.T_P/\pi \tag{3}$$

where u_p is the peak velocity and T_P is the tidal period in seconds and simply assumes a sinusoidal variation in velocity over the tidal cycle. Model output can be used to define the excursion, if available.

8.5.2 Exchange between channel and flats

Three methods have been used to-date for estimating the exchange between channel and flats.

(i) Use the channel estimate of δ, equation (2), and replace the csa, A ,with the A_{int}, given by:

$$A_{int} = L_R.tr/2 \tag{4}$$

where L_R is the length of the element (reach) and tr is the tidal range. The half makes this an average value based on the variation between high and low water.

(ii) Use equation (1) with the hydraulic depth based on the values for the tidal flat (note: this can be estimated using $h_{fl} = V_{fl}/S_{fl}$). Then obtain δ from equation (2), with the value of A defined by A_{int} as given in equation (4).

(iii) Use the rate of propagation across the tidal flat to estimate the transverse velocity:

$$u_{fl} = \pi.W_{fl}/(n_{bk}.T_P) \quad (5)$$

where W_{fl} is the average width of the tidal flats and can be estimated from S_{fl}/L_R and n_{bk} is the number of banks with flats associated with the width, W_{fl}. Then use equation (1) with h_{fl} and u_{fl} to obtain D_{fl}. The horizontal exchange onto the flat is then given by a modified form of equation (2):

$$\delta_{fl} = D_{fl}.A_{int}/W_{fl} \quad (6)$$

Experience to-date suggests that the third method is the most suitable but further work is needed to establish which of these is the most appropriate.

8.6 Advection

The model provides for advective flows through the system. Necessarily the flow in and out of an element must sum to zero and the code checks for this. The use of this facility is typically to include one or more river flows into the system. If a flow is introduced into the upstream channel then this must be propagated through each of the downstream channel elements to the open sea boundary. (For a single linear channel system, this means there should be the same flow in and out of each element).

Each inflow to the system can however, have a different sediment load. This is specified as the concentration imported by advection within the Element Specification, expressed as a concentration density ($kg.m^{-3}$) and an estimate can usually be obtained from measured data of the riverine input.

It is important to recognise that the model is seeking to impose an equilibrium concentration over the system as a whole, as the basis for volumetric equilibrium. This is why the option to take account of the flow in the definition of the equilibrium condition can be included by checking the box on the Configure Time Step GUI, Figure 20. (The basis of the flow adjustment to the equilibrium condition is explained in Appendix VI). If this option is not checked the flow conditions are in effect a perturbation to the system. This magnitude of this influence can be explored by setting all other changes (forced changes, transgression, slr and tidal range) to zero and running the model with and without this box checked. When the 'Equilibrium includes Flow' option is selected the element volumes should remain constant. When it is not selected the response will depend on the model configuration.

For a single (channel) element model a concentration associated with advective flow through the element, that is less than c_E , will give rise to net export from the system. This is because the advective flow out of the element is removing sediment at the concentration of c_E, whereas the inflow is only replacing this at the lower rate. The converse is obviously the case when the concentration of the inflow is larger, resulting in net import. It also follows that a value that is equal to c_E is equivalent to the no flow case.

For a multi-element definition of the channel, this is no longer the case, providing the diffusion between channel elements varies, and there are two or more channel elements, the element connected to the river inflow will adjust according to the exchange with the downstream element and this is distinct from the exchange of the last element that is connected to the open sea environment. The system can therefore co-adjust to take account of the different concentrations at the respective boundaries.

8.7 Forced Changes

Changes introduced by developments on an estuary can be represented as perturbations to the system at a given time step, or over a defined time interval. This might be useful to represent a capital dredge and the subsequent maintenance dredging as a series of volume changes in the relevant channel elements. If the dredging impacts on the tidal flats then associated changes in the areas of the flat and channel elements may also need to be defined. Similarly, a reclamation could be defined as a loss of volume and area (usually on the tidal flats). These changes are all defined in a Change spreadsheet and then loaded into the model as explained in Section 5.1.3.

8.8 Storage

Storage areas are independent of the main channel network and can be linked to channel or flat elements. The volume of water exchanged contributes to the downstream prism of the estuary but the estuary does not influence the storage element, other than controlling the rate of sediment supply. The basis for defining equilibrium of this type of sub-system is poorly defined and needs further development. The option currently available uses the ratio of volume and area of the storage element to the prism of the element.

8.9 Known Instabilities

The potential complexity of the model and the various options that can be selected means that it is possible to configure a model that is unstable in some way.

(i) Time Step

For models with very different sized elements, when a marsh is included, or a nodal tidal cycle is introduced, the model time step can become critical. This often generates output that looks to be chaotic and at the moment there is no internal check. In general, this can be cured by reducing the size of the time step but it may also be necessary to consider the element bed slope, particularly at high water (ie in the marsh and flat elements) if variable area is included in the model.

(ii) Channel elements infill

When an elements area or volume goes to zero, a warning is displayed in the Matlab command window. If any of these elements is a channel element then the model stops running. This reflects the model parameterisation and suggests that, for the given schemetisation, there is an imbalance in the way the model is configured. There can be a number of reasons for this and finding a solution usually involves exploring other parameter settings. For example the Wallasea model ran without problems for the sea level rise case but then stopped because a channel element infilled when the nodal tide was introduced. (*Note: introducing a small cyclic signal is a good test of whether the parameter settings are robust*). This was solved, in this case, by reducing the horizontal exchange between elements 7 and 9 and the associated flat (Figure 31).

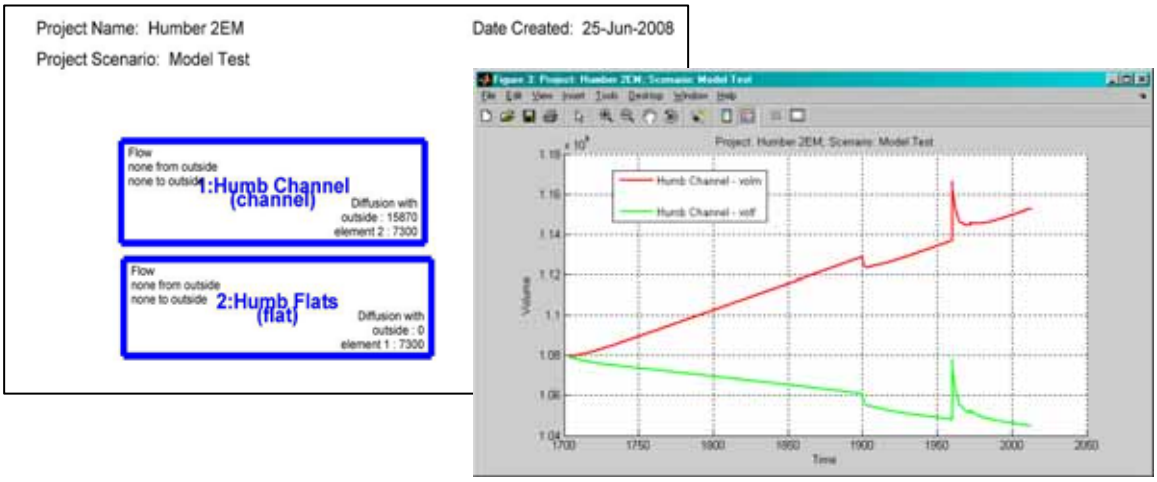
It is often worth checking that it is not something related to the constraints by running the model first with fixed area and then with fixed area at HW. If these configuration are stable then it may be that the element bed slopes, particularly for flats and marshes need to be re-considered. Altering the time step may also reduce model sensitivity, particularly if large perturbations are being introduced. This is particularly apparent when tidal pumping is included in a multi-element model. Another possible cause is a poorly specified balance of exchanges between elements and experimenting with different horizontal diffusion between elements, or changing the load associated with inputs (eg river sediment flux) may reveal particular sensitivities and so lead to a resolution of the problem. It is important to remember that the model is based on a simplified representation of the geomorphological components that make up an estuary and that exact representation of local detail is inappropriate. The aim is to simulate the large scale behaviour of the overall changes in volume and area.

9 EXAMPLE MODEL CONFIGURATIONS

9.1 Simple models

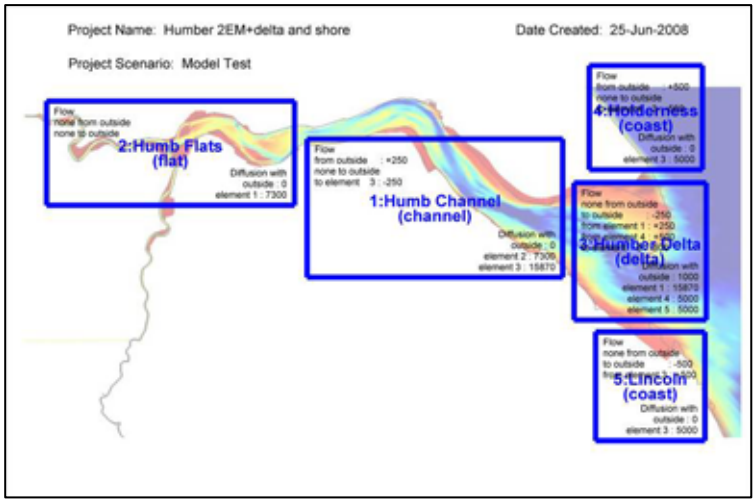
The set-up and a typical output for the Humber 2EM model is shown in Figure 25. The run shown includes the changes defined in '*Change.xls*', which defines a reclamation on the flats in 1900 and a capital dredge of the channel in 1960 followed by 16 years of maintenance dredging.

Figure 25 Model set up for Humber 2EM and sample output including forced changes



The Humber 2EM+store model includes an area representative of a managed realignment but is otherwise similar to the basic model. By adjusting the values of k(Vp) and k(Sp) different equilibrium conditions can be applied (see Section 5.2.5 and 8.8). The present model assumes that the total area of the storage area is fixed. Given that managed realignment sites are unlikely to represent an equilibrium condition, one option available is to use the CKFA model, representing the storage element as a tidal inlet. However, this is an area where more basic research is needed and this and the other options should be used with due care and extensive sensitivity testing.

Figure 26 Model set-up for 2EM+delta.



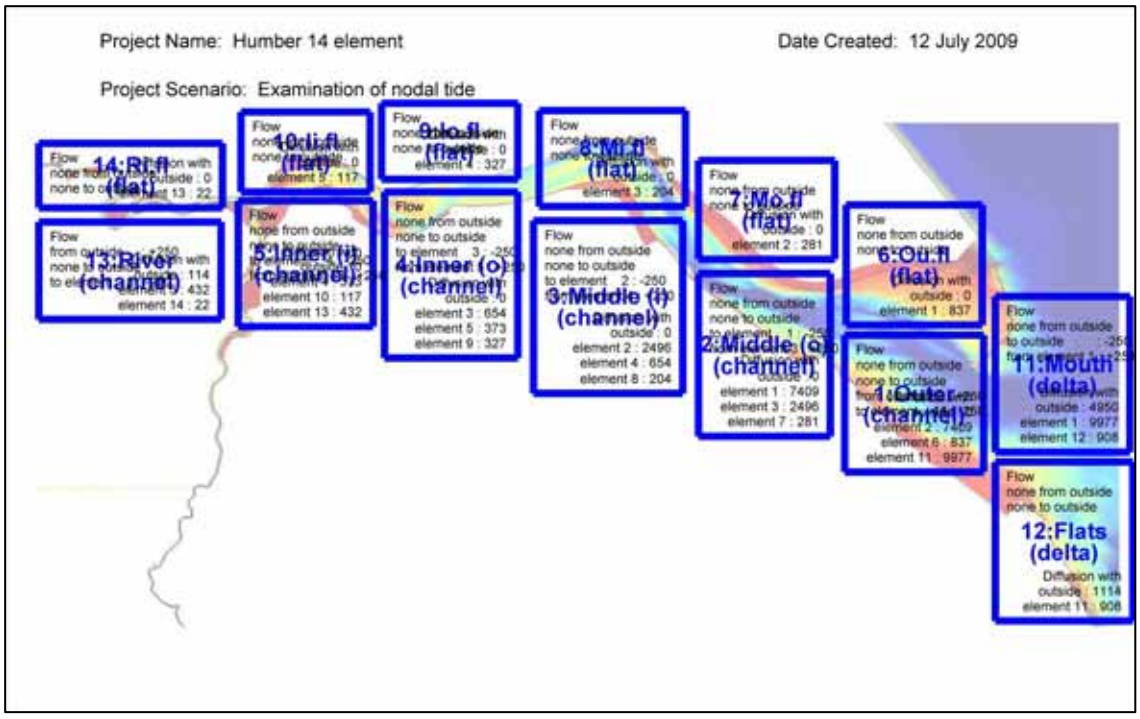
The model is also able to represent alongshore "flows" by including 'coast' elements either side of a 'delta' element, as illustrated in Figure 26. The alongshore drift is included by specifying a flow rate in to and out of the updrift and downdrift coast elements with an associated import sediment concentration defined for the updrift coast element. The load passing through coast and downdrift will be determined by the model based on the concentration in the downdrift coast element. The sample file also includes the river flow so that the interaction between fluvial and alongshore exchanges can be explored. *Note: the model is illustrative only, and has not been set-up and tested against real data for the alongshore conditions*.

9.2 Multi-element single channel model of the Humber Estuary

A much more detailed model of the Humber is provided in the file '*Humber 7 1.mat*'. This contains a total of 14 elements. There are 5 channel elements representing the main estuary, with a river channel element and a delta element at either end. Each channel element has an associated flat element, although this the tidal flat linked to the delta "channel" is represented as another 'delta' element. This allows for an exchange between the sub-tidal delta element and the intertidal delta element based on the defined vertical exchange but means that equilibrium is defined by tidal prism ratios in both cases whatever equilibrium option is selected. (If the intertidal part of the delta were to be included as a flat element, this would impose the idealised intertidal profile onto this element with some of the equilibrium options – ie. k(Vp)=2 or 3).

This model is also set-up with the parameters needed to include tidal pumping which can be included by checking the relevant box on the Configure Time Step GUI, Figure 20. The outputs shown in Figure 24 were obtained using this model (without tidal pumping and with cE=0.72) and summing the volume change for the channel elements 1-5 and similarly the tidal flat surface areas for flat elements 6-10.

Figure 27 14 element model of Humber with 6 channel and flat elements plus two delta elements



9.3 Multi-element model with two-sided flats in Southampton Water

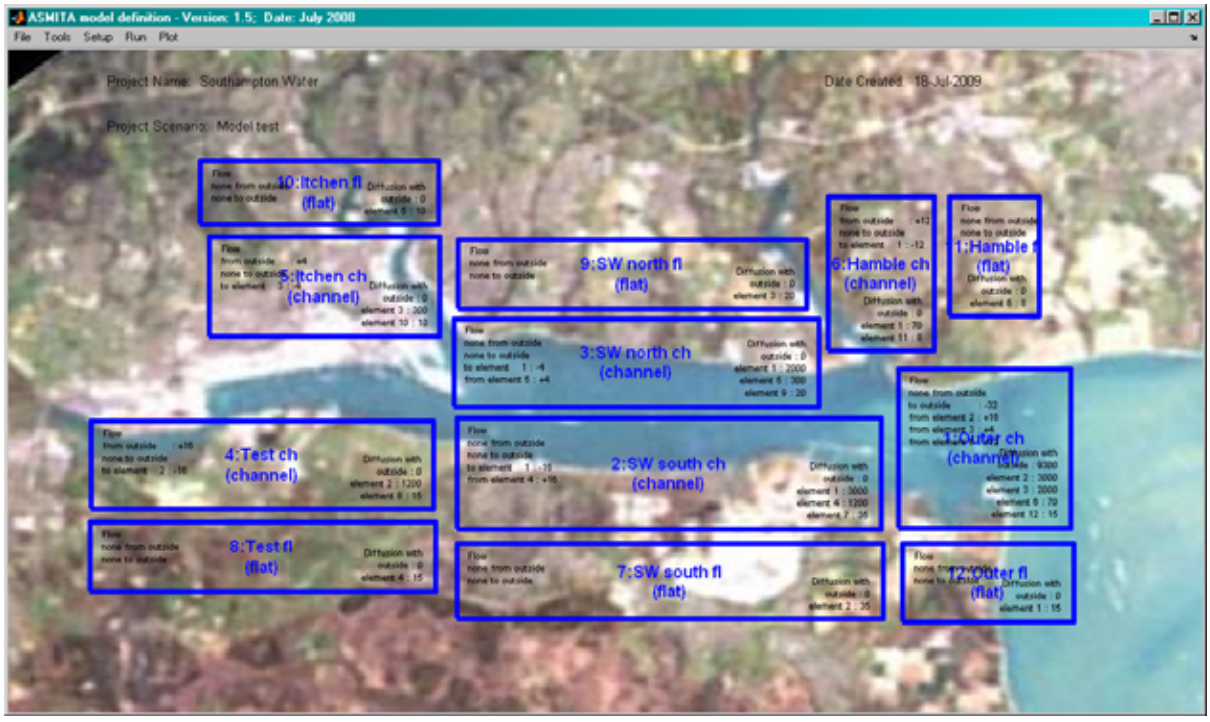
When there is a need to consider how individual tidal flats will evolve or if there is a distinct asymmetry in the estuary that is to be represented, then one way of doing this is to split the channels in two. This is nicely illustrated in the case of Southampton Water. Both the Itchen and the Test are effectively one sided channels because one bank has been extensively reclaimed to form a series of wharfs and quays. In addition, the northerly Western Shore is quite distinct from the Hythe Shore on the more southerly side of Southampton Water (SW in Figure 28). The outer part of Southampton Water and the Hamble more closely resemble two sided channel/flat systems.

The approach adopted in the representation shown in Figure 28 is to:

(i) represent the Test and Itchen as one-sided channel/flat systems;
(ii) divide Southampton Water into two distinct one-sided channel flat systems, roughly in proportion to the upstream tributaries and connect the south side to the Test and the north side to the Itchen;
(iii) add the Hamble as a conventional two-sided channel/flat system; and
(iv) connect the Hamble channel and the two Southampton Water channels to an Outer channel which is two-sided with an accompanying two-sided flat.

The resulting model is provided in '*Southampton Water 2shore.mat*' and there is also an example parameter file in '*SW 2shore model parameters.xls*'.

Figure 28 Southampton Water model with channel network and combination of one and two sided channel and flat elements



9.4 Multi-inlet model of Venice Lagoon

Single inlets can be modelled as multi-element systems, much as estuaries. However, where there is more than one inlet mouth and the inlets exchange flow internally, then model set-up is restricted to a single channel, flat and marsh per inlet mouth. Examples of this are the Chichester, Langston and Portsmouth harbours on the south coast of the UK and Venice Lagoon. The only other requirement

when setting-up this type of configuration, is to set the 'Seaward Element' to zero on the System Properties GUI (Figure 10).

The example shown in Figure 29 is for Venice Lagoon. This includes some relatively small river inflows into each channel element and exchanges between the channels of each inlet. This examples also has individual predefined ratios for the equilibrium ratios for the volume and surface area, as a proportion of the tidal prism. (The inclusion of saltmarsh requires the full version of ASMITA).

Figure 29 9 element model Venice Lagoon with a channel, flat and marsh element for each inlet

9.5 Multi-element branching channel with storage areas included, to represent managed realignment on Wallasea Island.

This application illustrates a number of aspects of model configuration. In representing the existing estuary of the Crouch-Roach a branching network was defined, as illustrated in Figure 30. In this case marshes were not included and every channel was associated with a single flat element, which represented both banks. The model is very sensitive to the horizontal exchanges to elements 9 and 10, particularly when a nodal tide is introduced. This is possibly because these two elements are much smaller than the others and the problem was overcome by reducing the horizontal exchange coefficients.

The managed realignment schemes were then introduced as a series of storage areas connected to the channel, Figure 31. (Storage areas can also be linked to flat element and a sensitivity test was run to see to show that this made little difference to the impact on the rest of the system.)

Figure 30 12 element model of the existing Crouch-Roach estuary around Wallasea Island. Comprises a network of 6 channel elements and associated flats, with channel branching indicated by arrows.

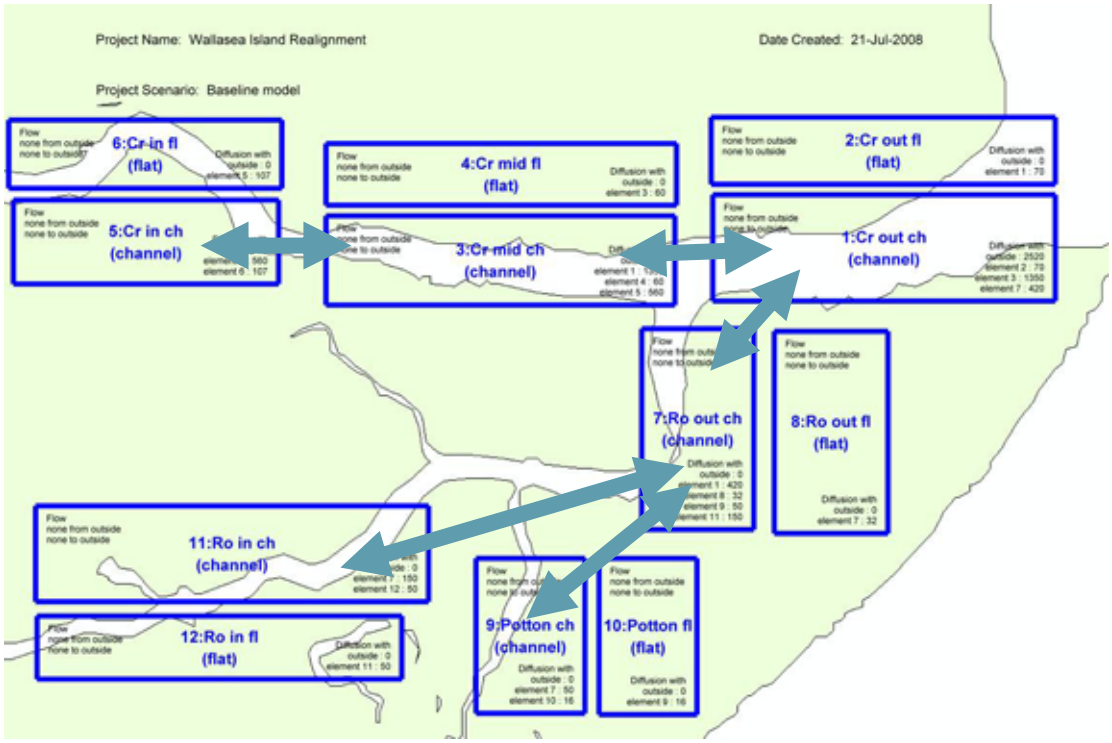
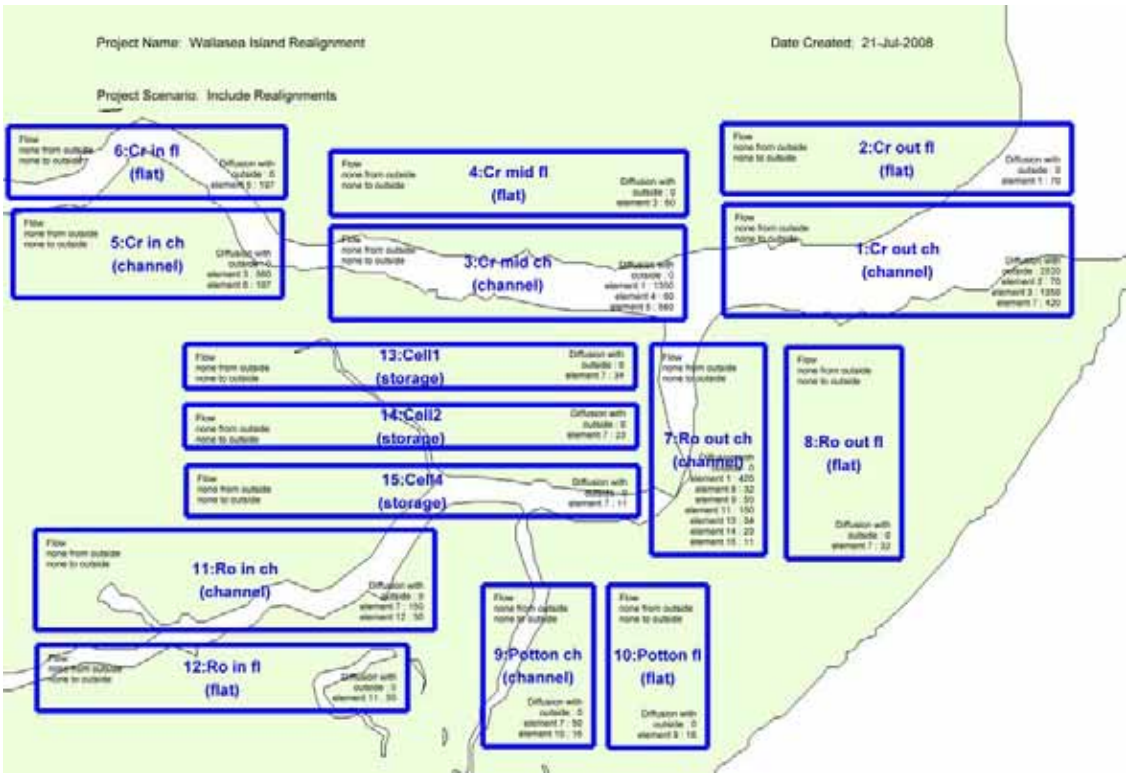


Figure 31 **15 element model with Wallasea Island Managed Realignment schemes added to baseline model. 3 storage elements connected to element 7.**



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11 APPENDICES

Appendix I Background to ASMITA model

I.1 Introduction

ASMITA (Aggregated Scale Morphological Interaction between a Tidal Basin and the Adjacent coast, Stive *et al*. 1998) is an approach developed for the study of estuary response to sea level rise. The model is based on an aggregated model that considers the estuary as a box (or set of boxes) that fills and empties under tidal action. The methodology was developed to look at the combined response of tidal delta, channel and tidal flats and has been applied to examine inlet response to human interferences (Kragtwijk *et al*. 2004), sea level rise (van Goor *et al*. 2003) changes in tidal range and the response of an estuary to the nodal tidal cycle (Jeuken *et al*. 2003).

This note summaries the basis of the ASMITA model, combining multiple elements with marine and fluvial sources. In addition the existing ASMITA, which only considers variations in estuary volume, is extended to represent time varying surface area. This allows perturbations to be introduced in the form of changes to the volumes and areas due to interventions such as dredging and reclamation, as well as sea level rise and cyclic variations in the tidal range. The basis of the empirical relationship used to define the equilibrium relationships is also given some further consideration.

I.2 Single element volume model

For a single element model, comprising just an estuary channel, the equilibrium state is derived from the equilibrium relationship assumed between the channel volume and the tidal prism:

$$V_{ce} = f(P) \tag{I.1}$$

Where V_{ce} is the equilibrium volume of the channel and P is the tidal prism (Eysink, 1990).

The other assumption made is that the ratio of the actual flow velocity to the equilibrium condition is proportional to the ratio of the equilibrium volume and actual volume. The local equilibrium concentration can therefore be written in terms of the actual volume, V, and the equilibrium volume, V_{ce}:

$$c_{ce} = c_E \left(\frac{V_{ce}}{V} \right)^n \tag{I.2}$$

Here c_{ce} is the local equilibrium concentration, n is the concentration transport exponent and c_E is the equilibrium concentration for the system as a whole (usually taken as the open boundary value). The difference between the actual concentration and the local equilibrium value induces morphological change governed by the exchange between the water column and the bed:

$$\frac{dV}{dt} = \frac{1}{c_b} wS\left(c_{ce} - c\right) \tag{I.3}$$

Where w is the vertical exchange coefficient, S is the surface or plan area of the channel, c is the actual concentration and c_b is the concentration of the bed (omitted in original derivation). If we now consider a sediment balance where the (long-term residual) sediment transport between elements is assumed to be simply diffusive (in this case the channel and the external environment):

$$wS\left(c_{ce} - c\right) = \delta_{co}\left(c - c_E\right) \tag{I.4}$$

The parameter δ_{co} is the horizontal exchange coefficient and the r.h.s. of equation (I.4) represents the exchange with the external environment.

Combining equations (I.2)-(I.4) and adopting a simple linear relationship for equation (I.1) of the form $V_e=\alpha P$, where α is an empirical coefficient, the morphological change in volume is given by:

$$\frac{dV}{dt} = \frac{1}{c_b} \cdot \frac{w\delta c_E S}{\delta + wS} \left[\left(\frac{V_e(t)}{V_m(t)} \right)^n - 1 \right] \tag{I.5}$$

This is a change relative to the initial volume and so does not include changes in water levels and tidal range. It is therefore referred to as the fixed surface volume change, V_f. The equilibrium volume, V_e, fixed surface volume, V_f, and the moving surface volume, V_m can be written:

$$\begin{aligned} V_e(t) &= \alpha \cdot P = P_o + \Delta P \\ V_f(t) &= V_{f0} + \int \frac{dV}{dt} dt \\ V_m(t) &= V_{m0} + \int \frac{dV}{dt} dt + \left(\frac{d\zeta}{dt} \cdot t + \frac{\eta}{2} \cdot e^{i\omega t} \right) \cdot S \end{aligned} \tag{I.6}$$

Where V_m includes the variation in volume due to sea level rise and some cyclic variation in tidal range, such as the nodal tidal cycle. The variables in equations I.5 and I.6 are defined as follows:

V_e – equilibrium volume
V_m – moving surface volume
V_f – fixed surface volume
P – tidal prism
P_o – initial prism at time t=0
α – volume to prism ratio

ζ – vertical sea level movement
ω – angular frequency of nodal tide
η – amplitude of nodal tide
S – surface area of basin
n – sediment transport exponent, usually taken as ~2.

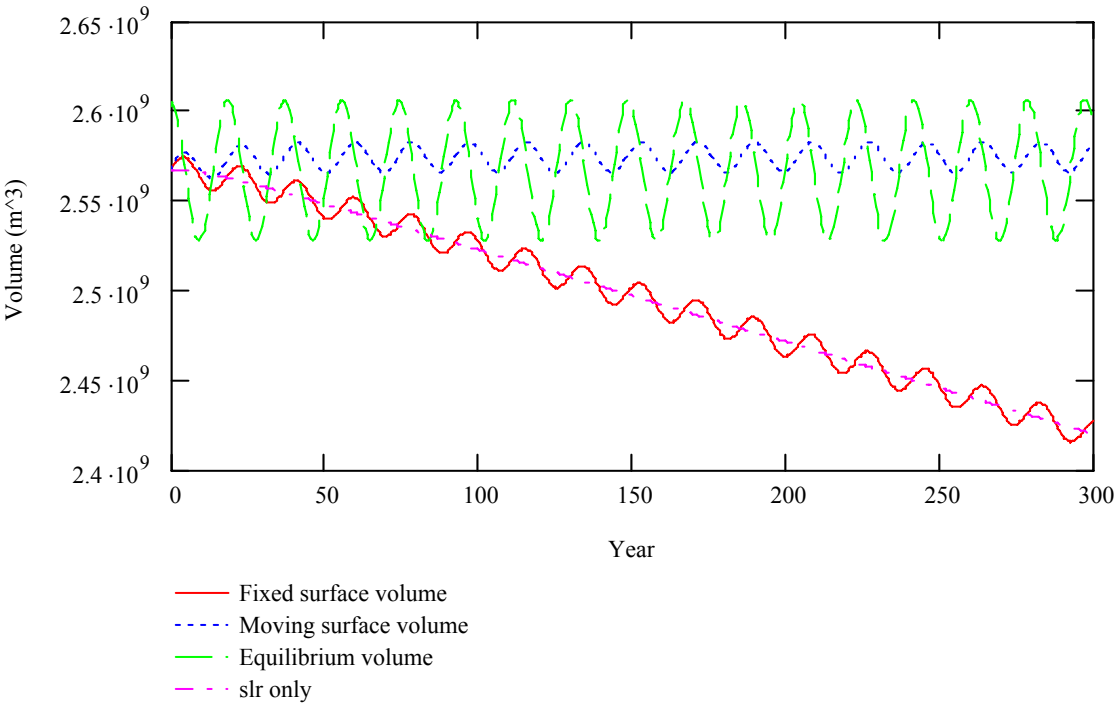
w – vertical exchange rate
δ – horizontal exchange rate
c_E – global equilibrium concentration
c_b - bed concentration

In this simple model the plan area is treated as constant. On the basis that $V_e \sim fn(P)$ any hydraulic changes that result in a change in tidal prism are represented in V_e but those that change the volume of the system (such as sea level rise, dredging or reclamation) are represented in V_m.

The variation in equilibrium, moving and fixed estuary volumes, due to a linear rise in sea level and the nodal tidal cycle, are illustrated in Figure I.1. The lag and damping of the response, relative to the equilibrium volume, is due to the dynamics associated with the morphological response time of the estuary (Jeuken *et al*. 2003).

The reduction of the volume relative to a fixed surface, shown in Figure I.1, reflects the infilling of the basin that takes place, in order for the morphology to "warp up" vertically to keep pace with sea level rise (and the superimposed nodal cycle). Thus, vertical translation of the system is incorporated in this model. If, however, we wish to include the possibility of horizontal translation, as well as the vertical response, it is necessary to adjust the plan area rather than treat it as constant.

In this formulation, the morphological timescale is determined by n and c_E. In addition, the horizontal exchange is related to the vertical exchange as a function of hydraulic depth and velocity. This means that by defining the vertical exchange, w, and the sediment transport exponent, n, based on the sediment characteristics of the estuary, and the global equilibrium concentration, c_E, to give the



correct morphological time scale, the horizontal exchange coefficient is scaled by some factor, ε, to calibrate the model (see Wang *et al*. 2007 for further details).

Figure I.1 – Variation in estuary volume for rising sea level and nodal tidal cycle as predicted by the single element model

I.3 Morphological Response Time

Linearising equation (I.5) around the equilibrium, Kragtwijk et al (2004) show that the morphological time scale can be expressed as:

$$\tau = \frac{1}{c_E \cdot n}\left(\frac{V_e}{w_s \cdot S} + \frac{V_e}{\delta}\right) \tag{I.7}$$

This makes clear that the morphological e-folding time scale (or half life) is a function of the system properties but not the disturbance. This equation is derived for a single element model and so also provides a response time scale for the system as a whole. For multiple elements, similar relationships can be derived for the individual elements (see Kragtwijk et al for further details). Another useful measure is proposed by van Goor et al (2003). They note that there is a permanent difference between the equilibrium volume with SLR (V_e*) and the equilibrium volume without SLR (V_e). This difference in equilibrium volume is necessary to maintain the demand of sediment that drives a sediment import into the system to such extent that the system does not drown. They show that the equilibrium volume with SLR V_e* becomes infinitely large when:

$$\frac{d\zeta}{dt} = \frac{w_s \delta c_E}{\delta + w_s S} \tag{I.8}$$

I.4 Multi-element volume model

The basic concept of the multi-element model is to subdivide the estuary into a number of elements and define the exchanges between elements and the equilibrium conditions for each element. As already noted, this has been presented in the literature as the ASMITA model (Aggregated Scale Morphological Interaction between a Tidal basin the Adjacent coast) and was introduced by Stive et al (1998; see also van Goor *et al*. 2003; and Kragtwijk *et al*. 2004). The system can be schematised

into any number of discrete elements, which might be sections along the channel as used in ESTMORF (Wang *et al*. 1998), or geomorphological components, such as the channel and tidal flats as typically used in ASMITA. This is illustrated in Figure 1, which shows the linkage between tidal flat, channel and tidal delta through to the open sea, referred to as the outside world. For each component the volume can be defined in terms of the sediment or water volume. In the derivation presented here, only water volumes are used and the equations presented reflect this (for the more general case see the papers noted above). So, for example, the scheme shown in Figure 1 would be represented by:

Tidal delta - total water volume over delta (where the delta has a volume relative to undisturbed coastal bed)`

Channel - total water volume below MLW

Tidal flats - total water volume between MLW and MHW over flats (ie not including the prism over the channel)

Marsh - total volume over the marsh (time average to MHW, noting that there will be greater inundation at springs than during neaps)

Storage - total volume in the storage area. below MHW

The variation in these volumes depends on the transport of sediment in and out of the elements and any changes to the water volume itself. The latter may be due to sea level rise, subsidence of the bed, or any form of progressive change in the basin volume. Hence, over the long-term (time scales much longer than a tidal cycle) the rate of change of the element volume depends on the residual flux, the change in sea level as follows and any change in tidal range:

$$\frac{dV_i}{dt} = \sum_j J_{i,j} + S_i \frac{d\zeta}{dt} + S_i \frac{d(tr)}{dt} \tag{I.9}$$

where J is the sediment volume flux between elements i and j, S is the plan area of the element and ζ is the elevation of mean sea level. The residual sediment flux between two elements is assumed to have advective and diffusive components:

$$J_{i,j} = q_{i,j} \cdot c_i - q_{j,i} \cdot c_j + D_{i,j} A_{i,j} \frac{\partial c}{\partial x} \tag{I.10}$$

where q (m^3s^{-1}) is the residual discharge rate ($q_{i,j} \neq q_{j,i}$), D (m^2s^{-1}) is the diffusion coefficient between the two elements, A (m^2) is the vertical area of the interface between the two elements and the sign convention reflects the change to the water volume. This can be written in a form similar to the r.h.s. of equation (I.4):

$$J_{i,j} = q_{i,j} \cdot c_i - q_{j,i} \cdot c_j + \delta_{i,j} \cdot \left(c_i - c_j\right) \tag{I.11}$$

In equations (I.10) and (I.11) the subscripts i and j refer to the elements the transport is from and to respectively. The advective component assumes that the concentration of the flux is that of the element supplying the sediment, which is important for external inputs such as from the rivers. In contrast the diffusive component simply uses the gradient between the elements.

Appendix II Matrix formulation

The equations presented for the single element model can be conveniently written in matrix form to represent a multi-element model. Here we follow the naming convention of Kragtwijk et al (2004) for volumes and add some additional terms to make the model more general with respect to diffusion, advection and the sources of perturbations in the volume.

For a multi-element model the variables used in Appendix I are defined as either vectors or matrices, as follows:

$\underline{V}$	element volumes	$\underline{\gamma}$	volume ratios $(V_{ke}/V_k)^n$
$\underline{S}$	element surface areas	$\underline{\sigma}$	surface area ratios $(S_{ke}/S_k)^{abs(n)}$
$\underline{c_e}$	local equilibrium concentrations	$\underline{\delta_{ext}}$	horizontal exchange coefficients with environment
$\underline{c}$	element concentrations	$\underline{n}$	concentration transport exponent. positive for wet volumes and negative for sediment volumes
$\underline{c_{ext}}$	concentrations for fluxes into the system from the environment	$\underline{c_b}$	concentration of bed
$\underline{q_{ext}}$	Advective flows into the system from the environment		
			Diagonal matrices:
D	horizontal exchange between elements	**W**	vertical exchange coefficient *w*
Q	advective exchange between elements	**S**	surface areas
B	Expression to scale rate of change	**I**	unit or identity matrix
$\underline{d}$	Expression for offset to rate of change	**M**	unit matrix with sign of n

The matrix **D** reflects the structure of the horizontal exchange between elements and with the outside world. For an n-element system with all elements linked and exchanging sediment with external environments, this would take the following form:

$$\mathbf{D} = \begin{pmatrix} \sum \delta_{1,n} + \delta_{1,E} & -\delta_{1,2} & \dots & -\delta_{1,n} \\ -\delta_{2,1} & \sum \delta_{2,n} + \delta_{2,E} & \dots & -\delta_{2,n} \\ \dots & \dots & \dots & \dots \\ -\delta_{n,1} & -\delta_{n,2} & \dots & \sum \delta_{n,n} + \delta_{n,E} \end{pmatrix} \quad \text{(II.1)}$$

For a 3-element system in which only element 3 is connected to the external environment (eg a tidal flat, channel and delta) this would take the form:

$$\mathbf{D} = \begin{pmatrix} \delta_{1,2} & -\delta_{1,2} & 0 \\ -\delta_{2,1} & \delta_{2,1} + \delta_{2,3} & -\delta_{2,3} \\ 0 & -\delta_{3,2} & \delta_{3,2} + \delta_{3,E} \end{pmatrix} \quad \text{(II.2)}$$

For diffusion the matrix is symmetric because $\delta_{i,j} = \delta_{j,i}$ and the direction of transport depends on the concentration gradient. However, for advective transport the flow has a specified direction and as already noted we adopt the convention of transport from element i to element j. The matrix for an n-element system is then given by:

$$\mathbf{Q} = \begin{pmatrix} \sum q_{1,n} + q_{1,E} & -q_{1,2} & \cdots & -q_{1,n} \\ -q_{2,1} & \sum q_{2,n} + q_{2,E} & \cdots & -q_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ -q_{n,1} & -q_{n,2} & \cdots & \sum q_{n,n} + q_{n,E} \end{pmatrix} \tag{II.3}$$

Where $q_{n,E}$ all relate to fluxes out of the system. In order to ensure continuity of water mass we also require that, for each element, the sum of the discharges in and out of the element is zero, ie $\Sigma q_i = 0$. However, provision is made for the sediment concentrations associated with these discharges to vary.

The basic equations can now be written:

$$\begin{aligned} &\frac{d\underline{V}}{dt} = \frac{1}{\underline{c_b}}\mathbf{MWS}(\underline{c_e} - \underline{c}) \\ &(\mathbf{D} + \mathbf{Q}^T)\underline{c} = \mathbf{WS}(\underline{c_e} - \underline{c}) + c_E\left(\underline{\delta_{ext}} + \underline{k_c} \cdot \underline{q_{ext}}\right) \\ &\underline{c_e} = c_E\underline{\gamma} \quad \text{and} \quad \underline{k_c} = \underline{c_{ext}} \Big/ c_E \end{aligned} \tag{II.4}$$

The basis for calculating the change in volume due to some perturbation is then as follows:

$$\begin{aligned} &\frac{d\underline{V}}{dt} = \frac{1}{\underline{c_b}}\left(\mathbf{B}\underline{\gamma} - \underline{d}\right) + \underline{\Delta V} \\ &\text{where} \\ &\mathbf{B} = c_E\mathbf{MWS}(\mathbf{I} - (\mathbf{D} + \mathbf{Q}^T + \mathbf{WS})^{-1}\mathbf{WS}) \\ &\underline{d} = c_E\mathbf{MWS}(\mathbf{D} + \mathbf{Q}^T + \mathbf{WS})^{-1}(\underline{\delta_{ext}} + \underline{k_c} \cdot \underline{q_{ext}}) \end{aligned} \tag{II.5}$$

The term $\underline{\Delta V}$ refers to any other changes in volume, introduced at any given time, within each element, eg due to reclamation or dredging. The change determined by equation (II.5) is the morphological adjustment relative to the initial volume and so does not include changes in water levels and tidal range but the volumes used in defining $\underline{\gamma}$ are based on the total water volume of the element at any given time interval. As in Appendix I, these are referred to as V_f and V_m respectively. When using the ratio of element volume to tidal prism as the basis for equilibrium, the equilibrium, fixed and moving volumes are given by:

$$\begin{aligned} &\underline{V_e} = \underline{\alpha} \cdot \underline{P} = \underline{\alpha} \cdot \left(\underline{P_0 + \Delta P}\right) \\ &\underline{V_f} = \underline{V_{f0}} + \int \frac{d\underline{V}}{dt} dt \\ &\underline{V_m} = \underline{V_{m0}} + \int \frac{d\underline{V}}{dt} dt + \left(\frac{d\zeta}{dt} \cdot t + \underline{trs} \cdot \delta tr\right) \cdot \underline{S} \end{aligned} \tag{II.6}$$

where *tr* refers to the tidal range and *δtr* is the variation in the tidal range from its mean value. The expression *trs* refers to multiplication by ½ with a sign that reflects whether the element is influenced by high or low water.

Appendix III Other Enhancements to ASMITA

III.1 Advective flow equilibrium

The original developers of the ASMITA model assumed that the equilibrium of the elements within the model domain was conditioned by the concentration in the "outside world" or external environment. When considering a delta/channel/flat system, as in the original applications, this global equilibrium is determined solely by the concentration in the "external" marine environment (ie a single value). The condition for equilibrium then requires that the volume rate of change goes to zero (equation I.3), which is equivalent to zero gradient in the concentration field. If other sources are introduced, such as a river input, this remains the basis for equilibrium provided the concentration is the same as the global concentration. However, if the concentration associated with the other sources is not the same then equation (I.3) no longer represents an equilibrium state, or put another way, the additional source constitutes a perturbation to the system. One way of overcoming this is to determine the equilibrium taking account of the additional inputs, on the assumption that these are intrinsic to the state of equilibrium represented by the initial state of the system being modelled. This is predicated on the idea that the form of the estuary (bathymetry etc) used to describe the existing state will be close to an equilibrium with the prevailing conditions and, consequently, the various inputs must all be represented in this state.

For a single element the for of equations (I.3) with the inclusion of a river input is as follows:

$$\frac{dV}{dt} = C\left\{\left(q_o + \delta_e\right)\left(\frac{V_e}{V}\right)^n - \left(q_r + \delta_e\right)\right\} \qquad \text{(VI.1)}$$

Where q_0 is discharge to the marine environment, q_r is the river discharge and δ_e is the horizontal exchange rate. In order to have a different concentration associated with the river flow but allow c_E to be factored into the coefficient C in equation (VI.1) the imported concentrations are expressed as $c_i = k_i \cdot c_E$. With some re-arrangement it can be shown that dV/dt =>0 if the equilibrium volume is factored by:

$$\alpha = \left(\frac{k \cdot q_r + \delta_E}{q_o + \delta_E}\right)^{1/n} \qquad \text{(VI.2)}$$

The adjusted equilibrium is then given by:

$$\frac{dV}{dt} = C\left\{\left(q_o + \delta_e\right)\left(\frac{\alpha \cdot V_e}{V}\right)^n - \left(q_r + \delta_e\right)\right\} \qquad \text{(VI.3)}$$

This is addressed in ASMITA by allowing the user to select the 'Include flow equilibrium' option on the Configure Time Step GUI, Figure 20. This is implemented in matrix form based on the initial conditions as:

$$\underline{eqS} = \left(\mathbf{F}^{-1} \cdot \underline{e}\right)^{1/n} \quad \text{and} \quad \underline{eqV} = \left(\mathbf{B}^{-1} \cdot \underline{d}\right)^{1/n} \qquad \text{(VI.4)}$$

The factors eqS and eqV are then used to adjust the equilibrium area and volume.

III.2 Tidal Pumping

For large macro-tidal estuaries the equilibrium state can have a variable along-estuary concentration, from a relatively low value at the mouth to a maximum some distance into the estuary. This reflects flood dominance due to internally generated asymmetry in the tidal flow transporting sediment landward and ebb dominance due to the river flow moving sediment downstream. The convergence of the two gives rise to a turbidity maximum at some point in the estuary depending on the relative strength of the two influences. The landward mechanism has been characterised as tidal pumping

(Scully & Friedrichs, 2007; Friedrichs *et al*. 1998) and can be thought of as an upstream directed discharge and associated sediment flux. For a convergent channel, the equations of mass continuity, momentum and the advection-dispersion are solved to obtain the net sediment flux, which can be expressed as (Friedrichs *et al*. 1998 eqn (18)):

$$J = \frac{3}{2} U \cdot c_m \cdot \alpha' \left\{ -\frac{u_{river}}{U} + \frac{a_{eff}}{h} kx - \frac{a_2}{a} \sin\theta_2 + \frac{1}{4} \frac{T_c U}{L_w} \right\} \qquad \text{(V1.1)}$$

where

J = net sediment flux over a tidal cycle,
a = amplitude of the dominant tidal frequency (usually M2 at mouth),
U = amplitude of the tidal velocity,
c_m = concentration scale,
α' = coefficient for sediment mobilisation
a_2 = amplitude of the overtide and θ_2 = phase of the overtide,
u_{river} = river flow velocity,
h = average depth of estuary,
x = distance from mouth of estuary,
L_w = e-folding length of width convergence,
$a_{eff} = (H_{hw}-H_{lw})/2$
T_c = adjustment time scale for the concentration field
k = tidal wave number = $2\pi/\lambda$, $\sigma = 2\pi/T_p$; $c = \sqrt{(gh)}$ and $\lambda = cT_p$.

For use in ASMITA we note that the river discharge is already handled and that concentration is defined locally for each element. We can therefore re-write (V1.1) as a discharge where in addition we will need to specify the following parameters:

aM4 = a_2, phM4 = θ_2, and eLw = L_w

And calculate the following from parameters already defined:
$h_{hw} = V_{hw}/S_{hw}$; $h_{lw} = V_{lw}/S_{lw}$; $a_{eff} = (h_{hw}-h_{lw})$

$h = (h_{hw}+h_{lw})/2$; $U = \sigma.a.L_w/h$; $x_i = \Sigma eLe(downstream)+eLe_i$

$T_c \sim h/w_s$ where w_s is the settling velocity (p321 of paper)

$A_i = (V_p/2+V_c)/L_c$ is the average cross-sectional area of the channel element. $A=(A_i+A_j)/2$ where i and j relate to the element that the flow is going from and to.

$$q_{tp} = \frac{3}{2} \frac{\sigma \cdot a \cdot L_w}{h} A \left\{ \frac{a_{eff}}{h} kx - \frac{a_2}{a} \sin\theta_2 + \frac{1}{4} \frac{\sigma \cdot a}{w_s} \right\} \qquad \text{(V1.2)}$$

The matrix for q_{tp} has the same form as that for advective flow, q. There is an additional term to be included in F, ee, B and dd when calculating eqV and eqS and in the main time loop.

Appendix IV Definition of Equilibrium

ASMITA works by relating volumes (and areas) to some equilibrium value that, if equal, would result in uniform concentration throughout the system. The most common way of doing this is to define a relationship with the tidal prism for each type of element (or for each individual element). This section explores the basis of an equilibrium based on the tidal prism in a UK context and an alternative approach based on an Equilibrium profile

IV.1 Tidal Prism Equilibrium Relationships

Equation I.1 postulates a link between the equilibrium volume and the tidal prism. Similarly the value of the equilibrium surface area S_e in Equation III.6 can be assumed to vary with the tidal prism. Townend (2005) showed that the tidal prism exhibits a strong correlation with the plan area and volume of the estuary. From a sample of 66 UK estuaries he found that the total surface area, total volume and tidal prism exhibited the following relationships:

$$S_{mtl} = 0.42P^{0.96}, \qquad R^2 = 0.92;$$
$$V_{mtl} = 0.073P^{1.13}, \qquad R^2 = 0.92. \tag{IV.1}$$

The elements used within ASMITA comprise deltas, channels and tidal flats. The UK estuaries database suggests that the channels and flats (when represented as a single element) can be adequately represented by simple linear relationships with exponents of one:

Table IV.1 Linear form-prism ratios

	Volume	R^2	Surface Area	R^2
Channel	$V_c = 0.418P$	0.93	$S_c = 0.076P$	0.95
Tidal flats	$V_f = 0.163P$	0.74	$S_f = 0.077P$	0.47
			$S_f = 28.9P^{0.75}$	0.82

However, individual estuaries can have values significantly different from the above. The following are the average values for the Humber over the period 1851-2000 (based on 22 bathymetric data sets) with standard deviations indicating a small variation over time:

Table IV.2 – Linear form-prism ratios for the Humber Estuary

	Volume	St.dev	Surface Area	St.dev
Channel	$V_c = 0.738P$	0.021	$S_c = 0.130P$	0.003
Tidal flats	$V_f = 0.249P$	0.011	$S_f = 0.067P$	0.003

One of the strongest correlations revealed by the UK data is between the surface area at mean tide level, prism and tidal range, which takes the form:

$$S_{mtl} = 1.07\frac{P}{tr} \qquad (R^2 = 0.996) \tag{IV.2}$$

This implies that the tidal prism is essentially the plan area at mean tide multiplied by the tidal range (particularly for the larger estuaries with $P>10^7 m^3$) and that the cross-shore shape of the intertidal is of secondary importance. Although the regression is strong it must be recognised that the error in predicting the plan area of an individual estuary can still be ±30% based on this data set, with most of the data points falling below this forced regression line (ie exponent=1 and intercept=0). The surface area at low water is also reasonably well represented by this form of relationship but the area of the

tidal flats shows a poorer correlation, Table IV.3. The coefficients specific to the Humber are similar for the mean tide and channel (mlw) relationships but differ significantly for the tidal flats.

Table IV.3 Linear form-prism ratios for surface area as a function of P/tr

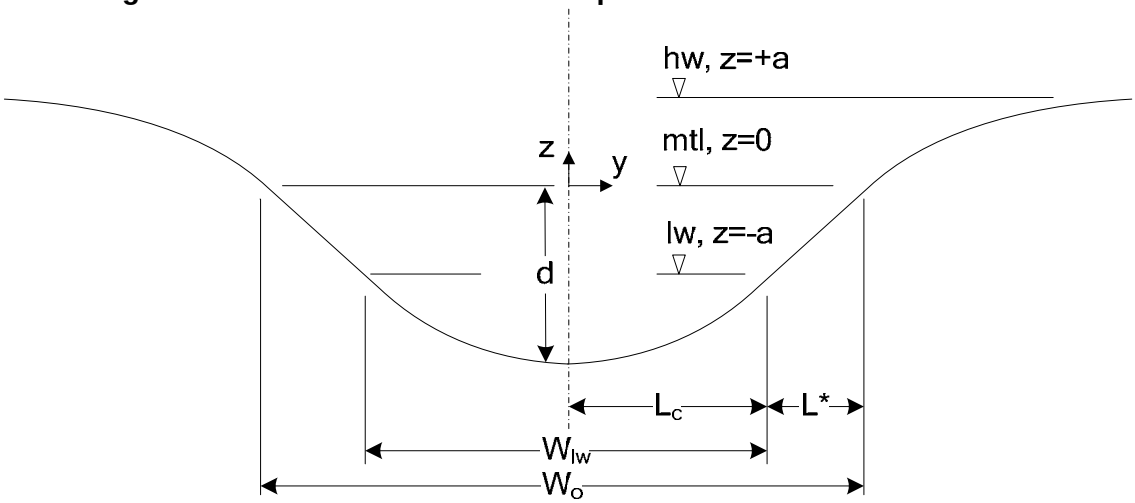
	UK estuaries	R^2	Humber estuary
Channel	$S_c = 0.775P/tr$	0.97	$S_c = 0.733P/tr$
Tidal flats	$S_f = 0.945P/tr$	0.77	$S_f = 0.386P/tr$
Mean tide level	$S_{mtl} = 1.07P/tr$	0.99	$S_{mtl} = 0.96P/tr$

A more detailed exploration of the inter-estuary, along-estuary and temporal variation of selected gross properties with tidal prism is provided in Appendix IV(a).

IV.2 Equilibrium Profile

An alternative approach is to use the equilibrium hypsometry relationships for channels (Cao & Knight, 1997) and tidal flats (Friedrichs & Aubrey, 1996) to define the form of the estuary cross-section, Figure 1. The resulting relationships can then be written in terms of volume and surface area by considering a representative length. Some trials for a number of estuaries suggest that this form description provides a reasonable characterisation of estuary cross-sections.

Figure IV.1 – Definition sketch for equilibrium form of channel and intertidal



From Friedrichs and Aubrey (1996, p414, eq(15)) we have the intertidal described by:

$$z = a \cdot \sin\left(\frac{y'}{L^*} - 1\right) \qquad \text{(IV.3)}$$

where $y' = y - L_c$. If we assume a symmetric channel it follows that:

$W' = W - W_{lw}$ and $L^* = (W_o - W_{lw})/2$, or more generally $L^* = (W_o - W_{lw})/n_{bk}$

where n_{bk} is the number of banks.

Whence $$z = a \cdot \sin\left(\frac{n_{bk} y - W_{lw}}{W_o - W_{lw}} - 1\right) \quad \text{for} \quad y \geq \frac{W_o}{n_{bk}} \qquad \text{(IV.4)}$$

and $$z = a \cdot \left(\frac{n_{bk} y - W_{lw}}{W_o - W_{lw}} - 1\right) \quad \text{for} \quad \frac{W_{lw}}{n_{bk}} > y < \frac{W_o}{n_{bk}} \qquad \text{(IV.5)}$$

Using entropy concepts Cao & Knight (1997) derive a parabolic equation for channel form:

$$d(y) = \frac{\mu W_{lw}}{2n_{bk}}\left[1-\left(\frac{n_{bk}y}{W_{lw}}\right)^2\right] \qquad \text{(IV.6)}$$

Where d is the depth at a distance y from the centreline, μ is the submerged static friction factor taken to be equal to $\tan\phi$, where ϕ is the angle of repose of the sediment. The value of m largely determines the aspect ratio. More generally, one might consider the exponent of 2 to be a variable, n. This determines the shape of the channel, the larger the value the closer the form is to a rectangular channel.

Consequently the cross-section of the estuary can be prescribed over three intervals:

$$\begin{aligned} z &= a\cdot\sin\left(\frac{n_{bk}y - W_{lw}}{W_o - W_{lw}} - 1\right) && \text{for } a > z > 0 \\ z &= a\cdot\left(\frac{n_{bk}y - W_{lw}}{W_o - W_{lw}} - 1\right) && \text{for } 0 > z > -a \\ z &= -a - \frac{\mu W_{lw}}{2n_{bk}}\left[1-\left(\frac{n_{bk}y}{W_{lw}}\right)^n\right] && \text{for } z < -a \end{aligned} \qquad \text{(IV.7)}$$

Friedrichs and Aubrey (1996) show that the lower intertidal width is a function of the equilibrium flow velocity and the angular tidal frequency: $(w_o\text{-}w_{lw}) = u_{eq}/\omega$. This implies that the lower intertidal width reflects flow field, the erodibility of the sediments and the rate of convergence of the estuary. We therefore assume that the slope of the lower intertidal is a characteristic value, which in terms of surface area is given by:

$$m_{eq} = \frac{W_o - W_{lw}}{n_{bk}a} \qquad \text{(IV.8)}$$

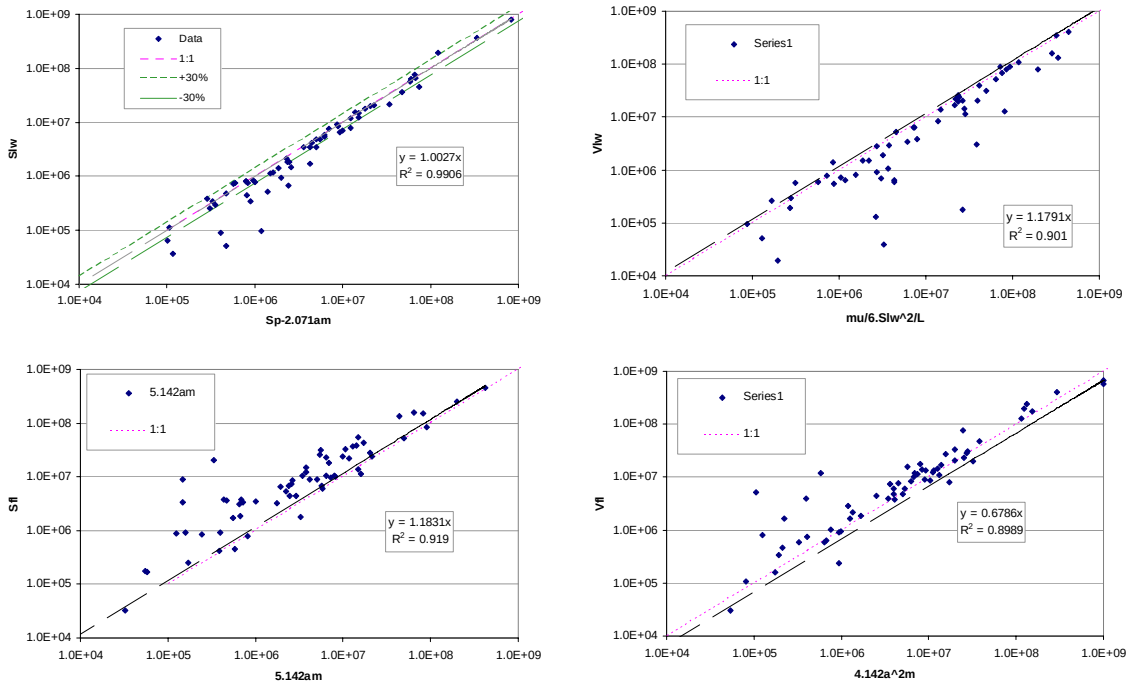
Now by assuming representative reaches the widths can be treated as surface areas. Furthermore integrating equations (IV.7) over the respective intervals provides cross-sectional areas of the upper and lower intertidal and channel, respectively. Again taking representative reaches allows these to be treated as volumes.

Using the initial estuary surface areas at mtl and lw, with the tidal range, the equilibrium slope can be calculated using equation (IV.8). Taking n=2, the value of μ can be obtained as the ratio of the volume and area at low water, with the introduction of the element length, L_e. If the slope, m_{eq} and coefficient μ are treated as being constant, equations (IV.9) can be used to derive updated equilibrium volumes and areas for the channels and flats given a new value of the tidal prism.

$$\begin{aligned} S_{lw} &= \frac{P}{2a} - n_{bk}\cdot a\cdot m_{eq} & V_{lw} &= \frac{\mu}{n_{bk}(n+1)}\cdot\frac{S_{lw}^{\,2}}{L_e} \\ S_{fl} &= \left(1+\frac{\pi}{2}\right)\cdot n_{bk}\cdot a\cdot m_{eq} & V_{fl} &= \frac{1+\pi}{2}n_{bk}\cdot a^2\cdot m_{eq} \end{aligned} \qquad \text{(IV.9)}$$

Based on the data from 66 UK estuaries these relationships are found to give reasonable representations, Figure IV.2.

Figure IV.2 Comparison of Equilibrium Profile estimates against observed values



Source file: Eq Hyps fits to JCR data.xls

Appendix V ASMITA_lite model sub-routine structure

The file 'ASMITA_lite Program Structure.xls' list the subroutines used in the program.

Description	Routine name & level 1	2	3	4	5	6	Notes	
Initiate user interface for asmita	asmui							
Define global variables		defglob						
Initialise variables and set default values		vardef					Header includes definitions of all global variables	
Define figure for main user interface		moddef_fig					Defines the calls for drop down menus	
							File	
Create a new model			new_project				File/New	
Open an existing model			cb_fil1				File/Open	
Save the model to existing file			cb_fil2				File/Save	
Save the model to a new file			cb_fil3				File/Save As	
Exit the program			exit_fig				File/Exit	
							Tools	
Load a background map or image			cb_fil4				Tools/Load Image	
Save an image of the model window to a jpg file			cb_fil5				Tools/Model Image	
Redraw map and elements			drawmap				Tools/Refresh	
							Tools/Clear	
Clear the model from memory			clear_model				Tools/Clear/Model	
Clear all open output plots			clear_figs				Tools/Clear/Figures	
							Setup	
							Setup/System	
Load existing/default system property values, call input form			gb_elm2				Setup/System/Properties	
Input system properties				gbspec_fig			Form	
Load new values into global variables					gb_spec		Called by Ready button on form	
Load existing/default water level values, call input form			wl-elm				Setup/System/Water levels	
Input system properties				wlspec_fig			Form	
Load new values into water level variables					wl_spec		Called by Ready button on form	
							Setup/System/Change	
Create new change .xls file based on model as defined			Systemchange(0)				Setup/System/Change/New	
Edit existing change .xls file			Systemchange(1)				Setup/System/Change/Edit	
Load selected change file into global variables			Systemchange(2)				Setup/System/Change/Load	
Prompts user for excel file name				GetExcel				
Reads selected file into the change variable				CheckExcel				
							Setup/Element	
Define new element (draw defining box in window)			cb_elm1(0)				Setup/Element/Define	
							Setup/Element/Specify	
Right mouse click on element to select Properties			rm_elm2				Properties	fig menu in drawmap
Load existing/default element property values, call input form			cb_elm2				Setup/Element/Specify/Properties	
Input individual element properties				elspec_fig			Form	
Load new values into global variables					cb_spec		Called by Ready button on form	
					getindex		aslo called in tf_spec, q_ready and d_ready	
Right mouse click on element to select Flow			rm_excq				Flow	fig menu in drawmap
Load existing flow values, call input form			cb_excq				Setup/Element/Specify/Flow	
Get index of element clicked on by user				getelem			also called in cb_excd	
Select elements and define flow				exchq_fig			Form	
Load new values into global variables					q_ready		Called by Ready button on form	
Right mouse click on element to select Diffusion			rm_excd				Diffusion	fig menu in drawmap
Load existing horizontal exchange values, call input form			cb_excd				Setup/Element/Specify/Diffusion	
Select elements and define exchange				exchd_fig			Form	
Load new values into global variables					d_ready		Called by Ready button on form	
Right mouse click on element to select Resize			cb_elm1(1)				Resize	fig menu in drawmap
Right mouse click on element to select Delete			rm_elm3				Delete	fig menu in drawmap
Delete an element			cb_elm3				Setup/Element/Delete	
Load existing/default run time values, call input form			cb_run1				Setup/Time Step	
Input individual run time settings				timest_fig			Form	
Load new values into global variables					cb_run1a		Called by Ready button on form	
							Run	
Carry out some diagnostics to check model is correctly specified			cb_run4				Run/Check Input	NB this incomplete
Run model			cb_run2				Run/Run Model	Also includes checks
Main computational routine that unloads variables from global defintions, initialises all variables required in calculation and runs the time step loop				asmita				
Subroutine to set up matrices defining element linkages					ele_link			
Subroutine to define equilibrium coefficients for mu, meq					mu_meq			
Subroutine to calculate high water volume						hw_vol		
Subroutine to subtract volume of expanding element from contracting element					ele_Vcorr			
Subroutine to calculate equilibrium S and V					eq_vands			
Subroutine to calculate tidal prism						prism		
Subroutine to set equilibirum coefficients based on initial definition of elements						eq_coefs		
Write output to excel file					writedata			
Print all input parameters to text and xls files				cb_print				
Routine to handle writing to Excel spreadsheets					xlswrite1			
							Plot	
Utlity to plot results			plot_fig				Plot Results	
Add to current plot				add_grp			Add button	
Create a new plot				new_grp			New button	
Delete line				del_grp			Delete button	