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Developing a prototype tool for mapping flooding from all sources Phase 2: MAST user guide

Project: SC080050/R3

Flood and Coastal Erosion Risk Management Research and Development Programme

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This report is the result of research commissioned by the Environment Agency's Evidence Directorate and funded by the joint Environment Agency/Defra Flood and Coastal Erosion Risk Management Research and Development Programme.

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84911-235-2

Email: fcerm.evidence@environment-agency.gov.uk.

Further copies of this report are available from our publications catalogue: http://publications.environment-agency.gov.uk or our National Customer Contact Centre: T: 08708 506506
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Dissemination Status: Publicly available

Keywords:
Flood mapping; all sources

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Project Number:
SC080050

Product Code: SCHO0711BUAQ-E-E

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Miranda Kavanagh

Director of Evidence

Executive summary

The MAST (Mapping All Sources Tool) prototype software enables sets of flood mapping data representing flooding from different sources to be combined to produce a flood map for multiple sources. The MAST method is practical and flexible to use, particularly in situations where fully integrated modelling of multiple sources is not appropriate. It has been developed to help meet the evolving needs of modern flood risk management, such as clearer communication and integrated management of 'all sources' of flood risk (including awareness raising, investment planning, spatial planning and planning for response to flooding incidents).

This user guide to the MAST prototype software explains how to apply the software to produce combined flood maps. It also contains a worked example (demonstrating typical input and output data), a technical description of the calculation method and a 'quick start guide'.

The prototype software has been developed to commercial standards. However, it is intended to be prototype software which will require further trialling and development before it is fully ready for 'production use' within operating authorities. An implementation plan for the software is provided in the companion report (Phase 2: Final Report, SC080050/R2).

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Glossary

AEP	Annual exceedance probability – the probability that a specific event will be exceeded in any given year.
ASCII grid	A simple, open and widely used file format for storing grid data (such as digital elevation data or flood depth data) (also called ESRI ASCII grid).
Flood source dataset	The term used in MAST to identify a set of data associated with a specific source of flooding (or one or multiple representations of that source; for example, if both broadscale and detailed results are available for one source of flooding then these would be two flood source datasets). Groups of *GIS data layers* combine to make a flood source dataset.
GIS data layer	The term used in MAST to describe the individual data files containing, for example, flood depth grids for a particular flood probability and source of flooding.
GIS view	The map-based view of the input and output geographical information systems (GIS) data used in MAST.
Joint probability	The chance of two or more conditions occurring at the same time.
MAST	Mapping All Sources Tool (method and software).
MAST project	A combination of one or more *simulation scenarios*.
Project tab	The main user interface screens in MAST which are used to enter data and set options for specific MAST calculations.
Shapefile	A commonly used GIS format for point, line and polygon features.
Simulation scenario	In MAST, this term is used to define a particular combination of *flood source datasets*.
XML	eXtensible Markup Language – a text-based format (set of rules) in widespread use for holding and transferring data.

1 Introduction

This report is a user guide to the prototype software tool developed in Phase 2 of the project *Developing a prototype tool for mapping flooding from all sources*. The prototype software is called 'MAST', which stands for 'Mapping All Sources Tool'. The tool is termed 'prototype' as further software development and implementation will be required before the tool would be ready for widespread use within the Environment Agency or by local authorities. Thus the anticipated audience for this user guide is those technical specialists who may need to evaluate the prototype tool prior to full implementation. This user guide will also provide the basis for much of the user documentation which will be required in due course for the final version of the tool (noting that some simplification and further explanation will be required in the user guide for the final version).

The user guide is structured as follows:

- Chapter 2 provides an overview of the structure of the software and how to use it. A 'quick start guide' is provided in Appendix C.
- Chapter 3 provides a detailed description of how to use the software.
- Chapter 4 uses an example application of the software to Christchurch to help users understand typical steps taken to apply the software.
- Chapter 5 is a technical description of the calculation method used within the software tool (readers of this chapter will require a good working knowledge of probability analysis).

Readers are referred to the Phase 1 report (SC080050/R1) for information on the project drivers, consultation, datasets and development of the method. The Phase 2 final report (SC080050/R2) discusses the development and testing of the prototype tool and provides an implementation plan.

2 Software overview

The main role of the MAST software is to combine data on flooding, which could include flooding from different sources, such as rivers, sea or surface water This information is combined to produce a single (potentially 'all sources') map of flooding.

The MAST software is shown diagrammatically in Figure 2-1 and each component is described in more detail in the following sections.

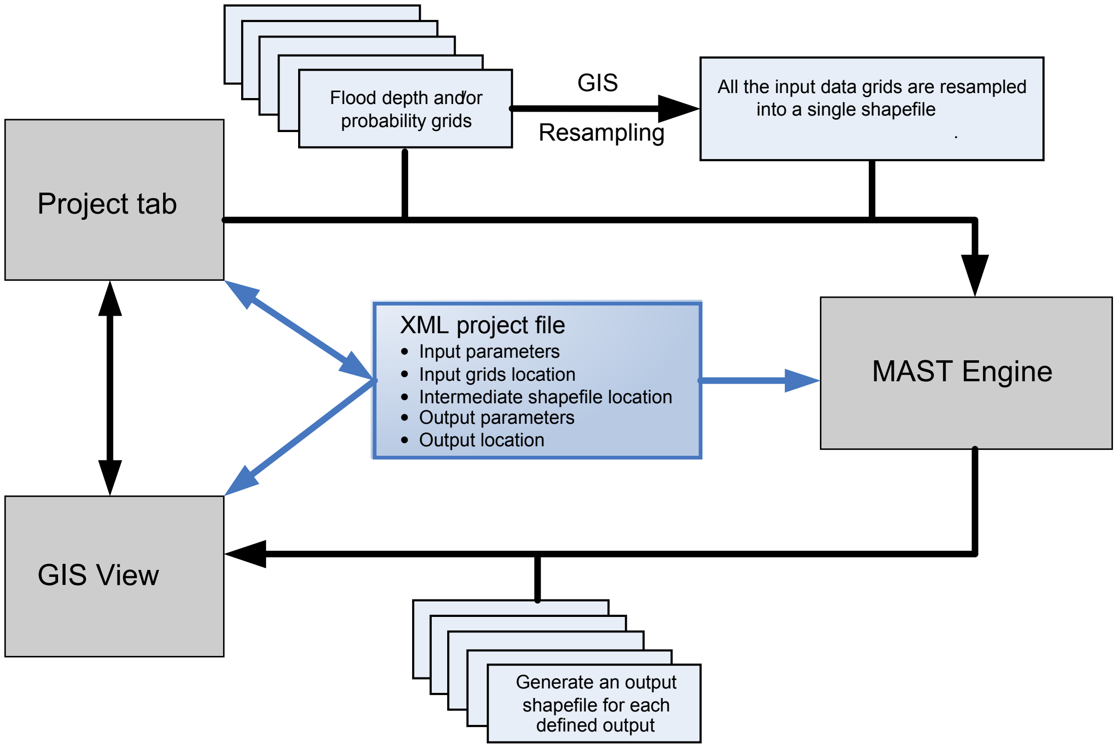


Figure 2-1 MAST components and data flows

2.1 MAST interface components

The MAST software consists of three distinct components. These are:

1. Project tab – This is the first component of the software that users see and it provides the functions to prepare a MAST simulation by:

    - Specifying the study area.
    - Specifying input flood data for any sources of flooding.
    - Specifying the chance of two or more conditions occurring at the same time (joint probability) between different sources of flooding.
    - Organising data and parameters to create input data suitable for the MAST engine to use.
    - Specifying the way results will be presented by specifying different types of thresholds. If 'depth threshold' type is chosen, the output will be a grid shapefile of the combined chance of the flood waters reaching a certain

depth; for example, this answers the question: What is the probability of a location being flooded with a water depth of 0.5 m?. If ‘probability threshold’ type is selected, the output will be a grid shapefile of combined flood water depth for a specified probability of occurrence.

2. GIS View – The MAST interface includes simple GIS viewer tools to help visualise input and output data (no specific GIS software is required to use MAST). The ‘GIS View’ tab provides users with the following functionality:
    - The ability to visualise flood mapping datasets, which must be GIS datasets representing either depth data or flood probability data.
    - Viewing the different attributes of the MAST combined output datasets. These are polygon shapefile format files.
    - Display background mapping (such as Ordnance Survey maps and the extents of previous floods) and provide simple GIS viewing functionality (including panning and zooming).
3. MAST Engine – This is the calculation engine of the MAST software which generates the combined probability data. It is activated from the Project tab of the interface by clicking the ‘Run Scenario(s)’ button (after input data have been defined). The engine reads the processed input data and calculates a result (using thresholds defined in the Project tab). For each threshold the engine will produce a ‘grid’ shapefile (each polygon square representing an analysis cell) with attributes that include the combined results along with uncertainty estimates for each particular cell plus contributions from the different sources of flooding.

2.2 MAST data components

The input data used by MAST exists in a hierarchy which is defined as follows:

GIS data layer

At the lowest level of the MAST project hierarchy are GIS layers. The compatible data formats are described in Section 2.4. Examples of **GIS data layers** are as follows:

- Probability grids for a particular depth threshold (such as the maps of the Environment Agency’s NaFRA (National Flood Risk Assessment)).
- Depth grids for a particular flood probability.
- Flood extent polygon shapefiles with known associated probability (such as the Environment Agency’s Flood Zones).
- Flood extent polygon shapefiles with unknown probability (such as maps of flooding, showing only extent of flooding without associated probability information).

The flood data must be in shapefile or ESRI ASCII grid format. If data exists in a different format, it must be converted to a compatible format as a pre-processing exercise. This can be done using a variety of commercially available GIS tools, such as ArcGIS or MapInfo.

Flood source dataset

A **flood source dataset** describes a source (such as river or surface water) of flooding that may affect a certain place. It is normally represented by a set of GIS data layers of model results, such as a river model run for a set of scenarios which have a different chance of occurring in any given year. Thus, a series of water depth grids or flood extent shapefiles produced from the model are used to represent one flood source in the MAST model. The MAST calculation engine will read the GIS data layers and derive a depth probability curve to describe the flood source. This curve is then combined with other flood sources by the engine to produce 'all sources' output. Note that if data are available for the same source of flooding but at two different resolutions, such as broadscale fluvial and detailed fluvial, these are added as two different flood source datasets with the detailed fluvial data given a higher priority.

Simulation scenario

In MAST, the term scenario is used to define a particular combination of different flood source datasets. Users can add several flood source datasets to one scenario for a particular analysis. This is called a **simulation scenario**. In addition to defining separate flood source datasets, users can also define any joint probability relationships between different flood source datasets. Several types of output can be defined from a simulation scenario, such as a probability grid shapefile or a depth grid shapefile.

MAST project

A **MAST project** contains a number of simulation scenarios and their respective flood source datasets. These settings can then be saved to a project file. This is an xml format file that stores all settings specified by the user: loaded datasets and defined sources and scenarios. The user can reload a project file to retrieve these data in a future session. Furthermore, project files act as an audit trail for outputs produced by MAST.

The output from MAST is a shapefile (polygon) grid with attributes detailing the calculated combined probability data. Attributes are:

- Calculated combined value for each grid cell – this can be a probability (for a specified depth threshold) or a depth (for a specified probability).
- Percentage contributions from each single data source present at grid cell locations.
- Combined uncertainty upper and lower bounds calculated by combining uncertainty data from individual sources (see Chapters 3 and 5 for an explanation of how uncertainty is assessed).
- A measure of dependence between the source results if source joint probability relation is provided.
- Details of any other data sources present at the grid cell location but not contributing to combined value, such as a reservoir inundation map with unknown occurring probability.

These attribute data can easily be exported as separate grids if required, for example a combined probability grid, or a grid of fluvial contribution percentages.

2.3 Undertaking a MAST simulation

In order to run a new simulation to calculate combined probabilities in MAST, the user must go through the following steps (Table 2-1):

Table 2-1 MAST step guide

Step	Process	Details
1	Start MAST	The project tab is displayed. The project tab stores all details of the defined MAST project. Users can recall an existing project or start to define a new project. Loading an existing project will also populate the MAST GIS viewer with all GIS datasets referenced in the project file.
2	Load GIS data	The user can add their flood modelling results to the viewer if they wish to visually explore them prior to analysis. The viewer is accessed in the interface by clicking on the 'GIS View' tab. All GIS data layers loaded are made automatically available for quick selection in the project tab. (It is not essential to enter any data into GIS View.)
3	Check required source types are defined	MAST stores a library of flood source types which the user can select when specifying their source data. These should be checked prior to specifying a new simulation to ensure all required source types are available (new ones can be added by the user).
4	Define flood source datasets	A flood source dataset will contain data from a particular source of flooding. The data layers for a flood source can be one of three types: ASCII grids, shapefile flood extent maps with specified probability and shapefile flood extent with no specified probability. Within a flood source all datasets must be the same type (although different flood sources in the same analysis can be different types).
5	Add layers to flood source dataset	All data associated with a particular flood source should come from different simulations of the same model. So, for example, if data were available from two fluvial models, such as a local detailed model and a coarse national model, they would be considered as different sources, and would be defined as separate datasets. Data can be added by browsing or selecting datasets loaded into the MAST GIS View.
6	Define analysis scenario	Add sources that are to be combined to the scenario and define any joint probability relationships between sources. Sources in a scenario can be different types and/or different resolutions (grid sizes).
7	Define output criteria for analysis	A boundary shapefile must be specified as the extent for analysis – only data within the boundary box will then be considered. Specify an output depth threshold (output will then be corresponding combined probability values at each grid cell) or a probability value (output will then be a combined depth value at each grid cell).
8	Run simulation	Select which scenarios to include in the simulation run from the available scenarios specified within the project.
9	View results in GIS View	Results generated can be loaded back into the GIS View for inspection. Output is in a grid shapefile format. Each polygon grid cell has attributes: - Combined probability/depth value. - Percentage contribution of each component source to the combined figure. - Reference to any source not used or that is present at this location but no probability value is specified for use in the calculation. Results can be further post-processed (in standard GIS software) to generate separate grids for individual attributes of the MAST results

Step	Process	Details
		file, such as grids of combined probability flood depths.
10	Save project and exit	The project file acts as an audit trail as it provides a record of the analysis performed and enables it to be recreated in the future.

2.4 Preparing compatible input datasets

MAST is compatible with a limited number of data formats. In the majority of situations these data formats will be the standard output from flood models or they can easily be created from model outputs (in advance of using them in MAST).

Depending on the input data type, it will be handled differently by MAST as explained below.

ASCII grids

This input format can be depth grids for a specified probability or probability grids for a specified depth threshold. To be compatible with MAST, grids must be standard ESRI ASCII format (with file extension '.asc') and orientated in the easting and northing directions, that is, zero rotation angle.

The following information might be needed for a MAST model:

- A flood depth ASCII grid corresponding to a certain occurring probability. The depth values are assumed by MAST to be in metres. This grid describes what the flood water depth is for a specified occurring probability, for example a one in 100 chance of occurring in any year.
- A flood probability ASCII grid corresponding to a certain depth threshold. For these input files the values must be given as probabilities between zero and one (they are not percentages), and therefore 0.01 represents the one in 100 chance of flooding to a specified water depth in any year.
- An example of flood depth ASCII format for MAST is shown below:

```
ncols        1000
nrows        1200
xllcorner    538500.25
yllcorner    178099.75
cellsize     2
NODATA_value  -9999
3.361 4.611 4.811 5.231 5.401 5.611 5.631 5.741 5.881 5.901 5.961 6.071 6.061 6.111 6.091
3.071 3.521 3.781 4.581 5.191 5.641 5.731 5.771 5.811 5.861 6.011 6.041 6.131 6.221 6.211
2.931 2.991 3.051 3.121 4.491 5.371 5.691 5.741 5.921 5.961 6.011 6.001 6.191 6.241 6.221
etc
```

For these data the spatially varied probability or depth value will be read directly from the file for each output grid cell. The user must specify more than one grid for a particular source (at least two different depth or probability thresholds). This enables MAST to convert these data into probability/depth curves at each output grid cell. Furthermore, for a particular source, all grids specified must be the same type: depths grids or probability grids.

Example modelling sources:

- Depth grids (for specified flood probability) produced from 2D hydraulic model results.
- Probability grids (for a specified depth threshold). NaFRA output is a typical probability grid with an associated depth threshold.

Shapefile flood extent maps with specified probability

This input format will be a polygon shapefile which signifies the outline of a flood extent for a known probability threshold, but does not contain actual flood depth information. The accepted format in MAST is standard ESRI polygon shapefile format (with file extension '.shp'). MAST can work with polygons containing bow ties, holes/islands, or multi-part polygons.

The user should specify more than one flood outline for a particular source, that is, at least two different event probabilities. This enables MAST to directly use the commonly available flood extent maps and to compute the combined flooding probability at the depth threshold of zero metres. This approach uses a subset of the full MAST method and focuses on the arguably most important zero metres depth threshold. If other output depth thresholds are intended, the grid input should be provided with more detailed depth/probability information for each cell.

If only a single dataset of this type is specified for a particular source, MAST will not allow it to be included in any simulations. Please refer to the next section about using a shapefile flood extent with no specified probability.

Example modelling sources include flood extent from hydraulic model results.

Shapefile flood extent with no specified probability

This input format will be a polygon shapefile which signifies the indicative outline of a flood extent, but the associated probability threshold is not known (such as a groundwater flooding map). The accepted format in MAST is standard ESRI polygon shapefile format. MAST can work with polygons containing bow ties, holes/islands, or multi-part polygons.

The user is only required to specify one flood outline for a particular source. MAST will then include the input data in the final output; however, input data will not be included in the calculation of combined probability values. Instead, it will appear as a separate output category so it can be seen if an output cell is inside or outside the risk area for flooding from the specified source.

Example sources include post-processed outputs from model results or a historic flood map.

3 How to use the software

3.1 Introduction

This chapter explains the operation of the MAST software, providing descriptions of:

- The inputs needed to set up and run a simulation.
- Simulation settings.
- Menus and other features that the user can adjust.

3.2 How to install the software

The prototype software does not use a full installation program and some manual configuration is required. The CD containing the software will have a folder named "MAST". The folder (and all its contents) needs to be copied to the root of the C: drive (**note – this folder name must be used for the example project to run seamlessly).**

There should now be two main folders:

C:\MAST\Program: this folder contains all the files required for the MAST software.

C:\MAST\Example: this folder contains sample MAST model files.

The software also requires the following third-party components to be installed on the target machine:

1. Microsoft .NET 2.0 redistributable software that .NET programs require. In many cases this will be installed on the PC already. If not, it can be downloaded from:

http://www.microsoft.com/downloads/details.aspx?familyid=0856EACB-4362-4B0D-8EDD-AAB15C5E04F5&displaylang=en

(On the MAST CD it can also be obtained from the "Supporting Files\dotNet" folder.)

To check whether the .NET 2.0 framework is installed check under "Add and Remove Programs" (or "Programs and Features" in Vista) in the control panel. If there is an entry for Microsoft .NET Framework 2.0, then it is installed.

2. Java Runtime 1.6 (update 20 or higher) engine installer. Again, in many cases this will already be installed on the PC. If not, it can be downloaded from:

http://javadl.sun.com/webapps/download/AutoDL?BundleId=39494

(On the MAST CD it can also be obtained from the "Supporting Files\Java Runtime" folder.)

To check whether the Java Runtime is installed, click 'Start, Run'. Enter "cmd" and press return. Type (without the quotes) "java-version". If there is an unrecognised command message or the version reported is less than 1.6, then the Java Runtime is not yet installed.

3. Mapwindow GIS control which MAST uses to load and view the results. It can be downloaded from:

http://www.mapwindow.org/download.php?show_details=2 and is named "MapWinGIS47SRa-x86-Setup.exe" (the first in the list).

(On the MAST CD it can also be obtained from the "Supporting Files\MapWindow" folder.)

The software is designed to run on computers running Windows2000/XP/Vista with hardware appropriate for technical computing (such as Intel Pentium D or upwards, at least 1GB of RAM, graphics card and sufficient free hard disk space for the size of data files that will be processed).

3.3 How to get started

Once the software has been successfully installed, the user launches the application by locating the MAST program file folder (usually C:\MAST\Program) and double-clicking on the MAST.exe executable file.

The interface will then be displayed. The interface consists of two tabs, entitled 'GIS View' and 'Project'. Upon start-up the project tab is initially active with default project data loaded (as a guide for defining the required information) as shown in the screenshot below:

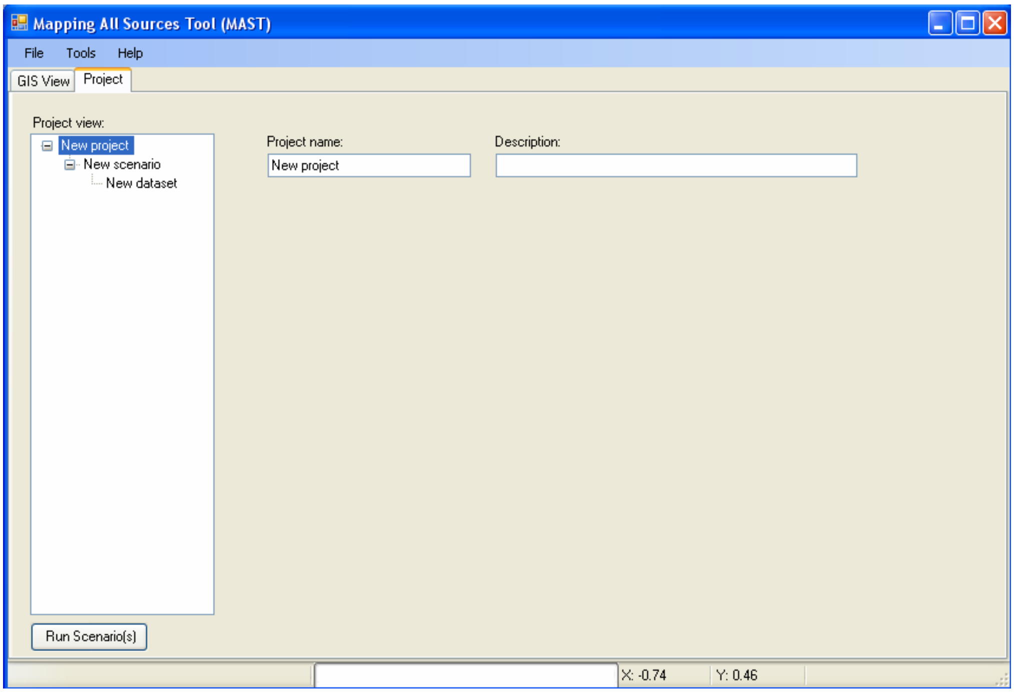


Figure 3-1 MAST start-up screen

Note: the prototype software includes a number of 'advanced options' (such as 'Extrapolation method' and 'Prioritise over composites sources'). These are identified by the use of grey text on the user interface. It is recommended that these options are kept at their default settings unless there is a strong reason to change them.

3.4 How to load input data

The GIS View tab provides a facility for loading and viewing GIS datasets. These could be input datasets containing flood data from individual sources or the combined probability output datasets produced by MAST. Clicking on this tab displays the viewer with the structure shown in the screenshot below:

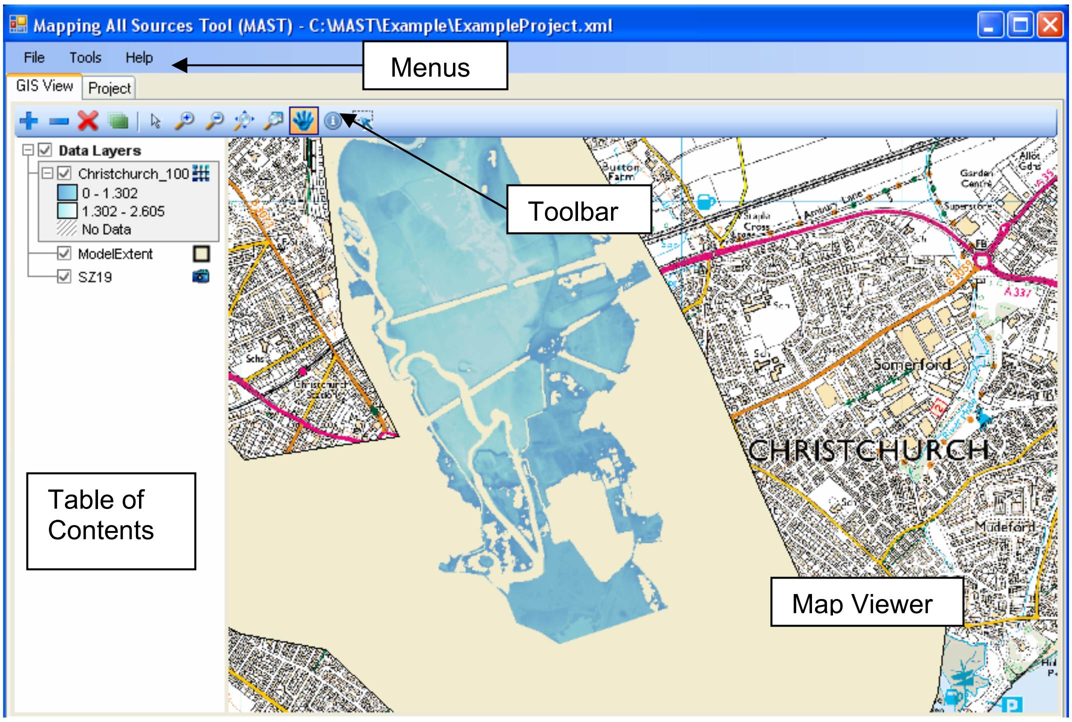
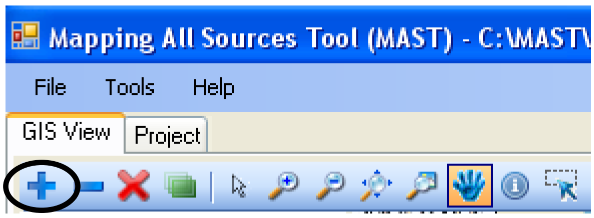


Figure 3-2 MAST GIS View screen

It is not necessary to pre-load any flood model grid or shapefile data into the viewer in order for it to be used in simulations. However, if data are pre-loaded this will provide the following advantages:

- Ability to explore the input dataset prior to the analysis.
- Ability to view extents of all input data and select a suitably sized boundary box to define the simulation area.
- Quick selection of datasets when defining input sources for simulation (as opposed to browsing to each file).

All compatible data, irrespective of the format, are loaded using the Load Data function. This is accessed from the toolbar by pressing the "+" button, as shown below:



The user is presented with a standard Windows Explorer browse window, which is set up to enable loading of the GIS file formats compatible with MAST, which are:

- ASCII raster grid with extension ‘.asc’ (ESRI version of ASCII text file format).
- Shapefile with extension ‘.shp’ (ESRI shapefile format).
- Jpeg image files with extension ‘jpg’.

Other GIS file formats may be loaded if the ‘All files’ option is selected in the Explorer window. However, these files will be for visualisation only as they will not be recognised by the MAST engine. Other supported image formats are: *.png, *.tif, *.bmp and *.gif.

To load the file into the GIS View, the user browses to the required file, highlights it and clicks the ‘Open’ button. Multiple files can be selected for loading at the same time by holding down the Ctrl or Shift keys while selecting files (files must be in the same folder).

Data may take a number of seconds to load. Loading speed depends on file size (very large files may take over a minute to load).

When the file has loaded, the data are displayed in the GIS View and the file name appears as a new data layer in the Table of Contents.

3.5 How to operate basic GIS controls

This section explains the various GIS controls of the GIS viewer within MAST.

These controls can be activated by the buttons on the Toolbar of the tool:

- Use  for panning and moving.
- Use  for zooming.
- Use  for adding and removing data layers from the GIS View.

Panning/Moving

The **Default Cursor** button  enables the default cursor mode in which the cursor looks like an arrow and it is possible to zoom in and out by using the middle button of the mouse. Scrolling the mouse wheel forwards zooms in to the layers loaded into the Table of Contents, scrolling the mouse wheel backwards zooms out.

In order to pan/move the layers, the Pan mode can be activated by clicking on the **Pan/Move** button . In this mode the mouse cursor will look like a hand. Pan the map by left mouse pressing anywhere on the map and then dragging the mouse in the intended direction.

Zooming

There are several buttons on the Zooming panel of the Toolbar, which allow the zooming operations described below.

Zoom In – There are two different ways of zooming in. After clicking on the 'Zoom In' button, the mouse cursor will start to look like a magnifying glass with a "+" in the middle, either:

- left-click on any point of the layer and the viewer will bring this point and the area around it closer.
- press on the left mouse button and while holding it draw a rectangle on the layers. After releasing the left mouse button, the viewer will zoom in to the area of the layers specified by the rectangle.

Zoom Out – Zoom out by left-clicking on any point of the visible part of the layers after clicking on the 'Zoom Out' button. When using this tool, the mouse cursor looks like a magnifying glass with a "-" in the middle.

Zoom to Full Extent- Displays the full extent of all layers currently loaded.

Creating a new MAST model extent

After loading all input datasets, MAST also requires the definition of a calculation boundary box. This defines the area in which combined probabilities will be calculated during a simulation. It can be predefined (by other GIS software) or – for rectangular boundary boxes only – it can be defined using functionality in the MAST GIS View.

The  control is used to generate a new rectangular shapefile. When this tool is activated the mouse pointer changes (to a pointing finger) to signify the drawing tool is active. To draw a new rectangle, click on the location of one corner of the required simulation extent and then drag the mouse with the left mouse button depressed. A rectangle with a dotted outline appears on the map view. When the mouse button is released the user is prompted to save the defined outline as a new shapefile, which is then added to the table of contents of the MAST GIS View.

External GIS tools (such as ArcGIS or MapInfo) can be used to create a boundary box of any polygon shape for use as a MAST model extent.

Viewing MAST output data for specific locations

The  control is used to load the results files generated after running one or more MAST scenarios. Results are created in a folder specified by the user and the GIS viewer will automatically load all results files located there.

After results have been loaded into the GIS View, the  control is used to display the details of results at specific locations (where the mouse button is pressed). When activated, this function changes the mouse pointer on screen to a letter 'i' symbol. For more information about viewing MAST output result, please refer to Section 3.12 showing results in the GIS View

3.6 How to define a new project

In order to define any analysis using MAST the user must first define a project:

- For a new project - select 'New Project' from the File menu.

- To reload a previously defined project - select ‘Open Project’ from the File menu of the GIS View. A standard Windows Explorer browse window is displayed allowing the user to select the required project file. The project file is an xml format file.

After a project file is selected, the project interface is displayed in a separate tab within the main MAST interface. The user can switch back to the GIS View at any time by selecting the GIS View tab.

If an existing project is loaded, the associated scenarios defined within the project are displayed in the ‘tree view’ on the left side of the window. The tree view is a hierarchical list which consists of three levels: project, scenario and flood source dataset. As the user selects items within the list, the right side of the interface is populated with the metadata associated with the selected level.

Project and scenario tree view entries can be expanded to display the underlying branches of data, for example to view the sources of flooding assigned to each scenario.

If the user specifies a new blank project, the tree view will be automatically populated with a single blank scenario (called ‘new scenario’), which in turn will be populated with a single dataset (which will hold a source of flooding). The user can then start editing these to define their simulation.

An example is shown below with a new blank project loaded.

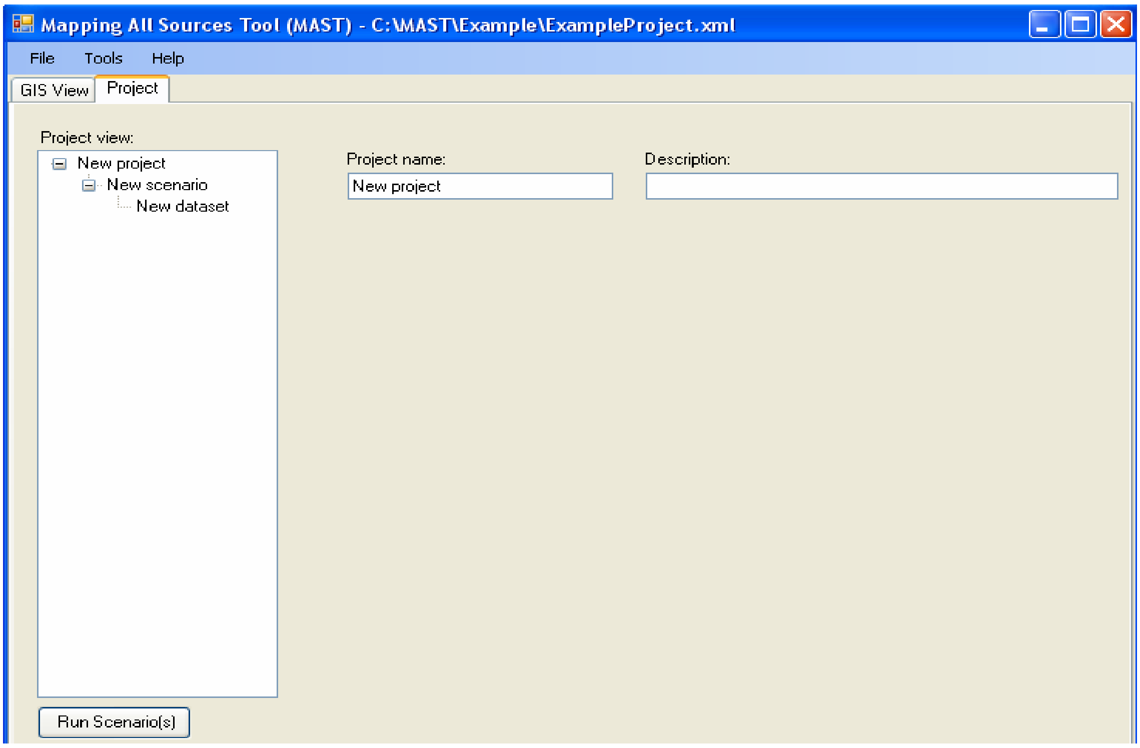


Figure 3-3 Define a MAST project

The user is initially prompted to provide a project name together with a description that can be used to reference the associated analysis.

The only other feature on the project display is a button located at the bottom of the window, below the project tree view. This is the ‘Run Scenario(s)’ button, which is used to start a simulation once the required scenarios are defined and populated with source data.

3.7 How to check source types available in MAST

When specifying a dataset for a scenario, the user is required to assign to it a specific 'source type'. This is the source of flooding associated with the input datasets, for example fluvial, coastal and so on. MAST stores a list of possible sources of flooding, which the user must select from when specifying a new dataset. Therefore, prior to defining a new simulation the user should check that the list of available source types meets their requirements.

All specified source types must relate to individual sources of flooding and not to a combination of multiple sources of flooding, for example the combined effect of fluvial and coastal flooding. If the user has model data that is derived from such combined sources of flooding, these data can still be used in MAST. Combined sources are defined in MAST as a combination of their components, for example tidal flood datasets would be defined as a combination of fluvial and coastal source types. Thus, it is not necessary to predefine combined source types.

To review currently available source types: select the Tools | Options item in the main menu. The Program Options window is then displayed as shown in the figure below.

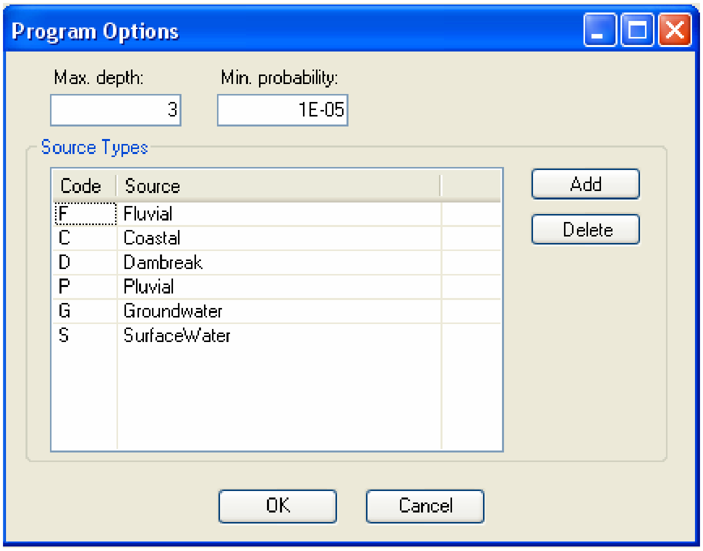


Figure 3-4 MAST data source types

The list shown displays the currently defined source types. To add a new source, click the 'Add' button. A new row is added to the list and the user is prompted to provide a source type name and a single unique code letter that will be used to represent this source type in each MAST project file (xml format) that uses this source type within a scenario.

A delete button is also provided alongside the source type list. Clicking this button will remove the highlighted source type from the list.

Two other program settings can be defined in the options window. These are:

- Maximum depth – this is the maximum flood depth that the MAST engine will write to the results file. If the calculation engine extrapolates a value greater than this from the input data, it will be capped at the value provided here. The default setting for maximum depth is three metres.

- Minimum probability – this is the minimum probability of flooding that the MAST engine will write to the results file. If the calculation engine extrapolates a value less than this from the input data, it will be capped at the value provided here. The default setting for minimum probability is 1 x 10^{-5}, that is, a one in 100,000 chance of occurring in any given year.

These cap settings prevent results from including values that are significantly outside the range of the input data, as by definition, these values would have a high uncertainty associated with them.

3.8 How to define new scenarios within a project

A new simulation is defined by one or more scenarios (which can be created from scratch or by editing an existing scenario). To add a new scenario to a project, right-click on the project name in the project tree view and select 'Add Scenario' from the displayed menu.

The display to the right of the project tree view will change to show the scenario definition window, as shown in the example below. In the tree view a new blank scenario will be added (initially called 'new scenario'), and a single blank source will be added to the scenario (initially called 'new dataset').

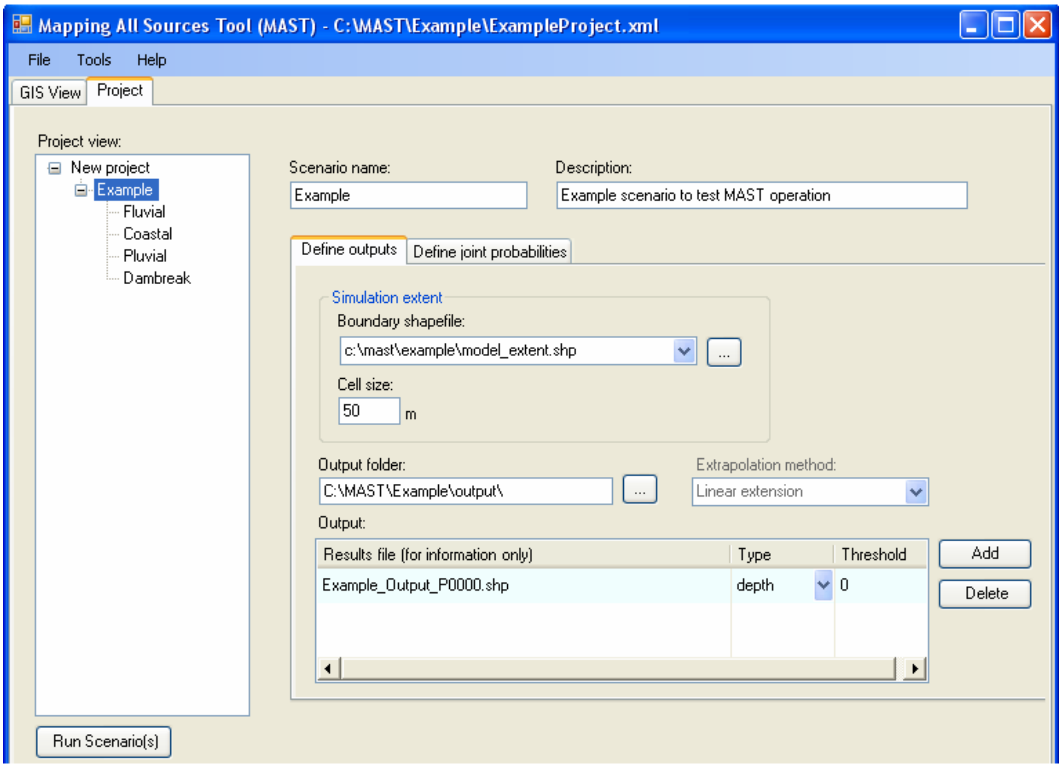


Figure 3-5 Define a new scenario in a project

The display consists of three distinct sections for the user to complete:

- Basic metadata – provide a scenario name and a brief description of the simulation it will represent in the textboxes provided at the top of the window.
- Define outputs tab – specify the extent of the MAST analysis and define the outputs to be produced from the current scenario.
- Define joint probabilities tab – define dependencies that exist between the individual sources present within the scenario.

At this stage it is only necessary to complete the scenario metadata. The definition of outputs and joint probability relationships are required when defining new simulation runs and are described in detail in the simulation definition section of this user guide.

Cell size: the minimum cell size is the minimum cell size of all input data layers.

3.9 Assigning datasets to the scenario

After defining a new scenario, it must be populated with the relevant input datasets that are to be used in the scenario simulation.

To define a new dataset within a scenario, right-click on the scenario name in the Project tree view and select ‘Add Dataset’ from the displayed menu. Alternatively, an existing dataset can be edited by highlighting it in the Project tree view. The dataset definition window is then displayed to the right of the tree view, as shown in the example below.

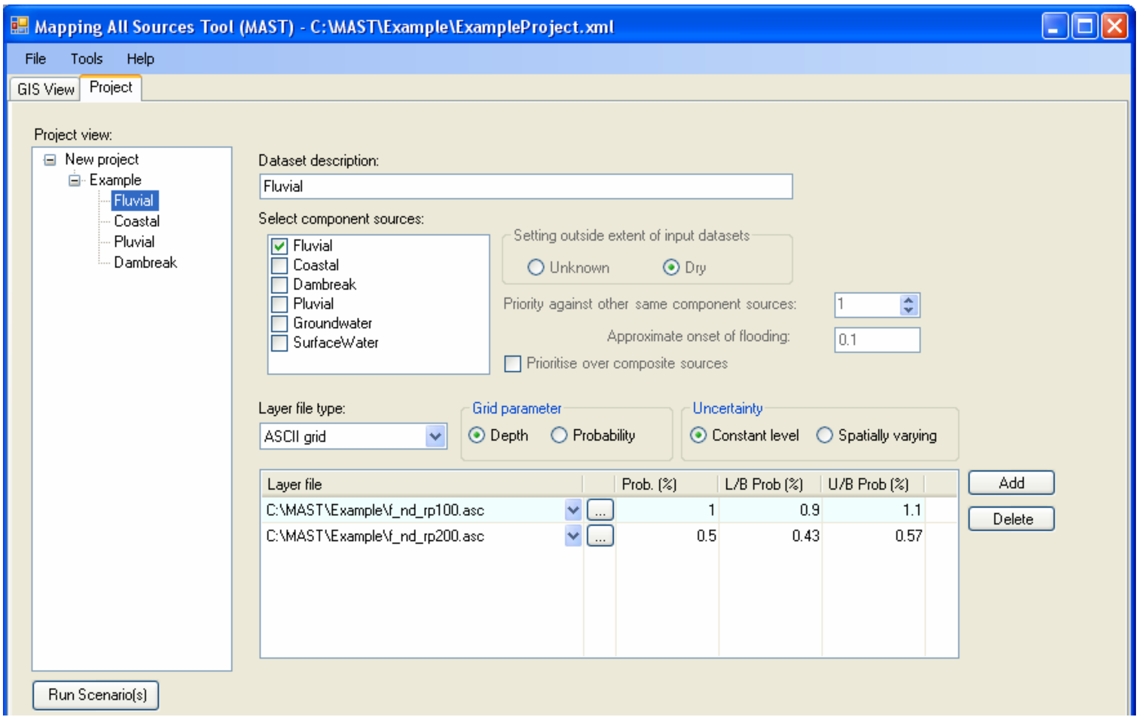


Figure 3-6 Assign datasets to the scenario

3.9.1 How to specify source independent setting

To fully define a new dataset the user must provide the following information:

- **Dataset description** – optional. The user can enter suitable text to further describe the dataset (beyond the assigned type) in the textbox provided.

- **Select component sources** – a table of component source types (as detailed in the general program options, see Section 3.7) is displayed. Alongside each component source type is a checkbox to enable the user to select a type. For composite sources the user should select two types (or more if required) from the list (for example, for tidal/estuary datasets select both fluvial and coastal).

- **Layer file type** – the user must specify the file type for all associated layers from the following options:

    - Shapefile with no associated probability data, such as flood extent outline. Only one layer of this type is required to define a dataset.

    - Shapefile with associated probability, such as flood extent outline with specified probability. At least two layers of this type must be specified to define a dataset.

    - ASCII grid. At least two layers of this type must be specified to define a dataset.

  In the MAST calculations, layers with associated probabilities are used to define depth versus probability curves. Therefore, a minimum of two layers of this type must be specified to define a valid dataset. However, we recommend specifying a larger number as low numbers of layers will lead to greater uncertainty in values interpolated from the defined curve. Furthermore, there is a higher likelihood for the need to extrapolate values from the curve, which would have even greater uncertainty associated with them.

  Once specified, all layers assigned to this source must be of this type. Do not use mixed results from different models: for example, for a river model with defences or without defences the flood map extents would be very different; these two types of model results can not be mixed in the MAST model's data layer input.

- **Grid parameter** – if the data are ASCII grids the user must specify whether the grid parameter is depths for a specified probability or probability values for a specified depth threshold. Once specified, all layers assigned to this dataset must be of this type. This setting is disabled for shapefile data files as it is not applicable.

- **Layer files** – a table is provided for the user to define the layer data files associated with the dataset. Each file appears on a new row. To add a new file:'

    - Click on the 'Add' button. The user is prompted to browse to their file and when selected, it is entered as a new row in the table.

    - Existing layer file names can be edited manually by typing into the relevant field in the table (double-click on the field to select it).

    - A delete button is provided to remove layer data rows.

    - The user is required to enter corresponding uncertainty data for each specified file. This is described in the next section of this guide.

- **Approximate onset of flooding** – This option limits the values calculated by the MAST engine to 'realistic' figures. Because of the lack of available data and without setting an approximate onset of flooding, areas which may not flood or flood to a much lower probability might be calculated with unrealistically high probabilities of flooding. An approximate onset of flooding probability will reset these calculated figures to the value set. This helps to counteract results that can occur from extrapolating a depth-probability curve. The value in the 'approximate onset of flooding' option needs to be entered as a decimal (where 0.1 represents a one in 10 chance of occurring in any year) which is applied to the whole study area for a particular source of flooding. Suggested values to use are the 'standard of protection' from NFCDD (National Flood and Coastal Defence Database) for a local defence or the design capacity of a drainage system for surface flood water. (Advanced option - can be left at the default value in the absence of evidence).

- **Setting outside extent of input datasets** – This defines what happens in areas outside the dataset region that are still inside the user defined analysis boundary box (typically applies to small local model datasets). The MAST engine needs to be instructed whether the area outside the input extent should be considered as dry or unknown probability from the corresponding source. The recommended procedure for a local detailed model overlain on a less detailed but larger scale model is as follows:

    - The local model source should be set with higher priority to ensure it takes precedence over the less detailed large-scale model.

    - The region outside the extent of the local model (but still within the simulated area) should be set as unknown to enable the engine to use the larger scale model results where no local data exist.

  (Advanced option – leave at default 'dry' option if no other evidence exists.)

- **Priority against other 'same component' sources** – When two sources of the same type exist at same location, only the one with the higher priority will be used (1 = highest priority) as this is deemed the most accurate data; for example, a local fluvial model (of priority 1) should be more accurate that a NaFRA national dataset (of priority 2). (Advanced option – usually can be left at the default value.)

- **Prioritise over composite sources checkbox** – When data from a single source and a composite source that contains the single source are available at the same location, MAST will automatically ignore the single source data in favour of the composite data, for example tidal (estuary) data will be used ahead of fluvial or coastal data. This can be overridden so that the single source will be used and the composite source ignored, by ticking the overriding tick-box to true. (Advanced option – usually leave at the default non-ticked state.)

3.9.2 How to specify uncertainty data

Uncertainty data are entered in MAST in the table of layer files defined for each dataset type. Thus, each specified layer has its own uncertainty levels defined separately. However, for a particular dataset all defined probability layers must use the same type of uncertainty specification: all constant (uniform) or all spatially varying.

Buttons are provided above the table of layer files allowing the user to choose either constant levels of uncertainty or spatially varying uncertainty. The latter option is only available for data defined by ASCII grids, thus the former option is the default setting.

When the user changes the uncertainty type from constant to spatially varying, the format of the layer files table automatically changes. The fixed value columns for upper and lower bounds are replaced by fields to hold filenames for the upper and lower bound grid files together with browse buttons to enable the user to specify these files.

Constant uncertainty

Uncertainty can be set as a spatially constant value for all cells of an input grid. Fields are provided in the layer definition table for the user to specify uncertainty values for each specified layer. Values are entered by using one of the following options:

- User-fixed uncertainty level – these can be low, medium or high and correspond to fixed percentage increases (for upper bound) and decreases (for lower bound) to the specified probability value. These options are accessed from a menu displayed when right-clicking on the relevant row in the layer definition table. The uncertainty cells will automatically be populated with values calculated based on the selected percentage change and the user specified probability value.

- User-entered uncertainty – select the uncertainty cell by double clicking on it. A cursor will then appear in the cell ready for the user to type in a value. This will be a discrete probability or depth value depending on the input data type.

The degrees of percentage change corresponding to low, medium and high levels built into MAST are fixed (cannot be edited by the user). These default options are provided for cases where the user does not know the uncertainty associated with a layer.

Example data and input entry: For an input data layer representing 'best estimate' flood depths with a one per cent chance of occurring in any year, reasonable upper and lower bound probabilities for this layer may be 1.1 and 0.9 per cent.

Layer file		Prob. (%)	L/B Prob (%)	U/B Prob (%)
C:\MAST\Example\f_nd_rp100.asc	...	1	0.9	1.1
C:\MAST\Example\f_nd_rp200.asc	...	0.5	0.43	0.57

Due to limitations in the MAST engine, the tool will only accept probability values and associated uncertainty lower/upper bound values specified to three decimal places. If data are entered to greater precision than this the tool will automatically round values within the calculation process, so if the user inputs an upper or lower bound value of 0.0433, this number will be truncated as 0.043.

Spatially varied uncertainty

For input data defined by ASCII grid data, the associated upper and lower bounds of uncertainty can also be defined by separate ASCII grids. This enables uncertainty data to vary spatially.

In these cases the analysis engine will compare output grid cells to user-specified grids that detail uncertainty to calculate the local uncertainty values for each output cell.

The ‘spatially varying’ setting should be ticked in order for the user to define spatially varying uncertainty data. The layer definition table then changes to prompt the user to provide an upper bound and lower bound uncertainty data file. Some of the uncertainty that could be captured by these grids includes:

1. Probability grids for a certain depth threshold.
    - The normal output from probabilistic modelling would generate upper/lower estimate outputs.
    - Where defence failure is considered in the modelling (such as NaFRA), different estimates for the same depth threshold could be generated considering, for example, lower and upper estimates of the defence failure probability for given loading.
2. Depth grid for a certain flood probability.
    - Hydrological analysis generates different estimates of the boundary conditions for hydraulic model, resulting in different depth grids.
    - The uncertainty could be associated with different climate change probabilities.

3.10 How to define new simulation runs

When all data associated with a scenario have been specified, the user should return to the scenario definition display to specify the analysis simulation to be run.

Return to the scenario definition display by selecting the appropriate scenario in the project tree view. The interface display will appear as shown in the figure below.

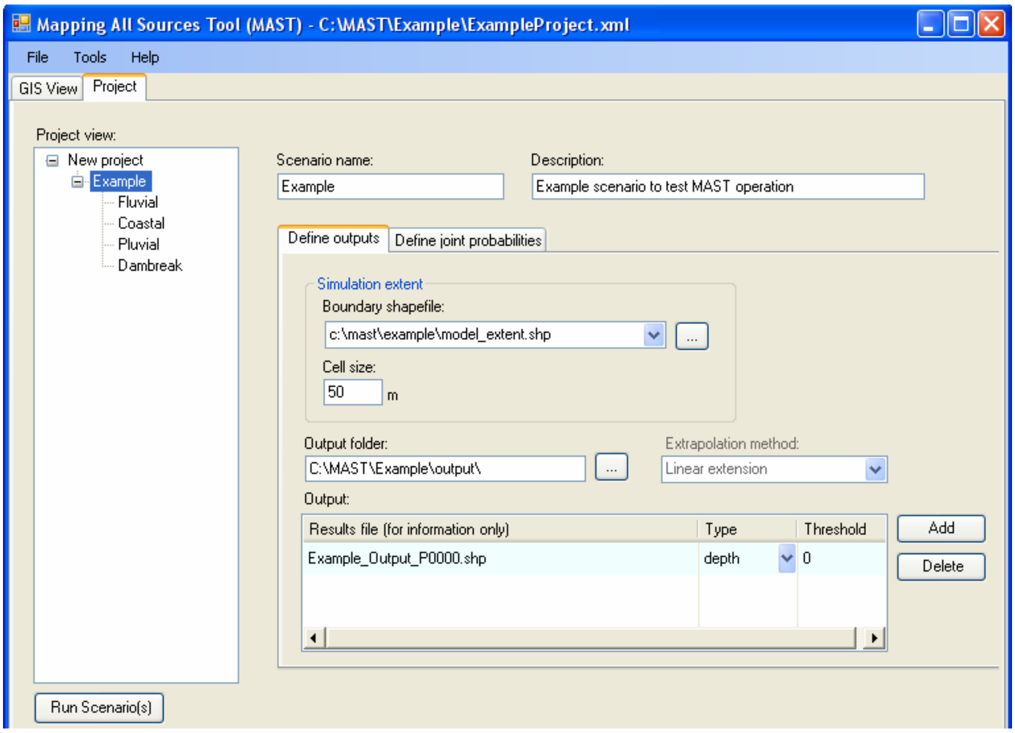


Figure 3-7 Define new simulation runs

The output definition is divided between two tabs on the display. These are the 'Define outputs' tab and the 'Define joint probabilities' tab.

On the 'Define outputs' tab the following settings must be defined by the user:

1. Boundary shapefile – this is the extent of the simulation as defined by a polygon shapefile. If this has been defined in the GIS View (and is still loaded) then it can be selected from the dropdown box. Alternatively, the user can browse to a suitable shapefile using the adjacent browse button.

2. Output cell size – the boundary shapefile extent is used to create the output 'grid' shapefile using the user-specified cell size. The minimum cell size should be the minimum cell size of all input data layers. If the model cell size is smaller than the smallest cell size of all input data layers, longer simulation run times will be required without achieving more accurate results.

3. Output folder - MAST will automatically select a name for the calculated output shapefile(s), but the user is prompted to define a folder for these data to be written to. This can be typed directly into the available textbox. Alternatively the adjacent browse button can be used to specify the required folder. See Appendix B for more details on format and naming of the output files.

4. Extrapolation method – this applies to data falling outside the interpolative range of input data. The options are:

   - Linear extension – best estimate calculation method uses extrapolation of the defined probability depth curve.

   - Average of U/B and L/B – averaging method simply calculates an average of upper bound and lower bound uncertainty values and uses this for all instances outside the interpolative range.

Advanced option - it is not advisable to change the default calculation method (Linear extension) without expert knowledge.

5. Outputs – a table is provided for the user to enter the output requirements and thresholds to be used in the simulation. One or multiple outputs can be defined for a single scenario. These can be depth threshold (output will be combined probability grid) or probability threshold (output will be a depth grid for combined probability). 'Add' and 'Delete' buttons are provided to add and remove rows.

   Table editing – select the required output type from the dropdown box and type the corresponding threshold value into adjacent field.

   - Example 1: if the defined output has a depth threshold of 0.0 m, the output shapefile will be the combined probability of flooding depth at 0.0 m or above at each computational cell.
   - Example 2: if the defined output has a probability threshold of 0.5, the output shapefile will be the combined flooding depth with a one in two chance of occurring in any year for each computational cell.

On the 'Define joint probabilities' tab the user can define dependency measures that exist between the individual sources defined for the analysis. Note that this will not change the calculated combined probability data. Instead, it will add extra fields to the output shapefile (one for each defined joint probability) in which the level of dependency between the probability pairs will be estimated (level 1, 2 or 3 – see Appendix B for details). By default, if the user defines any joint probabilities for a scenario these will automatically be included in the simulation output. This tab is shown in the example below.

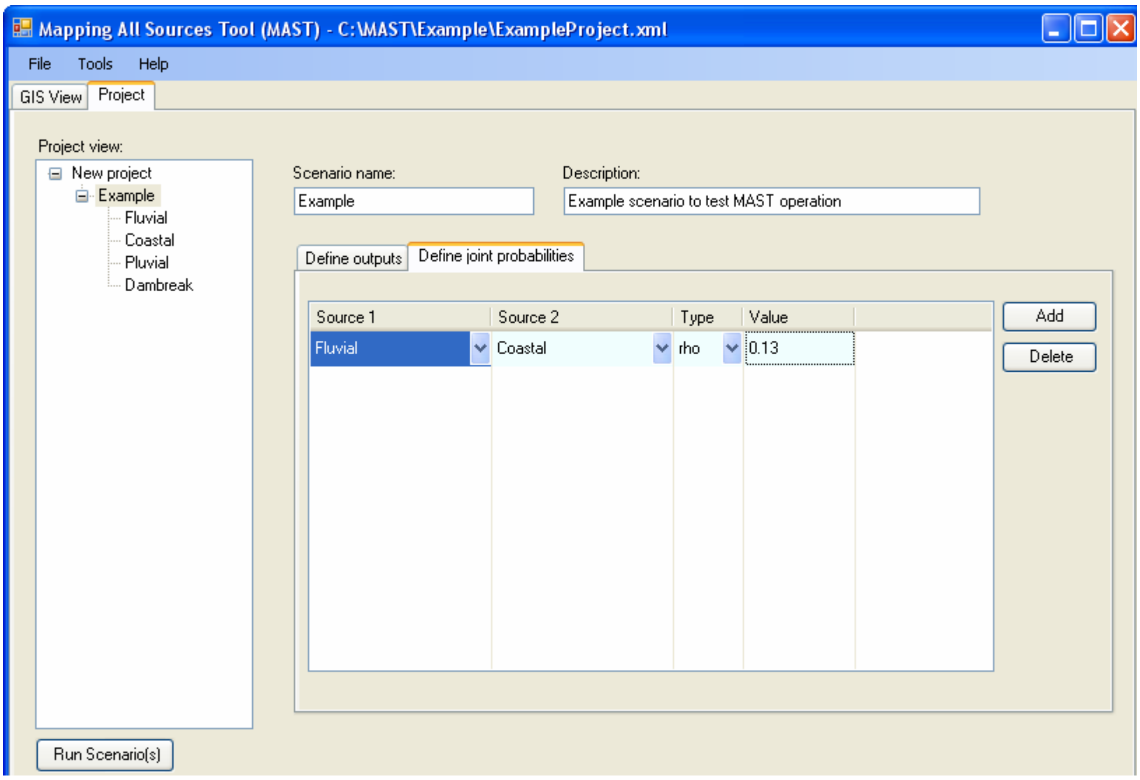


Figure 3-8 Define joint probabilities

A table is presented for the user to specify pairs of linked sources as follows:

- The user clicks the ‘Add’ button to add a new row to the table.
- Select Source 1 and 2 from dropdown lists of sources located next to each field in the table (all defined source types from the MAST settings are listed). The user should only select component sources associated with the current scenario (note that joint probability relationships are not applicable to composite sources).
- Select the joint probability type from the dropdown combo box. Available options are ‘rho’ and ‘chi’ (see Chapter 5 for definitions).
- Specify the parameter value, between zero and one, to be used in the joint probability calculation (see Chapter 5 for details).
- A ‘Delete’ function is provided to remove unwanted joint probability definitions.

Note that the user must first define the sources within the new scenario before returning to this window to define joint probability relationships.

To start the main MAST calculations, click the ‘Run Scenario’ button (located below the Project tree view) to start the MAST calculation engine. The user is prompted in a new window to select which of the defined scenarios to include in the subsequent simulation. An example is shown in the figure 3.9 below. Click the ‘OK’ button to begin calculations. A ‘Cancel’ button is also provided to enable the user to abort the simulation.

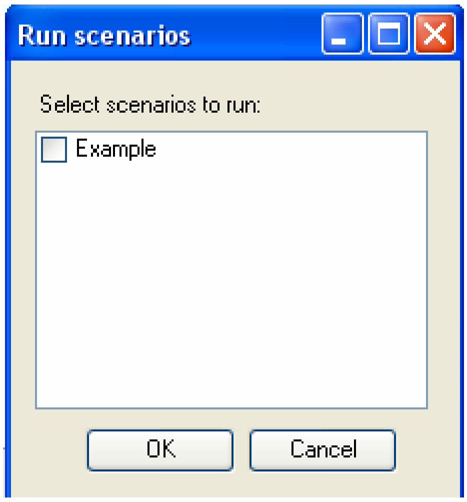


Figure 3.9: Run Scenario Example

The simulation engine may take some time to complete all simulations (run time will depend on the extent and resolution of datasets used in the analysis). A progress bar is provided by MAST to signify progress through the calculations.

After the user clicks the ’OK’ button, the MAST interface will do some simple validation process to check that:

- there are no empty scenarios defined in the simulation;
- flooding data layer files are correctly specified;

- input fields are correctly specified;
- there are no mistakes in the MAST project xml file.

3.11 Steps within the MAST simulation process

The processes within a MAST simulation are outlined as follows:

- Check input data are correctly specified – a series of checks are performed and if any anomalies or errors are identified the calculation process is aborted and the error is reported to the user. Examples of errors are:
    - Scenario contains joint probability definitions that include data that are not part of the scenario.
    - Only one dataset specified for data type ASCII grid or shapefile with probability value.
- Create input files for calculation engine – the project data defined for the simulation are converted to the following standard files required by the MAST calculation engine:
    - Input shapefile(s) – a 'grid' shapefile is created with the extent of the input boundary shapefile and the resolution as specified by the user. The associated dbf file contains all required data disaggregated to provide equivalent values for each grid cell (as some input datasets may be a different resolution to that specified for output).
    - Project xml file – the project xml file holds all data that defines the user's project: all scenarios and associated source data. Furthermore, the xml file contains the definitions of all field names in the input (and output) shapefile dbf file (field size limits for dbf files mean code names must be used).
- Engine validates input files – a separate calculation is performed for each grid cell (each row of the input shapefile). Examples of errors are:
    - Probability threshold values are specified incorrectly, for example probability values of less than zero or bigger than one.
    - Input shapefile does not match the parameters specified in the xml project file.
- Perform all calculations – calculation is performed for each grid cell (each row of the input shapefile).
- Generate output shapefile(s) – combined probabilities and associated data (individual sources of flooding included in the combined value, any sources of flooding present with unknown probabilities, and any defined joint probabilities) are written to each output grid cell. This is repeated for each scenario within the simulation.
- Create simulation log file – a separate log file for each scenario is generated to hold summary statistics of the overall analysis extent, for example

percentage of grid cells in which each input source type is dominant in the combined output.

The following steps define the detailed sequence of processes of a MAST simulation (readers may wish to skip this technical description of the internal processing):

1. The user is prompted to save their current project – a standard Windows browser window is displayed with a 'Save As' button.

2. The MAST project file is an xml format file divided into three distinct sections:

   - Project definition – contains all scenarios and assigned source datasets together with associated settings to enable simulations to be recreated.

   - MAST default settings – contains inbuilt settings used by MAST to cross reference data in the project file and simulation input and output shapefiles (such as abbreviations to use for shapefile dbf attribute headings).

   - GIS View settings – stores the list of GIS datasets loaded into the GIS View during the current MAST session. All layers will then be re-loaded if the project is re-opened later.

3. MAST checks inputs and formats and ensures all required user-defined settings have been made.

4. For each scenario, MAST creates an input grid (polygon) shapefile to hold all specified source data. This is created from the combination of the user-specified boundary box (for input shapefile extent) and the user-specified grid cell size. If the cell size does not create an exact number of whole cells within the boundary box, MAST will slightly extend the boundary dimensions accordingly. Each input shapefile takes the same name as the scenario and is saved into the project folder (as specified by the user in the project xml file – see Point 1).

5. For each scenario input shapefile there will be an associated dbf file in which each row represents the properties of a single grid cell within the simulation extent. The dbf file will be defined with attributes to represent for each source input: the specified value, the upper bound uncertainty value and the lower bound uncertainty value. In addition, each source type and other source properties will be stored in the project xml file (with cross-referencing information to the related attribute columns in the dbf files). The format of the input shapefile and associated dbf file is provided in Appendix A.

6. MAST considers each grid cell and calculates values from each source input dataset at the centre point of the input cell. This is done using a proximity function within the GIS component of MAST. These data are written to the appropriate attribute columns of each input shapefile. The process is repeated for upper and lower bound uncertainty if these data are specified by a GIS dataset (spatially varying).

7. Once all input shapefiles are generated (for all active scenarios) these data are passed to the MAST main calculation engine.

8. The calculation engine considers each row of each input shapefile separately, that is, each grid cell separately. For each input source it calculates a depth probability curve (where applicable, see Point 9 below). All defined curves are

then added together to produce a combined probability value or combined depth value (depending on required threshold outputs).

9. For sources with no probability data specified, the input shapefile will have identified if a grid cell is inside or outside a risk area. The calculation engine simply passes these data through as a separate output to the calculated combined value.
10. For each threshold of each scenario the calculation engine creates a separate output grid (polygon) shapefile. This has the same grid pattern as the input shapefile. The associated dbf file will be defined with separate attributes to hold the following information:
    - Combined probability or depth value (depends on threshold).
    - Percentage contribution (to the combined value) of each input source.
    - Additional input sources which had no probability data specified for the grid cell location – displayed as at risk/not at risk.
    - Joint probability dependency levels for each joint probability relationship defined as an input.

    The format of the output shapefile and associated dbf file is provided in Appendix B.
11. The calculation engine also creates a simulation log file for each threshold of each scenario. This holds summary statistics for the simulation extent as a whole. The output data are percentage areas where each individual input source made the dominant contribution to the combined value.

3.12 Showing results in the GIS View

At the end of a MAST simulation, the results generated will be automatically loaded into the MAST GIS View. The MAST GIS View is a very simple data viewer with limited functionality intended as an interim solution; many users will prefer to use ArcMap or similar to view the results. The MAST GIS View has the following options for customising the displaying of results.

Results Information tool – This is activated by clicking on the information tool icon, , in the toolbar. Once the tool is active, the user clicks on a location on the map view to display data at the click location associated with the selected results. A new window is displayed which contains a table of values from the selected location (attribute values from the results shapefile). A pie chart is also displayed which represents the relative contributions of each source of flooding to the calculated combined value. The user can choose to view results corresponding to the best estimate calculation (B/E) or the upper and lower uncertainty levels. Furthermore, if multiple scenarios were run for a simulation, the user can select from the top of the information window which scenario results to show. To view data from a different location, just click on the map view again at the required new location. The tool will remain active until the user clicks a second time on the results information tool icon in the toolbar.

Note: users need to have the project file loaded in order to use the result info tool.

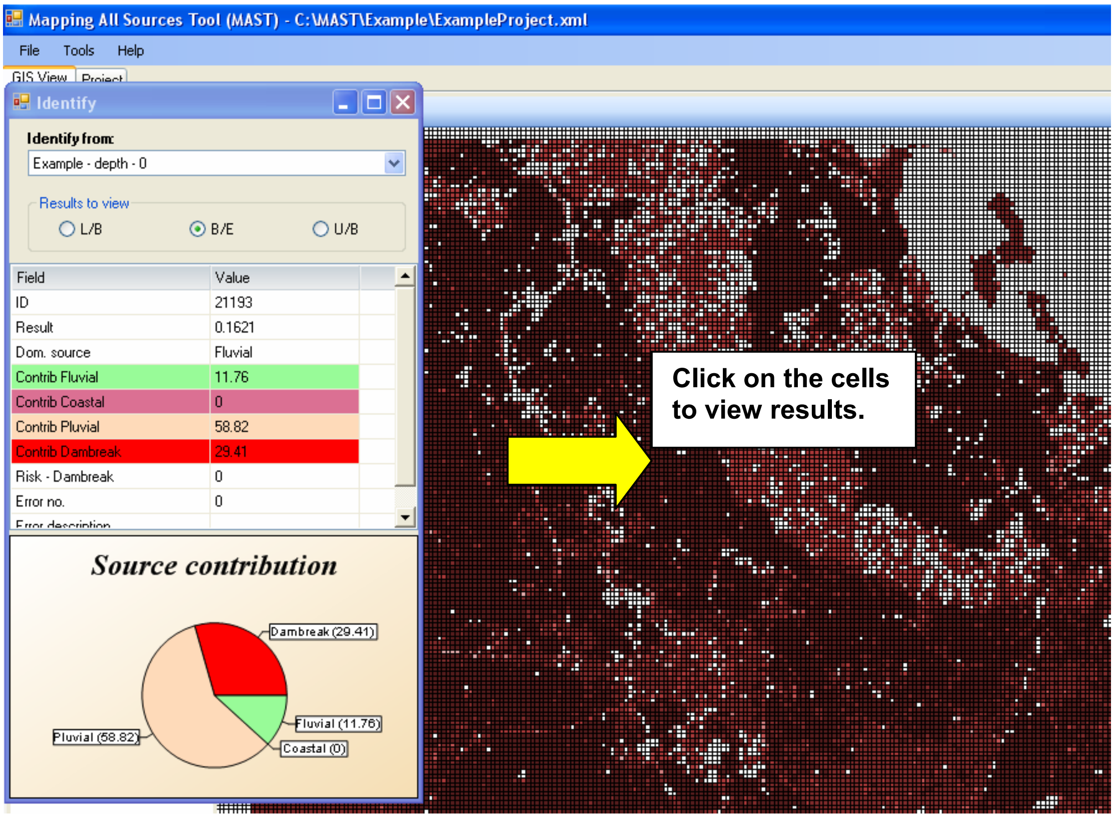


Figure 3-10 MAST info tool for viewing cell result

Colour legend – the user can customise the colour legend of an output by right-clicking on the appropriate layer in the Table of Contents and selecting the appropriate menu item.

1. Highlight result file in the Table of Contents of the GIS View.
2. Click the right mouse button and select 'Set Colour Theme'. The colour theme window will be displayed as shown below.
3. Select 'B/E Results' (best estimate) from the 'Attribute Field' dropdown list.
4. Select 'Probability' in the Theme dropdown box.
5. Click 'Apply' to activate these settings and then close to shutdown the colour theme window.

Users can produce a range of output maps including probabilities of best estimate, upper bound, and lower bound, contribution of certain flood source, depth grid at certain probability, and so on.

The following figure shows an example map output for the probability grid with predefined colour scheme.

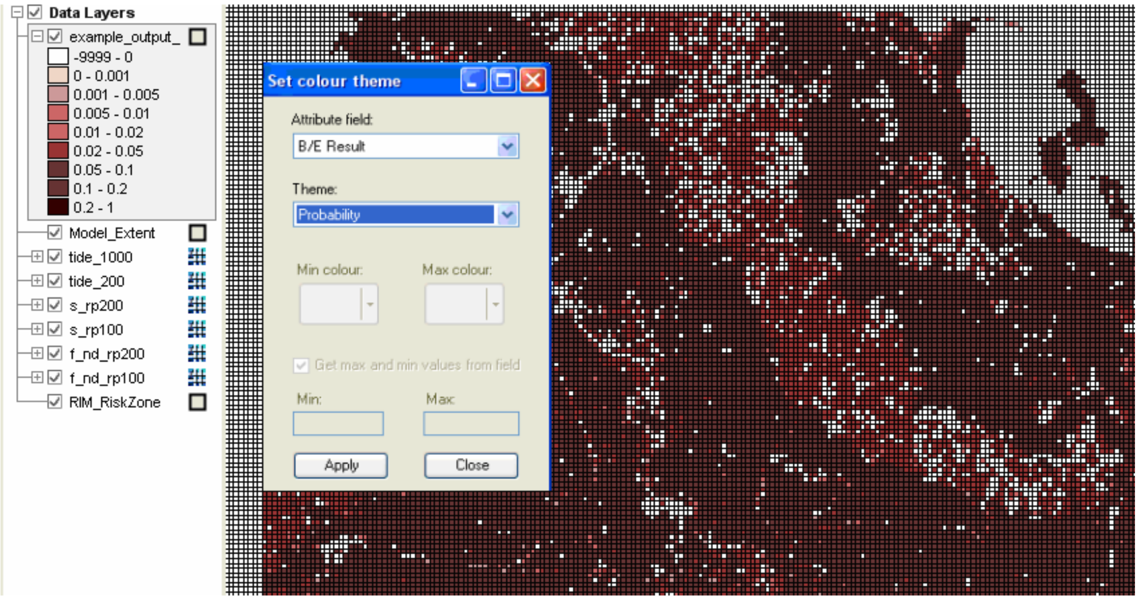


Figure 3-11 Set up a colour scheme for MAST output shapefile.

In addition, users have two options for exporting results out of the MAST software:

- Users can save the output shapefiles to a user-specified location and post process the output using other GIS software, such as ArcMap.
- Users can record a snapshot of the current view within the GIS View. This is saved to a standard image format.

The following figure shows the output shapefile attributes types and descriptions. For more information about the output file format, see Appendix B.

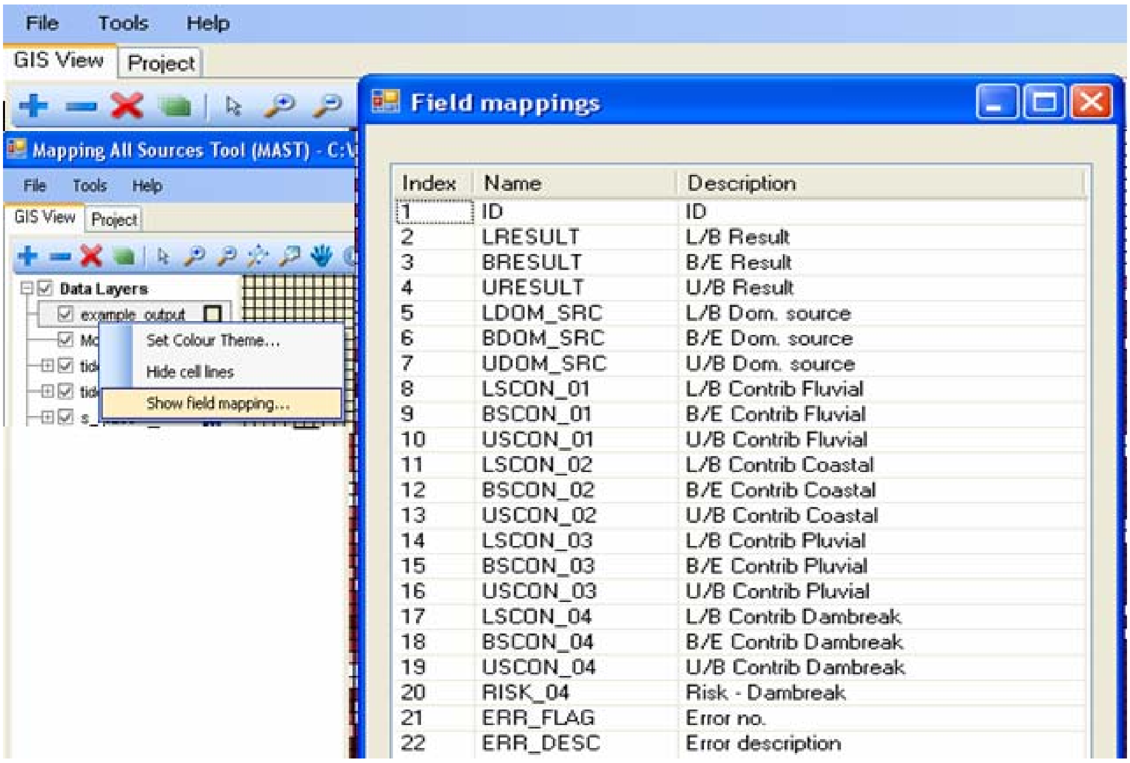


Figure 3-12 Output shapefile attributes and descriptions

Simulation log files - during simulations the MAST engine will generate two log files: engine log and summary log as text files. The engine log file name is generated as model name + "_full_" + date time string + ".log". The summary log file name is generated as model name + "_summary _" + date time string + ".log". The files are located in the main project data folder and can be viewed using a standard text viewer such as notepad. The following figure shows an example the summary log file.

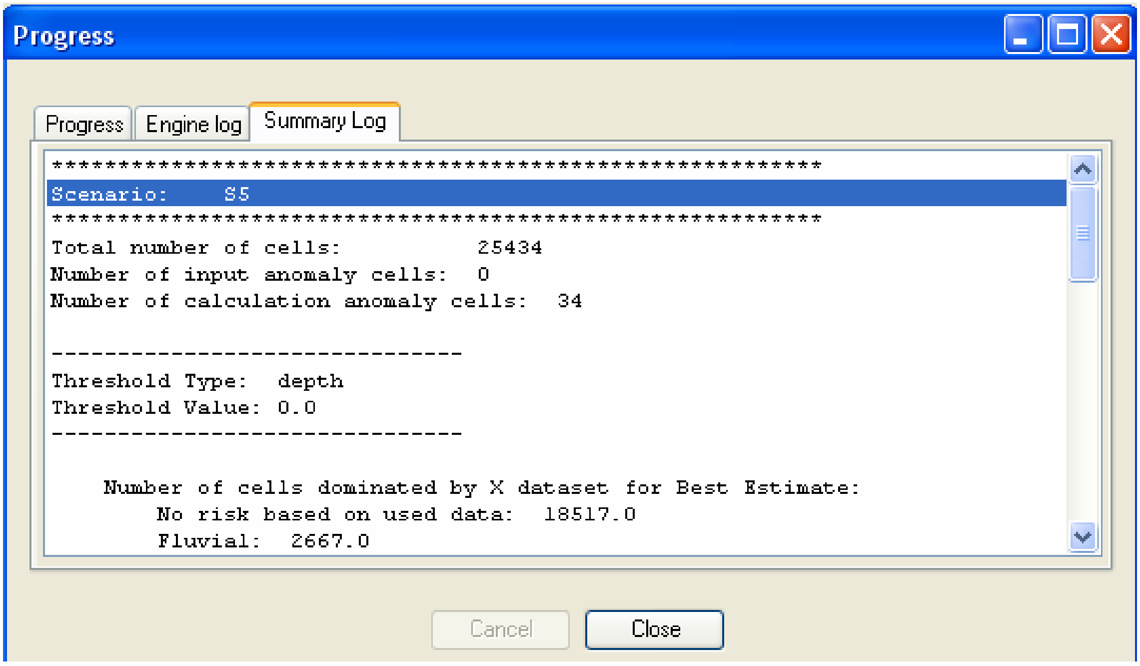


Figure 3-13 View of summary log information after simulation finishes

3.13 Using MAST to asses the impact of asset failure

MAST can be used to map the residual likelihood of flooding by combining flood extents that take account of asset failure with extents that assume no failure. Examples of the type of assets which typically contribute to the residual risk on a defended floodplain include raised flood defences (such as embankments and flood walls), barriers and weirs, and culverts and bridges. If flood extents modelling the consequences of these assets failing are available, and the probability of failure (through breaching, barrier failure or blockage, for example) can be estimated, MAST can incorporate these flood extents into the overall calculation of risk. The following example explains how MAST could be used to consider the residual risk from multiple breaching in a flood defence embankment. However, it is put forward tentatively, and would need to be more rigorously tested as part of the implementation phase. Note that the prototype software does not explicitly facilitate its use for combining failure and non-failure flood mapping.

The input required for the analysis of residual risk from multiple breaching is a set of flood extents (one for each breach and loading event, for example one and 0.1 per cent AEP), and information that enables estimation of the probability of each breach happening (such as defence fragility curves). For simplicity, assume here that the probability of breaching is 10 per cent at **three** (potential) breach locations (referenced in the following example as E10, E11 and E12). MAST will calculate the residual risk from multiple breaching as follows:

1. For each loading event E10, E11 and E12 are treated the same. So, for a multiple breach case, the probability of failure for E10 is calculated by assuming E10 failed, but E11 and E12 not failed:

    a. Pfail (E10) = Pfail * (1- Pfail) * (1- Pfail).

   Worked through, the probability of failure at each breach location is:

    b. Pfail = 10% * 90% * 90% = 8.1%

2. Once the probability of failure has been calculated for each breach location, it can be combined with the loading probability to establish an overall probability for each breach flood extent. This is calculated for each breach as follows:

    a. P (overall) = Pfail (E10) * P (loading)

    For a 1% event P = 8.1% * 1% = 0.081%

    For the 0.1% event P = 8.1% * 0.1% =0.008%

If a grid cell is flooded by all three breaches (say for a one per cent AEP event), the combined probability is close to 0.24 per cent, not exceeding the intrinsic loading probability of one per cent. The example used here assumes a low breach probability, so the probability of two (or more) breaches occurring at the same time is statistically small:10%*10%*90%= 0.9% compared to single breach (8.1% chance).

3.14 Using MAST to produce local NaFRA validation data

MAST can be used to integrate flood depth grids for a range of events (for example, 20, 10, 5, 2, 1, 0.5 and 0.1 per cent) typically available from local detailed hydraulic modelling studies. This results in an integrated depth-probability grid, a quick and easy validation dataset which can be used to check (and potentially supplement) outputs from the National Flood Risk Assessment model (NaFRA) with best available local data. As NaFRA takes account of asset failure in a probabilistic way, this type of validation would only be applicable for undefended floodplains, such as the Lower Thames, but nonetheless it represents an interesting secondary use for MAST.

3.15 Limitations

Users are alerted to the following limitations of the method (for further details refer to Section 5.4):

- Both the combined exceedance probability and the extrapolated value must be viewed alongside the uncertainty estimates, as the tool does not automatically select the most appropriate method.
- Some resolution in the input data will be lost where it needs to be scaled up to a grid with a larger common cell size.
- The classification thresholds for potential and likely interaction need to be confirmed as appropriate.

- Uncertainty information may not be available for some sources, even for "probabilistic" model outputs such as NaFRA.
- Dependency data is not available for some pairs of sources, most significantly local rainfall and fluvial flows.
- The tool cannot explicitly represent dependency between three or more sources.
- The method cannot deal with interaction/dependency for data sources represented by a single depth/probability grid (such as current national surface water mapping).
- The method concentrates on uncertainty in depths and probabilities, rather than in terms of spatial uncertainties (uncertainty in flood extent). For some input data types, the method will represent spatial uncertainty. For example, if a grid represents the "upper bound" water depth and this includes a greater flood extent that the "best estimate", the difference between the two extents can be represented spatially as a band of uncertainty.

4 Worked example

4.1 Christchurch MAST model

This section uses example data for Christchurch to illustrate how to use MAST. Steps involved in building a MAST model are: preparing the data, building the MAST project, running a simulation, and viewing output data. Note that the data for Christchurch is not provided with the software.

4.1.1 Prepare data

The following figure shows the Christchurch area with flood maps. The one in 1,000 chance in any year fluvial flood extent is shown on the map as a light brown colour. The one in 1,000 chance in any year coastal flood map is shown as a light blue colour and the national map of Areas Susceptible to Surface Water Flooding (AStSWF) is shown as a darker blue colour.

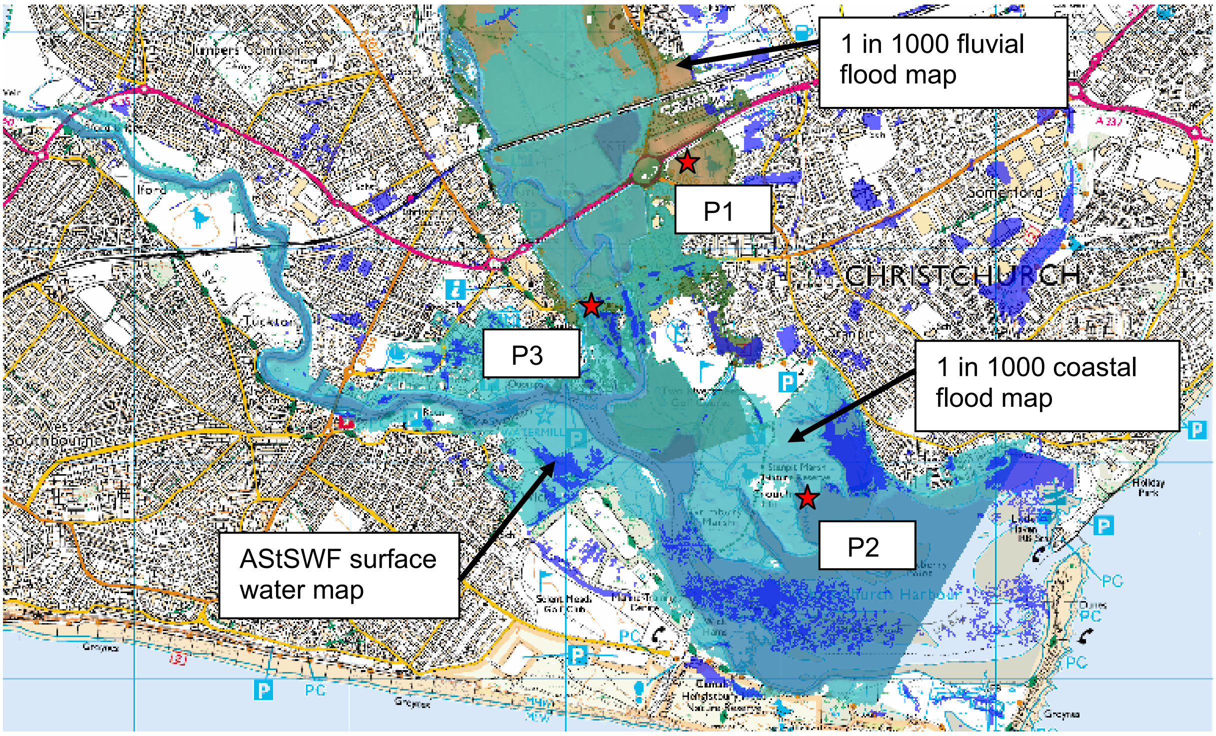


Figure 4-1 Christchurch with three flood maps

Three sample points have been defined using the red star icon:

- Point 1: (416605, 93348), the dominant flood risk at this location is fluvial.
- Point 2: (417171, 91944), the dominant flood risk at this location is coastal.
- Point 3: (416106, 92709), the flood risk at this location is a mix of fluvial and coastal.

These three points are used later in this chapter to check the combined probability and contributions from each source.

Input data for the Christchurch MAST model:

- **Fluvial flood modelling result:** Maximum depth grids for 1 in 2, 5, 10, 20, 50, 100, 200 and 1,000 chance of occurring in any year. These are ASCII grid files.
- **Coastal flood modelling result:** Maximum depth grid for 1 in 200 and 1,000 chance of occurring in any year. These are ASCII grid files.
- **Surface flood modelling result:** National map of Areas Susceptible to Surface Water Flooding (AStSWF), which has no explicit probability associated with it. This is in shapefile format.

4.1.2 Load data to GIS View

To load model input data, start the application, go to the GIS View tab and click the 'Add Layer' button to load the model input data including fluvial, coastal, and surface water model results.

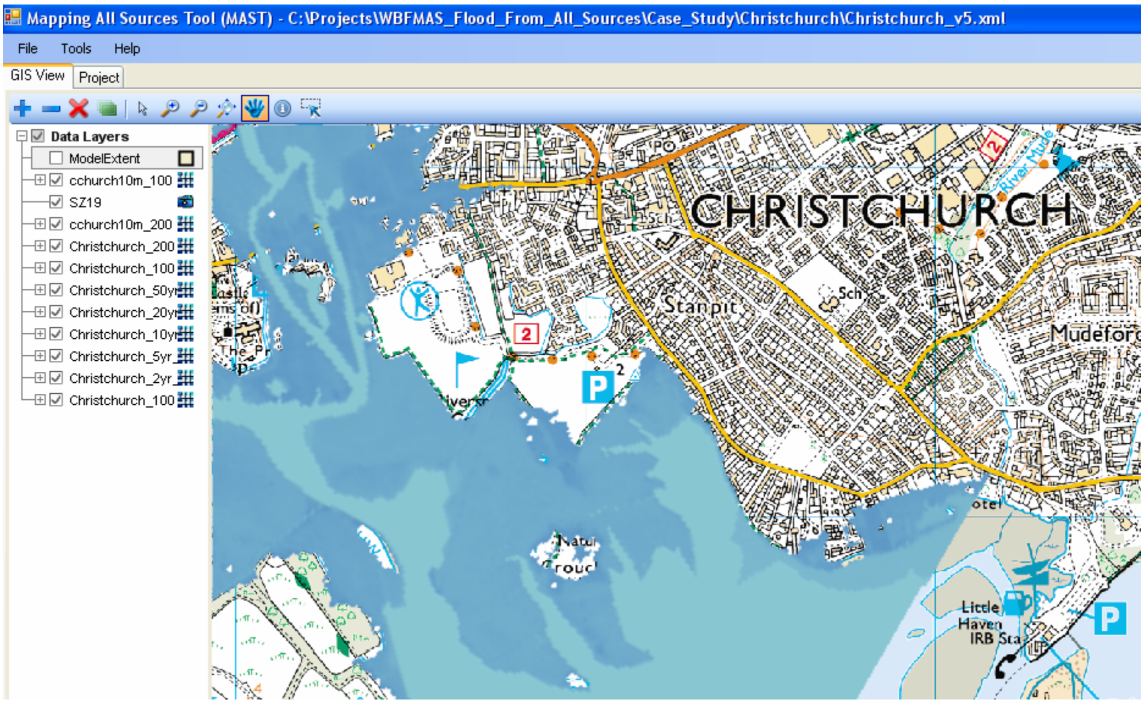


Figure 4-2 MAST GIS View

For more information about loading data to MAST GIS View, see Chapter 3..

4.1.3 Define MAST project

After loading all the input data, switch to the project tab, to specify the MAST project parameters. The project tab view is shown in the following figure. As can be seen in the figure, on the left side of the form, there is a tree view of the project hierarchy: project name → scenario name → dataset name. On the right hand side, the form shows the details of each item on the tree view.

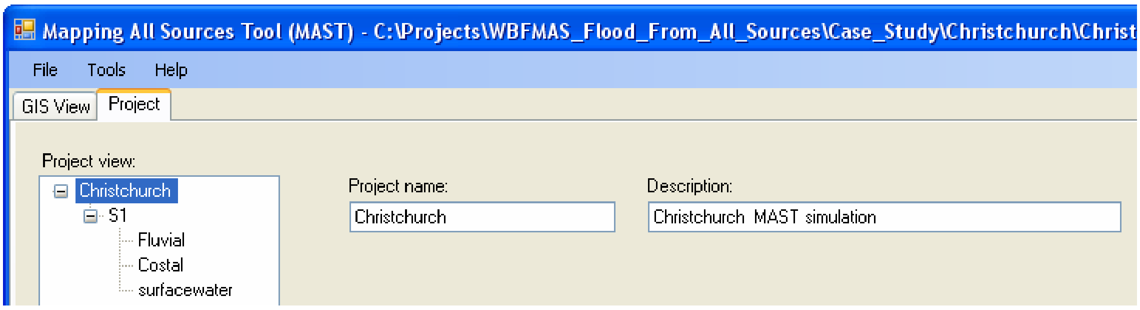


Figure 4-3 Define a new MAST project

Specify a name and description for the project: say Christchurch, and Christchurch MAST model.

For more information about defining a MAST project, please refer to Chapter 3.

4.1.4 Define a scenario

Specify the scenario name and add a simple description in the form. Model extents have to be defined; this is a polygon shapefile. Users can draw the shapefile in the GIS View using the drawing tool or create a shapefile using other GIS software such as ArcMap. Cell size has to be specified as the MAST calculation is done on a gridded basis.

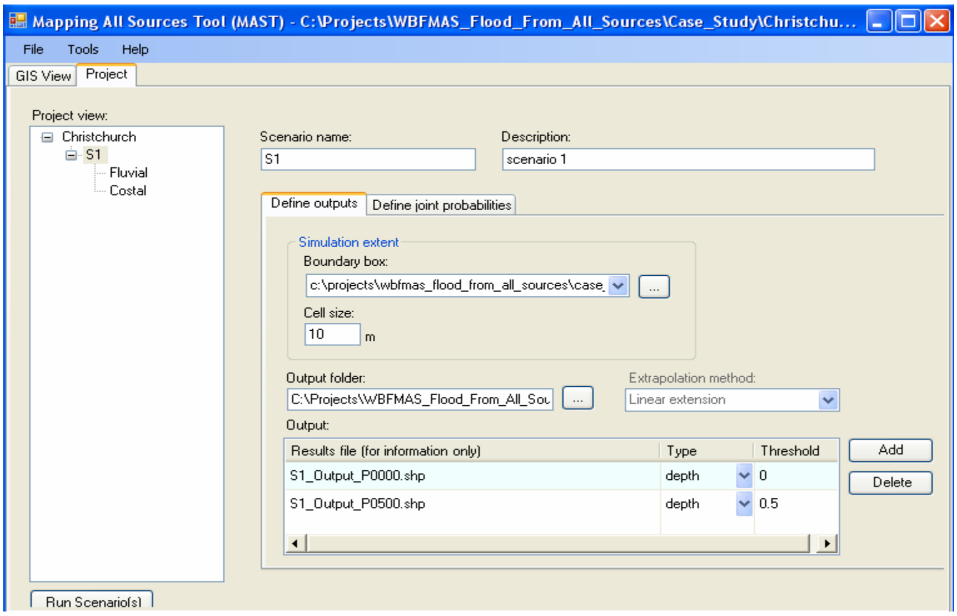


Figure 4-4 Define a new scenario in MAST model

For the Christchurch example, a large rectangular polygon was drawn and used as the model extents and 20 m was chosen as cell size. To draw a polygon in the MAST GIS View, go to GIS View tab and select the ’Create an extents shapefile’ button on the toolbar. Users can then use this tool to draw a polygon as the model extents. Note that this drawing tool can only draw rectangles.

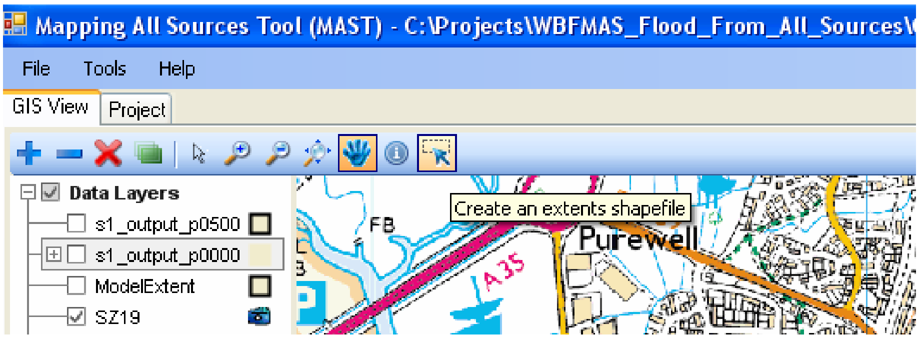


Figure 4-5 MAST create model extents tool

For more information about how to create model extents, please refer to Chapter 3. The following figure shows a rectangular model extents which can be used as the model extents; the area outside of the model extents will not be considered in the calculation.

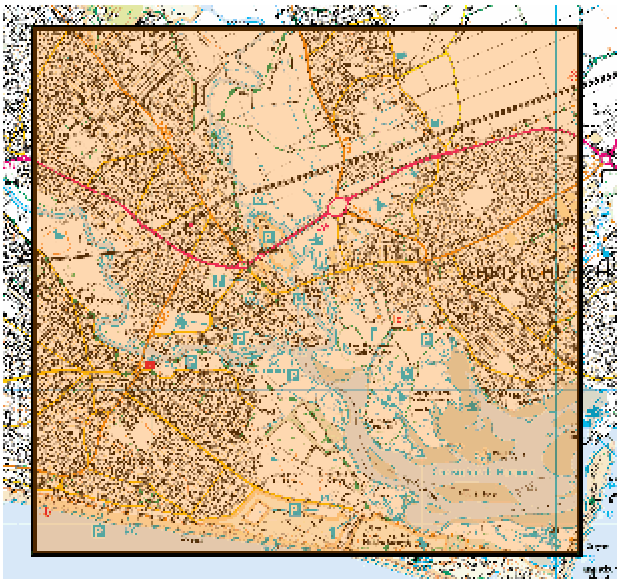


Figure 4-6 Christchurch MAST model extents

Output files have to be defined for this scenario. Users can define several output files by clicking the 'Add' button on the bottom right of the form. Note that the output file name is generated by the software and passed to the calculation engine. Users cannot modify the output file name. Each output has a threshold type and threshold value: for this example, probability outputs with thresholds of 0.0 m and 0.5 m were chosen.

4.1.5 Add datasets

After defining the scenario, different types of flooding data source can be added to the defined scenario. Three types of source have been provided for this model: fluvial, coastal and surface water. These ASCII grids of water depth relating to different probabilities for each flooding source have already been loaded to MAST GIS View.

First, the fluvial flooding source dataset is added as a group of ASCII depth girds associated with different probabilities. Each ASCII grid file is a layer in this flooding source. Take the flood depth grid representing the one in 20 chance of occurrence in any year as an example; the flooding probability at this depth threshold is five per cent. Lower bound and upper bound for the probability are also required for the uncertainty analysis, here estimated values are used as the lower and upper bound: the lower bound is taken as 4.9 and upper bound as 5.1 per cent.

The following table shows the fluvial input data files and their corresponding probabilities including lower bound and upper bound.

Table 4-1 Fluvial input data and probabilities

Chance of occurring in any year	Probability (%)	Lower bound (%)	Upper bound (%)
1 in 2	50	49	51
1 in 5	20	18	22
1 in 10	10	9.8	10.2
1 in 20	5	4.8	5.2
1 in 50	2	1.8	2.2
1 in 100	1	0.9	1.3
1 in 200	0.5	0.4	0.7
1 in 1,000	0.1	0.09	0.11

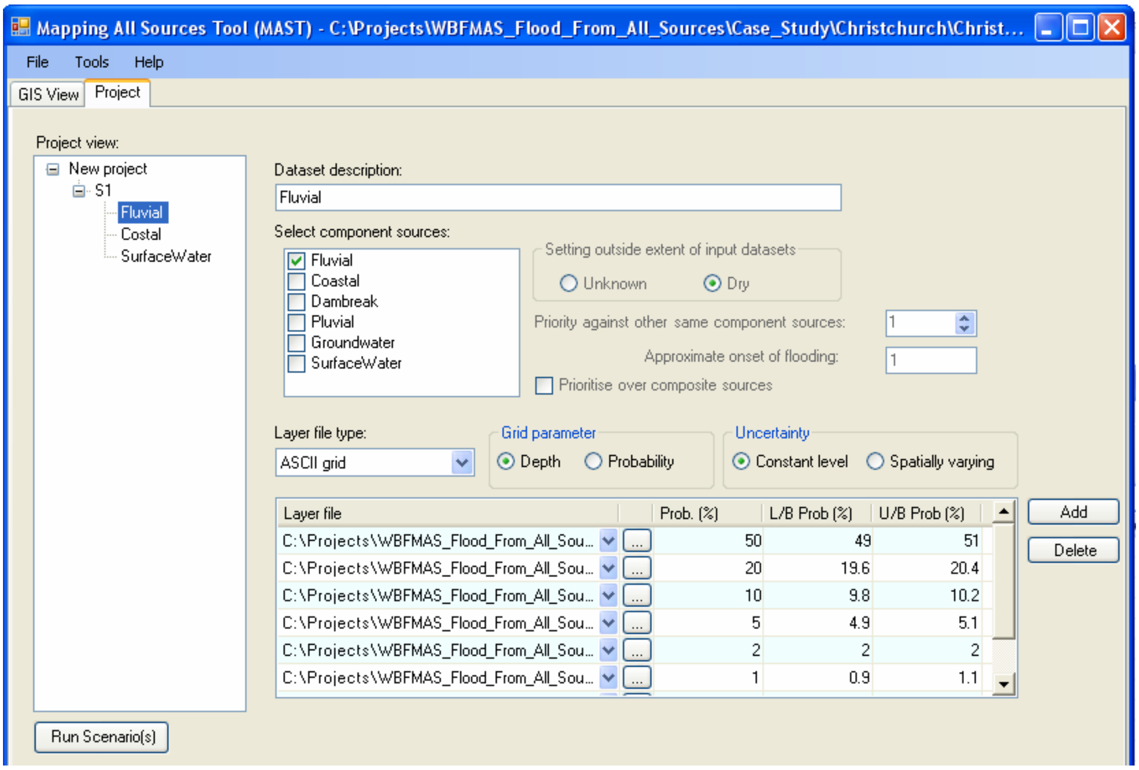


Figure 4-7 Add flooding dataset to scenario

Similarly, the coastal and surface water flooding data have been added to the scenario. Note that for the surface water result, a shapefile of flood extents with no probability is the input layer.

4.1.6 Save project file

After defining the project, scenario and flood data source and before running the simulation, it is advisable to save the project configuration as an XML project file. This xml file stores all the information about the project data and parameters. Users can reload this project file later on.

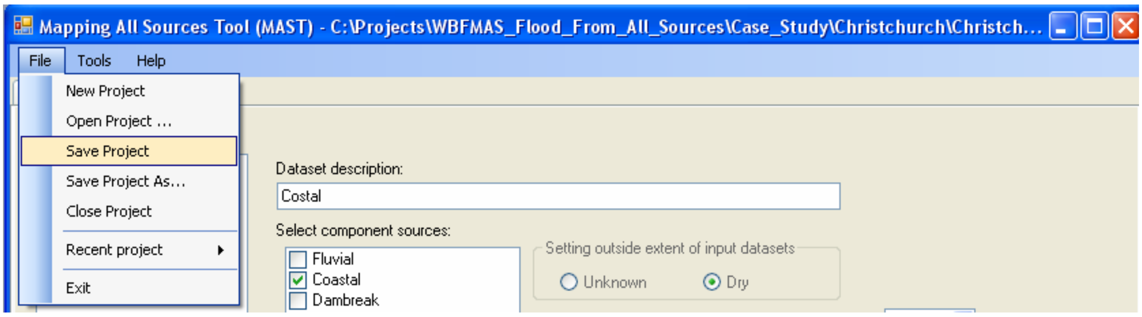


Figure 4-8 Save/load MAST project file

Note that the list of GIS layers loaded in the MAST GIS view is also stored in the xml project file.

4.1.7 Run scenario

There are two stages in the simulation: pre-process and engine calculation. During the pre-processing stage, MAST will read the input GIS data and process them to create an intermediary shapefile file for input to the engine. The intermediary input shapefile normally has a name of: "Scenario name_input.shp". For this example this shapefile would be: Example_input.shp, located in the same folder as the xml project file. If there is already such a shapefile in the folder, MAST warns the user. During the engine calculation stage, the MAST engine will take the intermediary input shape and calculate combined flooding probability and generate the output shapefiles. The output file name and folder are stored in the xml project file.

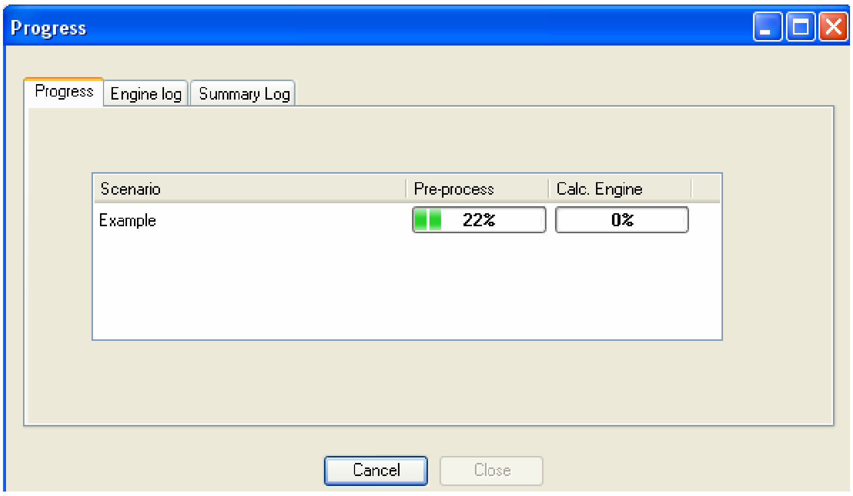


Figure 4-9 MAST simulation process

4.1.8 Result and discussion

After the simulation, the output shapefiles can be viewed in the GIS View tab of the MAST user interface.

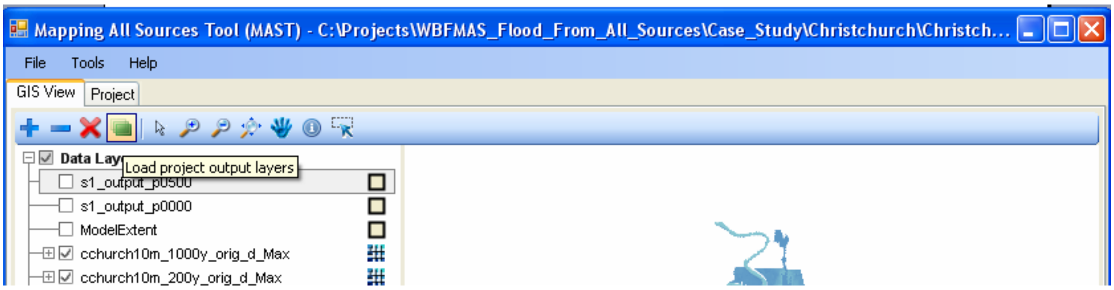


Figure 4-10 Load project output layers

The output shapefile is in the form of a 'grid' of polygons with each cell in the model extents having attributes in the dbf file. For more information about the output shapefile format, refer to Appendix B.

As all the results are stored in the dbf attribute table, users only see the 'grid' of polygons when the output shapefile is firstly loaded to the GIS View. Users can use the 'Info' tool to investigate the combined flooding probability on a cell-by-cell basis. The results from applying the 'info' tool at the three sample points shown in Figure 4-1 are shown below (the dominant flooding source is correctly identified).

P1 (416605, 93348) **P2 (417171, 91944)** **P3 (416106, 92789)**

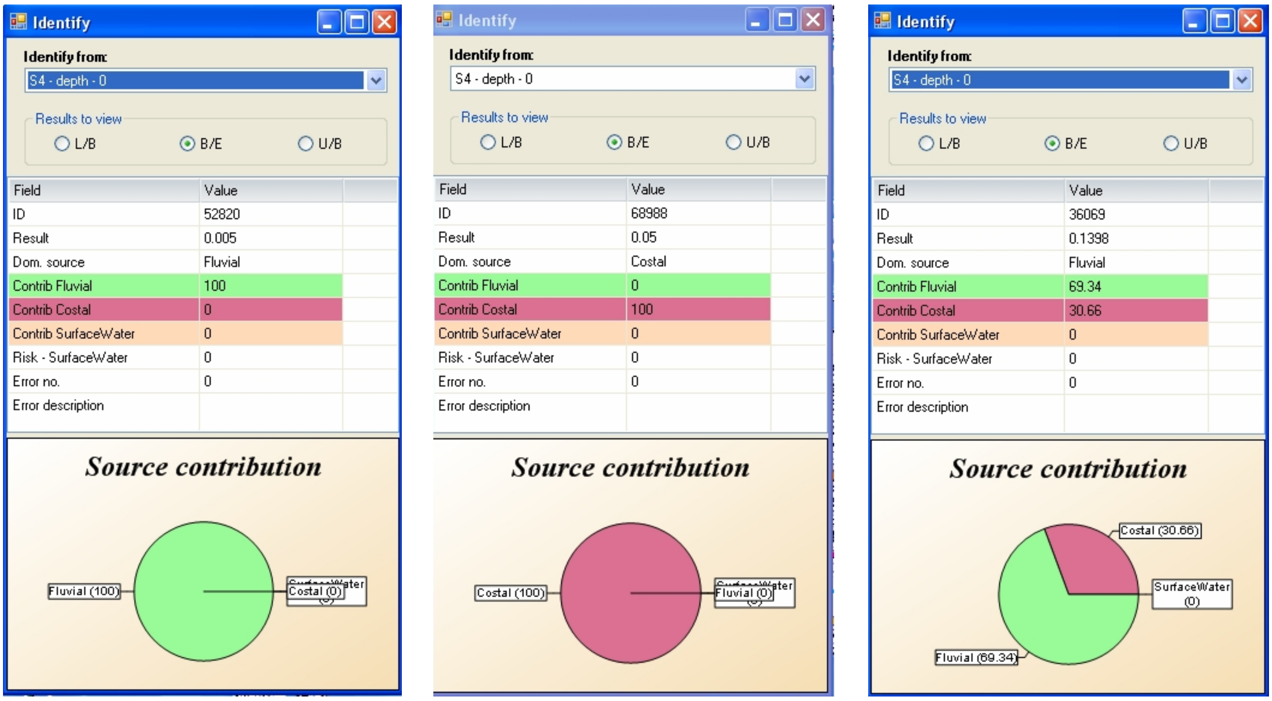


Figure 4-11 Cell-based calculation result

After running the MAST simulation, several summary output results can be used for reporting purpose. For this example, two output shapefiles were generated with the depth threshold of 0.0 m and 0.5 m. The output file names are: s1_output_p0000 and s1_output_p0500. For example, for the s1_output_p0000.shp file (zero metres depth threshold) the first action was to set up the colour scheme through right-clicking on the file and setting the colour theme.

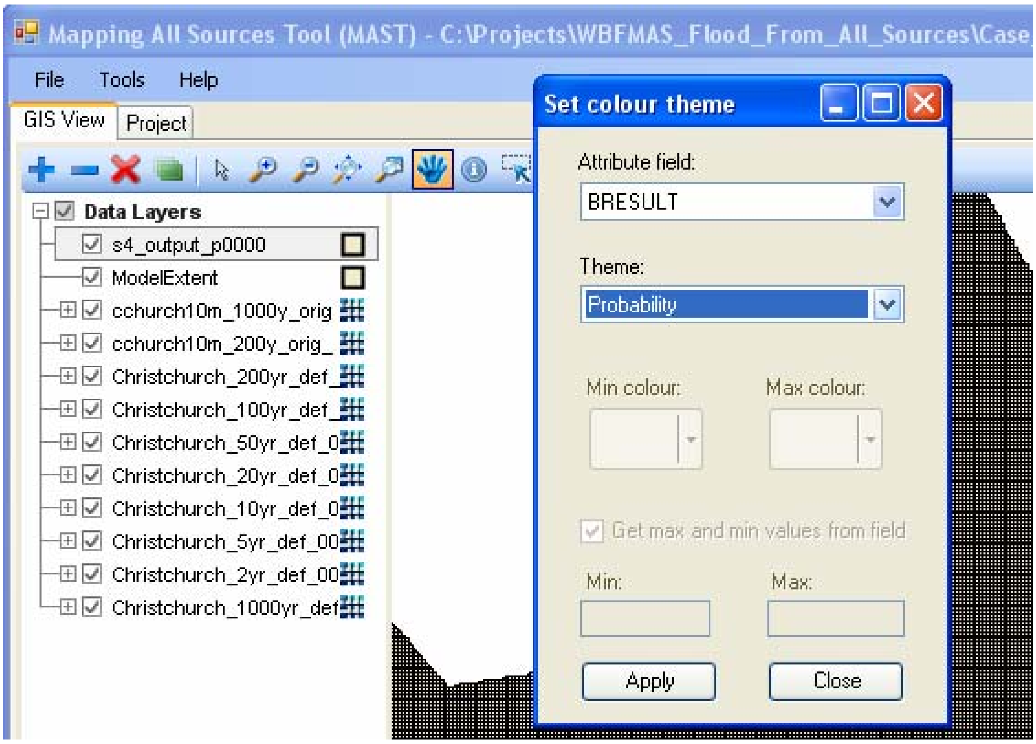
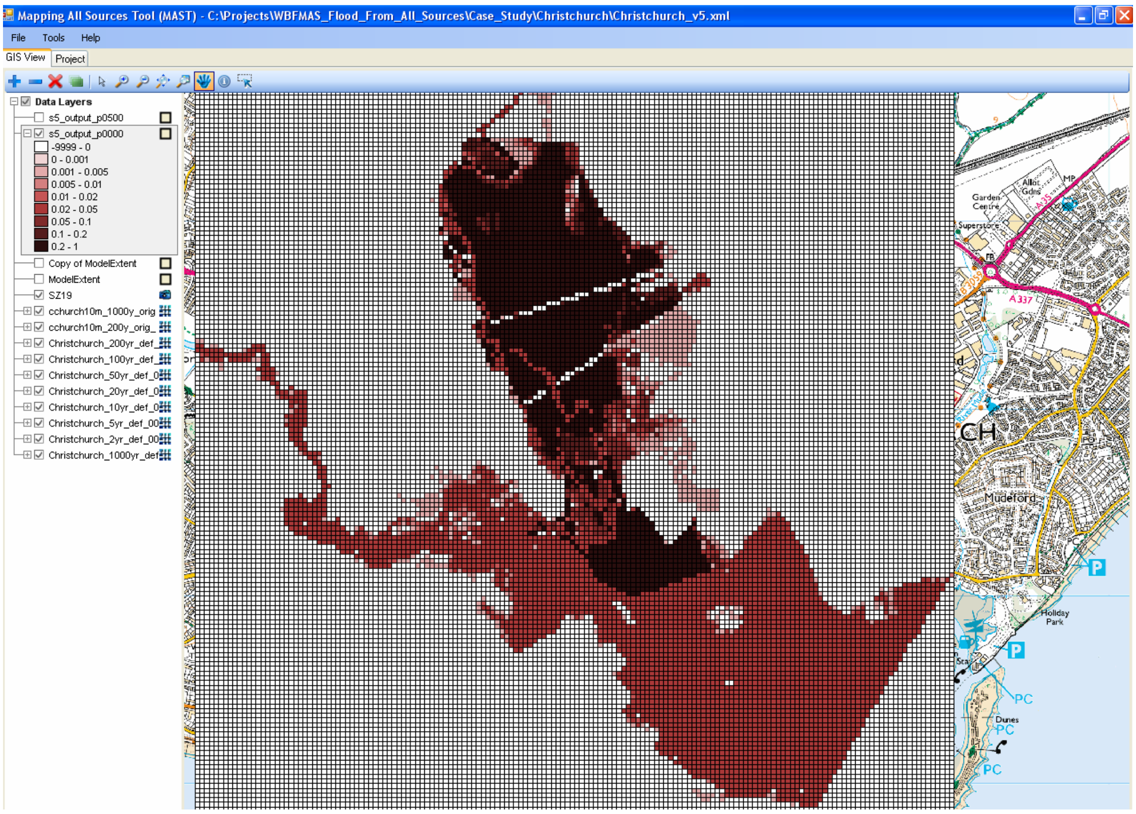
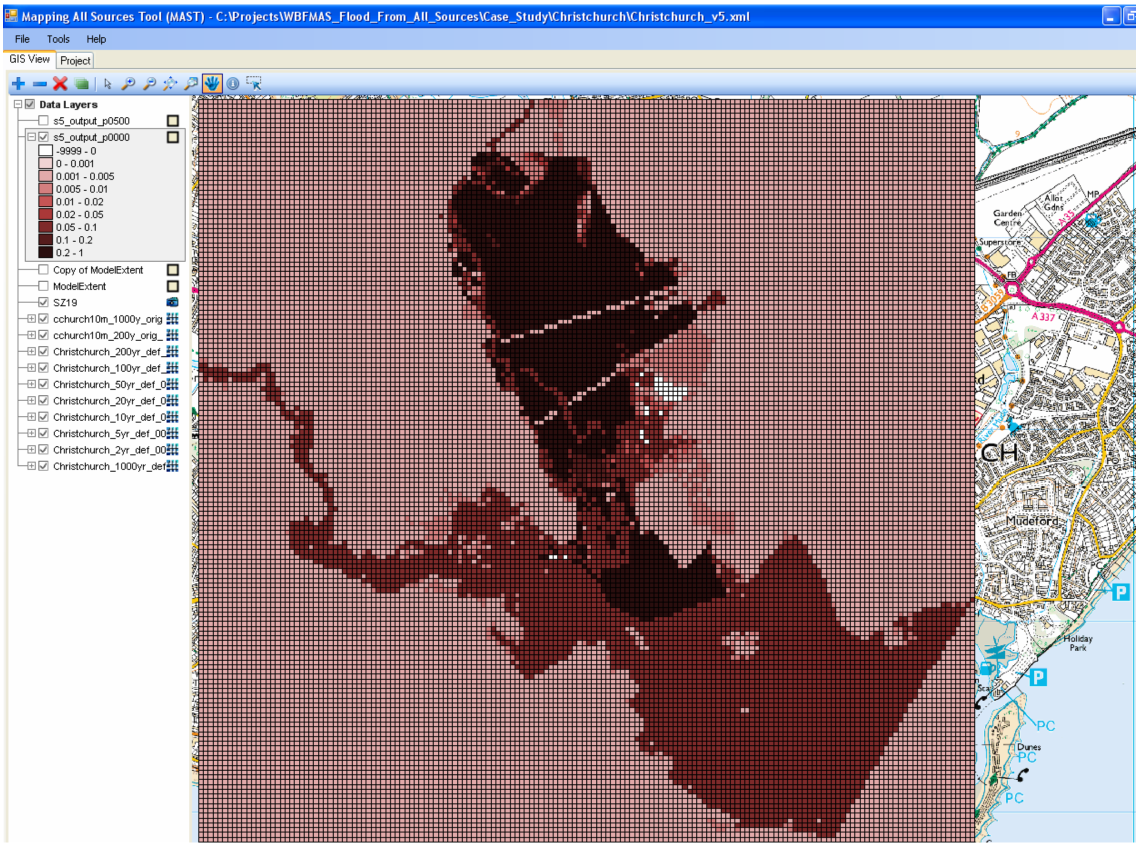


Figure 4-12 Set colour scheme for output shapefile

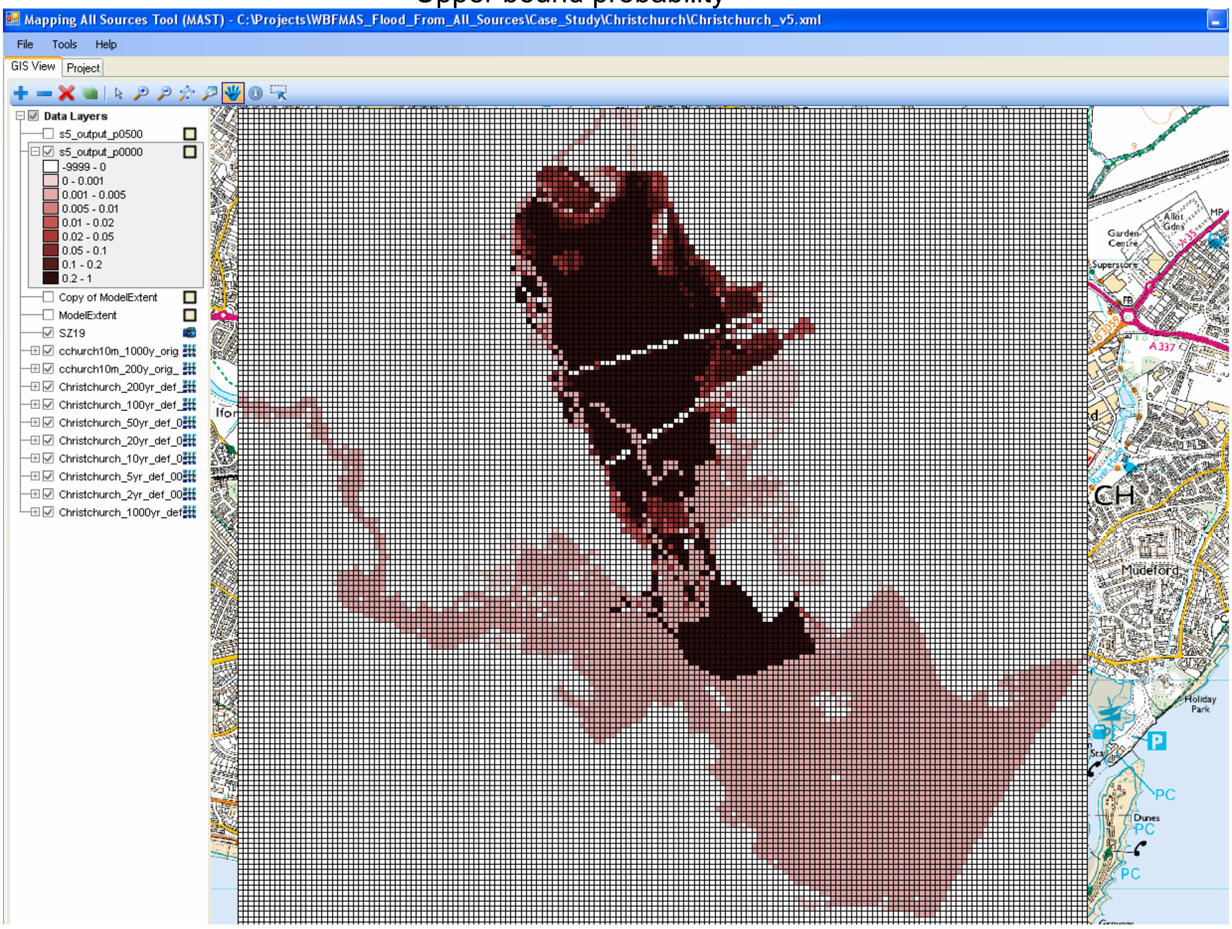
The following probability maps were generated for the combined flooding probability of the three sources: best estimate, upper bound and lower bound.



Best estimate probability



Upper bound probability



Lower bound probability

5 Technical method description

5.1 Introduction

This chapter describes the methodology used in MAST. The chapter assumes the reader has a good working knowledge of the probability of extreme events and some familiarity with joint probability methods as described in Hawkes (2005), *FD2308 Use of joint probability methods in flood management: a guide to best practice*.

A flow chart for the methodology is shown in Figure 5-1:

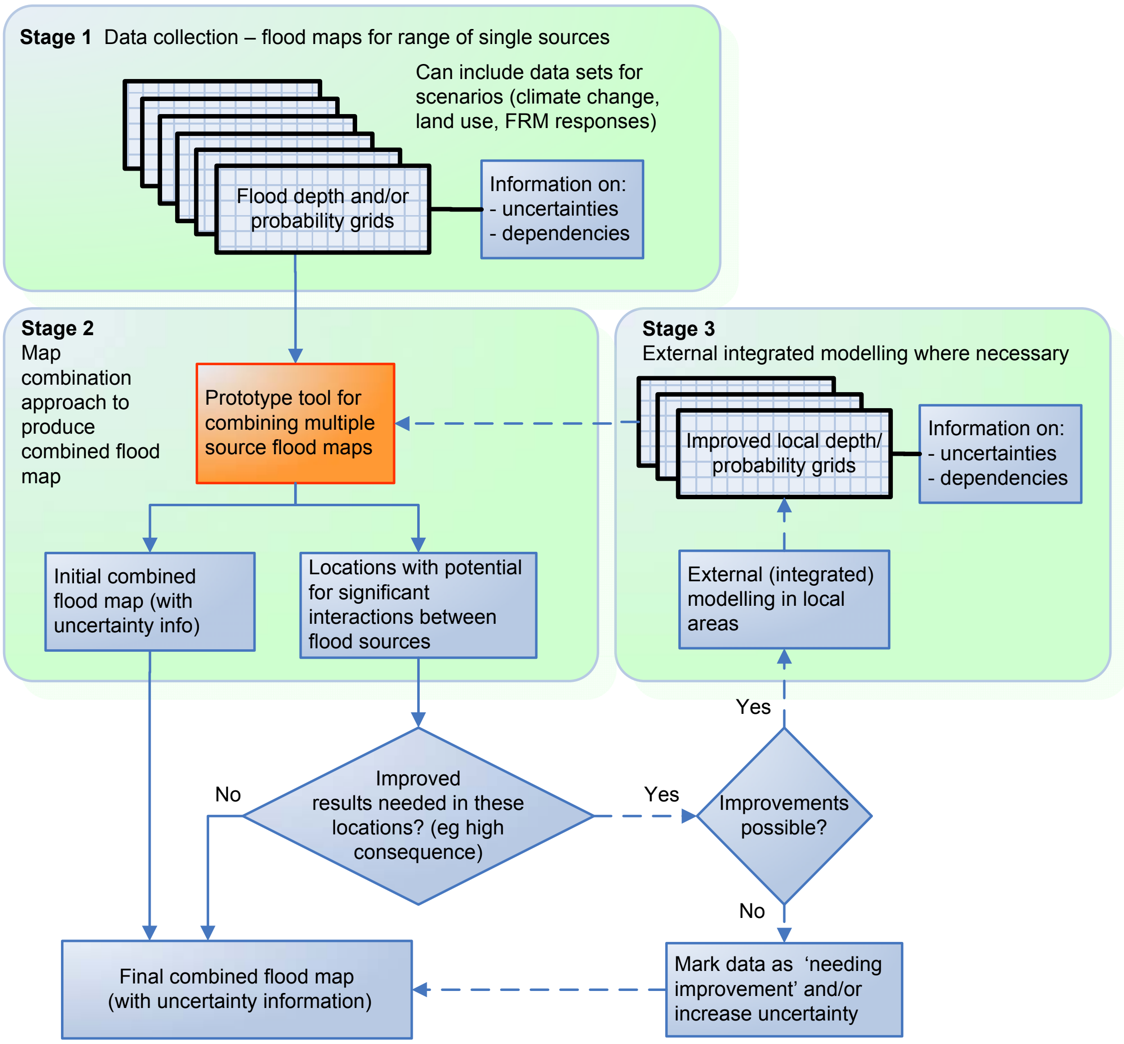


Figure 5-1 Flow chart for combined mapping of flooding from all sources

A typical application of the methodology is described as follows:

Stage 1 – Data collection	Collect existing flood information maps at national and possibly local scales.
	Collect information on uncertainty and dependencies, if available.
	Collect information on different scenarios (management options, data for future climates) if required.
Stage 2 – Use map combination approach to generate combined flood map	Use the software tool to generate an 'initial' combined map.
	Use tool outputs to assess locations where dependency may generate interactions, and decide whether these are in high consequence areas.
	Use tool outputs to assess areas where uncertainty is high, and decide whether these are in high consequence areas.
Stage 3 – Local modelling	Where necessary, use local models to map flood risk from combined sources and feed back into stage 2.
	Where necessary, use local models to map risk more accurately in high consequence areas and feed back into stage 2.

The two components at the core of this methodology are:

- **Method for combining existing flood maps** producing a single measure of combined hazard for each spatial element (such as floodplain cells or polygon elements). The spatial extent of these cells is determined by the input data.
- **Method for deciding where more accurate local modelling is required**, either due to dependency between sources, or uncertainty in national/catchment scale maps, where this coincides with high consequence areas.

5.2 Method

The method for combining maps needs to take a probabilistic approach to both deterministic and probabilistic model outputs, as both of these include information on flood probabilities. Development of the method starts with analysis of the case for independent sources, which is a useful simplification.

5.2.1 Theory of combining independent sources

Formally, independence between sources means the probability of event A conditional on event B is equal to the unconditional probability of A:

$$P(A|B) = P(A) \qquad (5.1)$$

It is not clear whether any sources of flooding are truly independent, as even a weak seasonality will tend to cause flooding to coincide. However, it is a useful limiting behaviour for weakly dependent sources.

The probability of either of two independent events A and B occurring is given by adding the mutually exclusive combinations of A and B:

$$P(A \text{ or } B) = P(A \text{ and } B') + P(A' \text{ and } B) + P(A \text{ and } B) \qquad (5.2)$$

A´ here indicates the probability of event A not occurring. In practical terms, this is a probabilistic description of flood risk from either of two sources, with events A and B representing the sources exceeding given thresholds such as river flow exceeding the one per cent Annual Exceedance Probability, AEP, flow).

Equation (5.2) can be simplified first by neglecting the $P(A \text{ and } B)$ term. Since sources A and B are independent, and we are dealing with rare events, the probability of them occurring at the same time is insignificant.

Taking fluvial and coastal flooding as an example, the probability of two one per cent AEP events occurring at the same time is less than 0.01 per cent. Even if a one per cent fluvial flood and a one per cent coastal flood occur in the same year, the probability of the flood event (lasting typically a few hours to a few days) coinciding with the highest tide of the year is small. The probability of events coinciding will be increased by dependency between the sources, event duration (long events are more likely to coincide) and seasonality (long flood events in a short flood season are more likely to coincide).

Combining (1) and (2) gives the familiar additive form for either of two events occurring:

$$P(A \text{ or } B) = P(A) + P(B) \qquad (5.3)$$

This is easily extended to more than two sources:

$$P(A \text{ or } B \text{ or } C \text{ or } \ldots) = P(A) + P(B) + P(C) + \ldots \qquad (5.4)$$

For any number of sources, the addition of probability can be “chained”, by combining A and B, then combining the result with C, and so on. The validity of Equations 5.3 and 5.4 decrease as the probabilities of events increase, and as the number of sources increases. This is because for more sources and more likely events, they are more likely to coincide even if independent.

This analysis is valid when applied to two or more sources of flooding at source level. The probabilities $P(A)$ and so on should be interpreted as the probability of source variables exceeding given thresholds, but since the possibility of this forcing occurring at the same time from two sources is being ignored, this is equivalent to the probability of floodplain depths (or other hazard measures) exceeding given thresholds. The probabilities for depth exceedances from two sources can be written as:

$$P(\mathrm{X}_{\mathrm{Combined}} > \mathrm{x}) = P(\mathrm{X}_{\mathrm{A}} > \mathrm{x}) + P(\mathrm{X}_{\mathrm{B}} > \mathrm{x}) + P(\mathrm{X}_{\mathrm{C}} > \mathrm{x}) + \ldots \qquad (5.5)$$

$P(\mathrm{X}_{\mathrm{A}} > \mathrm{x})$ represents the probability of the hazard X exceeding a threshold x due to the source A. The exceedance probabilities for floodplain hazards (receptor level) can thus be combined in the same way as at source level. For the following descriptions we deal exclusively with depths; extension to other hazard measures is in theory straightforward, although practical considerations (especially resolution) may make application to these measures more difficult.

5.2.2 Application to flood hazard data

While the theory of adding probabilities is simple, in practice the diversity of probabilistic data source types, uncertainty and incomplete information mean that the addition of probabilities must be carried out carefully.

In an ideal case, where the input flood hazard maps give a complete picture of how floodplain depths vary with probability, addition of probabilities requires interpolation between data points on the depth-probability curve (Figure 5-2). This allows the probability for a required output depth, or depth associated with an output probability, to be determined. In practice, the interpolation is carried out using reduced variates, such as the Gumbel (y_G) or logistic (y_L) reduced variates defined through the exceedance probability P:

$$y_G = -\ln(-\ln(1-P)) \tag{5.6}$$

$$y_L = -\ln\left(\frac{P}{1-P}\right) \tag{5.7}$$

For extreme events associated with small exceedance probabilities, both these variates reduce to $-\ln(P)$. Plotting depths against these reduced variates tends to produce straight (or straightish) lines, and so interpolation errors will be smaller using these variates rather than the exceedance probability itself.

Addition of probabilities as in Equation 5.5 also allows the contribution to the probability from each source to be determined.

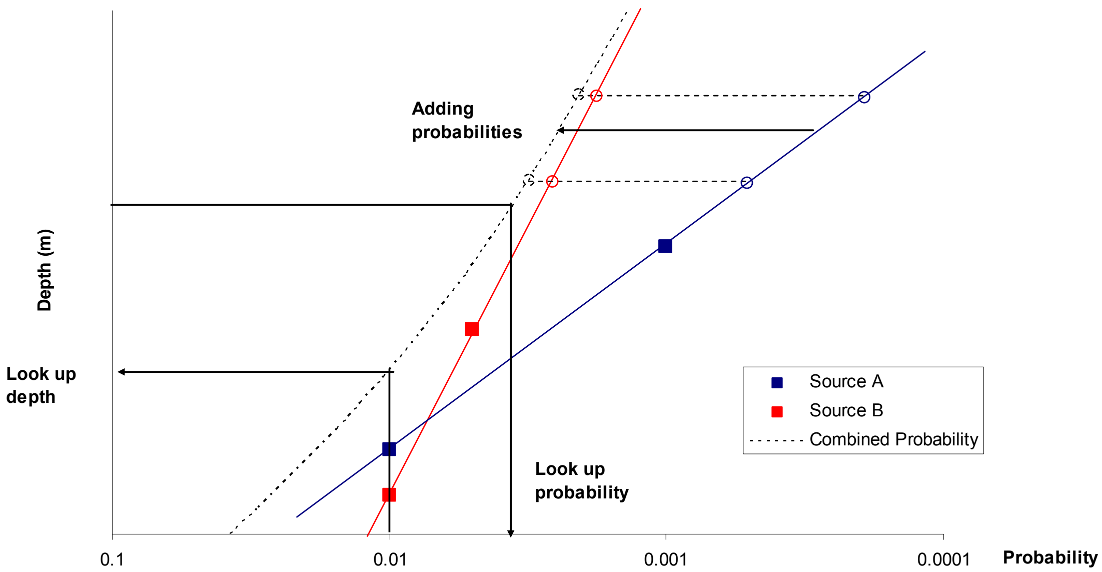


Figure 5-2 Addition of probabilities using interpolation of the depth-probability curve

Uncertainty, incomplete information and dependency are all dealt with using methods based on interpolation and addition of probability-reduced variate curves. These are described in detail in the following sections.

5.2.3 Example

Here is an example of a place at risk from three different sources: Source 1 – tidal; Source 2 – fluvial; Source 3 – surface water. Each of them has a different probability of flooding at different water depths.

Table 5-1 shows flooding probabilities for each source at different water depths.

Table 5-1 Example depth probability data

Tidal risk			Fluvial risk			Surface risk		
Depth (m)	0.68	1.18	Depth (m)	0.418	0.444	Depth (m)	0.018	0.022
Probability	0.005	0.001	Probability	0.01	0.005	Probability	0.01	0.005

The following figure illustrates depth-probability graphs for the three flooding sources:

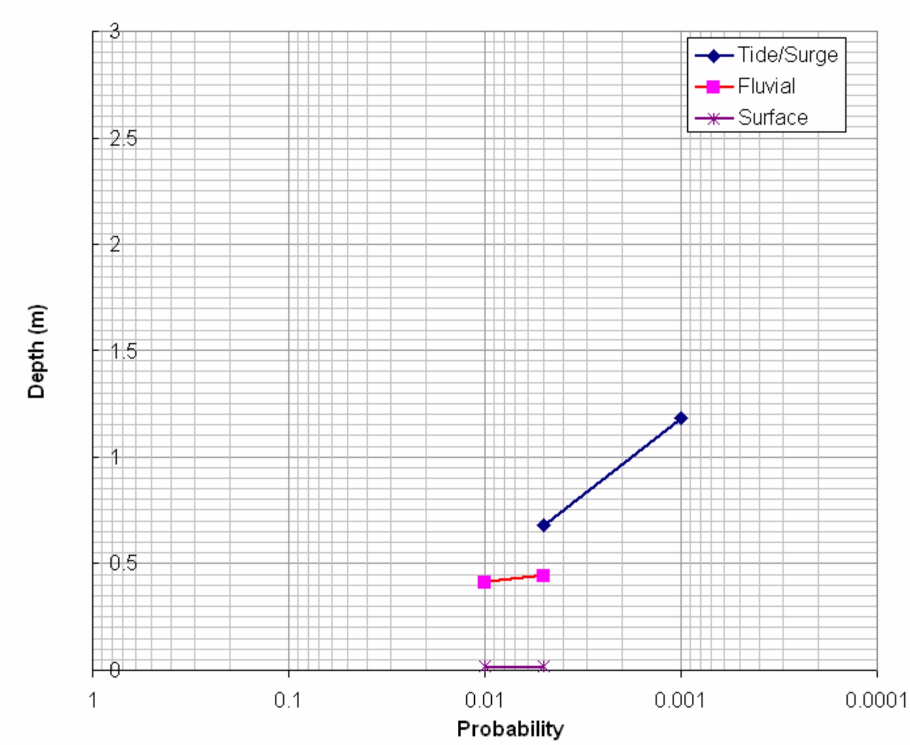


Figure 5-3 Depth-probability curve for example data

As can be seen in Figure 5-3, depth-probability curves for those three different sources fall at different depth ranges in the graph, and none covers the whole X-axis of probability from 0.0001 to one. As a result, before combining flooding probabilities from the three sources, outside range has to be estimated, that is the flood depth threshold at probability of areas like 0.5, 0.1 and 0.0005, as these are not covered by any of the curves.

As the first estimate, **linear interpolation/extrapolation** can be used for such areas.

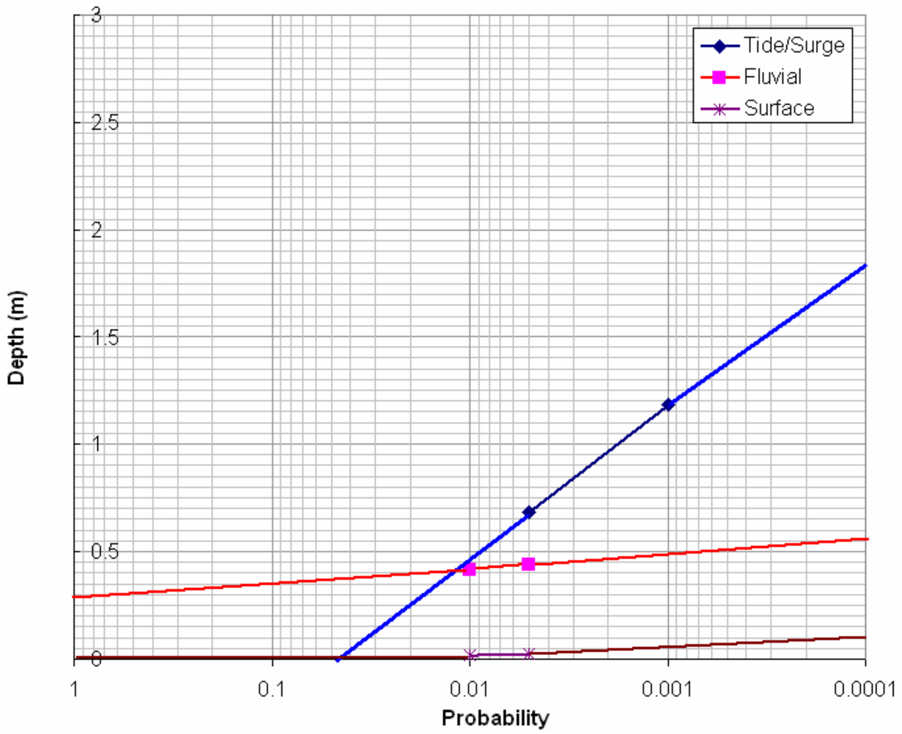


Figure 5-4 Interpolated/extrapolated curves for example depth-probability data

After interpolation and extrapolation of three depth-probability curves, combine those three lines into one depth-probability curve by adding probabilities at each depth to get to the best estimate depth-probability curve. The best estimate is the dotted line which combines three of the flooding probabilities.

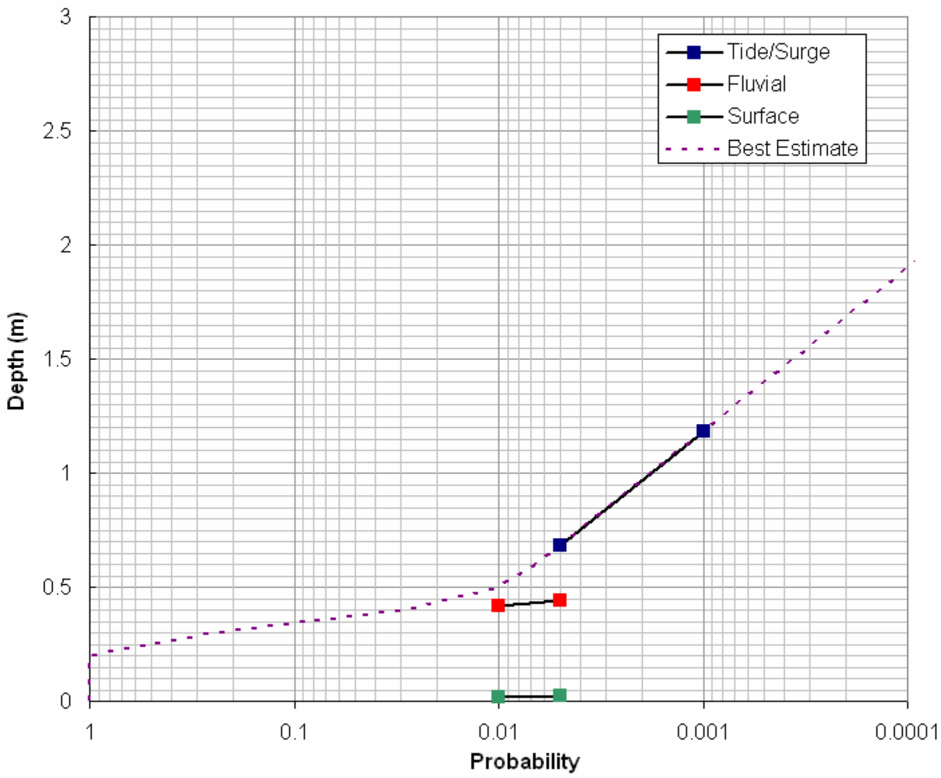


Figure 5-5 Best-estimated combined depth probability curve

Table 5-2 Calculated combined depth-probability values (best estimate)

Depth (m)	0	0.5	1	1.5	2	2.5	3
Best estimate	1	0.01004	0.001785	0.000357	0.000071	0.000014	0.000003

5.2.4 Representing uncertainty

The probability-depth curves of Figure 5-2 correspond to a complete understanding of the natural variability of floodplain depths. In practice, these estimates will be uncertain, and this uncertainty can be expressed as a range of probabilities at each depth, or a range of depths at each probability.

For this project, we propose dealing with uncertainty in a relatively simple way that still captures the interactions between knowledge uncertainty and natural variability. The depth-probability curve is represented as a range of probabilities, the ends of this range representing an upper and lower bound for the probability at each depth. Adding ranges of probabilities is carried out using the following equations:

$$P_{Upper}\left(\mathrm{X}_{\mathrm{Combined}} > \mathrm{x}\right) = P_{Upper}\left(\mathrm{X}_{\mathrm{A}} > \mathrm{x}\right) + P_{Upper}\left(\mathrm{X}_{\mathrm{B}} > \mathrm{x}\right) + P_{Upper}\left(\mathrm{X}_{\mathrm{C}} > \mathrm{x}\right) + \ldots \qquad (5.8)$$

$$P_{Lower}\left(\mathrm{X}_{\mathrm{Combined}} > \mathrm{x}\right) = P_{Lower}\left(\mathrm{X}_{\mathrm{A}} > \mathrm{x}\right) + P_{Lower}\left(\mathrm{X}_{\mathrm{B}} > \mathrm{x}\right) + P_{Lower}\left(\mathrm{X}_{\mathrm{C}} > \mathrm{x}\right) + \ldots \qquad (5.9)$$

These estimates of the upper and lower bounds will tend to overestimate the uncertainty (quantified as the difference between the bounds). A more rigorous approach would represent uncertainty as a convolution of the uncertainties in the input parameters, but this would require knowledge of the probability distributions representing uncertainty. These are unlikely to be available for many types of input data, and so Equations 5.8 and 5.9 offer a pragmatic approach to understanding uncertainty based on limited input data.

This addition of probability ranges is illustrated in Figure 5.6 for two sources. These upper and lower bounds can be used to represent any type of uncertainty that can be quantified in terms of the effect on flood depths and/or probabilities. Parameter uncertainty (due to imperfectly defined model inputs) and model error (due to imperfect models) will combine to produce an uncertainty in model outputs, and this can be represented as the upper and lower bounds.

For most data sources the uncertainty is expressed in terms of the depth rather than the probability. This can be transformed into upper/lower probability bounds using the gradient of the depth-probability (or reduced variate) curve.

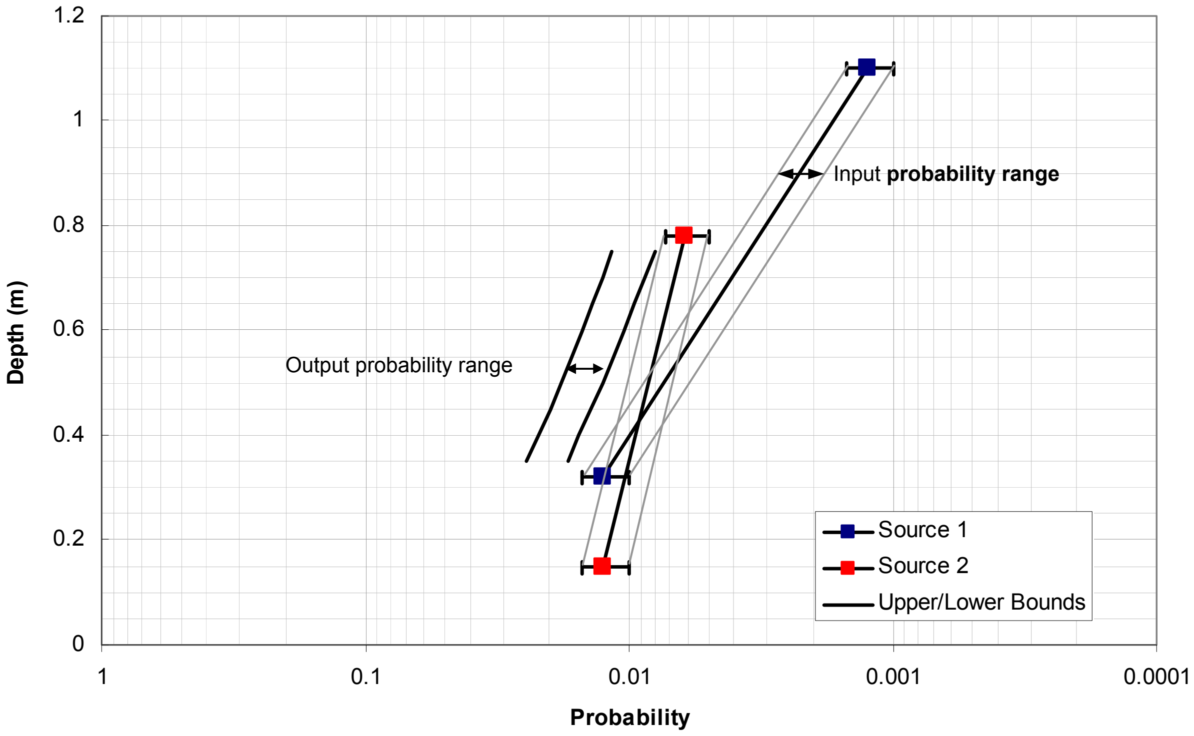


Figure 5-6 Addition of uncertain probabilities

5.2.5 Representing incomplete information

The method of combining probabilities must also deal with situations where there is incomplete information about the depth-probability curve:

- **Extrapolation** to depths/probabilities beyond the range of input variables.
- Data sources associated with a **single data point** on the curve (such as depth at an event probability).

The method used to deal with uncertainty described in the previous section can also be used to deal with incomplete information.

Data input to the method is in the form of lists of probabilities and associated depths. Extrapolation is required when the probability or depth to be calculated lies outside the range spanned by this list. An example might be where data input is in the form of depth maps for one and 0.1 per cent AEPs, and the depth for the five per cent AEP is required. By assuming that the depth-probability curve is monotonic (depth always increases as exceedance probability decreases), we can make the following statements about probabilities for depths outside the input range:

$$\begin{aligned} 0 \le P(X > x) < P(X > x_{Max}) \quad & for\ x > x_{Max} \\ 1 \ge P(X > x) > P(X > x_{Min}) \quad & for\ x < x_{Min} \end{aligned} \qquad (5.10)$$

Using the example above, this means that if at a point on the floodplain the one and 0.1 per cent depths are 0.5 and one metre respectively, all we can say about the probability of the depth exceeding 0.2 m is that it is greater than one per cent and less than or equal to one. Similarly, the probability of exceeding one metre is less than 0.1 per cent and greater than or equal to zero. These inequalities are used to calculate upper and lower bounds when data are extrapolated, with an example shown in Figure 5-7.

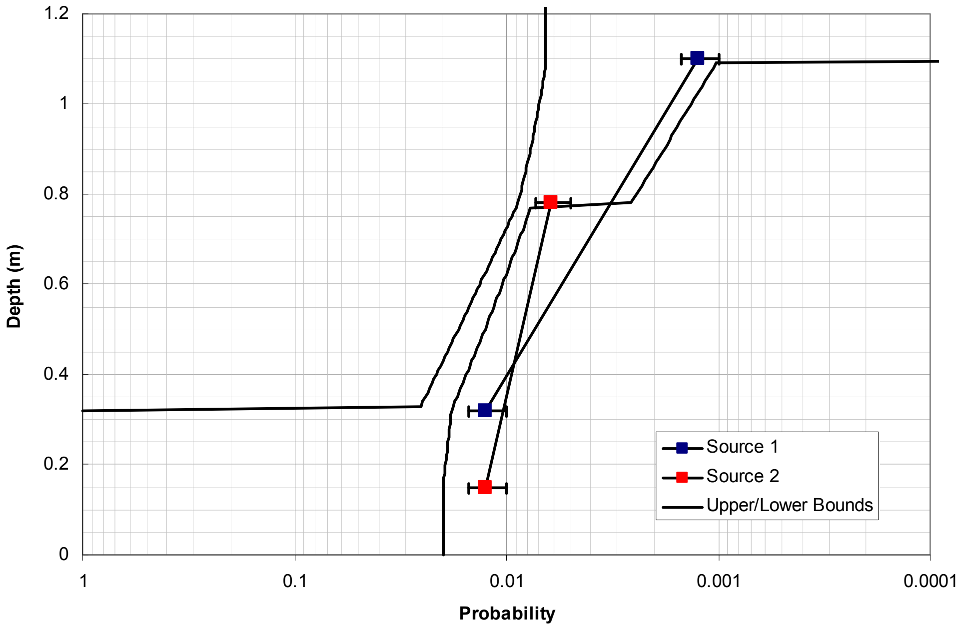


Figure 5-7 Addition of uncertain probabilities with upper and lower bounds used to represent extrapolation

The same method can be applied to data with only a single data point representing the depth-probability curve (such as a one per cent flood depth map). This is shown in Figure 5-8. Representing uncertainty in the probability associated with the single data point from uncertainty in depth is difficult since there is no gradient information.

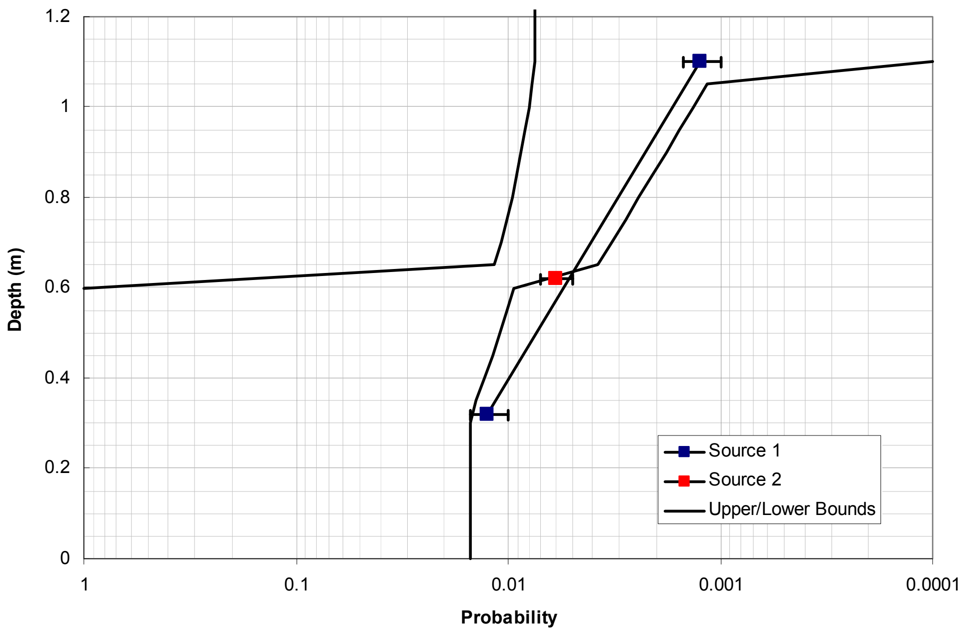


Figure 5-8 Addition of uncertain probabilities with upper and lower bounds used to represent extrapolation from a single data point

5.2.6 Example considering uncertainties

Continuing with the previous example, Table 5-3 shows revised depth-probabilities of the different sources.

Table 5-3 Example depth probability data with upper/lower bound uncertainties

Tidal risk			**Fluvial risk**			**Surface risk**		
Depth (m)	0.68	1.18	Depth (m)	0.418	0.444	Depth (m)	0.018	0.022
Probability	0.005	0.001	Probability	0.01	0.005	Probability	0.01	0.005
Lower bound	0.006	0.0008	Lower bound	0.009	0.0043	Lower bound	0.009	0.003
Upper bound	0.004	0.0012	Upper bound	0.011	0.0057	Upper bound	0.011	0.007

Lower/upper bound of probabilities can be added to the depth-probability curve; they are shown in following graph (Figure 5-9).Instead of one singe curve for each flooding source, there is an extended lower/upper bound of probability for each depth, and an area for each source.

The next question is: **what is the upper bound probability for the combined flooding risks?** To answer this, we need the depth-probability curve for the combined three flooding sources in worst case in the uncertainty range. Similarly, one may ask what the lower bound probability for the combined flooding risks is. This requires the depth-probability curve for the combined three flooding sources in a better-off case, in the uncertainty range..

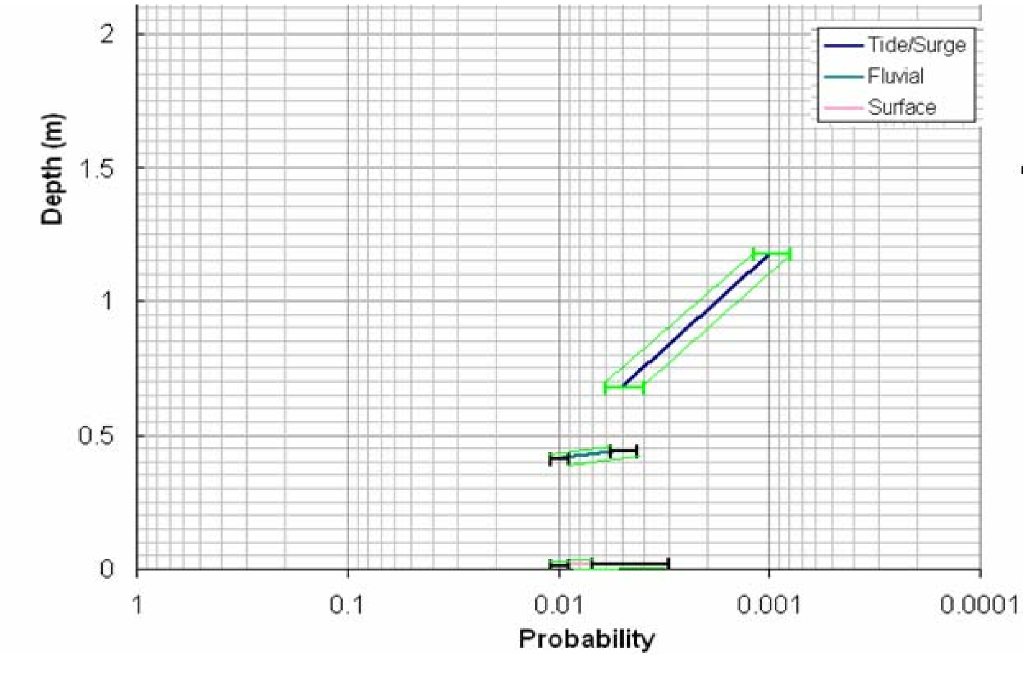


Figure 5-9 Depth-probability curves with upper/lower bounds

Combining upper bound depth-probability curves

Before combining probabilities from different flooding sources, we need to estimate the depth-probability relation which fell outside of the curve. Previously, **linear**

interpolation/extrapolation was used for outside areas, which was based on the assumption of 100 per cent confidence level for the depth-probability data for each source. For this case, where uncertainty was added and those areas are unknown, linear interpolation/extrapolation **CANNOT be** used for uncertain areas any more.

The following green dotted lines show the extrapolated depth-probability upper bound for unknown area. For an explanation of why the uncertainty upper bound probability is extrapolated in this way, see Section 5.2.5.

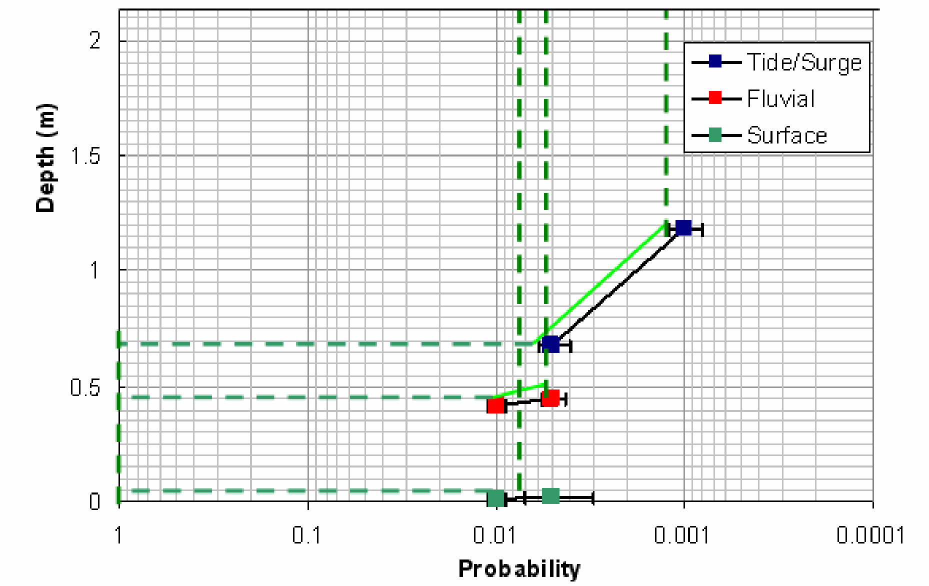


Figure 5-10 Interpolation/extrapolation for upper bound depth-probability curves

By adding the three upper bound probabilities for the three flooding sources, we get the following combined upper bound depth-probability curve (Figure 5-11). If this place is only at risk of those three different sources, the derived depth-probability curve represents the flooding risks at this place.

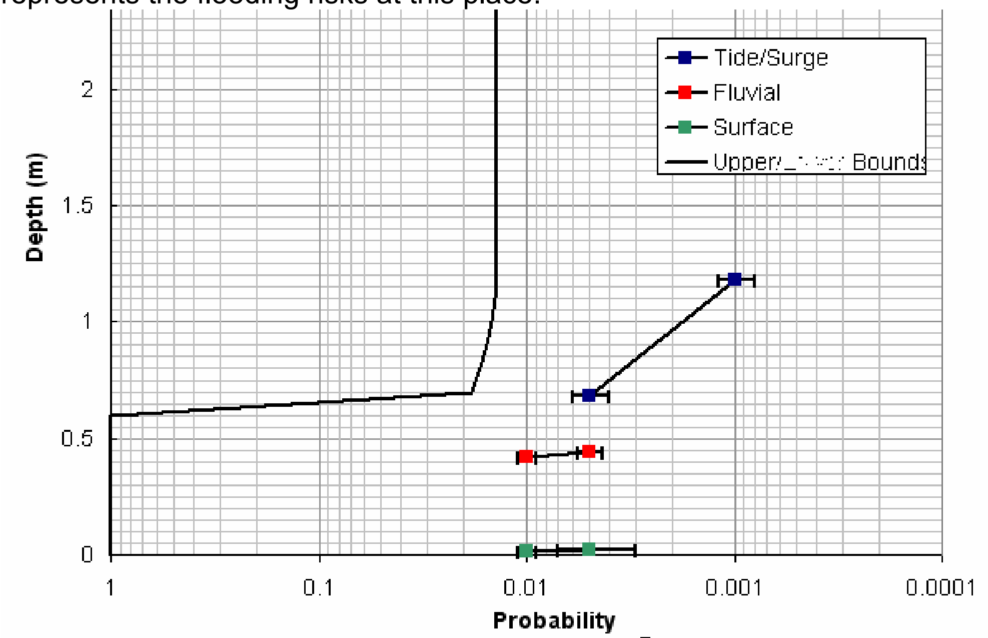


Figure 5-11 Combined upper bound depth-probability curve

Table 5-4 Calculated combined depth-upper bound probability values.

Depth (m)	0	0.5	1	1.5	2	2.5	3
Upper bound	1	1	0.014775	0.013845	0.013845	0.013845	0.013845

Combining lower bound depth-probability curves

The lower bound depth-probability extrapolation is done in a similar way. The following figures show the extrapolation for the three different flooding sources and the combined lower bound probability curve:

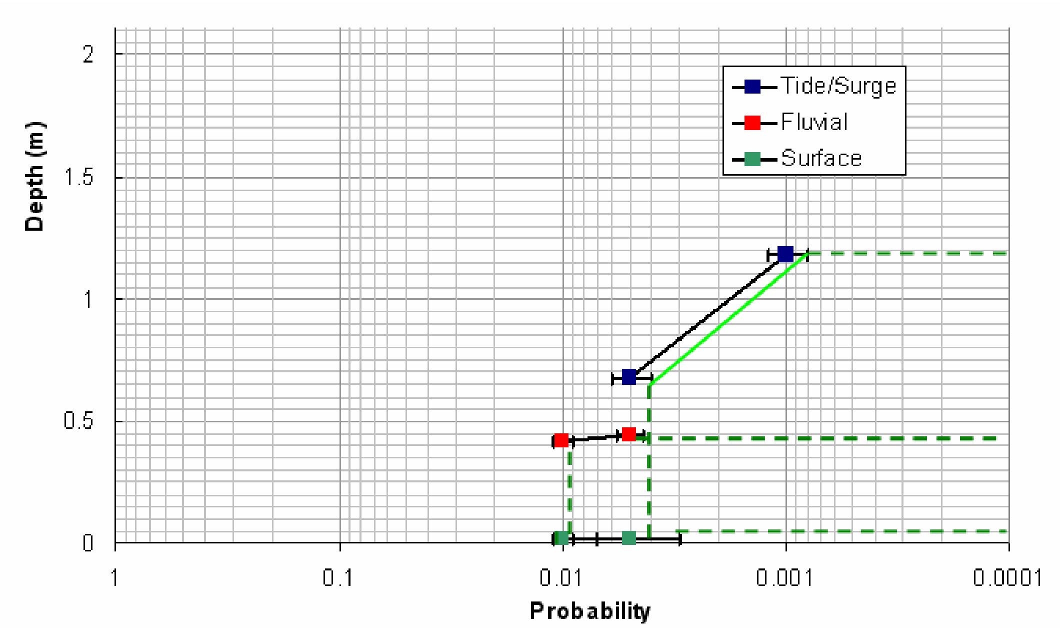


Figure 5-12 Interpolation/extrapolation for lower bound depth-probability curves

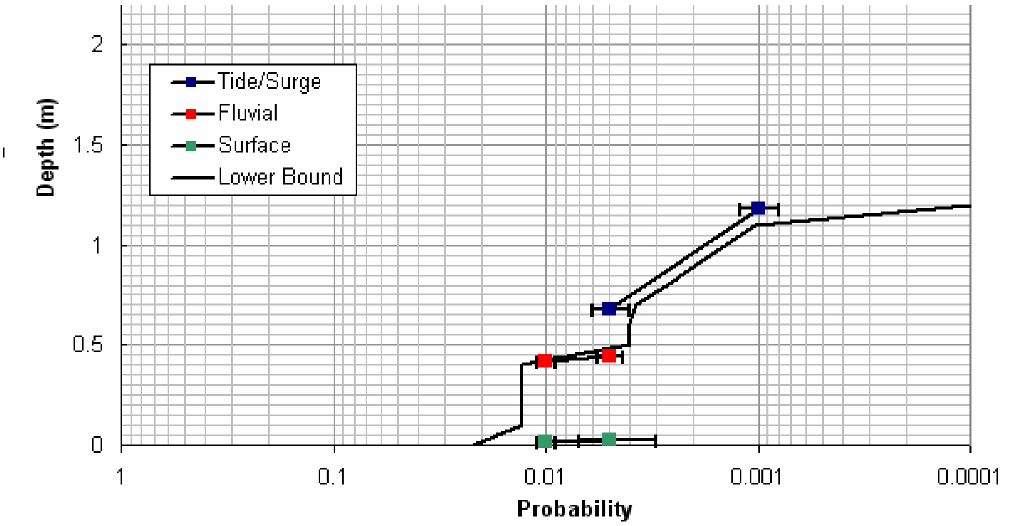


Figure 5-13 Combined lower bound depth-probability curve

Table 5-5 Calculated combined depth-lower bound probability values

Depth (m)	0	0.5	1	1.5	2	2.5	3
Lower bound	0.022	0.004	0.001428	0	0	0	0

5.2.7 Considering onset flooding probability

'Onset flooding probability' refers to the probability at which flooding at the location is expected to commence, for example, if a defence has a Standard of Protection such that it protects against an event with a one in 25 chance of exceedance in any year, this location is unlikely to flood more frequently that this standard. In this case, if the calculated combined probability of flooding is bigger than this onset flooding probability, the onset probability value should be used rather than the combined value. This conclusion is based on the assumption that onset flooding probability is more accurate than the MAST derived depth-probability value.

The onset flooding probability can be represented by a constant line perpendicular to the probability axis. The following figure shows a one in 10 (AEP=0.1) onset flooding probability on the depth-probability graph.

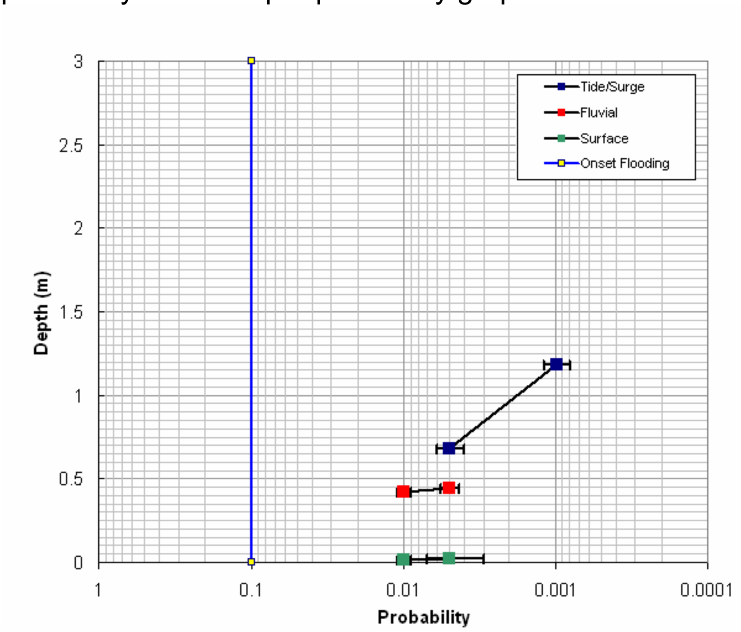


Figure 5-14 Onset probability curve in the depth-probability graph

If such an onset flooding probability exists, the combined depth-probability curve should be on the right of the onset flooding probability line, that is, any derived probability less than 0.1 has to be changed to 0.1.

5.3 Representing source interaction and dependency

The method described in the previous sections assumes that:

- Sources do not interact, so that the depth resulting from a forcing event (such as a fluvial flood) is not affected by another forcing event (such as a surface water event), unless the depth from the second exceeds the first.
- Sources are independent, so that the probability of two forcing events occurring at the same time can be ignored.

These assumptions allow depth grids to be combined without modelling any interaction between water from different sources. Modelling interaction requires detailed local data on joint probabilities and hydraulics, which at present have only been used in small-scale models. These effects may be important for some areas with high consequences, and the method described in this report allows the results of these local models to be included. To determine where local modelling may improve flood mapping, a method for determining where interaction and dependency may be significant is required.

The effects of the assumptions of no interaction and no dependency are strongly interlinked. If forcing events are more likely to occur together, their interaction may be more significant in generating flood risk. Nevertheless, interaction may be significant even for independent sources. An example is where it is extremely unlikely for sources alone to produce flooding above a depth threshold (say two metres), but there is significant consequence to flooding above a higher threshold (say 2.5 m). The probability of depth exceeding 2.5 m will in that case mostly come from a combination of sources, rather than each individually.

Representing the effects of interaction and uncertainty analytically in a computationally feasible way is extremely difficult. Instead, we have identified the key effects of interaction and dependency, and developed an approximate method to represent these effects (Figure 5-15). Within the framework developed here, if a more detailed understanding of source interaction and dependency is required, external modelling results can be brought in to represent this. External modelling should use the more rigorous methods described in Hawkes (2005), *FD2308 Use of joint probability methods in flood management: a guide to best practice*.

Figure 5-15 Effects of interaction and dependency to be represented by the method

	Effect	**Example**
1	Interaction and dependency will be most significant for areas where probabilities from two (or more) sources are approximately equal. Where one source dominates, interaction and dependency have little effect.	Dependency and interaction between fluvial and coastal flooding is most significant in the estuarine zone. Up and down stream of that, one or the other dominates.
2	Effects will depend on threshold depths and probabilities.	For a large threshold depth, the only events capable of producing flooding may be from a combination of sources. In this case the interaction and dependency may be major factors in determining risk.
3	Effects vary spatially across England and Wales, and the dependency can be characterised quantitatively using numerical dependency measures.	Tide/surge levels and river flows are more highly correlated for catchments in the west, compared to catchments draining to the east coast.

Effect 1 includes situations where sources may combine to produce flooding for events that, if they occurred in isolation, would be too small to generate flooding. An example is locking of storm water sewers or small drainage channels by high tide or river levels during a local rainfall event. This will tend to occur in locations where there is a probability of surface water flooding with ground levels close to sea or river levels, and hence where there is a probability of fluvial or coastal flooding. If this interaction is potentially significant, external modelling should be brought in to represent the effect.

We make the following assumptions to simplify the method used to represent the interaction and dependency effects:

- The interaction is modelled as being simply additive. If forcing events from two sources occur at the same time, the depth (or other hazard) is taken as the sum of the depths from the individual sources. This assumption will tend to overestimate depths. For example, increasing volumes of water filling a topographic depression will have less effect as depth increases, so doubling the volume will not double the depth.
- If we have a depth-probability relationship for each source, the depth-probability relationship for the sum of the depths is taken as the sum of the two source curves (adding depths). This approximates what should strictly be a convolution of the two probability distributions by a single point.
- Interactions and dependencies between three or more sources are assumed to be represented by the interactions and dependencies between each pair. Areas where three or more source interactions are important will thus coincide with interactions between each source pair, and the method described here will identify these.

Using these assumptions, we can simplify the FD2308 method of Hawkes (2005) to give a computationally tractable problem.

The description of joint probability between two variables is simplified by considering the distributions of individual variables (marginal distributions) and joint distribution separately. The marginal distributions can be described using standard statistical models (Gumbel, extreme value, generalised logistic and so on) which capture their behaviour for extreme events, and may be conditional on a threshold being exceeded (as in the peaks-over-threshold method). To represent the dependency, variables are transformed to variables with simpler distributions (such as uniform or normal), and dependency between these transformed variables expressed. The joint probability information in this transformed space is known as a copula. One useful property of the copula is that it is invariant under transformation of the marginal variables, and is thus independent of the details of the marginal distributions used to describe the probabilities for the individual sources.

FD2308 defines two copulas for use in modelling dependency between flood sources. The revised χ model is defined for two uniformly distributed random variables u and v (obtained by transforming the marginal distributions), and a dependency parameter α:

$$P(U > u \text{ and } \mathrm{V} > \mathrm{v}) = \exp\left(-\left[(-\log u)^{1/\alpha} + (-\log v)^{1/\alpha}\right]^{\alpha}\right) \tag{5.11}$$

The parameter α can be obtained from the χ parameter through:

$$\alpha = \frac{\log(2-\chi)}{\log 2} \tag{5.12}$$

The bivariate normal model is based on marginal variables transformed to normal distributions, and is itself a bivariate normal distribution with zero mean, unit standard deviation for both variates, and correlation parameter ρ. The parameters χ and ρ are given in map form in FD2308 for a number of pairs of variables, allowing the combined probabilities to be calculated. FD2308 defines the copulas for forcing (such as tide/surge height and river flow) rather than at receptor level, but since the copulas are invariant under transformation of the marginal variables, the copulas will also be applicable to floodplain depths. The only condition is that the relationship between forcing and water depth is monotonic and increases with flood magnitude (depth increases for bigger events).

The first step in the FD2308 method is to define the copula using χ or ρ, and to select a probability contour in [u,v] space, for example corresponding to the one per cent AEP. Examples of the χ copula are shown in Figure 5-16, and for the bivariate normal copula in Figure 5-17. The copula for χ=0 corresponds to independence between u and v, so that $P(U > u \text{ and } V > v) = P(U > u)P(V > v)$. For χ=1, u and v are totally dependent, and so $P(U > u \text{ and } V > v) = P(U > u)$ for u>v, and $P(V > v)$ for v>u. Figure 5-16 and Figure 5-17 illustrate how dependency, quantified by χ or ρ, makes most difference to probabilities near the diagonal of the plot. So for situations where u>>v, or v>>u, dependency has little effect on the probability, which accords with our intuitive understanding of joint probabilities in the first effect listed in Figure 5-15. Dependency has the greatest effect for areas of the [u,v] space near the diagonal, where the probabilities of flooding from the two sources are approximately equal.

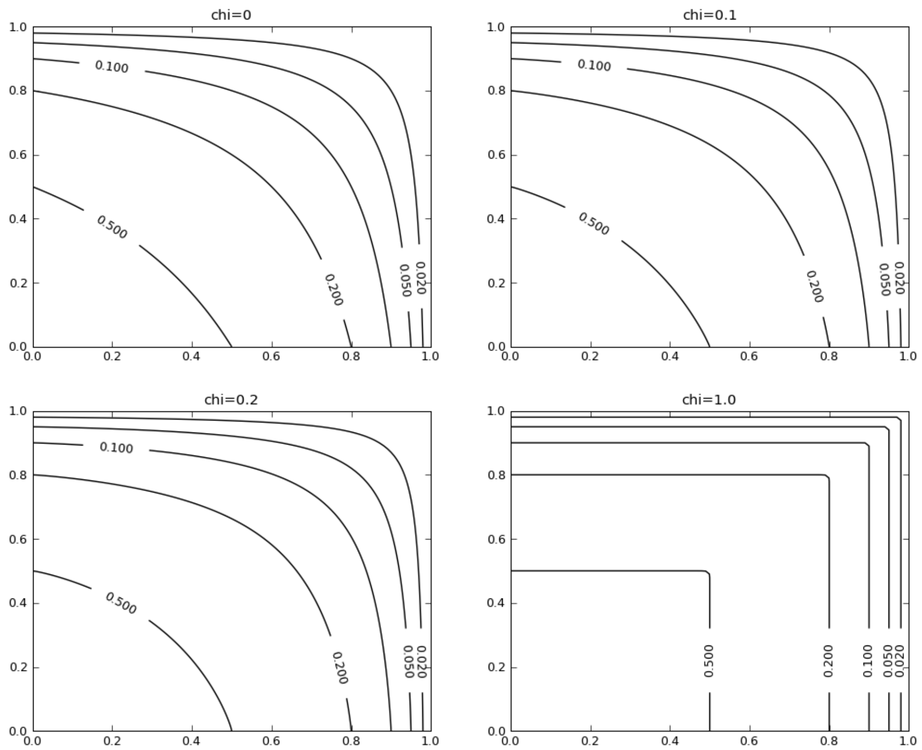


Figure 5-16 χ copulas for four different dependency parameters, drawn as contours of equal probability (labelled, not percent)

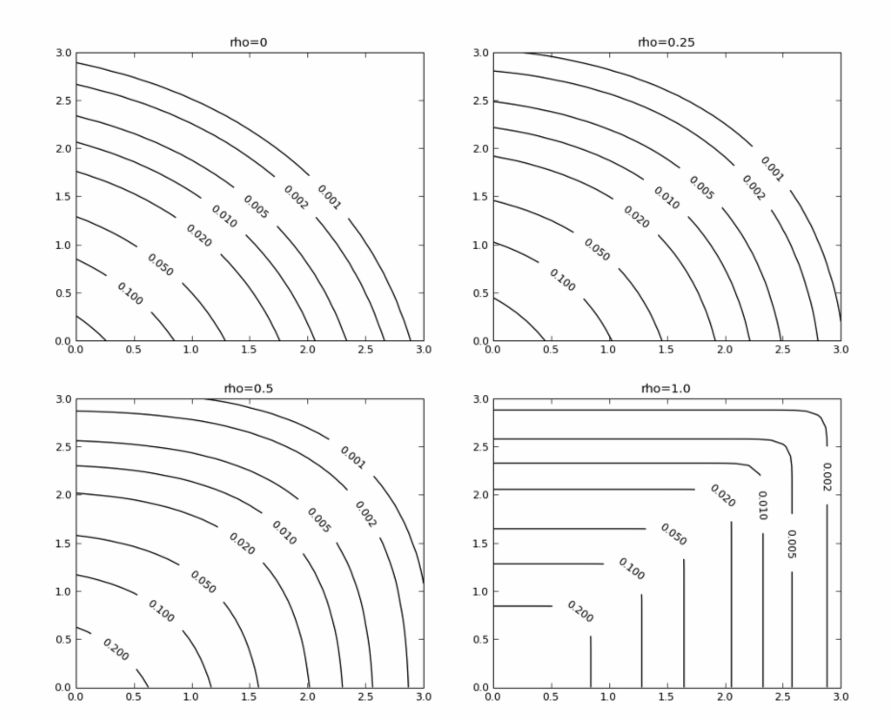


Figure 5-17 Bivariate normal copulas for four different dependency parameters, drawn as contours of equal probability (labelled, not percent)

The second step of the FD2308 method is to sample a number of forcing event condition sets (such as tide/surge levels and river flows) from along the chosen probability contour (one per cent in our example) in the [u,v] space. These can then be used to drive a hydraulic model, and the maximum depth (or other impact) from these models at the site of interest taken as the one per cent AEP depth.

For this project, we simplify this approach by firstly assuming that depths are additive, meaning that further model runs are not required. Secondly, we replace searching for the maximum depth along a probability contour, with searching for the maximum probability along a given depth contour. Thirdly, we only search three points: one on each axis, and one on the diagonal. The diagonal point is chosen as this is where dependency has the most effect on the probability given by the copula. The relative magnitude of the probability values at these three points gives a measure of the significance of interactions and dependency. This is illustrated in Figure 5-8 along with the equivalent method from FD2308. The algorithm is described below for two sources:

1. Select a depth threshold.
2. Calculate probabilities of this threshold being exceeded by each source individually, P_1 and P_2.
3. Create a lookup table of $d_{sum}(u)=d_1(u)+d_2(u)$, where u is the marginal variable transformed into a uniform or normal distribution (according to the copula being used), and d_1, d_2 are the depths from the two sources.
4. Use this lookup table to calculate the value of u for which d_{sum} is equal to the depth threshold.
5. Calculate the joint probability from the copula function, P_{Joint}.

6. Compare the probabilities from Steps 5 and 2, and classify according to:

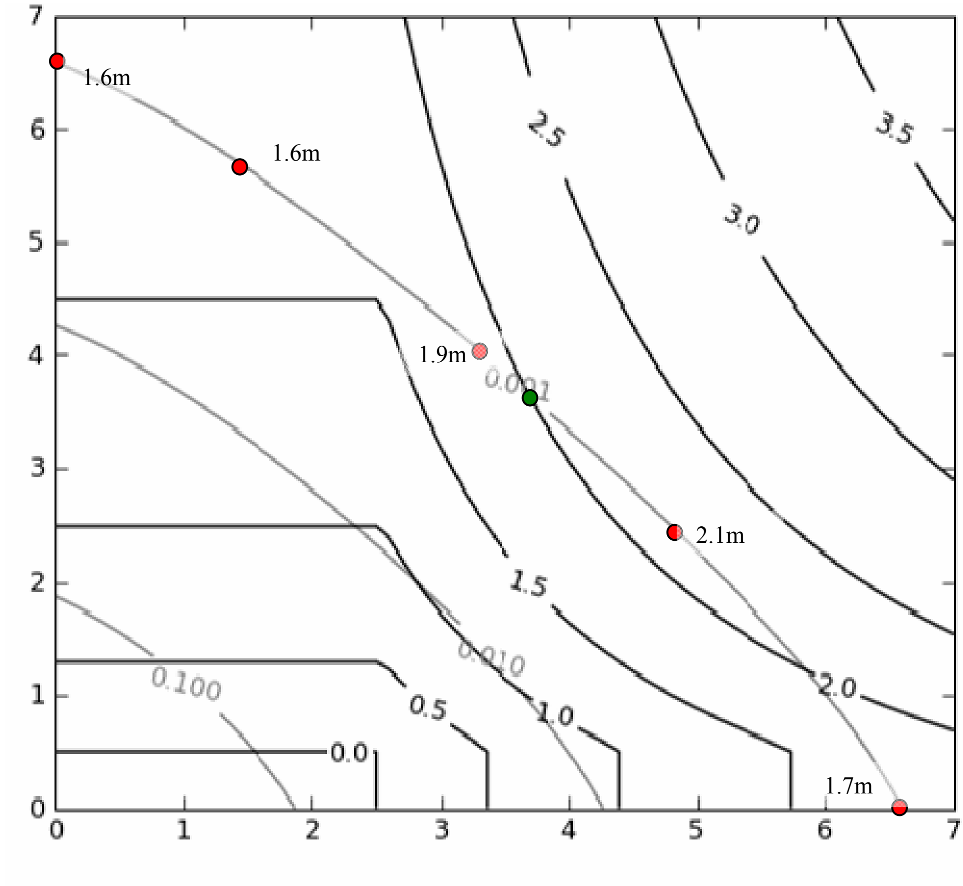
$\frac{P_{\text{Joint}}}{Max(P_1,P_2)} < 0.5$	Weak interaction/dependency
$1 > \frac{P_{\text{Joint}}}{Max(P_1,P_2)} > 0.5$	Potential interaction/dependency
$\frac{P_{\text{Joint}}}{Max(P_1,P_2)} > 1.0$	Likely interaction/dependency

7. When this classification has been calculated for each cell, display spatially.

The classifications in Step 6 are essentially arbitrary, but pilot testing demonstrated that these are reasonable.

For dependency between three sources, the method described above is applied to each pair of sources. This is possible since the method does not actually affect the output probability, and hence the calculation can be performed independently for a number of source pairs. Where interaction and dependency between three sources may be important, it can be identified as interaction/dependency areas common to the pairs. This is a heuristic argument for multivariate dependencies between flood data, but little information on suitable techniques and their application to England and Wales is available.

The method described here relies on the most common approach to representing dependency between extreme events: factoring out the marginal distributions and then describing the uncertainty between more well/behaved variates (uniform and normal in this case). This means the method should be relatively easy to update as further dependency information becomes available in the future. Currently, we have only a limited understanding of the contribution that dependency makes to flood risk at different scales (national, regional, local). While the method developed for the prototype tool is limited in its treatment of interaction between sources, it will allow us to make a consistent assessment of how widespread the effects of dependency and interaction are likely to be, and hence whether future risk assessments need to include more detailed approaches to mapping these effects.



FD2308 Method

1. Select probability contour e.g. AEP=0.1%.
2. Sample points along this contour (red dots).
3. For each point, calculate the equivalent values (e.g. tide/surge, flow) from marginal distributions.
4. Use these as boundary conditions in model to calculate depths (shown near red dots).

Take maximum depth as representative of 0.1% AEP = 2.1 m.

MAST Method

1. Select depth for which probability is required (e.g. 2 m).
2. Find intersection of diagonal and 2 m contour (green dot).
3. Find joint probability value of this point from copula (0.1%).

Compare this value with equivalent marginal distributions – if of similar magnitude, dependency and interaction may be important.

Figure 5-18 Method for calculating relative significance of interaction and dependency.
The copula function is plotted here in grey, against reduced variates to show extreme values better. The depths for interacting sources are shown in black, representing the result of summing the depths obtained from the marginal distributions.

5.4 Limitations

The following are considered to be the main limitations of the method or available data.

The method gives no indication of whether the combined exceedance probability or the extrapolated value is a better (more useful) estimate of combined probability. This is left as a choice for the user, but remains a subjective decision. Care will be required to inform users (who may be accessing outputs “second hand” rather than using the tool themselves) about the information that can be inferred from the tool’s outputs. We propose that the extrapolation method is used as a default, as this has been shown to give better results for the Hull pilot site. Both the combined exceedance probability and the extrapolated value must be viewed alongside the uncertainty estimates, which will guide the user on viewing the results with an appropriate level of confidence.

The data need to be scaled up to an appropriate level or the probability averaged over a larger cell.

The classification thresholds for potential and likely interaction need to be confirmed as appropriate.

Uncertainty information may not be available for some sources, even for “probabilistic” model outputs such as NaFRA. Future projects will supply information on uncertainty for some model outputs (such as SC090008/WP1 *Validation and Calibration of Probabilistic Flood Models*) which can be used with the method developed for this project. Other uncertainties, such as those associated with national surface water mapping, may be more difficult to quantify.

Dependency data is not available for some pairs of sources, most significantly local rainfall and fluvial flows. This is a complex issue linked to spatial-temporal rainfall behaviour and catchment hydrology across a broad range of scales. SC060088 *Spatial coherence of flood risk* may provide some information on dependency between flows in large and small catchments, which may be useful as a proxy for fluvial flows and local rainfall. It is also worth investigating the dependency between fluvial and coastal flooding, which may be useful in the future in mapping the effects of dependency.

Explicitly representing dependency between three or more sources. A heuristic method has been described in this section, but a more rigorous approach may be required for future versions of the tool. The tool as specified here will at least give some indications of areas where three-or-more way interactions may be significant, and hence whether a more sophisticated approach is required.

The method cannot deal with interaction/dependency for data sources represented by a single depth/probability grid (such as current national surface water mapping). More generally, single depth/probability grids give limited information when combined with other sources. A fuller description of the depth-probability curve is required to make the most of combined flood probability information.

The method concentrates on uncertainty in depths and probabilities, rather than in terms of spatial uncertainties (uncertainty in flood extent). For some input data types, the method will represent spatial uncertainty. For example, if a grid represents the “upper bound” water depth and this includes a greater flood extent that the “best estimate”, the difference between the two extents can be represented spatially as a band of uncertainty.

6 Appendices

Appendix A: Format of input shapefile for MAST calculation engine

The input grid shapefile naming convention

XXXXX_input.shp

XXXXX **-** Denotes the scenario name.

Definition of input grid shapefile fields:

Field Name	Type	Description
UID	Long	Unique ID of the cell
XXXXXXXX	Double	Resampled grid data stored as attributes of the Cell shapefile

Explanation of field names

Note: The length of the field name is restricted to nine characters due to the limitation of dbf file.

1 2 3 4 5 6 7 8 9 - Eight placeholders for nine characters in the filed name.

1 2 - Denotes flooding source type, 01 for fluvial, 02 for coastal, and so on.

3 - Denotes the hierarchy of the dataset for the flooding source type defined in 1 2 placeholder.

4 - Denotes the uncertainty category (L, B, U) of the dataset, (L for lower bound, B for best estimate and U for upper bound).

5 - Denotes the data type (D, P) of the spatial varied dataset, (D stands for input depth grid and P stands for input probability grid).

6 7 8 9 - Varies as follows:

- For a depth grid input (D for 5), the decimal part of the probability associated with the grid is used as an identifier with padded zeros if it is shorter than four placeholders (e.g. 0.01 is written as 0100, 0.005 is written as 0050).
- For a probability grid input (P for 5), the depth threshold associated with the grid is expressed in millimetres (e.g. 0 m is written as 0000, 1 m is written as 1000).

Example of field name

Field name **F1BD1000** indicates the cell value is the flood probability for depth threshold of one metre, from the best estimates of the hierarchy one fluvial flooding dataset.

Appendix B: Format of output shapefile for MAST calculation engine

The output cell shapefile naming convention

XXXXX_Output_YZZZZ.shp

XXXXX **-** Denotes the scenario name.

Y **-** Denotes the data type (D, P) of the spatial varied dataset, (D stands for input depth grid and P stands for input probability grid).

ZZZZ **-** Varies as follows:

- For a depth grid input (D for Y), the decimal part of the probability associated with the grid is used as an identifier with padded zeros if it is shorter than four placeholders (e.g. 0.01 is written as 0100, 0.005 is written as 0050).
- For a probability grid input (P for Y), the depth threshold associated with the grid is expressed in millimetres (e.g. 0 m is written as 0000, 1 m is written as 1000).

Definition of output grid shapefile fields

Field Name	Type	Description	Description of Placeholder
UID	Long	Unique ID of the cell	N/A
xResult	Double	One uncertainty category of the combined result according to the user output specification.	x stands for the uncertainty category of the results (L for lower bound, B for best estimate and U for upper bound).
xDOM_SRC	String	The dominant source for one uncertainty category result.	x stands for the uncertainty category as above.
xSCON_y	Double	The percentage contribution of the designated source towards the combined result for the indicated uncertainty category.	x stands for the uncertainty category as above. y stands for flooding source type, this is an integer reference as defined in associated MAST project file.
xDEP_y_y	Integer	The indicator of the dependence between the designated sources: 1 = weak dependency 2 = potential dependency 3 = likely dependency.	x stands for the uncertainty category as above. y stands for flooding source type as above.
ERR_FLAG	Integer	Error flag number.	N/A
ERR_DESC	String	Error description associated with ERR_FLAG.	N/A

Appendix C: MAST quick start guide

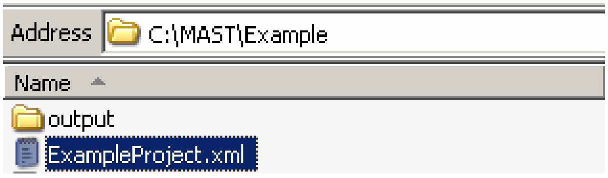
Introduction

This document provides a step-by-step guide on **how to load an existing MAST project** into the MAST interface and then run new simulations and view the results that are produced. It should be used in conjunction with the example MAST project file (ExampleProject.xml) and associated GIS data files that are included in the MAST installation. For more information about MAST installation, please refer to the 'MAST install read me' file which is provided with the software.

Step 1 Set up the example data

The project XML file uses an absolute file path to locate input data. To ensure the project file works correctly, do one of the following:

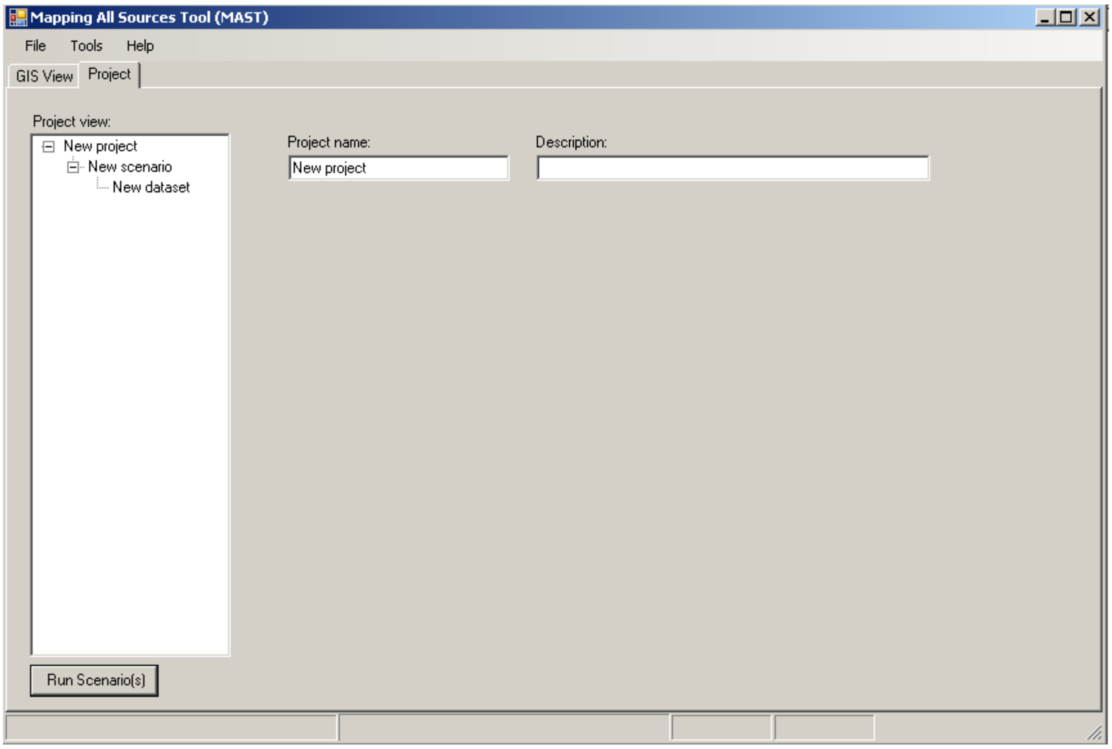
- If you have installed the software and examples as suggested in the installation 'read me' file, you do not need to do anything further.
- If you have specified a different folder location to the install default, copy the "Example" folder created by the install to the location: "C:\MAST" (you should now have a folder structure of "C:\MAST\Example" with contents as shown below). You should see the project XML file ("ExampleProject.xml") located in this folder – this is your MAST project file.



- If it is not possible to create this file path, you will need to open the example MAST project file ("ExampleProject.xml") in a text editor and manually edit all references to "C:\MAST\Example", changing them to the file path where you have located your "Example" folder.

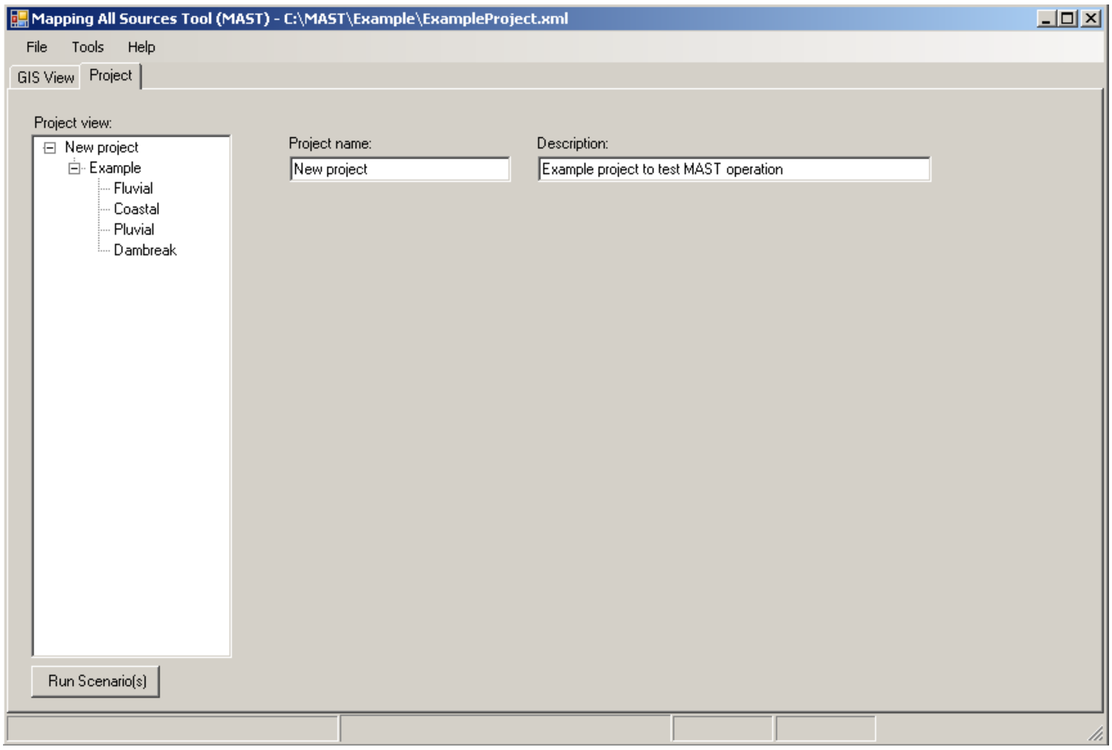
Step 2 Run MAST

Browse to the folder location where you installed MAST, open the "program" folder and double-click on the file: "MAST.exe". You should see the following display (Note: MAST might take a few seconds to start up).

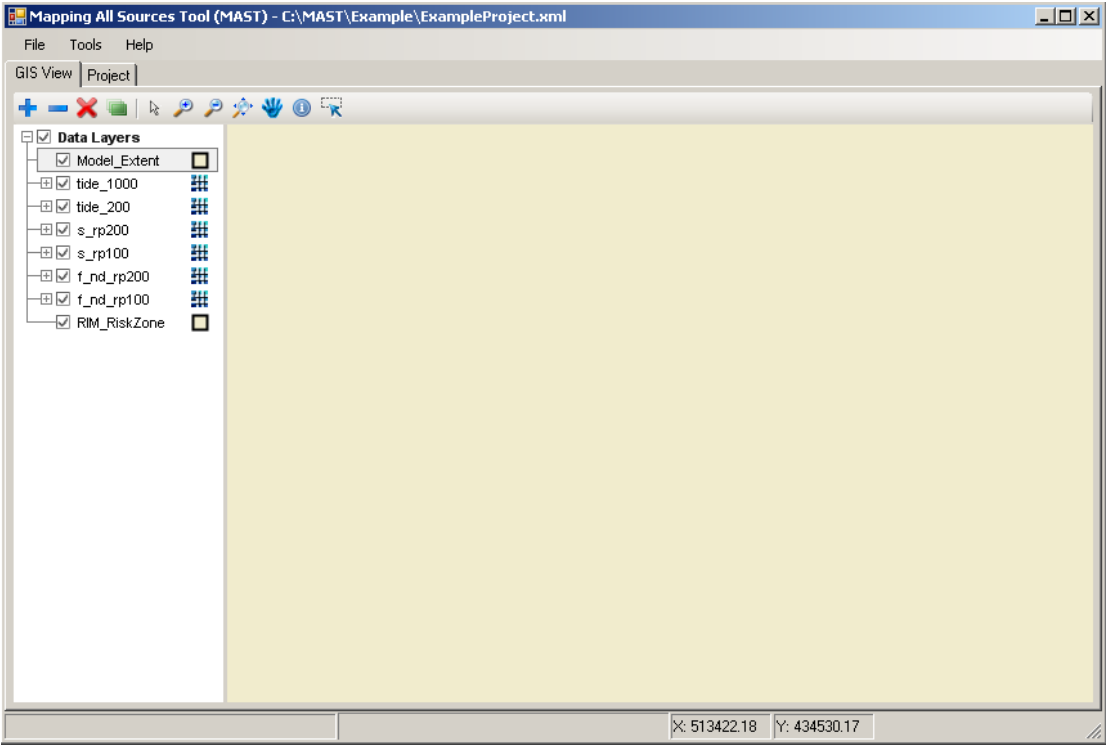


Step 3 Open the example project

Select ‘Open Project‘ from the File menu. A standard Windows Explorer window will be displayed. Browse to the location of your ExampleProject.xml MAST project file. Select the file and click ’Open’. The project data should start loading (this will take a few seconds). When loading is complete the MAST Interface should look like this:



And if you switch to the GIS View by clicking on the ’GIS View’ tab the display should be:

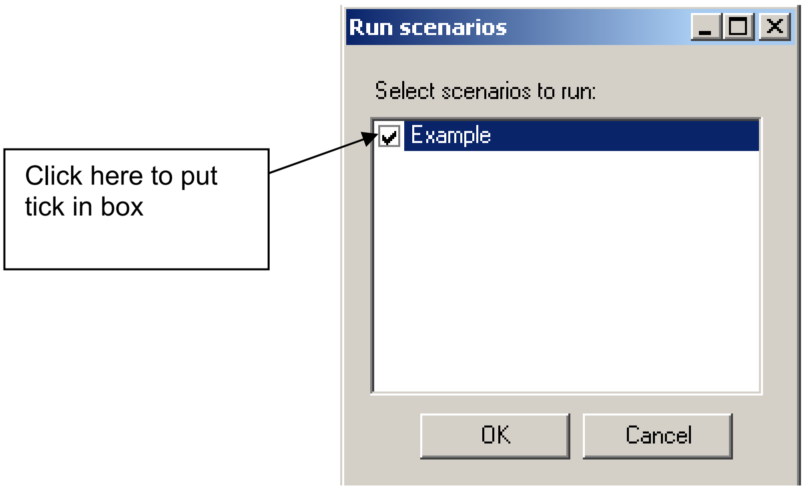


Initially all data layers are active (and you can only see the top layer entitled “Model_Extent”). You can switch off layers on the view, in order to view all data loaded, using the tick-boxes on the left of the screen (in the table of contents). Alternatively drag different layers to the top of the view by highlighting them, holding the left mouse button down and moving the layer up the order.

Step 4 Run a new simulation

A simulation is already defined in this example project (this will output probability results for an output depth threshold = 0 m). Thus, after loading this project into MAST you should be able to immediately click the ‘Run Scenarios’ button (located in the lower left corner of the Project tab) and proceed to run a new simulation.

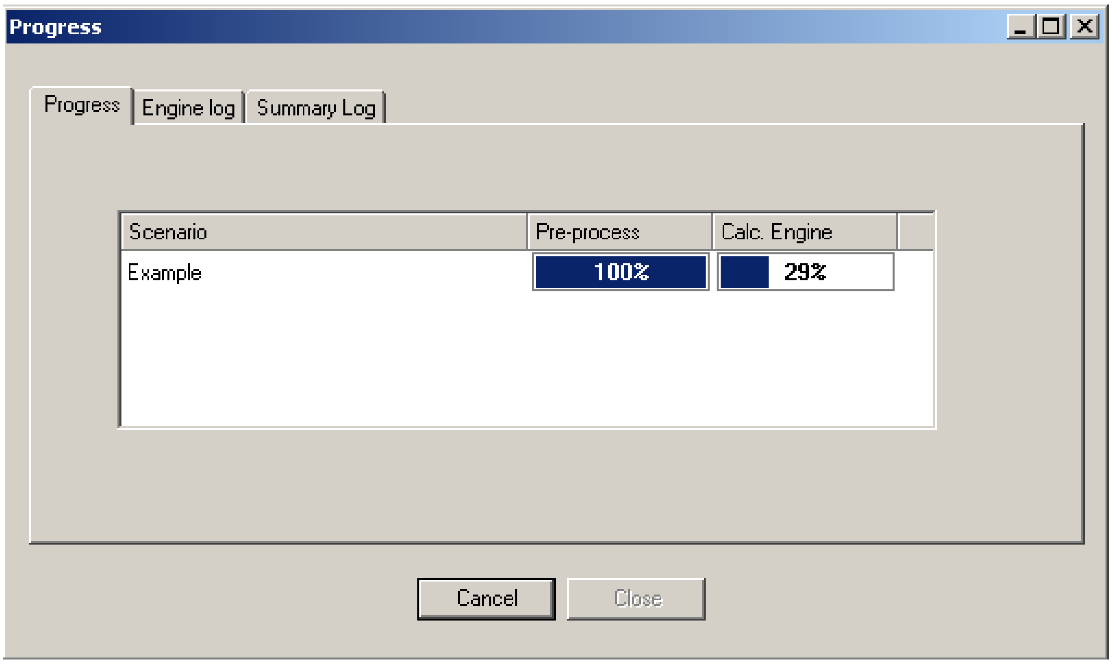
A window will be displayed listing the available scenarios to run within the project. There is only one, called Example, tick the tick-box alongside it to true and then click ‘OK’ to proceed, as shown below:



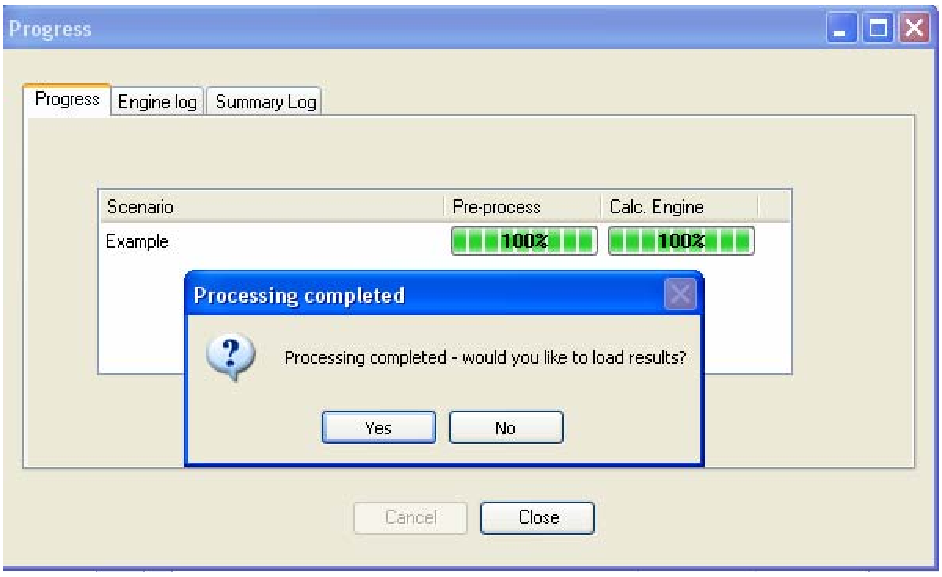
If you have already tried running a simulation you may be prompted to overwrite existing results files as shown below:

In this case click 'OK' to continue. On other occasions you may want to abort the simulation (by pressing 'Cancel') and then move the already generated results to a different location before re-starting your simulation.

Your MAST simulation will now begin. A Progress window will be displayed, as shown below, which shows progress through first the pre-processing stage and then the main calculation stage.



When the simulation is complete the following message box is displayed:



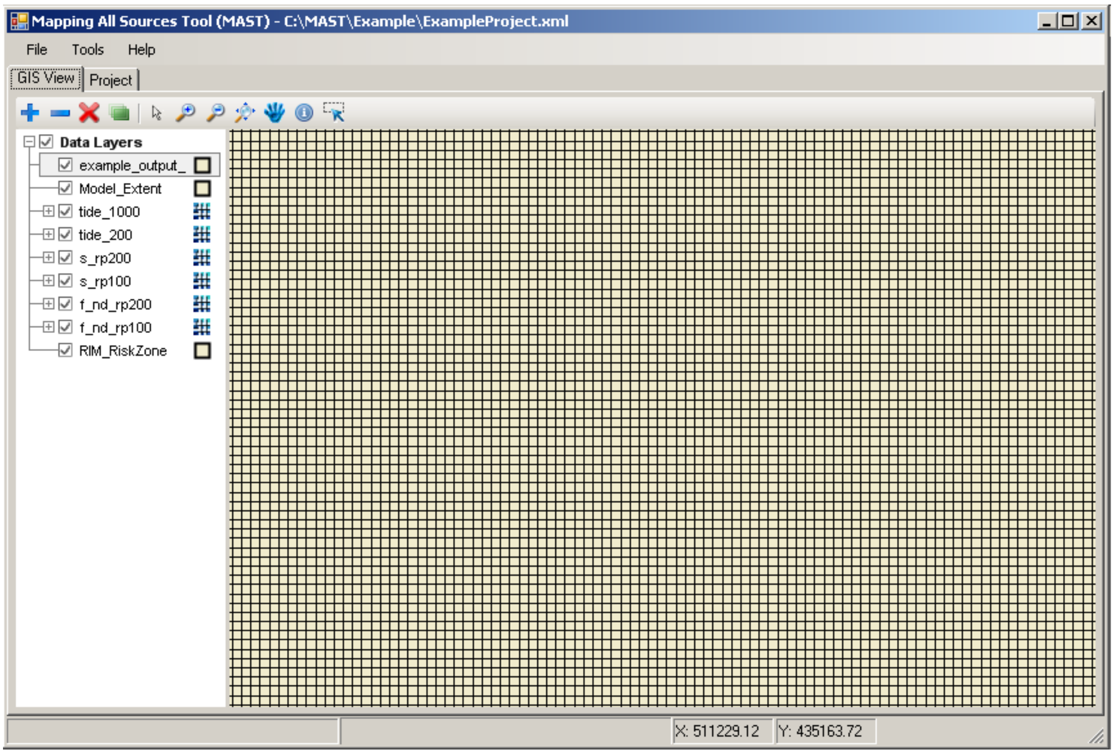
Click the ’Yes’ button to load the model result. If you prefer not to load the result file straight way, click the ’No’ button. The result file can be loaded to the GIS View later on.

You can now view the results your simulation has generated.

Step 5 Review your simulation results

Once your simulation has completed, click on the GIS View tab to display the map view. Then click the icon:  in the GIS View toolbar. This should automatically load your results to the top level of the map view. (If it does not work, use the icon:  in the GIS View toolbar to browse to your results file “*C:\MAST\Example\output\Example_Output_P0000.shp*” – after browsing, highlight the file and click ‘Open’ to add it to the map view.)

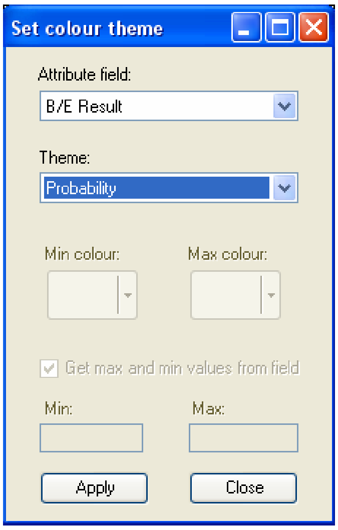
After the results data are loaded, the GIS View should look like the screenshot shown below:



This is your grid of calculation cells, but with no results data assigned to the colour scaling.

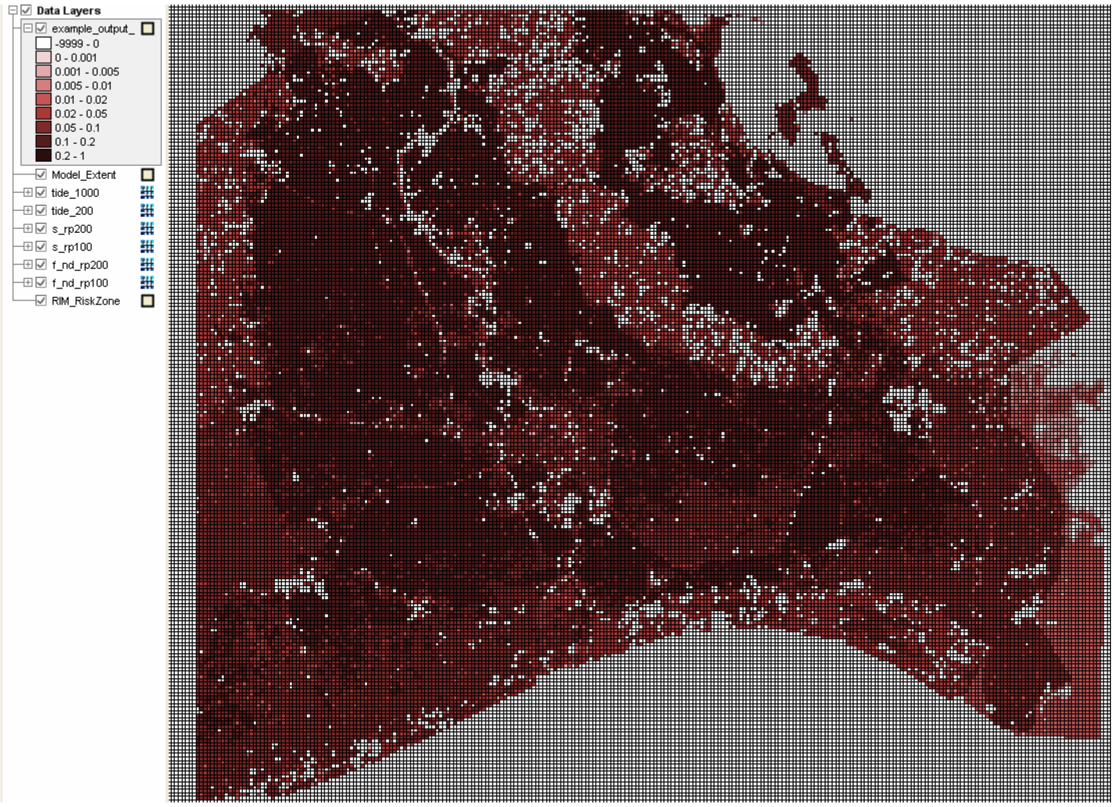
To show the <u>best estimate of combined flood probability values that correspond to a 0 m threshold</u>:

1. Highlight your results file in the Table of Contents of the GIS view.
2. Click the right mouse button and select ’Set Colour Theme’. The colour theme window will be displayed as shown below:



3. Select “B/E Results” (B/E means best estimate) from the “Attribute Field” dropdown list.
4. Select ”Probability” in the Theme dropdown box.
5. Click ‘Apply’ to activate these settings and then ‘Close’ to shut down the colour theme window.

The resulting data should look like the example shown below:

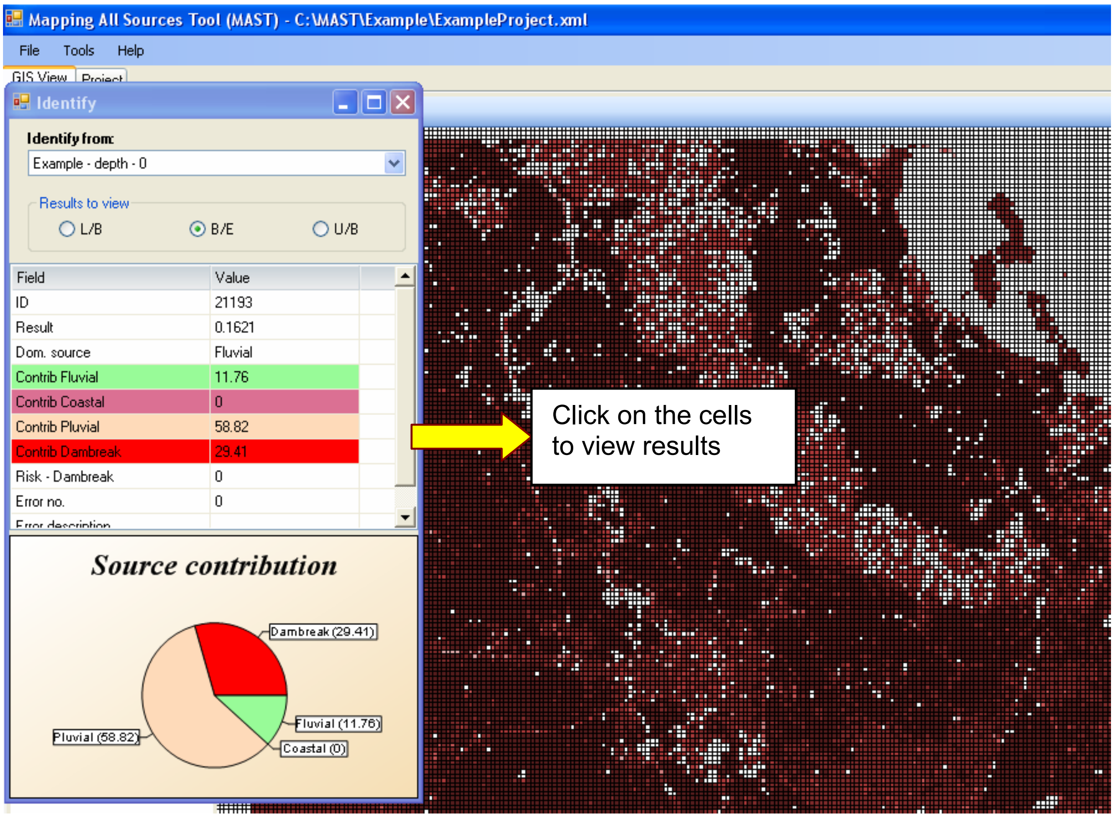


To view the information at a particular calculation cell:

1. In the GIS View, click on the information tool icon  in the GIS Toolbar. The mouse pointer will change to “**+i**“.
2. Click on an area of interest on the displayed map. An information window will be displayed as shown below.
3. The information window contains the combined probability from all sources (best estimate or B/E), the uncertainty associated with this result and the different component sources of flooding that produced the combined figure (together with their individual levels of contribution).

4. The information window will be refreshed every time you click on a different location on the map view.

5. The information tool is deactivated by clicking the icon  in the GIS Toolbar a second time. The information window will remain on screen until you close it (by clicking the button in the top right corner of the window).



Step 6 Next steps

You can now try to make changes to the example project and then re-run the simulation engine to produce your customised results.

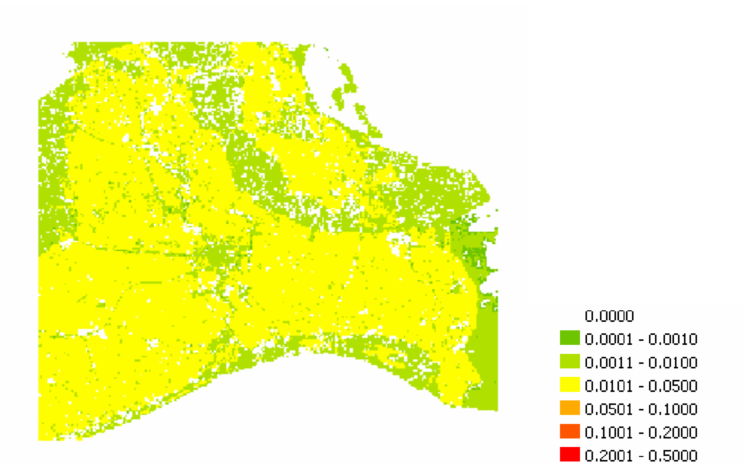
Steps 7 and 8 provide some guidance on making simple changes to your project. If you require further guidance on using the MAST interface, you should refer to the MAST User Guide.

In addition to further familiarising yourself with the MAST software, you can also load the MAST output file into a specialised GIS package, such as ESRI ArcMap. This should enable you to extract specific parameters held within the output shapefile's attribute file and export them as standalone grids. The way these are viewed can then be customised (for example, by changing the colour legend) to produce outputs such as the examples shown below.

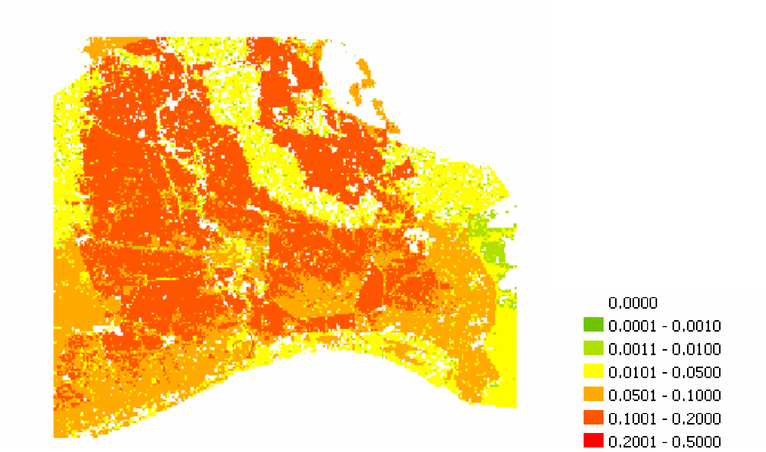
Sample outputs

The following output probability results are for an output depth threshold setting of zero (as already set in the example project):

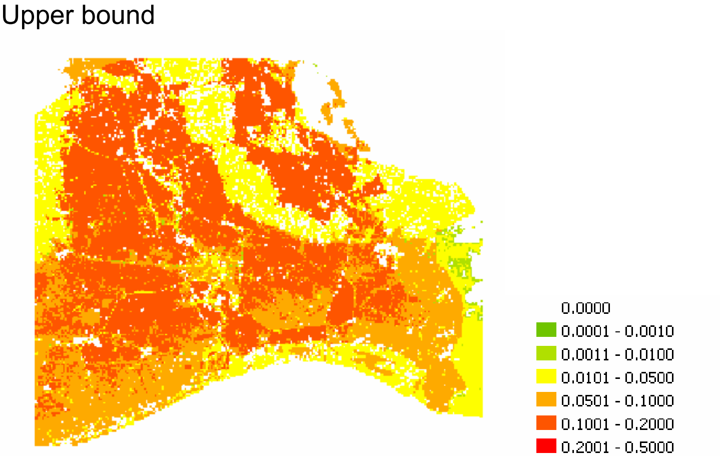
Lower bound



Best estimate



Upper bound



Step 7 Reviewing project data

To review the details of the datasets associated with your Project, first return to the Project view by clicking on the “Project” tab.
The “Project View” on the left side of the display shows a tree view made up of the following branch levels:

- **Top level = Project**, which is called “New Project” in this example.
- **Second level = Scenarios**, there is only one in this example, called “Example”.

- **Third level = Datasets**, there are four datasets assigned to the defined scenario (fluvial, coastal, pluvial and dam break).

For whichever branch of the tree view is highlighted, the associated metadata for that item will be displayed to the right of the tree view. If you click on a dataset in the tree view, you will be able to see:

- The source of flooding the dataset represents.
- What settings have been used (for example, how regions beyond the extent of the data layers are handled).
- Which data layers are specified within the dataset - details of the data layers held in the datasets within the example project are shown below:

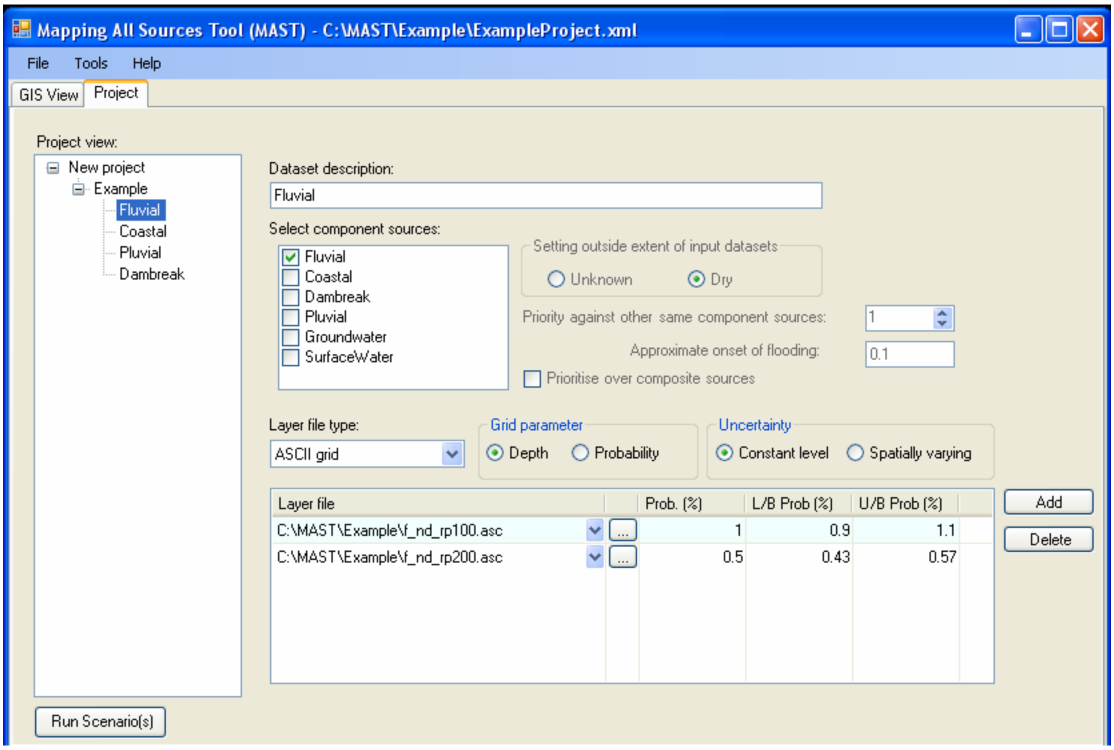
  Fluvial depth grids
  - 1 in 100: f_nd_rp100.asc
  - 1 in 200: f_nd_rp200.asc

  Coastal depth grids
  - 1 in 200: tide_200.asc
  - 1 in 1,000: tide_1000.asc

  Pluvial depth grids
  - 1 in 100: s_rp100.asc
  - 1 in 200: s_rp200.asc

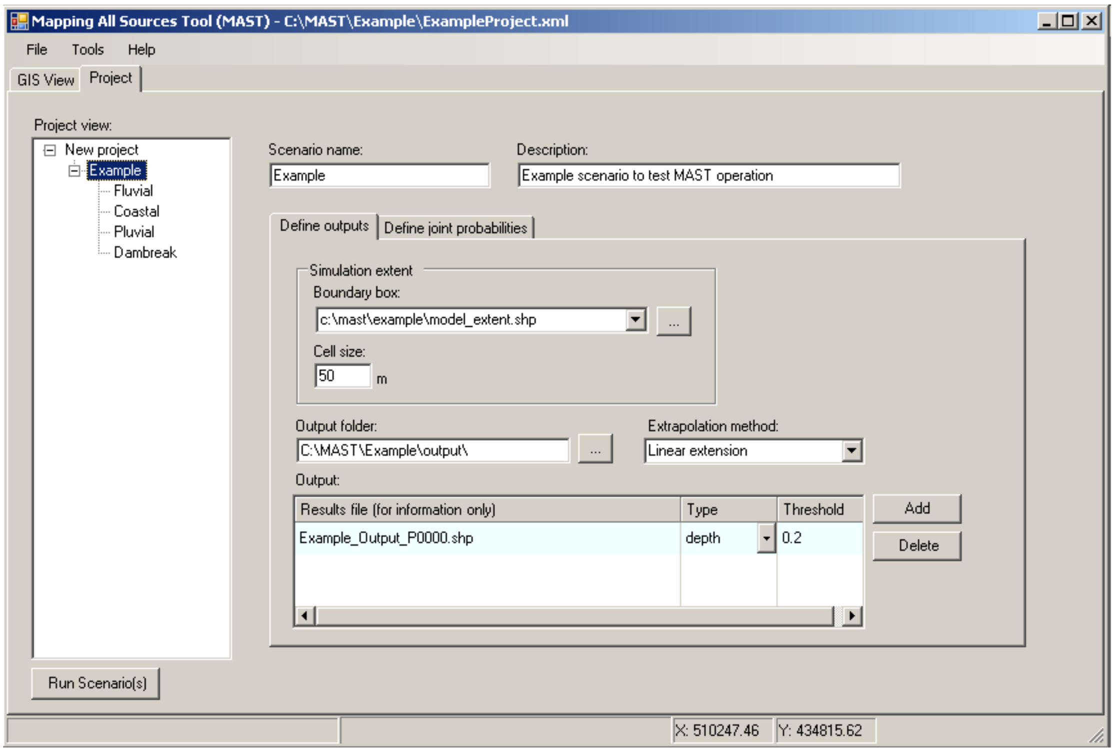
  Dam break risk zone shapefile:
  - RIM_RiskZone.shp

The example below shows the settings for the fluvial dataset:



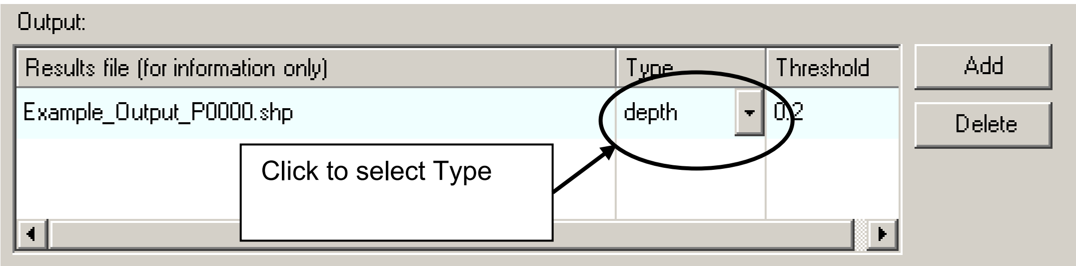
Step 8 Generating different results

The loaded data can produce many different outputs – these are defined in the 'Define outputs' tab within the Scenario definition. Here, we are going to change the threshold of flooding. Click on the scenario called "Example" in the Project View. The Project tab will then display the scenario settings as shown below:



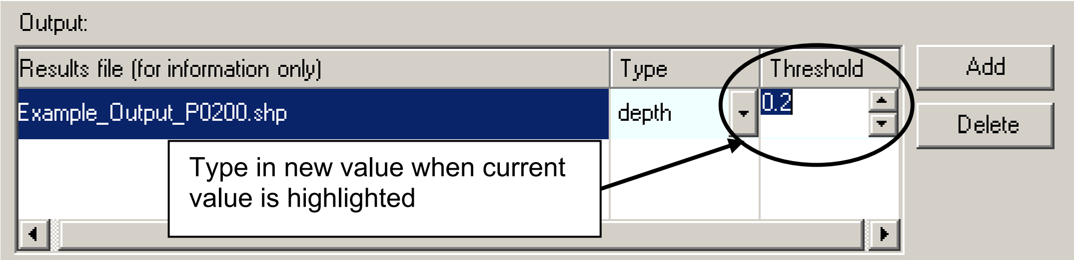
To create a new simulation output you need to edit the outputs table as follows:

1. Select the type of output – either depth (output will be probability of reaching the specified flood depth at each calculation cell) or probability (output will be depth in each calculation cell for specified probability of flooding).



2. Select threshold level – Double-click on threshold value in the Output table. The cursor should appear in the cell enabling you to enter a new value. Threshold depths should be entered in metres and threshold probabilities should be entered as AEP decimal values, that is, between zero and one (typical values are shown in the table below).

Chance of flooding in any year	Chance of flooding in any year	Annual exceedance probability (AEP)
1 in 10	10%	0.1
1 in 50	2%	0.02
1 in 100	1%	0.01
1 in 200	0.5%	0.005
1 in 1,000	0.1%	0.001



You can run simulations with multiple output thresholds defined. Use the ‘Add‘ (and ‘Delete‘) buttons to add (and remove) entries in the Output table. MAST will automatically generate a name for your output files, based on a combination of the scenario name, output type setting and output threshold value.

When you are satisfied with your defined outputs, save the project file to save your revisions (use File | Save Project in the main menu). Then click on the ‘Run Scenarios’ button to start your new simulation.

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