

TUFLOW FV Release Notes

Build 2019.01

www.tuflow.com

[TUFLOW FV Wiki](#)

[TUFLOW Tutorial Model](#)

support@tuflow.com

[GIS Integration Tutorial](#)

Document Updates and Important Notices

March 21th, 2019: TUFLOW FV 2019.01 is a major release that includes a significant range of new functionality, enhancements and minor bug fixes. For new modelling projects it is recommended to upgrade to Build 2019.01 to make use of this new functionality and improved workflows. For existing projects, while we have to provide backward compatibility it is possible that there will be slight variations in results due to changes in compiler and code enhancements provided in Build 2019.01. If upgrading an existing model the user is recommended to assess potential changes and re-calibrate if required.

Both Windows and Linux operating system builds are available on the [TUFLOW Download Page](#).

Note, this document will be updated from time-to-time with any new builds or new content. A new TUFLOW FV User Manual for 2019.01 is currently in final stages of documentation will soon be available. In the interim please use these Release Notes in combination with the existing [TUFLOW FV Manual](#).

A step-by-step GIS integration tutorial is also provided as Appendix A to these release notes.

Licensing and Executable Versions

To run simulations using the Windows or Linux 2019.01 build requires payment of the 2018/2019 annual software maintenance fee and for the TUFLOW licence to have been updated (ie. via RaC/RaU files). For tutorial and demo models, or if running in free demo mode, no licence is required. For any licensing enquiries please contact sales@tufLOW.com, or for general support support@tufLOW.com. Use of the TUFLOW software suite is bound by the [TUFLOW Products Licence Agreement](#).

Table of Contents

Document Updates and Important Notices	2
Licensing and Executable Versions	2
1 2019 Release Overview	5
2 Benchmarking	6
3 GIS Integration	7
3.1 TUFLOW FV Tutorials for GIS Integration.....	7
3.2 Set the GIS Format for Check File and Empty File Output	7
3.3 Set the Spatial Reference System.....	7
3.4 Creating 'Empty' GIS Template Files	8
3.5 Layering of GIS Inputs	9
3.6 Topographic/Bathymetric Update Commands.....	10
3.7 Read GIS Nodestring.....	13
3.8 Material Update Commands	14
3.9 GIS Check Files.....	15
4 Model Geometry	16
4.1 Elevation Polyline File.....	16
4.2 Surface Sigma Layers	16
4.3 Echo Geometry.....	16
5 Boundary Conditions	18
5.1 Grid Definition Block	18
5.2 New Sub-type for OBC boundary conditions.....	20
5.3 QN Boundaries	20
6 Hydraulic Structures	21
6.1 Linked Nodestring Boundaries	21
6.2 Real-Time Structure Controls	21
6.3 Autoweir	22
6.4 Scalar Functions	22
6.5 Structure Check Output	22
7 Output Types	24
7.1 XMDF.....	24
7.2 SMS Super Files .sup	24
7.3 Velocity Output	24
7.4 Flood Hazard Outputs.....	24
7.5 Profile Outputs	28

7.6	Evaporation Map Output.....	28
7.7	Structure Outputs.....	28
8	Visualisation and Model Development Tools	30
8.1	MATLAB Toolbox.....	30
8.2	Python Toolbox	30
8.3	TUFLOW Viewer QGIS Plugin.....	30
9	Atmospheric Heat Exchange Module	31
9.1	Ice Module	31
9.2	Precipitation Temperature	31
9.3	Wind Stress and Atmospheric Stability Commands	31
10	Water Quality Module	33
10.1	AED ² Version 1.3.0.....	33
10.2	Dynamic Coupling of Light and Light Extinction	34
11	Sediment Transport Module	35
11.1	Overview	35
12	Particle Tracking Model (Beta)	36
12.1	Overview	36
13	Mesh Generation Tools	37
13.1	Aquaveo SMS.....	37
13.2	Rising Water Software GIS Mesher.....	37
14	General Updates	38
14.1	Folder Creation	38
14.2	String Matching Bug Fix.....	38
14.3	Improved expected variable echoing in log files.....	38
14.4	Imperial Units	39
15	Licensing	40
15.1	New software lock licensing options.....	40
16	Tutorials and Supporting Materials	41
16.1	User Manual.....	41
16.2	Tutorial Models	41
16.3	TUFLOW FV Wiki	42
16.4	TUFLOW LinkedIn	42
17	Appendix A – TUFLOW FV GIS Tutorial	43

1 2019 Release Overview

The 2019 Release incorporates the significant investment and development added to TUFLOW FV over the past several years. Major new features and enhancements include:

- TUFLOW FV integration with Geographic Information Systems (GIS) to assist with rapid model development and improved spatial review
- Improved open boundary condition conditions
- New output formats and parameters
- New tutorial models for 3D hydrodynamics and water quality modelling
- Improved error messaging and logging
- Improvements to structure blocks and operational structures
- Water quality module default coupling with the AED² Version 1.3.0
- New 3D Particle Tracking Module (PT)
- Enhancements to the Sediment Transport Module (ST)

As always, it is recommended that when switching to a new build with an established model that test runs are carried out and comparisons made between the old and new builds (subtracting the two maximum data sets and reviewing any differences is an easy way to do this). If you have any queries or require clarification or more detail on the Release Notes please email support@tufLOW.com.

2 Benchmarking

The 2019.01 (Build ID 2019.01.008) Commercial Release of TUFLOW FV has been benchmarked against the UK Environment Agency 2D Hydraulic Model Benchmark Tests and the results are available via the [TUFLOW Website](#). The benchmarking report presents the performance of the TUFLOW Software suite against benchmark tests developed during the Joint UK Defra / Environment Agency (EA) research programme into assessing 2D hydraulic modelling software. The UK EA released their original report in 2010 and again in 2012 to accommodate new developments and software since 2010. There has been no update of the 2012 report as of 2019. The UK EA reports can be downloaded from:

<https://www.gov.uk/government/publications/benchmarking-the-latest-generation-of-2d-hydraulic-flood-modelling-packages>. This report presents the results using the 2019 release version of TUFLOW FV.

3 GIS Integration

Build 2019.01 of TUFLOW FV now integrates with GIS allowing you to assign nodestrings, cell materials and cell elevations independent of mesh generation. GIS integration in TUFLOW FV also provides you with access to a range of check files that make it easy to review your model. This set of GIS input and output files better aligns the workflow of TUFLOW FV with its sister products TUFLOW Classic and TUFLOW HPC and is a step towards further product integration.

The following sections outline the commands required to setup your new or convert an existing model integrated with GIS.

3.1 TUFLOW FV Tutorials for GIS Integration

For a step-by-step guide on GIS usage in TUFLOW FV [Tutorial Model 1](#) and [Tutorial Model 3](#) are currently being updated to include the new GIS workflow. An overview of GIS check files output by TUFLOW FV is also provided on the [TUFLOW FV Check Files](#) page of the [TUFLOW FV Wiki](#).

The GIS Tutorial Model is also provided as a standalone to the wiki via [Appendix A – TUFLOW FV GIS Tutorial](#) of these release notes.

3.2 Set the GIS Format for Check File and Empty File Output

The `GIS Format == {MIF} | SHP` command sets the output format for GIS check layers and GIS check file outputs. If the `GIS Format ==` command has not been specified, the default of using .mif files is adopted.

```
GIS Format == SHP                ! For ArcMap or QGIS Users
GIS Format == MIF                ! For MapInfo Users
```

Note: that the GIS format of an input layer is solely controlled by the file extension (ie. .mif for the MIF format and .shp for the SHP format). GIS file extensions should be used in filenames and TUFLOW FV control files.

3.3 Set the Spatial Reference System

When using GIS integration TUFLOW FV requires that all input and output files are in the same spatial reference system. This can be either a cartesian system such as a UTM projection when using `Spherical == 0` (the default) or a longitude latitude system if using `Spherical == 1`.

The .fvc commands `MI Projection ==` and `SHP Projection ==` are used for model inputs and outputs that are specified in Mapinfo MIF layers or ESRI Shapefile format respectively. If a model has a mixture of .mif and .shp files as input, then both `MI Projection` and `SHP Projection` are required.

Examples:

```
MI Projection == ..\model\mi\Model_Projection.mif
SHP Projection == ..\model\shp\Projection.prj
```

As an alternative to specifying a .mif or .prj file, the coordinate reference string can be copied out of the *.mif or *.prj file and read directly from the `MI Projection ==` or `SHP Projection ==` commands as follows:

```
MI Projection == CoordSys Earth Projection 8, 13, "m", 153, 0, 0.9996, 500000,
10000000 Bounds (-7745874.38492, 1999.40969607) (8745874.38492, 19998000.5903)
```

And / Or

```
SHP Projection ==
PROJCS["WGS_1984_UTM_Zone_60S",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["W
GS_1984",6378137,298.257223563]],PRIMEM["Greenwich",0],UNIT["Degree",0.017453292519
943295]],PROJECTION["Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAME
TER["central_meridian",177],PARAMETER["scale_factor",0.9996],PARAMETER["false_easti
ng",500000],PARAMETER["false_northing",10000000],UNIT["Meter",1]]
```

Note: All MID/MIF/SHP GIS layers read by TUFLOW FV MUST USE this projection or the following error message is produced:

ERROR 0305 - Projection of .shp file is different to that specified by the SHP Projection == command.

If you are confident that the projections you are using are in fact the same then you can change this error to a warning via the Use `GIS Projection Check == WARNING`.

3.4 Creating 'Empty' GIS Template Files

Different TUFLOW FV input files require specific input layer dependant GIS attributes. For example, material input files only require a single attribute (with the attribute – Mat) whereas a boundary condition may have a number of attributes (nodestring ID, type, sub-type etc.). **It is strongly recommended** that the prefixes described in [the table below](#) be adhered to for all GIS layers. This greatly enhances the data management efficiency and, importantly, makes it much easier for another modeller or reviewer to quickly interpret the model.

GIS Data Type	Suggested File Prefix	Description	Refer to Section
2D Land-Use (Materials) Categories	2d_mat_	Optional layers to define or change the land-use (material) types on a cell-by-cell basis.	3.8.2

GIS Data Type	Suggested File Prefix	Description	Refer to Section
Elevation Lines (Breaklines) (Ridges and Gullies)	2d_zln_	Optional 2D or 3D breaklines defining the crest of ridges (e.g. levees, embankments) or thalweg of gullies (eg. drains, creeks). Ridges and gullies cannot occur in the same layer so 2d_zlr_ is often used for ridges and 2d_zlg_ for gullies. These files are typically created by renaming the 2d_z__empty file.	3.6.3
Nodestrings	2d_ns_	Optional polyline layer that can used to define the location, direction and nodestring type of external nodestrings.	3.7

The .fvc command `Write GIS Empty Files == <Filepath>` can be used to automate the creation of template (empty) files which use the recommended GIS data naming convention and contain the correct GIS attributes. The command requires a location where you would like empty files written. The TUFLOW FV convention is the folder `model\gis\empty` as shown below.

```
Write GIS Empty Files == ..\model\gis\empty
```

You only need to write the empty files once during model setup. The TUFLOW FV simulation will stop after writing the empty files which is the same behaviour implemented in TUFLOW Classic. Once they are created you can comment the command out (or delete) and continue to develop your .fvc.

```
!Write GIS Empty Files == ..\model\gis\empty
```

3.5 Layering of GIS Inputs

The .2dm mesh forms the base layer for model development in TUFLOW FV. However, rather than contain all the bathymetric information in this one file, TUFLOW FV has a series of commands that assist with **building** the model. The commands are applied in sequential order; therefore, it is possible to override previous information with new data to modify the model in selected areas. This is very useful where a base dataset exists, over which areas need to be modified to represent other scenarios such as a proposed development. This eliminates or minimises data duplication, and provides better traceability of input layers / datasets

The commands can occur in any order (if it is a logical one).

If an unrecognisable command occurs, TUFLOW FV stops and displays the unrecognisable text.

Notes & Tips:

- 1 Elevations and materials are always read from the .2dm file first, regardless of the order of where the `Read Geometry 2d ==` command is in the .fvc. There can currently only be one mesh file (.2dm) per model.
- 2 Commands can be repeated any number of times.

- 3 Commands are executed in the order they occur. If the data for a cell is supplied more than once, the last data that is read in the fvc is used (i.e. the latter data for a cell overrides any previous data for that cell).
- 4 The new GIS commands whilst recommended over legacy commands such as `Cell Elevation File ==`, `Elevation Polyline File ==`, `Cell Elevation Polygon ==` etc. will still be read in sequential order. For example, cells intersected by the elevation polylines in the file 'Shipping_Channel.csv' below will be applied to the model, unless they spatially overlap with inputs from the `Read GIS Z Line ==` command, as the GIS Z Line command occurs after the polyline file, the breaklines in the GIS file will overwrite the data in the polyline file, if the same cells are selected. The checks files become a very useful tool to view the final elevations.

```
! Geometry Specification with Updates
Geometry 2D == ..\model\geo\Bosos_Port_Development_001.2dm
Read GRID Zpts == ..\model\geo\grid\Existing_Config.txt
Nodestring Polyline File == ..\model\geo\Shipping_Channel.csv
Read GIS Z Line == ..\model\geo\gis\my_road_001_L.shp | ..\model\geo\gis\my_road_001_P.shp
```

- 5 Use the `Write Check Files ==` command (refer Section 3.9) to cross-check and carry out quality control checks on the final mesh ZB and Material inputs.

3.6 Topographic/Bathymetric Update Commands

3.6.1 Set Zpts

Optional command to globally set all cell centroid elevations (ZBs)? DBs in the model domain to this value. The value specified with be in meters if using `Units == Metric` or feet when using `Units == Imperial | English | US Customary`

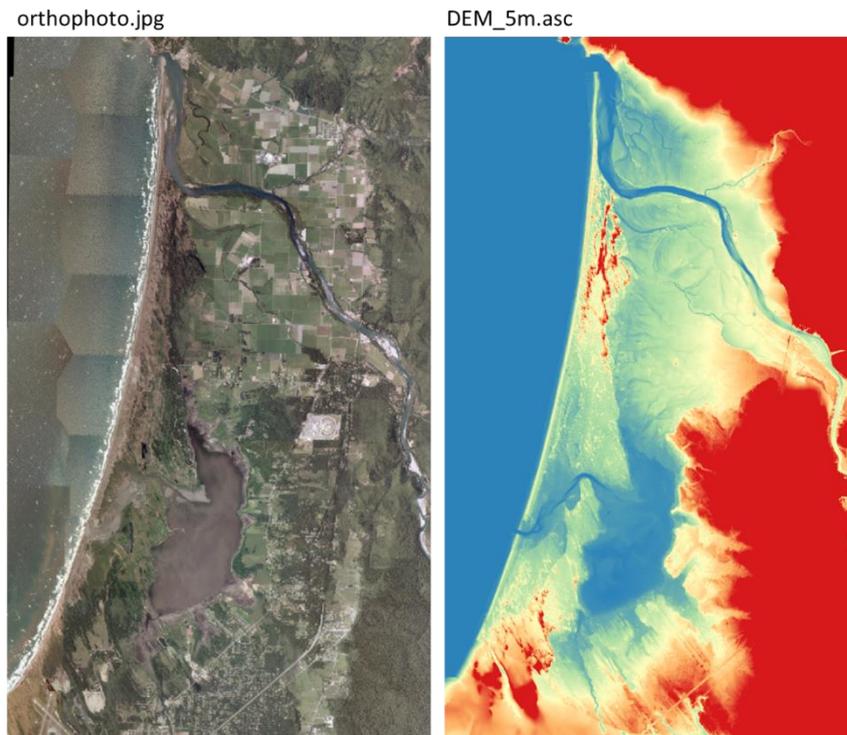
Example:

```
Set Zpts == 10.5          ! Set all cell centroids in the model domain to 10.5.
```

3.6.2 Read GRID Zpts

Directly interpolates an ESRI ASCII (.asc) or binary (.flt) grid to set the cell centroid elevations. The use of this command has significant advantages over the previous method of manually carrying out a manual cell inspection with the `Cell Elevation File ==` command and is now the recommended approach. Like other topographic update commands, `Read Grid Zpts ==` may be specified more than once. If a raster does not contain data for a cell centroid (i.e. DEM is null) then the elevation point is not updated in the model.

Example: `Read Grid Zpts == ..\model\geo\grid\DEM_5m.asc`



The below figure shows the results `_mesh_check` file coloured to show the interpolated ZB values from the grid `DEM_5m.asc`. Please refer to Section 3.9 for more information on TUFLOW FV Check Files.



3.6.3 Read GIS Z Line

2d_zln layers are used for adjusting the closest Zpt elevations to lines representing the crests or highpoint of levees, flood defences, roads, railways and other embankments that obstruct flow. The lines can be 3D in shape and height using elevation points. 2d_zln GIS layers are referenced using the command Read GIS Z Line.

GIS layers used for Read GIS Z Line can be split into more than one layers to better manage the variety of data these commands sometimes require. For example, one layer may contain road crests and another channel thalweg data. By keeping these as separate GIS files, the order which these are read (and therefore which prevails if they overlap) can be better controlled.

MapInfo allows different geometry types (points, line and regions) to occur within the same GIS file, however, for the Shapefile format, each of these different geometry types requires a separate GIS layer. The TUFLOW empty template files include the following filename suffixes to differentiate which files are suitable for point, line or region features.

- _P for point features (e.g. 2d_zln_M03_002_P.shp)
- _L for line and polyline features (e.g. 2d_zln_M03_002_L.shp)
- _R for region or polygon features (e.g. 2d_zln_M03_002_R.shp)

Note: other geometry types such as ellipses, rectangles, curved arcs etc. should be avoided for TUFLOW FV input files, if these are specified the warning:

WARNING 3023 Ignored Object in GIS Layer

Separating the different geometries is a user preference for MapInfo users, these can be kept in the same file, or separated.

If a GIS dataset is made up of more than one GIS file, each layer is separated by a vertical bar (“|”). For example, to read a Z Shape layer which has both line and points, the command may be:

```
Read GIS Z Line == gis\2d_zln_M03_002_L.shp | gis\2d_zln_M03_002_P.shp
```

Multiple points layers can be specified. The points layer can be referenced in any location except for the first layer within the command line entry.

Incorrect:

```
Read GIS Z Line == gis\2d_zln_M03_002_P.mif | gis\2d_zln_M03_002_L.mif
```

Correct:

```
Read GIS Z Line == gis\2d_zln_M03_002_L.mif | gis\2d_zln_M03_002_P.mif
```

The 2d zln input layer uses a single attribute ‘Z’ which is of data type float (i.e. contains real numbers and not integers)

No.	Default GIS Attribute Name	Description	Type
1	Z	Elevation of the point or polyline. Please note that if one or more points are snapped to vertices on a polyline layer the value in the Z attribute of the polyline object is ignored.	Float

3.7 Read GIS Nodestring

This command provides an alternative to the previous .csv file method “Nodestring Polyline File”. In the example below both open water level and flow boundary locations are specified in the GIS layer “2d_ns_Open_Boundaries_001_L.shp”. This layer is being used to apply open boundary nodestrings. The layer 2d_ns_Flux_Lines_001_L.shp has been separated for data management purposes and is reporting fluxes within the model.

Nodestrings input by the `Read GIS Nodestring ==` commands are additive to those existing in the .2dm or already specified in previous `Read GIS Nodestring ==` or `Nodestring Polyline File ==` commands.

The `Read GIS Nodestring ==` command requires that all nodestring ID’s in the model are unique. This includes if any have been specified in the .2dm or nodestring polyline file. If nodestrings with identical IDs are input TUFLOW FV will generate an error and you will need to renumber your inputs. Future versions of the software will include better handling of duplicate nodestring id’s such as automatic renumbering.

```
Read GIS Nodestring == ..\model\gis\2d_ns_Open_Boundaries_001_L.shp
Read GIS Nodestring == ..\model\gis\2d_ns_Flux_Lines_001_L.shp
```

No.	Default GIS Attribute Name	Description	Type
1	ID	Unique integer identifier for each nodestring 1: n.	Integer
2	Type	<p>Either set to ‘BD’ or left blank.</p> <p>If set to ‘BD’ this will use TUFLOW FV’s boundary algorithms to snap the nodestring along the outer edge of the model, as required for open boundary conditions. The ‘BD’ type should not be used for internal nodestrings such as those used to monitor flow or to define hydraulic structure locations.</p> <p>Leaving the field blank will snap the nodestring to the closest cell faces at cells that the polyline intersects.</p>	Char

3.8 Material Update Commands

3.8.1 Set Mat

Optional command to globally set all Material values in the model to a given value. This is useful if a certain material type tends to dominate the study area. This command is typically used in combination with Read GIS Mat commands. The order of these Mat commands is important as discussed in Section 0.

Example:

```
Set Mat == 2 ! Sandy bottom lake
```

3.8.2 Read GIS Mat

The `Read GIS Mat ==` command updates any cells that fall within the polygons in the 2d_mat layer with the Material attribute value of each polygon. More than one `Read GIS Mat ==` layer can be used. The order of these Mat commands is important as discussed in Section 0.

Only one attribute is required for the 2d_mat GIS layers input using the `Read GIS Mat ==` command as shown in the table below.

No.	Default GIS Attribute Name	Description	Type
1	Mat	Material ID of the cell.	Integer

3.9 GIS Check Files

There are several new GIS check files and GIS workspaces that assist with the review of model inputs. These include:

Filename prefix / suffix	Description
_mesh_check_R.shp	<p>GIS layer of the final 2D or 3D mesh. Represents the final mesh including modifications from the .fvc file, such as ZB updates.</p> <p>Please note reported ZB values do not include ZB modifications due to morphological changes when morphology is enabled. Model material, ZB, bed roughness and cell 2D and 3D ID are reported.</p>
_ns_check_L.shp	Shows the cell faces selected, the direction and ID of nodestrings. This includes both nodestrings assigned directly to the .2dm or by external nodestrings.
_bc_check_L.shp	Provides the cell faces selected to input nodestring boundary information. Returns the nodestring ID and the input CSV data file assigned to that boundary.
_zln_zpt_check_P.shp	GIS layer containing Zpts (ZB values at cell centroids) that have been modified by Read GIS Z Line == commands, the type of Z Line and the Z Line filename. This feature is very useful for checking which Zpts that the Z Lines have modified.
_sa_check_P.shp	If using QC or other cell-based input boundaries returns the cell centroid of each cell selected by the boundary.
_input_layers.mif	GIS layer containing full file paths to all input layers used to compile the model.

4 Model Geometry

4.1 Elevation Polyline File

A documentation error regarding the usage of the command 'Elevation Polyline' has been amended in the upcoming manual. Previously using `Elevation Polyline ==` led to an error. The correct command is:

```
Elevation Polyline File ==
```

4.2 Surface Sigma Layers

For 3D geometry the `Sigma Layers ==` command has been updated to `Surface Sigma Layers ==`. While both commands remain supported it is recommended to use `Surface Sigma Layers ==` for new models. This change is aimed to reduce confusion between the specification of a hybrid z vs. sigma only approach.

For example, the correct syntax when applying a hybrid Z/Sigma scheme as shown below.

```
!3D Geometry Commands Hybrid
Vertical Mesh Type == z
Layer Face File == ..\geo\3D_Z_Layers_003.csv
!Sigma Layers == 4
Surface Sigma Layers == 4
```

Where the layer face file is a .csv input with fixed layer face elevations specified in a singular 'Z' column. The surface sigma layers in this example are then distributed between the 'always wet' value of -3 and the water surface.

1	Z
2	-3
3	-4
4	-5
5	-6
6	-7
7	-8
8	-10

If using a sigma only based z layering scheme the correct syntax is provided below:

```
!3D Geometry Commands Sigma
Vertical Mesh Type == sigma
Layer Face File == ..\geo\3D_Sigma_Layers_003.csv
```

Where the layer face file is a csv input with distributed layers specified in a singular 'SIGMA' column. In this example there are 5 equal sigma layers each representing 20% of the water depth, noting 0 is the bed and 1 the water surface.

1	SIGMA
2	0.8
3	0.6
4	0.4
5	0.2

4.3 Echo Geometry

There have been changes to the echoing of model geometry and nodestring/topographic updates in TUFLOW FV 2019.01. The `Echo Spatial ==` command has been superseded with a series of echo geometry

commands as provided in the table below. The default is for no geometry outputs to be specified. i.e. `Echo Geometry == 0`.

For backward compatibility `Echo Geometry == 1` is still available.

Command	NETCDF Outputs	CSV Outputs
<code>Echo Geometry == 1</code> <code>Echo Spatial == 1 !Legacy</code>	_geo.nc	_geo_out.csv _geo.csv _geo_cellupdates.csv _geo_nodestring.csv
<code>Echo Geometry CSV == 1</code>	None	_geo_out.csv _geo.csv _geo_cellupdates.csv _geo_nodestring.csv
<code>Echo Geometry NETCDF == 1</code>	_geo.nc	None

5 Boundary Conditions

5.1 Grid Definition Block

Changes have been made to grid definition syntax. Grid definitions are used to describe the grid on which gridded boundary conditions types are applied. This grid definition creates an interpolation mapping from the grid to the cell-centres, or the boundary nodestrings as required.

Please note the grid definition file method is the only option available for 3D grid definitions. 2D grids are also supported using this command.

Grid definitions must now be applied within a grid definition block which are typically used for NetCDF inputs as follows:

```
Grid definition file == <FILE_NAME>
Grid definition label == <LABEL>
Grid definition variables == <X_VARIABLE>, <Y_VARIABLE>, <Z_VARIABLE>
Vertical Coordinate Type == < {elevation} | Depth | Sigma | Height>
Cell Gridmap == < {1} | 0 >
Boundary Gridmap == < 1 | {0} >
Suppress Coverage Warnings == < 1 | {0} >
End Grid
```

Command	Options	Description
Grid definition file	FILE_NAME	The NetCDF file containing coordinates used to define the grid on which gridded boundary conditions types are applied.
Grid definition label	LABEL	Name to apply to this grid and can be referred to by multiple boundary conditions later.
Grid definition variables	X_VARIABLE, Y_VARIABLE, Z_VARIABLE.	This command specifies which variables should be read from the NetCDF to create the grid map.
Vertical Coordinate Type	{ Elevation } Depth Sigma Height Default == Elevation	Vertical coordinate convention. For more information on the respective coordinate types please refer to: https://fvwiki.tuflow.com/index.php?title=Depth_Averaging_Results
Cell Gridmap	{1} 0	If set to 0, TUFLOW FV will not calculate the interpolation weightings of the cells in the model for this gridded boundary condition (may be more efficient for grids that are only going to be applied to the boundaries and not internal model domain).
Boundary Gridmap	1 {0}	Set to 1 to calculate interpolation weightings from the grid onto the boundary nodestrings (this is required for OBC_grid boundary conditions that are to be later applied to nodestrings).

Command	Options	Description
Suppress Coverage Warnings	1 or 0 Default == 0	If set to 1 suppresses warnings if the grid does not cover the entire TUFLOWFV domain. It may be more efficient in situations that the grid only needs to cover a small number of the cells in the model.
End Grid	NA	'Complete' the grid block opened by the Grid Definition File command.

5.1.1 2D Grid Input Example

The following .fvc snippet shows a typical grid definition file setup. In this example the NCEP Climate Forecast System Reanalyses (CFSR):

```
!Specifies a netCDF location and filename that defines grid coordinates
grid definition file == ./NPD_NCEP_CFSR_dlwr_Jan2011toDec2014.nc
  grid definition variables == lon, lat
  grid definition label == ncep
end grid
```

This grid definition is then later used to assign gridded boundary conditions such as wind using a bc block:

```
!Wind velocity at 10m (m s^-1)
bc == W10_grid, ncep, ./NPD_NCEP_CFSR_wind_Jan2011toDec2014.nc
  bc header == time,u,v
  bc update dt == 900.
  bc time units == hours
  bc reference time == 01/01/1990 00:00
end bc
```

5.1.2 3D Grid Input Example

The following .fvc snippet shows a typical 3D grid definition file setup. In this example the HYCOM Global Circulation Model:

```
! HYCOM exp 90.9
grid definition file == HYCOM_Jan2013_Mar2013.nc
  grid definition variables == x, y, z
  grid definition label == hycom
  boundary gridmap == 1
end grid
```

This grid definition is then later used to assign gridded boundary conditions such as wind using a bc block:

```
! Gridded BC for Input Global Ocean Model HYCOM
bc == OBC_GRID, hycom, HYCOM_Jan2013_Mar2013.nc
  sub-type == 6
  bc header == time,ssh,u,v,salinity,temperature
  bc nodestrings == 1
  bc update dt == 3600.
  bc time units == hours
  bc reference time == 01/01/1990 00:00
  bc offset == -0.33, 0.0, 0.0, 0.0, 0.0 ! ssh, u, v, salinity, temperature
  vertical coordinate type == depth
end bc
```

5.2 New Sub-type for OBC boundary conditions

A new Open Boundary Condition (OBC) sub-type is available to control the calculation of ghost-cell values at nodestring open boundaries. This specifies the water level directly but provides smoothing to the normal momentum flux to avoid over-specification and reflection of outgoing waves. This is like sub-type 4 though more robust for most models. This sub-type is recommended for fully-specified OBCs where both regional-scale currents and water levels are applied.

Sub-type == 6. ! within BC Block

5.3 QN Boundaries

There have been improvements to the computation of QN boundaries. For a QN type boundary condition:

- If `sub-type == 1` (default) the flux calculation uses a new boundary calculation method added to the 2019.01. This method should limit warning messages that could occur when using QN boundaries: *Unable to solve for specified inflow conditions at bc.*
- If `sub-type == 2` the flux calculation uses the pre-2019 TUFLOW FV Release's QN boundary flux calculation method and can be used for legacy simulations.

6 Hydraulic Structures

TUFLOW FV now includes a wide range of structure control options typically used in overland flow simulations. The term 'Structure' encompasses a range of hydraulic structures (bridges, culverts and weirs) and also topography/bathymetry control commands.

6.1 Linked Nodestring Boundaries

Linked nodestring momentum terms are now treated the same as single nodestring structures. For releases prior to 2019.01, momentum terms were not transferred through linked nodestrings when using the nlswe flux function. This allows the user greater control on the losses through linked nodestrings when using the command `Formloss Coefficient ==`. Specifying `Formloss Coefficient == 1` should provide backward compatibility with previous releases. Accordingly, linked nodestring structures may now have lower affluxes than in previous releases and users may find changes need to recalibrate their form losses. Please note: non-linked, single nodestring structures are unaffected.

6.2 Real-Time Structure Controls

Controlled structures have been upgraded in the latest release of TUFLOW FV. These allow users to adjust the flow rate through structures (or the bathymetry in part of the model) in response to measured values within other parts of the model.

Each structure can now have multiple (up to 10) controls of the same type, changing with different conditions. The multiple controls combine in the following ways:

- (a) **Fraction open:** All the different calculated fraction open values work as scale factors, and multiply together.
- (b) **Weir crest dz:** The final dz value defined in the control series is adopted (this may change in future releases).
- (c) **ZB adjust:** The final ZB value in the control series is adopted. For DZB options, the DZBs add together.
- (d) **Minflow:** The maximum value of all minimum flow options is adopted.

In addition to allowing multiple controls, sample-type controls can now measure any conserved variable (temperature, tracers, depth etc.). In prior builds only water level was available. This allows users to adjust structure flows based on any variable (or multiple variables if using multiple controls) within the model, at any point and any depth. An example of this is shown below, with a structure that scales the fraction open based on salinity in the surface 1 meter (in this case closing the structure when the salinity exceeds 20 PSU).

```

Structure == Nodestring, 5           ! Structure Location (NS 5)
flux function == timeseries         ! Specified flow rates with time
flux file == flow_pump.csv         ! csv with flow rates in it

control == Sample_Rule             ! Sample a point to control structure
sample point == 502645, 6962207    ! Sample location (this eg. in UTM)
vertical coordinate type == depth  ! Sample vertical coordinate reference
vertical coordinate == 0,1         ! Sample over top 1 meter
sample type == SAL                 ! Sample Salinity
sample dt == 300                   ! Sample over a 5 minute period (moving average)

control parameter == fraction open ! Adjust opening based on control
control update dt == 900           ! Only update every 15 minutes
start control state == 1           ! Start Open
control file == example_sample.csv ! CSV of control relationship
end control

end structure

```

Sample_Value	Fraction_Open
0	1
20	1
20.01	0

Time	Q
0	10
99999	10

6.3 Autoweir

TUFLOW FV 2019.01 fixes a bug with how autoweirs are reported to the structure logging csv file. TUFLOW FV Build 2019.01 correctly reports autoweir locations. No changes to model results are expected as autoweirs were functioning correctly internally.

6.4 Scalar Functions

TUFLOW FV now supports different ‘scalar functions’ through structures. Like the ‘flux functions’ that control the flow regime through a structure, these control the concentration of the scalar variables for AD, sediment and water quality models (such as salinity, temperature, etc.). Previously a scalar timeseries was the only other scalar regime that could be applied (specifying the scalar concentrations). Now several options are available:

- **None:** Scalar variables maintain their concentration (and mass) through the structure
- **Timeseries:** scalar concentrations can be specified by a separate timeseries (available previously)
- **Scale_factor:** scalar concentrations are all adjusted by a constant scale factor as they pass from one side of the structure to the other
- **Treatment:** Scalar concentrations are scaled by a factor, with no scaling applying below a minimum threshold, and the scaling being increased to ensure concentrations fall below a maximum threshold. This corresponds to many treatment plants where no treatment is required for low-concentration water and more treatment occurs for high-concentration water.

Additionally, minimum and maximum concentrations through structures can be combined with any of the above conditions. **NOTE:** These options are not mass conservative and can add or reduce mass from the model.

6.5 Structure Check Output

A new QA output type is available for ensuring structure behaviour is what the user expects. This shows the upstream scalar concentration and flow of water entering the structure, and the downstream scalar concentration and flow of water leaving the structure. This can be used in conjunction with the structflux



output types to diagnose any uncertainties with the behaviour of flux functions and scalar functions through structures. A more detailed description of this output can be found in Section 7.7.

7 Output Types

7.1 XMDF

XMDF output is now available. This result has cell vertex results interpolated from cell centres in the same way as the DATV format. XMDF allows multiple result outputs to be placed into a single file and has improved compression reducing overall model result size. The below provides an .fvc snippet using the `Output == xmdf` option.

```
! Example of XMDF Output Format
output == xmdf
  output statistics == max
  output statistics dt == 10
  output parameters == h, v, d, zb, taub
  output interval == 600.
end output
```

XMDF is a 2D only output but the same 3D depth averaging options available for DATV results apply to XMDF.

7.2 SMS Super Files .sup

For XMDF and DATV output types TUFLOW FV now outputs an Aquaveo SMS .sup file. This ASCII text file associates results with the input mesh and can be directly opened by SMS or the TUFLOW Viewer Plugin in QGIS.

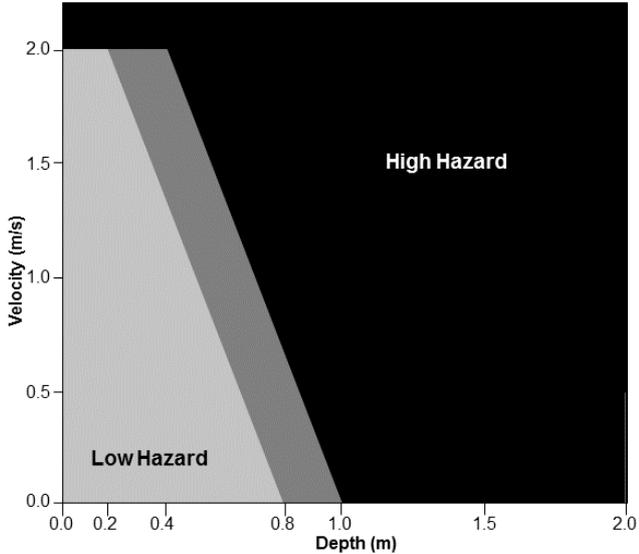
The .sup file will have the extension .xmdf.sup or .ALL.sup for XMDF or DATV outputs respectively.

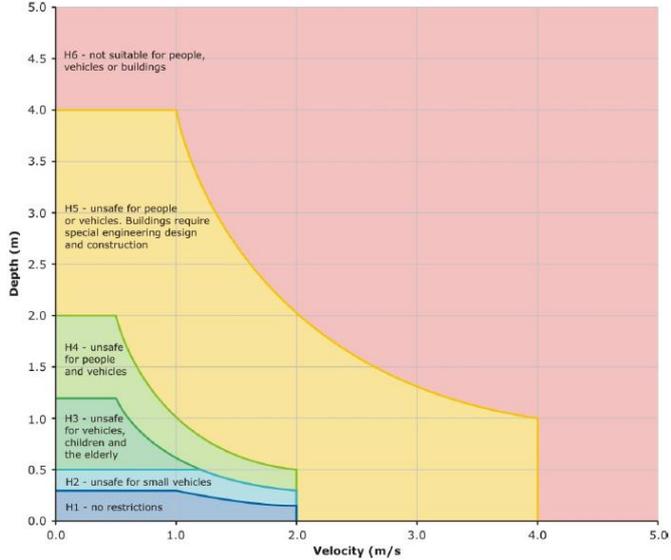
7.3 Velocity Output

When outputting velocity map results in XMDF or DATV format TUFLOW FV will now output both velocity vector and magnitude.

7.4 Flood Hazard Outputs

Three flood hazard outputs are now available using the HAZARD_Z1, HAZARD_ZAEM1 or HAZARD_ZQRA map output parameter. The table below provides an overview of each.

Flag	Map Output Hazard Type	Supported Formats	Description
hazard_z1	hazard_z1	All formats	<p>Flood hazard category based on the Australian NSW Floodplain Management Manual (NSWG, 2005). The output is an integer number from 1 to 3 as follows and as illustrated in the figure below.</p> <ul style="list-style-type: none"> 1 Low Hazard 2 Intermediate Hazard (dependent on site conditions) 3 High Hazard <p>Note: The maximum hazard value is monitored throughout the simulation and is not necessarily when the maximum water level occurs as with some other output.</p> 

Flag	Map Output Hazard Type	Supported Formats	Description														
hazard_zaem 1	hazard_zaem 1	All formats	<p>Flood hazard category as outlined by Australian Emergency Management Institute in 2014. ZAEM1 output values are 0 (zero) for no hazard and 1 to 6 for H1 to H6 respectively.</p>  <table border="1" data-bbox="734 1120 1433 1361"> <thead> <tr> <th>Hazard Classification</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>H1</td> <td>Relatively benign flow conditions. No vulnerability constraints.</td> </tr> <tr> <td>H2</td> <td>Unsafe for small vehicles.</td> </tr> <tr> <td>H3</td> <td>Unsafe for all vehicles, children and the elderly.</td> </tr> <tr> <td>H4</td> <td>Unsafe for all people and all vehicles.</td> </tr> <tr> <td>H5</td> <td>Unsafe for all people and all vehicles. Buildings require special engineering design and construction.</td> </tr> <tr> <td>H6</td> <td>Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.</td> </tr> </tbody> </table>	Hazard Classification	Description	H1	Relatively benign flow conditions. No vulnerability constraints.	H2	Unsafe for small vehicles.	H3	Unsafe for all vehicles, children and the elderly.	H4	Unsafe for all people and all vehicles.	H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.	H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.
Hazard Classification	Description																
H1	Relatively benign flow conditions. No vulnerability constraints.																
H2	Unsafe for small vehicles.																
H3	Unsafe for all vehicles, children and the elderly.																
H4	Unsafe for all people and all vehicles.																
H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.																
H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.																

Flag	Map Output Hazard Type	Supported Formats	Description																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
hazard_zqra	ZQRA	All formats	<p>Hazard categories for the Queensland Reconstruction Authority. Refer to http://qldreconstruction.org.au/u/lib/cms2/resilient-floodplains-part2-full.pdf (Queensland Reconstruction Authority, 2011-2012).</p> <p>Schedule 4 - Flood hazard criteria</p> <p>Indicative flood hazard criteria</p> <p>The following indicative flood hazard criteria have been prepared for use in preparing flood investigations (level 2), and planning evaluations based on latest available engineering guidance. In the absence of other more appropriate flood hazard definitions, the criteria below may be used.</p> <table border="1" data-bbox="746 696 1082 1010"> <tr> <td>1.0</td><td>0.2</td><td>0.4</td><td>0.7</td><td>0.9</td><td>1.1</td><td>1.3</td><td>1.5</td><td>1.7</td><td>1.9</td><td>2.1</td><td>2.3</td><td>2.5</td><td>2.7</td><td>2.9</td><td>3.1</td><td>3.3</td><td>3.5</td><td>3.7</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.1</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.2</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.3</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.4</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.5</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.6</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.7</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.8</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>1.9</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.0</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.1</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.2</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.3</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.4</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.5</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.6</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.7</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.8</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>2.9</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.0</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.1</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.2</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.3</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.4</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.5</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.6</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.7</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.8</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>3.9</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.0</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.1</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.2</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.3</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.4</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.5</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.6</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.7</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.8</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>4.9</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> <tr> <td>5.0</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.8</td><td>1</td><td>1.2</td><td>1.4</td><td>1.6</td><td>1.8</td><td>2</td><td>2.2</td><td>2.4</td><td>2.6</td><td>2.8</td><td>3</td><td>3.2</td><td>3.4</td><td>3.6</td><td>3.8</td><td>4</td><td>4.2</td><td>4.4</td><td>4.6</td><td>4.8</td> </tr> </table> <p>Rules</p> <table border="1" data-bbox="1098 719 1315 808"> <thead> <tr> <th></th> <th>Low</th> <th>Significant</th> <th>High</th> <th>Extreme</th> </tr> </thead> <tbody> <tr> <td>Depth</td> <td><0.5</td> <td><2</td> <td><2</td> <td>≥2</td> </tr> <tr> <td>Velocity</td> <td><1.5</td> <td><2</td> <td><2</td> <td>≥2</td> </tr> <tr> <td>DW Ratio</td> <td><0.6</td> <td>0.6 to <0.8</td> <td>0.8 to <1.2</td> <td>≥1.2</td> </tr> </tbody> </table> <p>Rationale</p> <ol style="list-style-type: none"> Low – self evacuation possible for adults and children, vehicle stability within tolerance for large 4WD Significant – working limit for trained safety workers, Vehicle evac unsuitable, Building Code limitation High – limit of uncompromised stability for adults (dangerous to most) Extreme – in excess of known stability limits <p>References</p> <ol style="list-style-type: none"> ARR Revision Project 10: Appropriate Safety Criteria for People <ol style="list-style-type: none"> Children – Significant Hazard DV ≤ 0.6 & D ≤ 0.5 Adult – Moderate Hazard DV ≥ 0.6 Working limit for trained safety workers or experienced and well equipped persons DV < 0.8 ARR Revision Project 10 State 2 Report: Appropriate Safety Criteria for Vehicles (Draft) <ol style="list-style-type: none"> Large 4WD DV ≤ 0.6 & D ≤ 0.5 Dale et al. (2004) Structural flood vulnerability and the Australisation of Black's Curves <ol style="list-style-type: none"> Fibro/Tile construction D < 0.5 & V < 2 Draft QDC for flood hazard areas for Deemed to Satisfy provisions – V < 1.5 BMT WBM (2012) Newcastle City-wide Floodplain Risk management Study and Plan P.81-82 <ol style="list-style-type: none"> Hydraulically suitable for wading by able-bodied adults V < 2 & D < 0.8 Hydraulically suitable for light construction (e.g. timber frame and brick veneer) V < 2 and D < 2 Jonkman et al. (2008) Methods for the estimation of loss of life due to floods: A literature review and proposal for a new method Natural Hazards P. 364 <ol style="list-style-type: none"> Level of hazard to people can be categorized as low, moderate, significant or extreme. 	1.0	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	4	4.2	4.4	4.6	4.8	1.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	1.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	2.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	3.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	4.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8		Low	Significant	High	Extreme	Depth	<0.5	<2	<2	≥2	Velocity	<1.5	<2	<2	≥2	DW Ratio	<0.6	0.6 to <0.8	0.8 to <1.2	≥1.2
1.0	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
1.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
2.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
3.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.1	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.2	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.3	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.4	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.5	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.6	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.7	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.8	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
4.9	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
5.0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
	Low	Significant	High	Extreme																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
Depth	<0.5	<2	<2	≥2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
Velocity	<1.5	<2	<2	≥2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
DW Ratio	<0.6	0.6 to <0.8	0.8 to <1.2	≥1.2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			

7.5 Profile Outputs

Profile outputs are now available that are directly produced during simulation. These are similar in setup to point output but provide full 3D information in NETCDF format.

```
Output == profile
      Output points file == ..\output\my_profiles.csv
End output
```

The output points file is a comma delimited file as per the example below.

```
X, Y, Label
159.0766, -31.3647, A
159.0930, -31.3908, B
159.1151, -31.4015, C
159.1233, -31.4288, D
159.1269, -31.4404, E
```

For legacy models you can also use X, Y, ID as a replacement for X, Y, LABEL where ID is an integer 1:n. If no ID is specified, TUFLOW FV will automatically assign numbers.

Please note there are also MATLAB and Python post-processing scripts available to create profiles files from existing 3D netcdf outputs (refer Section 8).

7.6 Evaporation Map Output

An Evaporation map output parameter has been added specifying the instantaneous evaporation rate at each output interval in units of m/day.

```
Output Parameters == EVAP ! Evaporation Rate m/day
```

7.7 Structure Outputs

7.7.1 Structure Flux

The structflux output can be used to output the flux that passes through a structure in a similar format to that stored in the standard flux output files. This shows a timeseries of the water mass flux (flow rate), the salt flux (salt mass per second), temperature flux (heat per second), and all other conserved tracer fluxes. If a scalar function is being used, then these scalar fluxes are the total fluxes that make their way through the structure and are effectively the amount output at the downstream side of the structure.

If users wish to further investigate the difference between upstream and downstream conditions going through the structure (for example when using the scalar functions) then a structcheck file can be used (refer Section 7.7.2).

An example of the first few lines of a structflux file for a simulation with two tracers (but no other conserved scalar variables) is shown below.

TIME	channel_FLOW [m ³ s ⁻¹]	channel_TRACE_1_FLUX [units m ³ s ⁻¹]	channel_TRACE_2_FLUX [units m ³ s ⁻¹]
0	0.00E+00	0.00E+00	0.00E+00
0.020503	9.46E+00	4.73E+01	6.15E+01
0.036742	1.91E+01	9.55E+01	1.24E+02
0.052968	1.44E+01	7.14E+01	9.28E+01
0.069502	7.90E+00	3.88E+01	5.05E+01
0.085937	9.34E+00	4.55E+01	5.91E+01
0.10224	1.63E+01	7.75E+01	1.01E+02

The output file has the suffix `_STRUCTFLUX.csv` and is in the folder set by the `Output Dir ==` command. An `.fvc` snippet for this output is provided as follows:

```
!Structure Flux
output == structflux
    output interval == 900.
end output
```

7.7.2 Structure Check

The structure check file outputs a timeseries of the flow and scalar concentrations on the upstream and downstream sides of the structure, as seen by the model when determining any processing internal to the structure. For most basic structures, the upstream and downstream flows will be equal, as will the scalar concentrations. Where these might differ are for structures with some losses, sources, or scaling of some of these parameters. An example is the 'treatment' type structure, that can be used to reduce the salinity through the structure by a constant scale factor (to simulate a desalination plant for example), this would show the concentration flowing into the structure (and flow rate), and the treated concentration coming out of the structure, which users can use to check that the structure has the desired behaviour.

An example of the first few lines of a structcheck file for a simulation with two tracers (but no other conserved scalar variables) is shown below:

TIME	channel_FLOW A [m ³ s ⁻¹]	channel_FLOW B [m ³ s ⁻¹]	channel_TRACE_1 A [units m ³]	channel_TRACE_1 B [units m ³]
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.020503	9.46E+00	9.46E+00	1.00E+01	5.00E+00
0.036742	1.91E+01	1.91E+01	9.98E+00	4.99E+00
0.052968	1.44E+01	1.44E+01	9.92E+00	4.96E+00
0.069502	7.90E+00	7.90E+00	9.83E+00	4.92E+00
0.085937	9.34E+00	9.34E+00	9.73E+00	4.86E+00
0.10224	1.63E+01	1.63E+01	9.54E+00	4.77E+00

The output file has the suffix `_STRUCTCHECK.csv` and is located in the folder set by the `Output Dir ==` command. An `.fvc` snippet for this output type is provided as follows:

```
!Structure Check
output == structcheck
    output interval == 3600.
end output
```

8 Visualisation and Model Development Tools

8.1 MATLAB Toolbox

A toolbox for visualising 2D and 3D TUFLOW FV results in MATLAB is available for download from the TUFLOW website. <http://www.tuflow.com/FV%20Utilities.aspx>. A wiki page with instructions on using the MATLAB toolbox is currently under construction and is available through https://fvwiki.tuflow.com/index.php?title=FV_MATLAB_Tools#MATLAB

8.2 Python Toolbox

Tools from the MATLAB Toolbox have been ported over to Python 3 including sheet, curtain, profile and timeseries plots. For more information on how to access the Python Toolbox please contact support@tuflow.com.

8.3 TUFLOW Viewer QGIS Plugin

The [TUFLOW Viewer QGIS Plugin](#) provides tools to improve the efficiency of setting up, running and viewing the results of TUFLOW FV models. There is no cost associated with using the TUFLOW Viewer. Some of the available functions are described below:

- Automated methods to create the TUFLOW FV folder directory and generate empty files.
- Incrementing the active layer by creating a copy, assigning a new revision number, and closing the original layer.
- Start a TUFLOW FV simulation from within QGIS.
- Tools to assist with model review and check files.

The TUFLOW Viewer Plugin is available as a free download via the QGIS Plugin Manager Installation instructions. For further details on using the tools please consult the GIS Integration section of [TUFLOW FV Tutorial Model 1](#).

9 Atmospheric Heat Exchange Module

9.1 Ice Module

The effect of ice formation on atmospheric heat exchange with the water body can now be modelled in TUFLOW FV. The model consists of an ice cover development that may consist of three layers: blue ice, white ice (also known as snow-ice) and snow. White ice and snow layers can only occur if snowfall is taken into consideration as a model input. The model assumes the ice-cap is immobile, therefore it does not predict ice transport in the surface layer. It also assumes the heat budget is in equilibrium over the time step.

Please contact support@tufLOW.com if you are interested in using the ice module and require further information.

9.2 Precipitation Temperature

Precipitation temperature can now be specified using the optional input type PRECIP_TEMP. If rainfall temperature is not explicitly specified rainfall temperature is set to the surface water temperature.

```
! Precipitation temp (degrees C)
bc == PRECIP_TEMP, weathermodel , ./weathermodel_preciptemp_Jan2011toDec2014.nc
bc header == time,raintemp
bc update dt == 900.
bc time units == hours
bc reference time == 01/01/1990 00:00
end bc
```

9.3 Wind Stress and Atmospheric Stability Commands

There have been changes to the default wind stress model in TUFLOW FV 2019.01 when using the atmospheric heat exchange module (i.e when `Include Heat == 1`). Improvements have also been to the formulation of sensible and latent heat fluxes when using `Latent Heat Model == 1`. The new defaults may modify results so please read through this section carefully. Where applicable backward compatibility commands are provided.

9.3.1 Wind Stress Model

In TUFLOW FV 2019.01 you now have the option to use three differing wind stress models using the `Wind Stress Model ==` command as follows:

```
Wind Stress Model == 1 ! Wu (default)
Wind Stress Model == 2 ! Constant
Wind Stress Model == 3 ! Kondo
```

In previous builds, if heat was enabled via `Include Heat == 1` only the Kondo wind stress model was applied.

9.3.2 Wind Stress Parameters

The calculation of wind drag coefficients is dependant on the selection of the wind drag model as detailed below:

Wind Stress Model	Specification of Wind Drag Coefficient
1	<p>If using the <i>Wu</i> Wind Stress Model (<code>Wind Stress Model == 1</code>) the wind stress parameterisation stays the same as pre-2019 builds.</p> <p><code>Wind Stress Parameters == <Wa (m/s), Ca (-), Wb (m/s), Cb (-)></code> (Optional); Default == <code><0.0, 0.8e-03, 50.0, 4.05e-03></code></p>
2	<p>If using a Constant Wind Stress Model (<code>Wind Stress Model == 2</code>) the wind stress parameterisation stays the same as pre-2019 builds and is applied using the Bulk Momentum Transfer Coefficient:</p> <p><code>Bulk momentum transfer coefficient == <CDN></code> (Optional, Default == <code>0.0013</code>)</p>
3	<p>If using Kondo Wind Stress Model (<code>Wind Stress Model == 3</code>) it is now possible to apply a scaling factor using a single term via the Wind Stress Parameters command.</p> <p><code>Wind Stress Parameters == <Scale_factor></code> (Optional, Default == <code>1.0</code>)</p> <p>Please note: This single scale factor term should not be confused with the four optional parameters specified using the <i>Wu</i> Model (<code>Wind Stress Model == 1</code>). If more than one comma delimited parameter is provided using <code>Wind Stress Model == 3</code> they are ignored.</p>

9.3.3 Wind Stress Backwards Compatibility

The below table outlines the changes to wind stress defaults and the commands to provide backward compatibility if running with atmospheric heat exchange module (`Include Heat == 1`).

Release	Default Wind Stress Model	Default Atmospheric Stability	Backward Compatibility Commands
Pre-2019	'Hard coded' to Kondo if <code>Include Heat == 1</code> . The Wind Stress Model command was not available.	'Hard coded' to enabled. The Atmospheric Stability command was not available. Applicable to the Kondo Model Only.	NA

2019.01	Wu <code>Wind Stress Model == 1</code>	No <code>Atmospheric Stability Model == 0</code>	To run with a wind stress defaults pre-2019 Release set: <code>Wind Stress Model == 3</code> <code>Atmospheric Stability Model == 1</code>
---------	---	---	--

9.3.4 Atmospheric Stability

There is a new command to enable or disable the consideration of atmospheric stability when using the Kondo Wind Stress Model (`Wind Stress Model == 3`) as follows:

```
Atmospheric Stability Model == 0    ! Not enabled (Default)
Atmospheric Stability Model == 1    ! Enabled
```

Please note the effects of atmospheric stability on wind stress and heat fluxes are ignored if using the Wu (`Wind Stress Model == 1`) or Constant (`Wind Stress Model == 2`) wind stress models.

9.3.5 Latent Heat Model and Atmospheric Stability

In versions prior to 2019.01 the calculation of latent and sensible heat flux calculations did not consider the effects atmospheric stability under `Latent Heat Model == 1`. This has been updated to include these features. Now wind momentum, latent and sensible heat fluxes are modified if the atmospheric stability model is enabled using either latent heat models 1 or 2.

If using `Latent Heat Model == 1` on previous projects, you may see some differences in heat flux and temperature results due to these changes.

If you require further information on the atmospheric heat module please contact support@tuflow.com.

9.3.6 Meteorological Sensor Height

The ability to specify a `Meteorological Sensor Height ==` other than 10m has been removed from 2019.01. Previously, this functionality was only available through Kondo (`Wind Stress Model == 3`) and the removal is to provide consistency with the approach used for the Wu model. If your sensor height is not the standard 10m height, meteorological boundary conditions should be adjusted to the standard 10m height prior to being applied to the model.

10 Water Quality Module

10.1 AED² Version 1.3.0

TUFLOW FV has been updated to couple with the advanced aquatic ecosystem model AED² release: libaed2 1.3.0 (<http://aed.see.uwa.edu.au/research/models/AED>).



10.2 Dynamic Coupling of Light and Light Extinction

The TUFLOW FV-AED² linkage has been upgraded to include dynamic coupling of light and light-extinction due to both suspended sediment and bio-turbidity.

11 Sediment Transport Module

For more information on licensing and usage of the Sediment Transport (ST) module please contact support@tuflow.com.

11.1 Overview

TUFLOW's ST module is a multiple fraction, multi-layered sediment transport and coupled hydrodynamic-morphological model. It is used for simulating non-cohesive (sands) or cohesive (muds) sediments.

ST "non-cohesive" simulates bedload and suspended load sediment transport following van Rijn's TRANSPOR model (van Rijn, 2004) and as of 2019.01 there is also the option to use the Meyer-Peter Muller bed transport model. The effect of bed armouring can also now be modelled via a newly available active layer bed armouring model.

ST "cohesive" simulates the re-suspension, dispersion and settling of cohesive clays and silts and can include the processes of flocculation, hindered settling and bed consolidation.

The sediment module can be coupled with 2D or 3D hydrodynamics. For 3D baroclinic simulations sediment can be taken into consideration to influence density. By optionally switching on morphology, the sediment transport module can be dynamically coupled to the bathymetry of the hydrodynamic model. This allows spatially, depth and time-varying changes in currents and bathymetry to interact.

We are currently developing a full manual for ST with an update expected towards the end of 2019. If you are interested in using the Sediment Transport Module please get in contact and we can arrange some training to get you started.

12 Particle Tracking Model (Beta)

For more information on licensing and usage of the Particle Tracking Model module please contact support@tuflow.com.

12.1 Overview

TUFLOW FV now includes a fully 3D enabled Particle Tracking Model with the following features:

- Lagrangian particle tracking with particles divided into named groups
- Fixed and moving source terms
- Particle advection plus diffusion (random walk component)
- Vertical advection/diffusion scheme (validated to reproduce analytical concentration profiles)
- Multiple particle groups
- Particle group properties such as:
 - (i) Particle age
 - (ii) Settling / buoyancy
 - (iii) Motility
- Particle deposition and resuspension (exchange with bed)
- Particle deposition/resuspension driven by current plus wave-driven bed shear
- Multiple bed layers allowing for consolidation and/or bioturbation
- Eulerian (particle concentration) outputs based on TUFLOW-FV mesh

13 Mesh Generation Tools

Although a separate component to TUFLOW FV, a suitable mesh generator is a fundamental component of flexible mesh modelling. This section provides an update on the Aquaveo SMS and Rising Water Software GIS Mesher software packages.

13.1 Aquaveo SMS

Aquaveo have recently released version 13 of SMS. You can find more information via <https://www.aquaveo.com/software/sms-surface-water-modeling-system-introduction>.

For a free trial of SMS you can download an evaluation version from <https://www.aquaveo.com/downloads?tab=2#TabbedPanels>

TUFLOW are current working with Aquaveo to provide an update to the TUFLOW FV – SMS interface which will likely be rolled out using SMS's new Dynamic Model Interface tool. We will provide further updates on this during future versions of the release notes.

There is also now a community edition of SMS that provides a reduced set of functionality to full version of SMS but is still useful for result viewing and mesh generation. It can be downloaded from: <https://www.aquaveo.com/software/sms-community>

13.2 Rising Water Software GIS Mesher

Rising Water Software have created a product "GIS Mesher", GIS Mesher is a new mesh generator for TUFLOW FV that develops flexible meshes comprising triangular and quadrilateral elements.

The GIS Mesher allows the user to create a mesh within their preferred GIS software and review it prior to running TUFLOW FV. A number of GIS input file formats are supported including ESRI Shapefiles and MapInfo GIS files (tab or mif/mid). The shape, alignment and size of mesh elements can all be controlled using GIS layers. A series of mesh check files is also available for review.

The GIS Mesher supports the use of:

- 1 Raster files (a number of formats are supported) to provide elevation data.
- 2 Material assignment to mesh elements via GIS polygon layers.
- 3 Nodestring assignment to mesh faces via GIS polyline layers.
- 4 Topographic breakline assignment using a combination of GIS polyline and point layers.

For a demonstration of the GIS Mesher's functionality please refer to this series of short videos: <https://www.youtube.com/channel/UC9SNGcShk6era1BpjKZdvZQ>

For more information on the GIS Mesher please check out the [GIS Mesher Website](#).

14 General Updates

14.1 Folder Creation

TUFLOW FV will now create output folders if they don't already exist. This includes folders required for output using the `Output Dir ==`, `Logdir ==` and `Write GIS Check Files ==` commands.

14.2 String Matching Bug Fix

Previously, when matching any two strings (such as when reading a header from a csv file), TUFLOW FV used the first string that matched the specified header inclusively, even if that string had subsequent characters that did not match. This meant that when searching for the header 'Z' in the following file, the column 'Z_test' would be selected erroneously:

ID	Z_test	Z	Z_maximum
1	-9999	-2.456	-2.456
2	-9999	-3.011	-2.551
3	-9999	-3.213	-2.697
4	-9999	-2.988	-2.445

TUFLOW FV 2019.01 now requires that the string matches not only match inclusively, but are also the same length (excluding any white-space).

14.3 Improved expected variable echoing in log files

Changes have been made to reduce confusion in the correct order of scalar variables specified with the command:

```
bc header == <variable_list>
```

The log file will now echo both the specified header name, and the default variable expected for that boundary conditions type. Users are encouraged to check the log files to ensure they have not mis-specified the boundary conditions, particularly when switching on/off the inclusion of different scalars (temperature, salinity, etc.) without updating boundary conditions specifications. An example of this logging is as follows:

```
BC 13, Type=WLS-
BC Nodestring id = 12-
BC variable name/s = Time, WL_A, WL_B, SAL_A, SAL_B, TEMP_A, TEMP_B, SED_1_A, SED_1_B, SED_2_A, SED_2_B, SED_3_A, SED_3_B,-
BC file header/s = Time, PT_12, PT_13, SAL_A, SAL_B, TEMP_A, TEMP_B, SED_1_A, SED_1_B, SED_2_A, SED_2_B, SED_3_A, SED_3_B,-
BC reference time = 01/01/1990 00:00:00-
```

The **BC Variable name/s** row specifies the default variable name expected by TUFLOWFV. The **BC file header/s** specifies the headers specified by the user.

14.4 Imperial Units

14.4.1 Bed Shear Stress

A fix has been added to correct the output units when using the output parameter TAUB with Imperial Units. In builds pre-2019 TAUB was incorrectly output in units of $\text{kg/m}^3 \cdot \text{ft}^2/\text{s}^2$. This has now been corrected to output lbf/ft^2 .

If you have TAUB results from a previous model you can convert the raw results to the correct units via post processing by multiplying a factor of 0.00194 to convert the units to lbf/ft^2 . Alternatively re-running your model in the latest build may be an easier alternative than post-processing the raw results.

14.4.2 Improved Warning Messages

Imperial Units are currently supported for 2D flood assessments. They are yet to fully implemented for use with the Advection Dispersion, 3D, Heat, Water Quality, Sediment Transport or Particle Tracking Modules. There has been improved error/warning message added to the 2019 Release if you try to use `Units == Imperial | US Customary | English` with unsupported modules similar to the following:

Imperial/US Customary/English Units are not yet supported for ice module. Please use Units == Metric



15 Licensing

15.1 New software lock licensing options

Software locks utilise the same WIBU licensing system as the currently issued TUFLOW dongles, and are available in the same local and network configurations as the physical dongles. Please refer to the TUFLOW Price List for more information on software locks. Software locks are tied to a machine and do not require a hardware lock (dongle).

16 Tutorials and Supporting Materials

16.1 User Manual

The 2019 User Manual will soon be available from the TUFLOW website:

<https://www.tuflow.com/FV%20Documentation.aspx>

In the interim please use these Release Notes in combination with the existing [TUFLOW FV Manual](#).

16.2 Tutorial Models

TUFLOW FV offers a range of tutorial models via our [TUFLOW FV Wiki](#). These models can be run license free by adding the following command to the top of your .fvc:

```
Tutorial Model == ON
```

16.2.1 GIS Integration

[Tutorial Model 01](#) and [Tutorial Model 03](#) have been updated to provide a step by step guide on how to implement the new GIS commands in TUFLOW FV 2019.01.

The data package can be downloaded for [Tutorial Model 01](#) and [Tutorial Model 03](#) respectively.

16.2.2 3D Estuary Tutorial Model

A new 3D Estuary and Water Quality Tutorial Model is available. Please contact support@tuflow.com if you're interested in obtaining a copy of the models. This model will form Tutorial Model 05 and will be available as a wiki step-by-step tutorial in the coming months.

16.2.3 3D Lake Tutorial Model

A new 3D Lake Tutorial Model is available. Please contact support@tuflow.com if you're interested in obtaining a copy of the models. This model will form Tutorial Model 06 and will be available as a wiki step-by-step tutorial in the coming months.



16.3 TUFLOW FV Wiki

Over the next 12-18 months we will be adding new tutorial models, tips and tricks and toolboxes. You can access the TUFLOW FV wiki via this link: <https://fvwiki.tuflow.com/>

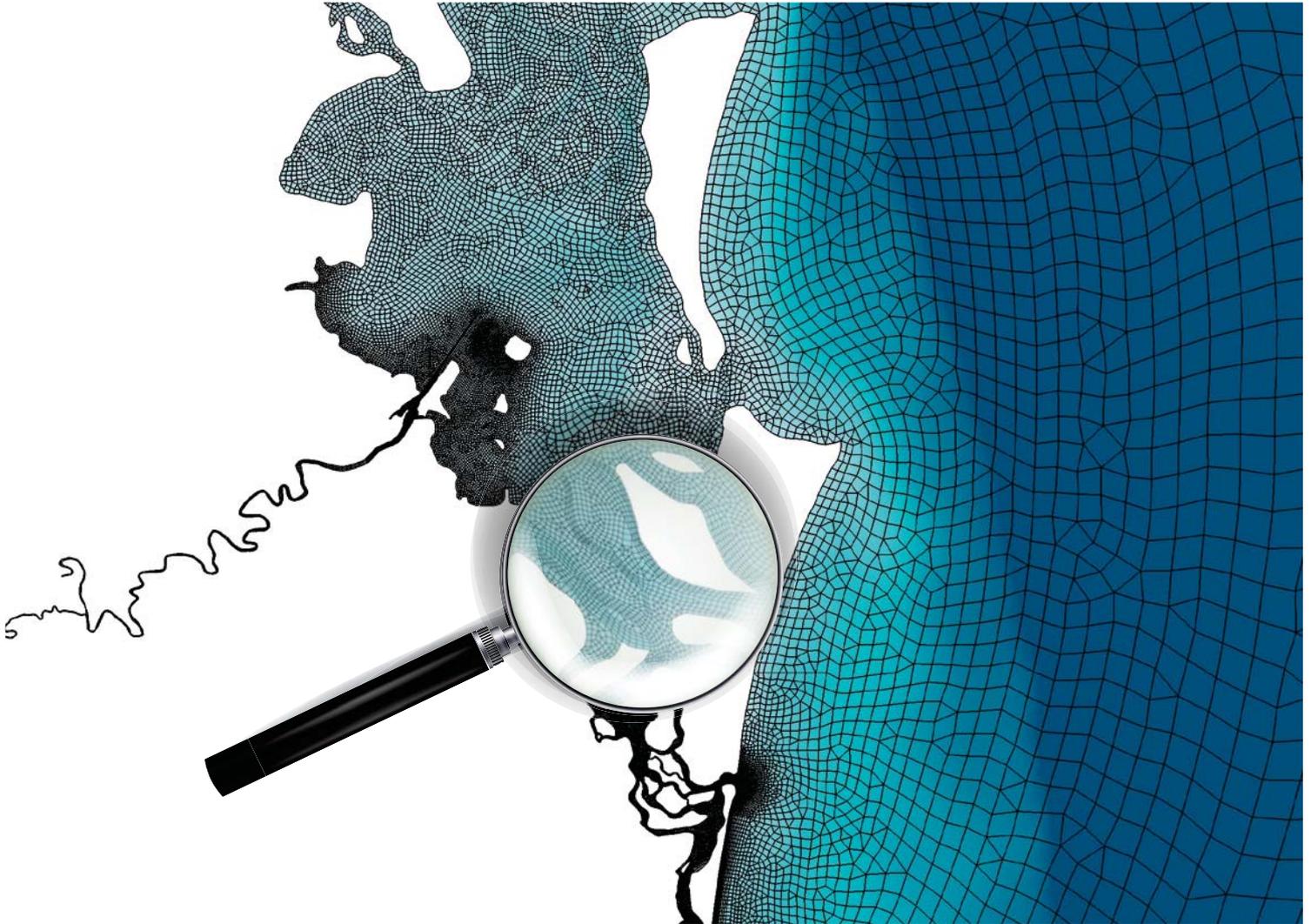
Please get in contact with support@tuflow.com if there are specific workflows or features you would like us to add to the wiki.

16.4 TUFLOW LinkedIn

If you're interested the TUFLOW Users Group on LinkedIn is a great place to keep up to date with all things TUFLOW. We will be retiring the previous TUFLOW FV LinkedIn Group in 2019 and all TUFLOW FV related posts will now be posted to the TUFLOW User Group: <https://www.linkedin.com/groups/1908583>



17 Appendix A – TUFLOW FV GIS Tutorial



TUFLOW FV GIS Tutorial

Build 2019-01

www.tuflow.com
[TUFLOW FV Wiki](#)
[TUFLOW Tutorial Model](#)
support@tuflow.com

Contents

Contents	1-1
1 Introduction	1-3
2 GIS Setup	2-4
2.1 Setup QGIS and TUFLOW Plugin	2-4
2.1.1 Download and Install QGIS	2-4
2.1.2 Install the TUFLOW Viewer Plugin	2-4
3 Configure Tutorial 01 with QGIS	3-6
3.1 GIS Workflow using Tutorial Model 01 - Pre-Requisites	3-6
3.2 Set Model GIS Projection and Create TUFLOW FV Empty (Template) GIS Files	3-6
3.3 Rerun Tutorial 01 Model to Create Check Files	3-11
3.3.1 Update FVC File	3-11
3.3.2 Running from a Batch File.	3-11
3.3.3 Inspect the Check Files	3-13
3.3.4 Viewing Modelling Results using TUFLOW Viewer	3-16
3.4 Set Nodestrings in QGIS	3-19
3.4.1 Update Input Files	3-19
3.4.2 Update the FVC File	3-23
3.4.3 Discussion	3-24
3.5 Define Materials using GIS File	3-24
3.5.1 Create 2d_mat File	3-24
3.5.2 Update FVC File	3-26
3.5.3 Discussions	3-26
3.6 Simple Geometry Update using GIS File	3-28
3.6.1 Create 2d_zline File	3-29
3.6.2 Update FVC File	3-30
3.6.3 Discussions	3-30
4 Tutorial 03 – Advanced GIS Updates	4-32
4.1 Pre-requisites	4-32
4.2 Set Model GIS Projection and Create TUFLOW FV Empty (Template) GIS Files	4-32
4.3 Geometry Update using GIS File	4-33

4.3.1	Copy model input files:	4-33
4.3.2	Update GIS inputs and FVC commands	4-34
4.3.3	Review GIS files in QGIS	4-34
4.3.4	Assign data to TUFLOW FV empty layers	4-37
4.3.5	FVC Updates	4-44
4.3.6	Review of Results and Discussion	4-45
4.4	Set Nodestrings for Structures	4-48
4.4.1	Update Input Files	4-48
4.4.2	Discussions	4-49

1 Introduction

The TUFLOW FV 2019 release has incorporated GIS functions that allow you to setup models in an efficient way using your favourite GIS. This document provides a step by step guide on how to setup your model with the new GIS workflow.

If you're not familiar with TUFLOW FV and Flexible Mesh modelling we highly recommend first completing our first four tutorial models documented in detail on the TUFLOW FV Wiki (<https://fvwiki.tuflow.com>) and at minimum Tutorial Model 1. The GIS methods presented here build on the material provided in Tutorial Models 1 and 3.

2 GIS Setup

2.1 Setup QGIS and TUFLOW Plugin

2.1.1 Download and Install QGIS

This tutorial has been setup to run with the Open Source GIS package QGIS. It is also possible to use Mapinfo or Arcmap with workflows for each of the these will be further developed.

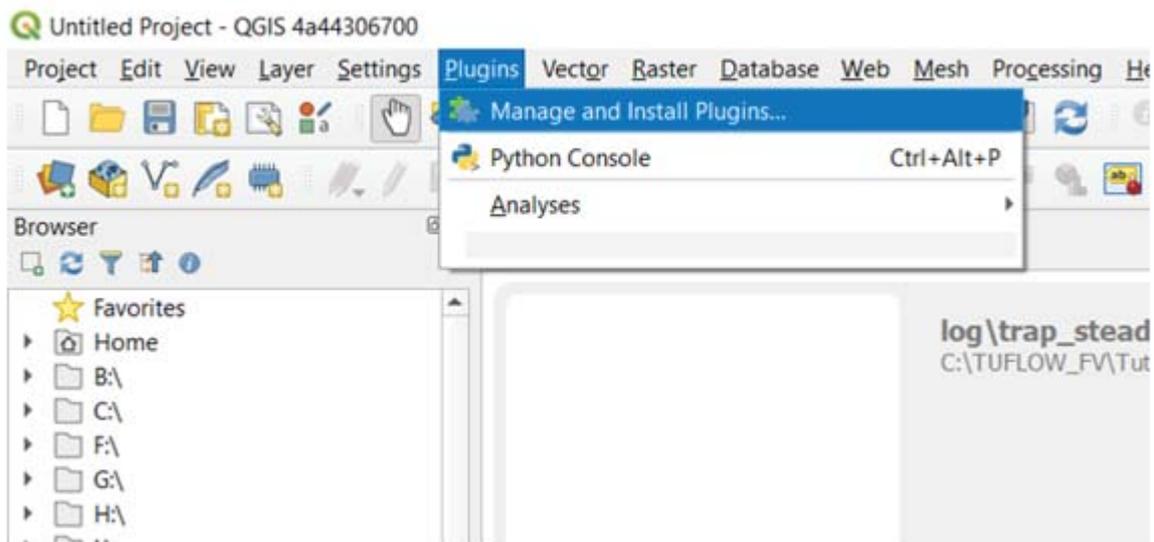
Download and Install QGIS from this website: <https://qgis.org/en/site/forusers/download.html>. We are going to download the latest release which at the time of writing was QGIS 3.6:



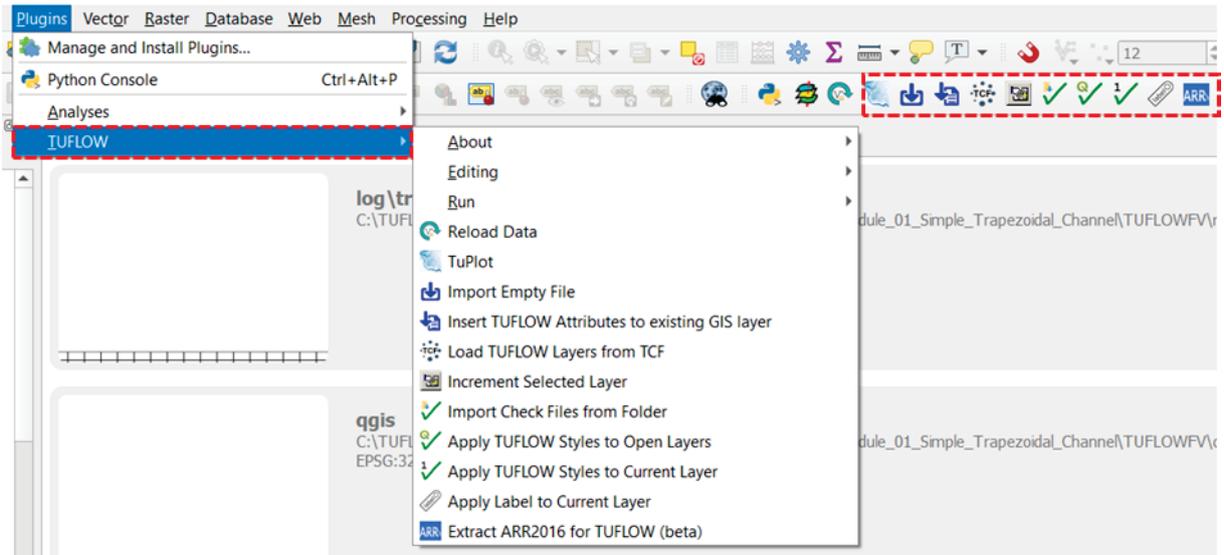
There is also a video here: <https://www.youtube.com/watch?v=hL-jTI2OzcY> that provides a handy resource to assist with the installation of QGIS and configuration for TUFLOW and TUFLOW FV.

2.1.2 Install the TUFLOW Viewer Plugin

Following installation, open QGIS and go to: **Plugins>>>Manage and Install Plugins...**, search for TUFLOW and install the TUFLOW Plugin.



If the plugin has correctly installed you should find the following toolbars and dialogue boxes in QGIS.



3 Configure Tutorial 01 with QGIS

3.1 GIS Workflow using Tutorial Model 01 - Pre-Requisites

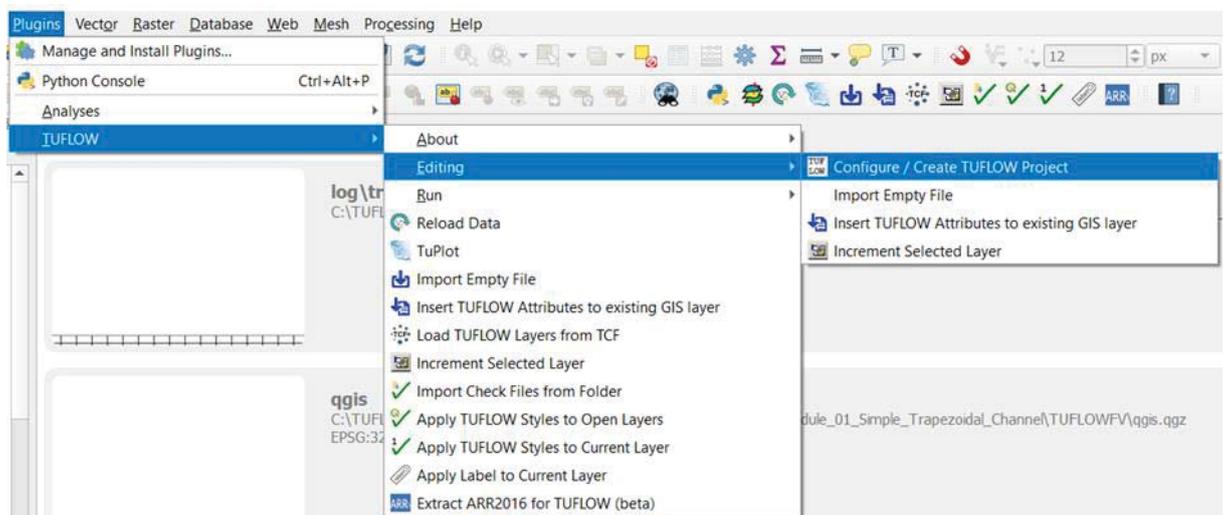
This tutorial assumes you have completed [up to and including Step 6 of Tutorial Model 01](#).

3.2 Set Model GIS Projection and Create TUFLOW FV Empty (Template) GIS Files

When using GIS integration with TUFLOW FV it is required that all GIS inputs and the mesh are in the same spatial reference system. Both spherical geographic coordinate systems and cartesian projected systems are accepted. The need for a singular spatial reference system for all inputs and outputs to TUFLOW FV is required to ensure GIS objects align correctly with the mesh or 'snap' to each other allowing them to be correctly read by TUFLOW FV.

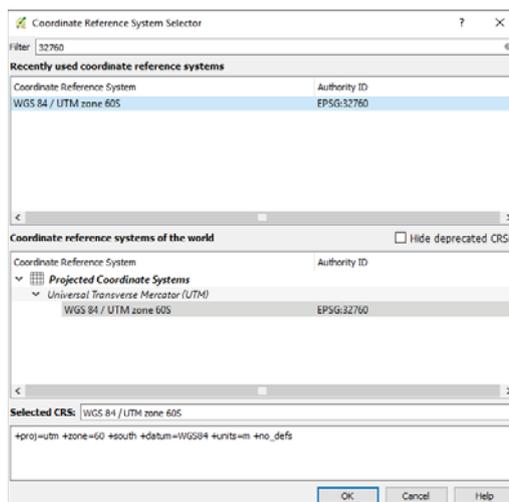
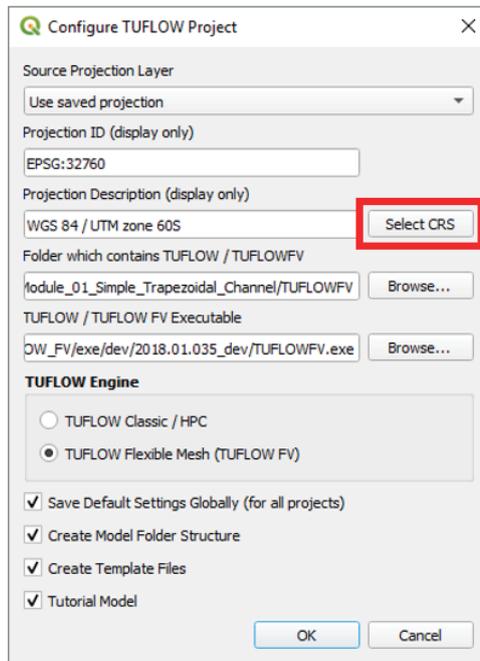
The first step to ensure this is to create a 'dummy' GIS layer with the model's GIS projection (i.e. the geographic coordinate system to be used for ALL the TUFLOW FV model inputs). For Tutorial 01 we are going to set the spatial reference system to the projected Mercator system WGS 84 / UTM zone 60S. This process is assisted by the QGIS TUFLOW Plugin as follows:

- Using the TUFLOW Plugin through **Plugins >>> TUFLOW >>> Editing >>> Configure / Create TUFLOW Project**

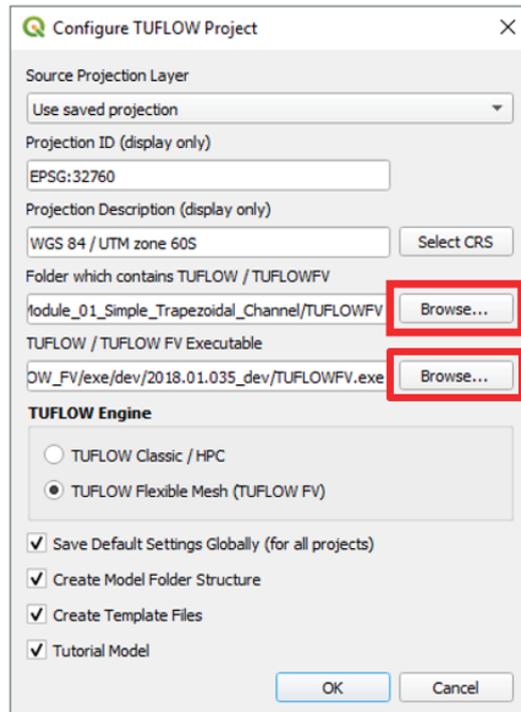


- In the following Dialog specify:

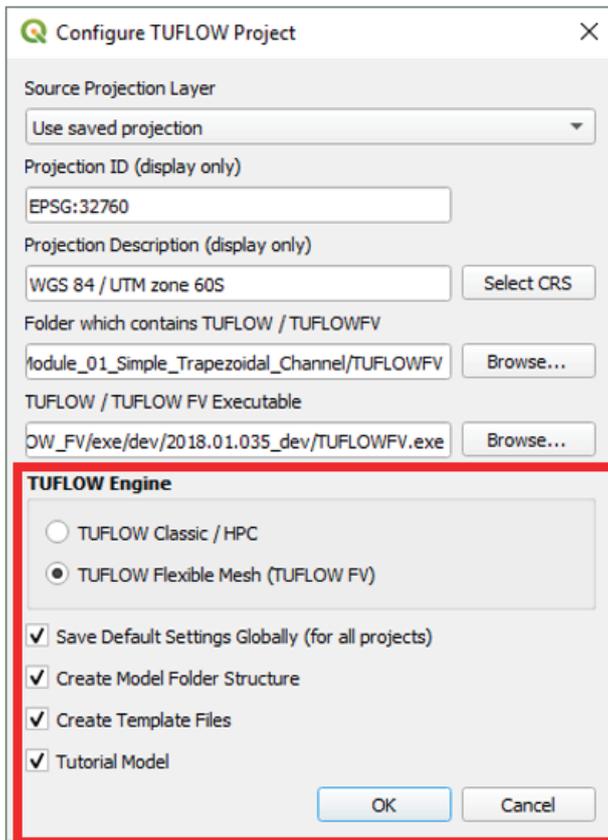
- The Projection** – Select the projection WGS 84 / UTM zone 60S



- **Project Folder** – The folder where you will undertake your modelling. It is the folder that will contain the folder TUFLOWFV and all its supporting subfolders. For example: C:\TUFLOWFV\Training_Workshop\Tutorial_01\TUFLOWFV.
- **TUFLOW (FV) exe** – The location of your Windows 64bit TUFLOW FV executable, for example: C:\TUFLOWFV\2019.01.008\ noting that your save location of the TUFLOW FV executable may be different to this.

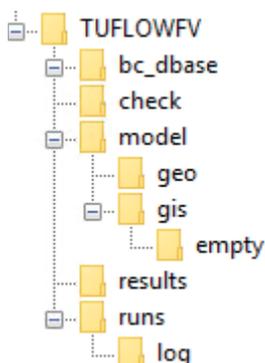


- Check **TUFLOW Flexible Mesh** radio button
- Check **Save Default Settings Globally (for all projects)**
- Check **Create TUFLOW Folder Structure**
- Check **Run TUFLOW to create template files**
- Check **Tutorial Model**

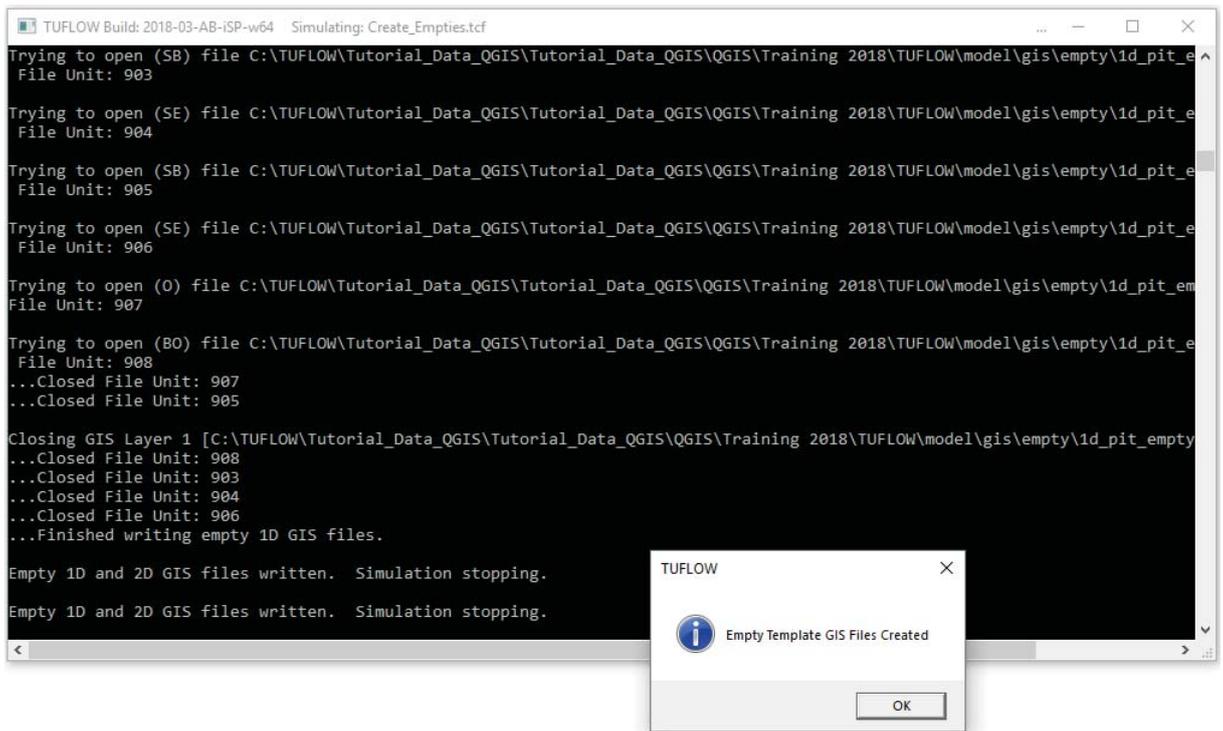


3. Follow all prompts to save the default settings, create the folder structure and empty template files. This will result in three main actions:

- Saving Default Setting Globally: The TUFLOW FV Plugin will be setup to allow you to run TUFLOW FV directly from QGIS. This will be saved for all QGIS projects. You will be setup to access tools on the QGIS plugin like 'import empty layers', 'increment layer' allowing for rapid model development.
- Create Model Folder Structure: This will create the default folder structure for TUFLOW FV as follows:



- Create Template Files: This will will create the projection file **.\TUFLOWFV\model\gis\Projection.prj**. For interest you can open this file in a text editor and view the long text string containing spatial reference information for our selected system UTM WGS 84 / Zone 60S. Please close this file without making any changes. The QGIS Plugin also creates the FVC file **Create_Empties.fvc** in **TUFLOWFV\runs** and this will be run in TUFLOW FV to create empty files in **TUFLOWFV\model\gis\empty**.



Please review the folder and associated files that have been written to the 'Empty' template files folder: **TUFLOWFV\model\gis\empty**. We will use these empty files as the basis for developing the materials, boundary locations, nodestrings and mesh topographic updates. Each empty file has been set with the projection UTM WGS / Zone 60S and has been populated with a series of attribute types that will allow us flexibility over how we assign components to our model.

3.3 Rerun Tutorial 01 Model to Create Check Files

Once ready, copy and save the **Create_Empties.fvc** file in the **TUFLOWFV\runs** folder as **trap_steady_04.fvc** and open this file in Notepad++. This file now only contains the command to define the GIS format and model projection. We will edit this file to create a new run file.

3.3.1 Update FVC File

1. Comment out the last command since we don't need to generate empty files again.

```
GIS FORMAT == SHP
SHP Projection == ..\model\gis\projection.prj
Tutorial Model == ON
!Write Empty GIS Files == ..\model\gis\empty
```

Note: If you have completed the first 6 sections of this tutorial and have successfully created and run `trap_steady_01.fvc` from the `TUFLOWFV\runs` folder, skip to step 5.

2. Go to the folder **Complete_Model\TUFLOWFV\runs**, copy the original tutorial FVC file **trap_steady_01.fvc** across to our working folder the **TUFLOWFV\runs** folder.
3. Copy across the input boundary data **steadyQ_01.csv** and **steadyWL_01.csv** from **Complete_Model\TUFLOWFV\bc_dbase** to our working folders of the model **.\TUFLOWFV\bc_dbase**
4. Copy the mesh file **trap_steady_01.2dm** from **Complete_Model\TUFLOWFV\model\geo** over to our working mesh folder **.\TUFLOWFV\model\geo**
5. Copy across **ALL** commands from **trap_steady_01.fvc** to the newly created **trap_steady_04.fvc** file, below the existing lines of code.
6. Change the output type to xmdf for easier viewing in using the TUFLOW Viewer in QGIS:

```
output == xmdf
```

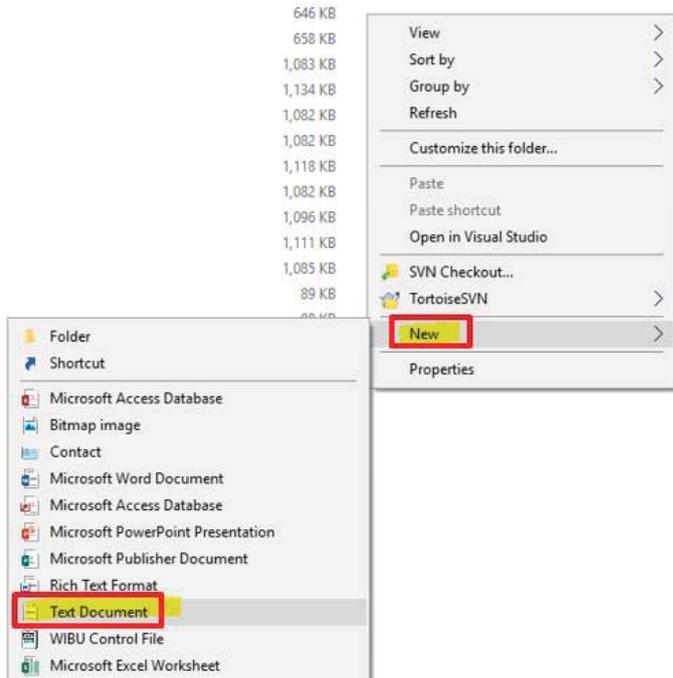
7. Additionally at the end of the file add:

```
Write Check Files == ..\check
```

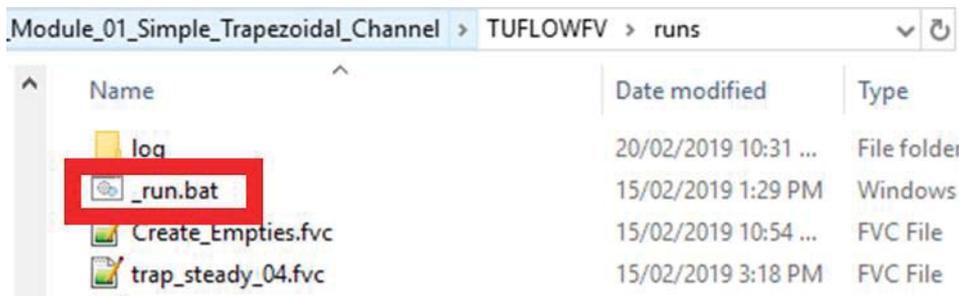
8. We are now ready to re-run our simulation with GIS check files enabled. We will run TUFLOW FV Using a Windows Batch File as detailed in the following section.

3.3.2 Running from a Batch File.

The preferred method to run TUFLOW FV is via a Windows batch file. We are going to create a batch file in the **.\TUFLOWFV\runs** folder called **_run.bat**. To do this, right click inside the runs folder, creating a new text file as follows:



Rename the newly created text file to **_run.bat** and open in Notepad++ (or your preferred text editor).



1. Once in a text editor add this command to set the path to FV executable:

```
set exe="Add your folder path to TUFLOW FV here\TUFLOWFV.exe"
```

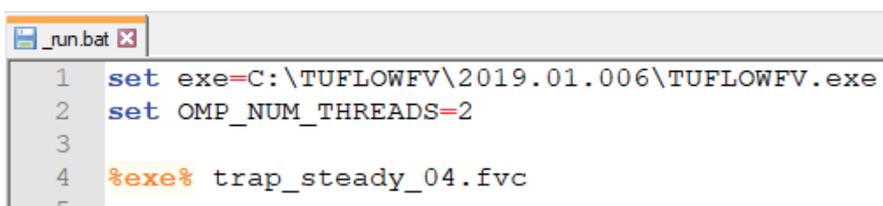
where path is the path to your TUFLOW FV executable. Please note that there is no space between exe= when assigning an environment variable with the set command.

2. Set the number of CPU threads used in the simulation based on your PC spec:

```
set OMP_NUM_THREADS=2
```

3. Add the following command to run the FVC file using the above FV executable:

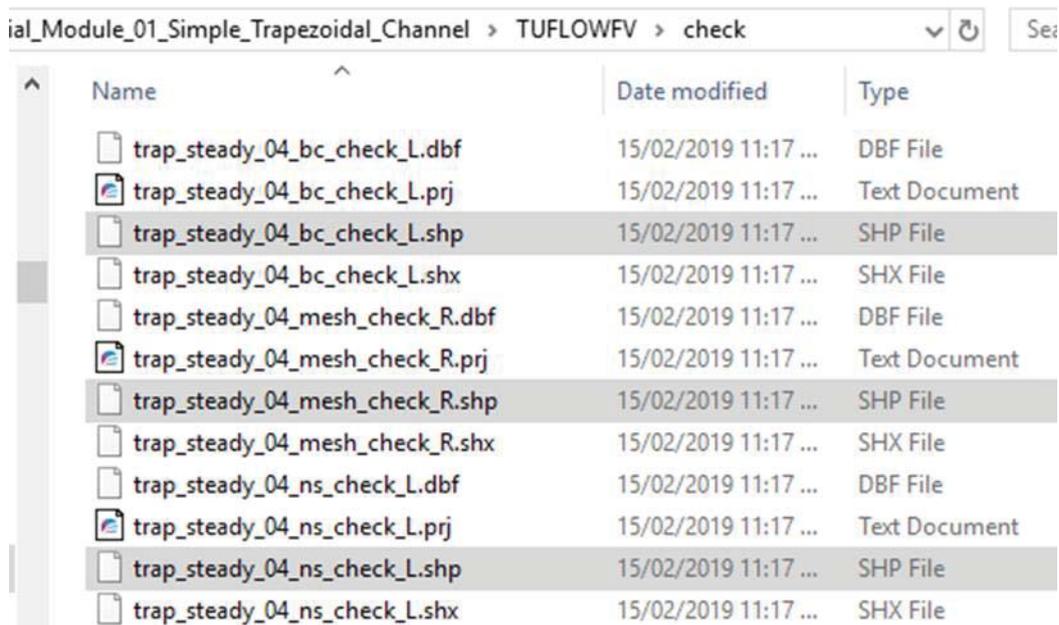
```
%exe% trap_steady_04.fvc
```



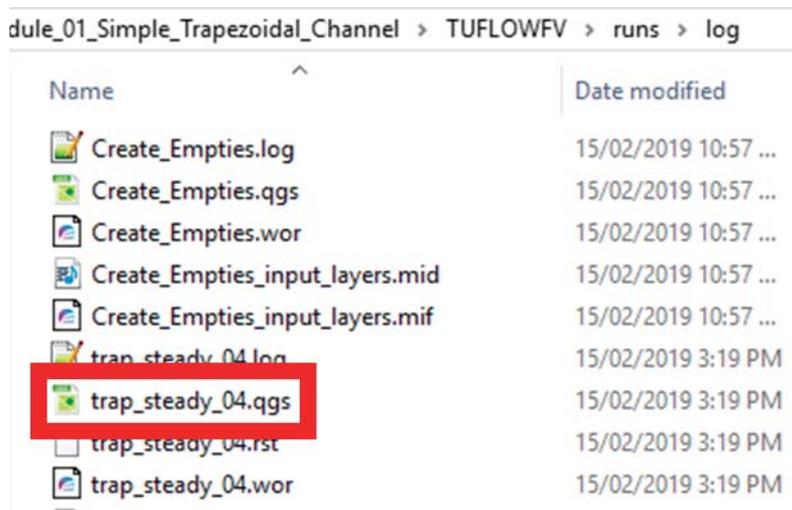
- Run the model by double clicking the batch file. If you want to know more about running TUFLOW FV from a batch check out our [Running TUFLOW FV from a batch file Wiki Page](#).

3.3.3 Inspect the Check Files

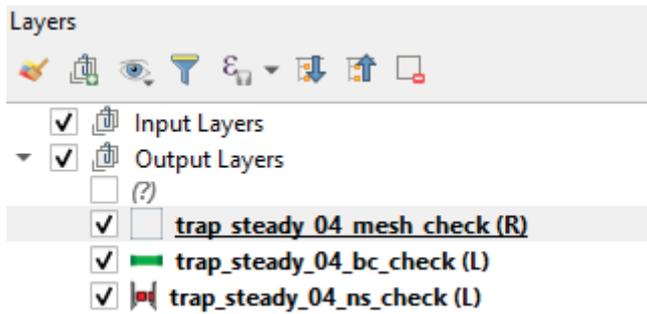
With GIS enabled and using the `Write Check Files == ..\check` command the TUFLOW FV 2019 release can export GIS files that assist you in reviewing what TUFLOW FV has used for input. We will start by investigating the three check files generated for `trap_steady_04.fvc` shown below.



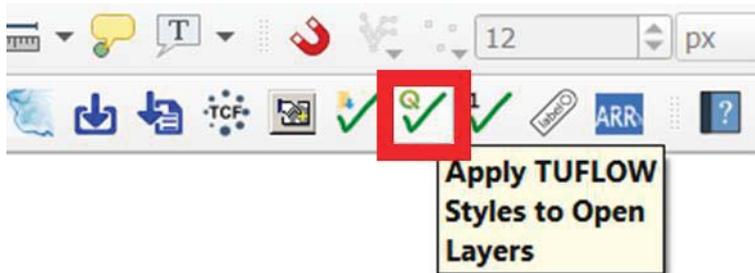
- Go to the TUFLOWFV\run\log folder, open **trap_steady_04.qgs** file by dragging this file into QGIS or simply double clicking it.



Now all the check files are opened in the “Output Layers”. (This model doesn’t have any input GIS layer, so the “Input Layers” group is empty).



2. Use the **Apply TUFLOW Style to Open Layers** button to check the styles of the check layers.



Note: If you cannot see the mesh at this point, select the 'trap_steady_04_mesh_check (R)' layer, go to view > 'zoom to layer'.

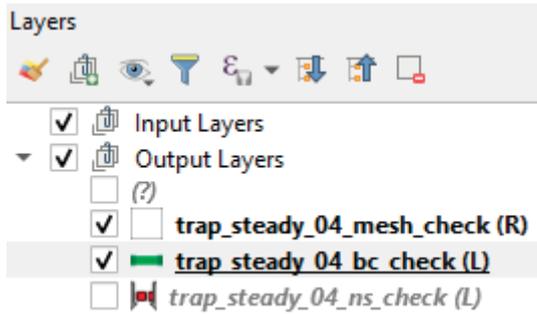
3. Right click on the **_mesh_check_R** layer and open Attribute Table.

	IDX2	IDX3	CTRDY	Mat	ZB	BRough
40	14	14	87.50000	1	-3.83750	0.01800
41	3	3	37.50000	1	-1.26875	0.01800
42	4	4	12.50000	1	-5.01250	0.01800
43	1	1	12.50000	1	-1.25625	0.01800
44	2	2	12.50000	1	-3.76250	0.01800

The following information can be check from the attributes:

- **IDX2**: 2D cell ID,
- **IDX3**: 3D cell ID (If the mode is 2D the IDX2 will equal IDX3),
- **CTRDY**: Cell center X coordinate,

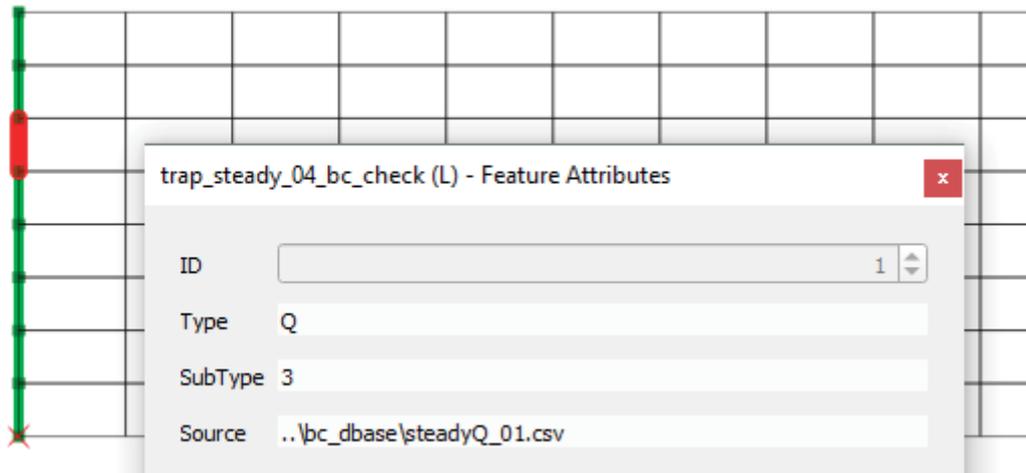
- **CTRDY**: Cell center Y coordinate,
 - **Mat**: Cell material ID,
 - **ZB**: Cell center bed elevation,
 - **BRough**: Bed roughness.
4. Uncheck the **_ns_check_L** check file in the Layer Panel to show the mesh check file and the BC check file only. All the boundary cell faces are represented by a line segment.



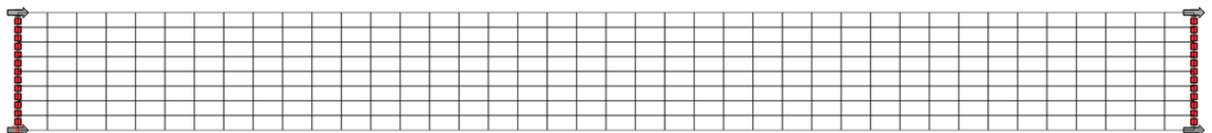
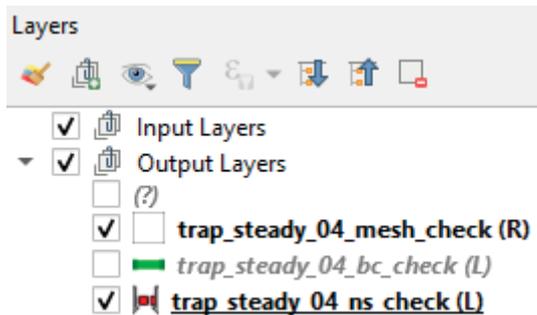
Select the **_bc_check_L** check file in the Layer Panel. Use the Identify Feature tool and click on one of the cell faces to open a Feature Attributes Window. The attributes include:

- **ID**: Nodestring ID associated with the boundary
- **TYPE**: Type of the boundary condition. In this model “Q” for flow boundary or “WL” for water level boundary.
- **Subtype**: Subtype of the boundary
- **Source**: Boundary source file linked with the boundary





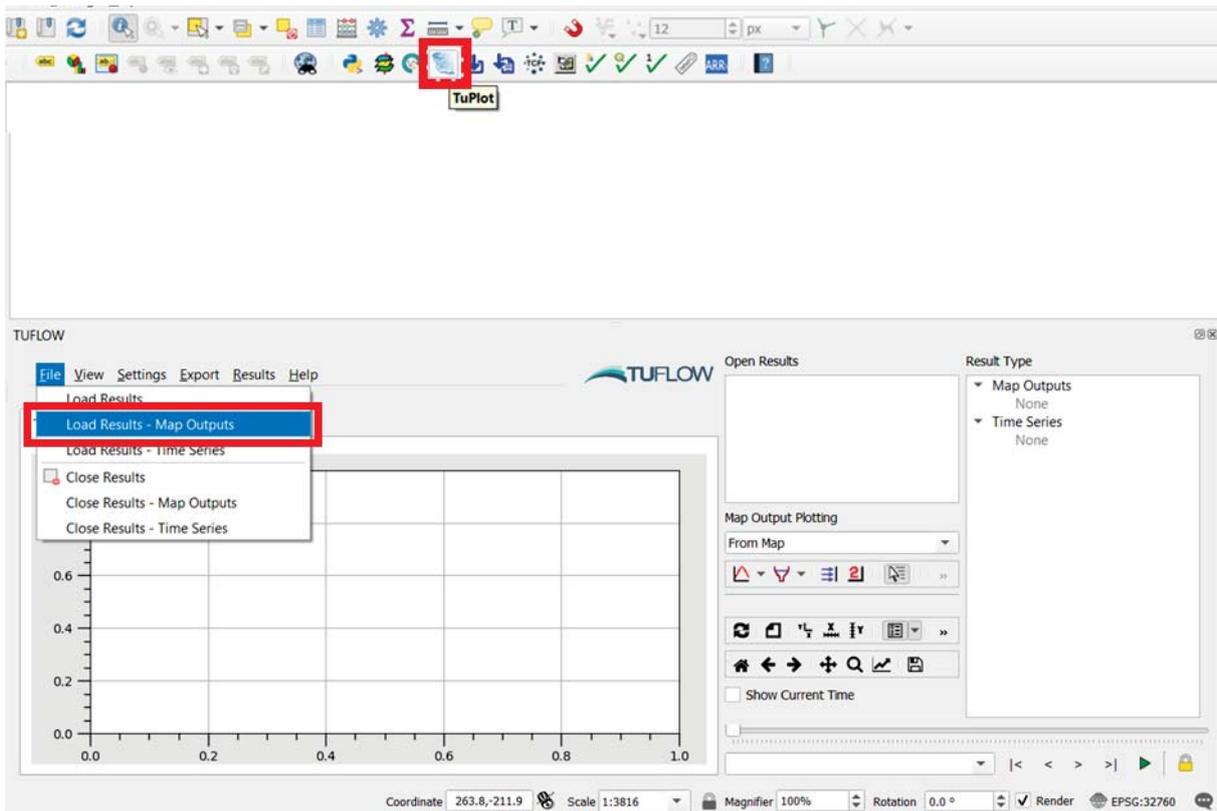
5. Uncheck the **_bc_check_L** and check the **_ns_check_L** in the layers panel to review the location and the direction of nodestrings. If the nodestrings are set correctly, the arrows should be pointing in the direction of flow.



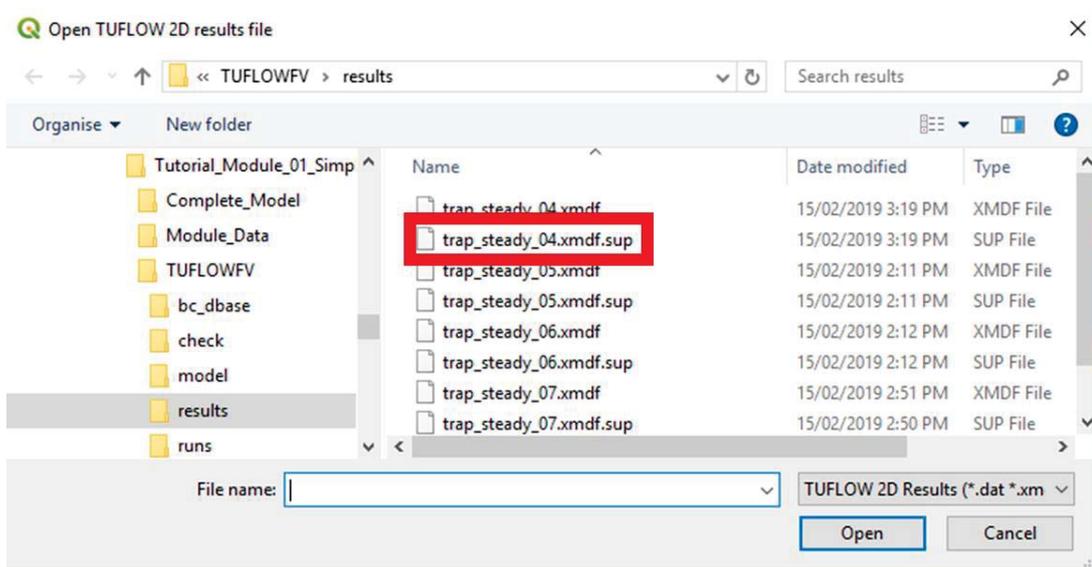
3.3.4 Viewing Modelling Results using TUFLOW Viewer

This section of the tutorial will show us how to use the TUFLOW Viewer in QGIS to view our XMDF results.

1. Click the **TUFLOW Viewer (TuPlot)** button to open the TUFLOW Viewer window.
Go to File>>>Load Results - Map Outputs.

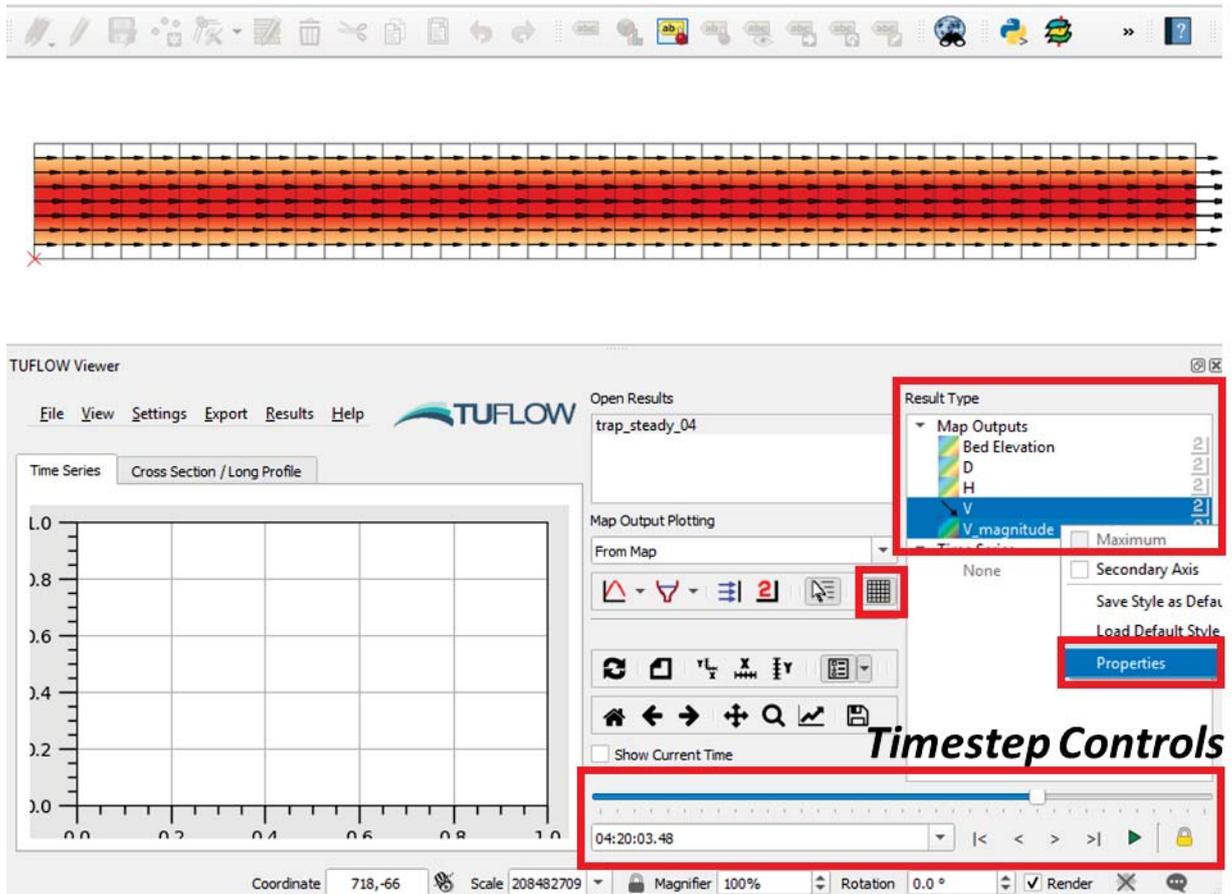


- In the pop-up window navigate to **TUFLOWFV**results and open **trap_steady_04.xmdf.sup**

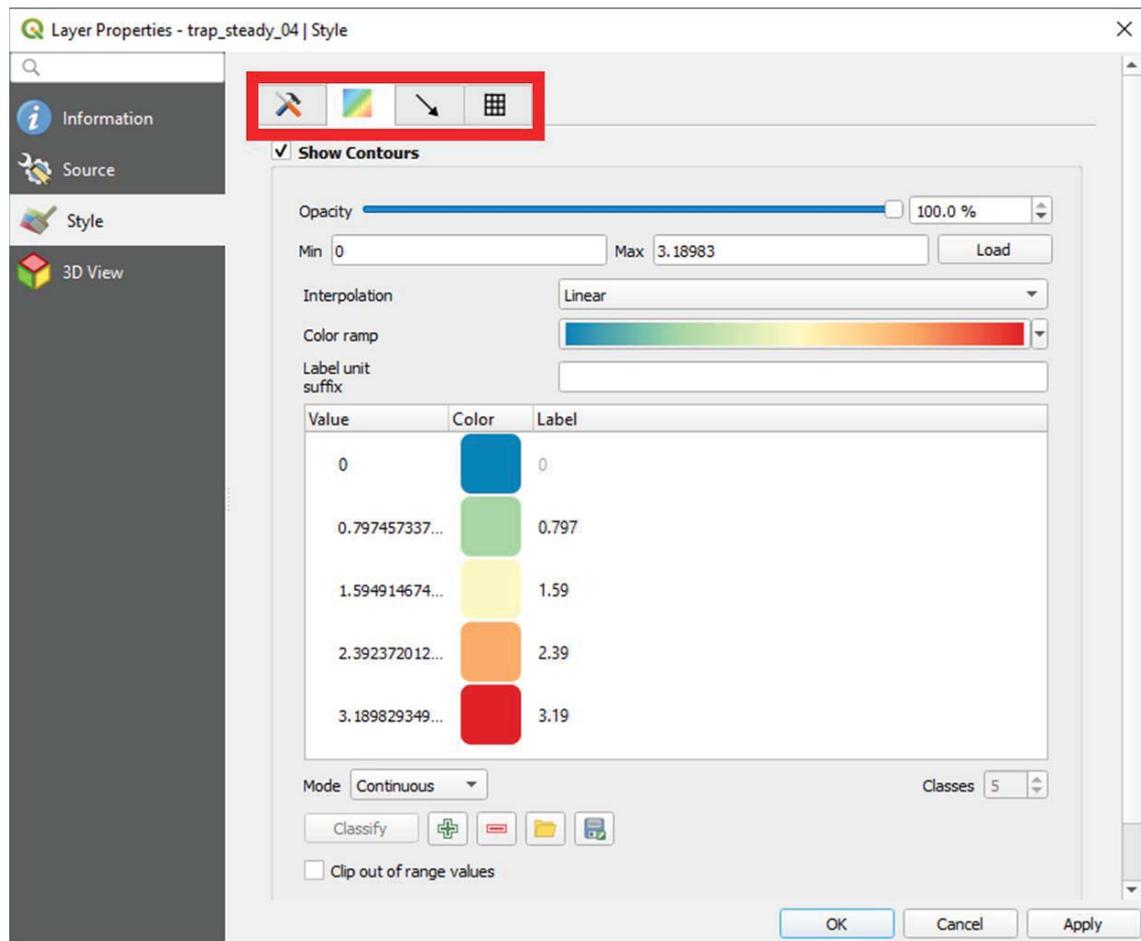


- In the TUFLOW Viewer, try:

- Click **Toggle Mesh Rendering**  to show and hide model mesh
- Change the vector and scalar to plot on the **Result Type** panel
- Use the timestep slider/buttons to advance through the time



4. Right click on the result type and change the plot style in the Contour/Vector/Mesh tabs.



3.4 Set Nodestrings in QGIS

In the original tutorial model boundary nodestrings were set in SMS each time the mesh was regenerated and saved to the 2dm file. With the GIS functionality now in TUFLOW FV 2019 Release, users can define nodestrings through GIS commands allowing nodestrings to be assigned somewhat independently to mesh generation and 2dm creation. We will now show you the steps involved to set nodestrings in this way.

3.4.1 Update Input Files

1. Save a copy of **TUFLOWFV\model\geo\trap_steady_01.2dm** as **trap_steady_05.2dm** and open this 2dm file in your preferred text editor.
2. Navigate to the bottom of the 2dm file, delete the two lines that start with "NS" and save the file (note: do not leave blank lines).

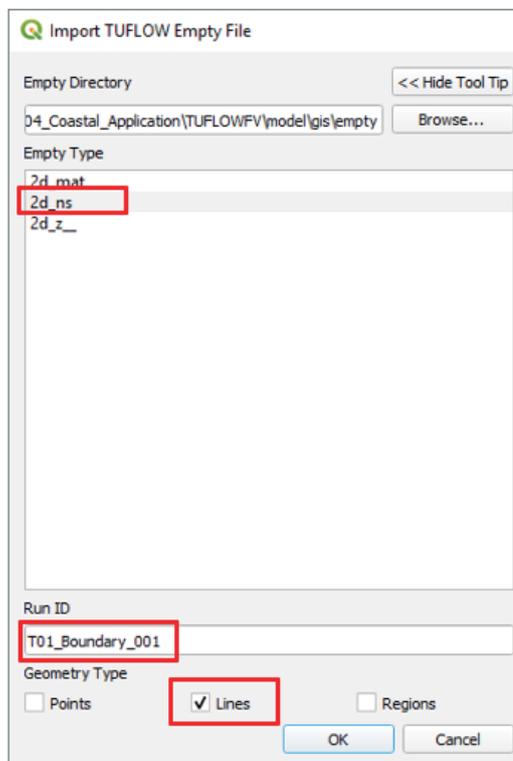
```

_trap_steady_04.fvc | trap_steady_05.2dm
684 ND 361 9.50000000e+002 1.25000000e+001 -2.95000000e+000
685 ND 362 9.75000000e+002 2.50000000e+001 -5.97500000e+000
686 ND 363 1.00000000e+003 3.75000000e+001 -6.00000000e+000
687 ND 364 9.50000000e+002 0.00000000e+000 -0.00000000e+000
688 ND 365 9.75000000e+002 1.25000000e+001 -2.97500000e+000
689 ND 366 1.00000000e+003 2.50000000e+001 -6.00000000e+000
690 ND 367 9.75000000e+002 0.00000000e+000 -0.00000000e+000
691 ND 368 1.00000000e+003 1.25000000e+001 -3.00000000e+000
692 ND 369 1.00000000e+003 0.00000000e+000 0.00000000e+000
693 NS 37 39 22 16 11 7 4 2 1 1
694 NS 369 368 366 363 359 354 348 341 333 2
695 BEGPARAMDEF
696 GM "Mesh"
697 SI 1
698 DY 0
699 TU ""
700 TD 0.00000000e+000 0.00000000e+000
    
```

3. In QGIS, use the **Import Empty file** to import a template 2d_ns layer.



Select the type **2d_ns**

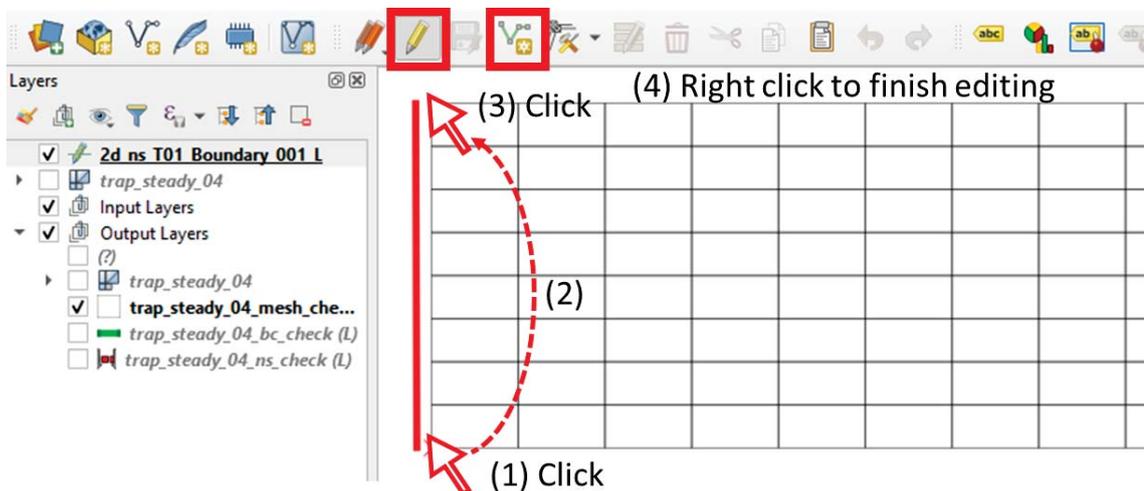


Give the Run ID as **T01_Boundary_001**

Check **Lines** as the geometry type and press OK

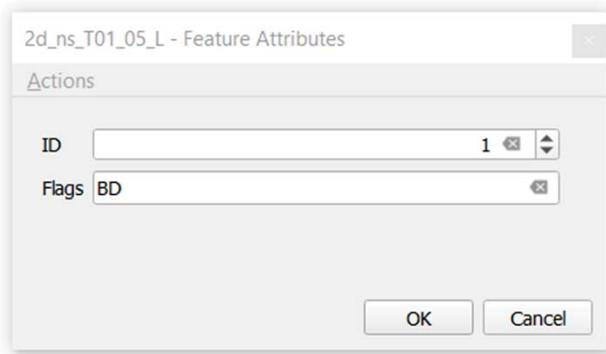
The plugin has made a copy of the empty template file from the `model\gis\empty` directory and saved it into the `model\gis` directory, the location where all our working gis files reside for our project. The Import Empty File tool has added our new layer to the QGIS map canvas available for further editing. Note the `_L` suffix added to the shp file indicating that it's a polyline geometry type.

4. Zoom to the upstream boundary (east side) of the model and toggle editing  for the layer `2d_ns_T01_Boundary_001_L`. Select the *Add Feature*  and create a line right next to the east domain boundary shown below. The direction of the line should be “from right to left looking downstream in the direction of flow”, i.e. from bottom to top in this model. After drawing the final vertex, use the right mouse button to finish the line. Please note the offset of the polyline from the mesh. This is the recommended approach for assigning ‘BD’ type nodestrings. TUFLOW FV will use its boundary algorithms to project onto the mesh.



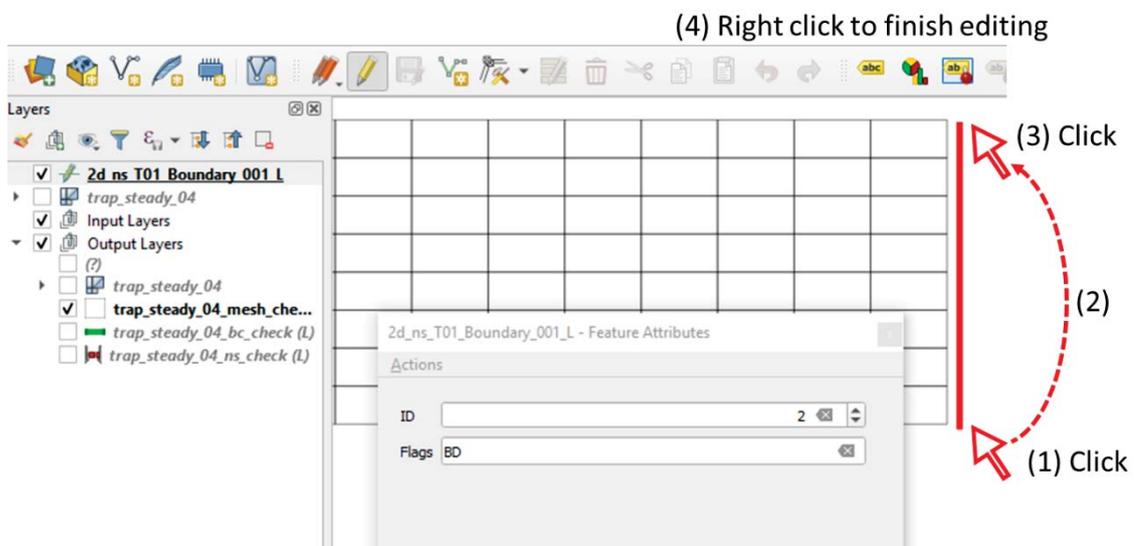
5. When you finish the line an attributes dialog will be displayed. Enter the following data:
 - ID = 1
 - Flags = BD

This designates the nodestring type with the ID “1”. The ‘BD’ indicates that the nodestring is to snap along the outside of the model domain. This flag is used to assign nodestrings associated with model open boundary inputs.



6. **Apply TUFLOW Style to Current Layer**  to check the noding direction.

7. At the downstream boundary (west or right side), add another noding next to the model domain boundary.



8. When you finish the line, enter the following feature attributes:

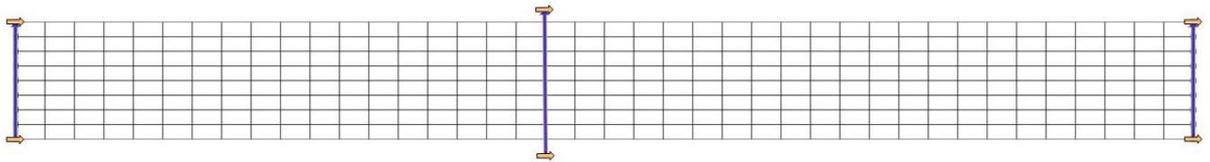
- ID = 2
- Flags = BD

9. Also add another noding in the middle of the channel with the following attributes. This noding will be used to monitor flux over time through the channel:

- ID = 3
- Flags = NULL (no need to add anything here, the default in QGIS is NULL)

Note typically when recording fluxes you should aim to have the noding drawn perpendicular to the dominate flow velocity.

10. Finish the edit by toggle the editing and when prompted, save the file. Now the model should look like the one below:



Finish the edit by toggle the editing and when prompted, save the file.

3.4.2 Update the FVC File

We need to read the boundary condition GIS files into the TUFLOW FV model.

1. Save **trap_steady_04.fvc** as **trap_steady_05.fvc** and open this file in your preferred text editor.
2. Update the geometry file to the 2dm with no nodestring we saved earlier:

```
Geometry 2d == ..\model\geo\trap_steady_05.2dm
```

3. In the boundary condition block, add the following command to read the SHP file that defines the nodestring:

```
Read GIS Nodestring == ..\model\gis\2d_ns_T01_Boundary_001_L.shp
```

```

34 !
35 ! BOUNDARY CONDITIONS
36 Read GIS Nodestring == ..\model\gis\2d_ns_T01_Boundary_001_L.shp
37
38 bc == Q, 1, ..\bc_dbase\steadyQ_01.csv
39     bc header == time,flow
40     Sub-type == 3
41 end bc
42 bc == WL, 2, ..\bc_dbase\steadyWL_01.csv
43     bc header == time,WL
44 end bc
45

```

4. In the output command block add the following commands to output the fluxes through the 3 nodestrings. This will output a timeseries of flux outputs every 600 seconds or 10 minutes.

```
Output == Flux
    Output interval == 600
End Output
```

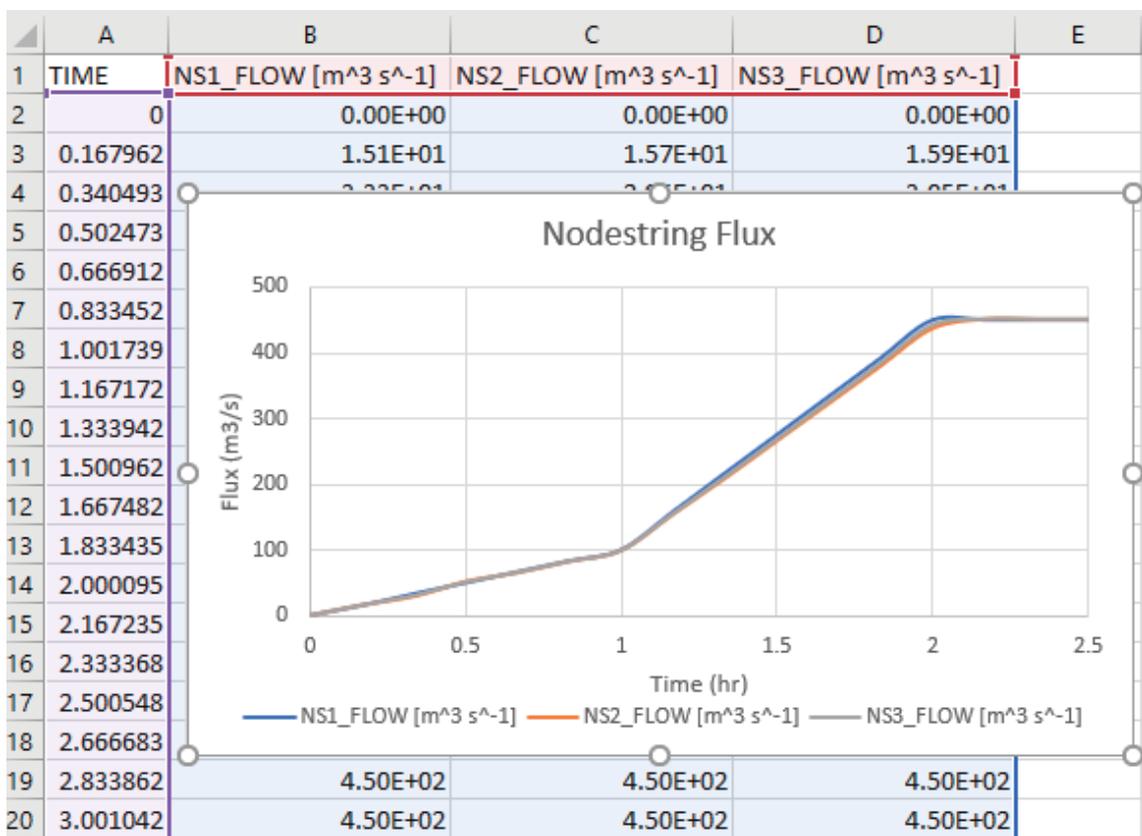
5. Update the batch file and run the model.

```

_run.bat
1 set exe=C:\TUFLOWFV\2019.01.006\TUFLOWFV.exe
2 set OMP_NUM_THREADS=2
3
4 ::%exe% trap_steady_04.fvc
5 %exe% trap_steady_05.fvc
6
    
```

3.4.3 Discussion

1. How does the `_ns_check` file looks comparing to the previous model?
2. Open the `TUFLOWFV\results\trap_steady_05_FLUX.csv` file in Excel and plot the data. Does the flux through the nodestring look sensible?



3.5 Define Materials using GIS File

Bed materials can also be defined via GIS in the TUFLOW FV 2019 Release. To show this functionality we will assign a higher Manning’s ‘n’ value to the right-side slope of the trapezoidal channel.

3.5.1 Create 2d_mat File

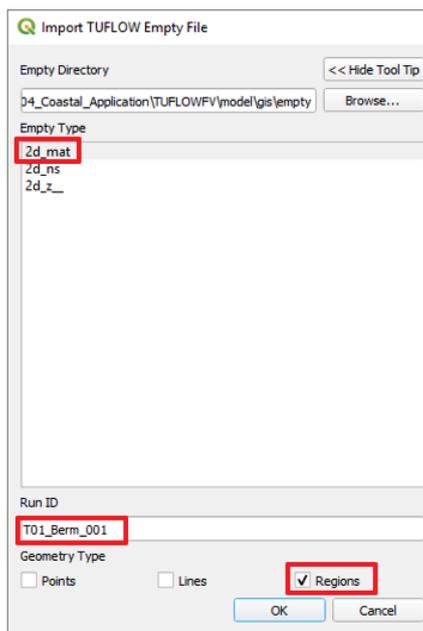
1. In QGIS, use the **Import Empty file** to import a template 2d_mat layer.



Select the type **2d_mat**

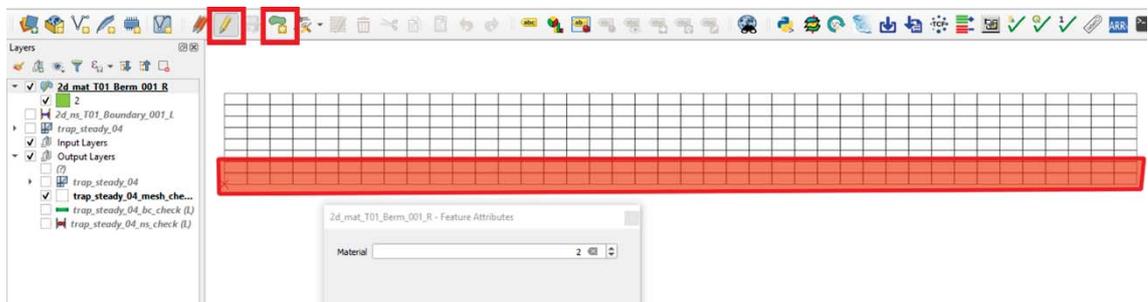
Give the Run ID as **T01_Berm_001**

Check **Region** as the geometry type and press OK



2. Toggle editing  for the **2d_mat_T01_Berm_001_R** layer and then select the *Add Polygon Feature* . Create a polygon to cover 2 rows of cells at the bottom of the model. As with the polylines once you are happy with your polygon, right click to finish the drawing. Enter the following data in the attributes dialog:

- Material = 2



Note that most of the cell will be assigned as “Material 1” using a global command and the polygon above will be used to override the material IDs for the selected cells. This means we don’t need to draw another polygon to select the rest of the cells.

3. Finish the edit by toggle the editing and when prompted, save the file.

3.5.2 Update FVC File

We need to set the material ID globally first, and then read the material GIS file into the TUFLOW FV model.

1. Save **trap_steady_05.fvc** as **trap_steady_06.fvc** and open this file in Notepad++.
2. In the material properties block, add:

```
Set Mat == 1
Read GIS Mat == ..\model\gis\2d_mat_T01_Berm_001_R.shp
```

The first command will set the cell material ID to 1 globally, and the second command will read the SHP file to override the cell material ID within the polygon.

3. At the end of the material properties block, also add the followings to define the Manning's n value for material 2:

```
Material == 2
    Bottom Roughness == 0.05
End Material
```

Now the material properties block should look like this:

```
22 geometry 2d == ..\model\geo\trap_steady_05.2dm
23
24 !
25 ! MATERIAL PROPERTIES
26 Set Mat == 1
27 Read GIS Mat == ..\model\gis\2d_mat_T01_Berm_001_R.shp
28
29 material == 1
30 bottom roughness == 0.018
31 end material
32
33 material == 2
34 bottom roughness == 0.05
35 end material
```

4. Update the batch file with **trap_steady_06.fvc** and run the model.

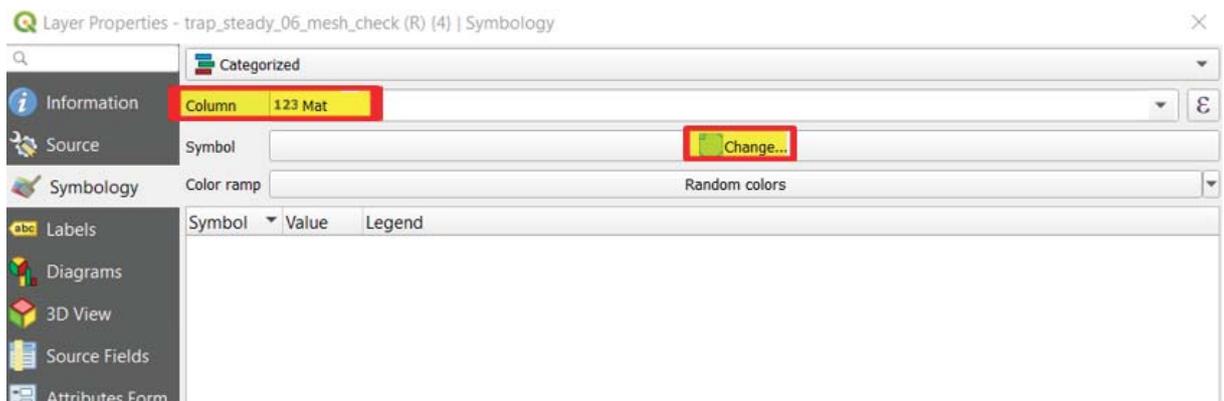
3.5.3 Discussions

1. Double click to open **trap_steady_06.qgs** workspace from the `\runs\log` directory and apply the default TUFLOW style to all layers.
2. Double click on the **trap_steady_06_mesh_check_R** layer and complete the following steps to “Categorize” the mesh colour based on “Mat”:

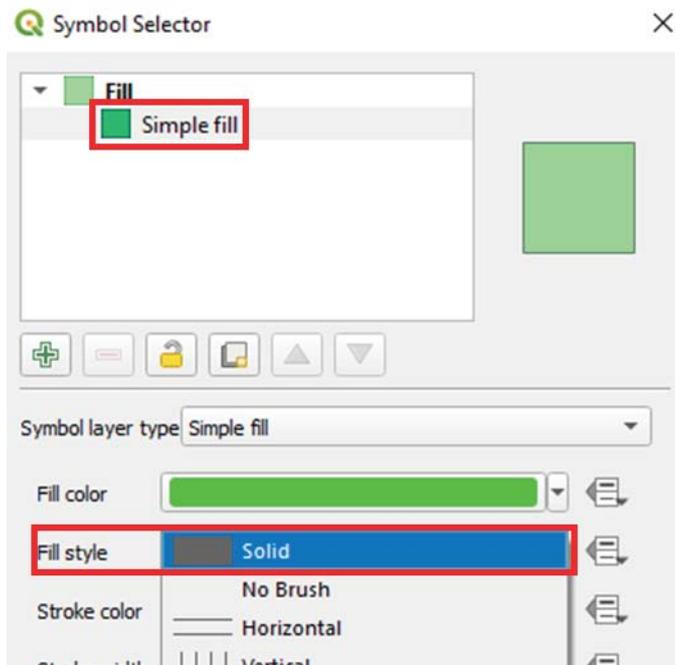
- In the “Symbology” tab, select “Categorized” from the first drag down list



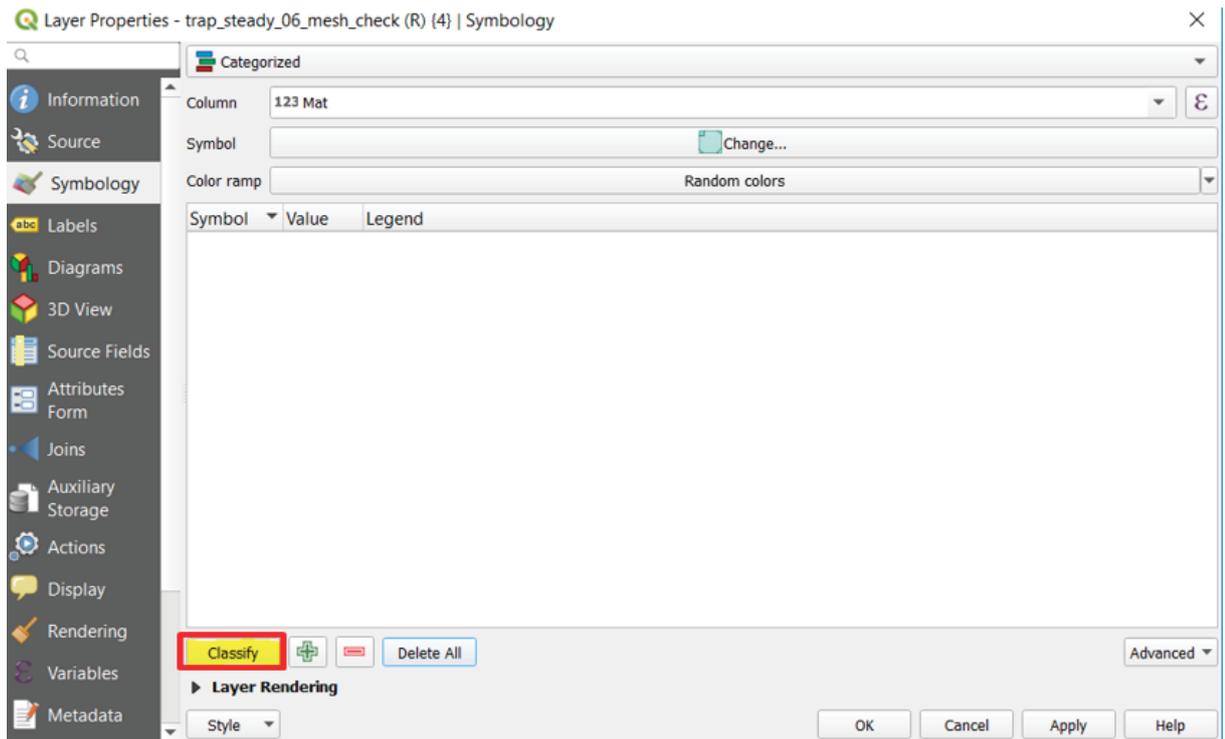
- Select “Mat” attribute from the Column drag down list, and click “Change” button,



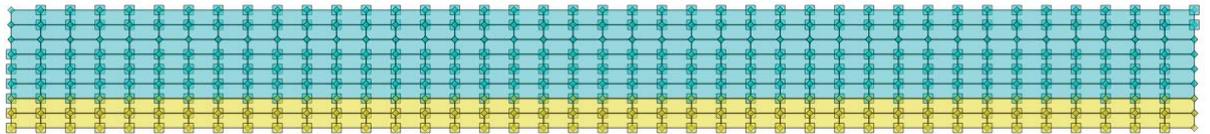
- Select “Simple fill” and change the “Fill style” to “Solid” if it hasn’t been selected



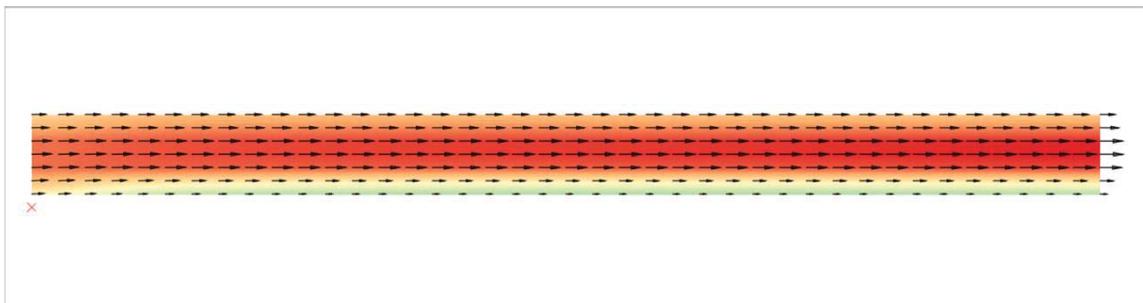
- “Classify” the mesh and press OK.



Is the material ID assigned properly to the cells?



3. Open **TUFLOWFV\results\trap_steady_06.ALL.sup** and compare the flow field with the previous models. Does the flow velocity become smaller where Manning's 'n' is higher?

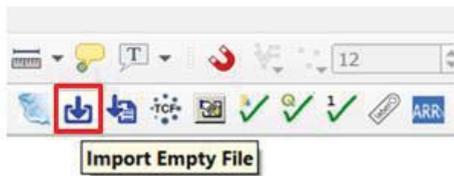


3.6 Simple Geometry Update using GIS File

In the TUFLOW FV 2019 Release it is now possible to update the topography/bathymetry directly from GIS using points, lines and polygon layers (and also GRIDS refer Tutorial Model 03). This was previously only available in TUFLOW FV using csv input which could be quite cumbersome. In this tutorial model we will create a small obstruction on both sides of the channel to highlight the use of topographic updates using GIS.

3.6.1 Create 2d_zline File

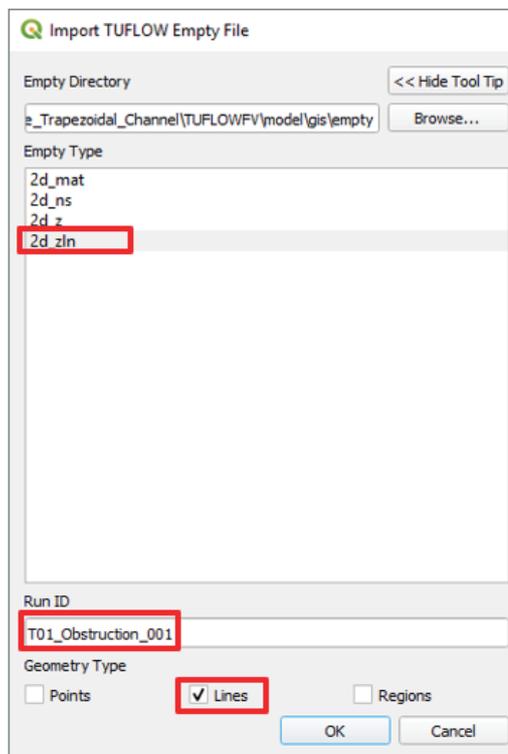
1. In QGIS, use the **Import Empty file** to import a template 2d_zln layer.



Select the type **2d_zln**

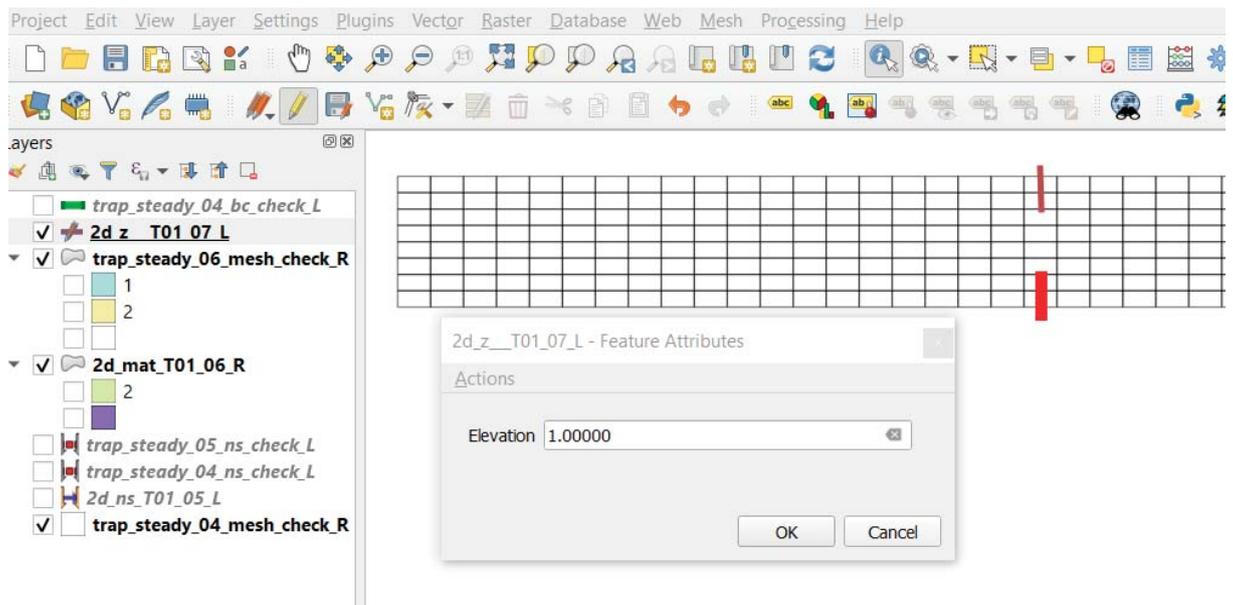
Give the Run ID as **T01_Obstruction_001**

Check **Lines** as the geometry type and press OK



2. Toggle editing  for the **2d_zln_T01_Obstruction_001_L** layer and then select the *Add Feature* . Create two lines at both side of the channel as shown below. When you finish the drawing enter the following data in the attributes dialog for both polylines:

- Elevation = 1



This will assign an absolute elevation of 1m to the cell centroids at cells intersected by each polyline.

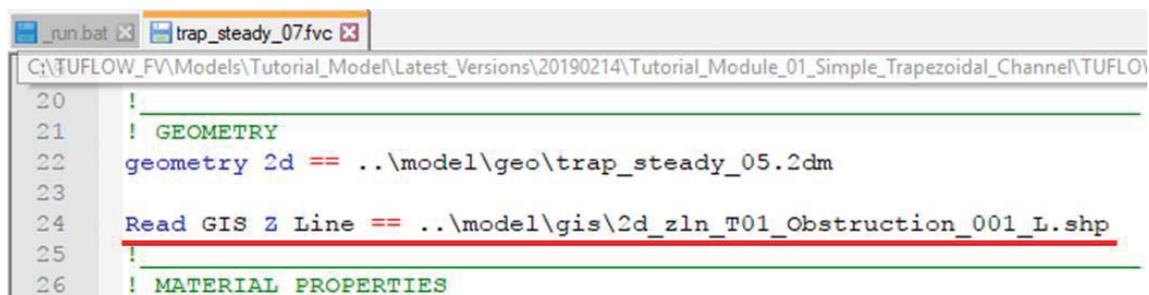
3. Finish the edit by toggle the editing and when prompted, save the file.

3.6.2 Update FVC File

We will update the fvc file to read the Zline GIS file into the TUFLOW FV model.

1. Save **trap_steady_05.fvc** as **trap_steady_07.fvc** and open this file in your preferred text editor.
2. After reading the 2dm file, add:

```
Read GIS Z Line == ..\model\gis\2d_zln_T01_Obstruction_001_L.shp
```

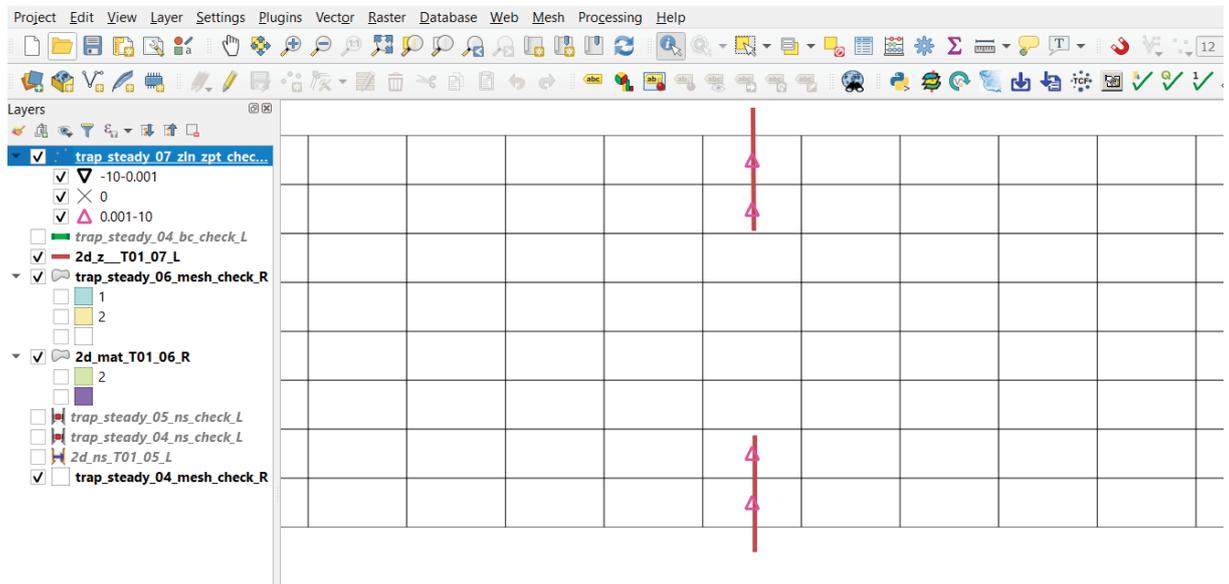


3. Update the batch file and run the model.

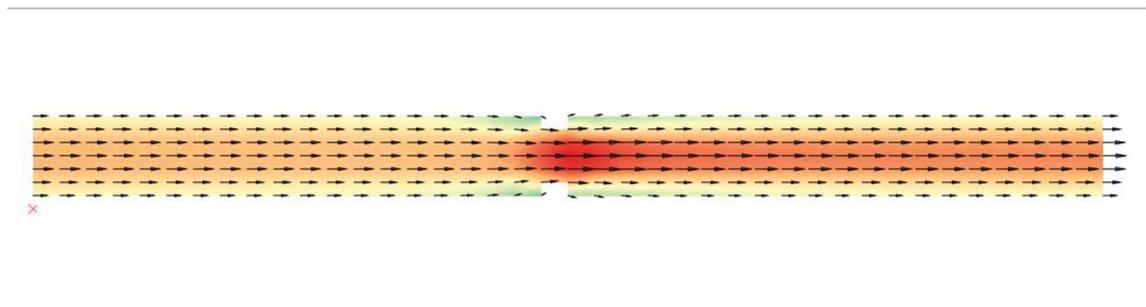
3.6.3 Discussions

1. Double click to open **trap_steady_07.qgs** workspace from the **\runs\log** directory, and apply the default TUFLOW style to all layers.

- The cell selected by the Z lines have an upward triangle sign to indicate the bed elevations have been modified. Check the attribute table and is the modification carried out correctly?



- Open **TUFLOWFV\results\trap_steady_07.xmdf.sup** and compare the flow field with the previous models. Does the flow field near the obstruction look reasonable? You can see the areas were the topographic updates are assigned are dry. Also, there is an increase in velocity through the vicinity of the constriction which we would expect to see through this area.



Well done. You have now covered the basics of integrating TUFLOW FV with GIS. For more advanced features please refer to the GIS component of Tutorial Model 3.

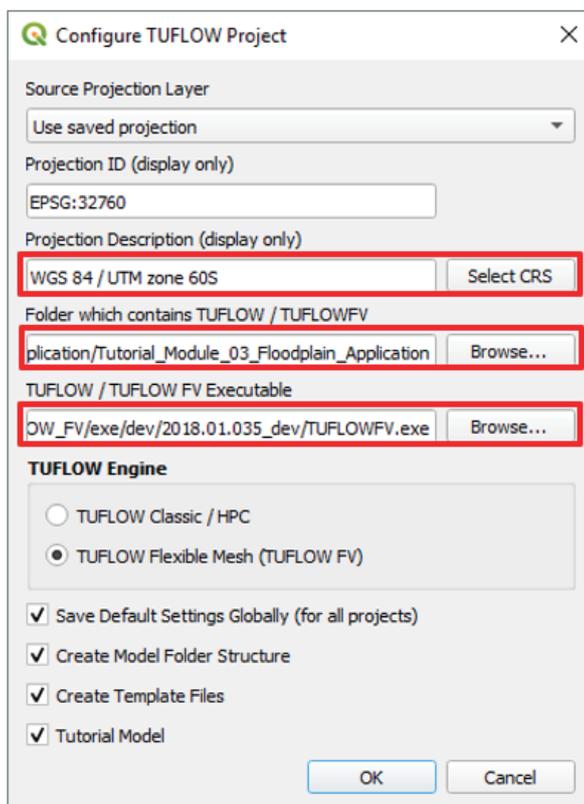
4 Tutorial 03 – Advanced GIS Updates

4.1 Pre-requisites

The GIS component of this tutorial assumes you have completed [Tutorial Model 01](#) and specifically the GIS introduction of Tutorial Model 01.

4.2 Set Model GIS Projection and Create TUFLOW FV Empty (Template) GIS Files

Firstly, we need to configure the TUFLOW Viewer Plugin (refer Section 3.2). Open QGIS and set the working folder to the location of your TUFLOWFV folder. Additionally set the Projection to WGS 84 / UTM Zone 60S and the path to your TUFLOWFV executable. For a full overview of what TUFLOW Viewer is completing please refer to Tutorial Model 01 Section 3.2.



4.3 Geometry Update using GIS File

The original Tutorial Model 03 updates cell elevations by reading CSV files. However, in this section of the tutorial this has been updated with efficient direct reading of GIS inputs. In this tutorial we will introduce advanced topography updates using GIS functions, including:

- Interpolating ZB elevations from an input DEM,
- Using a combination of lines and points to specify varied bed elevations along polylines,
- Setting a uniform bed elevation inside a polygon.

4.3.1 Copy model input files:

1. Copy and save the `Create_Empties.fvc` file (refer Section 3.2) in the **TUFLOWFV\runs** folder as **FMA2_Hydro_002_GIS.fvc** and open this file in Notepad++. At this point, this file only contains the command to define the GIS format and model projection. We will edit this file to create a new run file. For a full overview on creating TUFLOW FV empty GIS files please refer to Section 3.2.
2. Comment out the last command since we don't need to generate empty files again.

```
GIS FORMAT == SHP
SHP Projection == ..\model\gis\projection.prj
Tutorial Model == ON
!Write Empty GIS Files == ..\model\gis\empty
```

3. Go to the folder **Complete_Model\TUFLOWFV\runs** and copy the original tutorial FVC file **FMA2_Hydro_002.fvc** across to our working folder the **TUFLOWFV\runs** folder.
4. Copy across **ALL** commands from **FMA2_Hydro_002.fvc** to the newly created **FMA2_Hydro_002_GIS.fvc** file, below the existing lines of code.

Note: If you have already successfully created and run FMA2_Hydro_002.fvc from the TUFLOWFV\runs folder during the non GIS part of the tutorial please skip steps 5-8.

5. Copy across the following files from the **Module_Data** directory to the corresponding folders:
 - **inflows.csv** and **Tide.csv** from the **Module_Data\Boundary_Conditions** directory to the **.\TUFLOWFV\bc_dbase** folder,
 - **FMA2_FV01_Zb0m.2dm** from the **Module_Data\Geometry** directory to our **.\TUFLOWFV\model\geo** folder. All the vertex elevations are set as 0m in this 2dm file,
 - All the files that start with **2d***, from the **Module_Data\Geometry\GIS** to the **.\TUFLOWFV\model\gis** directory.
6. Create a **.\TUFLOWFV\model\struct** folder and copy across the files from the **Module_Data\Geometry\STRUCT** directory,

7. Create a `.\TUFLOWFV\model\grid` folder in your working directory and copy the **DEM_5m.asc** file from the **Module_Data\Geometry\GRID** directory into it. The bed elevations stored in this file will be read by a GIS command,
8. Create a `.\TUFLOWFV\model\csv` folder and copy across the files from the **Module_Data\Geometry\CSV** directory.

4.3.2 Update GIS inputs and FVC commands

1. Update the 2dm file read by the model:

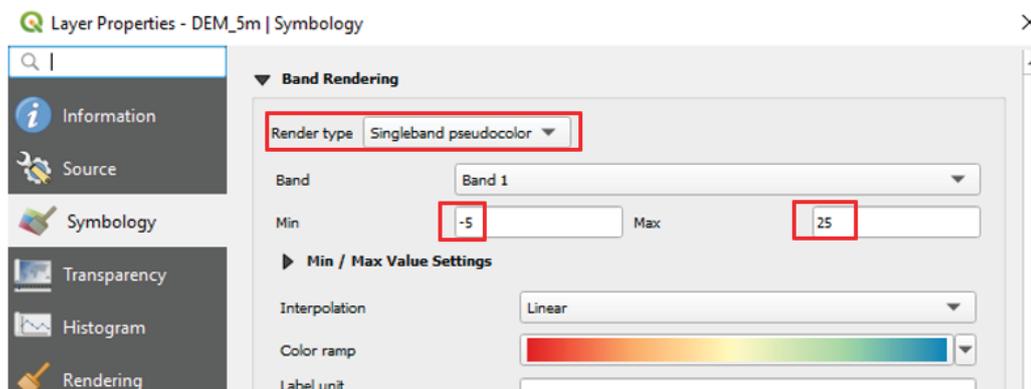
```
Geometry 2D == ..\model\geo\FMA2_FV01_Zb0m.2dm
```

2. On the next line down add a default value for the bed elevation above any expected modelled water level by adding the following command:

```
Set Zpts == 99
```

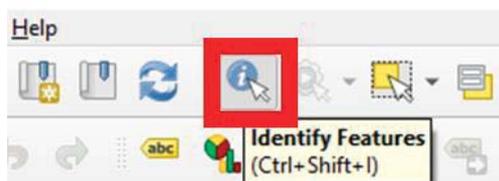
4.3.3 Review GIS files in QGIS

1. Open the **orthophoto.jpg** from `.\Module_Data\Geometry\APH` file and the **DEM_5m.asc** file from the `.\TUFLOWFV\model\grid\` folder in QGIS.
2. For improved viewing of the DEM, double click on the **DEM_5m** layer and change the render type to singleband pseudocolor:

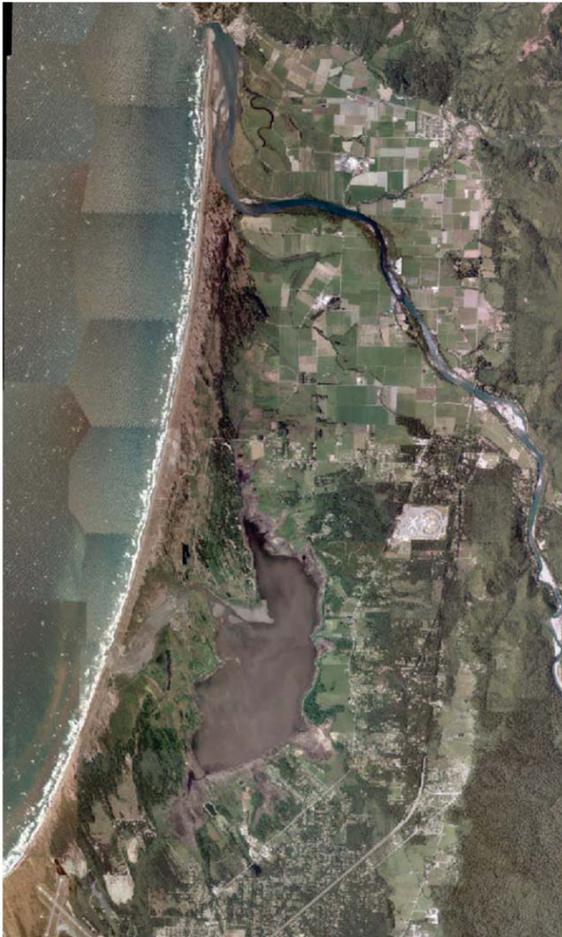


Additionally, change the min and max values to -5 and 25m respectively.

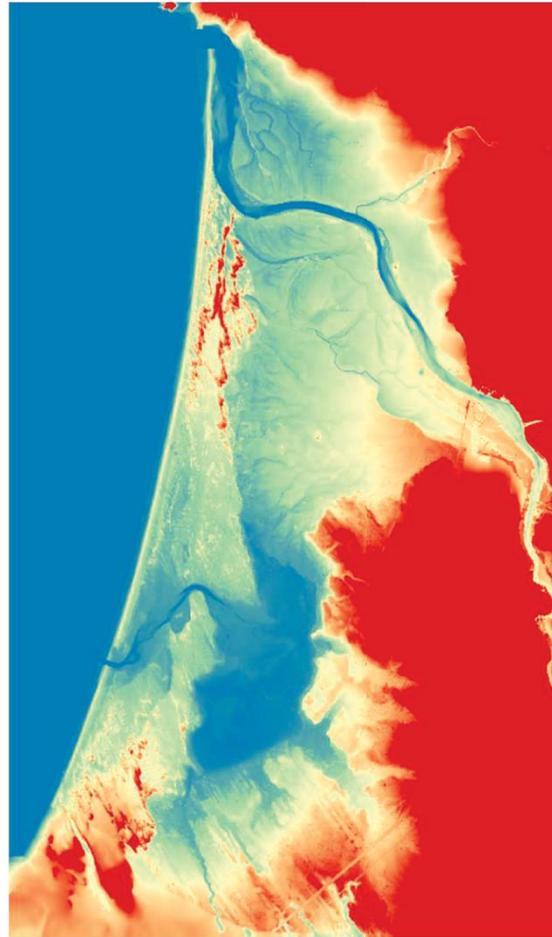
3. Review the bed elevations stored in the DEM. This can be done by using the identify features button as shown below:



orthophoto.jpg



DEM_5m.asc

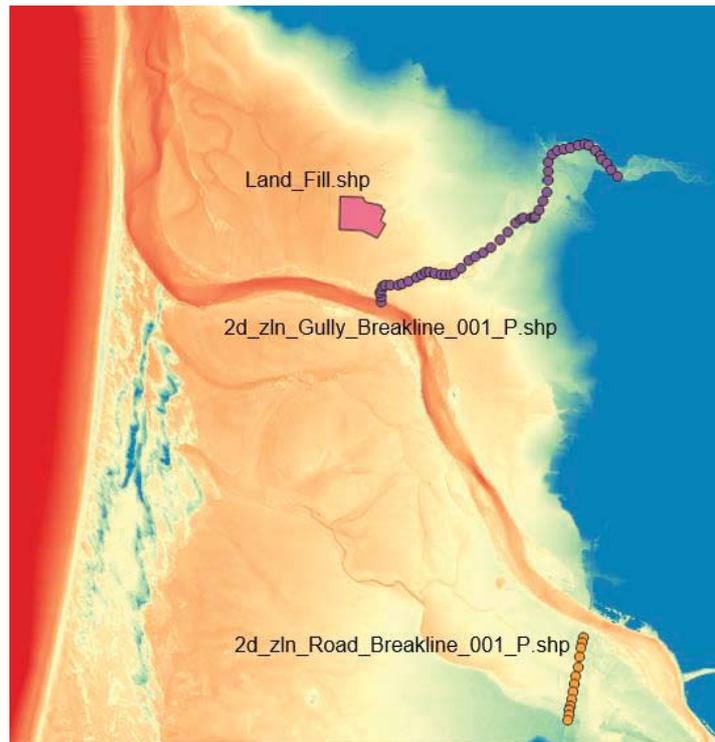


4. To read the DEM as the source of ZB data add the following command to **FMA2_Hydro_002_GIS.fvc** within the geometry commands:

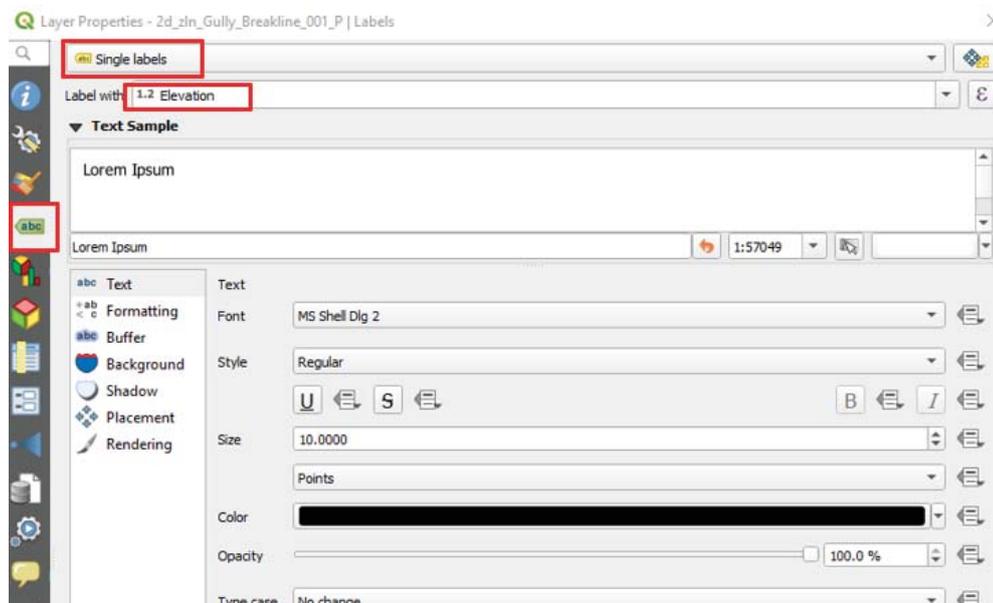
```
Read Grid Zpts == ..\model\grid\DEM_5m.asc
```

5. In QGIS, open the 2d_zln_Road_Breakline_001_P.shp and 2d_zln_Gully_Breakline_001_P.shp layers from the **.\TUFLOWFV\model\gis** folder (as copied previously). Additionally, open the Land_Fill.shp file from the **Module_Data\Geometry\GIS** folder to check the GIS objects and attributes. The layers include:
- The elevation points along the creek centre line of the north tributary;
 - The elevation points along a road crest located at the east of the model domain; and
 - A polygon that defines an area with a uniform elevation.

You will note that we haven't copied across the Land_Fill.shp file. This is because the **.\TUFLOWFV\model\gis** folder is reserved for model files that will be directly read by the model in TUFLOWFV format. We will convert Land_Fill.shp to the correct format later in the tutorial.



6. To display elevation labels for each for the points, first double click the **2d_zln_Gully_Breakline_001_P** layer to bring up the layer properties menu.
 - In the “Labels” tab, select “Single labels” from the first drag down list,
 - Select the “Elevation” attribute from the “Label with” drag down list,



- Press OK and repeat for the **2d_zln_Road_Breakline_001_P** layer to review the labelled elevation points.



4.3.4 Assign data to TUFLOW FV empty layers

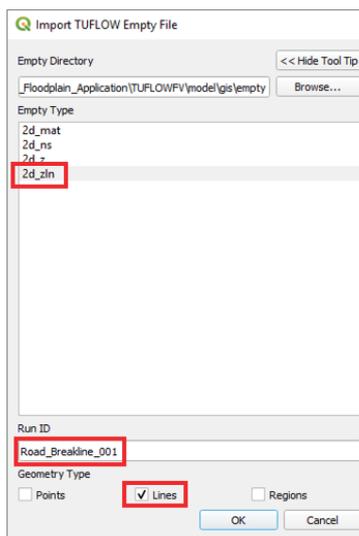
The 2d_zln_Road_Breakline_001_P.shp and 2d_zln_Gully_Breakline_001_P.shp files are already prepared in the correct TUFLOW FV input format and thus were ok to copy into our `.\TUFLOWFV\model\gis` folder. However, these files only depict elevation **points** as indicated by the “_P” suffix on the filenames. In order to run our TUFLOW FV model we will require breakline polyline geometry GIS layers as well as these point files.

1. We already have elevation points that define key locations on our roads and channel. What we need to do now is connect these points to provide a continuous breakline by using polyline gis features. To do this we will import an empty 2d_zln polyline layer using the **Import Empty file** tool.

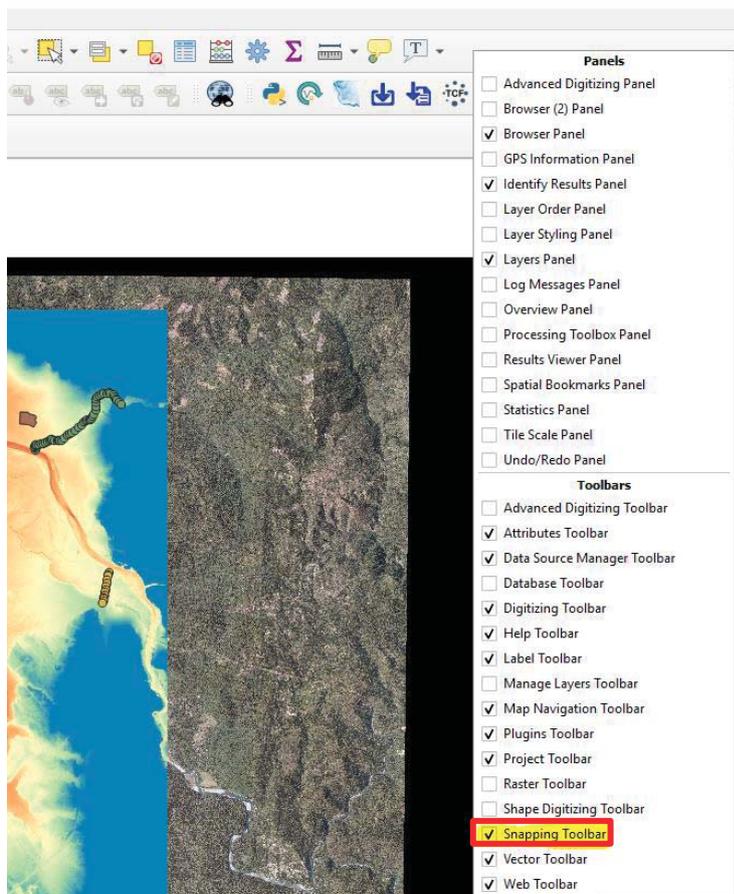


- Select the type **2d_zln**
- Give the Run ID as **Road_Breakline_001**

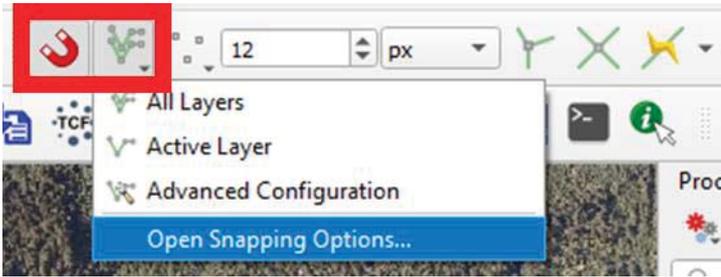
- Check **Lines** as the geometry type and press OK



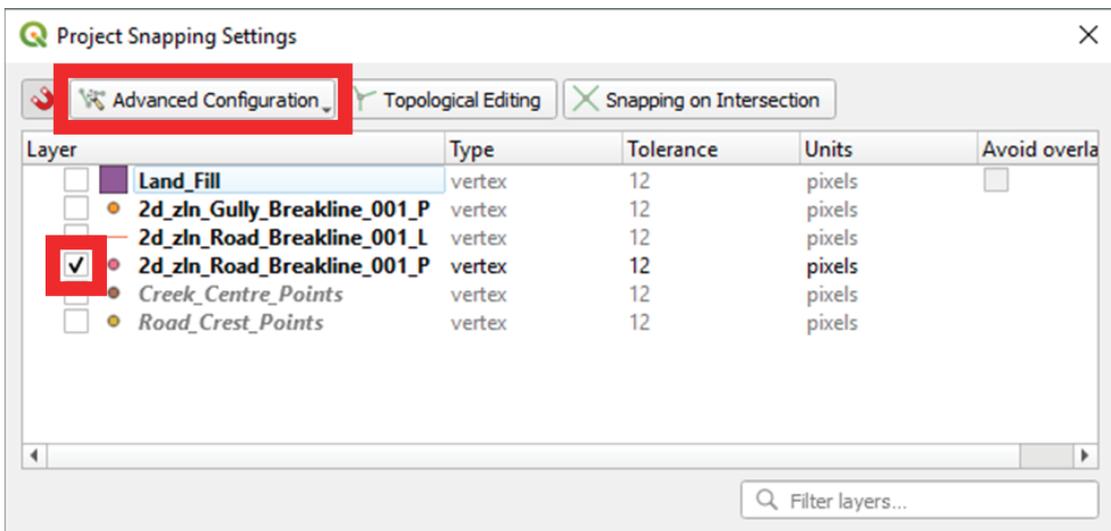
2. A 2d_zln polyline must be “snapped” to the points to connect them. If the points aren’t snapped correctly then TUFLOW FV will throw an error on startup. To snap, first ensure that the snapping toolbar is visible. Right click on the toolbar and check the Snapping Toolbar box.



- Then, enable snapping by clicking on , followed by the  button to open snapping options,



- Select “Advanced Configuration” from the second drop down list and check the **2d_zln_Road_Breakline_001_P.shp** layer,



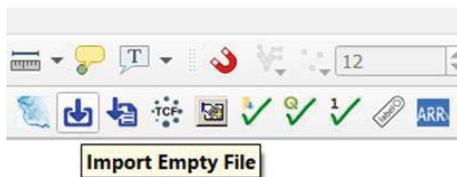
- Now select the **2d_zln_Road_Breakline_001_L** layer and toggle editing ,
- Using the *Add Feature*  tool, click and snap onto each elevation point to create a polyline. Note that a pink square appears when the mouse is “snapped” to a point.



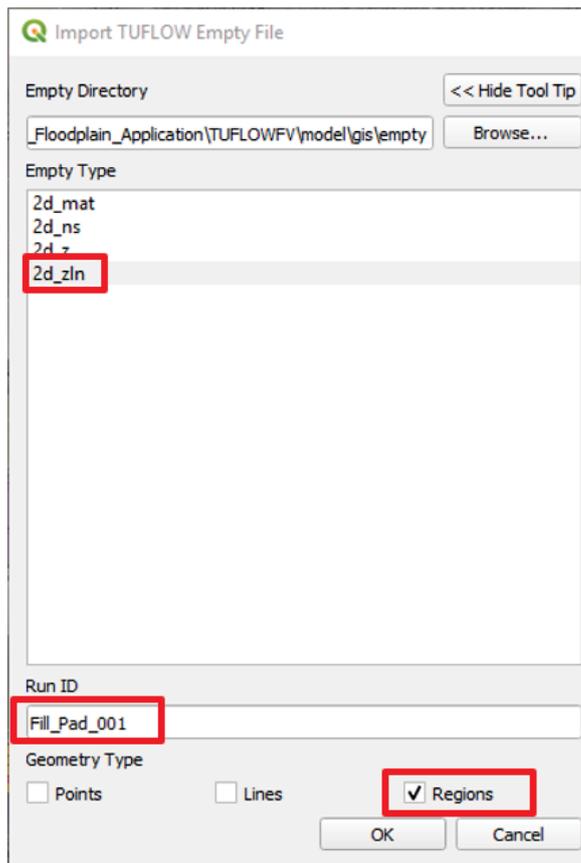
- Right click to finish editing. Leave the Elevation attribute as NULL since the elevations along the line are assigned to the line by linearly interpolating locations between those points. i.e. the polyline Z attribute in this case is ignored.
3. Finish and save your edits by toggling off the editing button.
 4. Repeat steps 1-3 for the gully breakline. Use the Import Empty file to import another template 2d_zln polyline layer.
 - Select the type **2d_zln**,
 - Give the Run ID as **Gully_Breakline_001**,
 - Check **Lines** as the geometry type and press OK,
 - Enable snapping for the **2d_zln_Gully_Breakline_001_P.shp** layer under the Snapping Options menu. Toggle editing **2d_zln_Gully_Breakline_001_P.shp** layer and connect those points one by one using the add line feature tool.



- Also leave the Elevation attribute as NULL and finish/save the edit by toggling off editing.
5. The last GIS file contains a pre-prepared polygon but it does not have any attributes. This time we are going to copy the polygon into a new empty 2d_zln region file and update the elevation attribute. Use the **Import Empty file** to import a template 2d_zln region layer.

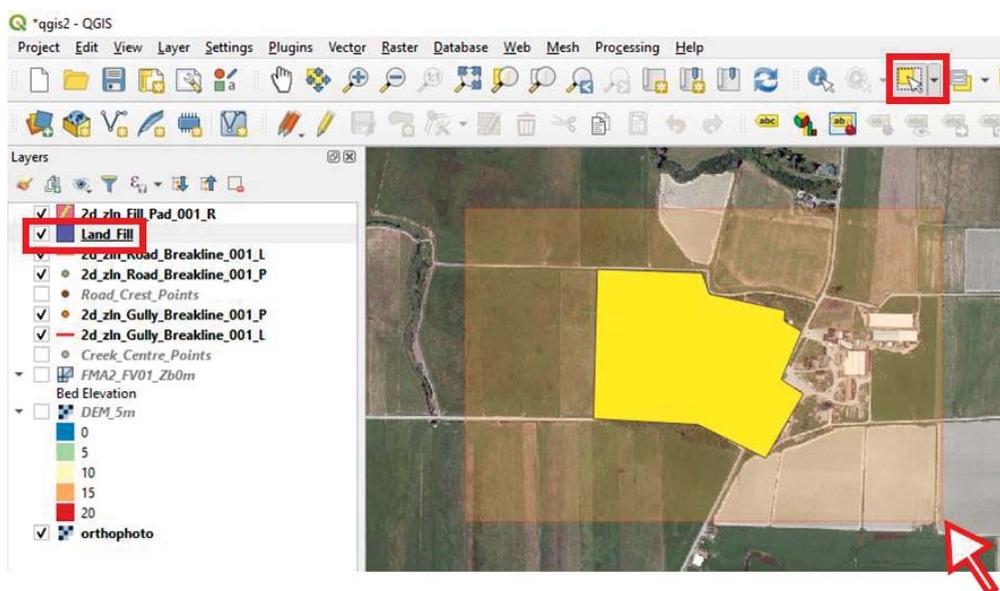


- Select the type **2d_zln**,
- Give the Run ID as **Fill_Pad_001**,
- Check **Regions** as the geometry type and press OK.

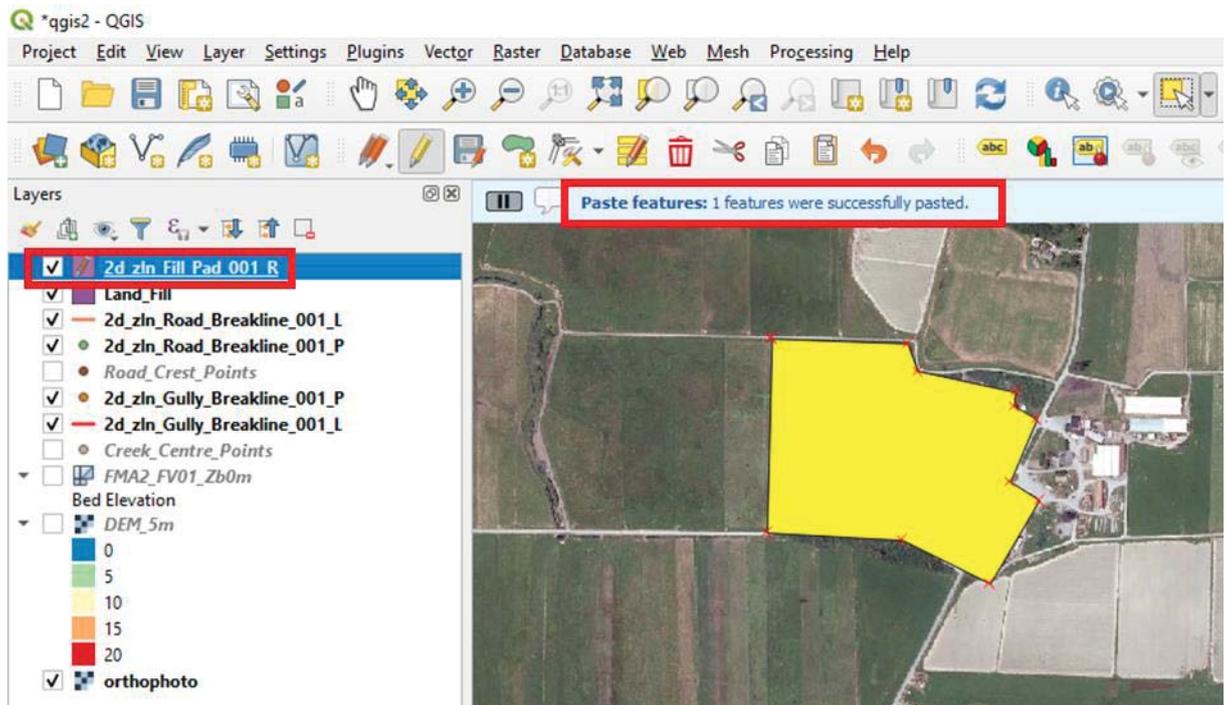


6. Toggle editing  for the **2d_zln_Fill_Pad_001_R** layer and select the **Land_Fill** layer in the Layer Panel.

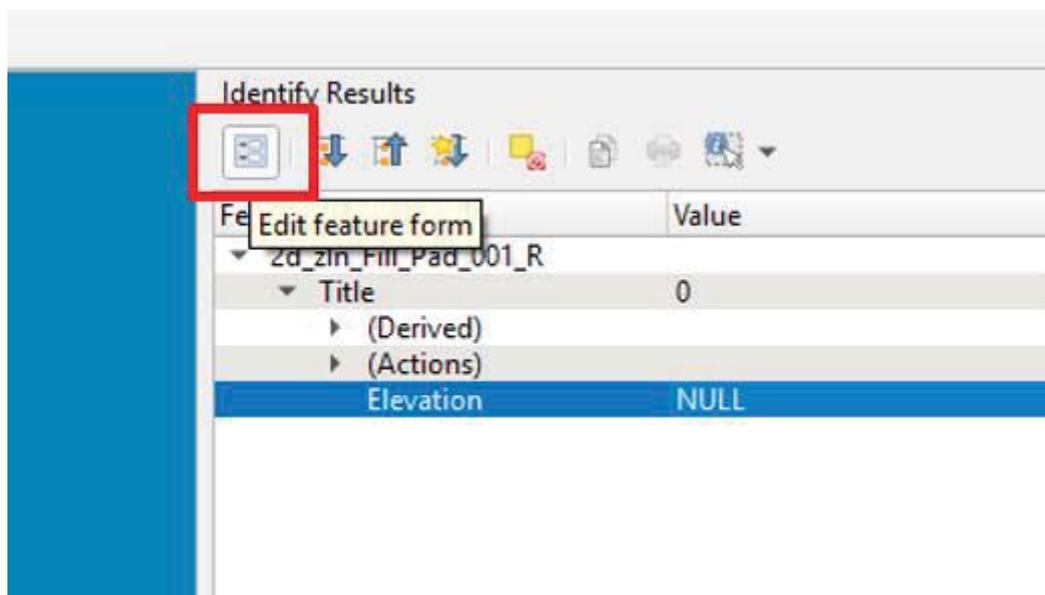
- Click the Select Feature button  and drag to select the polygon in the **Land_Fill** layer. The polygon turns yellow if it is successfully selected.



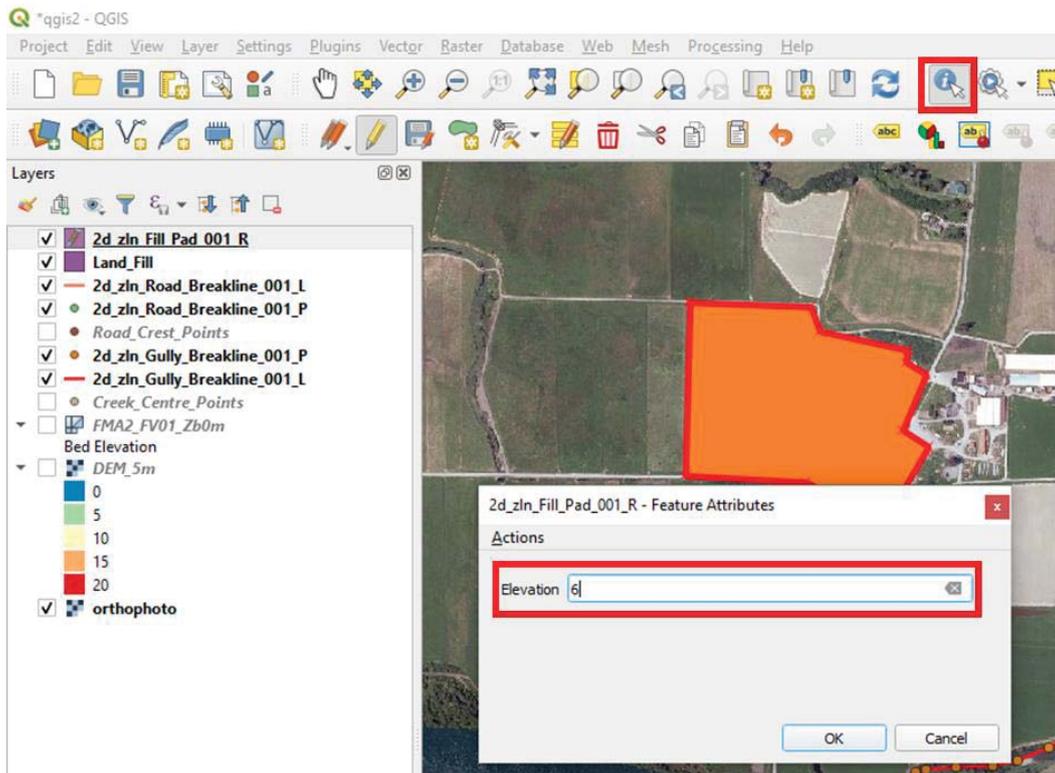
- Use **Ctrl + C** to copy the polygon, then select the **2d_zln_Fill_Pad_001_R** layer from the Layer Panel and use **Ctrl + V** to paste the polygon. Make sure you receive a message “1 features were successfully pasted.”



- Use the Identify Feature tool and click the polygon to open a Feature Attributes Window. Update the attributes by clicking “Edit feature form”:



- Set the **Elevation** attribute to 6, this will specify a uniform elevation of 6 m inside the polygon.



7. Finish the edit by toggling off the editing button and when prompted, save the file.
8. Remove the Land Fill shape file from your workspace as we no longer need it.

4.3.5 FVC Updates

1. Now we are going to replace the original csv-based topographic update layers with GIS commands. Please comment out the original geometry commands in **FMA2_Hydro_002_GIS.fvc** as shown below:

```
!Cell elevation polyline == ..\model\csv\Gully_Breakline_002_ptp.
!Cell elevation polyline == ..\model\csv\Road_Breakline_002_ptp.csv
!Cell elevation polygon == ..\model\csv\Fill_Pad_002_ptp.csv, 6.0
```

2. Add commands to read the breaklines and points. Use vertical bars “|” to read two files in one command:

```
Read GIS Z Line == ..\model\gis\2d_zln_Gully_Breakline_001_L.shp |
..\model\gis\2d_zln_Gully_Breakline_001_P.shp
```

```
Read GIS Z Line == ..\model\gis\2d_zln_Road_Breakline_001_L.shp |
..\model\gis\2d_zln_Road_Breakline_001_P.shp
```

3. Use the same command to read the polygon:

```
Read GIS Z Line == ..\model\gis\2d_zln_Fill_Pad_001_R.shp
```

Now the geometry commands block looks like this:

```

25 !
26 ! GEOMETRY COMMANDS
27 Geometry 2D == ..\model\geo\FMA2_FV01_2b0m.2dm !Base Topography Dataset [m]
28 Set Zpts == 99
29 Read Grid Zpts == ..\model\grid\DEM_5m.asc
30
31 !Cell elevation polyline == ..\model\csy\Gully_Breakline_002_ptp.csv !Cell elevation update using polyline [m]
32 !Cell elevation polyline == ..\model\csy\Road_Breakline_002_ptp.csv
33 !Cell elevation polygon == ..\model\csy\Fill_Pad_002_ptp.csv, 6.0 !Cell elevation update using polygon [m]
34 Read GIS Z Line == ..\model\gis\2d_zln_Gully_Breakline_001_L.shp | ..\model\gis\2d_zln_Gully_Breakline_001_P.shp
35 Read GIS Z Line == ..\model\gis\2d_zln_Road_Breakline_001_L.shp | ..\model\gis\2d_zln_Road_Breakline_001_P.shp
36 Read GIS Z Line == ..\model\gis\2d_zln_Fill_Pad_001_R.shp
37
38 Cell elevation file == ..\model\csy\Sand_Extraction.csv,coordinate,overwrite !Cell elevation update using point data
39

```

4. In the output commands block, also add:

```
Write Check Files == ..\check
```

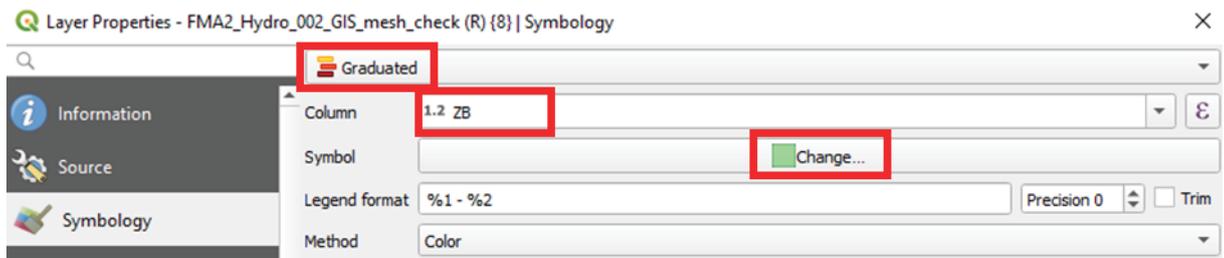
5. You have now updated your fvc file and included the relevant GIS and check commands. Please now update your batch file as shown below (refer Section 3.3.2) to include the latest run and run the model:

```
%exe% FMA2_Hydro_002_GIS.fvc
```

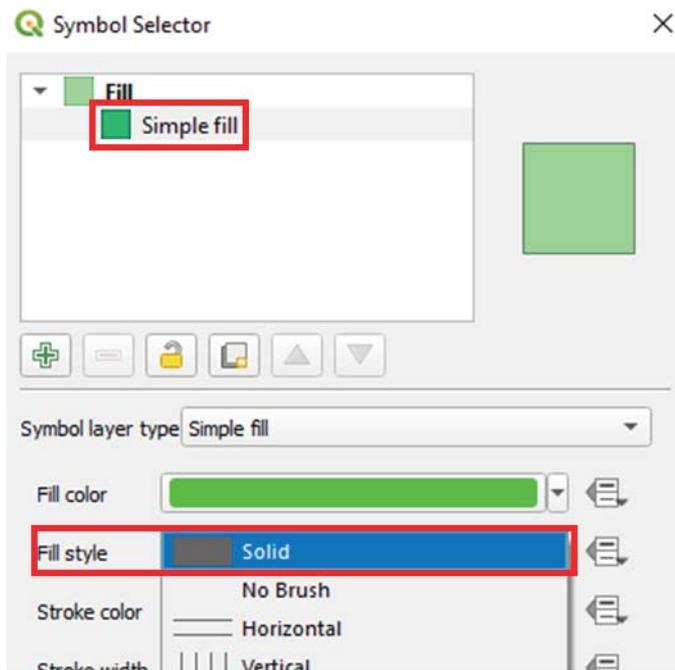
4.3.6 Review of Results and Discussion

1. Double click to open **FMA2_Hydro_002_GIS.qgs** workspace from the `\runs\log` directory, and apply the default TUFLOW style to all layers (refer Section 3.3.3).
2. Double click the **FMA2_Hydro_002_GIS_mesh_check_R** layer to render the mesh based on “ZB” attribute:

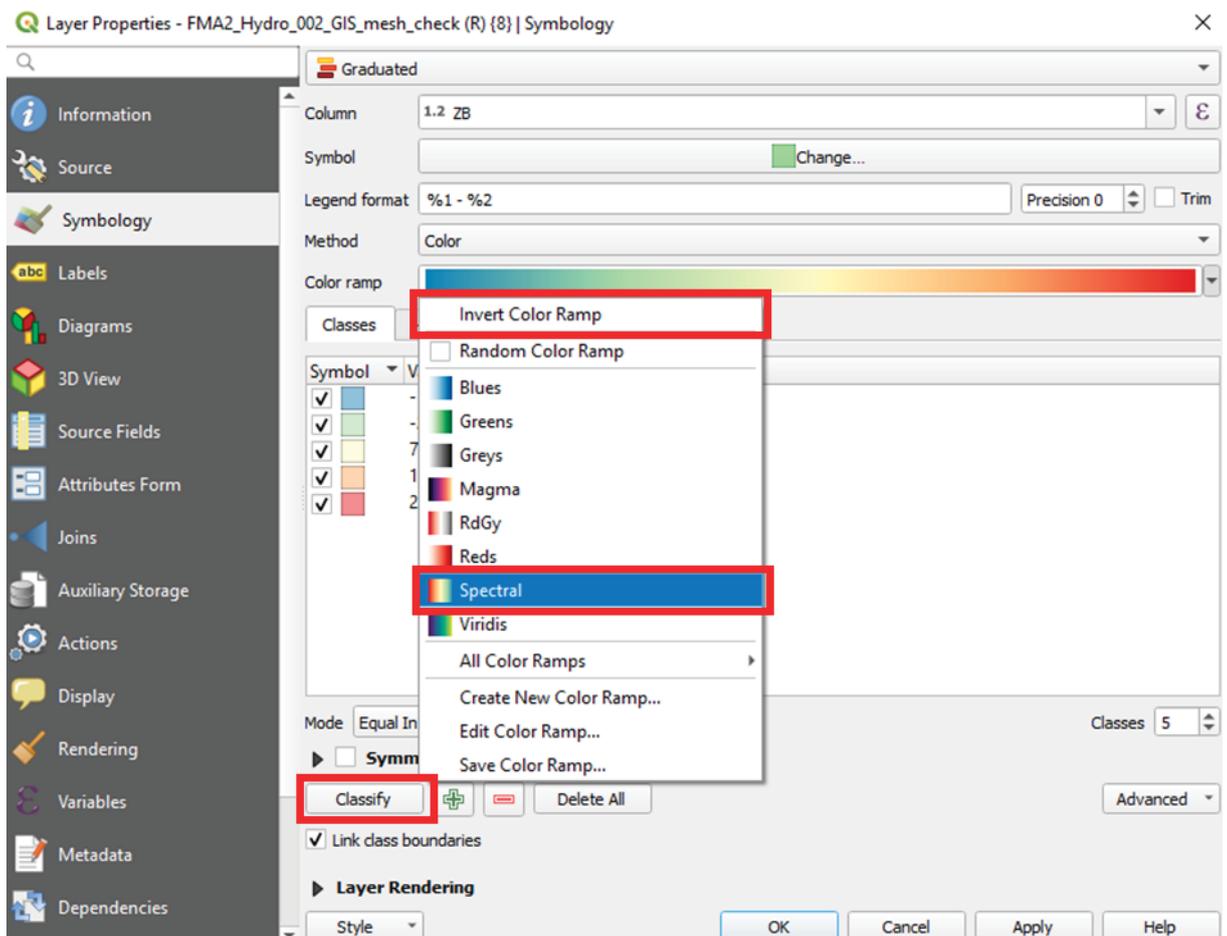
- In the “Symbology” tab, select “Graduated” from the first drag down list
- Select “ZB” attribute from the Column drag down list



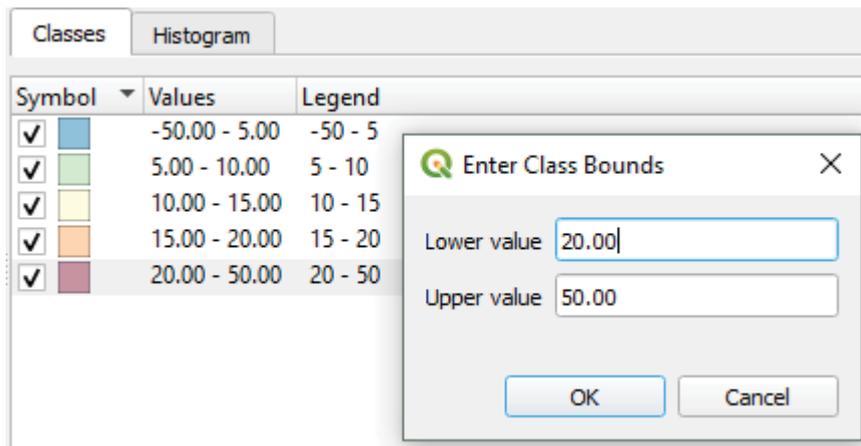
- Click “Change” button and select “Simple fill”. Change the “Fill style” to “Solid” if it hasn’t been selected



- Select “Spectral” from the Color ramp drop down list, followed by “Invert Color Ramp” and then click “Classify”,



- Adjust the value ranges by double clicking on the symbols,



- Press OK and check if the mesh elevation specified by the ASC grid look reasonable.



3. Also check the `_zln_zpt_check_P` file and apply TUFLOW Style (refer Section 3.3.3) to observe which cells have been raised/lowered by the polylines and the polygon,



Congratulations, you are now well on your way to integrating GIS topography with TUFLOW FV.

4.4 Set Nodestrings for Structures

Next, we will also set the structure nodestrings using GIS files instead of using CSV files.

4.4.1 Update Input Files

1. Open **TUFLOWFV\model\gis\2d_ns_Struct_001_L.shp** (as copied in Section 4.3) in QGIS if it hasn't already been opened and apply TUFLOW Style (refer Section 3.3.3). This file includes single nodestrings to present a weir and a bridge, and a coupled nodestrings to represent the inlet and the outlet of a culvert.



2. Save **FMA2_Hydro_002_GIS.fvc** as **FMA2_Hydro_003_GIS.fvc** and open this file in Notepad++.
3. Comment out the original CSV nodestring commands:

```
!nodestring polyline == ..\model\geo\STRUCT\FMA2_Struct_Nodestring_002.csv, 5
!nodestring polyline == ..\model\geo\STRUCT\FMA2_Struct_Nodestring_002.csv, 6
!nodestring polyline == ..\model\geo\STRUCT\FMA2_Struct_Nodestring_002.csv, 7
!nodestring polyline == ..\model\geo\STRUCT\FMA2_Struct_Nodestring_002.csv, 8
```

4. Add the following command to read the nodestrings from the GIS file:

```
Read GIS Nodestring == ..\model\gis\2d_ns_Struct_001_L.shp
```

5. Update the batch file with **FMA2_Hydro_003_GIS.fvc** and run the model.

4.4.2 Discussions

Double click to open workspace **\runs\log\FMA2_Hydro_003_GIS.qgs** and apply the default TUFLOW style to all layers (refer Section 3.3.3). Check the **_ns_check_L** file for how cell sides are selected by nodestrings. Note that GIS nodestrings do not need to always snap to the cell vertexes as TUFLOW FV will determine the closest cell faces for you. This check file is important to ensure that your GIS specified external nodestrings have been applied as you intended.



Thanks for completing the GIS integration components of the TUFLOW FV tutorial models. We will continue to add more functionality over time so please periodically review. If you want to keep up to date with all things TUFLOW and TUFLOW FV then please join our LinkedIn group here: <https://www.linkedin.com/groups/1908583>

If you have any further queries, feedback or requests for new functionality please feel free to get in contact with support@tuflow.com