Exercise 2: Flood inundation modelling from a river channel: a real-world example

This exercise is part of series designed to teach students how floodplain inundation can be simulated by numerical models and how flood risk maps can be produced from simulation results within the KULTURisk methodology framework. In this case the flood inundation model is LISFLOOD-FP (hereafter lisflood) however most two-dimensional hydraulic models can be used in much the same way. This exercise looks at using lisflood to model river flooding and floodplain inundation. It guides users through the two methods of representing river channels in lisflood and the three methods of modelling flow through these channels. This exercise builds on the test case contained in Bates and De Roo (2000) and the hydraulic model from this paper and that described in Trigg et al. (2009) and Neal et al. (2012). It may be useful before or after completing the exercise to take a look at these papers which describe the channel and floodplain solvers in more detail and give further example applications.

Bates, P.D. and De Roo, A.P.J., (2000). A simple raster-based model for floodplain inundation. *Journal of Hydrology*, **236**, 54-77.

Trigg, M. A., Wilson, M. D., Bates, P. D., Horritt, M. S., Alsdorf, D. E., Forsberg, B. R. & Vega, M. C., (2009). Amazon flood wave hydraulics. *Journal of Hydrology,* **374**, 92-105.

Neal, J., G. Schumann, and P. Bates (2012). A sub-grid channel model for simulating river hydraulics and floodplain inundation over large and data sparse areas, Water Resource. Res., 48, W11506, (http://dx.doi.org/10.1029/2012WR012514)

Background information

The 2D floodplain flow solvers used in this exercise are the **flow-limited** and **acceleration** solvers which were described in the previous exercise (Exercise 1). We will also use the 1D **diffusive, kinematic** and **subgrid** channel solvers.

The most simple of the channel flow solvers is the 1D **kinematic** wave approximation of the shallow water equations, which assumes all terms except the friction and bed gradient are negligible. The bed gradient is a simplification of the water slope term which takes into account the effect of changes in bed height with distance, but not changes in the water free surface height. In contrast, the **"diffusive"** solver uses the 1D diffusive wave equation which includes the friction slope and the full water slope term (free surface and bed gradients) and thus is able to predict backwater effects. Using the 1D channel solvers, once channel water depth reaches bank-full height, water is routed onto adjacent floodplain cells to be distributed as per the chosen floodplain solver. In this exercise the **flow-limited** solver will be used to distribute water once it has overflowed from the 1D river channels.

The **subgrid** solver is the most recently developed method for representing rivers. Flow between channel segments is calculated based on the friction and full water slopes and local water acceleration. Only convective acceleration is assumed negligible. For any cell containing a sub-grid channel segment, the solver calculates the combined flow of water within the cell, contained both within the channel located in that cell and across the adjacent floodplain. Water is distributed over the floodplain using the **acceleration** solver once water has overflowed from subgrid channels.

The governing equations for these solvers are detailed in the appendix.

Data provided

During this exercise we will simulate flooding due to river bank overflow in the same section of catchment (reach) as will be used for the rest of the exercises in this series. For this reach, flooding of the magnitude simulated flood is expected to have a 1 in 100 year recurrence rate. The folder "for simulation" contains all of the input files necessary for this task. From the DEM shown in Figure 1 one can see there is high land to the south of the river and an extensive floodplain to the north. This DEM is provided as a raster grid with resolution 50m and vertical accuracy of about 25cm. The position of the river channel has been digitised from a map of the area and is therefore available at a higher resolution. The model has been developed with spatially uniform distributions for floodplain Manning's friction, channel Manning's friction and channel dimensions. Given its short length the assumption that the flow is in steady state (inflow=outflow) is reasonable. Also visible in Figure 1 are the urban areas of Riverton and Waterville, these are not considered in this exercises but will be used in exercises later in the series.

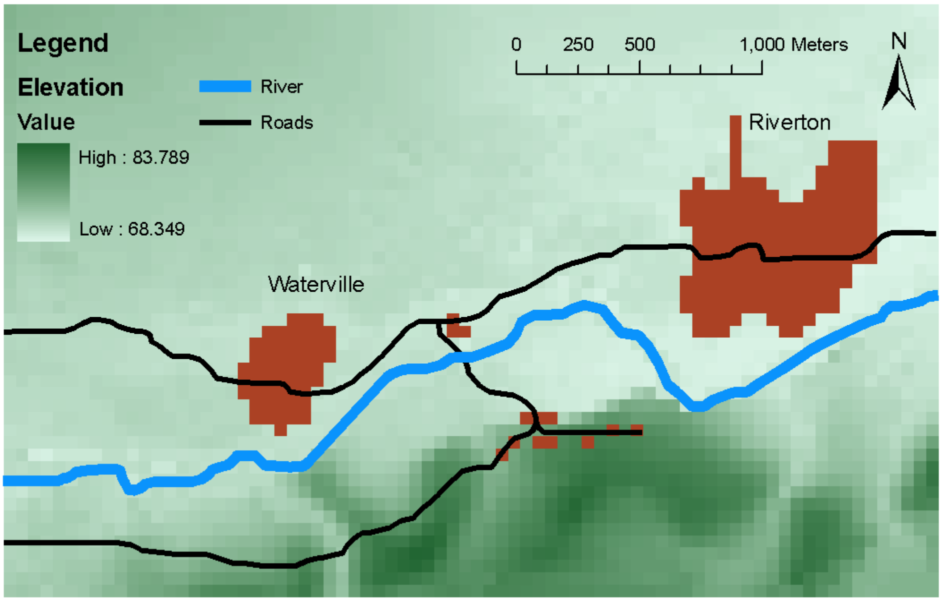

Figure 1

In addition to the DEM, the folder contains a number of other input files which will be used by lisflood depending on the options chosen for simulation. The folder contains:

- `dem` file – This provides the 2D raster elevation grid which is the model domain
- `par` files – these tell lisflood which settings to use and what input files to read in, there is one each for the three methods of modelling channel flow
- `bci` files – these tell lisflood about boundary conditions and point water sources in the domain. There are two files provided, one for use with the diffusive and kinematic solvers and one for use with subgrid
- `river` files – these tell lisflood where the river channel is located, and what its boundary conditions are. There are two files, one for use with the kinematic solver and one for the diffusive.
- `width` and `bed` files – these are used by the subgrid solver to input information about the river channel width and bed elevation
- `weir` file – use by all of the solvers to input the characteristics of a weir located on the river towards the eastern edge of the domain.

The letter K in the filename stands for the kinematic solver, D the diffusive and SGC for subgrid.

Exercise Tasks:

1. ***Exploring and understanding the input files***

Take a look at the `.par` files using your favourite text editor and examine the contents

Following exercise 1 you should be familiar with the layout and workings of the `.par` files and you will see that the first few lines of each `.par` file are very similar: you should be able to recognise that the file is instructing lisflood to load the DEM and weir files, save results to a named folder with particular file names, to run the simulation for a set length of time saving results in various formats at various intervals and to set a Manning's friction value for the floodplain. If you cannot pick out this information then look again at Exercise 1.

After this the `.par` files begin to differ. Channel properties are set in the `.river` files when using the kinematic and diffusive solvers, and using the files denoted by `SGCwidth`, `SGCbank` and `SGCbed` and the channel property `SGCn` whilst using subgrid. For the kinematic and diffusive solvers the flow limited solver for flood plain flow is activated (using the keyword `adaptoff`) and the diffusive channel solver is activated using the keyword `diffusive`. The subgrid channel method will always use the 2D acceleration solver for floodplain flow and the keyword `acceleration` is not needed. The subgrid method is activated whenever a `SGCwidth` file is specified.

With the aid of the user manual:

- Make sure you understand the details of the `.par` files already noted above and look up any items not mentioned to see what they are doing
- Examine the `.bci` files and check what they are doing. Why are they different? (Hint: `.river` files tell lisflood about water input to the domain from rivers using the diffusive and kinematic channel solvers, how is water input to the domain using the subgrid solver?)
- Examine the `.river` files used by the kinematic and diffusive solvers. What information is provided in these files? What are the standard differences between them?[1]
- Examine the various SGC files and familiarise yourself with their format and use

2. ***Use the input files provided to simulate flooding in the valley: run lisflood using each of the three `.par` files. If you do not know how to do this then refer to Exercise 1.***

[1] You will notice there are differences in the Manning's friction properties for all of the different model set-ups. This is because in each case the models have been calibrated to give the most accurate results.

3. *Viewing results*

Take a look at the `.mass` text files in the results directory (see exercise 1 for full details of all the columns). In particular look at `Qout` (the discharge in m^3s^{-1} leaving the downstream end of the model). Variation in `Qout` over the simulation shows the model ramping up from the initial conditions to steady state inflow discharge of 73 m^3s^{-1} over the whole domain.

You can view an animation of the flood dynamics using the `FloodView` windows viewer, located in the "for analysis" folder. To open `FloodView`, simply double click the icon. First, load in the DEM using the `File > Load DEM` menu. Then choose a set of results to view and load in the 10 output files ending with the extension `.wd` from the results folder using the `File > Open` menu (using the `ctrl` key to select all 10 files at once). As the model has ramped up from initial conditions to steady state, the final `.wd` file should be the most accurate. **`FloodView` is a bit crabby (with the tendency to crash) so make sure you do things in exactly this order.**

4. *Comparing and evaluating the models*

Lastly we want to calculate how well the models are performing in terms of the fit between the observed and predicted inundation extent. We have provided data from a SAR overpass (synthetic-aperture radar) conducted during a real "1 in 100 year" flood in area to which model results can be compared. The file `sargrid.asc` located in the "for analysis" folder consists of a grid of zeros and ones where zero represents dry areas and one represents inundated areas. To make the comparison easier we have provided a small programme called fstat.exe (also in the "for analysis" folder) which calculates the fit, F, between the model and the data. To compare the results the program populates the following contingency table with the number of pixels in each category:

	Observed = Dry	Observed = Wet
Model = Dry	A =- Dry/dry	B = predicted dry but observed wet
Model = Wet	C = Predicted wet but observed dry	D = Wet/wet

The fit, F, between the model and the data can then be calculated using the following formulae:

$$F = \frac{D}{B+C+D} \quad [1]$$

This divides the number of pixels correctly predicted as wet by the total number of 'floodplain' pixels. It doesn't account for the pixels correctly predicted as dry as this might bias the measure according to domain size (e.g. it is easy to predict a small flood in a large domain as most pixels will be dry). The value of *F* goes from 0 for a model with no overlap between observed and modelled data, to 1 for a model with perfect overlap.

To use the program, copy the final water depth file from the model simulation you want to calculate *F* for (`res_?-0010.wd`) into the directory with the `fstat.exe` executable in it and at the command line type:

```
fstat sargrid.asc res_?-0010.wd
```

This produces output detailing the number of pixels in categories A-D and the final *F* value.

For this example, which model is best at predicted the flood inundation event in the Flood River Valley?

Acknowledgments

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<u>Appendix – governing equations for lisflood 1D solvers</u>

All of the solvers use the same continuity equation, described as follows:

$$\frac{\partial Q_c}{\partial x} + \frac{\partial A}{\partial t} = 0$$

[2]

where Q_c is the volumetric flow rate in the channel, x the distance downslope, A the cross sectional area of the flow, and t time.

Kinematic 1D Channel Flow

Channel flow is calculated using a 1D kinematic approach that captures the downstream propagation of a flood wave and the response of flow to the bed slope. It can be described in terms of its momentum equation as:

$$\frac{\partial z}{\partial x} - \frac{n^2 P^{4/3} Q_c{}^2}{A^{10/3}} = 0$$

[3]

where symbols are as before with the addition of z the bed elevation, n the Manning's coefficient of friction, and P the wetted perimeter of the flow.

Diffusive 1D Channel Flow

Alternatively channel flow can be calculated using a 1D diffusive approach that captures the downstream propagation of a flood wave and the response of flow to the bed slope <u>and free surface slope</u>. It can be described in terms of its momentum equation as:

$$\frac{\partial z}{\partial x} - \frac{n^2 P^{4/3} Q_c{}^2}{A^{10/3}} - \left[\frac{\partial h}{\partial x}\right] = 0$$

[4]

where all symbols are as before except *h* which is the flow depth. The term in brackets is the diffusion term, which forces the flow to respond free surface slope as well as the bed slope.

Using these two methods each channel is discretised as a single vector along its centreline separate from the overlying floodplain raster grid. The channel therefore occupies no floodplain pixels, but instead represents an extra flow path between pixels lying over the channel. Floodplain pixels lying over the channel have two water depths associated with them: one for the channel and one for the floodplain itself. The channel interacts with the floodplain via a Manning type flow equation (as in equation 5), allowing water to flow between channel and floodplain nodes which lie over the channel.

Subgrid channels

The subgrid channel method captures the propagation of a flood wave and the effect of the friction and full water slopes and local water acceleration. It uses an explicit finite difference solution of a simplified shallow water equation to route water in the channel. In the channel the model calculates the flow between cells using:

$$\frac{\partial Q_c}{\partial t} + \frac{gA\partial(h+z)}{\partial x} + \frac{gn^2 Q_c^2}{R^{4/3}A} = 0$$

[5]

where all symbols are as above except *g,* gravity, and R, hydraulic radius which is found by *R* = *A*/*P*.

When water depths in the channel exceed the bank height, water is routed onto the adjacent floodplains where flow is distributed using the **acceleration** solver (see Exercise 1 for details).

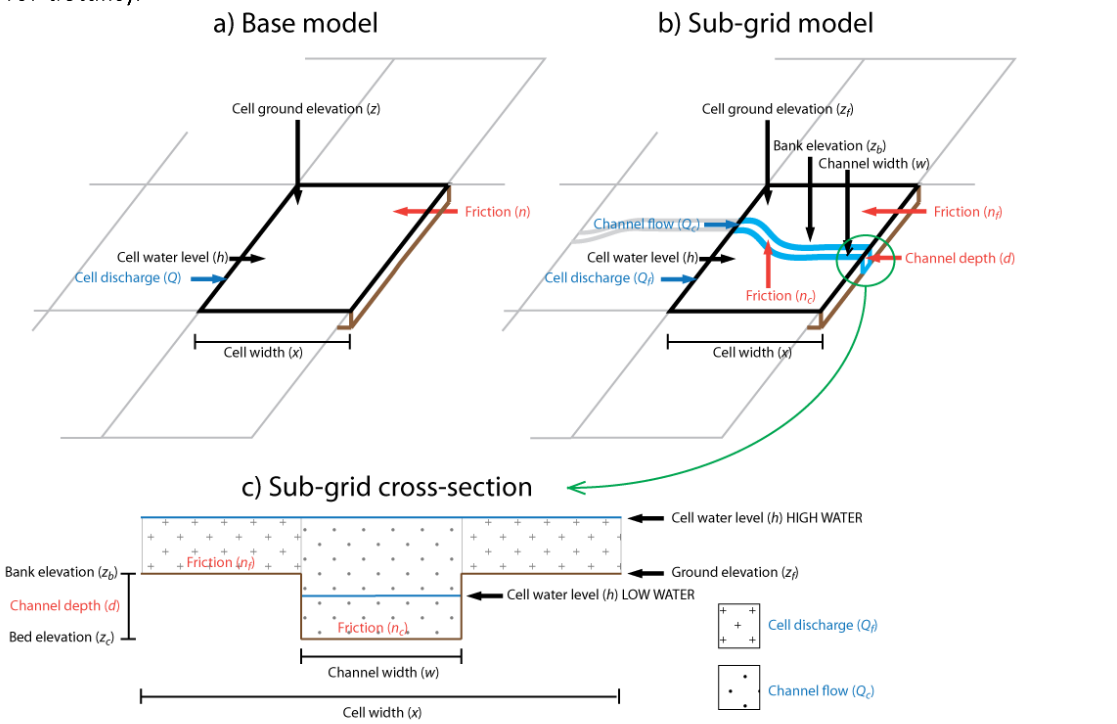

Figure 2 Model schematics for a. Floodplain only cell. b. Floodplain and channel cell c. interface between cells