Exercise 3 - Flood hazard risk mapping

This exercise is part of a series designed to teach students how floodplain inundation can be simulated using numerical models and how flood risk maps can be produced from simulation results. This exercise introduces users to the process of risk mapping using mock socio-economic data combined with the results of a real flood hazard simulation to create a flood risk map. Flood inundation was simulated by the LISFLOOD-FP model (hereafter lisflood), although the hazard mapping principals will apply to simulations from most two-dimensional hydraulic models.

It may be useful before or after attempting this exercise to have a look at the following reports which give details of more complex flood risk mapping methodologies on which this exercise is partially based.

Gallina V., Torresan S., Critto A., Zabeo A., Semenzin E., Marcomini A., Balbi S., Gain A. K., Giupponi C., Mojtahed V. (2013) Development of a risk assessment methodology to estimate risk levels, KULTURisk Project Report.

DEFRA, 2006a. Flood Risk to People Phase 2. The Flood Risk to People Methodology FD2321/TR1.

DEFRA, 2006b. Flood Risk to People Phase 2. Guidance Document FD2321/TR2.

Introduction

Flood inundation from diverse sources such as rivers, extreme rainfall events or the sea can have severe impacts on the population of affected areas. These impacts can be direct such as injuries or fatalities, or indirect such as the economic impact due to physical damage to buildings or through loss of earnings due to forced business closure. Floods can also have an environmental impact by physical damage to sensitive habitats or a social impact due to loss of recreational or culturally important sites. Formal calculation of the risks associated with flooding involve the identification of specific hazards (e.g. presence of water inundation), their severity (e.g. depth of water inundation) and their receptors (e.g. people or the environment). Information is then needed about the exposure of receptors to the hazard (e.g. data on where the receptor is located) and its vulnerability or susceptibility to damage (this could be related to the age of the population or the type of habitat in an area). Once this data is collected a measure of risk can be calculated and the data is often represented graphically as risk maps. The calculated risk could include physical and/or economic risk and a single or many receptors. Where different types of risk and/or different receptors are included in one map or calculation, the decision must be made on how to weight the various risks and receptors in the final calculation (i.e. how dependent the final value will be on each receptor or risk type).

Data provided

Provided in the exercise zip file are all of the data needed for this exercise. These include data relating to flood hazard (maximum water depth and maximum water velocity based on the 1 in 100 year flood simulated in Exercise 2) and receptors (exposure and susceptibility data for people, buildings and infrastructure). The data are provided as grids consisting of a data value for each cell of the map. They are ascii files (.asc) with headers specifically formatted to be read into ESRI ArcGIS packages. These files are also compatible with other data analysis packages such as MatLab[1], R and

[1] E.g. use the function provided “ascii_reader.m”: [dem, ncols, nrows, xllcorner, yllcorner, cellsize] = ascii_reader ('C:\MyFolder\MyFile.asc') or the MatLab function dlmread (see MatLab help files for more information). Because it is not

Excel[2]. The file Exercise_3.mxd is also provided. This is an ArcMap file which when opened will display all of the available data layers ready for analysis[3]. Details of the data contained within each file are given in Table 1 and figures showing the data within each file are given in the appendix[4].

Table 1

Data Layer	Description
flood_valley.dem.asc	Elevation data for the area, varying between 68 and 84 m
River.shp	Location of the river – shape file for display in ArcMap
maxdepth.asc	Maximum simulated depth of water in each cell, varying between zero and 2.71 m
maxVc.asc	Maximum simulated velocity of water into/out of each cell, between zero and 2.73 m/s
landuse.asc	Land use in each cell, 0 = rural/no buildings, 1 = residential, 2 = industrial, 3 = commercial
buildings.asc	Number of buildings in each cell, varying between zero and 15
buildings_cost	Average property price of buildings in each cell, varying between 10 and 150
population.asc	Population (number of people) per cell, varying between zero and 60
people_age.asc	% of the population in each cell aged 75 or greater, between 5 and 70%
people_mobility.asc	% of the population in each cell who are infirm/long term sick/disabled, varying between 7 and 28%
roads.shp	Location of roads in the area – shape file format for use in ArcMap
roads.asc	Location of roads in the area – ascii file format for use in other packages

<u>Producing a flood hazard risk map</u>

This exercise will guide users through the creation of a risk map for an area of river valley (reach). Data have been provided to allow the creation of flood hazard risk maps related to three common hazard receptors – people, buildings and infrastructure. To calculate risk, exposure and susceptibility, data relating to suitable indicators for each of the receptors are provided (Table 2). We will calculate the physical flood risk to people in terms of expected numbers of fatalities and injuries, to buildings in terms of the degree of damage expected and to infrastructure in terms of the length of roads which are expected to be inundated. We will also calculate the economic flood risk to buildings in terms of likely cost of damage to building structure and contents due to flooding. This exercise represents a simplified methodology; more complicated methodologies could include greater numbers of receptors (for example the natural environment, agriculture or cultural sites) or greater detail on the susceptibility of each receptor (e.g. buildings could be split into different construction types which have different levels of susceptibility). Please see the reports given as further reading for details of more complete methodologies. Instructions are provided here for

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an inbuilt function, to run the provided function ascii_reader you must first ensure MatLab can "see" the function by either following `File> Set path... > Add folder` and navigating to the folder containing the function, or putting the function in a folder which MatLab can already see (i.e. one already listed under the MatLab search path in the Set path... pop up window.

[2] E.g. use file>open specifying "All file types *.*" then choose "Delimited" and specify "Tab" and "Space" as the delimiters

[3] You may have to set the correct paths for the data layers. To do this right click on the data layer: Properties`> Source> Set data source> browse to correct file`

[4] There are additional files related to each of the data layers – these are used by ArcMap and should not be deleted

creating a risk map using ArcMap, but if you do not have this program or are more familiar with another suitable package then the methodology is suitably generic.

Table 2

Receptor	Indicator(s)	Typical data source	Related data files
People	*Exposure indicator:* Presence of people, in this case population per cell *Susceptibility indicator:* % of population age ≥75 and % population infirm/long term sick/disabled	Census data/land use map.	landuse.asc population.asc people_age.asc people_mobility.asc
Buildings – Split into residential, commercial, industrial	*Exposure indicator:* Presence of buildings, in this case number per cell	Land use map, street map, OS Map	landuse.asc buildings.asc buildings_cost,asc
Infrastructure	*Exposure indicator:* presence of roads	Land use map, street map, OS Map	roads.shp roads.asc

The fictional village of Waterville sits on an elevated position to the north of the river, in the western end of the valley (Figure 1). Further to the east is a larger urban area called Riverton. Waterville is a relatively wealthy place with a lower population density and higher property prices than the larger Riverton. Waterville also has a slightly older demographic and correspondingly a higher percentage of the general population who are infirm, sick or disabled. There is however a retirement village situated in the SW of Riverton which has a high population density and a very high percentage of elderly and infirm residents. Both Riverton and Waterville have a high street with commercial properties at the centre, whilst Riverton also has an industrial estate on its NE side. Between the two urban areas and close to the river is a sewage treatment plant, and on the south side of the river are a few larger rural homes.

Physical Risk Assessment for people

The first part of the assessment will involve calculating the hazard indicator for flood risk to people using values of the expected water depth and water velocity during a flood event. These are combined with measures of exposure and susceptibility to calculate the expected numbers of injuries and fatalities. The hazard posed to people by a flooding event (H_{people}) can be calculated according to equation 1 (DEFRA 2003)[5]:

$$H_{people} = d\,(v + 1.5) + DF \tag{1}$$

Where d is the water depth (m), v the water velocity (ms^{-1}) and DF the debris factor representing additional hazard due to debris in the flood water (Table 3).

[5] Note this has been updated in DEFRA 2006 to $H_{people} = d(v+0.5) + DF$

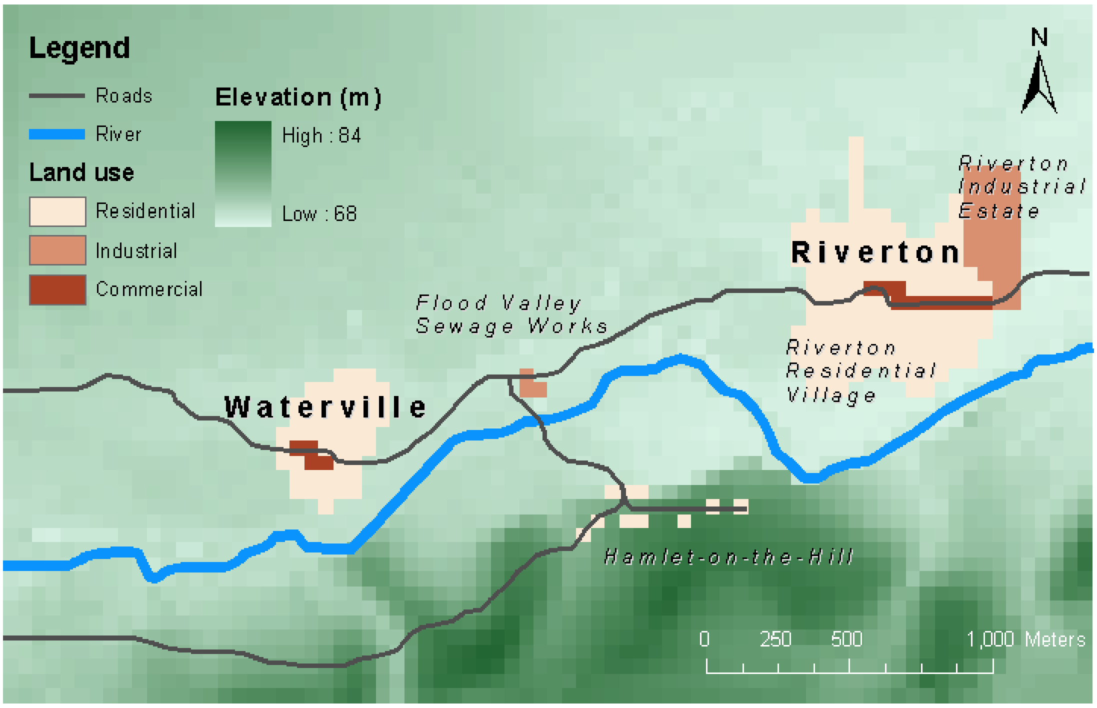

Figure 1

Table 3

Flood depth (d)	Debris factor (DF) for urban areas
d < 0.25 m	0
d ≥ 0.25 m or v ≥ 2 m/s	1

<u>A note on using water depth and velocity as hazard indicators:</u> In this exercise we will calculate the hazard factor using the max water depth and max cell velocity outputs from the flood simulation software lisflood. These are the maximum water depth experienced by each cell over the course of the whole flood event simulation, and the maximum combined water velocity (combination of velocity in x and y Cartesian directions) experienced by each cell over the course of the whole simulation. This is likely to be an overestimation of the actually maximum hazard experienced by a cell as these two maxima do not necessarily occur at the same time. In particular, during model simulations the highest velocities can occur during cell "wetting" (when water first flows into a cell) and therefore when cell water depths are actually very low. This brings up the question of which alternative measures might be most representative of the actual maximum hazard; water depth at maximum velocity, velocity at maximum water depth, or some other measure? Alternatively the hazard in each cell could be calculated for each time step of the simulation and the maximum of these values used. We will not address this question further in this exercise; however it is a pertinent point. The lisflood user manual provides details on other outputs from the program which could be used instead of the parameters suggested here.

Produce a raster layer containing the hazard to people in each grid of the domain using equation 1. Instructions are given below for calculating this in ArcMap, specifically v. 9.3. However, these simple calculations which could be carried out using other software if you wish.

First – open the file Flood_Valley.mxd in ArcMap[6]

Create the DF layer

Use **raster calculator** to create a new layer which has values of 1 where either maximum water depth is greater or equal to 0.25 m, or maximum water velocity of greater or equal to 2 m/s, and values of zero everywhere else

1) Open the **raster calculator**:
   - **`View > Toolbars > Spatial Analyst ↓> Raster calculator`**[7]
2) Use raster calculator to create new layer:
   - **`([Maximum depth] > = 0.25) | ([Maxiumum Velocity] > = 2)`**

   Under the layers tab, identify the newly created layer and rename it "`debris`"

Calculate the H_{people} layer

Use **raster calculator** to create a new layer according to equation 1 and rename it "`hazard_people`"

- **`(([Maximum Velocity] + 1.5) * [Maximum depth]) + [debris]`**
-

Once the H_{people} layer has been created we can move to the next stage: calculating the risks to people in terms of the expected numbers of injuries (R_1) and fatalities (R_2). This involves combining values for the hazard to people (H_{people}), exposure (E), population susceptibility (SF_{people}) and area susceptibility (SF_{area}) according to equations 2 and 3 (DEFRA 2006):

$$R_1 = 2E\left(\frac{SF_{area}}{100}\right)H_{people}\left(\frac{SF_{people}}{100}\right) \quad [2]$$

$$R_2 = 2R_1\left(\frac{H_{people}}{100}\right) \quad [3]$$

Please see DEFRA (2006) for an explanation of how these equations are formulated.

For simplicity we will assume that everyone is in their homes (i.e. not in commercial/industrial properties) and that they do not have access to any safe refuge. This means the exposed population in each cell is the total registered population of the residential area (population raster layer).

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[6] Once open you may have to set the correct paths for the data layers. To do this right click on the data layer: Properties> Source> Set data source> browse to correct file

[7] Note: in later versions of ArcMap the raster calculator is accessed through `Geoprocessing > ArcToolbox >> Spatial Analyst Tools > Map Algebra > Raster Calculator`

Factors expected to increase the susceptibility of the population to flood hazard (SF_{people}) are the presence of elderly people or those who are infirm or have other mobility problems. Layers have been provided which give the percentage of the population in each cell aged 75 or greater (SF_1), or who are infirm, long-term sick or disabled (SF_2). These can be combined to calculate the people susceptibility using equation 4:

$$SF_{people} = SF_1 + SF_2$$

[4]

Calculate the SF_{people} layer

Add together the `people_old` and `people_mobility` layers to create a new layer named "`sus_people`"

- **`Arc Toolbox > 3D Analyst Tools > Raster Math > Plus (or use raster calculator)`**

Lastly a value for area susceptibility (SF_{area}) must be defined. Area susceptibility varies from 3 to 9 and depends on a number of factors which can only be qualitatively assessed. The factors proposed by DEFRA (2006) are: the amount of warning an area is likely to receive before flooding; the typical speed of flooding onset (i.e. is the area prone to flash flooding?); the nature of the area (i.e. how many storeys do buildings typically have? Is there likely to be a safe refuge from flood water?). For simplicity we will assume that all areas have a susceptibility value of 9.

Produce two raster layers containing the expected number of people suffering from injuries or fatality in each grid of the domain using equations 3 and 4.

Calculate the R_1 layer (risk of injury to people)

Use **raster calculator** create a new layer according to equation 2 and rename it "`r1_people`"

- **`([Population] * 2) * 0.09 * [hazard_people] * ([sus_people] / 100)`**

Calculate the R_2 layer (risk of fatality to people)

Use **raster calculator** create a new layer according to equation 3 and rename it "`r2_people`"

- **`([r1_people] * 2) * ([hazard_people]/100)`**

In this exercise we are creating individual risk maps for each of the three receptors: people, buildings and infrastructure. Some risk analysis methodologies (e.g. Gallina et al., 2013) combine the risks related to individual receptors into an overall risk value for an area. To enable this, the risk to individual receptors must be normalised to a common scale, generally between zero and one. In the case of the physical risk to people, calculated R1 and R2 values (expected number of injuries/fatalities per cell respectively) could be divided by the total population in the most populous cell to express the risk in terms of its proportion to the highest possible number of injuries/fatalities in any one cell.

Physical Risk Assessment for buildings

The second stage of flood risk assessment for the area is the physical risk assessment for buildings. For this receptor the hazard indicators are maximum water depth and maximum water velocity, which are combined to identify risk classes according to the expected amount of damage to buildings (again, see previous note on the use of maximum hazard values). The classification system we will use is that used in the KULTURisk framework and based on the work of Clausen and Clark (1990) (Table 4 and Figure 2).

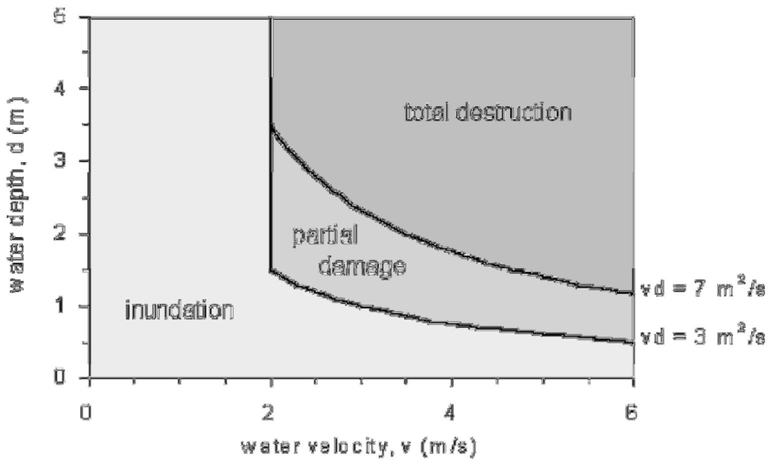

Figure 2 Identification of flood-related building damage, From the KULTURisk method and based on the work of Clausen and Clark (1990).

Table 4 Risk class definition table, modified from KULTURisk. Risk classes, definitions and indicator values are based on the work of Clausen and Clark (1990). Normalised scores were defined by a team of environmental risk experts as part of the KULTURisk project.

Risk Class	Hazard indicator value		Definition	Normalised score
	Water velocity (m/s)	Water velocity x water depth		
No inundation	0	0	N/a	0
Inundation	0<v<2	0<vd<3	Damage similar to that caused by a natural low-velocity river flood. No immediate structural damage	0.2
Partial damage	v>2	3<vd<7	Moderate structural damage, i.e. windows and doors knocked out. Little damage to the major structural elements of the building	0.6
Total destruction	v>2	v>7	Total structural collapse or major damage to the structure	1

			necessitating demolition and rebuilding	

Produce a raster layer containing the expected level of risk to buildings in each grid of the domain.

Calculate the "vd" layer

Multiply together the maximum water depth and maximum water velocity layers to create a new layer called "`water_vd`"

- **`Arc Toolbox > 3D Analyst Tools > Raster Math > Times (or use raster calculator)`**

Calculate the R_building layer

1) Reclassify the water velocity layer to create a new layer called "`temp1`" which has values of 0 where water velocity equals 0, values of 1 where water velocity is greater than 0 but less than 2, and values of 2 where water velocity is equal or greater than 2.
    - **`Arc Toolbox > Spatial analyst > Reclass > Reclassify`**[8]
2) Reclassify the `water_vd` layer to create a new layer called "`temp2`" which has values of 0 where velocity x depth equals 0, values of 10 where velocity x depth is greater than zero but less than 3, and values of 20 where velocity x depth is equal or greater than 3 but less than 7.

    Add together `temp1` and `temp2` to create a new layer called "`temp3`" whose values can be used to identify the risk class according to the values shown in Table 5.

Table 5

<table>
<tr><td colspan="4" rowspan="2">Risk Classes</td><td colspan="4">Calculated value of water velocity x water depth</td></tr>
<tr><td>0</td><td>0 <vd<3</td><td>3 <vd<7</td><td>>7</td></tr>
<tr><td>No inundation</td><td>inundation</td><td>Partial damage</td><td>Total destruction</td><td colspan="4">Reclassified value (temp9)</td></tr>
<tr><td colspan="2">Water velocity</td><td colspan="2">Reclassified value (temp8)</td><td>0</td><td>10</td><td>20</td><td>30</td></tr>
<tr><td colspan="2">0</td><td colspan="2">0</td><td>0</td><td>10</td><td>20</td><td>30</td></tr>
<tr><td colspan="2">0 <vd<2</td><td colspan="2">1</td><td>1</td><td>11</td><td>21</td><td>31</td></tr>
<tr><td colspan="2">>2</td><td colspan="2">2</td><td>2</td><td>12</td><td>22</td><td>32</td></tr>
</table>

3) Reclassify `temp3` to create a new layer called "`temp4`" which has values of 0 where `temp3` equals 0 (for no inundation), values of 1 where `temp3` equals 11, 21, 31, or 12 (for inundation), values of 2 where `temp3` equals 22 (for partial damage) and values of 3 where `temp3` equals 32 (total destruction). Values of `temp3` equal to 1, 2, 10, 20 or 30 could not occur in reality (i.e. values of one parameter are greater than zero whilst the other is zero)

[8] To reclassify the data type manually into the "Old values/New values" table e.g. old values = 0, new values = 0, old values = 0 – 2 new values = 1, old values = 2 – 3, new values = 2

but values of 1 and 2 can occur in results produced by lisflood because the highest velocity values can occur as water flows into the cell and so for that time-step there is no recorded depth of water in the cell. For the purpose of this exercise any such cells should also be reclassified with a value of zero at this stage.

4) Use **raster calculator** to create a new layer with values representing the building risk class only in those cells where buildings are present, and rename it "`r_class_build`". Note: in this scenario water depths and velocities are relatively low and so only building inundation is likely.
   - **([Land use] >= 1) * [temp4]**

In this exercise we are creating individual risk maps for each of the three receptors: people, buildings and infrastructure. If the risks to individual receptors were to be combined, then each of the risk classes in Table 4 would need to be given a normalised score. Normalised scores for building risk classes were developed by a team of environmental risk experts for the KULTURisk project, and are given for reference in Table 4.

Physical flood risk to Infrastructure

For simplicity in this exercise we look only at roads and do not differentiate between road types. More complex methodologies could include rail or communication/services infrastructure as well as differentiating between major and minor roads etc. Moreover, for this receptor the only hazard indicator considered is flood extent, allowing calculation of the percentage or length of roads that are inundated. We consider here only whether or not a road is flooded, in reference to its potential loss of service rather than any consideration of potential physical damage to the road. More complete assessments could link the depth of inundation and/or water velocity with the degree of damage expected, or follow on to look at the economic consequences of infrastructure flooding.

Create a layer which identifies and gives detail of the lengths of roads which are expected to be inundated during a flood event and those expected to remain dry

Create a polygon shapefile layer representing the extent of the flooded area

1) Reclass the `Maximum depth` layer to give a new layer called "`temp5`" with values of 1 where water depth is greater than zero, and "NoData" everywhere else
2) Convert this raster to a polygon shapefile called "`inundation`"
   - **`Arc Toolbox > Conversion Tools > From Raster > Raster to Polygon`**

Create a polyline shapefile identifying inundated sections of road and calculate their lengths

1) First, familiarise yourself with the roads shapefile. Right-click the `Roads` layer and open its attribute table. You will see there are 3 roads with FIDs 0, 1 and 2. Road 0 is the main road running west – east through Waterville and Riverton across the domain. Road 1 is the road branching off road south across the river and then back west along the valley and 2 is the

short road branching off road 1 east into "Hamlet-on-the-hill". If not already calculate their length:

- **Roads > Open attribute table > Options > add field > name this "Length_Tot" (short for Length_Total)**
- **Right click Length in the attribute table > Calculate Geometry... > Property > Length**

2) Use an overlay function (using the `Roads` and `inundation` shapefiles) to create a new shapefile layer called "`roads_flooded`" which identifies which roads are flooded
   - **Arc Toolbox > Analysis Tools > Overlay > Intersect**[9]
   Open the attribute table for the `roads_flooded` layer. You should see that two of the roads are identified as being inundated for part of their length, FID_Roads 0 and 1. The total length of each road should be displayed in this table, but you can also calculate the length of each road which is flooded by following the same procedure as above but naming the column Length_Fld (short for Length_Flood). What proportion of roads 0 and 1 are flooded?
3) Calculate the length of the flooded/not flooded sections of each of the three roads
   - **Road_flood > Open attribute table > Options > add field > name this "Length"**
   - **Right click Length in attribute table > Calculate Geometry... > Property > Length**

<u>Economic flood risk to buildings</u>

Calculation of the economic risk of flooding using an empirical relationship between water inundation depth and flood costs per building (often termed a depth-damage curve) is a common practice. An example depth damage curve recommended by the US Army Corps of Engineers (USACE 2003) is given in Figure 3. This shows the expected percentage of damage (in terms of total potential cost) to both building structure and building contents for a given water inundation depth. This example is for a typical building of 2 or more storeys without a basement and will be used to estimate likely economic costs of flooding to buildings in the valley. For simplicity we will use the same depth-damage curve for all buildings (residential, commercial and industrial) although depth-damage curves for specific building types and uses are available. USACE (2006) use a content-structure value ratio (CSVR) to estimate total content values based on the building structure value (i.e. the cost of contents compared to property value). Typical CSVR ratios vary with building usage/type: for residential buildings they are low, typically in the region of 0.5 for two storey buildings, whilst for commercial or industrial type buildings CSVRs are high, with typical values of 1.4 and 2.8 respectively (USACE, 2006). For the purpose of this exercise building property costs have been provided for the area in the data layer buildings_cost. Commercial properties are rated at 75 and industrial at 100. Residential property prices vary between 10 in the deprived central areas of River Town to 150 in the affluent leafy outskirts of Waterville.

[9] Hint: Using the drop down menu, add the `Roads` shapefile and the `inundation` polygon as input features.

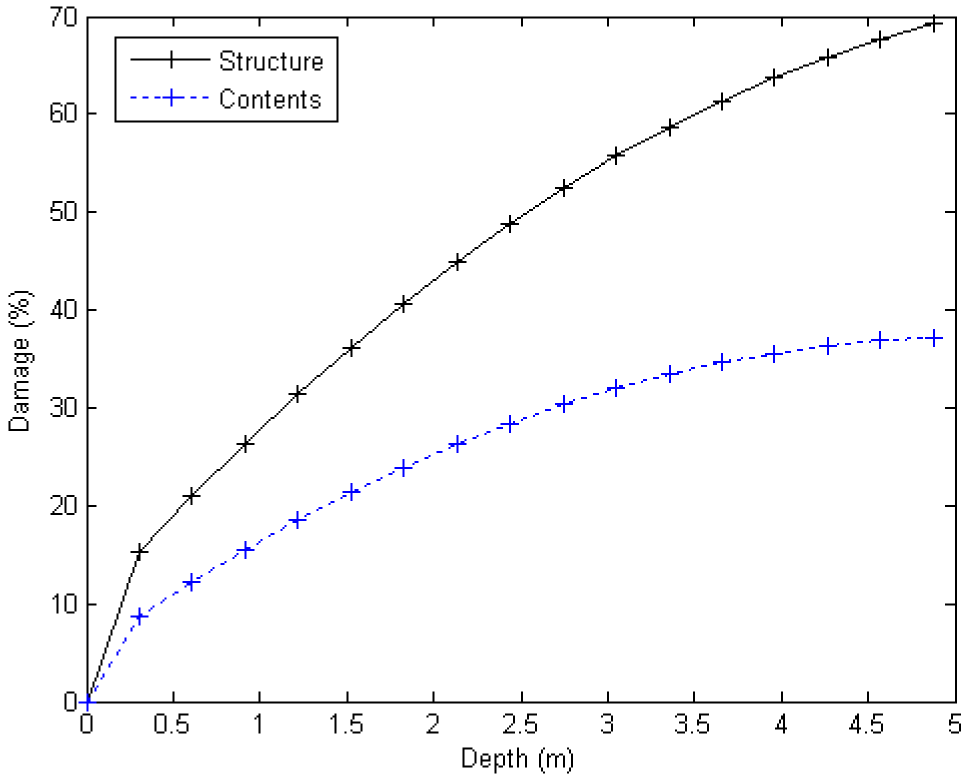

Figure 3 Example depth-damage curve. Data from USACE (2003).

Table 6 Example depth-damage curve data, reproduced from USACE (2003).

Water depth (m)	% Damage (structure)	% Damage (contents)	Water depth (m)	% Damage (structure)	% Damage (contents)
0.0	0	0	2.7	52	30
0.3	15	9	3.0	56	32
0.6	21	12	3.4	59	33
0.9	26	16	3.7	61	35
1.2	31	19	4.0	64	36
1.5	36	21	4.3	66	36
1.8	41	24	4.6	68	37
2.1	45	26	4.9	69	37
2.4	49	28			

Calculate the total economic cost per cell due to building inundation

Create a temporary raster layer containing the expected % of damage to contents and building structure for each cell using the depth-damage curves of USACE (2006)

1) Reclassify the layer `Maximum depth` using the depth-damage relationship for building

structure shown in Figure 3 to create a new layer called "`temp6`". For ease of reclassification, this data has been provided as a remap table ("`remap_structure`") which can be loaded using the "`reclassify`" dialogue box.

- **`Arc Toolbox > Spatial analyst > Reclass > Reclassify > "Load..."`**

2) Reclassify the layer `Maximum depth` using the depth-damage relationship for building contents shown in Figure 3 to make a new layer caller "`temp7`". For ease of reclassification, this data has also been provided as a remap table ("`remap_contents`").
3) The data in layers `temp6` and `temp7` is saved as unsigned integer values. Change these to floating point values to ensure that subsequent calculations using these layers will not be restricted to integer values, name these layers "`temp8`" and "`temp9`" respectively.

    - **`Arc Toolbox > 3D Analyst > Raster Math > Float`**

Create a raster layer containing the details of the total cost of flooding to buildings in each cell

1) Use the **raster calculator** create a new layer by multiplying (`temp8/100`) with the `buildings` layer and the `buildings_cost` layer and rename this layer "`bcost_structure`"
    - **([temp8] / 100) * [Number of buildings] * [Cost of buildings]**
2) Use the **raster calculator** create a new layer by identifying cells containing each of the building types and then for each set multiplying (`temp9/100`) with the `buildings` layer and the `buildings_cost` layer multiplied by the appropriate CSVR value. Rename this layer "`bcost_contents`".
    - **((([Land use] == 1) * [Number of buildings] * ([temp9] / 100) * ([Cost of buildings] * 0.5)) + ((([Land use] == 2) * [Number of buildings] * ([temp9] / 100) * ([Cost of buildings] * 2.8)) + ((([Land use] == 3) * [Number of buildings] * ([temp9] / 100) * ([Cost of buildings] * 1.4))**
3) Lastly, add these two layers (`bcost_structure` and `bcost_contents`) to create a layer containing values for total likely cost of flooding to buildings in each cell called "`bcost_flood`".

<u>Quick questions to check answers:</u>

1) Which cell/area of the domain contains the highest hazard to people? (irrespective of whether there is a population present)
2) Which cell/area of the domain is likely to sustain the most injuries to humans?
3) Which cell/area of the domain contains the highest physical risk to buildings? (irrespective of whether there are buildings present)
4) Which cell/area of the domain is likely to have the highest economic costs due to building damage if the area were to flood? What is this cost?
5) What is the total length of road expected to be flooded?

Answers to these questions can be found in the Answers.doc file.

Acknowledgments

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Appendix – overview of data provided

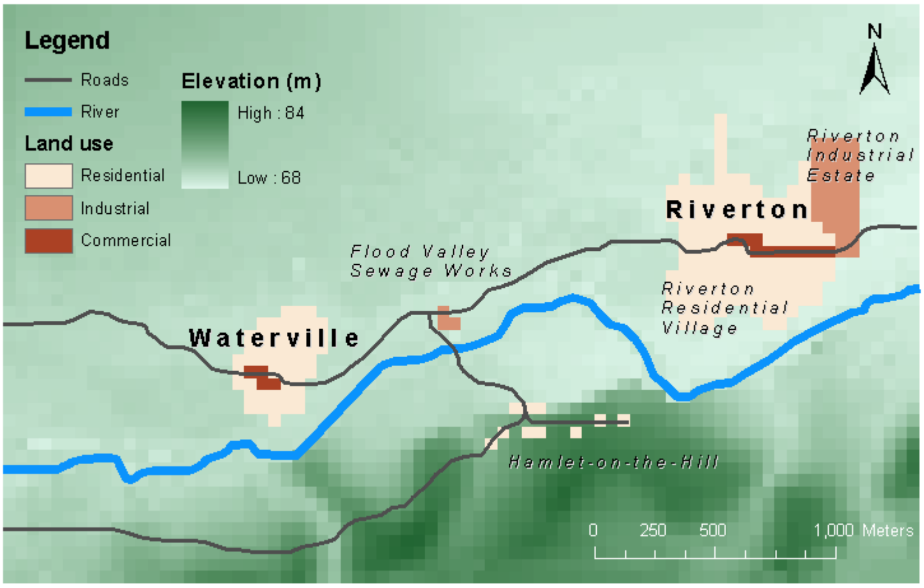

Figure 4 Land use classification in the area

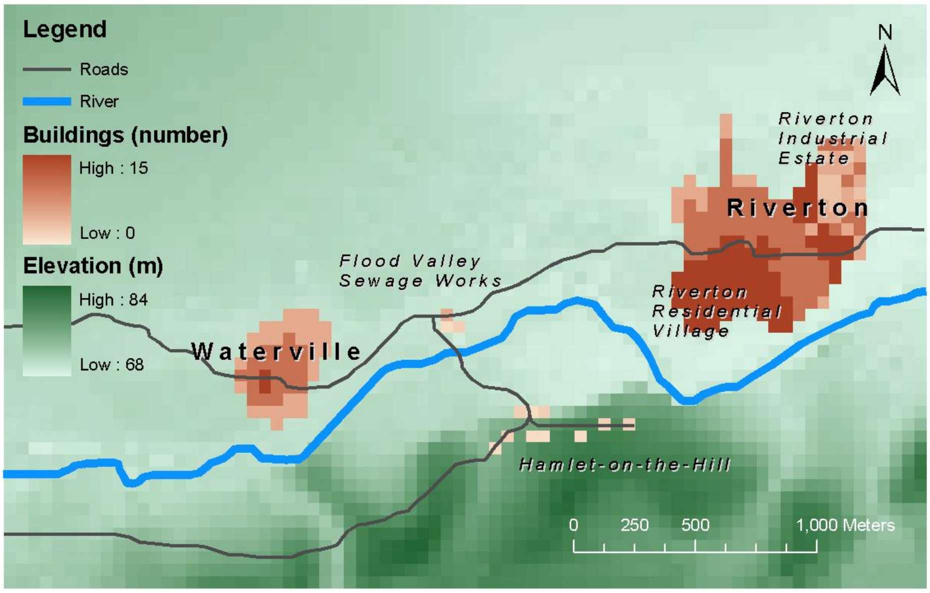

Figure 5 Number of buildings per cell in the urban areas of the valley

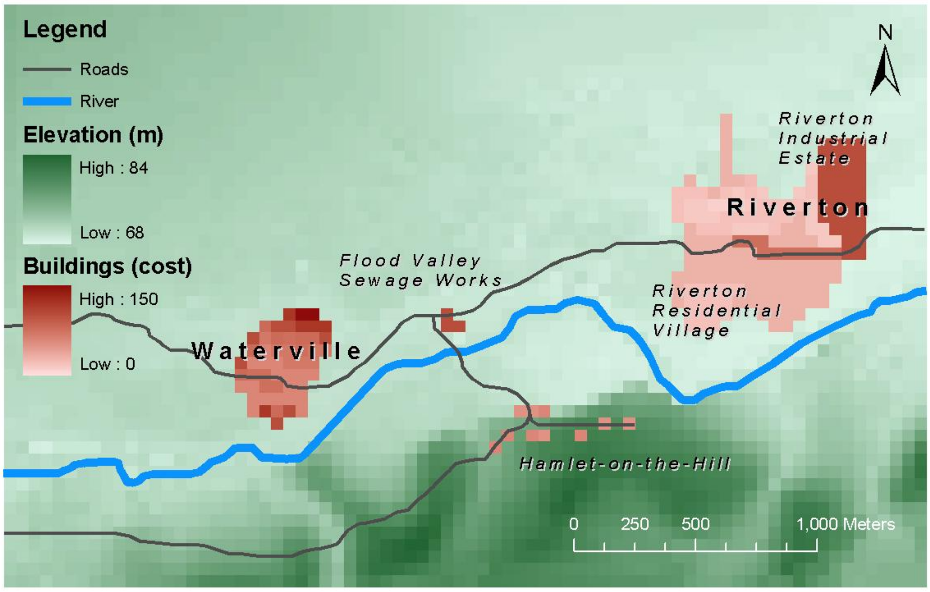

Figure 6 Average cost of buildings (in each cell) in the valley

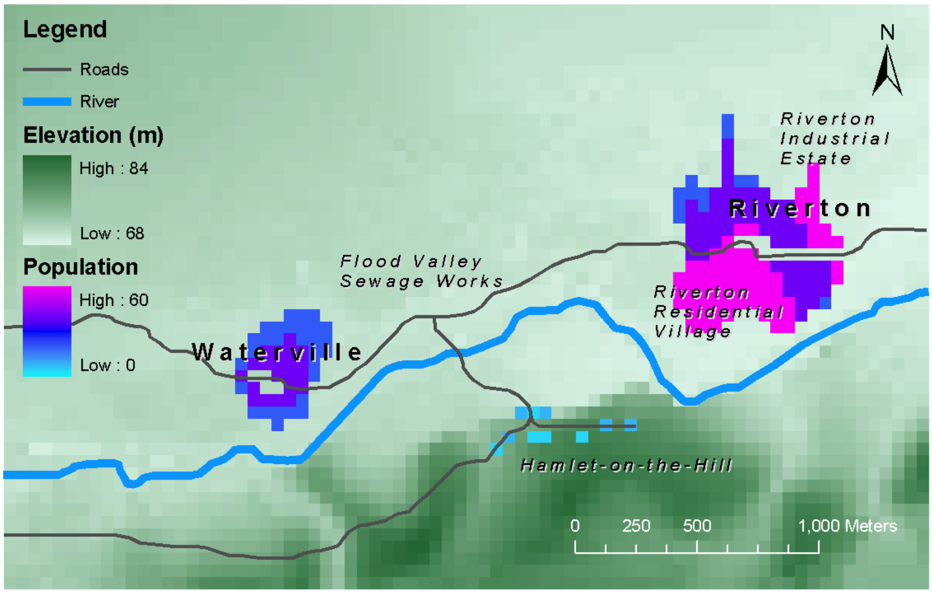

Figure 7 Resident population per cell in the area

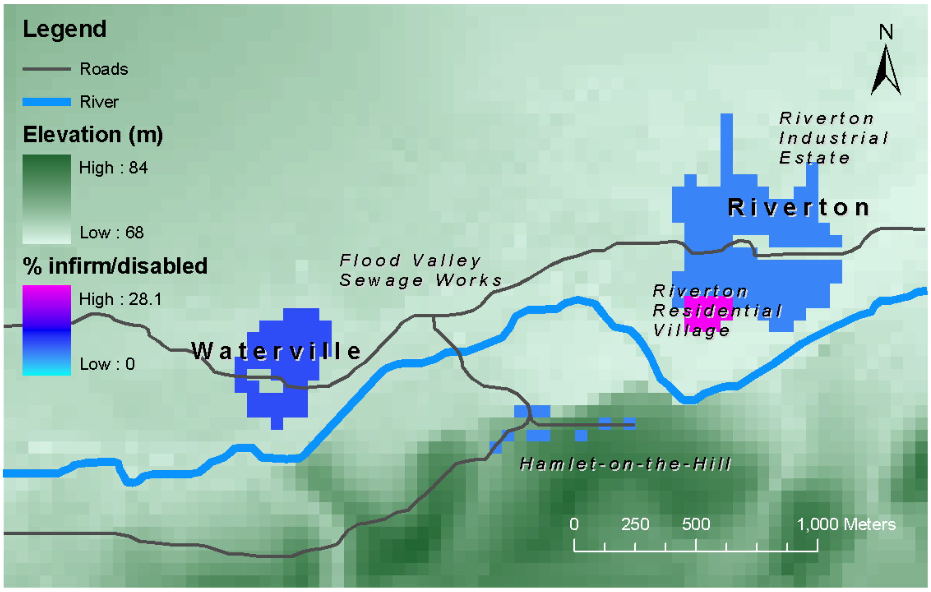

Figure 8 Number of people who are infirm or have a long term illness/mobility problems in the area, as a percentage of the total population in each cell

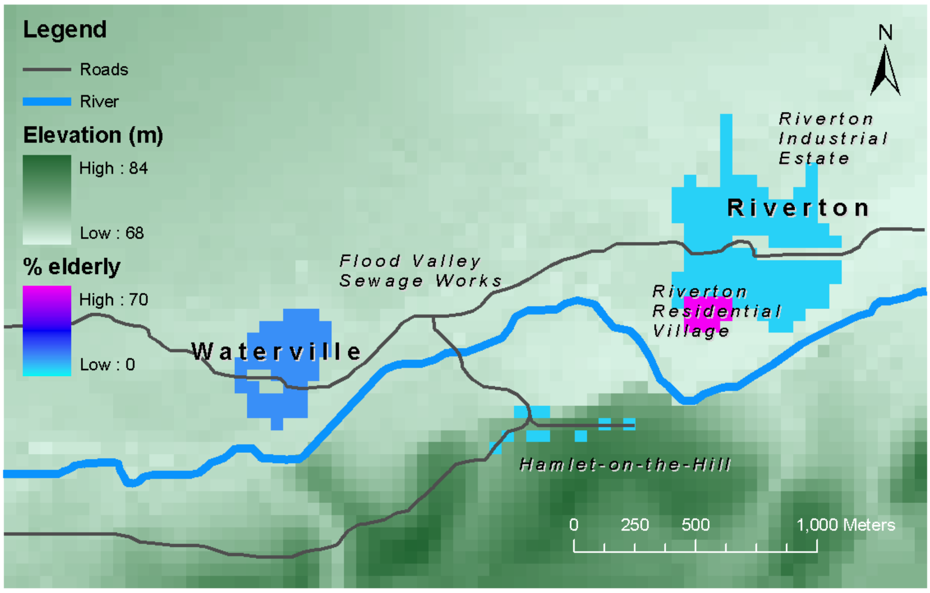

Figure 9 Number of people >75 years of age in the valley, as a percentage of the total population in each cell

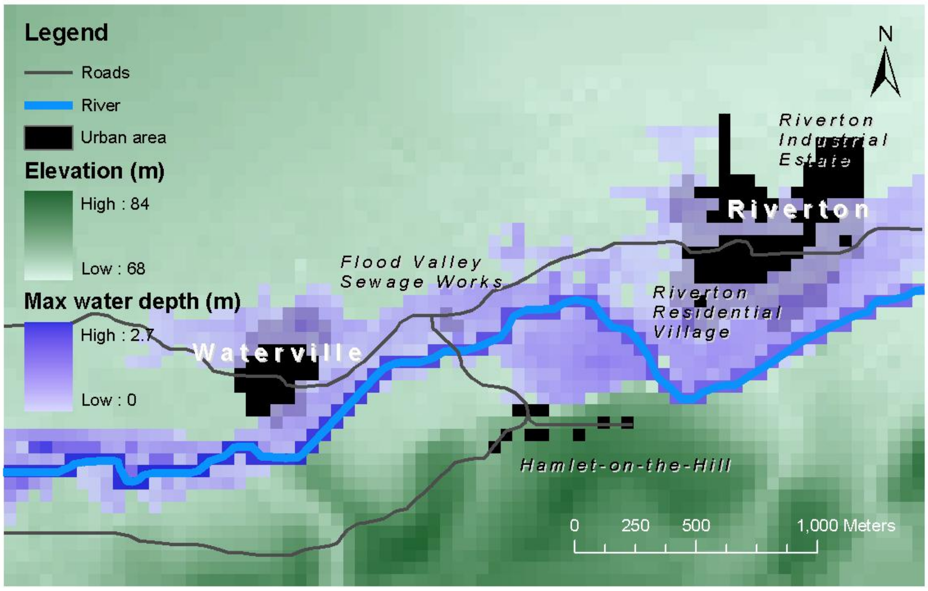

Figure 10 Maximum water depth expected in each cell during a flood event in the valley (as simulated by lisflood)

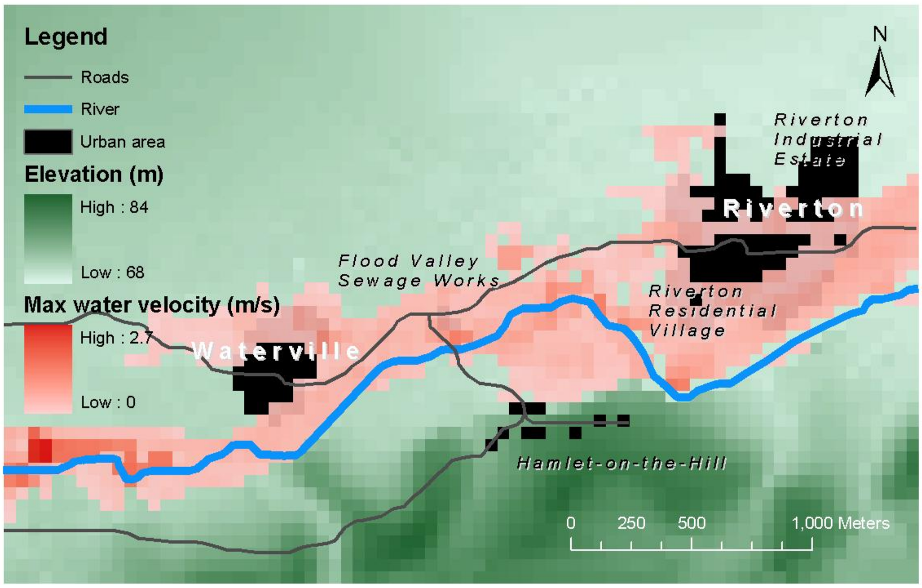

Figure 11 Maximum water velocity expected in each cell during a flood event in the valley (as simulated by lisflood)

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