Feedback Form

School of Geography FACULTY OF ENVIRONMENT UNIVERSITY OF LEEDS *Students to complete all of the following (or work will not be accepted)*	Name (optional): Richard Thomas
Student ID: **200818341**	Assessment Name (e.g. Essay 2, Group Project etc): Assignment #2: Flooding in Somerset Levels
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Module Title & Code: GEOG5060M: GIS & Environment	Word Count: (750 words max) **743**

Content, research and reading

Structure and argument

Writing, presentation and referencing

Areas for improvement to prioritise

Marker's signature:	Date:	Provisional mark:

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Hydrological modelling of river flood potential in SW England

INTRODUCTION

This paper will first analyse the hydrology behind the severe flooding in the River Parrett catchment in January 2014 (figure 1), before considering effects of upper reaches land use and related methods of reducing flooding.

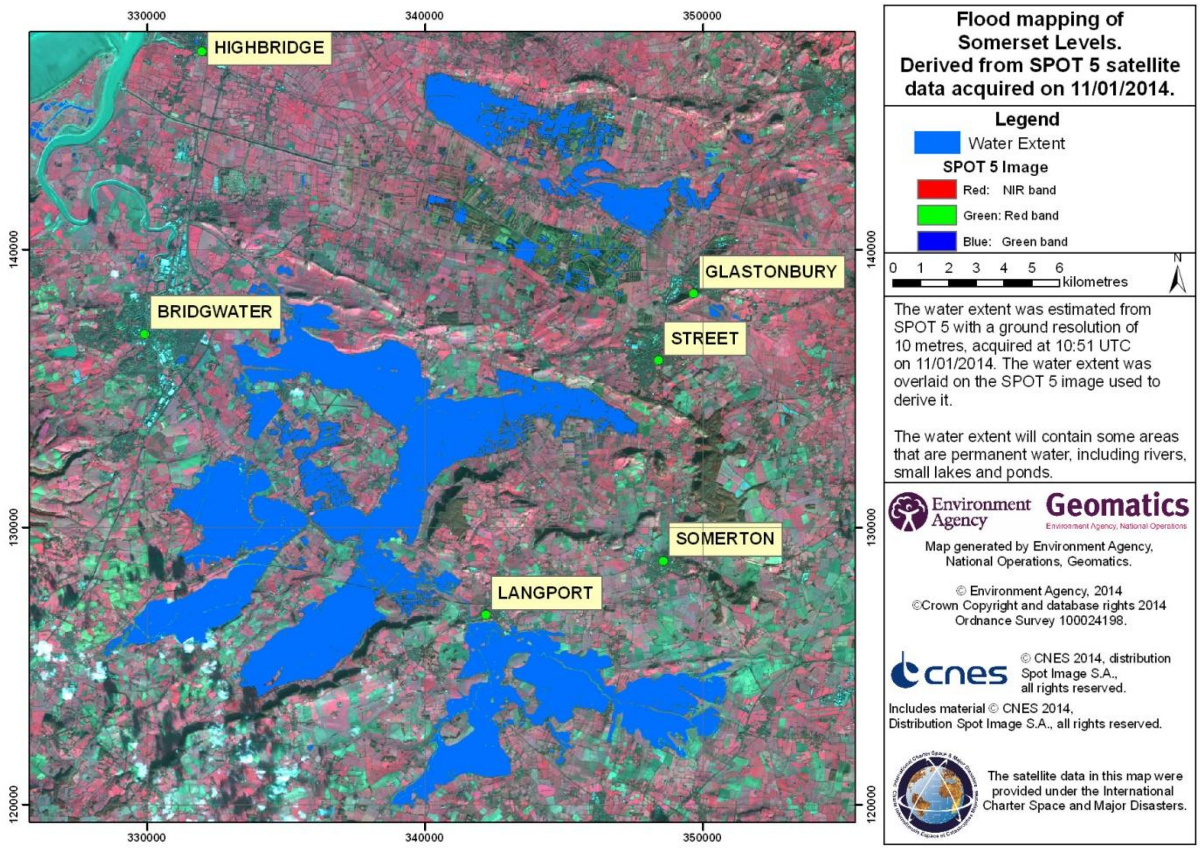

Figure 1: Location of Somerset Levels Flooding, January 2014

ANALYSIS

ArcGIS analysis using various data sources (table 1) produced location estimates for channels and watersheds. Figure 2 illustrates these, together with the actual river locations recorded in Ordnance Survey data; in the upper reaches of the watershed these are fairly consistent, but in flatter parts more errors emerge. For the adjacent River Brue catchment, the output can be seen to be quite unusable. This is partly due to the relatively low horizontal DEM resolution (50m), but more due to the lack of relief and presence of many man-made rhynes/drains.

Table 1: Data sources used

Source	Data set	Use in this paper
Met Office (2014)	Monthly regional rainfall measurements	The January total rainfall (166.4 mm) at the Yeovilton measuring station was used as an average figure to calibrate the model.
Ordnance Survey	Digital Elevation Model (DEM), vector data for river	Estimation and validation of modelling of river locations and behaviour.
NSRC	NATMAP soils dataset	Identification of soils at risk of erosion.
Centre for Ecology and Hydrology (CEH)	Land Cover Map 2007	Assessment of current use of upper reaches of the catchment basin.

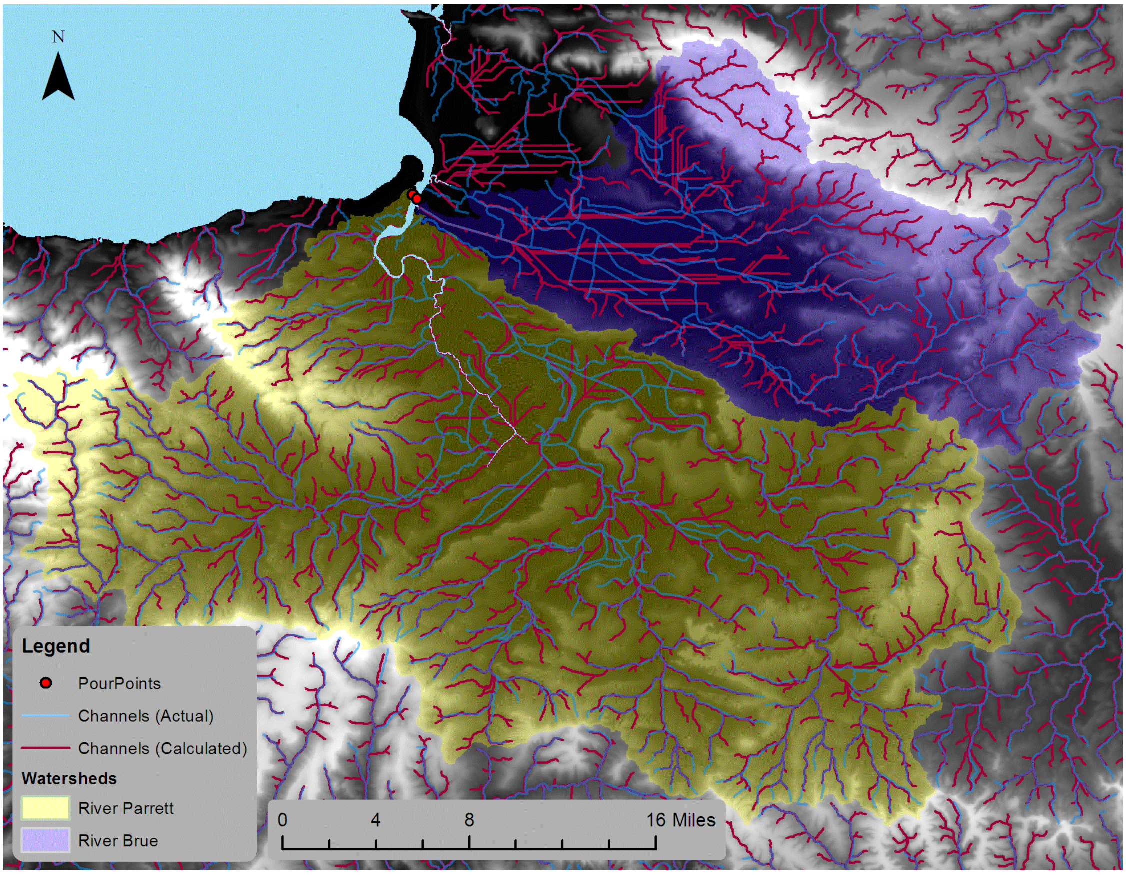

Figure 2: Somerset Levels calculated watersheds and stream networks (DEM and rivers copyright Ordnance Survey)

Calculations were then made to estimate discharge rate Q at different places across the watershed and flow time for rain falling anywhere in the basin to reach the output "pour point". Equations for this are derived in table 2, with details of ArcGIS operations required to implement them in table 3. Results are illustrated in figures 3-5.

Table 2: Calculations to estimate flow time

Variable	Calculation	Notes
Channel discharge rate Q (m^3/s)	(Rainfall rate per unit area Rf) . (Contributing catchment area Ac)	Making the simplification of assuming that under continually cold and wet conditions that the ground is saturated and there is little evaporation, so we are getting nearly 100% of rainfall converted to run-off. Also, under the equilibrium of continuous constant rain, the discharge Q from a cell will equal the input from previous cells + rainfall.
Channel Slope S0	(vertical drop) / (path length)	Need to evaluate on a cell-by-cell basis, but how to avoid noise?
Hydraulic Radius Rh (m)	(channel cross section area A) / (wetted perimeter P)	How to estimate?
Channel Velocity V (m/s)	$1 / n . Rh^{2/3} . S0^{1/2}$	Manning's equation: n is a coefficient of roughness that can be selected from a descriptive look-up table.
Channel discharge rate Q (m^3/s)	(Channel Velocity V) . (Channel cross-sectional area A)	This relationship can be used to help us derive Rh...
Channel cross-sectional area A (m^2)	$0.5 . PI . Rh^2$	Modelling the channel as (the ideal) semi-circular cross-section
Solving for Rh:	$Rh = \{ 2 . n . Q / (PI . S0^{1/2}) \}^{3/8}$	This would give the minimum channel size required to continuously transport "average" rainfall rate specified earlier.

Table 3: ArcGIS procedures to implement hydrology calculations

Processing Step	ArcGIS Command	Notes
Create depression-less DEM	Fill	
Determine direction and quantities of run-off flow	Flow Direction, Flow Accumulation	D8 Algorithm causes improbable 45 degree channel angles in areas of little change in height
Calculate Discharge Rate Q	Raster Calculator	Apply uniform rainfall across the whole of the watershed
Generate stream network	Con (FlowAcc > 300)	Apply a threshold of 300 as this seems to tie in with ends of marked network in OS Meridian vector set
Uniquely identify each stream section between nodes	Stream Link	Need to do this so we can calculate average slope between nodes to avoid noise of measuring slope at every pixel

Convert raster stream to vector	Stream to Feature	Creates polyline for each stream section. Ensure "simplify polylines" turned off so the process can be reversed exactly
Get average slope	3D Analyst: Add Surface Information	Calculates gradient average for each of the polyline segments
Convert back to raster	Polyline to Raster	Average slope now copied along full length of each stream section for ease of following Map Algebra
Estimate hydraulic radius Rh at each cell along the channel	Raster Calculator	(see following text)
Estimate velocity V (in m/s) at each cell along channel using averaged slope gradient for each network link	Raster Calculator	Apply Manning's n = 0.035 across all of watershed, assume channel is perfect semicircular of radius Rh
Calculate flow delay from each point in channel network to pour point	Flow Length	Use reciprocal of V as input weight factor

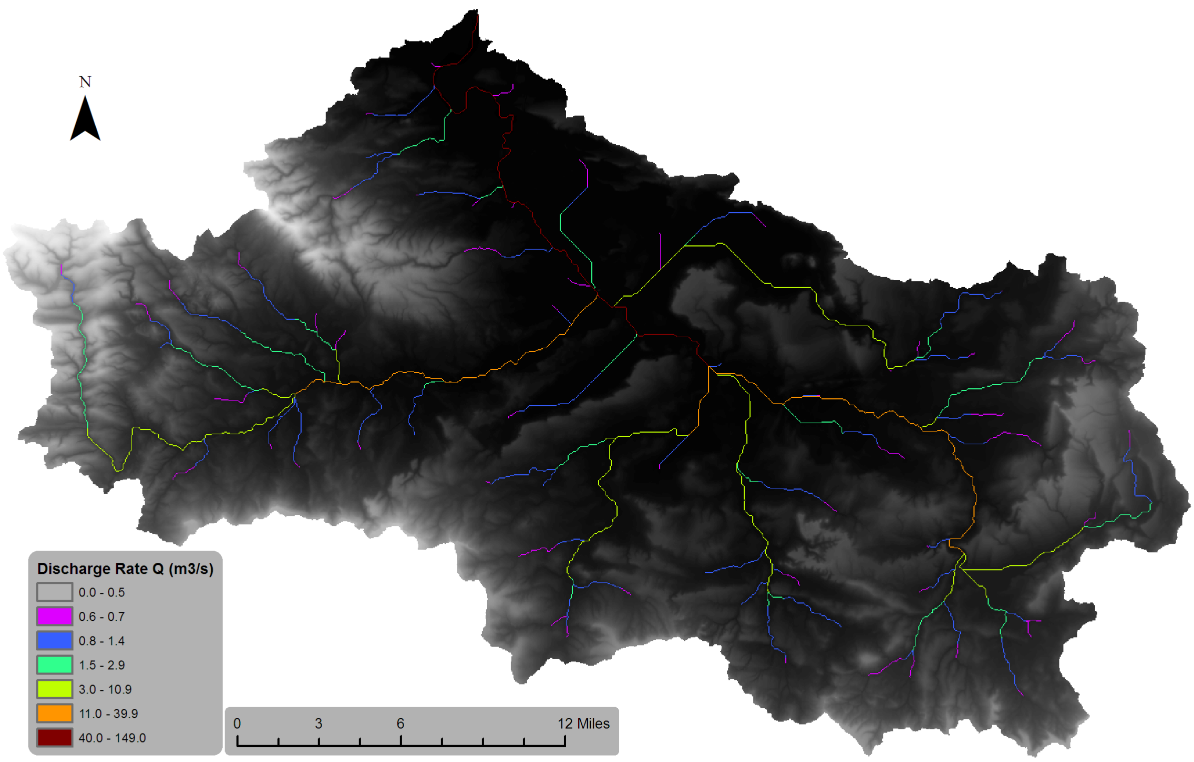

Figure 3: Estimated channel discharge rates (Q) for River Parrett watershed

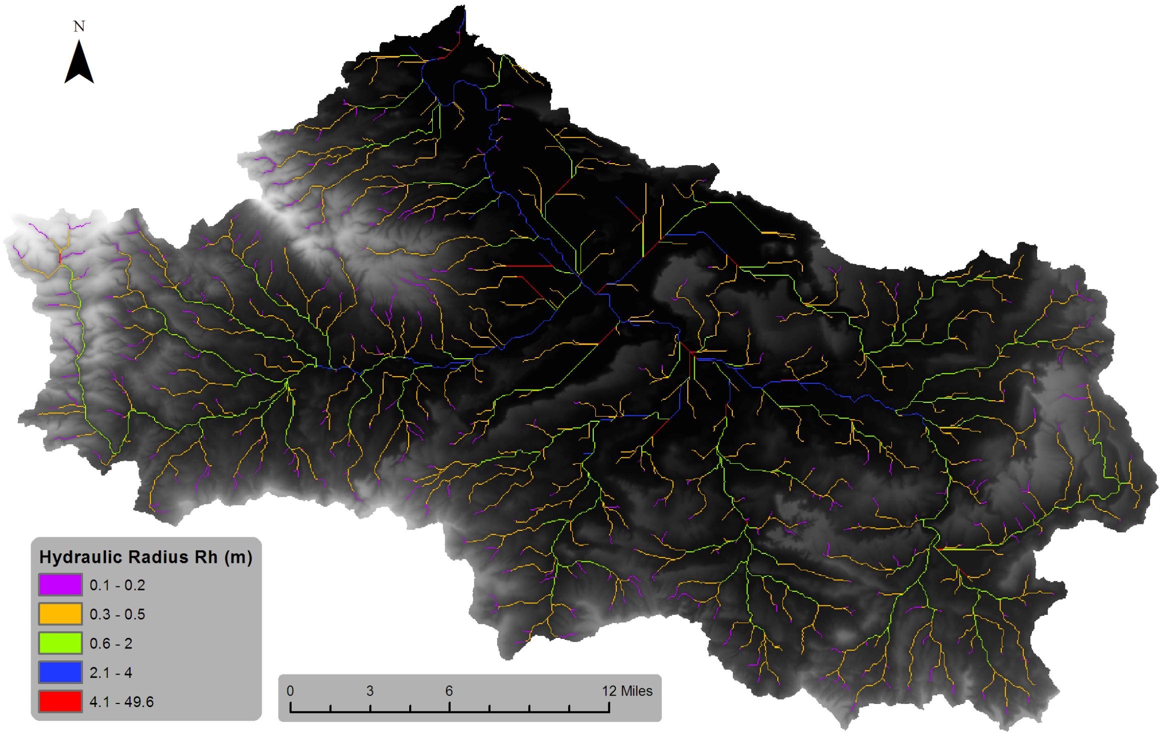

Figure 4: Estimated channel hydraulic radii (Rh) for River Parrett watershed

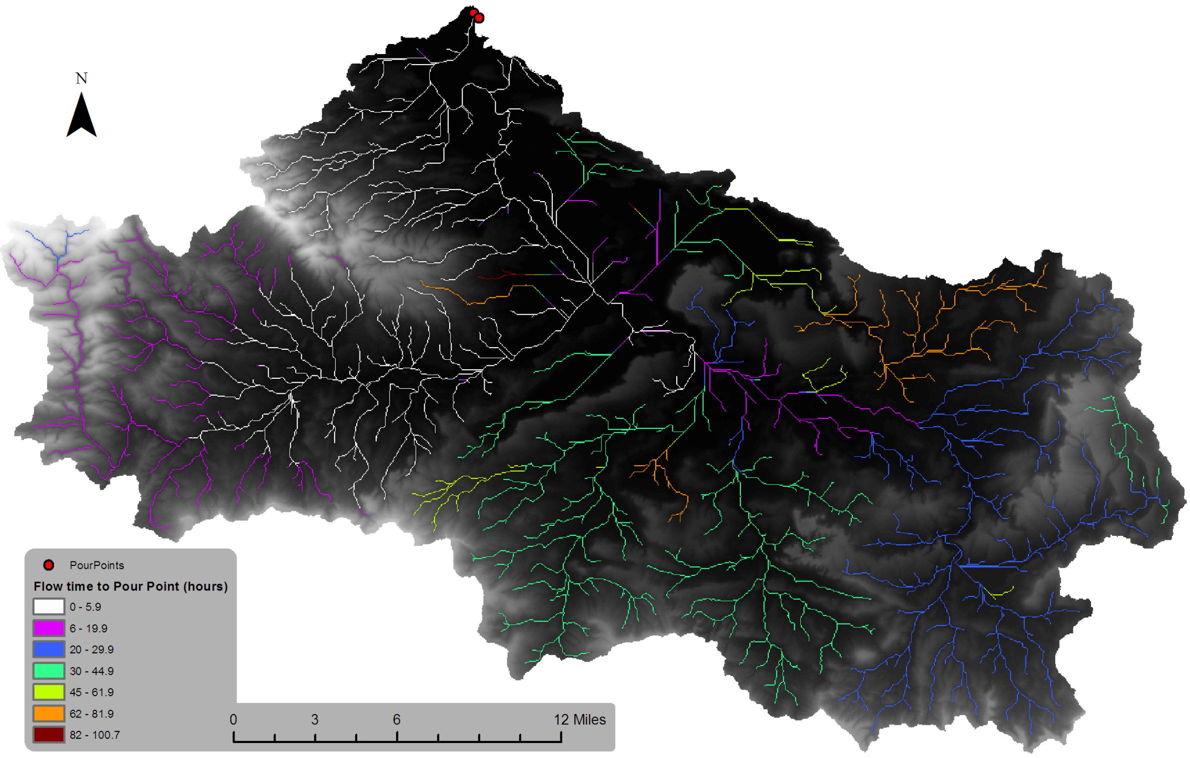

Figure 5: Estimated flow times to pour point at different places across the River Parrett watershed

Looking at discharge rates, it is clear that Q suddenly gets much larger just as the land flattens out, with lots of tributaries merging. Rh is notably at its widest (red) in several other relatively flat places further upstream – suggesting points of likely flood risk. The flow map suggests that it can take 20-40 hours to cross the watershed (about 20 miles) which seems a long time!

Note that these are channel flow times and do not include time for runoff from the land (or through ground flow) into the channels. To model this properly, a distributed model such as TOPMODEL (Beven et al, 1984) seems appropriate. Although off-the-shelf code for this is available to run in the open-source GRASS GIS, the large number of constraints parameters seem difficult to make reasonable estimates for. De Roo (1998) commented that (for erosion models) often a simpler model with “representative elements of the dominant processes” is likely to be as good as a spatial model. Consequently, some simpler modelling changes will be considered after first looking upstream...

INVESTIGATING EFFECTS OF UPSTREAM LAND USE

Excessive run-off from upland slopes can be a major contributor to lowland flooding but also causes serious problems due to soil erosion in upland areas (De Roo, 1998), with the Universal Soil Loss Equation (USLE) (proportional to Sediment Transport Index) a good quantitative measure for estimating likelihood of such erosion.

In southwest England, Palmer (2013) highlighted late-harvested crops such as maize as the most damaging - 75% of sites visited exhibited increased runoff combined with damaged soil structure. The runoff also has water pollution implications due to transport of organic material, fertilizers and pesticides. The 2007 Land Cover Map (Figure 6) shows that the uplands of the River Parrett watershed are extensively arable farmed.

Animal grazing also causes problems both in denuding landscape of vegetation and compacting the ground making it more impervious to water infiltration. For ground classified as “rough grazings” 90% of it is in the uplands, of which about 45% is at significant risk of erosion (Evans, 1990). However, Marshall et al (2014) outlines that land can recover and in tests runoff volumes were reduced by 48% by stopping grazing, increasing to 78% if trees were also planted.

Certain types of soil are particularly vulnerable to erosion. De Roo (1998) identifies a few specific types that are at great risk and for which farming practices should be considerate of. Using the detailed maps of the NATMAP soils data set, such soils in the Somerset area (also in the uplands) have been highlighted in figure 7.

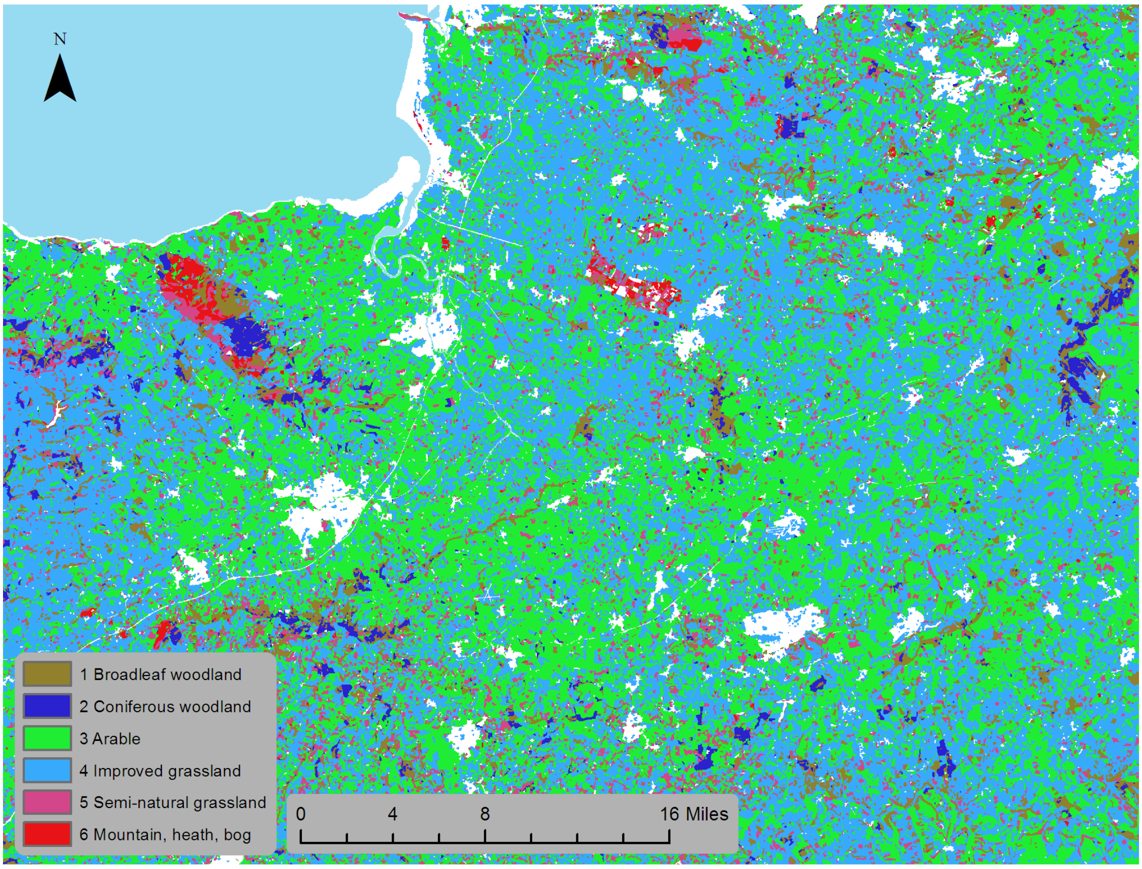

Figure 6: Land Cover Map 2007: Aggregate Classes relevant to rural upland areas

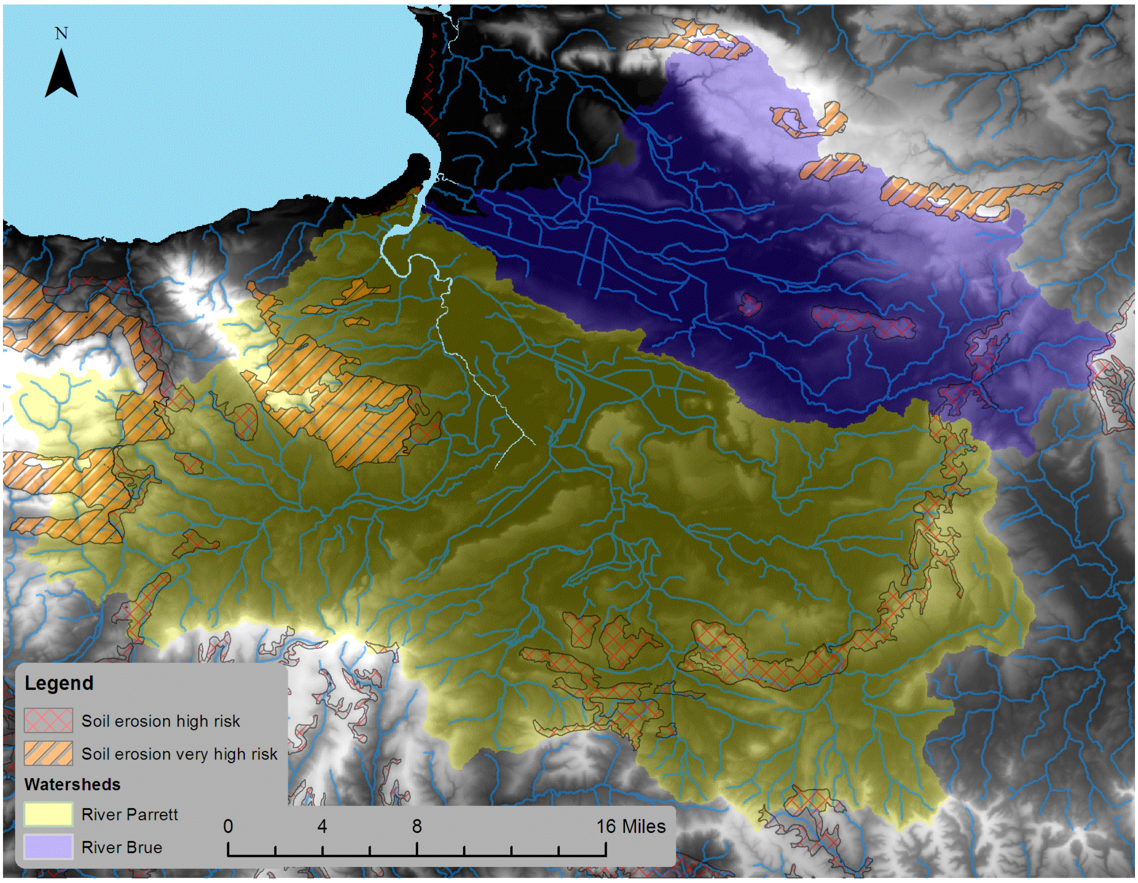

Figure 7: Somerset soils identified as at high erosion risk by De Roo (1998) using the NATMAP soils data set

Given these findings, I reworked my model to simulate switching all higher ground from arable farming to woodland. Following Marshall et al (2014), I implemented this as a 78% reduction in runoff for just the land above 100m. Figure 8 illustrates the resultant fall in discharge.

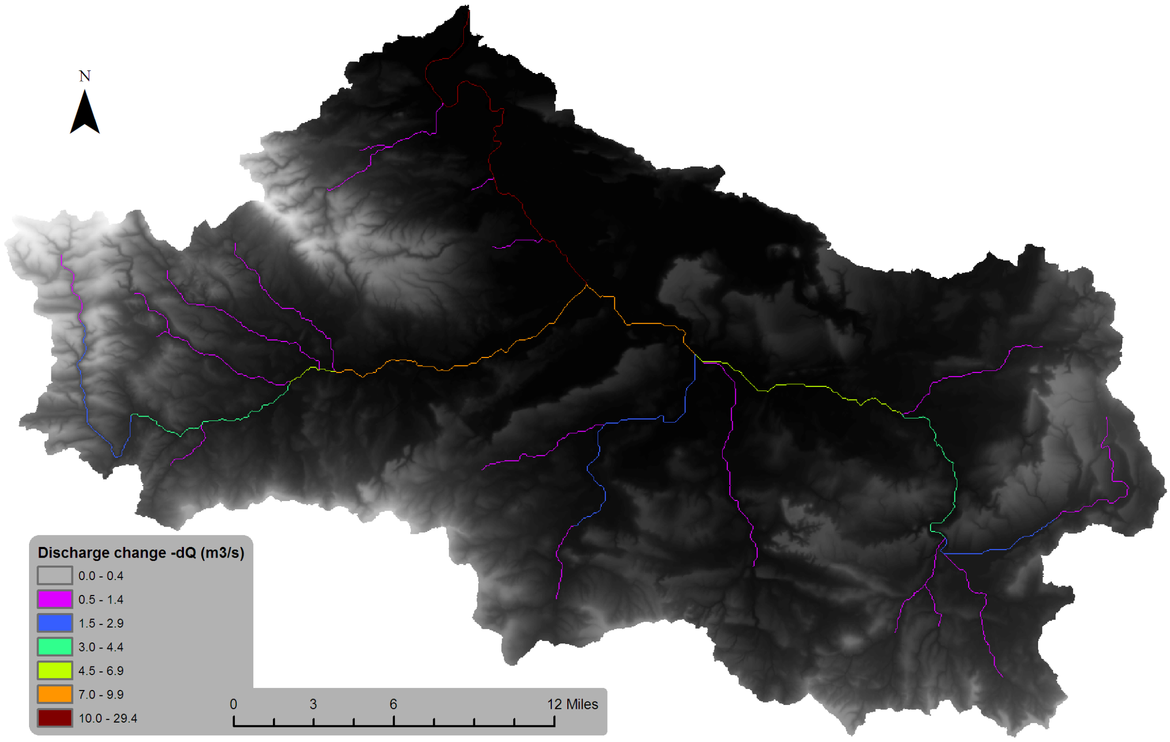

Figure 8: Estimated discharge rate reduction (-dQ) on planting upland trees

CONCLUSIONS

Although GIS is well-suited to spatial analysis and visualisation aspects of hydrology, temporal modelling often requires other (loosely coupled) software; indeed, I struggled (and failed) to generate within ArcGIS a Parrett hydrograph – useful to understand the system "impulse response" to sudden rainfall events.

As for flood prevention, one alternative is to create "washlands" (Morris, 2008) – areas set aside to be flooded in a controlled way – not a new approach: MacMillan et al (1993) developed DISTHMOD to model similar scenarios for distributed farm ponds in Canada.

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