Coupling of groundwater, river level and rainfall in an upland floodplain

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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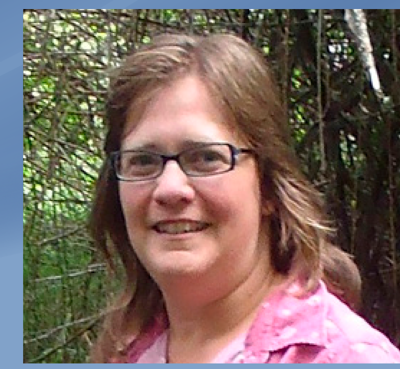


Introduction

Upland floodplains provide an important function in regulating river flows and controlling the coupling of hillslope stormflow with rivers. Recent exceptionally wet winters in the United Kingdom have emphasised the problem of flooding and the need for research into the connectivity of water flows in upland floodplains and adjacent hillslopes. This study investigated surface water-groundwater interactions in an upland catchment in the Scottish Borders.

Site area

The site area (red square in Figure 1) is 0.2 km^2, encompassing part of the floodplain and adjacent hillslope of the Eddleston Water (Figure 2). The site lies in the Eddleston Experimental Catchment, within which there are 11 river flow and rainfall monitoring stations.

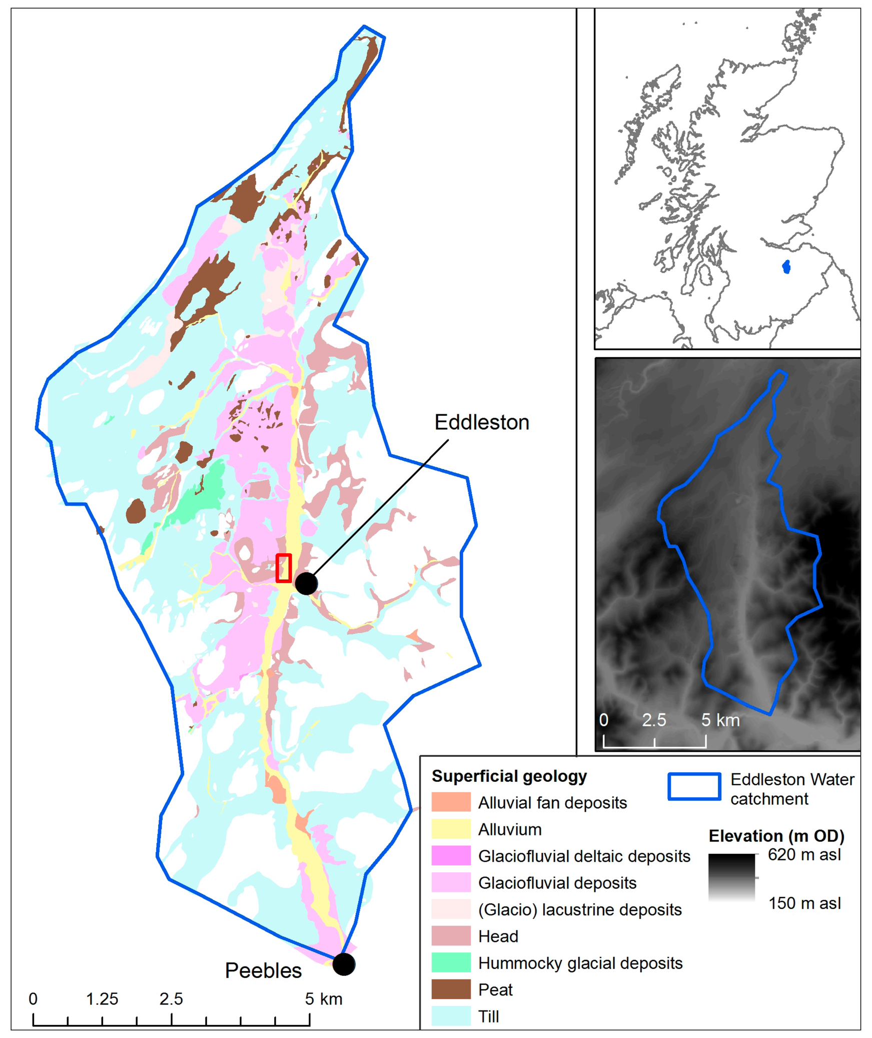


Figure 1 The Eddleston Experimental Catchment, Scotland, UK. Red square and photo shows site area.

Methodology

Drilling to install groundwater boreholes.

Validating river level.

Pumping tests of boreholes to estimate aquifer transmissivity.

Soil water content measurements in the hillslope.

The site area was characterised using surface geophysics (electromagnetic induction, 2D electrical resistivity tomography and ground penetrating radar), 3D geological mapping, hydrogeological testing and geochemical sampling. Hydrological monitoring of groundwater levels, river stage, soil moisture and meteorological parameters was done from September 2011 to February 2013, a period which included 9 months of exceptional rainfall, providing an excellent opportunity for investigating groundwater, river and soil moisture responses in flood conditions. Data were interpreted using a range of statistical techniques.

Results

3D modelling

A 3D model of superficial geology was developed (Figure 2), which illustrates how permeable slope/solifluction deposits extend from the hillslope into the edge of the floodplain, interfingering and connecting with the highly permeable floodplain aquifer and allowing significant subsurface water flow from hillslope to floodplain.

Hydrochemistry

Base metal ratios suggest that older, low oxygen groundwater (which has experienced more water-aquifer interaction) is more common closer to the river, while groundwater at the edge of the floodplain tends to be younger and higher in oxygen (Figure 2).

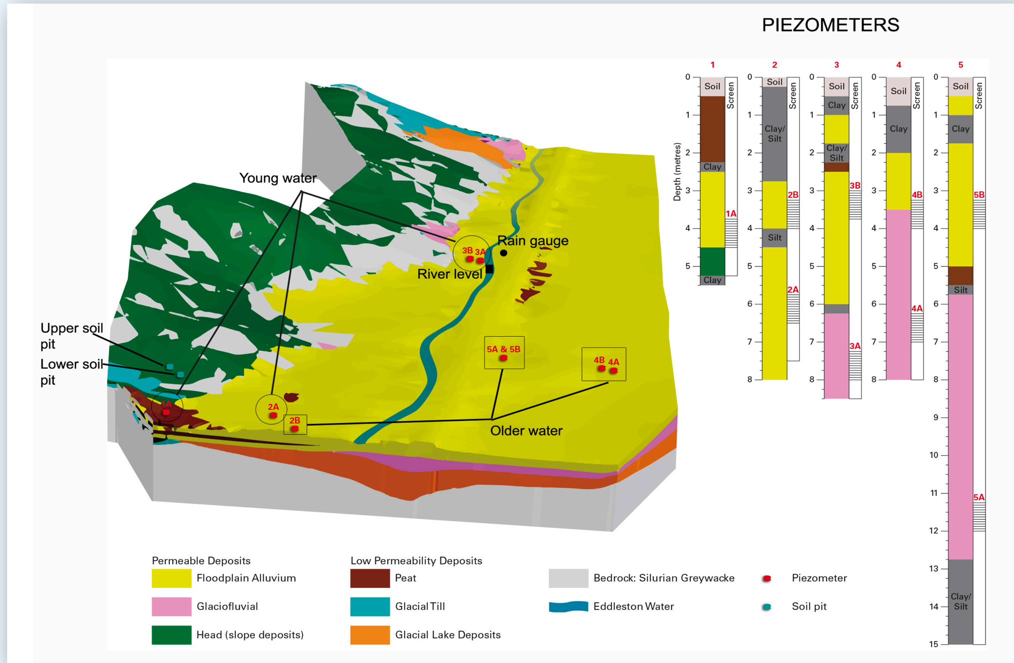


Figure 2 3D superficial geology model of hillslope-floodplain site area, also showing locations of groundwater piezometers and soil moisture gauges and piezometer geological logs.

Response times of soil moisture content, groundwater levels and river level to rainfall

Time Interval

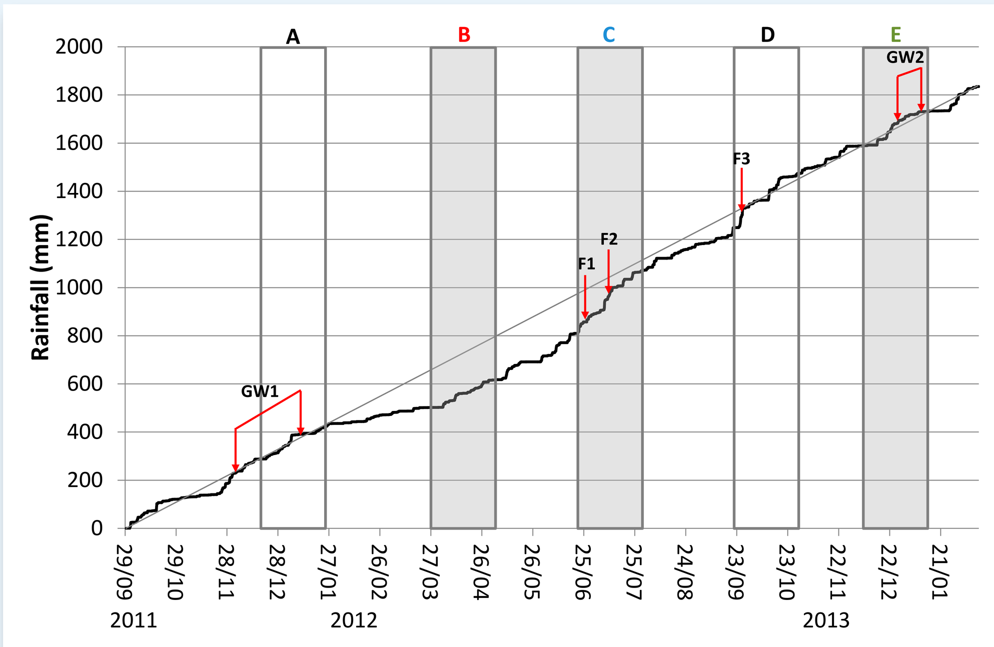


Figure 3 Cumulative rainfall, showing time periods investigated in depth (B, C, E) and times when river flooding occurred (F1, F2, F3) and groundwater became artesian but no river flooding occurred (GW1, GW2).

Time Interval

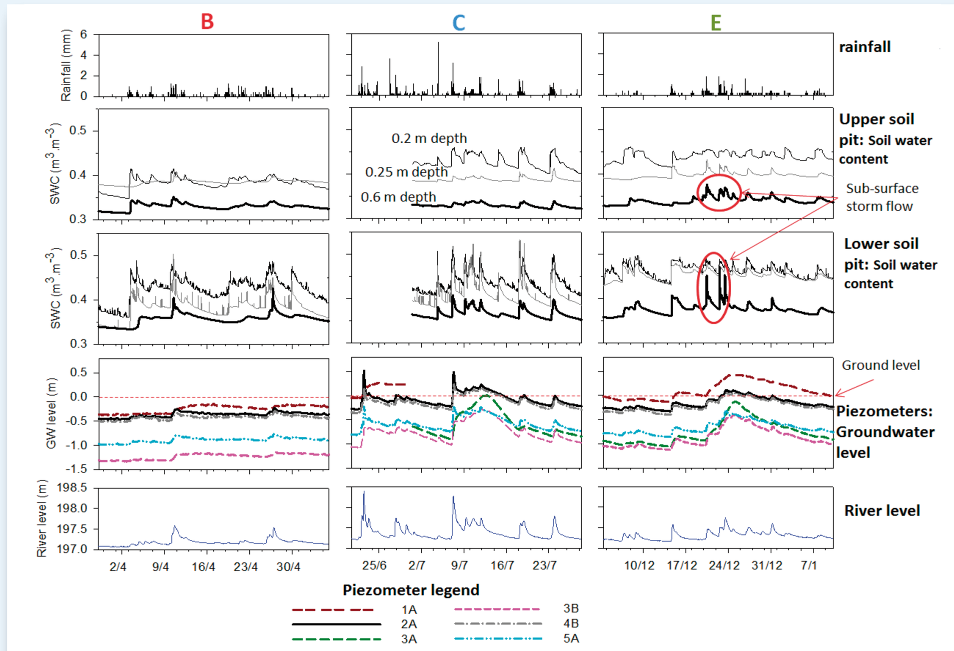
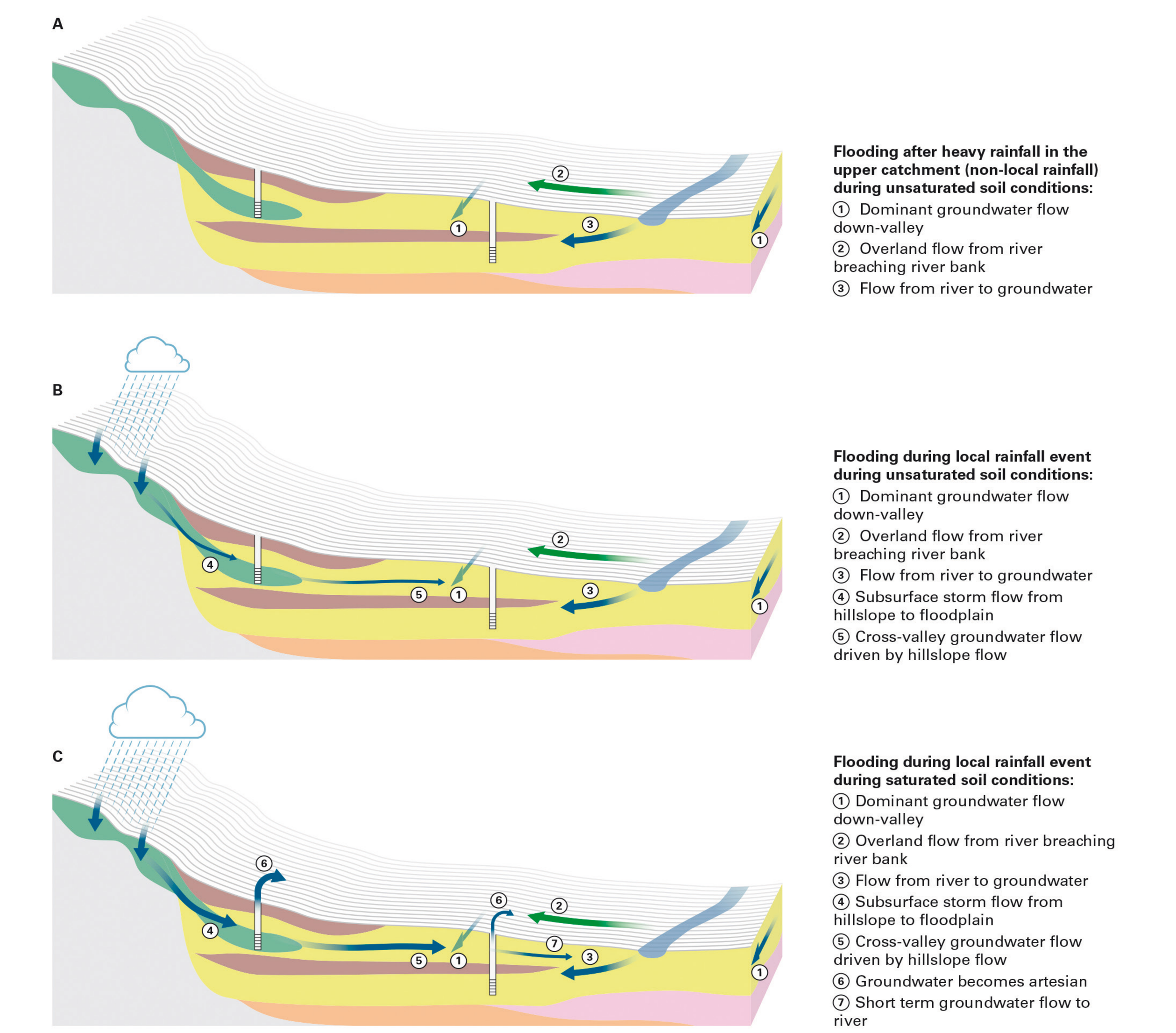


Figure 4 Hydraulic parameters monitored in time periods B, C and E: groundwater levels in selected piezometers (see Figure 2 for piezometer locations); soil moisture content in upper & lower soil pits at 3 depths; and river level near weather station (see Figure 2 for location).

Time Interval		Piezometers									River	Soil water content Upper Pit			Soil water content Lower Pit		
		1A	2A	2B	3A	3B	4A	4B	5A	5B	Level	0.2 m	0.35m	0.6 m	0.2 m	0.35 m	0.6 m
A	Lag hours	>96	37.75	9	*	>96	*	39	45.25	8	5.75	5	6.5	4.25	3.5	3	4.25
	coefficient	0.106	0.151	0.198	*	0.153	*	0.139	0.149	0.251	0.336	0.377	0.371	0.429	0.353	0.448	0.429
B	Lag hours	>96	15.25	15.5	*	>96	*	16.5	16.5	16	6.25	7.5	13.5	11	9.5	10.5	11
	coefficient	0.089	0.166	0.217	*	0.103	*	0.203	0.179	0.258	0.294	0.279	0.129	0.279	0.258	0.297	0.279
C	Lag hours	*	11.5	11	*	16	*	13.5		11.75	5.25	4.5	5	8	2	2	4
	coefficient	*	0.260	0.309	*	0.142	*	0.211		0.293	0.388	0.388	0.367	0.322	0.449	0.481	0.453
D	Lag hours	*	5.5	4.5	49.25	*	*	7.5	12.5	10.25	5	*	*	*	*	*	*
	coefficient	*	0.289	0.379	0.266	*	*	0.250	0.273	0.376	0.509	*	*	*	*	*	*
E	Lag hours	75.75	11.25	8.25	79.5	75.75	12.5	12.5	9.75	8.25	5.5	7.75	4	3.5	4	4	3.5
	coefficient	0.226	0.230	0.276	0.229	0.228	0.228	0.230	0.234	0.331	0.432	0.283	0.486	0.437	0.320	0.328	0.437

Table 1 Response times of groundwater levels, soil water content and river level to rainfall for time intervals A, B, C, D and E (shown in Figure 3). Lag is the average number of hours taken to respond to a rain event in each interval; in the colour range green denotes the longest and red the shortest number of hours. Coefficient is the cross-correlation frequency, where light grey shows the lowest correlation and dark grey the highest correlation. Asterisks indicate that data were not available.

Conceptualisation of hillslope-floodplain water flow under different antecedent conditions



Conclusions

- A superficial aquifer comprising highly permeable (transmissivity 200–1000 m^2/day) alluvial and glaciofluvial sandy gravels extends across the floodplain, between 8 and 15 m thick, and is coupled to the hillslope by permeable slope/solifluction deposits.
- There are two general patterns of groundwater behaviour in the floodplain: (1) closer to the river groundwater tends to be confined and groundwater levels closely follow river stage, driven by pressure changes; and (2) near the edge of the floodplain groundwater tends to be unconfined, less coupled to river stage and to respond more strongly to rainfall.
- The floodplain aquifer acts as a significant water store: under non-flood conditions, the river loses water to the aquifer which flows as groundwater and is discharged back to the river further downstream; and water flowing from the hillslope is buffered by the aquifer and does not directly flow to the river.
- Under flood conditions, the storage capacity of the floodplain aquifer can be exceeded and it no longer forms such a strong buffer between hillslope runoff and the river. Groundwater flooding can occur, with the areas close to the hillslope at the edge of the floodplain being most at risk. The potential for groundwater flooding in the floodplain remains high for longer periods than for river flooding.
- Antecedent soil moisture conditions strongly control the hydraulic connectivity between hillslope and floodplain, with more rapid floodplain groundwater level response when hillslope soils are saturated.

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