British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

How does geological heterogeneity control floodplain groundwater dynamics?

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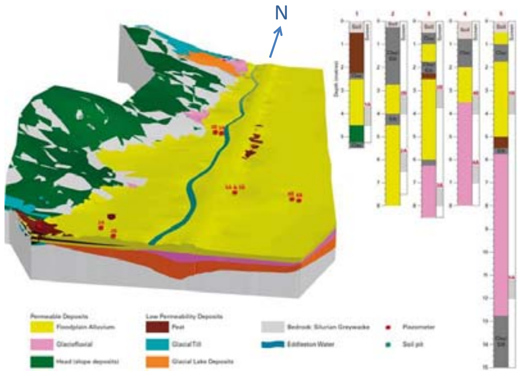
Evidence from an upland floodplain in southeast Scotland shows that lateral and vertical geological heterogeneity plays a key role in floodplain groundwater dynamics and groundwater-surface water interaction, regulating river flows and controlling hillslope runoff–river coupling

The Eddleston Water floodplain aquifer

The 3D geology, hydrogeology and hydrochemistry of a 0.2 km^2 study site across the Eddleston Water floodplain and adjacent hillslope were characterised by detailed field surveys and ongoing monitoring.

The floodplain contains an unconsolidated, permeable alluvial-glaciofluvial aquifer 8-15 m thick, with transmissivity 50-1000 m^2/d, which stores up to 20,000 m^3 of groundwater in each 100 m reach of the river. At the edge of the floodplain, alluvial aquifer sediments interfinger with permeable slope deposits, forming a direct connection between hillslope and floodplain.

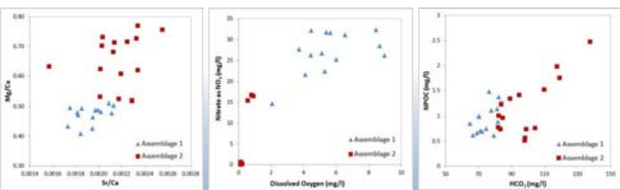


3D model of superficial geology of study site, showing piezometer locations and borehole geological logs with piezometer screened depths

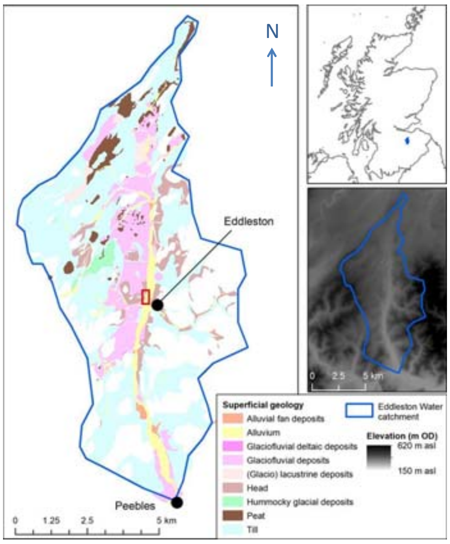
Hydrochemistry and residence times

Groundwater in the floodplain falls into two hydrogeochemical assemblages. Assemblage 1, in the west of the floodplain, is oxygenated, with lower levels of mineralisation and base metal ratios than in the eastern floodplain, but with notably higher nitrate concentrations. Assemblage 2, mostly in the eastern floodplain, is reducing, with higher levels of mineralisation, base metal ratios and dissolved organic carbon, and low or negligible nitrate, consistent with significant nitrate reduction.

Groundwater across the aquifer is a mix of modern recharge (within months) and water resident in the floodplain aquifer for 20 to 30 years. The largest fluctuations in the proportion of modern water are in the western floodplain close to the hillslope, reflecting active inflow of hillslope runoff.



Selected base metal ratios, ionic and biogeochemical relationships in floodplain groundwater show two distinct hydrogeochemical assemblages



Location of study site in the Eddleston Water catchment, showing superficial geology and LiDAR topography

Groundwater flow

Groundwater levels in the floodplain become shallower down-valley, from ~1 m below ground surface at the upstream end of the study site, to permanently at ground level in a groundwater–dependent wetland at the southern end. Dominant groundwater head gradient is down-valley towards the south, driving overall groundwater flow in this direction at an estimated velocity of ~1.1 m/d.

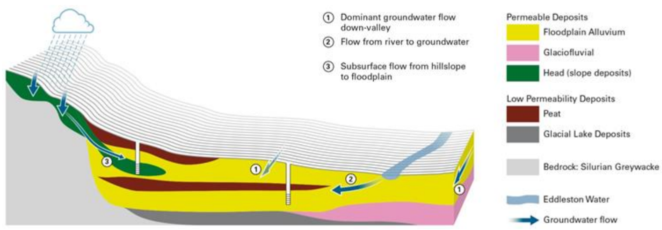
Year-round, groundwater levels are higher at the edge of the floodplain than near its centre, creating a hydraulic gradient that drives flow from the base of the hillslope into the floodplain aquifer. Close to the river, however, river stage is normally higher than adjacent groundwater levels, driving water flow from the river into the aquifer. This recharge to the aquifer from hillslope and from river losses is transported down-valley in the dominant direction of groundwater flow.

Groundwater–surface water interaction

The floodplain aquifer acts as a buffer between the hillslope and the Eddleston Water, 'capturing' hillslope runoff and recharge from the river and transmitting it down-valley as groundwater flow for delayed discharge to the river.

Across most of the floodplain, groundwater levels are controlled primarily by pressure head gradients driven by river stage fluctuations, rising within minutes to hours after river stage rise. However, close to the floodplain edge, groundwater is more strongly linked to shallow (<1m depth) sub-surface runoff from the adjacent hillslope, which causes floodplain groundwater levels to continue rising for up to 5 days after river stage declines at the end of a rainfall event, and can maintain high groundwater levels for several weeks. After extended periods of high rainfall, artesian groundwater levels can occur and can sustain periods of groundwater flooding.

Floodplain geology has a strong influence. At a local scale, the presence of low permeability clay, silt and/or peat layers leads to lateral and vertical variations in physical and chemical groundwater behaviour. Upward head gradients occur in a number of locations, and are linked to the occurrence of artesian conditions. The geological structure of the hillslope-floodplain transition is an important hydrological control in the hydraulic connectivity between hillslope runoff and the floodplain.



Conceptual model of groundwater flow in the floodplain aquifer, showing hillslope/river inflows

Implications for catchment management

Upland floodplain aquifers, such as that in the Eddleston Water catchment, store and transmit large volumes of catchment water as groundwater, with complex interactions with rainfall, river and hillslope flows. Lateral and vertical hydrogeological variations are important controls on groundwater mixing dynamics and groundwater-surface water interaction in the floodplain. Floodplains should not, therefore, be treated as homogenous units when interpreting water flows, hydraulic responses or hydrochemistry. Understanding the heterogeneous 3D geology and hydrogeology of floodplains is important for representative floodplain and catchment modelling, and for the effective implementation of natural flood management measures.

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