River Derwent at Hathersage, Derbyshire

[SK 209 822]–[SK 227 807]

Highlights

The River Derwent at Hathersage illustrates the effects of reservoir impoundments on downstream channel morphology. The reduction in discharge caused by the flow regulation of Ladybower Reservoir has produced a morphological response in the form of a low-flow bench within the existing channel, although this is only when a downstream sediment supply has become available.

Introduction

This reach of the Derbyshire Derwent flows between terrace remnants of two of the four lower terrace levels (Figure 6.13) identified in the Derwent-Wye catchment (Waters and Johnson, 1958), representing stages in the landscape development of the area. Along the Derwent near Hathersage is a type example of downstream channel adjustment to headwater impoundment, discharge regulation and sediment load reduction. The dominant adjustment of river channels to these changes is demonstrably a reduction in channel capacity (Petts, 1977). Between 4 and 8 km below the Ladybower dam, a flat bench has developed within the main channel, reducing channel capacity by approximately 40%. This adjustment becomes evident only below the river's confluence with the unregulated River Noe, because sediment from this tributary is probably the most significant factor controlling bench formation (Petts, 1977).

Description

The terraces

Erosion benches or flats are discernible throughout these Derbyshire river valleys at different heights above existing floodplains. Attention on the Derbyshire Derwent has been directed to the four better preserved terraces within the valley bottom (Waters and Johnson, 1958). Two are preserved in this part of the valley.

The Hathersage terrace is the oldest of the four, and is preserved around Hathersage. The rejuvenation head of this terrace on the Derwent is under the Ladybower Reservoir, and is not determined on the Noe, where it is near the head of the next lower terrace, the Hope. The Hope terrace is also represented on this stretch of the Derwent, where it is being actively undercut by the river. The Hathersage and Hope terraces are composite in places, but the discontinuous upper segments of these two terraces cannot be traced up valley to independent knickpoints on the streams. It would appear that in each case the rejuvenation head responsible for the formation of the lower segment has overrun that related to the upper part of the terrace. The justification for the distinction is in the clear and ubiquitous distinction between upper or lower members of one terrace and representatives of the next, higher or lower, terrace.

Hydrology

The regulation of the Derwent headwaters was authorized in 1899 and involved building the Howden and Derwent Reservoirs, which were completed in 1912 and 1914 respectively (Petts, 1988b). Hence between 1913 and 1933 the gauged monthly flows were reduced by 20% (0.5 m^3s^{-1}) (Richards and Wood, 1977) and the mean annual flows by 15%. The construction of the Ladybower dam in 1943 had the major impact on the Derwent. A comparison of the flow record at Yorkshire Bridge immediately downstream of the reservoir with naturalized flows derived from changes in reservoir storage was undertaken by Petts (1988b). This showed that summer maximum daily flows are reduced by flood storage and mean monthly flows are less, mainly through water supply abstractions, while extreme low flows are eliminated by a compensation release of up to 0.89 m^3s^{-1}.

Channel morphology

The river channel below the Ladybower dam has a stable course bounded by bedrock controls, boulders and trees (Petts, 1988b). Between the Ladybower dam and the confluence with the River Noe, local bank erosion has been observed. However, downstream of the confluence through the site the river is incised into terrace deposits, producing compound cross-sections that have lower channel capacities than would be expected from regional relationships (Petts, 1977).

Aerial photographs, historical maps and dendrochronological evidence suggest that between 4 and 8 km downstream from the Ladybower dam a flat bench, bounded by marked breaks of slope, has developed within the main channel of the Derwent, overtopped at high flows (Figure 6.14). Sampling from the compound sections shows that the depositional benches are formed of coarse sand and gravels, often with a coating of finer sand and silt, contrasting with the terrace materials, which have between 16% and 45% silt clay. The terrace deposits are similar to the bank materials exposed in simple sections both upstream and downstream. The benches, however, are not always depositional; a certain amount of bank collapse is evident, and on occasion this material has become stabilized and incorporated into a bench form (Pens, 1977).

Results of bankfull discharge calculations indicate that a close similarity exists between the calculated bankfull discharge and the 1.5 year flood for the reach. However, sedimentological and vegetational evidence suggest that this channel, having a compound section, is adjusted to a more frequent event, rather than having had insufficient time to reach equilibrium with the new flow regime (Petts, 1977).

The lack of historical records for dating deposits was overcome by dating the numerous trees lining the channel of the River Derwent to determine the minimum age of the bench features. All bench forms up to 1.5 m above water level (a.w.l.) are <51 years old and, secondly, a former bank level at approximately 2.0 m a.w.l. is suggested by the stranded forms.

Compound channel cross-sections having a flat bench within the main channel occur for 5 km below the Noe confluence. Above this, the channel bed is composed of gravel and small boulders, which provide a natural armoured layer, preventing degradation. Also, the absence of sediment input results in accommodation of the water discharge within the pre-dam channel. Downstream of the Noe confluence, estimates of the pre-dam channel form indicate that the deposition of a bench has reduced the channel capacity by nearly 40%. The bench is not evident until the tributary has joined the main stream, which implies that the introduction of sediment by the river Noe into the regulated main stream may be the significant factor controlling bench formation. The post-dam channel, adjusted to a flow event of greater frequency than the 1.5 year flood, may transport sediment more efficiently at moderate flows.

Bulk sediment samples taken along the river to just below the Wye confluence (Petts, 1988a) indicate that the D95 (where 95% of the sample is smaller than this value) decreases in size downstream from 47.8 mm on the River Ashope to 47.2 mm on the Derwent at Hathersage and 33.8 at Darley Dale. Freeze coring suggests that the River Noe is an important source of fine sediment, containing five times more material finer than 2 mm than the upper Derwent (Pens, 1988a,b). The influence of the River Noe sediments, indicated by the proportion of limestone in the sample, extends downstream for 3 km (Figure 6.15). The rate of gravel-bed siltation was estimated to be 500 m^2yr^{-1} with the greatest amount of finer sediment concentrated between 15 and 30 cm below the surface.

Interpretation

The morphology of a river channel reflects the river discharge that flows through the channel, the sediment that is transported by the flow, and the local characteristics, including bed and bank materials, vegetation and slope along the channel. The relation between form and process is an equilibrium or quasi-equilibrium relationship. When changes affect the drainage basin or the river channel upstream of a reach of a particular river channel, then the morphology of the river channel may change. This change can be expressed through adjustment of the degrees of freedom that the river channel possesses. Langbein (1964) suggested five degrees of freedom which may adjust to maintain quasi-equilibrium; namely, roughness, slope, width, depth and planform.

Channel changes can be induced by a number of causes, including the construction of dams and reservoirs. The retention and gradual release of water by a reservoir results in the reduction of peak discharges and the regulation of the flow regime. In addition, the reduction of flow velocities by lake storage results in the deposition and permanent storage of over 95% of the sediment load above the dam. It is the — often total —abstraction of the bed load that is significant for channel adjustment, because this induces clear water erosion downstream of the dam.

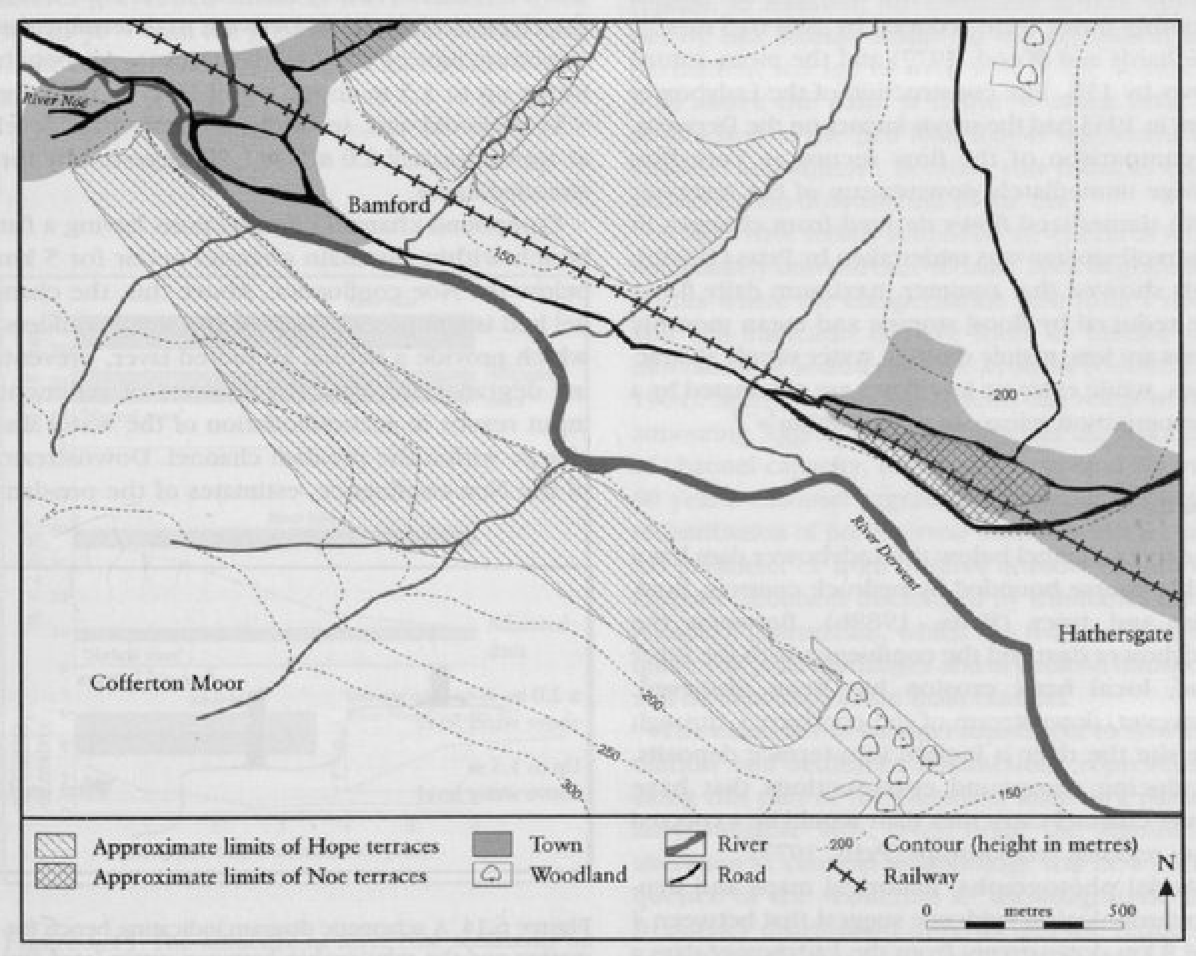
Studies have mostly addressed the effects of scour immediately downstream of dams. Such degradation occurs where the compensation flow from a reservoir has sufficient tractive force to initiate the movement of sediment in the channel (Gottschalk, 1964). Selective removal of fines can result in bed armouring. Aggradation, and therefore the reduction of channel capacity, has been recognized for over 50 years. Channel aggradation may occur by the redistribution of pre-reservoir sediment in the channel perimeter or from material introduced into the channel. Sediment discharged by tributaries into a regulated mainstream, which has reduced both frequency of peak discharges and of bedload transport, will be deposited in the main channel.

The examples of channel adjustment to flow regulation and sediment abstraction, represented along this part of the Derwent, make it a particularly valuable site. Over time, the significant alteration of channel morphology will be a consequence of the reduction of the magnitude and frequency distribution of flows and the reduction of sediment load to below-dam reaches. The reduction of channel capacity may adversely affect the efficiency of floodwater transmission downstream. However, although the more frequent floods are markedly reduced, the effect upon rarer events may be negligible. The successful operation of flow regulation schemes, necessary for both flood control and water supply, requires study of the range of geomorphological consequences, one of which is exemplified by this reach of the Derwent at Hathersage. The Hope terrace fragment incorporated is important in its wider context of the suite of terraces that result from the deglacial history of the Derwent valley system. It is also important because the inheritance of that development in the present river is exemplified by the undercutting and reworking of material from the terrace by the regulated and adjusting River Derwent.

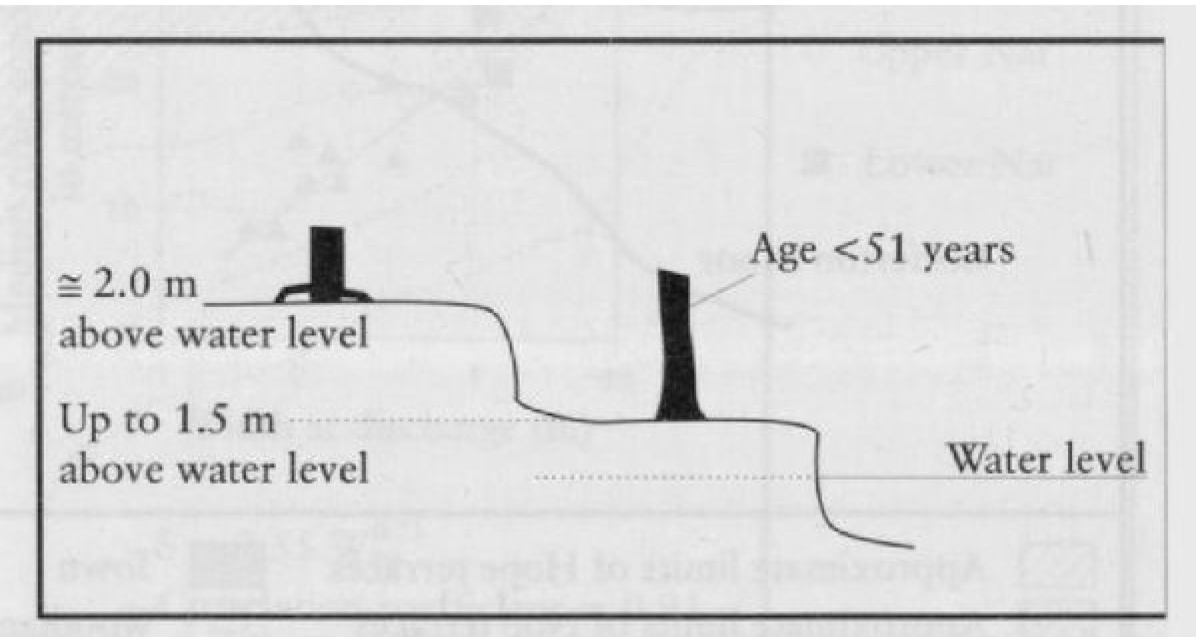
Conclusion

This reach of the River Derwent has been affected by construction of reservoirs in the catchment. The reservoirs have reduced peak discharges and have caused channel adjustment downstream. The main feature created has been a low bench along the channel, but this is only present downstream of tributaries, because the latter provided the sediment for the bench formation.

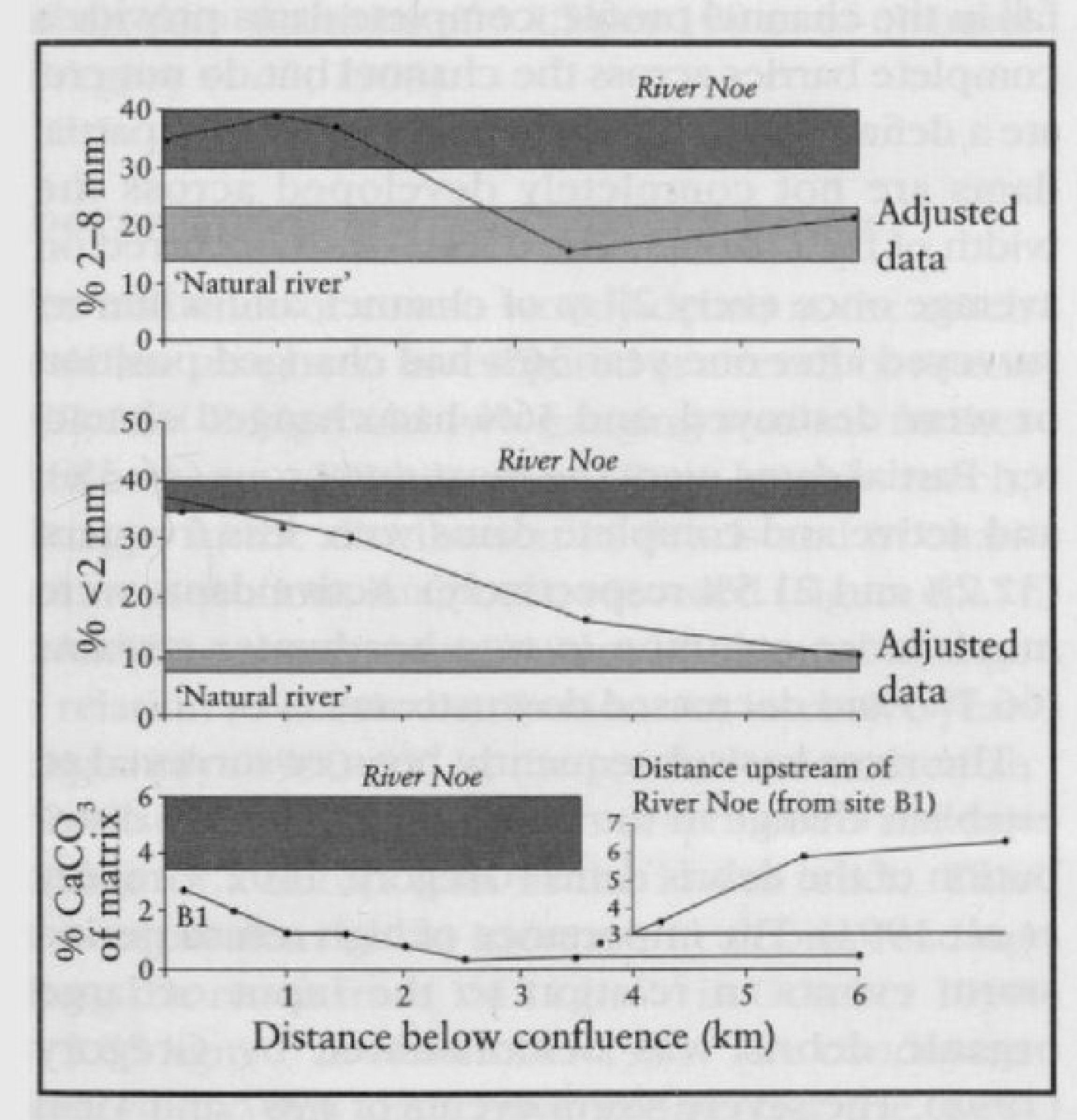
References



(Figure 6.13) The River Derwent at Hathersage: the distribution of river terraces.



(Figure 6.14) A schematic diagram indicating bench formation and the relationship between water level and tree growth. (Derived from data in Petts, 1977.)



(Figure 6.15) The influence of River Noe sediments on channel substrate downstream of the Noe confluence. (After Petts, 1988b.)