Upper River Severn between Dolwen and Penstrowed, Powys

[SN 996 851]–[SO 075 910]

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Highlights

This is the epitome of a laterally unstable gravel-bed river in Wales. It is illustrative of the variety of channel forms, sedimentary structures, ero-sion/deposition processes, and rates and modes of change which occur. Research at this internationally important site relates to sediment transport, bank erosion, flow pattern and meander changes.

Introduction

The River Severn, in the 17.5 km reach between Dolwen [SN 9960 8512] and Penstrowed [SO 0743 9103], is a very unstable gravel-bed river which exhibits a wide range of erosional and depositional forms and associated sedimentary features. It represents one of the most unstable sections of natural channel remaining in England and Wales.

The reach is located in the piedmont zone between the relatively steep headwater reaches, which are zones of sediment production, and the less steep alluvial reaches downstream, which have reduced transport capacity. It is the reduced gradient that facilitates rapid bar accumulation, and associated bank erosion and changes in channel planform (Figure 3.29) and (Figure 3.30).

At this site the river flows through a wide alluvial valley, which, in part, is a legacy of the last glacial period but also reflects post-glacial and contemporary fluvial activity. Within this relatively short reach there are straight, meandering and anastomosing sections, while contemporary and historical evidence indicates that the river has rapidly migrated over its floodplain to create meander cutoffs and oxbow lakes.

Many studies of channel processes have been 3. carried out in recent years on this reach, including work on: flow resistance (Hey, 1979); secondary flows and shear stress distribution in meandering and straight channels (Bathurst, 1979; Bathurst *et al.,* 1977, 1979; Thorne and Hey, 1979); sediment transport (Hey, 1980; Newson, 1980; Arkell *et al.,* 1983; Leeks, 1983, 1986; Hey, 1986; Newson and Leeks, 1987; Meigh, 1987); bank erosion (Thorne and Lewin, 1979; Thorne and Tovey, 1981; Lawler and Leeks, 1992); channel and sedimentary history 4. (Thorne and Lewin, 1979; Hey, 1980; Hey *et al.,* 1981); meander migration and cut-offs (Lewis 1982; Lewis and Lewin, 1983; Lewin, 1987); and the effect of river engineering, flow regulation schemes and environmental change (Hey, 1980; Hey, 1986; Higgs, 1987; Higgs and Petts, 1988; Leeks, 1986; Leeks *et al.,* 1988). The principal geomorphological features of the GCR site and their conservation value are reviewed by Hooke *et al.* (1994).

Description

Channel instability

This reach of river has a long history of instability, particularly in terms of changes in the channel plan. Evidence from historical maps and aerial photographs indicates that the river has changed its location considerably over the past 100 years (Figure 3.31).

Within the reach, the degree and type of instability vary considerably. Sections undergoing erosion, stable sections and those undergoing active deposition are systematically located along the length of the reach:

1. From Dolwen [SN 9960 8512] to Upper Penrhuddlan [SO 0016 8575], the river has incised into the valley flat, and bedrock is exposed in the channel at one location. Nevertheless, there has been little change in the plan position of

the river (Figure 3.31) over the past 100 years, probably due to the stabilizing influence of the bedrock outcrop and the presence of tree-lined banks.

2. Between Upper Penrhuddlan [SO 0016 8575] and Craig Fryn [SO 0150 8675], the river flows across an alluvial floodplain. For 1.85 km downstream from Upper Penrhuddlan, the river has essentially been stable over the past 100 years and very little lateral movement has taken place since it was straightened during railway construction in 1859 (Figure 3.31).
3. From Craig Fryn [SO 0150 8675] to Ty'n-y-coed [SO 0225 8780], the channel is very unstable and the position of the river has altered considerably over the last 100 years (Figure 3.31) due to rapid aggradation. The development of transverse bars and associated bank erosion has led to the creation of a braided channel system. Several islands have been formed which have since been vegetated by gorse and other small shrubs.
4. Between Ty'n-y-coed [SO 0225 8780] and Penstrowed [SO 0743 9103], the river meanders across its own floodplain. Extensive lateral gravel bars, slumped bank material, meander cutoffs and oxbow lakes all indicate rapid lateral migration of the channel, and this is confirmed by the considerable changes that have occurred in the channel pattern over the past 100 years (Figure 3.31). At Caersws, 9.2 km downstream from Dolwen, two major tributaries, the Trannon and the Garno, join the Severn. Channel sinuosity increased from 1.42 in 1883 to 2.00 in 1967 but has since fluctuated, partly due to artificial as well as natural cutoffs.

Channel form and sedimentary features

The river is now, with the exception of the anasto-mosing reach near Craig Fryn, a single-thread gravel-bed river flowing through a valley flat or over a wide alluvial floodplain. In general, sites undergoing active erosion have steeper gradients and coarser bed material than adjacent stable sections, and these in turn are steeper and coarser than aggrading reaches. Local variability in channel form depends on channel plan and the location of pools and riffles. These features are generally related and are precipitated by bed scour, bank erosion or bar development. The basic control on scour and fill relates to the local sediment budget, which reflects sediment supply and the local shear stress and bed material size. Patterns of secondary circulation in the channel, which depend on channel geometry and flow levels, significantly affect shear stress distributions and, therefore, have a major control on erosion, deposition and channel change.

A variety of types of bar is to be found along this reach of the River Severn, including lobate, don- gate medial, point and attached forms. Historical sources show that these bars often migrate downstream and can cause chute cutoffs and loop abandonment (probably related to high-magnitude floods). Channel shift has not always been followed immediately by re-sedimentation, so that various lakes and stillwater voids adjacent to the active channel are to be found downstream from Caersws. At Penstrowed, two cutoffs have occurred within the past 40 years when the breaching channel cut through a neck some 100 m across. In the meandering reach, rates of erosion and deposition and of meander migration and development vary temporally and spatially, but parts of the reach are very active.

Interpretation

Considerable research on a number of processes has been carried out along this reach.

Flow processes

Basic flow processes and patterns control the overall shape and dimensions of gravel-bed rivers. Field measurements taken with an electromagnetic flow meter have indicated that in meander bends there can be two secondary flow cells. In addition to the classic main cell, there may be a small cell of opposite polarity close to the outer bank of the meander bend, provided that the bank is steep (Bathurst *et al.,* 1979). At the inflexion point between bends, measurements indicate that the old main cell from the upstream bend is displaced by a new cell in the downstream bend. Secondary circulation distorts the primary isovel pattern and thereby affects the position and relative magnitude of the boundary shear stress peaks. High shear stresses are associated with regions of downwelling, and high velocity and low shear stresses with regions of low velocity and upwelling. These shear stress patterns explain local scour-and-fill activity in meander bends. Deposition occurs on the point bar, in spite of high shear stresses during flood discharges, because of the downstream decrease in shear stress. Scour occurs on the outside of the meander bend due to a downwelling where surface flows converge (Bathurst, 1979; Bathurst *et al.,* 1979).

Flow resistance

The resistance to uniform flow in gravel-bed rivers is basically dependent on the flow geometry and the size characteristics of the graded gravel-bed material. An equation has been developed for estimating the friction factor, and thereby the average velocity and discharge in the channel, which has proved very successful when applied to riffle sites where flow is approximately uniform (Hey, 1979).

(Table 3.2) Threshold discharges for bed material movement and type of reach (E = erosional; D = depositional; S = stable).

Site	Discharge m^3s^{-1}	
Dolwen	11.0	S
Lower Penrhuddlan	16.0	S
Craig Fryn	30.0	D
Llandinam	11.0	E
Maes-Mawr	16.2	E
Ty-Mawr	17.1	E
Penstrowed	17.1	E

Bed material transport

Experiments have been carried out in the reach to determine the threshold discharges for the initiation of bed material movement and surface armour at seven sites. The results, shown in (Table 3.2), confirm the location of the erosional, stable and depositional reaches identified previously. Any bed material being transported through Dolwen and Lower Penrhuddlan within the flow range 16.0–30.0 m^3s^{-1} will be deposited at Craig Fryn. Further downstream erosion will occur because flows will be above transport thresholds (11.0 m^3s^{-1}) and there will be no sediment input from upstream (Hey, 1986). Comparison of the threshold discharges with actual discharge values indicates that bed material transport events are relatively frequent along this stretch of channel.

Bedload transport measurements were made at Victoria Bridge [SO 0579 9240] in 1982–84 with a Helley-Smith bedload sampler (150 mm orifice). Bed material transport was initiated at approximately one third bankfull flow depth and the maximum observed transport rate for high, inbank flows was 3 kgs^{-1}. At higher discharges it was observed that the bed became fluidized and therefore transport rates would have been significantly higher (Meigh, 1987).

Bank erosion

Rivers flowing across gravel often have a composite bank structure, with cohesionless gravel, relict point bar deposits of bedload material, overlain by cohesive fine sandy, silty clay. This structure leads to undercutting and the production of cantilevers in the cohesive material. Upper bank retreat takes place predominantly by the failure of these cantilevers. Three failure mechanisms have been identified: shear, beam and tensile failure. The stability of the cantilever can be analysed using static equilibrium and beam theory, and dimensionless charts for cantilever stability have been constructed. Application of the charts requires only a few simple measurements of cantilever geometry and soil properties (Thorne and Tovey, 1981).

Meander development

Field observation of bank erosion processes at Maes-Mawr indicates that failure is predominantly due to fluvial undercutting, related to secondary flow and shear stress distributions in the bend, and mechanical failure of the cantilever in the upper bank. Failed material accumulates at the foot of the bank, from where it is removed by fluvial entrainment. Tracer experiments indicate that bank retreat rates are fluvially controlled, although failure mechanisms are not. Retreat rates in the period 1975–77 were measured at 0.5 m/year compared with up to 0.7 m $year^{-1}$ over the past 150 years.

Contrasting types of channel development have been identified from maps and aerial photographs, including complex loop formation, neck and chute cutoff, and the rapid abandonment of lengths of cut bank and deep channel (Thorne and Lewin, 1979). The sequence of development of loops through to cutoff has been traced and the subsequent sedimentary evolution of the abandoned channels has been investigated (Lewis, 1982).

Flow regime

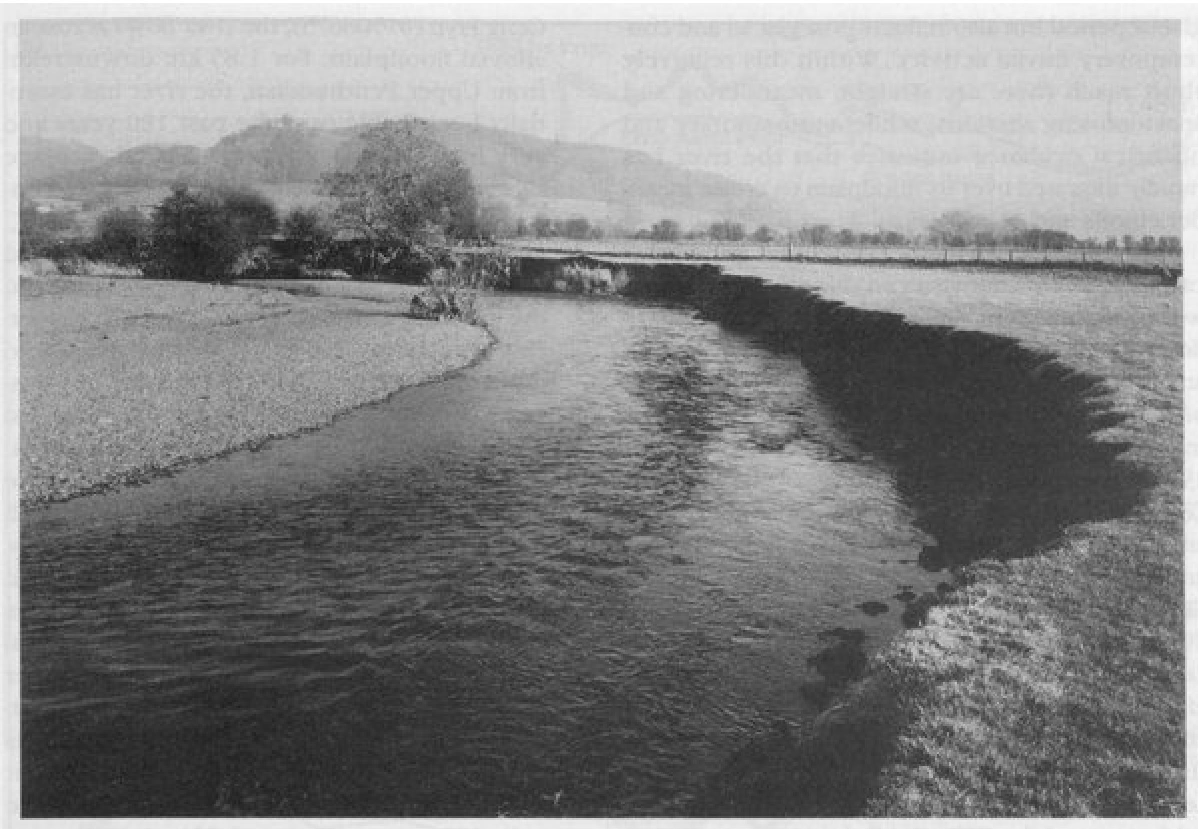
Analysis of hydrological variations in the reach over the period 1963–83 led Higgs (1987) and Higgs and Petts (1988) to conclude that although construction of the Clywedog dam and changes in land use in the catchment (mainly afforestation and upland drainage) had major impacts on the flow regime, the effects of climatic variation in rainfall were even greater. This appears to be confirmed by subsequent analysis of flow rates (Hooke *et al.,* 1994). The changes in flow regime have influenced the rates of erosion and amounts of floodplain reworking in the past 20 years (Hooke *et* al., 1994). Likewise, analysis of variations in channel pattern over the past 200 years, derived from sedimentary and documentary records (Passmore *et at.,* 1993), has shown a relationship to flood incidence.

Conclusion

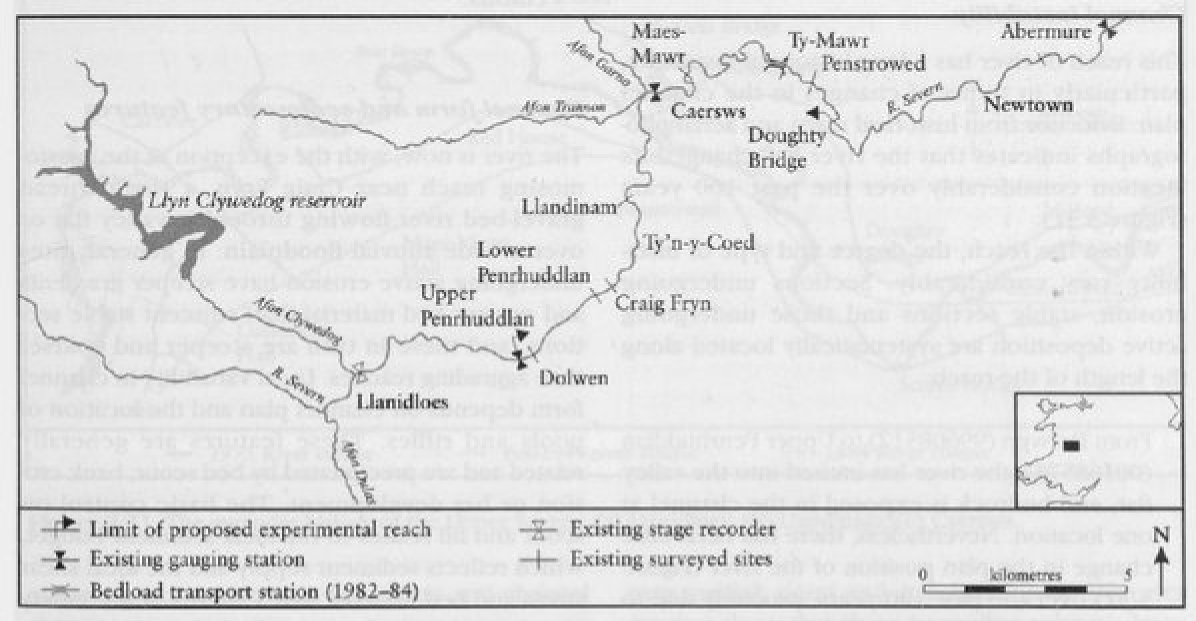
The reach of the River Severn between Dolwen and Penstrowed represents one of the most unstable sections of natural gravel-bed channel in England and Wales. Interpretation of historical maps and aerial photographs, and channel and sedimentary characteristics, together with observation of bed material transport thresholds has enabled stable reaches and those undergoing active erosion or deposition to be identified. These are systematically located along the length of the channel. Bar development is characteristic of aggrading reaches and, in its extreme form, leads to the development of islands and braided sections. Erosional reaches tend to produce incised or meandering channels.

A wide range of channel forms and processes are represented in this reach, and it is a classic site for the observation of these features and the integrated evolution of river meanders. Internationally important work on processes and on channel changes has been carried out at the site.

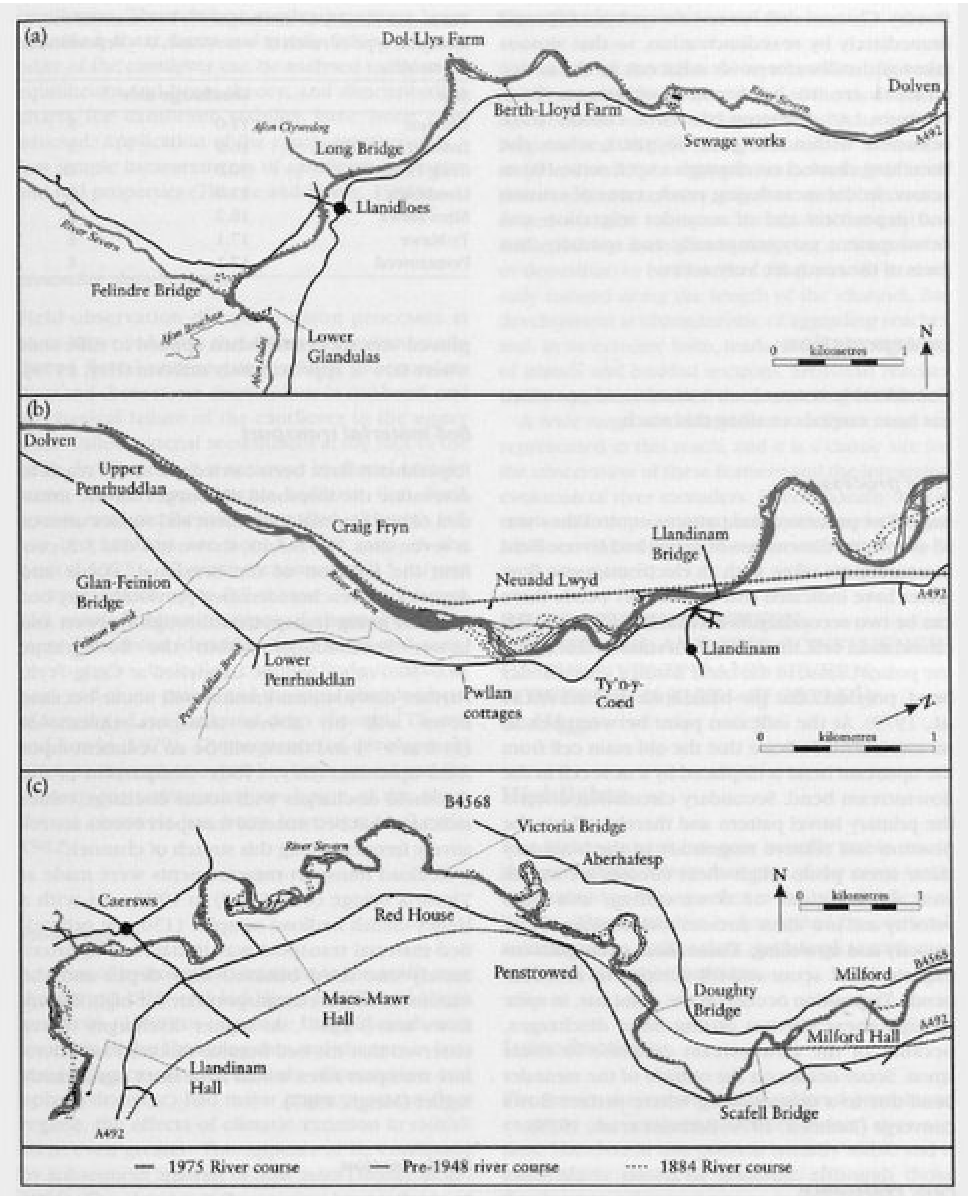
References



(Figure 3.29) The River Severn, at Caersws, showing active erosion of the outer bank of a meander, and deposition on the other. (Photo: S. Campbell.)



(Figure 3.30) A location map of the upper Severn, showing the positions of the measurement stations and survey sections.



(Figure 3.31) The meander history of the Upper Severn: (a) Llanidloes; (b) Llandinam; (c) Caersws.

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