8. DYNAMIC GEOMORPHOLOGICAL MODELLING STUDIES

8.1 LANDSCAPE CHANGE UNDER PRESENT-DAY HYDROLOGICAL CONDITIONS

8.1.1 A computerised modelling process (CAESAR) was used to determine the erosional and depositional impacts of the Ribble, Hodder and Calder Rivers upon the floodplain under present-day hydrological conditions and under predicted future conditions; this highlights those areas that are at greatest risk from fluvial change. The CAESAR programme was used simulate geomorphological change under the present-day hydrological regime and examined the tributary catchments of these rivers as well as the Lower Ribble reach.

8.1.2 The catchment scale runs (simulated time scale five years) predict a relatively high degree of geomorphological change (ie erosion and deposition coverage) within the Upper Ribble, and a relatively low amount of landscape change for the Calder. In general, this reflects the lower relief and slope angles over which water and sediment are moved from the West Pennine moor headwaters through the Calder system, and the higher slope angles involved in routing water and sediment from the central Pennines (ie Upper Ribble headwaters).

8.1.3 For the Upper Ribble (Fig 156a), CAESAR predicts a limited degree of hillslope erosion in steeper low-order tributary streams, with extensive sedimentation along the main river valley. This pattern appears to represent a coupled geomorphological effect, whereby storm-eroded hillslope stream/gully material is conveyed to the main valley in high-power discharge events, and subsequently redeposited across the valley floor within overbank flood waters. The most extensive form of erosion appears to have occurred in the form of undercutting at slope base locations along the margins of the river valley.

8.1.4 Results for the Hodder catchment (Fig 157a) show an intermittent pattern of hillslope erosion and valley floor deposition. Tributary stream/gully erosion is restricted to the steeper hillslope systems in the west of the catchment. In the upper part of the catchment, the pattern of valley floor sedimentation generally reflects the distribution of hillslope erosion. Widespread fluvial sedimentation has occurred only in the lower Hodder, where stream gradients are at a minimum. There, overbank floods have triggered undercutting and erosion of hillslope base sites along the flanks of the valley. Apparent extensive erosion shown within the main river valley close to the confluence with the Ribble is thought to be a result of problems with the DEM elevation data.

8.1.5 The Calder catchment (Fig 158) appears to have been very resilient to the geomorphological impacts of present-day hydrological forcings. Very little erosion and deposition has occurred within the hillslope tributary systems. The main focus for geomorphological change is the main river valley, but this was limited to two reaches in the upper and lower part of the valley. In these reaches, an alternating pattern of erosion and deposition has been modelled, probably representing a subtle geomorphological adjustment of local stream gradients to form pool–riffle-type channel bed morphology.

8.1.6 Geomorphological changes in the Ribble Valley (Fig 159) are dominated by sedimentation, almost all of which has occurred within the river channel, along relatively low gradient stretches in the upper and middle part of the reach. A limited degree of outer meander bend and valley marginal undercutting erosion has been simulated, suggesting low rates of landscape change as a result of lateral channel migration and overbank flood erosion respectively. The impact of the predicted fluvial change upon the identified archaeological resource is outlined in *Section 9.2*.

8.2 LANDSCAPE CHANGE UNDER FUTURE HYDROLOGICAL CONDITIONS

8.2.1 CAESAR was used to simulate geomorphological change under the UKCIP-forecasted hydrological regime for AD 2050 (higher winter rainfall scenario). For each study area, higher winter rainfall intensities, and hence flood magnitudes, have triggered a greater degree of geomorphological change than was simulated under the present-day hydrological scenario (*Section 8.1*).

8.2.2 For the Upper Ribble, the future hydrological scenario has resulted in the widespread extension of hillslope gully incision across many of the upland tributary valleys (Fig 156b). Fluvial sedimentation has extended across a larger area of the 'flood basin', and along the whole of the confined river to the south of it. Increased flood magnitudes appear to have triggered a greater degree of valley margin slope-base erosional activity, and alluvial fan-type deposits have been simulated at the base of some of the gully-eroded upland tributary sub–catchments (Fig 156b).

8.2.3 Differences between present-day and future modelled geomorphological responses appear to be most dramatic for the Hodder catchment (Fig 157), in which hillslope stream/gully erosion has extended into the majority of upland sub–catchments, and valley alluviation has spread across most of the main river and its piedmont tributaries. Slope undercutting as a result of overbank flooding now affects most of the confined valley floor reach. Increased hillslope gully/stream erosion, together with incomplete slope/channel coupling, has resulted in the development of several small alluvial fan or debris cone slope base deposits.

8.2.4 Unlike the northern catchments, the Calder catchment seems to have remained geomorphologically insensitive to simulated future hydro–climatic changes. Hillslope stream/gully erosion is virtually absent. Valley floor geomorphological changes modelled under future conditions are much more extensive within the main river and its major feeder tributaries, but as with the present-day scenario, occur only in the form of locally alternating erosion/deposition patterns indicative of minor channel bed (pool/riffle-type) gradient adjustment. The Calder is also a heavily urbanised catchment, with substantial flood protection measures in place that further reduce the potential for geomorphic change.

8.2.5 Once again, geomorphological changes in the Lower Ribble Valley (Fig 159b) are dominated by within–channel sedimentation. This sedimentation is clearly greater than under present–day conditions, having spread to all but the lowermost meander bend of the reach. Increased sediment supply because of hillslope erosion in the feeder catchments would appear to be responsible for this change. Despite increased flood magnitudes, burial of the floodplain by sediments contained within overbank flood water remains negligible. Floodplain erosional activity, mostly in the form of outer meander bend migration, has increased noticeably, particularly in the upstream section of the study reach. The impact of the predicted fluvial change upon the identified archaeological resource is outlined in *Section 9.2*.

8.3 FLOOD RISK DYNAMICS

8.3.1 The CAESAR flood inundation simulations for the Lower Ribble (Fig 160), flood events of estimated magnitude 200m³, 400m³, 600m³ and 800m³ s^{-1} were passed through the river–floodplain DEM produced by the reach scale geomorphological modelling runs under present-day and future hydrological conditions. Flood simulations were carried out along a 4km stretch of the river between Ribchester and Hothersall Hall.

8.3.2 For both modelled landscapes, each flood magnitude produced overbank water inundation, with the extent of inundation increasing in accordance with the size of the event. The maps clearly demonstrate that pre–existing fluvial morphology (terrace sequence and boundaries, palaeochannels) exert an important control on within-reach variations in flood extent. For example, the Ribchester meander bend, dominated by the highest fluvial terraces, T1 and T2, is unaffected by flooding. In contrast, the Osbaldeston meander, which includes a large extent of lower Terraces T3 and T4, is clearly at higher risk of flooding. Within the flooded areas, the position and arrangement of palaeochannel hollows clearly acts as a focus for overbank water flow. Inundation of a large palaeo–meander bend at Osbaldeston has resulted in the expansion of the inundated area onto the higher terrace zone for floods of 400m³ s^{-1} and higher.

8.3.3 For any given flood magnitude, the extent of inundation is significantly greater across the landscape produced under the future climatic scenario, and this reflects the reduced capacity of the channel to convey flood waters due to increased river bed sedimentation. For example, under the present-day scenario, a flood event of ~200 m^3s^{-1} appears capable only of inundating fragments of low Terraces T4 and T5, whereas inundation by the same event across the future landscape extends to the higher terrain of T3 and impinges into the large palaeochannel inset into T2. Thus, flood risk attributable to the future modelled 200 m^3s^{-1} flood is very similar to that produced by a larger, 400m^3s^{-1} flood under the present-day geomorphological configuration. The maps suggest that the change in flood risk (the difference in water extent) due to climatically induced geomorphological activity is greatest for the 200 m^3s^{-1} event, but declines with increasing flood magnitude. In this respect, the model runs indicate that the impacts of future climate change may be to increase the extent of flooding for relatively frequent (annual to interannual) events.

8.4 SUMMARY

8.4.1 The CAESAR model has proved to be a useful tool for assessing likely future geomorphological and hydrological changes in the Ribble catchment and its river–floodplain environments. The implications of these modelling scenarios are that future UKCIP-forecasted environmental changes (ie higher winter rainfall intensity) may be expected to increase dynamic erosional and depositional responses throughout the Ribble tributary catchments and within the Lower Ribble Valley.

8.4.2 The Upper Ribble, Hodder and Calder tributary catchments appear to have a different sensitivity to the geomorphological impacts of anticipated future environmental change. The geomorphological effects of heightened winter rainfall during the twenty-first century may, however, be expected to increase the frequency, extent, and hence high risk of flooding along the Lower Ribble. The model runs span a relatively short time period (ie five years). It seems likely that the impact of future climate change on geomorphological and flood risk dynamics would have been more dramatic given the availability of longer simulation periods.

8.4.3 ***Archaeological Impact:*** the detailed impact of continued geomorphological change upon archaeological monuments within the wider Ribble Valley is outlined in *Section 9.2*. Inevitably, the greatest change is in the immediate proximity to the present course of the rivers, and for the most part this impact relates to monuments that are specifically located so as to exploit the rivers. In general, because of the risk of flooding, the floodplain has been an area that has been avoided for settlement in the past; but industrial remains that exploit water power, or water retting, are inevitably adjacent to the rivers and therefore are at risk from changes to the course of the rivers. Similarly, communications across the rivers, such as bridges and similar features, can be affected by this geomorphic change.

