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A FIELD-BASED APPROACH TO INTEGRATING CATCHMENT AND RIVER CHANNEL PROCESSES

G. L. Heritage, A. Chappell and A. D. Thomas

Division of Geography,
School of Environment and Life Sciences, University of Salford

Email: g.l.heritage@salford.ac.uk

Abstract

The paper provides a methodology for teaching and learning of catchment landform and processes and their linkages to the dynamic behaviour of river channel form and process. Fieldwork is described. An overview is provided of the processes and landforms in the study area.

The paper is focused on teaching and learning. In addition it emphasises the need and importance of research into two key areas: (1) the spatial and temporal variation in sediment sources and their direct linkage to channel change using tracer studies; (2) the quantification of sediment-borne heavy metal contamination in the river channel and the efficacy of current engineering works in reducing contaminated sediment transfer to the channel and enhancing channel stability.

Keywords

River Nent, Catchment Management, River Engineering, Sediment Dynamics, Catchment Processes

Introduction

The drainage basin is important for studying fluvial geomorphology because it provides the fundamental unit to identify the factors (e.g. precipitation and temperature; geology, topography and lithology; soils, landuse and vegetation. Fig. 1), controlling the processes of sediment redistribution and landform creation (Morrisawa 1985). Sediment enters the river from the catchment or through local bank erosion. This material is then transported downstream or temporarily stored within the channel as barform deposits such as point bars, lateral bars, braid bars. The pattern of storage in the form of these bars then effectively defines the channel type of the river (e.g. single-thread, braided, step-pool).

River channel behaviour is intrinsically linked to processes operating within its drainage basin, in particular, changes to the flow and sediment regime lead to morphological adjustment. Sediment production and transfer is a discontinuous process (Knighton, 1997) but the landscape, particularly in the river valley can indicate current process response rates for a particular river. Natural catchment processes and human alteration of the landscape affect the distribution of sediment sources, throughputs and sinks in space and time. Locally the river may be seen as a reflection of past and present sediment regimes within the catchment. Under stable conditions temperate alluvial rivers may attain an equilibrium or regime in which their morphology is adjusted to the sediment supply conditions that exist within the catchment, i.e. sediment inputs are balanced by sediment outputs as a result of an efficient throughput mechanism. Where an imbalance exists it is often reflected in channel instability as the river attempts to readjust to the new catchment controlling factors.

The aim of this paper is to outline a methodology for teaching and learning of catchment landform and processes and their linkages to the dynamic behaviour of river channel form and process. The objectives are to:

1. review the literature on this topic, identify the key points and provide learning outcomes for students,
2. outline a field course and assessments that will enable students to investigate these key points, achieve the learning outcomes and demonstrate their level of understanding,
3. provide a brief overview, based on current research, of the processes and landforms in the study area, and
4. utilise the knowledge gained from the three objectives above to evaluate critically contemporary measures employed to stabilise the river channel at Nenthead, Cumbria.

Literature review to identify key points – learning outcomes

River channel behaviour is intrinsically linked to processes operating within its drainage basin, in particular, changes to the flow and sediment regime lead to morphological adjustment. Schumm (1977) developed a simple model of this linkage defining three zones along a river from source to mouth; the headwater sediment supply zone, the sediment transfer zone and the lowland storage zone. In the headwater zone sediment production over the catchment is highest, with climatic extremes enhancing the weathering processes. Valleys are narrow and confined allowing material generated on the catchment to enter the channel rapidly. Drainage densities are at a maximum and valley slopes are steep increasing the likelihood of sediment transfer from the catchment into the channel. Further downstream channel and catchment slopes decrease, the river valley widens out and drainage density reduces; sediment inputs to the channel reduce. The river remains steep allowing channel migration to rework local sediment deposits and to transport sediment delivered from upstream to the lowland storage zone. Here channel gradients reduce and fine sediment accumulates as in-channel bars and overbank floodplain deposits.

Natural catchment processes and human alteration combine to alter the distribution of sediment sources, throughputs and sinks in space and time. These processes include precipitation and temperature; geology, topography and lithology; soils, landuse and vegetation (Fig. 1).

The zonation proposed by Schumm (1977) represents a broad downstream categorisation of sediment sources. It can also be zoned laterally away from the channel (Sear *et al.* 1995) with in-channel sediment, floodplain sediment, valley-side sediment and catchment slope colluvial deposits (Fig. 2). Sediment production and transfer is a discontinuous process (Knighton 1997) but the landscape, particularly in the river valley can indicate current process response rates for a particular river. Levels of sediment mobilisation and consequent throughput downstream vary, with the fastest downstream transfer occurring for in-channel deposits, reducing for floodplain, valley-side and colluvial deposits.

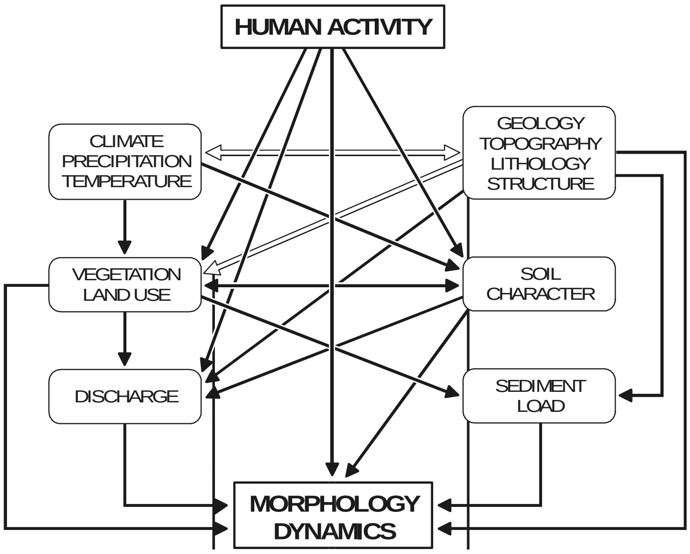

Figure 1. Catchment influences on river channel form (after Morrisawa 1985).

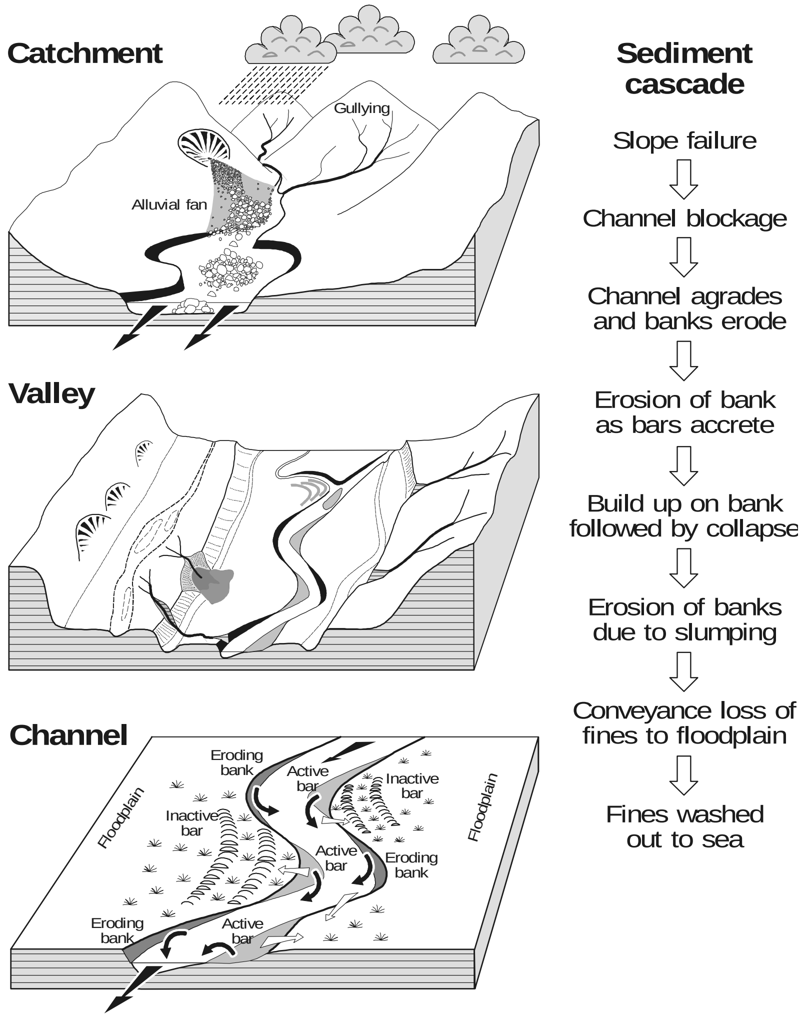

Figure 2. Lateral variation in sediment sources and flux rates to a river channel (modified from Sear et al. *1995).*

The form of a river reflects the activities occurring within the drainage basin. Channel classifications have been proposed (Fig. 3) that relate river form to catchment controlling factors (Schumm 1981, 1985, Mollard 1973). Stable fine-grained channels with low sediment load are likely to be anastomosed or single thread. Coarser sediment inputs could also lead to single thread or wandering channels. Significant inputs of coarser material increase local channel instability forming braided channel networks. Thus, river form can provide significant evidence of changes in the catchment. The process character of these and other broad channel types may be summarised in Table 1.

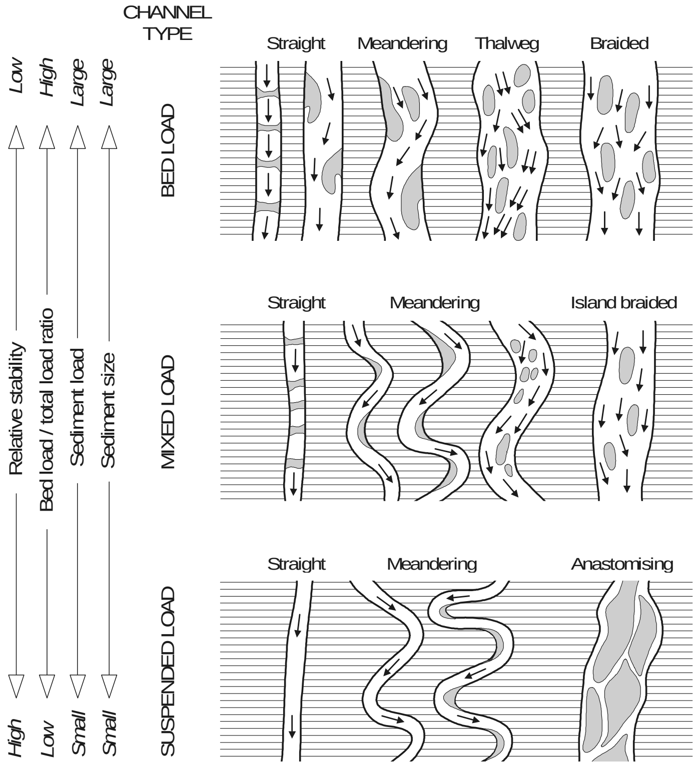

Figure 3. *Channel and catchment process categorisation based on channel morphology (after Schumm 1985).*

Table 1. *Process characterisation of river channel types.*

Channel type	Process character
Bedrock channel	Steep gradient, high energy, often incised over-deep channel, very efficient at transporting all delivered sediment including boulders at very high flows. *Subject to variable sediment delivery rates.*
Step-pool channel	Steep gradient, high energy, confined valley, able to transport delivered sand, gravel and cobble bed material. Boulders may cluster as step morphological units. Some in-channel deposits in low energy zones. *Subject to variable sediment delivery rates.*
Alluvial single thread channel	Shallower gradient alluvial channel, may be straight or sinuous, transports delivered suspended load and sand and fine gravel, coarser deposits moved at a slower rate accumulating as bar features and large scale bedforms (riffles). *Subject to moderate sediment delivery rates.*
Wandering channel	Alternating single thread-braided channel system steeper than single thread channels. Multi-thread destabilised segments represent local sinks for sediment as a series of bar features and distributary channels. *Subject to moderate and high sediment delivery rates*.
Anastomosed channel	Low energy, shallow gradient multi-thread channel network split by stable islands and bar deposits. Moderate to low levels of fine sediment throughput. *Subject to low sediment delivery rates.*
Braided channel	Steep gradient multi-thread channel network exhibiting higher energy levels than single thread and wandering systems. Able to transport sand, gravel and cobble material, instability reflects high sediment delivery rates. *Subject to high sediment delivery rates.*

Local channel morphology responds to lateral and longitudinal sediment budgets linked to the intrinsic efficiency of the river at transporting delivered sediment (Fig. 4). Lateral inputs of material may come from a variety of point sources including tributaries, gullies and rills. Other sources include the erosion of floodplain and valley side colluvial deposits. Such deposits may be variable in age, representing medium- and long-term stores of material being moved down the valley.

The pattern of changing sediment stores and delivery ratios may be reconstructed using Table 1 linked to field investigation. The influence of sediment storage and delivery rates on channel morphology and channel dynamics may also be inferred. The current efficiency of movement of material reflects contemporary delivery processes, and the overall competence of the river channel. Bedrock channel segments act as very efficient transport agents (Table 1) for all but the largest calibre of sediment, delivering it downstream and forming the next channel type. Where the channel gradient reduces and sediment inputs are high, braiding may occur. Using this information linked to field evidence it is possible to reconstruct the pattern of contemporary sediment stores and delivery rates and demonstrate their influence on channel morphology and channel change.

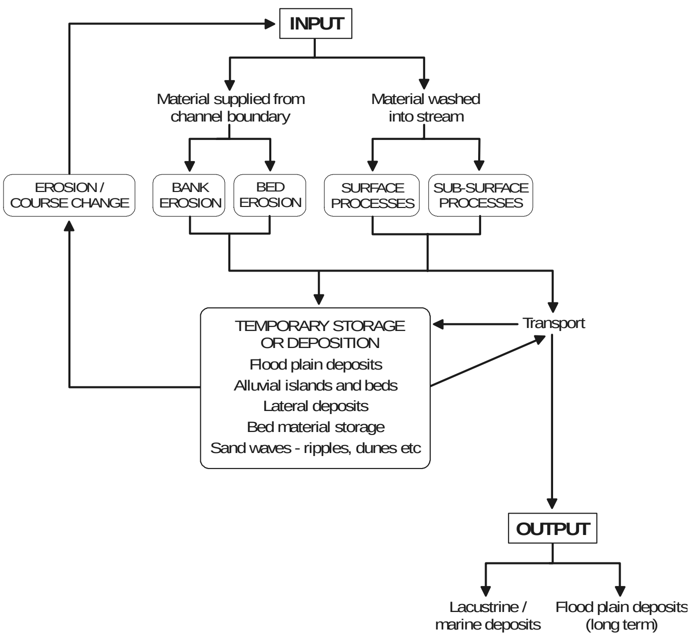

Figure 4. *A linked model of channel morphology and catchment sediment inputs to describe the dynamics of a river channel.*

It can be seen that a picture of the present sediment budget of a river channel may be deduced from observational evidence of geomorphic units and processes occurring across the catchment. This is demonstrated for a small upland catchment in the North Pennines through field observation and data collection.

Field site

The catchment under consideration is the River Nent, located to the east of the village of Alston in the North Pennines. It drains an upland area of 29.4km^2 (Macklin 1986) before flowing into the River South Tyne just west of Alston as a 4th order stream (Fig. 5). The geology of the basin consists of sedimentary rocks, principally sandstone, shale, and limestone that has undergone extensive base metal mineralisation to produce deposits of galena (PbS) and Sphalerite (ZnS) along with other economically exploitable minerals (Macklin 1986). Mining of these ores reached a peak between 1850 and 1900 (Dunham 1944), but ceased in 1950 (Macklin 1986).

Current land-use patterns consist principally of extensive sheep farming. No attempt has been made to utilise the small floodplain areas for arable use due to the instability of the river channel and the nature of the sediments which are heavily contaminated with heavy metals. The population of the catchment is low, mostly resident on scatted farms and in the villages of Nenthead and Alston.

Fieldtrip structure and itinerary

The fieldtrip should be conducted over a minimum of 4 days beginning with an introduction to the links between catchment processes and channel form, followed by sessions mapping and interpreting valley and river landforms and processes. A final day is spent considering aspects of channel management in the light of catchment destabilisation through an evaluation of the Nenthead sediment control project implemented in 1999 (Table 2.). Details of the daily activities and the techniques required are given in Appendices 1 and 2.

Field course learning outcomes

The fieldwork was designed for level 2 undergraduates studying a course on Soil Geomorphology and Rivers. The fieldwork is the culmination of the course. The aim of the students' fieldwork is to practice the skills described and investigated during the course and to explain the interaction between catchment and channel landform and

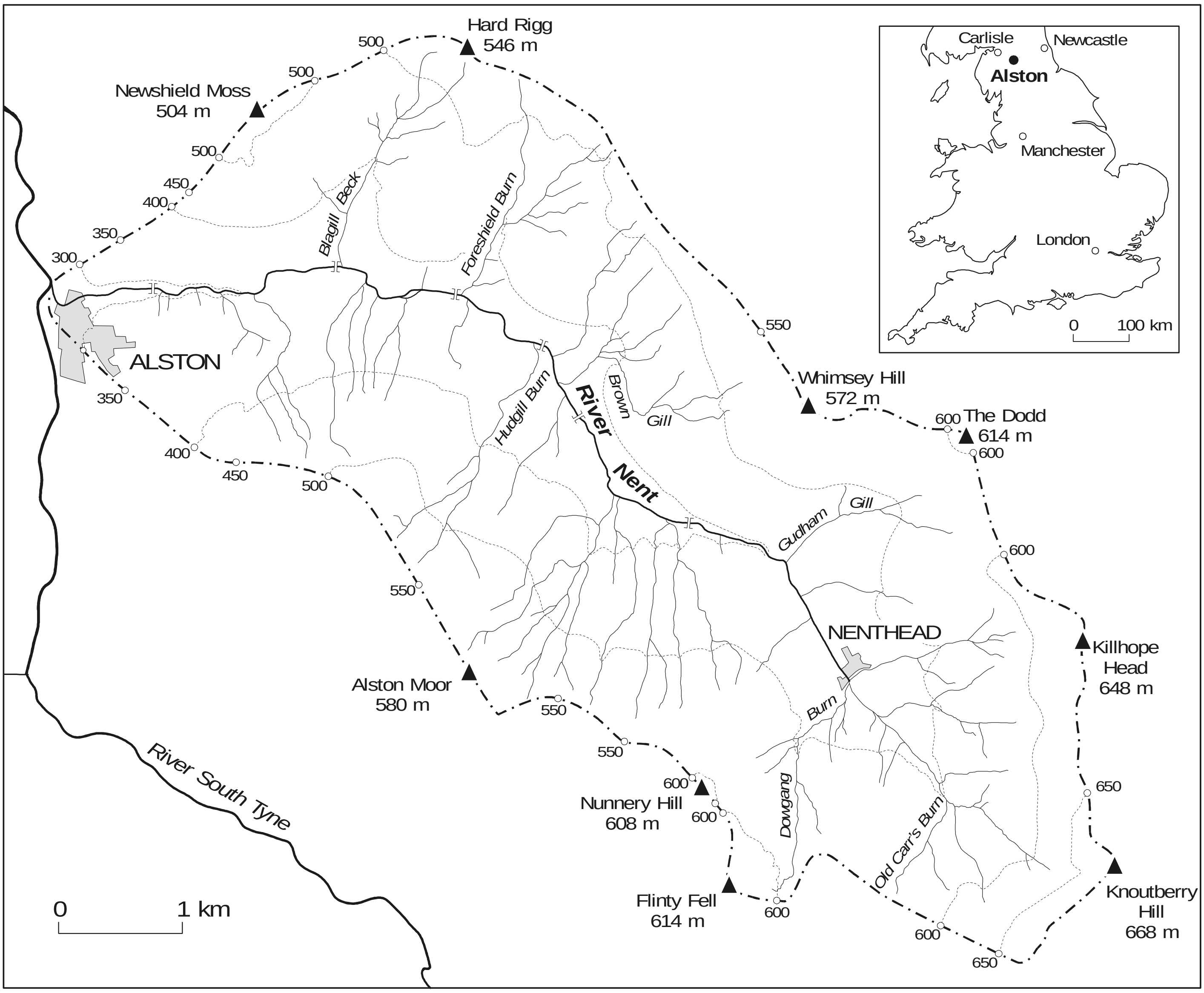

Figure 5. The River Nent catchment, Cumbria.

process at different spatial and temporal scales. The intention is that students will use the following superficial learning outcomes:

1. Recognise river and valley form and process in single-thread, multi-thread and bedrock river systems including the contrasting types and levels of activity between each channel type.
2. Identify relict and active landforms and reconstruct their processes of formation by constructing a geomorphological map from existing morphological and sedimentological evidence
3. Discriminate between contemporary and relict sediment production and transport processes operating in the basin.

These will then be used to reach higher level learning outcomes which require a deeper understanding of the holistic behaviour of the catchment:

4. Identify a sediment source-transfer-sink system operating in the catchment.
5. Explain the form and behaviour of the current river channel in order to construct a model of the flux of sediment in the catchment over space and time.
6. Evaluate remedial measures to ameliorate instability zones within the catchment.

Assessment

Students should be encouraged to keep a detailed notebook which will expected to be used in the field and added to in the evening using reflective writing. The intention is that the notebook will be structured according to the guidelines below in order to divide the writing between observations made by the student and reflection for themselves and feedback for the lecturers:

Observations

- Ideas / thoughts
- *Findings / data*
- *Concepts*

Reflective writing / feedback

- Practical difficulties
- Conceptual problems
- *Potential solutions and actions*

These notebooks should be written prior to each evening's debriefing session. Students will be encouraged to record data during the fieldwork and to consider its significance prior to the debriefing sessions. Group presentations are scheduled for each evening to assimilate individual experiences and to reinforce the overall objectives of the day using a specific task or model around which the final discussion should be centred (Table 2.). The students are also expected to complete a geomorphological audit (Newson and Sear 1993) of the catchment and river detailing current conditions and evaluating ameliorative measures used within the catchment. This approach to channel evaluation has been adopted by the Environment Agency in their efforts to standardise baseline data collection and process evaluation for river systems across England and Wales (Newson 1996). The audit should contain reference to the following topics:

1. Statement of the problem
2. Catchment location and characteristics
   - Geology
   - Topography
   - *Precipitation and evapotranspiration*
3. Historical context
   - Flow regime
   - Past channel changes
   - *Past land use changes*
4. Environmental impacts
5. Maintenance activity (Channel and catchment)
6. Fluvial audit
   - Current channel form
   - Current floodplain form
   - *Current character of the wider catchment*
7. Evaluation of current conditions
8. Statements concerning the causes of any river and catchment instability
9. Recommendations concerning future catchment and channel management

An executive summary and concise conclusion are expected. The reflective writing in student notebooks should prove useful for the audit. A full report is required at the end of the course and must include the audit and the notebook. One way in which learning will be assessed is to look for evidence in the notebook that has been influential in the construction of concepts in the full report. The full report is criterion assessed so that it is explicit that the students are required to include information from all sources throughout the field course.

Table 2. Summary of field and summary activities linked to the project.

Calendar	**Field objectives**	**Methodologies**	**Assimilation session**
Day 1: Introduction to river and valley morphology, soil character, instability recognition and process quantification.	The geography of the field study area will be elucidated through a series of visits to river valley sites in the South Tyne and Nent catchments. Channel and valley form will be introduced and the idea of sediment sources, throughputs and sinks discussed in the context of catchment and valley source areas and river channel transport efficiency.	Geomorphological mapping and process quantification techniques will be introduced.	A group discussion should be conducted concerning the nature of the channel types encountered and the conditions relating to sediment supply over the catchment.
Day 2: Quantification of river and valley processes: Channel types on the middle and lower Nent.	Recognition and quantification of the channel processes occurring in bedrock, single-thread and multi-thread channel section of the River Nent will allow these river types to be characterised according to their transport efficiency and susceptibility to channel change. This will be contrasted against contemporary and relict catchment and valley sediment delivery agents to produce an understanding of the linkage between catchment process and channel form.	Geomorphological mapping and quantification; soil profiling; slope measurement; shear stress estimation.	Maps detailing the spatial distribution of channel and valley features and process should be produced for group presentation. A summary session should compare and contrast the findings for each river type.
Day 3: Quantification of river and valley processes: Channel types on the upper Nent.	Two sites will be visited in the upper catchment that display contrasting valley processes as a result of mining activity. These sites offer the opportunity to observe and quantify significant rates of sediment delivery from the valley sides and to determine effect of the river channel locally. Assimilation of ideas on channel behaviour and sediment transport capacity produced on days 1 and 2, together with a picture of the wider catchment activity, will be used to construct a model of contemporary sediment routing within the Nent catchment.	Geomorphological mapping and quantification, soil profiling, slope measurement, shear stress estimation.	Maps detailing the spatial distribution of channel and valley features and process should be produced for group presentation. A summary session will contrast activity in the mined and un-mined valleys.
Day 4: Attempts to manage catchment processes: The River Nent at Nenthead.	Following concerns of high levels of fine material and associated base metal contaminants entering the River Nent around the village of Nenthead as a result of the erosion of valley floor spoil heaps, European Union money has been invested in rehabilitating the valley in the vicinity of the mining village. Extensive engineering works have been conducted to stabilise and vegetate the spoil heaps and the channel to the river has been heavily revetted. Gradient control structures have been emplaced to reduce the overall energy of the channel. A walkover survey of the extent and types of engineering works linked to the condition of the channel and catchment up and downstream will allow the works to be evaluated.	Geomorphological mapping and quantification, soil profiling.	A brief discussion session on the effect-iveness of the management options will be held concentrating on local advantages and disadvantages and potential effects up and downstream.

Discussion on the use of learning outcomes for knowledge consolidation

The catchment of the River Nent exhibits features formed over a range of time scales: high elevation relict erosional scars now relict (Plate 1) through to fluvio-glacial fan deposits and contemporary gully erosion (Plate 2). Despite the potential for these forms to contribute material to the fluvial system it appears that currently the most active sediment source is spoil from the base metal mining. Old shallow shake holes are located throughout the landscape of the upper catchment but appear to be linked to local stable deposits of mine waste not actively contributing sediment to the river system. Organised base metal mining in the early 1900s led to the construction of large scale spoil heaps in the tributary and main river valleys of the Nent around the village of Nenthead (Plate 3). The very high heavy metal contamination of these deposits has prevented vegetative colonisation and stabilisation generating widespread instability, active sediment production and currently active delivery of sediment to the river. The deposition of mine spoil over restricted floodplain areas adjacent to the main channel has provided additional potential point sources which complicates the linkage between sediment delivery and channel change over space and time.

Plate 1.

Plate 2.

Plate 3.

Plate 4.

Elsewhere in the upper catchment the un-mined headwaters remain fairly stable displaying few features that would indicate high levels of contemporary degradation (Plate 4). Local erosion of previously deposited fan material and floodplain alluvium is supplying additional sediment to the river system (Plate 5); similarly there are areas of active gully erosion at various points along the river. Despite the cessation of mining, sediments continue to enter the river system in the upper catchment due to the erosion of spoil deposits (Plate 6).

Overall the site provides the opportunity for students to demonstrate their level of understanding and their evaluative skills will prove to be a valuable way of assessing their learning. The assessment could be used to more appropriately direct future works to reduce the influx of sediment-borne toxic heavy metals into the channel system.

Despite the localised major source of sediment for the River Nent a survey of its 8km length revealed a pattern of stable and unstable reaches. This pattern appears to be related to the ability of the river system to transport material emanating from the upper catchment around Nenthead. High energy reaches such as confined bedrock sections remain relatively free of sediment except for isolated deposits in local zones of reduced channel energy. Lower gradient reaches where the valley becomes less confined are characterised by wandering channels (intermediate single-thread and braided zones) which represent contemporary depositional zones or sinks (Plate 7). Material is stored in these reaches forming a coarse matrix floodplain infilled with fines from the mining activity. Reworking is occurring in stages and across the floodplain features may be classified according to their present activity which relates to the spatially variable flux of material moving downstream

Plate 5.

Plate 6.

(Plate 8). Unstable river reaches characterised by the wandering gravel-bed channel networks may be related to the processes generating sediment in the headwaters of the catchment and the transport capacity of the intervening channel type segments (Fig. 4). One explanation of channel stability downstream may be the provision of sediment by distal sources and subsequent transport downstream rather than to local inputs (tributary, gully or reworked deposits) destabilising the system.

Recent engineering works around the village of Nenthead appear to have been designed to ameliorate the effect of mining in the local vicinity and to stabilise the mine spoil dumped on the valley floor (Plate 3). However, there is mounting evidence that these works were inappropriate and that the ameliorative impact will be limited by enhanced instability within the engineered reach. The channelised reach is located along the steep upper reaches of the river where considerable channel energy remains to alter the channel in response to any changes in the sediment balance or local hydraulics (Plate 9). It is postulated that the channel revetment will reduce the friction of the bed and banks and increase flow velocities. Gradient control structures will may reduce the water surface slope locally at low flow dissipating the energy at well protected drop structures, but these structures are unlikely to be large enough to operate effectively at elevated flows. Local sediment inputs appear to have been reduced as a result of bank protection and stabilisation of the spoil deposits. High flows will be starved of sediment and have high energy. At high flows bank protection will be under threat from erosion and the bed of the channel downstream of the works appears to be experiencing degradation as a consequence. Headcut erosion may continue to propagate upstream of the works further destabilising the unprotected headwater valleys. Further downstream, the reduced sediment supply may result in incision of the channel into the previously deposited floodplain sediments in the wandering gravel-bed reaches similar to that described by Macklin (1986) following the cessation of mining in the 1950s.

The engineering works appear to be having considerable effects on the present channel and floodplain system. Knowledge of the present catchment conditions and the current mechanisms by which sediment is moved through the system should allow for early recognition of destabilisation and destabilising phenomena. This knowledge should enable an assessment of the efficacy of the engineering works in ameliorating the effect of mining and stabilising the mine spoil.

Plate 7.

Plate 8.

Plate 9.

References

Dunham K C 1944 The production of galena and associated minerals in the northern Pennines; with comparative statistics for Great Britain *Transactions of the Institute of Mining and Metallurgy* 53 181-252

Hey R D 1997 Geomorphologic basis of river restoration in **Large A R G** ed *Floodplain rivers: hydrological processes and ecological significance* British Hydrological Society Occasional Paper 8 104-119

Knighton D 1997 *Fluvial forms and processes - a new perspective* Edward Arnold, London

Macklin M G 1986 Channel and floodplain metamorphosis in the River Nent, Cumberland in **Macklin M G and Rose J** eds *Quaternary river landforms and sediments in the North Pennines, England* Field Guide, British Geomorphological Research Group/ Quaternary Research Association 19-33

Mollard J D 1973 Airphoto interpretation of fluvial features *Fluvial Processes and Sedimentation, Proceedings of the Hydrology Symposium, University of Alberta* 342-380

Morisawa M 1985 *Rivers* Longman, London

Newson M D 1996 Catchment plans: a new geographical resource and challenge *Geographical Review* 9 17-24

Newson M D and Sear D A 1993 River conservation, river dynamics, river maintenance: contradictions? in **White S Green J and Macklin M G** eds *Conserving our landscape* Joint Nature Conservancy UK 205-229

Schumm S A 1977 *The fluvial system* John Wiley and Sons, Chichester

Schumm S A 1985 Patterns of alluvial rivers *Annual Review of Earth and Planetary Science* 13 5-27

Schumm S A 1981 Evolution and response of the fluvial system: sedimentologic implications *Society of Economic Palaeontologists and Mineralogists Special Publication* 31 19-29

Sear D A 1996 The sediment system and channel stability in **Brookes A and Shields F D Jr** *River channel restoration: guiding principles for sustainable projects* John Wiley and Sons, Chichester 148-177

Sear D A Newson, M D and Brookes A 1995 Sediment-related river maintenance -the role of fluvial geomorphology *Earth Surface Processes and Landforms* 20 629-647

Appendix 1: Fieldwork itinerary

This section contains a detailed daily activity breakdown to aid leaders in setting daily goals that may be assessed partially using structured debriefing sessions. The field visit may be completed in 4 days and each day's activities and assimilation sessions are designed to build on previous work.

Day 1: Introduction to river and valley morphology, soil catena, (in)stability recognition and process quantification.

The geography of the field study area will be elucidated through visits to several river valley sites in the South Tyne and Nent catchments. Channel and valley form will be introduced and potential sediment sources, throughputs and sinks will be exemplified and discussed in the context of spatial and temporal variation in catchment and valley source areas and river channel transport efficiency. Geomorphological mapping and process quantification techniques will be introduced.

Techniques:

Geomorphological mapping and quantification, soil classification, slope measurement, low flow shear stress estimation, Channel sedimentology and system energy.

Sites:

Location	Character	Activity
South Tyne, Featherstone Castle *(NT 674598)*	Wandering gravel-bed river, braid channel features, channel instability. Stable catchment, low sediment delivery, wide valley, low terracing.	Geomorphological mapping and soil profiling and classification techniques. Channel and valley process recognition. Attaching timescales to catchment activity. Observation of multi-thread channel character and processes.
Low Thornhope *(NT 683509)*	Single-thread pool-riffle sequence flowing through a well developed set of terrace features, stable catchment.	Recognition and relative dating of valley storage features. Observation of single-thread channel character and processes.
R. Nent, Blagill *(NT 733468)*	Bedrock channel, limited step-pool sequence, confined valley.	Observation of bedrock channel character and processes.
R. Nent, Blagill *(NT 737469)*	Single-thread pool-riffle channel, evidence of enhanced valley processes.	Recognition of enhanced valley sediment delivery processes.
R. Nent, Blagill *(NT 743469)*	Wandering gravel-bed river, braid channel features, channel instability. Evidence of gully sediment delivery and relict alluvial fan. Slope instability observable.	Identification and quantification of gullies. Soil profiling and classification. A single morphologic unit or process operating at the Blagill site must be quantified.

Assimilation of field information:

A group discussion should be conducted concerning the nature of the channel types encountered and the conditions relating to sediment supply over the catchment. This should be based around the construction of a process-based river continuum similar to that produced by Mollard (1973). A blank version of Figure 3 may be used and the student results compared with this model to conclude the session. Sediment sources should also briefly be discussed in the context of downstream and lateral zonation, this should be conducted using figure 2 as a template. The attempts at the production of a classification will highlight the lack of quantitative knowledge concerning channel and catchment processes making it difficult to position each channel type. In particular the bedrock channel will prove problematic as the classification of Mollard (1973) is drawn up for alluvial channels.

Presentation topic	Presenters	Principal questioners
Bedrock	Group 1	Group 2
Multi-thread	Group 3	Group 4
Single-thread	Group 2	Group 3
Comparison of all three	Group 4	Group 1

Learning outcomes:

- Locate the study sites in the South Tyne and Nent river catchments and identify the geomorphological difference between the catchments
- Recognise and record basic channel types, valley forms and a soil catena to interpret landform processes and sediment transport pathways
- Discriminate between contemporary and relict catchment and valley-side features and processes.

Day 2: Quantification of river and valley processes: Channel types on the middle and lower Nent.

Recognition and quantification of the channel processes occurring in bedrock, single-thread and multi-thread channel section of the River Nent will allow these river types to be characterised according to their transport efficiency and susceptibility to channel change. This will be contrasted against contemporary and relict catchment and valley sediment delivery agents to produce an understanding of the linkage between catchment process and channel form. Students should aim to work in at least two of the three channel types present in the study reach.

Techniques:

Geomorphological mapping and quantification, Soil profiling, Slope measurement, Shear stress estimation, Channel sedimentology and system energy.

Sites:

Before leaving for the field the students should be given the opportunity to present their attempt to quantify a landform or process from the previous days fieldwork. As a group constructive criticism should be made of each approach to make the students aware of the difficulties in accurately recording features and processes in the field.

Location	Character	Activity
R. Nent, Blagill *(NT 733468)*	Bedrock channel, limited step-pool sequence, confined valley.	Observation of bedrock channel character and processes.
R. Nent, Blagill *(NT 737469)*	Single-thread pool-riffle channel, evidence of enhanced valley processes.	Recognition of enhanced valley sediment delivery processes.
R. Nent, Blagill *(NT 743469)*	Wandering gravel-bed river, braid channel features, channel instability. Evidence of gully sediment delivery and relict alluvial fan. Slope instability observable.	Identification and quantification of gullies. Soil profiling.

Assimilation of field information:

Maps detailing the spatial distribution of channel and valley features and process should be produced for group presentation, students should be restricted to one geomorphological map and one summary table. A summary session should compare and contrast the findings for each river type. The order of presentations will be as follows:

Presentation topic	Presenters	Principal questioners
Bedrock	Group 1	Group 2
Multi-thread	Group 3	Group 4
Single-thread	Group 2	Group 3
Comparison of all three	Group 4	Group 1

Learning outcomes:

- Recognise river and valley form and process in single-thread, multi-thread and bedrock river systems.
- Identify the type and quantify the extent and activity of channel types and valley processes.

Day 3: Quantification of river and valley processes: Channel types on the upper Nent.

Two sites will be visited in the upper catchment that display contrasting valley processes as a result of mining activity. These sites offer the opportunity to observe the wider catchment and record the processes and levels of activity on their catchment maps. They will also have the opportunity to locally assess and quantify significant rates of sediment delivery from the valley sides linked to geological influences and to determine effect of the river channel locally. Assimilation of ideas on channel behaviour and sediment transport capacity produced on days 1 and 2, together with a picture of the wider catchment activity, will be used to construct a model of contemporary sediment routing within the Nent catchment. Students should aim to work in both of the valleys.

Techniques:

Morphological mapping and quantification, Soil profiling, Slope measurement, Shear stress estimation, Channel sedimentology and system energy.

Sites:

Location	Character	Activity
Three tributaries *(NT 762 465)*	Extensive views of the wider catchment allow quantification of the nature and wider extent of valley processes lithology and erodibility. 1^{st} order streams in an area of the catchment unaffected by mining activity. Some relict valley process features.	Observation of river channel type and evidence of sediment transport processes. Mapping and quantification of valley sediment sources and delivery processes. Wider observation of the state of the catchment and character of the processes operating. The visit to this site should conclude with an opportunity to revisit their catchment maps given their new insight into catchment processes gained from the field evaluation of the site.
Nenthead *(NT 782435)*	Destabilised valley displaying extensive contemporary erosion processes as a result of mining activity. Neighbouring 1^{st} order stream, less affected by mining, displays reduced activity.	Observation of river channel type and evidence of sediment transport processes. Mapping and quantification of valley sediment sources and delivery processes.

Assimilation of field information:

Group activities will vary for this session which is designed to bring together catchment process evidence and link it to channel activity through the construction of a sediment source-sink-throughput diagram similar to figure 4. Maps detailing the spatial distribution of channel and valley features and process should be produced for group presentation. A summary session will contrast activity in the mined and un-mined valleys. A discussion of the distribution and degree of valley and channel activity will conclude the session, this should be related to the conceptual model of sediment movement (Fig. 4). The order of presentations will be as follows:

Presentation topic	Presenters	Principal questioners
Nenthead mined tributary	Group 2	Group 1
Unmined 1st order streams	Group 4	Group 3
Conditions within the catchment	Group 3	Group 2
Linking sediment sources storage and transport zones	Group 1	Group 4

The first two presentations should highlight the importance of the mining activity in providing large amounts of sediment locally to the river system. The third presentation should begin to quantify the processes going on in the wider catchment contrasting the largely stable majority of the upper catchment with the destabilised areas associated with the base metal mining. The final presentation is crucial as it should draw on the whole group's experiences and through the construction of a catchment based map highlight the areas within the watershed that still require further observation in order to complete the geomorphological audit. The discussion centred around the map produced by group 1 should be used to plan the sites to visit at the end of day 4 to allow the students to finish the data collection required to complete the map required for the geomorphological audit coursework.

Learning outcomes:
- Identify the spatial impact of base metal mining in the catchment.
- Explain how sediment sources, throughputs and sinks relate to delivery zones within the catchment, channel type transport reaches and depositional areas.

Day 4: Attempts to manage catchment processes: the River Nent at Nenthead.

Following concerns of high levels of fine material and associated base metal contaminants entering the River Nent around the village of Nenthead as a result of the erosion of valley floor spoil heaps, European Union money has been invested in rehabilitating the valley in the vicinity of the mining village. Extensive engineering works have been conducted to stabilise and vegetate the spoil heaps and the river channel has been heavily revetted. Gradient control structures have been emplaced to reduce the overall energy of the channel. A walkover survey of the extent and types of engineering works linked to the condition of the channel and catchment up and downstream will allow the works to be evaluated. Additionally a brief tour of the catchment should be planned based around the recommendations of the previous nights assimilation session. This will allow the students to finish the data collection required to complete the map required for the geomorphological audit coursework.

Techniques:
Morphological mapping and quantification.

Sites:

Location	Character	Activity
Nenthead *(NT 778440)*	Extensive engineering works conducted to stabilise the spoil heaps and the channel including revetments and gradient control structures.	Observation of river engineering approach and evidence of channel instability. Mapping and quantification of local sediment sources and delivery processes.
Various locations in the catchment	Various, to be decided by the students.	A brief tour to allow the students to finish the data collection required to complete the map required for the geomorph-ological audit coursework.

Assimilation of field information:
A brief discussion session on the effectiveness of the management options will be held concentrating on local advantages and disadvantages and potential effects up and downstream. The effect of altering the sediment regime locally and the channel processes by altering the gradient should be emphasised.

Learning outcomes:
- Explain why alteration to the regime of the river as a result of adjustments to the sediment budget or channel hydraulics will lead to a response within the engineered reach as well as up and downstream.
- Construct an overall model of catchment and channel linkages extended to the full geomorphological mapping of the Nent drainage basin.

Appendix 2: Fieldwork techniques

This section details the methods students may use to assess channel, valley and catchment morphology and processes.

Morphological mapping and quantification (simple recognition and mapping of river and valley features, morphological measurement and process interpretation.)

This technique allows a landscape to be mapped quickly and efficiently noting the principal morphological features, their character and the processes operating over them.

(a) Feature mapping

Modern analytic geomorphological maps have developed around five fundamental landform concepts:

1. Morphology: the appearance and shape of the landscape.
2. Morphometry: the measurements, dimensions, and slope values of landforms.
3. Morphogenesis: the origin of each landform.
4. Morphochronology: the age of each landform.
5. Morphodynamics: the land-forming processes presently active on the landscape or those that may become active in the future.

Geomorphological mapping begins with the identification of the fundamental 'homogeneous' units that comprise the landscape. However, this is a scale-dependent selection and the mapping of the same region at different resolutions will provide different basic units. The purpose of the map must be identified and the geomorphic unit carefully chosen to be homogeneous and indivisible at the scale of mapping. In general, the geomorphic unit should be defined in terms of (1) genetic or structural pattern or in terms of (2) location and dimensions of geometric elements.

(b) Process interpretation

The features present in the landscape can be used to indicate the types and levels of processes operating to cause instability, Tables a and b list features present in the channel and floodplain environment together with associated process interpretation. This should be used in conjunction with the geomorphological map to infer contemporary catchment and channel dynamics.

Table a. Indicators of channel instability (after Hey 1997)

Field evidence		Instability tendency
Channel morphology	Undermined bank protection structures, bridge footings	Incision, overdredged
	Buried structures, bridge footings	Aggradation
	Erosion of both banks with (a) no central bar/island (b) central bar/island	 Incision, tree removal, under designed Aggradation
	Channel filling and lateral contraction with vegetation encroachment	Aggradation
	Enlarged channel	Incision, lateral erosion
	Increased meander bend bank erosion, associated unvegetated point bars	Degradation
Floodplain sedimentary sequences	Buried soils with alluvium	Aggradation, made ground
	Textural changes in the alluvial sequence (a) coarse overlying fine (b) fine overlying coarse	 Aggradation, made ground Incision, lateral contraction
	Elevation of channel bars higher than fossil bars exposed in bank	Aggradation
	Elevation of channel bars lower than fossil bars exposed in bank	Incision
Floodplain morphology	Inactive multi-channel system on floodplain	Incision, canalisation
	Terraces on valley floor	Long-term incision/aggradation cycles (10s-100s years)
Historic evidence	Changes in cross-section	Incision, lateral erosion, aggradation, contraction
	Increased sinuosity	Incision, lateral erosion
	Decreased sinuosity (approaching braiding)	Aggradation

Table b. Field indicators of stability (after Sear 1996)

Feature	Stability
Channel features	
Braiding	Unstable
Active meandering: large frequent unvegetated 'loose' bars, cut-off channels present	Unstable
Meandering: point bars unvegetated, uncompacted sediments	Unstable/stable
Meandering: point bars and berms of fine sediments, seasonal vegetation cover	Unstable/stable
Large unvegetated unstained uncompact bars downstream of tributaries	Unstable
Loose uncompact unvegetated sediments with evidence of fluvial sorting	Unstable/stable
Shallow pools filled with loose mixed sediments	Unstable
Dissected riffles of loose unstained mixed sediments	Unstable
Bank features	
Large or frequent eroding cliffs of unconsolidated sediment	Unstable
Erosion of both riverbanks for over 50% of reach, slab, block and rotational failure; small terrace like features within bank indicating previous slips	Unstable
Erosion of outer bank of meanders	Unstable/stable
Collapsed fence lines, fallen vegetation, damaged embankments	Unstable
Unvegetated banks with old slump scars	Unstable
Presence of bank protection, erosion structures	Unstable
Floodplain features	
Cut-off channels recent or old, degree of infilling and vegetation development, relative size	Unstable
Old boulder splays (note lichen cover)	Unstable
Old bank lines, terraces and river cliffs	Unstable/stable
Terrace relief clarity of feature and proximity to channel	Unstable/stable
Age and location of structures and field boundaries	Unstable/stable
Landuse	Unstable/stable
Type and extent of recent overbank deposits	Unstable/stable
Vertical structure of floodplain sediments	Unstable/stable

Soil profile observations and geomorphic inferences

The development of a soil is dependent on, amongst other things, the position in the landscape, which affects the amount of water, heat-energy and weathering of parent materials. The presence of certain vegetation species may be used as an indicator of soil type assuming knowledge of the vegetation characteristics, i.e. what conditions the species prefer to grow under. The vegetation itself may have a feedback effect (e.g. reducing infiltration by increasing interception) and alter the development of part of the soil. In many situations the position in the landscape is of overriding importance in understanding the development of a soil. This has led to the concept of the soil catena which illustrates soil development, for example as a function of position in a cross-section down a valley. Whilst this concept may provide the basis for understanding the fundamental differences in soil at different locations within the catena it takes little account of sediment redistribution in space and time.

It is necessary to observe and record the variation in the soil profile and of the geomorphic context of the profile so that inferences can be made about the processes of development. Of particular importance to this work is the ability to identify past and present sediment redistribution in the soil profile in order to elucidate spatial and temporal variation in the sediment transport pathways. A soil profile log should be recorded by dividing the profile according to sedimentology (e.g. particle size and texture) and stratigraphy (e.g. lamination and dip of strata).

Slope and channel measurement (the use of levelling instruments)

Slope profiles, channel cross-sections and channel long-section gradients may be quantified using an optical level. The levelling instrument should be set up and levelled using the levelling bubble. Readings should be taken from this point towards the levelling stave which should be placed at every break of slope across and downstream for the cross-section and long profiles. The upper, middle and lower stadia readings should be noted. The drop (y) from the levelling instrument is given by the middle stadia reading and the distance (x) from level to stave is given by:

$$Distance = (Upper\ stadia - Lower\ stadia) \times 100$$

Measurement error should be less than 2mm and may be checked using the following formula:

$$Error = \frac{Upper\ stadia - Middle\ stadia}{Middle\ stadia - Lower\ stadia}$$

Shear stress estimation (the use of 'Statzner's hemispheres')

The available energy within a river system to transport delivered sediment may be estimated from basic indices such as stream gradient or they may be measured. The shear force generated by the flowing water exerts a drag on the bed of the channel which, when it overcomes the resisting forces of the bed-material, leads to erosion and sediment transport. This shear force may be estimated using a set of variable density spheres. Rubber balls may be pre-filled with cement mixed with variable amounts of expanded polystyrene balls to alter the density and these should be placed in the river. The highest density ball provides a measure of the relative stress operating on the bed-material. The shear stress can be treated as a simple index related to ball mass or converted to a measure of actual stress (t) using the following general equation for non-uniform gravel-bed rivers:

$$\tau = 0.047(\rho_s - \rho_w)gD_g$$

where ρ_s = ball density (kg.m^{-3}), ρ_w = water density (1000kg.m^{-3}),
g = gravitational acceleration (9.81m.s^{-1}), D_g= ball diameter (m).

Channel sedimentology and overall estimation of channel energy

The surface sediment within the river channel can provide an approximate relative measure of the long-term energy levels experienced by the system, the larger the overall sediment size the greater the energy required to transport it.

The sediment may be characterised by sampling 100 stones from the surface of the channel using a pebblometer or using a ruler to measure the intermediate or 'b' axis of each clast. The stone sizes are then ranked within the following size divisions:

0-5mm, 5-10mm, 10-15mm, 15-20mm, 20-25mm, 25-30mm, 30-35mm, 35-40mm, 40-45mm, 45-50mm, 50-60mm, 60-70mm, 70-80mm, 80-90mm, 90-100mm, 100-120mm, 120-140mm, 140-160mm, 160-180mm, 180-200mm, 200-240mm, 240-280mm, 280-320mm, 320-360mm, 360-400mm…..

The exceedence probability should then be calculated from the following formula:

$$exceedence\ probability = \frac{N + 1}{m}$$

where m = the clast rank and N = the sample population (100).

The median grainsize (D_{50}) may be determined from the clast size corresponding to an excellence probability of 50%. The larger the overall size of the median clast diameter the greater the energy required within the system to transport it.