Stott, TA

Bedload Transport in Rivers: Trapping and Tracing

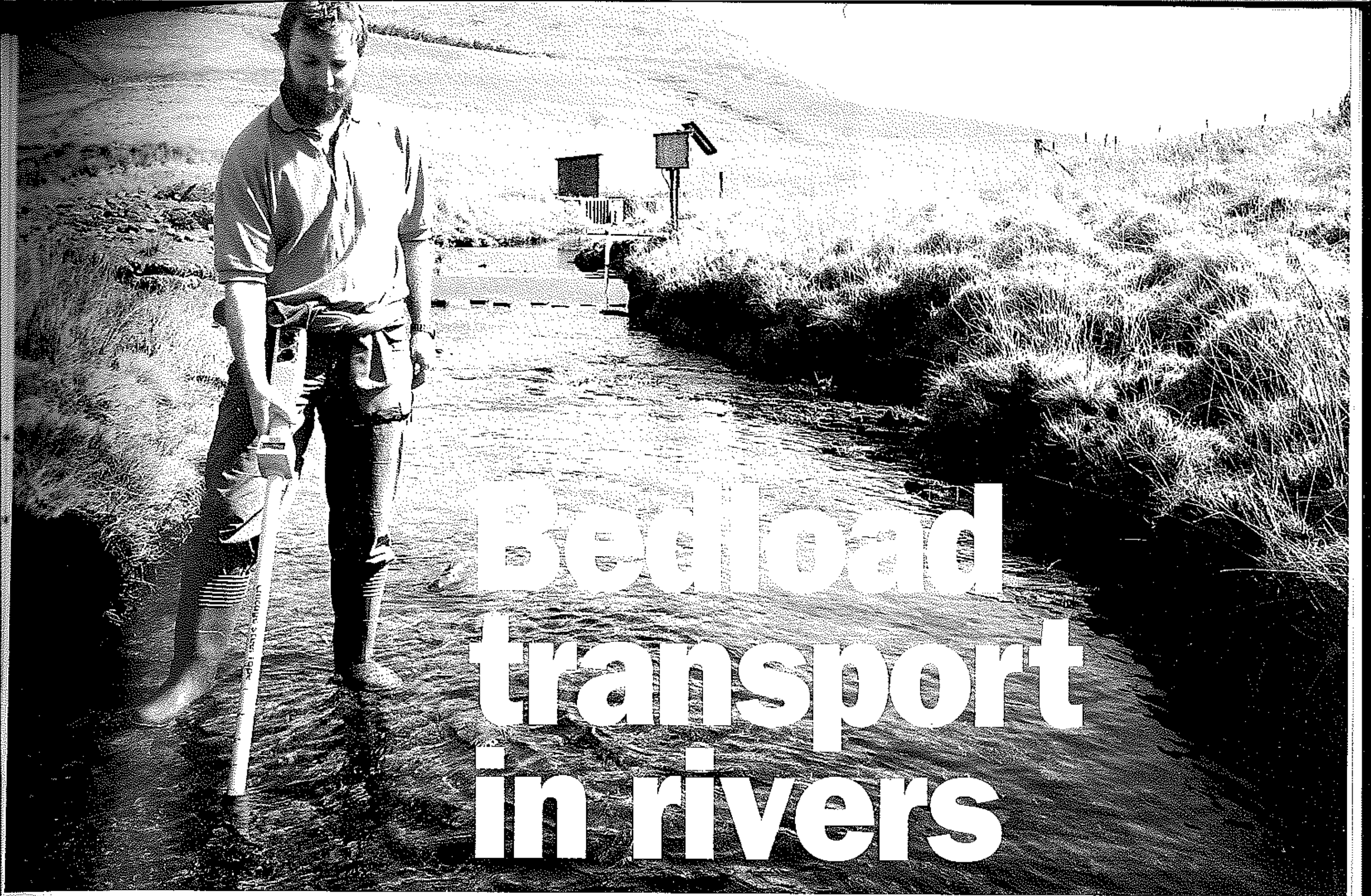
Stott, TA (2000) Bedload Transport in Rivers: Trapping and Tracing. Geography Review, 5 (13). pp. 23-27. ISSN 0950-7035

Geography Review

Volume 13 Number 5 May 2000

Sheltering under Lomé

philip allan UPDATES



Bedload transport in rivers

Trapping and tracing

Tim Stott

Many students considering A-level projects in physical geography are put off studying river processes and dynamics because they perceive the fieldwork as dangerous or requiring expensive equipment. With a little ingenuity, forward planning and patience it is perfectly possible to overcome these problems and conduct an interesting and rewarding project on some aspect of bedload transport or stream dynamics. This article outlines the reasons why research into bedload transport and river dynamics is necessary and discusses some of the techniques researchers use. Particular emphasis is given to the simpler techniques which might be suitable for project use.

A good deal of geomorphological research effort in Britain goes in to measuring, explaining and trying to predict what, why and how bedload is transported in rivers. But what is the attraction of bedload transport as a theme to study? Is it because bedload moves, it's dynamic? Is it because its movement is relatively unpredictable and therefore geomorphologically 'exciting'? Is it because the research has particularly important applications? Or because we don't have active glaciers or volcanoes to study in Britain?

These may all be good reasons. Certainly bedload in rivers can be transported rapidly in comparison with other geomorphological materials. River floods, and therefore bedload transport, occur relatively frequently in comparison to the imperceptibly slow movement of glaciers, the infrequent occurrence of landslides and debris flows, or the rarity and danger associated with studying volcanoes. In contrast, rivers and streams are common and accessible. Most are unpredictable but some (e.g. glacier-fed rivers) respond to diurnal temperature rhythms in a more predictable way.

Background to bedload dynamics

'Bedload' is that fraction of a river's sediment load which is transported on or close to the river bed, by rolling, saltating (bouncing) or sliding because it is too heavy to be held in suspension. It ranges in importance from as little as 5% in lowland rivers to as much as 80% in very active channels with gravel beds. Bedload is usually only transported when the river's discharge is higher than normal – after rain, snowmelt or during warm summer days when glacier-fed streams and rivers swell.

Why should river managers and engineers be interested in bedload movement? After all, when a river is in flood it goes all brown and muddy and you can't even see any bedload moving! Here are some reasons why river bedload is an important research issue today:

(1) The nature of the river bed and the channel capacity will affect how a river responds to flood water. For example bedload deposited on a river bed will reduce the channel capacity, making the river more likely to burst its banks and flood. The excess energy

acquired by a river having deposited bedload might be used to erode its banks. A river engineer concerned with protecting land on either side of the river may therefore need to know if a river is aggrading.

(2) An extreme case of aggradation is the formation of mid-channel bars (known as 'braiding'). Much research effort has been devoted to predicting where mid-channel bars will next form in the Ganges delta (see Brammer 1996). This knowledge could be used to predict where the main channel will move to next, and so which areas of floodplain will next be flooded. Local people could then be warned and lives might be saved in these unstable environments.

(3) Land-use changes may alter the bedload supply to rivers. Drainage ditching has been shown, in some cases, to release extra bedload into streams. Clearfelling can result in dead wood entering streams, creating debris dams which hold back stores of bedload. This may in turn affect fisheries. Salmon lay their eggs deep in the gravel in upland streams. If the size distribution of the gravel is changed and, for example, it becomes clogged with fine silt eroded from drainage ditches, the salmon eggs may become deprived of fresh oxygenated water and die. The spawning will fail and the whole viability of the salmon population could be called into question.

(4) An engineer building a bridge over a river would be interested in bedload transport within the river as this might be an important consideration when designing the bridge and any abutments which need to be placed in the river.

(5) The transport of bedload in rivers can be of interest to water engineers building dams on rivers for hydroelectric power schemes, river regulation or drinking water supply. Knowing the rate of bedload transport allows engineers to calculate the time it will take for the reservoir to fill up with sediment.

(6) Miners and prospectors can often benefit from a knowledge of bedload dynamics and sedimentary sequences in rivers. Precious metals such as gold can accumulate as placer deposits in river beds and a knowledge of river bedload dynamics can assist in predicting where to find these deposits.


Painted pebbles reintroduced to a stream bed in a forested mountain stream.

inset 1

Bedload transport theory: equal mobility or size-selective transport?

This is a question which has occupied the thoughts of many river researchers in recent times. The theory goes something like this. For an individual pebble (properly called a **clast**) on the stream or river bed to become **entrained** (picked up by the flow) the force applied by the water flowing past it (called the **bed shear stress**) must exceed the resistive force. The resistive force has been shown to depend not only upon the size of individual particles, but also upon the precise way they lie on the river bed, whether they are organised into inter-locking groups or even **imbricated** (packed together in general alignment) when the bed may be said to be **armoured**.

In the absence of interaction between particles, only smaller particles (because they are lighter) will be picked up at lower flows. In practice, smaller particles become 'hidden' or sheltered behind larger ones which protrude into the flow. Although the flow may have enough energy to transport a particular size of particle, if there are larger particles on the bed surface hiding those particles, they will not move until the larger particles move. The result is an equal mobility of all particle sizes at the same flow threshold, controlled by the size of the largest available particles. Such equal mobility is particularly associated with armoured channels. However, most channels show some selective transport, with a tendency for smaller particles to move more often than big ones.

Techniques for measuring bedload transport

Here are some techniques which can be used to investigate bedload transport. I shall concentrate on those most applicable to A-level projects, but will mention some more advanced techniques also.

(1) Measuring movement of individual clasts: tagging and tracing

The first thing you will need to do here is to collect a representative sample of pebbles or **clasts** from your chosen stream. This is most easily done by pacing around on the stream bed in your wellingtons and picking up the clast which you first touch with a pointed finger at the toe of your right boot (with eyes averted or closed, of course!). The size of your sample may depend on how much time you wish to spend, though as a general rule, the more you use the more reliable your results are likely to be.

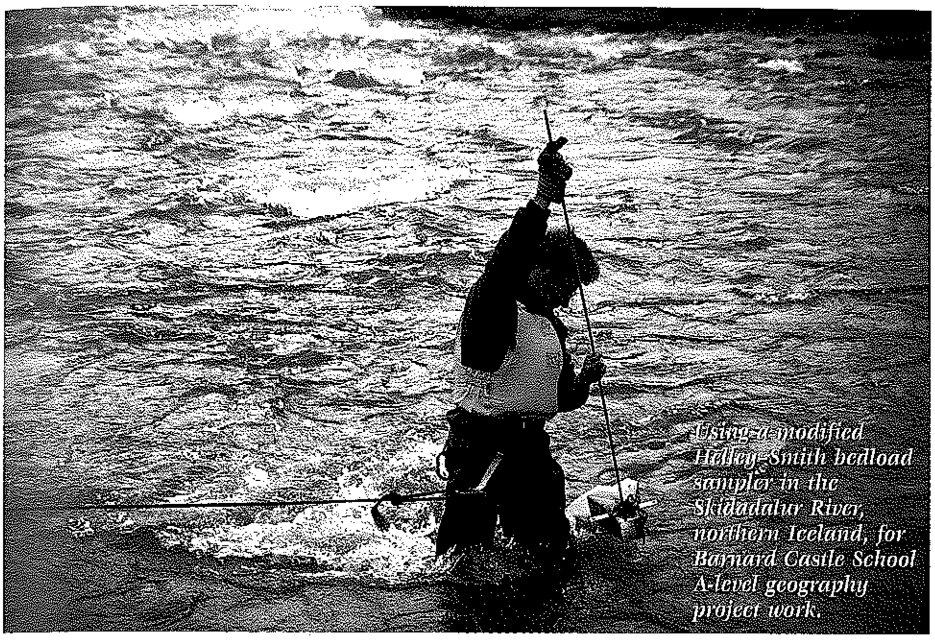
(a) Painting pebbles

Dry your clasts (usually best done at home or in a laboratory or classroom at school) and paint them all over with your favourite colour gloss paint. A bright colour like yellow is best, though you could use different colours for different size classes. You then need to paint on to each clast a unique number or code and measure its 'vital statistics': its a, b and c axes (i.e. the length, width and depth). With these measurements you will be able to work out the shape and size classes for your analysis later (see Briggs 1980). Weighing them will also be useful.

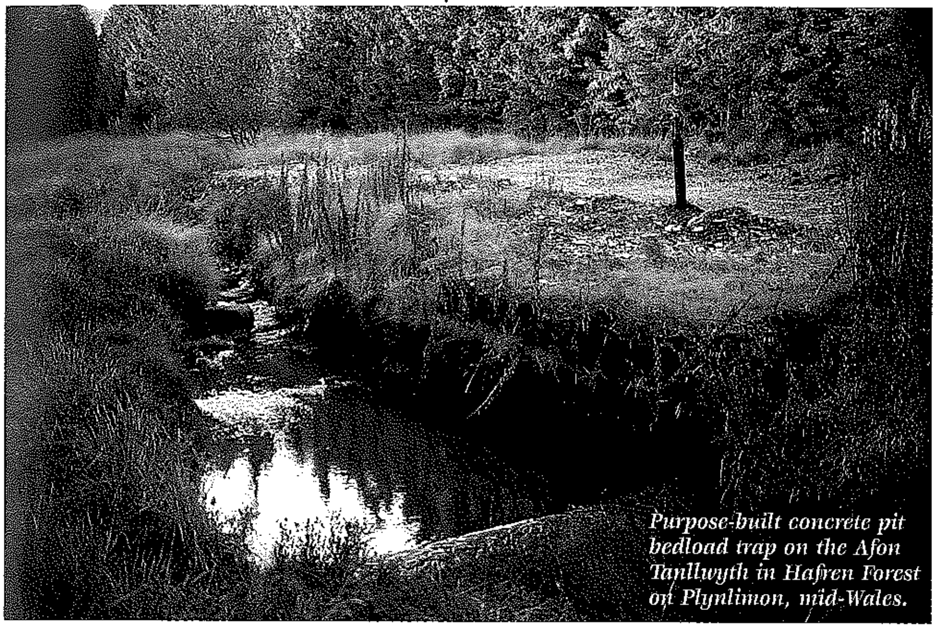
Return your painted pebbles to the same spot in the stream where you sampled them. You have to decide whether simply to drop them on to the bed (see the photograph above), which will probably enhance their chances of being entrained (picked up by the flow) during the next flood, or to 'seed' them. Seeding them means you try to push them back into the gravel so that they are in similar positions to when you sampled. The idea of the experiment is that your painted clasts have the same chance of moving as the rest of the bedload in that part of the stream bed. You might like to try both methods and see if there's a difference in the distance they move. Most researchers will ignore the first 'leap' or 'step' when calculating transport rates just in case it is biased due to the reintroduction process.

(b) Floating markers

In order to trace the path of bedload moving in active glacial meltwater streams, researchers have fixed lengths of fishing line (~ 1 m) on to bedload clasts (either using epoxy resin or drilling a hole through and tying). On to the other end of the line is fixed a ping-pong ball or other buoyant and highly visible marker. In this way it has been possible to observe bedload moving in highly turbid streams by watching the floating marker. You can drill most rock with an ordinary masonry drill. A



Using a modified Helley-Smith bedload sampler in the Skidadalur River, northern Iceland, for Barnard Castle School A-level geography project work.



Purpose-built concrete pit bedload trap on the Afon Tanllwyth in Hafren Forest on Plynlimon, mid-Wales.

drill stand and clamp are essential to make the task safe. Safety goggles must always be worn when drilling and this should only be attempted under the supervision of someone qualified, such as a member of staff from your school's technology department.

(c) Magnetic tagging and tracing
This is a technique which researchers have used quite widely in different forms. Holes have been drilled in clasts and a piece of metal rod inserted into the hole. The metal rod needs to be slightly smaller in diameter than the hole you drill. The rod can be an iron nail or welding rod cut to length using a metal saw. It is sealed in, along with a label with a number on it, using epoxy resin. A metal detector is then used to pick up the signal from the tagged pebble, now called a 'tracer'.

This technique has one great advantage over painting clasts, which is that clasts which have moved and become buried in the stream or river bed can still be located even if out of sight. In a recent study on Plynlimon in mid-Wales, where over 300 clasts were traced in two streams, recovery rates using this system were usually greater than 90%.

(d) Radio tracing
Researchers in Germany have developed a pebble transmitter system where transmitters (with batteries) are implanted into individual cobbles and a computerised receiver, stationary antenna, switchboard, and data logging system are used to monitor the movement of clasts during floods!

(2) Trapping

Whether you decide to use a 'net' or trap depends essentially on the size of your stream or river. Ultimately, of course, it will depend on safety considerations and the sort of questions you are trying to answer.

(a) Bedload samplers
These have been developed in various sizes and shapes but usually derive from the original Helley–Smith sampler developed by the United States Geological Survey. The photograph top left shows a modified sampler designed for hand-held use. The sampler in the photograph was made for me in my school's technology department. It consists of a square metal orifice which is held on the bed by means of a wading rod. Bed material passing through is caught in a net, the mesh size of which determines the lower size limit of sediment sampled. The sampler is held on the bed for a fixed length of time (e.g. 2 minutes) and then removed (a bit like fishing!). The net can be removed, emptied and the bed material sampled can be weighed and maybe sieved to estimate its size distribution.

The original Helley–Smith sampler was developed for use off bridges and may be lowered on a rope (see photo on page 26) or cableway. One drawback of such bedload samplers is that they can only be used when the river or stream is in flood and bedload is actually moving. It can be difficult to achieve this unless you are always on 'standby' or you can get to work in a glacial meltwater stream where you know discharge peaks every afternoon.

More recently, large frame-net bedload samplers (1 m wide by 0.45 m tall) have been used. These allow capture of the largest particles in motion.

With all these techniques, safety must always be considered and in fast-flowing rivers it may be necessary to wear a harness and be belayed by a system. Never work alone and, if in doubt, stay on the bank.

Inset 2

Surveying errors

One consideration you must make when measuring channel cross-sections is to estimate how accurate your survey is. In other words, what is your error? This can be estimated by repeating a survey of the same cross-section several times (say 10 times), using the same points each time. At each point it is then possible to calculate the mean depth and standard deviation. Once you know this you can calculate the standard error of the mean (SE):

$SE = s / \sqrt{n}$

where s is the standard deviation of depth readings at one point and n is the number of depth readings at the same point.

By averaging the standard error from all points across your section you can come up with a standard error figure which will depend on things like how accurately you read your metre rule and the size of the bed material. Let's say you calculated a mean standard error of 45 mm. This would tell you that any changes in bed profile which measured greater than 45 mm could be interpreted as 'real'. Any measured changes less than 45 mm would be within your measurement error and you could not be confident in stating that a change in bed height had really taken place since your last survey.

Inset 3

Tips for your project

Your own safety Don't necessarily think 'big river', but rather 'small stream'. Why opt for all the problems of studying processes in a large (potentially dangerous) river when the processes are all happening just as well in a small stream? If you pick a suitable gravel-bed stream a pair of wellies should be all you need. Even so, never work alone — always take someone with you. They can help write down your data (very useful when your hands are wet) as well as acting as a safety net!

Vandals, public interference This can be a problem in many areas. For example, children paddling in a stream who come across several of your brightly-painted yellow pebbles can't resist collecting and playing with them. On the one occasion when I recorded that a marked clast had moved upstream (!) I had to explain it by such 'interference'. This may be one advantage of magnetic tagging of particles — they are less visible. The best advice you can take to overcome this problem of interference is to seek permission to study a stream in a remote area (e.g. in the uplands) or on private land which has no public access.

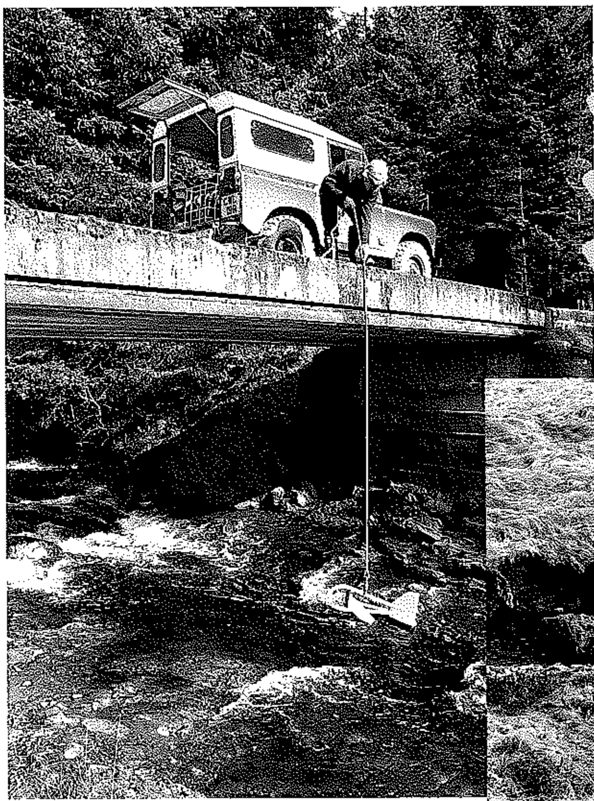
Time scale Allow enough time for several floods to occur. Floods are more likely to occur in Britain between September and April (though we do occasionally get heavy thunderstorms in August) so your study should ideally span this time of the year if you are to increase your chances of observing any bedload movement and channel change. Remember, if several flood events occur in your study period but you observed little or no movement of pebbles or no accumulation of sediment in your traps, this does not mean your experiments have failed. Though this may be a little disappointing, your results are just as valid provided you have collected your data in a scientific way.

Equipment Look at the list of techniques described in this article. You should be able to design a study using easily-available materials such as paint to mark your pebbles, or fishing line to tether them. Maybe you can borrow a metal detector? Could you build your own bedload trap on a small stream or a forest ditch? Can you find a natural pool or existing structure (like a weir or flume) in which bedload might accumulate and then resurvey this after floods using a timber baton and metre rule?

(b) Trapping bedload

A structure such as a weir, flume or dam installed in a river or stream will tend to accumulate bedload behind it. Excavation or survey of the sediment accumulating behind such structures is a technique which has been widely used to estimate bedload transport. In central Scotland, reservoirs which have been drained for maintenance purposes have been surveyed, and estimates of bedload yield have been made from the deposits for an 85 year period.

The bottom photo on page 25 shows a purpose-built bedload trap on the Afon Tanllwyth channel in the Hafren Forest on Plynlimon which has been in operation since 1972. Here, bedload simply falls into a 1 m deep concrete pit in the stream bed and is re-surveyed and excavated regularly to estimate bedload transport rates.



Left: Helley-Smith bedload sampler being lowered from a bridge in Kirkton Glen in central Scotland.

Below: Conducting a levelling survey to assess changes in the river cross-section due to fluvial processes, Monachyle Glen, Balquhidder.

An inexpensive alternative is a trap made from logs and lined with plastic netting which is pinned to the stream bed and catches all sediment coarser than the netting mesh size of 2.8 mm. Again, this was excavated regularly (about once per month) to assess bedload yield and any changes due to afforestation of the surrounding land.

One final technique I have seen used was to install small 'traps' in the stream bed. These traps are not permanent and tend to rely on bedload transport of the surface layers only. Provided the gravel depth of your stream is great enough, plastic flower pots (weighted down) can be sunk into the gravel bed so that the rim is level with the gravel surface. Any bedload moving over the pot should then drop in and be trapped. You must remember to mark the location of your pots in case they get completely filled. In the same way, metal baskets have been dug into the gravel in Alpine pro-glacial streams and emptied daily to estimate bedload transport rate.

(3) Budgeting approaches

It is possible indirectly to determine whether bedload has been transported in a particular stream or river by measuring how the bed of the river changes after floods.

Repeat levelling surveys require a fixed bench mark on each bank of your river. This allows fixed cross-sections of a river channel to be resurveyed using the levelling technique shown in the photograph above. If you are unable to use a level and staff as shown here, it is perfectly possible to conduct these repeat levelling surveys on smaller streams by placing a piece of timber baton (50 mm × 25 mm × ~3 m) across your stream. It can be placed on top of your bench marks, which need to be installed at similar heights on opposite banks, and may even be cut to size. The depth to the stream bed from the timber baton can then be 'plumbed' at fixed intervals (say every 100 mm) across the channel using a metre rule (try to read it to the nearest mm) to obtain a profile.

Repeat surveys of the same cross-section (e.g. after a flood) allow changes in profile in both the bed (build up of the bed if deposition or aggradation has occurred; lowering of the bed if scour or downcutting has occurred) and banks (erosion and slumping) to be identified. They can be quantified by superimposing plotted cross-profiles upon each other. Computer programs are now available to make this task easier. See Inset 2.

If several cross-profiles are re-surveyed over a channel reach a three-dimensional picture of where the channel has changed can be built up and from this it may be pos-

Questions you could investigate in a project

Inset 4

Using pebble tracers

- What is the travel distance of different particles after a flood? How does their size, shape and weight affect the distance they move? Does seeding the tracer make any difference?
- Does their position on the stream bed affect how far they move? (e.g. pebbles placed in riffles compared to pools; pebbles placed on gravel bars compared to those placed in the main flow.)
- What are the most frequent points on the bed where pebbles get deposited? Are they found in pools, riffles or on side bars, or is there no real pattern?

Using traps

- Can you install simple bedload traps to compare the bedload yield of two streams? (e.g. one that has had ploughing on its catchment compared to one which has not.)
- How is the size of a rainstorm and flood event related to the amount and size of bedload trapped?
- Does your bedload trap catch any organic material or other debris? Where does it come from? Can you sort it out into categories? (e.g. leaves, pine cones, litter, moss etc.) How do the relative amounts of debris trapped vary seasonally? (e.g. is there more litter in the tourist season, more leaves in autumn, etc?)

Doing surveys

- What is the measurement error of a particular cross-section survey? How does the size of the bed material affect the error? How does reducing or increasing the interval between measuring points affect the accuracy?
- How do particular river or stream cross-sections respond to flood events? Do they aggrade or scour? How does the response of the river bed change with the size of the flood?
- Is a particular river or stream reach accumulating or exporting bedload over the short term? What are the implications further downstream? If your reach is exporting sediment where is it going? Is there any evidence for increased deposition or increased bank erosion further downstream?

sible to work out where bedload has been removed (scour) and deposited (fill) within your reach. Over discrete time periods a budget for your particular reach can be calculated (rather like a bank balance, but using bedload instead of pounds!). In such a budget, the net bed increase (or aggradation) is balanced against the net lowering (or scour) to decide whether your reach is aggrading or downcutting. Comparison between several time periods can reveal net changes which can perhaps be attributed to flood dynamics, changes in sediment supply (e.g. due to land-use changes upstream) or installation of engineering structures (such as a bank stabilisation scheme or dam construction). ◻

References

Brammer, H. (1996) 'Bangladesh's braided Brahmaputra: living in an unstable environment', Geography Review Vol. 10, No. 2, pp. 2–7.

Briggs, D. (1980) *Sediments*, Blackwell, London.

Stott, T. A. (1989) 'Upland afforestation: does it increase erosion and sedimentation?', Geography Review Vol. 2, No. 4, pp. 30–32.

Waugh, D. (1990) *Geography: an Integrated Approach*, Chapter 3, Nelson, London.

***Dr Tim Stott** is a Senior Lecturer in Physical Geography and Outdoor Education and Route Co-ordinator for the BSc (Hons) with QTS in Outdoor and Science Education in the School of Education and Community Studies at Liverpool John Moores University. His PhD is in fluvial geomorphology and current research interests are in fluvial geomorphology and environmental education. He is a member of the British Geomorphological Research Group's 'Geomorphology in Schools' Working Party. He has previously been a geography tutor with the Field Studies Council and a secondary school geography teacher.*