Proceedings of ICE
Civil Engineering 164 May 2011
Pages 81–87 Paper 1000023

doi: 10.1680/cien.2011.164.2.81

Keywords
disaster engineering; footbridges; military engineering

Caroline Livesey (née Graham-Brown)
MEng, MSc, CEng, MICE, MInstRE, RE

is a captain in the Royal Engineers and second-in-command of 527 Specialist Team Royal Engineers, part of 170 (Infrastructure Support) Engineering Group based in Nottingham, UK

The Barker Crossing: Royal Engineers reconnect Workington

The British military routinely provides assistance to the emergency services during UK disasters. Since it was officially established in 1852, The Corps of Royal Engineers has constructed hundreds of bridges to aid civil communities worldwide, but the bridge at Workington was unusual in its expediency. The team delivered a 52 m span footbridge across the River Derwent, converting a greenfield site into a working crossing within 13 days. This paper illustrates some of the difficulties faced during the design, and highlights how familiarity with the equipment and concurrency of design and construction activities resulted in successful installation of the crossing in such a short time-frame.

Continuous rain throughout October and November 2009 in Cumbria caused minor flooding, but the storm which occurred during the night of 19–20 November produced 316 mm of rain in just 24 h (Met Office, 2011). This level of rainfall was unprecedented and all of the major rivers across Cumbria flooded as a result. The River Derwent, fed by the River Cocker, rose to previously unseen levels, causing damage to many bridges and flooding Cockermouth town centre (Figure 1).

Following the storm, Cumbria County Council deemed it necessary to close

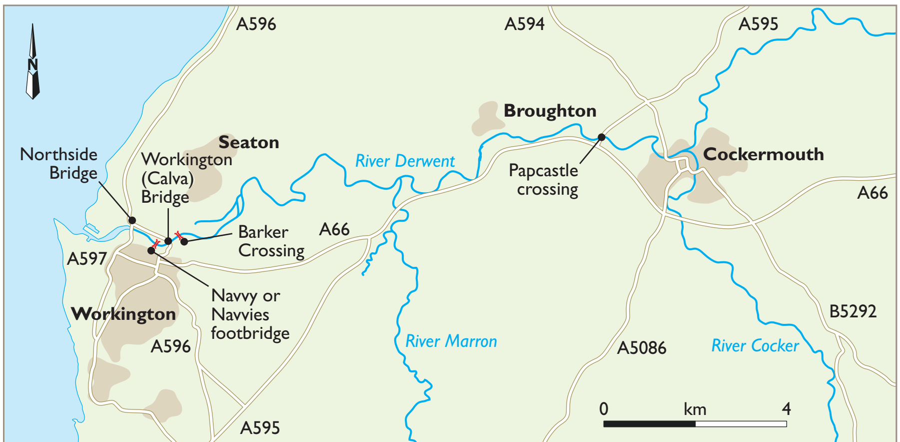

Figure 1. Map of the lower reaches of the River Derwent showing the location of bridges in Workington – until the Barker Crossing was opened on 8 December 2009, the nearest useable bridge after the 20 November floods was 15 km upstream at Papcastle

ice
Institution of Civil Engineers

Figure 2. The A597 Northside Bridge over the River Derwent in Workington collapsed on the afternoon of 20 November 2009, killing police officer Bill Barker

Figure 3. Aerial view looking downstream showing the collapsed Navvy or Navvies footbridge (top right), the damaged A596 Workington (Calva) bridge (centre) and the Barker Crossing site (bottom left)

15 bridges in Allerdale Borough alone (Cumbria County Council, 2011). Workington, being the most downstream of the major towns and situated on the estuary of the River Derwent, lost all three of its major bridges. The A597 Northside Bridge (Figure 2) and the Navvy or Navvies footbridge collapsed completely, while the A596 Workington (Calva) Bridge suffered structural damage and was deemed unsafe for use (Figure 3). Tragically, the collapse of Northside Bridge caused the death of police officer Bill Barker during the afternoon of 20 November.

With all of its main bridges out of use, Workington was now a divided community as the next crossing point was some 15 km upstream at Papcastle. The Seaton community on the north side of the river was cut off from schools, family and essential shopping in the south. As the floods receded and the county council began its relief efforts, an infrastructure recovery group was set up. This was led by the county council and included members of the police, National Health Service, ports authorities, local borough councils and the military. It aimed to bring the organisations together to co-operate in the repair of infrastructure damaged by the flooding, and began immediately to examine ways of providing a temporary bridging solution in the vicinity of Workington town centre. It was at this stage that the The Corps of Royal Engineers (RE) was asked to investigate the possibility of a military bridging solution.

Reconnaissance and site survey

On 24 November a small team from 170 (Infrastructure Support) Engineer Group deployed to Cumbria to assess the situation. Guided by 42 (North West) Brigade, the aim of this team was to assess whether the military could have a positive impact on the Workington community through an expedient temporary bridge providing pedestrian or vehicle access, or both. The requirement at this stage was not specified clearly as the flood water prevented most site information from being obtained. One of the first tasks of the team was to identify the key people involved in the project (see Table 1) and obtain a specific requirement.

The initial team rapidly grew to a full reconnaissance team from 64 Works Group RE, which conducted a site survey at first light on 25 November. Table 2 shows the full project delivery team layout which was in place roughly 24 h later. The availability of suitably qualified RE personnel, who were able to deploy at short notice with the equipment required to set up a small design consultancy in a remote location, was absolutely key to the success of the task.

Several sites were surveyed, but the decision on the preferred location had to be taken early in the conceptual design phase. This was mainly because of land ownership, the need for a large construction area and for a suitable launch plain. Figure 3 shows the location of the borough-council-owned site relative to the Workington (Calva) Bridge, with the collapsed Navvy or Navvies bridge in the top right corner. The design team was asked to provide a go/no-go decision to the brigade as soon as possible. This was confirmed on the morning of Friday 27 November, just 48 h after the first RE team arrived on site. To get to this point the design team worked up to 22 h a day, an ability perhaps not unique to the military, but one that is frequently tested on operations. The design parameters, specified and implied, are shown in Table 3.

On 27 November the design and construction teams were also given a deadline for the opening of the bridge of 7 December, agreed between the military and the county council, in time for schoolchildren to walk to school. The deadline was based on detailed planning carried out between the crossing site commander and his design and construction team commanders.

Table 4 highlights the design and construction time line, showing how crucial the capability to design and build concurrently was to meeting the deadline. The RE carries out design and build under time constraints regularly on operations, and this experience was invaluable during the Workington task.

An RE construction materials technician was present for the initial site survey and rudimentary site investigation was undertaken on both the north and south

Table 1. Key people involved in the Barker Crossing project

Name	Organisation	Position/role in recovery operations	Role in Barker Crossing
Brigadier Alcot	42 (North West) Brigade	Brigade commander	Military liaison
Lt Col Robert Blackstock	170 (Infrastructure Support) Engineer Group	Military infrastructure adviser	Barker Crossing site commander
Andrew Moss	Cumbria County Council	Head of infrastructure recovery group	Adviser and coordinator
Geoff Holden	Cumbria County Council	Major projects manager	County council liaison and coordination
Andrew Butler	Cumbria County Council	Area engineer (Allerdale)	Enabling works to connect with highway network
Mark Wear	Cumbria Constabulary	Deputy inspector/police adviser	Police liaison and security
Rob Terwey	Cumbria County Council	Head of transport	Public transport provision

Table 2. Project team

Crossing site commander	
Reconnaissance/design team	**Operations team**
Liaison officer Lead bridge designer Military clerk of works (2 no.) Military plant foreman (2 no.) Construction materials technician Surveyor Draughtsman	Chief of staff Liaison officer Handover coordinator Health and safety adviser Resources specialist

Table 3. Design parameters

Specified	Implied
• Location of crossing to be within walking distance of town centre. • Time line for construction: 10 days (to meet local and media expectations). • Complete inventory of available bridge parts not initially known. • Construction solution must be within military engineer capabilities. • 6-month design life. • Pedestrian access only (confirmed only once construction was underway). • Be prepared to develop into vehicle crossing in future. • Maximum wind speed of 15 m/s during build.	• Crossing width/width between suitable abutment locations. • North bank site restrictions. • Launch plain (bank height differences) affecting nose design. • Most expedient solution required. • Bridge superstructure to be designed for least number of panels. • Flood plain and grade 2 listed site of special scientific interest. • Ground conditions. • Bridge and surrounding site to be adjusted to meet pedestrian safety requirements.

Table 4: Design and construction time line

Date/time	Activity
24 Nov 1800	Initial site reconnaissance and requirements identification.
25 Nov 0700	Site survey – four sites initially investigated.
25 Nov 1200	Two detailed site surveys, initial ground investigation.
25 Nov 1800	Site chosen, detailed design begins.
26 Nov 0700	Further detailed site survey, landowners identified.
26 Nov 1000	Design team confirms crossing can be done using logistic support bridge.
26 Nov 1200	Major logistic support bridge components available are confirmed and their movement begins, 70% stores bid submitted.
26 Nov 1400	Construction team reconnaissance component arrives, site set up begins.
26 Nov 2100	Groundworks team arrives and completes site set up.
27 Nov 1200	Ground works design completed, work begins on site.
28 Nov 0700	Rehearsals for construction take place off site.
01 Dec 0300	Superstructure design completed.
01 Dec 0800	Superstructure construction begins.
03 Dec 1200	North abutment construction begins.
04 Dec 2100	Nose of bridge reaches far bank.
05 Dec 0200	Full ground investigation complete.
05 Dec 1200	Bridge is decked, access and egress work begins.
07 Dec 0800	Bridge opening.
08 Dec 1200	Handover to Cumbria County Council.

banks in a number of locations. Trial pits were excavated and initial samples taken on the preferred site. Initial results from the 500 mm deep trial pit showed that the ground to the south of the river was well-graded river gravel. However, the ground on the north side had been capped with a solid layer which could not be excavated with hand tools. The team established from the county council that the north bank had previously been the site of a railway and this may have been capped when it was removed. Until the construction team was able to get to the north bank with plant, no further ground investigations could be conducted.

For the full site investigation, specialist RE technicians had to be called forward from Nottingham with equipment to bore to a depth of 4 m. These bores were drilled with a Commachio Geo 205 using 83 mm auger flights. Standard cone penetration tests were carried out to give *N* values which were then used in the abutment design. This further highlighted the need for the depth of RE technical knowledge.

Logistic support bridge

The choice of superstructure was a simple one as the 'logistic support bridge' (LSB) was the only suitable military bridge available for the task, due to its span and the site restrictions. Developed from the Bailey bridge, the LSB is a Mabey & Johnson steel panel bridge which has been specially supplied to the military to cater for operational requirements (Figure 4). The standard panels are pinned together to form trusses for the through bridge and can be used in a variety of configurations depending on span and load. Transoms then connect the trusses and carry the steel decking. Most of the bridge sets are deployed on current operations and it was therefore unclear at the beginning of the design process the exact military equipment available in the UK. This affected the initial stages of the superstructure design, which in turn determined the final design solution. The reduced time for design meant early decisions were key to success.

On operations where the bridge is temporarily on a level site and monitored regularly during heavy trafficking, a chartered engineer is not required for the design work. The bridge can be designed according to its equipment support manual by a qualified officer or senior non-commissioned officer. This is still a labour-intensive task and requires the designer to be intimate with the pitfalls which are present in the design process. In the case of the Barker Crossing, however, the bridge was not to be used as an operational bridge in a war scenario. It was to be used by the British public for a prolonged period of time and therefore had to conform to British standards for access and safety.

The recent flooding of the site and a height difference between the banks of 1·6 m added to the complexity of the design. For these reasons, design by a chartered engineer was absolutely necessary. The RE team had a full range of design skills available, and an operating policy which included full technical design review and checking procedures throughout design before drawings were issued.

Foundation design and construction

Design of the foundations moved quickly through the concept stage. While various options were considered, including piled foundations and concrete pads, it was established that to meet the deadline the most expedient solution was required. Department of Transportation type 1 aggregate (0–50 mm) and geotextile abutments were therefore chosen to minimise construction time, but also to ease their removal in the future when the county council returns the site to its original state. A geotextile company with long-established links to the British Army was contacted both to ensure the most effective design solution had been selected and to confirm the availability of its triaxial geogrid.

Factors of safety at this stage were kept at over double the typical 2–3 for assumed ground conditions. This allowed for construction to begin ahead of the full site investigation, which was being conducted concurrently. The construction platform was also designed at this stage and it was here that the geogrid really proved its worth. Instead of having to excavate topsoil for an area of approximately 60 m by 20 m, the geogrid was laid directly onto the existing ground. The construction sequence utilised required minimal vehicular trafficking

Figure 4. The logistic support bridge is made from standard steel truss panels and then launched from rollers on a geotextile-reinforced construction platform

on the wet topsoil so the geogrid could be laid by hand. The combination of clever sequencing and elimination of excavation simplified the construction and saved significant time.

The construction platform had to be finished to tight tolerances (±20 mm) because of levelling requirements for the geogrid and for the bridge rollers. A construction platform which was not level could have resulted in a skewed bridge later on in the build sequence. The roller configuration can be seen in Figure 4, with packing used to gain the height necessary to support the rollers. The time taken to level the rollers was significantly reduced due to the level surface on the platform.

The abutments on the south bank had two main design loading considerations. At this stage, both pedestrian and vehicular loading were possible, so both were considered. However, there were also temporary loads during construction which were greater than long-term loadings. The greatest load that had to be considered was that of the bridge at its heaviest during construction (92 t), with all of its weight onto the front rollers on the southern ground beam assembly. The technique of moving the centre of gravity forward of the front home-bank rollers is occasionally used in construction to bring the nose down on the far bank. While this situation did not in fact occur in construction, it was considered during design. This gave a maximum (temporary) stress of 51 kN/m^2 to be considered during design.

Resourcing was crucial throughout, but especially during the groundworks phase where little lead time was given for critical materials to be on site. The military resourcing chain was fully tested, and the success on site was largely due to background planning undertaken within this chain. The large quantities of both aggregate and riprap required were ordered with little more than 24 h notice and it is a credit to the local companies used that they were able to respond on time.

The site chosen for the southern abutment was on an existing flood plain so it was necessary to protect against flooding. The design team worked with the Environment Agency flood engineers to establish the 1-in-100-year-flood levels in this area. This was deemed to be the minimum requirement for the structure despite the proximity to a major flood event, and the fact that the base of the southern abutment is on a site which floods almost annually. Riprap, consisting of 200–500 mm angular carboniferous limestone, was chosen because of the temporary nature of the construction, and designed to wrap around the southern abutment (Figure 5). The northern abutment was above the 1-in-100-year levels and therefore did not require additional protection.

Once plant was able to access the northern site to excavate for the abutment, contaminated ground was discovered. Unfortunately, the bridge was already in an advanced state of construction on the south bank. This led to some tense moments for the design team as the ground was assessed and the material removed. The construction materials technician who discovered the material was competent in assessing contamination and had a good environmental awareness, again highlighting the need for such skills within the RE. The borough council reacted quickly and found a safe area for the contaminated material to be stored for future treatment. An amount was removed for testing (in accordance with BS EN 12457 part 3 (BSI, 2002)) and later found to be an inert material (according to the unpublished Severn Trent Report MID/664797/2010), perhaps a by-product from an old ironworks. Sound foundation material, sub-angular gravel with maximum particle size of 20 mm, was found beneath the contamination of a similar type to the south bank.

The design for the abutments was then completed, with finish levels dictated by the restricted space on the north bank for stripping panels as they came across the landing rollers (Figure 6). An existing road beyond the north site also limited the excavation which could be conducted.

Bridge design and construction

Design of the 52 m span superstructure was mainly in accordance with the Mabey & Johnson guidance, but there were still a number of considerations. The height difference from the launch platform to the landing rollers, and the existence of a retaining wall on the north bank, meant there was a danger the deflection of the bridge would cause the nose to land too low or hit the existing retaining wall. With this span of bridge, a deflection of 1·4 m was expected at full cantilever extension. This meant the nose required a further set of nose links inserted to give

Figure 5. Limestone riprap was used to protect the southern abutment from 1-in-100-year floods

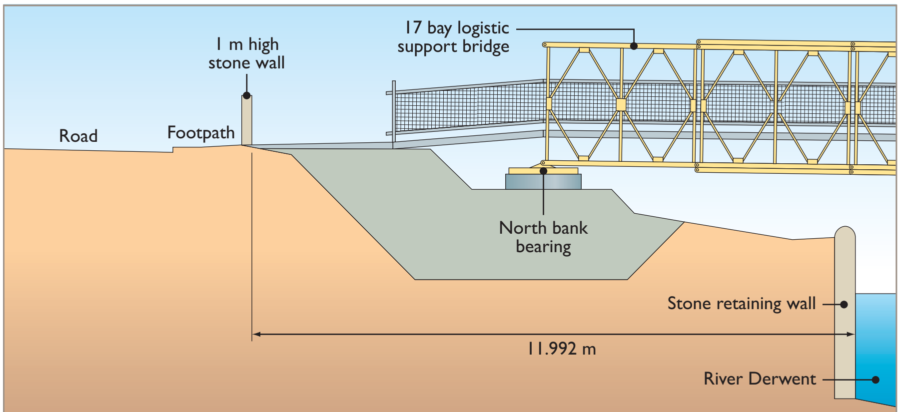

Figure 6. Cross-section of the northern abutment, where there was just 12 m between the existing river retaining wall and roadway

additional clearance. It was also necessary to check the deflection of this span of bridge taking into consideration pedestrian loading and resonance.

Once the bulk of the superstructure design had been completed, the construction team could begin with the main build. The team were 3 Armoured Engineer Squadron supported by members of the bridging team from the RE battlefield engineering wing. The construction followed the sequence typical for this type of bridge set out in Army Equipment Support Publication 5420-C-125 (British Army, 2007), with variation only where site restrictions dictated. Familiarity with the equipment was crucial to the speed of the construction and rehearsals off site ensured the construction team was familiar with the details. Figure 7 shows the part-completed superstructure being winched across the river, with the upward-tilting nose nearing the north bank.

Throughout the design phase there were ongoing discussions between key stakeholders as to the load the crossing should carry. Although the LSB superstructure would have been capable of carrying a total vehicle load of at least 40 t, the abutments were not of a suitable construction material for regular trafficking by large vehicles. More permanent abutments would have been within the capabilities of the RE team, but would not have met the required timeframe. There were also surrounding issues related to vehicle access and egress for the bridge. The decision to keep the bridge solely as a pedestrian crossing was only made during the construction process, and the design team developed two design solutions in parallel to ensure one was ready for that decision point. This concurrency throughout the design process was key to the expediency of the project and ensured no delays were incurred.

Making the bridge safe for pedestrians brought with it problems of a different nature. Access and egress had to be suitable for wheelchairs, bicycles and safe for children. Given the attempts by desperate locals to cross the structurally unsound Workington (Calva) Bridge, there was also a requirement to prevent vehicle access across the temporary crossing. However, the military wished to retain the bridge in a suitable condition for the future, so that it could be recovered and used again. This limited the design options available and the resulting scaffolding with timber stanchions – which was used both to provide the pedestrian handrail and prevent children falling from the bridge – was a necessarily temporary solution.

Figure 7. Aerial view showing the 92 t structure being winched across the river – the upward curve of the lightweight nose sections compensates for the 1·4 m deflection

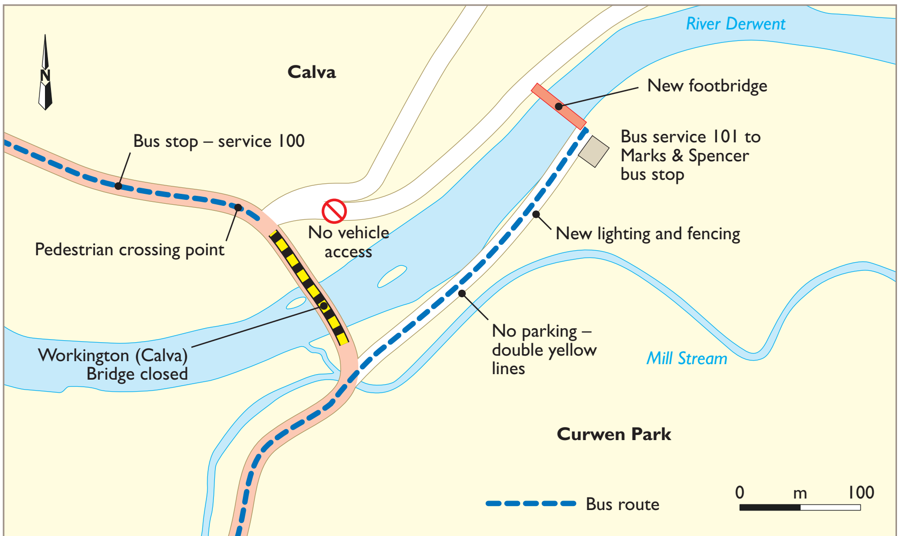

Figure 8. New bus routes together with footpaths, lighting and fencing were organised to facilitate access to the new crossing

Co-operation between teams

One of the main advantages of the RE undertaking the work was the ability to coordinate closely the construction force, which was from a different RE unit, and the design team. The extremely tight time lines for design and construction, and the 24 h working day on site, meant co-operation between the two was essential. While the design team members worked on the detailed design, they also spent time on site to ensure that the construction conformed to the design, and resolved any misunderstandings. This ease of communication between designer and contractor is perhaps unusual within the construction industry, but is a core strength of the RE. Without this capability the project would not have succeeded. The 24 h working days for both teams delivered the project in under half the time that would normally have been achieved.

The co-operation was also essential to the relationship between the RE and the local agencies involved in the flood relief effort. The RE team could not have delivered the bridge without the expert help and local knowledge provided by the police, councils and many other local people. The crossing needed to be meshed with the local pedestrian footways to provide access to schools and to Workington town centre. Lighting, surfacing and safety were all addressed in a very short time by the council. The access for buses and taxis to either end of the bridge significantly increased its utility, especially for older members of the community and school children (Figure 8).

Completion

On completion the bridge was handed over to the county council to be maintained until it is no longer needed and can be removed (Figure 9). A full package of design work was provided and a maintenance regime agreed by both parties. Notably, it was considered necessary to monitor the levels of the bankseat beams on each abutment for settlement. This would be especially important in any future flood event where the safety of the bridge could be compromised. It was recommended that if water levels came up around the southern abutment, monitoring should take place to gauge any subsidence, and for a period afterwards. Fortunately at the time of writing the river levels have not risen beyond their banks and the abutments are sound.

The county council has since installed a pedestrian-traffic-monitoring system on the bridge, and it is notable that at its peak some 35 000 pedestrians a week were crossing the bridge. In April 2010 the county council managed to open a vehicle crossing just upstream of the collapsed Northside Bridge and planned to reopen the repaired Workington (Calva) crossing early in 2011. The Barker Crossing was recovered by the RE in late February 2011, following the repair of the Calva Bridge. This bridge is still undergoing some work, but is open to pedestrians, which has removed the necessity for the logistic support bridge. The author was lucky enough to be part of the recovery team.

Conclusion

There are many things the engineering community can take away from this example of successful disaster relief in the UK. The RE has a unique capability in 170 (Infrastructure Support) Engineer Group with chartered civil engineers, and mechanical and electrical engineers in charge of teams of experienced clerks of works, draughtsmen, surveyors and construction materials technicians. The advantage of these small teams of technically qualified engineers is their capacity to deploy rapidly to areas still suffering from lack of basic services after natural disasters.

Teams from the group regularly spend time on operations and exercises carrying out design work and project-managing construction in areas where materials may be scarce or time short. This capability may only seem useful for military operations, but it was easily adapted for flood relief in Cumbria. Experience solving design problems under pressure with limited resources was crucial for efficient delivery. Deft project management, clear command structure, intimate knowledge of the construction force and the ability to design and build concurrently also proved essential for the challenges faced.

The project also highlighted the ability of local agencies to work together in times of need. The RE could not have delivered the bridge without the support and quick response of all of the people involved. Both the county and borough councils ensured that resources were available and that the RE was a fully integrated part of the flood relief effort.

Regular infrastructure working groups attended by representatives from the police, health services, ports authorities, councils and media ensured that all those involved were kept informed, and were involved in any major decisions taken about the crossing. The RE chartered civil engineers rapidly demonstrated professional competence to their civilian counterparts and integrated into civil agencies at every level. This level of competence, experience and dexterity has been hard-earned on operations, and the Barker Crossing was a thorough test of the RE capability to design, resource and construct under pressure.

Figure 9. Up to 35 000 people a week have used the crossing, which was taken out of service in February 2011

References

British Army (2007) *Army Equipment Support Publication 5420-C-125 Vol. 1 Issue 2, Logistic Support Bridge*. Ministry of Defence, London.

BSI (British Standards Institution) (2002) BS EN 12457-3:2002: Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (without or with size reduction). BSI, Milton Keynes.

Cumbria County Council (2011) See http://www.cumbria.gov.uk/news/2009/november/25_11_2009-100422.asp (accessed 02/02/2011).

Met Office (2011) See http://www.metoffice.gov.uk/climate/uk/extremes/#rainfall (accessed 02/02/2011).

What do you think?

If you would like to comment on this paper, please email up to 200 words to the editor at journals@ice.org.uk.

If you would like to write a paper of 2000 to 3500 words about your own experience in this or any related area of civil engineering, the editor will be happy to provide any help or advice you need.