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Groundwater – surface water interactions: A survey of UK field site infrastructure

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Professor Mike Depledge Head of Science

Executive Summary

The Environment Agency has established a research programme studying the interactions between groundwater (aquifers) and surface water (principally rivers and streams). The research examines the processes that affect pollutants, reducing their mass, concentration, toxicity or mobility. It focuses on how these processes operate at the interface of groundwater and surface waters, known as the hyporheic zone.

The research is needed to improve understanding of the processes that control water flow and pollutant movement between groundwater and surface waters. This information will be useful to national regulatory bodies, government departments, water and sewerage companies and national conservation bodies.

A better understanding of the groundwater-surface water system is needed to make decisions related to water resources and environmental quality. Such information is also required to implement the EU Water Framework Directive.

This report reviews current field-based facilities in the UK used for the research on groundwater – surface water interactions.

Contents

1 Introduction and aims

There is considerable UK field-based activity studying the interactions between groundwater (aquifers) and surface water (principally rivers and streams). As a result of recent initiatives, such as the Lowland Catchment Research (LOCAR) and Catchment Hydrology and Sustainable Management (CHASM) programmes, there is now an extensive network of experimental infrastructure in the UK.

This report documents current related field-based programmes within the UK, and gives a detailed inventory of the infrastructure in place. The emphasis in the report is on hydrological studies, and the processes that operate at the interface of groundwater and surface waters, known as the hyporheic zone.

Where possible, publications associated with the listed field programmes are cited. As many studies are relatively new, an attempt has been made to cite publications in preparation or theses. For the catchments recently developed under LOCAR and CHASM, details are provided of borehole installations as these are currently unavailable in the literature.

Table 1 lists the field sites reported here along with principal contacts and general aims of the work. Further contact details are provided in Appendix 1.

Table 1 Summary of field sites described in this report

Report reference	Location	Organisation	Funder	Contact	Research title/aims
LOCAR-P	Frilsham, River Pang	LOCAR Infrastructure	NERC LOCAR/JIF	Prof Denis Peach Tel: 01491 838800 dwpe@bgs.ac.uk	To investigate hydrological, hydrogeological, geomorphological and ecological interactions within permeable catchment systems.
LOCAR-L	Boxford, River Lambourn				
LOCAR-T	Helshaw Grange, River Tern				
Lancaster-CEH-Lambourn	Great Shefford, River Lambourn	Lancaster University CEH Wallingford	NERC LOCAR	Prof Andrew Binley Tel: 01524 593927 A.Binley@lancaster.ac.uk	Characterisation of groundwater sources in the River Lambourn
Lancaster-CEH-Tern	Helshaw Grange, River Tern	Lancaster University CEH Wallingford	Environment Agency / NERC LOCAR	Prof Andrew Binley Tel: 01524 593927 A.Binley@lancaster.ac.uk	Groundwater-surface water interaction in the River Tern
QMUL-Lambourn	Westbrook Farm, River Lambourn Bagnor, River Lambourn	Queen Mary University of London	NERC LOCAR	Dr Mark Trimmer Tel: 020 7882 3007 m.trimmer@qmul.ac.uk	Ecological significance of surface-subsurface hydrological exchange in lowland rivers. Distribution of hyporheic invertebrates and their functional significance in a chalk river
Exeter-CEH-D-Frome	10 sites on Frome/Piddle	Exeter University CEH Dorset	NERC LOCAR	Sean Arnott Tel: 01305 213635 sarn@ceh.ac.uk	To identify and trial new methods of locating up-welling and down-welling sites

Table 1 Summary of field sites described in this report (cont.)

Report reference	Location	Organisation	Funder	Contact	Research title/aims
CEH-D-Frome	Notten, River Frome East Stoke, River Frome	CEH Dorset	CEH	Dr John Davy-Bowker Tel: 01305 213560 jobo@ceh.ac.uk	Benthic and hyporheic macroinvertebrate responses to up and down welling vertical hydraulic exchange that occur naturally at the heads and tails of riffles.
CHASM-Eden	Great Musgrave, Appleby, River Eden	University of Newcastle	NERC/JIF	Dr Geoff Parkin Tel: 0191 222 6146 Geoff.Parkin@newcastle.ac.uk	Infrastructure for characterisation of groundwater-surface water interactions in the Eden catchment.
Aberdeen	Allt a' Mharcaidh Feshie Girnock	University of Aberdeen	Various including CHASM	Prof Chris Soulsby Tel: 01224 272344 c.soulsby@abdn.ac.uk	Groundwater contributions in mountainous catchments. Hyporheic water quality and salmon egg survival.
Southampton	Rivers Test (Hants.), Blackwater (Hants.), Ithon (Powys), Aran (Powys)	Southampton University	Defra	Prof Paul Carling Tel: 023 8059 2214 P.A.Carling@soton.ac.uk	Modelling sediment levels in Salmonid spawning gravels.
Bristol-Severn	Leighton, River Severn	University of Bristol University of Durham	NERC	Prof Paul Bates Tel: 0117 928 9108 paul.bates@bristol.ac.uk	Monitoring and modelling of floodplain hydrology and transport processes.
Birmingham-Tame	Witton, West Midlands	University of Birmingham	Environment Agency	Dr Mike Rivett Tel: 0121 414 3957 M.O.Rivett@bham.ac.uk	To assess the interaction of Triassic Sherwood Sandstone groundwater and the River Tame, and the impact of a groundwater contaminant plume on river quality.

Table 1 Summary of field sites described in this report (cont.)

Report reference	Location	Organisation	Funder	Contact	Research title/aims
Birmingham-Lea	Hatfield, Upper Lea	University of Birmingham	University of Birmingham/ Environment Agency	Dr Mike Rivett Tel: 0121 414 3957 M.O.Rivett@bham.ac.uk	Assessment of potential contamination from groundwater contaminant plume.
BGS-Plynlimon	Plynlimon, Afon Hafren	BGS Wallingford CEH Wallingford	BGS	Dr Paul Shand Tel: 01491 838800 psd@bgs.ac.uk	Groundwater-river interaction in forested upland catchments.
UEA-Slea	River Slea, Lincolnshire	University of East Anglia	Environment Agency	Dr Kevin Hiscock Tel: 01603 593104 k.hiscock@uea.ac.uk	Understanding movement of pollutants through the River Slea catchment.

2 LOCAR sites

The Lowland Catchment Research (LOCAR) Programme has established a number of field sites for research into hydrological and ecological processes in lowland catchments (Adams *et al.,* 2003a, 2003b). The initiative focuses on three study areas: the Frome/Piddle in Dorset, the Pang/Lambourn in Berkshire and the Tern in Shropshire. The LOCAR programme has funded development of infrastructure within these study areas in addition to funding research projects (Wheater and Peach, 2004; see also http://www.nerc.ac.uk/funding/thematics/locar/). References to relevant projects are made later in this report. In this section attention is focussed on the LOCAR infrastructure relevant to groundwater-surface water interaction studies.

The three main LOCAR field sites are Frilsham on the River Pang in Berkshire, Boxford on the River Lambourn in Berkshire and Helshaw Grange on the River Tern in Shropshire. Boreholes were installed in 2001 at each of these sites. The borehole arrays span the river and twin piezometers allow sampling at various depths. An open hole (for pumping tests or tracer tests) also exists at each site. The original plans were to also provide an inclined borehole under the river bed but fear of interference with the river system led to abandoning this at the time of drilling.

2.1 LOCAR-Pang

The location of the site at Frilsham (LOCAR reference PL11) is shown in Figure 2.1. The river flow is gauged close to the site by an existing Environment Agency weir (Environment Agency gauge 2140, NGR SU 537 730), downstream of the borehole array (see Figure 2.1). In addition, a rated section upstream of the borehole array has been developed by Lancaster University. Figure 2.2 shows the location of boreholes within the site and Table 2.1 gives relevant completion details for the boreholes (including an indication of which piezometers are currently being logged with pressure/temperature probes). Several piezometers are also currently being sampled for water chemistry by the catchment service teams.

The Frilsham site also contains an instrumented LOCAR ‘recharge site’ comprising of tensiometer arrays, neutron probe access tubes and suction lysimeters. An automatic weather station is also located on site.

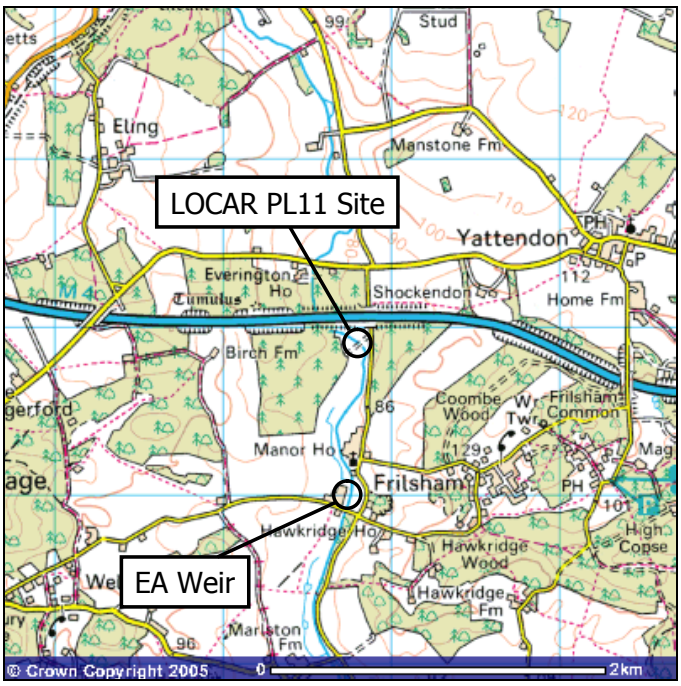

Figure 2.1 Location of LOCAR PL11 (Frilsham) site
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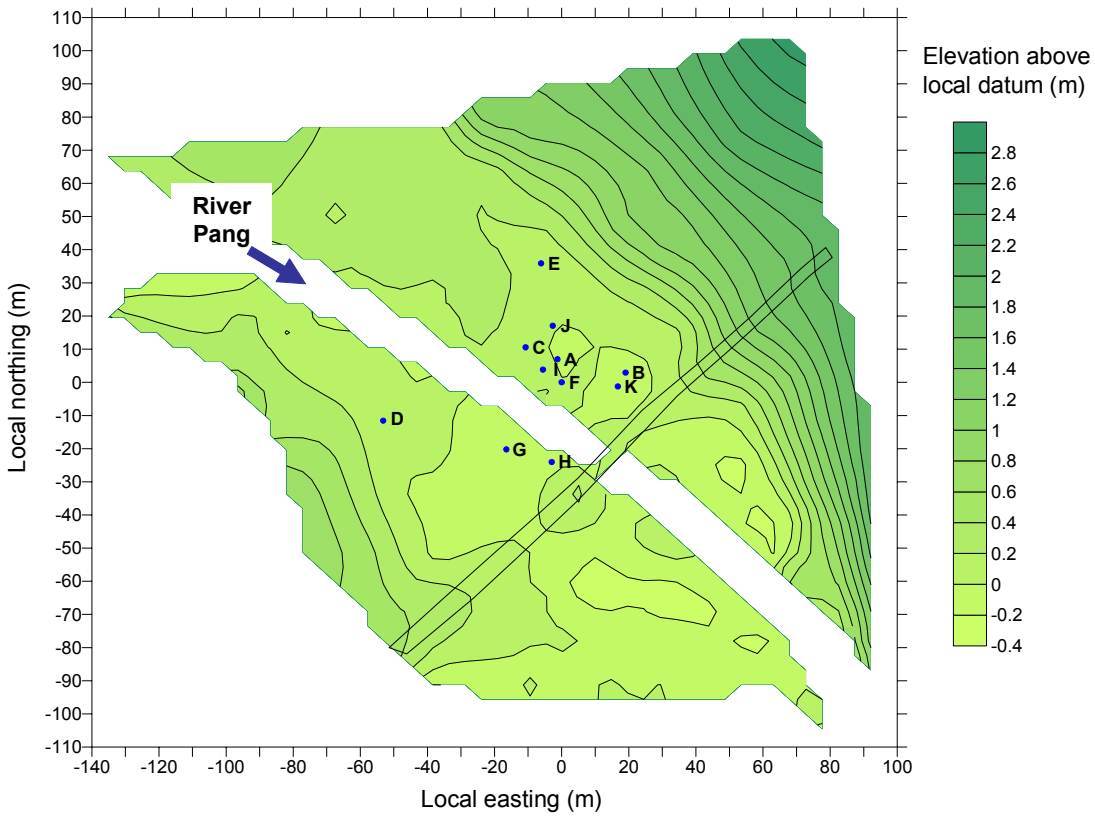

Figure 2.2 Location of LOCAR PL11 (Frilsham) borehole array
(Survey carried out by Lancaster University).

Table 2.1 LOCAR PL11 (Frilsham) borehole details
(* indicates piezometers being logged for pressure/temperature by LOCAR Catchment Service Team)

Borehole	Piezometer	Easting (m)	Northing (m)	Total Depth (m bgl)	Depth to Screen (m bgl)		Diameter (mm)
					Top	Bottom	
PL11A	OPEN HOLE	453809.41	173934.19	41.35			195
PL11B	OPEN HOLE	453829.46	173928.12	40			145
PL11C	OPEN HOLE	453800.30	173938.57	60			140
PL11D	1*	453758.37	173910.60	37.61	36.56	37.61	80
	2*			10.5	9.50	10.50	80
PL11E	1*	453807.32	173963.44	74.7	73.80	74.70	80
	2*			45	44.10	45.00	80
PL11F	1*	453810.28	173926.84	40	33.00	34.00	80
	2*			14.1	13.10	14.10	80
PL11G	1*	453791.89	173908.18	39.5	38.50	39.50	80
	2*			20.5	19.50	20.50	80
PL11H	1*	453805.17	173903.24	43	42.00	43.00	80
	2*			40	32.00	33.00	80
PL11I	1*	453804.96	173931.49	5.4	5.00	5.30	80
PL11J	1	453809.04	173944.27	5.45	5.00	5.35	80
PL11K	1*	453826.57	173924.10	5.3	5.00	5.30	80

2.2 LOCAR-Lambourn

The location of the Boxford site (LOCAR reference PL26) is shown in Figure 2.3. Figure 2.4 shows the location of boreholes within the site and Table 2.2 gives relevant completion details. The nearest operational river flow gauge is Welford (Environment Agency gauge 2255, NGR SU 411 731). In addition, British Geological Survey Wallingford recently installed additional shallow boreholes at the site as part of the project "Hydrogeochemical functioning of lowland permeable catchments: from process understanding to environmental management" (NERC reference NER/T/S/2001/00942), although details are currently not available.

A small wetland downstream of the PL26 site has been the focus of previous studies by Reading University (see for example, Prior and Johnes, 2002). These and other wetland studies (for example, WS Atkins, 2001) offer other sources of data and infrastructure within the riparian zone.

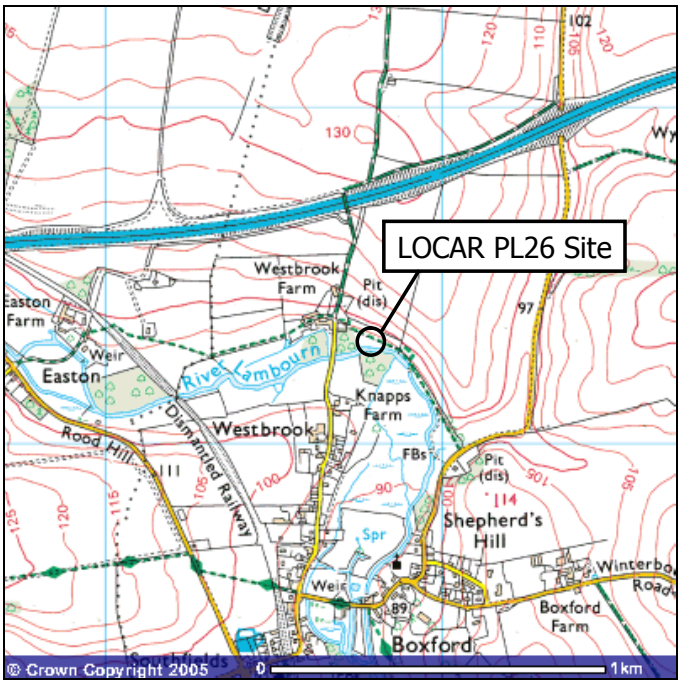

Figure 2.3 Location of LOCAR PL26 (Boxford) site
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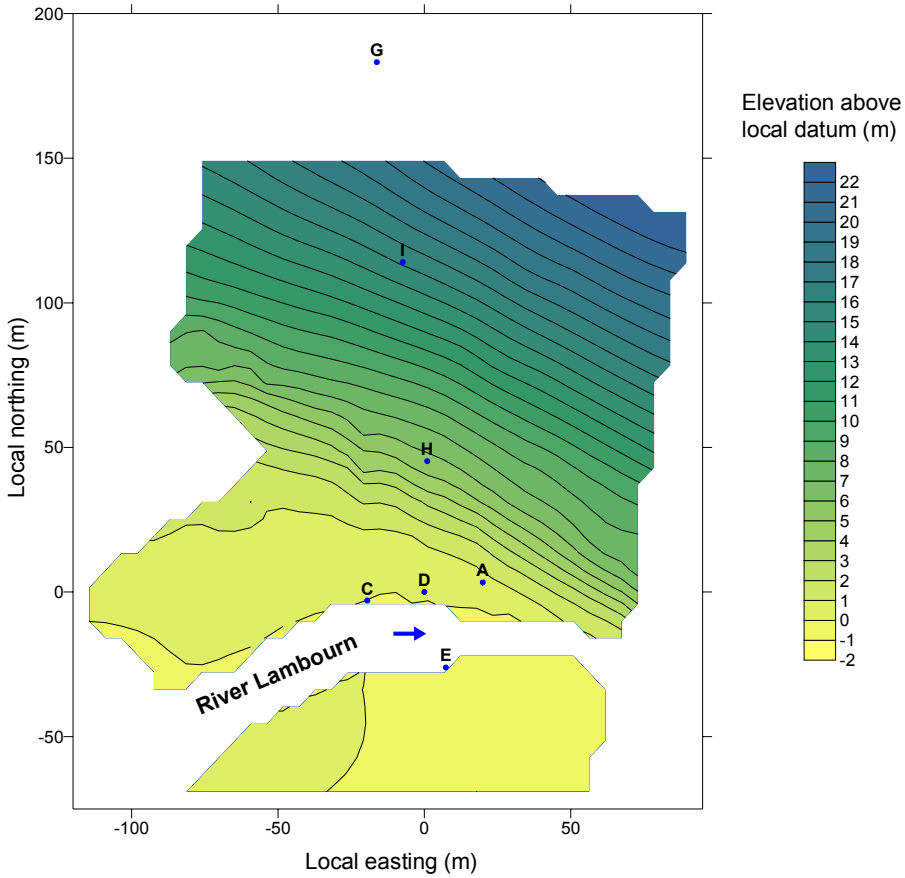

Figure 2.4 Location of LOCAR PL26 (Boxford) borehole array
Borehole BH26F is not shown on the map. It is located approximately 35 m south of borehole E. (Survey carried out by Lancaster University)

Table 2.2 LOCAR PL26 (Boxford) borehole details
(* indicates piezometers being logged for pressure/temperature by LOCAR Catchment Service Team)

Borehole	Piezometer	Easting (m)	Northing (m)	Total Depth (m bgl)	Depth to Screen (m bgl)		Diameter (mm)
					Top	Bottom	
PL26A	1*	442822.67	172295.09	24.02	23.10	23.87	80
	2*			1.78	1.00	1.78	80
PL26C	1*	442782.75	172298.07	23.9	22.98	23.67	80
	2*			4.7	3.80	4.50	80
PL26D	1*	442802.40	172296.50	25.13	24.30	25.13	80
	2*			3.64	2.80	3.64	80
PL26E	1*	442803.46	172269.47	25.2	24.50	25.20	80
	2*			4.4	3.70	4.40	80
PL26F	1*	442800.03	172231.89	28.94	11.07	28.94	215
PL26G	1*	442829.01	172478.10	90.3	44.30	90.30	34
	2*			41	28.30	41.00	50
PL26H	1*	442814.06	172340.09	29	28.00	29.00	80
	2*			22.1	21.10	22.10	80
PL26I	1*	442822.67	172295.09	50	41.40	49.91	80
	2*			32.34	31.30	32.25	80

2.3 LOCAR-Tern

The LOCAR site for groundwater-surface water interactions on the Tern is located at Helshaw Grange, upstream of Stoke on Tern (see Figure 5). Seven boreholes were installed as part of the LOCAR programme; these are supplemented by two existing Environment Agency boreholes. Tables 2.3 and 2.4 give completion details for the boreholes. The Tern site also contains a LOCAR 'recharge site' (LOCAR reference TE11) comprising of tensiometer arrays, neutron probe access tubes and suction lysimeters. The nearest flow gauge is at Tern Hill (Environment Agency gauge 54044, NGR SJ 628 315, LOCAR reference TE05). An automatic weather station is also located at NGR SJ 625 255 (this is also a LOCAR 'recharge site' site – TE10). The Tern catchment is part of the Environment Agency Shropshire Groundwater Scheme and thus additional hydrogeological information is available to support the new infrastructure.

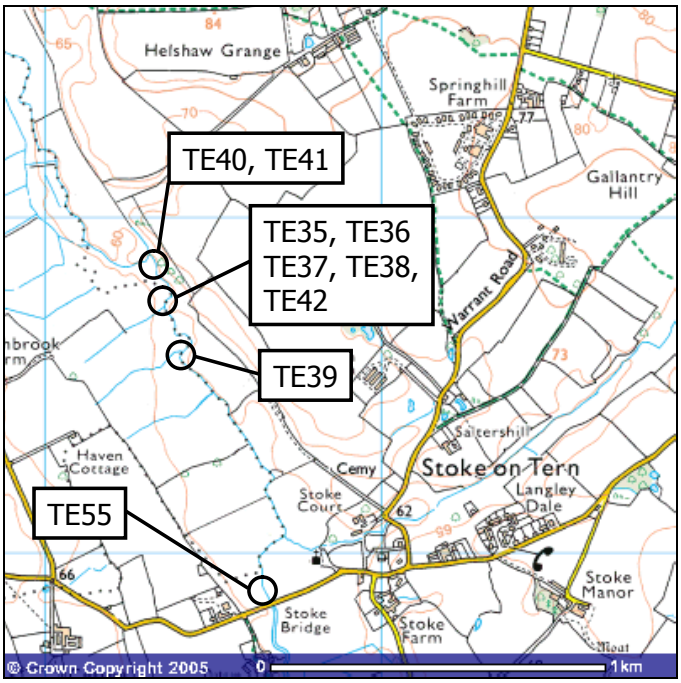

Figure 2.5 Location of LOCAR Tern (Helshaw Grange) site
Approximate locations of boreholes indicated on map.
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Table 2.3 LOCAR Tern (Helshaw Grange) borehole details

Name	Grid Reference	Description	
TE35	SJ 63343 28721	Borehole array	open hole
TE36	SJ 63332 28713	Borehole array	2 piezometers
TE37	SJ 63358 28731	Borehole array	2 piezometers
TE38	SJ 63350 28739	Borehole array	2 piezometers
TE39	SJ 63397 28596	Downstream of borehole array	2 piezometers
TE40	SJ 6332 2887	EA borehole	
TE41	SJ 6334 2887	EA borehole	
TE42	SJ 63374 28741	Borehole array (across stream)	2 piezometers
TE55	SJ 63645 27846	Stoke on Tern bridge	1 piezometer

Table 2.4 LOCAR Tern (Helshaw Grange) piezometer details
(* indicates piezometers being logged for pressure/temperature by LOCAR Catchment Service Team)

Piezometer	Diameter (mm)	Screen interval (m bgl)
TE36-1*	90	19.3 to 21.8
TE36-2	90	1.7 to 2.7
TE37-1*	90	19.5 to 22
TE37-2*	90	2.5 to 3.5
TE38-1*	90	20.5 to 23
TE38-2*	90	2.5 to 3.5
TE39-1*	90	24.8 to 25.8
TE39-2*	90	4 to 5
TE42-1*	90	22.5 to 25
TE42-2*	90	2 to 3
TE55-1*	90	

3 Lancaster-CEH-Lambourn

This LOCAR project is investigating groundwater-surface water interaction within the Pang and Lambourn catchments using a range of in-stream and borehole monitoring techniques (NERC reference NER/T/S/2001/00948). The project team measured flow accretion profiles with the two catchments between 2002 and 2004. These surveys, coupled with various river and groundwater chemical sampling (radon, CO_2, dissolved metals) have identified specific reaches of contrasting groundwater-surface water interaction.

During 2003 and 2004 the measurement programme was supplemented by finer spatial sampling surveys over a number of these reaches (including PL11 and PL26). In 2004 the project team installed instrumentation along a reach of the River Lambourn near the village of Great Shefford. Two borehole arrays were installed (see Figure 3.1): one at Maidencourt Farm (reference MCT) and one downstream of Great Shefford (reference GSF). Between these two sites significant flow accretion has been noted (see Figure 3.2).

Figure 3.3 and 3.4 show the site layout for the two arrays. Tables 3.1 and 3.2 indicate the relevant borehole completion details and locations of in-hole pressure/temperature loggers. In addition, an in-stream logging stage/temperature/electrical conductivity/pH recorder is installed close to the upstream borehole array.

Further details of the project can be found at http://www.nerc-wallingford.ac.uk/research/locar/geophys/index.htm and are reported in Crook *et al.* (2004).

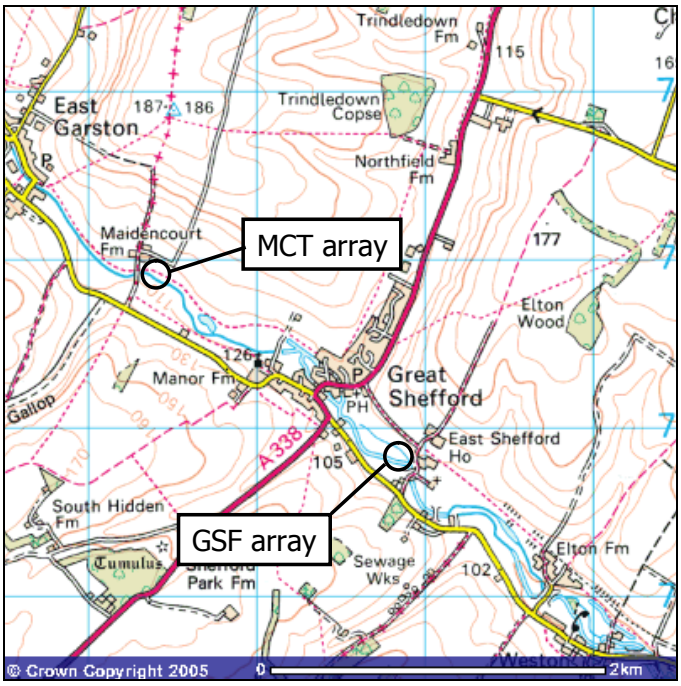

Figure 3.1 Location of Lancaster-CEH-Lambourn borehole array sites on River Lambourn

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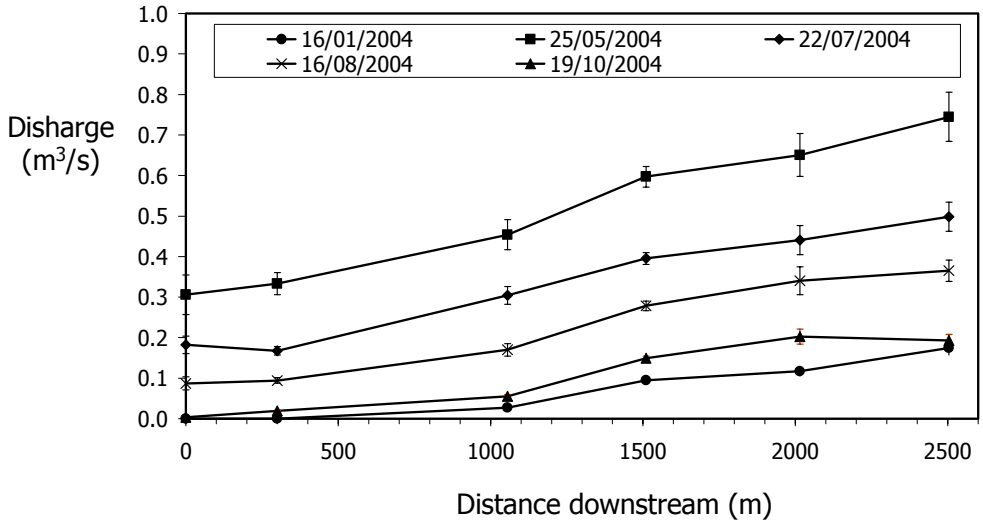

Figure 3.2Example flow accretion profiles on Lancaster-CEH-Lambourn Great Shefford reach

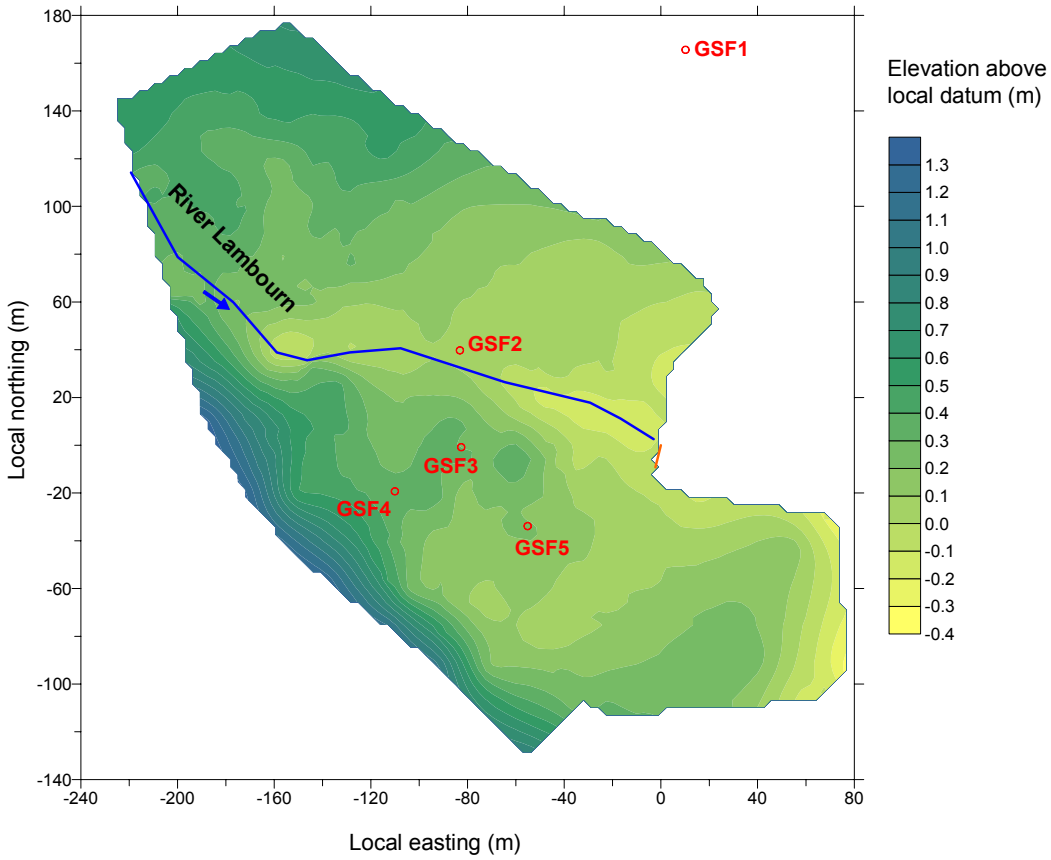

Figure 3.3 Location of Lancaster-CEH-Lambourn borehole array at Great Shefford site
(Survey carried out by Lancaster University)

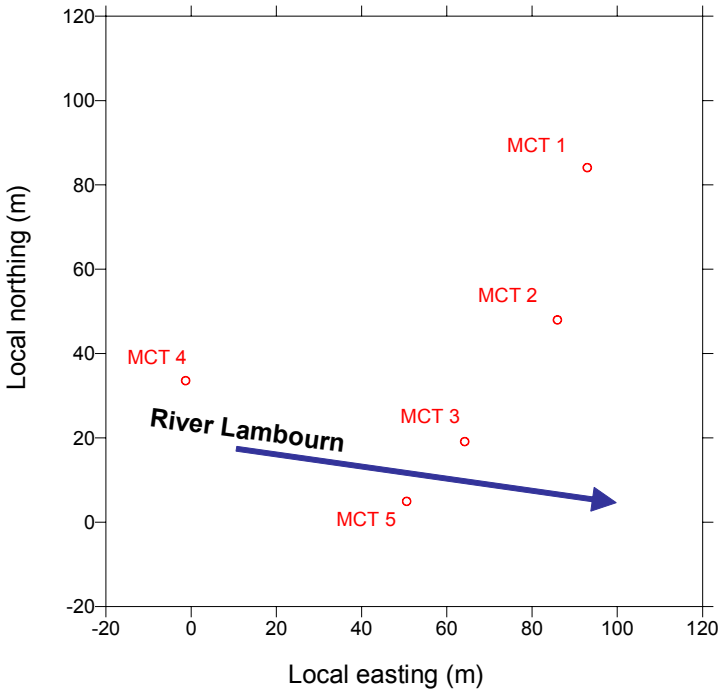

Figure 3.4 Location of Lancaster-CEH-Lambourn borehole array at Maidencourt Farm site
(Survey carried out by Lancaster University)

Table 3.1 Borehole details for Lancaster-CEH-Lambourn site at Great Shefford
(* indicates piezometers being logged for pressure/temperature by Lancaster – CEH Wallingford team)

Borehole	Piezometer	Total Depth (m bgl)	Depth to Screen (m bgl)		Diameter (mm)
			Top	Bottom	
GSF1	1*	13.08	12.14	12.95	50
	2	10.11	9.17	9.98	50
GSF2	1*	6.03	5.22	5.82	50
	2	3.12	2.18	2.99	50
	3	1.21	0.36	0.88	50
GSF3	1*	5.13	4.19	5.00	50
	2	2.63	1.68	2.53	50
	3	1.21	0.30	1.04	50
GSF4	1	4.45	3.50	4.31	50
	2	2.10	1.16	1.97	50
GSF5	1	5.04	4.09	4.90	50
	2	3.13	2.21	3.02	50

Table 3.2 Borehole details for Lancaster-CEH-Lambourn site at Maidencourt Farm (* indicates piezometers being logged for pressure/temperature by Lancaster – CEH Wallingford team)

Borehole	Piezometer	Total Depth (m bgl)	Depth to Screen (m bgl)		Diameter (mm)
			Top	Bottom	
MCT1	1*	10.09	9.16	9.97	50
	2	6.11	5.18	5.99	50
MCT2	1*	5.12	4.18	4.99	50
	2	2.15	1.20	2.02	50
MCT3	1*	6.07	5.13	5.97	50
	2	3.5	2.55	3.40	50
	3	0.83	0.23	0.79	50
MCT4	1	5.13	4.19	5.00	50
	2	3.13	2.19	3.03	50
MCT5	1*	6.9	5.96	6.77	50
	2	4.04	3.10	3.91	50
	3	1.24	0.42	1.10	50

4 Lancaster-CEH-Tern

The Lancaster-CEH Wallingford LOCAR project is also working at the Helshaw Grange site on the River Tern. The project is investigating stream-groundwater interactions in lowland chalk catchments (NERC reference NER/T/S/2001/00948).

Additional funding from the Environment Agency for this project has added extra experimental equipment to the Tern Helshaw Grange field site. Twelve continuous logging river bed piezometers were installed in 2005 in four patches, each with piezometers at three depths in the river bed sediments. In addition, twenty continuously logged temperature probes were installed in five arrays, each with four sensors at various depths. The equipment was designed to assess vertical fluxes to the river using (natural) thermal tracers.

The work has been supplemented by river flow accretion and river and groundwater chemistry monitoring. During 2005 groundwater and river bed sediment tracer experiments are planned at the site.

5 QMUL-Lambourn

Two LOCAR funded projects are currently running at Queen Mary University of London (LOCAR reference NER/T/S/2002/00228). Both operate on the River Lambourn in Berkshire and are studying the ecological significance of surface-subsurface hydrological exchange in lowland rivers.

Project 1 (from April 2003 to April 2006) is looking at nutrient availability and biogeochemical processing in the hyporheic zone and is led by Dr Mark Trimmer and Dr James Petty. Work is being carried out at two main sites on the River Lambourn: Westbrook Farm (NGR SU 427 723) in the vicinity of the LOCAR Boxford field site (PL26), and at Bagnor (NGR SU 453 693). At the Westbrook Farm site, the LOCAR infrastructure provides all the semi-permanent instrumentation.

Project 2 (from October 2003 to October 2006) is studying invertebrate communities in the hyporheic zone, and is led by Dr Jenny Schmid-Araya and Steven Tod. This project is concentrating on the Bagnor site (listed above) and has about 40 standpipes installed in the river, which act a colonisation traps for the invertebrates in the riverbed.

The project team is aiming to tie these two projects together by relating the isotopic signatures (^{15}N) of different nutrient sources (NO_3^- and NH_4^+), basal food resources (biofilm) and consumers (hyporheic invertebrates). The team is also investigating whether invertebrate productivity relates to biogeochemical processes.

Figure 5 shows an example of some of the results from piezometer measurements at Bagnor on the River Lambourn. No publications currently exist for this work.

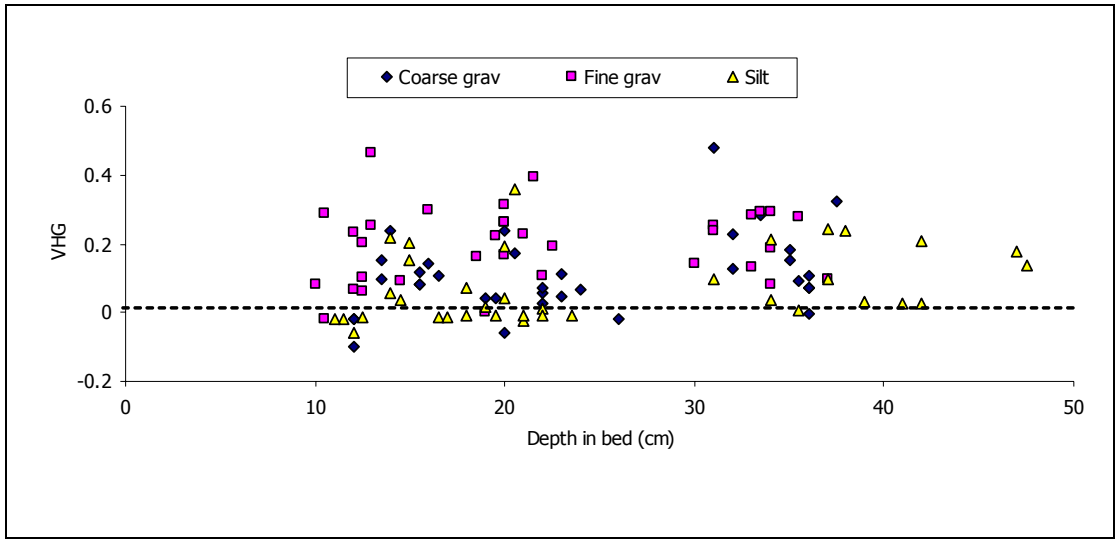

Figure 5 Vertical Hydraulic Gradient (VHG) at Bagnor
The River Lambourn is dominated by positive VHG indicating up-welling but differences in VHG exist among different substrata at different depths. Strongly negative VHG occurs infrequently but tends to be associated with coarse gravels, suggesting localized (small-scale) down-welling of surface water in the coarser substrata.
Figure supplied by Dr James Petty.

6 Exeter-CEH-D-Frome

Sean Arnott (PhD student at CEH Dorset) is currently investigating up-welling and down-welling in southern chalk streams. The studentship “Using physical and chemical properties to characterise river/groundwater exchanges in LOCAR catchments” is funded by the NERC LOCAR program, and is due to be completed by November 2006.

The main objective of the project is to identify and trial new methods of locating up-welling and down-welling sites. To achieve these objectives, different methods are being tested within the Frome/ Piddle catchments. Ten field sites have been selected (see below) in order to test the methodologies across different hydrological and geological conditions. At each site a 1km reach has been identified and a shallow (2m deep) borehole installed close to the river. The sites selected for this work are listed in Table 6.

At each site the flow is gauged to assess accretion over the reach. Temperature, electrical conductivity, pH longitudinal surveys are also carried out, and water samples are analysed for a variety of chemicals (including radon). The temperature of the river bed sediment is measured, and tracer experiments are conducted within the river.

No publications currently exist for this work.

Table 6 Site locations for Exeter-CEH-D-Frome work

Site	Location
1	Minterne Parva. Close to the source of the River Cerne
2	Nether Cerne. Downstream of site No. 1 (above).
3	River Hooke. Between Higher and Lower Kingcombe.
4	River Frome. South of Maiden Newton.
5	River Frome at Woodsford Bridge.
6	River Piddle. Downstream of Little Puddle.
7	River Frome at Frampton.
8	River Piddle at Alton Pancras.
9	South Winterborne at Winterbourne Steepleton.
10	River Laboratory on the Frome at East Stoke.

7 CEH-D-Frome

John Davy-Bowker at CEH Dorset has been working for several years on the hyporheic zone, the interface between groundwater and surface water. This has concentrated on the River Frome in Dorset, mainly at Notton (just downstream of Maiden Newton) but also (to a lesser extent) on the lower reaches of the River Frome (near the IFE River Laboratory at East Stoke). The subject of this work has been on benthic and hyporheic macroinvertebrate responses to up and down welling vertical hydraulic exchange that occur naturally at the heads and tails of riffles. The work has been funded by CEH internal funds and it is hoped that this will continue over the next few years.

The work has principally been carried out by Dr Davy-Bowker together with the input of three MSc degree students (see Sweeting, 2001; Wright, 2002; Ball, 2003) and occasional help from one PhD student and other CEH Dorset staff.

Figures 7.1 and 7.2 show details of the location of the study area close to Notton (NGR SY 608 959). Here, two arrays of piezometers exist: ten at the riffle head, ten at the riffle tail.

No publications of the work exist although a manuscript is currently in preparation (Davy-Bowker *et al.* (in prep.)).

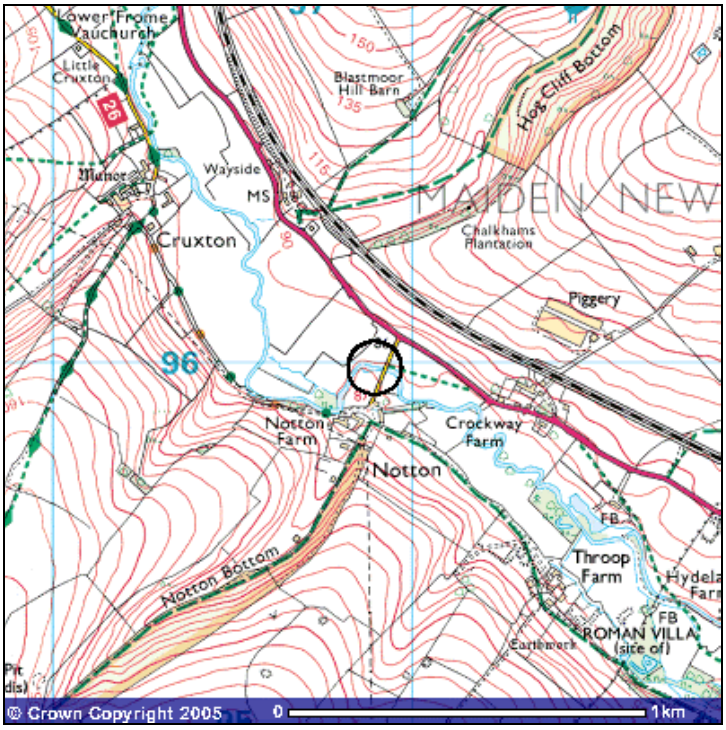

Figure 7.1 Location of CEH-D-Frome study area on River Frome
Basemap reproduced from (July 2005) Ordnance Survey map with the permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright NC/05/100041705.

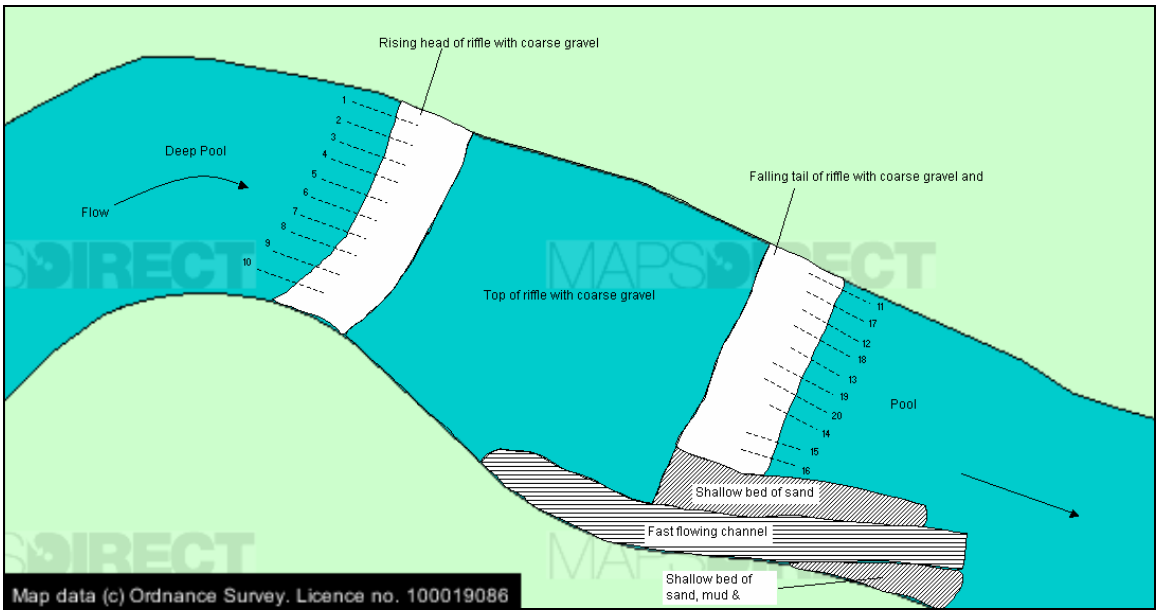

Figure 7.2 Notton study riffle on River Frome showing location of piezometer arrays
Figure and caption supplied by Dr Davy-Bowker.

8 CHASM-Eden

The CHASM-Eden project studying groundwater-surface water interaction is located at the River Eden above Appleby. The site is between Great Musgrave and Little Musgrave, adjacent to the weir operated by the Environment Agency (NGR NY 760 130). Here, the Penrith Sandstone is in hydraulic contact with the river.

The infrastructure at the CHASM-Eden site was designed to allow:

- identification of the three-dimensional distribution of piezometric levels in the groundwater near to the River Eden;
- characterisation the relationship between aquifer groundwater levels and river levels at all spatial and time-scales;
- hydrochemical sampling in the river-aquifer interface zone.

The project also collects data used to model the impact of groundwater abstractions on river flows (related to the Environment Agency's Impact of Groundwater Abstraction on River Flow (IGARF) programme).

The CHASM-Eden site is divided into three areas: A, B and C (see Figure 8). At sites A and B an array of multi-level monitoring piezometers near to the river exists, along with a cored open borehole near to the river, an inclined piezometer beneath the river, and a transect of multi-level piezometers across the floodplain. Sites A and B differ in their geomorphological and land management characteristics. At site C an array of multi-level piezometers exists. Table 8 provides borehole locations and some completion details.

The basic monitoring associated with the sites includes:

- water level, temperature, electrical conductivity measurements in piezometers and boreholes;
- borehole water sampling for quality analysis;
- borehole geophysical studies (gamma, resistivity, caliper, flow metering, etc);
- simultaneous river flow gauging at several locations along the river to characterise accretion profiles;
- surface geophysics using mobile instruments to identify local patterns of the spatial distribution of groundwater levels;
- in-river studies, including temperature, electrical conductivity and dissolved oxygen.

In addition, the following experimental studies have also been proposed by the CHASM team:

- pumping tests;
- artificial tracer experiments;
- surface and borehole-to-borehole geophysical imaging;
- temperature measurements at or around introduced heat sources buried in the aquifer, to determine groundwater flow variations;
- in-river studies involving the use of in-river biota as indicator species of groundwater ingress, dissolution of Plaster of Paris standards, gel probes.

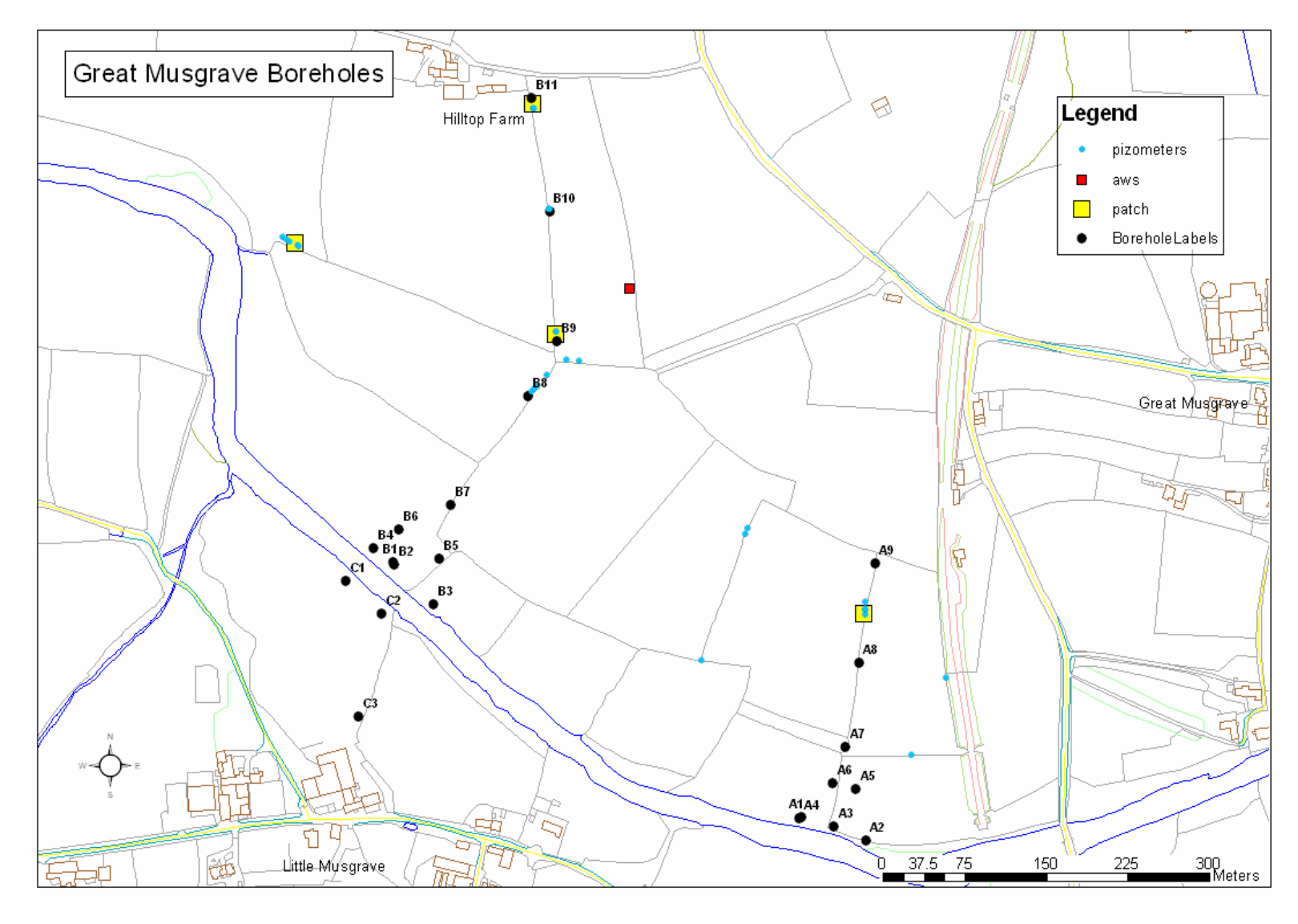

Figure 8 Layout of river-aquifer borehole arrays at CHASM River Eden sites

Four University of Newcastle MSc dissertations on groundwater systems and river-aquifer interactions in the upper Eden have been completed (McKevitt, 2000; Miller, 2002, Schaeffer, 2003; Zardava, 2003).

Table 8 Completion details of CHASM Eden borehole for river-aquifer interaction work

Borehole reference	East (m)	North (m)	Elevation (m)	Installation type	Casing ID (mm)	Screened interval (m)	Measured Total Depth from Datum (m)
A1	376330.452	513150.655	144.552	Inclined Piezometer	50.8	1	21.59
A2a	376389.846	513129.905	145.178	Piezometer	25	1	8.7
A2b	376391.155	513129.624	145.502	Piezometer	25	1	11.99
A3	376360.883	513142.016	145.308	Open Hole	152.4		21.58
A4a	376329.074	513150.204	145.502	Piezometer	25	1	7.58
A4b	376330.939	513149.688	145.515	Piezometer	25	1	10.8
A5a	376380.48	513175.893	145.817	Piezometer	25	1	5.72
A5b	376380.313	513175.051	144.137	Piezometer	25	1	11.21
A6a	376359.863	513182.065	146.459	Piezometer	25		6.69
A6b	376359.514	513179.474	146.519	Piezometer	76.2	1	23.06
A7a	376371.142	513214.319	147.133	Piezometer	25	1	8.12
A7b	376371.165	513215.94	146.579	Piezometer	25	1	12.3
A8a	376383.385	513290.774	145.398	Piezometer	25	1	9.21
A8b	376383.594	513292.558	145.398	Piezometer	25	1	12.06
A9a	376398.32	513381.009	145.637	Piezometer	25	1	6.24
A9b	376398.82	513383.208	145.71	Piezometer	76.2	1	22

Table 8 Completion details of CHASM Eden borehole for river-aquifer interaction work (contd.)

Borehole reference	East (m)	North (m)	Elevation (m)	Installation type	Casing ID (mm)	Screened interval (m)	Measured Total Depth from Datum (m)
B1	375954.844	513382.518	144.653	Inclined Piezometer	50.8	1	23.49
B2	375956.079	513380.401	145.38	Piezometer	25	1	6.66
B3	375992.236	513344.124	145.459	Open Hole	152.4		21.68
B4a	375937.347	513395.272	145.189	Piezometer	25	1	11.32
B4b	375935.877	513396.448	145.186	Piezometer	25	1	6.02
B5a	375997.932	513385.589	144.774	Piezometer	25	1	5.5
B5b	375996.445	513384.335	144.769	Piezometer	25	1	11.43
B6a	375960.438	513412.298	143.443	Piezometer	25	1	6.97
B6b	375962.558	513410.905	144.688	Piezometer	76.2	13.5	23
B7a	376008.529	513434.593	143.059	Piezometer	25	1	5.07
B7b	376007.534	513432.672	143.556	Piezometer	25	1	11.07
B8a	376078.991	513532.67	144.981	Piezometer	25	1	3.23
B8b	376077.144	513529.973	143.972	Piezometer	25	1	11.64
B9a	376106.016	513582.874	147.333	Piezometer	25	1	7.48
B9b	376105.658	513585.018	146.34	Piezometer	76.2	12.5	21.82
B10a	376099.013	513700.09	157.707	Piezometer	25	1	5.31
B10b	376099.687	513697.355	157.094	Piezometer	76.2	18	32.35
B11	376082.919	513803.097	170.692	Piezometer	152.4	58.8	62.2
C1a	375912.184	513365.054	145.216	Piezometer	25	1	11.8
C1b	375913.378	513364.205	145.22	Piezometer	25	1	5.78
C2a	375944.342	513335.49	145.342	Piezometer	76.2	14	20.6
C2b	375944.492	513334.271	145.331	Piezometer	25	1	2.47
C3a	375923.385	513242.464	146.212	Piezometer	76.2	27.5	
C3b	375923.093	513241.252	146.5	Piezometer	25	1	4.22

9 Aberdeen

The group at Aberdeen University, led by Prof Chris Soulsby with co-workers at the Fisheries Research Services Marine Laboratory, has carried out considerable work on groundwater-surface water interaction. Earlier studies concentrated on borehole/spring work in the Allt a' Mharcaidh catchment (a 10km^2 catchment on the western side of the Cairngorm mountains) using ^{18}O isotopes and alkalinity as natural tracers (see for example, Soulsby *et al.*, 1999). This work led to the further similar studies in the Feshie catchment (see for example, Rodgers *et al.*, 2004) using data from in-stream and shallow observation wells. Figure 9.1 shows the extent of infrastructure in the Feshie, which forms part of the upper Spey catchment, and also the location of the Allt a' Mharcaidh catchment.

The Feshie was designated as one of the CHASM catchments and it was intended that this would lead to further extensive infrastructure within the catchment, particularly through the addition of drill holes in the Feshie braids. The subsequent designation of the Cairngorms as a National Park led to refusal of drilling proposals, although work within the Feshie still continues (Soulsby, pers. comm.).

The Aberdeen based group is currently developing site infrastructure at Girnock Burn (see Figure 9.2). Here work is focussing on understanding the relationship between hyporheic water quality and salmon egg survival. Figure 9.3 (after Malcolm *et al.*, 2004) illustrates the type and scale of instrumentation located within areas of the Girnock catchment. Future extensions to this work are planned (Soulsby, pers. comm.).

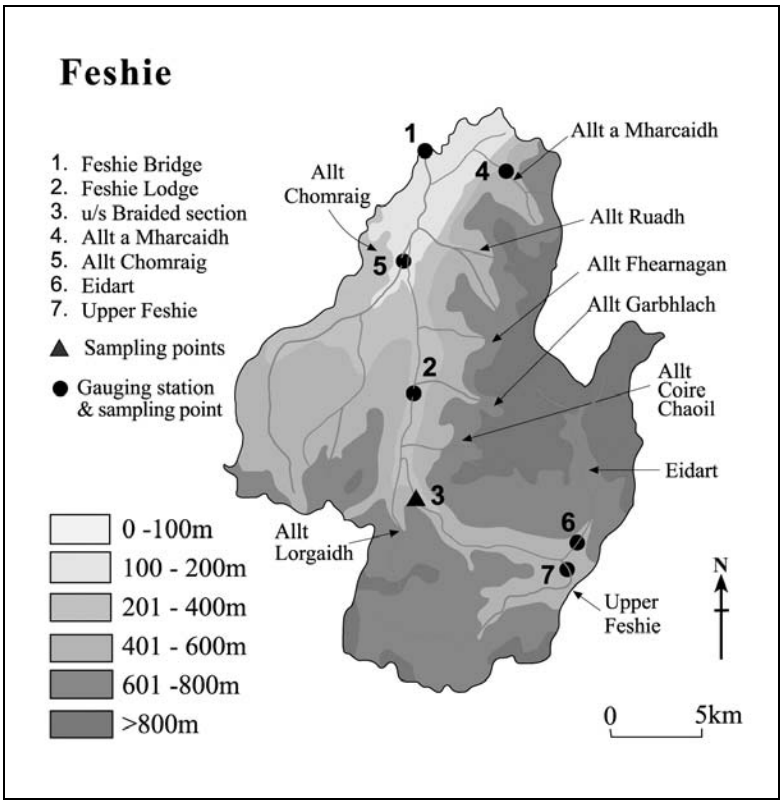

Figure 9.1 Instrumentation in the Feshie catchment (Figure supplied by Prof Chris Soulsby)

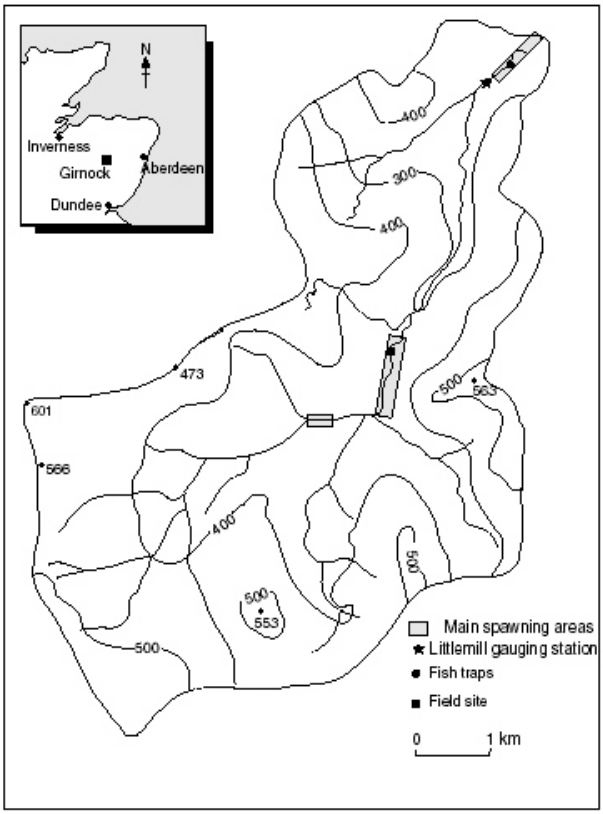

Figure 9.2 Girnock Burn catchment showing main field site locations
(After Malcolm *et al.*, 2004.)

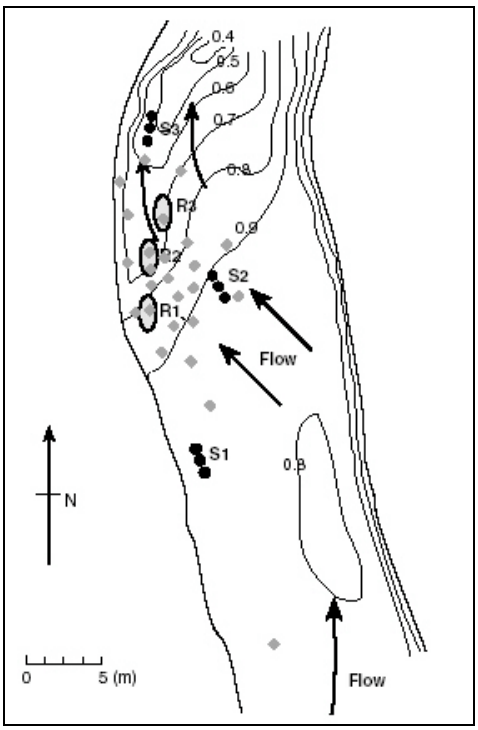

Figure 9.3 Girnock Burn field site infrastructure
Piezometer nests are indicated by “S”, artificial redds indicated by “R”. Contours show stream-bed topography. (After Malcolm *et al.*, 2004.)

10 Southampton

Prof Paul Carling and Dr David Sear at Southampton University have been studying physical and chemical characteristics of salmonid spawning gravels and redds in a number of UK rivers. The work, “Modelling sediment levels in salmonid spawning gravels”, was funded by Defra (reference SF 0225). The project operated from 2001 to 2004, but Prof Carling and Dr Sear have requested funding for an extension to 2006.

The aim of the work was to carry out a fully-integrated study of sediment dynamics, silt intrusion, dissolved oxygen, egg survival and alevin emergence in salmonid spawning gravels and redds within key UK rivers. This provided results from two field seasons to allow calibration of the "Sediment Intrusion and Dissolved Oxygen Transport Model (SIDO) for use within the UK” (SIDO-UK) software.

A detailed hydraulic flume study of the infiltration process of different size fractions of sediment and simulated fish redd was also completed. Carbon cubes and dye tracers were used to map the three-dimensional interstitial flow patterns in the redd. Testing of the SIDO-UK model was completed using parameter specifications obtained in published literature and from the field and flume studies.

The field sites selected and study years were (see Figure 10 for location):

River Test, Hampshire (groundwater-dominated) (2001-2002),
River Blackwater, Hampshire (lowland freshet) (2002-2003),
River Ithon, Powys, Wales (upland freshet) (2001-2002),
River Aran, Powys, Wales (upland freshet) (2002-2003).

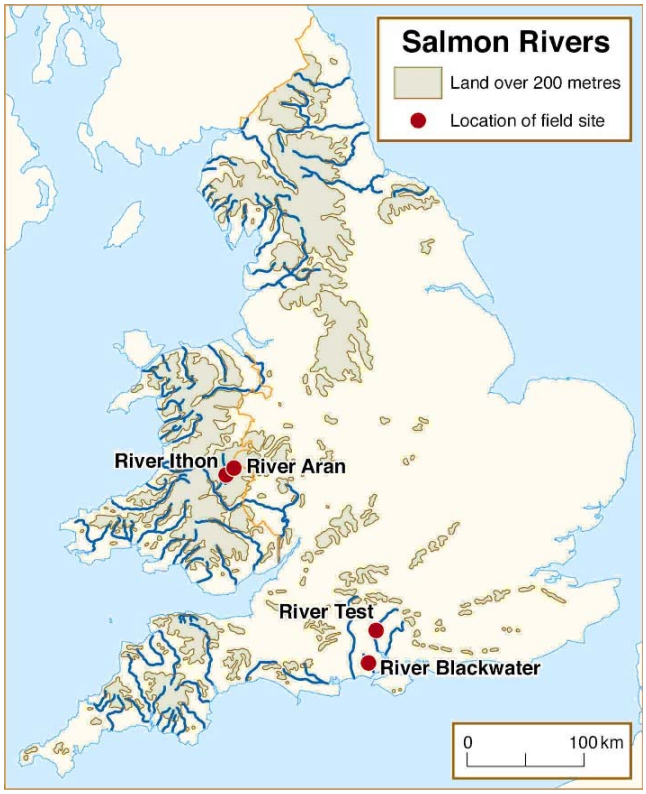

Figure 10 Location of Southampton field study sites
Figure supplied by Prof Paul Carling.

Instrumentation at the sites includes: interstitial flow monitoring standpipes, alevin emergence traps, interstitial dissolved oxygen recording, water stage, water temperature, silt deposition traps.

Results are soon to be published and are documented in the following articles in preparation/review: Carling *et al.* (2005a), Carling *et al.* (2005b), Greig *et al.* (2005), Greig *et al.* (in prep.[a]), Greig *et al.* (in prep.[b]), Greig *et al.* (in prep.[c]).

11 Bristol-Severn

Prof Paul Bates and co-workers have been running a field and model based study of floodplain hydrology near the village of Leighton on the River Severn since June 1997. The work has been principally funded by NERC (Grant ref. GR3/09925) and Bristol PhD studentships to Amanda Claxton and Hannah Cloke (both NERC awards). The site is approximately 4km upstream of Buildwas (gauging station 2134, NGR SJ 644 044). The site was selected partly because of the regular occurrence of bankfull discharge.

Hand auger holes drilled at the site reveal sand clay to a depth of 2.4 to 5.5 m overlying gravels with various fines. Two lines of piezometers were installed in the gravel layer (for locations see Figure 11) providing pressure head time series at a temporal sampling of 5 minutes. In addition, river stage, rainfall and other weather station data have been logged at the site (for details see Burt *et al.*, 2002).

Example field and modelling results from the site are documented in Stewart *et al.* (1999), Burt *et al.* (2002) and Claxton *et al.* (2003). The team intend to keep the site active for at least a further 18 months, although recently submitted research proposals, if successful, may extend this. Dr. Hannah Cloke is currently overseeing management of the field site.

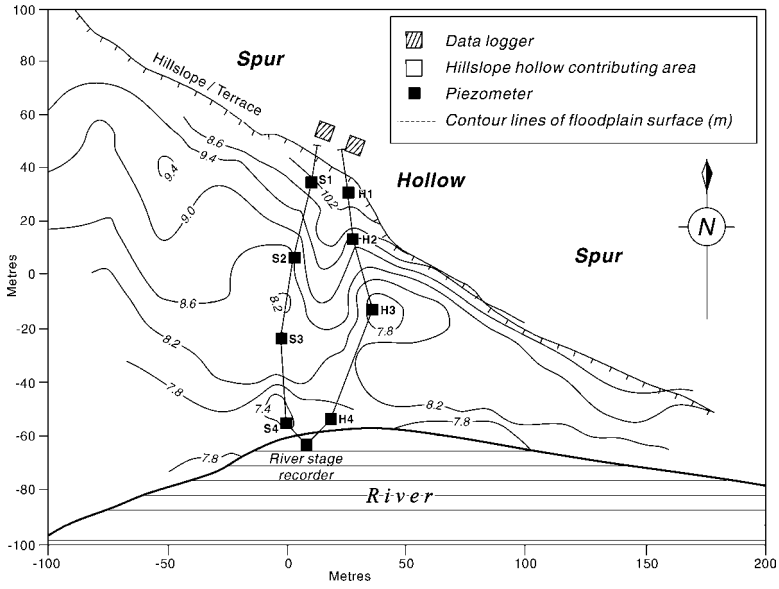

Figure 11 Map of Leighton field site on the River Severn showing location of piezometers and floodplain topography
Figure supplied by Prof Paul Bates.

12 Birmingham-Tame

Ellis (2002) studied the mechanics that control transport of groundwater contamination to an urban river using a variety of measurement techniques. The study focussed on a 7.3 km section of the River Tame, Birmingham and drew attention to the spatial and temporal variability of physical and chemical processes. Ellis made use of existing piezometers at the study site and combined data from these with an array of 96 river-bed piezometers installed at 18 different sections along the river to depths ranging from 15 to 200cm. Existing shallow piezometers were available from:
(a) 30 (10 to 35m) deep boreholes drilled in 1993 as part of the Severn Trent Water Company Black Country Trunk Sewer Extension Project;
(b) Environment Agency boreholes drilled in 2000 as part of the River Tame Asset Survey.

The study was carried out along a stretch of the river upstream of the Water Orton gauging station. In addition to analysing existing data, Ellis carried out flow accretion surveys, river water quality sampling, groundwater quality sampling, groundwater head surveys, river-bed temperature surveys. These were interpreted in conjunction with hydraulic characterisation of river bed sediments using slug tests and grain-size analysis.

Figure 13.2 shows the location of the surface water gauging and sampling sites. Figure 13.1 shows the dense array of shallow piezometers installed by Ellis, alongside the existing Environment Agency borehole network. Ellis also used models to improve understanding for groundwater flow to the river by analysing high and low flow events.

Most of the field work for the project was carried out during 2000 and 2001. Much of the river-bed piezometer network still exists although parts may not be fully functioning.

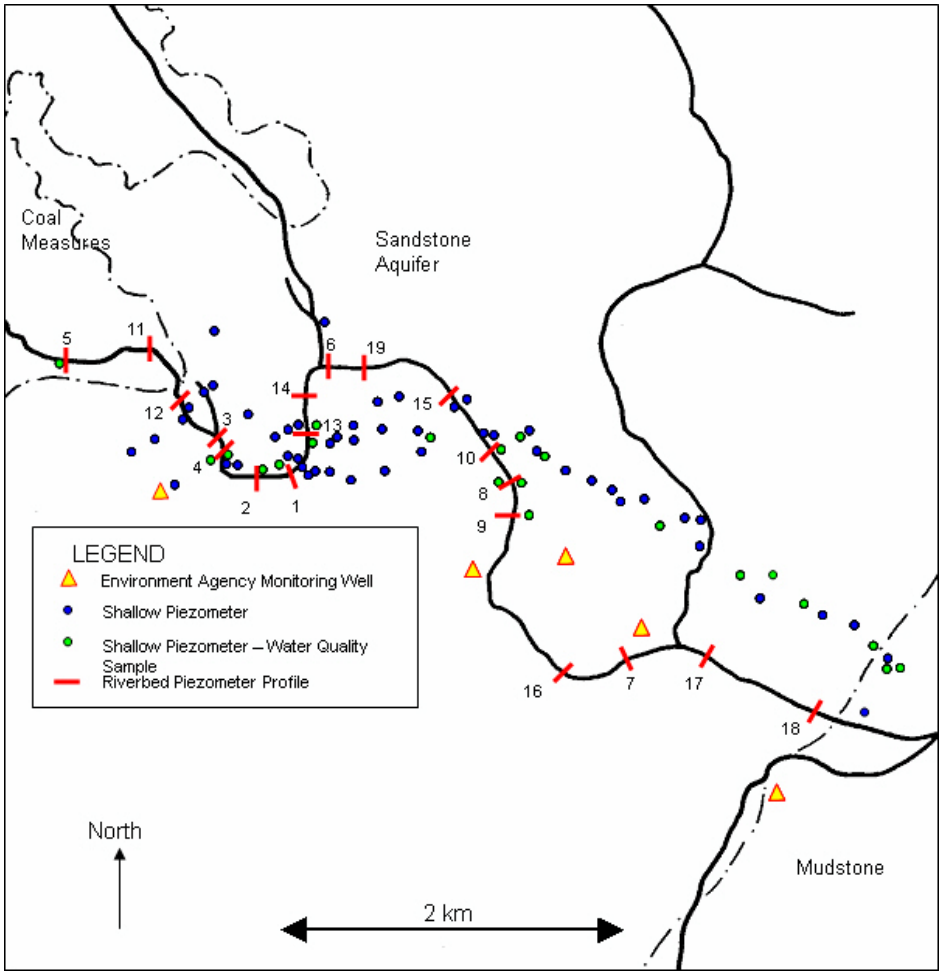

Figure 12.1 Layout of piezometer and borehole network for River Tame study (After Ellis, 2002.)

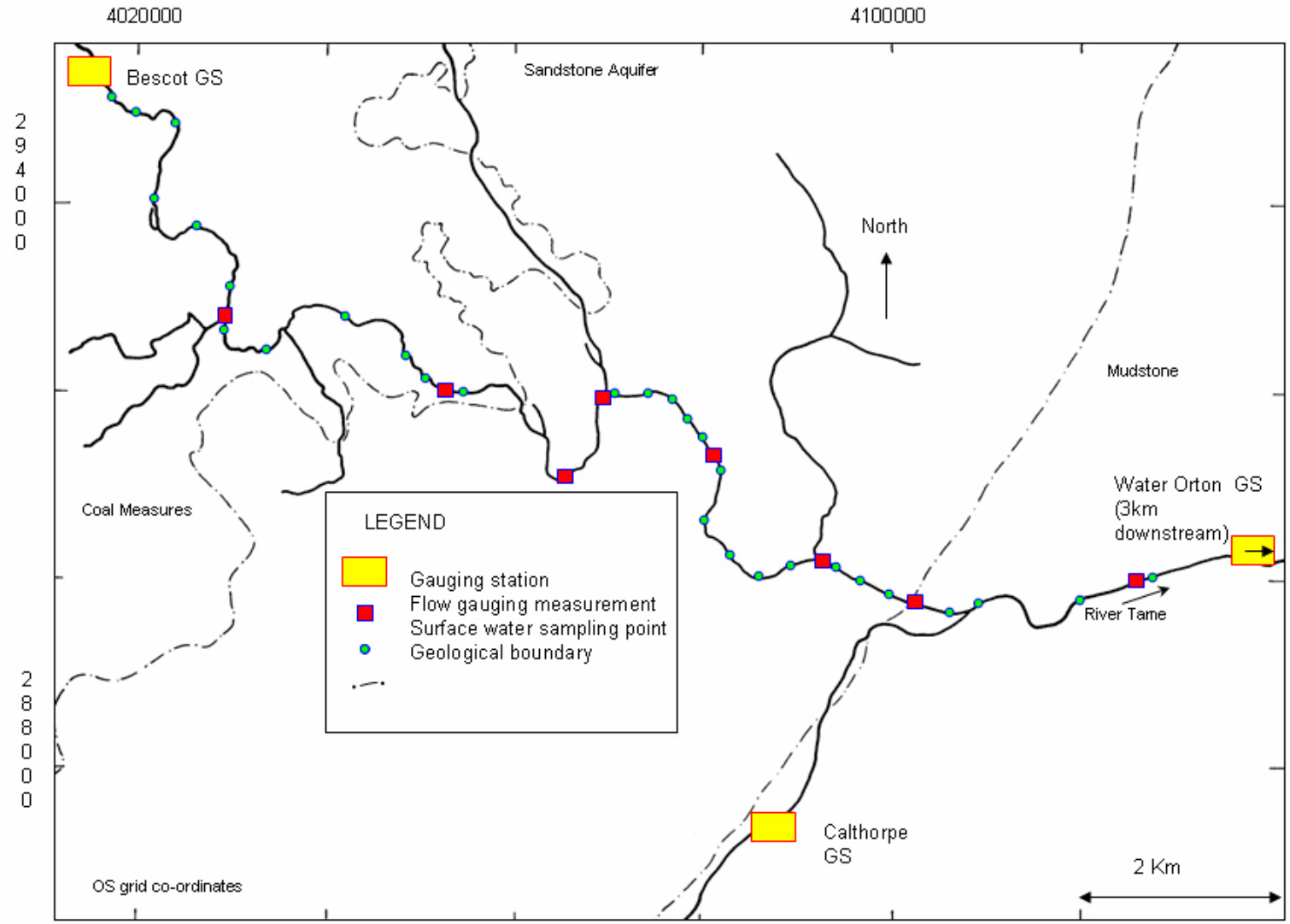

Figure 12.2 Layout of surface water sampling network for River Tame study (After Ellis, 2002.)

13 Birmingham-Lea

Crane (2003) studied groundwater-surface water interaction at a site near Hatfield, Hertfordshire, on the River Lea (also Lee). The principal aims of this work were to establish whether the river was gaining or losing and thus understand the hydrological setting of the river in the context of the regional chalk aquifer. The work was driven, in part, by the need to understand whether a bromate plume (observed in groundwater wells) was a risk to surface water contamination.

Crane used a combination of three existing Environment Agency boreholes, piezometers installed in the river bed and the river as sampling sites for water quality and hydraulic head in order to assess hydrological linkage between groundwater and surface water at the site. Four piezometers were installed in 2002 in an array to a maximum depth of 107 cm. Negative head gradients and similarity between water chemistry in river and river bed samples indicated a losing river section at the site.

It is unclear if the piezometers installed at the site are still operational.

14 BGS-Plynlimon

Haria and Shand (2004) document a detailed physical and chemical analysis of data collected at a hillslope transect in Plynlimon, mid-Wales. The aim of the study was to determine the extent of groundwater-stream mixing.

Boreholes were drilled along a transect to provide nested piezometers for water level and chemical sampling. Piezometer depths range from just over 1m to approximately 30m. Figures 14.1 and 14.2 show the layout of the site.

Haria and Shand (2004) concentrate on observations made in the borehole array, although some in-stream sampling is reported. They conclude that the bedrock groundwater has an important impact on stream chemistry and that transport characteristics are highly variable (spatially and temporally).

Rainfall data appears to be available from a meteorological station approximately 250m from the site. It is unclear, however, what infrastructure exists for in-stream flow gauging and chemistry sampling, if any. It is also unclear if the site is currently operable.

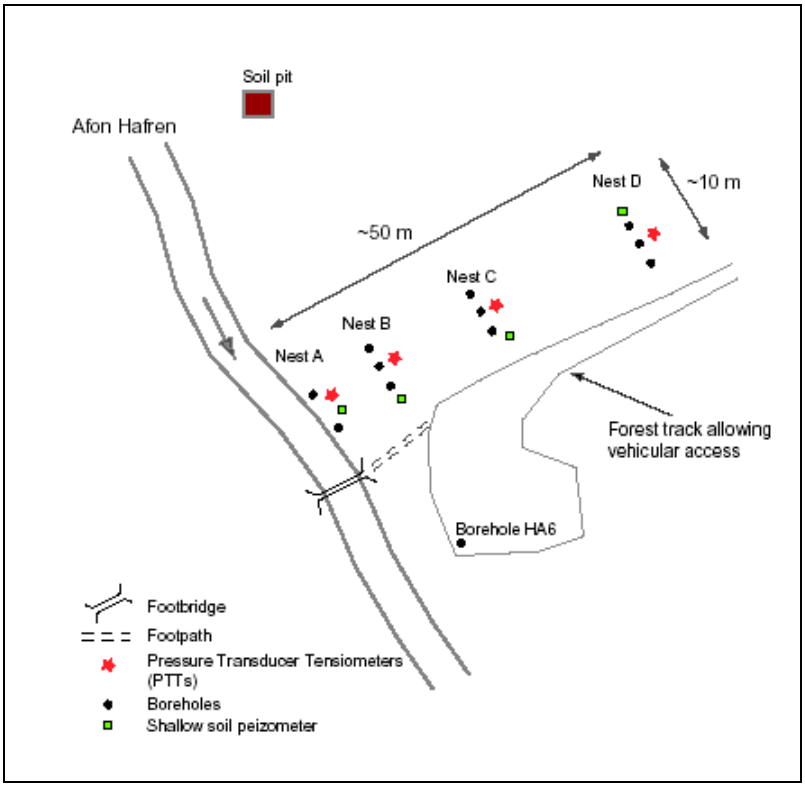

Figure 14.1 Layout of Plynlimon study site (After Haria and Shand, 2004.)

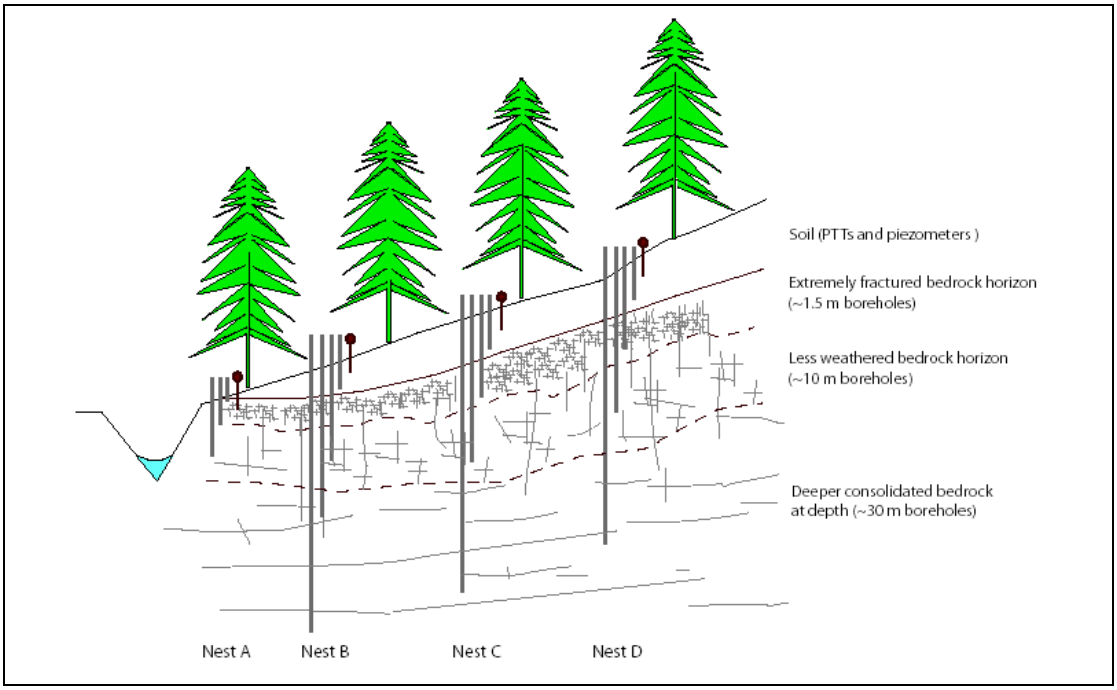

Figure 14.2 Cross section (schematic) of Plynlimon study site
(After Haria and Shand, 2004.)

15 UEA-Slea

The Environment Agency is supporting research led by Dr Kevin Hiscock, University of East Anglia to address nitrate vulnerability in the River Slea catchment, Lincolnshire. This forms the UK element of the European Water4All initiative (http://www.water4all.com/). The project aims to improve knowledge of the linkage between soil water, groundwater and surface water with a view to being able to better manage water quality in this intensively farmed catchment. Data sources for the project appear to be based on existing (Environment Agency) monitoring networks.

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