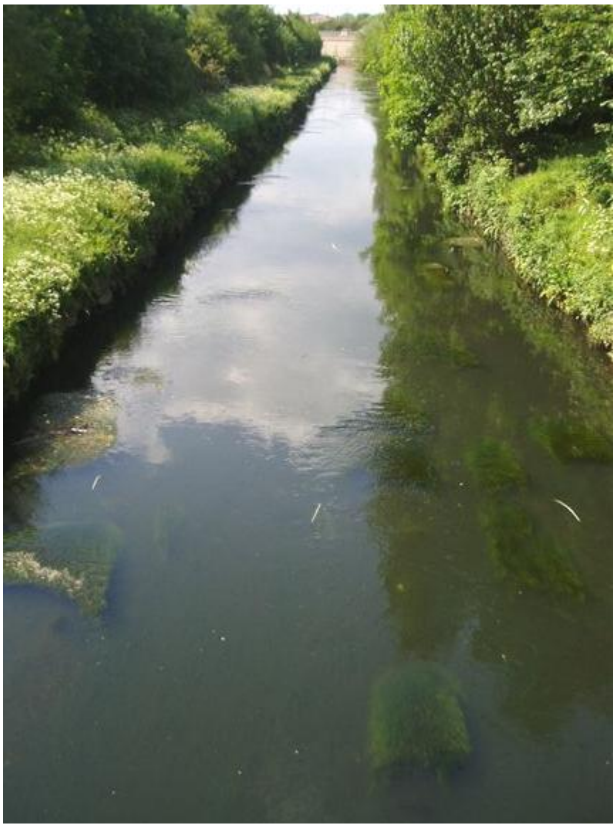

River Tame hyporheic zone test site – data report

SWITCH and Environment Agency Science Report – SC050070/SR

This report is the result of research conducted under the SWITCH (*Sustainable Urban Water Management Improves Tomorrow's City's Health*) integrated research project. SWITCH is supported by the European Commission (EC) Sixth Research Framework Programme (FP6). The research was also commissioned and co-funded by the Environment Agency's Science Programme.

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SWITCH Deliverable Briefing Note – D5.3.13

D5.3.13 Successful demonstration of applications in Lodz and Birmingham, and full-scale field studies in Cartagena, Cali (Columbia), Netherlands and Birmingham

SWITCH Document

Cuthbert, M.O., Durand, V., Greswell, R.B., Aller, M.-F, Rivett, M.O., Mackay. R., 2011. River Tame hyporheic zone test site – data report. SWITCH and Environment Agency Science Report SC050070/SR, Web-only publication at: http://www.switchurbanwater.eu Publ. SWITCH CMU, Delft, The Netherlands. 36 pp.

Audience

This document is targeted primarily to a technical audience, including the science community (specific topic and perhaps more general urban/environmental), practitioner community – consultants /engineers, technical regulatory.

Purpose

This data report provides an overview of the substantial volume of data arising from the University of Birmingham SWITCH Hyporheic Zone Research Site Study (2007–09). The appendices (electronic data files largely), available through contacts given in the report, collate all the data obtained with appropriate meta-data – they hence provide a data repository for the study. The report provides a brief summary of the methods used to collect the data in each case; example outputs are shown for illustrative purposes. The report hence serves to provide an illustrated methodology of urban hyporheic zone natural attenuation potential field assessment.

Background

The aims of the research were: to evaluate the potential of the urban hyporheic zone to naturally attenuate water contamination; and, to predict potential for engineered enhancement of hyporheic zone attenuation. It is important that such natural attenuation based research is undertaken at the real field scale in order that the controlling processes can be suitably studied. Hence the development of the

University of Birmingham SWITCH Hyporheic Zone Research Site Study on the River Tame headwaters, arguably the UK's most urbanized catchment. The site was located within Birmingham, a SWITCH Learning Alliance city. The hyporheic zone or riverbed, essentially the zone at the groundwater – surface-water interface, is generally thought to represent a zone of enhanced natural attenuation of contaminants and thereby to limit the transfer of contaminants between groundwater and surface water. It is a key zone of interest under the EC Water Framework Directive in that it represents an important *natural system for water self purification* within the urban water cycle. It is thus important to understand processes controlling contaminant natural attenuation in the hyporheic zone, whether they are sufficient under a range of natural conditions to offer receptor protection, or whether they require engineered enhancement to do so. The research effort focused upon providing field-scale understanding of the processes (through acquisition of field data and (numerical) model interpretation) that underpin design criteria and computer models for simulation of self-purification capacity of water bodies.

This report is underpinned by the earlier report:

Durand, V., Rivett, M.O., Mackay, R., Aller, M.F., Greswell, R.B., 2008. Development of the Hyporheic Zone Test Site and Experimental Design. EC 6th Framework Programme, Sustainable Water Management in the City of the Future, SWITCH Project Report 018530, Web-only publication at: http://www.switchurbanwater.eu Publ. SWITCH CMU, Delft, The Netherlands. 42 pp.

Potential Impact

Key findings and associated potential impacts are:

- Development of improved methodologies (field and modelling interpretation) to assess urban hyporheic zone natural attenuation potential.
- Availability of a significant field-scale dataset that focused on the dynamic behaviour of an urban hyporheic zone and its natural attenuation potential.
- Process understanding achieved from this dataset allowed the development of concepts that could be used as part of any urban river restoration project to minimise potential risks from contaminated groundwater discharges to a river in the future.

Issues

Key issues encountered in undertaking the research:

- Excellent facilitation of the research was provided by both riparian landowners and the Environment Agency (part funder) who provided many

supporting data and project design and steering

- The main summer period targeted for field monitoring was unusually wet and caused some difficulty in the timely execution of fieldworks under ideal low river flow conditions. Benefits of these conditions were that natural attenuation potential was assessed under a good range of transient river conditions – ie the real-world relevance of the study was increased.

Recommendations

Recommendations/ largely directed to technical practitioner and regulators, include

- A variety of field techniques are now available (as demonstrated at the study site) that allow reasonably effective assessment of the natural attenuation potential of the urban hyporheic zone. It is emphasized that a range of techniques should be adopted to provide a lines-of-evidence approach. Ideally they should include automated data collection devices (transducers, concentration loggers) that allow the influence of transient conditions to be understood
- The variability in space and time of contaminant natural attenuation in the urban hyporheic zone needs to be better appreciated. From a practitioner viewpoint, although full understanding of a site would be difficult to gain, there is a sufficient knowledge base (from our work and that of others) for general predictions of attenuation to be reasonably made for river reaches with modest data.

Dr Michael Rivett, University of Birmingham March, 2011

Executive summary

The University of Birmingham (Water Sciences Group, School of Geography, Earth & Environmental Sciences) has undertaken research on the urban hyporheic zone in conjunction with the Environment Agency for the past decade. The data presented in this report relate to recent investigations that were carried out as part of the SWITCH (Sustainable Urban Water Management Improves Tomorrow's City's Health) collaboration. This large-scale integrated project is part of the European Community's Sixth Research Framework Programme (FP6), and is part-funded by the Environment Agency.

The research reported here focused on the dynamic behaviour of the hyporheic zone. We wanted to assess the natural capacity of the hyporheic zone to attenuate contamination over a continuous period of time or across a specified area. We aimed to develop concepts that could be used as part of any urban river restoration project to minimise potential risks from contaminated groundwater discharges to the river in the future.

An urban river-based experimental test facility, the SWITCH hyporheic zone test site ('HZ test site') has been developed on the River Tame in Birmingham, UK. The site contains an extraction borehole next to the river which is used to modify the interactions between the aquifer and the river to determine the hydraulic controls that govern the thickness of the hyporheic zone.

Prior to any experimental manipulation of flow conditions via the borehole, the river reach (about 200 m) that formed part of the experimental facility was chemically and physically characterised. This baseline assessment revealed the extent and thickness of the hyporheic zone under natural conditions. We then performed a suite of long-term flow experiments to resolve the impact that pumping may have on river-groundwater mixing in the hyporheic zone and any related chemical effects.

This data report provides an overview of the substantial volume of data produced by the project during 2007–09. We first describe the HZ test site, then present each dataset in turn in its raw form. All the data are collated in electronic appendices that accompany this report or that are available from the Environment Agency on request. The report provides a brief summary of the methods used to collect the data in each case; example outputs are shown for illustrative purposes.

The report provides three main datasets (the numbers of locations at which the data were collected are given in the brackets):

i. **Continuous monitoring (five-minute logged data).**
River stage (2); bed hydraulic head (12); river electrical conductivity (2), borehole electrical conductivity (1); riverbed electrical conductivity (4); river temperature (1); riverbed temperature (3); borehole discharge (1).

ii. **Data from sampling campaigns.**
Water quality (28); riverbed hydraulic head (46).

iii. **Supporting data.**
Topographical data (1611); sediment cores (9); river water surface elevation (21); hydraulic parameters (19).

Our integrated analysis and interpretation of these data still continue; we will present further findings in subsequent publications. We expect that the interpretation of the integrated suite of data will provide significant insights into the dynamic behaviour of an urban hyporheic zone.

Acknowledgements

This study has been performed under Work Package 5.3 of the SWITCH (Sustainable Urban Water Management Improves Tomorrow's City's Health) integrated research project. SWITCH is supported by the European Commission (EC) Sixth Research Framework Programme (FP6) and contributes to the thematic priority area of "Global Change and Ecosystems" [1.1.6.3] Contract n° 018530-2. Co-funding for the study has been provided by the Environment Agency, which is one of the members of the Birmingham Learning Alliance.

Members of The Learning Alliance have supported this research as part of a range of research activities in Birmingham to investigate future integrated urban water management options for Birmingham. We gratefully acknowledge the owners of the land on which the HZ test site is located for their facilitation of the field research programme.

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1 Introduction

1.1 Research context

The urban hyporheic zone (HZ) is where groundwater and surface water mix beneath a river. The HZ represents an important natural system for water self-purification. The University of Birmingham (School of Geography, Earth & Environmental Sciences) has undertaken research to better understand and exploit the urban HZ system as part of the work package on Natural Systems (WP 5.3) of the SWITCH (Sustainable Urban Water Management Improves Tomorrow's City's Health) collaboration. This large-scale integrated project is supported by the European Community's Sixth Research Framework Programme (FP6), and is part-funded by the Environment Agency. The data presented in this report relate to recent investigations that were carried out as part of the

The research is field-based and set within the 'SWITCH Demonstration City' of Birmingham, UK. The research represents the most recent phase of work by the university into urban HZ processes undertaken in conjunction with the Environment Agency over the past decade. The European Water Framework Directive has been a significant driver of this research programme.

1.2 Aims and objectives of the research

The overarching aim of this research is to learn more about the dynamic behaviour of the HZ and confirm that the zone has a capacity for continuous spatial and temporal attenuation of contaminants. Our purpose is to develop appropriate concepts that can be employed as part of any urban river restoration project to help minimise potential risks from contaminated groundwater discharges to the river in the future.

The key objectives are to:

- confirm or reject the concepts derived from previous hyporheic investigations concerning the mixing processes and their importance within the body of the HZ;
- provide new insights into the dynamic behaviour of the HZ to confirm the temporal persistence of the zone;
- develop new insights into the potential of this zone to attenuate chemicals;
- to determine the spatial relationship between the zone's capacity for chemical attenuation and any patterns in groundwater-surface water flows;
- establish (after achieving the previous objectives) models of the HZ that can contribute to the design of river restoration initiatives.

1.3 Study approach

The study objectives outlined in Section 1.2 are being accomplished through a variety of activities and experiments. These activities include:

- the assimilation of recent research knowledge generated and published as part of ongoing international actions related to the HZ;
- the development of an urban river-based experimental test facility that can be used to modify dynamically the interactions between the aquifer and river and thereby determine the hydraulic controls that govern the thickness of the HZ;
- the chemical and physical characterisation of the river reach that forms part of the experimental facility to quantify the extent and thickness of the HZ under natural conditions (i.e. prior to any modification of flow conditions);
- a suite of long-term flow experiments to resolve the impact that pumping in the test site borehole has on the river-groundwater mixing in the HZ and to identify any related chemical effects;
- numerical modelling of the river reach to describe the flow and chemical responses in the HZ during the different field experiments;
- the use of these models to explore ways in which the attenuation capacity of the HZ can be exploited as part of a river restoration scheme;
- the elucidation of the data that would be required to quantify the conditions beneath a river as part of any future assessment of its restoration potential.

1.4 Report context

This data report provides an overview of the substantial volume of data produced by the project during 2007–09. We first describe the HZ test site, then present each dataset in turn in its raw form. All the data are collated in electronic appendices that accompany this report (also available from the Environment Agency on request). The report provides a brief summary of the methods used to collect the data in each case; examples of quality-checked outputs are shown for illustrative purposes. Integrated analysis and interpretation of these data still continue; we will present further findings in subsequent publications.

Journal publications arising from the HZ test site to date include:

- Greswell et al. (2009) on the design and implementation of monitoring methods;
- Cuthbert et al. (2010) on the Impacts of river bed gas on the hydraulic and thermal dynamics of the hyporheic zone; and,
- Rivett et al. (2011) on the influence of urban groundwater baseflow upon inorganic river-water quality on the wider unconfined aquifer reach that includes the HZ test site.

2 The River Tame hyporheic zone test site

2.1 Location

The HZ test site is located in an industrial area of north Birmingham (Figure 2.1 and Figure 2.2) within the 7 km section of the river that drains the unconfined Triassic sandstone aquifer underlying the city. This stretch of the river has been the subject of significant previous investigations by the University of Birmingham (Ellis *et al.*, 2007; Ellis and Rivett, 2007; Rivett *et al.*, 2008; Roche *et al.*, 2008; Rivett et al., 2011).

The River Tame is approximately 10 m wide at the HZ test site and 30 to 80 cm deep within the centre of the channel during low flow periods. The river has mean flows of a few m^3/d; the water is gained predominantly from the underlying aquifer often via intervening superficial deposits of varying lithology and thickness. An overview of the hydrogeology, hydrology and background water quality data for the area is given by Durand *et al.* (2008).

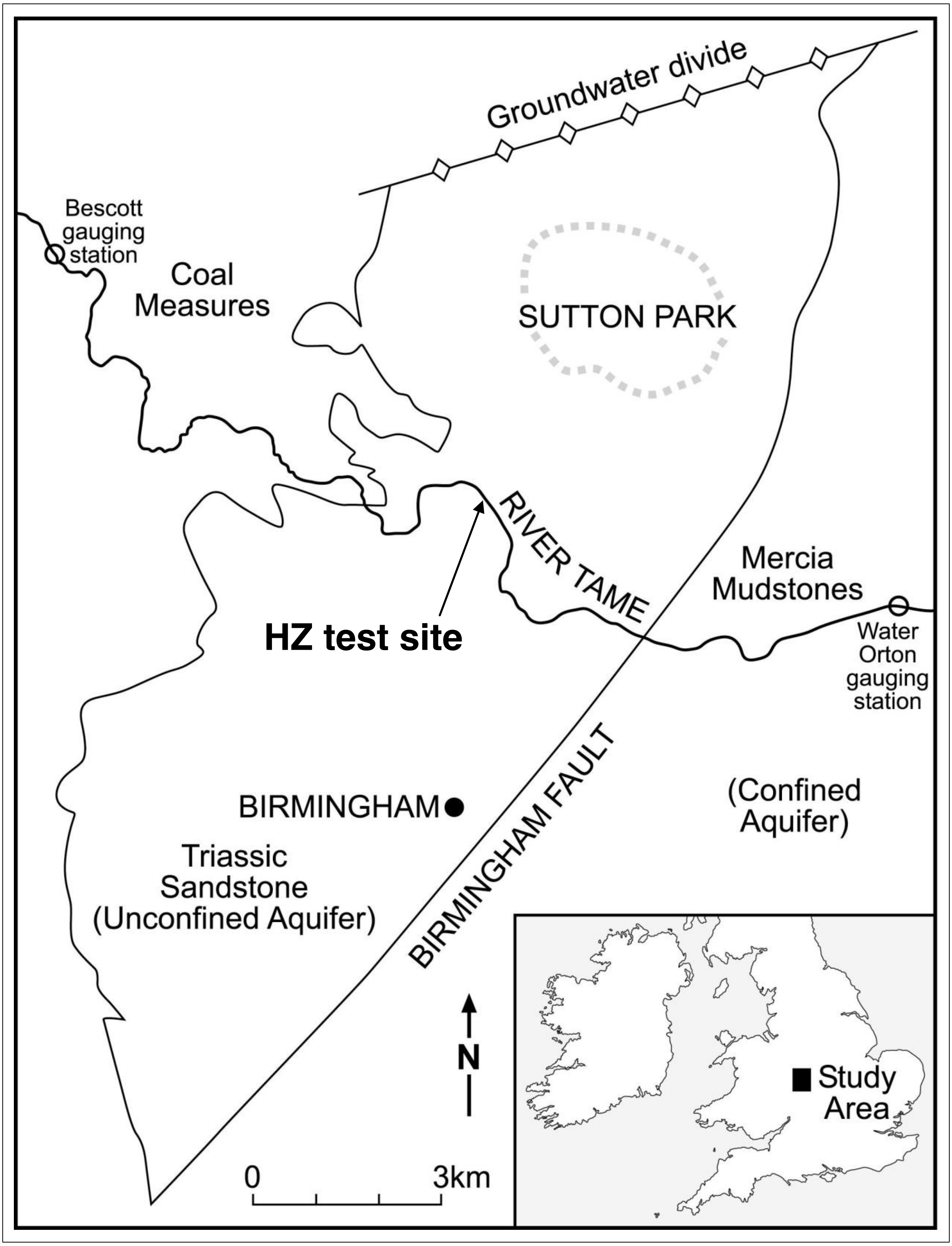


Figure 2.1 Location of the HZ test site set within the 7 km long unconfined aquifer

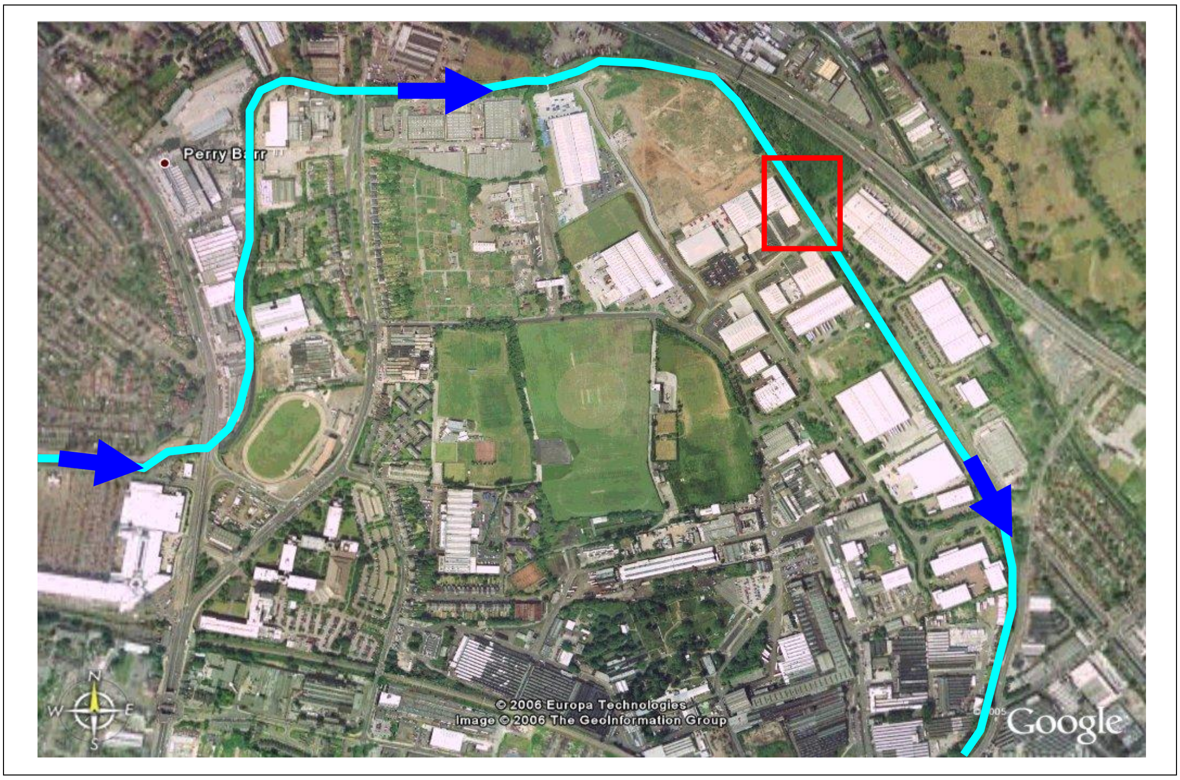


Figure 2.2 Google Earth image indicating the location of the HZ test site

2.2 Long-term monitoring installations

2.2.1 Extraction borehole

An extraction borehole was installed in July 2007 at the HZ test site after an agreement had been signed with the site owner and consent for a groundwater investigation had been granted by the Environment Agency under Section 32 of the Water Resources Act (E/UT/28/09/0082; E/UT/28/08/0161). The consent allowed for both drilling and test pumping of the extraction borehole.

The borehole is located on the east bank of the River Tame (5 m from the bankside) in Witton, Birmingham. Operation of the extraction borehole was designed to explore the influence of groundwater abstraction on hydraulic gradients and, in turn, to evaluate the residence times of solutes and contaminants in the adjacent HZ.

The borehole log and completion details are shown in Figure 2.3. The borehole was completed at a diameter of 150 mm throughout to a depth of 16.5 m below ground. The successive lithologic layers (as measured by drill cuttings, rather than core) were:

- top soil;
- made ground;
- sands and gravel;
- weathered sandstone;
- Triassic sandstone (at the bottom).

The borehole was lined with plain casing from the surface to 10 m below ground. Slotted uPVC casing (3 mm slot-size) was used from a depth of 10 m to the base of the hole, thereby screening the Triassic sandstone. A gravel pack was installed over the screened interval to filter out fine particles and improve hydraulic efficiency of the borehole. On the surface, the borehole was completed with a block-built concrete sump and a cast-iron plate cover.

The borehole extraction site is located at approximately 96 m AOD. The surface of the borehole is about 3 m above the riverbed; the borehole screen therefore intersects the sandstone about 7–13 m below the riverbed.

Borehole water levels and electrical conductivity were monitored continuously using a CTD 'Diver®' (Schlumberger Water Services/Van Essen instruments) at five minute intervals.

The borehole discharges directly to the adjacent river through a pipe (diameter approximately 100 mm) installed with a flowmeter. The flowmeter is connected to a datalogger and records the discharge at five minute intervals.

2.2.2 Piezometer network

A network of piezometers was installed in July 2007 to monitor hydraulic and water quality conditions along a reach of about 200 m centred at the extraction borehole. The design and installation methods for the network were similar to those described by Rivett *et al.* (2008) for other studies on the River Tame. The installation of the devices used manual drive point methods to cause minimal disturbance of the riverbed. Photographs of multilevel samplers are shown in Figure 2.4.

The piezometer network was composed of three elements:

i. **Piezometers.**
A total of 18 drive point piezometers (9 mm Internal Diameter (ID), 12 mm Outside Diameter (OD) High Density Poly Ethylene (HDPE) were installed to measure hydraulic head.

ii. **Combined piezometer-multilevel samplers (Figure 2.4).**
A total of 28 drive point piezometers (as above) were combined with between five and 10 multilevel chemical sampling tubes (1.6 mm ID, 3.2 mm OD Teflon® tubes). The sampling tubes were arranged to surround the piezometer tube. The sample points were spaced at 0.1 m depth intervals. These multilevel samplers were used to collect water quality data and determine depth quality profiles of the HZ.

iii. **Transducer-piezometers.**
A set of eight drive point piezometers (4 mm ID, 5 mm OD nylon) were linked to bespoke, automated pressure monitoring transducer devices (Figure 2.5).

The transducer-piezometers measure pressures relative to river pressures using a transducer logging system developed by the University of Birmingham (Greswell *et al.*, 2009). In this device the logger, circuit board and power supply (6 x 1.2v NiMh batteries) are housed in a waterproof enclosure (OtterBox™ 8000) which has a re-sealable lid. This lid allows rapid access to the interior to download data from the logger or to change the battery pack (Figure 2.5). Each port of the pressure transducer is connected to a short length of 5 mm diameter copper pipe using flexible Viton® hose. The copper pipe is soldered into drilled 8 mm brass bolts that pass through two holes in the enclosure. A nut on the exterior side of the bolt is tightened to compress a pair of washers and rubber gaskets on each side of the box wall and produce a watertight

seal. A smear of silicone rubber sealant is also applied to the faces of the gaskets as an extra waterproofing measure.

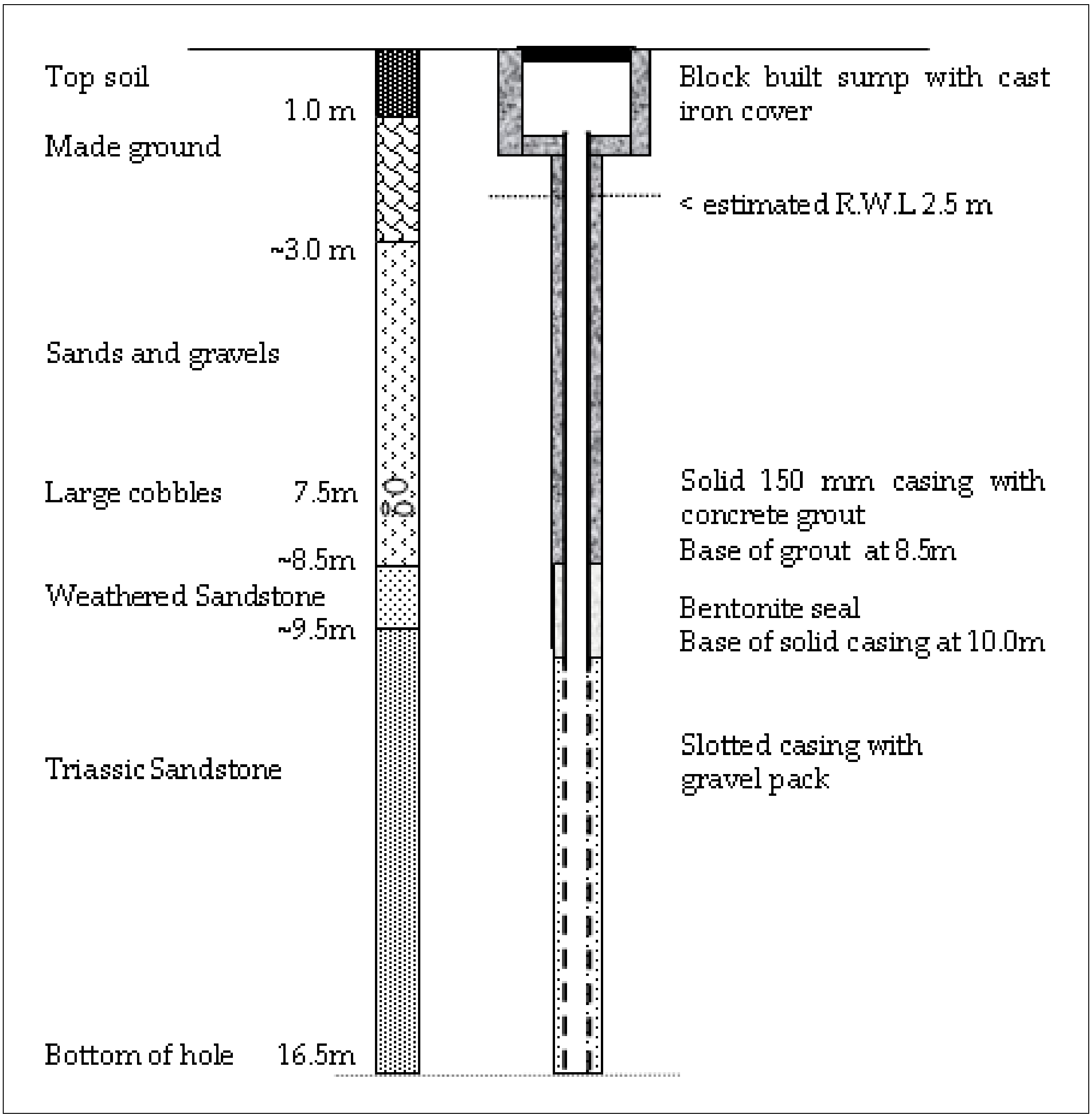


Figure 2.3 HZ test site extraction borehole completion and geological log (metres below ground surface)

The copper pipe which extends from the 'high' pressure port was attached using a brass compression fitting to the length of 5 mm OD flexible nylon pipe that forms the piezometer itself. The piezometer was built and installed using the method described by Rivett *et al.* (2008). Some of the pipe was left free above the riverbed so that the entire box could be lifted clear of the water's surface to allow servicing of the device without having to disconnect the piezometer. The remaining 'low' pressure port was left open to the river.

To prevent strain on the piezometer pipe a tether was constructed from a ~1 m length of 3 mm diameter stainless steel rope which was attached to a 6 mm diameter x 600 mm long stainless steel rod driven into the riverbed next to the piezometer. The other end of the steel rope was formed into a loop to which a screw link was used to attach the tether to a loop of nylon cord tied to the piezometer enclosure. At full extension the tether was just shorter than the pipe.

The piezometer system is able to measure differential pressures with an accuracy of 3–4 mm; time intervals between measurements can be set between one second and 12 hours. The loggers can record up to 44,000 measurements before the data has to be downloaded. The standard time interval for measurements was set to five minutes, so data could be collected continuously for several months.

(a) (b)

Figure 2.4 Photographs of the combined piezometer-multilevel samplers showing: (a) the complete sampling device; (b) close-up of a monitoring point for water quality sampling

The sample points are distributed in several discrete transects along the river reach (Figure 2.6, Figure 2.7).

Various types of sampling point were installed; they can be distinguished by the following naming convention:

P	sample point
+ or −	upstream or downstream from the borehole location, respectively
3 digits	distance along the centre line of the river of the transect from the borehole (in metres), followed by a hyphen
1 digit	the order across the transect (1 is closest to the borehole side of the river) with up to six piezometers installed across a single transect
1 letter	the type of measurement i.e. multilevel (m), simple piezometer (p), pressure transducer (p) or temperature device (T)
other	any other supplementary details i.e. '-bis' (replacement installation), '-short' or '-long'

The distance between successive cross sections is smaller in the vicinity of the extraction borehole to allow higher resolution monitoring in this area. Piezometers penetrate to different depths across the network. The shallowest is set at 0.15 m and the deepest at 1 m; the mean depth for the entire network is 0.4 m.

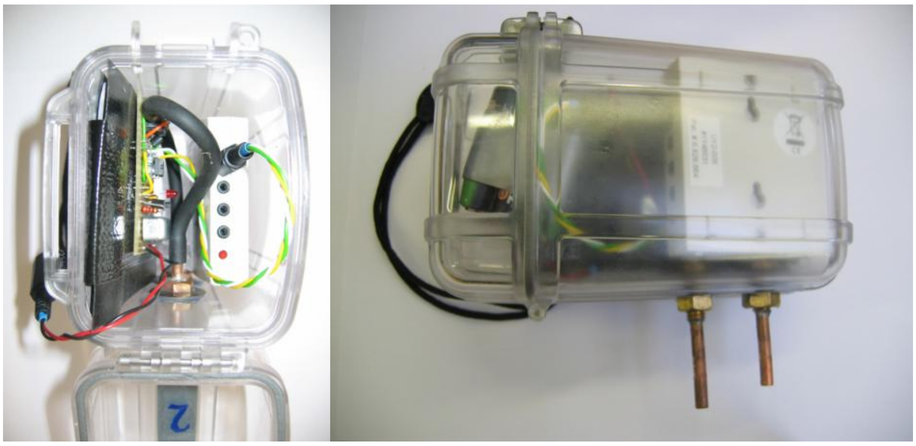


Figure 2.5 Automatic pressure transducer devices and logging equipment in a watertight box connected to a piezometer tube and to the river

2.2.3 River stage monitoring locations

Stilling wells, enabling the measurement of hydraulic head close to the riverbed, were installed at two locations on the site (see Figure 2.6). These were constructed from steel tubes (approx 25 mm diameter) that were driven into the riverbed to a depth of about 30 cm. About 40 cm of tube was left protruding from the riverbed; the lower 10 cm of this length was drilled with holes that were roughly 5 mm in diameter. A ‘Diver®’ (Schlumberger Water Services/Van Essen instruments) was installed in each stilling well to monitor water levels and electrical conductivity at five minute intervals.

Table 2.1 provides a complete list of long-term monitoring installations.

Table 2.1 Details of piezometers and long-term monitoring devices installed the riverbed at the HZ test site. Sample round numbers d1 to d8 refer to the dates of sampling campaigns (as shown in Figure 4.1)

Location Reference	Monitoring Device	Data type	Frequency	Sample round/Date range	Location of data
P-090-1m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d7	HZ_ChemicalData.xls
P-090-2m	Multilevel piezometer - 4 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d7	HZ_ChemicalData.xls
P-050-1m	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d4, d5, d7	HZ_ChemicalData.xls
P-050-2m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7	HZ_ChemicalData.xls
P-050-3m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7	HZ_ChemicalData.xls
P-050-4m	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7	HZ_ChemicalData.xls
P-050-5m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7	HZ_ChemicalData.xls
P-050-6m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d4, d5, d7	HZ_ChemicalData.xls
P-022-1m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3	HZ_ChemicalData.xls
P-022-1m-bis	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d4, d5, d7, d8	HZ_ChemicalData.xls
P-022-2m	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3, d4, d5, d7, d8	HZ_ChemicalData.xls
P-022-3m	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3, d4, d5, d7, d8	HZ_ChemicalData.xls
P-004-1m	Multilevel piezometer - 7 ports	River bed porew ater chemistry	Discrete sampling campaigns	d1, d2, d3	HZ_ChemicalData.xls
P-004-1m-bis	Multilevel piezometer - 8 ports	River bed porew ater chemistry	Discrete sampling campaigns	d4, d5, d6, d7, d8	HZ_ChemicalData.xls
P-004-2m	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3	HZ_ChemicalData.xls
P-004-2m-bis	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d4, d5, d6, d7, d8	HZ_ChemicalData.xls
P-004-3m	Multilevel piezometer - 7 ports	River bed porew ater chemistry	Discrete sampling campaigns	d1, d2, d3	HZ_ChemicalData.xls
P-004-3m-bis	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d4, d5, d6, d7, d8	HZ_ChemicalData.xls
P+005-1m	Multilevel piezometer - 5 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3, d4, d5, d7, d8	HZ_ChemicalData.xls
P+005-2m	Multilevel piezometer - 6 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3, d5, d7, d8	HZ_ChemicalData.xls
P+005-3m	Multilevel piezometer - 7 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d3, d4, d5, d7, d8	HZ_ChemicalData.xls
P+023-1m	Multilevel piezometer - 8 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7, d8	HZ_ChemicalData.xls
P+023-2m	Multilevel piezometer - 8 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7, d8	HZ_ChemicalData.xls
P+023-3m	Multilevel piezometer - 8 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5, d7, d8	HZ_ChemicalData.xls
P+070-1m	Multilevel piezometer - 10 ports	River bed porew ater chemistry	Discrete sampling campaigns	d1, d2	HZ_ChemicalData.xls
P+070-2m	Multilevel piezometer - 10 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2	HZ_ChemicalData.xls
P+110-1m	Multilevel piezometer - 10 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5	HZ_ChemicalData.xls
P+110-2m	Multilevel piezometer - 10 ports	River bed porew ater chemistry	Discrete sampling campaigns	d2, d4, d5	HZ_ChemicalData.xls
P-022-1p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	04/12/07 to 17/11/08	HZ_Heads_"x"...xls
P-022-1m-bis	Transducer piezometer	Differential pressure betw een river bed and river	5 min	10/12/09 to present	HZ_Heads_"x"...xls
P-022-2p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	04/12/07 to 17/11/08	HZ_Heads_"x"...xls
P-022-2s	Transducer piezometer	Differential pressure betw een river bed and river	5 min	10/12/09 to present	HZ_Heads_"x"...xls
P-022-3p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	19/02/08 to 25/06/08	HZ_Heads_"x"...xls
P-004-2p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	04/12/07 to 17/11/08	HZ_Heads_"x"...xls
P-004-2m-bis	Transducer piezometer	Differential pressure betw een river bed and river	5 min	10/12/09 to present	HZ_Heads_"x"...xls
P-004-3p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	04/12/07 to 17/11/08	HZ_Heads_"x"...xls
P-004-3m-bis	Transducer piezometer	Differential pressure betw een river bed and river	5 min	10/12/09 to present	HZ_Heads_"x"...xls
P+005-1p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	19/02/08 to present	HZ_Heads_"x"...xls
P+005-2p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	19/03/08 to present	HZ_Heads_"x"...xls
P+023-3p	Transducer piezometer	Differential pressure betw een river bed and river	5 min	19/2/08 to present	HZ_Heads_"x"...xls
P+005-1T	Multilevel thermisters	River bed temperature	5 min	13/08/08 to present	HZ_Temperatures.xls
BedEC1	Diver in probe housing	River bed EC/pressure/temperature	5 min	26/01/09 to 06/03/09	HZ_BedEC.xls
BedEC2	Diver in probe housing	River bed EC/pressure/temperature	5 min	26/01/09 to 06/03/09	HZ_BedEC.xls
BedEC3	Diver in probe housing	River bed EC/pressure/temperature	5 min	20/03/09 to 13/05/09	HZ_BedEC.xls
BedEC4	Diver in probe housing	River bed EC/pressure/temperature	5 min	20/03/09 to 13/05/09	HZ_BedEC.xls
DiverAtmos	Diver at UoB	Air pressure/temperature	5 min	04/12/07 to present	HZ_Heads_"x"...xls
U/S River Diver	Diver in stilling w ell	River pressure/temperature/EC	5 min	12/02/09 to present	HZ_Heads_"x"...xls
D/S River Diver	Diver in stilling w ell	River pressure/temperature/EC	5 min	04/12/07 to present	HZ_Heads_"x"...xls
Borehole Diver	Diver in borehole	Borehole pressure/temperature/EC	5 min	04/12/07 to present	HZ_Heads_"x"...xls
Borehole Discharge	Logger from flow meter	Discharge	5 min	04/07/08 to present	HZ_BHDischarge.xls

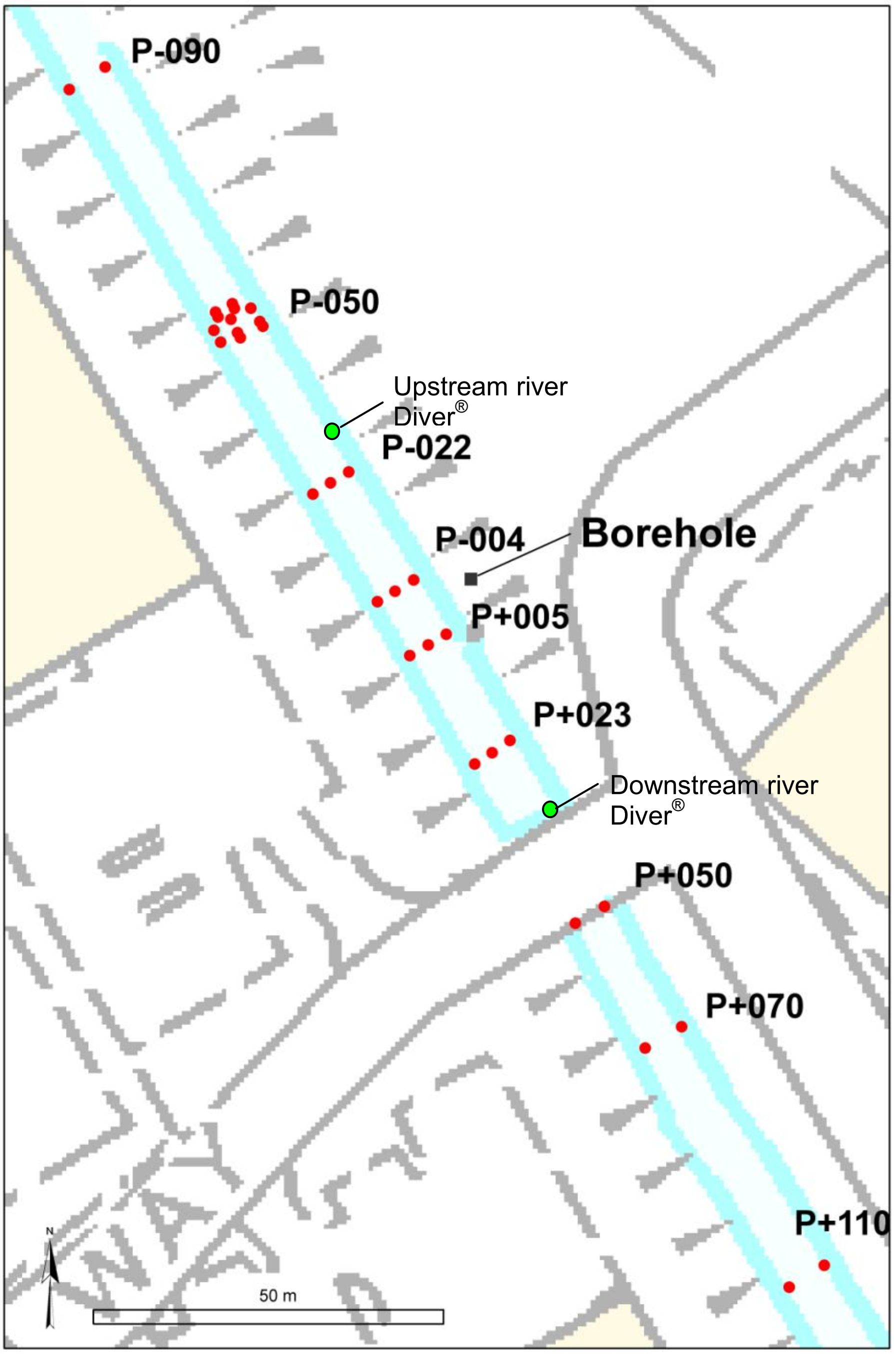


Figure 2.6 Locations of the main piezometer transects, extraction borehole and river level monitoring points

Figure 2.7 Looking upstream along the HZ test site

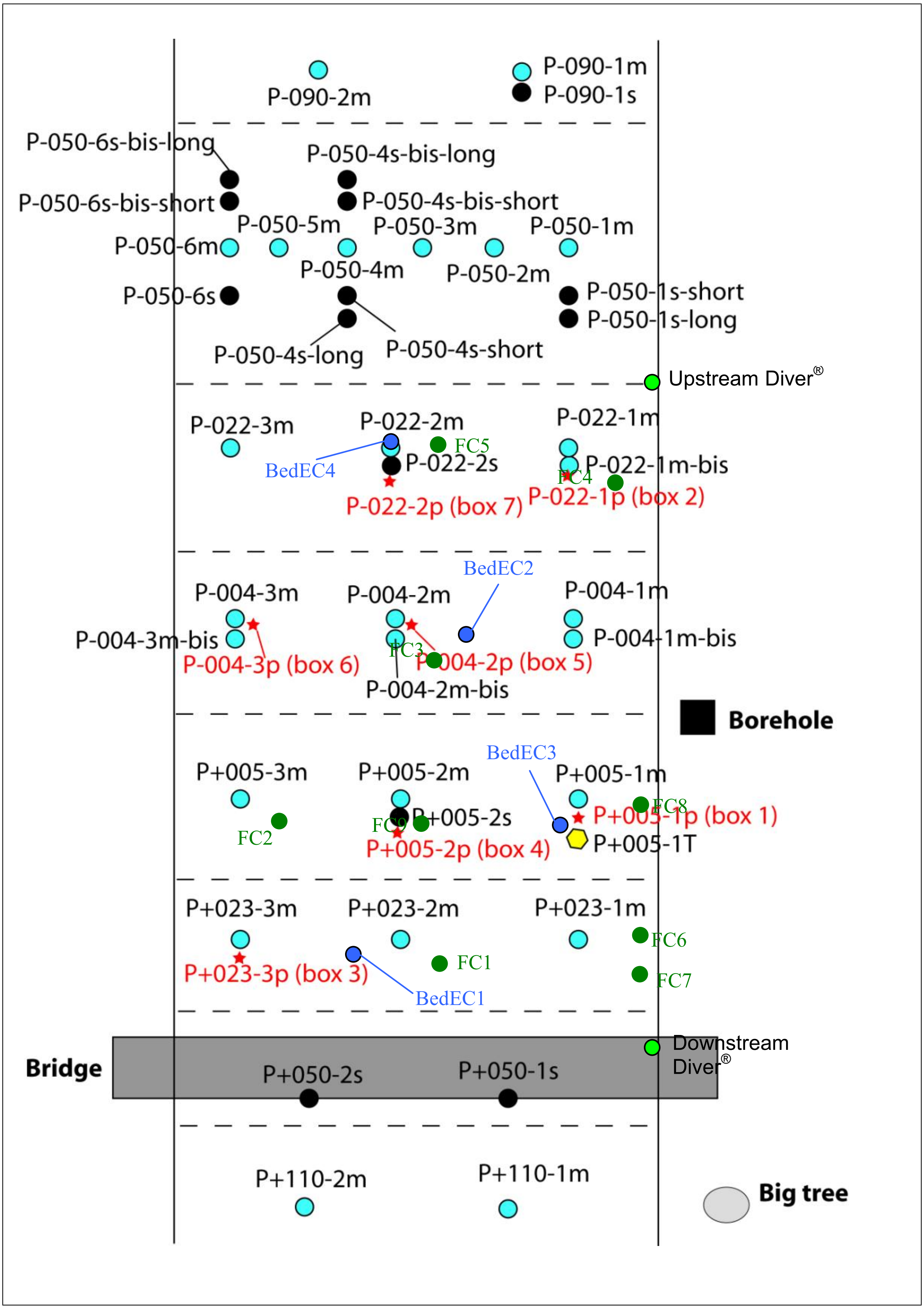


Figure 2.8 Schematic diagram of the HZ test site indicating relative locations of the monitoring network

2.3 Data overview

The data collected for the project broadly fall into three groups: continuous time-series data recorded by automatic devices; data that have been collected manually during sampling campaigns; and data generated from site surveys and tests carried out during the course of the project.

Table 2.1 summarises the type, frequency and monitored time periods for all data. The corresponding sample locations are indicated in Figure 2.8.

Unless stated, all data are given relative to a site datum located at the extraction borehole cover plate, estimated (but not levelled in to a benchmark) to be at an elevation of 96 m AOD.

3 Continuous monitoring data

3.1 Introduction

This chapter outlines the data recorded by on-site logging devices installed in the river, riverbed and borehole.

3.2 River stage and borehole water levels

River Divers® were installed within the two stilling wells at the study site and within the extraction borehole. They record absolute pressure. These values were converted to a measure of total hydraulic head via the following process:

i. The measured pressures are adjusted for atmospheric pressure using data from the Diver® (DiverAtmos) located at the University of Birmingham to yield values of pressure head.

ii. Pressure heads are then added to the elevation of the Diver® pressure sensor relative to a site datum to give values of total hydraulic head.

The data are collated in a series of spreadsheets which process and display the data graphically. Owing to the large number of data points, the data are divided into six spreadsheets which cover the date ranges:

- 4/12/07 to 29/01/08 (HZ_Heads_A.xls);
- 29/01/08 to 19/05/08 (HZ_Heads_B.xls);
- 19/05/08 to 31/08/08 (HZ_Heads_C.xls);
- 31/08/08 to 25/11/08 (HZ_Heads_D.xls);
- 25/11/08 to 08/01/09 (HZ_Heads_E.xls);
- 08/01/09 to 12/-6/09 (HZ_Heads_F.xls).

To make comparisons between the data easier, these spreadsheets also include data for river and borehole electrical conductivity and temperature, and hydraulic data logged by the riverbed piezometers.

3.3 Riverbed pressures

We have collated the data logged by the eight installed transducer-piezometers (see Section 2.2.2). Several of these piezometers became clogged over time, so the electronic transducer-logger boxes (herein termed 'logger boxes') were retro-fitted to some of the 'simple' piezometer tubes during December 2008.

Raw output voltage data from the dataloggers are included in the data files along with a conversion into total hydraulic head. This value is calculated by the following process:

i. A small correction is applied to the data to compensate for the variation in temperature experienced by the electronic equipment (temperature has a

small effect on output voltage). The method for this correction is described by Greswell *et al.* (2009).

ii. These adjusted output voltages are converted into a differential pressure measurement (Figure 3.1) using calibration data for each pressure transducer that was recorded in the laboratory prior to the deployment of the transducers in the field. Positive values for differential pressure imply higher hydraulic heads in the riverbed compared to the river. The calibration data are given in the accompanying spreadsheet file HZ_LoggerCalibrations.xls.

iii. The differential pressures heads are then added to the hydraulic head values measured in the river at the site (as described in Section 3.2) to attain values for the total hydraulic head for each piezometer at each time point.

The pressure data are presented in the spreadsheets that accompany this report (see list in Section 3.2), alongside the hydraulic data from the river and borehole.

These data should be interpreted carefully because their quality varies considerably. All raw voltage data are included in the spreadsheets, but we have tried to make the interpretation of the data easier by only plotting time series of hydraulic head for those data which are thought to be of reasonable quality.

Spreadsheet cells which are coloured red indicate that the data are considered spurious and are excluded from the plots. Data were omitted on the basis of highly erratic readings that were inconsistent with manual head readings taken in the vicinity. This unreliable behaviour of the devices is thought to be due to electronic malfunction and/or blockages in piezometer tubes or pressure ports.

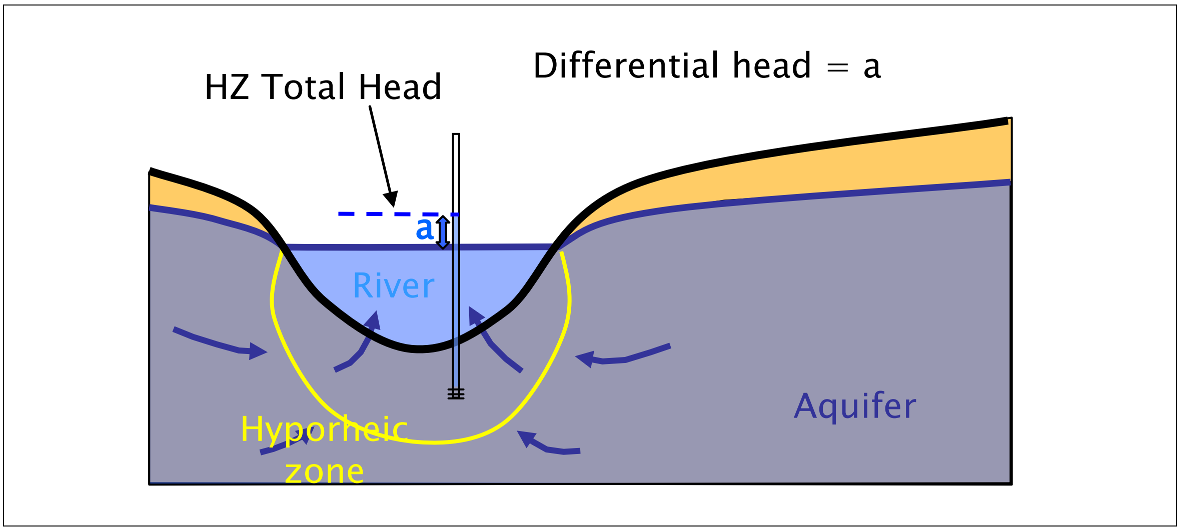


Figure 3.1 Schematic figure illustrating the concept of differential head data collected by the transducer logger boxes

An illustrative example of hydraulic data plotted from measurements taken by the Divers® and bespoke piezometer-transducer logger boxes is shown in Figure 3.2.

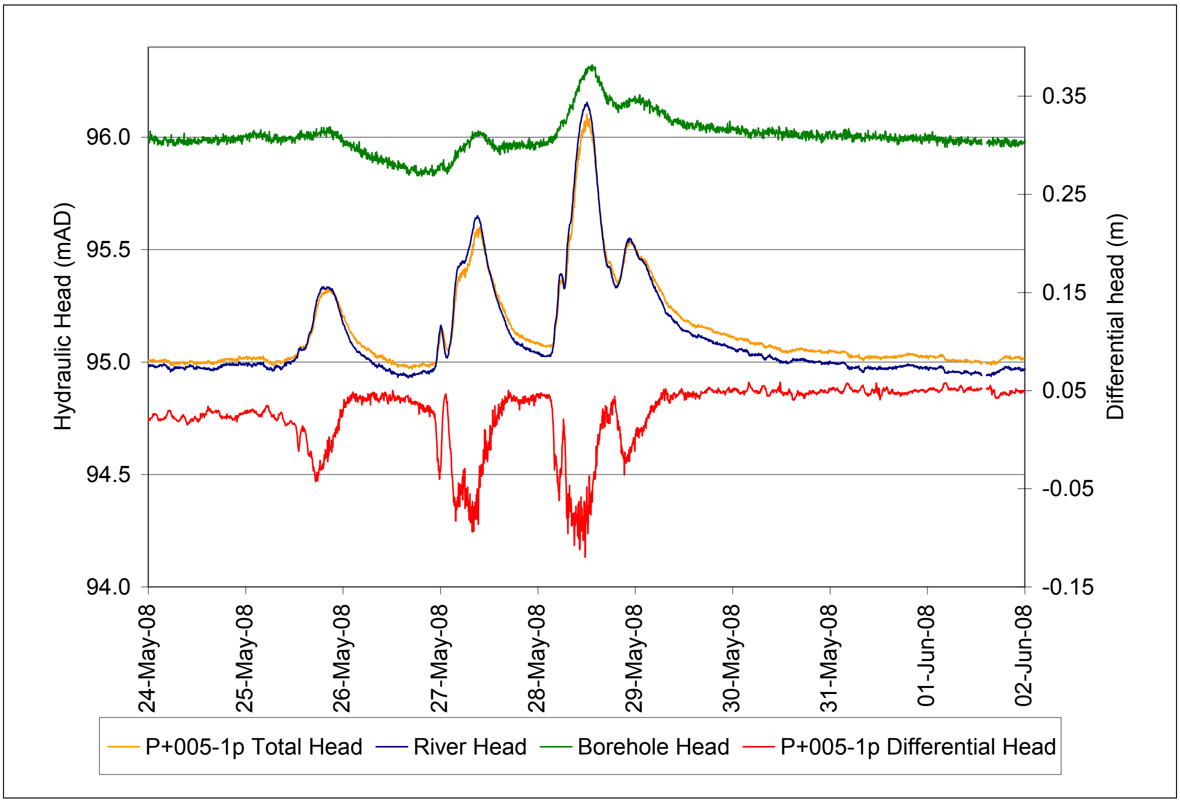


Figure 3.2 Example output of logged hydraulic data

3.4 Electrical conductivity

High temporal resolution electrical conductivity (EC) data have been collected from the river (upstream and downstream), borehole and riverbed (BedEC1–4) using Divers®.

A special housing was constructed out of uPVC tube to install the riverbed Divers®. Holes were drilled in the riverbed at the location of the EC and pressure sensors; the tube was then wrapped in a nylon mesh to keep out fine-grained sediment. The Diver® and its housing was installed into the riverbed to the desired depth (using a lost point method) and then tethered to the riverbed. The complete probe, housing and tether combination prior to installation are shown in Figure 3.3.

Figure 3.3 EC bed probe housing and tether prior to installation

The river and borehole EC data are included in the series of spreadsheets listed in Section 3.2 alongside the hydraulic data; an illustrative plot is shown in Figure 3.4. It should be noted that data are expressed as EC uncompensated for temperature until 26/01/09 and as specific conductance (i.e. expressed as equivalent EC at 25°C) thereafter.

The riverbed EC data are presented in the accompanying spreadsheet HZ_BedEC.xls.

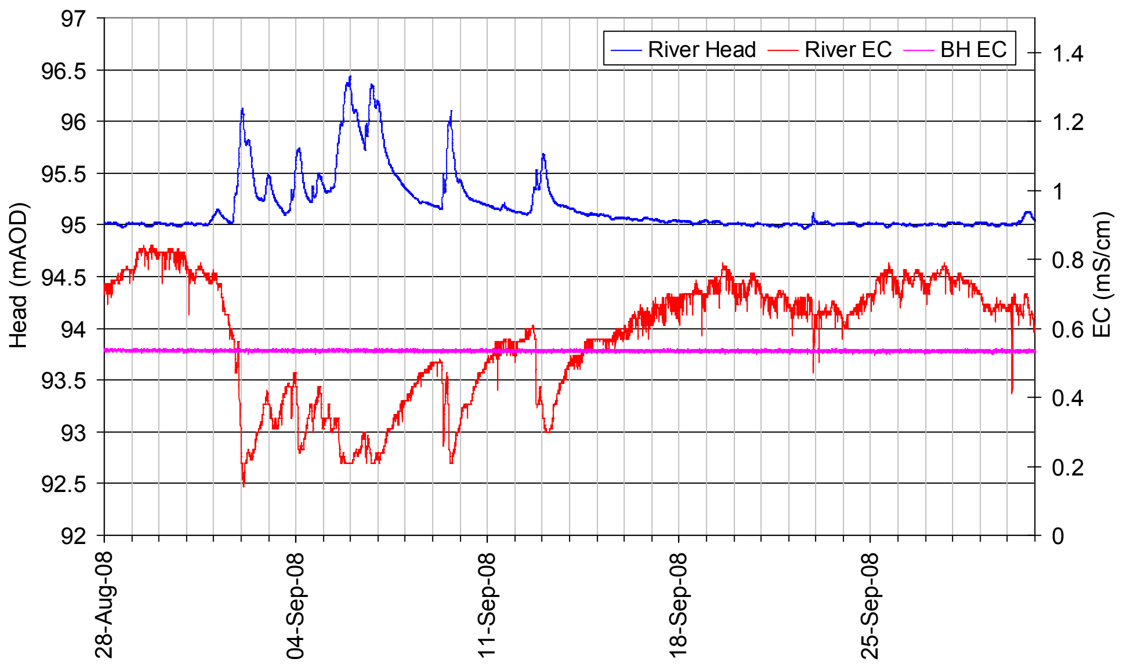


Figure 3.4 Example output of logged EC data for the downstream Diver® monitoring location plotted alongside river stage

3.5 Temperature

High temporal resolution temperature data have been collected from the river (upstream and downstream Divers®), the borehole (borehole Diver®), and the riverbed (BedEC1–4 Divers®).

In addition, a vertical array of thermisters was installed (P+005-1T). The thermisters were connected to a Hobo datalogger housed inside a submerged and tethered OtterBox™ in the same manner as the pressure transducer systems described in Section 2.2.2.

The temperature data generated by the Divers® are included in the spreadsheets listed in Section 3.2 alongside the hydraulic data. Data from the thermister array are collated within the spreadsheet file HZ_TemperatureData.xls which accompanies this report. An illustrative plot of the output data is shown in Figure 3.5.

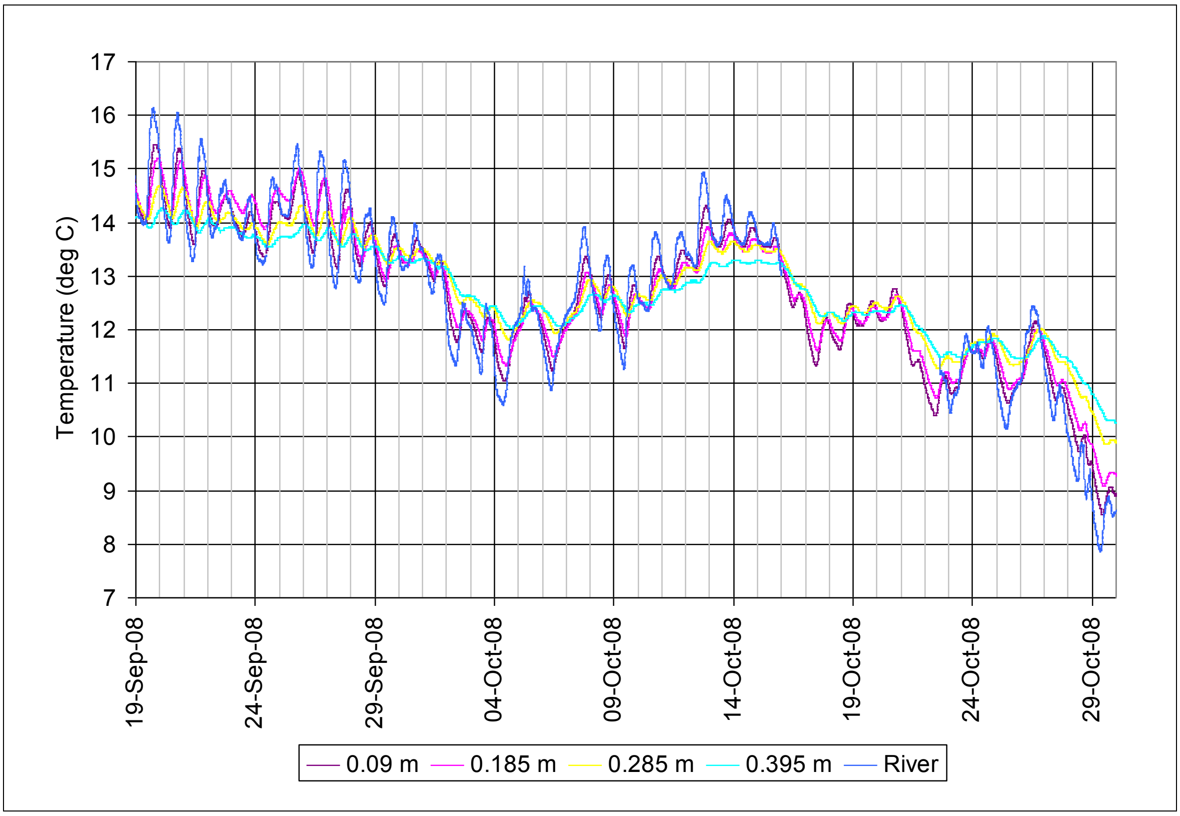


Figure 3.5 Example output of logged temperature data at different depths within the riverbed for the vertical thermister array (P+005-1T)

3.6 Borehole discharge

The flowmeter located inside the outfall pipe of the extraction borehole was attached to a Hobo datalogger for continuous monitoring at five minute intervals during the pumping period. The output data are included in the spreadsheet HZ_BHDischarge.xls.

4 Data from sampling campaigns

4.1 Introduction

In addition to the continuous automated sampling described in Chapter 3, we also carried out a number of sampling campaigns during which samples were taken from the riverbed piezometers for water quality analysis. Manual readings of heads in the riverbed piezometers were also taken at the same time.

4.2 Water quality

4.2.1 Preliminary sampling for regulatory compliance

Chemical sampling was carried out as part of the applications for the borehole groundwater licence and the associated discharge consent to surface water. Samples were collected for both the groundwater discharged from the HZ test site extraction borehole and the river water taken from a point in midstream adjacent to the borehole. Chemical analyses of the samples were performed by independent accredited commercial laboratories. Table 4.2 and Table 4.3 show the results for the determinands requested by the Environment Agency. The data are also included in the accompanying spreadsheet HZ_PrelimChemReport.xls and reported in HZ_PrelimChemReport.pdf.

4.2.2 Sampling rounds

Since September 2007 eight sampling rounds of the multilevel piezometer network have been carried out. The timing of the sampling rounds is given in Table 4.1 and shown against river stage and borehole discharge in Figure 4.1.

Sampling of the multilevel sampler ports for chemical water quality was undertaken with a peristaltic pump connected to plastic sample bottles or a flow-through cell for well-head field determinands of pH, Eh, electrical conductivity (EC), temperature, alkalinity and dissolved oxygen. The field determinand data are given in the spreadsheet file HZ_FieldChemistry.xls. An example plot of the EC profiles for multilevel piezometers within the P+023 transect is shown in Figure 4.2.

Samples for cation analysis were filtered in the field with 0.45 µm filters and acidified the same day on returning from the field. All samples were kept refrigerated whilst awaiting analysis. Cation and anion analyses were carried out using Inductive Coupled Plasma (ICP) and Ion Chromatography (IC) analysis, respectively, at the laboratory within the Earth Sciences department at the University of Birmingham.

A histogram of the ion balance error is presented in Figure 4.3. The errors show a normal distribution around a mean of −3.9 per cent, but an additional peak is seen at −15 to −30 per cent. This result is caused by a cluster of anomalous data points from sampling round number 5, the reasons for which are currently under investigation. With these data removed, the distribution has a mean of around −1.6 per cent and a

standard deviation of 7.3 per cent, indicating that the quality of the data is sufficient for subsequent analysis.

Table 4.1 Summary of chemical sampling rounds

Period	Sampling Round Number	Sampling Date
1. Natural flow conditions 25/9/07 to 4/7/08	1	25-Sep-07
	1	27-Sep-07
	2	18-Oct-07
	2	23-Oct-07
	2	24-Oct-07
	2	25-Oct-07
	2	29-Oct-07
	2	31-Oct-07
	2	01-Nov-07
	3	04-Jun-08
	3	05-Jun-08
	3	06-Jun-08
	3	11-Jun-08
	4	17-Jun-08
	4	18-Jun-08
	4	19-Jun-08
	4	22-Jun-08
	4	24-Jun-08
	4	25-Jun-08
	4	26-Jun-08
	4	27-Jun-08
2. Extraction test 1 (*c*. 80 l/min) 4/7/08 to 18/12/08	5	30-Jul-08
	5	31-Jul-08
	5	05-Aug-08
	5	06-Aug-08
	5	07-Aug-08
	6	12-Sep-08
	7	15-Oct-08
	7	17-Oct-08
	7	24-Oct-08
3. Extraction test 2 (c. 135 l/min) 18/12/08 to 29/5/09	8	16-Mar-09
	8	17-Mar-09
4. Natural flow conditions 29/5/09 to 30/6/09	-	-

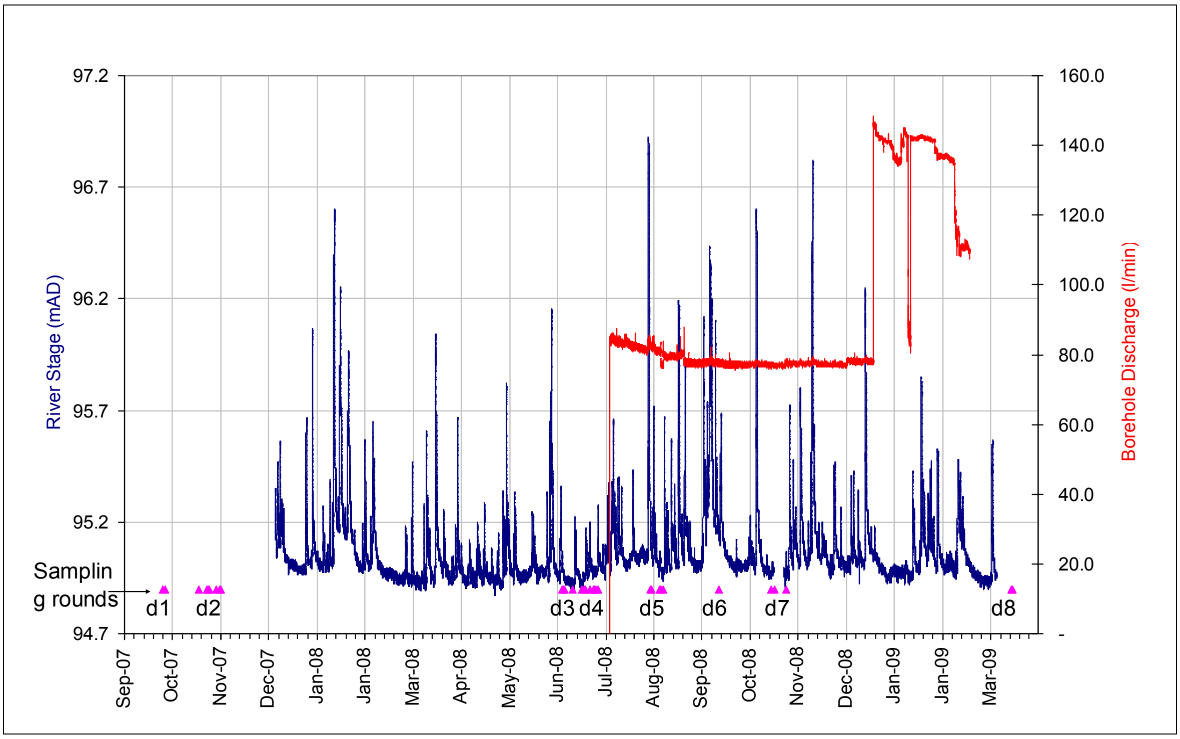


Figure 4.1 The timing of chemical sampling rounds with respect to river stage and borehole discharge

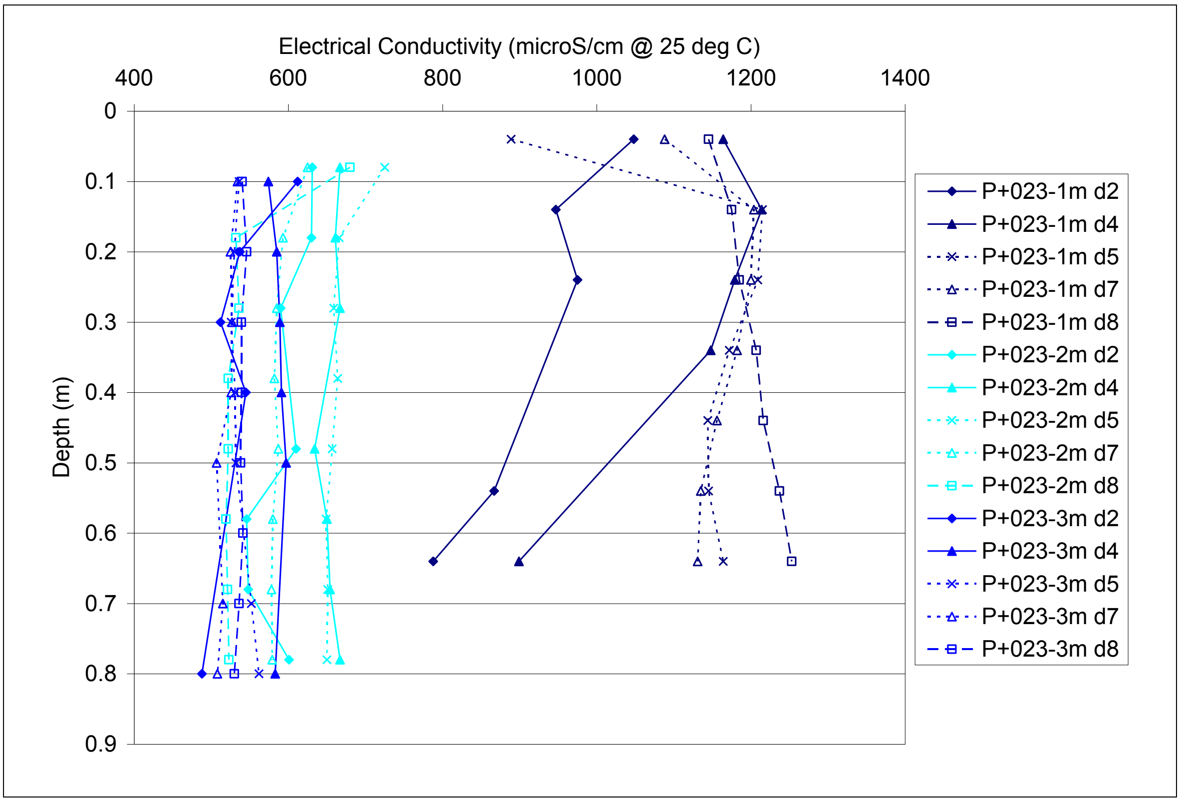


Figure 4.2 Field determined EC profiles for multilevel piezometers at transect P+023

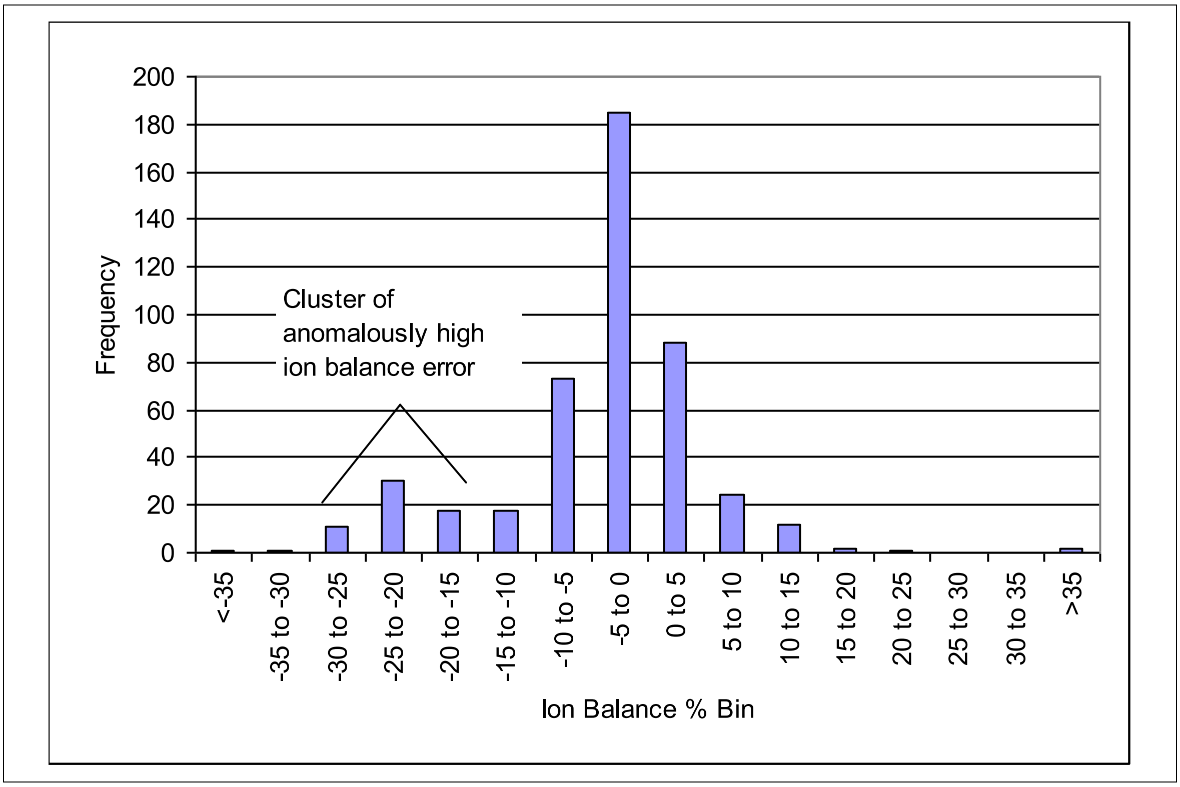


Figure 4.3 Histogram of ion balance error

Table 4.2 Principal chemical characteristics of the water in the HZ extraction borehole and of the River Tame

Element	Groundwater	River Tame
General elements		
pH	7.8	7.4
Suspended solids (mg/l)	10	18
Total hardness as $CaCO_3$ (mg/l)	326	327
Total hardness as Ca (mg/l)	131	131
Phenol index as C_6H_5OH (mg/l)	0.9	0.8
Cations (mg/l)		
Calcium (Ca)	102	97.5
Magnesium (Mg)	17.3	20.3
Iron (Fe)	0.05	0.13
Manganese (Mn)	0.007	0.004
Boron (Bo)	0.15	0.52
Cadmium (Cd)	<0.0001	0.0001
Chromium (Cr)	0.001	0.003
Nickel (Ni)	<0.001	0.029
Copper (Cu)	0.024	0.008
Lead (Pb)	<0.001	0.002
Zinc (Zn)	<0.002	0.036
Ammoniacal nitrogen as N	0.01	0.04
Acid Herbicides (ng/l)		
2,4-D	<11	<11
2,4-DB	<10	<10
Benazolin	<9	<9
Bentazone	<8	<8
Bromoxynil	<10	<10
Chlorthal	<12	15
Clopyralid	<19	<19
Dicamba	<13	<13
Dichlorprop	<11	<11
Fenoprop	<10	<10
Fluroxypyr	<10	<10
Ioxynil	<8	<8
MCPA	<9	<9
MCPB	<11	<11
Mecoprop	<10	54
Pentachlorophenol	<9	12
Picloram	<9	<9
Triclopyr	<15	<15

Table 4.3 Volatile organic compounds (VOCs) in the extraction borehole and River Tame ($\mu g/l$)

Element	Groundwater	River Tame
Dichlorodifluoromethane	<1	<1
Chloromethane	<1	<1
Vinyl Chloride	<1	<1
Bromomethane	<5	<5
Chloroethane	<5	<5
Trichlorofluoromethane	<1	<1
1,1-Dichloroethene	<1	<1
trans 1,2-Dichloroethene	<1	<1
1,1-Dichloroethane	<1	<1
2,2-Dichloropropane	<1	<1
cis 1,2-Dichloroethene	<1	<1
Bromochloromethane	<1	<1
Chloroform	<5	<5
1,1,1-Trichloroethane	<1	<1
Carbon Tetrachloride	<1	<1
1,1-Dichloropropene	<1	<1
Benzene	<1	<1
1,2-Dichloroethane	<1	<1
Trichloroethene	<5	<5
1,2-Dichloropropane	<1	<1
Dibromomethane	<1	<1
Bromodichloromethane	<1	<1
cis 1,3-Dichloropropene	<1	<1
Toluene	<1	<1
Trans1,3-Dichloropropene	<1	<1
1,1,2-Trichloroethane	<1	<1
Tetrachloroethene	<5	<5
1,3-Dichloropropane	<1	<1
Dibromochloromethane	<1	<1
1,2-Dibromoethane	<1	<1
Chlorobenzene	<1	<1
Ethylbenzene	<1	<1
1,1,1,2-Tetrachloroethane	<1	<1
m and p-Xylene	<1	<1
o-Xylene	<1	<1
Styrene	<1	<1
Bromoform	<1	<1
iso-Propylbenzene	<1	<1
1,1,2,2-Tetrachloroethane	<1	<1

Table 4.3 continued overleaf

Table 4.3 continued

Element	Groundwater	River Tame
Propylbenzene	<1	<1
Bromobenzene	<1	<1
1,2,3-Trichloropropane	<1	<1
2-Chlorotoluene	<1	<1
1,3,5-Trimethylbenzene	<1	<1
4-Chlorotoluene	<1	<1
tert-Butylbenzene	<1	<1

The chemical data from the sampling rounds have been collated in the accompanying spreadsheet file HZ_ChemicalData.xls.

Illustrative chemical depth profiles for the four piezometer transects closest to the borehole are shown in Figure 4.4.

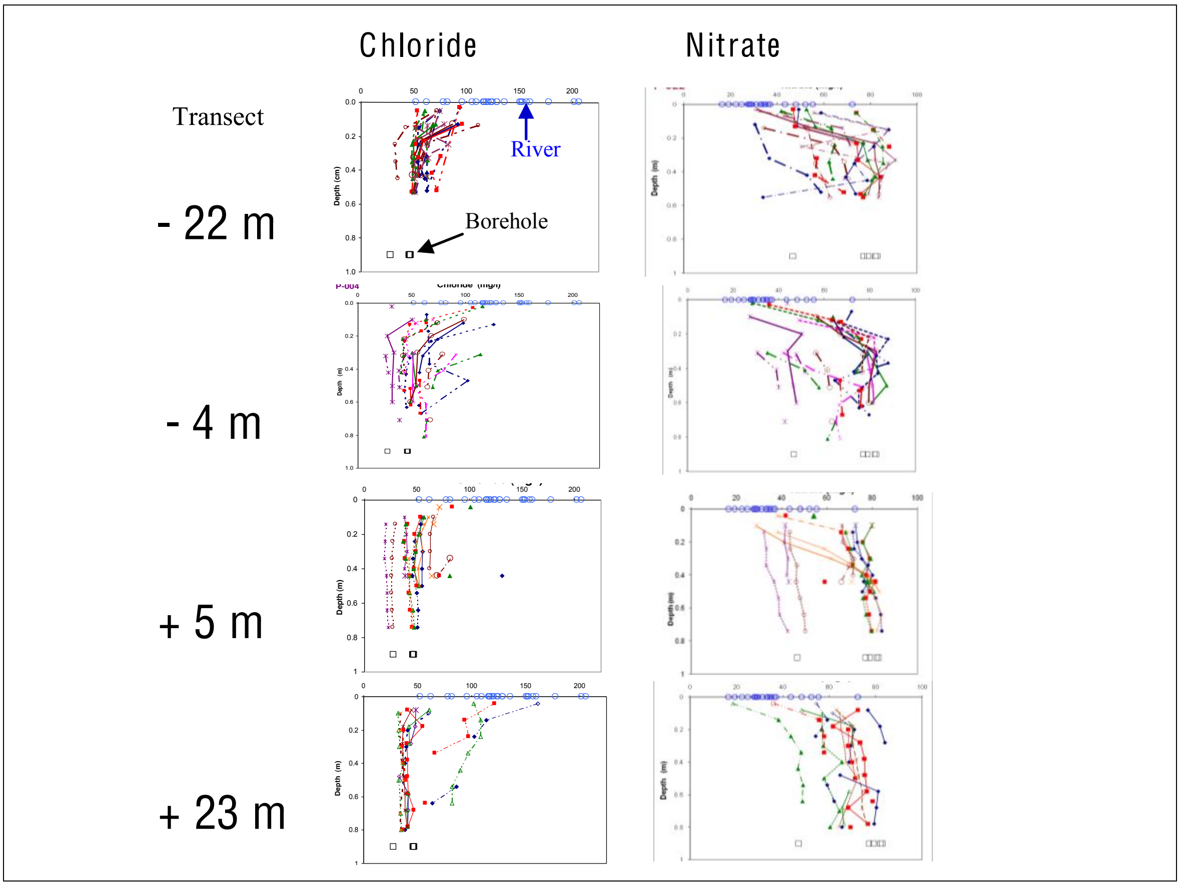


Figure 4.4 Illustrative chemical depth profiles of various anions for four of the multilevel piezometer transects

4.3 Riverbed pressures

During each sampling campaign for water chemistry, hydraulic heads were measured manually in the wider diameter piezometer tubes at the HZ test site, either visually or with a narrow coaxial cable dipper. These data are included in the spreadsheet files

HZ_ManualHeads.xls and HZ_FieldChemistry.xls. An illustrative plot of the data is given in Figure 4.5.

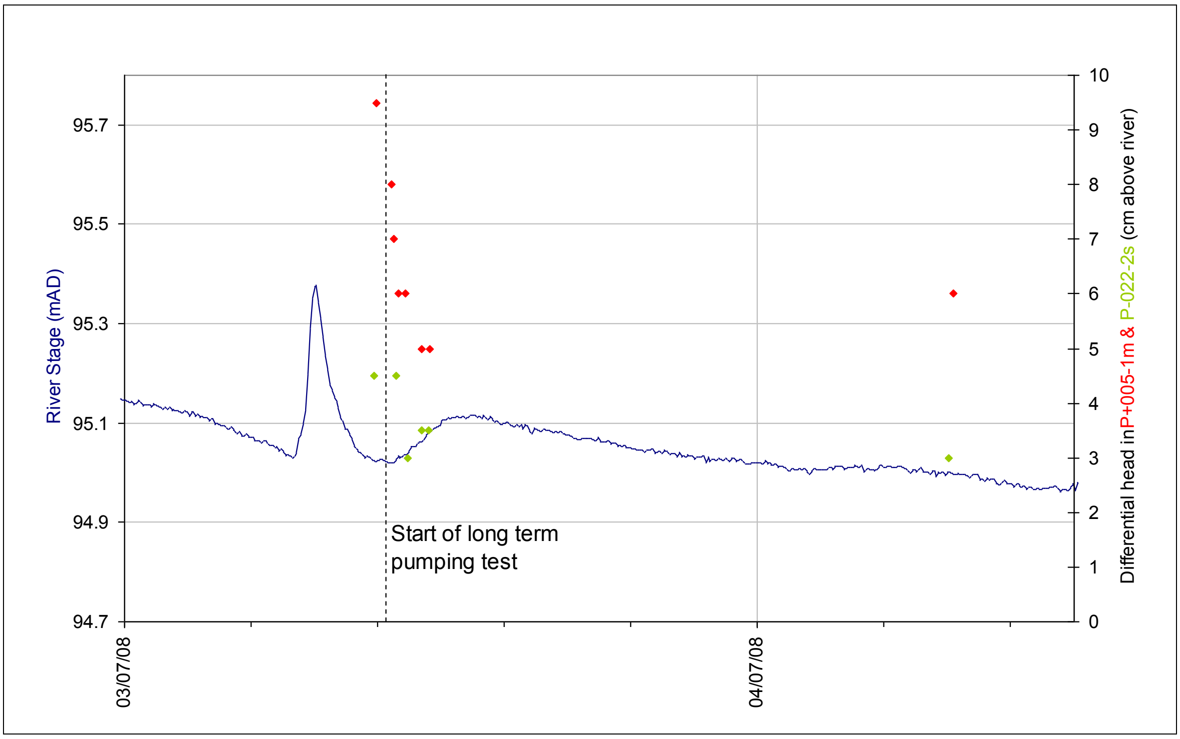


Figure 4.5 Illustrative plot of manual head measurements for two piezometers against river stage

5 Supporting data

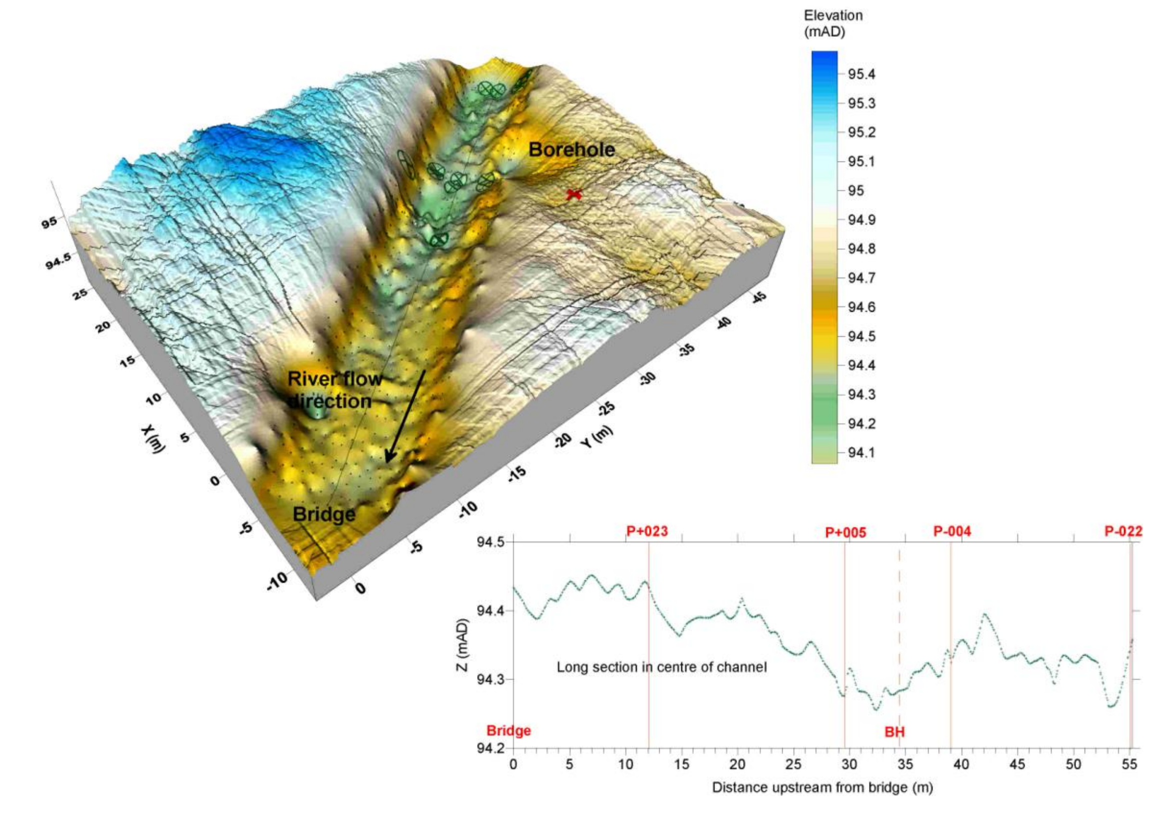
5.1 Introduction

In addition to the semi-continuous logged data and data from discrete sampling campaigns, several one-off surveys and experiments have also been conducted on the site. This section gives an overview of the data that these additional activities produced.

5.2 Topography

Several surveys of the HZ test site were conducted using a total station (electronic theodolite and distance meter) to measure the relative elevations of monitoring points and to gain an impression of the riverbed topography. The point data produced by the surveys are given in x,y,z format in the accompanying spreadsheet file HZ_Topography.xls.

An example plot of the bed topography is given in Figure 5.1.



Note: elevations extrapolated beyond the surveyed channel are not accurate.

Figure 5.1 Illustrative plot of topographical data for the riverbed at the HZ test site

5.3 Geology

5.3.1 Introduction

The geology of the site has been investigated via drilling of the extraction borehole, and the extraction of sediment cores within the riverbed.

5.3.2 Borehole log

The geological log for the extraction borehole is given in Figure 2.3.

5.3.3 Sediment coring

A freeze coring technique (Stocker, 1972) was used to take relatively undisturbed samples of the River Tame riverbed at shallow depths. Cores were retrieved successfully from nine locations (see Figure 2.8). Samples were analysed in the laboratory to determine the distributions of particle sizes in the major lithological units. A constant head permeameter was also used to measure the permeability of a limited number of samples – both undisturbed plug samples of the finer grained material, and repacked samples of the coarser samples.

Photographs of each freeze core are shown alongside the results of the laboratory analyses by Shepherd (2009) (the cited MSc thesis in included as a folder in the electronic appendices). An example output is shown in Figure 5.2.

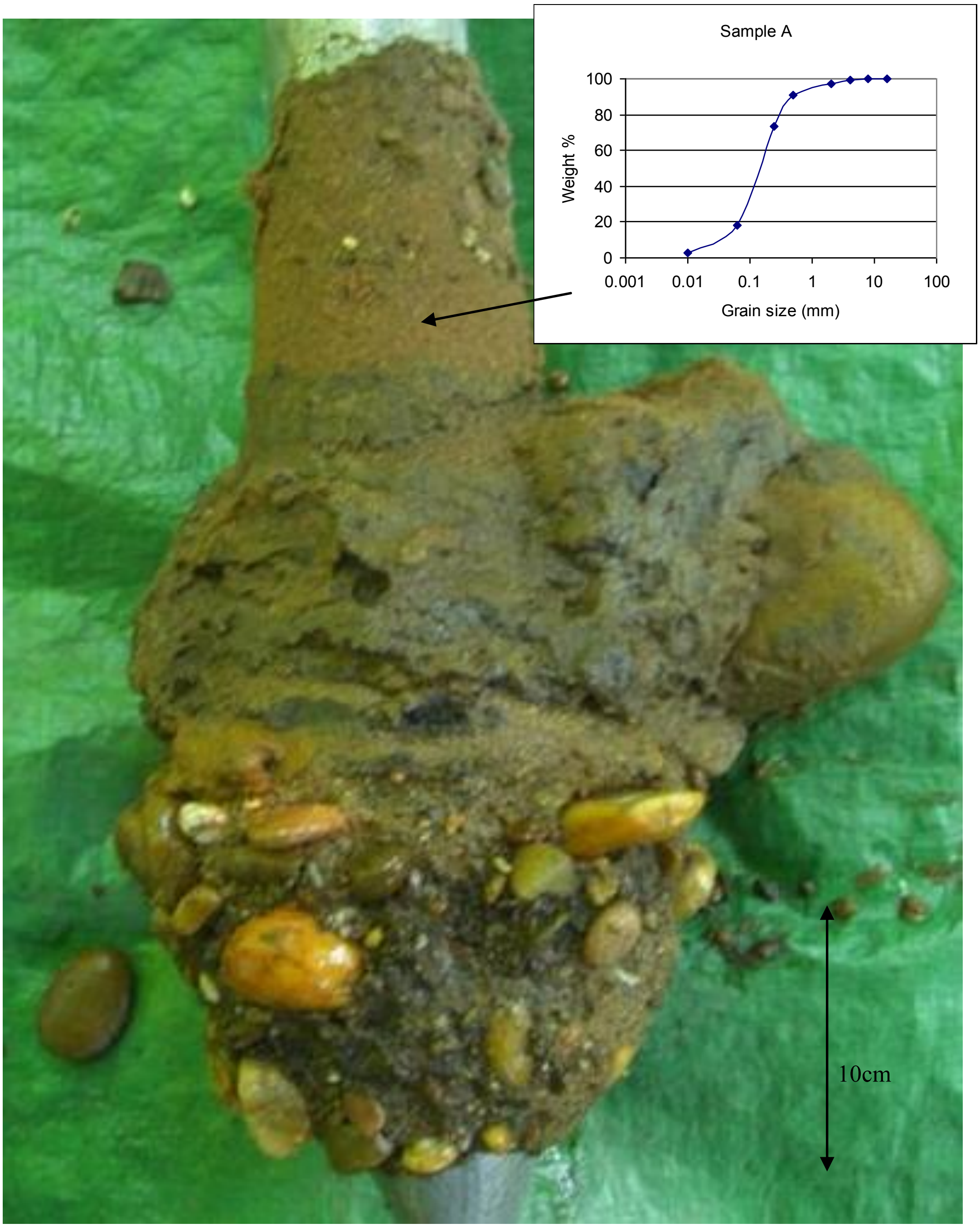


Figure 5.2 Photograph of freeze core (FC1) and a typical particle size distribution curve

5.4 River water surface elevation

A survey of the river water surface was carried out using the total station. A researcher held the prism at the water surface within a portable stilling well. Measurements were taken at various points along the river reach within the HZ test site at the centre of the channel. The results are given in the accompanying spreadsheet file HZ_StageSurvey.xls and illustrated in Figure 5.3.

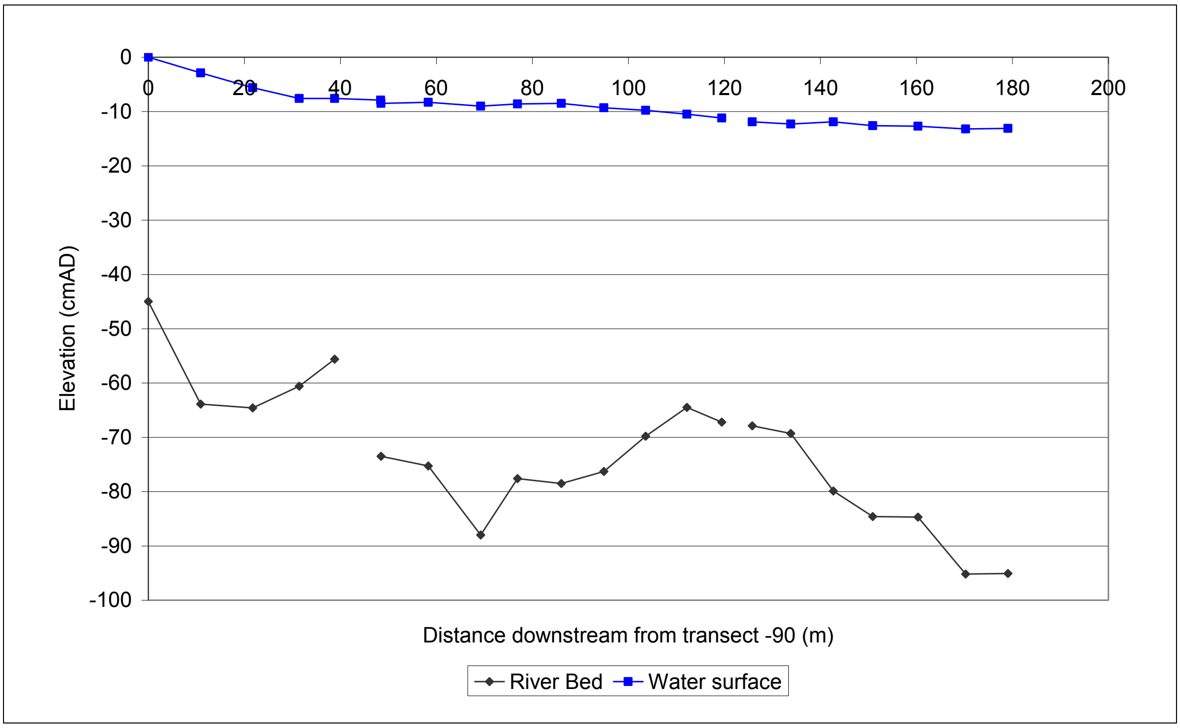


Figure 5.3 River water surface and bed elevations along the centre of the channel on 08/01/09

5.5 Hydraulic parameters

5.5.1 Falling head tests on riverbed piezometers

Falling head tests were carried out on a number of piezometers at the HZ test site using a bespoke pressure transducer/datalogger system. Measurements were analysed using the Hvorslev (1951) method. Three or four repeat tests were carried out on each piezometer on two separate occasions.

An example set of results for piezometer P-090-1s is shown in Figure 5.4 alongside average values of hydraulic conductivity (K) calculated for each piezometer. All data are collated in the spreadsheet file HZ_KTests.xls.

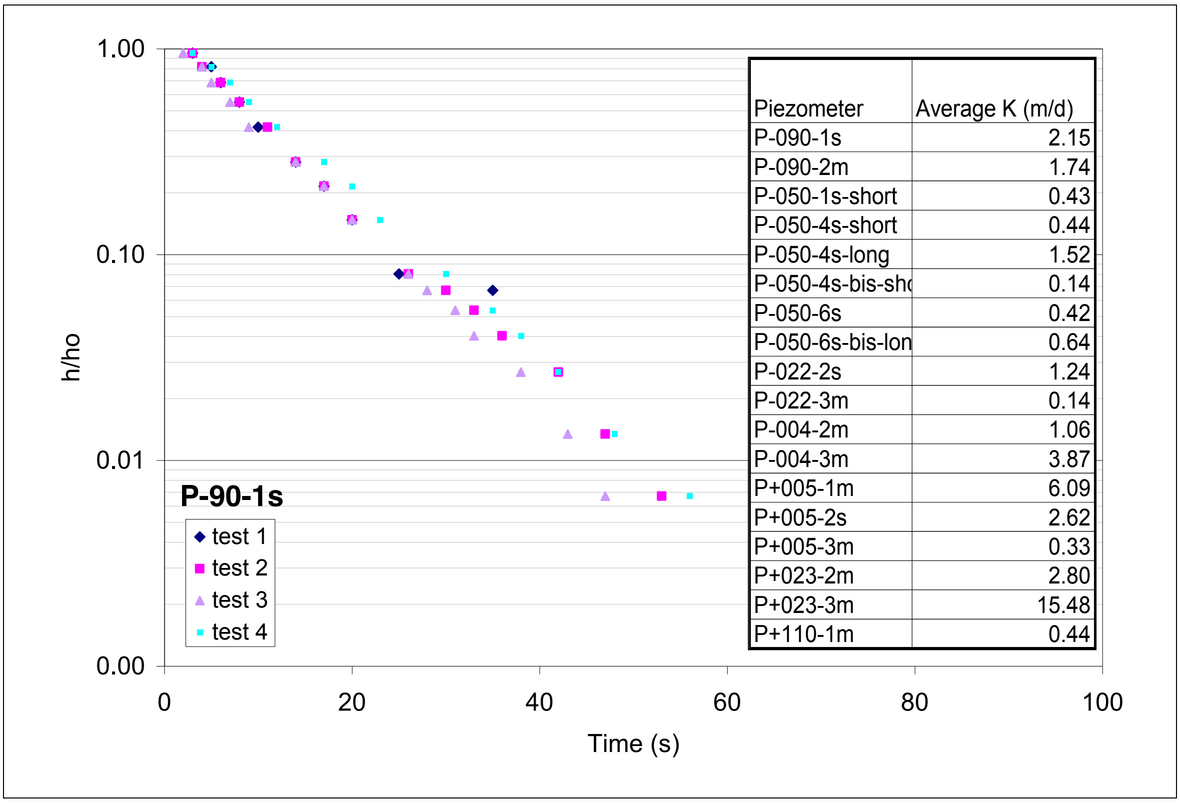


Figure 5.4 Falling head test results for piezometer P-090-1s

5.5.2 Borehole pumping tests

We conducted a constant rate pumping test as part of the process for gaining Section 32 consent from the Environment Agency for conducting groundwater investigations. A subsequent series of step tests was also carried out. The data are presented in the spreadsheet files HZ_PTest.xls and HZ_StepTests.xls, respectively.

A Jacob interpretation of these data gave an average transmissivity of approximately 6 m^2/d. The recovery data from the step tests are presented in Figure 5.5 alongside a summary of hydraulic parameters derived from each test.

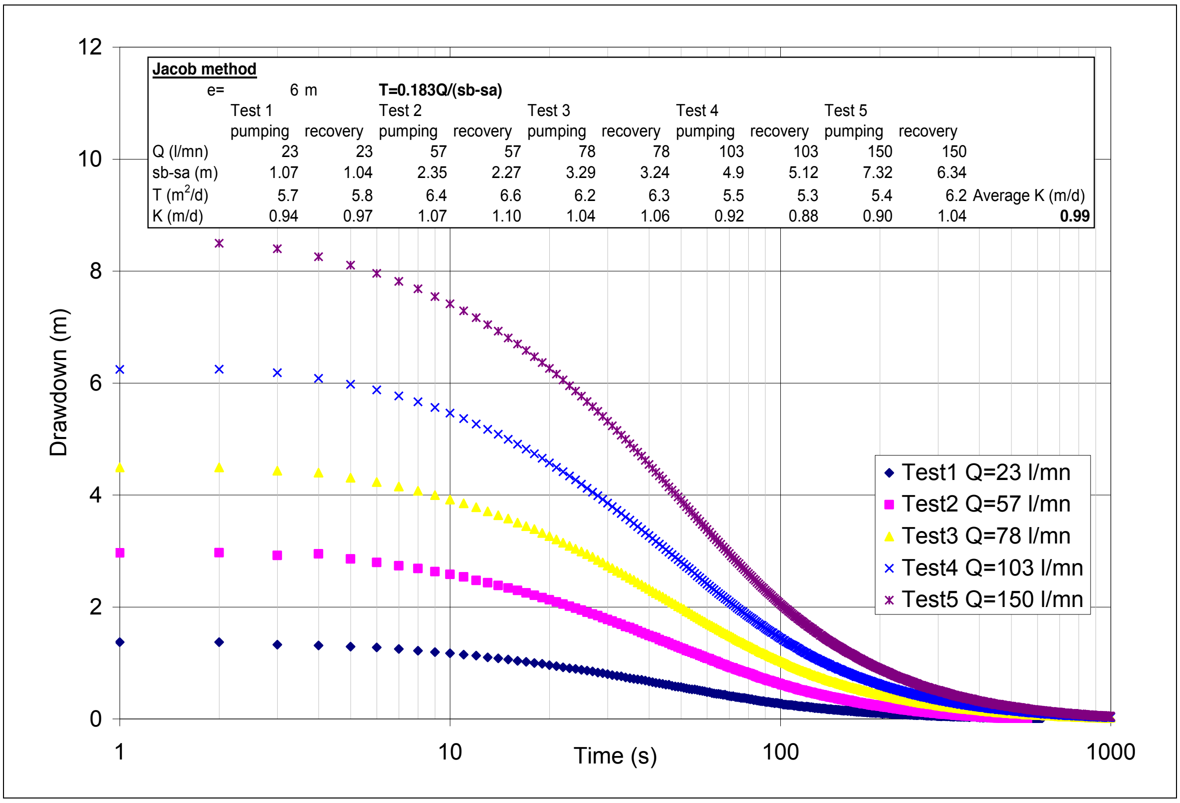


Figure 5.5 Results of step tests carried out on the HZ extraction borehole

6 Summary and conclusions

A reach of the urban River Tame in Birmingham, UK, has been monitored with high resolution using a network of instrument to develop better understanding of the hyporheic zone.

This report provides an overview of the substantial volume of data produced by the project to date. The report's introductory sections described the HZ test site. Each dataset has been briefly described; the raw data is supplied in electronic appendices which accompany this report. A brief summary of the methods used to collect the data have been described in each case and example outputs (which have been checked for quality) have been presented for illustrative purposes.

The three main datasets, collected over the period October 2007 to June 2009 will now be integrated, analysed and interpreted. The output from these assessments will be presented in subsequent publications.

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List of Electronic Appendices

The following files referred to in the text are included as electronic appendices to this report. They are available upon request from the SWITCH Project University of Birmingham research team via the SWITCH CMU (Central Management Unit) contact address provided in the report preface.

- HZ_Heads_A.xls - River stage and borehole water levels (4/12/07 to 29/01/08)
- HZ_Heads_B.xls - River stage and borehole water levels (29/01/08 to 19/05/08)
- HZ_Heads_C.xls - River stage and borehole water levels (19/05/08 to 31/08/08)
- HZ_Heads_D.xls - River stage and borehole water levels (31/08/08 to 25/11/08)
- HZ_Heads_E.xls - River stage and borehole water levels (25/11/08 to 08/01/09)
- HZ_Heads_F.xls - River stage and borehole water levels (08/01/09 to 12/06/09)
- HZ_LoggerCalibrations.xls – Pressure Transducer Calibration Data.
- HZ_BedEC.xls - Riverbed EC Data
- HZ_TemperatureData.xls – River Bed Temperature Data
- HZ_BHDischarge.xls – Borehole Discharge Data
- HZ_PrelimChemReport.xls – River and Groundwater Quality Data
- HZ_PrelimChemReport.pdf - River and Groundwater Quality Data
- HZ_FieldChemistry.xls – Field Chemical Analysis Data
- HZ_ChemicalData.xls – Chemical Quality Summary Data
- HZ_ManualHeads.xls – Hydraulic Head Data (Collected Manually)
- HZ_FreezeCores.xls – Photographs and Analysis of Freeze Cores
- HZ_Topography.xls – Topographic Survey Data
- HZ_StageSurvey.xls – River Water Surface Elevation Survey Data
- HZ_KTests.xls – Piezometer Hydraulic Conductivity Test Data
- HZ_PTest.xls – Borehole Constant Rate Test Data
- HZ_StepTests.xls - Borehole Step Test Data
- Folder: Shepherd (2009) MSc thesis - Switch HZ site K data