Engineering

Groundwater Level Monitoring

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Contents

Executive Summary

The purpose of this report is to update, summarise and evaluate the available ground water level monitoring information across the Crossrail alignment. The report is produced periodically and the next update is planned for summer 2012. A separate report (CRL1-GCG-C2-RAN-CRG03-00001) presents information specifically for Crossrail construction dewatering activities.

Knowledge of groundwater pressures has already informed the design. For the construction phase, groundwater information is need for safe and good quality construction, to verify the design assumptions and to demonstrate and ensure that construction effects on third parties are; (i) as predicted, and (ii) suitably mitigated.

Data is presented in this report from Crossrail and third party piezometers for the shallow aquifer in the River Terrace Deposits, the intermediate aquifer in the Lambeth Group (where it exists, as it is impersistent) and the deep aquifer in the Thanet Sand/ Chalk.

This report provides the following information.

- A schedule of piezometers installed in Crossrail ground investigations and relevant third party piezometers, together with information on their reliability/ condition;
- The Crosssrail digital groundwater database (in spreadsheet format);
- Time plots of piezometric levels measured in the post-2002 Crossrail piezometers;
- Piezometric profile plots presenting the groundwater pressure variation for each "route section". (The tunnelled alignment is divided into route sections so that each route section covers a short length of running tunnel or a major structure such as a station, portal, cross-over or shaft.)
- Contour plots of the ground water levels and ground water level changes in the shallow and deep aquifers;
- Summary plots of the measured tidal variation and its pattern over the Crossrail route;
- An analysis and commentary on the above data.

Conclusions

Since the start of Crossrail ground investigations in 1992, some 1300 piezometers have been installed to monitor the groundwater conditions. This information has been augmented by groundwater data from third parties. A detailed picture of the ground water conditions along and around the Crossrail tunnelled alignment is available and this has informed and continues to inform the project.

1 Introduction

The purpose of this report is to summarise the available groundwater level monitoring data for the Crossrail Alignment. Limited evaluation of the data is reported since a detailed interpretation of the data is included in the Geotechnical Sectional Interpretative Reports (GSIRs) (Refs. [1], [2], [6] and [7]), in other specific reports, namely “Monitoring of Construction De-watering” and “Monitoring of Groundwater Response to Tidal Variations” (Ref. [31] and [32]).

Data from piezometers installed during the site investigations carried out in the 1990’s as well as the current, ongoing post-2002 investigations are presented. It is intended that the report will be updated periodically as further piezometers are installed and new readings are obtained from existing instruments. All of the available data is included in the report although some of it is considered unreliable.

Data from both the shallow aquifer in the River Terrace Deposits and the deep aquifer in the Thanet Sand/ Chalk is presented. For the deep aquifer, data on groundwater levels from the Environment Agency (Ref. [4]) has been used in combination with Crossrail and third party data to assess the variation in groundwater level both regionally and specifically along the Crossrail Alignment. A review of the piezometric profiles between the two aquifers is also included for all route sections between Royal Oak and Pudding Mill Lane and Plumstead Portals. These profiles highlight water pressures in the intermediate aquifer - intermittent zones where sand channels in the Lambeth Group have coalesced into a significant water bodies. Recommendations are made for future monitoring in line with the requirements of the project.

This report is based on Crossrail Alignment Revision “S” (Ref. [14]).

2 GROUNDWATER LEVEL MONITORING REQUIREMENTS

Monitoring of groundwater (piezometric) pressures is essential to determine the state of in situ effective stress in the ground and, as such, piezometric data are a key input into the design and construction of underground structures. The Crossrail project incorporates construction of stations, shafts, portals and tunnels, as summarised below.

Eight underground stations are proposed to be constructed for the Crossrail Alignment: Paddington; Bond Street; Tottenham Court Road; Farringdon; Liverpool Street; Whitechapel; Isle of Dogs and Woolwich. The existing at-grade Custom House Station on the North London Line will be redeveloped as part of Crossrail Alignment. The stations will typically be constructed using a combination of contiguous piling, sheet piling, diaphragm walling and sprayed concrete lining (SCL).

The Crossrail Alignment Rev. S includes 20 cross passages and 10 sumps between the running tunnels. These replace some of the fourteen shafts that were proposed to be constructed for the Crossrail Alignment Rev. M. Currently, only five shafts are still proposed to be constructed: Fisher Street; Stepney Green; Mile End Park; Eleanor Street and Limmo Peninsula. These shafts will typically be constructed using a combination of underpinned precast concrete rings and SCL. The cross-passages will be constructed using SGI segments of SCL lining.

Five portals are being constructed for the Crossrail Alignment: Royal Oak; Pudding Mill Lane; Victoria Dock; North Woolwich; and Plumstead. The TBM launch/reception chambers and the walls for the cut and cover and retained cut sections of the portal will all generally be constructed using diaphragm walls. Sheet piles or bored piles will provide ground support to sections with a small retained height.

The bored tunnels linking the stations, shafts and portals along Crossrail Alignment will be constructed primarily using tunnel boring machines (TBMs) and lined with segmental precast concrete linings. SGI segments may be used at connections to stations and shafts and SCL may also be used in certain areas. Depending upon the type of tunnelling technique being used, groundwater pressures can present more or less of an issue to tunnel construction.

Knowledge of groundwater pressures for these structures is required to:

1. Identify granular strata with significant pore water pressures that may present an instability hazard to construction activities.
2. Estimate magnitudes of groundwater inflows during construction and the corresponding level of groundwater control expected to be needed during construction.
3. Determine the need for ground treatment to facilitate excavation, e.g. dewatering or grouting of high permeability strata.
4. Assess the effects of any dewatering settlements on adjacent buildings, services, structures and tunnels.
5. Determine appropriate construction technique(s), e.g. inclusion of cut-off walls or the use of caisson construction techniques.
6. Assess long-term settlements.
7. Assess the potential for base heave or structure flotation.
8. Form a baseline of natural groundwater fluctuations for a sufficient period prior to construction activities.
9. Assess the impact of construction de-watering proposal on local abstractors.
10. Design of the sub-surface structures, including the design of any tunnel or shaft linings.
11. Assess any changes to the local hydrogeological regime as a result of construction and the effects on neighbouring structures and potential contaminant transport.

12. Assess the effects of long-term changes in groundwater pressures and the design of the tunnels and structures to accommodate these changes.
13. Determine soil strength and stiffness (dependant upon the state of effective stress) for ground movement analyses.

3 GEOLOGICAL SETTING

3.1 Regional Geology

The Crossrail alignment between Royal Oak and Pudding Mill Lane and Plumstead Portals is covered by the following British Geological Survey 1:50 000 maps: Sheet 256 (North London, 1994), Sheet 257 (Romford, 1996), and sheet 271 (Dartford, 1998). The relevant sections of these maps are reproduced as Figure 3.1.1. The parts of the alignment covered by the three Geotechnical Sectional Interpretative Reports are indicated on the figure. A geological long section for the whole alignment is reproduced as Figure 3.1.2.

The generalised geological succession in the London Basin is outlined in Table 1. The floor of the basin comprises Cretaceous Chalk, overlain successively by Palaeogene deposits: Thanet Sand Formation, Lambeth Group, Harwich Formation and London Clay Formation. Near surface the more recent Quaternary deposits comprise River Terrace Deposits, Langley Silt and Alluvium. A variable thickness of Made Ground is to be expected from the surface within the urban environment along the route.

Figures 3.1.1 and 3.1.2 show that the full sequence of strata (excepting the impersistent Harwich Formation and recent Holocene deposits) typical of Central London are present over virtually all of the area covered by GSIR 1/2 (Ref. [1] and [2]) between Royal Oak Portal and Liverpool Street Station. River Terrace Deposits are absent in the extreme west around Royal Oak Portal and Paddington Station. Alluvium is only mapped as present associated with major tributaries of the Thames (including the Rivers Westbourne, Tyburn, Fleet and Walbrook), where RTD may be locally absent. Localised deposit of Langley Silt are mapped around Paddington, Hyde Park, south of Fisher Street Shaft and in the area of Farringdon and Liverpool Street. Harwich Formation is thin and impersistent in central London. It has only been identified intermittently around Tottenham Court Road, Bond Street Station and Liverpool Street Station areas. A significant zone of faulting / folding has been identified in the Farringdon area (Ref. [1] and [2]). There is also some evidence of faulting in the Lambeth Group at the east end of Tottenham Court Road Station (Refs. [35], [36] & [45]) and at Bond Street Station (Ref [50] and [51]).

In the area covered by GSIR 3 (Ref. [6]), between Liverpool Street Station and Pudding Mill Lane Portal and west of Isle of Dogs Station, the full sequence of strata is also present except in the eastern part of this area, along the Isle of Dogs branch, where the alignment crosses the London Clay subcrop east of Limehouse at EB Chainage 13000. London Clay is present throughout the Pudding Mill Lane branch but the end of the portal / ramp structure is within about 100m of the mapped subcrop of the London Clay. Harwich Formation was identified in approximately 51% of boreholes which penetrated through London Clay. The Lambeth Group contains sand channels which coalesce into continuous or semi-continuous bodies over much of the GSIR3 area, and constitute an intermittent intermediate aquifer between the deep and shallow aquifers. Alluvium can be expected at Pudding Mill Lane Portal in the River Lea valley and close to the Isle of Dogs Station in the Thames flood plain, and locally in other areas associated with minor water courses.

The geology is more complex in the area covered by GSIR 4 (Ref. [7]) between Isle of Dogs Station and Plumstead Portal. At the Isle of Dogs Station, London Clay is absent on the western side and re-appears at EB Chainage 13750, where the subcrop crosses the Isle of Dogs Station footprint (Ref. [7] & [21]). Immediately to the east, the alignment between Custom House Station and the North Woolwich Portal, the London Clay Formation, the Lambeth Group and the Thanet Sand Formation successively subcrop below the River Terrace Deposits. Harwich Formation was identified in 94% of the boreholes which penetrated through London Clay. Similarly, the Lambeth Group contains sand channels which have coalesced into a continuous Sand Unit over this stretch of the alignment, and which sub-crop beneath the RTD at Connaught Tunnel.

At the North Woolwich Portal and below the River Thames, River Terrace Deposits directly overlie Chalk. A filled-basin/scour feature has been identified in the Chalk below the River. This too could be fault controlled. To the south of the River, the alignment runs within the mapped limit of Head Deposits. River Terrace Deposits, where present, directly overlie Thanet Sand or Lambeth Group. Lambeth Group material is only encountered locally along the alignment, in-filling an apparent erosion feature in the surface of the Thanet Sand.

Alluvium can be expected to overlie the River Terrace Deposits over almost all of the area covered by GSIR 4, with the possible exception of the area south of the River Thames where head deposits are indicated on Figure 3.1.1. The material mapped as Head Deposits was recovered in Package 10 & 20 ground investigation boreholes and careful logging has indicated that it is in-situ weathered Thanet Sand. Discussion on the head deposit and in-situ Thanet Sand is given in GSIR 4 (Ref. [7]).

Faults have been identified at Isle of Dogs, Limmo Peninsula, North Woolwich (associated with the Greenwich fault zone) and Woolwich Station. Further discussion on faulting across the Crossrail alignment is given in GSIR4 and in the tunnel fault crossings (Ref. [7] and [35], respectively).

3.2 Lithology

Chalk is a soft, very pure white limestone formed from the skeletal remains of submicroscopic algae. Two features commonly found in Chalk are flints and marl seams. Flint is a microcrystalline silica rock that occurs usually as black nodules or as tabular bands or sheets. Flints represent very strong, brittle inclusions in the comparatively weak host Chalk matrix. Marl seams are horizons with increased concentrations of clay. As a result of its nature, the Chalk is a low storage high transmissivity aquifer with dual porosity. The majority of the flow occurs in the fractures, whereas the most of the storage is in the matrix, with water slowly released to the fractures when ground water levels fall (e.g. ref. [5]).

The Thanet Sand Formation is the oldest Palaeogene deposit and is characterised as a homogeneous, grey, silty, fine to medium sand. At the base, the Bullhead Beds, a thin conglomerate of rounded flint gravels and larger nodular flints in a matrix of greenish grey to dark grey, glauconitic, sandy clay lies unconformably on the Chalk.

Much work has been done in recent years in examining the stratigraphy and engineering characteristics of the Lambeth Group (formerly known as Woolwich and Reading Beds) as described by Page and Skipper (Ref. [18]) and Hight et al. in CIRIA Funders' Report CP/83 (Ref. [10]). This work has resulted in some changes to the nomenclature of the Lambeth Group units as summarised below:

Unit	Former Classification	Formation
Upper Shelly Beds (USB)	Upper Shelly Clay (USC)	Woolwich
Upper Mottled Beds (UMB)	Upper Mottled Clay (UMC)	Reading
Laminated Beds (LTB)	Laminated Sands and Silts (LSS)	Woolwich
Lower Shelly Beds (LSB)	Lower Shelly Clay (LSC)	Woolwich
Lower Mottled Beds (LMB)	Lower Mottled Clay (LMC)	Reading
Upnor Formation (UF)	Pebble Bed and Glauconitic Sand (PB and GS)	Upnor

- ***Upper Shelly Beds:*** comprising hard cemented shell conquinas, leaf beds and laminated dark grey shelly clays.
- ***Upper Mottled Beds:*** comprising predominantly stiff to hard fissured and mottled multicoloured silty clays.
- ***Laminated Beds:*** comprising very stiff light grey finely laminated clay-silt and silt-sand with occasional shell beds.
- ***Lower Shelly Beds:*** comprising very stiff mid-dark grey laminated clay, sandy clay and shells.
- ***Lower Mottled Beds:*** comprising intermittently a duricrust at the top (details of which is given below) and predominantly hard fissured mottled multicoloured sandy clays, occasionally silty sands or pebbles.
- ***Upnor Formation:*** comprises pebbles and flint gravel in sandy matrix, laminated grey clay and brown to grey sand, glauconitic fine to coarse sand with occasional black pebbles and shells.

A duricrust, generally consisting of a hardened accumulation of calcrete, silcretes (mainly in the northwest region of the London Basin) or ferricretes (mainly in the southeast region of the London Basin) may have formed at or close to the top of the Lower Mottled Beds. This duricrust is commonly encountered at or just below the Mid Lambeth Hiatus, which represents the transition from terrestrial to marine deposition identified by the boundary between the LMB and the overlying LSB.

Within the Lambeth Group, in the area covered by GSIR 3 (Ref. [6]), sand filled channels can be expected stratigraphically at the top of, or within the Upper Mottled Beds and the Laminated Beds. Sand Channels have also been found within the Lower Mottled Bed. The sand is characterised as clean or pyritic quartz fine to medium sand. The channels are laterally extensive and they can be up to about 2m in depth and up to about 5m wide, possibly in hydraulic continuity. In GSIR4 area, it has been found that the Sand Channels have coalesced into a previously unmapped sand layer - this is referred to as the Lambeth Group Sand Unit. The sand unit occurs beneath the Harwich Formation at the top of Lambeth Group overlying either the Upper Mottled Beds, which it commonly replaces or erodes, or the Laminated Beds. With regard to the Crossrail alignment this unit is persistent between EB Chainage 14450 - 17700 (Route Sections J to L) (see GISR4, Ref. [7]). Sand Channels have also been found in GSIR1&2 areas, e.g. Bond Street Station (thicker than 6.6m in places) and Farringdon Station.

The variation in the characteristics of the Lambeth Group lithologies results from the different depositional environments in which they were laid down and the subsequent post-depositional changes. The Upnor and Woolwich Formations were deposited in shallow marine or estuarine waters while the Reading Formation was deposited in alluvial or supratidal environments. The cycles of regression and transgression of sea level resulted in the heterogeneity of the deposits and in their high vertical and lateral variability.

The Harwich Formation corresponds to the former Division A1 of the London Clay Formation and is divided into three units, although all units may or may not be present at any given location:

- ***Swanscombe Member:*** comprising glauconitic sandy clay with common thick-shelled molluscs.
- ***Oldhaven Member:*** comprising fine glauconitic sand with shells and, at the base, a bed of large black, rounded flint pebbles which may be thick and shelly.
- ***Blackheath Beds:*** the oldest unit comprising rounded to subrounded flint pebbles with a limited matrix of fine to coarse sand or clay.

London Clay consists of mainly dark bluish to brownish grey clay, containing variable amounts of fine-grained sand and silt. The clay generally weathers to a chocolate brown colour. London Clay is relatively homogeneous in lithology in comparison with, for example, the Lambeth Group, but there are distinct vertical lithological changes which are persistent regionally in the London area. The London Clay Formation was divided by King (Ref. [11]) into the successive lithological 'Divisions' A, B, C, D and E. For the Crossrail underground route alignment, only the lower part of the London Clay Formation is present, comprising Divisions A, B and C. (Division C is only present between Royal Oak Portal and Hyde Park.) Division A1 has been reclassified as part of the Harwich Formation, as detailed above.

The River Terrace Deposits in the London area were formed during the colder climatic periods of the Pleistocene. They consist of gravel sheets that were formed in response to heavy seasonal snow-melt run-off. This run-off formed a series of braided channels that meandered and interlinked across a wide flood plain. The material deposited is a well-graded mixture of sand and gravel, occasionally with cobbles where stream flow was intense, and occasionally with silt or silty sand layers formed in slacker water.

Alluvium comprises river deposits (mainly sand, silt and clay) laid down in the recent Holocene period. Langley Silt, where present, overlies the River Terrace Deposits and was formed in the

Devensian Period, either as a loess deposit or as a fluvial overbank loam deposit. Langley Silt was formerly known as “Brickearth” and comprises grey, buff, orange or brown coloured, sandy silt and clayey silt with occasional gravel bands.

It was mined extensively for the manufacture of bricks; hence the remaining deposits can be discontinuous.

Made Ground is the most variable of all the strata. Its nature and thickness depends on previous developments and land uses that have taken place at a particular location including the cycles of reconstruction. Made Ground normally contains a high proportion of locally excavated soils, demolition rubble and previous building foundations, but also could contain contaminants from industrial processes and active service pipes and utilities.

Further details of the lithology along the Crossrail alignment can be found in the Geotechnical Interpretative Reports (Ref. [1], [2], [6] and [7]).

3.3 Crossrail Ground Investigations

Ground investigations were carried out between 1992 and 1996 for the original Crossrail scheme between Royal Oak Portal and Liverpool Street Station. Additional ground investigations for the extended Crossrail Alignment (post-2002 investigations) have been carried out for the new stretch of the alignment to the east of Liverpool Street Station towards Abbey Wood, south of the River Thames. Several more ground investigations have also been undertaken to provide up-to-date information throughout the tunnelled alignment, to revisit specific locations where changes in the alignment occurred (e.g. at cross passage locations) or to investigate specific issues identified during design development.

The sequence of investigations is summarised in Table 2 together with the borehole prefixes relevant to each phase/package of work. The extent and timing of the various phases have been determined primarily by financial constraints. The works included in each phase were established in liaison with the project designers and have taken into consideration the information obtained from earlier ground investigations as well as changes in vertical and horizontal tunnel alignments (Alignment Revisions “H” to “S”).

In addition, further ground investigation may be carried out by the appointed Contractor to investigate specific issues or to provide additional information for design purposes (e.g. for the design of ground treatment measures).

3.4 Route Stratigraphy

Figure 3.1.2 illustrates a schematic of the geological profile, the piezometric levels of the deep aquifer and vertical piezometric profiles for the Crossrail Alignment (Royal Oak Portal to Plumstead and Pudding Mill Lane Portals). Piezomteric levels are given for August 2008 (baseline before start of Crossrail de-watering) and August 2011 (the latest data, which also reflects the effect of IoD de-watering). Further details of the de-watering are given in Section 4.2.1.2. The piezometric profiles along the alignment are discussed in Section 4.4.

Between Royal Oak Portal and Fisher Street Shaft, the station and portal structures will be constructed primarily in London Clay and the overlying superficial deposits. The lower levels of Bond Street Station, Tottenham Court Road Station and Fisher Street shaft are expected to just penetrate the Upper Mottled Beds of the Lambeth Group. Over these route sections, the running tunnels and cross-passages will be constructed in London Clay. Between Fisher Street

Shaft and Farringdon Station, increased penetration into the Lambeth Group is expected with the running tunnels and cross-passages being constructed in Lambeth Group. Farrington Station is located within a faulted zone. Between Farringdon and Liverpool Street Stations the running tunnels will be constructed in a mix of London Clay and Lambeth Group soils; the lower levels of Liverpool Street Station are expected to just penetrate into the Lambeth Group.

To the east of Liverpool Street Station as far as EB Chainage 9600 the running tunnels and cross-passages continue in a mix of London Clay and Lambeth Group soils. Further to the east, the alignment rises above the London Clay / Lambeth Group interface such that Whitechapel Station is expected to be constructed almost entirely in London Clay. The running tunnel vertical alignments diverge east of Whitechapel Station towards the junction at Stepney Green: the shallower eastbound tunnel is within London Clay and the deeper westbound tunnel enters the Lambeth Group and is partly within this stratum at Stepney Green.

As the London Clay thins towards the south and east, the running tunnels and structures associated with the Isle of Dogs branch of Crossrail Alignment will penetrate further into the Lambeth Group and will enter the Thanet Sand Formation (EB Chainage 12100). Along this part of alignment the running tunnels and cross-passages are generally in mixed face Lambeth Group / Thanet Sand, occasionally fully within the Thanet Sand, through the Isle of Dogs, with the lower part of Isle of Dogs Station being constructed in the Thanet Sand Formation. East of Isle of Dogs the London Clay thickness increases rapidly due to the faulting system identified at Limmo Peninsula and the tunnels are predominantly in London Clay between Limmo shaft and Victoria Dock Portal. Exceptions are a short section where up to a half face of Lambeth Group will be encountered and a section close to the portal where River Terrace Deposits locally thicken.

The existing Connaught tunnel and portal structures encompasses the mapped subcrops of the London Clay Formation and the Lambeth Group, although the tunnels are predominantly located within the River Terrace Deposits and overlying superficial deposits.

From North Woolwich to Woolwich Station, construction will primarily be in Chalk. Thanet Sand Formation and River Terrace Deposits will be encountered at the portal and station along this section of the alignment. The cross-passages will be in chalk. To the east of Woolwich station the running tunnel and cross-passages will be constructed primarily in Chalk.

For the Pudding Mill Lane branch of the alignment, running north-east of Stepney Green junction, the shallower eastbound tunnel remains in London Clay until prior to Eleanor Street shaft, where it enters the Lambeth Group soils. The deeper westbound runs in a mix of London Clay and Lambeth Group soils and then joins the eastbound before Eleanor Street shaft. Further east penetration into the Lambeth Group soils increases as the thickness of the London Clay reduces. River Terrace Deposits and Alluvium will be encountered close to and at Pudding Mill Lane Portal.

4 HYDROGEOLOGY

4.1 General

The hydrogeological regime of the London Basin incorporates a deep aquifer comprised of the Chalk and lower Palaeogene deposits of the Thames Group (i.e. the Thanet Sand Formation and the Upnor Formation (Lambeth Group)). There is also a variable shallow aquifer within the more recent Pleistocene River Terrace Deposits. In Central London, the deep and shallow aquifers are separated by the low permeability London Clay and low permeability units of the Lambeth Group. As these strata thin towards the margins of the Basin, the deep aquifer becomes linked with the shallow aquifer. Localised shallow perched water tables may also be present above low permeability layers within the Alluvium, Langley Silt and Made Ground at some locations.

Groundwater abstraction from the deep aquifer during the last two centuries has led to significant lowering of the piezometric pressure in Central London resulting in underdrained piezometric profiles where pore pressures within the London Clay and Lambeth Group are generally lower than hydrostatic from the water level in the shallow aquifer. Groundwater abstraction peaked in the 1960s, by which time the groundwater level in the deep aquifer had dropped to 88m below sea level (12m ATD) (Ref. [5]). The subsequent reduction in abstraction resulted in a gradual rise of the groundwater levels in the deep aquifer, as described by Simpson et al (Ref. [20]).

Rising groundwater levels in the deep aquifer would change the piezometric profiles in the London Clay, Lambeth Group, Thanet Sand Formation and Chalk. As a consequence, buried structures may be subjected to an increase in pore water pressures leading to a reduction in stability and/or deformation of the structure (Ref. [30]).

GARDIT (General Aquifer, Research, Development and Investigation Team) was established in 1992 as a group of parties interested in controlling groundwater in the deep aquifer and included Thames Water, London Underground and the Environment Agency. The objective of the five phase GARDIT strategy is to increase abstractions ‘to control groundwater level in the Chalk aquifer under Central London in order to maintain the integrity of underground structures and foundations in the London Clay (Ref. [5]). This strategy was fully implemented by about 2004 with most of the key abstractions having been developed (ref. [5]) and the water levels well controlled. However, the issue of groundwater level control is ongoing and the Environment Agency remains responsible for monitoring groundwater levels and management of the abstraction licensing. More recently, the increasing use of open loop Ground Heat Source Pumps (GHSP) has added a new variable to factors affecting the water levels in the deep aquifer. Schemes usually take several years to progress from proposal through investigation to implementation. In addition, water usage is seasonal. Further discussion on the deep aquifer is given in Section 4.6.

Apart from the upper and lower aquifers, other potential groundwater bearing strata of relevance to Crossrail alignment are the Harwich Formation as well as Sand Channels and other granular strata present within the Lambeth Group. In some locations these strata are laterally extensive and have a significantly high permeability. Where separate upper and lower aquifers exist, these strata are not in hydraulic continuity with either the deep or the shallow aquifer and so comprise an intermediate aquifer. They can lead to substantial seepage flows into excavations. Measured pore water pressures within the intermediate aquifer are consistent with the surrounding soils (see Section 4.4).

4.2 Construction De-watering

De-watering activities have been planned at several sites along the Crossrail alignment to correspond with stations, portals, shafts and cross-passages depending on the ground conditions, groundwater conditions, geometry and proposed construction method. Table 3 presents an outline programme for the Crossrail works that will involve major de-watering schemes during construction (based on Ref. [54]). Where construction extends close to or into the Lambeth Group some de-pressurisation of sand horizons within the Lambeth Group may be required.

Further details on the de-watering scheme associated with the Crossrail alignment are described in Ref. [33].

To date, de-watering has commenced only at Isle of Dogs (IoD) for the construction of the IoD Station (Ref. [31] & [33]).

4.2.1 Isle of Dogs

4.2.1.1 Background

Several cycles of de-watering have been undertaken at the Isle of Dogs in order to allow the construction of different structures at/near to Canary Wharf. The first phase of de-watering of the deep aquifer took place between July 1994 and April 1997 to allow the construction of Canary Wharf Station for the Jubilee Line Extension. During this phase 10 abstraction wells were installed around Canary Wharf. However, only 6 wells were pumped achieving a stabilised groundwater level of about 74m ATD. Following the completion of construction, de-watering ceased and the piezometric level returned to the previous state between 90 and 94m ATD (Ref. [22] and [26]).

A second phase of de-watering of deep and shallow aquifer was undertaken from late 1998 to 2001 for the development of the Dockland Square and Heron Quays sites. In particular, the deep aquifer de-watering scheme was designed to lower the groundwater level below 72m ATD in order to allow the construction of foundation piles under dry conditions. However, the deep aquifer was lowered to a minimum level of 70m ATD (Ref. [23] and [24]). The de-watering scheme exhibited effects several kilometres to the east and west of the Canary Wharf underlining the effects of regional drawdown (Ref. [25]).

The third phase of de-watering was carried out between 2001 and 2005 for construction at Blackwall Place. The aim was to reduce the water level of the deep aquifer to 77m ATD (Ref. [23] and [24]), which was achieved in 2005.

The forth phase of de-watering of deep and shallow aquifer was undertaken west of Canary Wharf for the Riverside South project. For the de-watering of the shallow aquifer, there was in place a network of 17 boreholes, to achieve a groundwater level between 99-95m ATD. This abstraction activity commenced in April/May 2007. In addition, de-watering of the deep aquifer was carried out between January and July 2008, achieving a level in the deep aquifer of 74m ATD (Ref. [28]). The effects of these pumping activities in the shallow and deep aquifer have been recorded at a maximum distance of approximately 680m north and 1000m east from the abstraction site, respectively (see Section 4.3.5.1).

De-watering at Isle of Dogs has highlighted a difference in the deep aquifer's response between the west and east side of West India Dock (North); with the eastern end experiencing less drawdown and a faster recharge rate. This is likely to be related to the presence of a scour hollow at the eastern end of Isle of Dogs providing a means for easier/direct recharge from the River Thames/shallow aquifer. In addition, a fault through the Thanet Sand and Chalk Formation at West India Dock (North) appears to serve as a partial barrier to flow within the aquifer which decelerates recharge in the western block of the aquifer (Ref. [21] and [23]). Figure 3.1.2 shows this fault schematically, near EB Chainage 14300. Groundwater monitoring data showing the variation in response to the dewatering scheme are presented and discussed in Section 4.3.5.1 and 4.4.

4.2.1.2 Crossrail De-watering at Isle of Dogs

De-watering activities in preparation for the construction of the Isle of Dogs Station commenced in early August 2008 with the installation of fourteen deep wells screened in the Chalk. The target was to lower the groundwater level in the deep aquifer to 63m ATD and it was achieved in December 2008. Since then, the rate of pumping has been reduced to "maintenance" levels with 12 to 14 wells in operation around West India Dock (North).

Groundwater monitoring data showing the variation in the deep aquifer level induced by this de-watering activity are presented and discussed in details in the relevant Construction De-watering report (Ref. [31]). Figure 3.1.2 summarises the current situation which shows de-watering drawdown extending west towards Stepney Green and east as far as Connaught Tunnel, with local recharge at scour hollows near EB Chainage 14300 and 15900.

4.3 Piezometric Data

4.3.1 General

During the course of the ground investigations that have been carried out as part of the Crossrail project, 1314 piezometers have been installed in boreholes along the route alignment. This total comprises 233 piezometers from the 1992 ground investigations and 1081 piezometers from the post-2002 ground investigations. In addition, arrangements have been made by CRL to collate data from additional 81 installation owned by third parties (i.e. LUL and Canary Wharf Contractors (Crossrail)).

4.3.2 1992 Crossrail Piezometers

Details of the piezometers installed during the 1992 ground investigations are given in Appendix A. The piezometers that were installed during these ground investigations included pneumatic piezometers, standpipes and standpipe piezometers. In July 1997, (when monitoring was discontinued) only 64 of these piezometers were functioning, with the remainder either broken/destroyed or of unknown condition. More recently, surveys to identify any remaining functional standpipes / standpipe piezometers were undertaken by Norwest Holst Soil Engineering Ltd (NHSEL) in 2004 (Ref. [16]) and by GCG in 2006. It is considered that pneumatic piezometers are unlikely to be functional or reliable due to damage to the valves, blockages in the tubing or de-saturation of filters and no attempt has been made to locate these instruments.

Only 7 standpipes / standpipe piezometers were found to be fully functional after the completion of the first phase of remedial works (refer to Ref. [40] for more details). A further 2[1] installations were identified which may be recoverable. The remediation works for the pre-2000 piezometers are currently completed. Two installations are still under observation (refer to Ref. [40] for more details). Another round of remediation/ maintenance work might be carried out soon. On this basis, the maximum number of functional piezometers could become 28, if all remedial works are successful - i.e. approximately 2% of the instruments installed. Common reasons for piezometers being non-functional were the inability to locate the installation, normally as a result of resurfacing of the roadway or redevelopment of the site, or damage/blockage to the piezometer installation. An update summary of the problems identified with the 1992 piezometers is given in Appendix C.

Plots of the recorded piezometric groundwater levels against time for the 1992 piezometers are reported in Appendix B. The data are grouped according to the alignment sections defined in the 1992 Geotechnical Interpretative Reports (Ref. [1] & [2]) and shown in Figure 3.1.2. The raw data for these plots are tabulated in Appendix A.

4.3.3 Post-2002 Crossrail Piezometers

Details of the piezometers installed during the post-2002 ground investigations are given in Appendix A. The piezometers included standpipe, gas standpipe, Casagrande standpipe, PiezoPress and vibrating wire piezometers. Two Solexperts Multi-Port Sampling (MPS) systems were installed at Whitechapel as part of the Package 1 ground investigations – additional details

[1] An additional 17 installation were noted as "not located". A further attempt may be made to find these piezometers and it may be that some of them may be recoverable.

of these installations are given in Ref. [6] and [9]. In addition, five multi-level piezometer systems have been installed at Stepney Green. These comprise three multi-level grouted in vibrating wire systems, two Waterra continuous multi-channel tube (CMT) systems and a Solexperts multi-port sampling system (MPSS). Details of these installations carried out as part of Package 12 and Package 13-VO2 are given in Refs.[8], [37], [38], [39] and [41]. Following the successful trial at Stepney Green (ref [8]), the Waterra CMT system has been rolled out as follows: two CMT-7 boreholes have been installed at Tottenham Court Road as part of Package 16 ground investigation, four CMT-7 and one CMT-3 boreholes at Farringdon as part of Package 13 and nine CMT-7 boreholes as part of Package 16A ground investigation between Paddington and Tottenham Court Road. Several vibrating wire piezometers have been installed at Isle of Dog. However, a number of the piezometers that have been installed are either no longer functioning or are deemed unreliable, as indicated by the colour coding in Appendix A. The first phase of remediation/ maintenance works has been completed and reported. The second phase is currently in progress. A summary of the piezometers scheduled for remediation, and proposed/ implemented remedial actions are given in Ref. [34], [40] & [46]. Further details and an update on progress to date are given in Section 4.3.4

The piezometers discussed above are designed to measure the groundwater conditions along the alignment. Additional information on groundwater conditions away from the Crossrail alignment can be obtained from 3rd party piezometers and Environmental Agency data, as well as planned off-alignment Crossrail sentinel wells (Package 27B, Ref. [48]). These off-alignment piezometers are useful for establishing groundwater drawdown cones from construction dewatering activities.

Figures 4.3.1 to 4.3.31 are plots of the recorded piezometric groundwater levels against time for the post-2002 piezometers grouped by Route Section (Table 4). The digital data for these plots is presented in the Crossrail Groundwater Database, in Appendix A.

4.3.4 Piezometer remediation

Piezometers require maintenance after installation for a number of reasons. The main problems encountered with the Crossrail piezometers are:

- Boreholes not located - likely to have been tarmaced over during road resurfacing, covered by grass and/or fly tipping, or in areas that become redeveloped/ paved since the piezometer was installed.
- Borehole headworks covers that could not be opened – due to stripped screw-tops and/or rusted screws
- Borehole headworks flooded – most typically due to blockage of the headworks filter/ drainage system
- Borehole headworks flooded – due to sunken headworks or headworks that were set low from the onset, relative to the surrounding ground level. This leads to ponding of water in the headworks and inflow of surface runoff into standpipe piezometers in an erratic manner that renders the measured data unreliable.

- Piezometer standpipes that are set low in the headworks, below the headworks drainage outlet. As a result, when surface run-off enters the headworks, the piezometer standpipe gets flooded first, before the water level reaches the headworks drainage outlet.

- Boreholes installations blocked or reporting high and variable water level (e.g. due to a possible inflow of surface water into the piezometer standpipe).

- Borehole reporting high water levels in comparison with most other installations in the surroundings

On the basis of the pattern of problems observed above, a first phase of remediation/ investigation work was undertaken between February 2009 and March 2010. The scope of this phase of remediation work included 121 piezometers (see Ref. [34] & [46]). Of these 71 installations were successfully remediated and brought back to working conditions, whereas 38 were founded to have been destroyed or were abandoned as not serviceable. A remaining 12 installations are still under remediation/ investigation & observation. The next phase of piezometer remediation work is currently on going; further details can be found in Ref. [40].

4.3.5 Down-hole piezometric data loggers

In standpipe piezometers it was possible to install a submersible piezometric data logger known as a “Diver”. The Diver is a self-contained instrument manufactured by Van Essen Instruments comprising a sealed stainless steel cylinder housing a pressure sensor, temperature sensor, solid state memory and a long-life battery (Ref. [3]). An optical link is used to both program and download data from the Diver. The Divers record absolute pressure which needs to be corrected for changes in barometric pressure; the latter being readily achieved using a similar type of data logged instrument referred to as a “BaroDiver”, which measures atmospheric pressure at the ground surface.

Divers were installed in various piezometer installations for the following purposes:

- Continuous monitoring to evaluate groundwater response to tidal variation

- Continuous monitoring of the de-watering drawdown

- Investigate anomalous behaviour (e.g. high or unexpectedly variable groundwater levels, water level recovery after cleaning/ flushing out problematic piezometers etc.)

- Continuous monitoring during pumping tests carried out as part of CRL ground investigations

- Permeability testing in low permeability soil

Section 4.3.5.1 gives a brief commentary on the diver data that record particular groundwater features (such as effects of third party pumping activities). In addition, separate reports have been produced to present and discuss the specific aspect investigated using diver data. In particular, the tidal report presents detailed analysis of the influence of tidal variations (Ref. [32]). The Monitoring of Construction De-watering reports (Ref. [31]) provide a detailed commentary on the diver monitoring data, which show the effect of current Crossrail de-watering for the construction of IoD station (Section 4.2.1.2). Diver data obtained during the piezometer remediation/ investigation work, in relation to the investigation of anomalous piezometers, are presented and interpreted in Ref. [40]. Analyses of relevant pumping test diver data and diver data obtained during permeability testing will be conducted, in order to obtain information on the mass permeability and hydraulic interconnectivity for Geotechnical Interpretative Reports that are in preparation. Finally, the permeability report presents the diver data obtained during permeability testing (Ref. [47]).

4.3.5.1 Commentary on data

All diver data have been included in the groundwater data base (Appendix A) as daily average values[2] and have been presented in Figures 4.3.1 to 4.3.31 together with the manual dipped measurements. Separately, all available diver data have been checked for tidal variation response, as discussed in Section 4.7 and reported in tidal report (Ref. [32]). A detailed review of the diver data collected up to 2009 is given in the previous revision of this report, Ref. [55]. However, the main findings have been reported in points below:

- The diver data collected for the shallow aquifer within the Isle of Dogs demonstrates the effect of the pumping that occurred on the west side of Westferry Road between April and August 2007. The data shows that this pumping activity had a zone of influence greater than 960m and that it affected not only on the River Terrace Deposits but also the underlying strata, such as the LSB. This pumping relates to the River South project, see Section 4.2.1.

- The data collected from piezometers located in the deep aquifer within the Isle of Dogs before 2008, shows a rise in the groundwater level of about 2 and 2.5m over a period of 4 and 10 months (refer to Figure 4.3.33 for borehole locations). This behaviour is believed to be due to the recovery in the deep aquifer following cessation of the third

[2] For completeness, all pumping test data, at the monitoring frequency utilised during the pumping tests, are also included in Appendix A as separate spreadsheets. This includes flow rate measurements.

phase of dewatering for construction at Blackwall Place (Section 4.2.1 refers). All deep piezometers located within the Isle of Dogs exhibited similar behaviour. Figure 4.3.34 presents the rate of recharge (m/month) recorded in 2007-08 in each installation against the distance from Cartier Circle, which has been assessed as the centre point of the pumping wells active during the third phase of Blackwall Place dewatering. A different behaviour is exhibited by CH35P, CH1R and CH2R: this is believed to be due to the presence of a fault running through West India Dock (Ref. [21]), which acts as a barrier to flow in the deep aquifer. The combination of the pumping activity and the fault emphasizes the difference in groundwater level between the western and eastern side of Isle of Dogs (refer also to Section 4.4)

- The data collected for the deep aquifer within the Isle of Dogs in 2008 show the effect of the fourth dewatering scheme carried out between January and July 2008 for the River South project (see Section 4.2.1). Looking at the responses of the piezometers within Isle of Dogs to the abstraction activity (Figure 4.3.33), the data shows that the rate of drawdown is inversely proportional to the distance from the pumping site, see Figure 4.3.35. Envelopes indicating the lower and upper bounds of the data are presented on Figure 4.3.34. Boreholes on the northwest of the site lie close to the lower bound whereas those on the eastern side are close to the upper bound. This behaviour could be related to the difference in groundwater levels before pumping, which increased to the east. It could also be related to the fault at the Isle of Dogs. If indeed the fault is serving as a barrier to flow, then piezometers between the fault and the pumping zone would experience rapid draw down as recharge from the far field on the east side would be inhibited by the fault. On Figure 4.3.34 the response of CH1R, CH35P and CH2R has been highlighted; these instruments are to the east but do not lie on the upper bound line as expected. This is likely to be due to the combination of the effects of the fault through the West India Dock (Ref. [21]) on the flow and of the recharging of the deep aquifer, which is controlled from the east.

- Figure 4.3.36 presents a summary and comparison of the entire diver data collected for the shallow aquifer within the Isle of Dogs in Package 15A boreholes. Note that instruments in boreholes IOD100, IOD102 and IOD104 are located below the West India

- Dock. The data exhibit the same behaviour in all piezometers and show a groundwater level generally around 100.5m ATD, confirming that the piezometers are in hydraulic continuity. However, IOD102 exhibits the same pattern as the others but shows a higher groundwater level of around 101.3m ATD. This could be due to infiltration/leakage from the overlying dock water into the piezometer or due to a localised high water level. However, it has not been possible to further investigate the reliability of this piezometer as it was destroyed during the Isle of Dogs construction works. Figure 4.3.46 also presents dock water levels (Ref. [29]). The difference between the dock water level (average level 104.25m ATD) and the groundwater level at IOD100, IOD102 and IOD104 (located below the West India Dock) is believed to be due to the cut off created by the Dock Sediment. Therefore, at this location the shallow aquifer is confined by the overlying Dock Sediment, with a hydraulic head of some 3m across the dock silt layer This appears to be confirmed by the data recorded during the period in which draining of the Isle of Dog station box was carried out. There is no significant response of pore water pressure in the RTD to the lowering of the dock water level (see Figure 4.3.36). However, a rise in the upper aquifer water level has been observed in April 2009 and July 2010. The former event is believed to be due to the cessation of the shallow aquifer activity at Riverside South project (refer to Section 4.2.1.1 for more details). It is not clear what the cause of the second rise in July 2010. However, it should be noted that the water levels are currently decreasing.

4.4 Piezometric Profiles

Profiles showing the variation in piezometric pressure with elevation have been generated using the data from the 1992 and post-2002 piezometers. Also shown are the best-judgement lines fitted to data collected up to August 2011. Where a piezometer is no longer working, or where a piezometer is believed to be reporting unreliable pressures, these profiles have been generated using the last reliable reading from that instrument. Some of the post-2002 piezometers are still stabilising or have preliminary information that needs to be verified. Where appropriate, this has been noted on the profiles. Figure 3.1.2 presents the profiles plotted on the geological long section for illustrative purpose only, while Figures 4.4.1 to 4.4.30 present the detailed profiles according to the Route Section as defined in Table 4 and Figure 3.1.2.

The 1992 Geotechnical Interpretative Reports for the historic Crossrail scheme (Ref. [1] and [2]) provided design piezometric profiles for subsections of the route alignment between Royal Oak and Allen Gardens. However, monitoring of some of the piezometers was continued until 1998, post dating the interpretative reports by up to 6 years. In light of these data and the additional piezometric readings post-2000, the 1992 piezometric profiles have been reviewed and updated profiles are suggested in Figures 4.4.1 to 4.4.10. Figures 4.4.1 to 4.4.10 are grouped according to the revised alignment route sections (Ref. [1] and [2]) summarised in Table 4. The monitoring data of the post-2002 piezometers installed during Package 13, 16, 16A, 17B, 29[4], 29VO1 and third party data have also been considered in reviewing these piezometric profiles. It must be emphasised that the piezometric profiles presented in these figures are only tentative suggestions as some piezometers have not stabilised yet. Therefore, additional monitoring is required to improve the definition of these profiles (see Section 5). In reviewing the 1992

[4] Up to date Package 29 draft data, where available, has also been considered in the review.

piezometric profiles, consideration has also been given to the current groundwater levels in the deep aquifer (see Section 4.6).

The profiles presented in Figures 4.4.1 to 4.4.10 indicate the piezometric pressures to be hydrostatic from the water level in the shallow aquifer in the upper part of the London Clay Formation. Below this, piezometric pressures become sub-hydrostatic and in many cases reduce to zero in the Upnor Formation within the Lambeth Group. Hydrostatic increase in pressure with depth can again be expected below the water level in the lower aquifer. These piezometric profiles are characteristic of the underdrained conditions typical throughout the London area (Section 4.1). Towards the western end of the alignment, near Paddington Station, the piezometric profiles are observed to be hydrostatic over the depths of interest but, because of the large thickness of London Clay, no reliable instruments are yet available to define the full piezometric profile in particular for route sections P and Q, Figures 4.4.1 and 4.4.2, respectively. Package 16A ground investigation has provided more information for route sections R and S (Figure 4.4.3 and 4.4.4, respectively), however, the reliability of most of the new data is yet to be confirmed and hence the piezometric profiles have not been further defined. .However, many of the Package 16A monitoring data are still stabilising or need to be verified. The soil stratigraphies shown in Figures 4.4.1 to 4.4.10 are based on interpretation of the available geological information as reported in GSIR 1&2 (Ref. [1] and [2]), Packages 13, 17A, 17B, 29, 29V01, 16, 16A and Bond Street Western Ticket Hall ground investigation data.

For route section W (Farringdon Station Figures 4.4.8 and 4.4.9) only recent monitoring data has been used to populate the presented profiles. This can be done because there is a lot of recent monitoring data in this area, including information from new installations associated with Package 13, 29 and 29VO1 ground investigations. Also, for this route section, the soil stratigraphy presented has been updated to include information obtained from Package 13, 29, 29VO1 and the BGS review of the faulting in the vicinity (Ref. [36] & [49]).

Piezometric profiles for the route sections east of Liverpool Street Station defined from post-2002 boreholes are shown in Figures 4.4.11 to 4.4.30[5]. Part of this area is currently affected by the IoD de-watering scheme. For the route sections affected by de-watering two profiles have been presented, where possible: one showing the baseline data or “natural” groundwater level (August 2008) and the other showing the current effects of Crossrail de-watering.

As with the profiles determined from the 1992 piezometers, the characteristic underdrained profile is evident in Route Sections A to J (Figures 4.4.11 to 4.4.22 respectively and Figure 3.1.2). However, the de-watering activity at IoD has led to further lowering of the piezometric pressure in the lower aquifer resulting in enhancement of the underdrained piezometric profiles (e.g. Figures 4.4.19 and 4.4.25). In particular, as a consequence of the de-watering activity,

[5] Figure 4.4.30 present piezometric profile for the area east of Plumstead Portal – Abbey Wood.

underdrained profiles develop currently up to the Connaught tunnel. East of the Connaught tunnel, outside the subcrops of the London Clay and Lambeth Group, no effects of the IoD de-watering works have been recorded (see Figure 3.1.2). Here, the upper and lower aquifers are directly linked resulting in a conventional hydrostatic pore pressure profile (Figures 4.4.26 to 4.4.30).

Across the Isle of Dogs Station (Route Section I - Figure 4.4.21), two different piezometric profiles were recommended prior to de-watering (i.e. baseline conditions[6]). Also shown is the drawn-down water level in the lower aquifer. The piezometric profiles shown thus bound the current profile. Further information on the effects of the de-watering activities is given in Ref. [31].

Of particular interest is the hydrostatic portion of the profile evident in the Lambeth Group for Route Sections A, D, E and F to EB Chainage 12100m (Figures 4.4.11, 4.4.13, 4.4.14 and 4.4.15 respectively). It is possible to model this piezometric behaviour using Darcy's Law and the selection of appropriate strata permeabilities (Ref. [6] and [30]). This analysis suggests that to produce hydrostatic conditions, a significantly higher permeability must exist in this layer, relative to the over- and underlying strata. The profiles for Route Sections A, D, E and F (up to EB Ch 12100m) are hydrostatic within the Lambeth Group above the Mid-Lambeth Hiatus (MLH) where a large number of Sand Channels have been encountered within the Upper Mottled Beds (UMB) and the Laminated Beds (LTB). The data are consistent over a wide area and, in order for the Sand Channels to influence the pore pressure profiles to this extent, there must be a high degree of lateral interconnectivity between them. This pattern was independently confirmed along the GSIR 3 area by a detailed study of the distribution of sand channels and granular Harwich units (see GSIR 3 for more information, (ref [6]). The pore pressure profile for Route Section C does not seem to exhibit this hydrostatic profile in the Lambeth Group; this implies a lower concentration of channels in the Whitechapel area which is consistent with the borehole records (Dwg No. 1D0101-G0G00-G00-P-03023). It should be noted, however, that paucity of piezometers in the Lambeth Group, or scatter in the available data could mask the identification of other areas of hydraulic connectivity in the intermediate aquifer by identification of a hydrostatic pore pressure profile. Further discussion on the lateral continuity of Sand Channels can be found in GSIR3 (Ref. [6]). Recently completed pumping tests may also give further information in this regard (Pk13 VO2 & PK29).

[6] The piezometric profiles are based on August 2008 data and reflect only the effects of the dewatering undertaken in Isle of Dogs for the River South project.

In contrast with the above referenced hydrostatic profile within the Lambeth Group, the central part of Route Section F (from EB Chainage 12100 to 13800m, Figures 4.4.16 and 4.4.17) depicts high level, non-hydrostatic water pressures in the Lambeth Group. The installations exhibiting this unusual high groundwater level were tested during the first phase of the piezometer remediation works – in an attempt to verify these installations and associated readings. The installation were inspected and flushed to remove any accumulated silt/blockage. Thereafter, rising head tests (RHT) were carried out and divers were installed to closely record the recovery phase (refer to Ref. [40] for further details on the remediation works carried out). Some of the investigated piezometers are still under observation (as noted on the figures), since the groundwater levels are still stabilising or it is not yet possible to draw clear conclusions on their status. Further monitoring and additional investigations will be undertaken.

Figure 3.1.2 shows the best-judgement profile lines shown on a backdrop of the geological cartoon. It illustrates clearly how the piezometric profile changes along the alignment as the ground conditions change, and the effect of Crossrail dewatering.

4.5 Shallow Aquifer

4.5.1 General

The shallow aquifer is recharged by surface water infiltration (i.e. rainfall), and from surface and subsurface sources of water such as rivers, canals, water mains and sewers (Ref. [17]). As a consequence tidal, seasonal and other less predictable fluctuations in the groundwater level of the upper aquifer are to be expected.

Approximately 27 piezometers were installed in the River Terrace Deposits (RTD) between Royal Oak Portal and Liverpool Street Station, during the 1992 ground investigations. Near-surface seepages were observed during drilling of some boreholes, however it is noted that water added to assist boring through the superficial deposits would have obscured seepages in a significant number of boreholes. Groundwater levels in the RTD were generally reported to be 0.5m to 1.0m above the top of the London Clay, Figure 3.1.2. Occasionally, higher groundwater levels (2 to 4.5m above the London Clay) were reported mostly associated with local depressions in surface of the London Clay and / or the flow regime in the upper aquifer – e.g. at the boundary between RTD terraces such as that at Pudding Milll Lane and at EB Ch12750 on the south east branch (also see ref. [1] and [2]). Figure 4.5.1 presents this historic information as contours of recorded piezometric level measurements in the RTD, taken between 1992 and 1997. The locations of the measurements points used for the contours are also indicated on the figure as the density of the data points governs the accuracy of the contours at any particular location.

A more recent contour of ground water levels in the shallow aquifer is presented in Figure 4.5.2 for the whole alignment, based on readings taken between July 2009 and August 2011. It draws from the following sources:

- Existing Crossrail shallow aquifer piezometers from the pre-2000 investigations were used where they remained functional and accessible;

- An additional 35 piezometers were installed in River Terrace Deposits (RTD)[7] in route sections from P to X (Royal Oak Portal to Liverpool Street Station) during Packages 13,16, 16A, 29 and 29VO1 ground investigations.

- Third party data, where relevant and available, were used.

As noted above the accuracy of these contours is governed by the availability of data points, therefore, the contours should only be considered indicative of the general flow regime. Comparing Figure 4.5.1 and 4.5.2 over the area covered by GSIR 1&2, it can be seen that the more recent monitoring data (August 2011) generally confirm the 1992-1997 data, reporting groundwater level to be on average 1m above the top of London Clay, with the exception of the Farringdon Station area. In Farringdon, the recent data gives upper aquifer groundwater levels of 103 to 113m ATD, whereas no information was available in 1992 to 1997 and the contour for this period interpolated over this area. Thus the difference in Farringdon is due to: (i) absence of piezometers in this area in the 1992-1997 data (see Figure 4.5.1), (ii) availability of only a limited number of piezometers from the more recent ground investigations (see Figure 4.5.2), and (iii) the potential for significant local modifications to the upper aquifer ground water levels from obstructions, foundations, tunnels, services, etc. in this area.

To the east of Liverpool Street Station, water strikes were similarly encountered in some boreholes and 202[8] piezometers have been installed in the shallow aquifer during the post-2002 ground investigations (including Package 29VO1). In general, the groundwater levels recorded in the upper aquifer for the section of alignment between Liverpool Street Station and EB Chainage 12400 were typically 2.4 to 3m above the top of the London Clay, Figure 3.1.2. Pudding Mill Lane Portal is in the River Lea flood plain and the Isle of Dogs branch is within the Thames flood plain from EB Chainage 12400 eastwards. The aquifer potentially becomes confined by the presence of recent alluvium (Figure 3.1.1) and the water table is generally 5 to 8m above the London Clay/Lambeth Group (Figure 3.1.2). East of Connaught tunnels, River Terrace Deposits directly overlie Thanet Sand and Chalk. Groundwater inflow from the River

[7] 31 piezometers have also been installed in Alluvium and Made Ground.

[8] Including installations in Alluvium and Made Ground.

Thames and River Lea control the groundwater level, which is typically between 100m and 101.5m ATD ± the tidal fluctuations (see Figure 4.5.2). The Royal Docks at Connaught Tunnel and the Isle of Dogs have a water level that is at about 104m ATD and so appear to be largely hydraulically separated from the water level in the upper aquifer.

Groundwater flow in the shallow aquifer will regionally be to the south and east towards the River Thames and the River Lea following the surface topography. Local influences on the groundwater regime will include basements, retaining walls, buried services, tunnels, water wells, leaking boreholes and present and historic watercourses (such as the Grand Union Canal, the River Lea and the lost rivers, see Figure 4.5.2 for their locations). Furthermore, local influences such as derived tidal variations in the vicinity of the River Thames and the River Lea can be expected (see Section 4.7). Despite these limitations, it can be seen from Figure 4.5.2 a relatively low easterly hydraulic gradients along most of the alignment, except for the Farringdon area where a steeper flow gradient is apparent. The local flow at Farringdon appears to be towards the Fleet (also see Figure 3.1.2). However, it should be noted that the steep gradients could be influenced by the limited monitoring data available in this area and other reasons previously discussed. Therefore, the contours in this area may be to some extent unrepresentative. Further monitoring and investigation is required to better define the water conditions in the upper aquifer in this zone. At Limmo, a small cone of depression is located over the scour hollow at the mouth of the River Lea. This needs further confirmatory investigation, but if proven would be evidence of hydraulic connectivity and flow between the upper and lower aquifers at this location. (Also, see Section 4.7.2 for more discussion.)

In general, the flow rate in the upper aquifer is generally expected to be relatively low, as a result of the generally flat topography resulting in limited pressure head differentials. Importantly, however, the flow will dominate the migration of water-borne contaminants in the shallow aquifer. Local flows will also have an important bearing on the feasibility of ground freezing as a ground treatment option.

The 3000-series drawings (Dwg Nos. 1D0101-G0G00-G00-P-03000 to -03170) show where water strikes were encountered and the recorded groundwater water levels along with piezometer locations and the associated piezometric pressures.

Detailed evaluation of the groundwater conditions in the upper aquifer, relevant to the structures required for Crossrail Alignment, are given in the relevant Geotechnical Sectional Interpretative Report (Ref. [2], [6] and [7]).

4.5.2 Seasonal Variations

Inspection of the monitoring data from standpipes in the River Terrace Deposits suggests that there is relatively little seasonal variation in the shallow aquifer level. The data from instruments showing the greatest variation are reproduced in Figure 4.5.3, and 4.5.4.a&b. These figures cover Route Sections E, F and G (Stepney Green to Pudding Mill Lane) indicating a maximum fluctuation in the groundwater level of about 1.0m, achieved during the 2003 & 2010 winter.

Figures 4.5.3, and 4.5.4.a&b presents also the monthly rainfall data obtained form the Meteorological Office (Ref. [13]) for the same time period. The monitoring groundwater levels collected appear to exhibit a direct response to rainfall events. Further investigations have been undertaken to establish whether there is a direct linkage between rainfall and ground water levels, comparing piezometric data recorded using Divers installed in different piezometers and daily rainfall data. Daily rainfall data were recorded almost continuously using a MET-CHECK MET126RL rain gauge for the period 14/11/2005 to 17/03/2007; rainfall data outside of this period was obtained from the Meteorological Office (Ref. [13]). Figures 4.5.5 to 4.5.13 present plots of the daily average piezometric level together with the corresponding daily rainfall.

Data collected east of the Connaught Tunnel (i.e. NW12, NW16R and NW18R, Figures 4.5.9 to 4.5.11, respectively) are dominated by large variations in the piezometric level due to tidal effects (see Section 4.7), obscuring any short or long-term responses to rainfall. For boreholes PML7, PML8, IOD15, CH6R, WP21 and WP23 no direct response to rainfall events (except for the possible flooding of the headworks of CH6R) and no significant seasonal variation are evident in the piezometric data with variations in head generally being less than 0.5m. It therefore appears that there is a direct response of the shallow aquifer to the overall events (i.e. average monthly rainfall) but not to the single/ specific event (i.e. average daily rainfall). This could depend on the magnitude of the rainfall event and also on the storativity of the aquifer and the infiltration rates. However, further monitoring will be undertaken in particular in the area where seasonal variation has been identified to aid interpretation.

4.6 Deep Aquifer

As noted in Section 4.1, the deep aquifer comprises the granular material of Thanet Sand Formation and Chalk Group in hydraulic continuity with the Upnor Formation of the Lambeth Group.

August 2011 monitoring data from Crossrail piezometers, installed in the deep aquifer, have been combined with data provided by the Environment Agency (Ref. [4]) for Jan 2011[9] and with data provided by Thames Water for December 2010 to produce the contour plot shown in Figure 4.6.1. Note that the accuracy of these contours is governed by the available data points (as indicated on the figure), and that due to the limited quantity and temporal variations in the data, the contours should only be considered indicative of the general flow regime. In addition, construction de-watering is currently active for the construction of the Crossrail IoD Station (see Section 4.2.1) and tidal variation in piezometric levels occurs in the vicinity of the River Thames and the River Lea (see Section 4.7). Use of open loop Ground Heat Source Pumps is also beginning to become a significant contributor to temporal variations of the deep aquifer ground water levels in central London. Demand for this use is seasonal.

[9] At the time of writing, there were no data available from the Environmental Agency for August 2011.

Minimum contours level comprising 55 to 60m ATD are located in two different areas along the Crossrail alignment: in the Isle of Dog (IoD) area and in the Central London area between Paddington and Bond Street respectively. In the IoD area the minimum contour (55m ATD) is recorded at West India Dock. This cone is induced by the pumping activity which is undergoing in this area for the construction of the Crossrail IoD station (see Section 4.2.1). The contours are closely spaced to the east and the south of the Dock, indicating a steep gradient up to a distance of 500m from the pumping area, where the gradient become shallower. This is likely to be due to influence of the scour hollows and/or faulting in the Limmo peninsula area. The drawdown does extend a greater distance to the east, up to Connaught tunnel, than to the west, Stepney Green Area. This is consistent with the concept of zonal boundaries developed by Mott MacDonald in their London Basin Groundwater Model (Ref. [15]). Detailed information on the effect of the IoD de-watering activity and comparison with the predicted drawdown can be found in the specific construction de-watering report, Ref. [31].

Paddington and Bond Street, there is no great availability of data points, and the 60m ATD contour line is controlled by four EA monitoring wells, TQ28/97, TQ28/119, TQ28/153 and TQ38/263A. The gradient is relatively gradual towards Royal Oak Portal in the west (61m ATD) and towards Stepney Green Junction in the east (74m ATD). The contours are mostly equally spaced running across the figure mainly from south-west to north-east, with except for the area affected by the de-watering activity. Where there is a greater concentration of data, the gradient is the greater suggesting that the width of the band is less than indicated by the contouring routine. Thus the loss of piezometric head is concentrated into relatively narrow zones: this is consistent with the concept of zonal boundaries developed by Mott MacDonald in their London Basin Groundwater Model (Ref. [1]). The maximum level along the alignment of about 100m ATD occurs where London Clay and Lambeth Group are absent and the upper and lower aquifers are directly linked. Specific interpretation is given in the relevant GSIRs, for the areas shown on the figure.

The piezometric elevation in the deep aquifer along the Crossrail alignment is shown on the geological long section in Figure 3.1.2. This figure presents deep aquifer piezometric elevation for August 2008, before IoD de-watering activity commenced, and for August 2011 after IoD de-watering drawdown stabilised (Ref. [31], refers). The August 2011 line shows the extend of the IoD de-watering drawdown along the Crossrail alignment – Stepney Green to Connaught Tunnel along the IoD to Plumstead branch and Stepney Green to Eleanor Street Shaft along the Pudding Mill Lane branch. West of Liverpool Street the ongoing Package 16A and 29A ground investigations have provided information to better define the deep aquifer elevation for August 2011.

A substantial degree of underdrainage exists between Royal Oak Portal and Pudding Mill Lane Portal, and Stepney Green to Isle of Dogs Station. In the later, underdrainage has been increased by the de-watering activity ongoing at the IoD. Along the Crossrail alignment, the piezometric level is below the top of the aquifer[10] from about EB Chainage 2500 to just past Farringdon Station. In the south east branch of the alignment, it is below the top of the aquifer from about EB Chainage 12800m to just east of IoD Station. East of IoD station the degree of underdrainage is minor.

The 2011 data provided by the Environment Agency has been combined with deep aquifer groundwater level trends determined from the Crossrail piezometers to produce the annual rate of change contours shown in Figure 4.6.2. Along the Crossrail alignment, the rate of change for 2007[11] (prior to any de-watering activity) was generally less than 1m/year. In 2008, instead, the rate of change had a maximum (reduction) of -28m/year at West India Dock, due to the IoD de-watering which commenced that year. In 2009, the annual rate of change decreased and had a maximum annual rate of change value (reduction) of -3m/year at West India Dock, confirming that the target drawdown had been achieved in December 2008 and that the pumping rate had been reduced to maintenance levels during 2009/ beginning of 2010 (refer to Ref. [31] for more details). Consistent with this, the contours for 2011[12] (Figure 4.6.2) indicate a maximum (reduction) of -1m/year.

In 2009 the rate of change, along the remaining part of the alignment not affected by the IoD pumping, was generally around 0.5m/year. However, in 2010 the maximum (reduction) of -3m/year was registered around Paddington. This is indicated by the EA monitoring well TQ28/53, which shows a water level change of -3.4m over the period considered. The water level change in this area is not related to the Crossrail works and is thought to be due to substantially increased abstractions by the water companies in this area in 2009 (see refs [4] & [5]). This is also confirmed by the 2011 data (Figure 4.6.2), which show an increase of 3m in the same area, indicating that any abstractions on going in 2010 have ceased.

The accuracy of the contours in Figure 4.6.2 is governed by the available data points (as indicated on the figure), and apart from at the data points, the contours should only be considered indicative of the present rate of change in the deep aquifer levels. Arrangements are currently being made to obtain data from additional licensed abstraction and from monitoring

[10] taken as Thanet Sand since the Upnor Formation is not separately identified on Figure 3.1.2

[11] Note that the rate of change is determined over a one year period, generally calculated from January of each year.

[12] Note that the rate of change for 2011 has been determined using data between the period of August 2011 and September 2010.

wells owned by third parties, in order to improve the accuracy of these contours (Ref. [33] refers).

4.7 Tidal Variations

4.7.1 General

Tidal variations can occur in either the shallow or deep aquifer or both, provided that a number of criteria are met:

1. The aquifer is directly and effectively connected to a tidal waterway;
2. The average groundwater level is within the tidal range;
3. The distance from the waterway in combination with the permeability and storativity of the aquifer is sufficiently small. Note that when the aquifer is confined the storativity is effectively zero and the response is much greater.

With respect to the Crossrail alignment:

1. Both aquifers are connected to the River Thames where the London Clay and Lambeth Group are absent – this is the subcrop of the Lambeth Group as marked by the red boundary on Figure 4.7.1 and any scour hollows which penetrate to the Thanet Sand or lower. The location of the known scour hollow which penetrates to the Chalk is also shown on Figure 4.7.1. Figure 3.1.2 also shows where the two aquifers are potentially connected.
2. The shallow aquifer could be considered likely to be in direct connection throughout the relevant length of the River Thames; however the river wall can effectively cut the connection if it penetrates to the London Clay or Lambeth Group.
3. The maximum predicted tidal water level is about 104mATD at Silvertown and, consequently, if the base of the RTD is above about 105m ATD no tidal influence would be expected. The areas where the base of the drift deposits are above 105m ATD is shown shaded in white on Figure 4.7.1.
4. The aquifers are only likely to be confined where Alluvium overlies the RTD: this can be approximated by the 98m ATD contour for the base of drift deposits. This is the area shaded in yellow on Figure 4.7.1.

5. The River Lee (Bow Creek) is tidal as far north as the Bow Locks at the north-east end of the Limehouse Cut, but the Three Mills / Waterworks River which runs about 600m east of Pudding Mill Lane Portal, is fully tidal.

In combination, these factors mean that tidal effects are only likely to be significant east of Stepney Green along the Isle of Dogs branch and locally at Pudding Mill Lane portal.

In order to accurately investigate any tidal variation, it is required a high frequency of monitoring. Therefore, data loggers known as Divers were installed in standpipe and standpipe piezometers to monitor the groundwater level with a frequency faster than 1 reading per hour. To date 185[13] installations east of Liverpool Street have been investigated and a tidal response, exhibited by the characteristic sinusoidal variation in piezometric level, has been identified in only 98 of the 185 piezometers investigated, as listed in Table 5.

Where a tidal response was identified, the data were plotted / analysed against the recorded water level in the River Thames, as shown in Figure 4.7.5. The River Thames tidal variations were plotted from the Port of London Authority tidal monitoring station at Silvertown (location shown in Figure 4.7.1). At each location, magnitude of the measured tidal response and time lag between peak river water level and peak piezometric level were evaluated and tabulated in Table 5. The data are also presented on Figures 4.7.1 to 4.7.4. The latter three Figures are a zoom in of the Woolwich, Limmo and IoD areas. In these figures the aquifers are differentiated by symbol and the magnitude of the tidal response recorded indicated by colour coding.

4.7.2 Commentary on Data

In this section it is intend to present only a summary of the main features identified during the investigation of the tidal response. Detailed tidal monitoring data, interpretation and discussion are given in the relevant tidal report Ref. [32].

As expected, east of Connaught Tunnel, where the River Thames is in direct connection to the deep aquifer and the Lambeth Group is absent (except locally at the Connaught Tunnel and at the east end of the proposed Woolwich Station) all instrument within about 1km of the river exhibit tidal response. In particular, the instruments closest to the River Thames at North Woolwich (NW16R and NW18R) and at Woolwich (WP1R and WP17P) exhibit the shortest phase shift and the largest tidal response in both shallow and deep aquifer. In agreement with this, the value of the piezometric response decreases gradually with the increase of the distance from the river, as depicted in Figure 4.7.1.

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[13] Including 1 third party monitoring well – Hanson Quarry pumping well.

Several instruments located between IoD and the Connaught Tunnel have shown a tidal response (Figures 4.7.1 to 4.7.4). In this area even where the shallow and deep aquifers are separated by the London Clay and Lambeth Group, the static pressure in the two aquifers has been in hydrostatic equilibrium before Crossrail dewatering at Canary Wharf (Figure 3.1.2 and Section 4.4). Hydrostatic equilibrium in Route Section J where the two aquifers are separated by clay layers is likely due to the complex geology features present in this area: scour hollows, which penetrate through the LG and LC, and faulting system at the Limmo Peninsula. The first provide a potential connection between the River Thames, the upper aquifer and the deep aquifer, the latter may also provide a pathway from the nearby River Thames and River Lea.

Further evidence of the hydrogeology of the Limmo and Isle of Dogs areas are provided by the tidal monitoring data obtained for Crossrail (Figures 4.7.2 and 4.7.4). Additional piezometers and more extensive monitoring have now provided a much clearer picture of the hydraulic interconnectivity around the scour hollows. Figure 4.7.3 shows the scour hollows at Limmo. Well constrained contours show the base of the drift deposits extending well below 80m ATD at this scour hollow. Significant tidal responses have been observed in piezometers in; (i) the upper aquifer, (ii) strata between the upper and lower aquifers, and (iii) the lower aquifer. The tidal piezometers cluster around scour hollow between EB chainage 15600 ands 15800 approximately. Large tidal variations (>1m) are observed in instruments up to 140m away from the 80m ATD contour for the base of drift. A tidal response is even observed in piezometers in the London Clay (e.g. CH15P (LC(A2)), CH16R (LC(B) & LC(A2)), CH79 (LC(A2)), CH80 (LC(A2)) and CH82 (LC(A2)), refer to Table 5 for more details). Calculations showed that the observed London Clay pore pressure cycles were one or two orders of magnitude greater than that attributable to undrained cyclic loading by the tidal River Lea and River Thames (ref [37]). The observed tidal response must therefore be due to direct hydraulic connection to either or both rivers, likely through silt layers and the scour hollow/ faulting.

Figure 4.7.4 shows a similar plot for the scour hollow near the Isle of Dogs, between EB Ch 14300 to 14900 approx. Contours show that the base of the drift deposits extends below 70m ATD. Looking at the adjacent ground conditions, as indicated in Figure 3.1.2, the scour hollow should therefore penetrate at least down to the Thanet Sand. Again, a significant tidal response is registered by piezometers in the upper aquifer, lower aquifer and strata in between. The tidal piezometers are observed up to 400m from the 80m ATD base of drift contour. These observations all indicate the existence of hydraulic connectivity in this area between the upper aquifer, intermediate strata, the lower aquifer and the River Thames.

With regard to the area between IoD and Stepney Green, and from Stepney Green and Pudding Mill Lane, only one instrument IOD19P showed tidal response, Figure 4.7.1. Here London Clay and Lambeth Group are present through the area, separating the shallow and deep aquifers. The unexpected (but isolated) result obtained for the IOD19P Thanet Sand piezometer suggested the possibility of a local connection between the River Thames and the deep aquifer. Partly for this reason, this piezometer was investigated under the remediation works package. During this works a leakage was identified in this piezometer (Ref. [40]). The leakage was due to faulty connection(s) in the piezometer pipe between 30 and 32m depth. The Lambeth Group (LMB) was identified in the borehole log to exist at this depth. Consequently, it is believed that the piezometer is reading the (higher) groundwater level within the Lambeth Group instead of that in the Thanet Sand Formation. Consequently, it is planned to undertake further monitoring to aid investigation of the significant tidal variation in the Lambeth Group implied by this new information.

5 PLANNED GROUNDWATER MONITORING AND INTERPRETATION

The following further groundwater monitoring and interpretation of the recorded data are planned:

1. Complete remedial works on problematic piezometers.
2. Three monthly monitoring of all functional piezometers (1992 & post-2002). Further details on the monitoring strategy are given in Strategy Monitoring report in Ref. [33]
3. Update this report regularly as monitoring information become available.
4. Review the groundwater levels recorded for the shallow and deep aquifers and the associated flow regimes using latest available data.

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TABLES

Table 1. Generalised geological succession.

Period	Series	Deposits
Quaternary	Holocene	Made Ground Alluvium
	Pleistocene	Langley Silt River Terrace Deposits
Palaeogene	Eocene	London Clay Formation Harwich Formation
	Palaeocene	Lambeth Group Thanet Sand Formation
Cretaceous	Upper Cretaceous	Chalk

Table 2. Crossrail Alignment ground investigations.

Package[3]	Description	Route Sections[1]	Borehole prefix[2]	Commencement date
A	Paddington to Balderton Street	-	P, RT	February 1992
B	Balderton Street to Charing Cross Road	-	B, T, RT	March 1992
C	Charing Cross Road to Aldersgate Street	-	RT, F	March 1992
D	Alderstgate Street to Vallance Road	-	RT, L	April 1992
1	Whitechapel Station	C	WH	September 2002
2	Liverpool Street to Bow and Isle of Dogs (Phase 1)	A, D, E, F, G H	LW, SG, BT, IOD	November 2002
3	Liverpool Street to Bow and Isle of Dogs (Phase 2)	A, B, E, H	LW, SG, IOD	August 2003
4	Isle of Dogs to Plumstead (Phase 1)	J to M	CH, NW	March 2004
6	Woolwich Reach Geophysical Investigation	N	Not Applicable	January 2004
7	Woolwich Reach Ground Investigation	N	TRC	March 2004
8	Liverpool Street to Bow and Isle of Dogs (Phase 3)	F, G	BT, PML, IOD	November 2004
9	Plumstead Portal	O	WP	April 2005
10	Isle of Dogs to Plumstead (Phase 2)	N, O	WP	November 2005
11	Isle of Dogs to Plumstead (Phase 3)	I to N	IOD, CH, NW	August 2006
12	Liverpool Street to Bow (Pudding Mill Lane) and Isle of Dogs (Phase 4)	A, C, D, E, F, G	LW, SG, BT, PML, WH	September 2006
13	Farringdon Station to Whitechapel Station	V to X, A, C	F, L, LW, RT, SG, WH	March 2009
13 VO1	Whitechapel Station	C	WH	July 2009
13 VO2	Stepney Green	E	SG	July 2009
13 VO3	Farringdon Station	W	F	July 2009
14	West India North Dock, Bow Creek,	G, I and J	Not applicable	June 2006

Package[3]	**Description**	**Route Sections**[1]	**Borehole prefix**[2]	**Commencement date**
	Lee Navigation and City Mill River Geophysical Investigations			
15	Isle of Dogs Station	H to I	IOD	April 2007
15A	Isle of Dogs Station	I	IOD	December 2007
16	Royal Oak Portal to Farringdon Station	P to V	P, T, BST, RT	January 2008
16A	Royal Oak Portal to Farringdon Station	P to V	P, T, BST, RT	March 2010
17A	Paddington Station	R	RT	January 2009
17B	Royal Oak Portal	P	ROP	March 2009
18	North Woolwich to Woolwich	N1	TRC	2007
19	Costume House Station to North Woolwich	L to M	CH, NW, WS, TP	June 2009
19A	Limmo Peninsula	J	CH, WS, TP	September 2009
20	Woolwich to Plumstead Portal	N2 to N3	WP	October 2008
21	Plumstead Portal to Abbey Wood	O	WP	January 2009
22	Victoria & Albert Dock	L	Not applicable	2009
23*	Tunnelling Academy	Not applicable	CBR, IL, TP	Not finalised
24*	North Pole Depot	Not applicable	DP, NP, TP, WS	Not finalised
25	Pudding Mill Lane	G	PML, TP, WS	June 2009
25 VO1	Pudding Mill Lane	G	PML, TP, WS	December 2009
25VO2	Pudding Mill Lane	G	PML, TP, WS	June 2010
26*	Wallasea Island	Not applicable	-	Not finalised
27*	Sentinel BH	Not applicable	SN	August 2010
28	Bow Creek Geophysics	J	Not applicable	October 2009
29	Farringdon Station to Whitechapel Station	V to X, A, C	BT, F, L, LW, RT, SG, WH, WS	March 2010
29VO2	Farringdon Station to Stepney Green	V to X, A, to D	BT, F, L, LW, RT, SG, WH,	July 2010

Package[3]	Description	Route Sections[1]	Borehole prefix[2]	Commencement date
			WS	
30	Cross Passages South-East of Farringdon	X, A, J, K and L	IOD, CH, TP	August 2010
31	North Woolwich and Plumstead Portals	M, O	NW	July 2010
33*	Old Oak Common	Not applicable	NP, TP, WS	February 2010
35	Connaught Tunnel	L	NW	March 2011
36	Canary Wharf Box	I	Not applicable	December 2010
37	Woolwich Station	M	WP	March 2011
BST WTH [4]	Bond Street	T	BST	March 2011

[1] as defined in the GCG Geotechnical Sectional Interpretative Reports (Ref. [2], [6] and [7]).

[2] P = Paddington Station
T = Tottenham Court Road Station
L = Liverpool Street Station
WH = Whitechapel Station
SG = Stepney Green
IOD = Isle of Dogs
NW = North Woolwich
PML = Pudding Mill Lane
TP = Trial Pit
ROP = Royal Oak Portal
CBR=Californian Bearing Ratio
DP= Dynamic Probe
SN= Sentinel
B = Bond Street Station
F = Farringdon Station
RT = Running Tunnel
LW = Liverpool Street to Whitechapel Stations
BT = Bow Triangle
CH = Custom House
TRC = Thames River Crossing
WP = Woolwich to Plumstead
BST = Bond Street Station
WS = Window sampling
IL= Ilford Tunnel
NP= North Pole Depot

[3] * signifies not along the underground section of the Crossrail alignment

[4] BST WTH = Bond Street Station Western Ticket Hall Ground Investigation

Table 3. Construction of De-watering activities programme

Crossrail Worksite [4]	Main Construction Start	De-watering Development	De-watering Required	Strata	Reporting Start
Isle of Dogs Station	Q1 2009	Q3 2008	63m ATD	Thanet / Chalk	Q3 2009
Woolwich Station [1]	Q3 2011	Q1 2012	Localised ~92m ATD	Thanet / Chalk	Q1 2012
Connaught Tunnel	Q2 2011	Q1 2012	88m ATD	UF / Thanet / Chalk	Q1 2012
Plumstead Portal [2]	Q1 2012	Q2 2012	Localised >90m ATD	RTD/ Thanet / Chalk	Q2 2012
Limmo Shaft	Q4 2011	Q2 2012	62m ATD (tbc)	Thanet / Chalk	Q2 2012
North Woolwich Portal [2]	Q1 2013	Q2 2013	Localised >90m ATD	RTD & Chalk	Q2 2013
Eleanor Street Shaft	Q4 2013	Q3 2014	<72m ATD (tbc)	HF/LG; UF/TS	Q3 2014
CP13	Q1 2013	Q3 2012	59m ATD	Chalk	Q3 2012
CP14	Q1 2013	Q4 2012	68m ATD	Chalk	Q4 2012
CP15	Q2 2014	Q2 2014	NF	Chalk	Q2 2014

[1] Pumping inside the station box
[2] Pumping inside the box with recharge to the River Terrace Deposit
[3] NF = Not Finalised
[4] CP = Cross Passage

Table 4. List of Crossrail Alignment route sections.

Route Section	From	To	Construction elements
P	Royal Oak Portal		Tunnel eyes
			TBM reception shaft
			Cut-and-cover tunnel
			Retained cut
Q	Royal Oak Portal	Paddington Station	Running tunnel
			Sump
			Crosspassage CP1
R	Paddington Station		Station
S	Paddington Station	Bond Street	Running tunnels
			Sump
			Crosspassages CP2, CP3 and CP4
T	Bond Street	Tottenham Court Road Station	Bond Street Station
			Sump
			Crosspassage CP4a
			Running tunnels
U	Tottenham Court Road Station		Station
V	Tottenham Court Road	Farringdon Road	Running tunnels
			Fisher Street Shaft
			sumps
			Fisher Street Crossover
			Crosspassage CP5
W	Farringdon Station	Liverpool Street	Farringdon Station
			Sump
			Crosspassage 5a
			Running tunnels
X	Liverpool Street Station		Station
A	Liverpool Street Station	Whitechapel Station	Running tunnels
			Crosspassages CP6 and CP8
			Sump
C	Whitechapel Station		Station
D	Whitechapel	Stepney Green	Running tunnels
			Crosspassage CP9
			Sump

Route Section	From	To	Construction elements
E	Stepney Green		Step-plate junctions
			Shafts
F	Stepney Green	Bow Triangle	Running tunnel
			Niche
	Mile End Park		Shaft
	Eleanor Street		Shaft
	Bow Triangle	River Lea	Running tunnels
G	River Lea	Marshgate Lane	Pudding Mill Lane Portal Cut-and-cover tunnel
	Marshgate Lane	Waterworks River	Viaduct
H	Stepney Green	West India Quay	Running tunnels
			Crosspassages CP10, CP11 and CP12
			Sump
I	Isle of Dogs Station		Station platforms
			Running Tunnels
J	Isle of Dogs Station	Victoria Dock Portal	Running tunnels
			Crosspassages CP13, CP14 and CP15
			Sump
	Limmo Peninsula		Shaft
K	Victoria Dock Portal		Tunnel eyes
			TBM reception shaft
			Cut-and-cover tunnel
			Retained cut
L	Victoria Dock Portal	North Woolwich Portal	At-grade track and Connaught tunnel (existing)
M	North Woolwich Portal		Retained cut
			Cut-and-cover tunnel
			TBM reception shaft
			Tunnel eyes
N1	North Woolwich	Woolwich	Running tunnels
			Crosspassages CP16 and CP17
			Sump
N2	Woolwich Station		Station

Route Section	From	To	Construction elements
N3	Woolwich	Plumstead	Running tunnels
			Crosspassages CP18 and CP19
O	Plumstead Portal		Tunnel eyes
			TBM reception shaft
			Cut-and-cover tunnel
			Retained cut

Table 5. Details of tidal monitoring.

Piezometer[1]	Date	Measured Tidal Amplitude (m)	Recorded Piezometric Amplitude (m) [2]	Time lag (hh:mm) [2]	Distance from River Thames (m)	Base of Drift (mATD)
Area 1: Plumstead Portal to Connaught Tunnel						
NW6R SP (TS)	10/04/09	7.0	0.045	07:00	350	91.72
NW7 S (RTD)	09/08/10	6.25	0.51	02:00	262	90.00
NW7 SP (CK)	28/07/10	6.0	0.30	03:20	262	90.00
NW10R S (RTD)	10/04/09	7.0	0.49	02:05	250	89.26
NW11R S (RTD)	10/04/09	7.0	0.42	02:50	250	90.55
NW11R SP (CK)	10/04/09	7.0	0.44	02:55	250	90.55
NW12 S (RTD)	19/09/05	6.9	0.46	02:45	205	88.72
NW12 SP (CK)	05/12/09	6.8	0.09	04:10	205	88.72
NW15R S (RTD)	10/04/09	7.0	0.72	02:25	200	90.68
NW15R SP (CK)	10/04/09	7.0	0.70	02:20	200	90.68
NW18R S (RTD/CK)	21/08/05	6.9	2.80	00:20	50	90.02
NW18R SP (CK)	09/04/09	6.9	2.90	00:35	50	90.02
NW16R S (AL/RTD)	11/03/05	7.0	3.20	00:35	30	89.47
NW16R SP (CK)	10/04/09	7.0	3.20	00:35	30	89.47
NW20P S (RTD)	10/04/09	7.0	0.52	03:00	200	89.74
NW27R S (CK)	10/04/09	7.0	0.56	03:20	200	90.57
NW29R SP (RTD)	09/08/2010	5.8	0.06	04:10	226	91.51
NW29R SP (CK)	28/07/2010	6.0	0.15	04:30	226	91.51
WP1R S (MG/TS)	16/12/08	6.7	1.44	00:10	24	97.31

Piezometer[1]	**Date**	**Measured Tidal Amplitude (m)**	**Recorded Piezometric Amplitude (m) [2]**	**Time lag (hh:mm) [2]**	**Distance from River Thames (m)**	**Base of Drift (mATD)**
WP1R SP (CK)	16/12/08	6.7	2.00	00:20	24	97.31
WP17P SP (TS)	16/12/08	6.7	1.12	00:30	78	99.00
WP17P SP (CK)	16/12/08	6.7	1.36	00:30	78	99.00
WP7R S (TS)	27/05/09	6.8	0.16	01:00	420	105.16
WP7R SP (CK)	16/12/08	6.7	0.56	00:25	425	105.16
WP35R SP (CK)	16/12/08	6.7	0.34	02:00	520	90.18
WP41R SP (TS)	19/09/09	7.3	0.03	02:00	525	104.91
WP41R SP (CK)	19/09/09	7.3	0.13	02:00	525	104.91
WP44 SP (TS)	19/09/09	7.3	0.025	02:30	700	99.66
WP44 SP (CK)	19/09/09	7.3	0.20	01:20	700	99.66
WP46R SP (CK)	19/09/09	7.3	0.14	03:00	928	90.52
WP47R SP (RTD)	19/09/09	7.3	0.05	04:30	1225	87.61
WP48RA SP (RTD)	19/09/09	7.3	0.04	04:30	1330	89.71
WP49R S (RTD)	19/09/09	7.3	0.035	04:45	1400	87.73
WP51RA S (RTD)	19/09/09	7.3	0.05	04:15	1190	87.57
WP51RA SP (CK)	19/09/09	7.3	0.04	05:15	1190	87.57
WP6R SP (CK)	25/06/09	6.9	0.52	00:50	420	105.66
WP37P S (TS)	25/06/09	6.8	0.04	03:20	350	106.32
WP37P SP (CK)	25/06/09	6.8	0.4	01:30	350	106.32
WP39R SP (TS)	25/06/09	6.8	0.29	01:05	525	107.26
WP39R SP (CK)	25/06/09	6.8	0.29	02:20	525	107.26

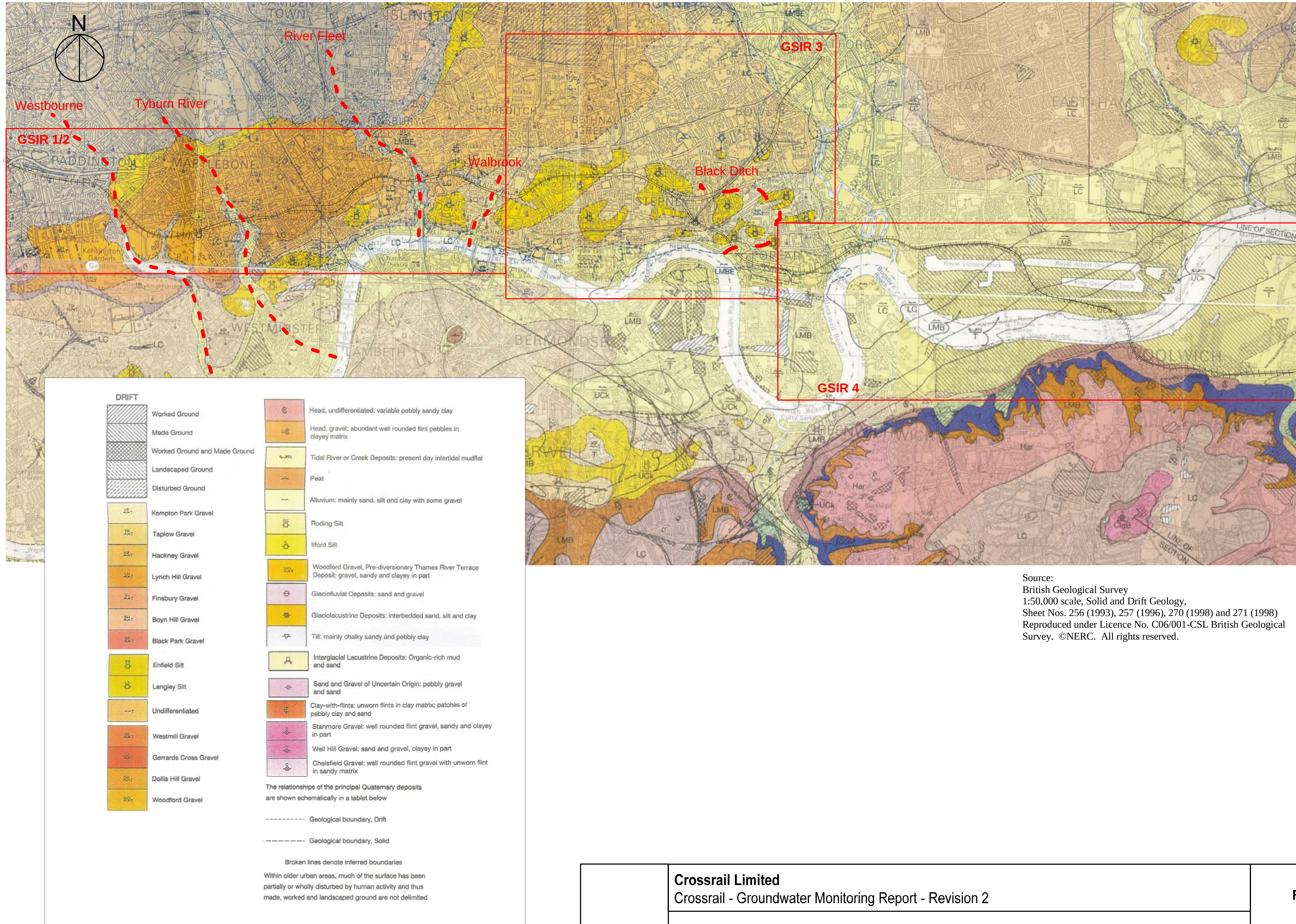
Piezometer[1]	Date	Measured Tidal Amplitude (m)	Recorded Piezometric Amplitude (m) [2]	Time lag (hh:mm) [2]	Distance from River Thames (m)	Base of Drift (mATD)
WP40R SP (TS)	25/06/09	6.8	0.36	01:05	490	102.7
WP40R SP (CK)	25/06/09	6.8	0.67	00:45	490	102.7
WP42R SP (CK)	25/06/09	6.8	0.17	03:00	560	98.73
WP43R SP (CK)	25/06/09	6.8	0.12	02:25	700	99.77
WP86PB SP (CK)	25/06/09	7.0	0.55	00:50	350	104.38
WP96 SP (CK)	25/06/09	6.8	0.44	01:25	455	102.67
WP96 SP (CK)	25/06/09	6.8	0.45	00:50	455	102.67
WP97R SP (TS)	25/06/09	6.8	0.19	01:20	455	102.41
WP38R SP (CK)	26/06/09	6.8	0.06	02:50	385	104.41
WP18P S (UF)	15/12/08	6.8	0.02	02:15	590	103.4
WP10R SP (UF)	16/12/08	6.7	0.20	01:00	625	105.57
WP10R SP (CK)	16/12/08	6.7	0.34	00:40	625	105.57
WP13R SP (CK)	16/12/08	6.7	0.20	01:40	710	104.64
WP19R SP (CK)	16/12/08	6.7	0.19	01:40	845	109.78
WP14R SP (CK)	15/01/09	7.0	0.20	01:00	820	105.86
WP21R SP (RTD)	15/11/05	6.1	0.075	02:30	1025	91.51
WP23R SP (RTD)	15/11/05	6.1	0.02	03:45	1130	90.53
WP25R SP (RTD)	15/01/09	7.0	0.06	02:40	1190	91.47
WP25R SP (TS)	15/01/09	7.0	0.08	04:00	1190	91.47
Area 2: Connaught Tunnel to Isle of Dogs						
CH1R SP (CK)	28/10/08	6.0	0.08	02:15	480	94.80
CH35P SP (TS)	28/10/08	6.0	0.09	01:00	480	94.80

Piezometer[1]	**Date**	**Measured Tidal Amplitude (m)**	**Recorded Piezometric Amplitude (m) [2]**	**Time lag (hh:mm) [2]**	**Distance from River Thames (m)**	**Base of Drift (mATD)**
CH2R SP (TS)	07/05/08	7.1	0.13	01:30	377	92.51
CH3R SP (CK)	28/10/08	6.0	0.23	01:40	300	88.40
CH4R SP (HF)	03/08/07	6.6	0.09	02:15	258	92.74
CH4R SP (TS)	12/01/09	6.4	0.48	01:40	258	92.74
CH6R SP (RTD)	07/10/06	6.9	0.54	03:25	160	94.27
CH7RA SP (TS)	12/03/08	7.5	0.55	01:00	210	94.03
CH9R SP (LC(A2))	04/03/10	7.4	0.08	03:20	304 (13)	95.84
CH9R SP (UF)	04/03/10	7.2	0.09	01:50	304 (13)	95.84
CH13 S (LTB)	26/04/09	6.8	1.33	01:35	150 (60)	93.1
CH14R S (AL/RTD)	26/04/09	6.8	3.0	00:50	(40)	93.07
CH14R SP (UF)	21/04/08	7.2	0.22	02:00	(40)	93.07
CH15P S (RTD)	26/04/09	6.8	2.25	01:00	(56)	93.53
CH15P SP (LC(A2))	21/04/08	7.2	0.23	02:00	(56)	93.53
CH16R SP (LC(B))	21/04/08	7.2	1.23	01:30	(115)	93.80
CH16R SP (LC(A2))	21/04/08	7.2	0.1	01:00	(115)	93.80
CH17RA SP (SU)	26/04/09	6.8	0.3	01:20	(85)	93.88
CH27 SP (TS)	26/04/09	6.8	0.15	03:25	1000	92.35
Hanson Quarry pumping well (CK)	10/05/09	6.3	0.99	06:55	35	No log available
CH48 SP (HF)	14/07/10	6.2	0.16	04:00	(327)	94.61
CH56RB S (HF)	30/04/10	6.64	1.0	02:20	(53)	94.10
CH57R S (CK)	30/03/10	7.0	0.9	00:30	(87)	94.50

Piezometer[1]	**Date**	**Measured Tidal Amplitude (m)**	**Recorded Piezometric Amplitude (m) [2]**	**Time lag (hh:mm) [2]**	**Distance from River Thames (m)**	**Base of Drift (mATD)**
CH61R S (CK)	30/03/10	7.0	0.85	00:00	(66)	94.27
CH72RC S (TS)	30/03/10	7.0	1.07	00:40	(55)	92.14
CH79 SP (LC(A2))	30/03/10	7.4	0.36	03:50	(29)	93.41
CH80 SP (LC(A2))	30/03/10	7.1	1.05	02:30	(22)	94.88
CH81 SP (RTD)	28/07/10	6.2	0.98	01:50	(5)	74.90
CH82 S (RTD)	28/07/10	6.0	0.95	02:00	(8)	92.22
CH82 SP (LC (A2))	28/07/10	6.0	0.05	04:00	(8)	92.22
CH83R S (TS)	30/03/10	7.1	1.04	00:40	(64)	93.11
CH87R SP (SU/LTB)	30/3/10	7.1	N/D	N/D	(72)	94.42
CH88R S (SU/LTB)	30/03/10	7.1	1.0	01:30	(81)	94.73
CH89R S (HF)	30/03/10	7.1	1.0	01:00	(70)	94.27
CH90R S (TS)	30/03/10	7.1	1.0	01:10	(68)	93.35
CH91R S (CK)	30/03/10	7.1	1.0	00:10	(43)	93.50
CH92RA S (HF)	18/04/10	7.0	0.5	02:20	(41)	93.47
CH93R S (SU/LTB)	30/03/10	7.1	1.1	01:00	(60)	94.00
Area 3: Isle of Dogs to Stepney Green						
IOD19P SP (TS)	15/11/08	6.7	0.30	03:50	334	103.16

[1] S Standpipe
SP Standpipe Piezometer
O Open hole in response zone
[2] N/D Not determined

FIGURES



Source:
British Geological Survey
1:50,000 scale, Solid and Drift Geology,
Sheet Nos. 256 (1993), 257 (1996), 270 (1998) and 271 (1998)
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	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	BGS Geological Mapping	**3.1.1**

Royal Oak Portal to Pudding Mill Lane

Stepney Green to Plumstead Portal

Notes:

1. Do not scale off these drawings. The information shown is only indicative and should not be relied upon. Precise information on groundwater monitoring is provided in Groundwater Level Monitoring Report Documentum No. CRL1-GCG-C2-RAN-CRG03-00002 Rev.2 and precise information on tidal variation is provided in Monitoring of Groundwater Responses to Tidal Variations, Report No. CRL1-GCG-C2-RAN-CRG03-00003 Rev. 1
2. The groundwater pressure profiles shown represent best-judgement lines fitted to data collected up to August 2011.
3. Each groundwater pressure profile presents conditions over a chainage range that is between 100 and 2000m long. Each profile therefore reflects the average ground conditions over its chainage range. This may lead to some discrepancy between the profiles and the local ground conditions at the position at which the profiles have been presented in this figure.
4. Temporal variations in the deep aquifer level could also lead to differences relative to the information presented in this figure (e.g. tidal variations, variations due to changes in deep aquifer abstraction rates etc.).
5. The geological information shown is simplified and approximate based on drawings 1D0101-G0G00-G00-P-03000 to -03074. Refer to these drawings for detailed geological information. The geological profile is based on the eastbound tunnel in general.
6. The vertical alignment and the running tunnel and structure profiles shown are derived from the Alignment S model files: C122-OVE-R4-DMA-CR001-12000 Rev. P09 (dated 26/05/2010), C122-OVE-R4-DMA-CR001_Z-22008 Rev. P19.1 and C122-OVE-C4-DMA-CR001_Z-22001 Rev. P22.1. The cross passages shown are from model file C122-OVE-C4-DMA-CR001_Z-22009 Rev. P14 dated 13/08/2010.
7. The ground level shown is derived from model file C122-OVE-R4-DMA-CR001-12000 Rev. P09 (dated 26/05/2010) and bathymetric surveys of West India Dock and River Thames at North Woolwich from Crossrail ground investigations.
8. The westbound tunnel is shown where the vertical alignment is significantly different from the eastbound tunnel. The westbound alignment shown is distorted slightly due to the difference between the eastbound and westbound chainages.

Superficial Deposits

River Terrace Deposits

London Clay (including Harwich Formation)

Deep Aquifer Piezometric Level (August 2008)

Deep Aquifer Piezometric Level (August 2011)

Groundwater Profile

Effect of de-watering

Lambeth Group (-·-·- Mid Lambeth Hiatus)

Thanet Sand

Chalk

Eastbound Tunnel

West bound Tunnel

Cross Passage

0 500m 1000m

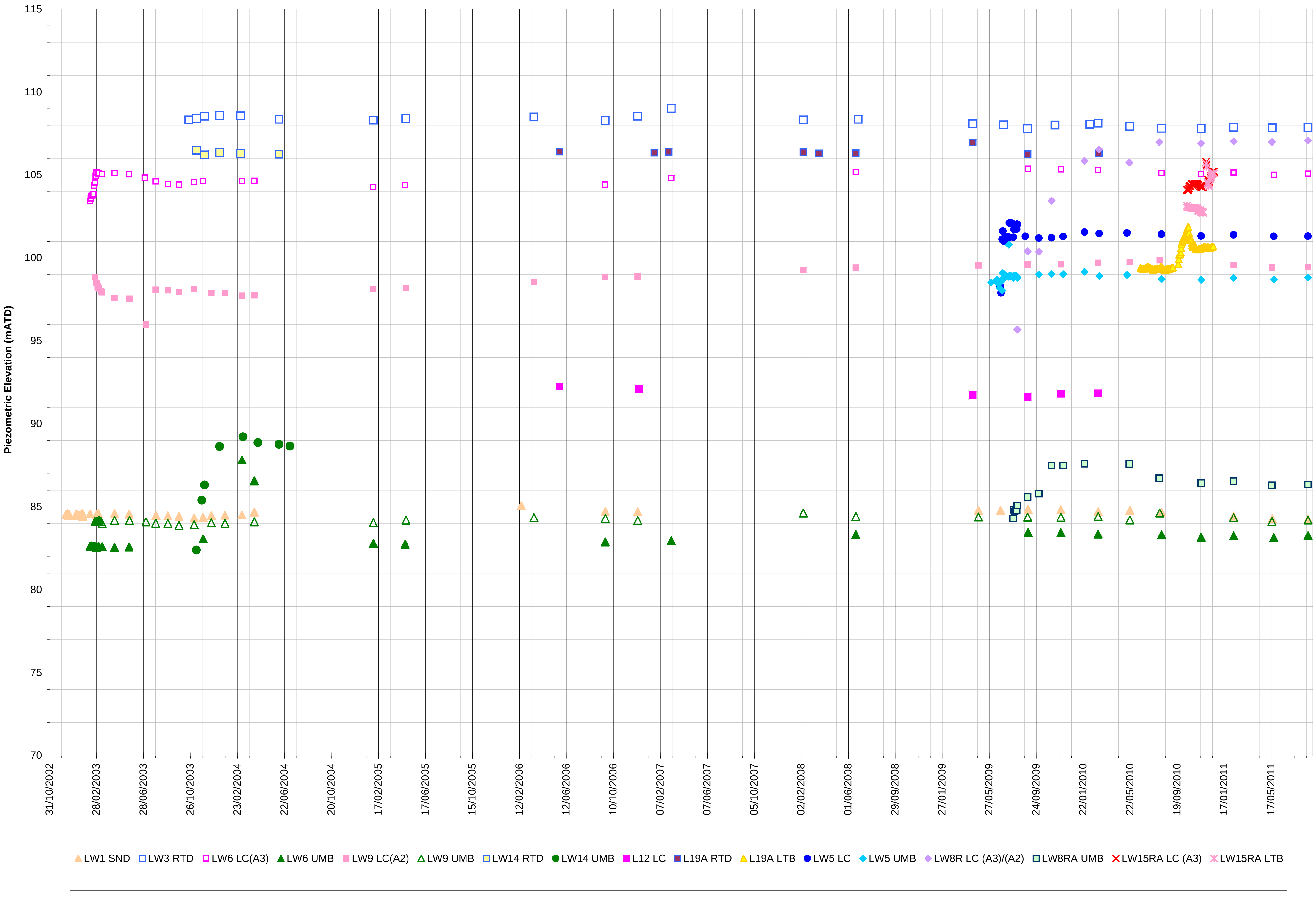
Horizontal Scale

0 50m 80m

Vertical Scale

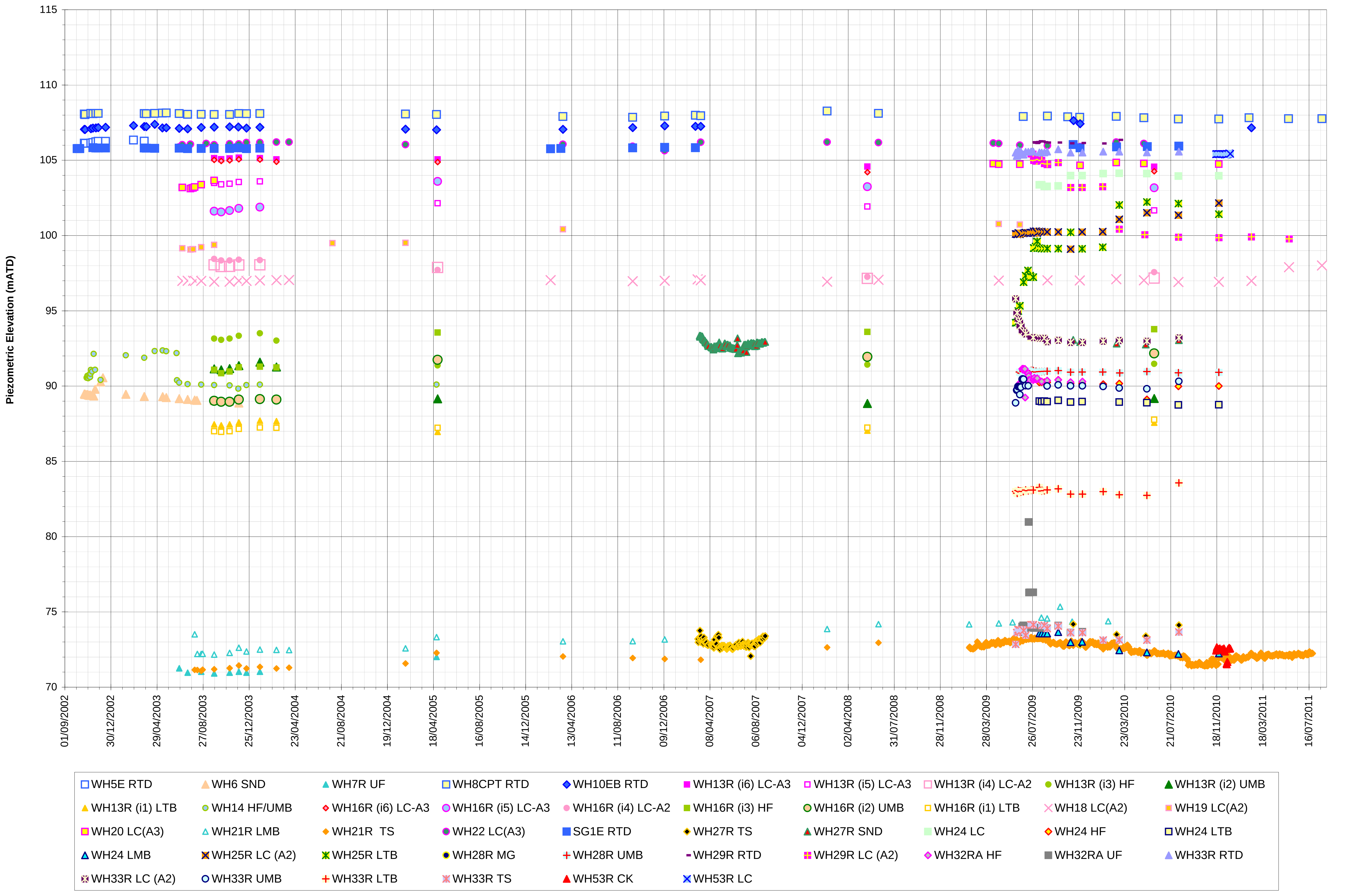
Vertical Exaggeration x 10

Crossrail Limited Crossrail Groundwater Level Monitoring Report - Revision 2	Figure 3.1.2
Geological and Groundwater Profiles	



Note:
LW3 (LC(A2)) is not plotted as it is not reliable

Crossrail Limited	Figure 4.3.1
Crossrail - Groundwater Monitoring Report - Revision 2	
Ground water levels versus time	
Route Section A - Liverpool Street to Whitechapel	



Note:
WH4P (CK), WH6 (LC(A2)), WH7R (LC(A2)), WH11R (LC&CK), WH12 (RTD&UMB), WH14 (LC(A3)), WH15(LC(A3)&(A2)), WH17 (UMB) are not plotted as they are not reliable.
WH33 (LC(A3)) was destroyed during installation

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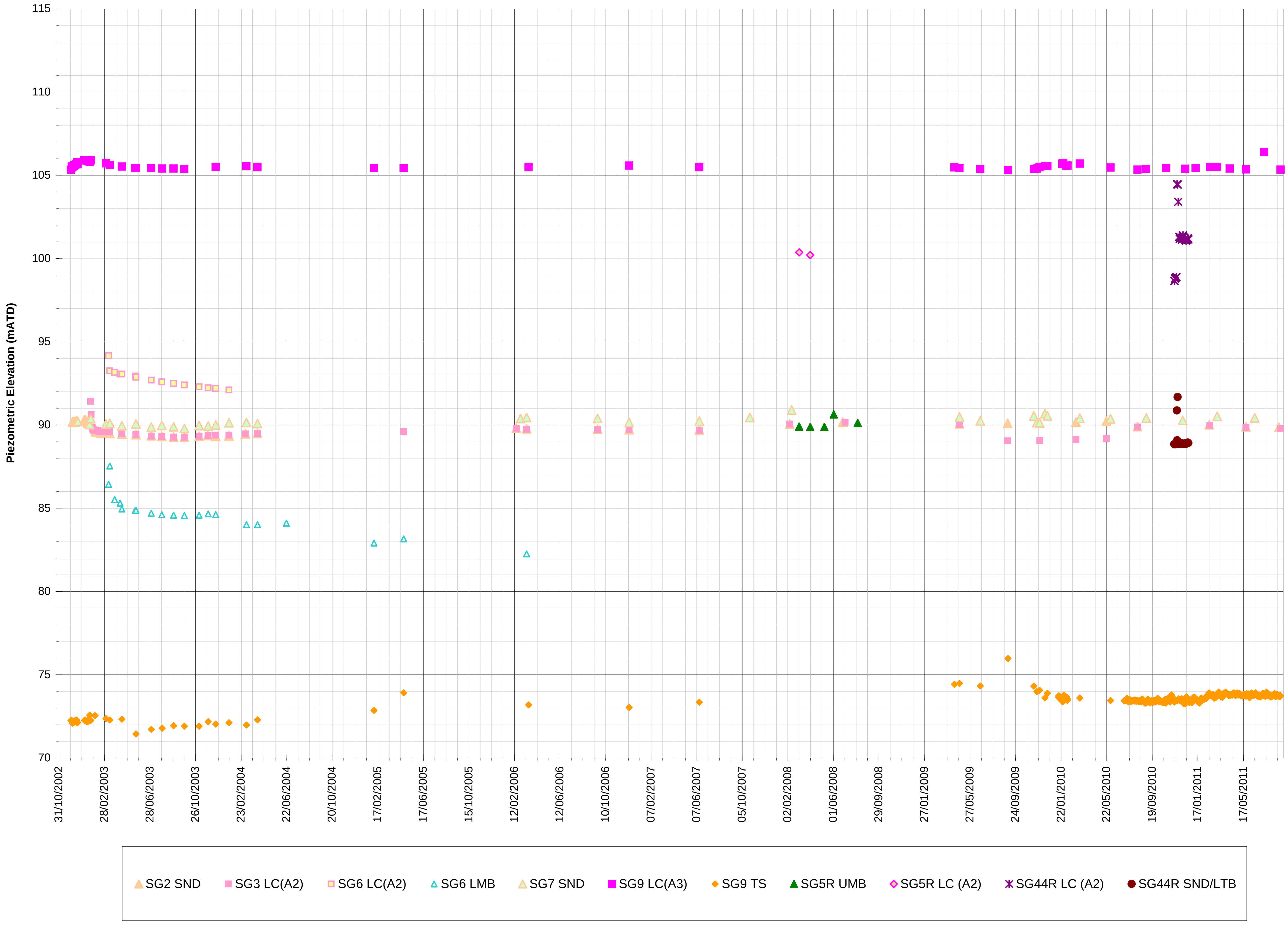
Ground water levels versus time

Route Section C - Whitechapel Station

Figure 4.3.2



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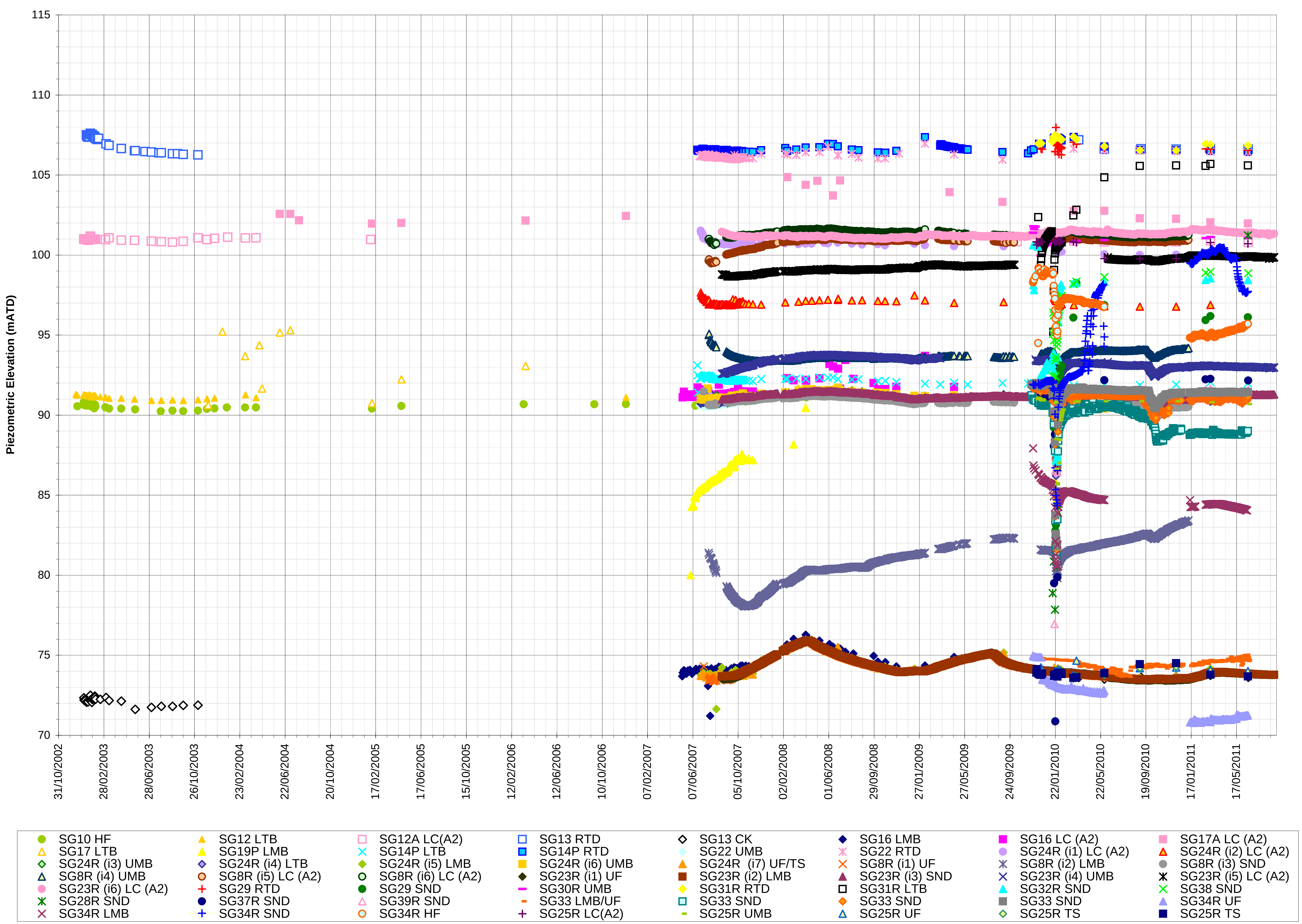
Ground water levels versus time

Route Section D - Whitechapel to Stepney Green

Figure 4.3.3



Note:
SG11R SND, SG11 TS, SG15 LC(A2) and SG15R UF are not plotted as they are not reliable

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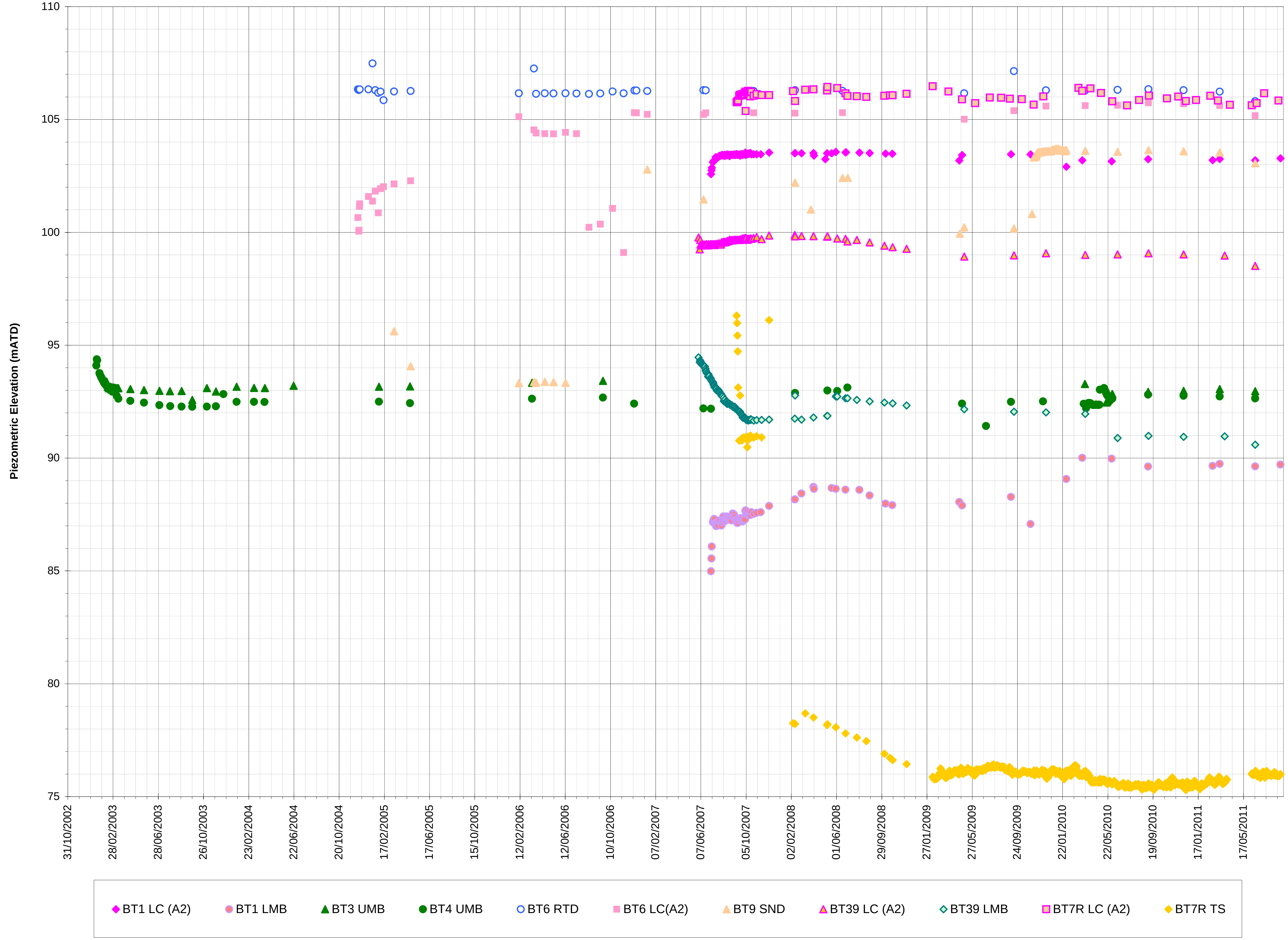
Ground water levels versus time

Route Section E - Stepney Green

Figure 4.3.4



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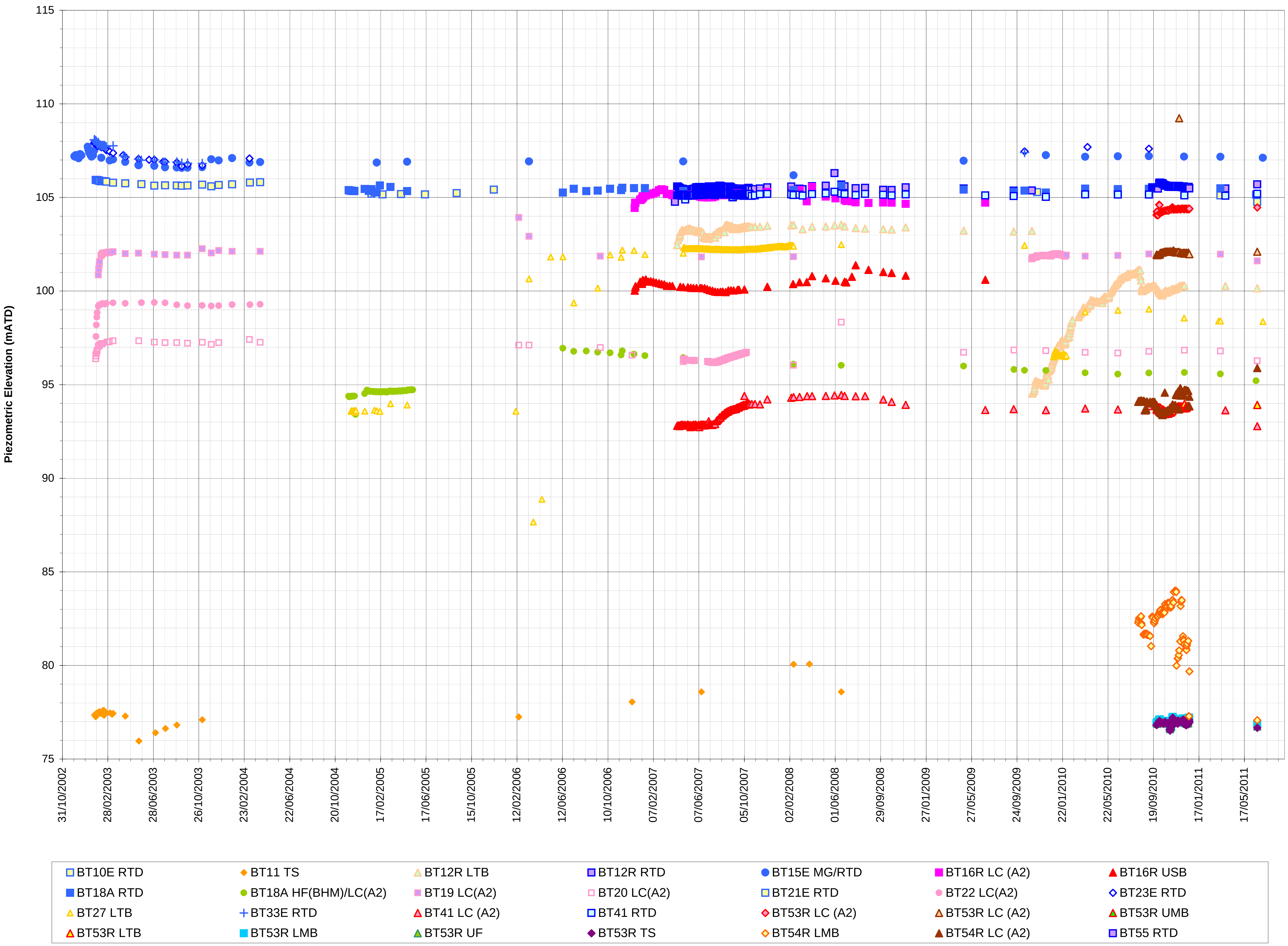
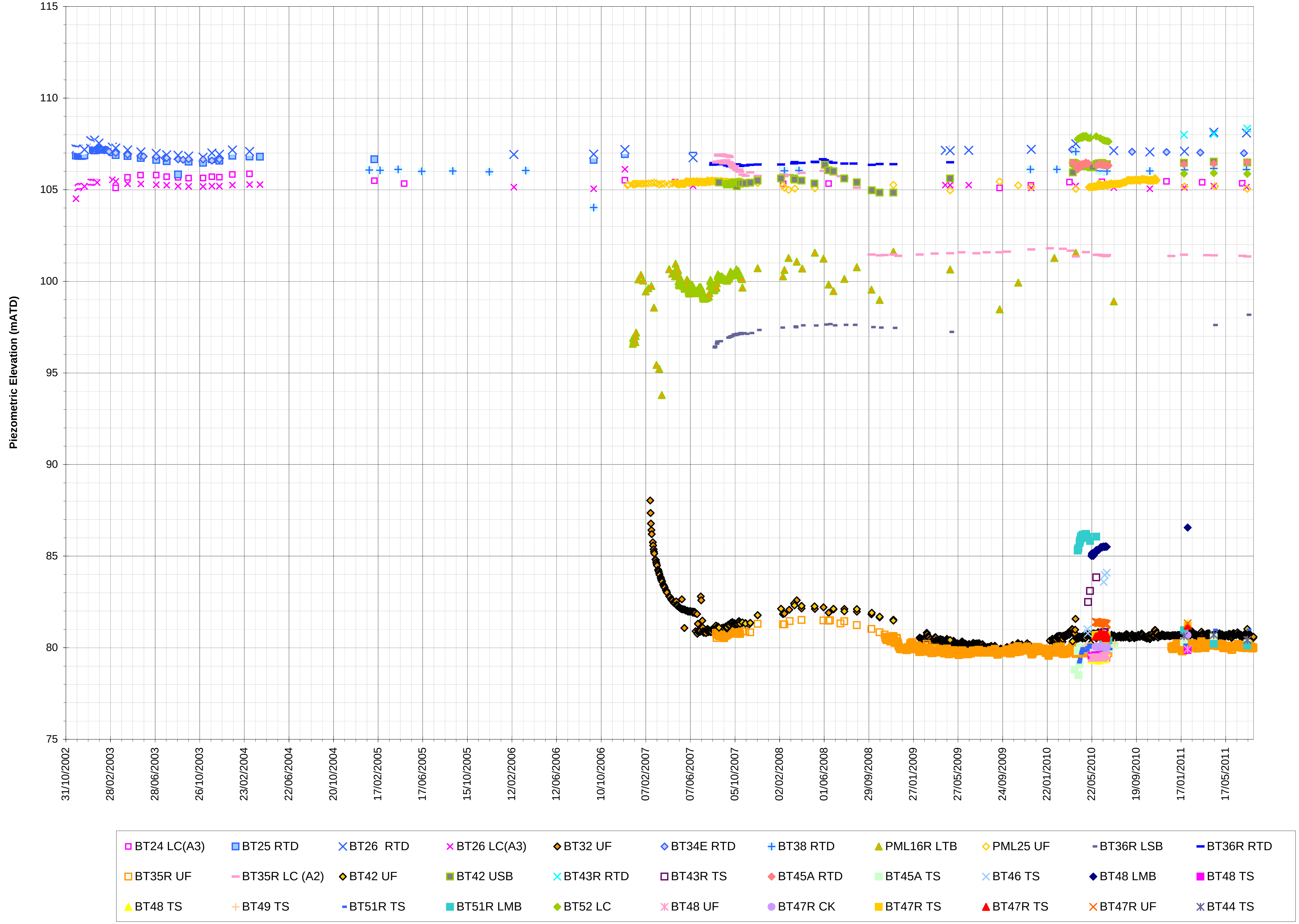
Ground water levels versus time

Route Section F (to EB Chainage 12300m)

Figure 4.3.5



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.6**
	Ground water levels versus time Route Section F (from EB Chainage 12300 to 12800m)	



Note:
BT38 (UF), BT29 (UMB), PML 16R (TS) and BT30 (SND) are not plotted as they are not reliable

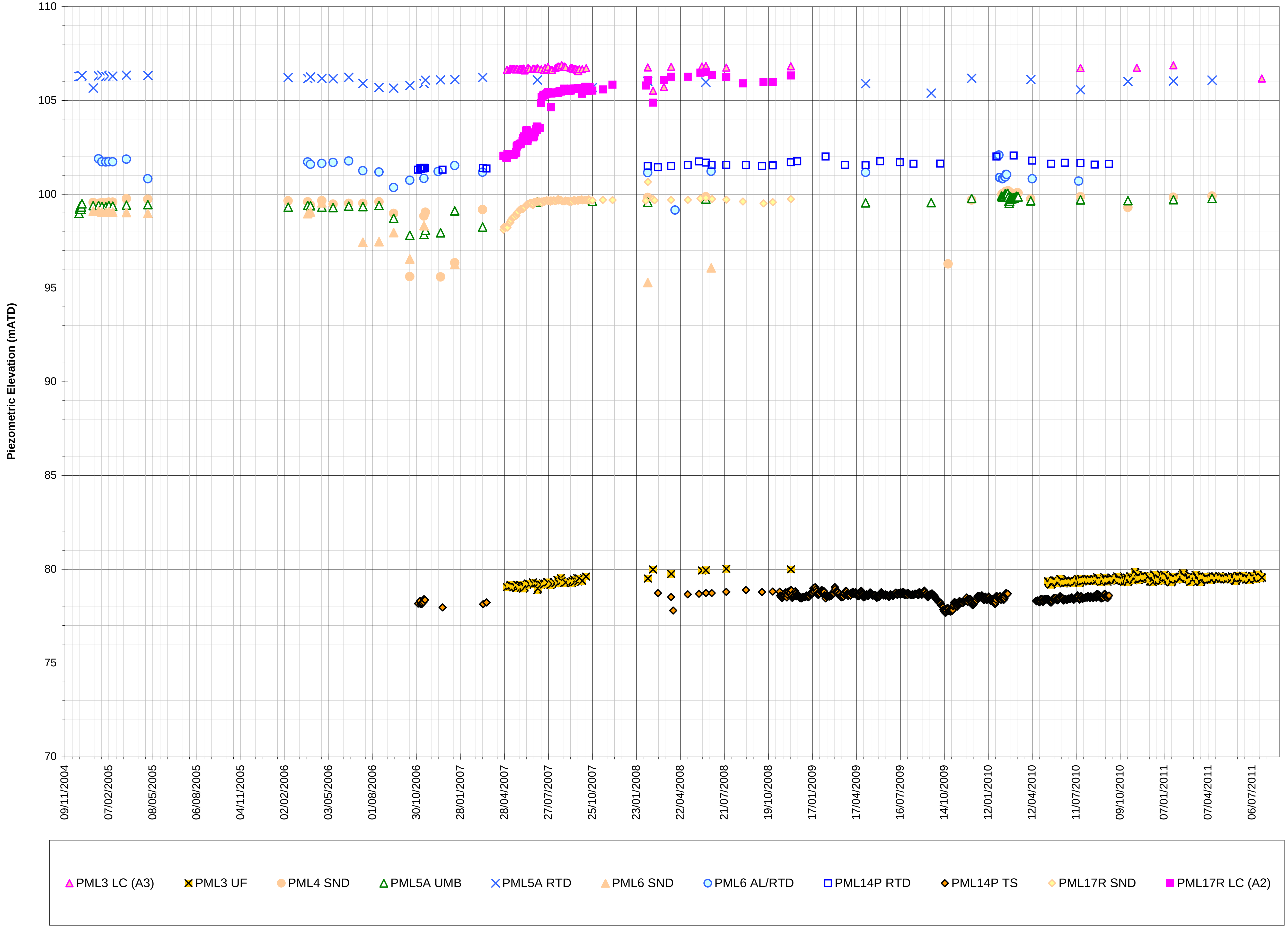
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section F (from EB Chainage 12800 to 13800m)

Figure 4.3.7



Note:
PML1 (LC(A2)) and PML1 (LSB) are not plotted as they are not reliable

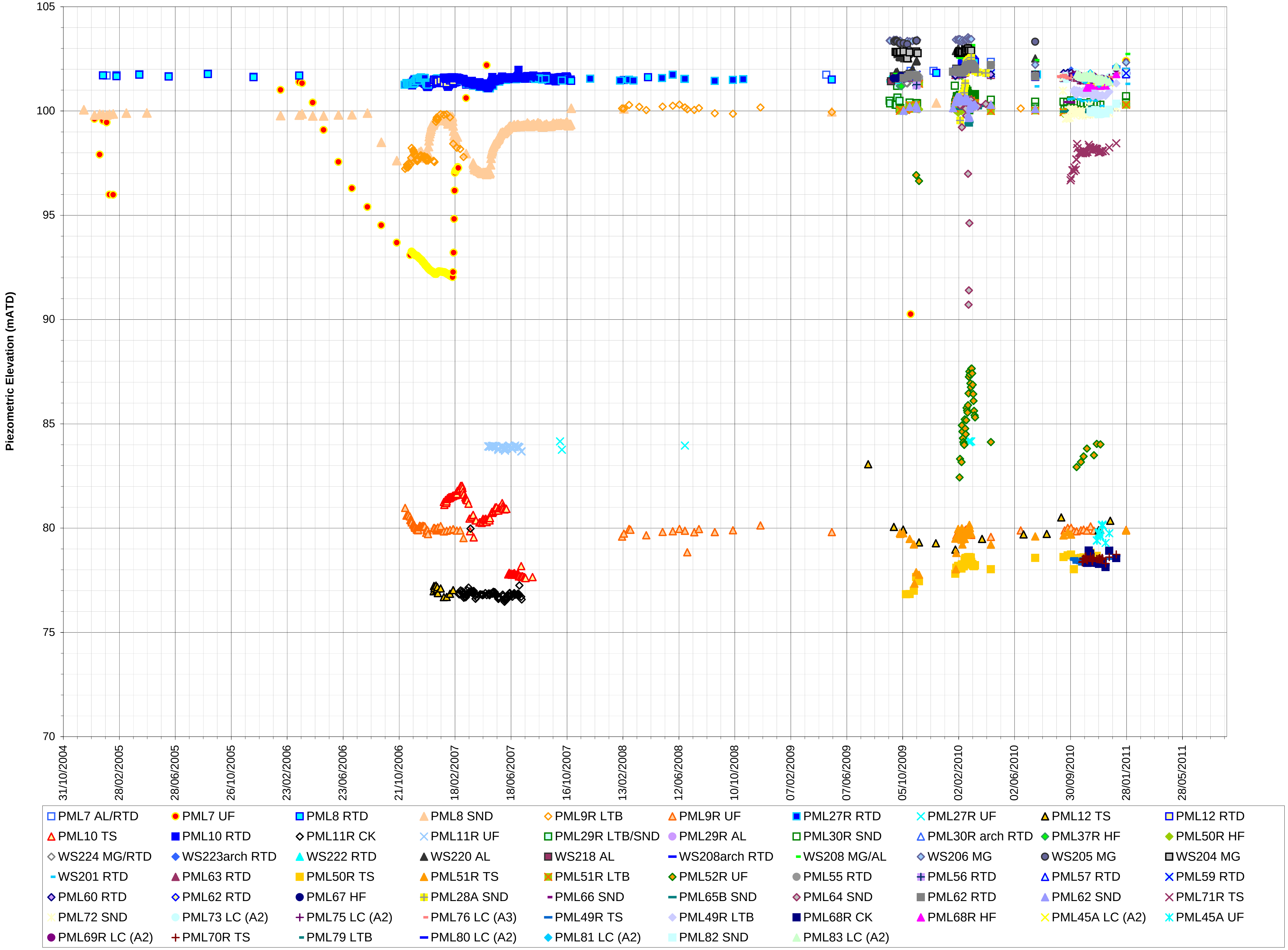
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

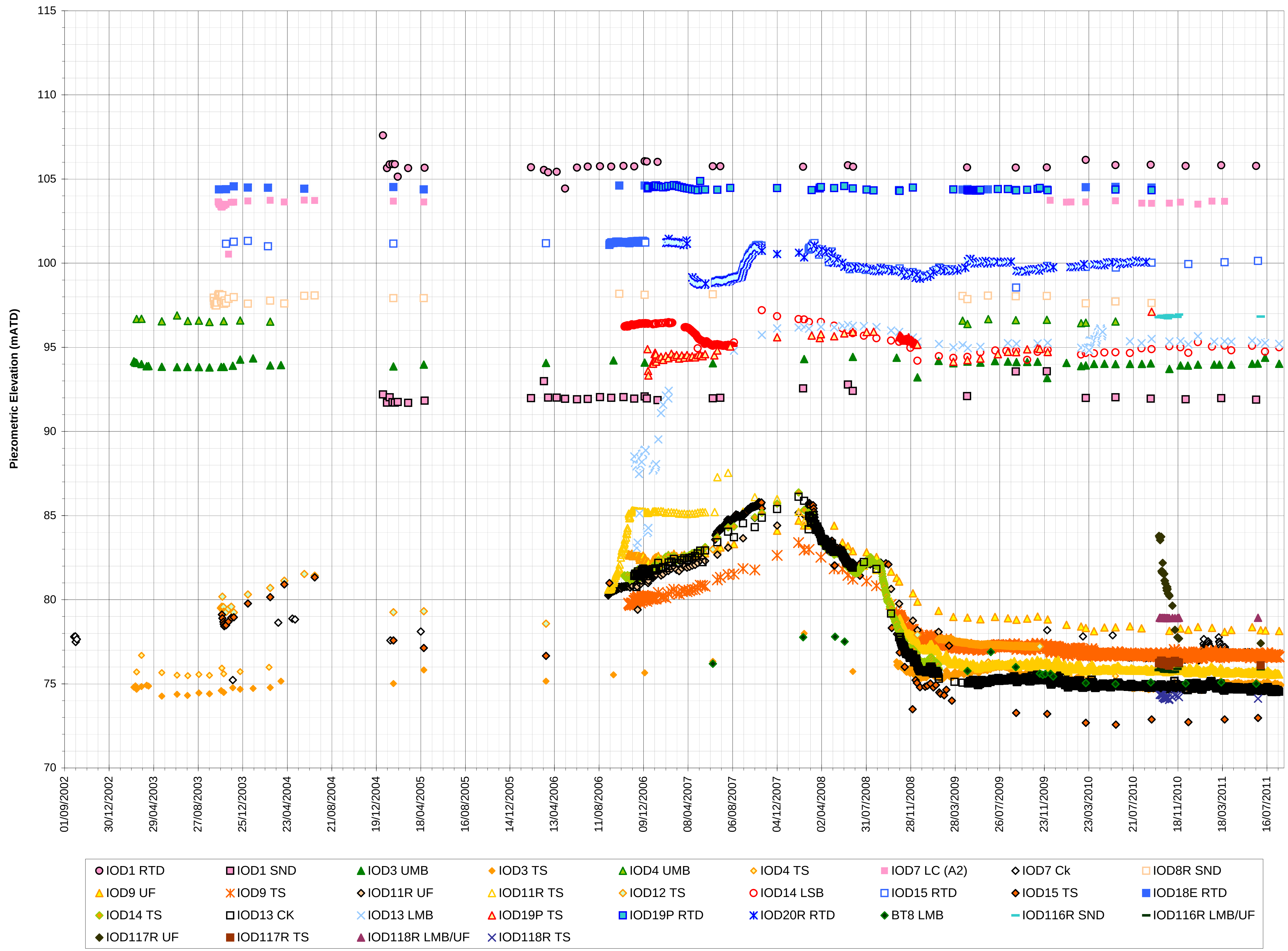
Ground water levels versus time

Route Section F (from EB Chainage 13800m)

Figure 4.3.8



Crossrail Limited	**Figure**
Crossrail - Groundwater Monitoring Report - Revision 2	**4.3.9**
Ground water levels versus time	
Route Section G - Pudding Mill Lane	



Note:
IOD12 CK and IOD 20R CK are not plotted as they are unreliable

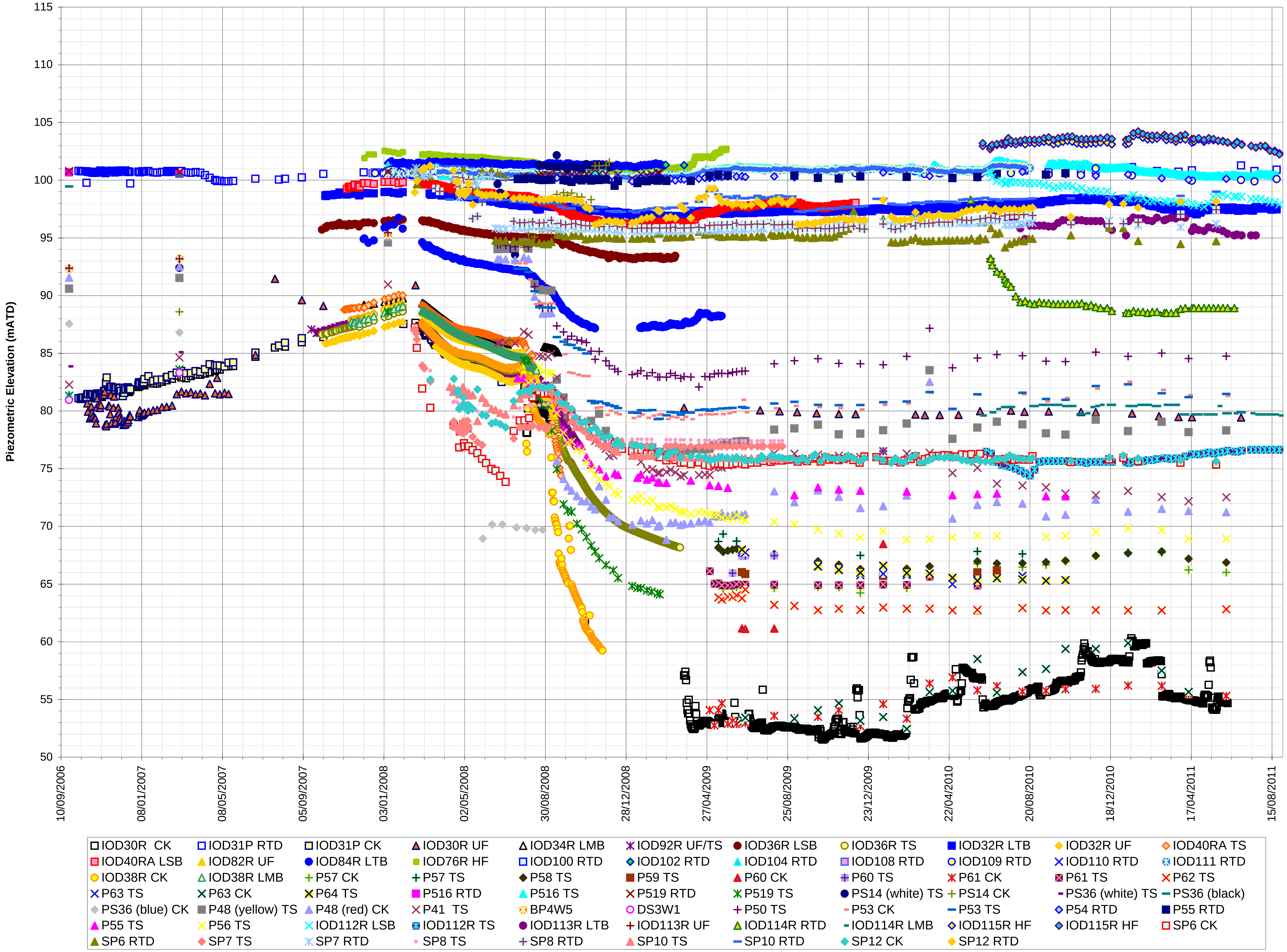
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section H - Stepney Green to Isle of Dogs

Figure 4.3.10



Note:
P514 RTD, P514 TS, P41 RTD, P43 TS and PS14 RTD are not plotted as they are unreliable

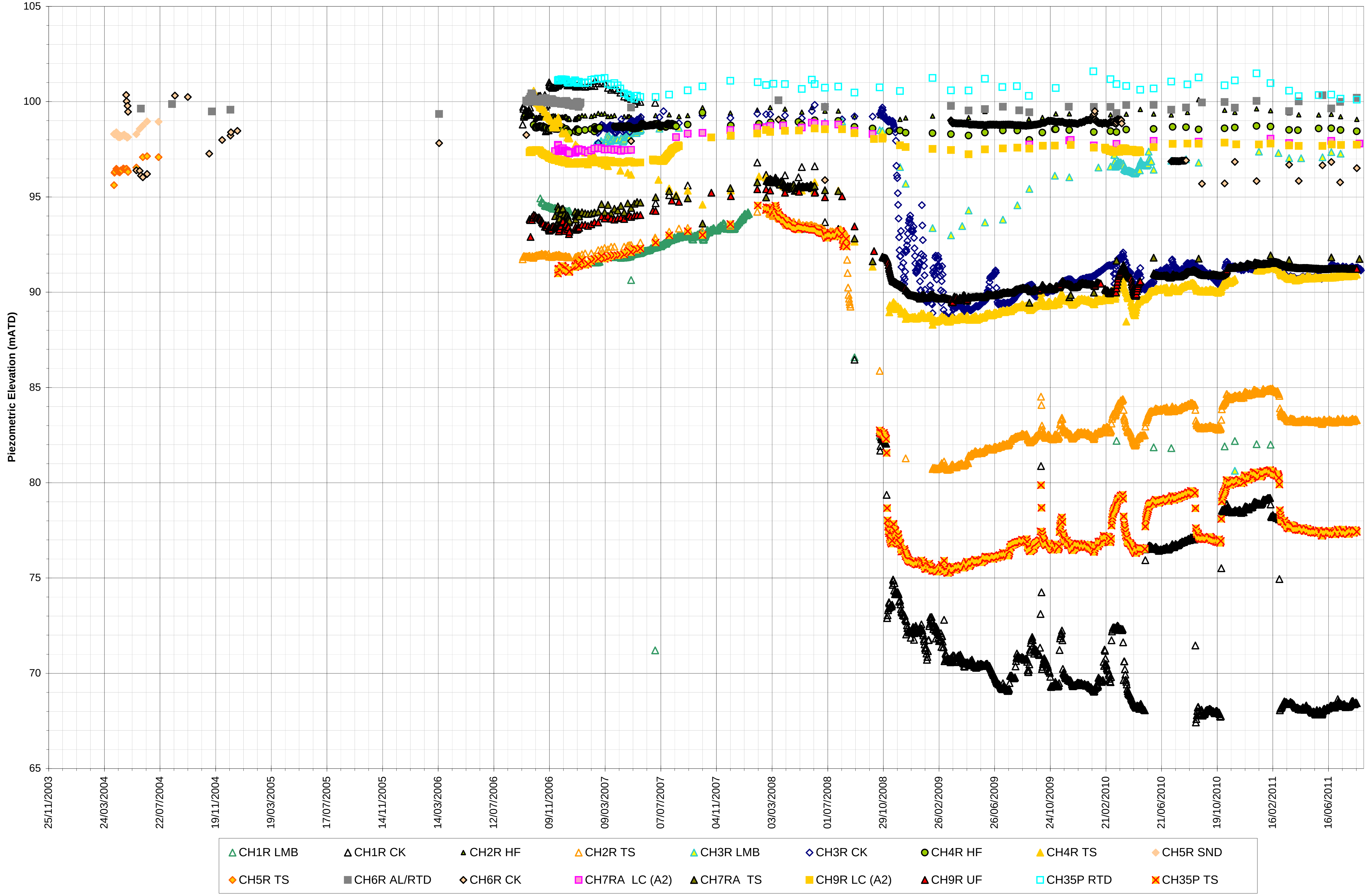
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section I - Isle of Dogs Station

Figure 4.3.11



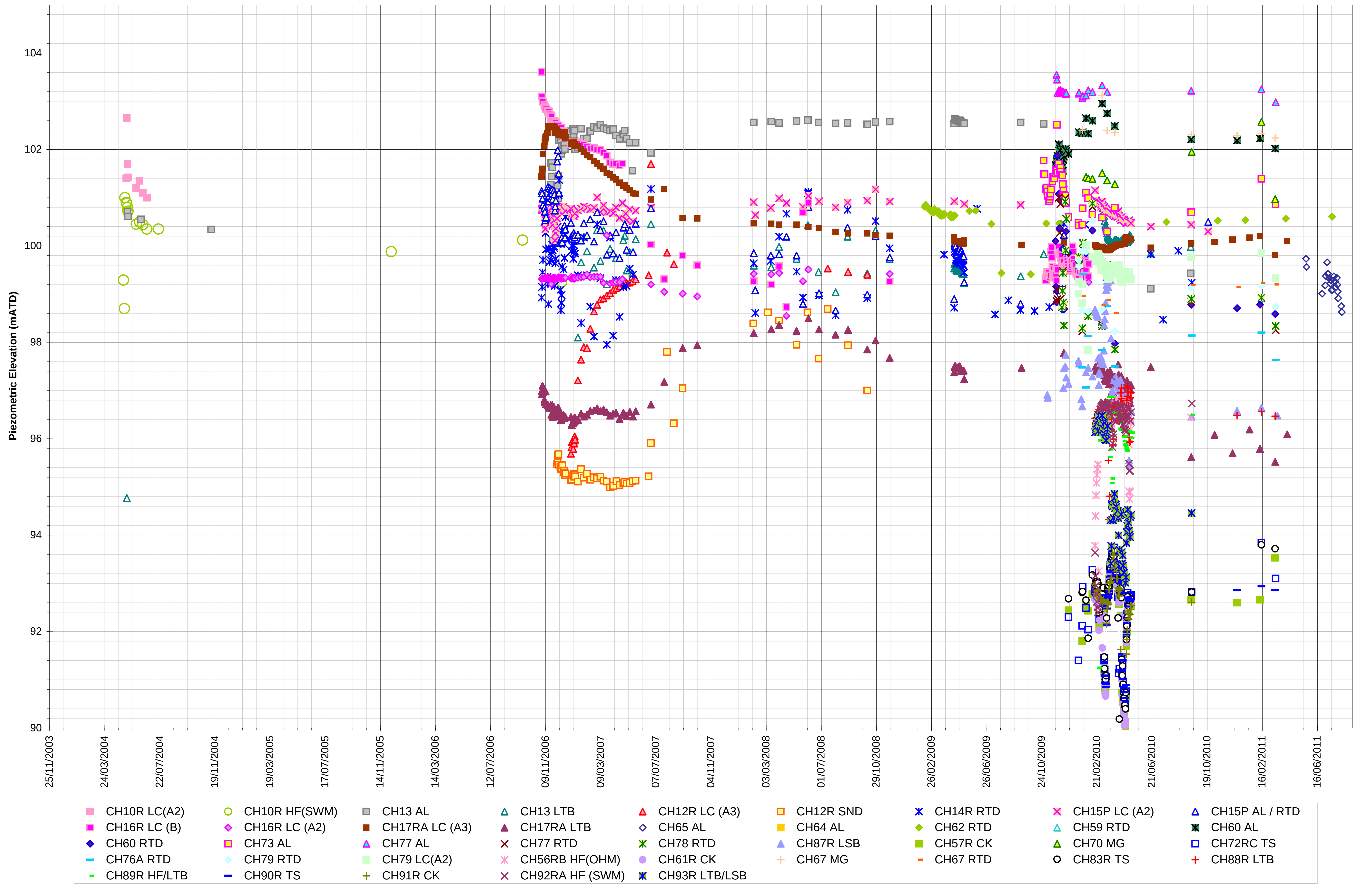
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

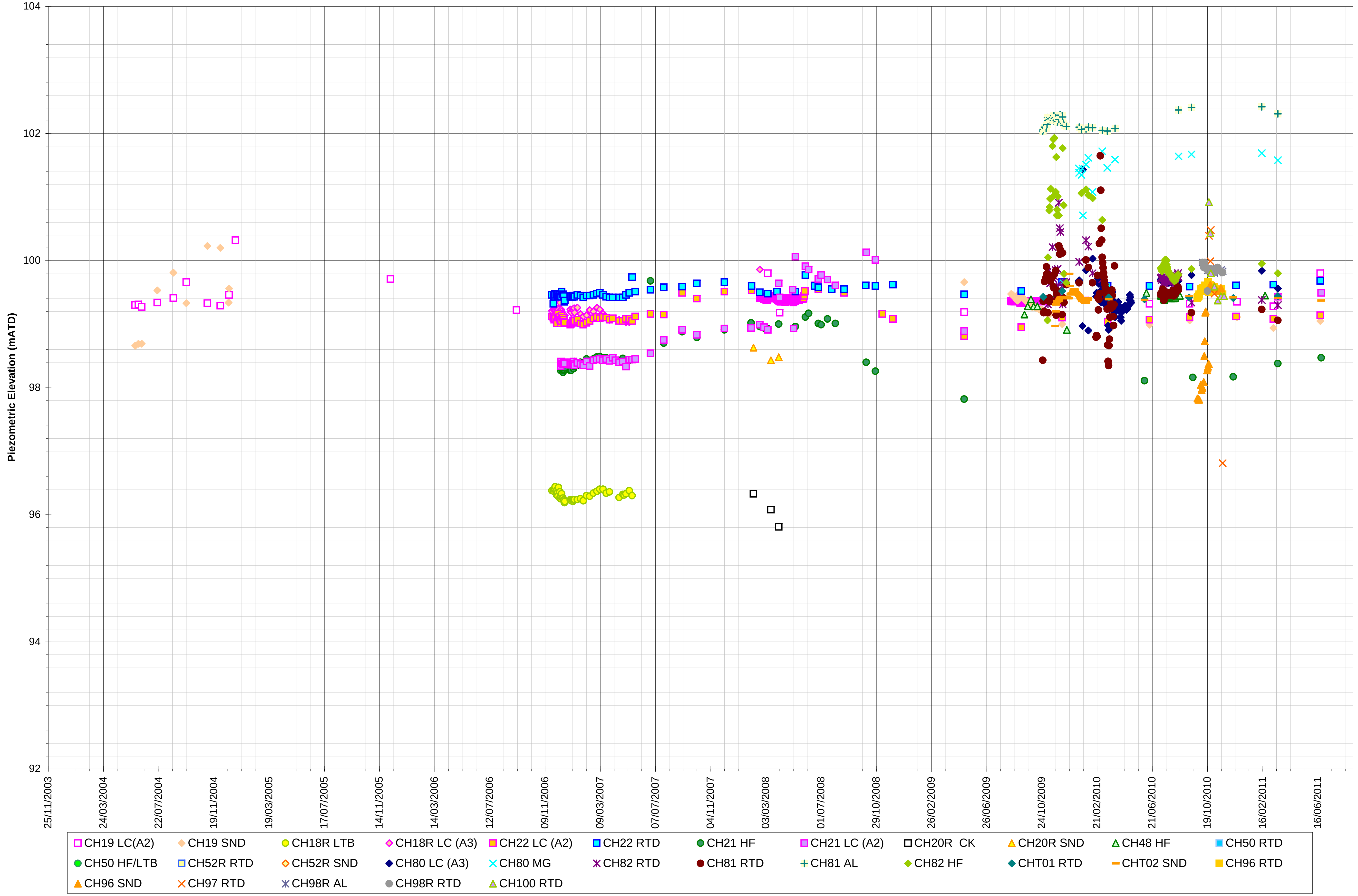
Ground water levels versus time

Route Section J (to EB Chainage 15300m)

Figure 4.3.12



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.13**
	Ground water levels versus time Route Section J (from EB Chainage 15300m to EB Chainage 15900m)	



Note:
CH49 RTD and CH49 HF are not plotted as no data are avaliable

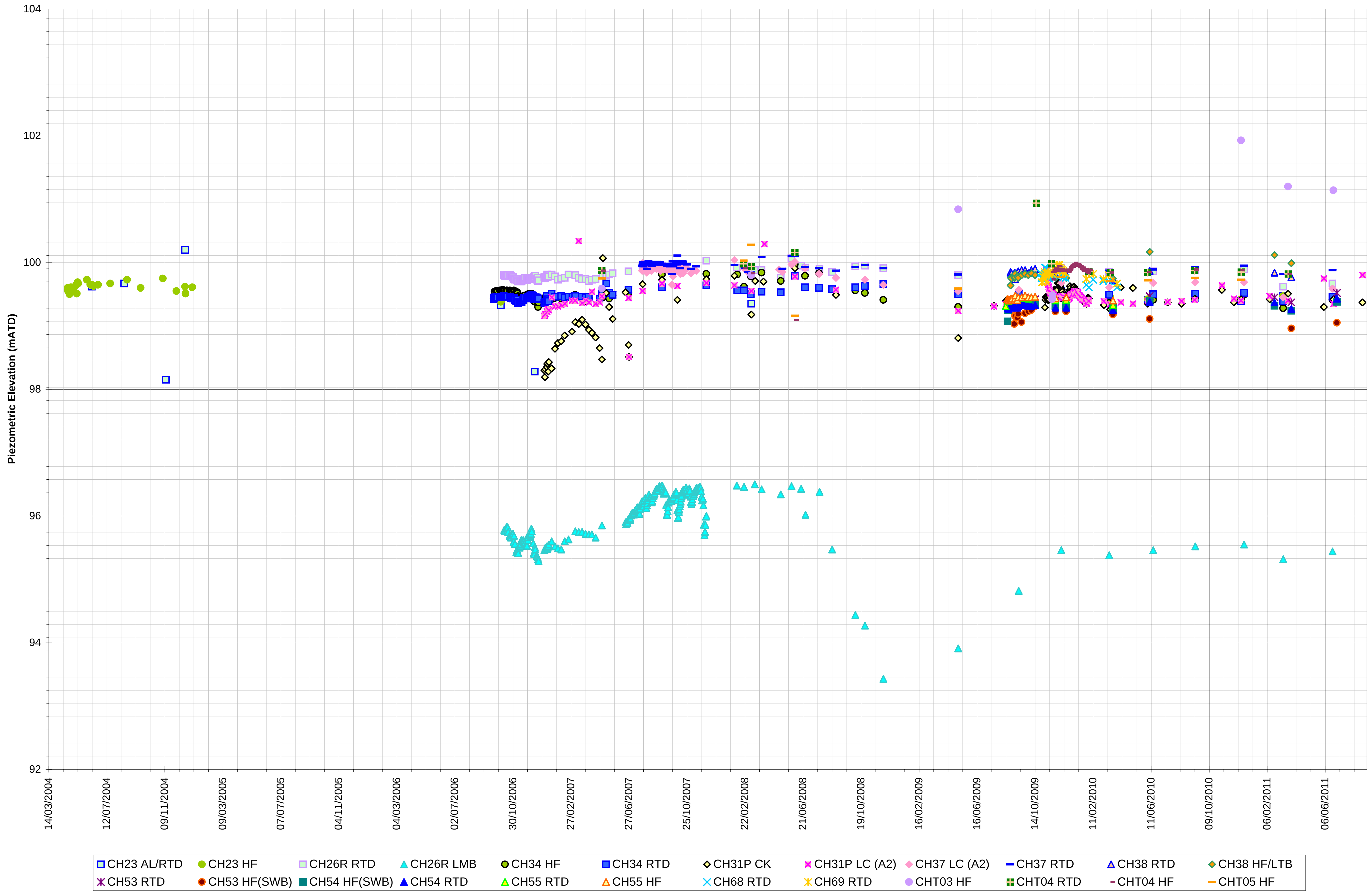
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section J (from EB Chainage 15900m)

Figure 4.3.14



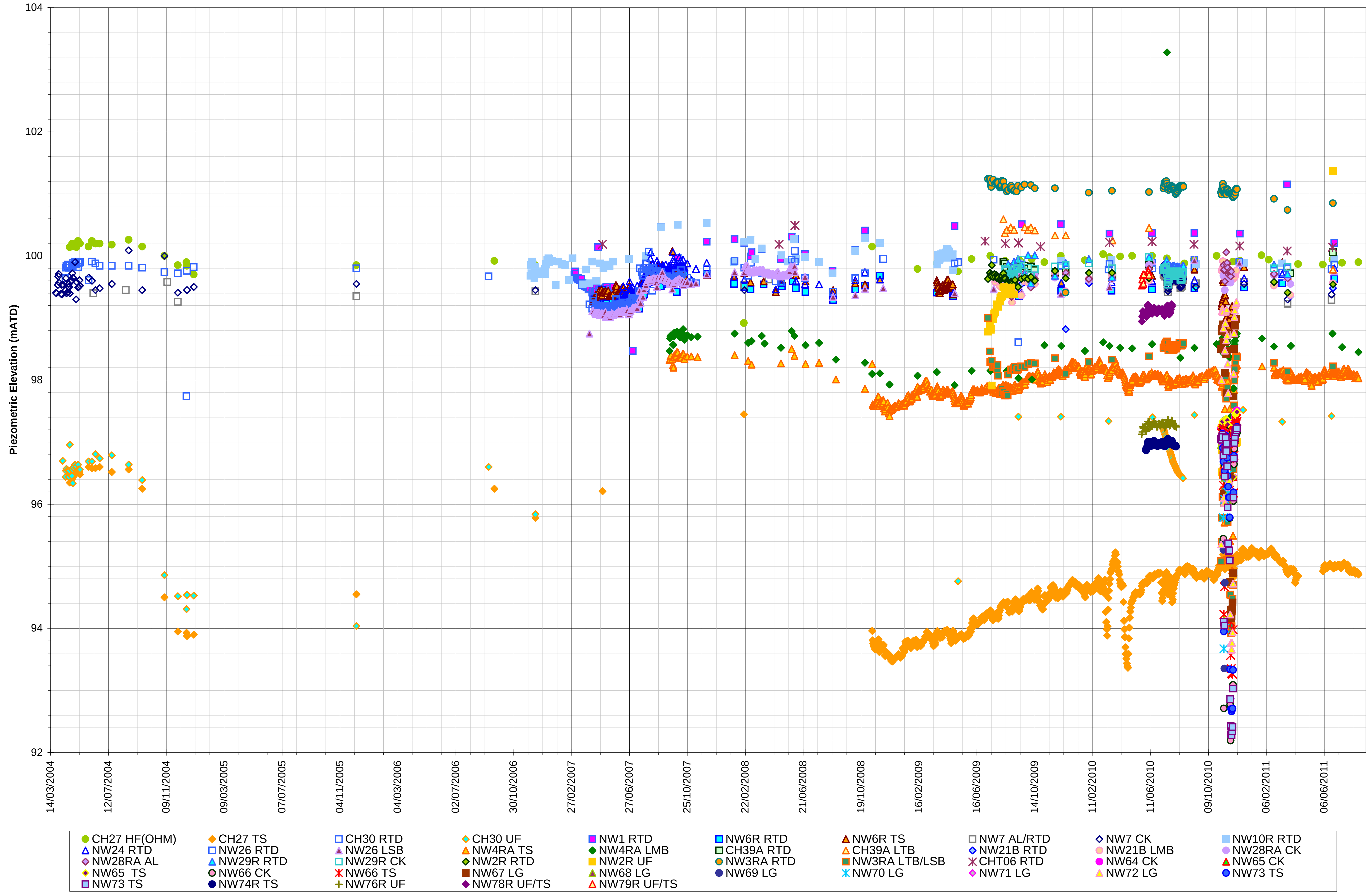
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section K - Victoria Dock Portal

Figure 4.3.15



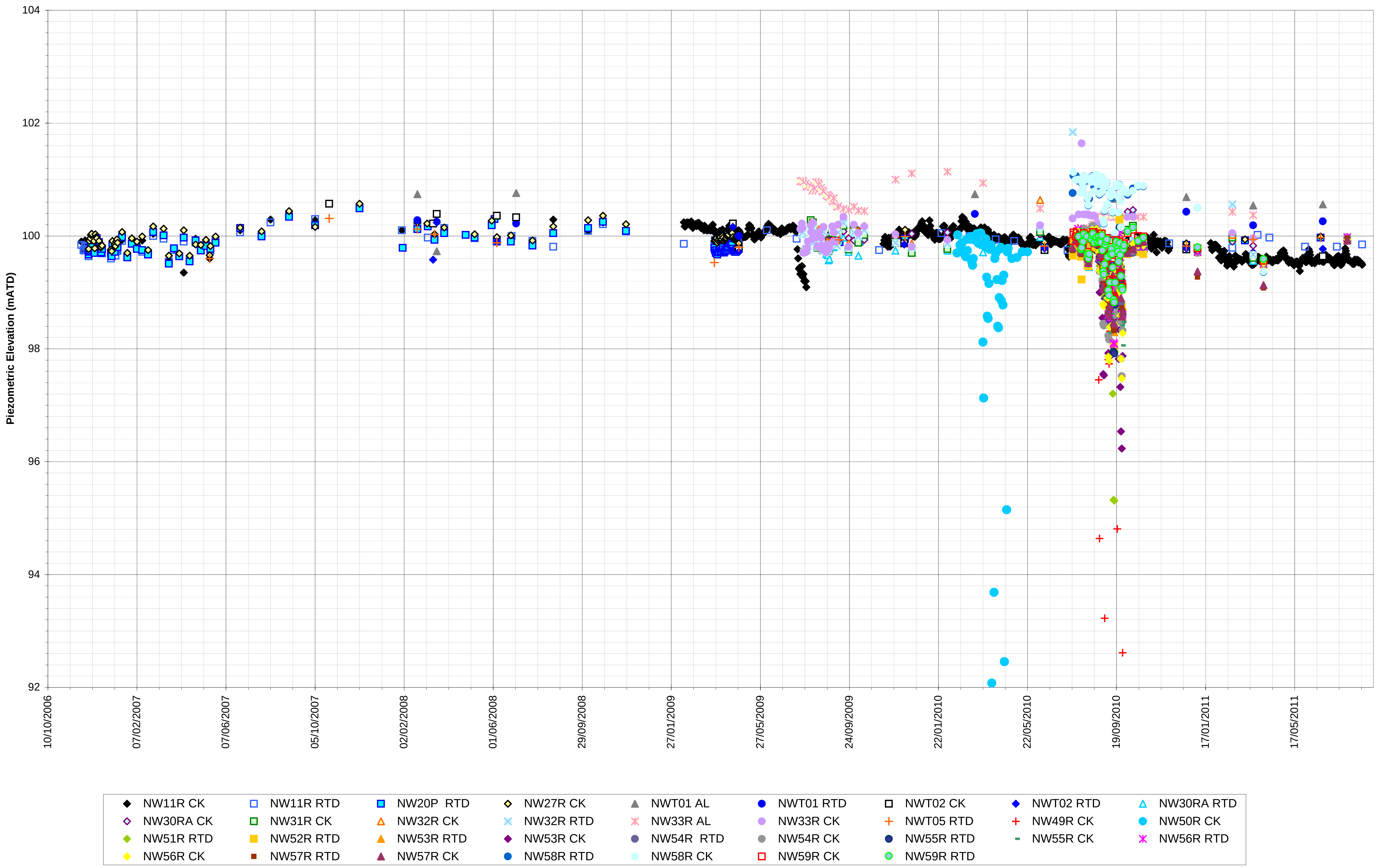
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

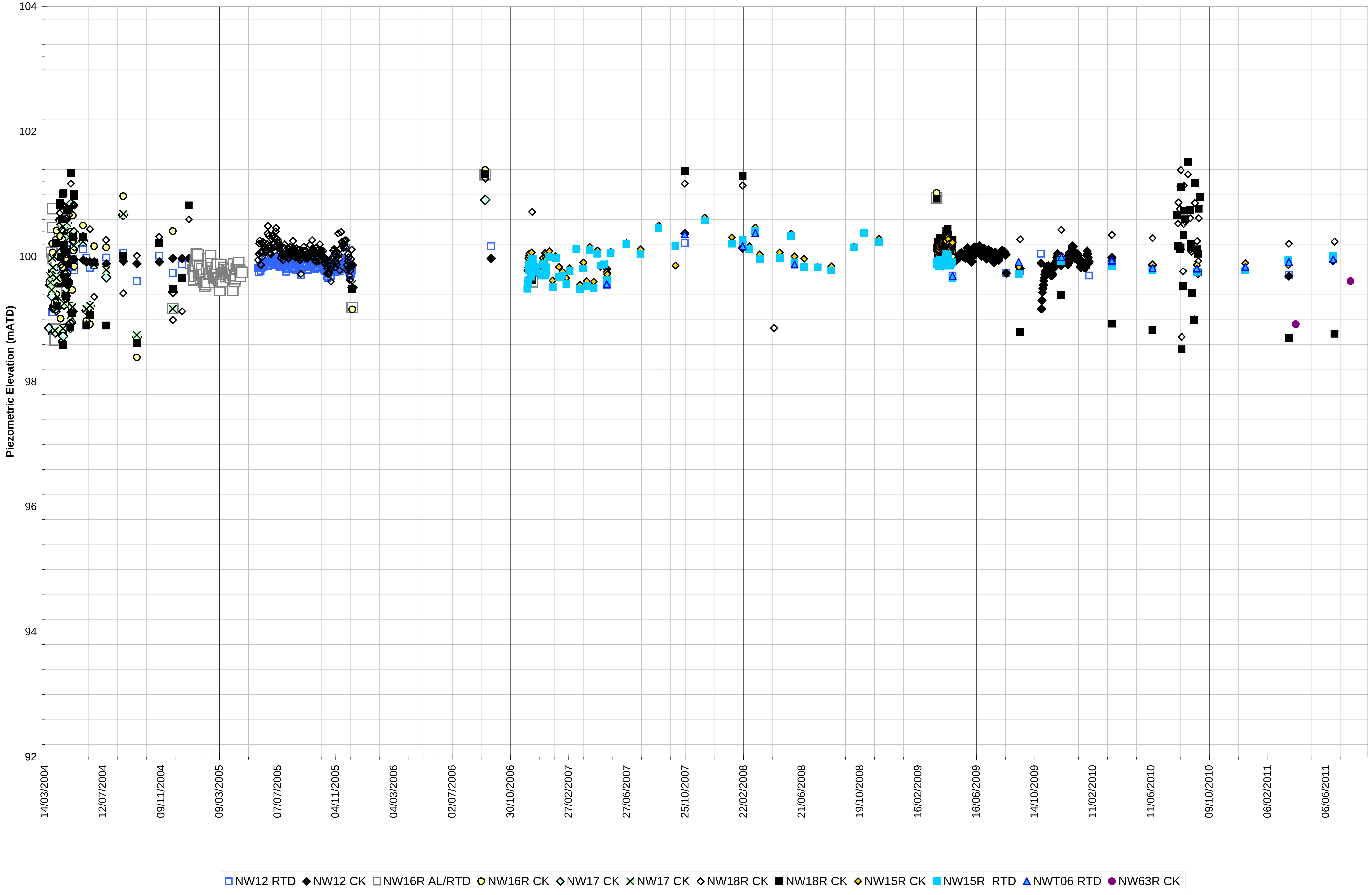
Ground water levels versus time

Route Section L - Victoria Dock Portal to North Woolwich

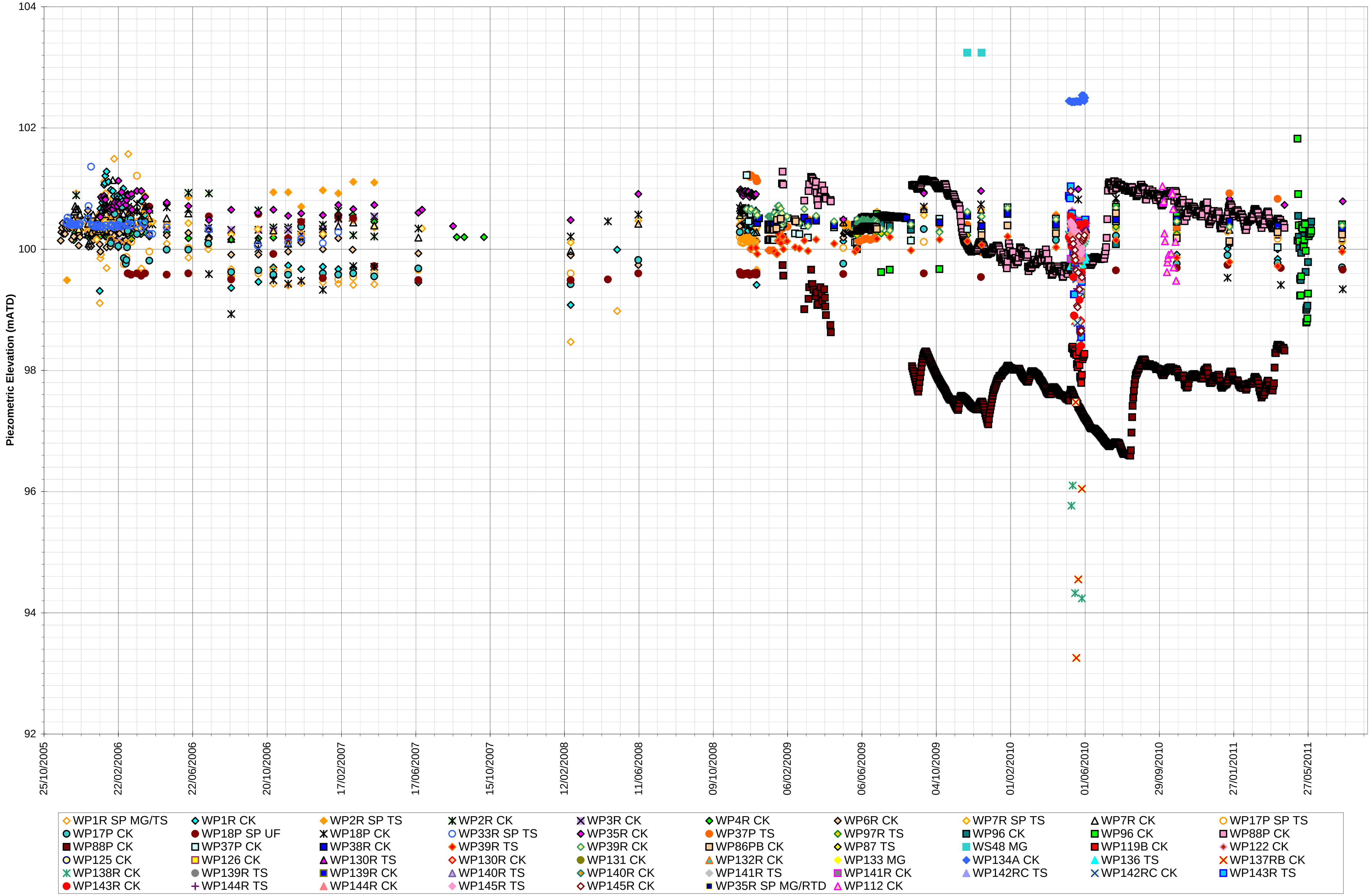
Figure 4.3.16



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.17**
	Ground water levels versus time Route Section M - North Woolwich Portal	



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.18**
	Ground water levels versus time Route Section N1 - North Woolwich	



WP88P CK is not plotted as it was destroyed during installation

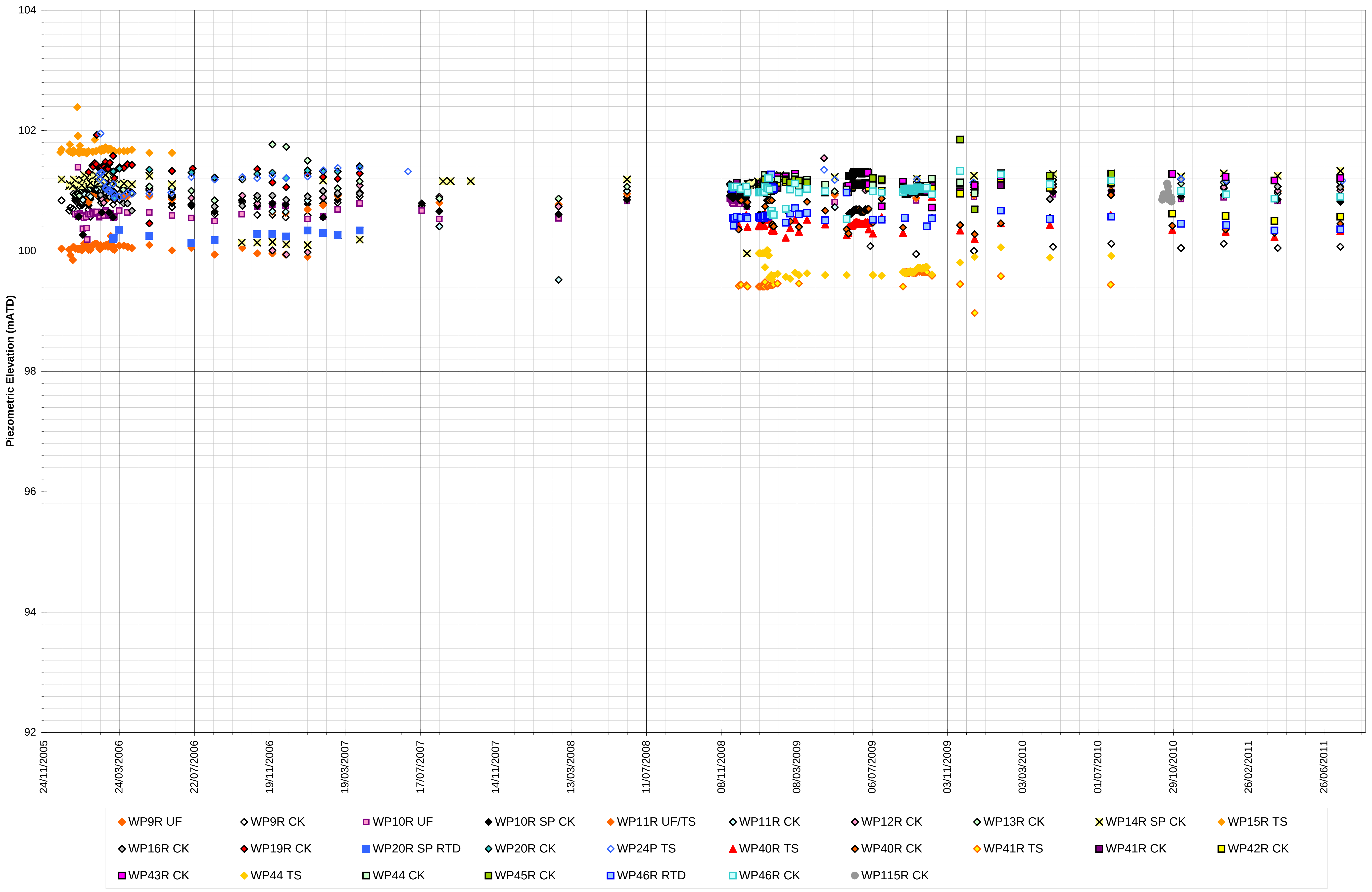
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

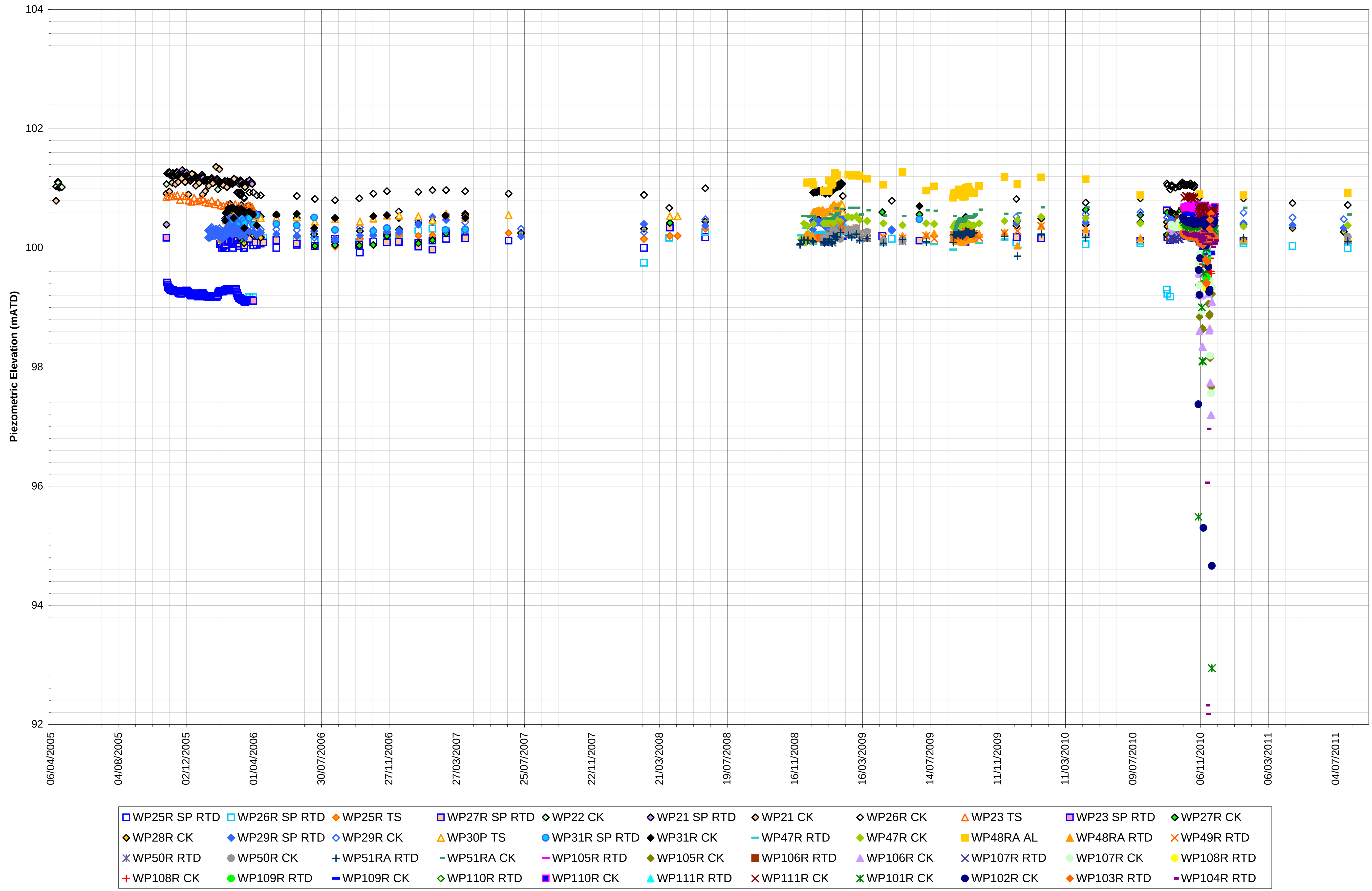
Ground water levels versus time

Route section N 1 & N2 - Woolwich to Woolwich Station

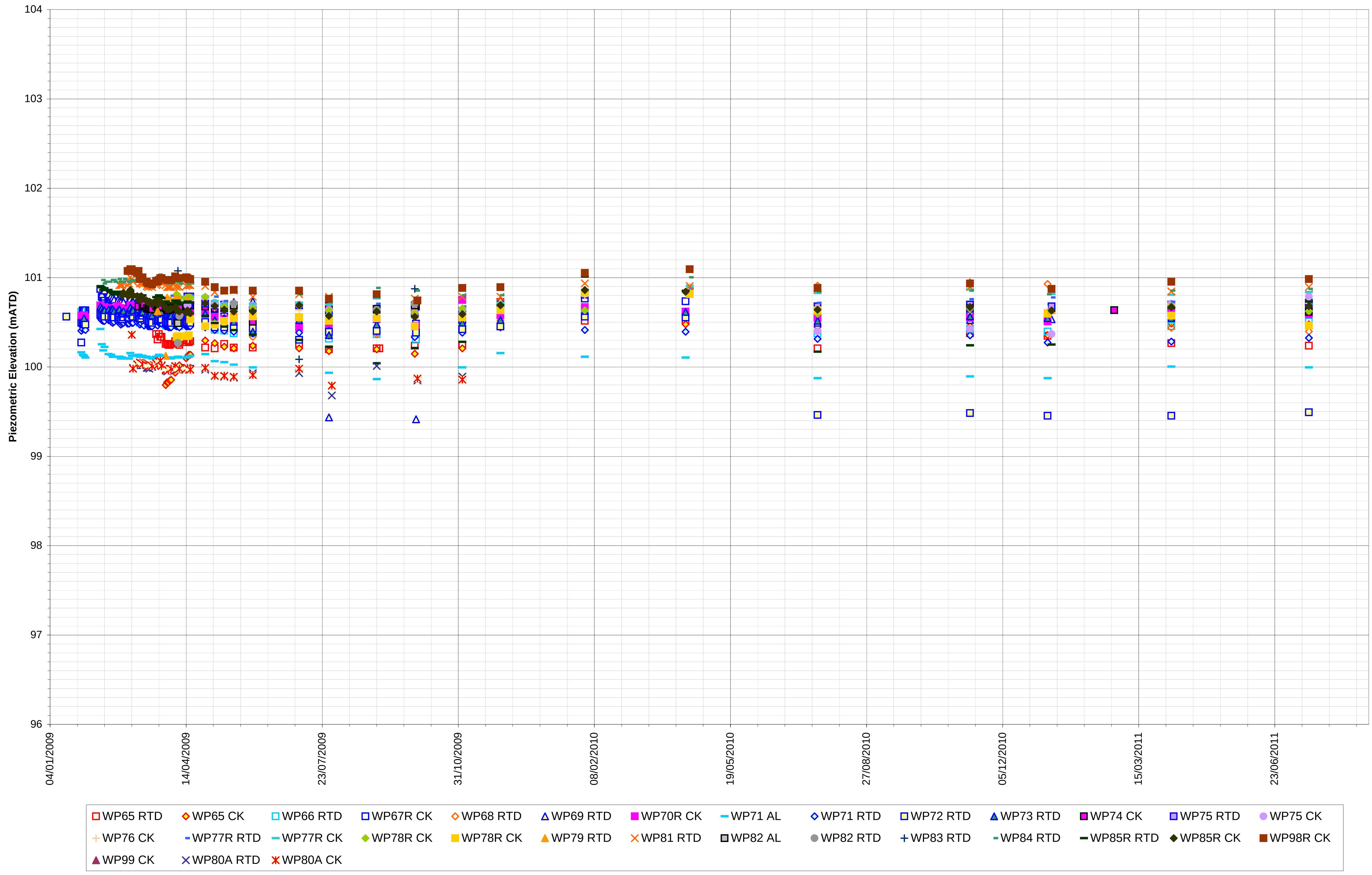
Figure 4.3.19



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.20**
	Ground water levels versus time Route Section N3 - Woolwich to Plumstead	



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure** **4.3.21**
	Ground water levels versus time Route Section O - Plumstead Portal	



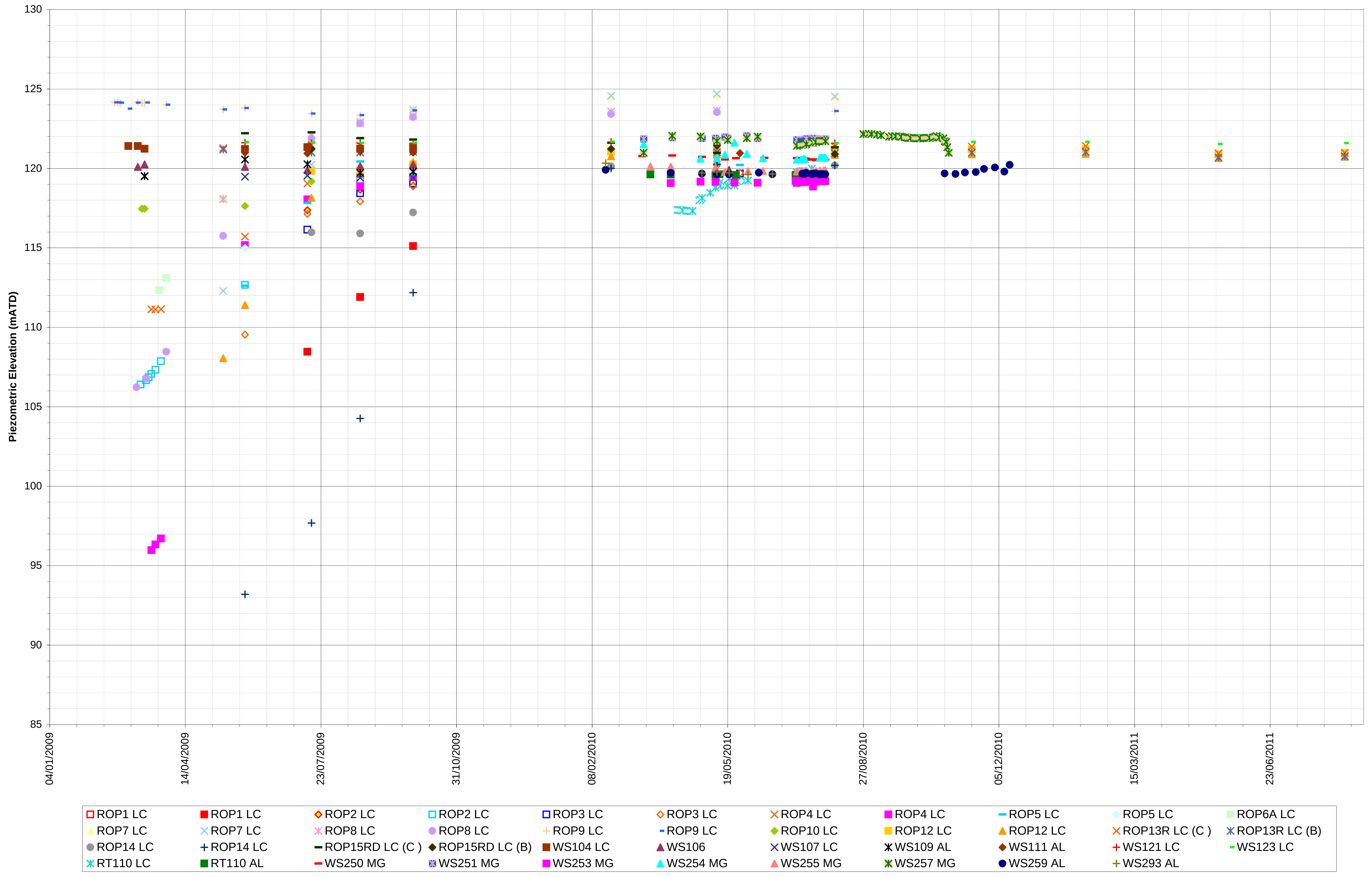
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

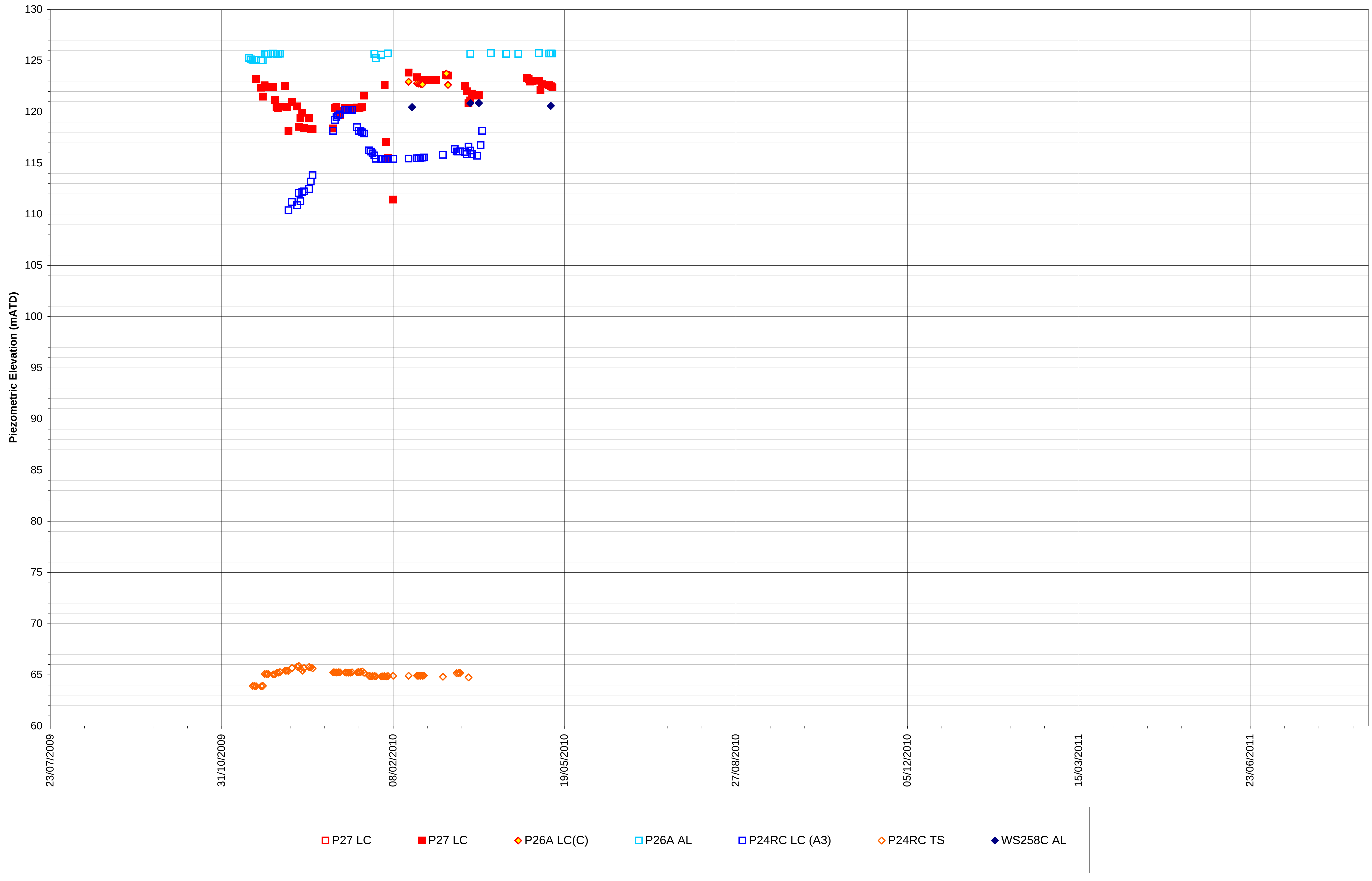
Ground water levels versus time

Route Section Abbey Wood

Figure 4.3.22

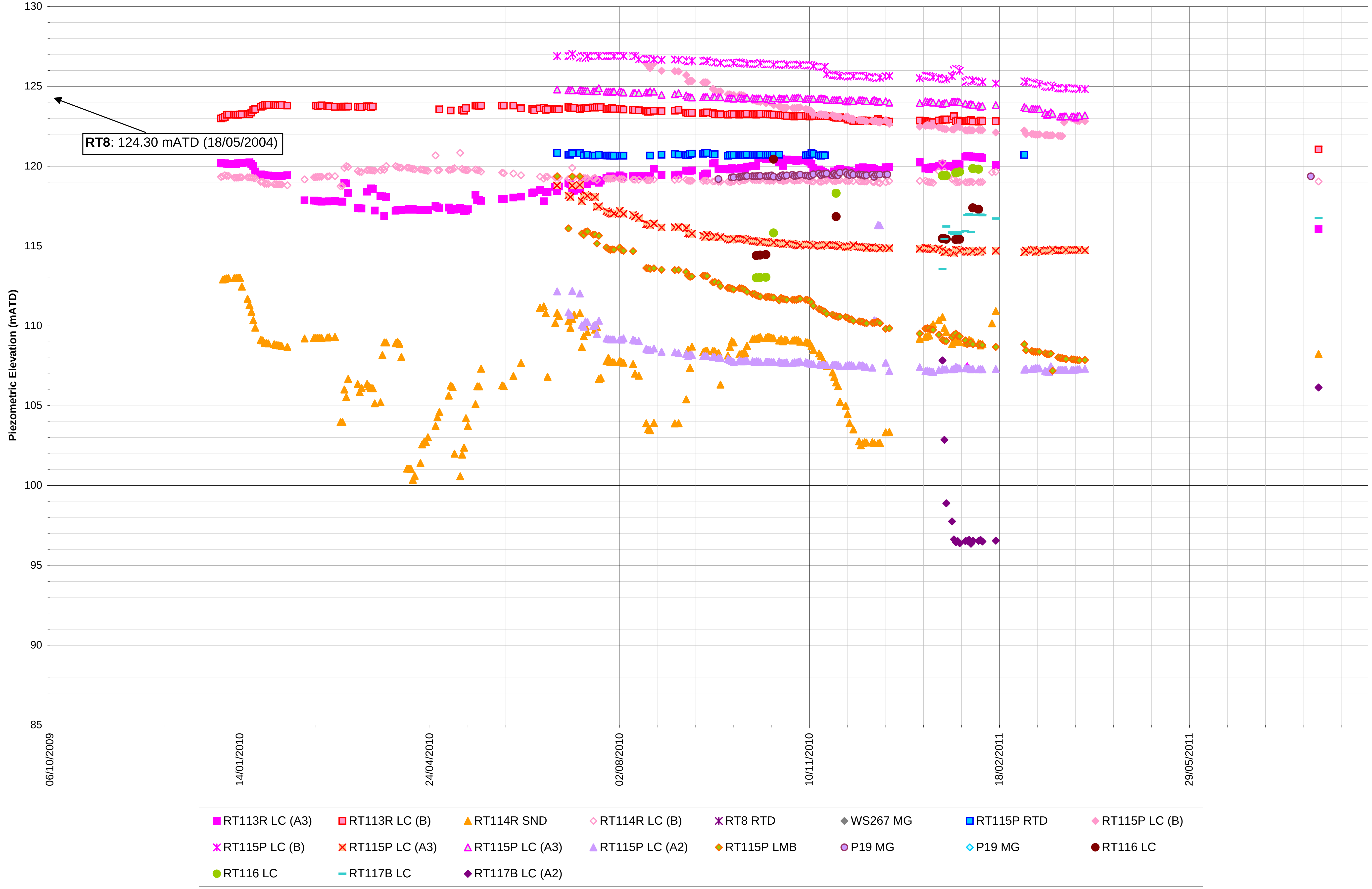


	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.23**
	Ground water levels versus time Route Section P - Royal Oak Portal	

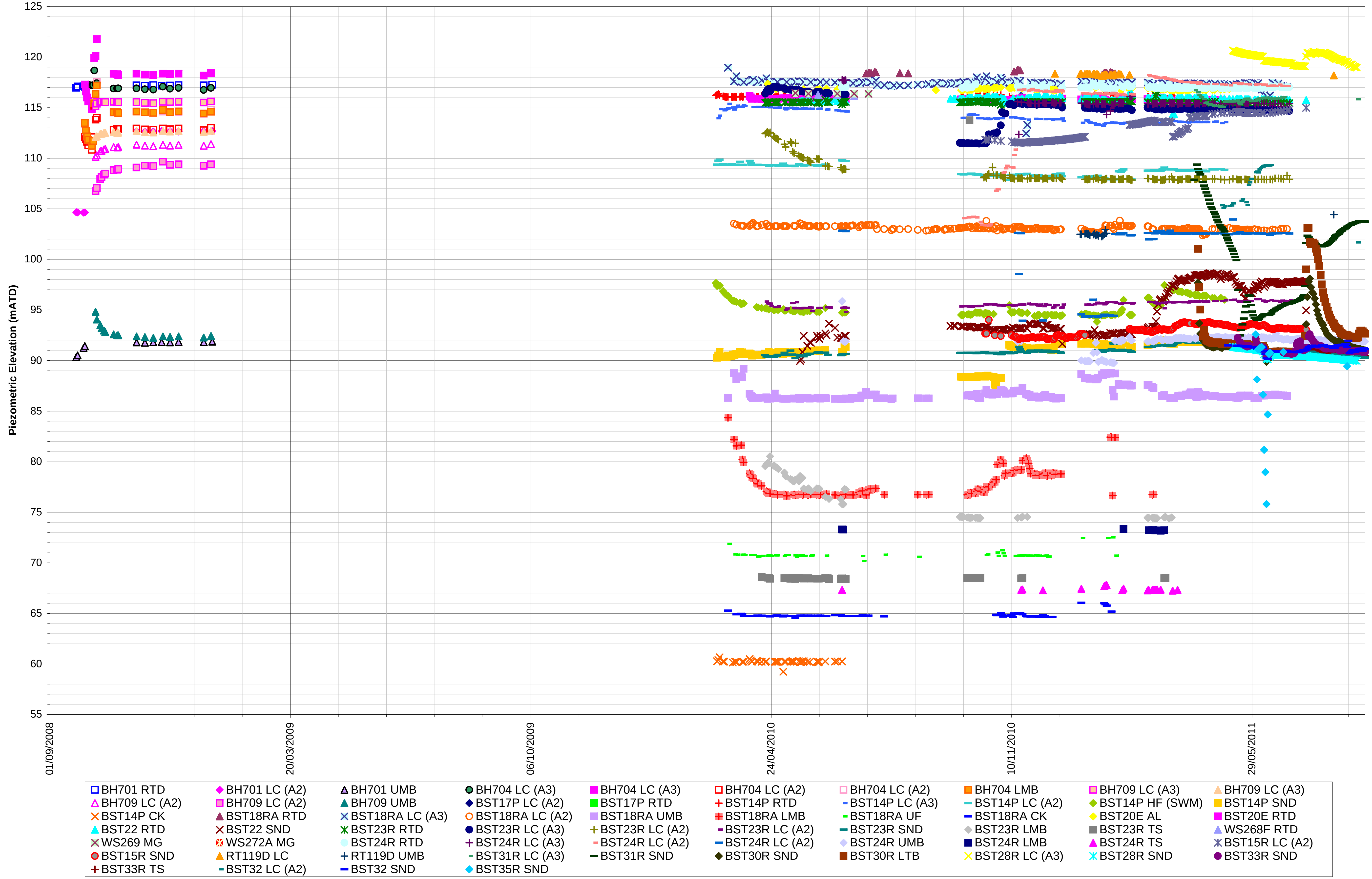


	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.24**
	Ground water levels versus time Route Section Q - Royal Oak to Paddington	

Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.25**
Ground water levels versus time Route Section R - Paddington Station	



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure 4.3.26**
	Ground water levels versus time Route Section S - Paddington to Bond Street	



Note:
BST14P TS not plotted as it is considered unreliable

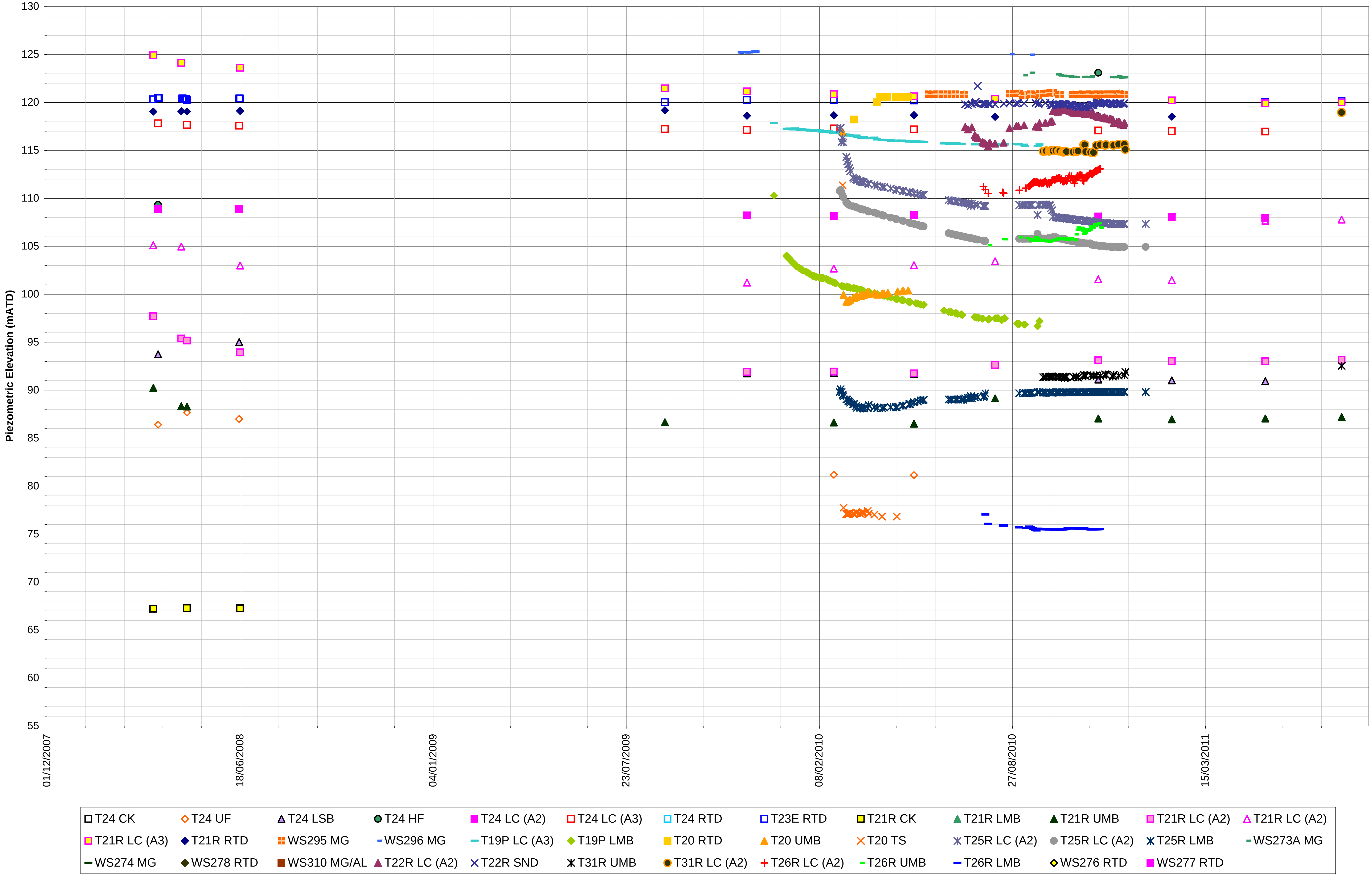
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section T - Bond Street to TCR

Figure 4.3.27



Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section U - TCR Station

Figure 4.3.28

Note:
RT43 TS not plotted as it is considered unreliable

Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section V - TCR to Farringdon

Figure 4.3.29

Note:
RT48 UF, F25 UMB, F25 UF and F4 CK are not plotted as they are considered unreliable

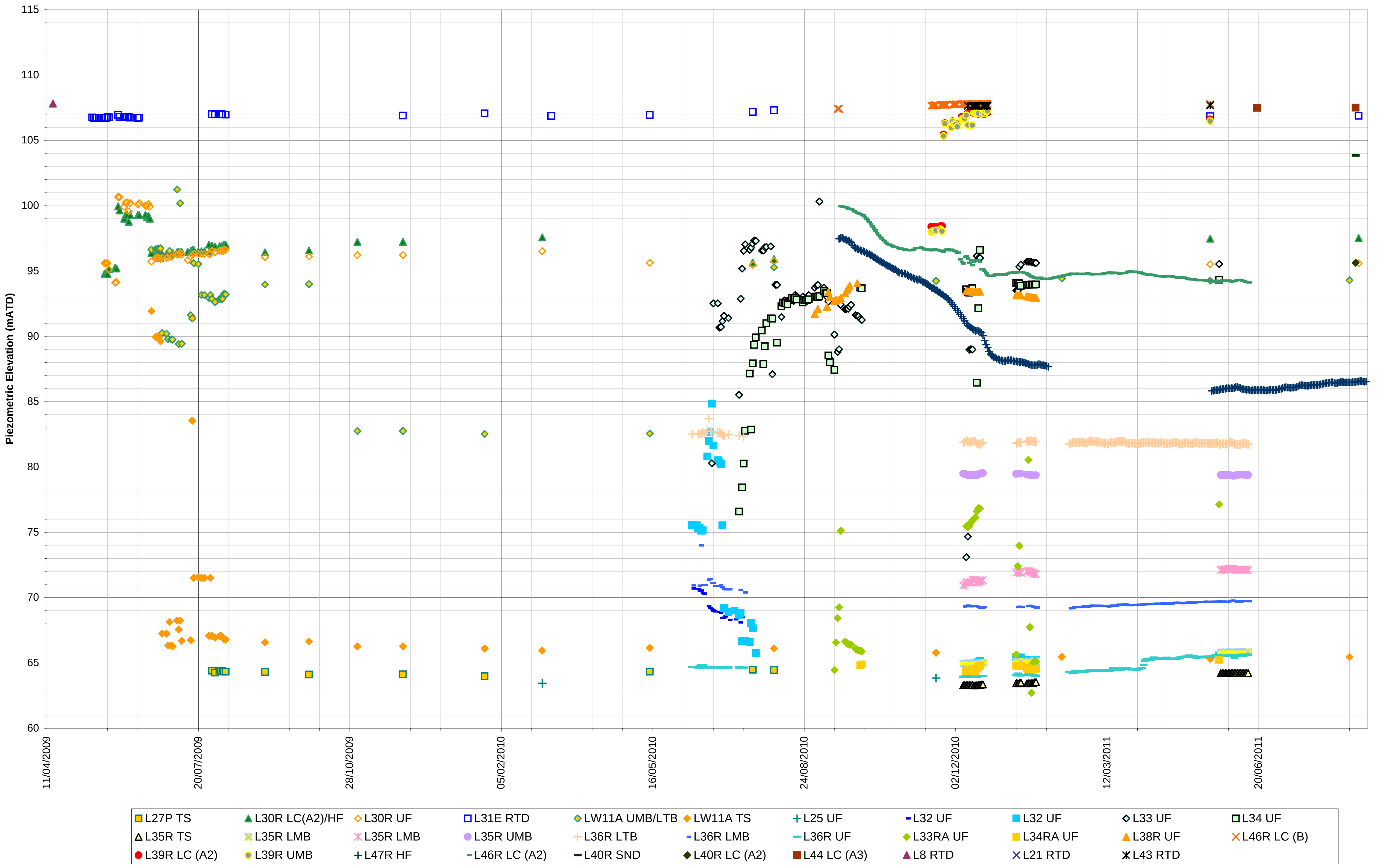
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section W - Farringdon to Liverpool Street

Figure 4.3.30



Note:
L8 UMB not plotted as it is not reliable

Crossrail Limited

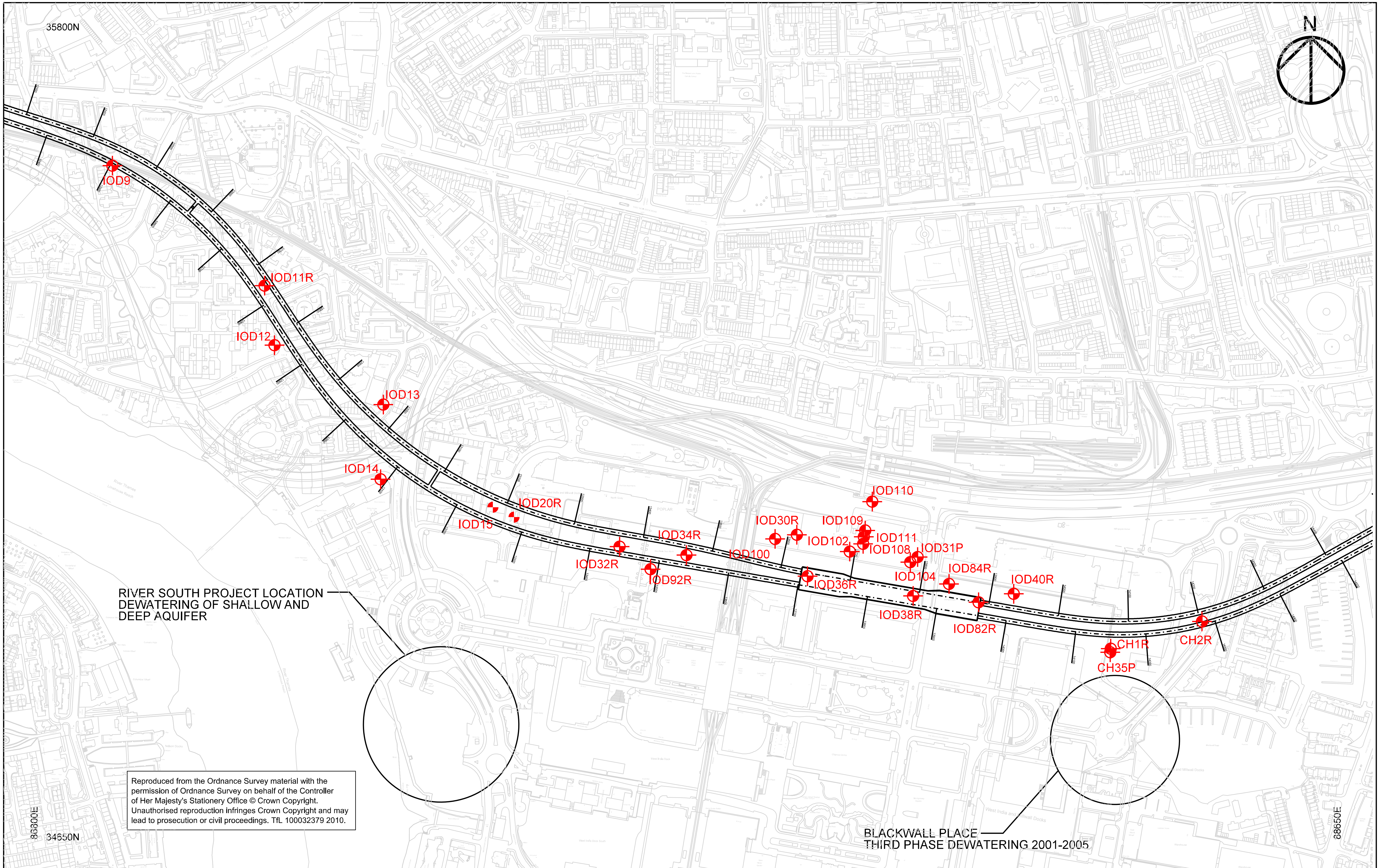
Crossrail - Groundwater Monitoring Report - Revision 2

Ground water levels versus time

Route Section X - Liverpool Street Station

Figure 4.3.31

Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2		**Figure 4.3.32**
Ground water levels versus time Off-Alignment Boreholes		



Scale 1:5000

100m 0 100m 200m 300m 400m 500m

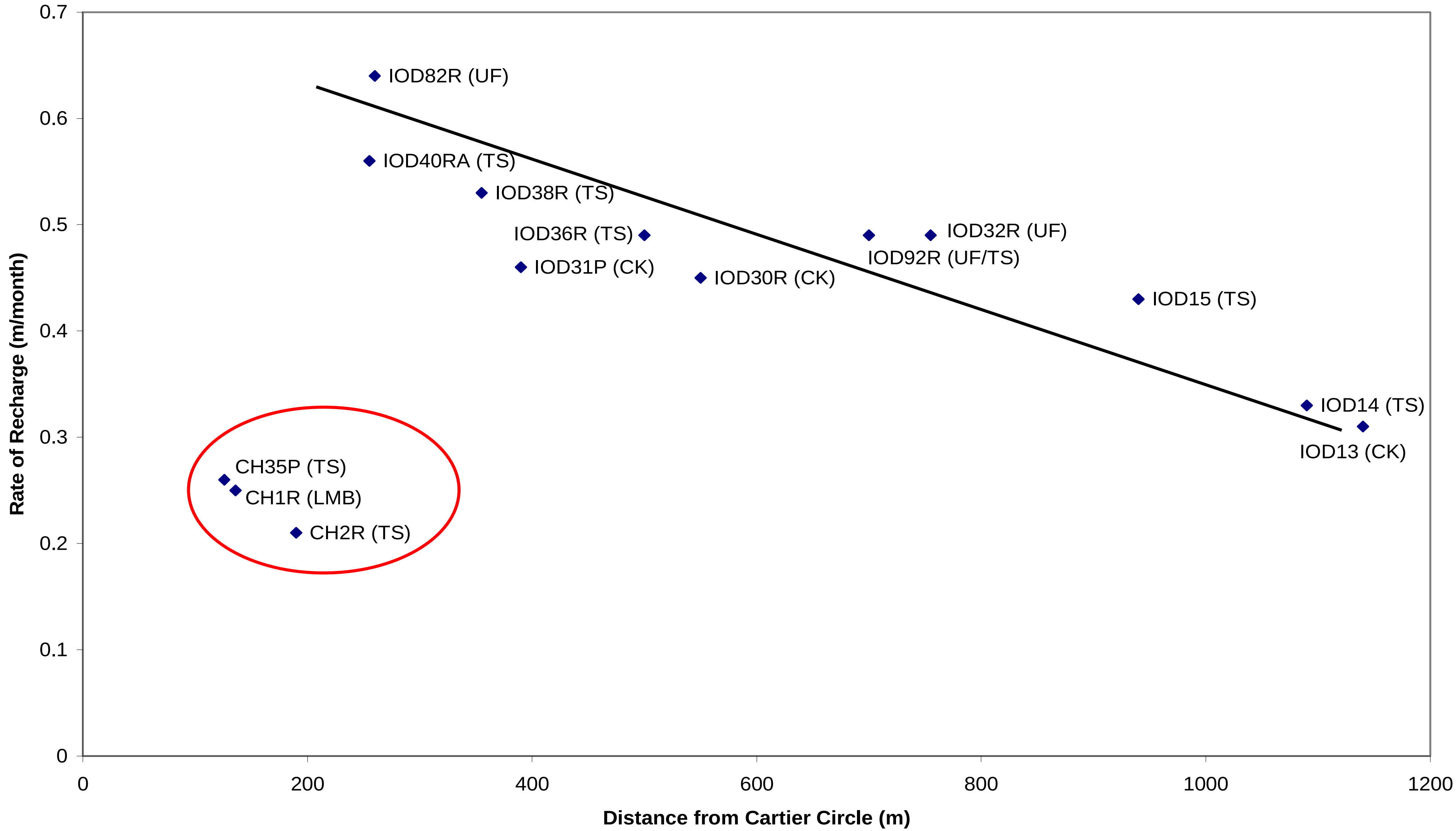
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

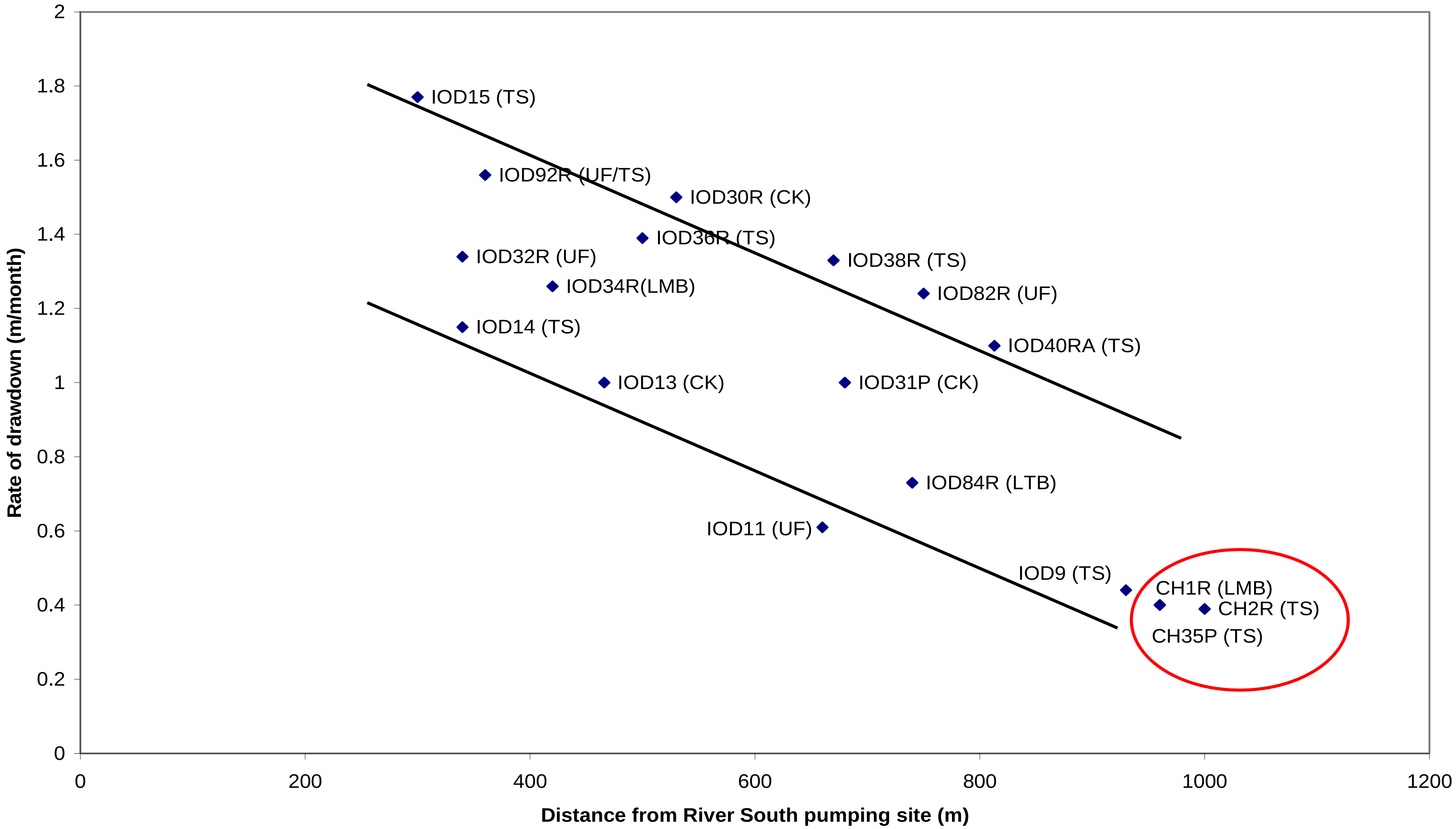
Borehole Location - Isle of Dogs -
Piezometers Logged With Datalogger

Figure

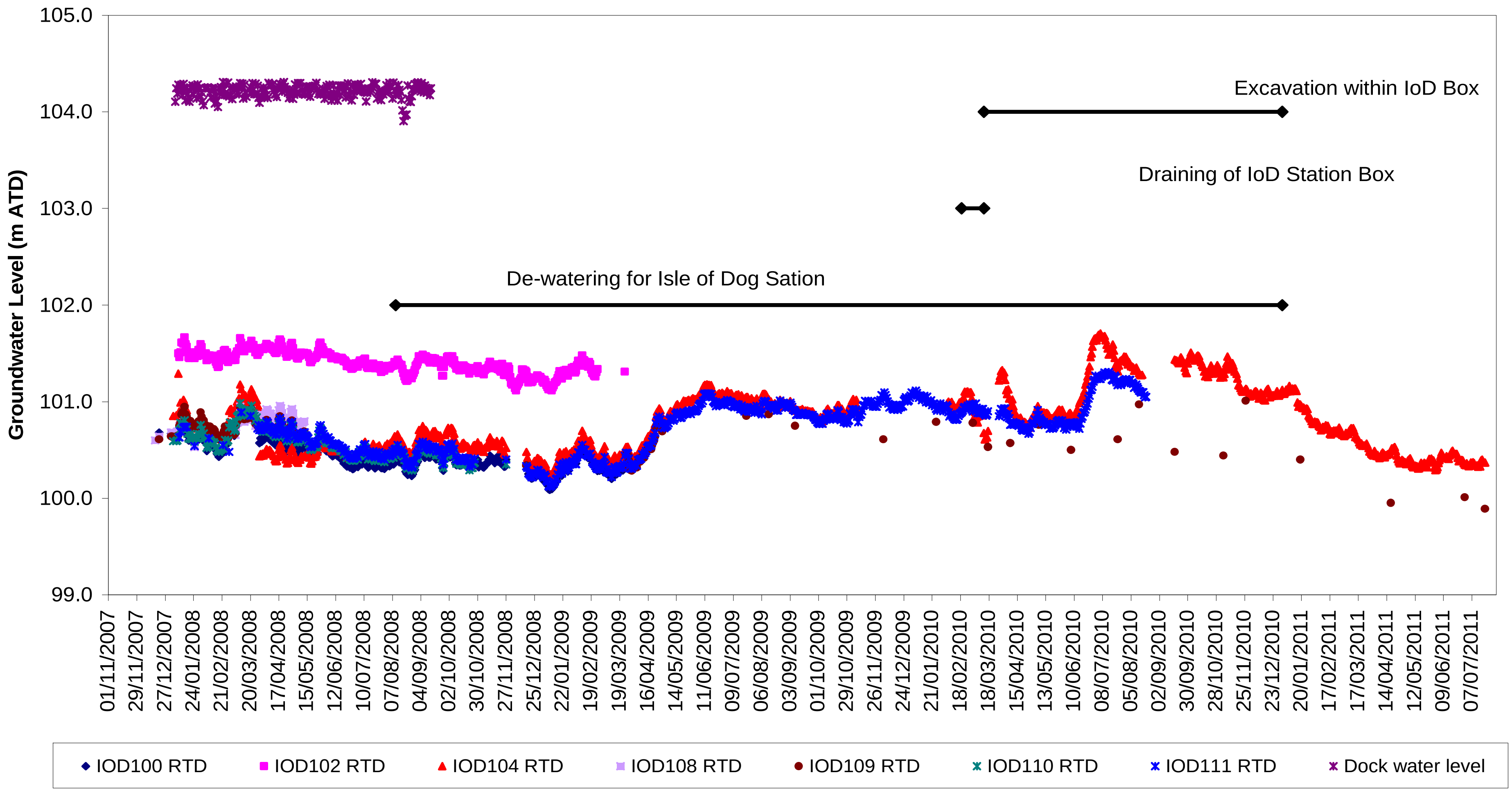
4.3.33



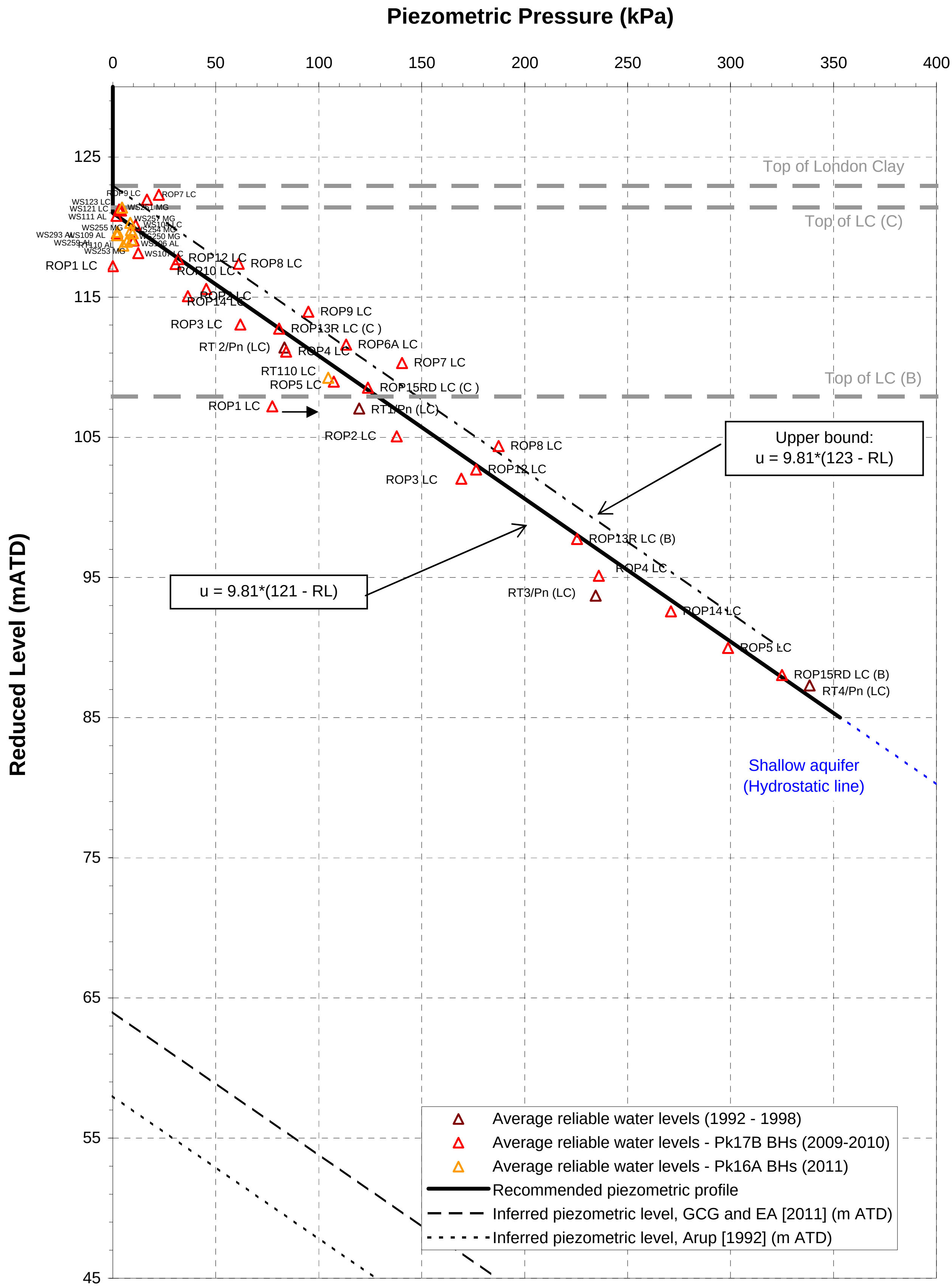
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	Isle of Dogs - Rate of recharge of deep aquifer groundwater level between 2007 and 2008	**4.3.34**



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	Isle of Dogs - Rate of drawdown of deep aquifer groundwater level between January and July 2008	**4.3.35**



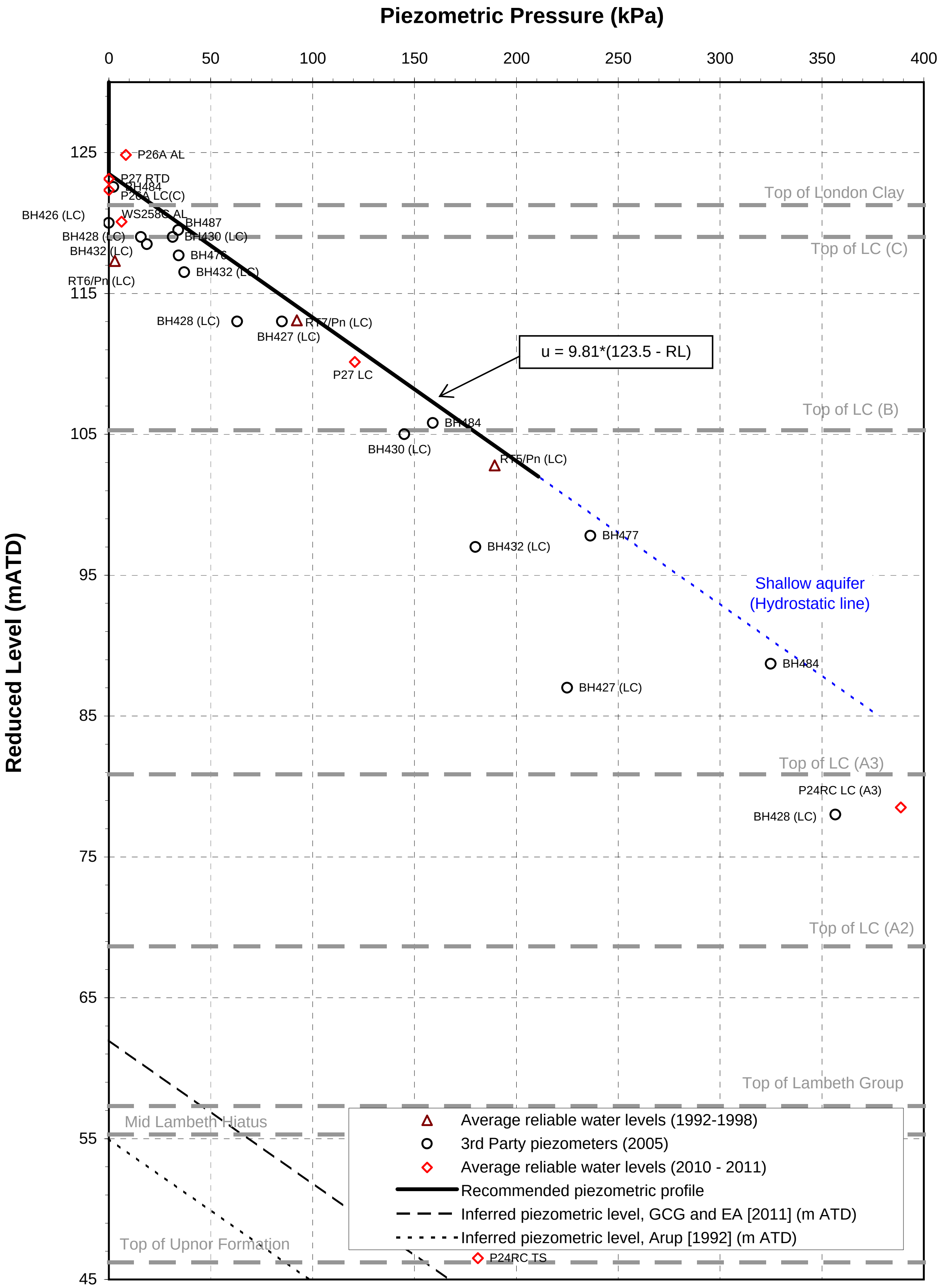
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	Route Section I - Borehole IOD100-102-104-108-109-110-111 Piezometric Data Measured Piezometric Level	**4.3.36**



[1] Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A, Pk17A and Pk17B.

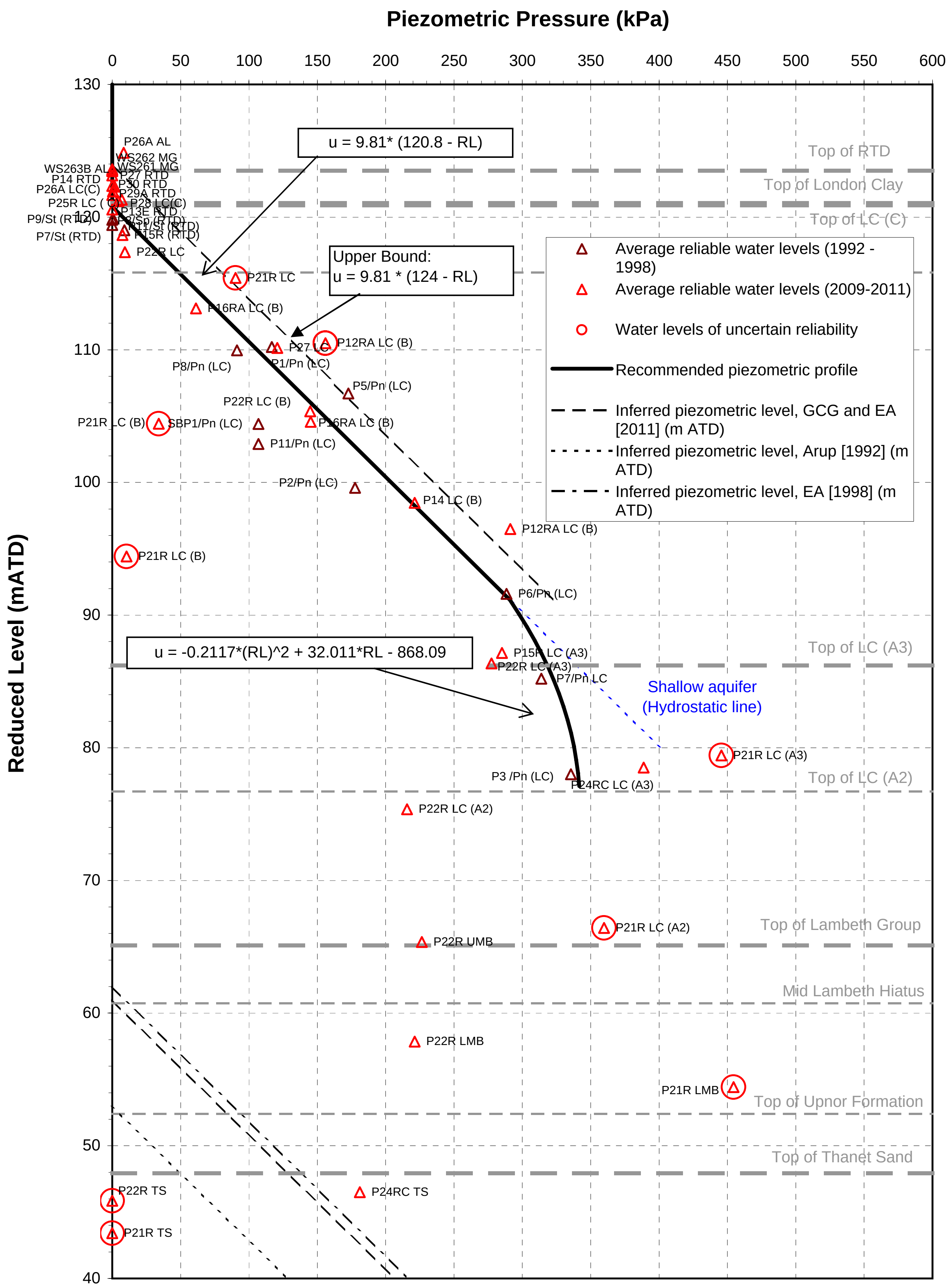
[2] ROP1 water level was rising. Last monitoring reading was taken on 29/09/2009. The piezometer is now destroyed.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section P - Royal Oak Portal	**4.4.1**



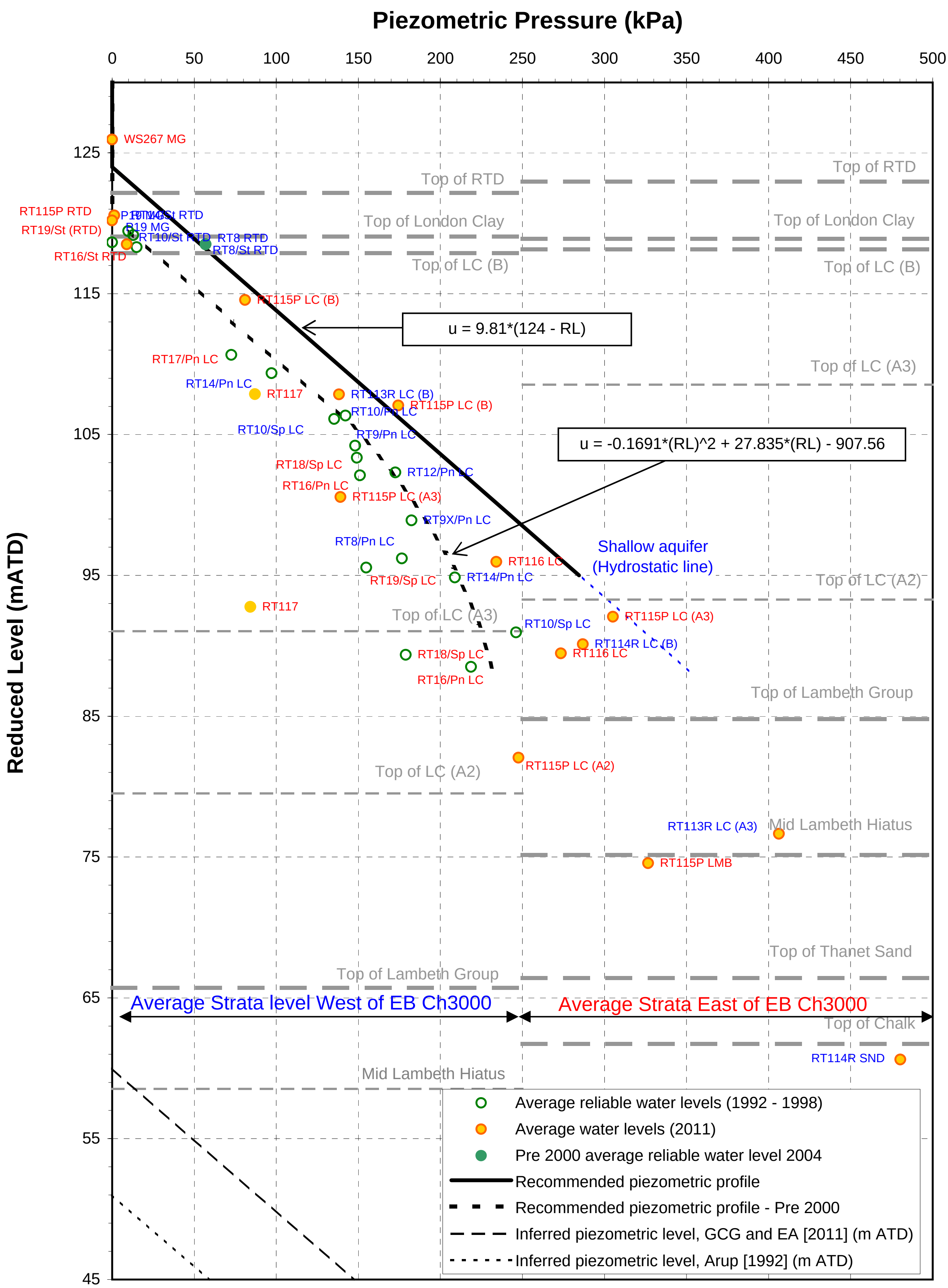
[1] Stratigraphic levels based on the average value as reported in GSIR1& 2 Rev A, Pk16 & Pk16A data.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section Q - Royal Oak Portal to Paddington Station	**4.4.2**



1. Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A, Pk16 & Pk16A data.
2. P12RA levels are abnormally high. Possibly influenced by leaky nearby groundwater main.
3. P21R readings to be verified - Pk16A

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section R - Paddington Station	**4.4.3**

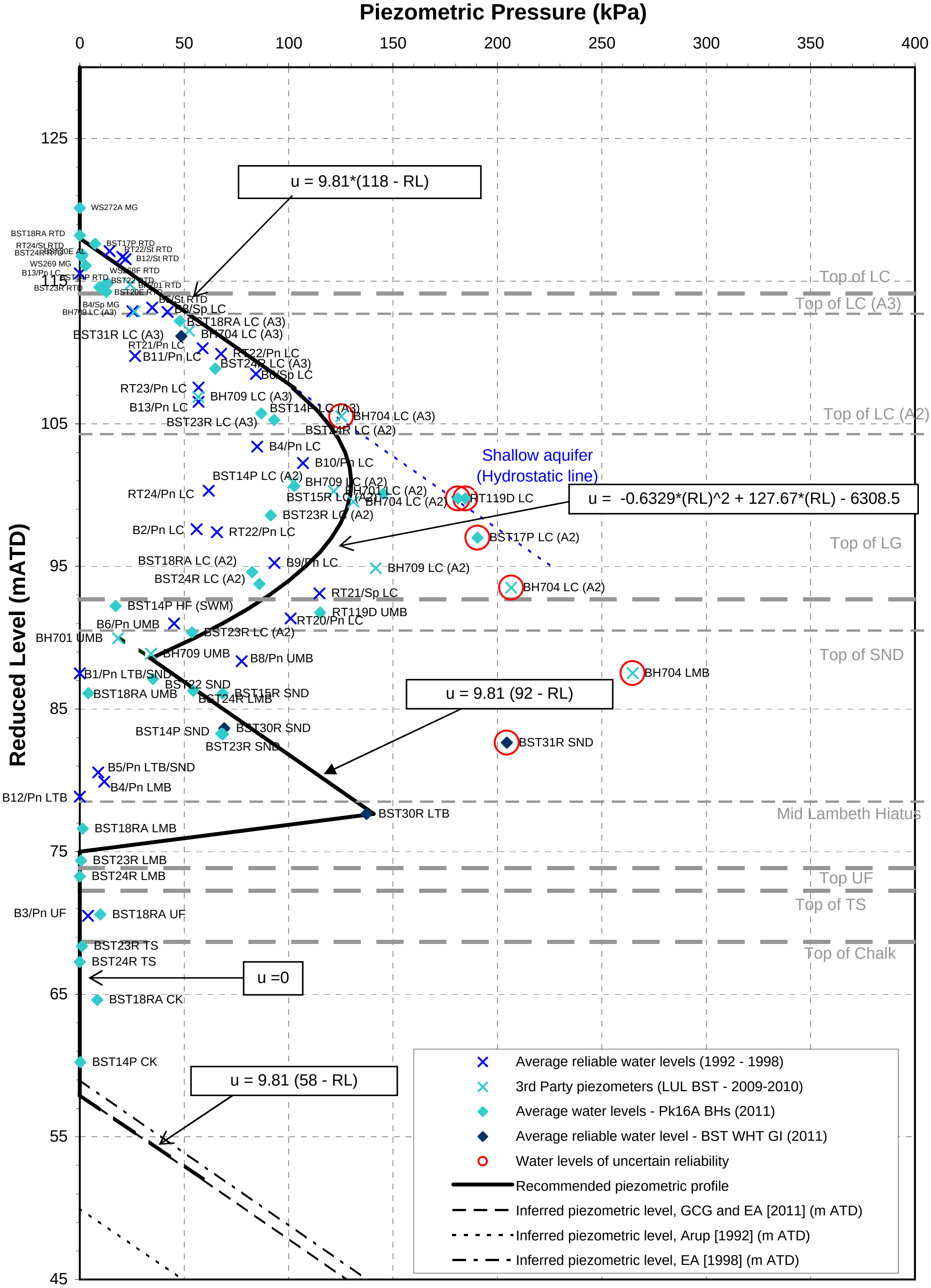


[1] Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A, Pk16 & Pk16A data.

[2] The stratigraphy lines shown represent the average strata levels encountered to the west and to the east of EB Ch3000m. Text coloured coded to match.

[3] Pk16A Piezo RT113R, RT114R & RT115P - reliability to be confirmed

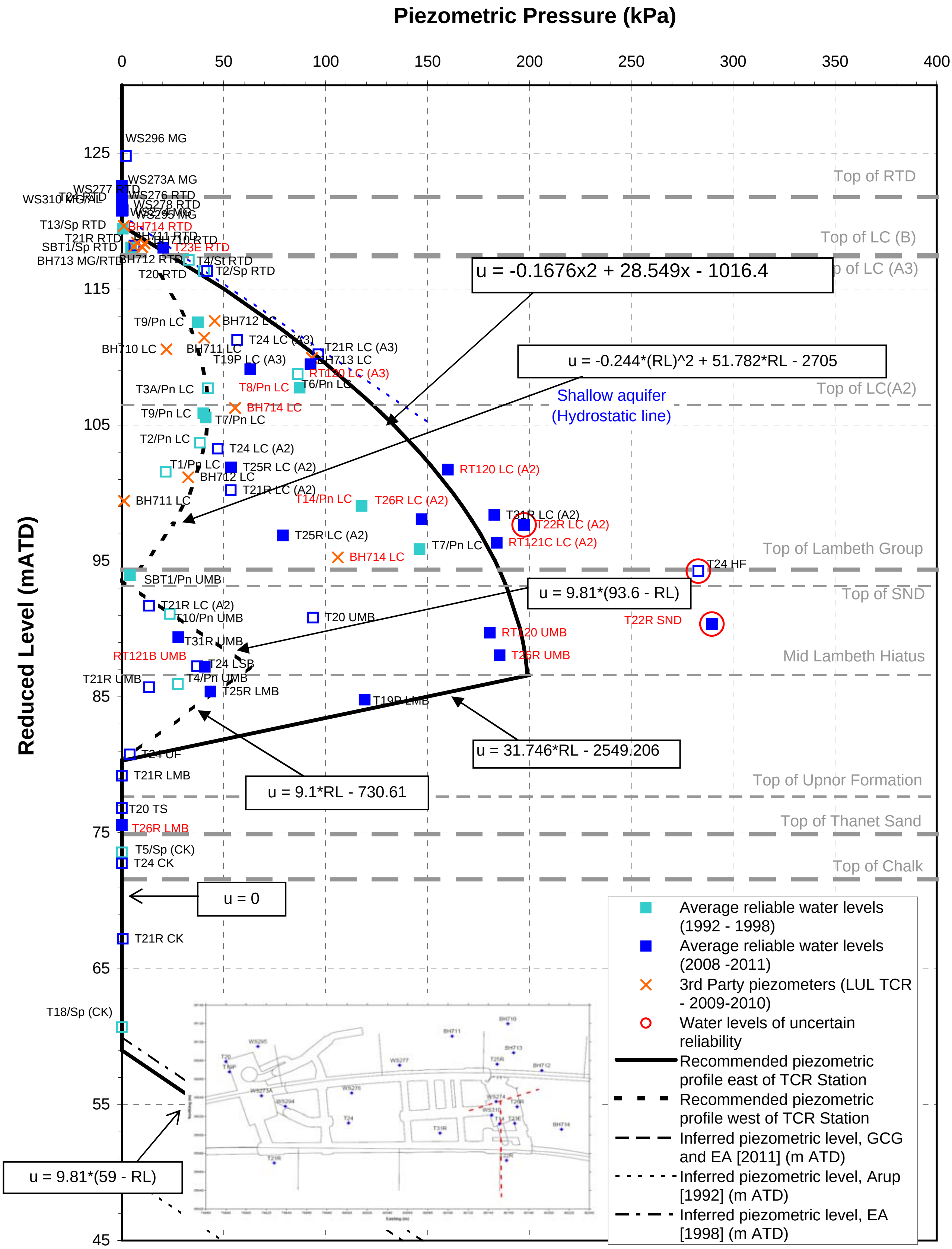
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section S - Paddington Station to Bond Street	**4.4.4**



[1] Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A, Pk16 & Pk16A data and BST WTH GI

[2] BH704 (LC(A2) - LMB), BST17P (LC(A2)) and RT119 (LC) thought to be unreliable (piezometers connectivity to upper aquifer); however there is insufficient information to discount their data completely

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section T - Bond Street to Tottenham Court Road Station	**4.4.5**

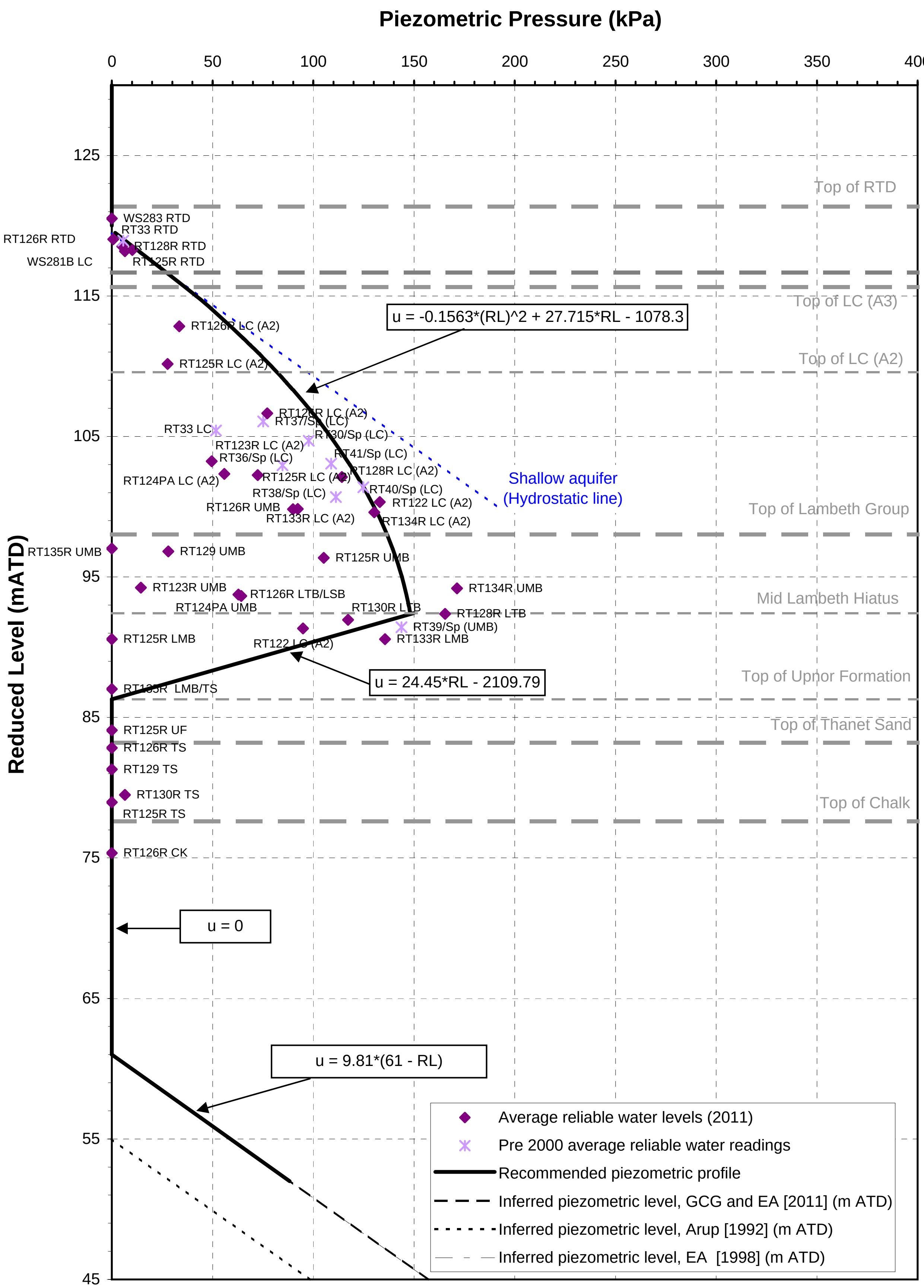


[1] Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A, Pk16 & Pk16A data.

[2] T22R(LC A2, SND) are thought to be unreliable piezometers (connectivity to upper aquifer); however there is insufficient information to discount their data completely.

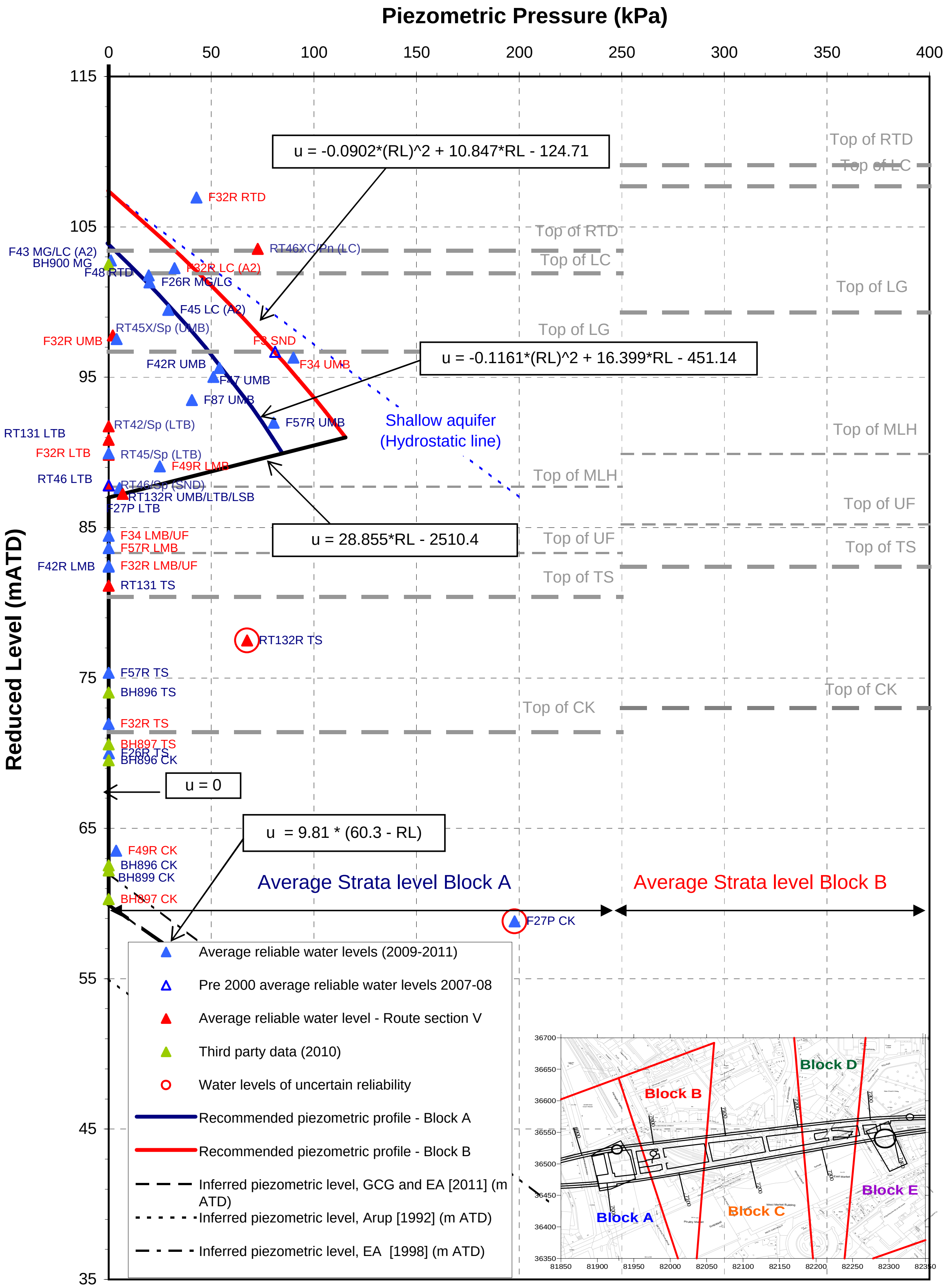
[3] Installations with red labels are located in the faulted zone at the east end of the station.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section U - Tottenham Court Road Station	**4.4.6**



[1.] Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A, Pk16 & Pk16A data.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section V - Tottenham Court Road Station to Farringdon	**4.4.7**



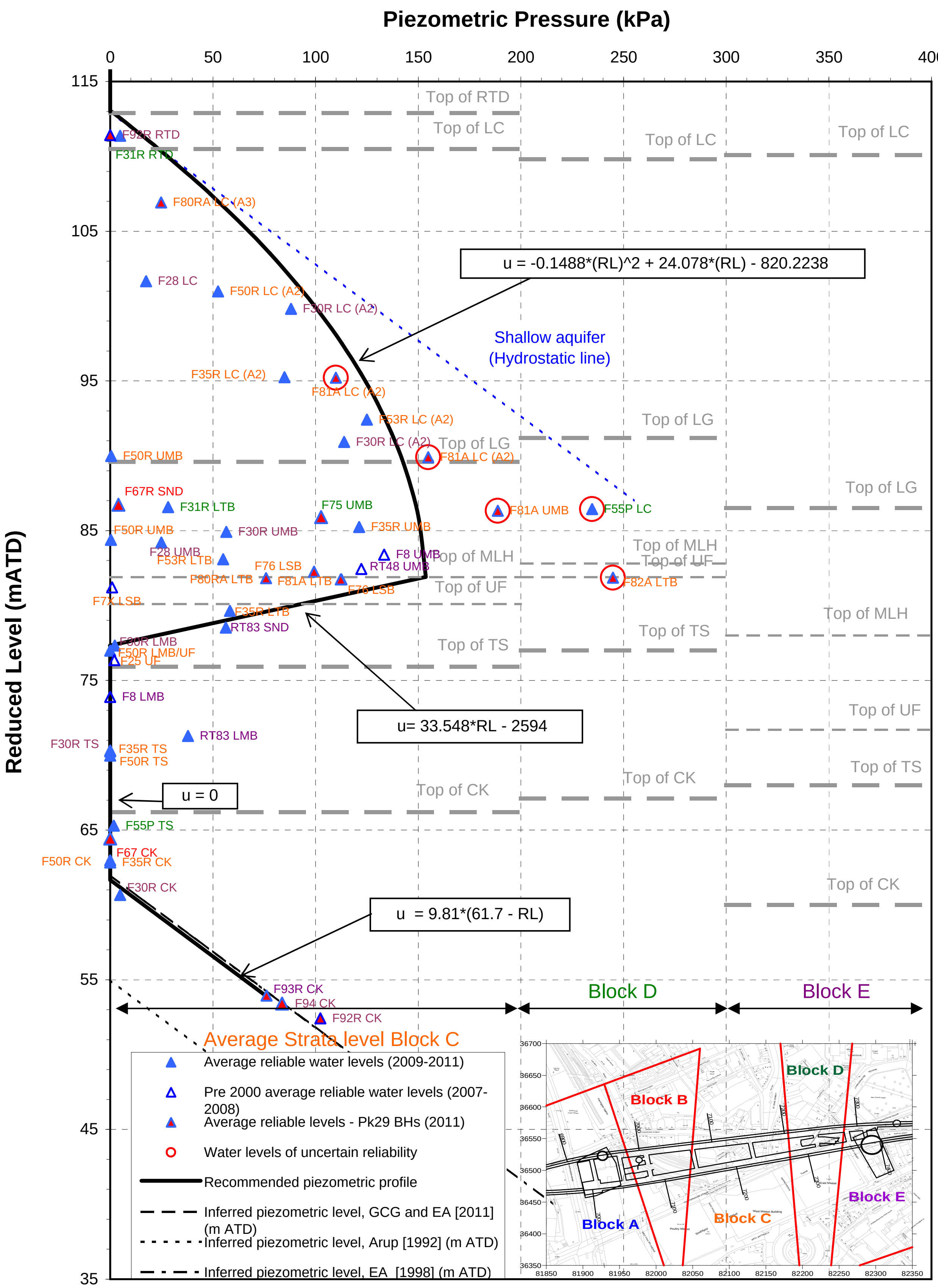
[1] The stratigraphy lines shown represent the average strata levels encountered in each block on the west side of the main fault/fold zone.

[2] F27P CK ground water levels thought to be unreliable. However, this piezometer has been destroyed by demolition work and verification is not possible

[3] Pk16A piezometers RT132R(TS) - reliabilty to be confirmed

[4] RT46XC (LC) - This is located in Route Section V, where the ground level is higher than the Farringdon area.

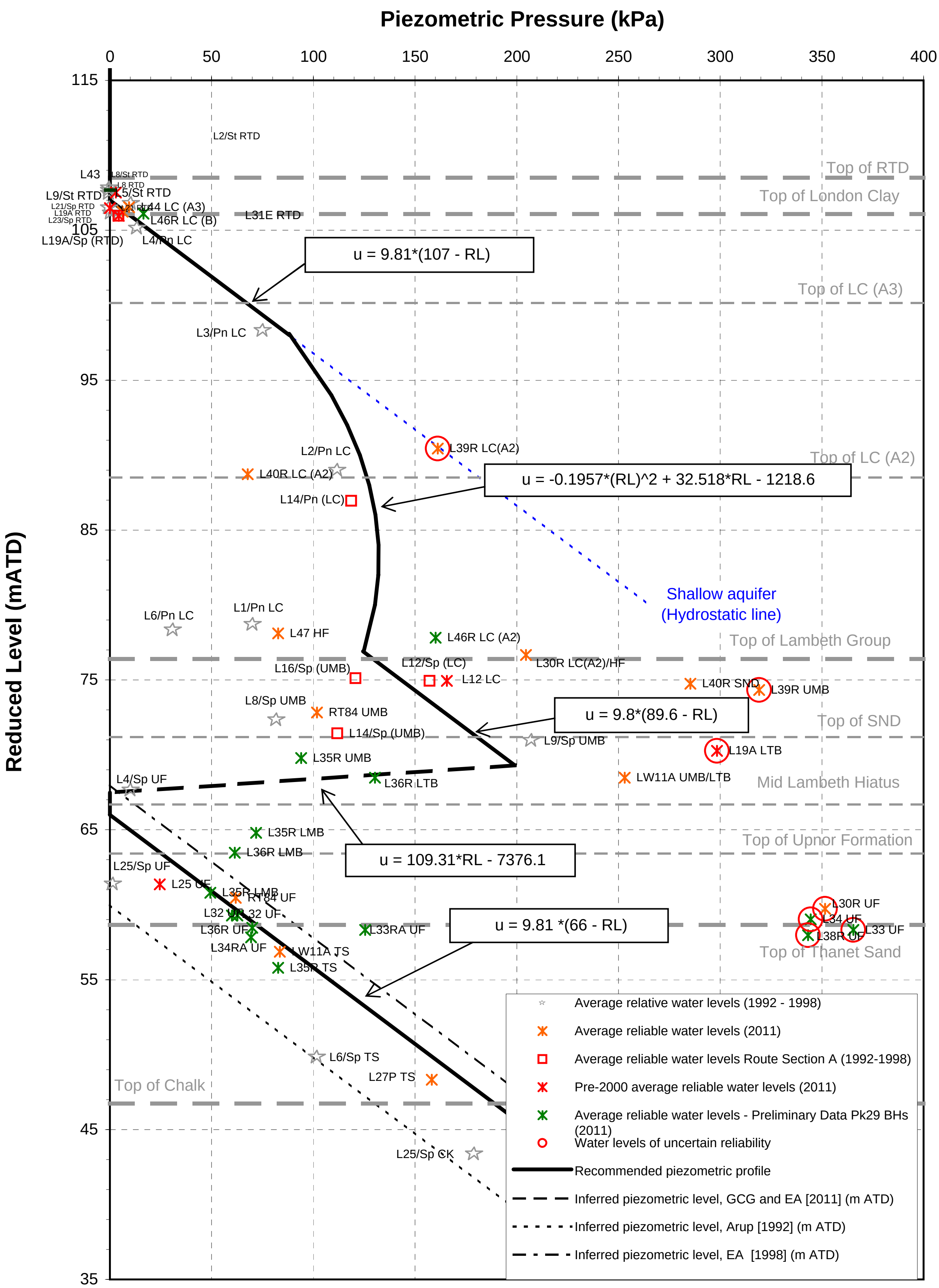
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section W - Farringdon to Liverpool Street (west of Smithfield Fault, Ref. [36] & [49])	**4.4.8**



[1.] The stratigraphy lines shown represent the average strata levels encountered in each block on the east side of the main fault/fold zone.

[2.] Pk29 piezometer F81A - preliminary data used; reliabilty to be confirmed

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section W - Farringdon to Liverpool Street (east of Smithfield Fault (Block B & C), Ref. [36] & [49])	**4.4.9**



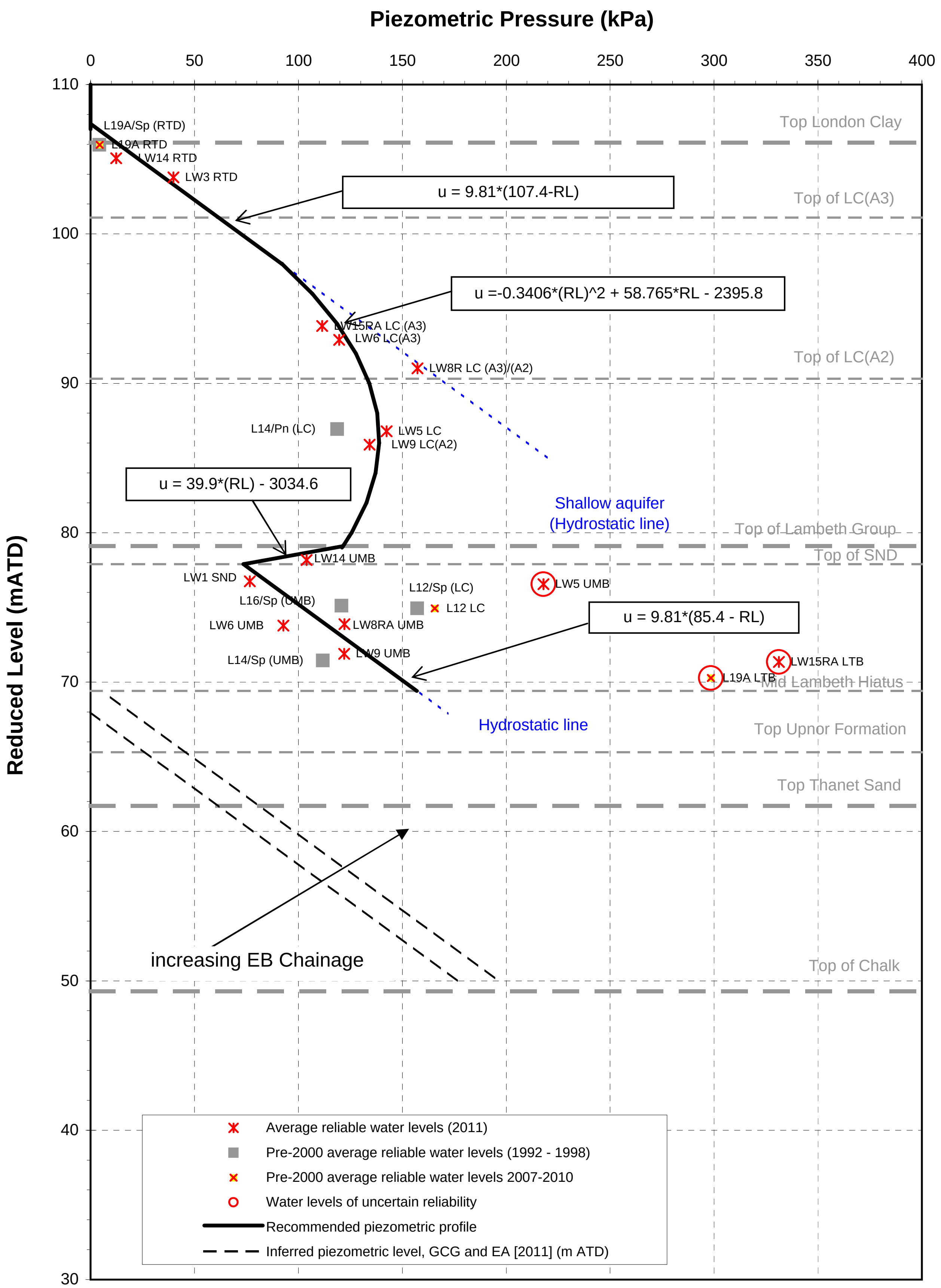
[1] Stratigraphic levels based on the average value as reported in GSIR1&2 Rev A.

[2] L30R (UF) is under observation/investigation.

[3] Pk29 and 29VO1 piezometers L33, L34, L38R(UF) and L39A - reliability to be confirmed

[4] L19A LTB - investigated; functonality under question.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section X - Liverpool Street Station	**4.4.10**

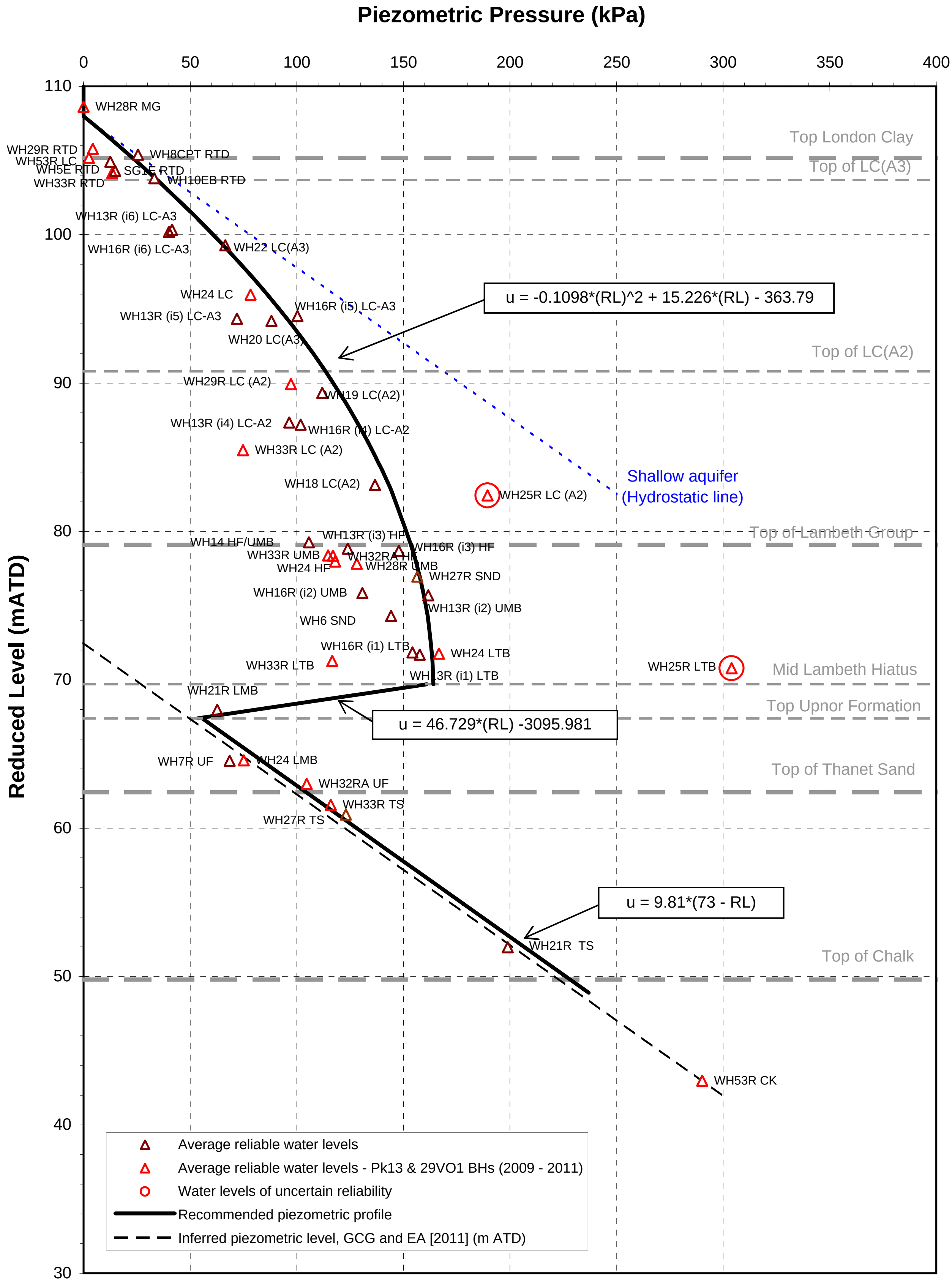


[1] Stratigraphic levels based on the average value as reported in GSIR3 Rev E.

[2] LW5 (UMB) and LW15RA (LTB) to be investigated.

[3] L19A(LTB) - investigated; functionality under question.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section A - Liverpool Street to Whitechapel Station	**4.4.11**



[1] Stratigraphic levels based on the average value as reported in GSIR3 Rev E.

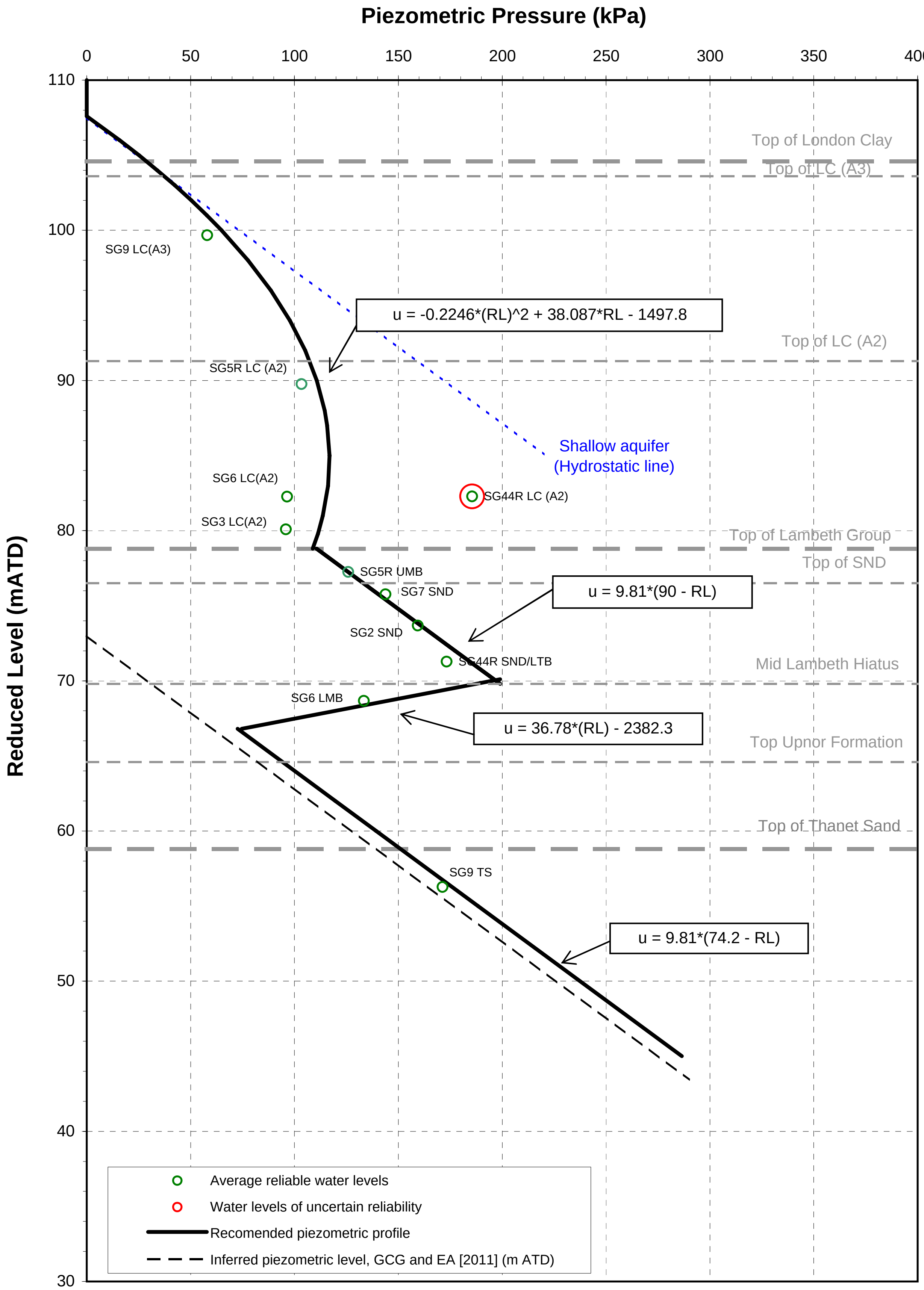
[2] . WH25R (LC(A2)) and (LTB) to be investigated.

Crossrail Limited
Crossrail – Groundwater Monitoring Report

Pore Water Pressure Profile
Route Section C - Whitechapel Station

Figure

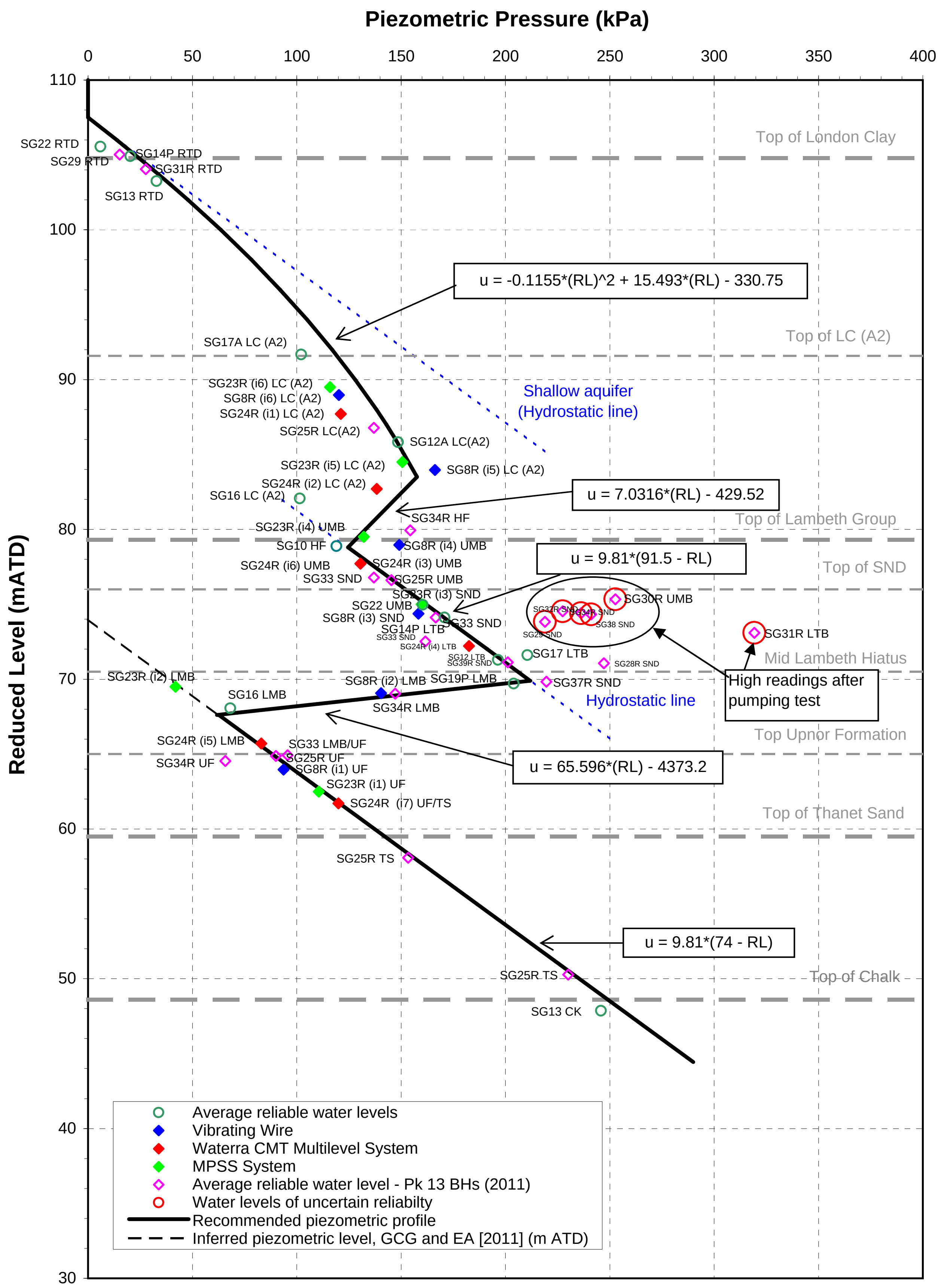
4.4.12



[1] Stratigraphic levels based on the average value as reported in GSIR3 Rev E.

[2] SG44R LC(A2) reliability to be confirmed

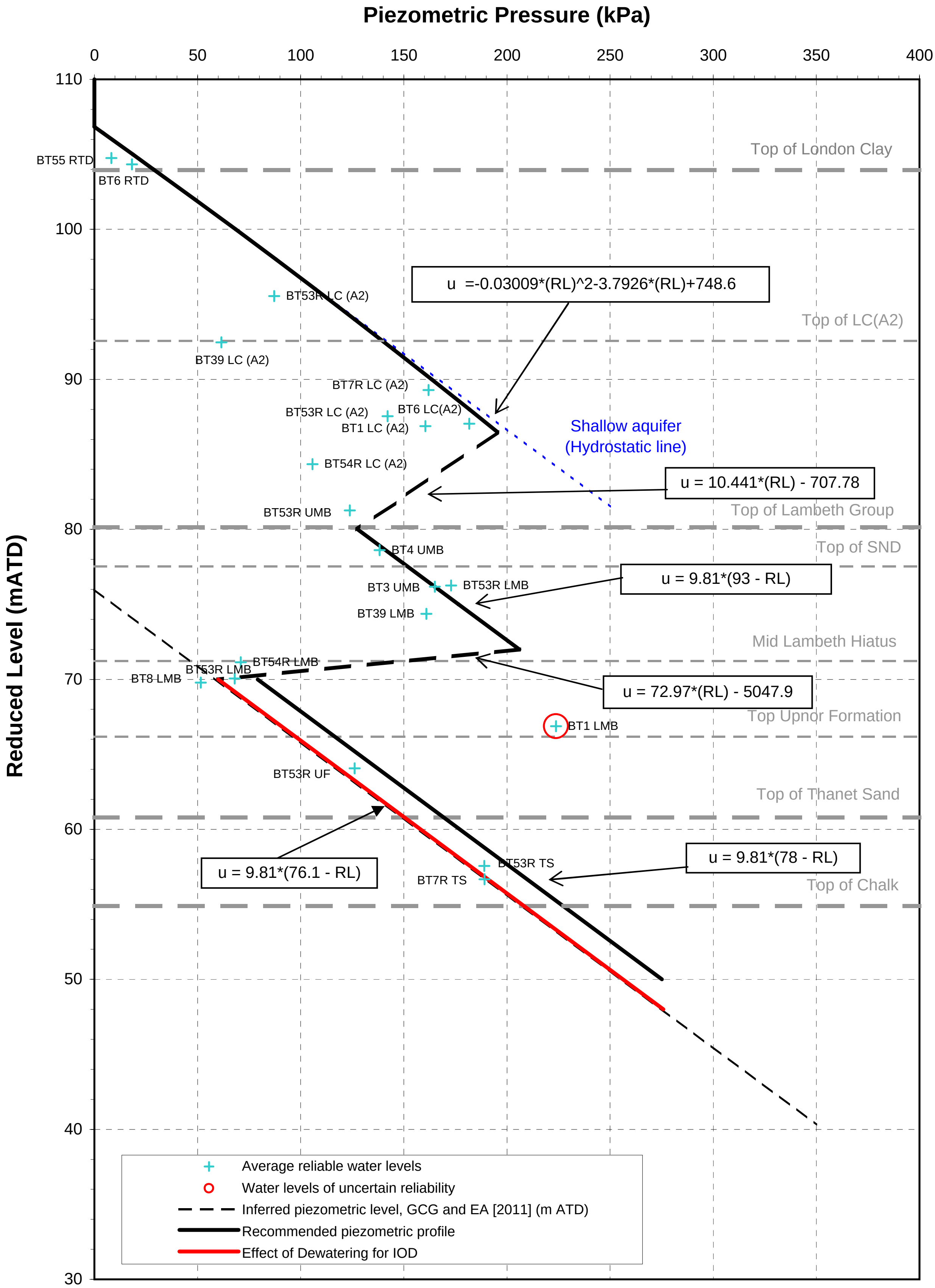
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section D - Whitechapel Station to Stepney Green	**4.4.13**



1. Stratigraphic levels based on the average value as reported in GSIR3 Rev E.

2. Pk13A piezometers SG29(SND), SG30R(UMB), SG31R(LTB), SG32R(SND), SG34R(SND) and SG38(SND) to be investigated.

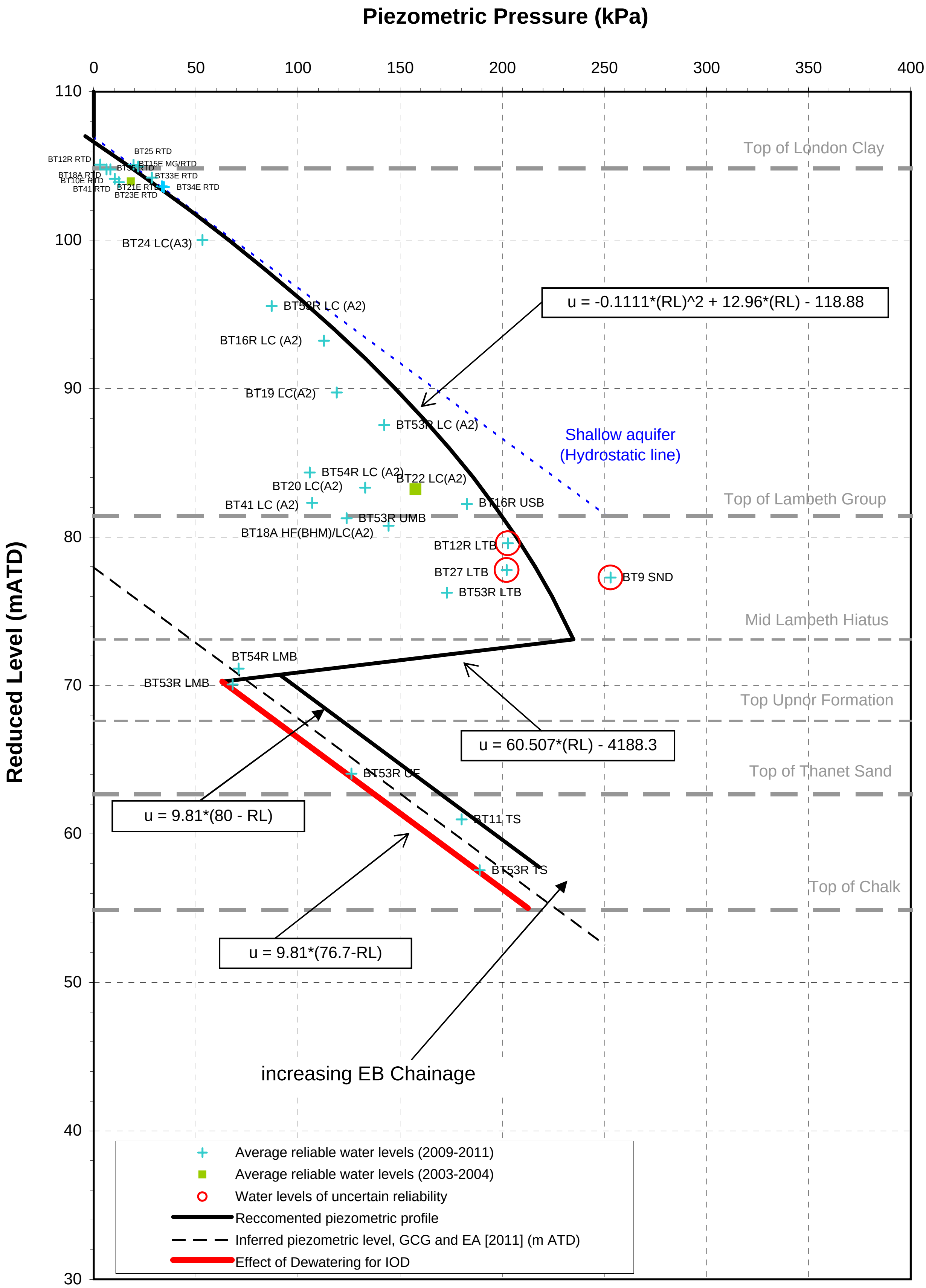
	Crossrail Limited Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section E - Stepney Green	**4.4.14**



[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

[2] BT1(LMB) investigated; functionality under question but insufficient information to dicount this data completely.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section F (to EB Chainage 12100m, Alignment S)	**4.4.15**

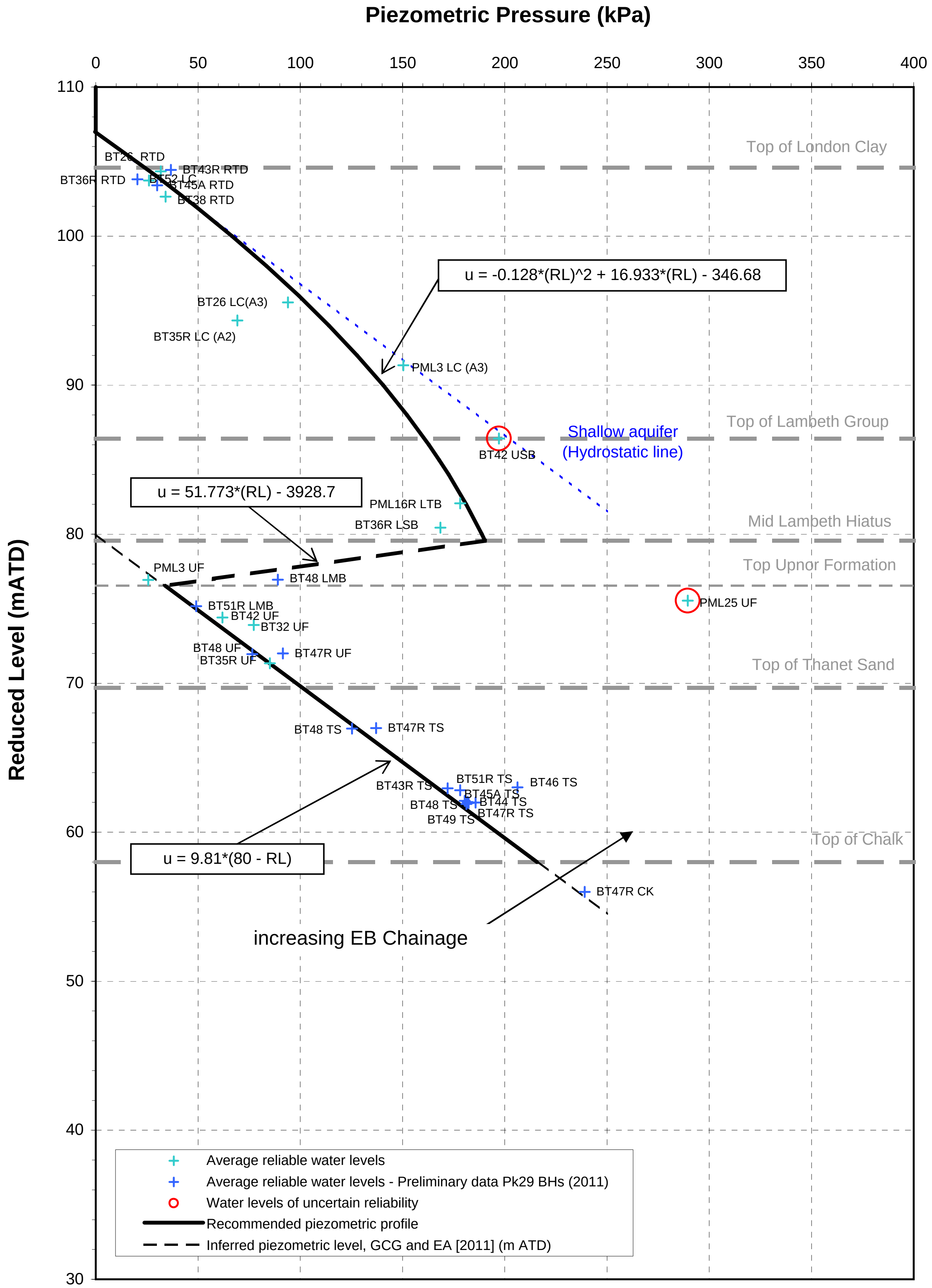


[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

[2] BT11(TS) was last monitored in June 2008.

[3] BT9R (SND), BT12R (LTB) and BT27 (LTB) investigated, functionality under question but insufficient information to discount the data completely

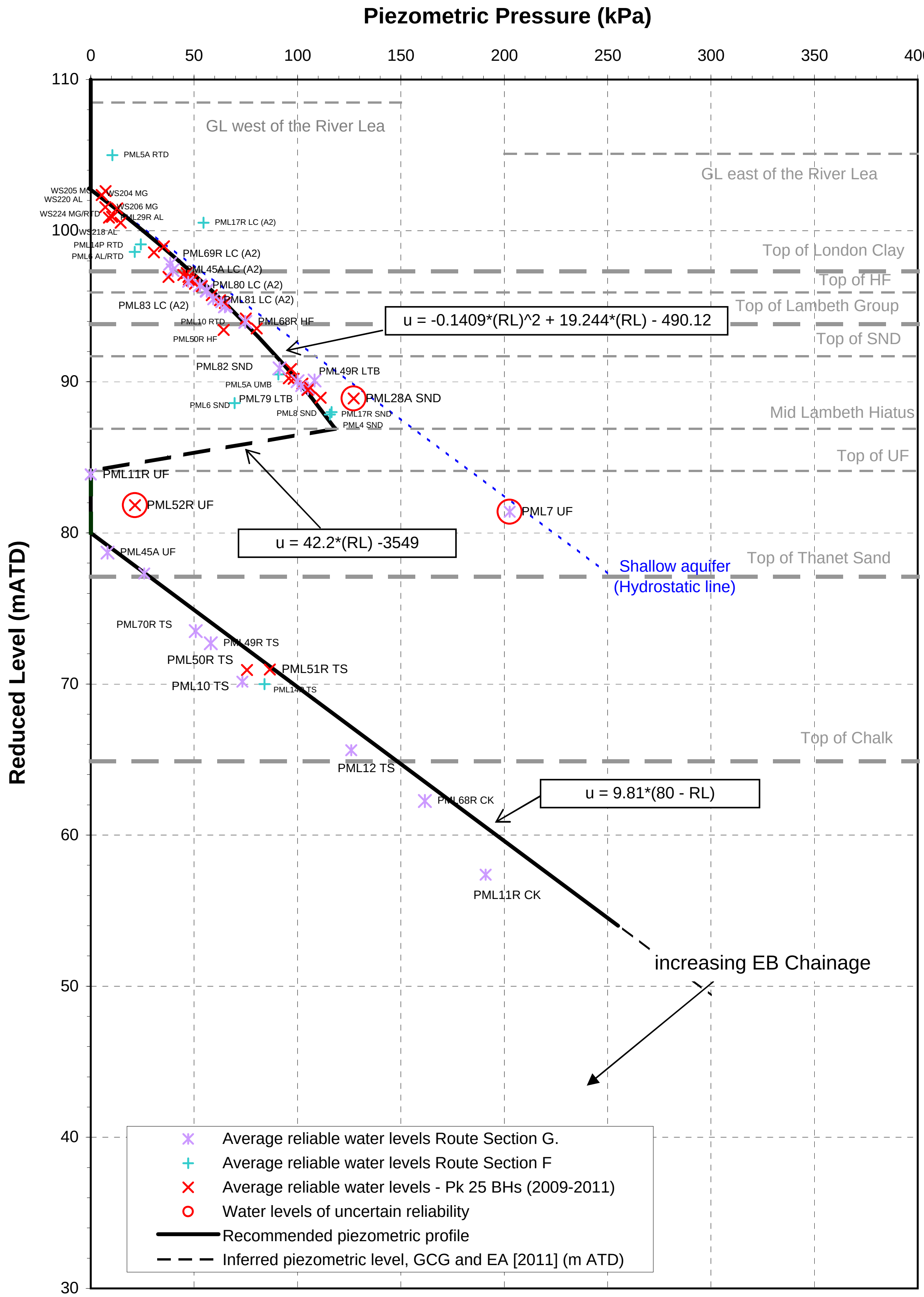
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section F (from EB Chainage 12100 to 13050m, Alignment S)	**4.4.16**



[1.] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

[2.] Piezometers BT42 (USB), and PML25 (UF) investigated, functionality under question but insufficient information to discount the data completely.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section F (from EB Chainage 13050 to 13800m, Alignment S)	**4.4.17**



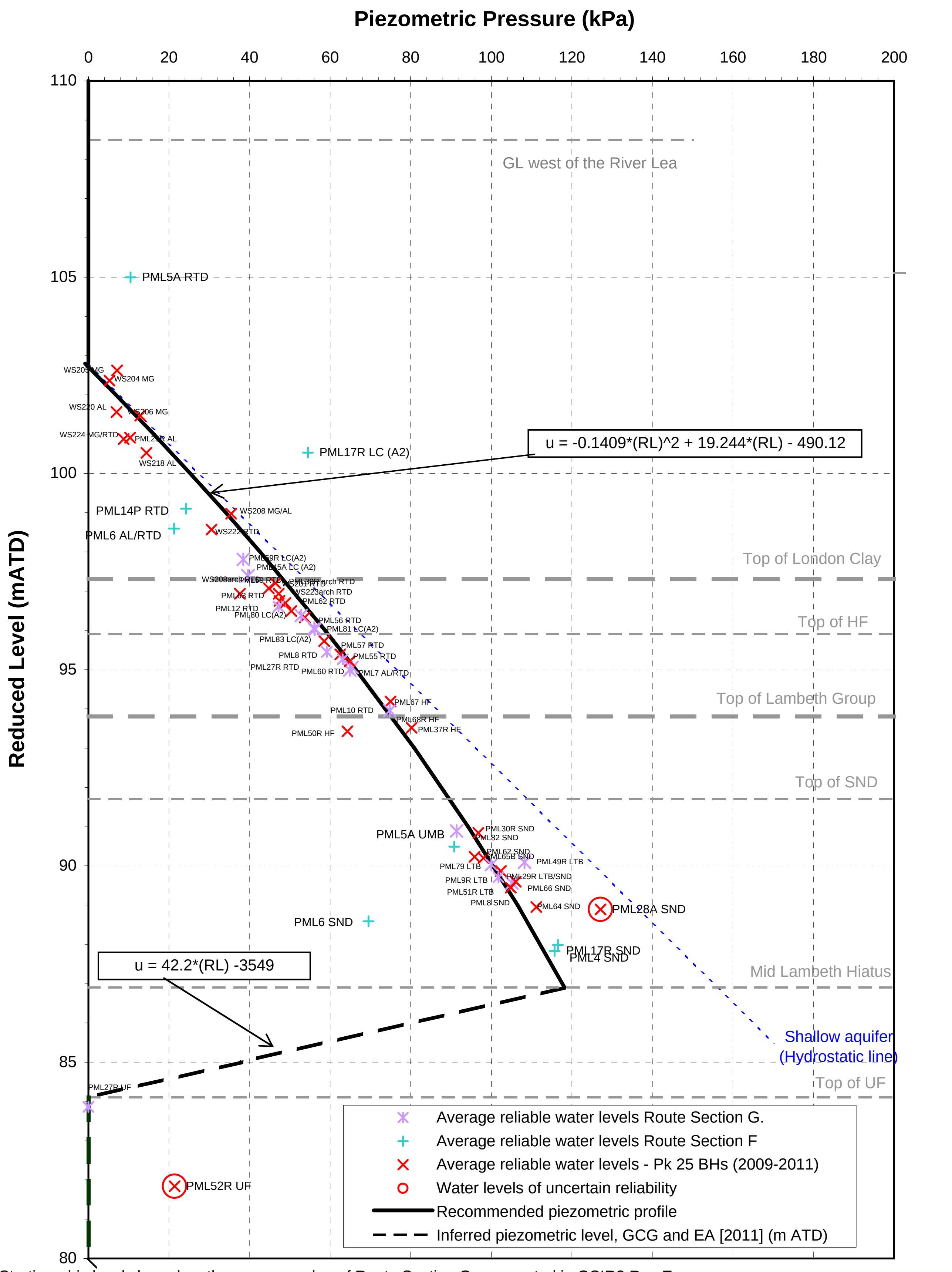
1. Stratigraphic levels based on the average value of Route Section G as reported in GSIR3 Rev E.

2. PML4, PML5A and PML17R are located west of the River Lea.

3. PML52R latest reading is "dry"; awaiting confirmation by more data

4. PML28A(SND) to be investigated. However this piezometer has been destroyed and verification not possible

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Sections F (from EB Chainage 13800m, Alignment S) and G	**4.4.18A**



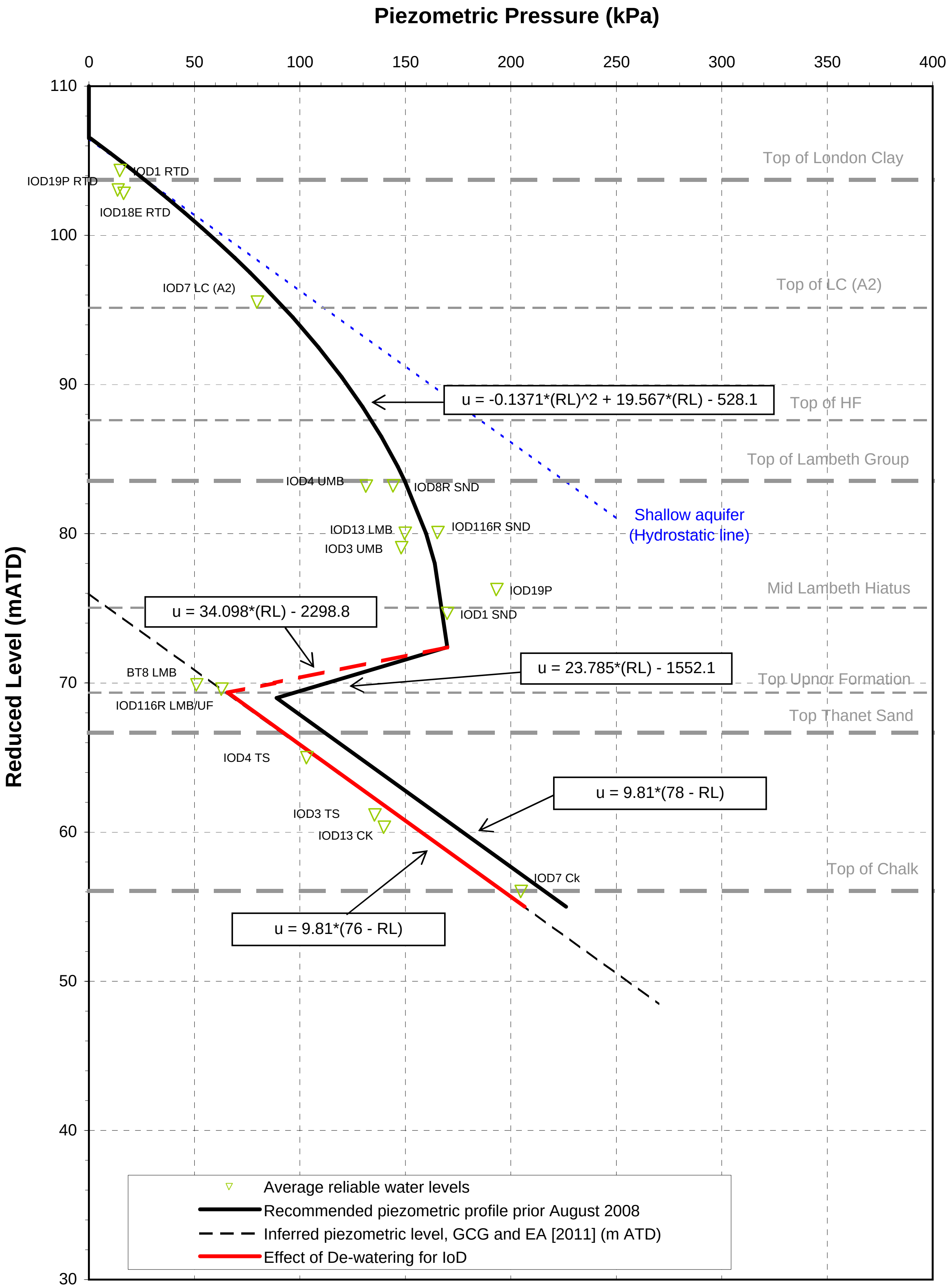
1. Stratigraphic levels based on the average value of Route Section G as reported in GSIR3 Rev E.

2. PML4, PML5A and PML17R are located west of the River Lea.

3. PML52R latest reading is "dry"; awaiting confirmation by more data

4. PML28A(SND) to be investigated. However this piezometer has been destroyed and verification is not possible

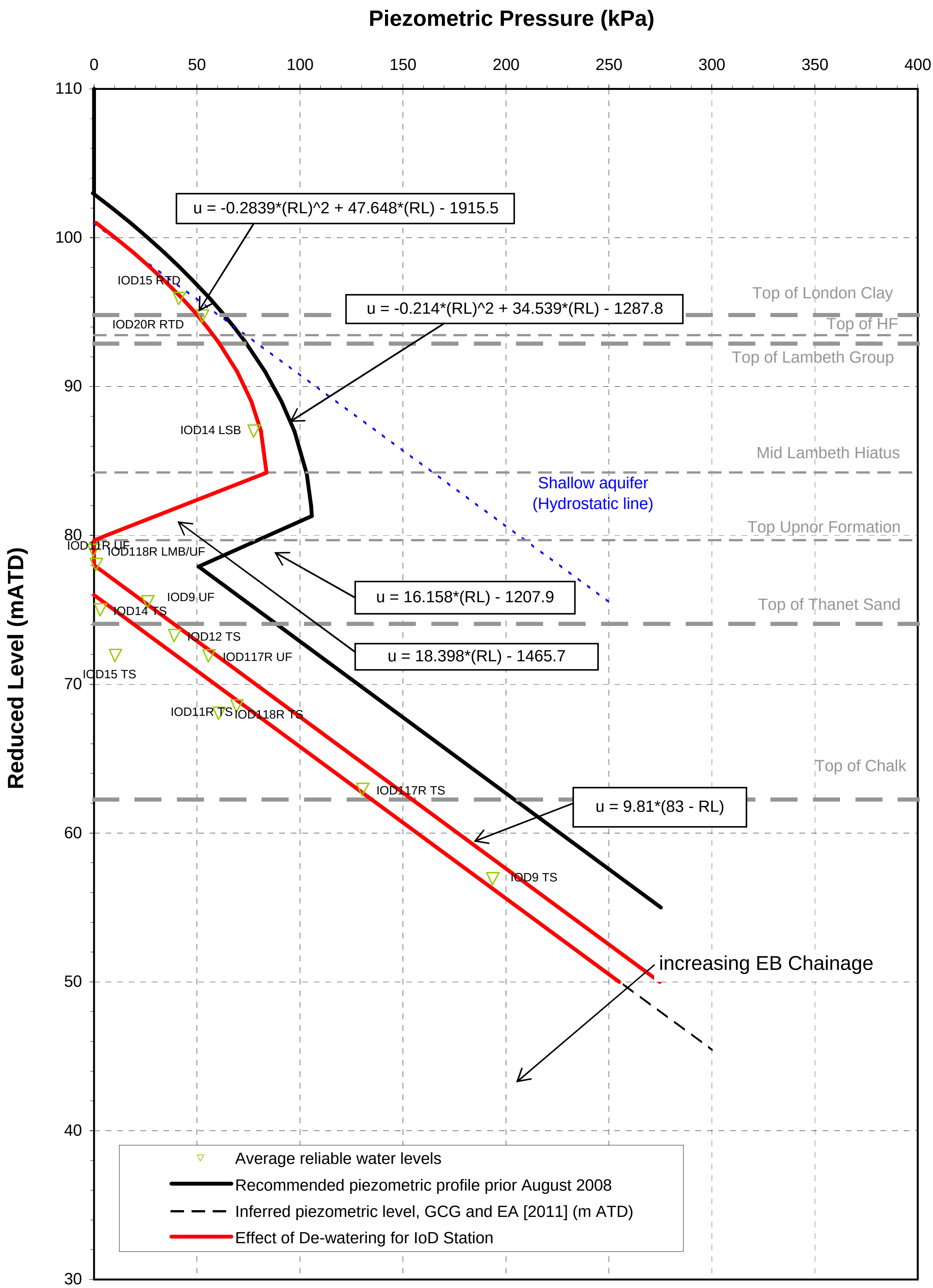
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Sections F (from EB Chainage 13800m, Alignment S) and G	**4.4.18B**



[1.] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

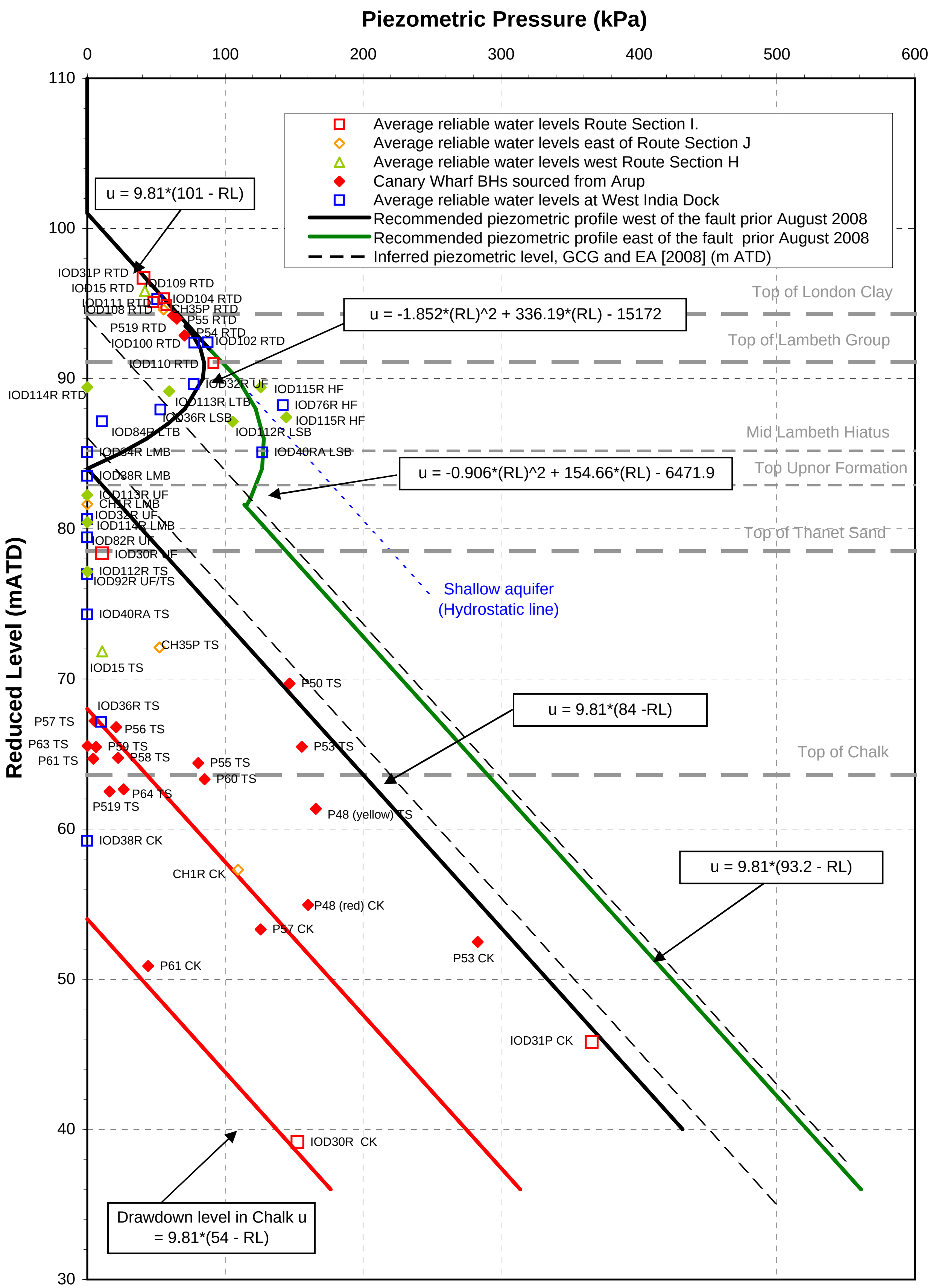
[2.] IOD19P(TS) was destroyed during remediation work (standpipe jointing broken and leak created in SND). Observed water level consistent with gwp in LG strata.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section H (to EB Chainage 12400m, Alignment S)	**4.4.19**



[1.] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

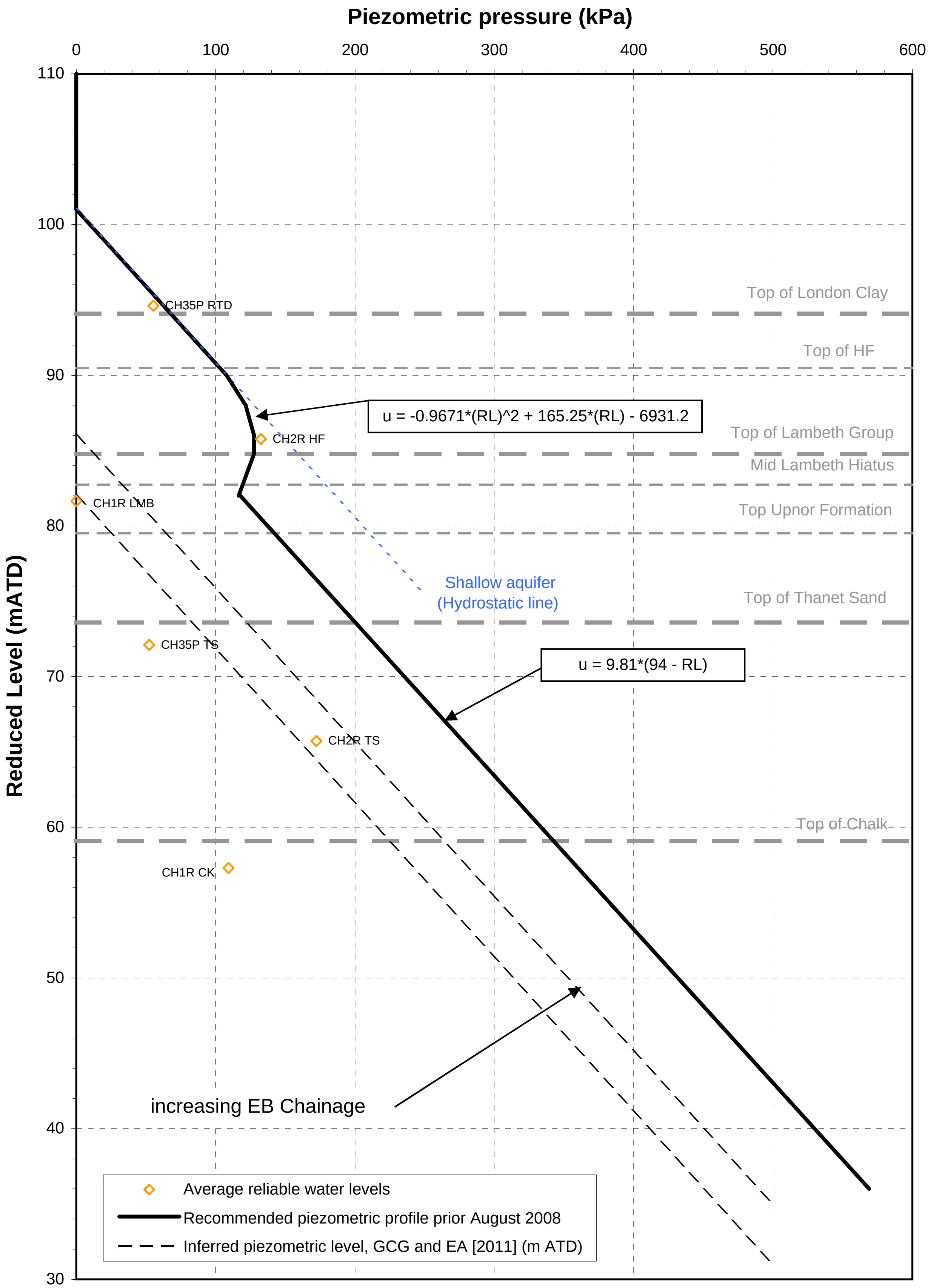
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section H (from EB Chainage 12400m, Alignment S)	**4.4.20**



[1] Stratigraphic levels based on the average value as reported in GSIR4 Rev C.

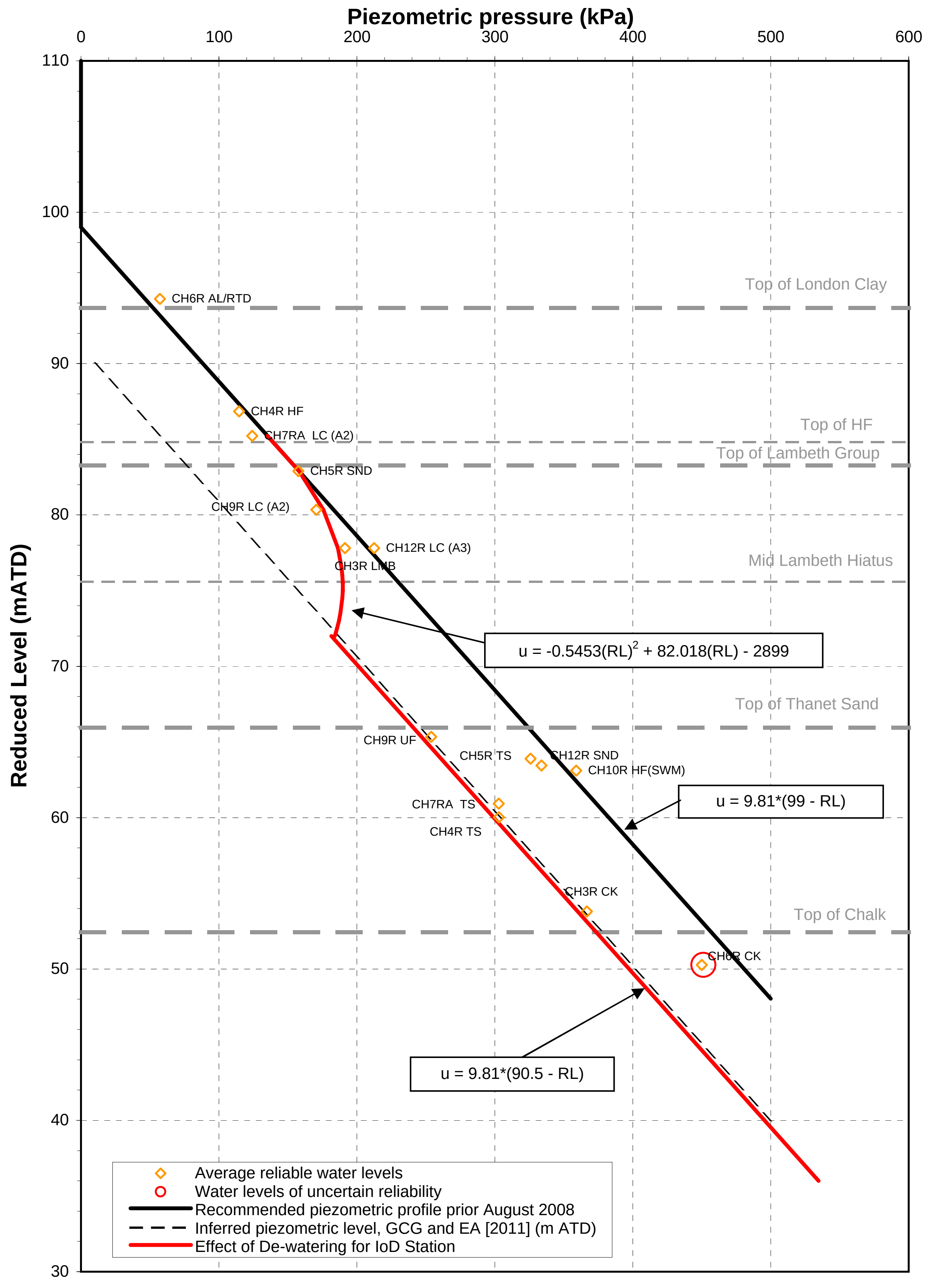
[2] Piezometric profile affected by dewatering activites undergoing in the area.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section I - Isle of Dogs Station	**4.4.21**



[1.] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section J (to EB Chainage 14200m, Alignment S)	**4.4.22**



[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

[2] CH5R, CH10 and CH12R last reading were taken in 2004, 2006 and 2008, respectively since then the profile water level in the deep aquifer has changed.

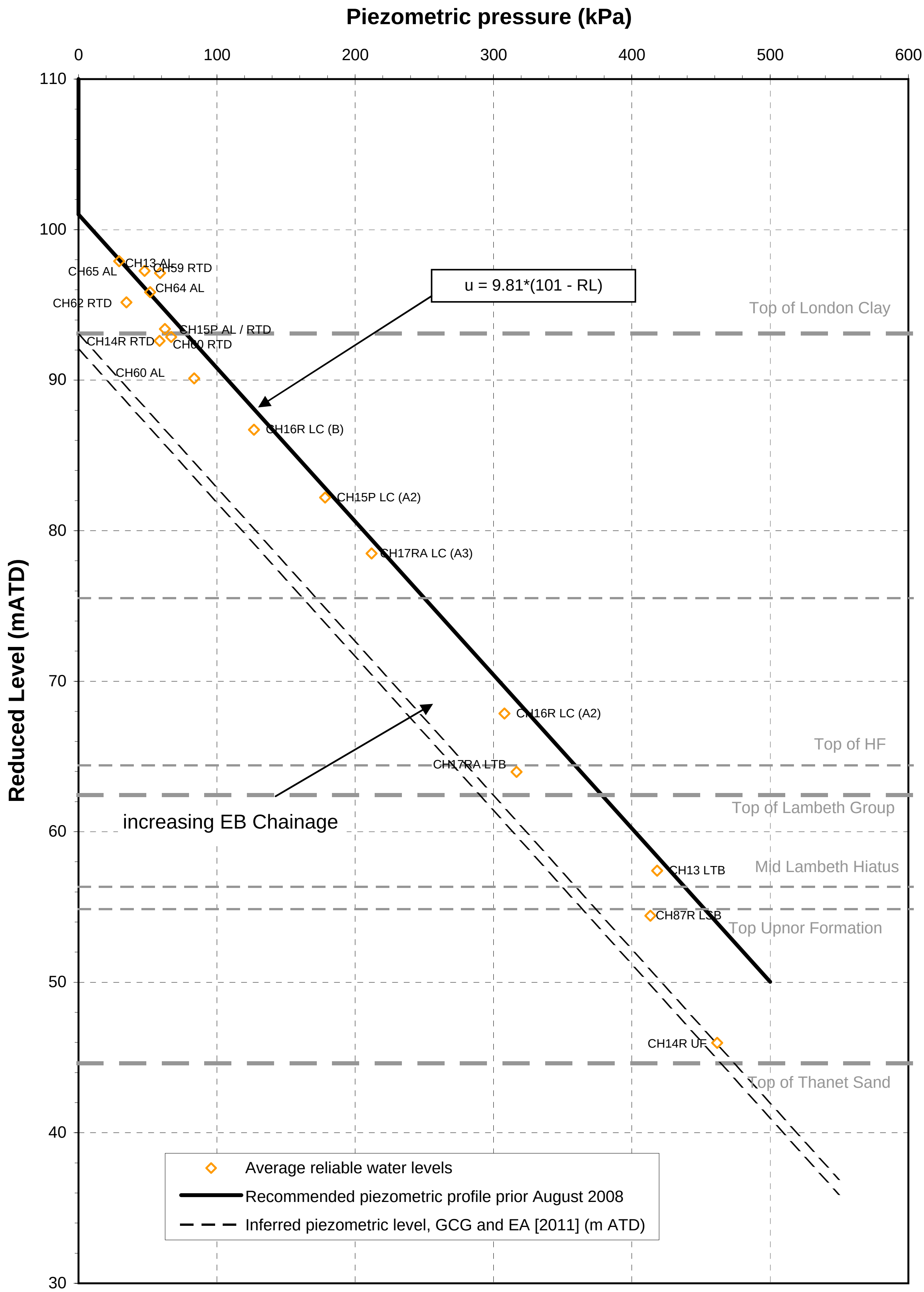
[3] CH6R(CK) is under observation/investigation.

Crossrail Limited
Crossrail – Groundwater Monitoring Report

Pore Water Pressure Profile
Route Section J (from EB Chainage 14200m to 15300m, Alignment S)

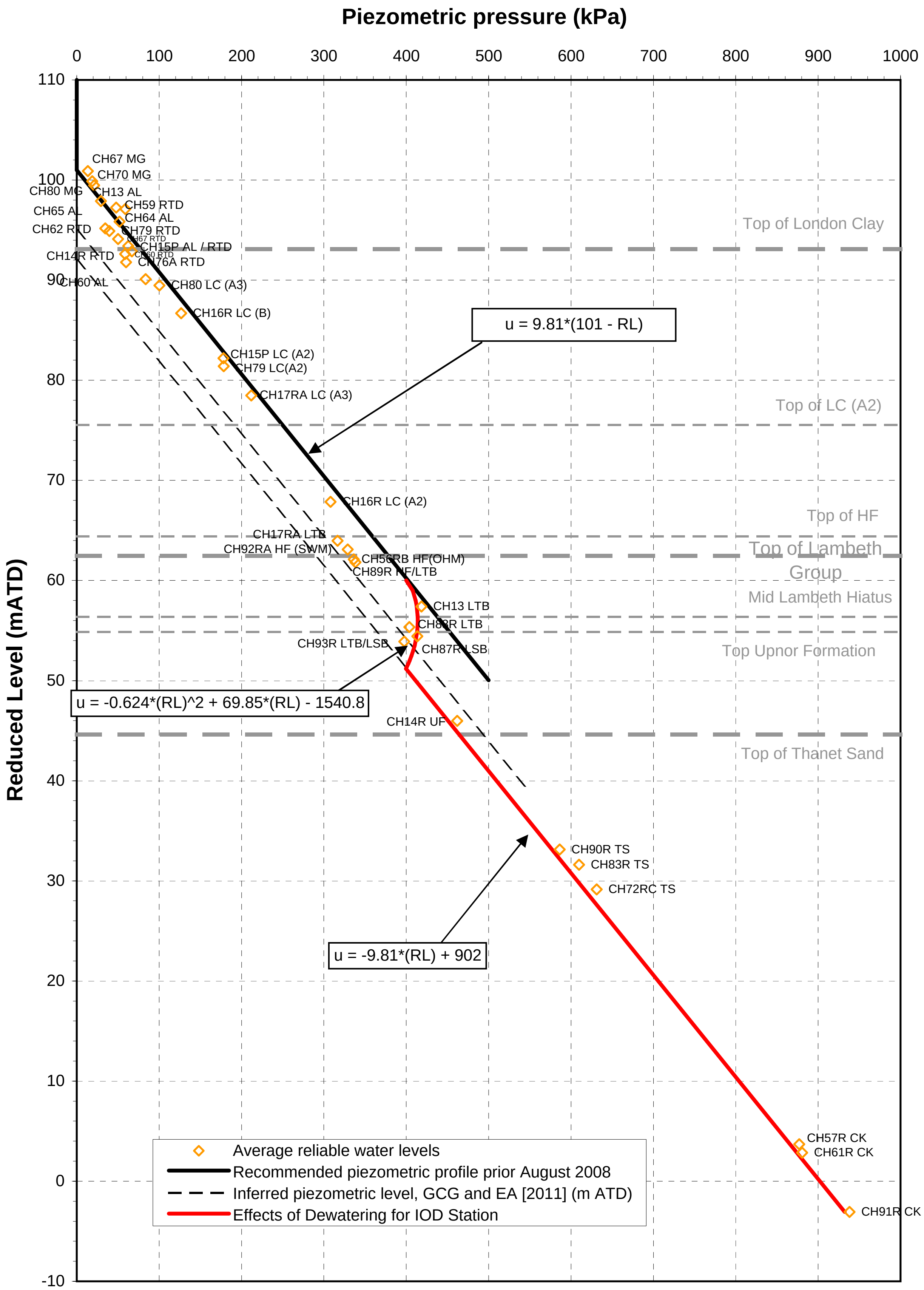
Figure

4.4.23



[1.] Stratigraphic levels based on the average values encountered in the BHs shown in the Figure.
[2.] This section of the alignment includes a zone of possible faulting.

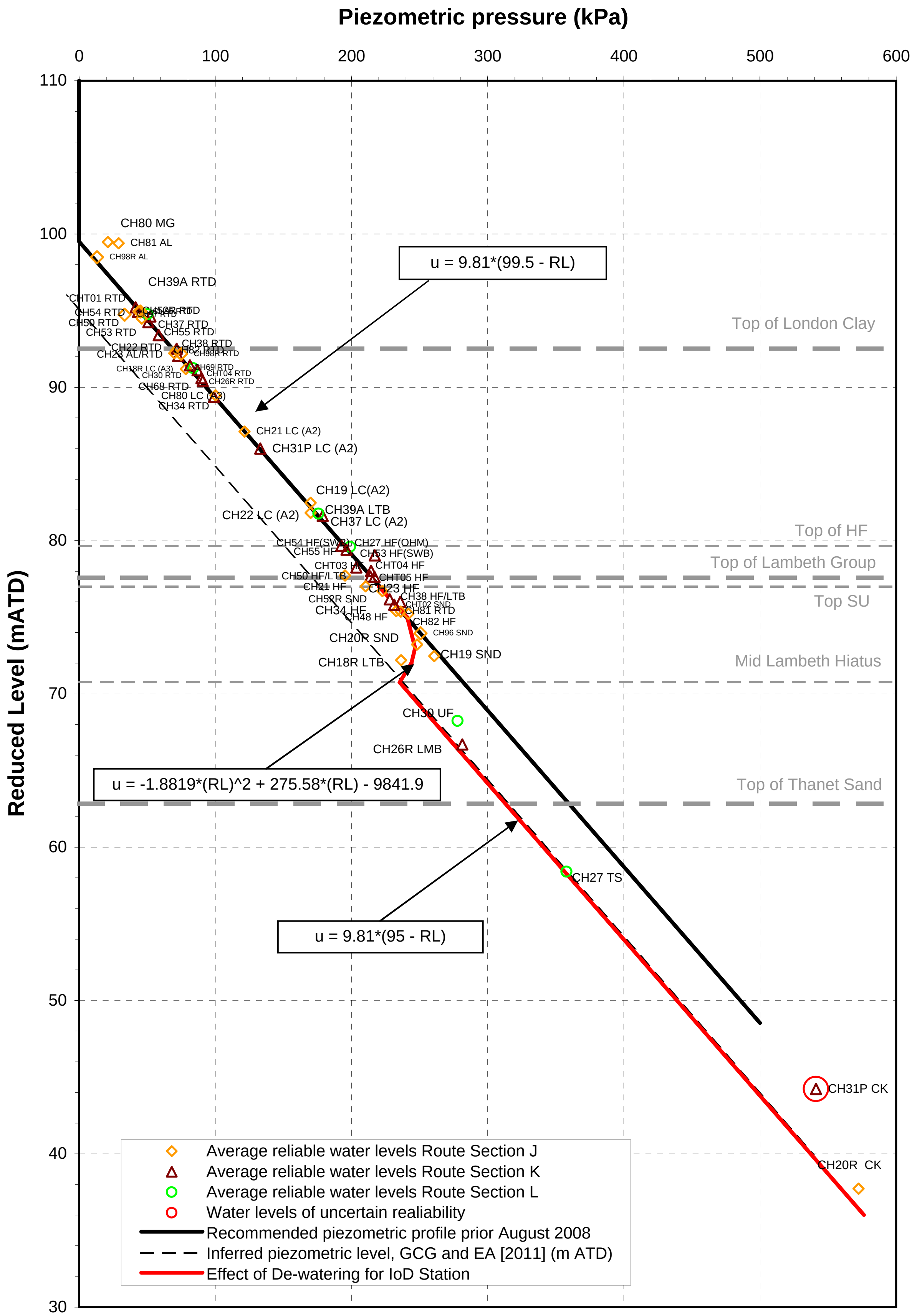
GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section J (from EB Chainage 15300m to 15900m, Alignment S)	**4.4.24A**



[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

[2] This section of the alignment includes a zone of possible faulting.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section J (from EB Chainage 15300m to 15900m, Alignment S)	**4.4.24B**

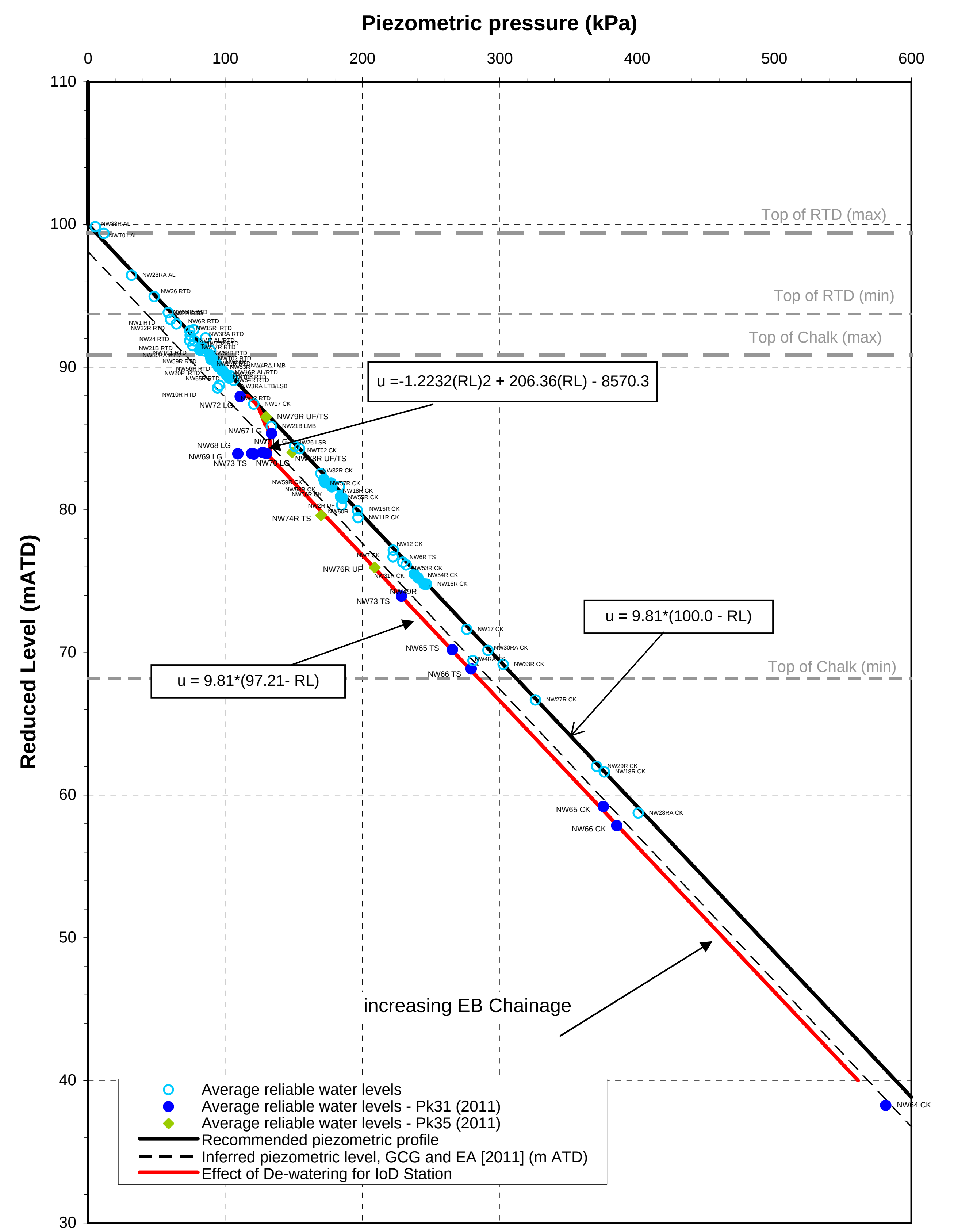


[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

[2] CH81 encountered a scour hollow.

[3] CH31P (CK) is under observation/investigation.

	Crossrail Limited Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section J (from EB Chainage 15900m), K & L (to EB Chainage 17600m, Alignment S)	**4.4.25**



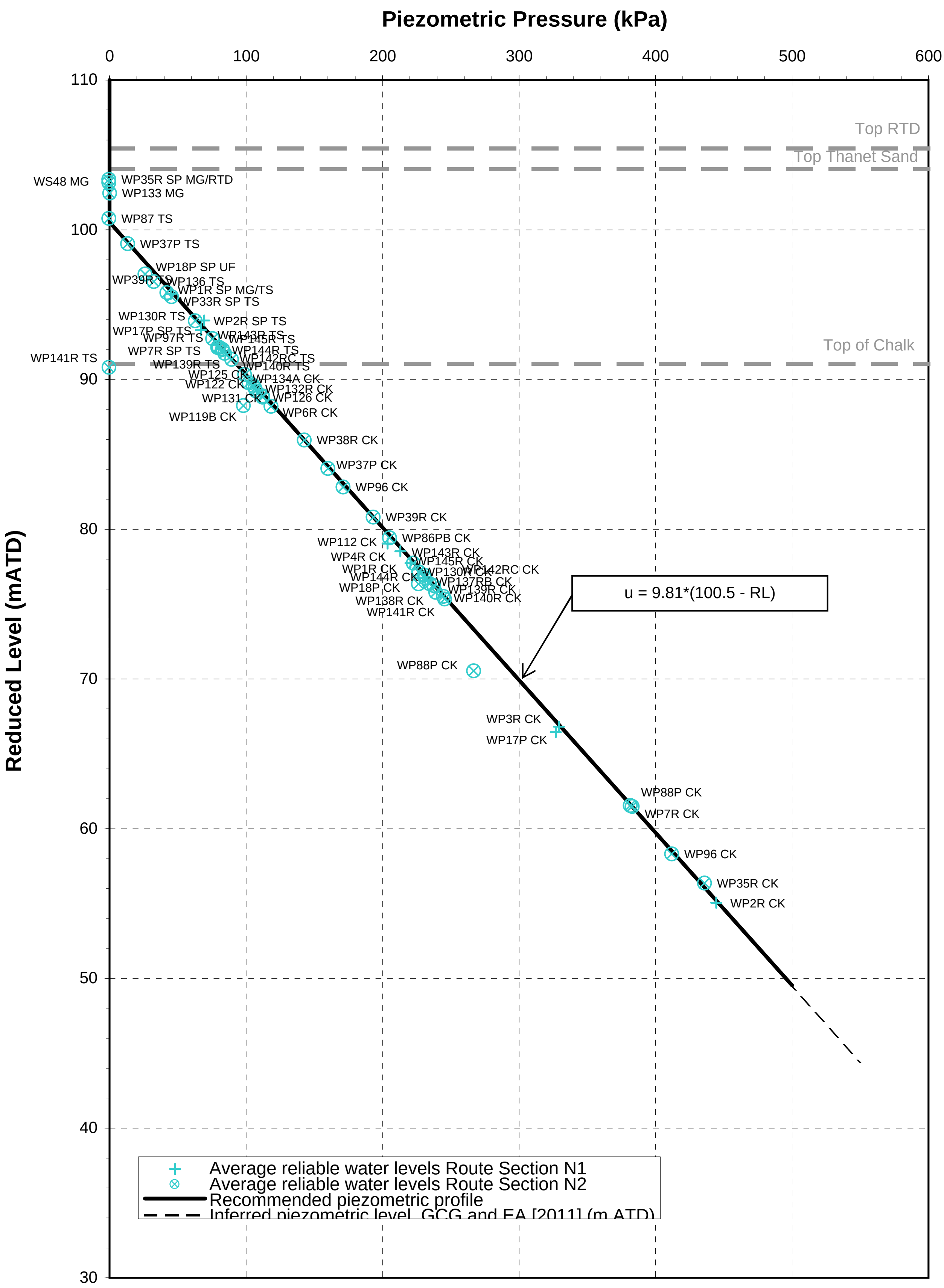
[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

Crossrail Limited
Crossrail – Groundwater Monitoring Report

Pore Water Pressure Profile
Route Sections L (from EB Chainage 17600m), M & N1 (to EB Chainage 20100m, Alignment S)

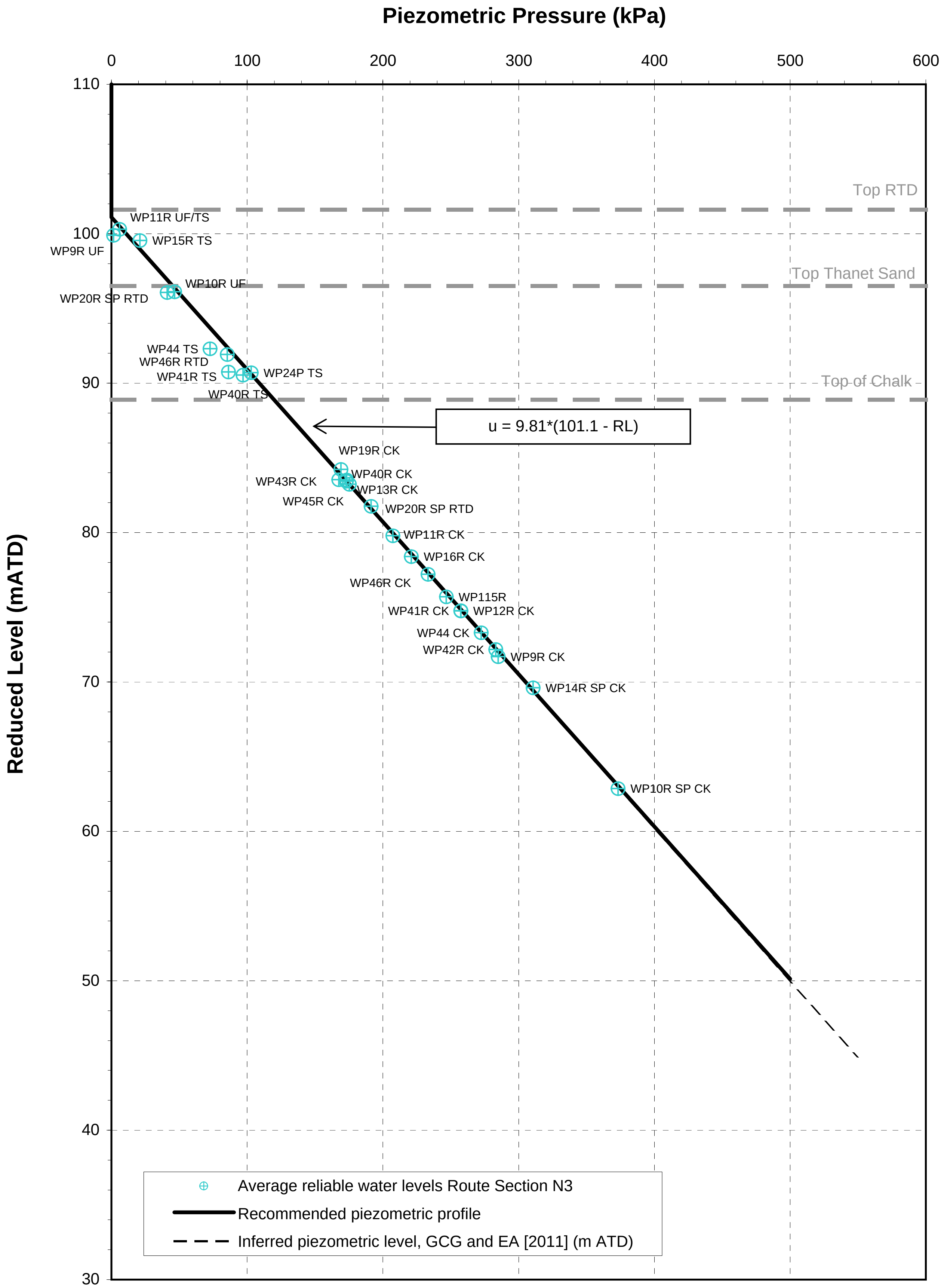
Figure

4.4.26



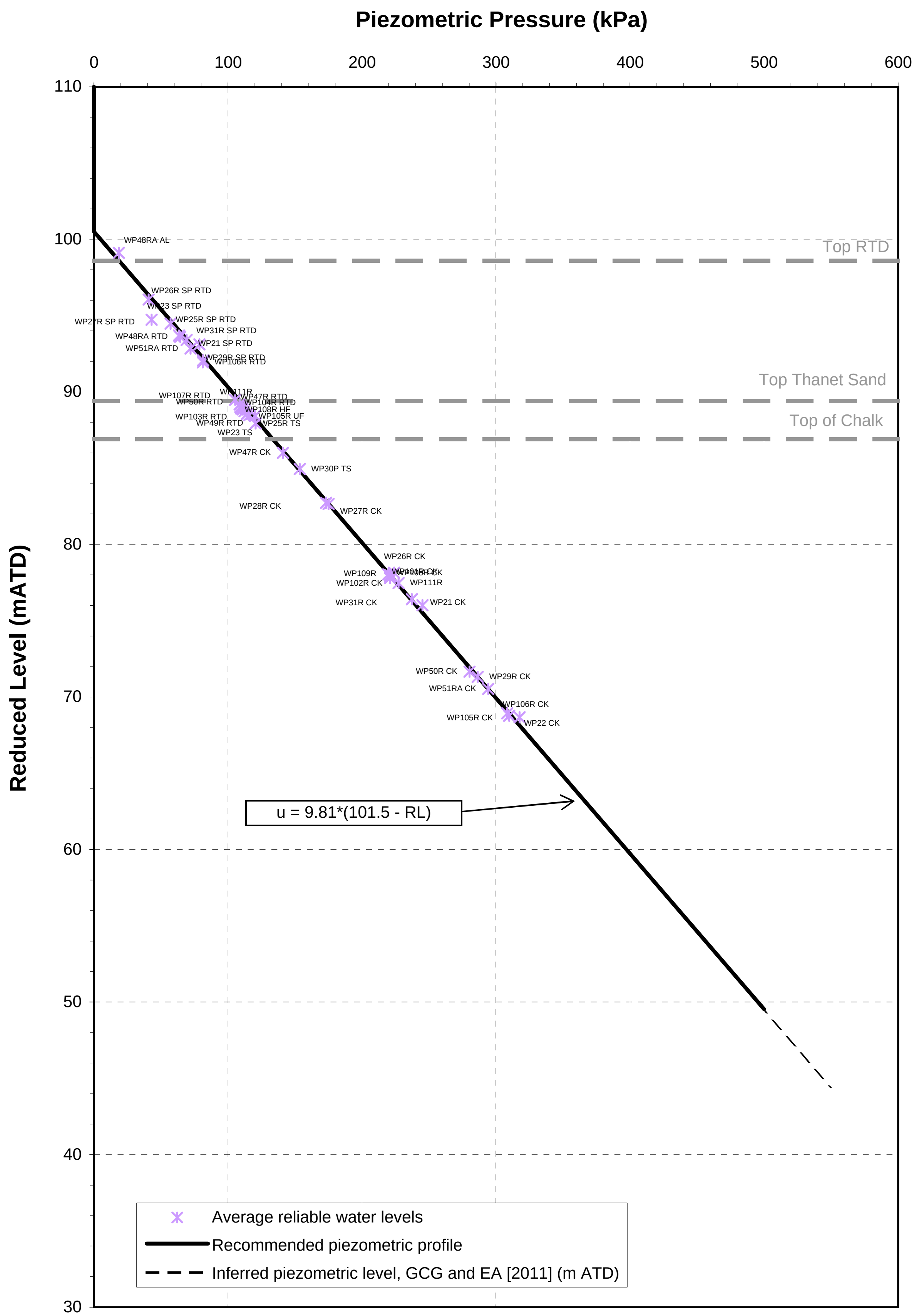
[1.] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section N1 & N2	**4.4.27**



[1] Stratigraphic levels based on the average value as reported in GSIR4 Rev C.

GCG	**Crossrail Limited** Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section N3 - Woolwich to Plumstead	**4.4.28**



[1] Stratigraphic levels based on the average value as reported in GSIR4 Rev C.

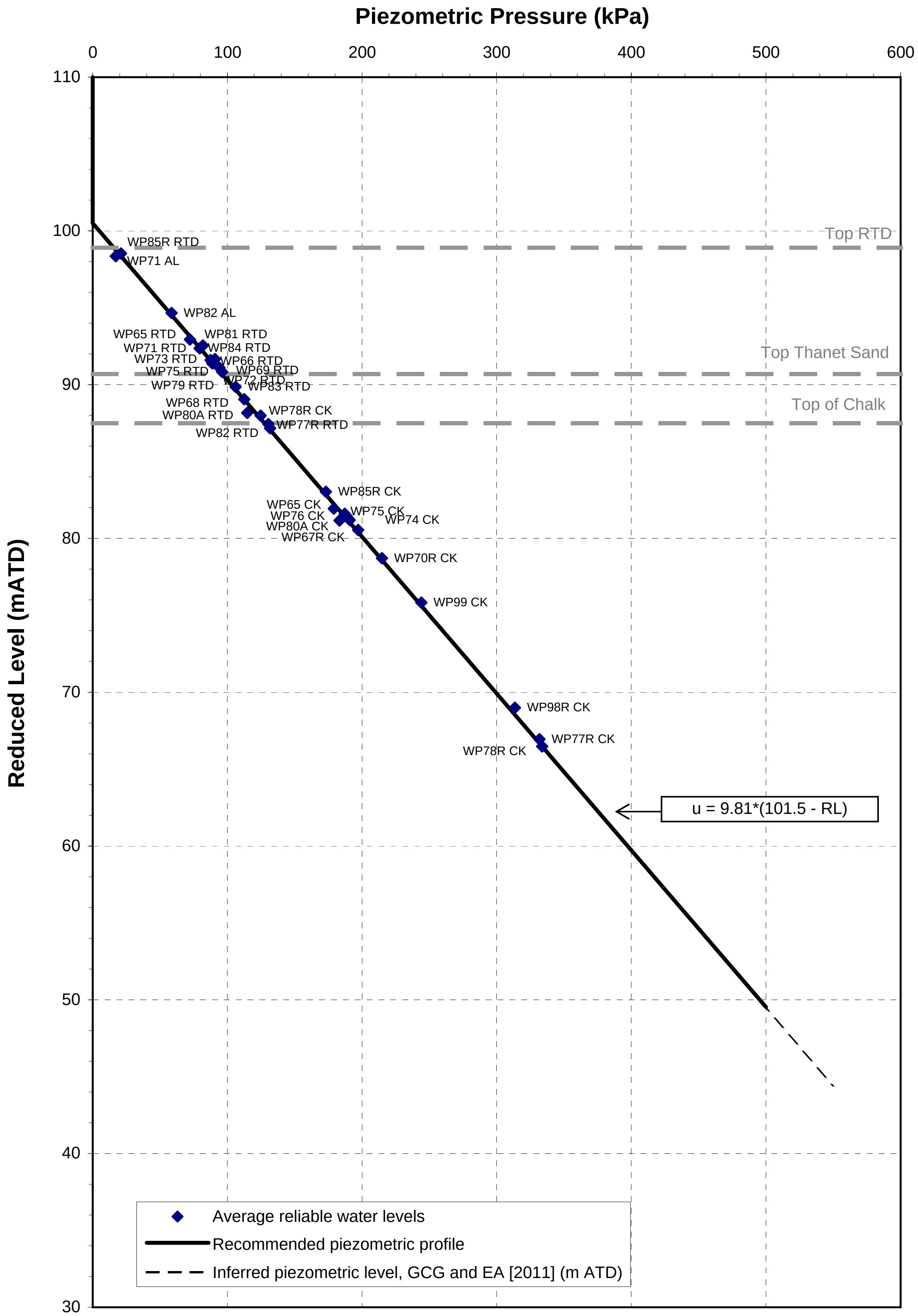
GCG

Crossrail Limited
Crossrail – Groundwater Monitoring Report

Pore Water Pressure Profile
Route Section O - Plumstead Portal

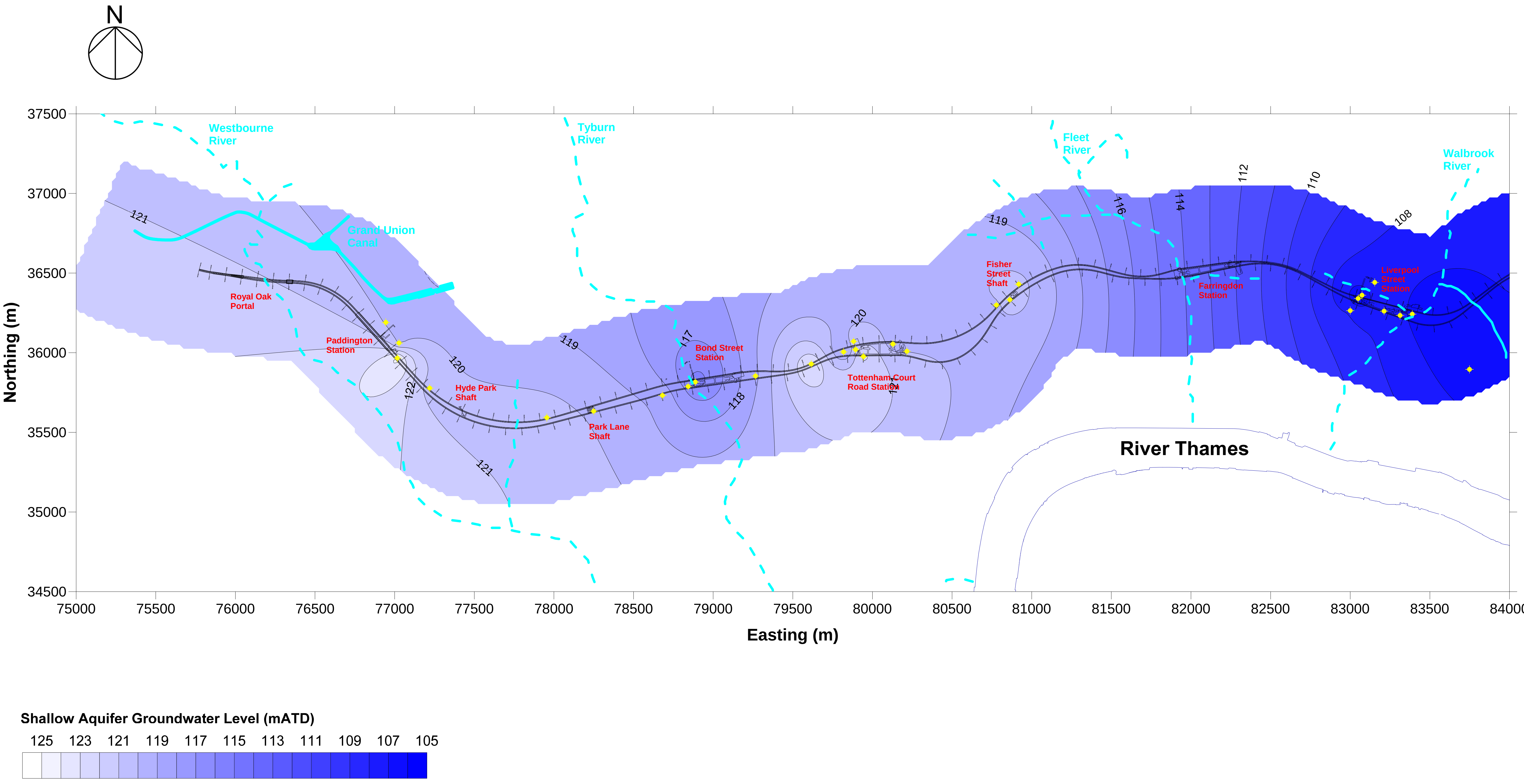
Figure

4.4.29



[1] Stratigraphic levels based on the average values encounterd in the BHs shown in the Figure.

	Crossrail Limited Crossrail – Groundwater Monitoring Report	**Figure**
	Pore Water Pressure Profile Route Section Abbey Wood	**4.4.30**

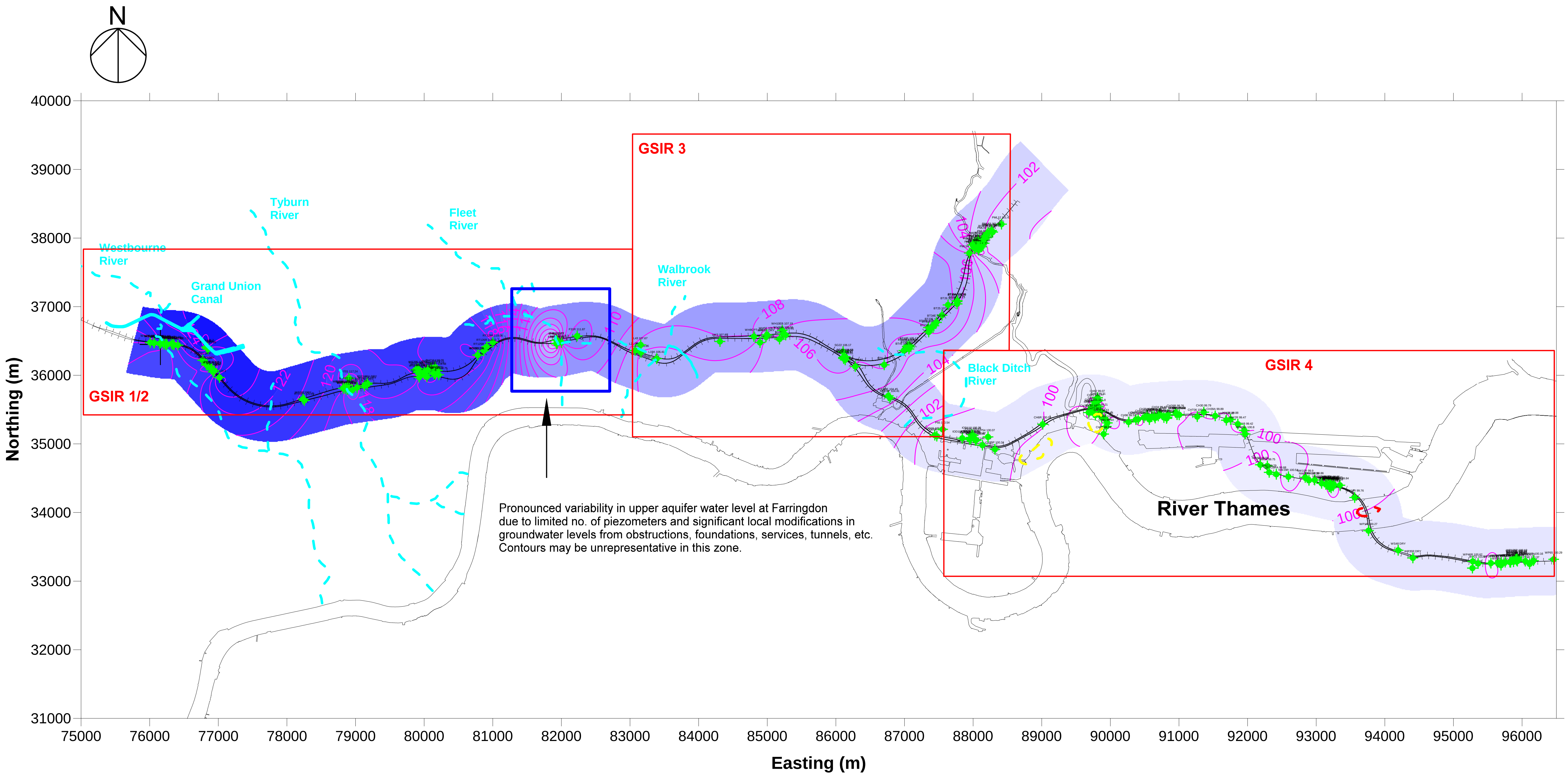


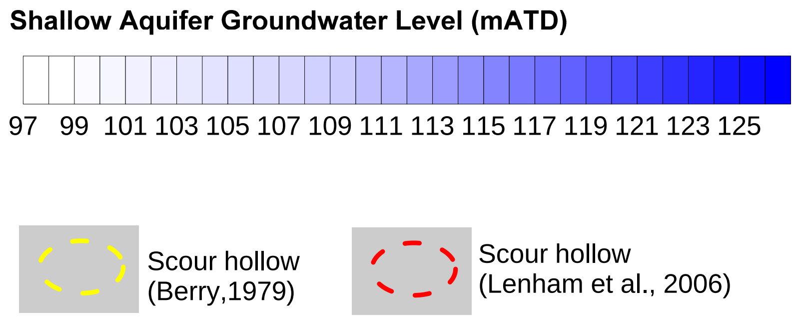
NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings between 1992-1997.
3. Accuracy of the contours is governed by the available data (positions indicated).
4. Due to the limited database and temporal variations in the shallow aquifer groundwater levels, the contours shown should only be considered as indicative.
5. The courses of the lost rivers shown are approximate based on Barton (1992).

Scale 1:25000

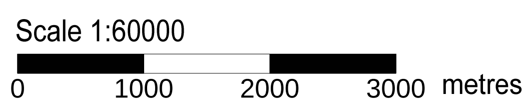
0 200 400 600 800 1000 metres

Crossrail Limited		Figure
Crossrail - Groundwater Monitoring Report - Revision 2		
Shallow aquifer groundwater level contours - (1992-1997)		**4.5.1**
Royal Oak Portal to Plumstead Portal		

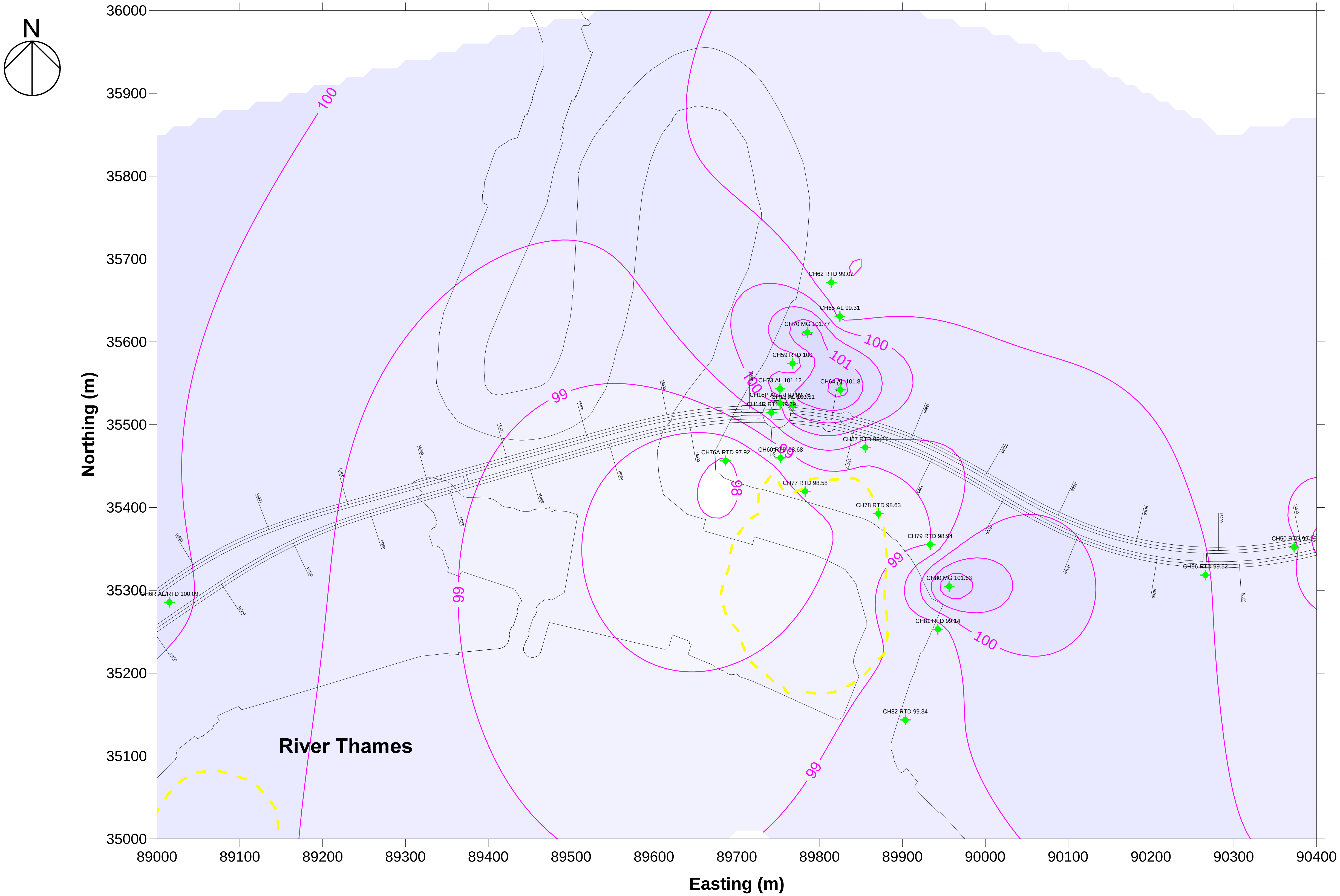




NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings between 2009 and 2011.
3. Accuracy of the contours is governed by the available data (positions indicated).
4. Due to the limited database and temporal variations in the shallow aquifer groundwater levels, the contours shown should only be considered as indicative.
5. The courses of the lost rivers shown are approximate based on Barton (1992).



Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2		**Figure**
Shallow aquifer groundwater level contours - August 2011 Royal Oak Portal to Plumstead and Pudding Mill Lane Portal		**4.5.2**



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings between 2009 and 2011.
3. Accuracy of the contours is governed by the available data (positions indicated).
4. Due to the limited database and temporal variations in the shallow aquifer groundwater levels, the contours shown should only be considered as indicative.

Shallow Aquifer Groundwater Level (mATD)

97 99 101 103 105 107 109 111 113 115 117 119 121 123 125

Scale 1:5000

0 100 200 300 metres

Scour hollow (Berry,1979)

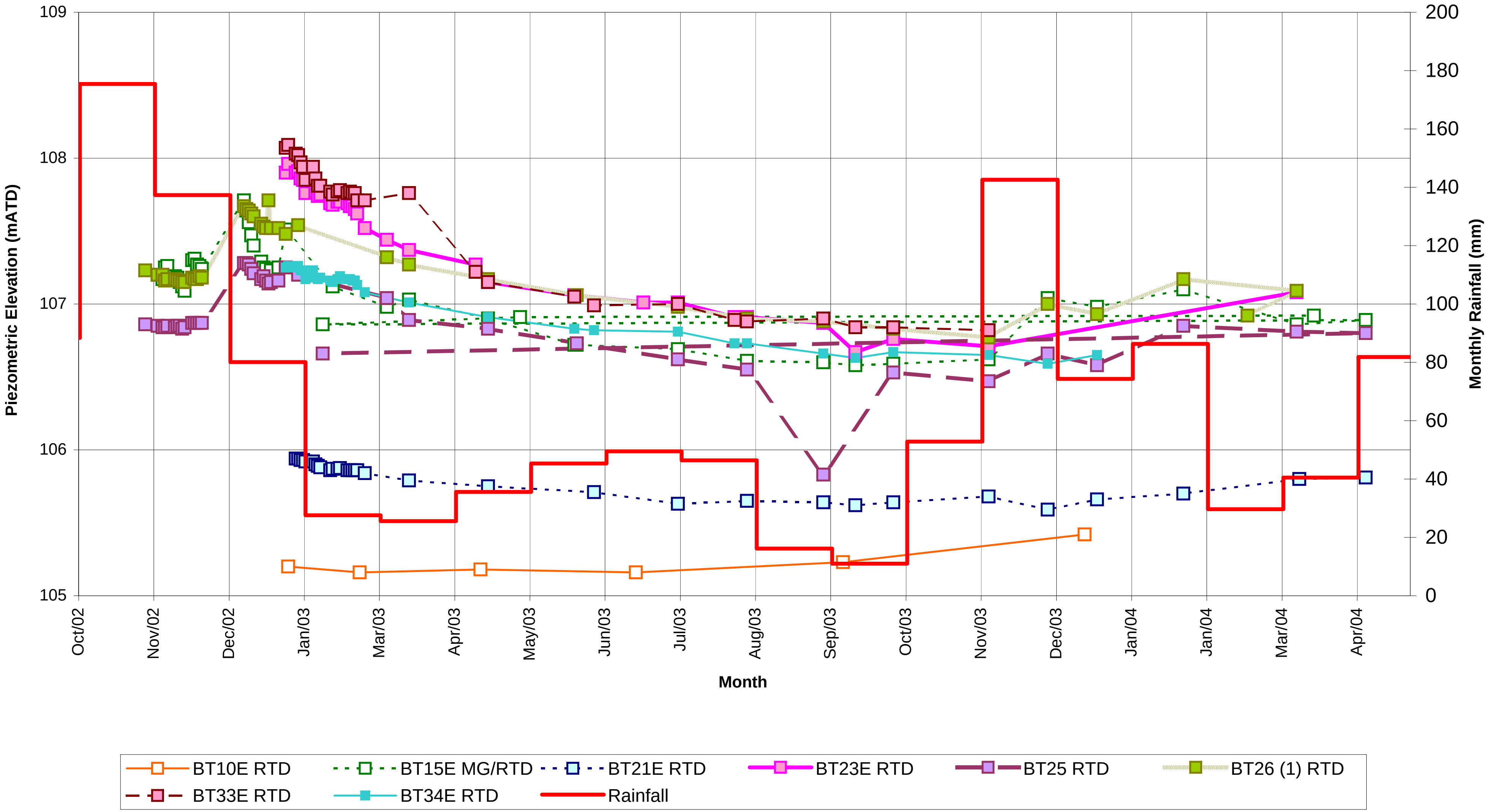
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

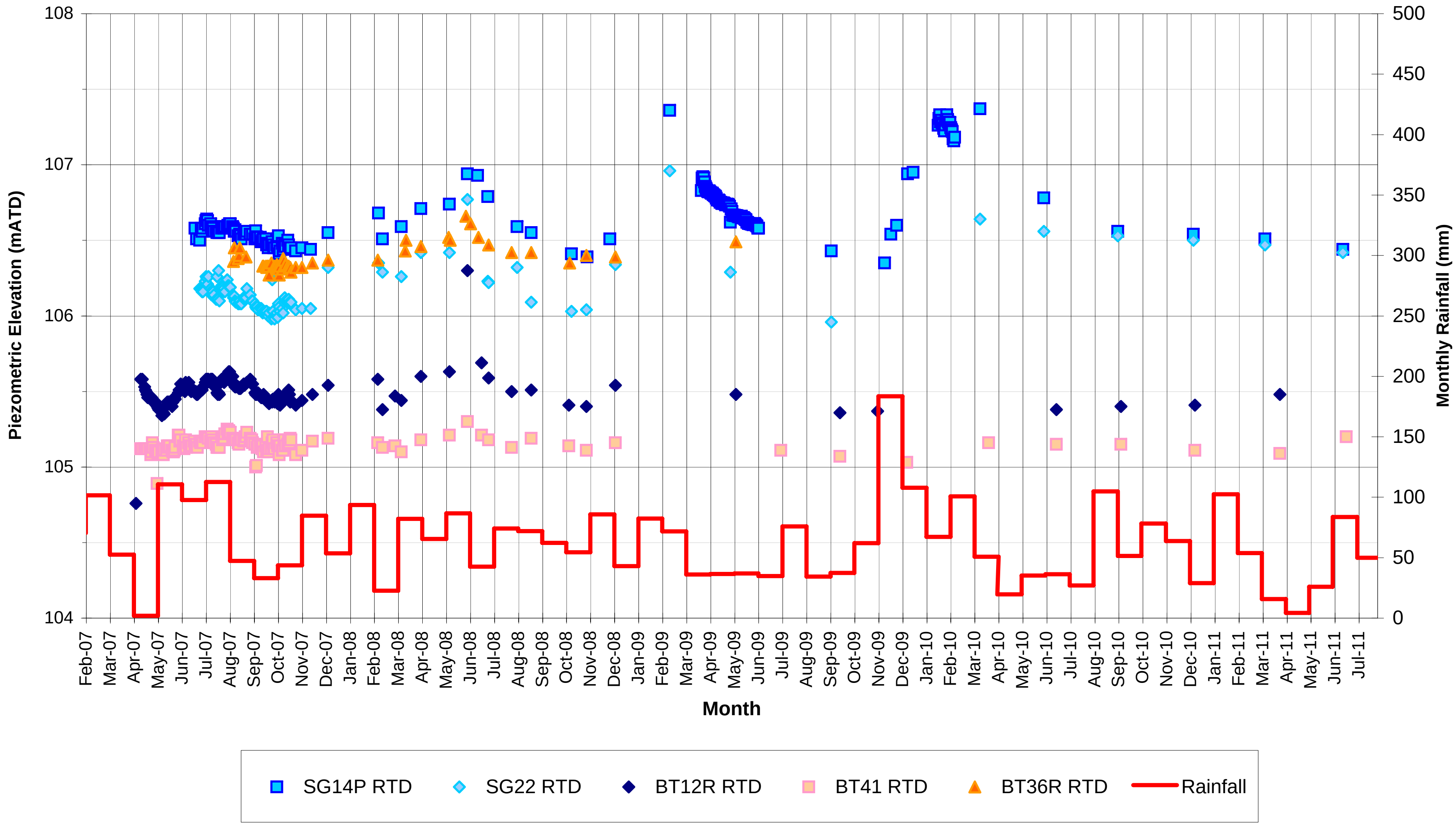
Shallow aquifer groundwater level contours - August 2011

Limmo Peninsula

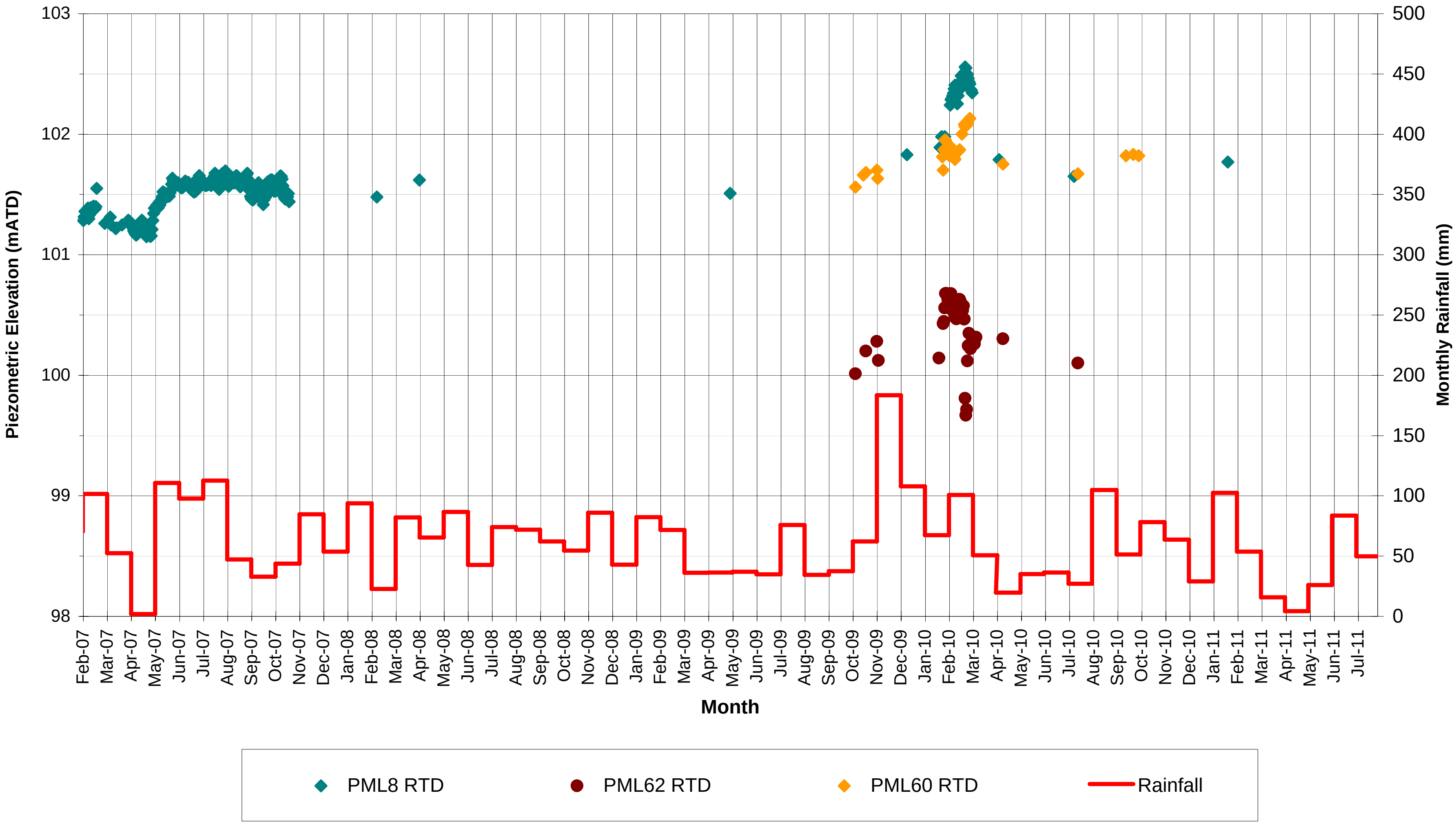
Figure 4.5.2.b



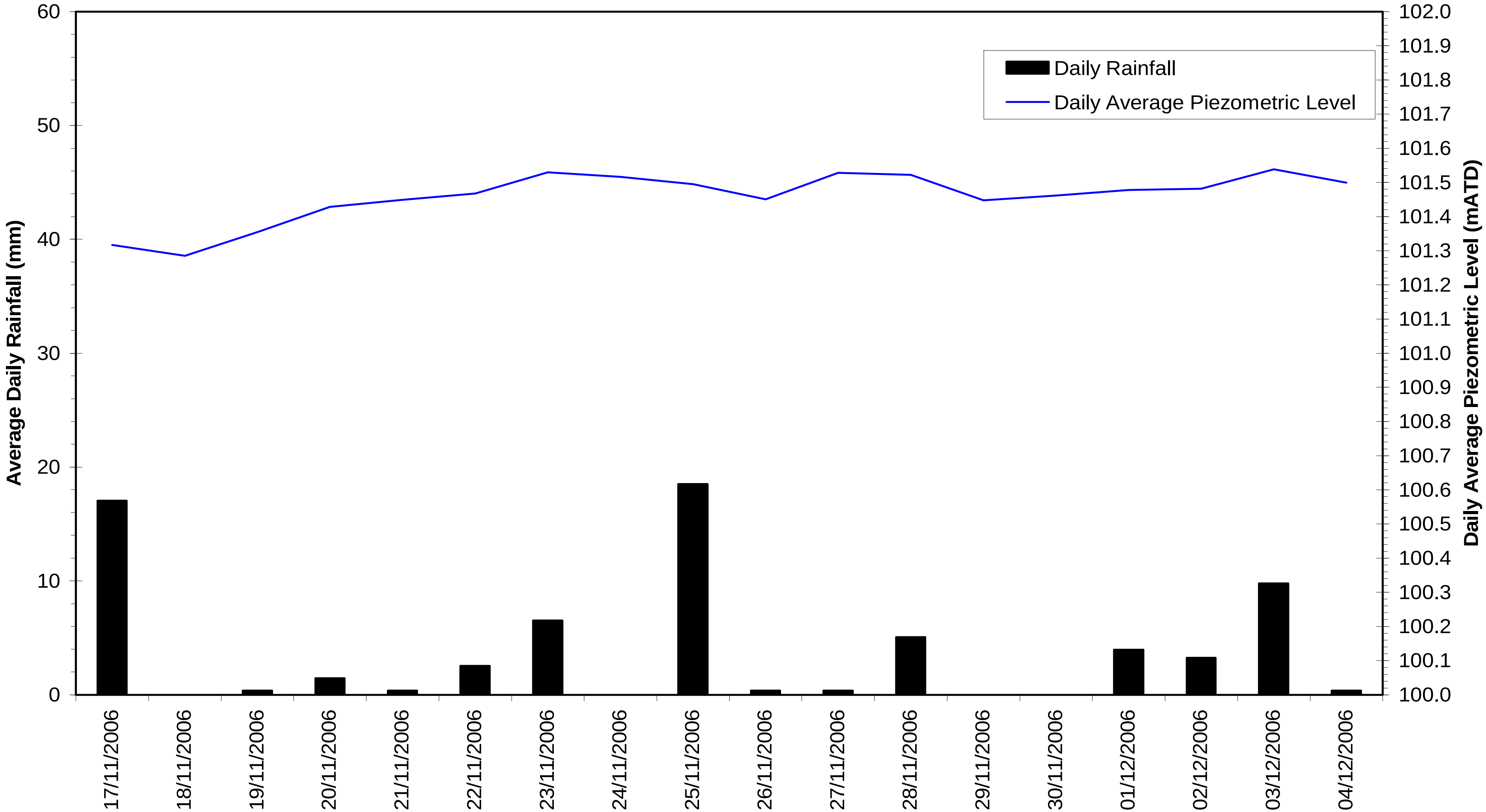
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure** **4.5.3**
	Data showing seasonal Influence	



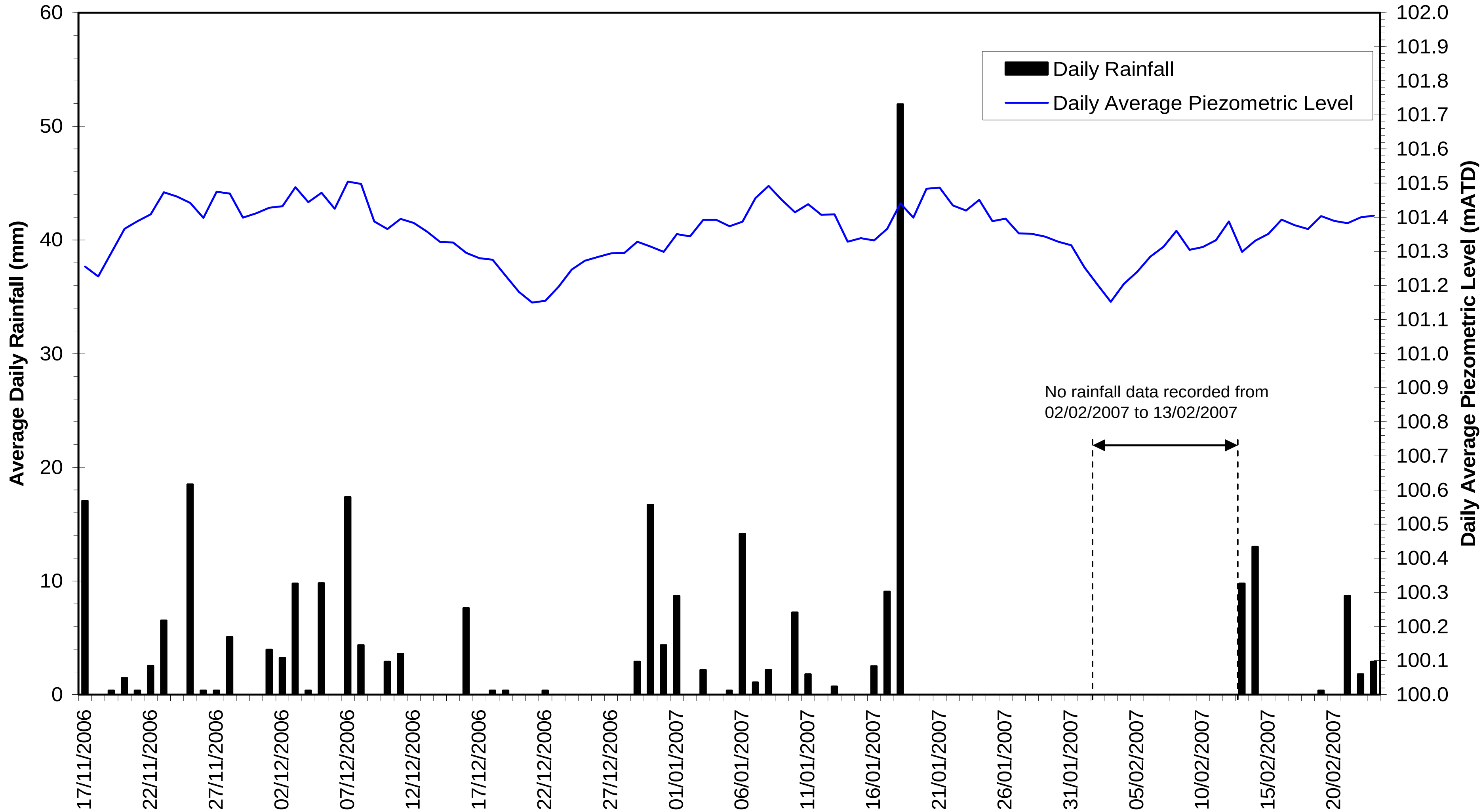
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure** **4.5.4.a**
	Data showing sesonal Influence Route Section E & F - Stepney Green to Pudding Mill Lane	



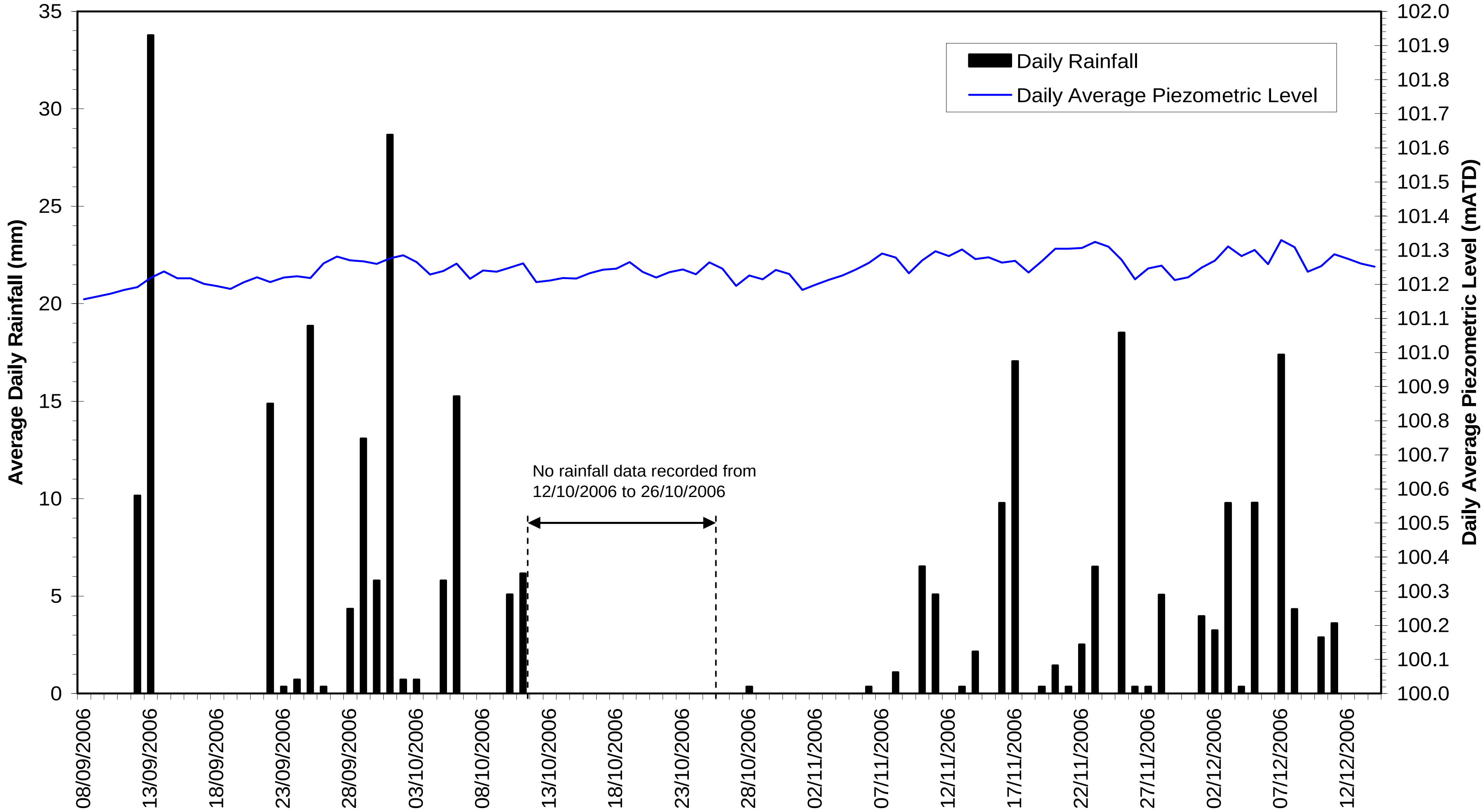
Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
Data showing sesonal Influence Route Section E & F - Stepney Green to Pudding Mill Lane	**4.5.4.b**



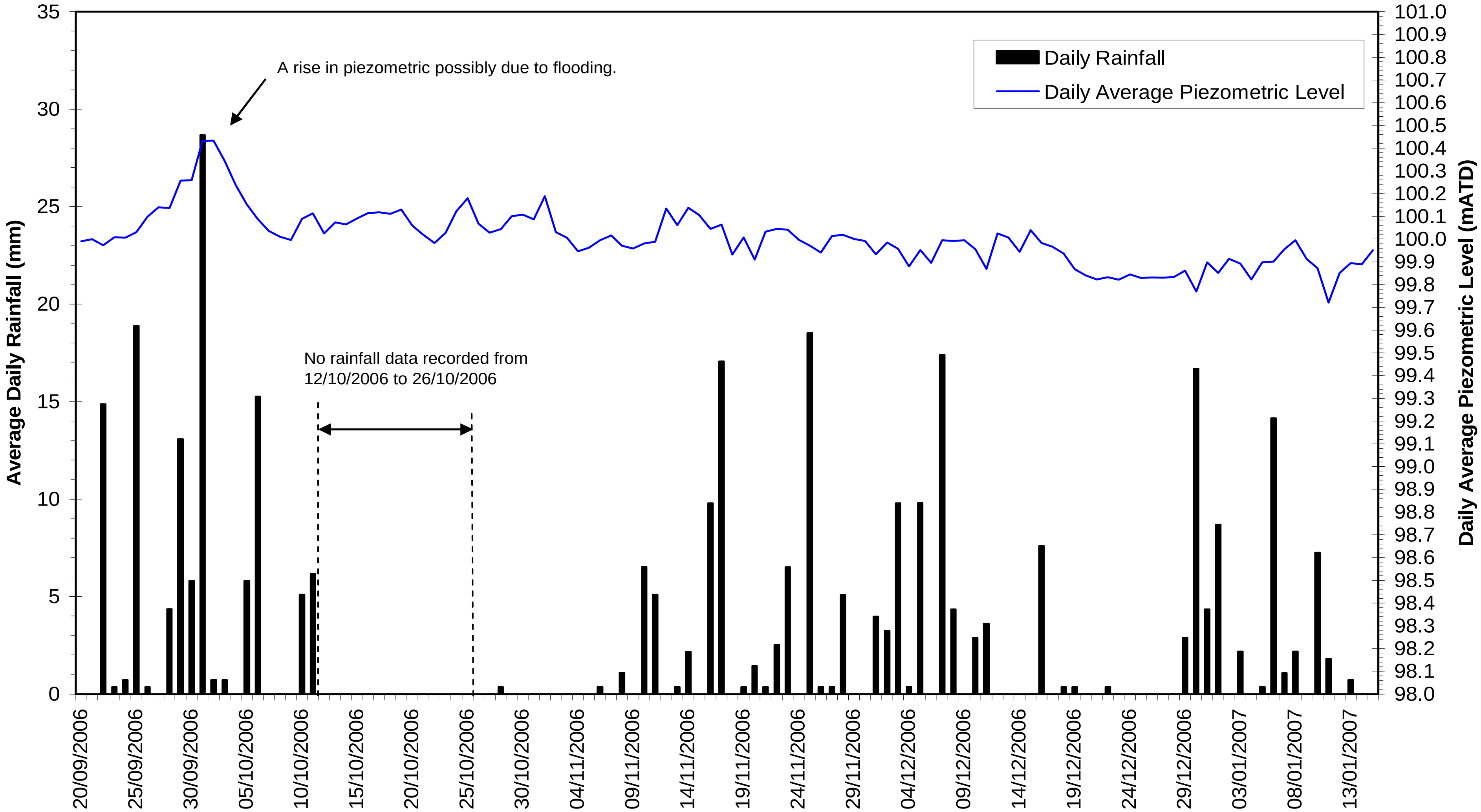
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	Route Section G - Borehole PML7 SP - Piezometric Data Daily Average Piezometric Level and Daily Rainfall	**4.5.5**



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	Route Section G - Borehole PML8 SP - Piezometric Data Daily Average Piezometric Level and Daily Rainfall	**4.5.6**



Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2		**Figure**
Route Section H - Borehole IOD15 - Piezometric Data Daily Average Piezometric Level and Daily Rainfall		**4.5.7**



Crossrail Limited

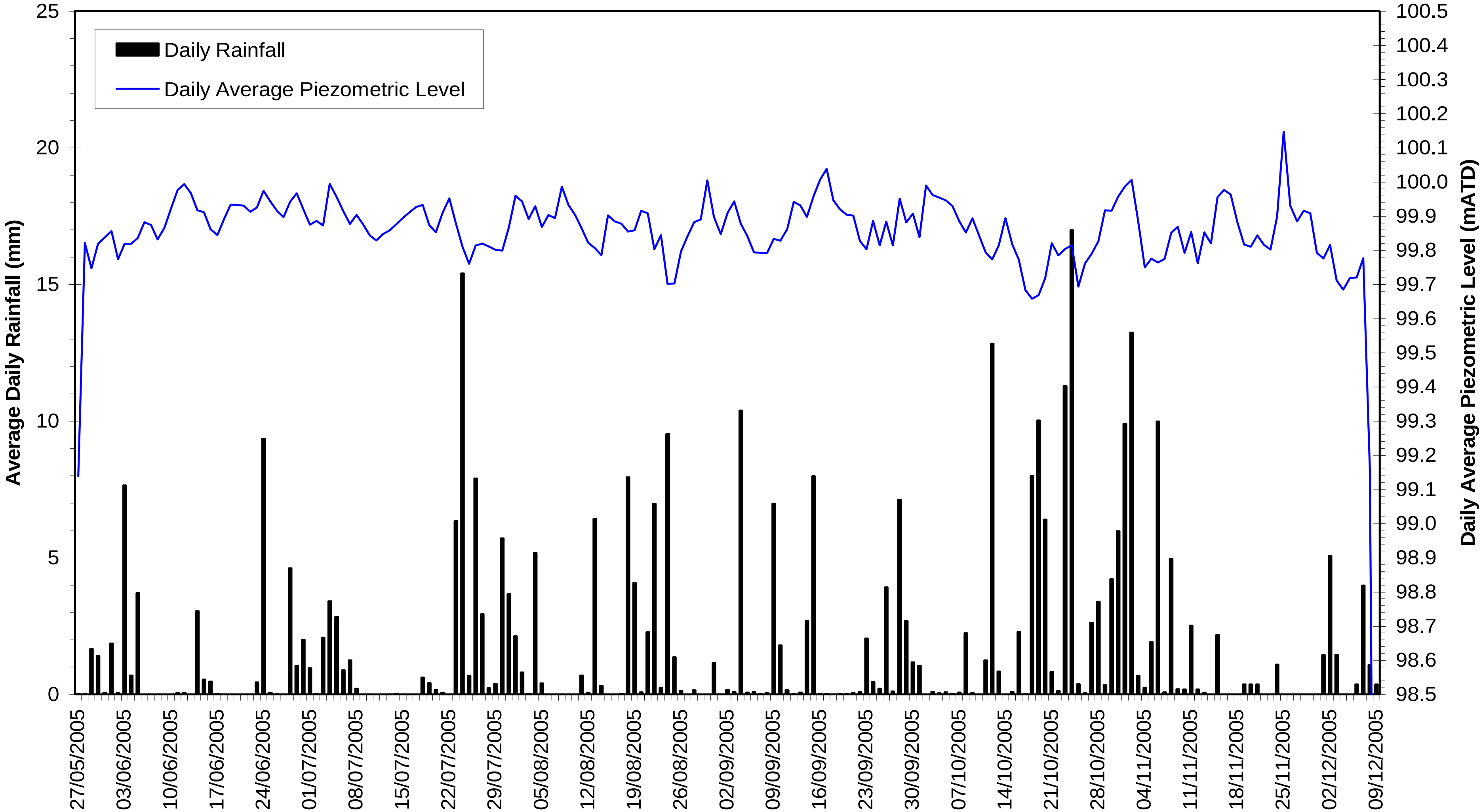
Crossrail - Groundwater Monitoring Report - Revision 2

Route Section J - Borehole CH6R - Piezometric Data

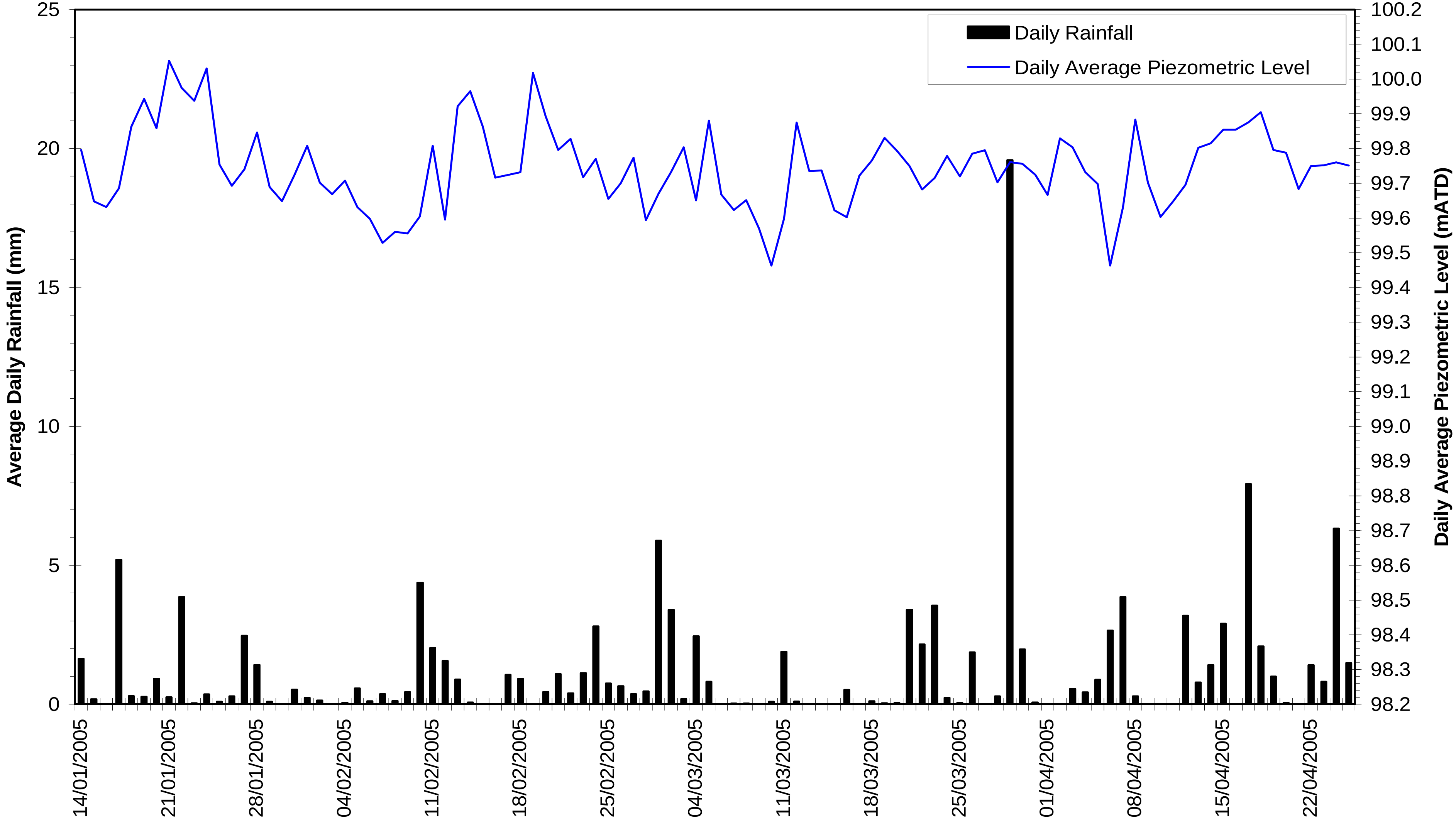
Daily Average Piezometric Level and Daily Rainfall

Figure

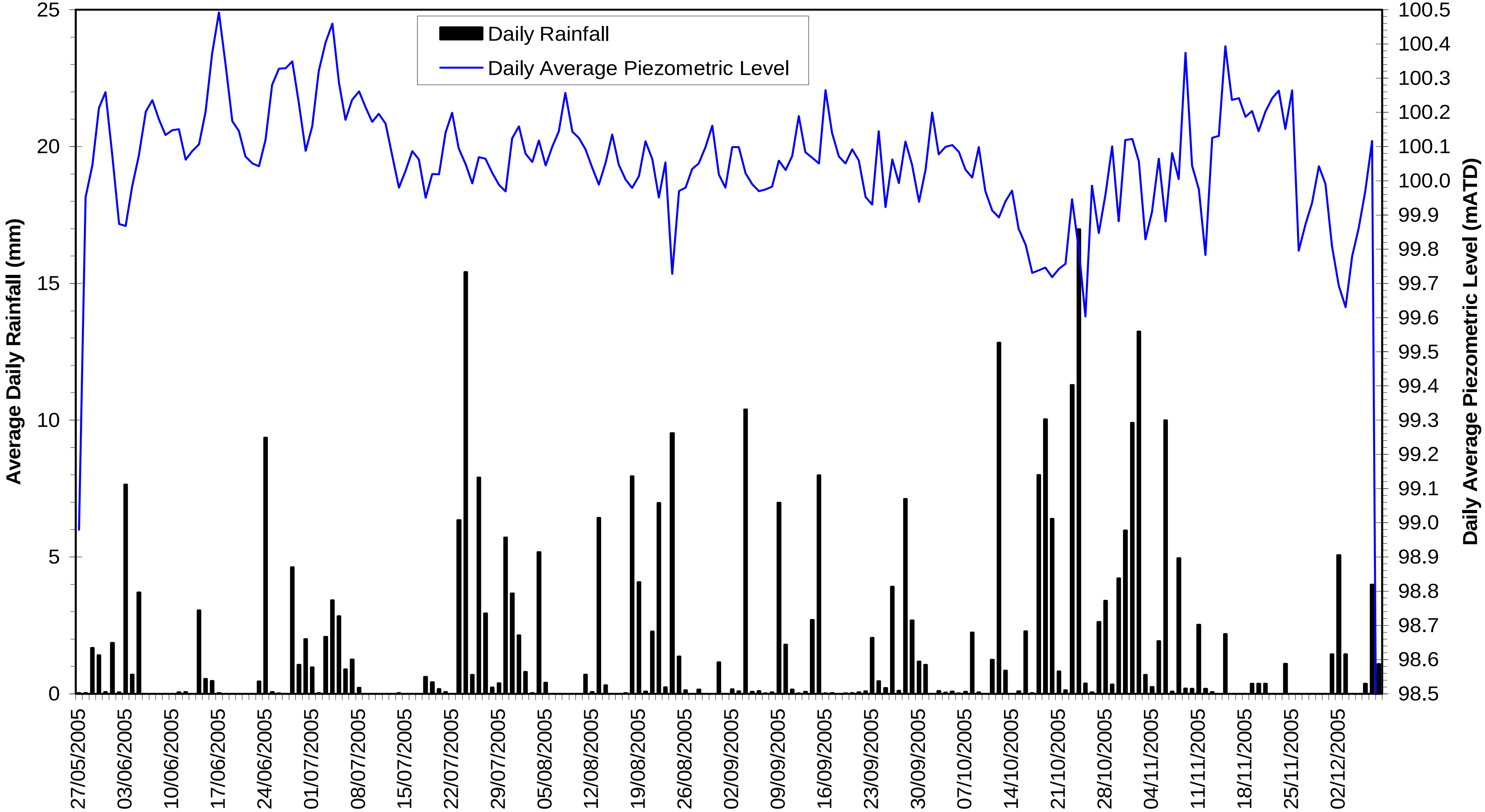
4.5.8



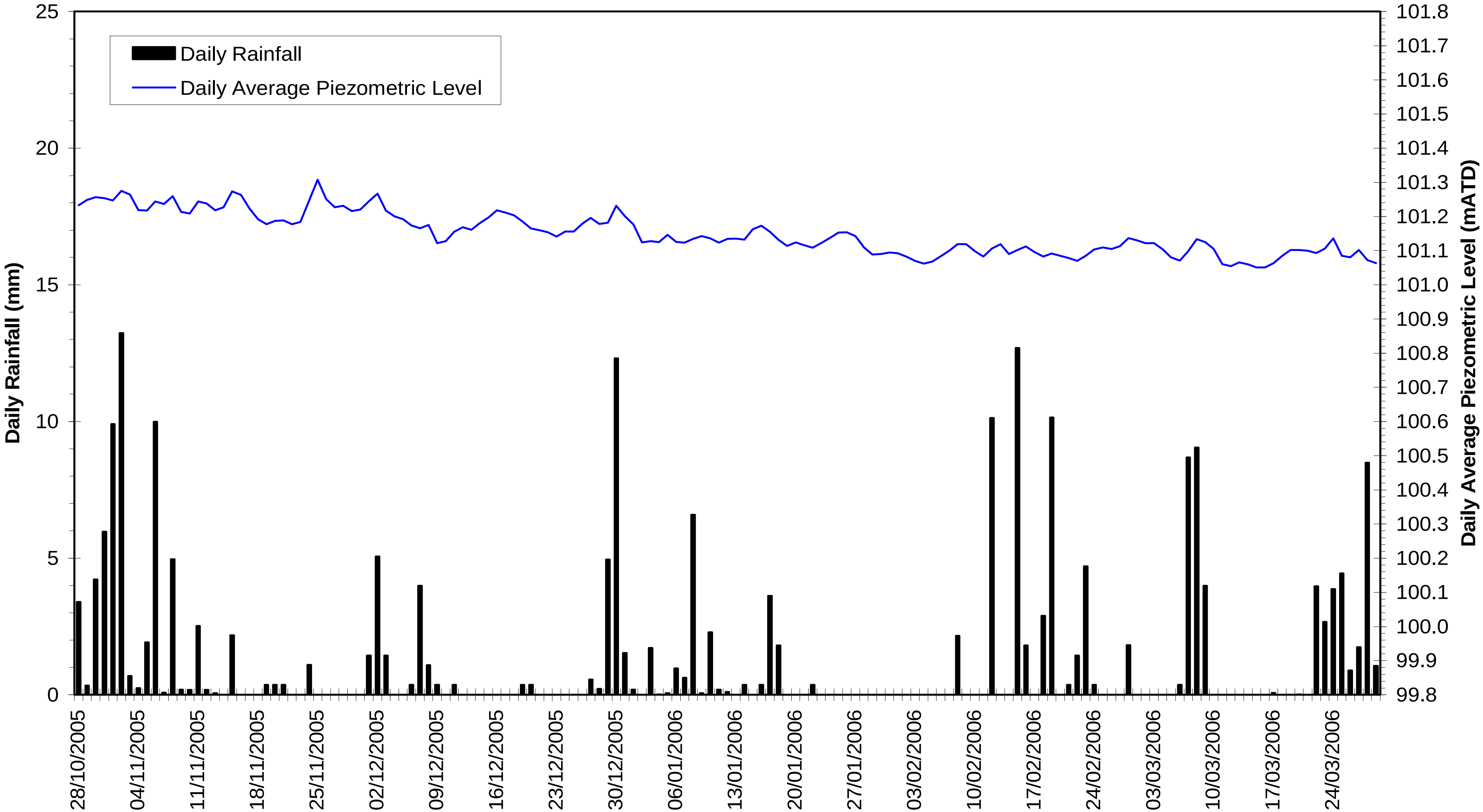
Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**	
Route Section N - Borehole NW12 - Piezometric Data Daily Average Piezometric Level and Daily Rainfall	**4.5.9**	



Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**	
Route Section N - Borehole NW16R - Piezometric Data Daily Average Piezometric Level and Daily Rainfall	**4.5.10**	



Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
Route Section N - Borehole NW18R - Piezometric Data Daily Average Piezometric Level and Daily Rainfall	**4.5.11**



Crossrail Limited

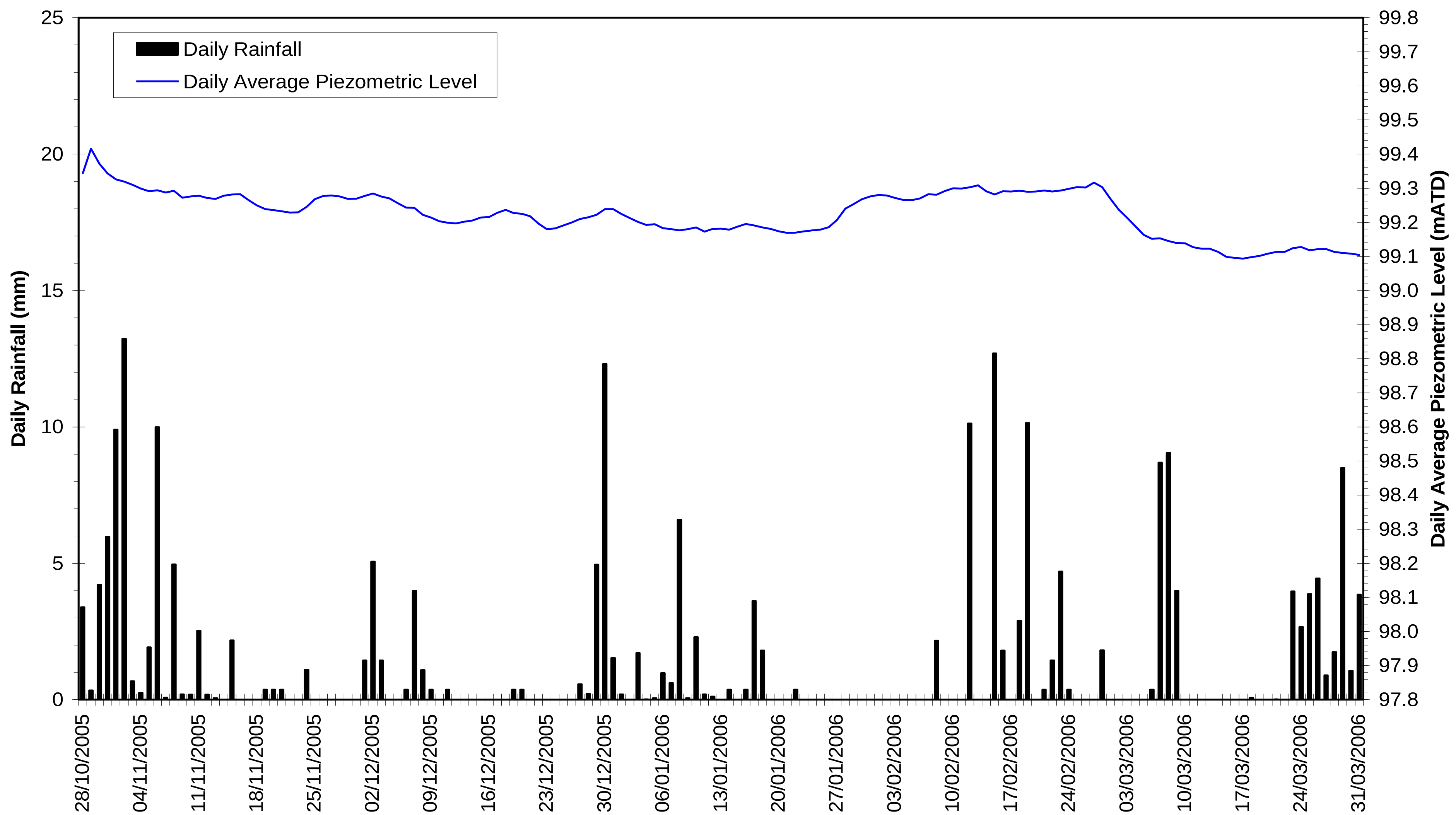
Crossrail - Groundwater Monitoring Report - Revision 2

Route Section O - Borehole WP21 - Piezometric Data

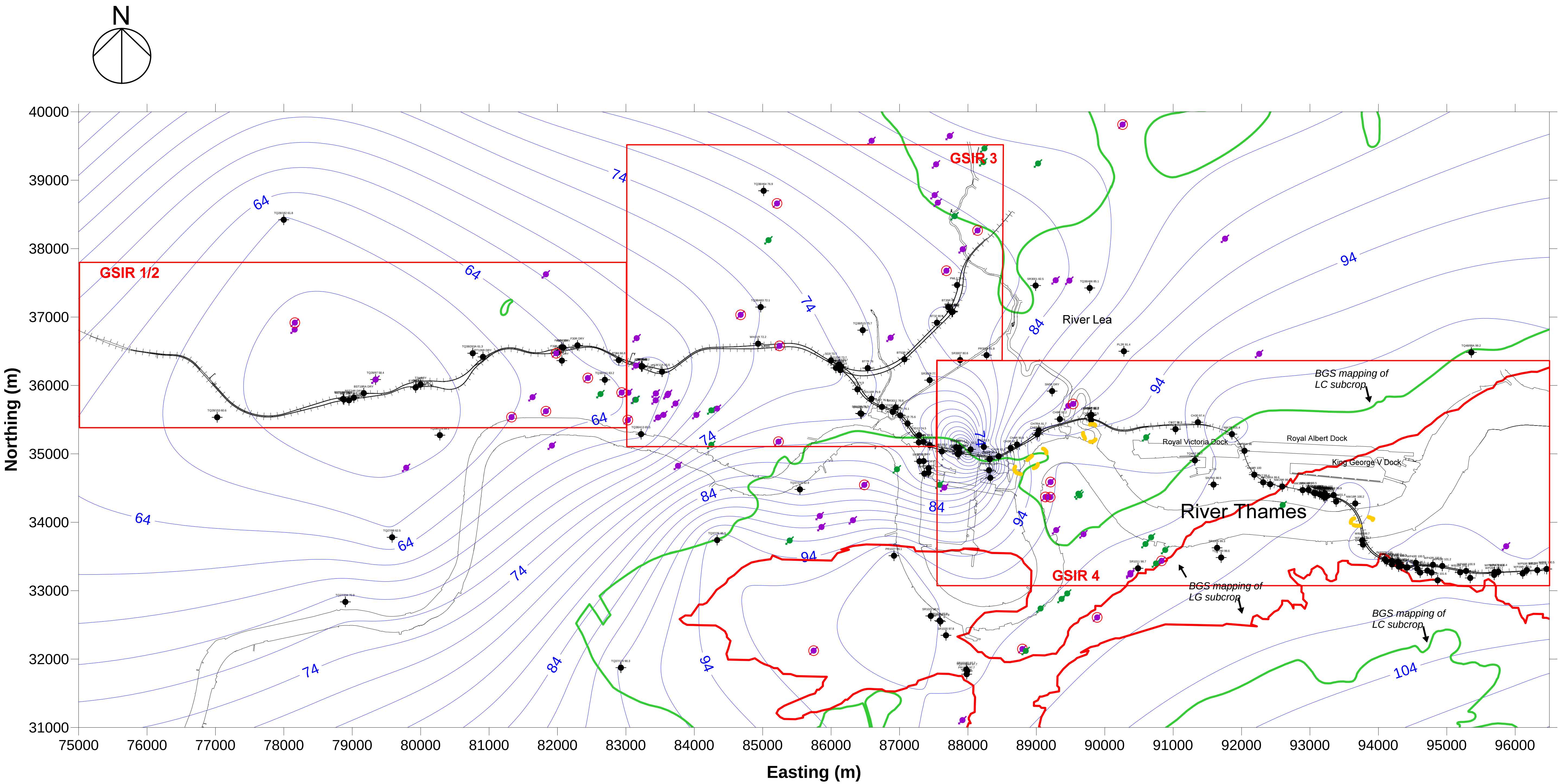
Daily Average Piezometric Level and Daily Rainfall

Figure

4.5.12



Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
Route Section O - Borehole WP23 - Piezometric Data Daily Average Piezometric Level and Daily Rainfall	**4.5.13**



KEY:
- Location of scour hollows identified by Berry (1979) and Lenham et al. (2006)
- Crossrail borehole / EA / TW monitoring well
- Abstraction Well (location +/- 100m)
- EA Abstraction Well (2010 new licence)
- Expired/Revokated licences (Refer Table 8)
- Groundwater level (mATD)

NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings August 2011, supplemented with Environment Agency monitoring data for Janruary 2011 and Thames Water London Tideway monitoring data for Dec 2010.
3. Accuracy of the contours is governed by the available data (borehole positions indicated).
4. Due to the limited database and temporal variations in the deep aquifer groundwater levels, the contours shown should only be considered as indicative.

Scale 1:60000

0 1000 2000 3000 4000 metres

Crossrail Limited

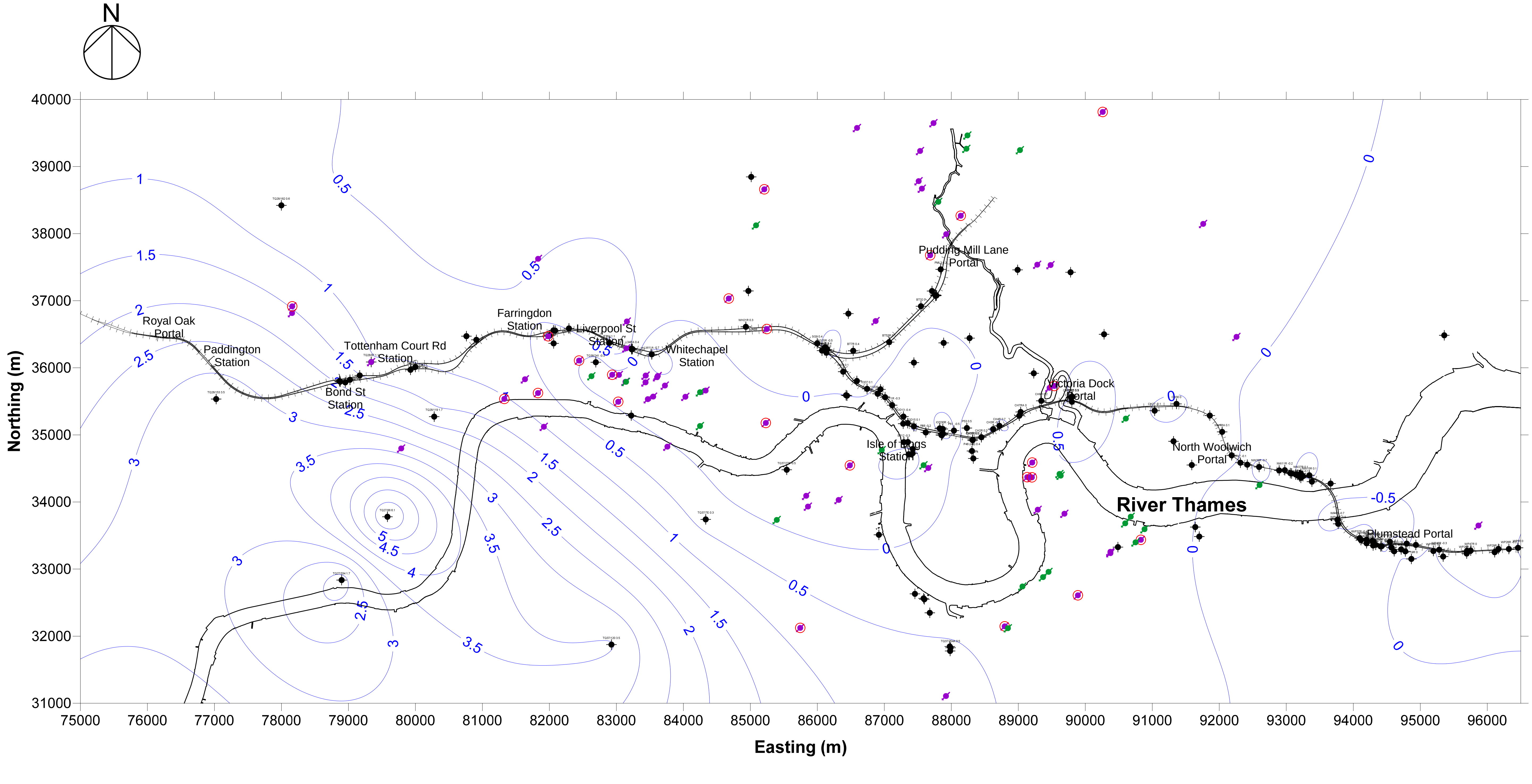
Crossrail - Groundwater Monitoring Report - Revision 2

Deep aquifer groundwater level contours - August 2011

Royal Oak Portal and Plumstead Portal

Figure

4.6.1



NOTE:

1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings between August 2011 and September 2010, supplemented with Environment Agency monitoring data.
3. Accuracy of the contours is governed by the available data (borehole positions indicated).
4. Due to the limited database and temporal variations in the deep aquifer groundwater levels, the contours shown should only be considered as indicative.

Scale 1:60000

0 1000 2000 3000 4000 5000 metres

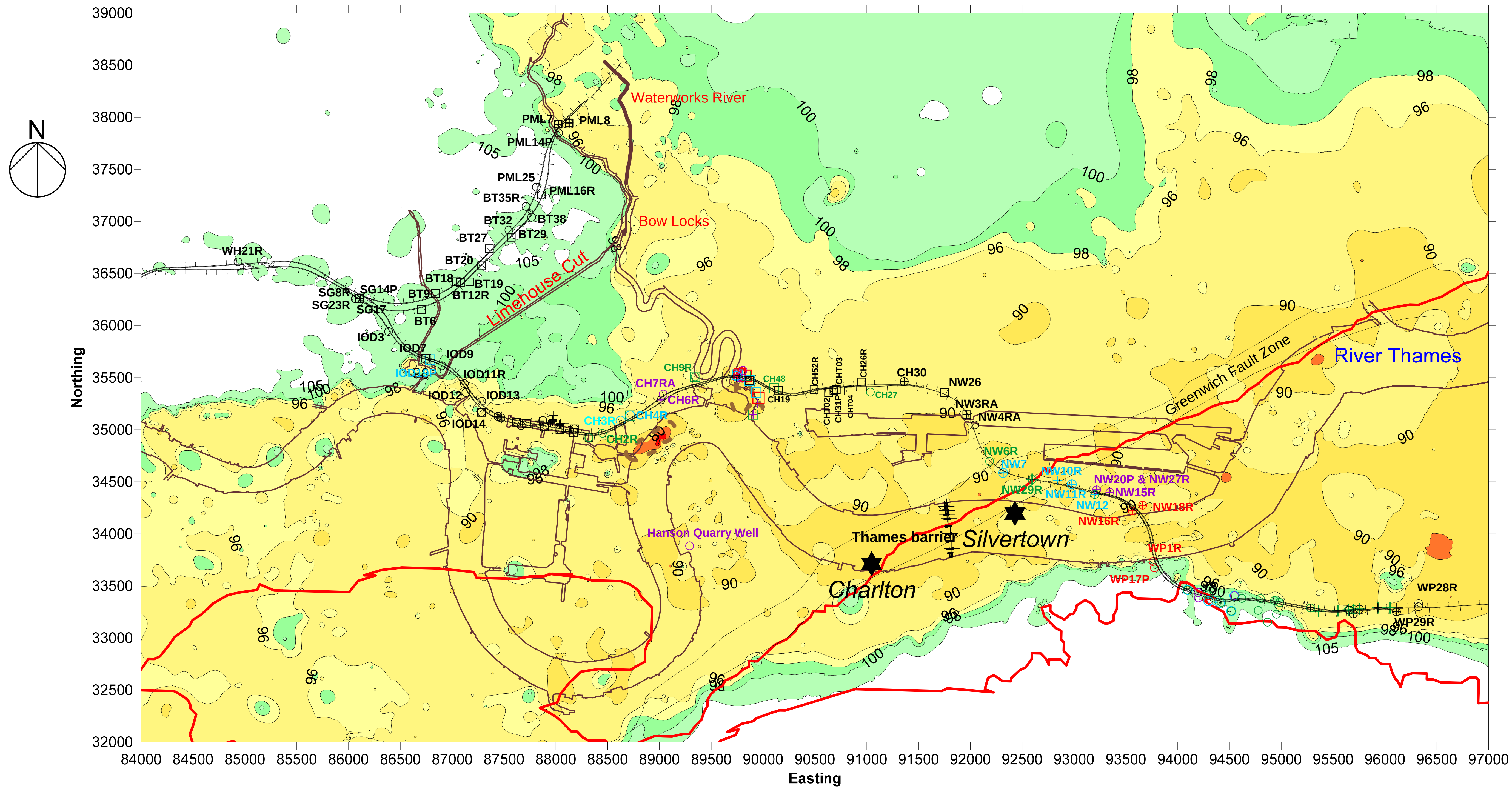
Crossrail Limited

Crossrail - Groundwater Monitoring Report - Revision 2

Rate of change of the deep aquifer groundwater level contours - August 2011

Royal Oak Portal to Plumstead Portal

Figure 4.6.2



Contours given in m ATD

60 | 70 | 80 | 90 | 96 | 98 | 100 | 105

BGS Mapping of LG subcrop

Locations of scour hollows identified by Berry (1979)

Port of London Authority Tidal Monitoring gauge

Symbols Key:

- Shallow Aquifer
- Strata between shallow and deep aquifer
- Deep Aquifer

Colours Key:

- 0m
- 0 - 0.2m
- 0.2 - 0.5m
- 0.5 - 1.0m
- >1.0m

Note:
1. Coordinates and elevations are to LUL grid and height datum.
2. Accuracy of the contours is governed by the available data.
3. Due to the limited database, the contours shown should only be considered as indicative.
4. The locations of the boreholes monitored in the Woolwich, Limmo and Isle of Dogs area are shown in Figures 5, 6 and 7, respectively.

Scale 1:40000

0 1000 2000 3000 metres

Crossrail Limited

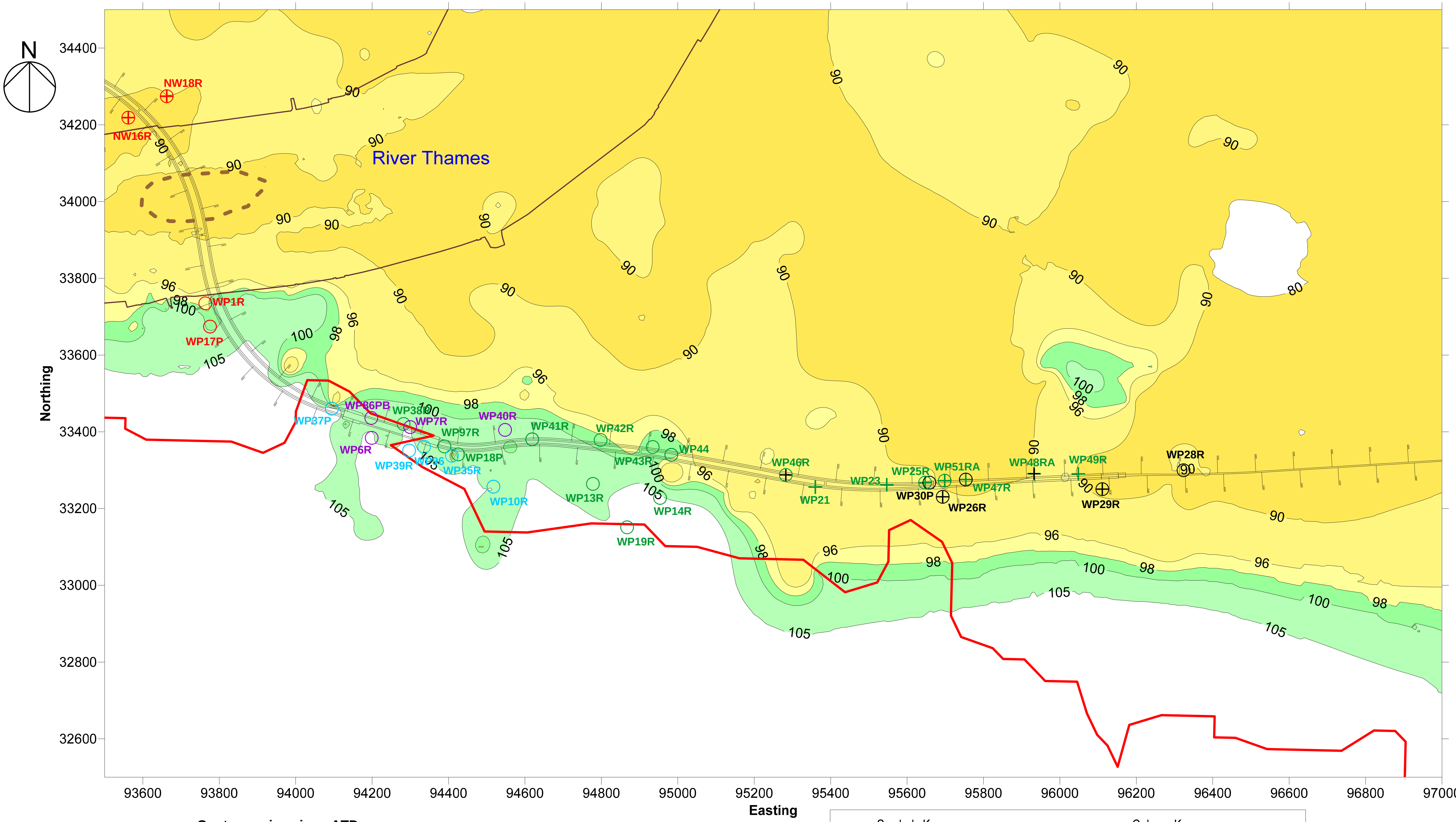
Crossrail - Groundwater Monitoring Report - Revision 2

Tidal influence

Contours of base of Drift and Summary of tidal monitoring results

Figure

4.7.1



Contours given in m ATD

80 | 90 | 96 | 98 | 100 | 105

Symbols Key:

- + Shallow Aquifer
- □ Strata between shallow and deep aquifer
- ○ Deep Aquifer

Colours Key:

- 0m
- 0 - 0.2m
- 0.2 - 0.5m
- 0.5 - 1.0m
- >1.0m

BGS Mapping of LG subcrop

Locations of Scour Hollows identified by Lenham et al. (2006)

Note:
1. Coordinates and elevations are to LUL grid and height datum.
2. Accuracy of the contours is governed by the available data.
3. Due to the limited database, the contours shown should only be considered as indicative.

Scale 1:10000

0 200 400 600 800 1000 metres

Crossrail Limited

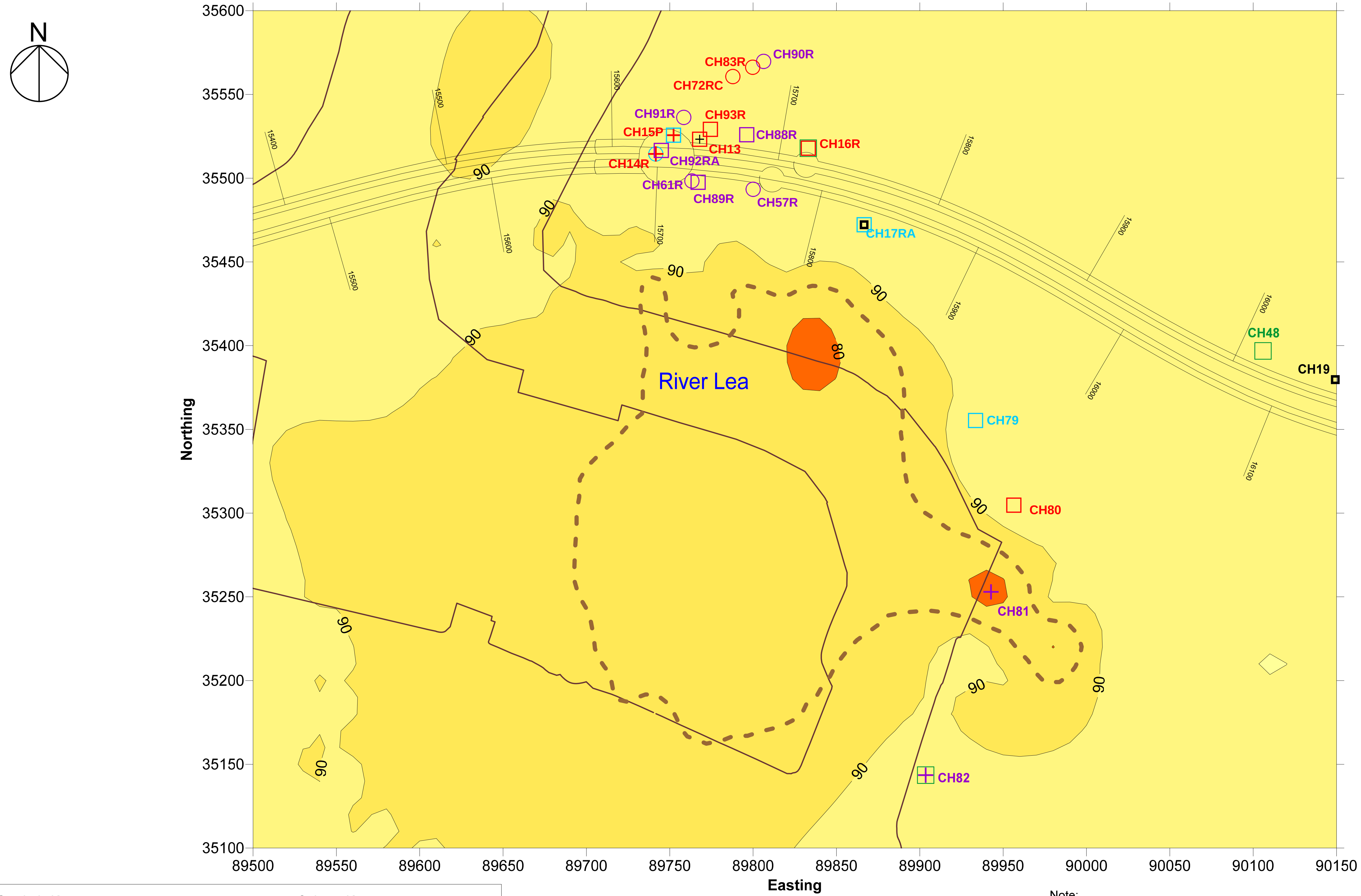
Crossrail - Groundwater Monitoring Report - Revision 2

Tidal influence

Contours of base of Drift Deposits and Summary of tidal monitoring results - Woolwich to Plumstead

Figure

4.7.2



Symbols Key:

- + Shallow Aquifer
- □ Strata between shallow and deep aquifer
- ○ Deep Aquifer

Colours Key:

- 0m
- 0 - 0.2m
- 0.2 - 0.5m
- 0.5 - 1.0m
- >1.0m

Scale 1:1500

0 50 100 150 200 metres

Contours given in m ATD

60 80 96 100

Note:
1. Coordinates and elevations are to LUL grid and height datum.
2. Accuracy of the contours is governed by the available data.
3. Due to the limited database, the contours shown should only be considered as indicative.

BGS Mapping of LG subcrop

Locations of scour hollows originally identified by Berry (1979) and updated further based on recent geological information

Crossrail Limited

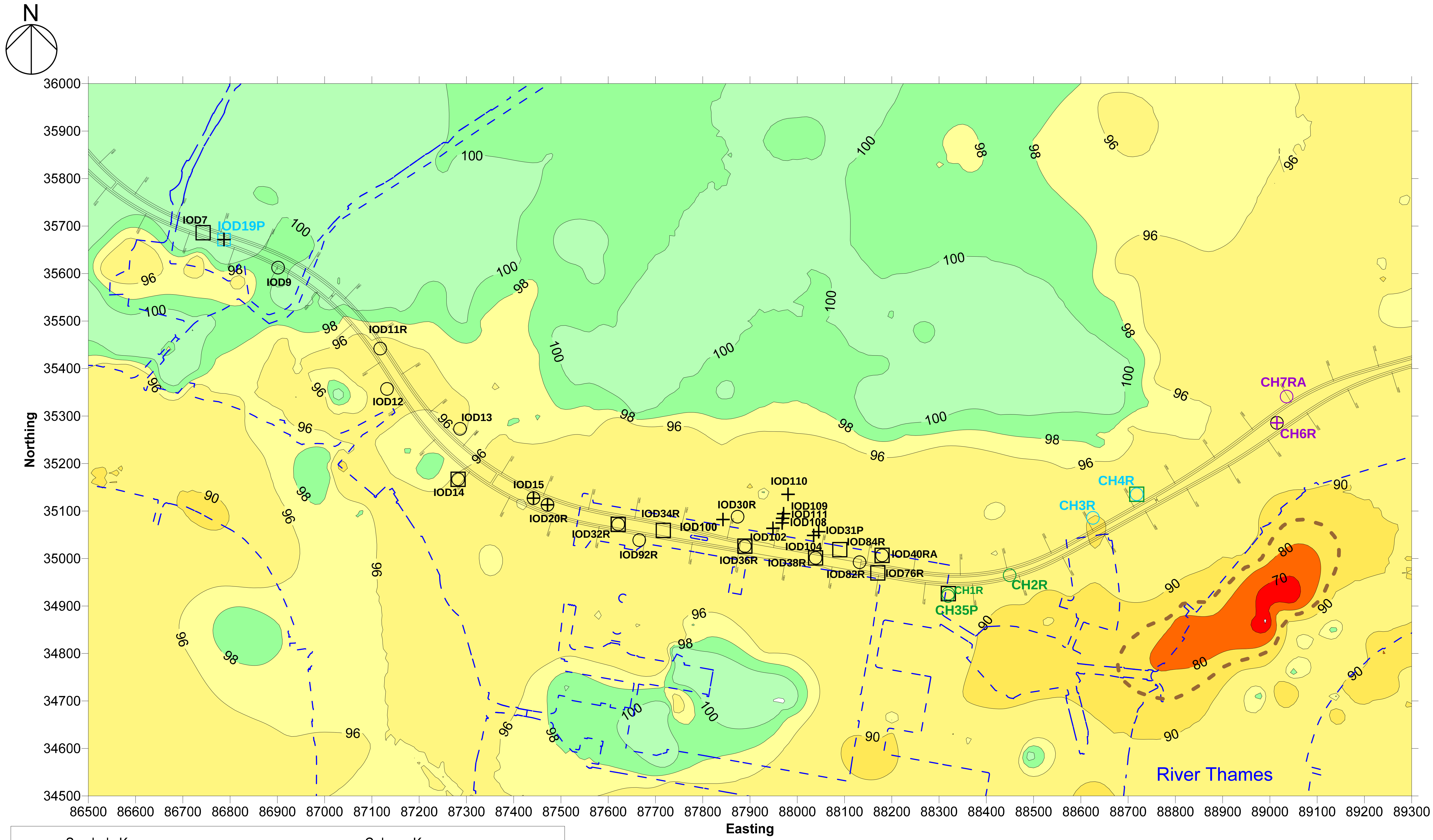
Crossrail - Groundwater Monitoring Report - Revision 2

Tidal influence

Contours of base of Drift Deposits and Summary of tidal monitoring results - Limmo Peninsula

Figure

4.7.3



Symbols Key:

- + Shallow Aquifer
- □ Strata between shallow and deep aquifer
- ○ Deep Aquifer

Colours Key:

- 0m
- 0 - 0.2m
- 0.2 - 0.5m
- 0.5 - 1.0m
- >1.0m

Scale 1:8000

0 100 200 300 400 500 600 metres

Locations of scour hollows identified by Berry (1979)

Contours given in mATD

60 70 80 90 96 98 100 105

Note:
1. Coordinates and elevations are to LUL grid and height datum.
2. Accuracy of the contours is governed by the available data.
3. Due to the limited database, the contours shown should only be considered as indicative.

GCG

Crossrail Limited

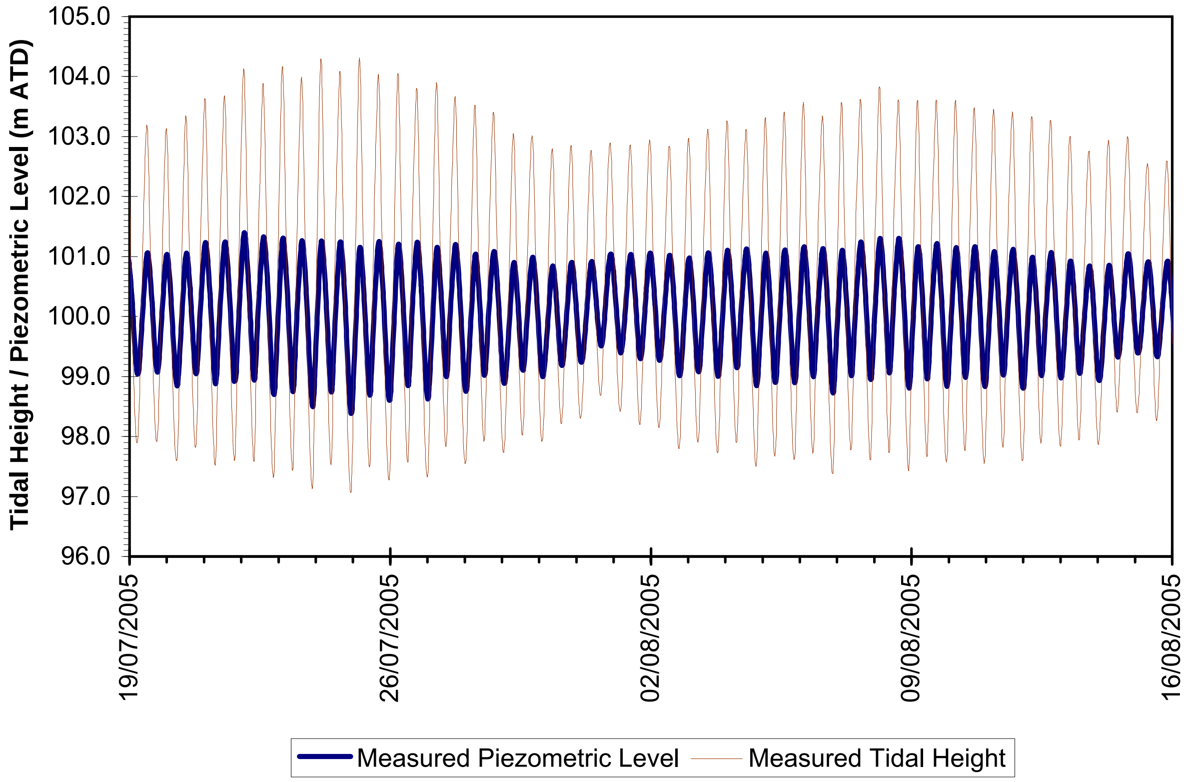
Crossrail - Groundwater Monitoring Report - Revision 2

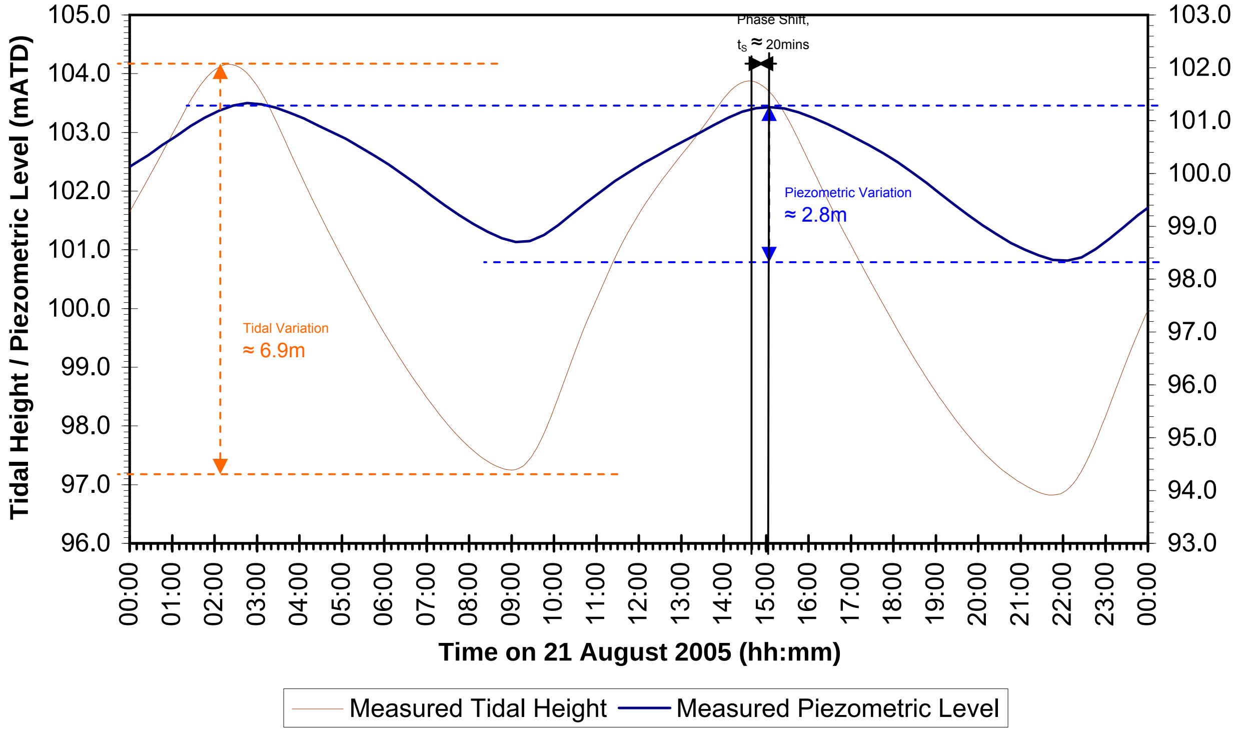
Tidal influence

Contours of base of Drift and Summary of tidal monitoring results - Isle of Dogs

Figure

4.7.4





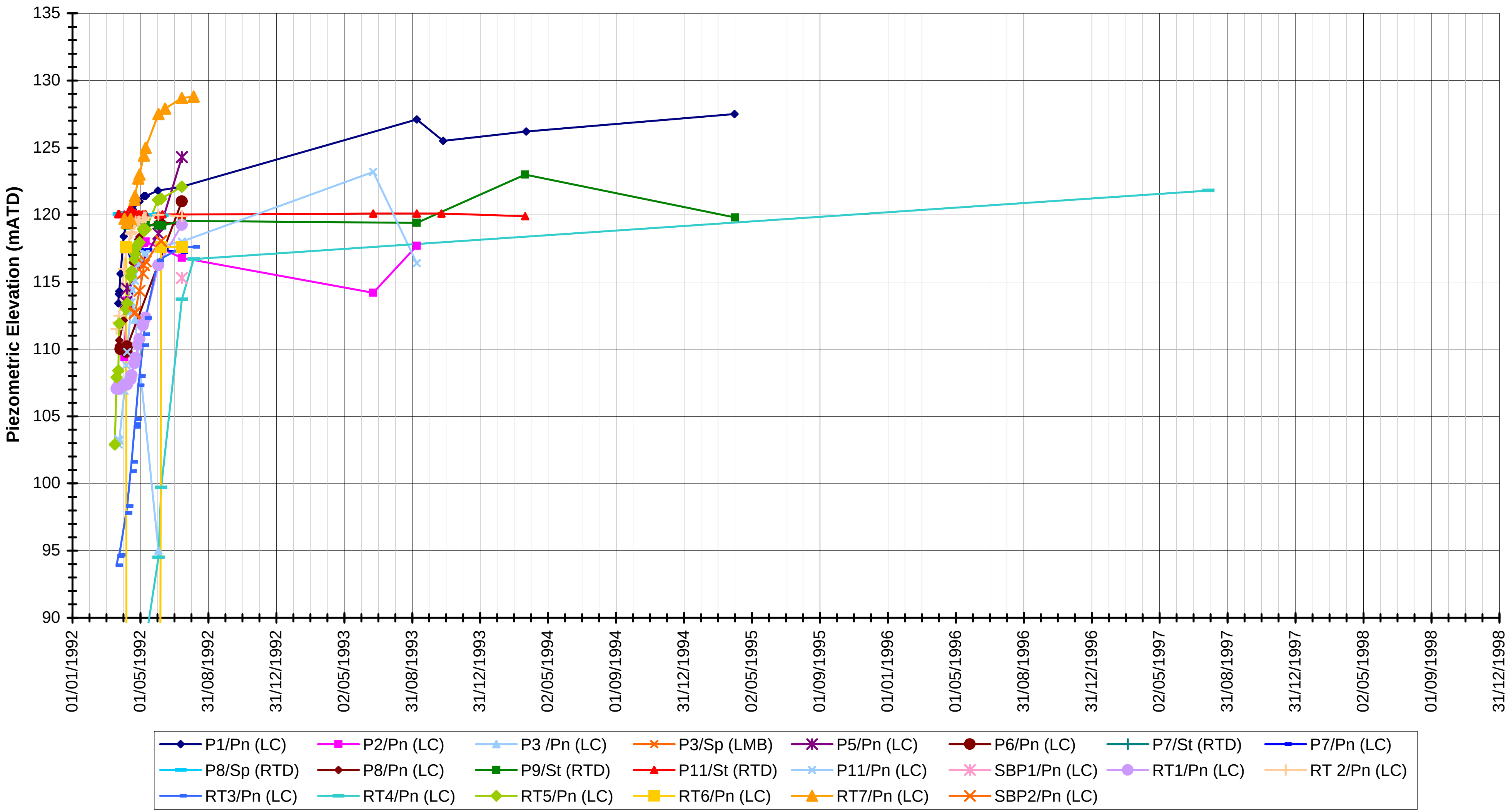
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	Borehole NW18R (RTD/CK) - Piezometric Data - Example Piezometric Response to Tidal Variations	**4.7.5**

APPENDIX A:

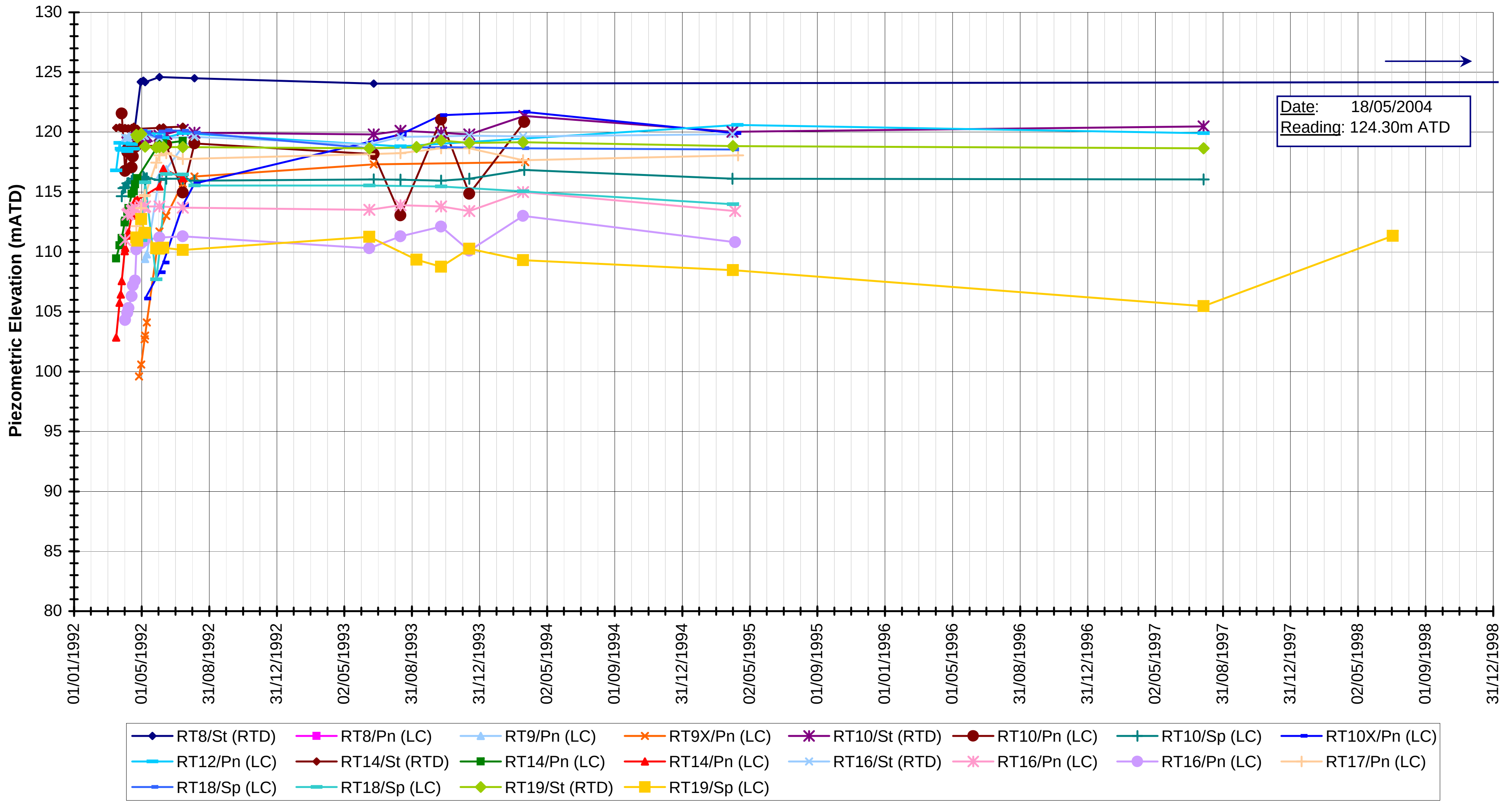
Crossrail Piezometers – Digital Data

APPENDIX B:

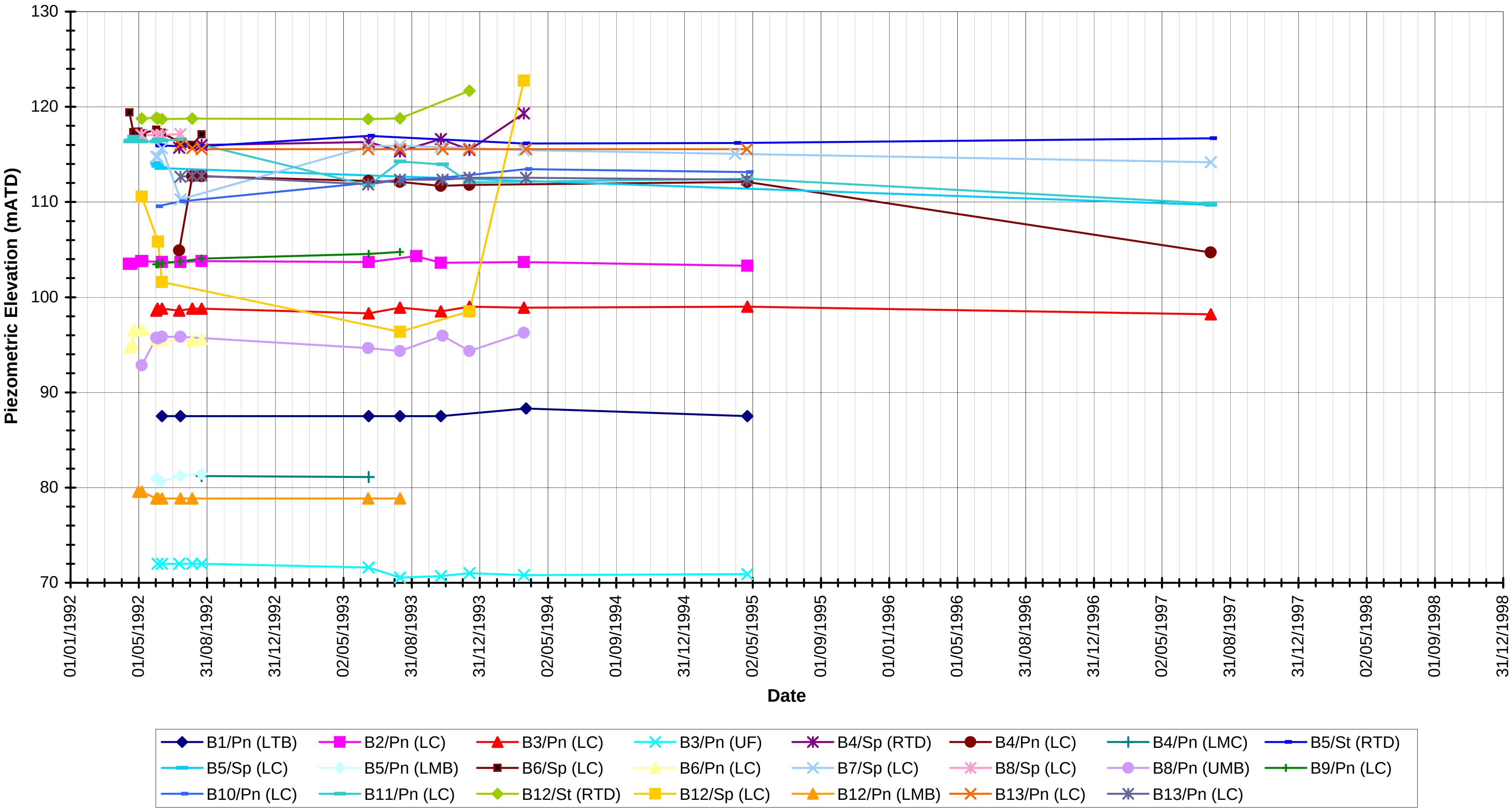
Piezometric groundwater levels of the Piezometers Installed during the 1992 Crossrail Ground Investigations



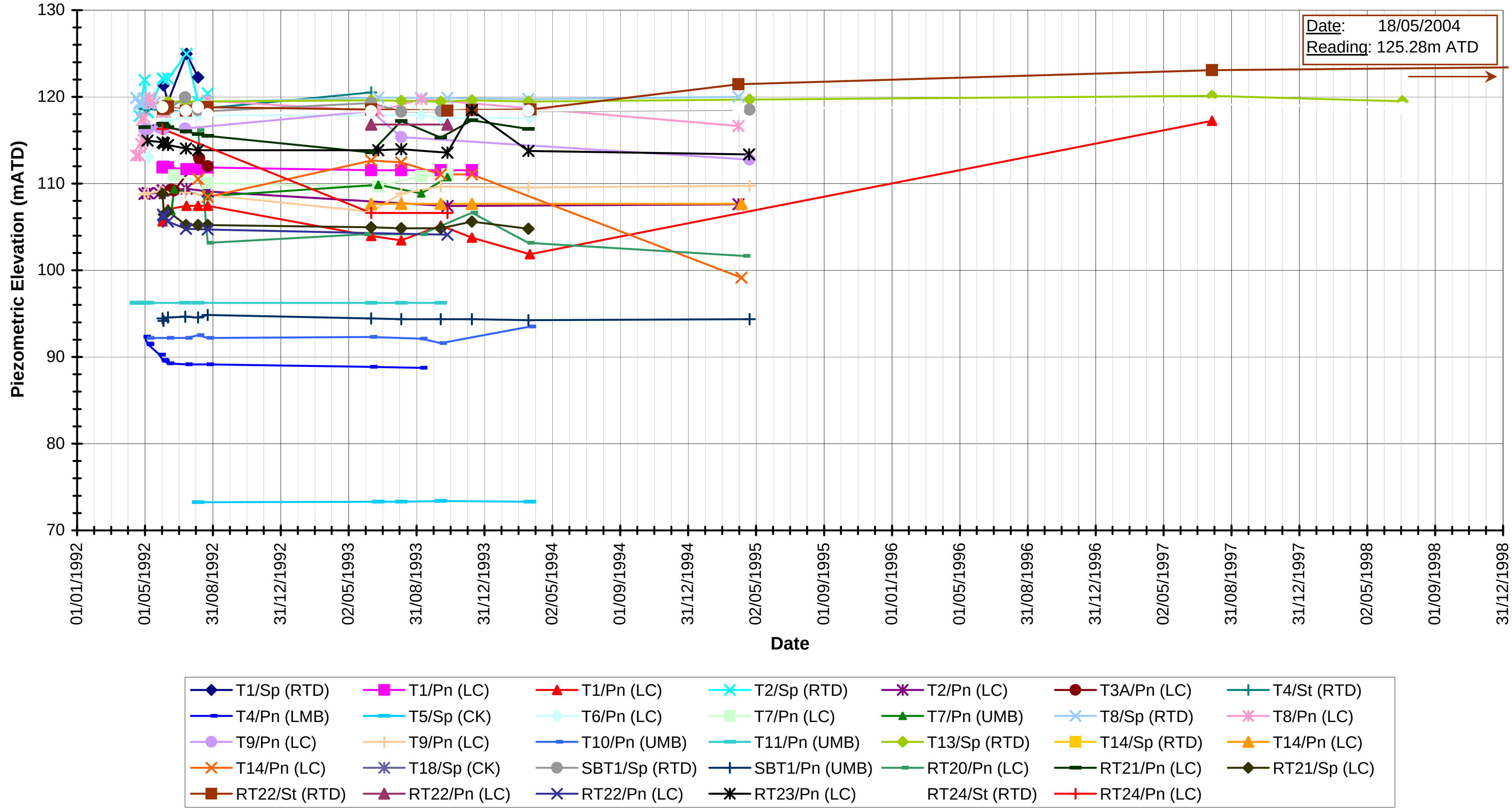
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Westbourne Park to Paddington	**B1**



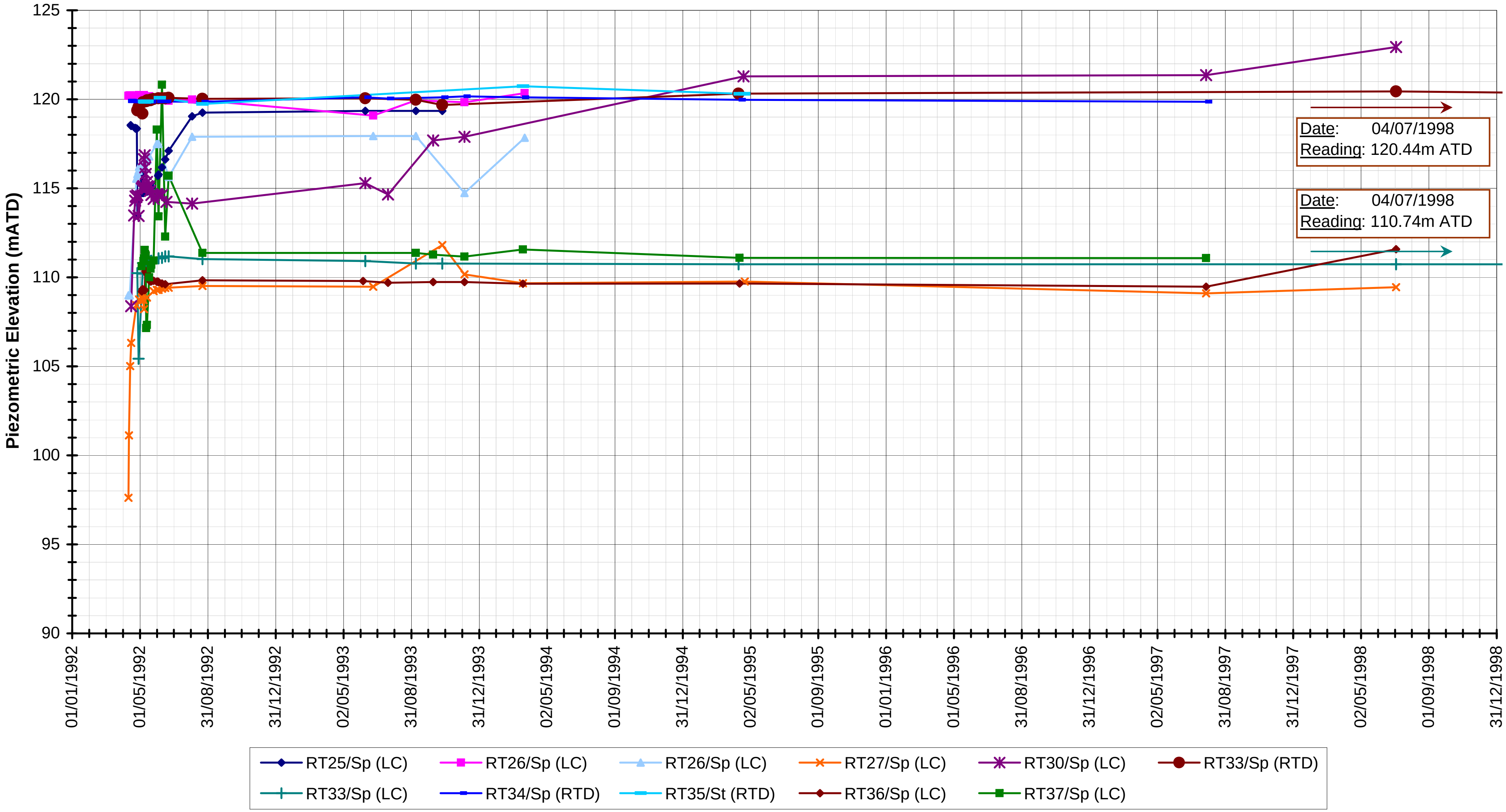
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Praed Street to Balderton Street	**B2**



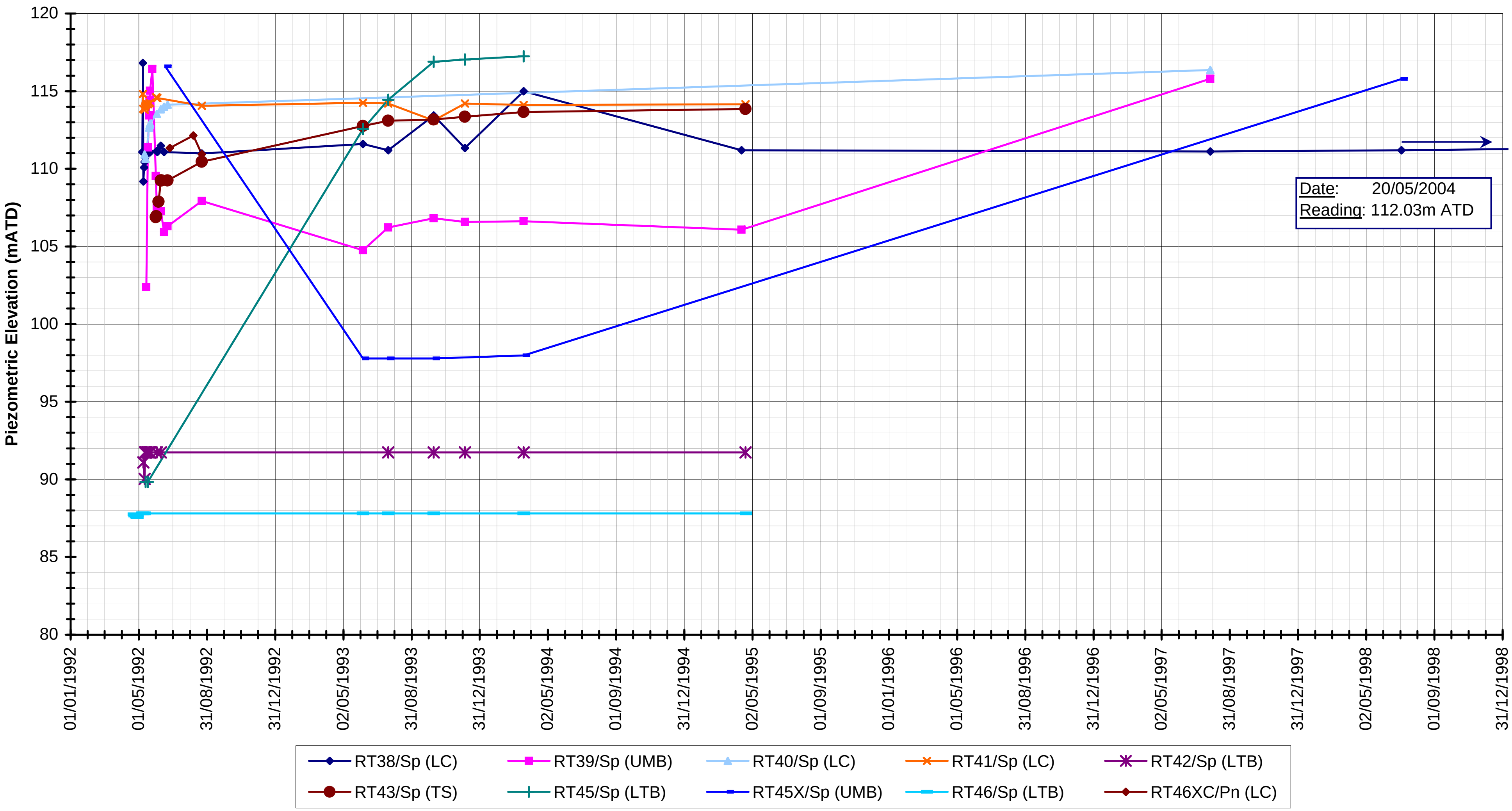
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Bond Street Station	**B3**



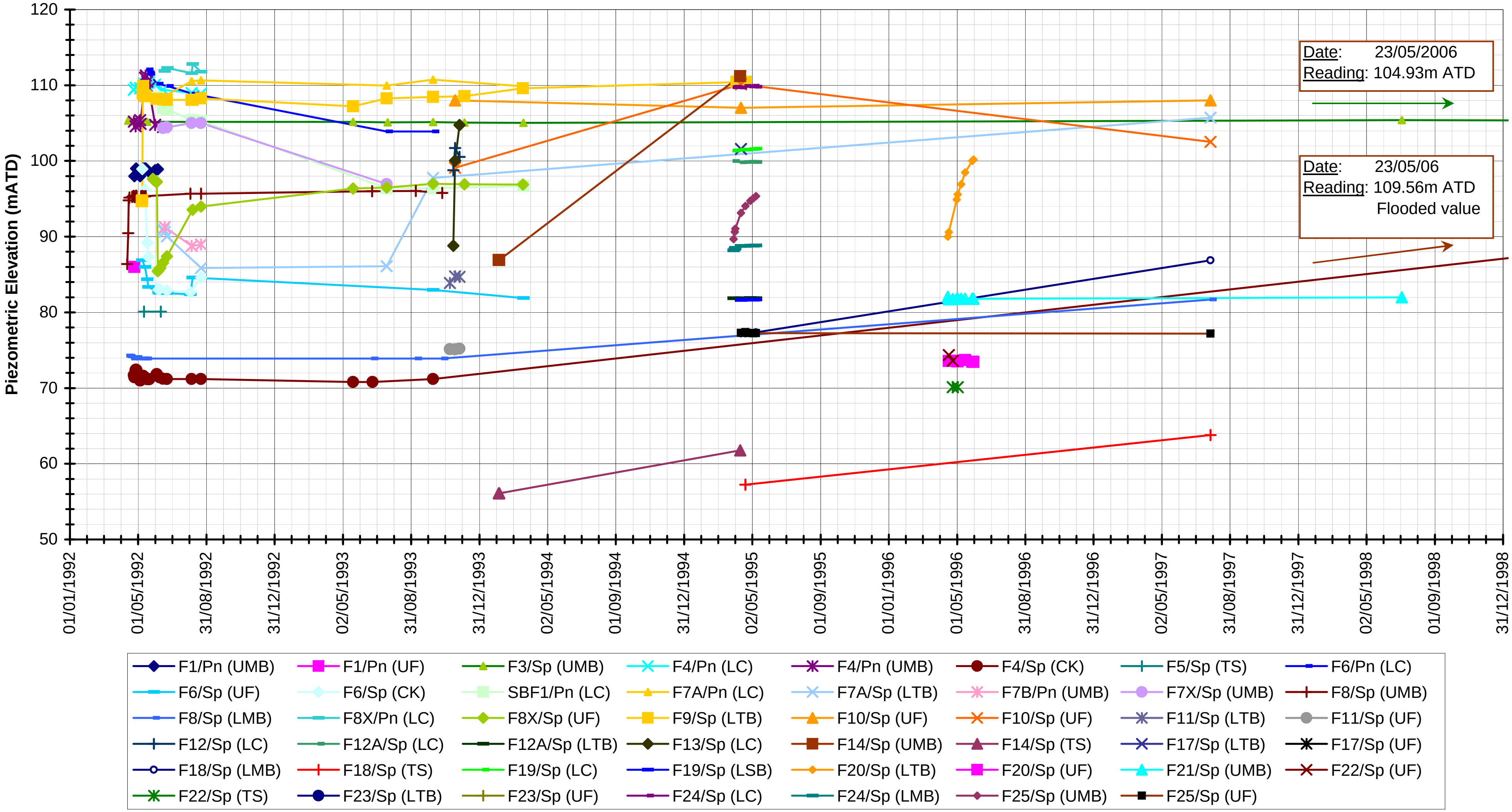
	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Argyll Street to Tottenham Court Road Station	**B4**



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Charing Cross Road to Red Lion Square	**B5**



Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**	
1992 Piezometric Data Red Lion Square to Farringdon Road	**B6**	



Crossrail Limited
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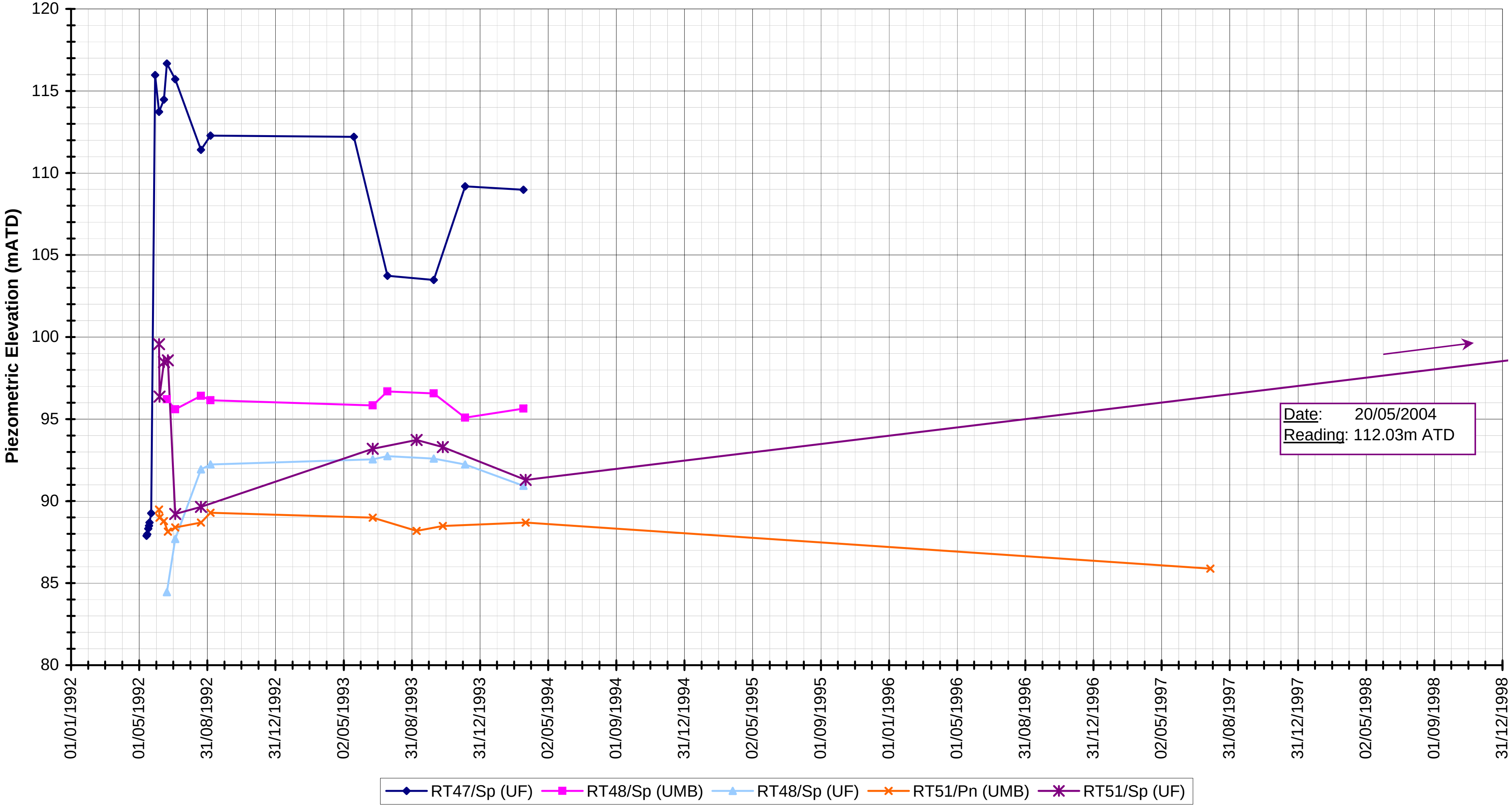
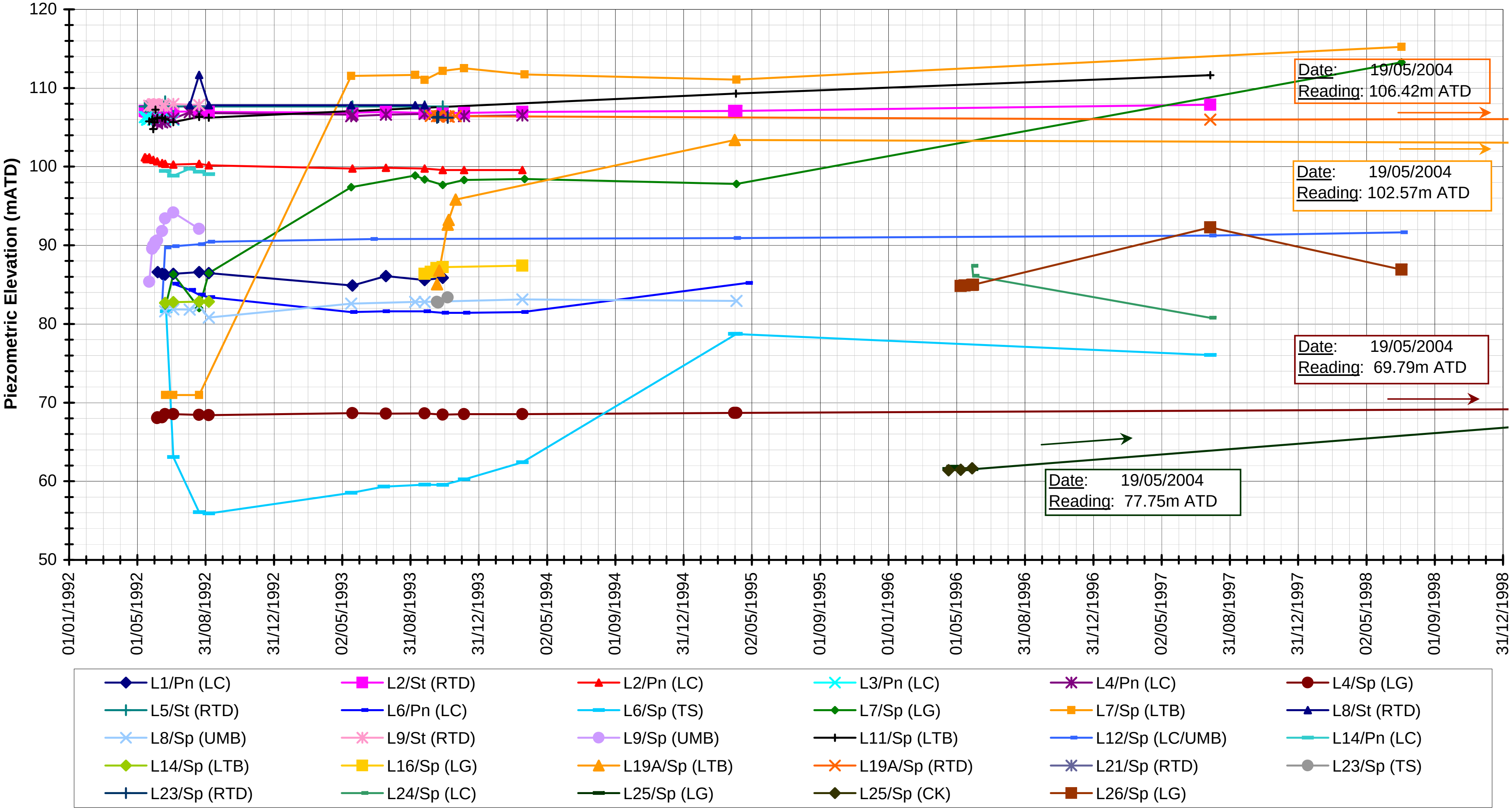
1992 Piezometric Data
Farringdon Station

Figure

B7



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Aldersgate Street to Moor Lane	**B8**



Crossrail Limited
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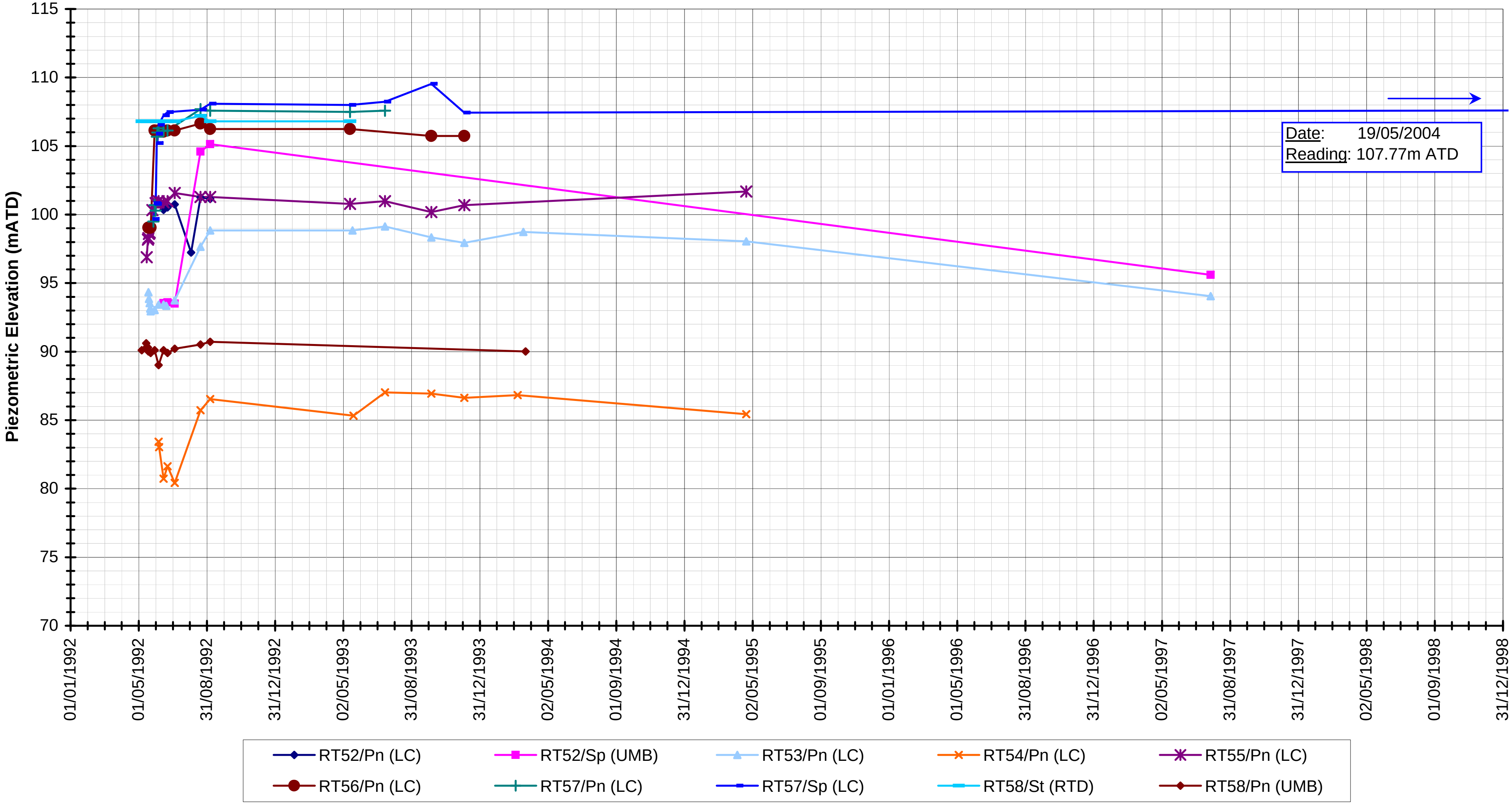
1992 Piezometric Data
Liverpool Street Station

Figure

B9



Crossrail Limited
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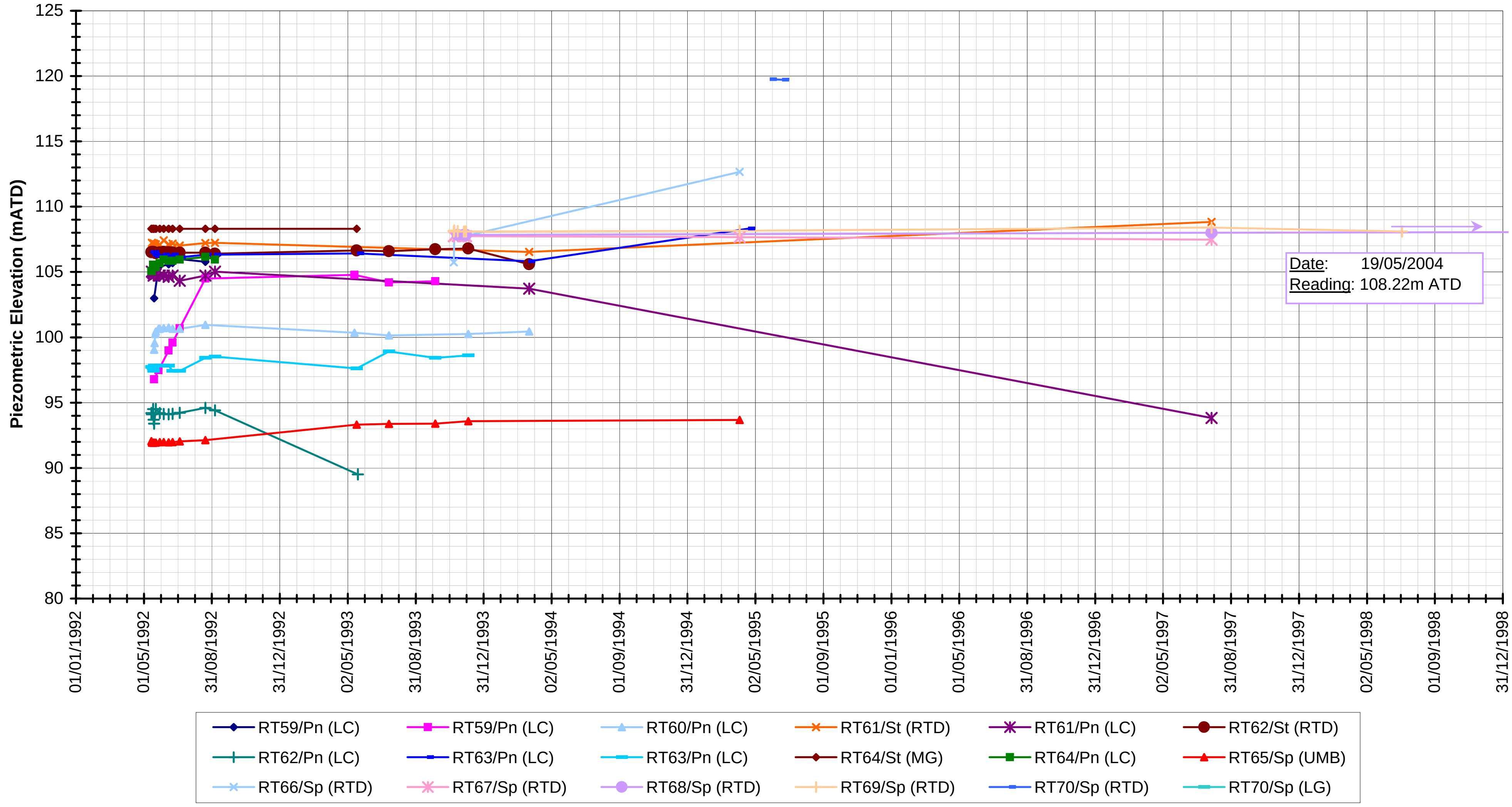
1992 Piezometric Data
Bishopsgate to Allen Gardens

Figure

B10



	Crossrail Limited Crossrail - Groundwater Monitoring Report - Revision 2	**Figure**
	1992 Piezometric Data Allen Gardens to Vallance Road	**B11**

APPENDIX C:

Summary of Problems Identified with Piezometers Installed during the 1992 Crossrail Ground Investigations

BH No.	Piezo Type	Coordinates		Location	CrossRail (historic)			Norwest Holst (May 2004)			GCG (May 2006)			GCG (Dec 2006)			GCG (June 2008)			GCG (March 2010)		GCG (September 2010)		GCG (August 2011)		Comments
		Easting	Northing		Operation	Depth to tip (m)	Water level (m)	Operation	Depth to tip (m)	Water level (m)	Operation	Depth to tip (m)	Water level (m)	Operation	Depth to tip (m)	Water level (m)	Operation	Depth to tip (m)	Water level (m)	Operation	Piezometer Status	Operation	Piezometer Status	Operation	Piezometer Status	
Paddington Station																										
P1	Pn	76761.48	36250.52	Eastbourne Terrace (opposite No.10)	NW	16.90	destroyed	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
P2	Pn	76806.47	36180.36	Eastbourne Terrace (opposite No.30)	NW	27.00	18.10	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
P3	Pn	76842.28	36161.32	Eastbourne Terrace (outside No.20)	NW	48.50	17.00	NL	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
P3	Sp	76842.28	36161.32	Eastbourne Terrace (outside No.20)	NW	73.40	flooded/silted	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
P5	Pn	76937.72	36034.66	Eastbourne Terrace (outside No.50)	NW	19.00	damaged	NL	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
P6	Pn	76867.64	36111.43	Eastbourne Terrace (outside No.40)	NW	34.80	broken	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
P7	St	76992.28	36114.7	Paddington Station BR (Lawn concourse)	?	4.30	dry	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Lawn no longer exists. Area developed into shopping centre.
P7	Pn	76992.28	36114.7	Paddington Station BR (Lawn concourse)	?	38.50	32.00	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Lawn no longer exists. Area developed into shopping centre.
P8	Sp	76980.5	36139.98	Paddington Station BR (Lawn concourse)	?	3.85	3.80	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Lawn no longer exists. Area developed into shopping centre.
P8	Pn	76980.5	36139.98	Paddington Station BR (Lawn concourse)	?	13.80	9.30	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Lawn no longer exists. Area developed into shopping centre.
P9	St	77027.62	36060.33	Praed Street (outside GWR Hotel)	?	6.80	6.10	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV		Area resurfaced.
P11	St	76945.02	36189.66	Paddington Station BR (platform)	?	4.80	3.90	SNV			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV		
P11	Pn	76945.02	36189.66	Paddington Station BR (platform)	?	20.90	13.50	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
SBP1	Pn	76870.04	36109.63	Eastbourne Terrace (outside No.40)	?	22.10	broken	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
SBP2	Pn	76132.23	36463.62	London Taxi area	?	10.00	6.40	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
Bond Street Station																										
B1	Pn	78803.48	35841.68	Gilbert Street (outside Moore Flats)	?	33.50	waterlogged	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
B2	Pn	78892.31	35889.11	South Molton Street (outside No.36)	NW	24.50	destroyed	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
B3	Pn	78886.18	35855.12	Davies Street (corner of South Molton Lane)	OK	20.50	destroyed	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
B3	Pn	78886.18	35855.12	Davies Street (corner of South Molton Lane)	OK	47.80	destroyed	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
B4	Sp	78888.1	35815.89	Davies Street (outside No.65)	OK	6.50	dry	NL			SNV			SNV			SNV			SNV	not located/considered destroyed	SNV	not located/considered destroyed	SNV	Considered Destroyed	Road resurfaced
B4	Pn	78888.1	35815.89	Davies Street (outside No.65)	OK	16.00	broken?	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
B4	Pn	78888.1	35815.89	Davies Street (outside No.65)	NW	39.50	broken	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
B5	St	78843.05	35787.61	St. Anselm's Place (opposite No.27)	OK	5.90	tarmaced over	NL			SNV			SNV			SNV			SNV	tarmaced over	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
B5	Sp	78843.05	35787.61	St. Anselm's Place (opposite No.27)	OK	22.00	tarmaced over	NL			SNV			SNV			SNV			SNV	tarmaced over	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
B5	Pn	78843.05	35787.61	St. Anselm's Place (opposite No.27)	NW	38.50	broken	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
B6	Sp	78949.28	35846.08	South Molton Street (outside No.50)	NW	13.00	damaged	NL			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
B6	Pn	78949.28	35846.08	South Molton Street (outside No.50)	NW	30.50	broken	NL	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
B7	Sp	79048.54	35812.56	Haunch of Venison Yard (outside No.3)	OK	23.00	tarmaced over	NL			NL			SNV			SNV			SNV	tarmaced over	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
B8	Sp	79124.12	35875.33	Tenterden Street (outside No.1)	NW	11.00	destroyed	NL			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
B8	Pn	79124.12	35875.33	Tenterden Street (outside No.1)	OK	35.50	not located	NL	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
B9	Pn	79200.76	35853.85	Hanover Square (outside No.20)	NW	28.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
B10	Pn	79198.2	35907.8	Hanover Square (outside No.15)	?	22.00	10.90	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
B11	Pn	79161.13	35806.31	Brook Street (outside No.8 to 12)	OK	12.30	0.10	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Last reading considered unreliable.
B12	St	79265.5	35854.07	Hanover Square (opposite No.4)	NW	6.80	tarmaced over	NL			NL			SNV			SNV			SNV	tarmaced over	SNV	Considered Destroyed	SNV	Considered Destroyed	Inspection is blocked by car
B12	Sp	79265.5	35854.07	Hanover Square (opposite No.4)	NW	27.00	tarmaced over	NL			NL			SNV			SNV			SNV	tarmaced over	SNV	Considered Destroyed	SNV	Considered Destroyed	Inspection is blocked by car
B12	Pn	79265.5	35854.07	Hanover Square (opposite No.4)	NW	44.50	broken	NL	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Inspection is blocked by car
B13	Pn	79370.8	35869.74	Hanover Square (opposite No.20)	NW	9.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
B13	Pn	79370.8	35869.74	Hanover Square (opposite No.20)	NW	18.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
SBB1	Pn	78887.09	35818.85	Davies Street (outside No.65)	?	18.00	obstructed	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
Tottenham Court Road Station																										
T1	Sp	79943.33	35976.02	Carlisle Street (outside No.4)	?	8.70	not located	NL			NL			SNV			SNV			SNV	not located	SNV	not located	SNV		
T1	Pn	79943.33	35976.02	Carlisle Street (outside No.4)	NW	13.50	broken	NL	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
T1	Pn	79943.33	35976.02	Carlisle Street (outside No.4)	OK	23.50	not located	NL	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
T2	Sp	79882.12	36070.4	Great Chapel Street (outside No.3 to 4)	NW	9.30	silted	NL			SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
T2	Pn	79882.12	36070.4	Great Chapel Street (outside No.3 to 4)	?	21.90	no return flow	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
T3A	Pn	79918.2	36077.6	Dean Street (outside No.1)	NW	18.00	broken	SNV	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
T4	St	79894.06	36019.37	Great Chapel Street (outside No.15 to 19)	NW	8.30	broken	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
T4	Pn	79894.06	36019.37	Great Chapel Street (outside No.15 to 19)	NW	39.50	broken	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
T5	Sp	80043.92	36062.64	Soho Square (opposite No.14)	OK	51.50	blocked	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
T6	Pn	80037.78	35975.87	Soho Square (opposite No.30)	?	15.90	8.80	SNV	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
T7	Pn	80157.5	36073.2	Sutton Row (next to the Astoria)	NW	20.50	broken	SNV	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
T7	Pn	80157.5	36073.2	Sutton Row (next to the Astoria)	NW	28.85	broken	SNV	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
T8	Sp	80216.9	36009.1	Denmark Street (outside No.19)	?	5.00	4.76	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
T8	Pn	80216.9	36009.1	Denmark Street (outside No.19)	?	17.00	8.90	NL	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
T9	Pn	80131.87	36097.75	Falconberg Mews (next to the Astoria)	?	12.00	not located	SNV	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
T9	Pn	80131.87	36097.75	Falconberg Mews (next to the Astoria)	?	19.00	not located	SNV	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
T10	Pn	80003.79	36093.43	Soho Street (outside No.11)	?	34.50	no return flow	SNV	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
T11	Pn	80069.04	36098.43	Falconberg Mews (behind 16 Soho Square)	?	28.00	not located	SNV	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
T13	Sp	80129.05	36054	Sutton Row (outside St. Patrick's Church)	OK	5.30	5.25	SNV			NL			SNV			SNV			SNV	not located	SNV	not located	SNV		
T14	Sp	80151.06	36011.35	Goslett Yard	?	6.40	flooded	NL			NW		Flooded	NW			NW			NW	not located	NW	not located	SNV		Road resurfaced
T14	Pn	80151.06	36011.35	Goslett Yard	NW	17.00	destroyed	NL	-		NW		Flooded	NW			NW			NW	Destroyed	NW	Destroyed	NW	Destroyed	Road resurfaced
T14	Pn	80151.06	36011.35	Goslett Yard	NW	25.60	destroyed	NL	-		NW		Flooded	NW			NW			NW	Destroyed	NW	Destroyed	NW	Destroyed	Road resurfaced
T18	Sp	79902.69	36008.54	Great Chapel Street (outside No.10 to 12)	NW	65.00	destroyed	SNV			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
SBT1	Sp	80136.24	36099.18	Falconberg Mews (next to the Astoria)	?	6.40	not located	SNV			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
SBT1	Pn	80136.24	36099.18	Falconberg Mews (next to the Astoria)	?	30.50	not located	SNV	-		NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
Farringdon Station																										
F1	Pn	81889.6	36448.2	Farringdon Road (opposite No.2)	NW	19.50	no return flow	SNV	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F1	Pn	81889.6	36448.2	Farringdon Road (opposite No.2)	NW	30.50	no return flow	SNV	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F3	Sp	81956.8	36597.3	Turnmill Street (outside No.94 to 98)	?	14.80	6.10	NL			OK	13.80	6.55	OK	13.80	6.57	OK	13.82	6.53	OK?		OK?		OK?		Piezo functional - blocked at 13.8m?Scheduled to be fixed Ref. [34].
F4	Pn	82016.1	36557.8	Cowcross Street (outside No.67 to 69)	NW	8.00	broken	SNV	-		NW			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F4	Pn	82016.1	36557.8	Cowcross Street (outside No.67 to 69)	NW	20.00	broken	SNV	-		NW			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F4	Sp	82016.1	36557.8	Cowcross Street (outside No.67 to 69)	OK	41.70	dry	SNV			OK	41.80	3.43	NW			NW			?		NW	Destroyed	NW	Destroyed	Not possible to remove the blockage during the 2010 piezometer remediation works
F5	Sp	81976.25	36516.5	LUL Operational Land	?	26.50	no access	SNV			SNV			SNV			SNV			SNV	no access	SNV	no access	SNV		Access issue
F6	Pn	82171.4	36524.5	Charterhouse Street (outside No.89)	NW	11.50	broken	NL	-		NW			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F6	Sp	82171.4	36524.5	Charterhouse Street (outside No.89)	NW	37.00	destroyed	NL			NW			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F6	Sp	82171.4	36524.5	Charterhouse Street (outside No.89)	NW	51.20	destroyed?	NL			NW			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F7A	Pn	82176.8	36525.7	Charterhouse Street (outside No.89)	?	8.50	no return flow	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
F7A	Sp	82176.8	36525.7	Charterhouse Street (outside No.89)	OK	32.50	blocked	NL			SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
F7B	Pn	82175.6	36525.2	Charterhouse Street (outside No.89)	?	27.00	blocked	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F7X	Sp	82148.6	36585.8	St. John Street (opposite No.22)	NW	34.50	tarmaced over	NL			OK	32.70	27.92	OK	32.63	27.84	SNV			OK?	blocked	OK?	blocked	OK	Functional	Piezo flushed Ref. [40]
F8	Sp	82295.8	36532.1	Lindsey Street (behind No.4)	?	25.50	blocked	NL			SNV			OK	24.61	11.85	SNV			SNV	blocked	SNV	blocked	SNV	blocked	blocked? Piezo likely to be functional. Access issue.
F8	Sp	82295.8	36532.1	Lindsey Street (behind No.4)	OK	35.00	27.20	NL			SNV			OK	34.00	dry	SNV			SNV		SNV		SNV		blocked? Piezo likely to be functional. Access issue.
F8X	Pn	82229.8	36567.2	Charterhouse Street (opposite No.107)	NW	18.00	damaged	NL	-		NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced.
F8X	Sp	82229.8	36567.2	Charterhouse Street (opposite No.107)	?	37.00	destroyed	NL			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced.
F9	Pn	82311.9	36584.2	Charterhouse Square (opposite No.33)	?	17.00	?	NL	-		NW			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F9	Sp	82311.9	36584.2	Charterhouse Square (opposite No.33)	NW	35.50	destroyed	NL			NW			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F10	Sp	82055.4	36520	Courtyard to rear of 70-77 Cowcross Street	OK	27.70	not located	SNV			NW			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Piezo blocked and flooded; headworks good condition
F10	Sp	82055.4	36520	Courtyard to rear of 70-77 Cowcross Street	OK	30.80	not located	SNV			NW			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Piezo blocked and flooded; headworks good condition
F11	Sp	82099.72	36551.56	Cowcross Street (opposite Peter's Lane)	NW	32.70	destroyed	SNV			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F11	Sp	82099.72	36551.56	Cowcross Street (opposite Peter's Lane)	NW	40.00	destroyed	SNV			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F12	Sp	82093.97	36416.98	Basement of Smithfield Market (beneath East Poultry Avenue)	?	14.50	not located	SNV			SNV			SNV			SNV			SNV		SNV		SNV		
F12A	Sp	82157	36411	Basement of Smithfield Market (beneath West Smithfield)	?	16.00	not located	NL			SNV			SNV			SNV			SNV		SNV		SNV		
F12A	Sp	82157	36411	Basement of Smithfield Market (beneath West Smithfield)	?	29.40	not located	NL			SNV			SNV			SNV			SNV		SNV		SNV		
F13	Sp	82274.3	36545.25	Basement of Smithfield Market (adjoining LUL operational land)	?	20.20	not located	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F14	Sp	82295.22	36491.66	Lindsey Street (outside No.2)	?	39.00	4.90	NL			NL			SNV			SNV			SNV		SNV		SNV		Last reading not considered reliable.
F14	Sp	82295.22	36491.66	Lindsey Street (outside No.2)	?	60.00	54.31	NL			NL			SNV			SNV			SNV		SNV		SNV		
F17	Sp	81967.85	36572.06	Turnmill Street (outside No.101 to 102)	?	20.00	not located	SNV			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F17	Sp	81967.85	36572.06	Turnmill Street (outside No.101 to 102)	?	26.00	not located	SNV			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F18	Sp	82165	36361	West Smithfield (west side of spiral car park ramp)	OK	39.00	not located	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F18	Sp	82165	36361	West Smithfield (west side of spiral car park ramp)	OK	54.18	not located	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F19	Sp	82223	36383	West Smithfield (east side of spiral car park ramp)	?	22.92	not located	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F19	Sp	82223	36383	West Smithfield (east side of spiral car park ramp)	OK	37.10	not located	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
F20	Sp	82078.5	36341.24	Smithfield Street Car Park (northern corner)	?	34.00	13.06	NL			NL			SNV			SNV			SNV	no access	SNV	no access	SNV	no access	
F20	Sp	82078.5	36341.24	Smithfield Street Car Park (northern corner)	?	40.00	39.81	NL			NL			SNV			SNV			SNV	no access	SNV	no access	SNV	no access	
F21	Sp	82087.08	36284.63	Hosier Lane Car Park (north west corner)	OK	38.00	30.38	SNV			NL			SNV			SNV			SNV	no access	SNV	no access	SNV	no access	
F22	Sp	81975.07	36290.9	Corp. of London salt store (beneath corner West Smithfield/Snow Hill)	?	32.00	no access	NL			NL			SNV			SNV			SNV	no access	SNV	no access	SNV	no access	
F22	Sp	81975.07	36290.9	Corp. of London salt store (beneath corner West Smithfield/Snow Hill)	?	35.50	no access	NL			NL			SNV			SNV			SNV	no access	SNV	no access	SNV	no access	
F23	Sp	81945.86	36329.28	Snow Hill underground car park (west side)	?	23.50	not located	NL			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
F23	Sp	81945.86	36329.28	Snow Hill underground car park (west side)	?	28.60	not located	NL			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
F24	Sp	82045	36636	Britton Street (near corner with Eagle Court)	NW	11.96	destroyed	SNV			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F24	Sp	82045	36636	Britton Street (near corner with Eagle Court)	NW	28.49	destroyed	SNV			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
F25	Sp	82156	36599	St. John Street (opposite No.30)	?	30.25	blocked	SNV			NW	2.70	-	NW	2.40	-	?	11.66	Dry	NW	Destroyed	NW	Destroyed	NW	Destroyed	Not possible to remove the blockage during the 2010 piezometer remediation works. Refer to Ref. [40].
F25	Sp	82156	36599	St. John Street (opposite No.30)	OK	40.15	blocked	SNV			?	37.50	Dry	NW	36.99	Dry	?	36.74	36.72	NW	Destroyed	NW	Destroyed	NW	Destroyed	Not possible to remove the blockage during the 2010 piezometer remediation works. Refer to Ref. [40].
SBF1	Pn	82175.8	36526.4	Charterhouse Street (outside No.89)	NW	20.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Latter readings not considered reliable.
Liverpool Street Station																										
L1	Pn	82976.64	36317.09	Fore Street Avenue (next to Moor House)	NW	35.00	damaged	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	
L2	St	82999.86	36263.97	London Wall (junction with Coleman Street)	OK	6.20	not located	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
L2	Pn	82999.86	36263.97	London Wall (junction with Coleman Street)	NW	24.00	destroyed	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
L3	Pn	83032.8	36296.94	Moorfields (outside No.4)	NW	15.00	concreted	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	concreted
L4	Pn	83072.89	36418.54	Moorfields (outside Moorfields House)	NW	8.50	destroyed	OK	-		SNV			SNV			SNV			NW	Destroyed	NW	Destroyed	NW	Destroyed	
L4	Sp	83072.89	36418.54	Moorfields (outside Moorfields House)	OK	46.00	blocked at 29.5m?	OK	46.30	45.65	SNV			SNV			SNV			NW	Destroyed	NW	Destroyed	NW	Destroyed	
L5	St	83154.35	36441.34	South Place (outside No.16)	NW	6.50	tarmaced over	NL			SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced.
L6	Pn	83154.34	36312.42	Finsbury Circus (opposite Salisbury House)	NW	35.00	destroyed	NL	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
L6	Sp	83154.34	36312.42	Finsbury Circus (opposite Salisbury House)	OK	63.50	not located	NL			NL			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced
L7	Sp	83268.8	36318.03	Finsbury Circus (opposite No.18)	?	37.00	0.21	NL			SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced. Last reading considered unreliable.

BH No.	Piezo Type	Coordinates Easting	Coordinates Northing	Location	CrossRail (historic) Operation	Depth to tip (m)	Water level (m)	Norwest Holst (May 2004) Operation	Depth to tip (m)	Water level (m)	GCG (May 2006) Operation	Depth to tip (m)	Water level (m)	GCG (Dec 2006) Operation	Depth to tip (m)	Water level (m)	GCG (June 2008) Operation	Depth to tip (m)	Water level (m)	GCG (March 2010) Operation	Piezometer Status	GCG (September 2010) Operation	Piezometer Status	GCG (August 2011) Operation	Piezometer Status	Comments
L7	Sp	83268.8	36318.03	Finsbury Circus (opposite No.18)	?	42.50	0.21	NL			SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	Road resurfaced. Latter readings considered unreliable.
L8	St	83212.67	36261.23	Finsbury Circus (outside London Wall Buildings)	OK	5.50	dry	OK	5.75	Dry	OK	5.57	Dry	OK	5.64	Dry	OK	5.66	Dry	OK		OK		NW	Destroyed	Piezo functional.
L8	Sp	83212.67	36261.23	Finsbury Circus (outside London Wall Buildings)	?	41.00	dry	NW	16.70	Dry	NW	16.56	Dry	NW	16.00	Dry	NW	16.64	Dry	?		NW	Considered Destroyed	NW	Considered Destroyed	Piezometer flushed to remove blockage. RHT carried out to test functionality. See Ref. [47] for more details.
L9	St	83313.36	36234.26	Blomfield Street (opposite No.4)	NW	5.50	dry at 5.75m	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced.
L9	Sp	83313.36	36234.26	Blomfield Street (opposite No.4)	NW	42.00	destroyed	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced.
L11	Sp	83397.39	36292.62	Liverpool Street (opposite No.1)	OK	43.50	destroyed	NL			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced.
L12	Sp	83528.93	36200.73	Alderman's Walk (outside White Hart Court)	OK	40.50	23.78	SNV			NW	25.65	22.99	NW	25.65	23.70	SNV			?		NW	Considered Destroyed	NW	Considered Destroyed	Piezometer flushed to remove blockage. RHT carried out to test functionality. See Ref. [47] for more details.
L14	Pn	83571.96	36135.93	Bishopsgate (outside No.106)	NW	28.00	tarmaced over	NL	-		SNV			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced.
L14	Sp	83571.96	36135.93	Bishopsgate (outside No.106)	NW	44.00	tarmaced over	NL			SNV			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced.
L15A	Sp	83544.38	36230.42	Liverpool Street (outside No.32)	OK	40.00	?	SNV			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
L16	Sp	83514.1	36220.39	Liverpool Street Station Met/Circle Line platform No.2	NL	33.20	not located	SNV			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
L19A	Sp	83389.64	36242.49	Broad Street Avenue (end of cul-de-sac)	OK	7.50	7.48	OK	7.50	7.17	OK	7.39	7.05	OK	7.39	7.13	OK	7.45	7.16	OK		OK		OK		Piezo functional
L19A	Sp	83389.64	36242.49	Broad Street Avenue (end of cul-de-sac)	OK	43.20	10.07	OK	43.05	11.11	OK	42.97	11.19	OK	42.97	11.22	OK	45.92	10.01	OK		OK?		OK?	Under Observation	Piezometer flushed to remove blockage. RHT carried out to test functionality. See Ref. [40] and [47] for more details.
L21	Sp	83073.53	36361.26	Moor Place (south side)	OK	7.40	dry	SNV			OK	7.23	Dry	OK	7.25	Dry	SNV			OK		OK		NW	Destroyed	
L23	Sp	83050.47	36339.61	Moorfields (outside No.16)	NW	7.60	tarmaced over	NL			NL			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced
L23	Sp	83050.47	36339.61	Moorfields (outside No.16)	NW	61.30	tarmaced over	NL			NL			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced
L24	Sp	83033.7	36305.63	Fore Street Avenue (outside No.6)	OK	36.60	not located	NL			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
L25	Sp	83071.93	36361.65	Moor Place (south side)	?	52.50	dry at 31.5m	NW	40.16	36.40	NW	4.96	Dry	NW	4.96	Dry	NW	4.96	Dry	OK?		OK?		OK		Piezometer flushed to remove blockage. RHT carried out to test functionality. See Ref. [40] and [47] for more details.
L25	Sp	83071.93	36361.65	Moor Place (south side)	?	70.50	dry at 31.5m	NW	43.30	Dry	NW	4.89	Dry	NW	4.89	Dry	NW	4.89	Dry	NW		NW	Destroyed	NW	Destroyed	Piezo blocked. Not possible to remove blocakage. See Ref. [40] and [47] for more details.
L26	Sp	83067.45	36405.22	Moorfields (south of Moorfields House)	OK	33.70	26.59	NL			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
SBL2	Pn	84353.56	36796.6	Allen Gardens (off Eckersley Street)	NW	27.00	?	SNV	-		SNV			SNV			SNV			SNV	Considered Destroyed	SNV	Considered Destroyed	SNV	Considered Destroyed	

Running Tunnels

BH No.	Piezo Type	Easting	Northing	Location	CrossRail Operation	Depth to tip (m)	Water level (m)	Norwest Holst Operation	Depth to tip (m)	Water level (m)	GCG (May 2006) Operation	Depth to tip (m)	Water level (m)	GCG (Dec 2006) Operation	Depth to tip (m)	Water level (m)	GCG (June 2008) Operation	Depth to tip (m)	Water level (m)	GCG (March 2010) Operation	Piezometer Status	GCG (September 2010) Operation	Piezometer Status	GCG (August 2011) Operation	Piezometer Status	Comments
RT1	Pn	75930.84	36489.79	BR Operational Land	?	14.90	12.20	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT2	Pn	76058.64	36471.12	BR Operational Land	?	10.20	8.50	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT3	Pn	76129.13	36464.46	London Taxi area	?	27.90	23.90	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT4	Pn	76230.1	36450.14	London Taxi area	OK	34.50	34.50	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT5	Pn	76389.55	36446.36	London Taxi area	NW	19.40	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT6	Pn	76572.64	36424.59	London Taxi area	NW	5.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT7	Pn	76637.29	36340.52	BR Operational Land	?	10.00	9.40	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT8	St	77016.27	35966.1	Spring Street (outside No.30)	NW	6.20	broken	OK	5.40	0.40	NW	4.96	flooded	NL			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Piezometer tarmaced over.
RT8	Pn	77016.27	35966.1	Spring Street (outside No.30)	NW	28.50	destroyed	OK?	-		?			NL			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Piezometer tarmaced over.
RT9	Pn	77069.24	35905.58	Spring Street (near corner of Sussex Gardens)	?	20.00	15.10	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT9X	Pn	77152.61	35780.81	Sussex Square (opposite No.73)	NW	25.00	concreted	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	concreted
RT10	St	77219.93	35777.13	Sussex Square (opposite No.1)	OK	4.70	3.38	NL			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
RT10	Pn	77219.93	35777.13	Sussex Square (opposite No.1)	OK	17.50	no return flow	NL	-		NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
RT10	Sp	77219.93	35777.13	Sussex Square (opposite No.1)	?	32.90	no return flow?	NL			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
RT10X	Pn	77244.42	35693.78	Brook Street (west side)	?	17.50	13.80	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT12	Pn	77572.61	35551.3	Hyde Park (near North Carriage Drive)	OK	19.90	17.60	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT14	St	77955.64	35591.67	Hyde Park (near North Carriage Drive)	NW	4.90	destroyed	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT14	Pn	77955.64	35551.67	Hyde Park (near North Carriage Drive)	NW	15.00	destroyed	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT14	Pn	77955.64	35551.67	Hyde Park (near North Carriage Drive)	NW	29.50	destroyed	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT16	St	78249.38	35632.63	Hyde Park (Park Lane Subway)	NW	8.70	destroyed	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT16	Pn	78249.38	35632.63	Hyde Park (Park Lane Subway)	OK	24.90	broken	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT16	Pn	78249.38	35632.63	Hyde Park (Park Lane Subway)	?	38.50	no return flow	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT17	Pn	78444.76	35721.34	Green Street (outside No.52)	NW	15.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT18	St	78579.15	35708.92	North Audley Street (outside No.39)	?	22.00	blocked at 7.5m	NL			NL			SNV			SNV			SNV	blocked at 7.5m	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced
RT18	Sp	78579.15	35708.92	North Audley Street (outside No.39)	?	36.00	17.76	NL			NL			SNV			SNV			SNV	not located	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced
RT19	St	78681.98	35731.57	George Yard (outside Chesham Flats)	OK	4.90	dry	NL			NL			SNV			SNV			SNV	not located	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced
RT19	Sp	78681.98	35731.57	George Yard (outside Chesham Flats)	OK	28.00	12.22	NL			NL			SNV			SNV			SNV	not located	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced
RT20	Pn	79471.48	35894.66	Argyll Street (outside No.1 to 4)	?	33.50	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT21	Pn	79536.44	35878.38	Great Marlborough Street (outside No.35)	NW	14.30	destroyed	NL	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced.
RT21	Sp	79536.44	35878.38	Great Marlborough Street (outside No.35)	NW	31.50	damaged	NL			SNV			SNV			SNV			SNV	damaged	SNV	damaged	SNV	damaged	Road resurfaced.
RT22	St	79616.19	35928.88	Great Marlborough Street (outside No.49)	OK	7.80	1.82	OK	7.70	0.32	OK	6.50	0.27	OK			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Scheduled to be drilled out during Package 16A Ground Investigation.
RT22	Pn	79616.19	35928.88	Great Marlborough Street (outside No.49)	NW	15.00	damaged	OK?	-		OK?			OK?			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	Scheduled to be drilled out during Package 16A Ground Investigation.
RT22	Pn	79616.19	35928.88	Great Marlborough Street (outside No.49)	NW	27.50	damaged	OK?	-		OK?			OK?			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	Scheduled to be drilled out during Package 16A Ground Investigation.
RT23	Pn	79734.69	35980.79	Noel Street (outside No.19)	?	18.50	no return flow	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT24	St	79819.15	36004.56	Wardour Street (outside No.183)	OK	8.60	6.52	NL?			SNV			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced.
RT24	Pn	79819.15	36004.56	Wardour Street (outside No.183)	NW	25.00	damaged	NL?	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced.
RT25	Sp	80308.8	35946.3	St. Giles Passage	NW	25.50	destroyed	SNV			NL			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
RT26	Sp	80301.1	36069.2	Earnshaw Street (corner of St. Giles High Street)	NW	5.00	tarmaced over	SNV			NL			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced
RT26	Sp	80301.1	36069.2	Earnshaw Street (corner of St. Giles High Street)	NW	16.00	tarmaced over	SNV			NL			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced
RT27	Sp	80369.4	35951.5	Shaftsbury Avenue (opposite The Shaftsbury Hospital)	OK	25.00	13.18	SNV			NL			SNV			SNV			SNV	not located	SNV	not located	SNV		
RT30	Sp	80700.1	36079.1	Macklin Street (opposite No.13)	OK	18.25	0.00	SNV			NL			SNV			SNV			SNV	not located	SNV	Considered destroyed	SNV	Considered destroyed	Latter readings not considered reliable.
RT33	Sp	80863.3	36332.8	Catton Street (corner of Southampton Row)	?	6.00	4.49	NW			OK	5.50	5.42	NL			SNV			SNV	tarmaced over	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced
RT33	Sp	80863.3	36332.8	Catton Street (corner of Southampton Row)	?	19.50	14.19	NW			OK	19.55	14.23	NL			SNV			SNV	tarmaced over	SNV	Considered destroyed	SNV	Considered destroyed	Road resurfaced
RT34	Sp	80778.8	36298.8	Southampton Place (outside No.9)	OK	5.00	4.70	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
RT35	St	80919.2	36429.8	Red Lion Square / Drake Street	NW	6.50	destroyed	?			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Edge of cover tarmaced over - unable to open (2004)
RT36	Sp	81006.9	36379.8	Eagle Street (outside Sunley House)	OK	22.00	13.36	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
RT37	Sp	81094.3	36463	Red Lion Street (outside No.23)	OK	18.50	blocked at 3.25m	NW	6.80	4.12	OK?	6.00	3.10	OK?	6.00	4.65	OK?	6.05	0.75	OK?		OK?		OK	Under Observation	Piezo blocked at 6.0m.Scheduled to be fixed Ref. [34]. Blockage removed Ref. [40].
RT38	Sp	81159.6	36524.3	Bedford Row (outside No.34)	OK	24.00	13.49	OK	23.88	12.66	OK	23.70	10.00	OK	23.68	6.94	OK?	23.73	0.56	OK?		OK		OK		Piezo functioning.Piezometer flushed to remove blockage. RHT carried out to test functionality. See Ref. [40] and [47] for more details.
RT39	Sp	81228.3	36517.2	Jockey's Fields (opposite No.8)	OK	32.00	not located	SNV			NL			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Scheduled to be drilled out during Package 16A Ground Investigation.
RT40	Sp	81293.9	36553.9	Gray's Inn (behind 6 Raymond Buildings)	OK	19.10	4.12	SNV			NL			SNV			SNV			NW		NW		NW		Blocked. Drilled out during Package 16A Ground Investigation.
RT41	Sp	81412.3	36551.1	Gray's Inn Road (opposite No.56)	NW	17.50	destroyed	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Road resurfaced
RT42	Sp	81496.4	36530.3	Baldwin's Gardens (opposite St. Alban's School)	OK	28.00	dry	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
RT43	Sp	81562.5	36498	Dorrington Street (outside Brook's Market)	OK	44.50	dry	NL			OK	42.43	12.17	OK	42.43	12.09	OK	42.46	10.40	OK?	Considered destroyed	OK?	Considered destroyed	OK?	Considered destroyed	Scheduled to be drilled out during Package 16A Ground Investigation.
RT45	Sp	81718.6	36453.9	Hatton Garden (outside No.23)	NW	27.80	destroyed	NL			NW			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Piezos blocked and headworks flooded
RT45X	Sp	81704.3	36522.7	Hatton Garden (outside No.31)	OK	20.00	2.00	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	Road resurfaced
RT46	Sp	81817.8	36465.4	Bleeding Heart Yard (outside No.7)	OK	27.80	dry	OK	28.30	Dry		28.30	Dry		28.30	Dry	SNV			SNV		SNV		NW	Destroyed	Borehole drilled out under Package 16A Ground Investigation.
RT46XC	Pn	81767.5	36528.9	Kirby Street (outside No.36 to 43)	NW	13.00	destroyed	OK?			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	Installation OK, but piezometer not read (2004)
RT47	Sp	82457.86	36610.36	Aldersgate Street (opposite No.131)	NW	50.00	tarmaced over	SNV			NL			SNV			SNV			SNV	tarmaced over	SNV	tarmaced over	SNV	tarmaced over	Road resurfaced
RT48	Sp	82624.11	36500.29	Barbican Complex (outside Defoe House)	?	30.50	not located	SNV			SNV			SNV			SNV			OK?		OK?		NW		Piezometer flushed to remove blockage. RHT carried out to test functionality. See Ref. [40] and [47] for more details.
RT48	Sp	82624.11	36500.29	Barbican Complex (outside Defoe House)	?	40.50	not located	SNV			SNV			SNV			SNV			SNV		SNV		OK?		Piezo functioning
RT51	Pn	82946.39	36453.52	Moor Lane (opposite Willoughby House)	OK	32.50	4.20	OK?	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	Not read (2004)
RT51	Sp	82946.39	36453.52	Moor Lane (opposite Willoughby House)	?	49.00	dry/blocked	NW	15.50	7.00	SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	Piezo blocked at 15.5m (2004)
RT52	Pn	83695.52	36229.81	New Street (outside No.16)	NW	25.00	destroyed	?	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	No access
RT52	Sp	83695.52	36229.81	New Street (outside No.16)	OK	39.00	19.53	?			SNV			SNV			SNV			SNV	to be visited	SNV	Considered destroyed	SNV	Considered destroyed	No access
RT53	Pn	83768.63	36308.77	Middlesex Street (outside No.121)	OK	23.00	broken	NL	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT54	Pn	83932.45	36379	Behind White's Row Car Park	NW	34.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT55	Pn	83971.12	36445.4	Brushfield Street (outside No.61)	?	18.50	no return flow	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT56	Pn	84067.51	36581.2	Hanbury Street (opposite No.4)	?	16.00	no return flow	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT57	Pn	84234.88	36673.93	Brick Lane (outside Truman's Brewery)	NW	15.00	damaged	OK?	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	Pneumatic peizo not read (2004)
RT57	Sp	84234.88	36673.93	Brick Lane (outside Truman's Brewery)	NW	15.00	damaged	OK	14.80	4.82	SNV			SNV			SNV			OK?	to be visited	OK?	to be visited	SNV	to be visited	Piezo fuctioning (2004)
RT58	St	84305.21	36766.1	Buxton Street (corner of Code Street)	OK	5.10	not located	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
RT58	Pn	84305.21	36766.1	Buxton Street (corner of Code Street)	?	34.00	no return flow	NL	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT59	Pn	84349.97	36796.28	Allen Gardens (off Eckersley Street)	NW	10.00	damaged	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT59	Pn	84349.97	36796.28	Allen Gardens (off Eckersley Street)	NW	15.00	damaged	SNV	-		SNV			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT60	Pn	84440.39	36840.27	Pedley Street (next to BR cutting)	NW	24.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT61	St	84488.46	36858.48	Pedley Street (corner of Fleet Street Hill)	OK	6.50	3.20	SNV			SNV			SNV			SNV			SNV	No access	SNV	Considered destroyed	SNV	Considered destroyed	
RT61	Pn	84488.46	36858.48	Pedley Street (corner of Fleet Street Hill)	OK	19.00	0.80	SNV	-		SNV			SNV			SNV			SNV	Damaged/considered Destroyed	SNV	Damaged/considered Destroyed	SNV	Damaged/considered Destroyed	Last reading considered unreliable.
RT62	St	84574.99	36864.05	Allen Gardens (east of Weaver Street)	NW	6.50	destroyed	SNV			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT62	Pn	84574.99	36864.05	Allen Gardens (east of Weaver Street)	NW	29.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT63	Pn	84613.53	36883.28	Allen Gardens (east of Weaver Street)	NW	8.50	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT63	Pn	84613.53	36883.28	Allen Gardens (east of Weaver Street)	NW	15.00	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT64	St	84652.97	36902.42	Allen Gardens (north of Fakrudden Street)	NW	4.00	destroyed	SNV			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT64	Pn	84652.97	36902.42	Allen Gardens (north of Fakrudden Street)	NW	10.35	destroyed	SNV	-		SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT65	Sp	84718.36	36894.14	Vallance Road (opposite No.122)	NW	28.50	destroyed	SNV			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT66	Sp	84105.7	36613.3	Truman's Brewery (adjacent to Corbet Place)	NW	8.00	destroyed	NL			SNV			SNV			SNV			SNV	Destroyed	SNV	Destroyed	SNV	Destroyed	
RT67	Sp	84150.8	36677.7	Truman's Brewery (adjacent to Grey Eagle Street)	OK	6.90	5.91	NL			SNV			SNV			SNV			SNV	not located	SNV	not located	SNV	not located	
RT68	Sp	84195	36658.9	Truman's Brewery (adjacent to Brick Lane)	OK	7.50	5.23	OK	5.95	5.02	SNV			SNV			SNV			SNV	to be visited	SNV	to be visited	SNV	to be visited	Piezo fuctioning (2004)
RT69	Sp	84227.5	36726.6	Truman's Brewery (adjacent to Brick Lane)	OK	6.20	5.18	NL			SNV			SNV			SNV			SNV	to be visited	SNV	Considered destroyed	SNV	Considered destroyed	
RT70	Sp	80856.06	36356.54	Fisher Street (junction with Southampton Row)	?	5.00	5.02	SNV			NL			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	
RT70	Sp	80856.06	36356.54	Fisher Street (junction with Southampton Row)	?	36.50	dry	SNV			NL			SNV			SNV			SNV	Considered destroyed	SNV	Considered destroyed	SNV	Considered destroyed	

KEY:

NW	Not Working
OK	Operational
NL	Not Located
SNV	Site not visited
?	Unknown
RHT	Raising Head Test
	Piezometer functional
	Piezometer functionality uncertain
	Piezometer nonfunctional