Engineering

Crossrail Project Dewatering Works - Close-out Report

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Executive Summary

For the construction of Crossrail, dewatering was necessary at some stations, portals, shafts and cross-passages, to ensure ground stability, control inflows into open excavation and allow safe construction.

Dewatering works associated with construction can affect the host aquifer and such, usually transient effects, were anticipated in the Project Environment Impact Statement (EIS). During the dewatering works, monitored groundwater level and quality was carried out at each dewatering site. This information was regularly collated, interpreted and reported to demonstrate that the impact on groundwater resources and receptors from the dewatering activities were within acceptable limits and were suitably mitigated. Some 58 reports with the interpreted results have been prepared and submitted to the EA for information.

This close-out report summarises the history and key characteristics of the Crossrail deep aquifer dewatering works and discussed its impacts, by consideration of the monitored results. (Close monitoring of the dewatering works to follow and control these impacts has been undertaken by the project for a period of some 8 years.)

It was found that the temporary effect of the Crossrail dewatering was significant. At peak Crossrail abstraction, a drawdown cone of 5.9 km x 7 km in plan was created, with a maximum drawdown in the Chalk of about 35m. It is notable, however, that this is less than that envisaged in the EIS.

With termination of Crossrail dewatering, the drawdown cone induced by Crossrail has now fully dissipated. The residual cone that remains is due to continued groundwater abstraction at Canary Wharf Station by Canary Wharf Contractors, for the ongoing Wood Wharf Development. This residual drawdown cone is more than 50% smaller (in plan) than the cone which existed at peak Crossrail abstraction. It is shown that the transient effects of the Crossrail dewatering have fully dissipated.

For the dewatering works, the Crossrail EIS predicted no derogation of the licensed abstractors' rights and no significant residual impacts. However, it required vigilance during construction to validate the predictions and to develop alternative mitigation measures, if necessary. This was done.

The report makes the following conclusions.

- The temporary impacts of the Crossrail dewatering works have all dissipated.
- No permanent adverse impacts remain as a result of the Crossrail dewatering works.
- No derogation of the abstraction rights of licensed third party abstractors was observed or reported during the Crossrail dewatering works.
- Crossrail has therefore, met its obligations with respect to dewatering, as enshrined in the Crossrail Act and subsequent agreements and licences.

1 INTRODUCTION AND BACKGROUND

1.1 Background

Crossrail is building a new high frequency, high capacity railway which will serve 40 stations and link Reading and Heathrow (in the west) to Shenfield and Abbey Wood in the east. The central section, through London, is underground, at up to 40m depth, comprising 2 x 6.8m external diameter bored tunnels over a 21km length, and 9 stations. Active dewatering works was required in the vicinity of stations, shafts, portals and cross passages, to facilitate their safe and efficient construction. Dewatering of controlled waters was undertaken with EA consent, obtained via the Schedule 17 consent process, as recognised by the Hybrid Bill – the Act of Parliament which authorises the construction of this railway (for examples of the Schedule 17 consent process see refs [8] to [18]). This is reflected in Crossrail's Environmental Impact Statement (refs [1] & [2]).

Due to the tunnel alignment and its juxtaposition with the local geology, dewatering of the major aquifer, the deep aquifer in the Thanet Sand and Chalk strata, was necessary in the eastern part of the tunnelled alignment. Dewatering was at multiple Crossrail work sites in a simultaneous and interactive manner, which is discussed later. At each dewatering site, works was undertaken by the relevant Construction Contractor, working to an EA consented Schedule 17 application. The contractor monitored the dewatering works at each site, in compliance with; (i) his dewatering design requirements for the site, (ii) the conditions on the Schedule 17 consent for that site, and (iii) general requirements of the Crossrail Groundwater Strategy Report (ref [4]), as modified for that site. Each contractor concentrated on the environs of his dewatering site.

In order to demonstrate continued compliance of the whole Crossrail deep aquifer dewatering works to the Hybrid Bill requirements, the Projects Environmental Impact

Statement and specific agreements with the Environment Agency (EA), Crossrail as the Owner of the railway took further steps.

Rather than just relying on disparate information from various contractors, each working to its own programme and construction drivers, Crossrail commissioned the Geotechnical Consulting Group (GCG), working as part of the Owner's Team, to provide regular overarching reports that:

- collated information and monitoring results from all the Crossrail dewatering sites,
- augmented this information with relevant data from third parties (including the EA) and from published sources,
- to produce a comprehensive, interpreted overarching report on the totality of Crossrail dewatering works and its impact.
- to track the impact of Crossrail dewatering on groundwater resources and receptors and demonstrate that they were within acceptable limits and were suitably mitigated.

A total of 58 such reports were produced for the EA (refs [5] and [6]). These were issued at a typical frequency of one report every 1 to 3 months, depending on the intensity of ongoing dewatering works and their impacts.

1.2 Minor aquifers in the project area

The Intermediate Aquifer

In the Crossrail Project area, the intermediate aquifer exists in the sand channels and sand unit of the Lambeth Group and Harwich Formation. This aquifer is enclosed by the clayey units of the Lambeth Group (below it) and the London Clay (above it). Crossrail construction activities in this minor aquifer involved de-pressurisation works, with the aim of reducing water pressures, rather than removing water itself. Consequently, flow rates associated with these works were no more than a few litres per second at peak flow and usually much less. As the effects of these de-pressurisation works on the intermediate aquifer were negligible, a different consenting process from that used for the major aquifer in the Chalk and Thanet Sand was agreed with the EA and implemented (ref [3]).

The Upper Aquifer

In the project area, the upper aquifer in the River Terrace Deposits (RTD) and Made Ground (MG) is a minor aquifer, separated from deeper aquifers by intervening clay layers. The exception to this is in the eastern part of the tunnelled alignment, where the upper aquifer and lower aquifer are hydraulically connected. In the upper aquifer, Crossrail activities have involved construction of deep diaphragm or secant pile retaining walls through the MG and RTD well into the strata below, to allow construction of stations, shafts and portals. Dewatering activities in the upper aquifer have therefore typically involved the dewatering (by local pumping or sump flows) of the MG and RTD enclosed within the impermeable retaining walls. This is undertaken during excavation within these retaining walls and generates no affect on the upper aquifer outside the retaining walls. The EA consent process for such excavations recognises this.

In conclusion, dewatering works associated with the Crossrail Project significantly affected the deep aquifer and did not affect intermediate and deep aquifers in the project area.

1.3 Scope of this close-out report

This close-out report relates to dewatering works in the deep aquifer. Its purpose is to:

- summarise the history and key characteristics of the Crossrail deep aquifer dewatering works and its impact on the groundwater,

- to demonstrate that following cessation of pumping, that groundwater levels and conditions have recovered to pre-dewatering conditions,

- to further demonstrate that there are no permanent adverse effects due to the Crossrail deep aquifer dewatering works,

- hence to confirm that Crossrail Ltd (CRL) has complied with its obligations as enshrined in the Crossrail Act and subsequent agreements and licences.

This report contains data available from February 2008 (which is the baseline for the Crossrail dewatering works) up to May 2016, covering the termination of Crossrail dewatering and subsequent recovery of groundwater. Detailed characteristics of the Crossrail dewatering works are already presented in the individual dewatering reports given in refs [5] and [6]. These details are not repeated here and only the key findings are drawn out in this report.

2 CONSTRUCTION AND DEWATERING ACTIVITIES

De-watering was necessary at stations, portals, shafts and cross-passages, depending on the local ground and groundwater conditions, geometry and construction method employed. A summary of the Crossrail deep aquifer de-watering sites is presented in Table 1. Dewatering was required to ensure ground stability, to control inflows into open excavation and thus to allow safe construction.

Figure 1(a) shows the de-watering and de-pressurisation locations, differentiating between deep and shallow aquifer de-watering and local de-pressurisation in the Harwich and/or Lambeth Group Formation. Figure 1(b) shows the plan locations of the Crossrail piezometers and abstraction wells at which the water level in the deep aquifer was measured.

The designations used for the various dewatering locations in this report are as follows.

- Canary Wharf Station – designated as Canary Wharf

- Limmo Shaft – designated as Limmo
- Connaught Tunnel – designated as CT
- Plumstead Portal – designated as PLP
- Woolwich Station – designated as WOL
- North Woolwich Portal and Store Road – designated as NWP
- Eleanor Street Shaft – designated as ELS
- Cross Passage xx – designated CPxx, where xx is a number
- Niches – designated as Nx, where x is a number
- Pudding Mill Lane Portal – designated as PML

Table 1: Construction and deep aquifer de-watering sites.

Crossrail Project Worksite [4]	Construction Contractor	Main Construction start and purpose	Dewatering Sub-Contractor	De-watering Development	De-watering Required	Strata	Appendix of the dewatering report with detailed information
Canary Wharf Station	Canary Warf Contractors Limited	Q1 2009 initially for the construction of the CW station and contribution to adjacent cross passages	WJ Groundwater	CRL dewatering started on 11/08/2008 and ceased on 31/08/2015 but abstraction still continues by CWC	63m ATD	TS/ CK	C (Rev.A - 51)
Limmo Shaft	Dragados Sisk JV (DSJV)	Q4 2011 for the construction of the Limmo shaft, auxiliary shaft and SCL adits and contribution to adjacent cross passages	WJ Groundwater	Initial pumping commenced on 16/12/2011 and completed on 17/10/2012; restarted on 4/11/2013 to assist CP13 and CP14 dewatering works and completed on 14/ 03/ 2016	<68m ATD	TS/ CK	D (Rev.7 - 51)
Connaught Tunnel	Vinci Construction UK Ltd	Q2 2011 for the re-excavation and refurbishment of the existing tunnel	WJ Groundwater	Deep aquifer dewatering commenced on 08/05/2012 and terminated on 25/04/2014. Shallow dewatering works at east and west approach ramps commenced on 20/05/2015 and completed on 7/10/2015	88m ATD	LG(UF) / TS / CK & RTD	E (Rev.8 - 45)
Plumstead Portal [2]	Hochtief Murphy JV (HMJV)	Q1 2012 for the construction of the portal structure, the TBM reception chamber & the Marmadon sewer diversion works	WJ Groundwater	Pumping commenced on 6/06/2012 and completed on 18/07/ 2014	Localised, up to 85.3m ATD	RTD/ TS/ CK	F (Rev.8 - 33)
Woolwich Station [1]	Berkley Homes	Q3 2011 for the construction of Woolwich station box	WJ Groundwater	Dewatering started on 6/07/2012 and completed on 23/11/2012	Localised ~92m ATD	TS/ CK	G (Rev.9 - 23)
North Woolwich Portal[2]	HMJV	Q1 2013 for the construction	WJ	NWP dewatering commenced on 13/05/2013 and completed on	Localised up to	RTD & CK	H

and Store Rd[2]		of the portal structure	Groundwater	22/05/2014 ; Store Rd started on 05/06/2013 and completed on 29/10/2013	86.5m ATD		(Rev.9 - 33)
Eleanor Street Shaft	CSJV	Q1 2013 for the construction of the shaft and connecting adits	WJ Groundwater	Dewatering works commenced on 8/07/2013 and terminated on 8/10/2015	<71m ATD	HF/LG; UF/TS	L (Rev.20 - 47)
CP11	DSJV	Q1 2014 for its construction	WJ Groundwater	Pumping commenced on 2/05/2014 and completed on 16/01/2015	61.8m ATD	TS/ CK	K (Rev.25- 45)
CP13	DSJV	Q1 2014 for its construction and contribution to adjacent cross passages	WJ Groundwater	Pumping started on 26/11/2013 and terminated on 3/08/2015	59.6m ATD	TS & CK	K (Rev.19 - 45)
CP14	DSJV	Q1 2014 for its construction	WJ Groundwater	Pumping commenced on 16/12/2013 and terminated on 27/07/2015, but with temporary pauses between 17/01/2014 to 4/08/2014 and 28/11/2014 to 5/05/2015	68.6m ATD	LG	K (Rev.28 - 45)
Niche N3	DSJV	Q1 2014 for its construction	WJ Groundwater	Pumping commenced on 03/07/2014 and terminated on 12/01/2015	52m ATD	LG, TS & CK	K (Rev.33 - 45)
Pudding Mill Lane Portal	Morgan Sindall JV	Q4 2011 for the cut and cover excavation of the portal box	WJ Groundwater	Dewatering works commenced on 17/10/2011 and completed in March 2014	<80m ATD (LG&SND) and <102m ATD (RTD)	LG&SND/RTD	Data reported up to July 2012 in Appendix J (Rev.8 - 16)

[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

Figure 2(a) summarises the deep aquifer pumping records for the whole Crossrail Project tunnelled section, as flow rates and active well numbers.

With reference to Figure 2(a) and Table 1, it can be seen that Crossrail Project dewatering commenced on 11th August 2008 for works at Canary Wharf Station. The bulk of the Crossrail Project dewatering was turned off in August 2015, with termination of pumping at Cross Passage 13 and a substantial reduction of pumping at Limmo. All dewatering was finally terminated on 14th March 2016 with the end of remaining dewatering activity at Limmo. At Canary Wharf, abstraction from the deep aquifer for Crossrail Project purposes ended on 31 August 2015. However, in reality pumping still continues, uninterrupted, but with abstraction by Canary Wharf Contractors (CWC) for the construction of the Wood Wharf Development.

Figure 2(a) shows that the total abstraction rate from the deep aquifer reached a maximum of about 620.5 l/s on 28/01/2014, from the active pumping at 7 sites; Canary Wharf, Limmo, CT, CP13, ELS, PLP and NWP. This peak abstraction rate is significantly less than the peak abstraction rate assumed in the Crossrail Project Environmental Impact Statement (EIS) of 726L/s.

Figure 2(b) shows that the measured flow rate-time profile compared with the C122 dewatering prediction of May 2011. The actual flow was generally less than the predicted profile and was being achieved earlier than predicted, until week 63, when more flow than expected occurred in CP13.

3 GROUNDWATER LEVEL

3.1 Historically contours and profiles of the observed groundwater level

Prior to commencement of any Crossrail Project construction works, monitored ground water levels were taken in February 2008. A contour of the measured baseline groundwater level conditions is given in Figure 3(a). These contours are well conditioned by off-alignment piezometric data from the EA and data from the Greenwich Peninsula from Atkins/ Greater London Authority. Water levels in the deep aquifer varied from 75m ATD at Stepney Green to 100m ATD at PLP and 80 to 82m ATD along the PML branch of the alignment. *[Note 100m ATD = 0m OD, so 80m ATD = -20m OD]*

The first dewatering works for the Crossrail project commenced at Canary Wharf, in August 2008, where a peak abstraction rate of 186 L/s was reached on 6th November 2008 (refer to Figure 2(a)). A contour of the measured groundwater levels at that time is shown in Figure 3(b). Water levels at Canary Wharf Station had reduced to 61m ATD.

With more Crossrail Project dewatering sites coming on line, monitoring data from Crossrail Project deep aquifer piezometers, combined with data provided by the EA and Thames Water, have been used to generate accurate groundwater level contour plots for the area in and around the project location. Some typical examples of the groundwater level (GWL) contours are presented in Figures 3(c) to 3(h) in this report. These have been selected to illustrate key stages in the build-up and wind-down of the Crossrail Project dewatering works.

- Figure 3(c) – end of April 2012 – illustrates the condition when Limmo pumping first comes on line so that Canary Wharf and Limmo sites were in operation at peak capacity (refer also to time plot in Figure 2(a) for the flow rate history);

- Figure 3(d) – end of Sept 2012 – shows the GWL contours for a local peak flow rate of about 450L/s (as indicated in Figure 2(a)). At that time dewatering was ongoing at Canary Wharf + Limmo + CT + PLP + Woolwich Station (but only internal dewatering within the enclosed confines of the Woolwich Station box diaphragm walls, Table 1).

- Figure 3(e) – Oct 2013 – showing the condition close to a local peak flow rate of about 260 to 280 L/s (Figure 2(a)). At this time abstraction was ongoing at Canary Wharf + Limmo (from passive wells only) + CT + NWP (with recharge) + ELS + PLP. As shown in Table 1, pumping at NWP was within the portal retaining walls, but with recharge external to the Portal walls, as discussed later (Section 4.3).

- Figure 3(f) – Jan 2014 – showing the condition at peak flow of 620.5 L/s (Point A in Figure 2(a)). At this time, dewatering is ongoing at 7 sites; ELS + Canary Wharf + CP13 + Limmo + CT + NWP + PLP.

- Figure 3(g) – July 2014 – showing the condition for a flow of about 400 L/s (in Figure 2(a)). At this time, dewatering is ongoing at ELS + N3 + CP11 + Canary Wharf + CP13 + Limmo + PLP.

- Figure 3(h) – August 2015 – showing the condition for Crossrail Project abstraction with flow having reduced from 232 L/s to 22 L/s as dewatering winds down (Figure 2(a)). At this time, dewatering is ongoing at ELS + Canary Wharf + Limmo + CT (but from shallow wells drawing only, which drew about 18% of their yield from the deep aquifer.)

Drawdown Contours

Based on the difference between these groundwater level contours and the baseline condition of February 2008, the resultant monitored drawdown is also presented as a contour plot in Figures 4(c) to 4(h). These plots show clearly the drawdown in meters at each site as they come on line and track the build-up and dissipation of the effects of the Crossrail Project abstractions. The drawdown cone, defined by the 2m drawdown contour, reaches a maximum of 5.9km x 7km in plan, in January 2014, before diminishing in extent as GWL recovery occurs. The maximum drawdown occurs in the chalk at Canary Wharf (about 35m drawdown) in July 2014 before commencement of recovery.

Note that a drawdown of 2m has been taken in the EIS to represent the minimum reliable discernable change to the deep aquifer, taking cognisance of the usual background temporal and spatial variations of the aquifer.

The last Chalk wells at Limmo were disconnection in mid-March 2016, marking the end of Crossrail Project deep aquifer dewatering works. However, abstraction rates had been declining from a Project peak on 28 January 2014 of 620.5L/s. The decline in Crossrail Project abstractions was most rapidly in July-August 2015, when dewatering at CP14 and CP13 ended, and the associated abstraction at Limmo was also greatly reduced (Figure 2(a)). In this period (21st July 2015 to 7th August 2015) the total Crossrail Project abstraction fell from about 295L/s to about 75L/s.

Groundwater recovery was monitored from August 2015 to May 2016. Groundwater level contours for mid-May 2016 are shown in Figure 5, representing the final condition. It shows the full recovery that has been achieved at Limmo all other Crossrail Project sites, except the Canary Wharf, where the deep central cone still exists. It still exists because at Canary Wharf, deep aquifer dewatering is still on going by Canary Wharf Contractors for the Wood Wharf scheme currently under construction.

In Figure 6, the monitored drawdown is shown for mid-May 2016, relative to the project baseline of Feb 2008. The drawdown cone has diminished from a maximum of 5.9km x 7km in January 2014 to about 3.7km x 4.8km in plan in mid-May 2016; the existing drawdown in May 2016 being due to the ongoing Canary Wharf Contractor dewatering works.

The piezometric elevations along the Crossrail Project alignment from Stepney Green to Plumstead and from Stepney Green to Pudding Mill Lane are presented in Figures 7 and 8, respectively. These plots represent a longitudinal vertical section along the tunnel alignment, passing through the tunnel centreline. To aid interpretation, the sections also show the piezometric levels (i.e. the water levels) relative to the ground conditions.

In these sections, groundwater levels at the following key points in time are shown;

(i) baseline conditions of Feb2008,

(ii) conditions for peak abstraction at Canary Wharf alone at Dec 2008,

(iii) Jan2014, representing the maximum abstraction,

(iv) Sept14 (max effect of CP11 dewatering), and

(v) the GWL in mid-April 2016 & mid-May 2016, representing the latest available information.

Conditions for the sustained pumping at Canary Wharf alone is represented by the data for November 2013 and shown as point "O" in Figure 2(a). This represents the conditions prior to switch on of Limmo dewatering and any other Crossrail Project dewatering sites in the vicinity of Canary Wharf. It is therefore useful as a good approximation for the baseline conditions toward which the groundwater should equilibrate, after termination of Crossrail Project dewatering, but with Canary Wharf Contractors continuing to dewater at Canary Wharf. This approximate baseline (with Canary Wharf dewatering ongoing alone) is shown in Figure 7 as the line labelled "Pre-Limmo dewatering Baseline Level Nov13 with Canary Wharf only ongoing".

From the GWL profiles in Figure 7, it can be seen that the drawdown cone at Canary Wharf is still present, with Canary Wharf Contractor's abstraction still on-going. To *the west* of Canary Wharf, the maximum drawdown due to CP11 dewatering was observed in September 2014 to 59m ATD. Currently, in the area around CP11, the water levels have recovered to within the 2m of the pre-CP11 levels; albeit with continued pumping at Canary Wharf by Canary Wharf Contractors. *[Note a drawdown of 2m has been defined in the EIS as the minimum limit of discernable effects to the aquifer.]* To the east of Canary Wharf, the drawdown cone-let at Limmo Peninsula and CP13 have fully dissipated with the groundwater levels in both Thanet Sand and Chalk having recovered to the pre-Limmo baseline from the condition at maximum abstraction of Jan 2014.

From Stepney Green to Pudding Mill Lane the piezometric groundwater elevation profiles are illustrated along the Crossrail Project alignment in Figure 8. The GWL profile of March 2016 indicates full recovery along the Stepney Green to Pudding Mill Lane branch.

Figure 9 shows the licensed third party abstraction wells with respect to the 2m drawdown contour for Crossrail Project deep aquifer dewatering, both predicted and measured. Measured contours are shown in dotted line with predicted contours in solid lines. The measured drawdown is shown for Jan 2014, when CRL abstraction was at its peak (Point A in Figure 2). It can be seen that the drawdown contour at peak abstraction is much smaller in plan extent than the predicted contours assumed in the EIS, thus that the EIS was conservative. The May 2016 measured 2m drawdown contour illustrates the recovery that has occurred with the cessation of Crossrail Project dewatering. The residual drawdown cone due to Canary Wharf Contractor dewatering in May 2016 is about 55% smaller in plan area than the drawdown cone at peak Crossrail Project abstraction (January 2014).

It is also noteworthy that even when pumping was at maximum abstraction, no derogation was observed or reported at the abstractions licensed by the Environment Agency; whether in terms of quantity and quality of the groundwater available to the licensees (refs [5] & [6]).

Since 31 August 2015, the vast bulk of deep aquifer dewatering in the project area has been by Canary Wharf Contractors for Wood Wharf development. From mid-March 2016, the only dewatering in the project area was by the same group for the same project. Therefore, by agreement with the EA, GWL and GWQ monitoring of *third party* deep aquifer abstractors by Crossrail Project ceased in January 2016. (Note: this was only for third party abstractors. Crossrail Project monitoring of GWL in piezometers distributed across the project area continued till mid-May 2016.)

3.2 Time plots of the observed groundwater level

Time histories (hydrographs) of the measured piezometric levels between January 2008 and mid-May 2016 are presented in Figures A.1 to A.10 in Appendix A. Observations on the groundwater level regime at each dewatering site are summarised below:

- At Limmo pumping in the last two Chalk wells ended on 14th March 2016; this generated an immediate response in the water levels of both TS and CK piezometers as indicated in Figures A.4 (a) & (b). Prior to this, in August to October 2015, GWLs at Limmo had recovered very substantially due to termination of dewatering at the adjacent CP13 site and substantial reduction of the dewatering effort at Limmo which was contributing to drawdown for CP13. Groundwater levels at Limmo have recovered to pre-Limmo baseline levels, accounting for ongoing dewatering at Canary Wharf by Canary Wharf Group.

- At Canary Wharf, only limited groundwater information has been available from Sept 2015 till mid-May 2016 (see Figure A.2). Available information shows that there was a recovery of about 7m in both the Chalk and Thanet Sand following cessation of pumping at CP13 and Limmo. Pumping still continues at Canary Wharf for Wood Wharf Development, with local Chalk water levels being as low as 57.2m ATD (-42.8m OD, ref [25]).

- At Cross passage CP13 (see Figures A.3(a) & (b)). Chalk and Thanet Sand piezometers responded with a large and rapid recovery in August to Nov 2015, when CP13 dewatering was halted and supportive dewatering at Limmo was also dialled back. A further small rise in their water levels occurred in March to May 2016, following shutdown of the last Limmo Chalk wells. Currently, the GWLs in the Chalk and Thanet Sand have recovered to the pre-Limmo equilibrium baseline level. As recovery has progressed towards the ambient baseline conditions, the rate of change of rise of piezometric levels has diminished. In the Chalk at CP13, the rate of rise of water level has decayed to about 0.57m/month. In the TS, the rate of recovery has reduced to about 0.4m/month. These are now slow rates indicating that further recovery would only be marginal and even slower.

- At Cross passage CP11 (Figure A1.b), the Crossrail Project deep aquifer drawdown has dissipated to within 2m of the applicable ambient conditions – i.e. with Canary Wharf abstraction for Wood Wharf ongoing. The recovery rate of the Chalk and Thanet Sand groundwater levels has decayed to about 0.16m/month.

- At Eleanor Street Shaft, drawdown recovery is now complete (see Figure A.6).

- In the Greenwich Peninsula (see Figures A.3(d) & (e)), several points can be made.

    - The deep aquifer at Greenwich Peninsula (GP) was drawn down by up to 23m, due primarily to CP13 dewatering works. The water levels in the deep aquifer have recovered fully to ambient conditions, with termination of the CP13 dewatering in August 2015 with a little more recovery (about 1m) on switch off of Limmo wells in March 2016.

- The upper aquifer in the Greenwich Peninsula (GP) did not respond to dewatering abstraction for the Crossrail Project works, throughout the monitored period from 2010 to 2016. This shows that the upper aquifer (which is known to be contaminated) was hydraulically separated from the deep aquifer at GP. Thus it is shown that Crossrail Project dewatering abstraction did not generate cross-aquifer contamination at GP. This is also supported by the GWQ information (discussed later in Section 4.3).

- At Niche N3, full recovery in the groundwater level in TS, close to the pre-Niche N3 dewatering level, was observed (as indicated in piezometers NP2, see Figure A.6).

- At Connaught Tunnel, and from Connaught Tunnel to North Woolwich Portal, the groundwater levels in both CK and TS have recovered fully to the pre-dewatering levels of about 100m ATD for NWP and 92 to 95 for CT; see Figures A.5(a)&(b) for Connaught area and A.8(a)-A.10(d) for Woolwich Station to North Woolwich Portal).

- Time plots for the Sentinel wells water levels are presented in Figures A.7(a)&(b) of Appendix A. The location of the sentinel wells is shown in Figure 1(b). Groundwater level data up to mid-May 2016 show full recovery of piezometers in the deep aquifer to pre-dewatering levels, after accounting for continued pumping at Canary Wharf by Canary Wharf Contractors for Wood Wharf Development. The Sentinel Wells in the RTD around NWP showed a drawdown during pumping at NWP, but recovered to ambient levels on termination of that dewatering in June 2014. Thereafter, the tidal variation in this stratum at NWP is reflected.

4 GROUNDWATER QUALITY

Prior to construction, groundwater quality monitoring was undertaken to establish baselines and inform the design. During and after construction, GWQ monitoring was carried out to:

- verify the performance of dewatering,
- meet conditions on the EA Schedule 17 consent (where GWQ issues were of concern);
- to demonstrate that there was no derogation of the groundwater quality for licenses abstractors;

For early warning of possible adverse trends of contamination transport, monitoring of Sentinel Wells was undertaken, with these wells being located away from the dewatering site – at locations selected to give such advance warning. Contingency measures and mitigation actions were developed on a site-by-site basis, dependent on the local concerns and the Schedule 17 consent conditions for each site.

Groundwater quality testing was carried out on samples from licensed third party abstractors, sentinel wells, Crossrail Project dewatering abstractions and some monitoring piezometers. The plan locations of relevant Crossrail Project piezometers and abstraction wells are shown in Figure 1(b). In general, the groundwater quality data was reviewed and compared with the Drinking Water Standard limits (DWS), unless different Environmental Quality Standards were more appropriate and were applied.

GWQ monitoring was most extensive at the following deep aquifer dewatering sites:

- Limmo,
- Cross passage CP13,
- CT
- NWP

This was usually because the risk contamination mobilisation was recognised, e.g. from existing contamination hotspots within the groundwater. For this reason, more detail and focus is given to these sites in the GWQ information and discussion presented below.

4.1 Third party abstractions

Groundwater quality results of third party abstractors were reviewed in the regular dewatering reports (refs [5] & [6]) and presented as time plots in these reports. The plots are numerous and are not reproduced here. Instead, the consistent findings from these dewatering reports are summarised below.

In general, available water quality data for licensed abstractors show no significant change since commencement of dewatering works in August 2008. Data for most wells showed stable conditions, falling at about the limit of detection (LOD). Values which exceeded the DWS have not worsened or have been historically elevated and have not worsened. For instance, historically high dissolved sodium and chloride concentrations, which exceeded the DWS, existed at Britannia Hotel, Stave Hill Ecology Park, Harmsworth Quays Printing Ltd (formerly Associated Newspapers) & English Partnerships (see Figure 9 for locations); concentrations were elevated but stable well before and during the Crossrail Project dewatering. Historically elevated concentrations of Ammoniacal Nitrogen have also been reported at Britannia Hotel and London Brough of Southwark.

In conclusion, there was no significant deterioration in the water quality of licensed abstractors during Crossrail Project dewatering.

Monitoring of GWQ at third party abstractors ceased in January 2016, on termination of the vast majority of the Crossrail Project dewatering works, when Canary Wharf Contractor became the main deep aquifer abstractor in the area. Termination of monitoring of the third party abstractors was implemented after agreement with the EA (ref [7]).

4.2 Sentinel Wells

The GWQ data from the off-alignment sentinel wells SN1RA to SN10R, along with data from sentinel wells SN11-SN15, around North Woolwich Portal, were also reviewed on a regular basis in the routine dewatering reports (refs [5] & [6]). This information was also presented as time plots in the dewatering reports and is not reproduced here. Instead, key findings are highlighted.

The GWQ data from most of the sentinel wells showed stable conditions, at about the limit of detection. However, there were some elevated values. For instance, high background salinity was observed in all sentinel wells due to proximity of River Thames. Occasional elevated levels, above the DWS, were observed in Arsenic, Boron and Manganese in SN11-SN15 at NWP. These wells were closely monitored and it was observed that there was no worsening of the water quality during the dewatering works at NWP.

Monitoring of GWQ at Sentinel wells was ceased in January 2016, with the EA's agreement (ref [7]).

It is concluded that the Sentinel Wells successfully acted as early warning detectors for the project dewatering works.

4.3 Crossrail Project dewatering abstractions and monitoring piezometers

A summary of the keys findings from monitored GWQ at Crossrail Project abstraction wells and at monitoring piezometers at the various dewatering sites is given below:

Canary Wharf

There was no perception of a significant contamination risk in this area. Therefore the GWQ of abstracted water was just tested for routine surveillance during dewatering. The measured parameters included: hardness, sodium dissolved, iron dissolved, nickel, chloride, ammonical nitrogen, sulphate dissolved, dissolved oxygen, chromium, pH and electrical conductivity. The quality of groundwater abstracted from Canary Wharf was found to be generally stable and below the limit of detection or the DWS, except for sodium, chloride and electrical conductivity, which were was over the DWS limits.

Limmo and Greenwich Peninsula

There was no perception of a significant contamination risk at this site for dewatering purposes. The initial phase of Limmo dewatering (for the excavation and construction of the Limmo Shafts, themselves, 16/11/2011 to 17/10/2012) involved routine water quality monitoring. The second phase of dewatering at Limmo was to support CP13 construction from 4/11/2013 to 3/8/2015, and then Limmo dewatering continued to 14/3/2016 to permit internal fit-out of Limmo shafts. This second phase of dewatering involved a higher perception of contamination risk.

The higher risk was associated with dewatering for CP13. It was appreciated that CP13 dewatering would influence the Greenwich Peninsula (GP), where the upper aquifer was known to have some residual historically contamination, following remediation works in 1996 – 1998. The deep aquifer at GP was known to have a limited amount of pre-existing contamination for the same reason. A Tier 4 Quantitative Risk Assessment (QRA) was therefore conducted for CP13 dewatering, as part of the Schedule 17 Consent application for CP13 dewatering. The purpose of the QRA was to assess the risk of contamination transport (ref [8]). This included dewatering from the Limmo wells in support of CP13 works. The QRA, augmented by results of the long-term, post-remediation monitoring of the GP, was used to identified 7 potential chemicals of concern (PCoC), namely, (i) Ammoniacal Nitrogen, (ii) Sulphate, (iii) Copper, (iv) Naphtalene, (v) Pyrene, (vi) Benzene and (vii) Aliphatics > C6-C8.

Table A summarises and comments on the GWQ data for Limmo, highlighting the PCoCs as red text. The determinand concentrations are compared to the DWS. Only Sodium, Chloride and Ammonical Nitrogen were consistently above the DWS; however, these were stable throughout the dewatering works. With regards to the PCoCs at the Limmo CK wells (Ammoniacal Nitrogen, Copper and Sulphate), these were below or slightly higher than the DWS limit and were stable. For the other 4 PCoCs (Benzene, Naphthalene, Pyrene and Aliphatics C6-C8) baseline measurements at Limmo in Sept 2012 recorded values less than the limit of detection. In agreement with the EA, it was therefore decided not to test these 4 determinants on a routine basis, but to test for them if concentrations of the PCoCs at CP13 became significant – i.e. exceeded the CP13 trigger values. No exceedence occurred at CP13 and there were no further tests for these 4 PCoCs at Limmo during the dewatering works.

With the termination of abstraction at Limmo on 14th March 2016, GWQ monitoring ceased.

GWQ monitoring at GP was also carried out during the CP13 dewatering works. The purpose of this was to verify that the input concentrations of the contaminants at GP, assumed in the QRA for CP13, were not exceeded by the actual concentration of these contaminants at GP – thus that the predictions of the QRA remained conservative. This was a condition of the CP13 Schedule 17 consent by the EA. The measured GWQ data for the GP PCoC is presented as Figure 11, compared to the input concentration values adopted in the CP13 QRA (ref [8]). The QRA model had adopted two source concentration values at GP, based on the historic monitoring of the GP from 2001 to 2012. One source value was based on the mean of these historic values. The other was based on the maximum value recorded during the historic monitoring. These minimum and maximum model input values are shown as dotted line in Figure 11, for comparison to the monitored values at GP during the Crossrail Project dewatering works. It is clear from Figure 11 that the input assumptions of the CP13 QRA were met.

Cross passage CP11

At Cross passage CP11, groundwater quality testing of the abstracted water was taken at a low frequency due to the low perceived risk for this site. The standard suite was monitored comprising; suspended solids, total alkalinity, acidity, hardness, chloride, fluoride, total sulphur, calcium, magnesium, sodium, potassium, nickel, chromium, cadmium, copper, lead, zinc, manganese, iron, arsenic, boron, mercury, vanadium, ammoniacal nitrogen, nitrate, nitrite, total oxidised nitrogen, phosphate and total organic carbon. Monitoring data showed that the determinands were below the DWS limit and were stable at CP11.

Cross passage CP13 and Greenwich Peninsula

The background to the groundwater quality measurements at CP13 are described in the section on Limmo above, as both dewatering sites are linked. In addition, the EA requested for additional tests on chlorinated solvents and PAH to be conducted to check the baseline conditions for these chemicals at CP13. Table B summarises and comments on the GWQ data for CP13. It highlights determinants that displayed stable, low or high concentrations relative to DWS and EQS. (The EQS used for the River receptor was Fresh Water Environmental standards for aquatic life in the R. Thames and DWS for abstractions (assumed to be portable water)). Figure 10 presents time plots of measured concentrations of the Primary Chemical of Concerns (PCoCs) at CP13 abstraction wells and compares them to the predictions of the QRA.

Table B shows that sodium and chloride ion concentrations were consistently above the DWS due to proximity to the River Thames and hydraulic connectivity from the drift filled hollows; but although elevated, the concentrations were stable. No hydrocarbon contaminants were detected at CP13, confirming the findings of the QRA – that contamination from GP was not mobilised by the Crossrail Project works. For the same reason, discharge of the abstracted water to the River Thames presented no issues.

The seven PCoCs identified from the CP13 Quantitative Risk Assessment were found to be below the limit of detection, below the QRA predictions and below the EQS (these are values measured at the CP13 abstraction wells, Figure 10). The exception was Ammoniacal Nitrogen, which was above the DWS and just above the EQS at the well heads. If dilution by the River Thames is taken into account, even if by very conservative means, the EQS would not be exceed and a large margin to the EQS would be available (ref [8]). The ammoniacal nitrogen concentration was therefore not deemed to be of concern and was regularly reviewed at the CRL-EA liaison meetings (e.g. refs [19] to [20]).

During the dewatering works at CP13, continuous GWQ and GWL monitoring at the Greenwich Peninsula area was carried out to verify that the contaminated upper aquifer was not being drawdown into the lower aquifer by the Crossrail Project dewatering works. The GWL data showed that the contaminated upper aquifer was hydraulically isolated from the lower aquifer, under the Crossrail Project pumping regime (e.g. Figure A3). The GWQ data showed that determinand concentrations in the deep aquifer at GP were stable, at the historical values which existed there before Crossrail Project abstraction (Figure 11). Thus the GWQ and GWL data showed that at GP cross-contamination of the deep aquifer by the shallow aquifer was not occurring under the Crossrail Project pumping regime.

Connaught Tunnel

Dewatering activities in the CT took place in two phases (see Table 1). Deep aquifer dewatering was conducted from 8/5/2013 to 25/4/2014 to allow deepening of the tunnel invert and construction of the sump and connecting pipe-jacked tunnel. Shallow aquifer pumping was carried out in 20/5/2015 to 7/10/2015 to facilitate fit-out of the CT approach ramps. Discharge was to the royal docks.

Water quality monitoring of the deep aquifer was undertaken at CT during the deep aquifer dewatering activities. There was some concern that hydrocarbons may have been present in the in the groundwater from the ground investigation information. A comprehensive suite of GWQ testing was therefore adopted, reflecting recommendations and conditions by the EA in their consent of the Schedule 17 application for CT (refs [11] & [12]). The tested suite was: pH, conductivity, s solids, alkalinity, acidity, hardness, chloride, fluoride, total sulphur, calcium, magnesium, sodium, potassium, nickel, chromium, cadmium, copper, lead, zinc, manganese, iron, arsenic, boron, mercury, vanadium, ammoniacal, nitrogen, nitrite, total oxidised nitrogen, phosphate, total organic carbon, TPH, dissolved oxygen, trichlorethene, tetrachlorethane and PAH. Trigger levels on PAH were set on discharge to the dock, with contingency measures including discharge to sewer and provision of a treatment plant if required.

For the deep aquifer dewatering, monitored GWQ results showed that historically elevated concentrations were observed in some determinants, but in general chemical concentration trends were stable or remained at low levels, below the limits of detection or the DWS. Use of a water treatment plant was never required.

For the shallow aquifer a QRA was carried out (refs [26] & [27]). Trigger levels were set for the sentinel well concentrations of CoC, based on the attenuation and travel times predicted in the QRA. These trigger levels were set so that when exceeded at the sentinel wells, there was a risk that the abstracted water at CT would be unfit for disposal in the Royal Docks. Trigger levels were also applied to the discharge water from the abstractions. Mitigation actions on exceedence of the red trigger level included halting discharge to the dock and switching to sewer discharge or storing on site.

During the shallow dewatering works at CT, the values of most of the CoCs for the abstracted water were below the threshold trigger limits. The exceptions were continuous exceedances observed for Selenium and Ammonia, above the Amber level. However, there were no immediate concerns as the measured concentrations were stable and did not worsen. These determinands were reviewed at the EA-CRL Liaison meetings.

Woolwich Station

Internal dewatering was conducted at Woolwich Station box, with abstraction from within the confines of a pre-installed, impermeable, deep diaphragm wall enclosure. This internal pumping had no effect on the aquifers outside the retaining wall box. Discharge was to the River Thames via a private surface sewer.

The GWQ suite tested was pH, ammoniacal nitrogen, alkalinity, hardness, nitrate, nitrite, phosphate, chloride, fluoride, sulphate, suspended solids, TOC, total oxidised nitrogen, arsenic, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, sodium, vanadium, zinc, PAH, benzene, toluene, ethyl benzene, xylene and TPH.

GWQ measured during active internal pumping showed that most of the determinands were of stable concentrations and remained at or below the DWS.

North Woolwich Portal & Store Road

At NWP, the upper aquifer in the RTD is hydraulically connected to the lower aquifer in the Chalk, as there are no intervening London Clay and Lambeth Group acquicludes, or indeed the Thanet Sand, at this location. In addition compressible layers of Alluvium and Peat exist above the RTD. Dewatering works for the NWP comprised internal abstraction from the RTD and Chalk soils enclosed within the portal retaining wall structure, with recharge outside the portal retaining wall in the RTD and Alluvium. Recharge of the RTD and Alluvium was necessary to limit drawdown outside the portal to small values (1m drawdown) and thus to avoid excessive consolidation settlement of the Alluvium and Peat. About 40% to 60% of the abstracted water was recharged during the works.

There was a perceived risk of hydrocarbon contamination within the groundwater in the NWP area, from existing contamination hotspots or unknown contamination plumes in the groundwater. A detailed QRA was therefore undertaken, backed by a long period of extensive baseline monitoring. (The GWQ baseline monitoring was for over 9 months, the GWL monitoring had been ongoing for much longer, see ref [8, rev 20] for more information on baseline monitoring and ref [21] for details of the QRA.)

The outcome of the QRA and implementation methodology development was:

(i) The identification of a suite of the Chemicals of Concern (CoCs)

(ii) Development of trigger levels, based on the baseline conditions and appropriate EQS. Different trigger levels applied to the sentinel wells and to the abstracted water.

(iii) Provision of a ground water treatment plant, on standby basis; the plant had the capability of treating the abstracted water for recharge or for discharge to the River Thames. The scheme included automatic online monitoring.

(iv) A strict regime was also implemented of GWQ and GWL monitoring and review, including regular visual and olfactory inspections.

(v) The monitoring regime included use of a system of Sentinel Wells positioned to give advance warning of problems.

(vi) Abstracted water would be recharged into the ground and discharged to the River Thames, unless the relevant Action Levels were exceeded as pre-defined. In such an eventuality, groundwater treatment would be instigated before recharge or before discharge to the River Thames. Discharge to a sewer was also available as a contingency measure.

A summary of identified CoC from risk analysis of the dewatering at NWP is given in Table C. The GWQ monitoring data spanned from February 2013 to July 2014.

Limited contamination was observed as most of the values of the CoCs were below the 1st warning level. There have been a few isolated exceedances of the 2nd Warning level and on the odd occasion single exceedence of the Action Level. However, these exceedences were isolated results verified by subsequent, rapid-turnaround results to have fallen back below the LOD or the relevant trigger levels.

Following demonstration over many months of the very low risk of contamination in the discharged and recharged water, and of the efficacy of the monitoring and review processes, the standby water treatment plant at NWP was removed from site on 23rd January 2014, in agreement with the EA (e.g. ref [23]). The standby groundwater treatment plant was never been triggered for operation by the monitored results over the period of standby.

Plumstead Portal

The ground conditions at PLP comprised Made Ground, Alluvium and RTD over Thanet Sand and Chalk. The upper and lower aquifers were therefore hydraulically connected at the site. Dewatering involved internal abstraction within the impermeable retaining walls of the portal, pumping from the enclosed RTD, Thanet Sand and Chalk. External recharge, outside the retaining wall, was required to limit drawdown to small values so that the Alluvium at the site was not under-drained, leading to excessive settlement. About 90% of the abstracted water was recharged.

Groundwater contamination was not perceived to be a high risk at PLP and routine GWQ monitoring was undertaken. The suite tested included: Ammoniacal Nitrogen, Arsenic, Alkalinity, Boron, Cadmium, Selenium, Calcium, Chloride, Chromium, Copper, Fluoride, Hardness, Iron, Lead, Magnesium, Manganese, Mercury, Nickel, Nitrate, Nitrite, Phosphate, Potassium, Sodium, Sulphate, Suspended Soil, Total Oxidised Nitrogen, Total Organic Carbon, Vanadium, Zinc and TPH (C10-C40).

The groundwater quality data showed that most of the determinants were of stable and remained at or below the DWS.

5 POST-CONSTRUCTION MONITORING

Cessation of GWQ monitoring for abstraction wells coincided with the cessation of pumping because that marked the end of representative samples of the abstracted water. Post-construction monitoring of groundwater levels continued until mid-May 2016, after GWL recovery at the last Crossrail Project dewatering site (Limmo Site, ref [22]).

6 CONCLUSIONS

This report has set out the history of the Crossrail Project dewatering works and its impacts. It has shown and documented the following.

- The Crossrail Project deep aquifer abstraction commenced on 11/8/2008 and terminated on 14/3/2016.
- The deep drawdown cone generated by the Crossrail Project dewatering works has dissipated. The remnant drawdown cone still in existence is due to the

continued dewatering at Canary Wharf by The Canary Wharf Contractors, for the Wood Wharf Development.

- Therefore, the temporary impacts of the Crossrail Project dewatering works have all dissipated.
- No permanent adverse impacts remain as a result of these dewatering works.
- No derogation of the rights of licensed third party abstractors was observed or reported during the dewatering works.
- The Crossrail Project EIS predicted no derogation of the licensed abstractors' rights and no significant residual impacts. However, it required vigilance during dewatering to validate the predictions and to develop alternative mitigation measures, should they become necessary. This has been done.
- Crossrail Project has therefore, met its obligations with respect to dewatering, as enshrined in the Crossrail Project Act and subsequent agreements and licences.

REFERENCES

[1] Cross London Rail Links Ltd, Environmental Statement (February 2005), Volume 2, Chapter 8, Section 8.14.

[2] Cross London Rail Links Ltd, Amendment of Provision Environmental Statement. Volume 3 (7 November 2006) Chapter 10.

[3] EA Letter entitled "Schedule 17 consent requirements – depressurising the aquitard", dated 23/7/2010

[4] Geotechnical Consulting Group (2009). Crossrail Limited, Groundwater Monitoring Strategy Revision B. Report No. 1D0101-C1G00-00571_RevB.

[5] Geotechnical Consulting Group (2008 – 2009) Doc. No.1D0101-G0G00-00569; Crossrail Limited, Monitoring of Construction De-watering December 2008 (Revision A) to March 2009 (Revision G) – 7 nos reports

[6] Geotechnical Consulting Group (2010 to 2016) Doc. No. CRL1-GCG-C2-RAN-CRG03-00001; Crossrail Limited, Monitoring of Construction De-watering June 2010 (Revision 1) to February 2016 (Revision 51) – 51 nos reports

[7] Minutes of the Crossrail Project-EA Liaison meeting of Thursday 18th February 2016.

[8] *CP13 Sch 17* DSJV (2013) Sch 17 Pt 3 Supporting Information, CP13 dewatering, report C305-DSJ-T1-QAP-CRG03-50035 Rev 1 dated 20/9/2013.

[9] *Limmo Sch 17* C123 (2010) Intermediate Shafts "Limmo Peninsula schedule 17 Dewatering and Discharge Consents – Supporting Information", Document No C123-JUL-T1-RST-CR144-SH011-Z-00003 Rev.5.0 dated 08/12/2010.

[10] *Limmo Sch 17 Approval* Environment Agency approval letter to Crossrail Ltd (CT/Sc17/27/SE/Limmo Dewatering–Application for Consent: Crossrail Act 2008-

Schedule 17, Pt 3 CRL ref: ENV/NEW/9/4 Limmo Dewatering and Discharge, dated 14/02/2011.

[11] *CT Sch 17* C315 Connaught Tunnel (2012) "Connaught Tunnel Schedule 17 Dewatering consent supporting information", Document No. C315-VIN-T1-RST-CR146-ST003-50001 Rev 2.0 dated 05/01/2012.

[12] *CT Sch 17 Approval* Environment Agency approval letter to Crossrail Ltd (CT/Sch17/33) Application for Consent: Crossrail Act 2008- Schedule 17, Pt 3 CRL ref: ENV/NEW/1/02 Connaught Tunnel Dewatering, dated 02/02/2012.

[13] *CT Sch 17 Approval Variation* Environment Agency approval letter to Crossrail Ltd (CT/Sch17/55) Application for Consent: Crossrail Act 2008- Schedule 17, Pt 3 CRL ref: ENV/NEW/1/04, C315 Connaught Groundwater Discharge into the Royal Docks variation, dated 10/04/2014.

[14] *Canary Wharf Sch 17 Approval* Environment Agency approval letter to Crossrail Ltd (CT/Sch17/02/SE/IOD) Application for Consent: Crossrail Act 2008- Schedule 17, Pt 3 CRL ref: ENV/THA/7/02, Canary Wharf Station-dewatering of Lower Aquifer, dated 24/11/2008.

[15] *NWP Sch 17* C310 (2012) Thames Tunnel Method Statement- Dewatering System Installation- North Woolwich Portal, Document No C310-HTM-Z-GMS-CR146-50033 Rev 1.0 dated November 2012.

[16] *NWP Sch 17 Approval* Environment Agency approval letter to Crossrail Ltd (CT/Sch17/59) Application for Consent: Crossrail Act 2008- Schedule 17, Pt 3 CRL ref: ENV/NEW/12/07, North Woolwich Portal, Installation and commissioning of dewatering wells dated 20/12/2012.

[17] *PML Sch17* C350 Pudding Mill Lane (2011) "Groundwater Control and Pore Water Depressurisation Plan", Document No 100211CR-PLN00025-C350-MRG-C-STP-CRG06-50025 Rev 2.0 dated June 2011.

[18] *PLP Sch 17 Approval* Environment Agency approval letter to Crossrail (CT/Sch17/34/SE/Plumstead) Application for Consent: Crossrail Act 2008- Schedule 17, Pt 3 CRL ref: ENV/GRE/2/02, Plumstead Portal site- dewatering, dated 05/04/2012.

[19] CRL-EA Liaison Meeting of 14/12/2013 *[CP13 GWQ data discussed in some detail]*

[20] CRL-EA Liaison Meetings of 14/3/2014, 25/9/2014 & 13/8/2015 *[examples of meetings where CP13 and GP GWQ data were reviewed]*

[21] C310 (2012) "C, rev 2.0 dated 11/12/2012 C310 Thames Tunnel Report, NWP Groundwater Contamination Level Response for Dewatering Scheme", eb no C310-HTM-RGN-CR146-50005

[22] C305 email (BG) to EA (DB) dated 10/9/2015 11:34 with last update of GP GWQ data and plots, and C305 (BG) email to EA (DB) dated 11/9/2015

[23] CRL-EA Liaison Meeting of 16 Jan 2014 *[NWP groundwater treatment plant decommissioning discussed and agreed]*

[24] CRL-EA Liaison meeting of 12th May 2016

[25] WJ Groundwater, Canary Wharf Monitoring report, Ref J1505-MR219 dated 27/5/2016.

[26] C610 Connaught Tunnel Monitoring Strategy for Dewatering Works, Doc C610-ATC-T1-RGN-CRG03-50046 Rev 1.0 dated 16/4/2015

[27] C610 Connaught Quantitative Risk Assessment of Dewatering Works (Schedule 17(3) ref. ENV/NEW/1/08), Doc C610-ATC-T1-ASM-CRG03-50003 Rev 1.0 dated 20/2/2015

TABLES

Table A Determinands of interest at Limmo site

	List of chemicals	Comment
Basic/ Standard Suite (data from 26/02/2010 to 9/03/2016)	Total Alkalinity as CaCO3	Stable
	Total Acidity as CaCO3	Nill
	Total Hardness as CaCO3	Stable
	Chloride as Cl	Stable but above DWS with a range of exceedances between 294-2170mg/l
	Fluoride as F	Stable & below DWS
	Total Sulphur as SO4 (Dissolved)	Stable & below DWS
	Calcium as Ca (Dissolved)	Stable
	Magnesium as Mg (Dissolved)	Stable
	Sodium as Na (Dissolved)	Stable but above DWS with a range of exceedances between 217-763mg/l
	Potassium as K (Dissolved)	Stable
	Nickel as Ni (Dissolved)	Stable with only three exceedances above DWS (0.031,0.089 & 0.045mg/l) recorded in April2012, Dec2013 & Feb2014, respectively
	Chromium as Cr (Dissolved)	Stable & much lower than DWS
	Copper as Cu (Dissolved)	Stable & much lower than DWS
	Lead as Pb (Dissolved)	Stable & much lower than DWS
	Zinc as Zn (Dissolved)	Stable
	Manganese as Mn (Dissolved)	Stable & below DWS (only two exceedances above DWS (0.646 &0.085mg/l)recorded in Feb 2010 and Jan 2012 respectively
	Iron as Fe (Dissolved)	Stable with only three exceedances above DWS (4.08,0.69 & 1.54mg/l) recorded in Jan, April & Sept 2012, respectively
	Arsenic as As (Dissolved)	Stable & below DWS
	Boron as B (Dissolved)	Stable & much lower than DWS
	Mercury as Hg (Dissolved)	Stable & much lower than DWS
	Vanadium as V (Dissolved)	Stable
	Ammoniacal Nitrogen as N	Stable but above DWS with a range of exceedances between 0.6-1.5mg/l
	Nitrite as N	Stable & much lower than DWS
	Nitrate as N	Stable & much lower than DWS
	Total Oxidised Nitrogen as N	Stable
	Phosphate as P	Fluctuations between <0.01 and 1.07mg/l
	Total Organic Carbon	Stable
	pH units	Stable
	Suspended Solids	Stable
	TPH	Stable
Additional PCoCs (from Greenwich QRA)	**Benzene**	Data available, all less than LOD. No reported exceedance at CP13 which would have trigger further testing for these contaminants at Limmo.
	Naphthalene	
	Pyrene	
	Aliphatics C6-C8	
	Total PAH	

Additional EA request; chlorinated solvents and PAH	Vinyl Chloride	No data available since no reported exceedance at CP13 (which would have triggered testing for these contaminants at Limmo).
	Tetrachloroethene	
	Trichloroethene	

In situ testing	Electrical Conductivity	Stable & below DWS
	Turbitity N.T.U	Stable
	Dissolved Oxygen	Stable

Notes:
1. DWS=Drinking Water Standards
2. Determinands stated to be "much lower than DWS" are no more than about 1/3 of DWS limit
3. Primary Chemicals of Concern (PCoCs) that could potentially migrate from Greenwich Peninsula are shown in bold red text
4. LOD=Limit Of Detection
5. Range of exceedance = range of values measured which were above the limit or standard of interest

Table B Determinands of interest at Cross passage CP13

	List of chemicals	Comment
Basic/ Standard Suite (data available from 22/01/2014 to 29/07/2015)	Total Alkalinity as CaCO3	Stable
	Total Acidity as CaCO3	Nill
	Total Hardness as CaCO3	Stable
	Chloride as Cl	Stable but above DWS with a range of exceedances between 745-1740mg/l
	Fluoride as F	Stable & much lower than DWS
	Total Sulphur as SO4 (Dissolved)	Stable (below DWS)
	Calcium as Ca (Dissolved)	Stable & low
	Magnesium as Mg (Dissolved)	Stable & low
	Sodium as Na (Dissolved)	Stable but above DWS with a range of exceedances between 307-966mg/l
	Potassium as K (Dissolved)	Stable & low
	Nickel as Ni (Dissolved)	Stable with only three exceedances above DWS (0.024,0.037&0.027 mg/l) recorded in Feb2014,Feb2014 & April 2014 respectively
	Chromium as Cr (Dissolved)	Stable & much below DWS
	Copper as Cu (Dissolved)	Stable with a few isolated peaks above DWS, these peaks are generally between 0.002-0.0117mg/l
	Lead as Pb (Dissolved)	Stable & much lower than DWS
	Zinc as Zn (Dissolved)	Stable with occasional fluctuactions
	Manganese as Mn (Dissolved)	Stable & much lower than DWS
	Iron as Fe (Dissolved)	Stable & much lower than DWS
	Arsenic as As (Dissolved)	Stable (much below DWS)
	Boron as B (Dissolved)	Stable (below DWS)
	Mercury as Hg (Dissolved)	Stable (below DWS)
	Vanadium as V (Dissolved)	Stable (below DWS)
	Ammoniacal Nitrogen as N	Stable but above DWS with a range of exceedances generally between 1.45 and 4.1mg/l
	Nitrite as N	Stable & much below DWS
	Nitrate as N	Stable & much below DWS
	Total Oxidised Nitrogen as N	Stable
	Phosphate as P	Stable & low
	Total Organic Carbon	Stable & low
	pH units	Stable
	Suspended Solids	Stable & low
	TPH	Stable
Additional PCoCs (data available 3/10/2013-29/07/2015)	**Benzene**	Stable (below EQS)
	Naphthalene	Stable (below EQS)
	Pyrene	Stable (below EQS)
	Aliphatics C6-C8	Stable (below EQS)
	Total PAH	Generally Stable with some fluctuations

Additional EA request; chlorinated solvents and PAH (data available 3/10/2013-29/07/2015)	Vinyl Chloride	Stable (but appears to be above EQS because LOD that was achievable was above EQS)
	Tetrachloroethene	Stable
	Trichloroethene	Stable

Notes:
1. EQS= Enviromental Quality Standards
2. DWS=Drinking Water Standards
3. Determinands stated to be "much lower than DWS" are no more than about 1/3 of DWS limit
4. Primary Chemicals of Concern (PCoCs) that could potentially migrate from Greenwich Peninsula are shown in bold red text
5. LOD=Limit Of Detection
6. Range of exceedance = range of values measured which were above the limit or standard of interest

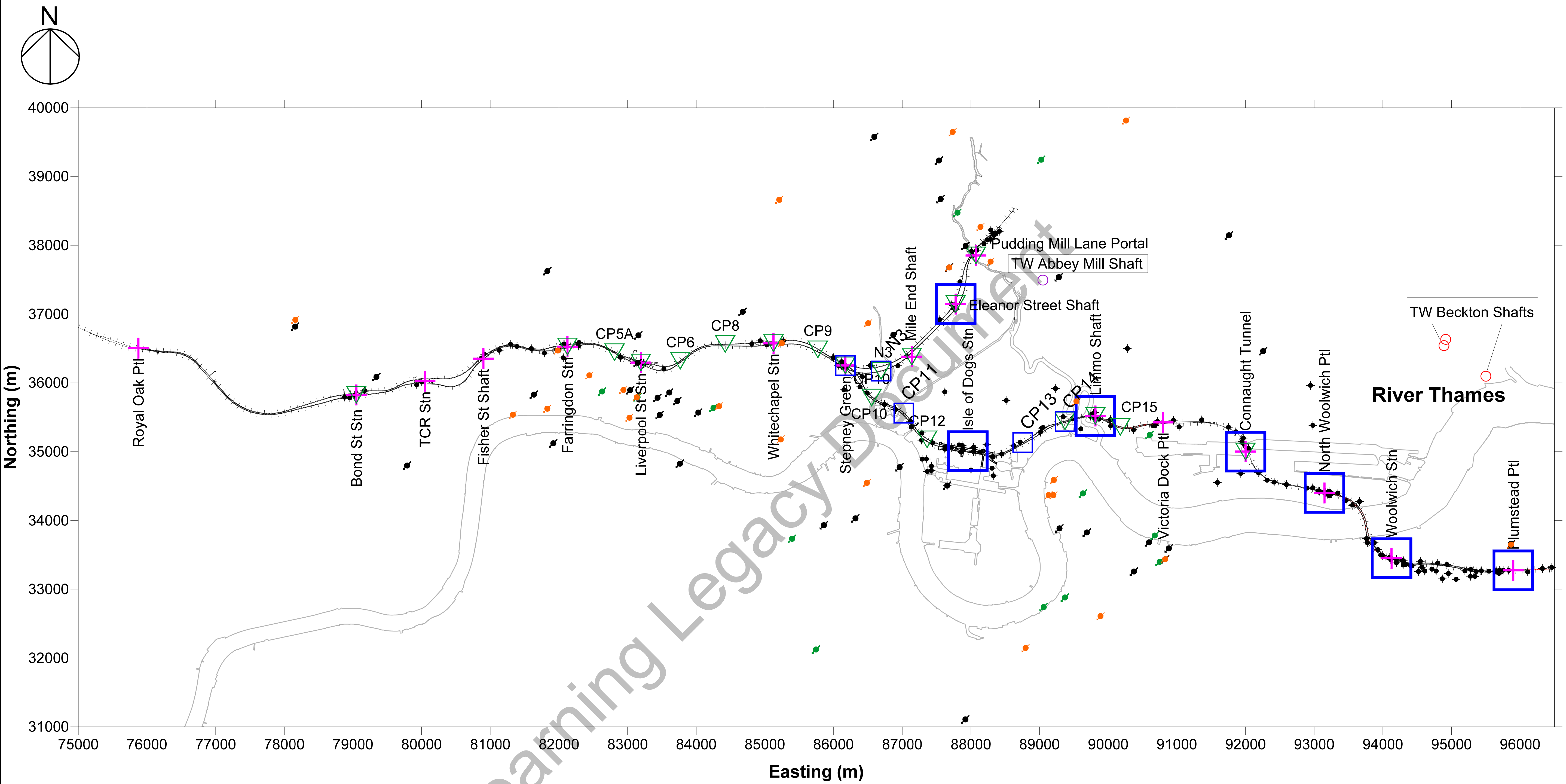
Table C Determinands of interest at North Woolwich Portal & Store Road

	List of CoCs chemicals	Units	Comment	Response levels: 1st Warning level	2nd Warning level	Action level
Chemicals of Concern (CoCs) - Data available from 19/02/2013 to 30/07/2014)	Benzene	µg/l	Stable - below 1st warning level	4	6	8
	EthylBenzene	µg/l	Stable - below 1st warning level	2.3	3.45	4.6
	M/P Xylene	µg/l	Stable - below 1st warning level	15	22.5	30
	O Xylene	µg/l	Stable - below 1st warning level	15	22.5	30
	Toluene	µg/l	Stable - below 1st warning level	20	30	40
	TPH (C10-C40)	**µg/l**	Stable with occasional exceedances up to Action level recorded in sentinel-RTD, NW- RTD, NW-CK wel and discharge water. Up to 2nd warning level in piezo NWPEP-RTD, sentinel -CK wells & up to 1st warning level in piezo NEWPEP-CK wells and the discharge water	250	375	500
	TPH (C5-C6 aliphatic)	mg/l	Stable - below 1st warning level	0.03	0.045	0.06
	TPH (C6-C7 aromatic)	mg/l	Stable - below 1st warning level	0.03	0.045	0.06
	TPH (C6-C8 aliphatic)	mg/l	Stable - below 1st warning level	0.03	0.045	0.06
	TPH (C7-C8 aromatic)	mg/l	Stable - below 1st warning level	0.03	0.045	0.06
	Speciated TPH (C8-C10 aliphatic)	mg/l	Stable - below 1st warning level	0.03	0.045	0.06
	Speciated TPH (C8-C10 aromatic)	mg/l	Stable - below 1st warning level	0.03	0.045	0.06
	Speciated TPH (C10-C12 aliphatic)	**mg/l**	Stable - below 1st warning level	0.0288	0.0431	0.0575
	Speciated TPH (C10-C12 aromatic)	mg/l	Stable - below 1st warning level	0.015	0.0225	0.03
	Speciated TPH (C12-C16 aliphatic)	mg/l	Stable - below 1st warning level	0.0403	0.0604	0.0805
	Speciated TPH (C12-C16 aromatic)	mg/l	Stable - below 1st warning level	0.0403	0.0604	0.0805
	Speciated TPH (C16-C21 aliphatic)	mg/l	Stable - below 1st warning level	0.115	0.1725	0.23
	Speciated TPH (C16-C21 aromatic)	mg/l	Stable - below 1st warning level	0.0173	0.0259	0.0345
	Speciated TPH (C21-C35 aliphatic)	mg/l	Stable - below 1st warning level	0.0403	0.0604	0.0805
	Speciated TPH (C21-C35 aromatic)	mg/l	Stable - below 1st warning level	0.0173	0.0259	0.0345
	TPH (C35-C40 aliphatic)	mg/l	Stable - below 1st warning level	0.0115	0.01725	0.023
	TPH (C35-C40 aromatic)	**mg/l**	Stable - below 1st warning level	0.0115	0.01725	0.023
	TPH sum of aliphatic species (C8-35)	mg/l	Stable - below 1st warning level	0.213	0.319	0.426
	TPH sum of aromatic species (C8-35)	mg/l	Stable - below 1st warning level	0.069	0.1035	0.138
	Naphthalene	µg/l	Stable with occasional exceedances up to 2nd warning level recorded in piezos NW & NWPEP RTI wells	0.92	1.38	1.84
	Acenaphthylene	µg/l	Stable with occasional exceedances up to Action level recorded in NW & NWPEP RTD wells & up to 1s warning level in sentinel CK wells and discharge water	0.16	0.23	0.31
	Acenaphthene	µg/l	Stable with occasional exceedances up to Action level recorded in NW & NWPEP RTD wells & up to 1s warning level in sentinel CK wells & NWPEP CK wells	0.17	0.26	0.35
	Fluorene	µg/l	Stable with occasional exceedances up to Action level recorded in NW RTD wel	0.25	0.38	0.51
	Phenanthrene	µg/l	Stable with occasional exceedances up to Action level recorded in NW RTD wel	0.5	0.75	1
	Anthracene	µg/l	Stable with occasional exceedances up to Action level recorded in sentinel RTD wells and NW RTD wells	0.15	0.22	0.3
	Fluoranthene	**µg/l**	Stable - below 1st warning level	1.04	1.55	2.07
	Pyrene	**µg/l**	Stable with occasional exceedances up to 1st warning level recorded in NW RTD wel	0.75	1.12	1.5
	Benzo(a)Anthracene	**µg/l**	Stable with occasional exceedances up to 2nd warning level recorded in NWPEP RTD wells & up to 1s warning level in sentinel CK wells	0.27	0.41	0.54
	Chrysene	**µg/l**	Stable with occasional exceedances up to 1st warning level recorded in NWPEP RTD and sentinel C wells & up to 1st warning level in sentinel CK wells	0.41	0.61	0.82
	Benzo(b)fluoranthene	µg/l	Stable with occasional exceedances up to 1st warning level recorded in NWPEP RTD and sentinel C wells & up to 1st warning level in sentinel CK wells	0.32	0.48	0.64
	Benzo(k)fluoranthene	µg/l	Stable with occasional exceedances up to 2nd warning level recorded in NWPEP RTD wells & up to 1s warning level in sentinel CK wells	0.3	0.45	0.6
	Benzo(a)Pyrene	µg/l	Stable with occasional exceedances up to 2nd warning level recorded in NWPEP RTD wells & up to 1s warning level in sentinel CK wells	0.24	0.36	0.48
	Indeno(123-cd)Pyrene	µg/l	Stable with occasional exceedances up to Action level recorded in NW & NWPEP RTD well	0.16	0.24	0.32
	Dibenzo(ah)Anthracene	µg/l	Stable with occasional exceedances up to Action level recorded in NW & NWPEP RTD wells	0.17	0.25	0.33
	Benzo(ghi)Perylene	µg/l	Stable with occasional exceedances up to Action level recorded in NWPEP RTD wells & up to 1s warning level in sentinel CK wells	0.17	0.26	0.35
	PAH(total)	µg/l	Stable with occasional exceedances up to 1st warning level recorded in NW & NWPEP RTD wells	4.49	6.73	8.97
	Benzo(b)fluoranthene + Benzo(k)fluoranthene	µg/l	Stable with occasional exceedances up to 1st warning level recorded in NWPEP RTD and sentinel C wells & up to 1st warning level in sentinel CK wells	0.62	0.93	1.24
	Indeno(123-cd)Pyrene + Benzo(ghi)Perylene	µg/l	Stable with occasional exceedances up to Action level recorded in sentinel RTD wells and NW RTD wells	0.33	0.49	0.66
	Benzo(b)fluoranthene + Benzo(k)fluoranthene + Indeno(123-cd)Pyrene + Benzo(ghi)Perylene	µg/l	Stable with occasional exceedances up to 2nd warning level recorded in NWPEP RTD wells & up to 1s warning level in sentinel CK wells	0.95	1.42	1.9
	Phenol (GC-MS)	µg/l	Stable - below 1st warning leve	15	22.5	30

Notes:

1. Action levels agreed with the EA (ref[21])= Maximum recorded background concentration + 15% or WQS standard (higher value is the action level) EXCEPT, where no detections were recorded in background. In this case (indicated by grey highlight) Action Level = 3x Limit of Detection, Warning Level 2 = 75% of Action Level. Action triggered when Action level is exceeded in 3 subsequent samples from same well surface sheen/ free product is identified in recharge tanks (see ref[21] for details).

FIGURES



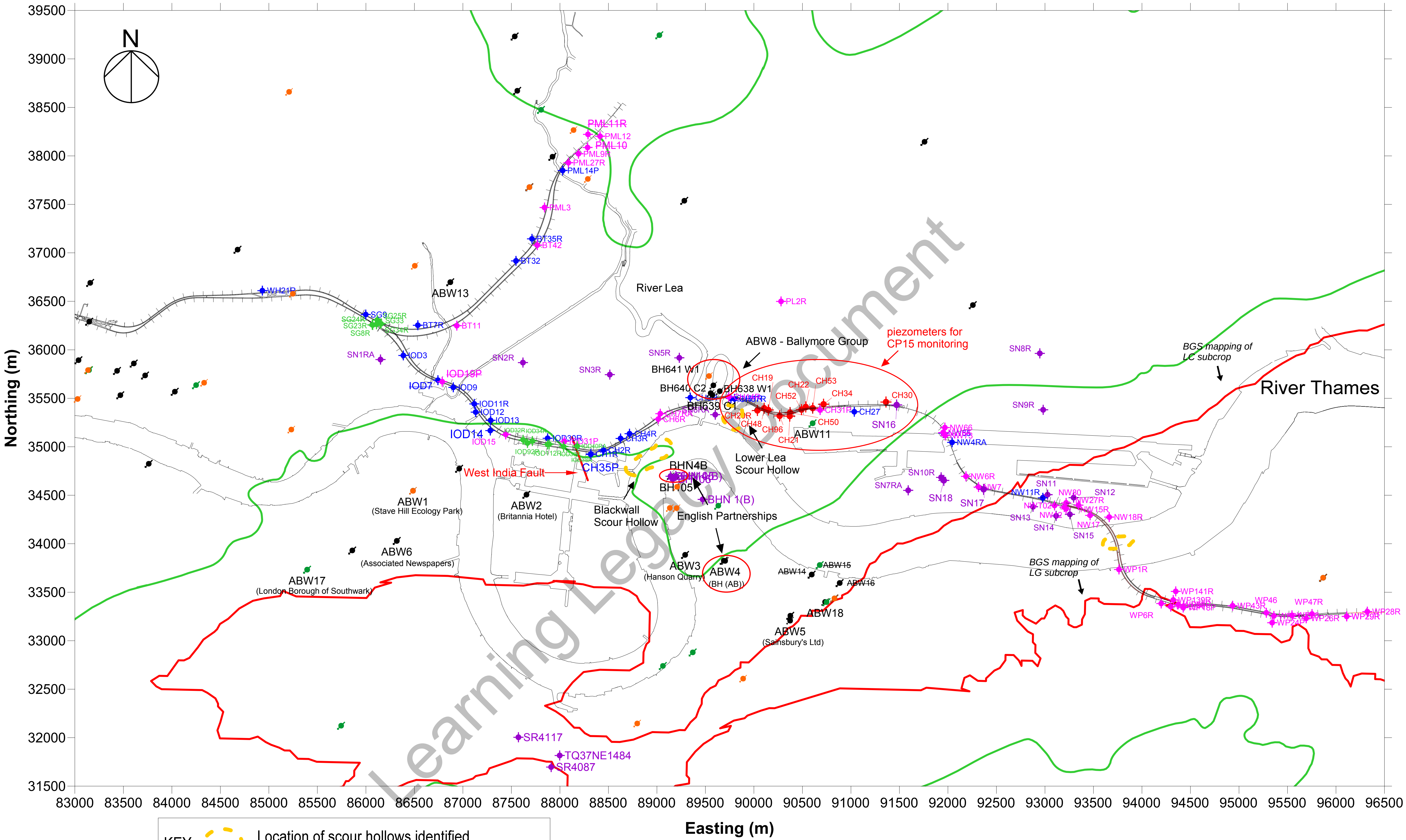
KEY:
- Deep Aquifer De-watering Location
- Shallow Aquifer De-watering / Groundwater Control Measures
- Depressuration Location
- EA/TW Abstraction Well (location +/- 100m)
- EA Abstraction Well (2010 - 2011 new licence)
- Expired/Revokated licences (Refer Table 5)
- Crossrail Borehole
- Thames Water Beckton Shafts
- Thames Water Abbey Mill Shaft

Note:
Abstraction at Bond Street Station (BOS) and Pudding Mill Lane (PML) were from the intermediate aquifer.
Flow rates at BOS were up to 5.0L/s and at PML up to 3.9L/s.

Scale 1:60000

0 500 1000 1500 2000 metres

	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	De-watering Locations	**1(a)**

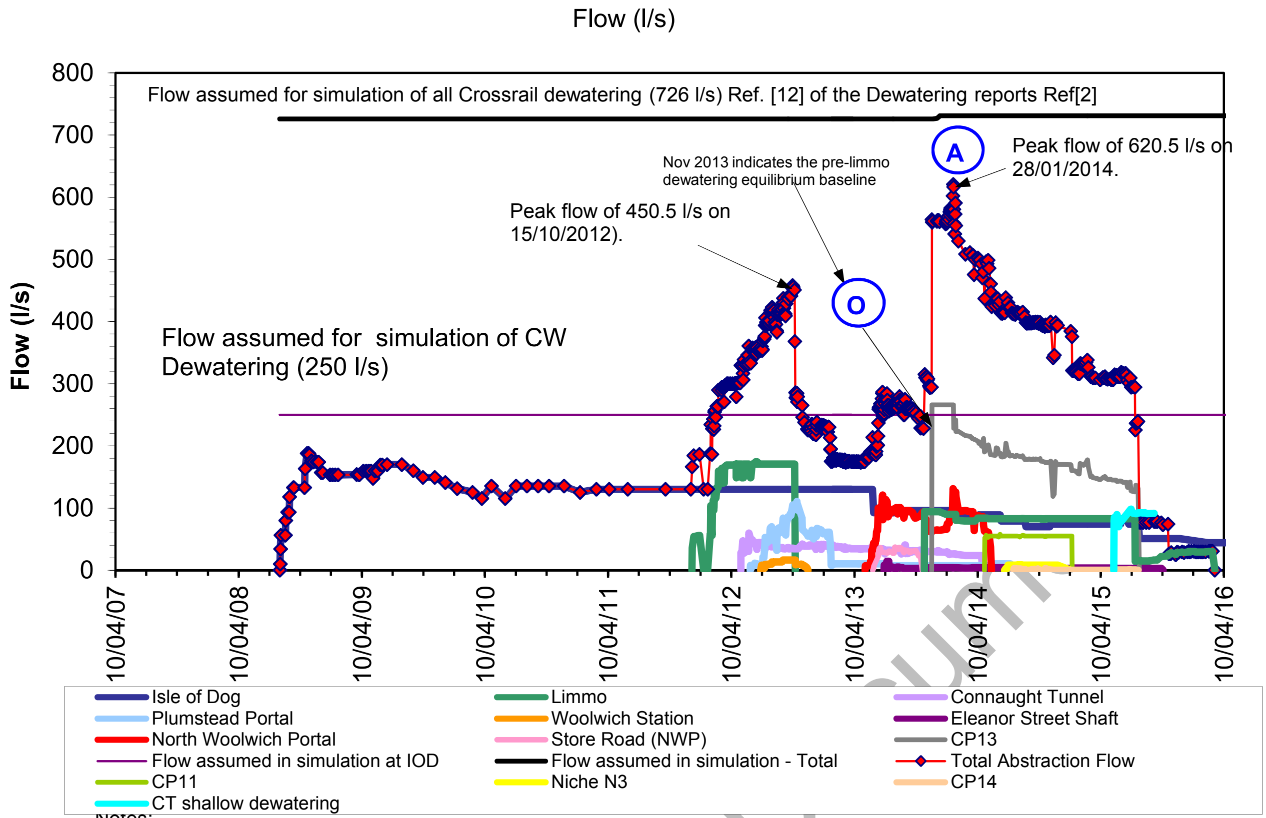


KEY:
- Location of scour hollows identified by Berry (1979) and Lenham et al. (2006)
- Piezometers with Divers
- Piezometers without Divers
- Multilevel & Vibrating Wire piezometers
- Off Alingment Piezometers
- Abstraction Well (location +/- 100m)
- EA Abstraction Well (2010 - 2011 new license)
- Expired/Revoked lincences (Refer Table 5)

Scale 1:40000

0 400 800 1200 1600 metres

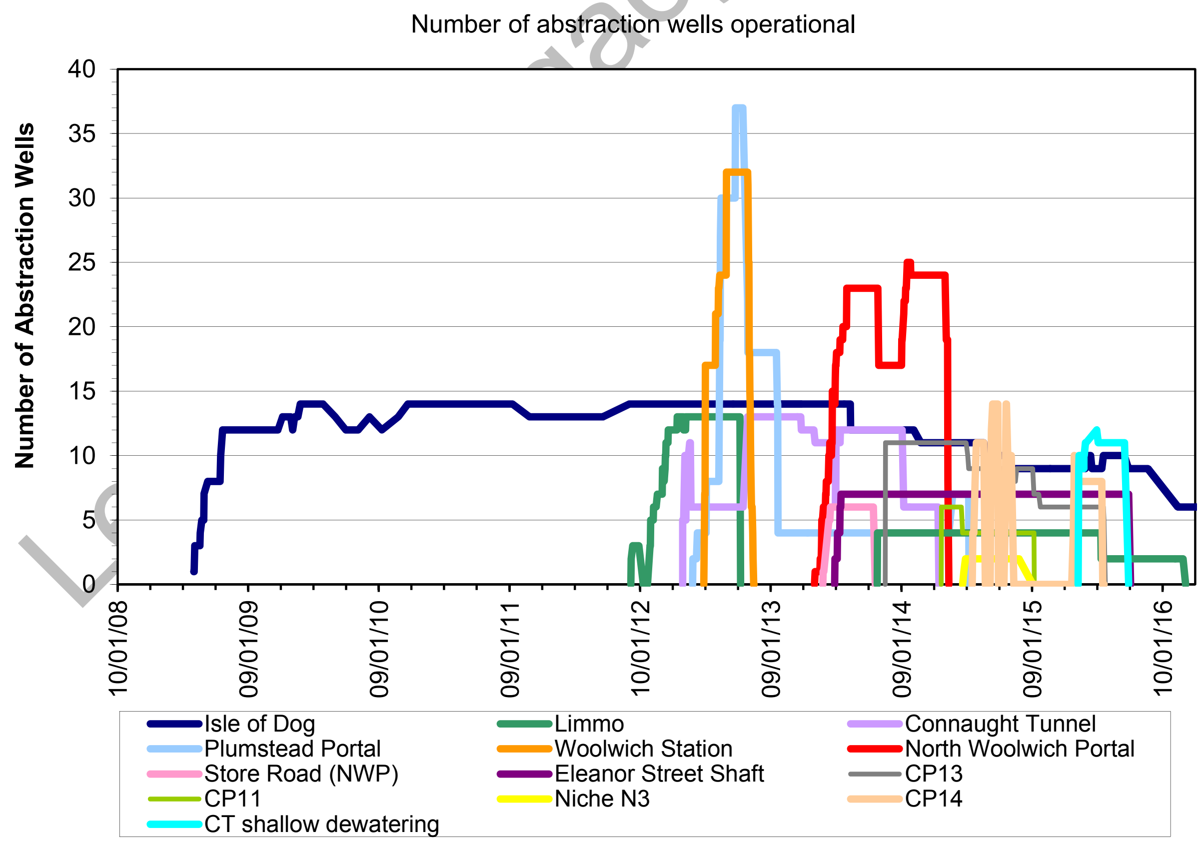
Crossrail Limited Groundwater Monitoring Report - Effects of Dewatering	**Figure**
Piezometers Location Map	**1(b)**



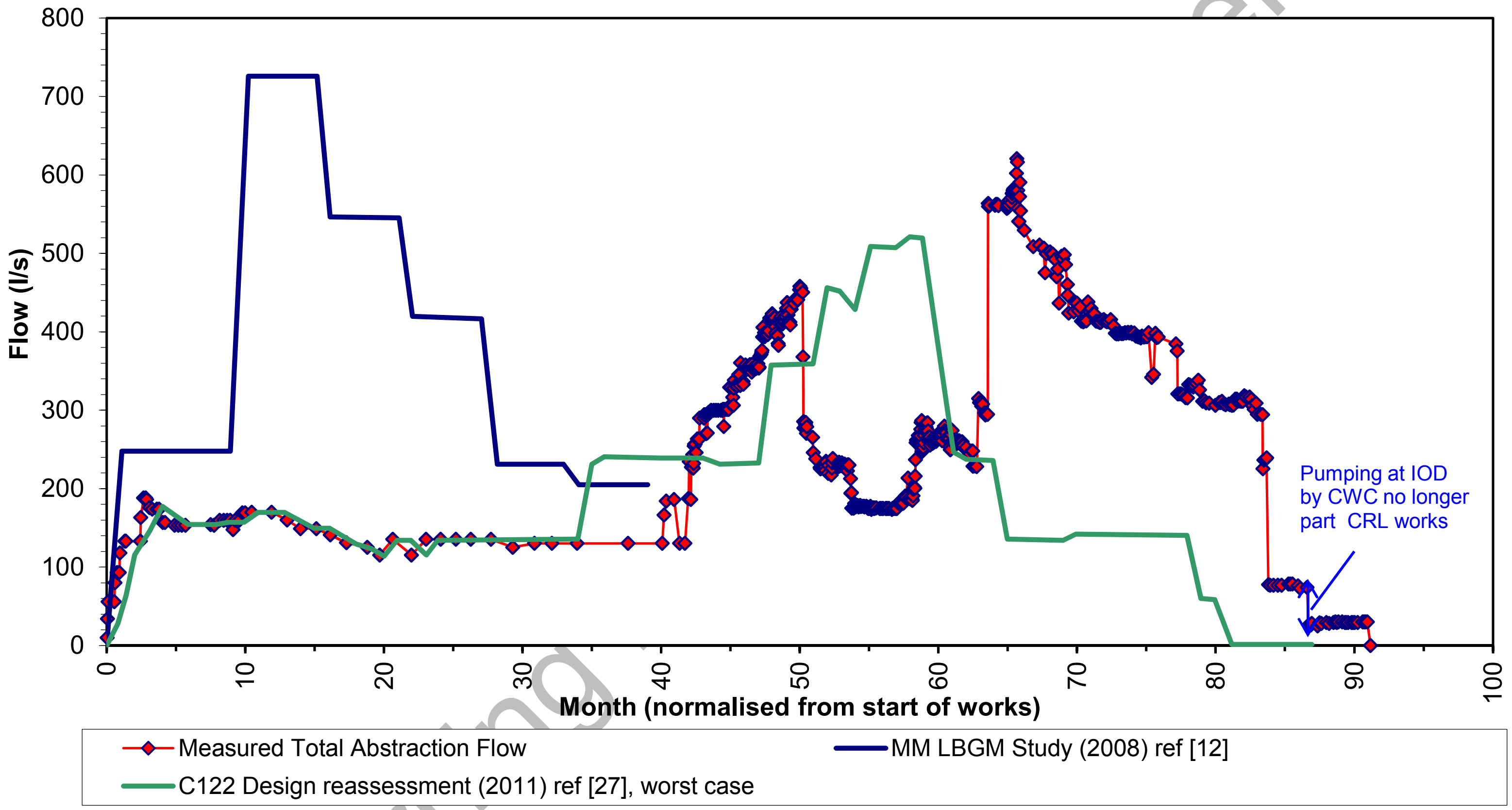
Notes:

(1) From 31/08/2015 CRL ceased pumping at IOD. Physical pumping continued uninterrupted by CW contractors for their own purposes.

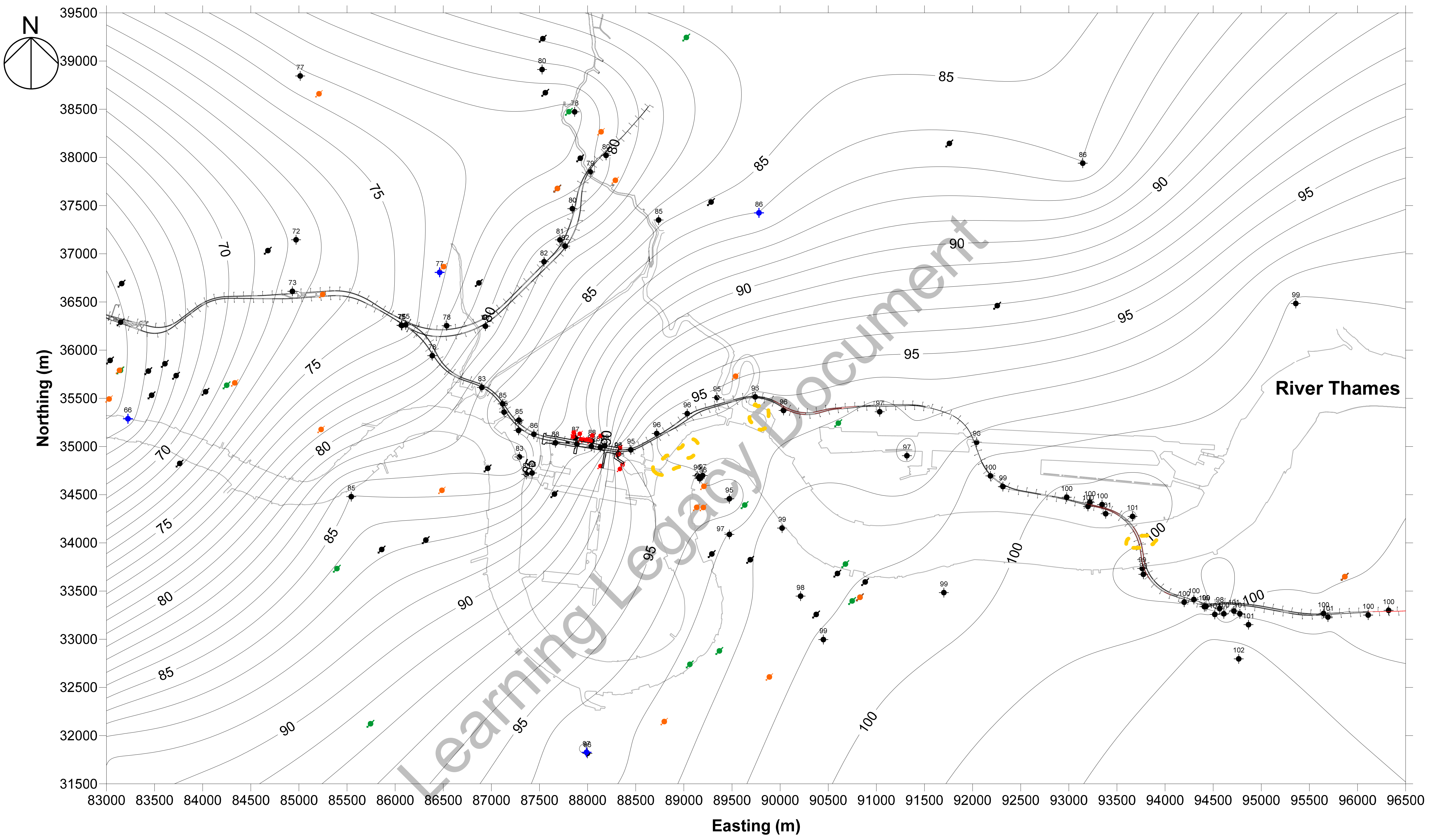
(2) 18% of the CT East Ramp upper aquifer abstraction is drawn from the deep aquifer. This quanity is included in this graph.



	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Pumping rate (l/s) and number of operational wells - Crossrail dewatering sites	**2(a)**



	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure** **2(b)**
	Comparison of the measured flow from the deep aquifer due to all Crossrail dewatering with assumptions in earlier simulations and predictions	



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings in February 2008, supplemented with CWC(C) monitoring data within Isle of Dogs and EA data for January 2008.
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.
5. Data for Greenwich Peninsula monitoring now included (8 piezos).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail Isle of Dogs Station
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

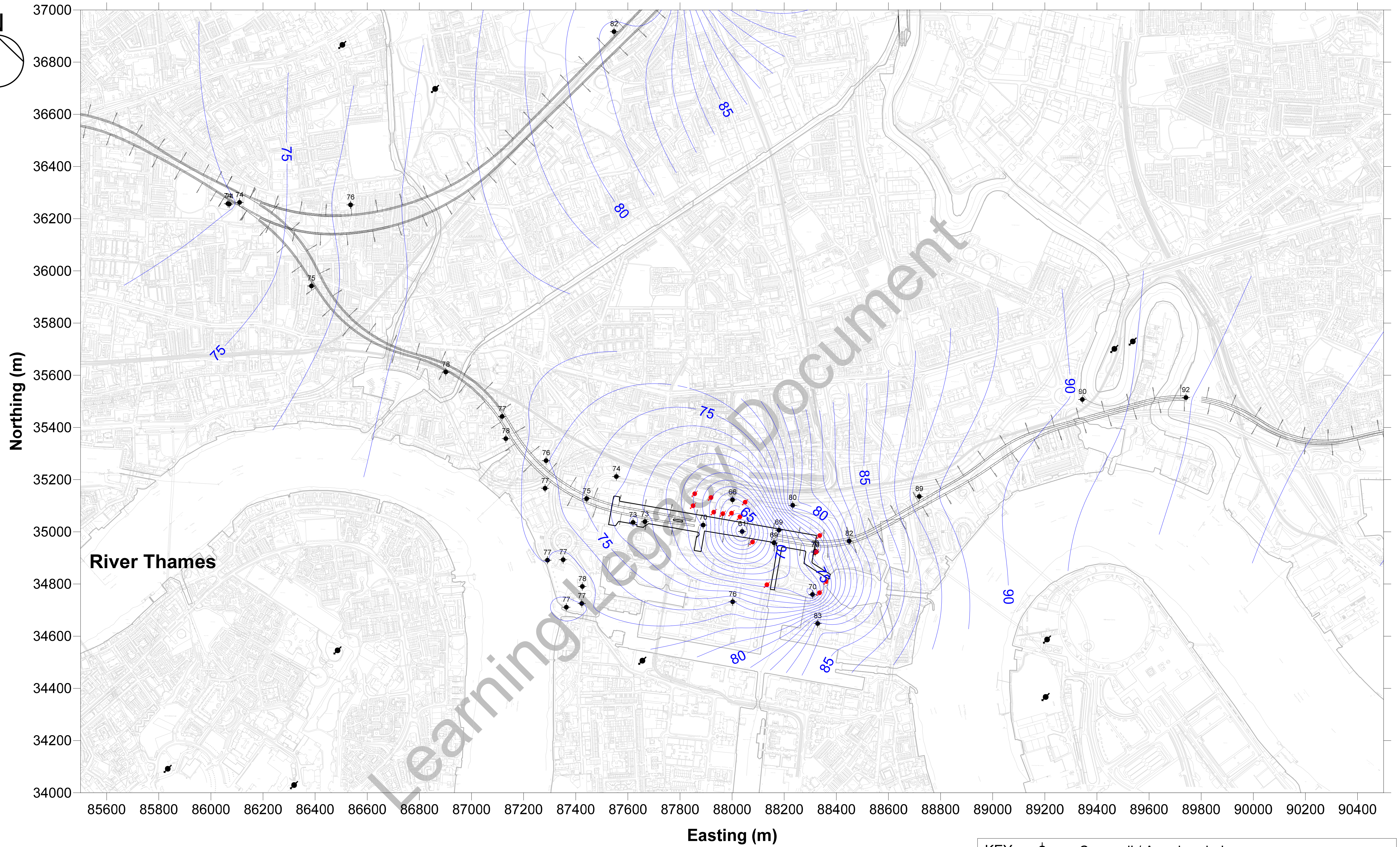
Crossrail Limited

Groundwater Monitoring Report - Effects of Dewatering

Deep aquifer groundwater level contours - Baseline - February 2008 (Version 2)

Liverpool Street to Plumstead and Pudding Mill Lane

Figure 3(a)



KEY:
- Crossrail / Arup borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail Isle of Dogs Station
- Groundwater Level (mATD)

NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings in December 2008, supplemented with Arup monitoring data within Isle of Dogs.
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 1:15000

0 500 1000 1500 metres 2000

GCG

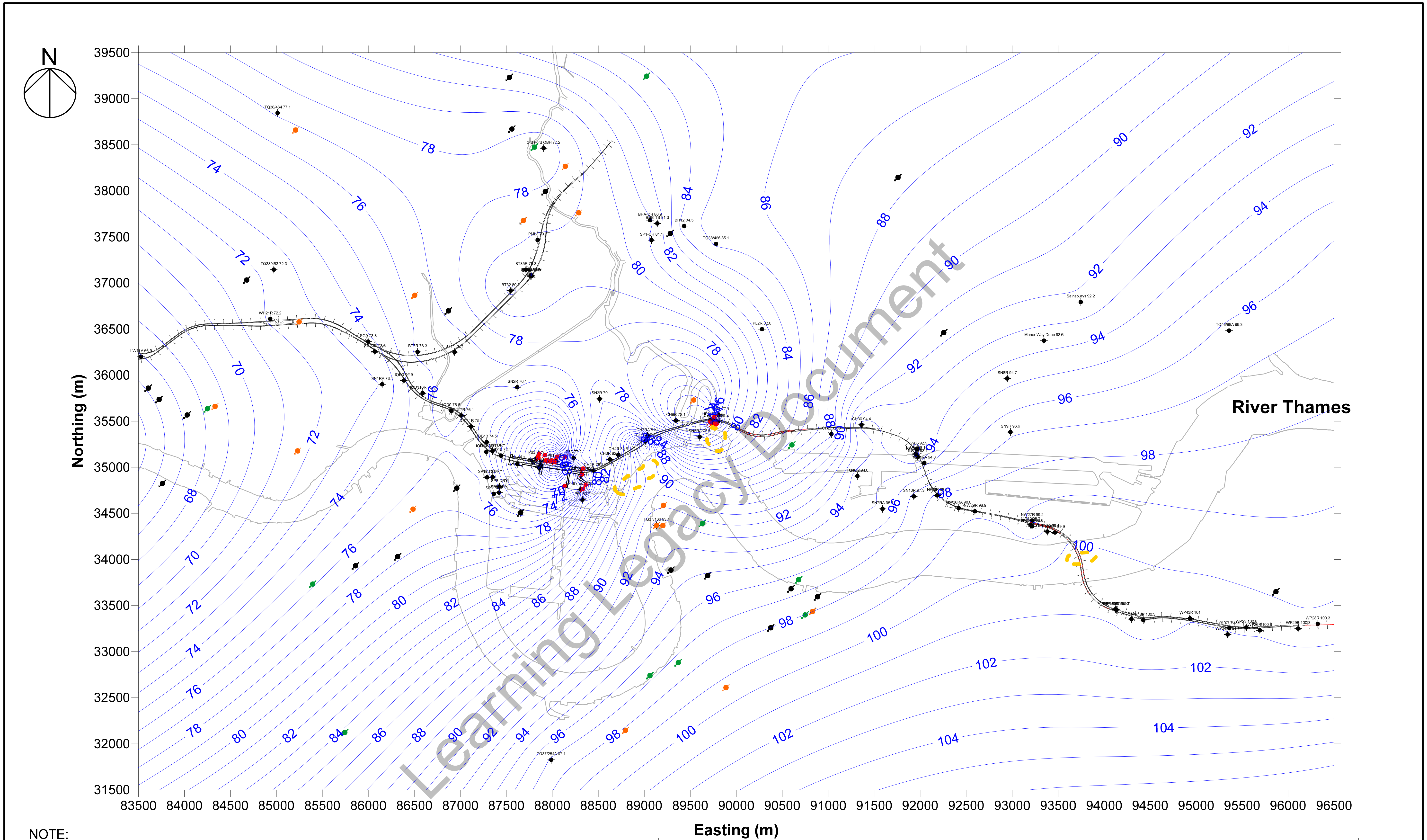
Cross London Rail Links Ltd

Groundwater Monitoring Report - Effects of Dewatering for IoD Station - December 2008

Deep aquifer groundwater level contours - December 2008

Stepney Green to Limmo Peninsula

Figure 3(b)



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings between March 2011 and April 2012, supplemented with EA data for January 2012, TW data and CWC(C) monitoring data within Isle of Dogs.
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.
5. Close to the area of pumping at IoD Station, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

Crossrail Limited

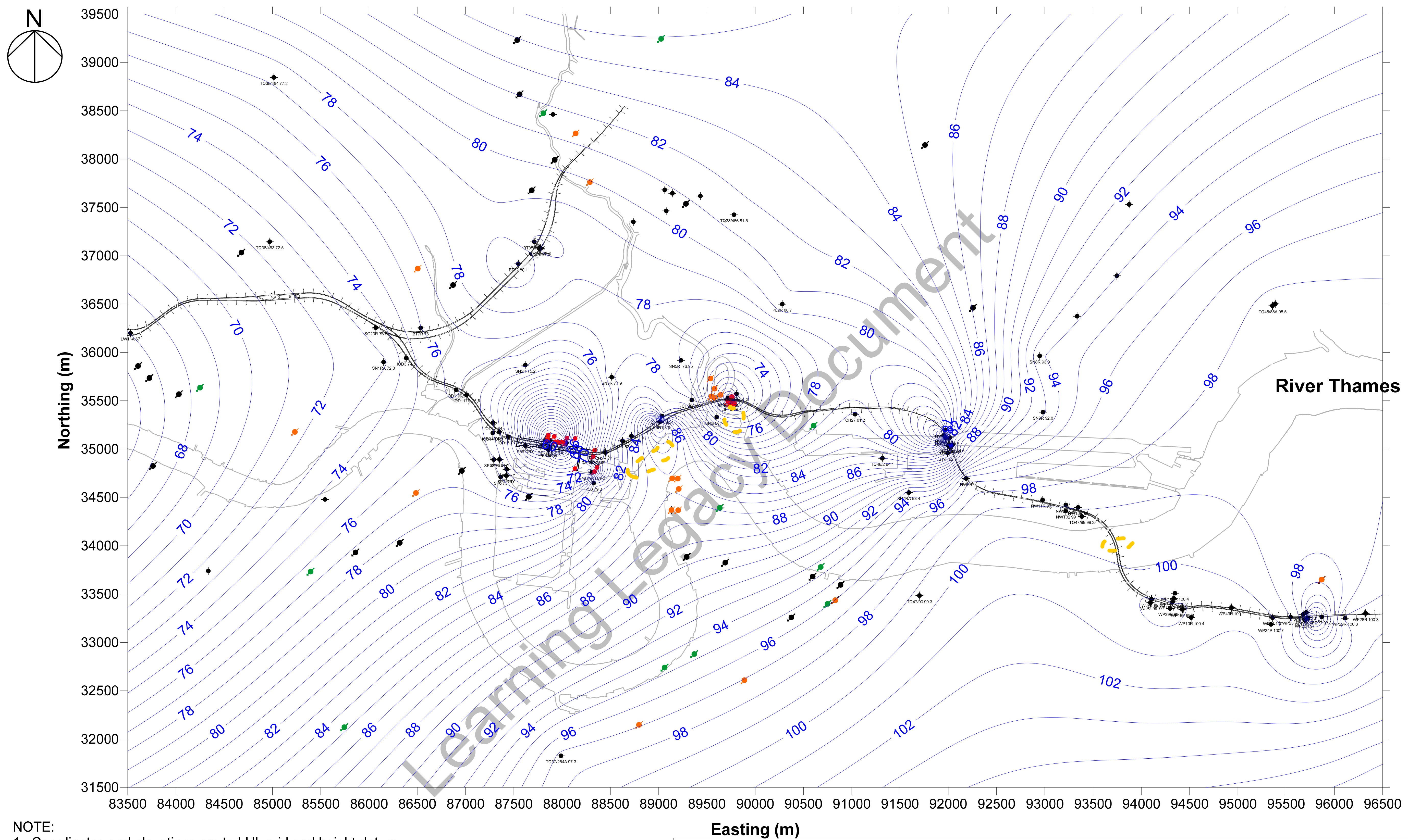
Groundwater Monitoring Report - Effects of Dewatering - (IOD + Limmo)

Deep aquifer groundwater level contours - April 2012

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

3(c)



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings up to September 2012, supplemented with EA data up to August 2012.
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.
5. Close to the area of pumping at IoD and CT, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

Crossrail Limited

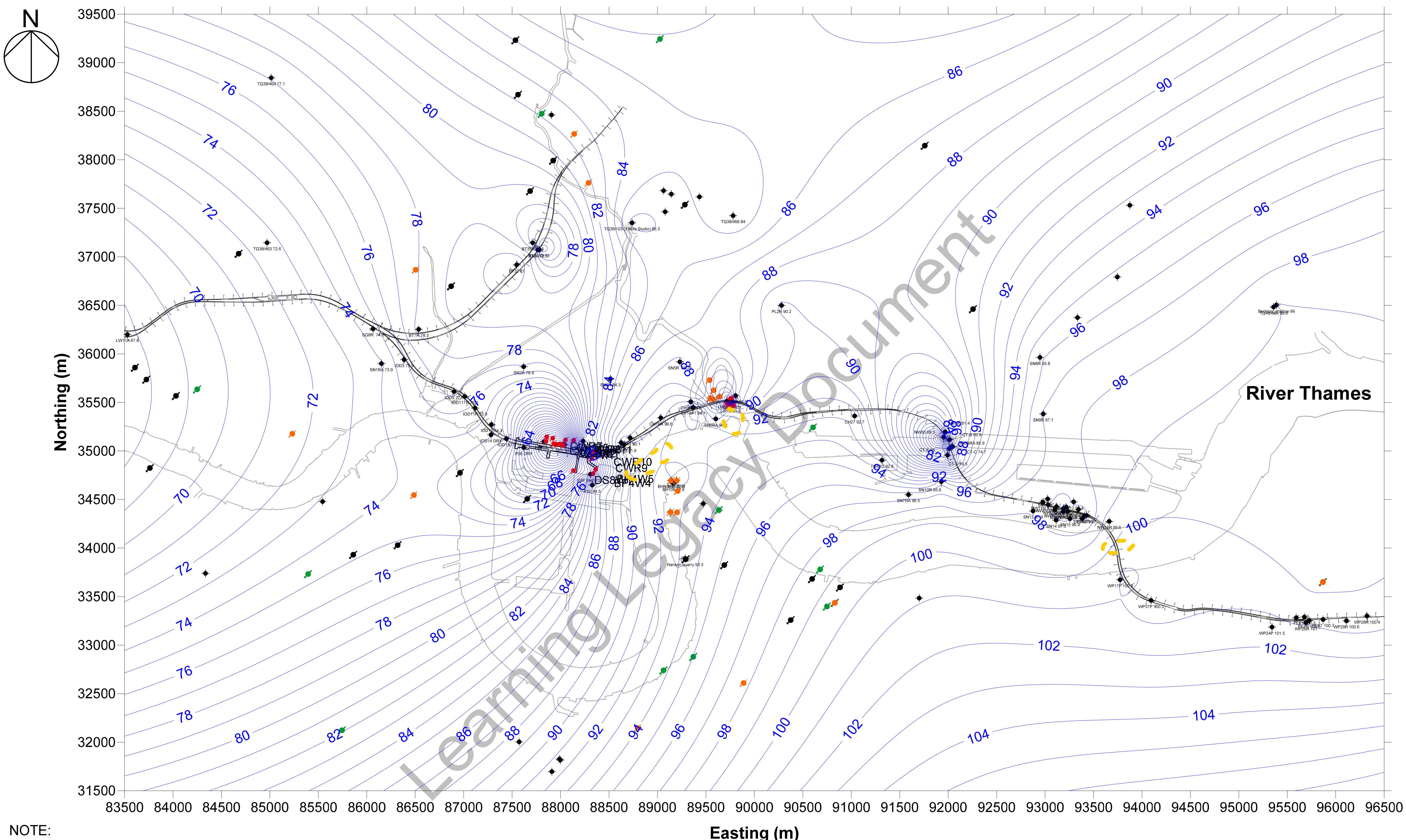
Groundwater Monitoring Report - Effects of Dewatering -(IOD+Limmo+CT+PLP+Woolwich St)

Deep aquifer groundwater level contours - September 2012

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

3(d)



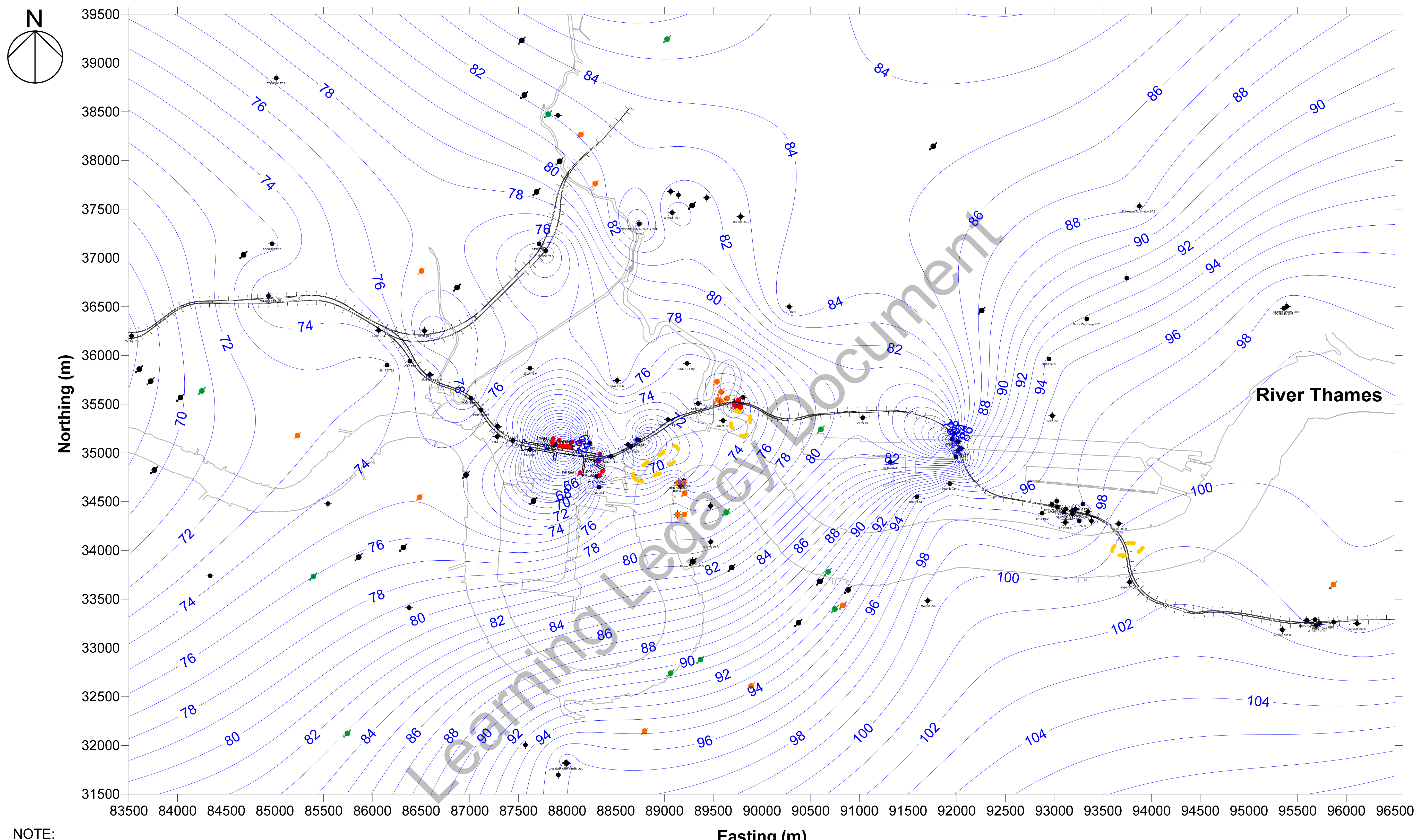
NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings up to October 2013, supplemented with EA and TW data up to September 2013.
3. Accuracy of the contours is governed by the available data (borehole positions indicated).
4. Due to the limited database and temporal variations in the deep aquifer groundwater levels, the contours shown should only be considered as indicative.
5. Close to the area of pumping at IoD and CT, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.
6. Data for Greenwich Peninsula monitoring now included (4 piezos).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

Crossrail Limited Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo (passive wells)+CT+NWP+ELS+PLP)	**Figure**
Deep aquifer groundwater level contours - October 2013 Liverpool Street to Plumstead and Pudding Mill Lane	**3(e)**



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings up to January 2014, supplemented with EA and TW data between December 2013 and January 2014.
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.
5. Close to the area of pumping at IoD and CT, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.
6. Data for Greenwich Peninsula monitoring now included (4 piezos).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

Crossrail Limited

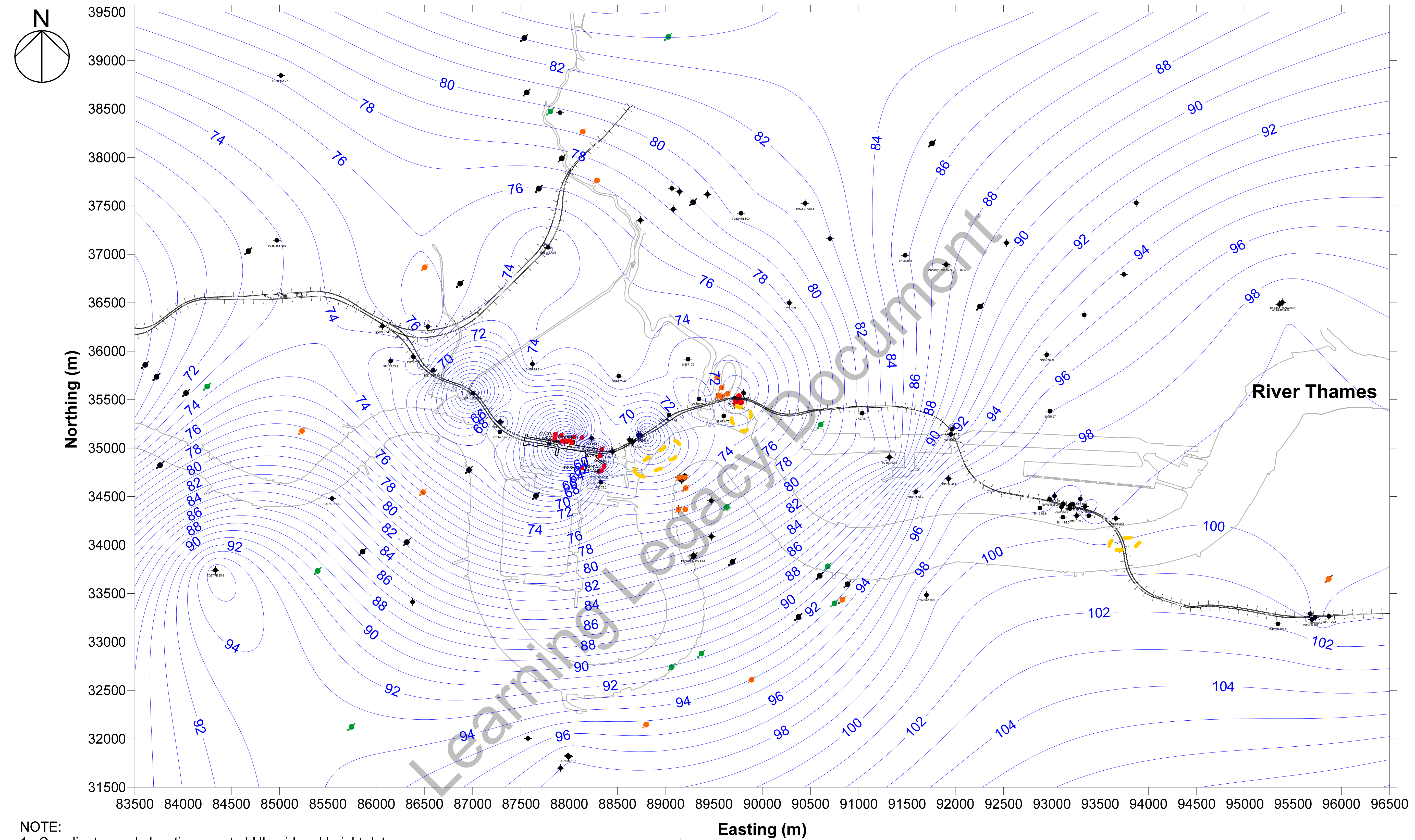
Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo+CT+CP13+NWP+ELS+PLP)

Deep aquifer groundwater level contours - January 2014

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

3(f)



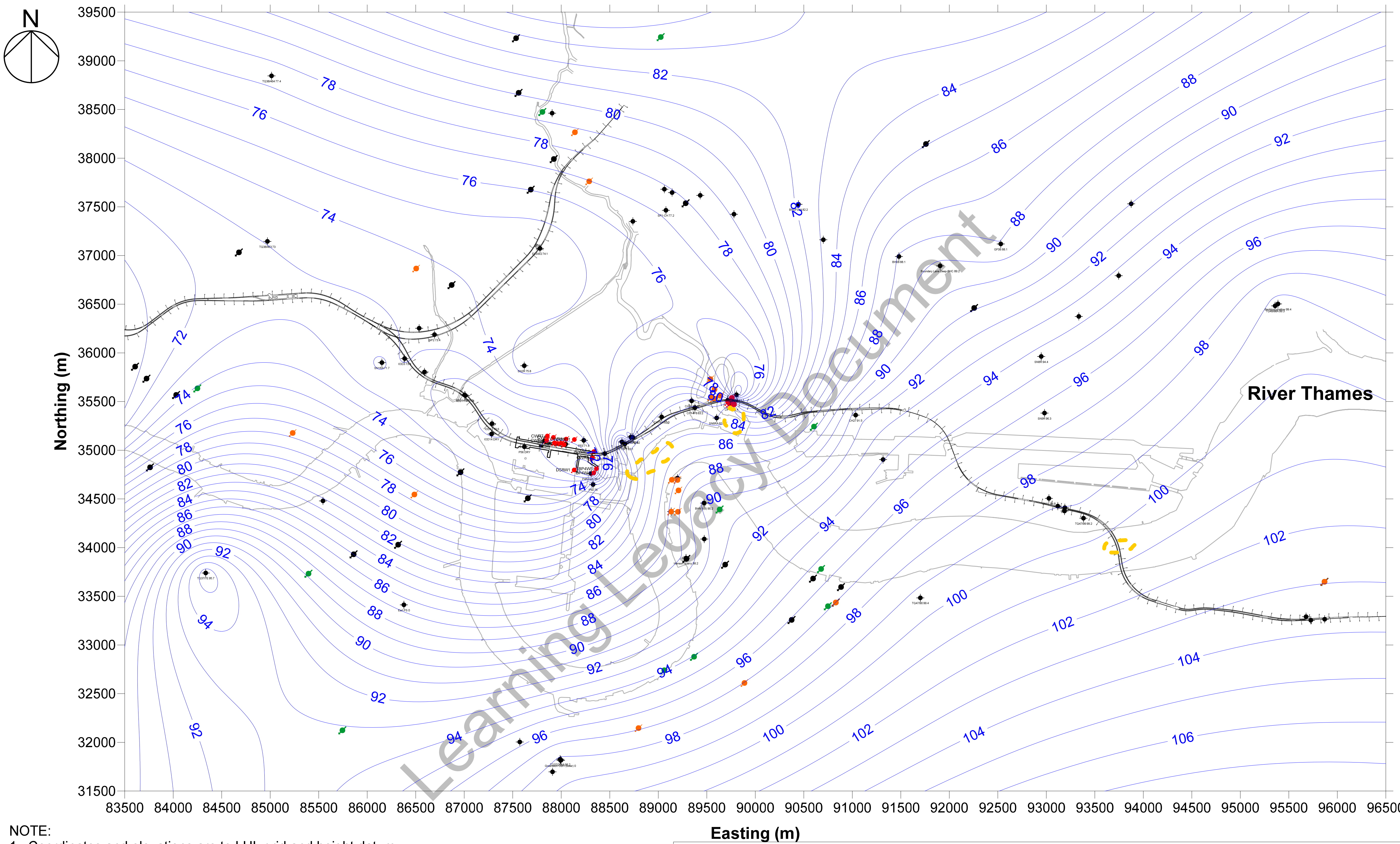
NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings up to July 2014, supplemented with EA and TW data for June 2014.
3. Accuracy of the contours is governed by the available data (borehole positions indicated).
4. Due to the limited database and temporal variations in the deep aquifer groundwater levels, the contours shown should only be considered as indicative.
5. Close to the area of pumping at IoD and CT, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.
6. Data for Greenwich Peninsula monitoring now included (4 piezos).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

Crossrail Limited Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo+CP13+CP11+N3+ELS+PLP)	**Figure**
Deep aquifer groundwater level contours - July 2014 Liverpool Street to Plumstead and Pudding Mill Lane	**3 (g)**



NOTE:

1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings up to August 2015, supplemented with EA and TW data between July and August 2015.
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.
5. Close to the area of pumping at IoD and CT, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.
6. Data for Greenwich Peninsula monitoring now included (4 piezos).

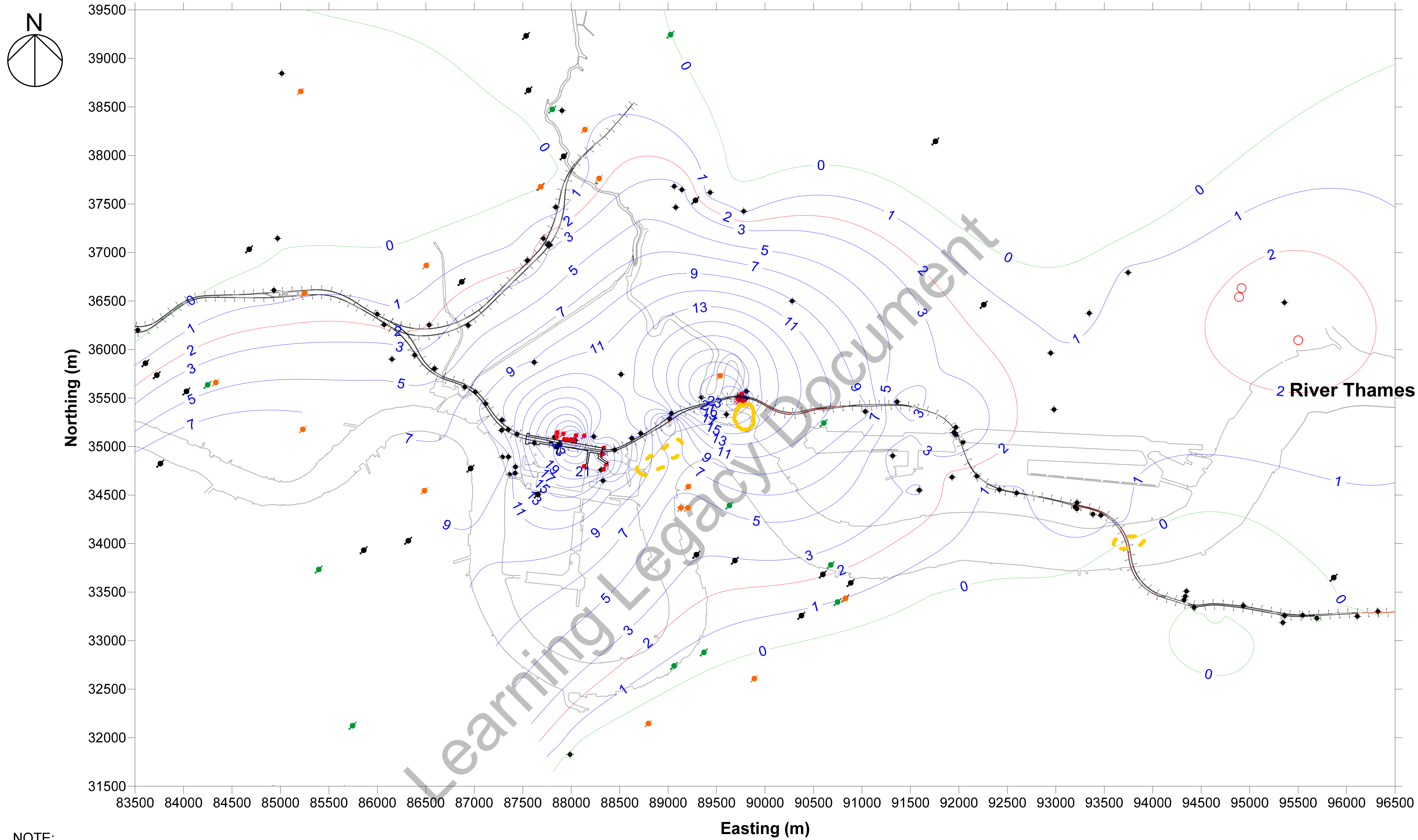
Scale 1:40000

0 500 1000 1500 2000 metres

KEY:

- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

	Crossrail Limited Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo+ELS+CT(shallow))	**Figure**
	Deep aquifer groundwater level contours - August 2015 Liverpool Street to Plumstead and Pudding Mill Lane	3(h)



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer from April 2012 and baseline groudwater reading from February 2008, supplemented with CWC(C) monitoring data within Isle of Dogs and EA and TW 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 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts

Crossrail Limited

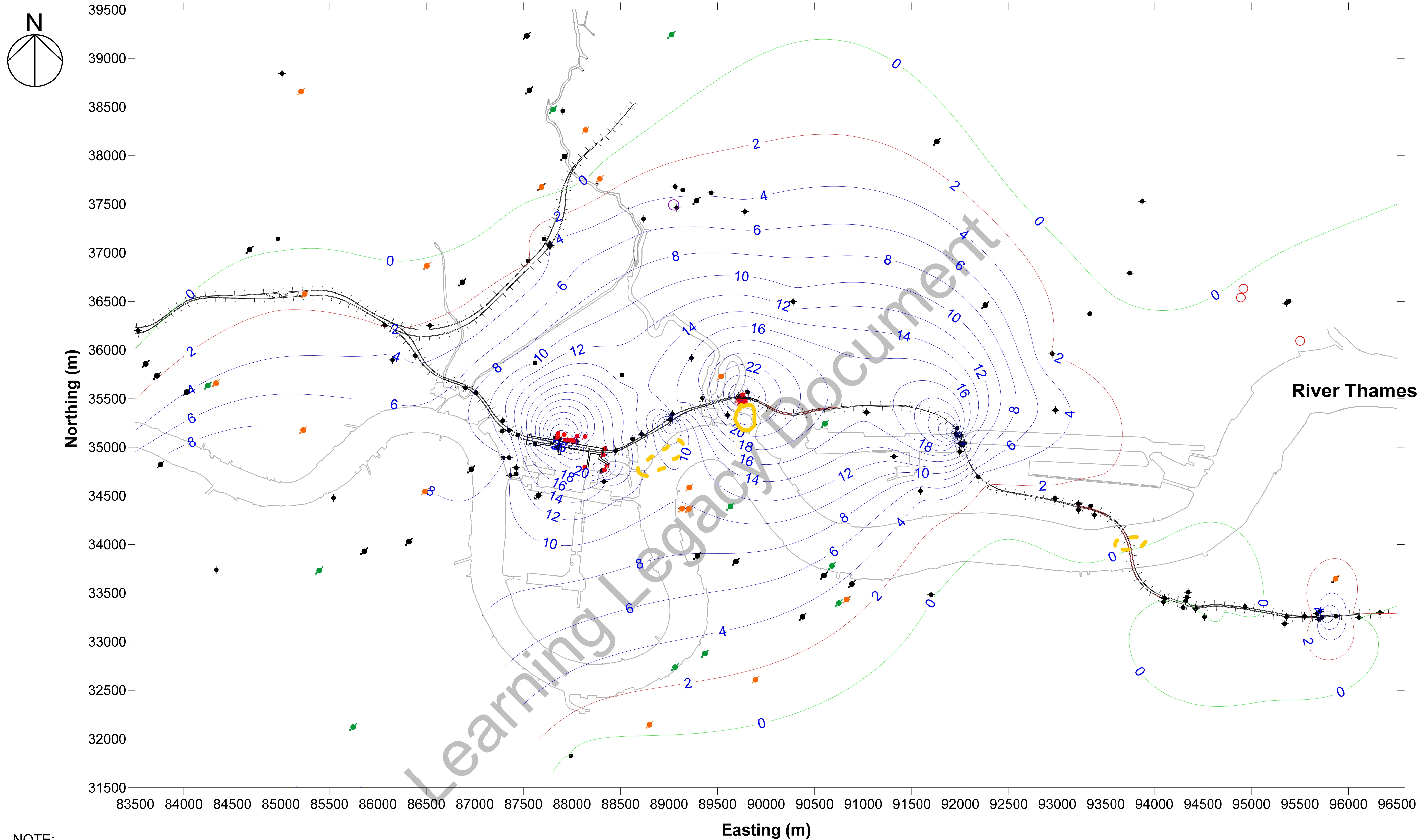
Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo)

Measured Drawdown contours - April 2012

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

4(c)



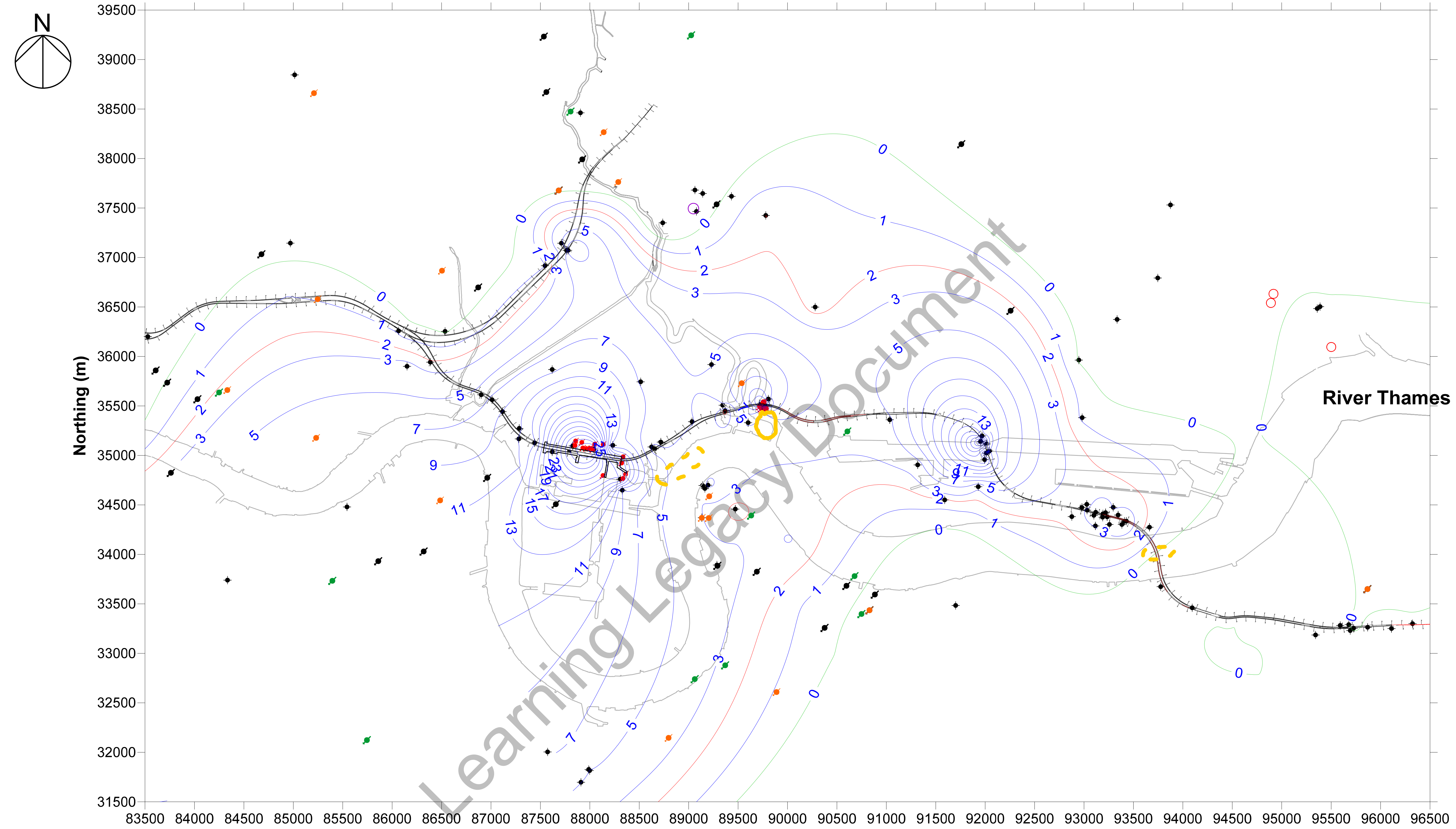
NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer from September 2012 and baseline groudwater reading from February 2008, supplemented with EA data up to August 2012.
3. Accuracy of the contours is governed by the available data (borehole 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.

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts
- Abbey Mill Shaft

Scale 1:40000

0 500 1000 1500 2000 metres

Crossrail Limited	Figure
Groundwater Monitoring Report - Effects of Dewatering -(IOD+Limmo+CT+PLP+Woolwich St)	
Measured Drawdown contours - September 2012	4(d)
Liverpool Street to Plumstead and Pudding Mill Lane	



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer from October 2013 and baseline groundwater reading from February 2008, supplemented with EA & TW data up to September 2013.
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.
5. Data for Greenwhich Peninsula monitoring now included (8 piezos in 2008, 4 piezos in 2013).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts
- Abbey Mill Shaft

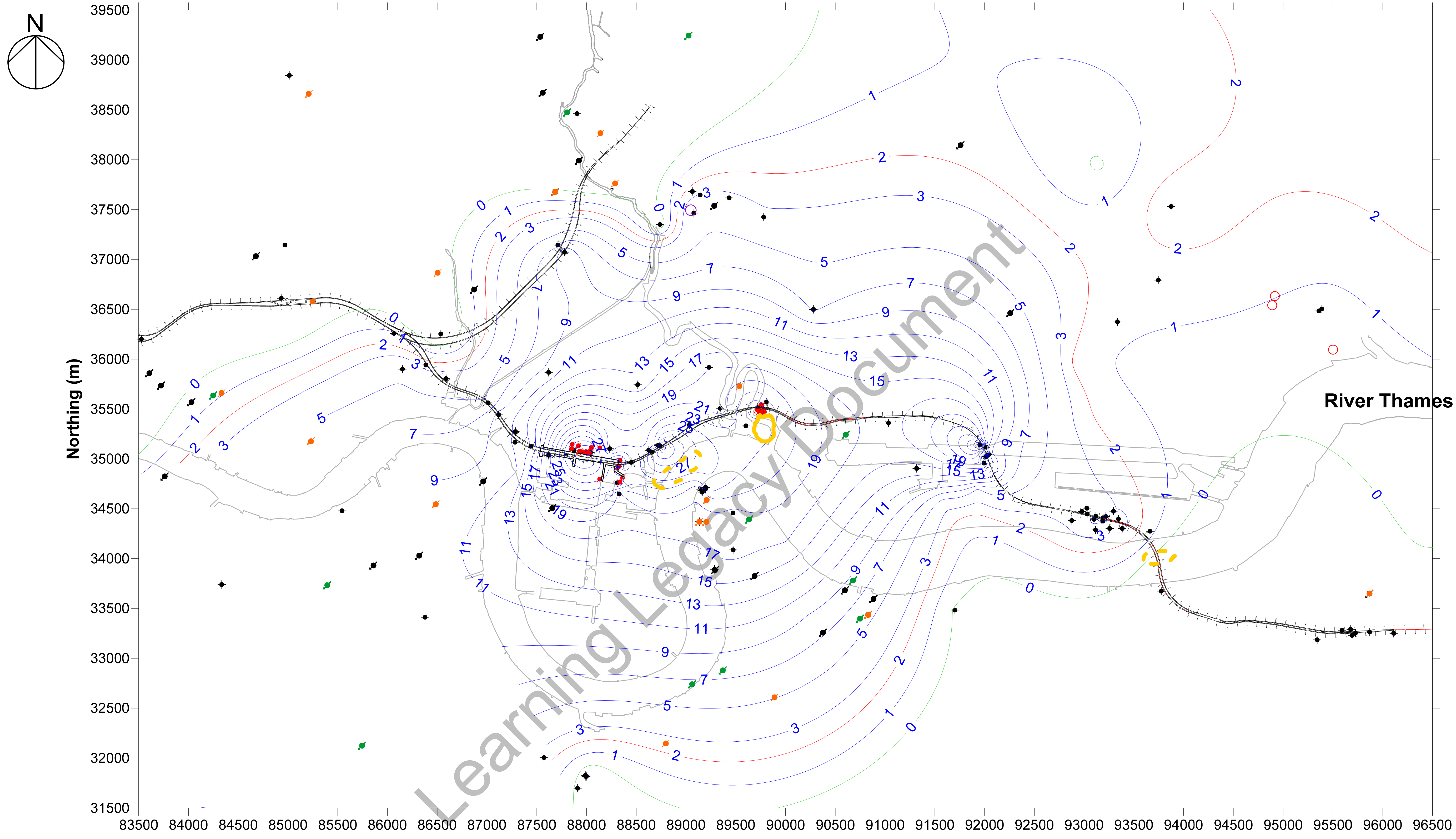
Crossrail Limited

Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo (passive wells)+CT+NWP+ELS+PLP)

Measured Drawdown contours - October 2013

Liverpool Street to Plumstead and Pudding Mill Lane

Figure 4(e)



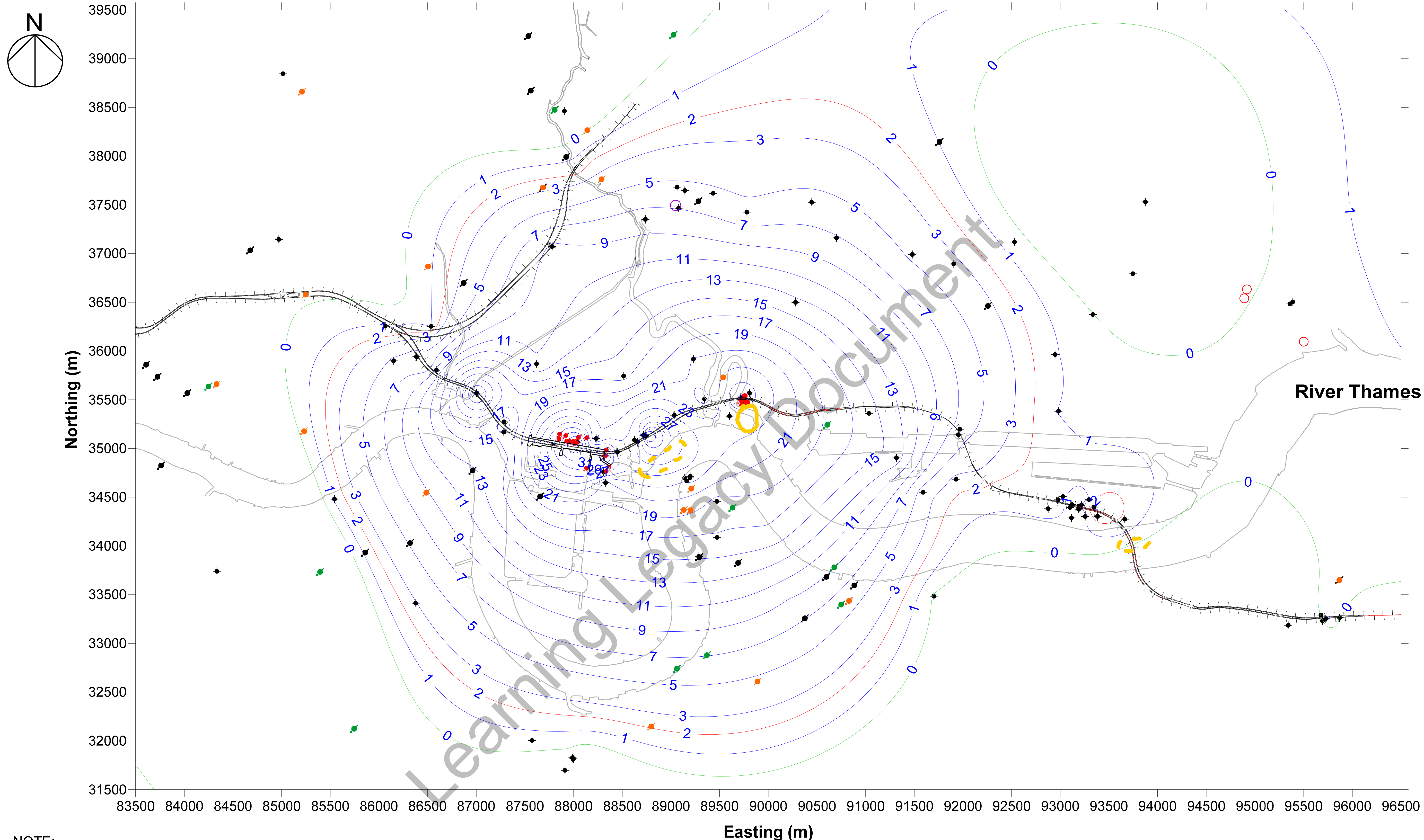
NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer from January 2014 and baseline groundwater reading from February 2008, supplemented with EA & TW data bewteen Dec 2013 and Jan 2014.
3. Accuracy of the contours is governed by the 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.
5. Data for Greenwhich Peninsula monitoring now included (8 piezos in 2008, 4 piezos in 2013).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts
- Abbey Mill Shaft

Crossrail Limited		**Figure**
Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo+CT+CP13+NWP+ELS+PLP)		
Measured Drawdown contours -January 2014		**4 (f)**
Liverpool Street to Plumstead and Pudding Mill Lane		



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer for July 2014 and baseline groundwater reading from February 2008, supplemented with EA & TW data for June 2014.
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.
5. Data for Greenwhich Peninsula monitoring now included (8 piezos in 2008, 4 piezos in 2013).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts
- Abbey Mill Shaft

Crossrail Limited

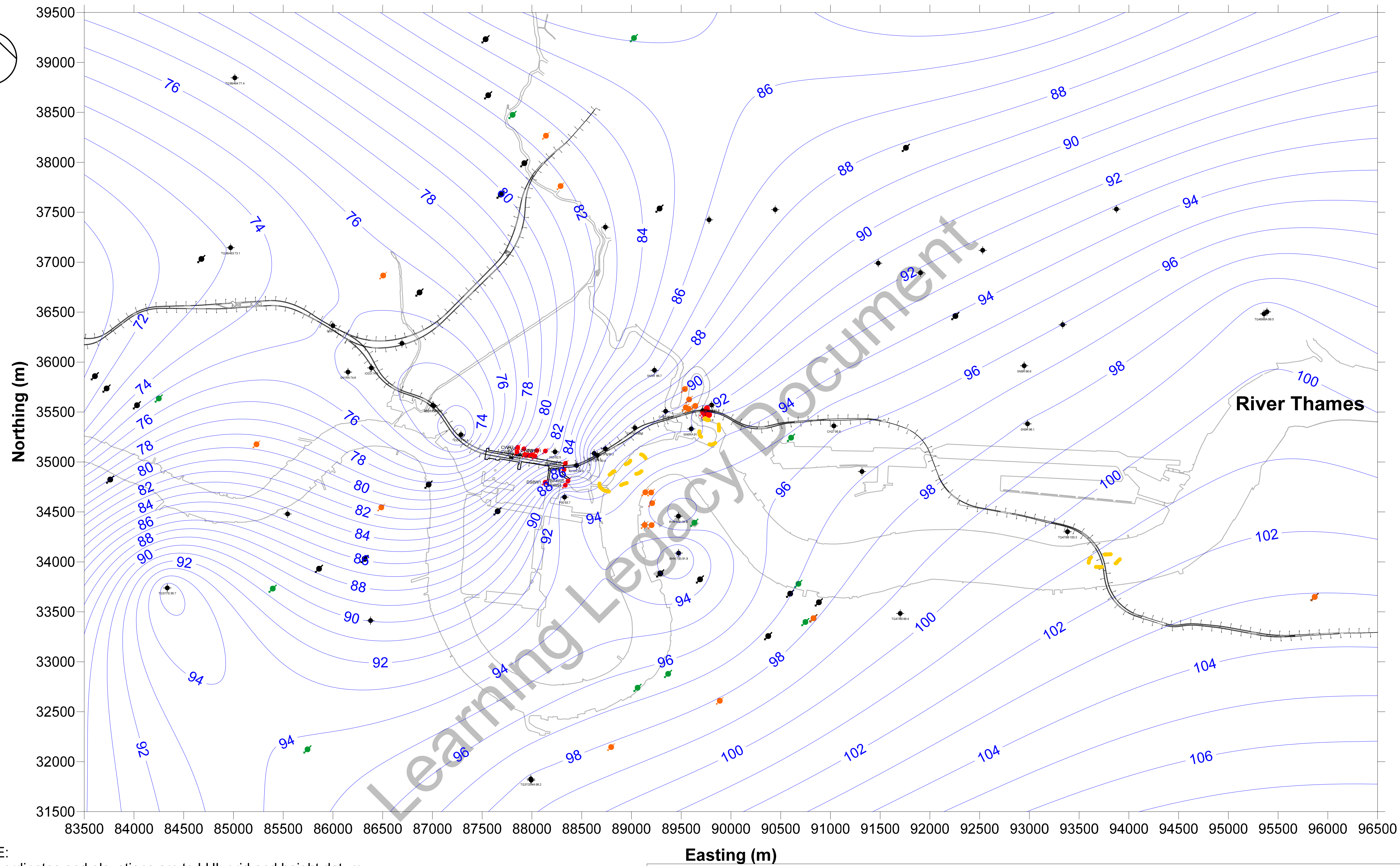
Groundwater Monitoring Report - Effects of Dewatering - (IOD+Limmo+CP13+CP11+N3+ELS+PLP)

Measured Drawdown contours - July 2014

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

4 (g)



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Contours based on Crossrail piezometer readings up to mid-May 2016, supplemented with EA in February 2016.
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.
5. Close to the area of pumping at IoD and CT, there is currently underdrainage of the TS layer. The contours shown in this zone are of water levels in the chalk.
6. Data for Greenwich Peninsula monitoring now included (4 piezos).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA / TW/ C305/ C315 borehole used in contour data
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)

Crossrail Limited

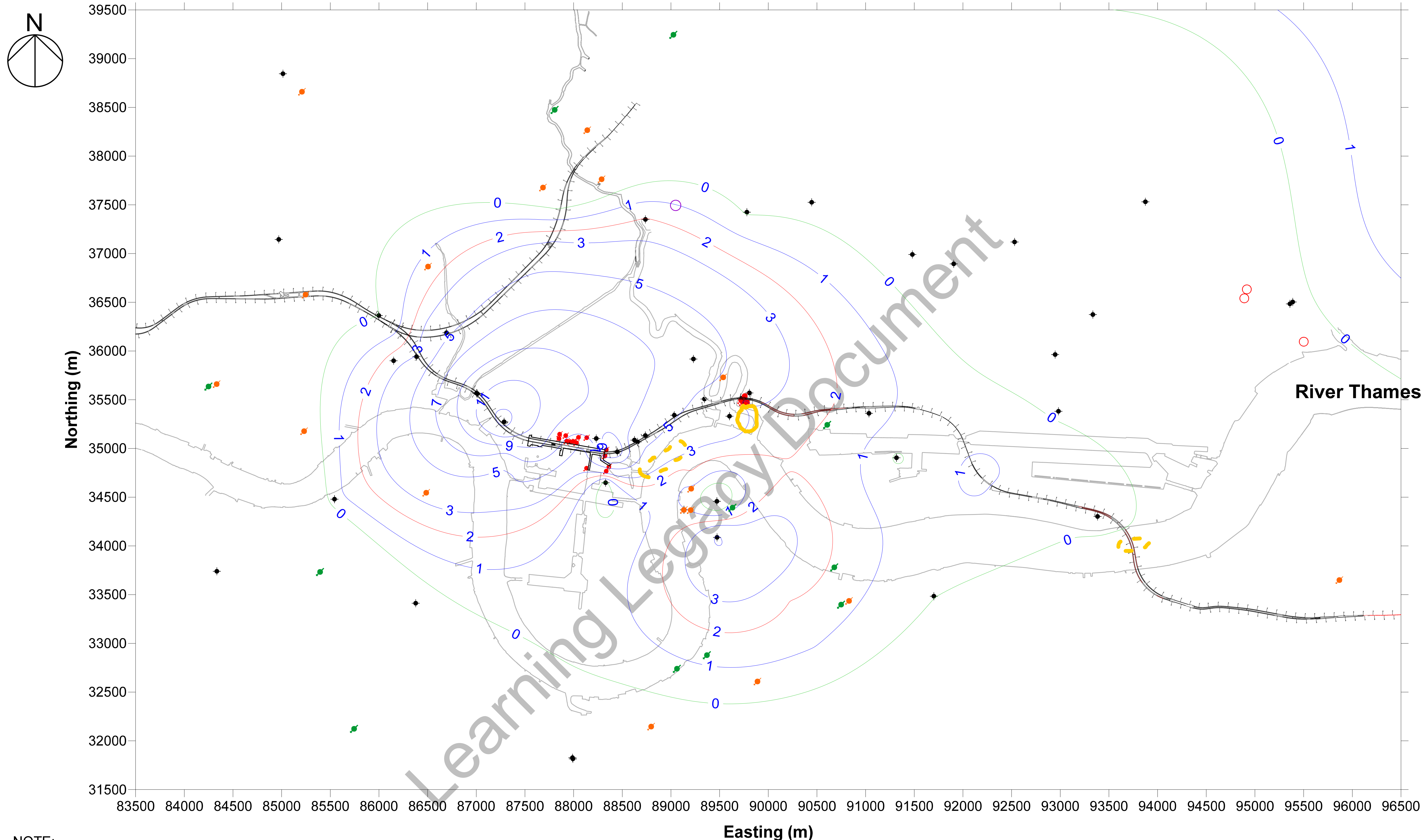
Groundwater Monitoring Report- Effects of Dewatering - (Full recovery with IOD only ongoing)

Deep aquifer groundwater level contours - mid-May 2016

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

5



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer up to mid-May 2016 and baseline groundwater reading from February 2008, supplemented with EA in February 2016.
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.
5. Data for Greenwich Peninsula monitoring now included (8 piezos in 2008, 4 piezos in 2013).

Scale 1:40000

0 500 1000 1500 2000 metres

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts
- Abbey Mill Shaft

Crossrail Limited

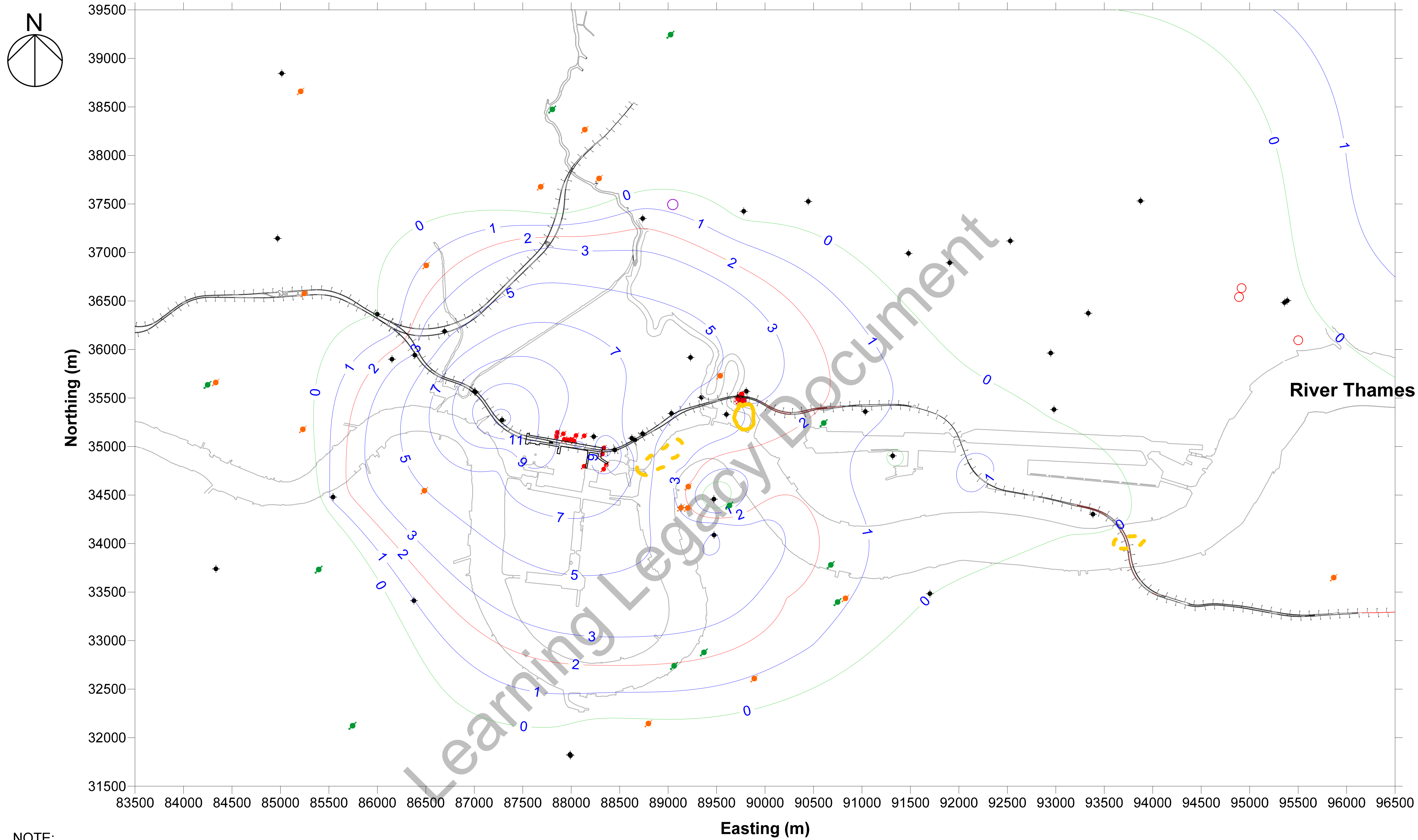
Groundwater Monitoring Report- Effects of Dewatering - (Full recovery with IOD only ongoing)

Measured Drawdown contours - mid-May 2016

Liverpool Street to Plumstead and Pudding Mill Lane

Figure

6



NOTE:
1. Coordinates and elevations are to LUL grid and height datum.
2. Drawdown contours based on Crossrail piezometer up to mid-May 2016 and baseline groundwater reading from February 2008, supplemented with EA in February 2016.
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.
5. Data for Greenwich Peninsula monitoring now included (8 piezos in 2008, 4 piezos in 2013).

KEY:
- Crossrail / CWC(C) / EA/ TW borehole
- Abstraction Well (location +/- 100m)
- Abstraction Well for Crossrail
- EA Abstraction Well (2010 - 2011 New licence)
- Expired/Revoked licence (Refer Table 5)
- Location of scour hollows indentified by Berry (1979) and Lenham et al. (2006)
- Groundwater Level (mATD)
- Thames Water Becton Shafts
- Abbey Mill Shaft

Scale 1:40000

0 500 1000 1500 2000 metres

Crossrail Limited

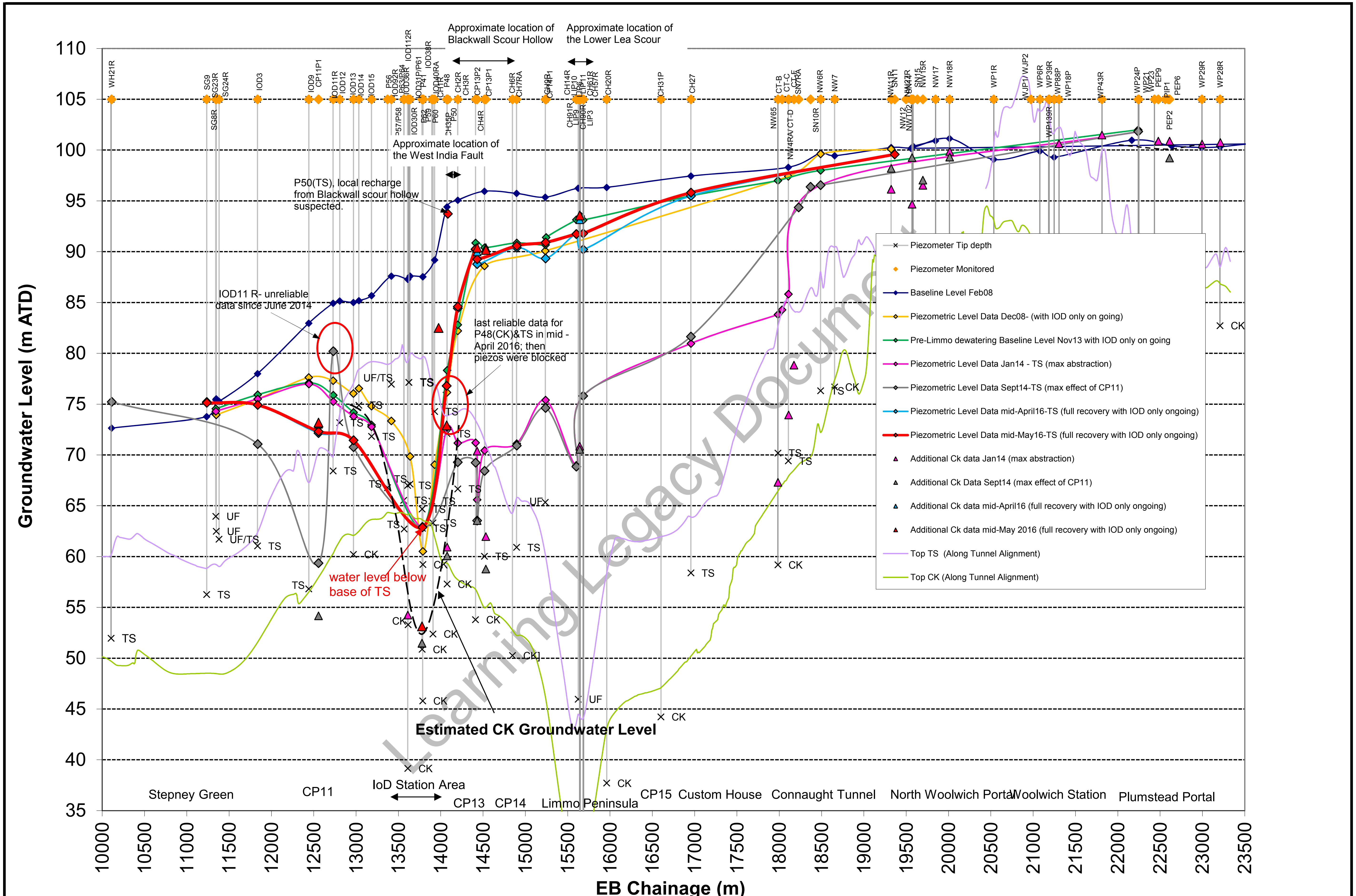
Groundwater Monitoring Report- Effects of Dewatering - (Full recovery with IOD only ongoing)

Measured Drawdown contours - mid-May 2016

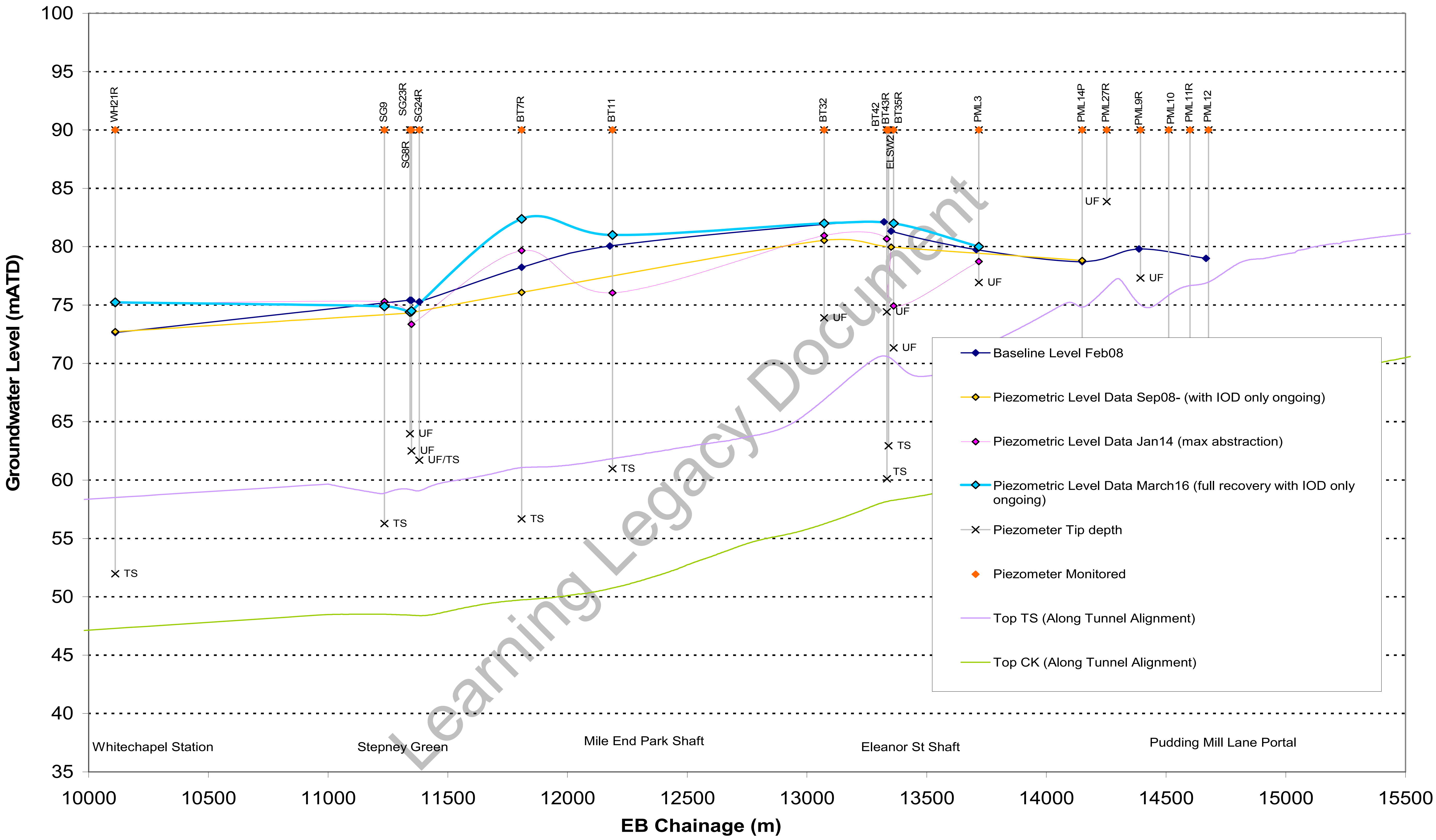
Liverpool Street to Plumstead and Pudding Mill Lane

Figure

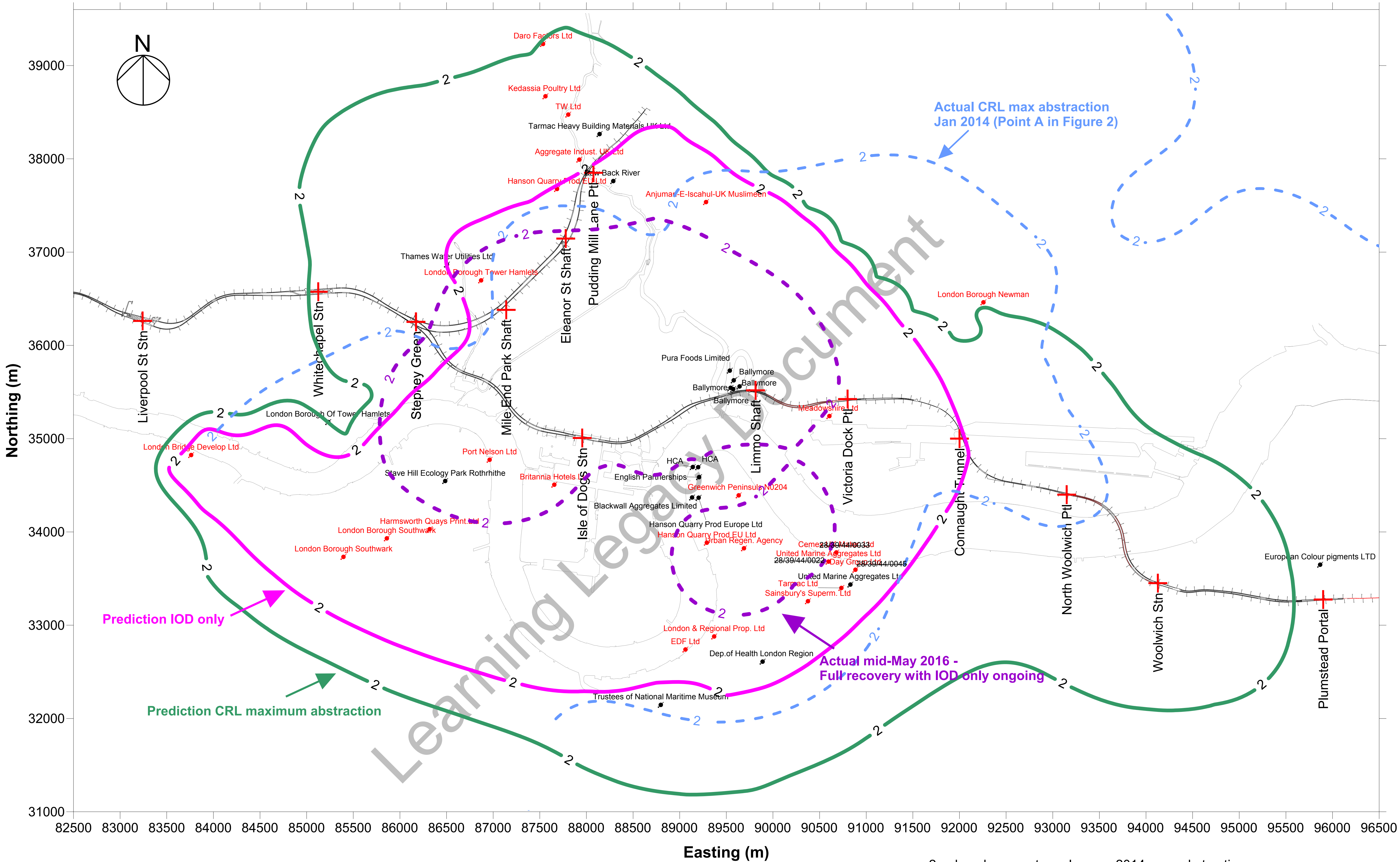
6



Crossrail Limited Crossrail Dewatering Works - Close out Report	Figure 7
Deep aquifer groundwater level (m ATD) Stepney Green to North Woolwich	



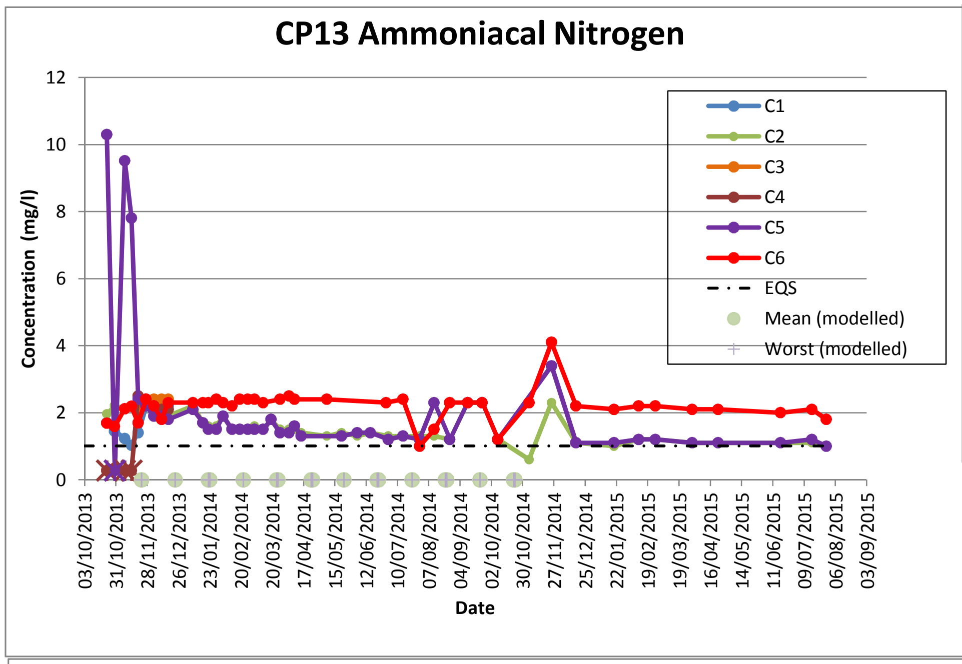
	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure** **8**
	Deep aquifer groundwater level (m ATD) Stepney Green to Pudding Mill Lane	

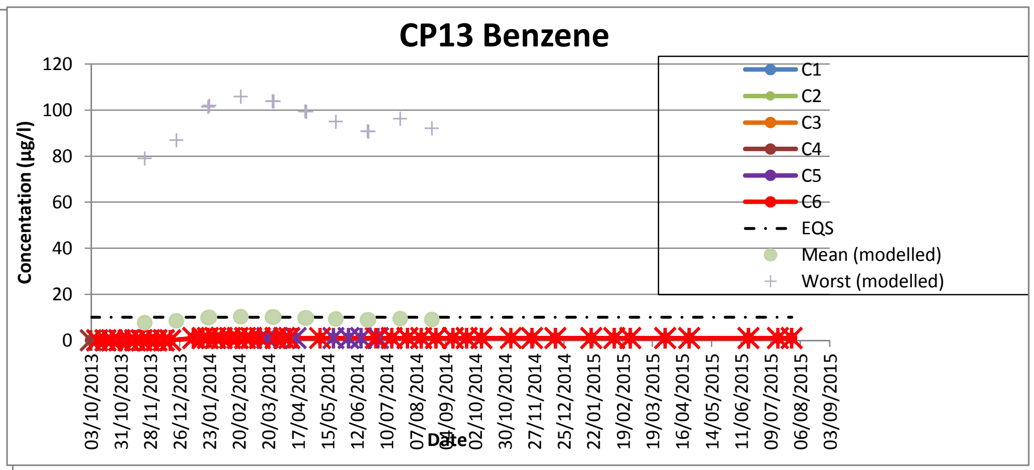


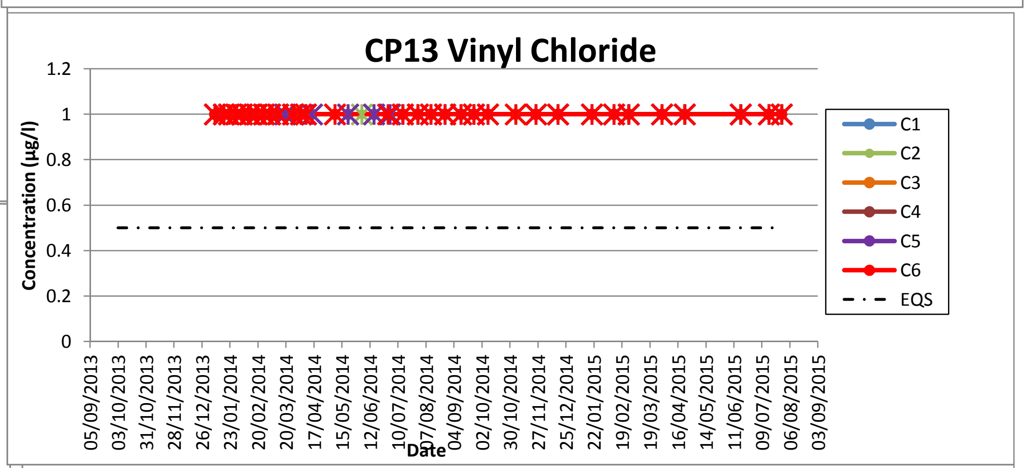
- - 2m drawdown contour_January 2014_max abstraction
- - 2m drawdown contour_Mid- May 2016_ fully recovery with IOD only ongoing

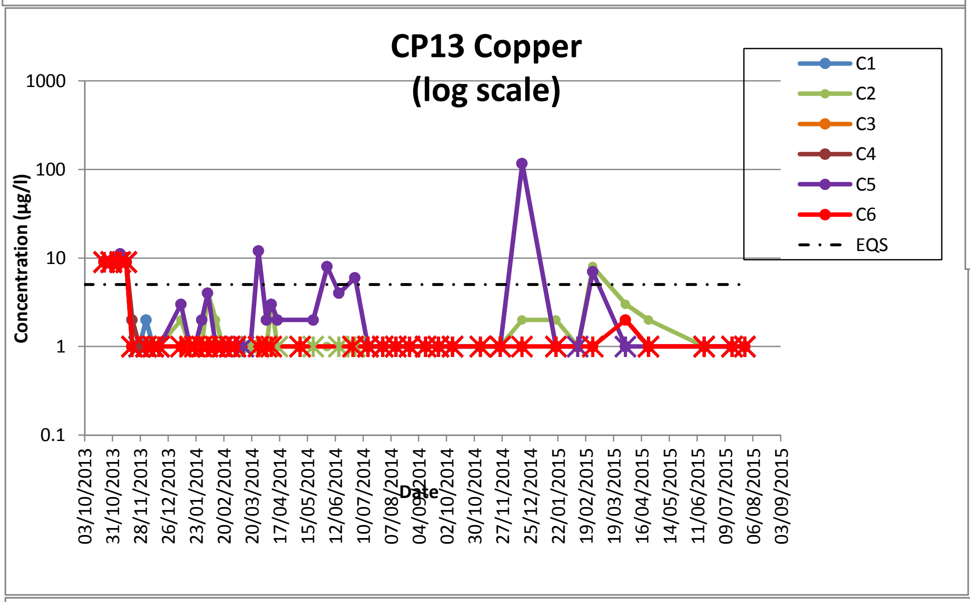
- Abstraction Licences monitoring within C305 scope
- Expired/Revoked Abstraction Licences within C305 scope
- Mott Macdonald Predicted 2m Drawdown for Overall Dewatering
- Mott Macdonald Predicted 2m Drawdown for IoD Dewatering

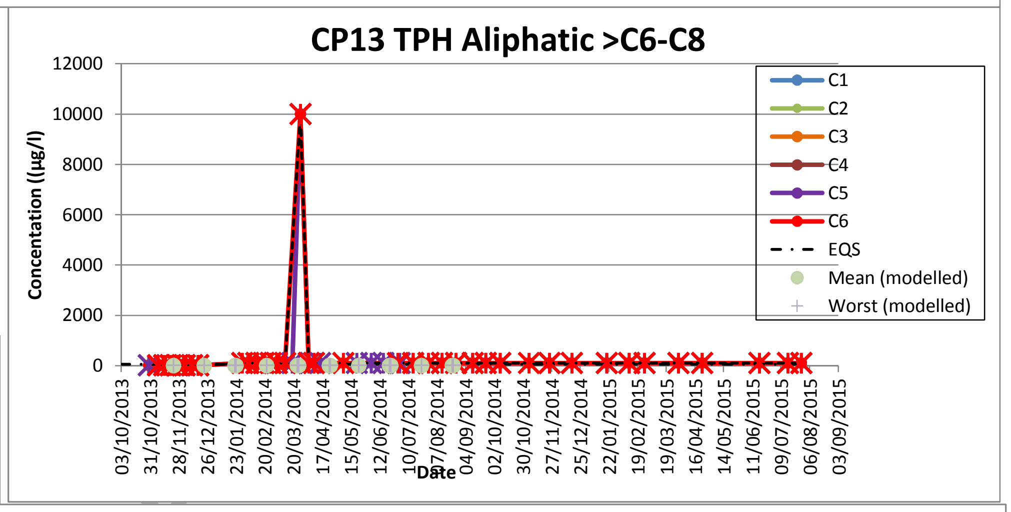
Crossrail Limited Crossrail Dewatering works - Close out Report	Figure
Available Third Party Abstraction and 2m drawdown contours	9

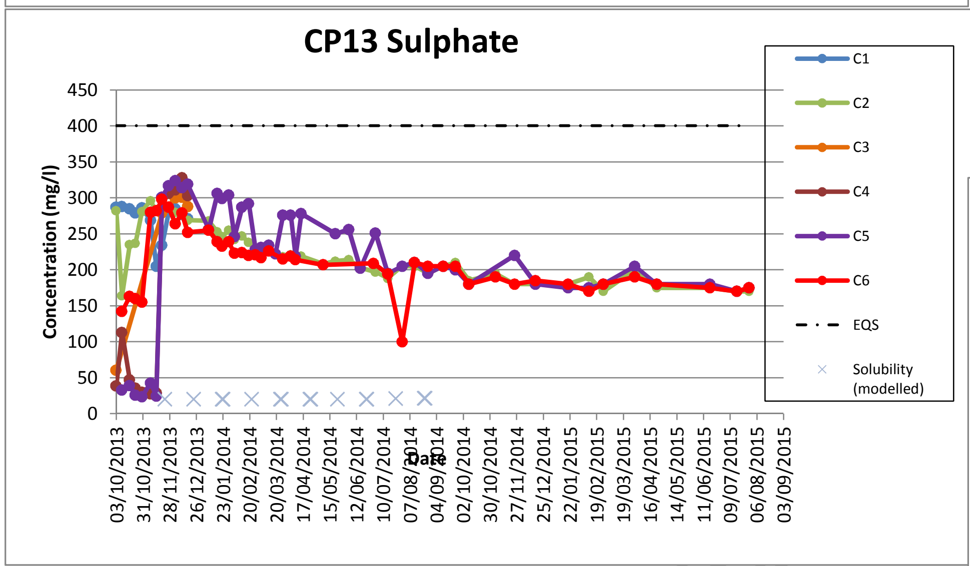


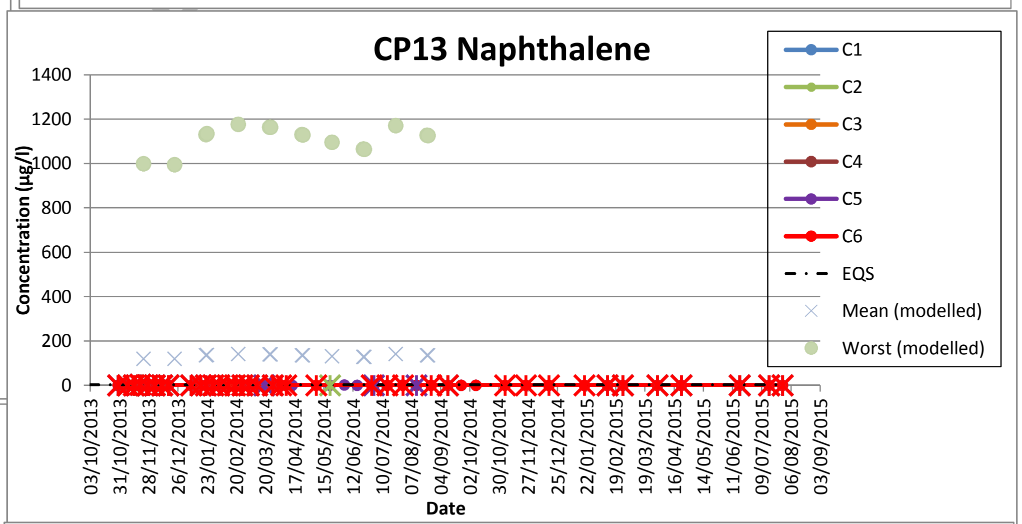


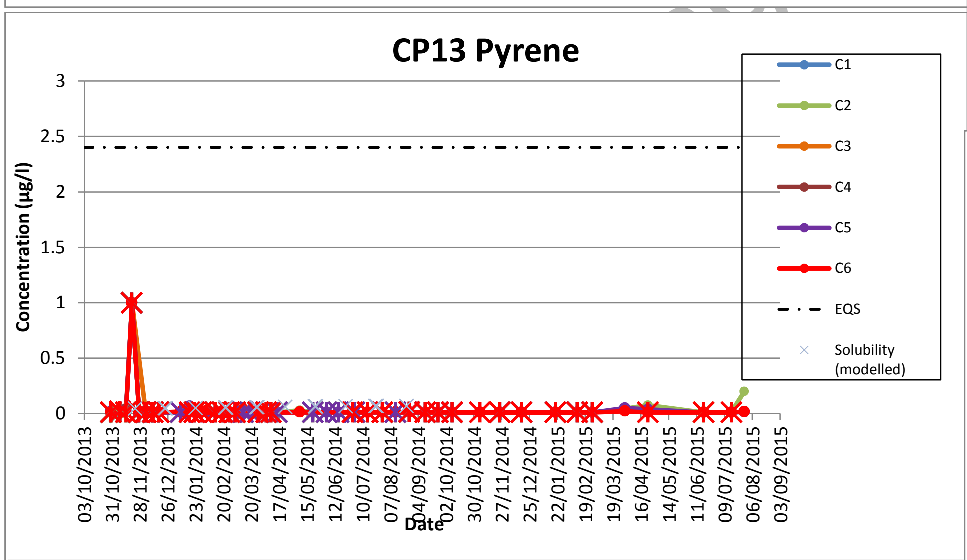


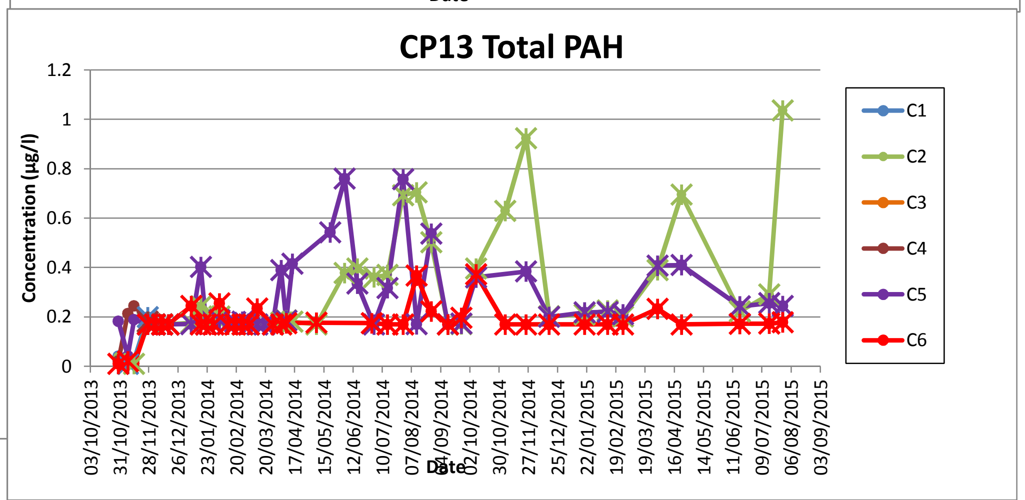


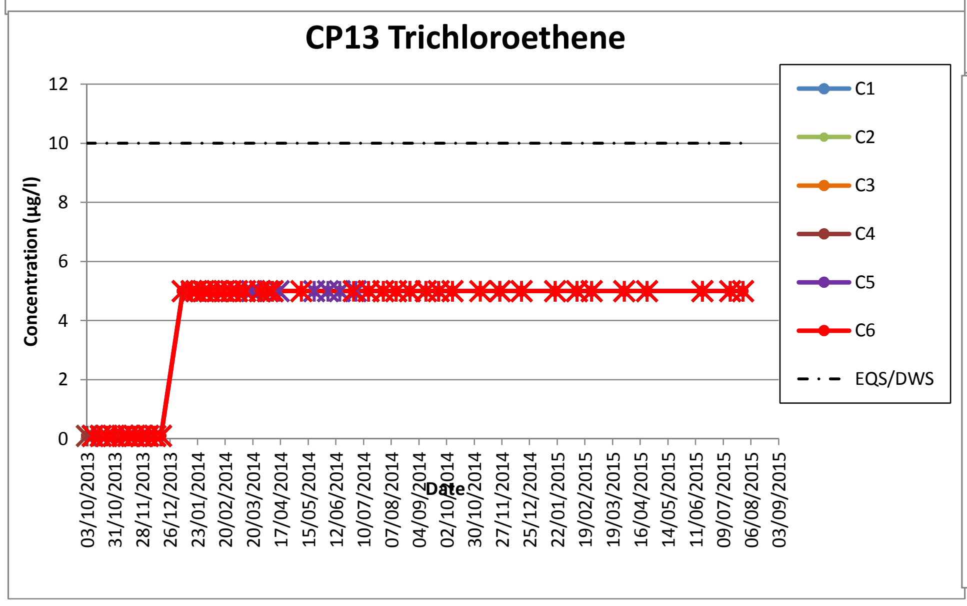












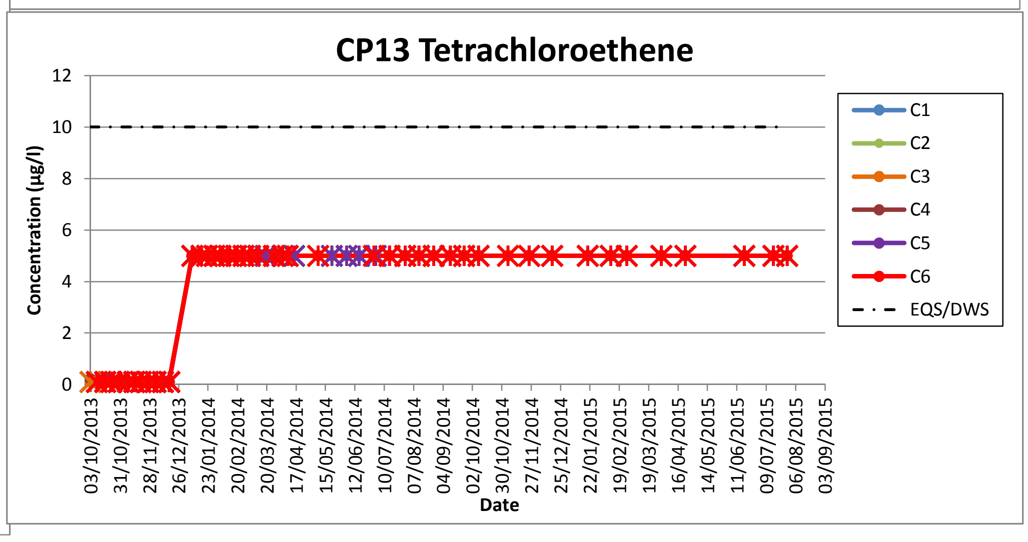


Figure 10. GWQ data for PCoCs - samples abstracted for CP13 wells up to 29/07/2015 (Atkins data ref[22])

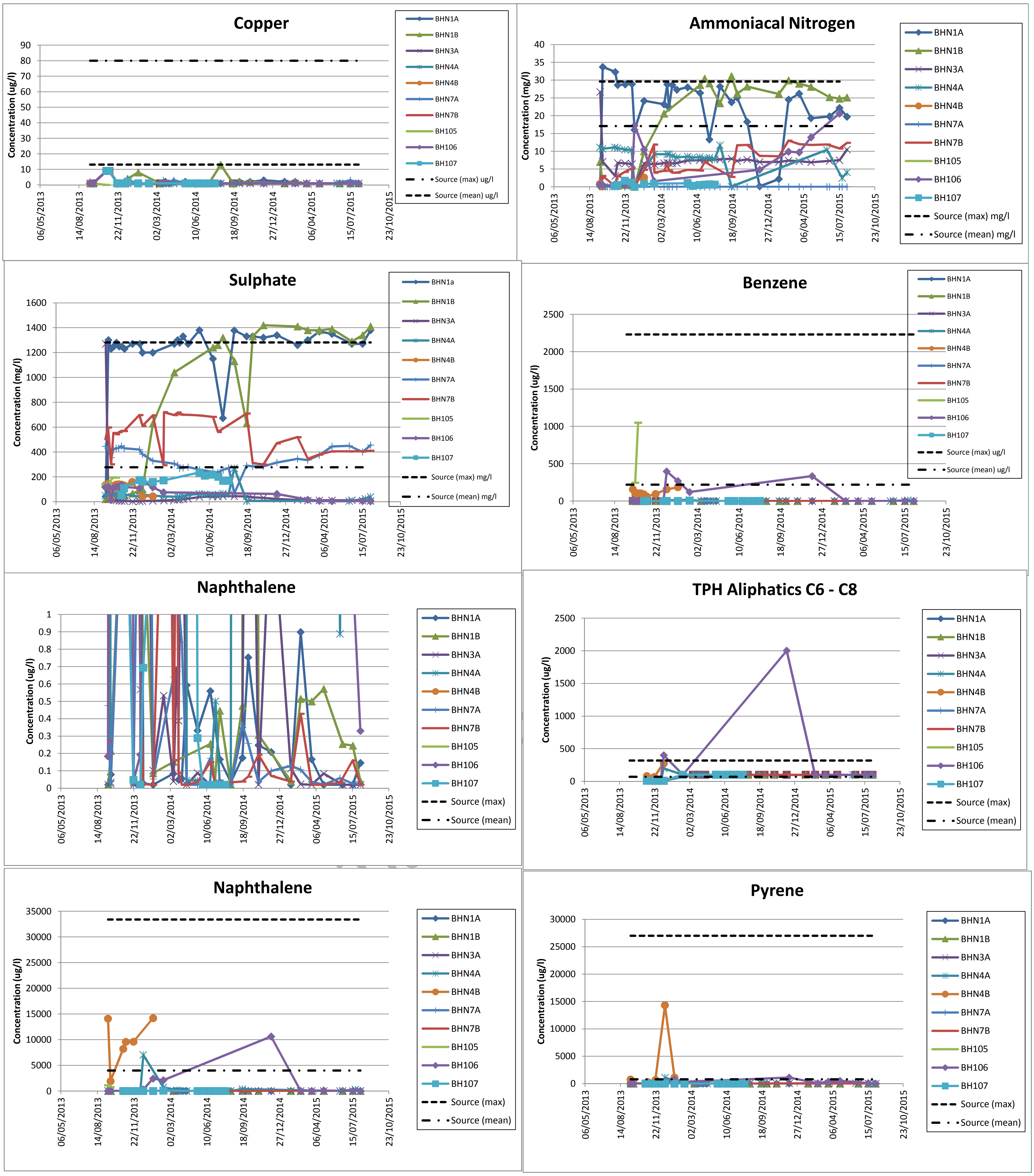


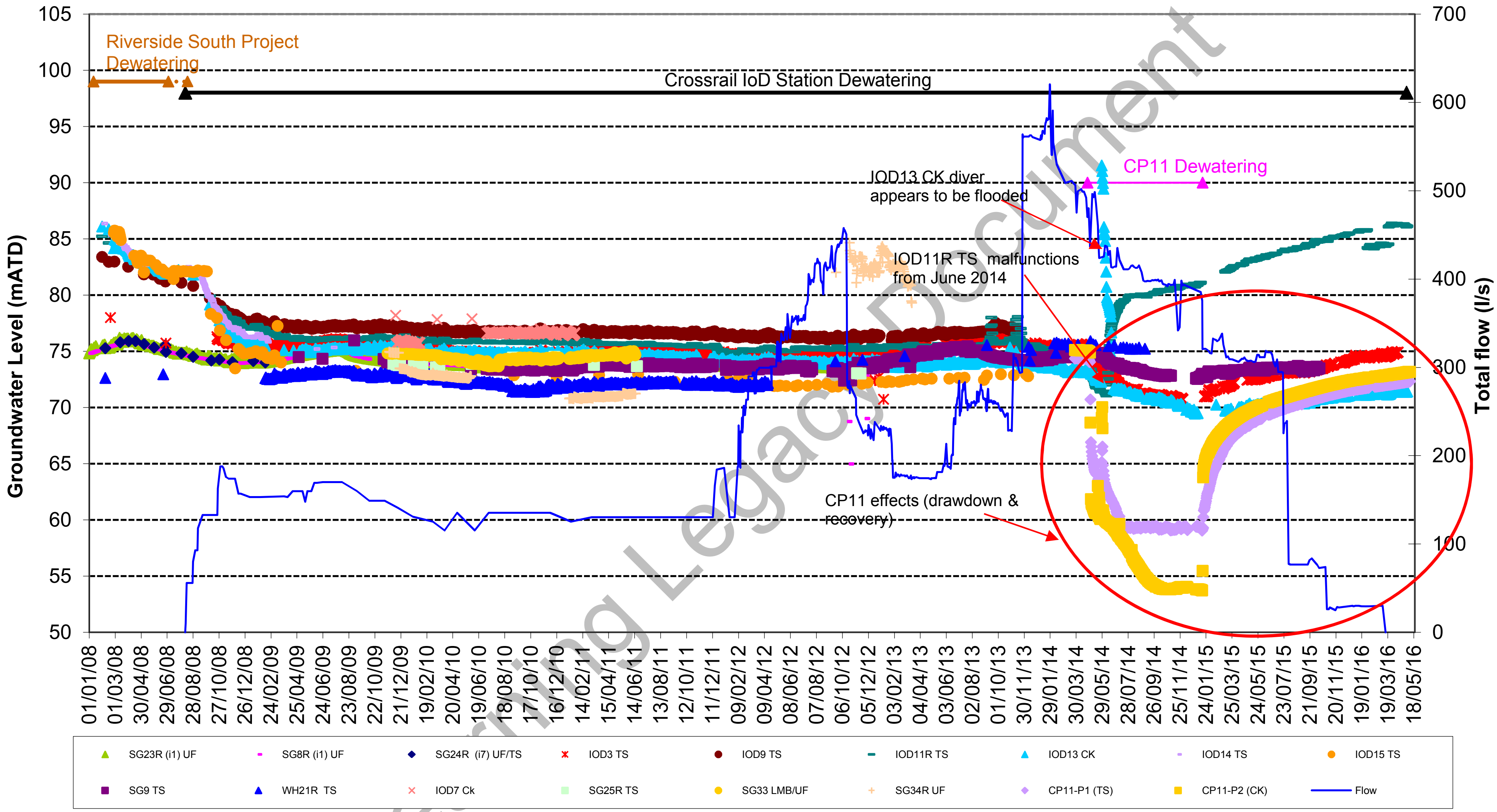
Figure 11. GWQ for PCoCs- samples from Greenwich Peninsula wells up to 06/08/2015 (Atkins data ref[22])

APPENDIX A

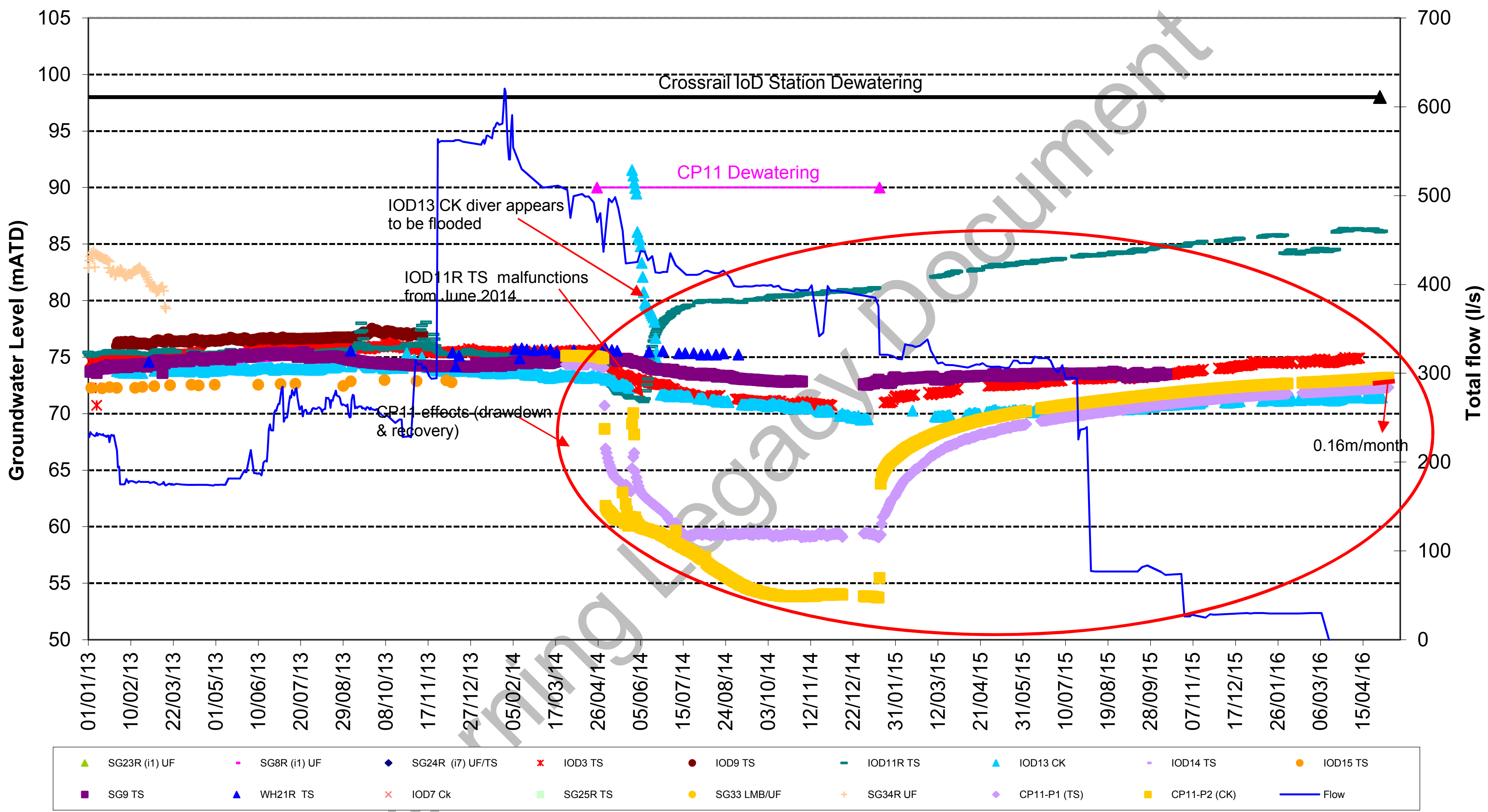
Water Level Time Plots for all Dewatering Sites

CROSSRAIL LEARNING LEGACY WEBSITE VERSION

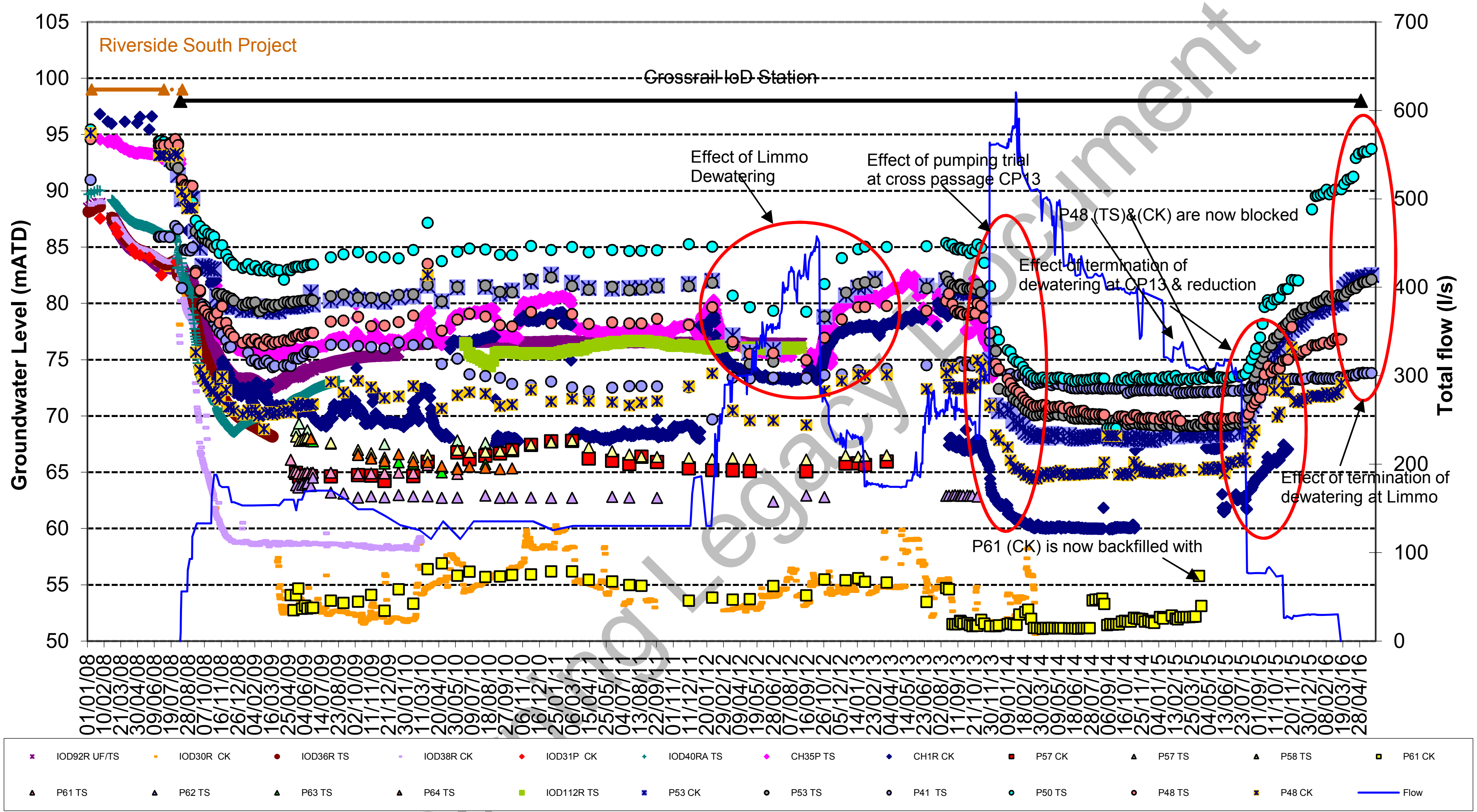
Any references in these figures to IOD or Isle of Dogs should be taken to mean Canary Wharf



Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
Measured Piezometric Level Stepney Green to West India Dock (North)	**A.1a**



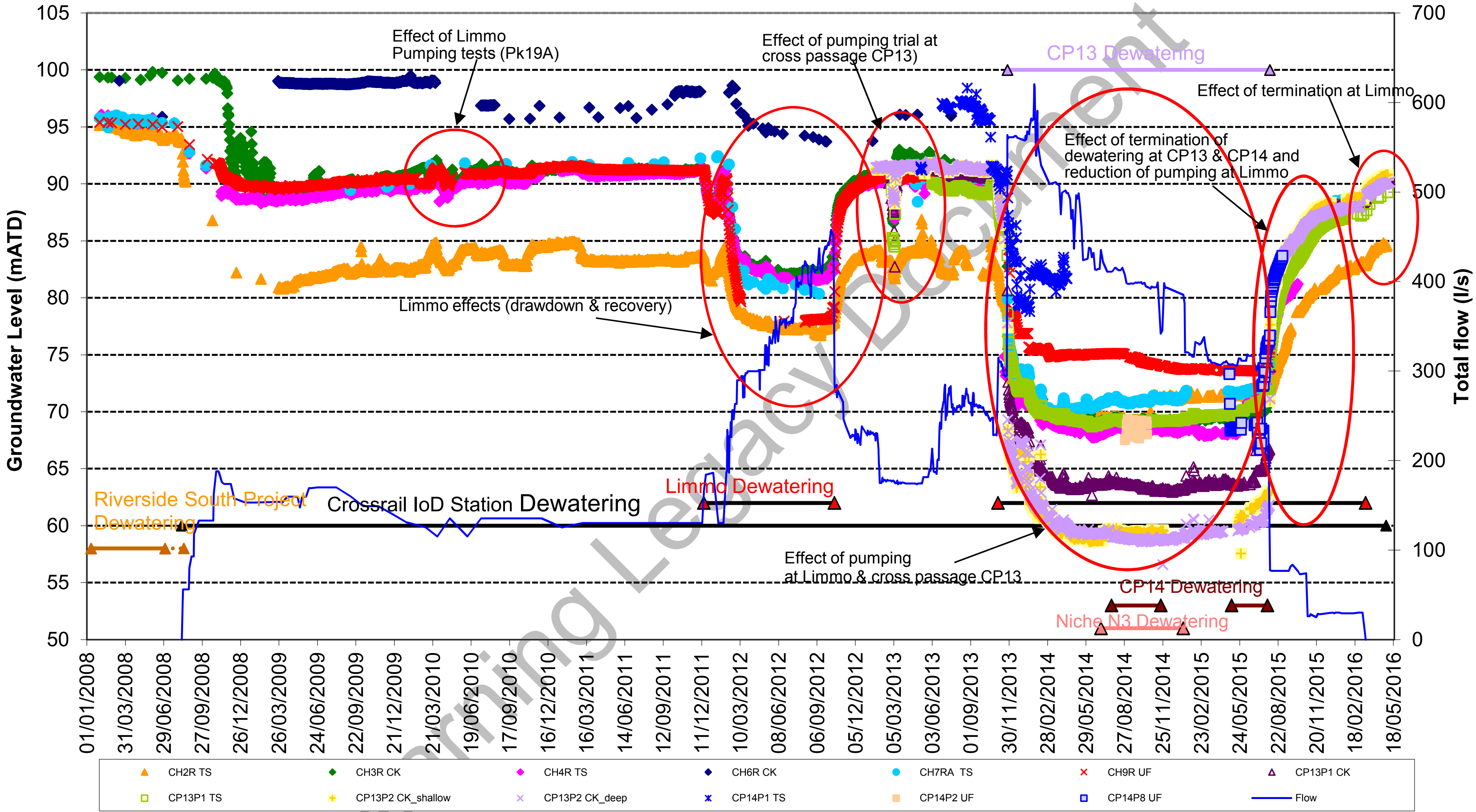
Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
Measured Piezometric Level Stepney Green to West India Dock (North)	**A.1b**



Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
West India Dock (North)

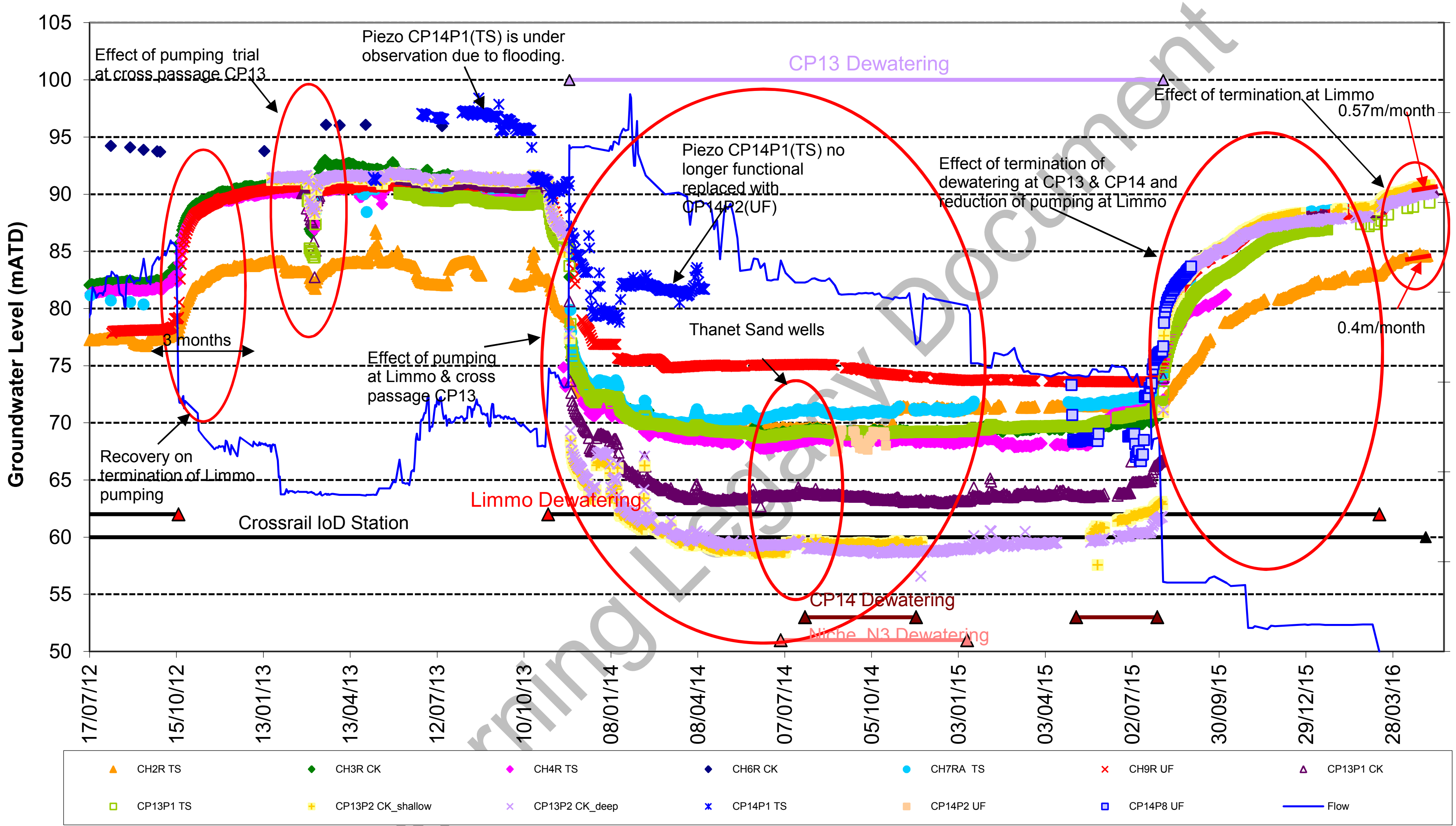
Figure
A.2



Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
West India Dock (North) to Limmo Peninsula

Figure
A.3a



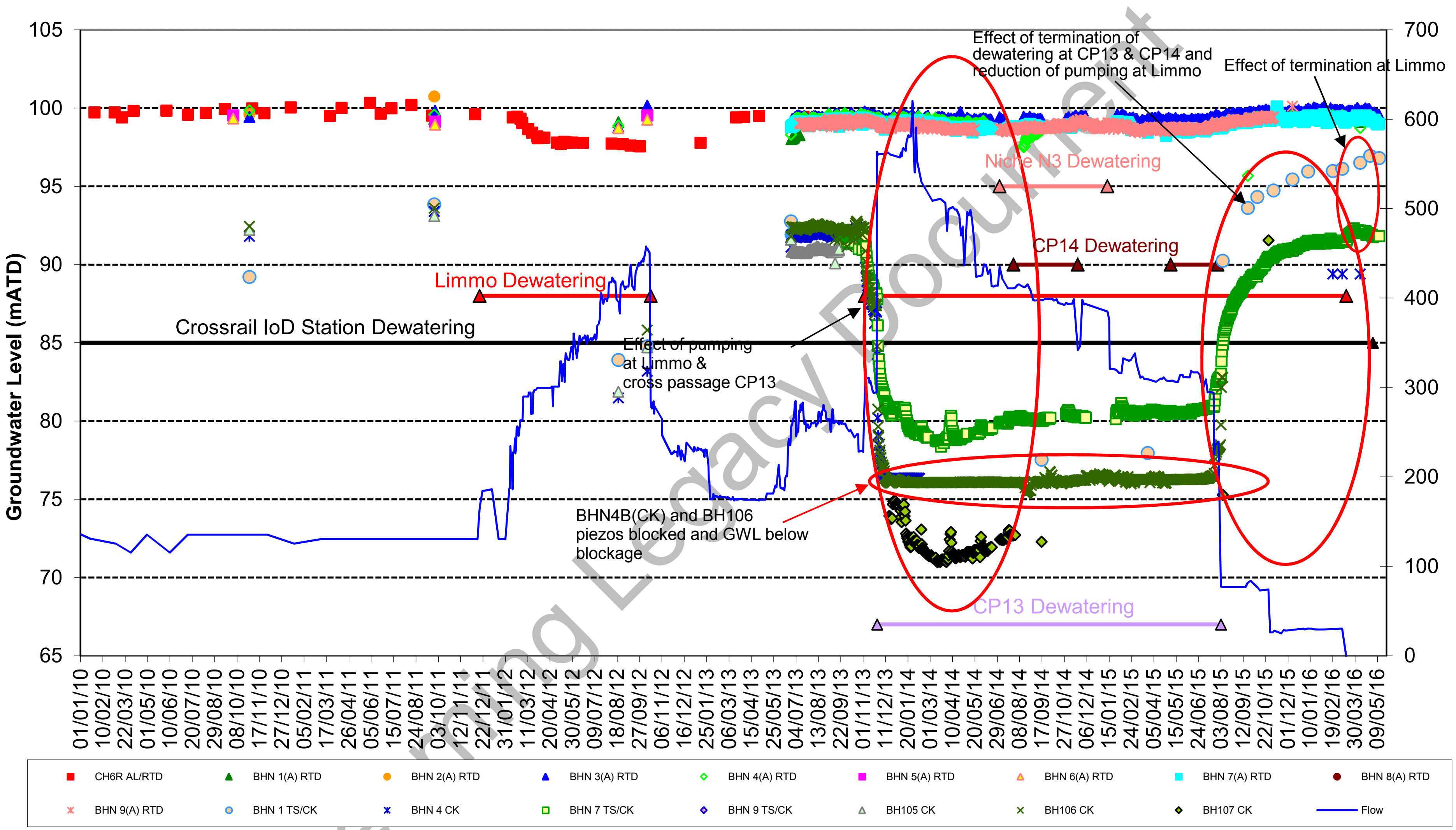
Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level

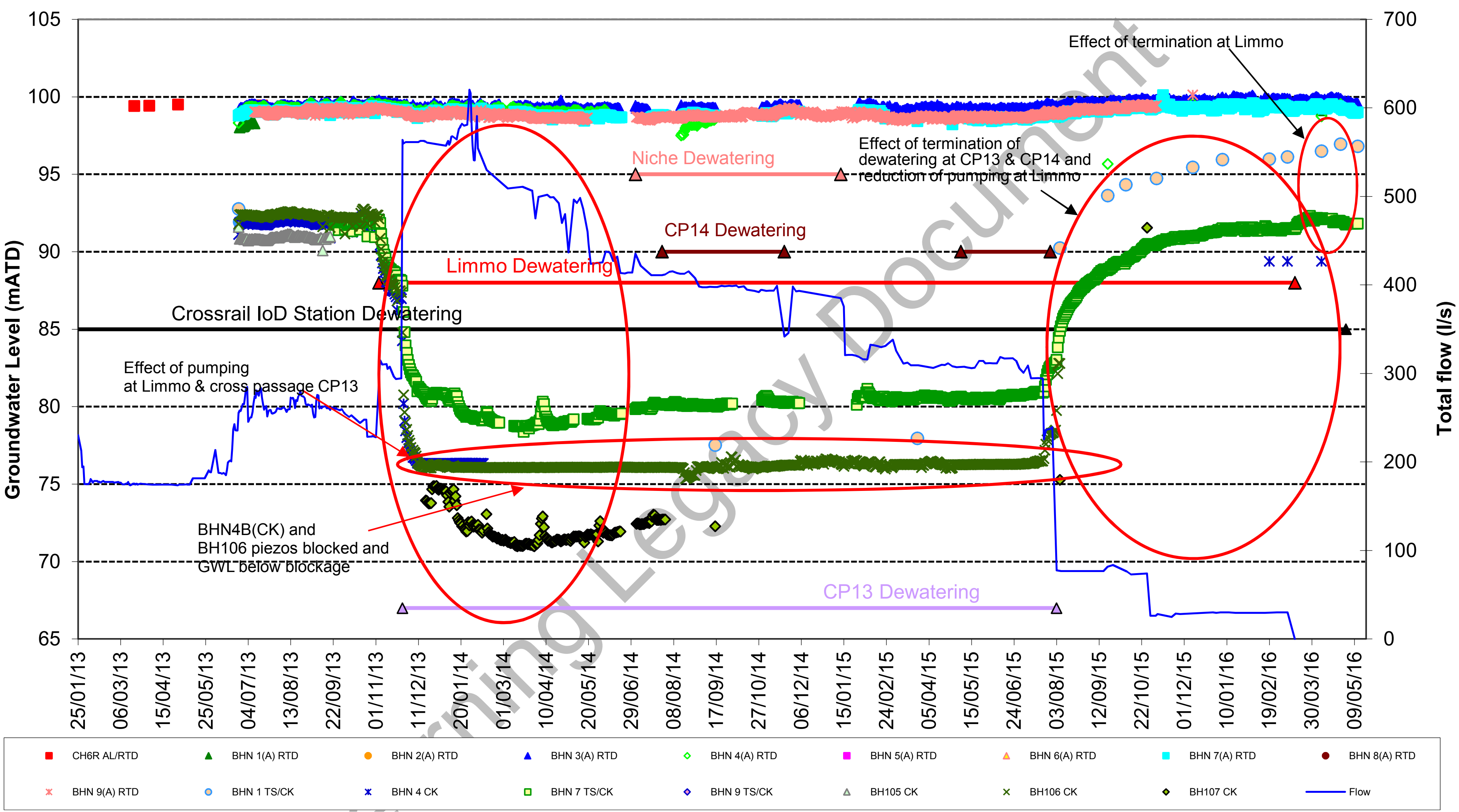
West India Dock (North) to Limmo Peninsula

Figure

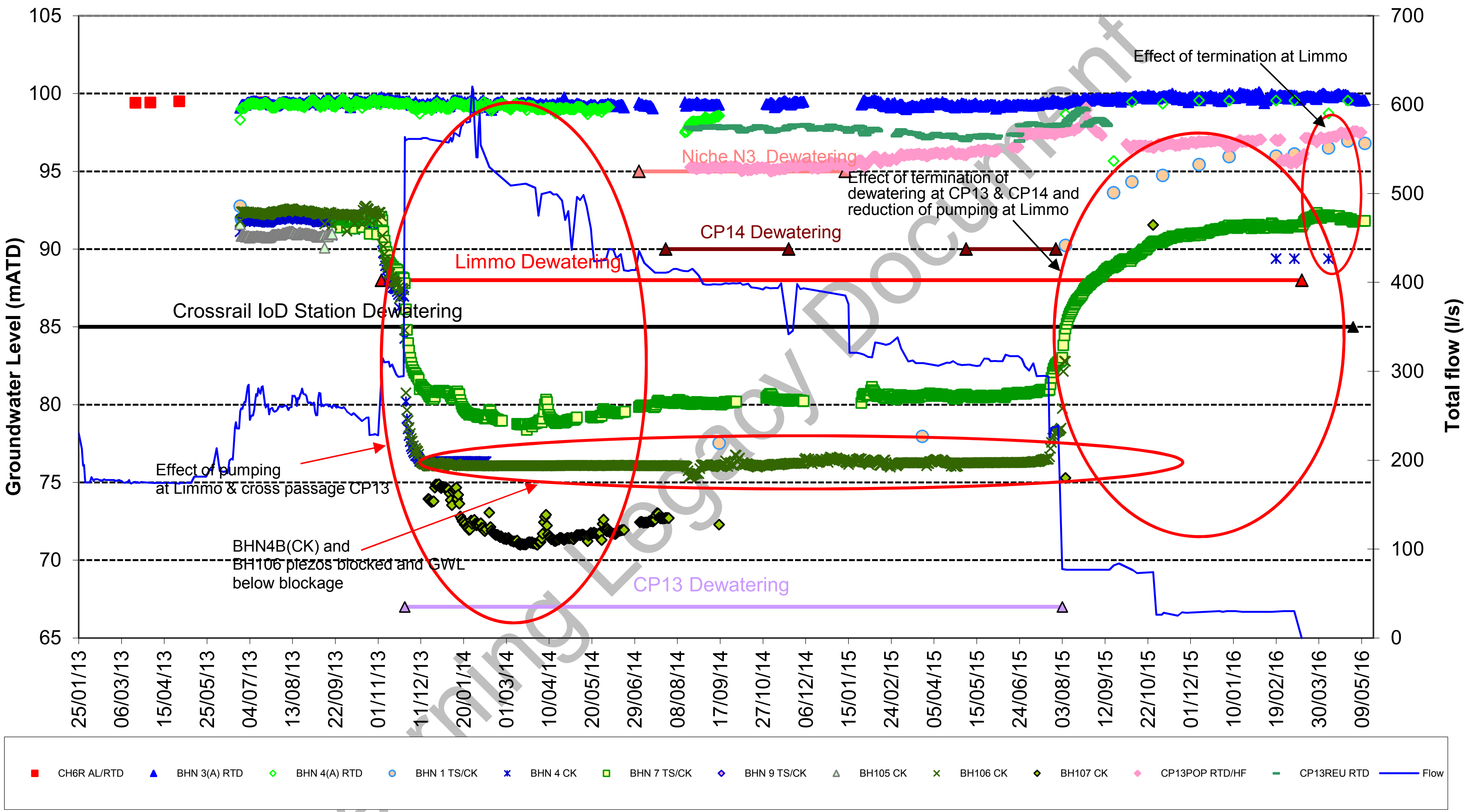
A.3b



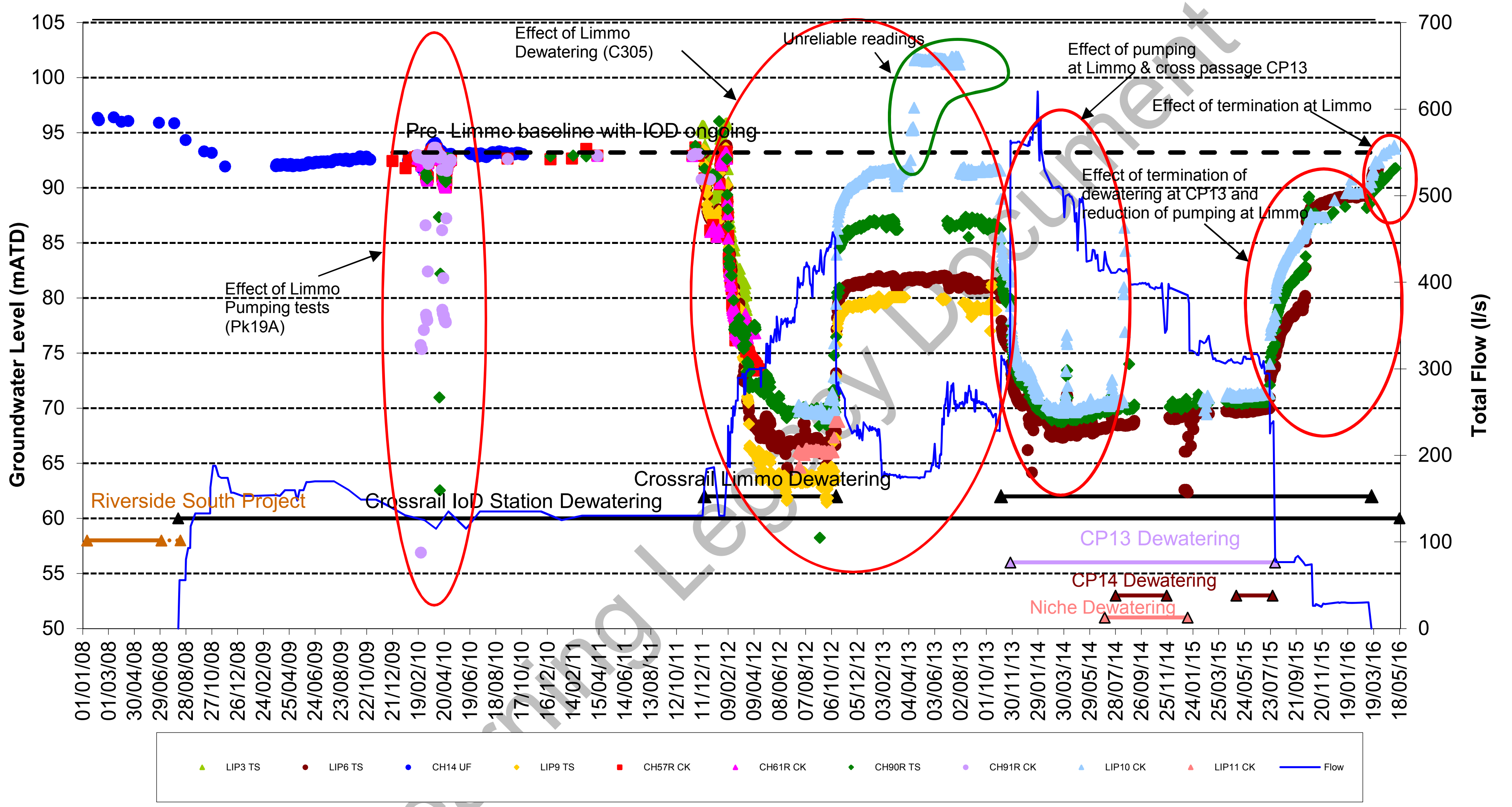
	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level West India Dock (North) to Greenwich Peninsula	**A.3c**



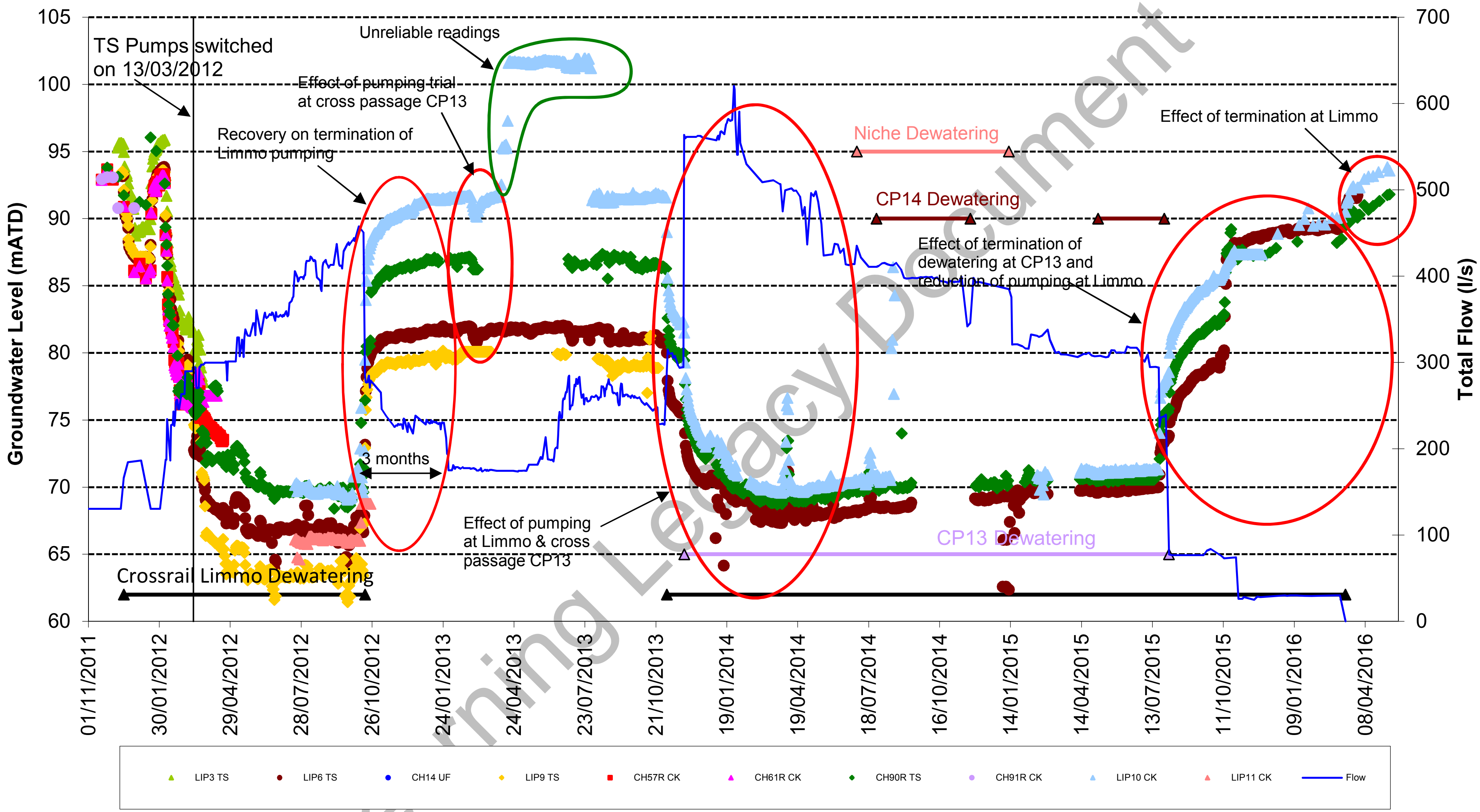
	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level West India Dock (North) to Greenwich Peninsula	**A.3d**



	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level West India Dock (North) to Greenwich Peninsula	**A.3e**



Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
Measured Piezometric Level Limmo Peninsula	**A.4a**



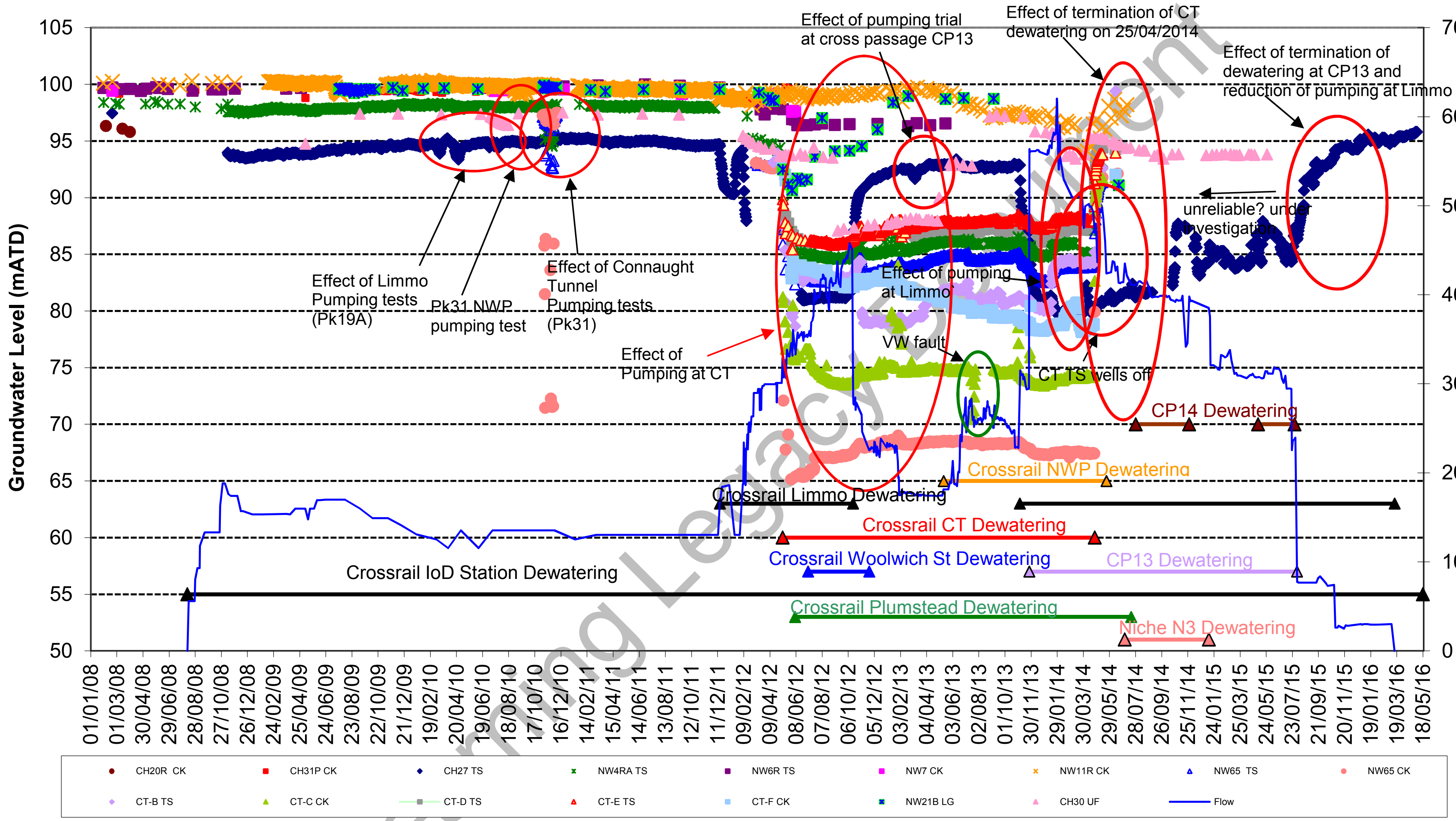
Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level

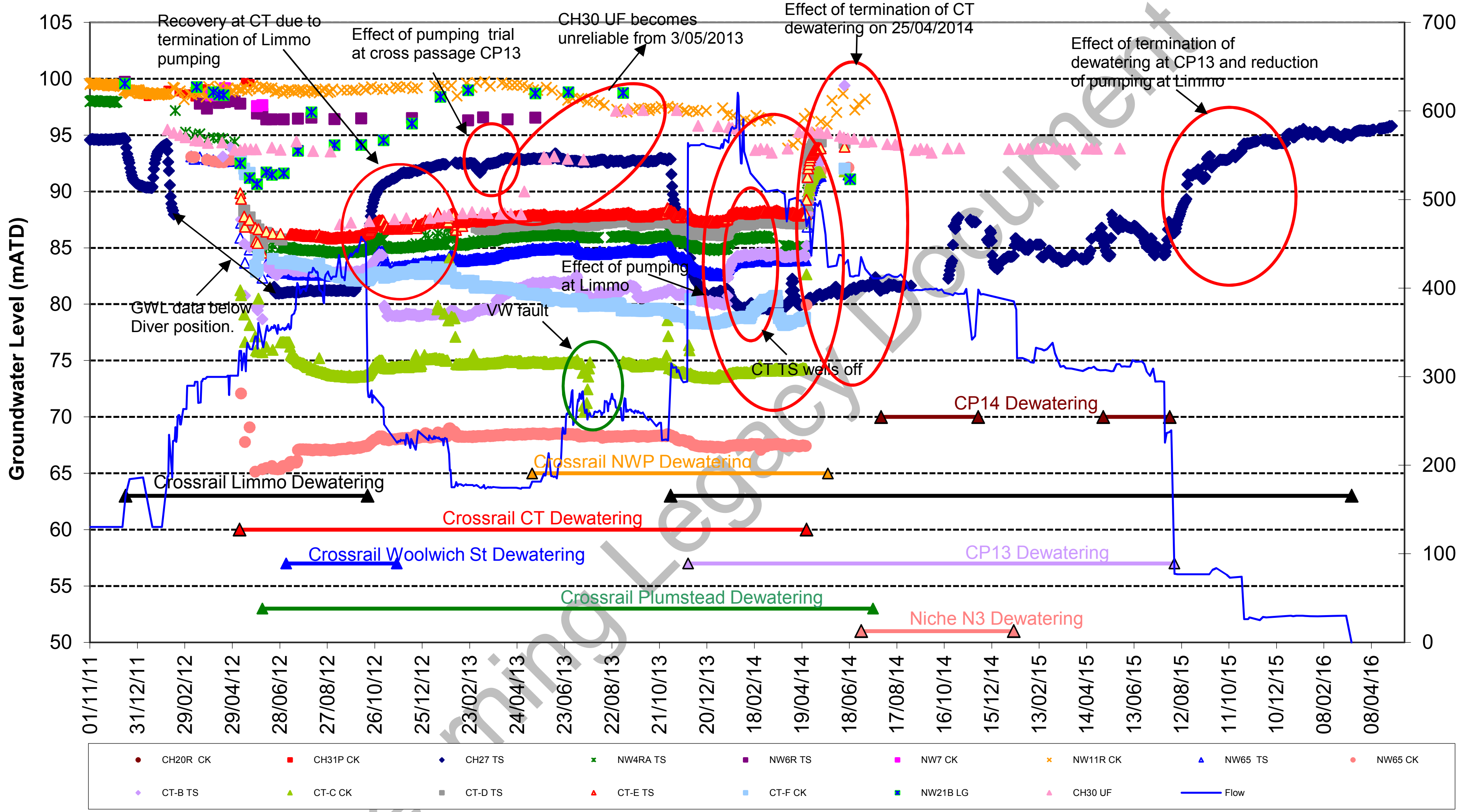
Limmo Peninsula

Figure

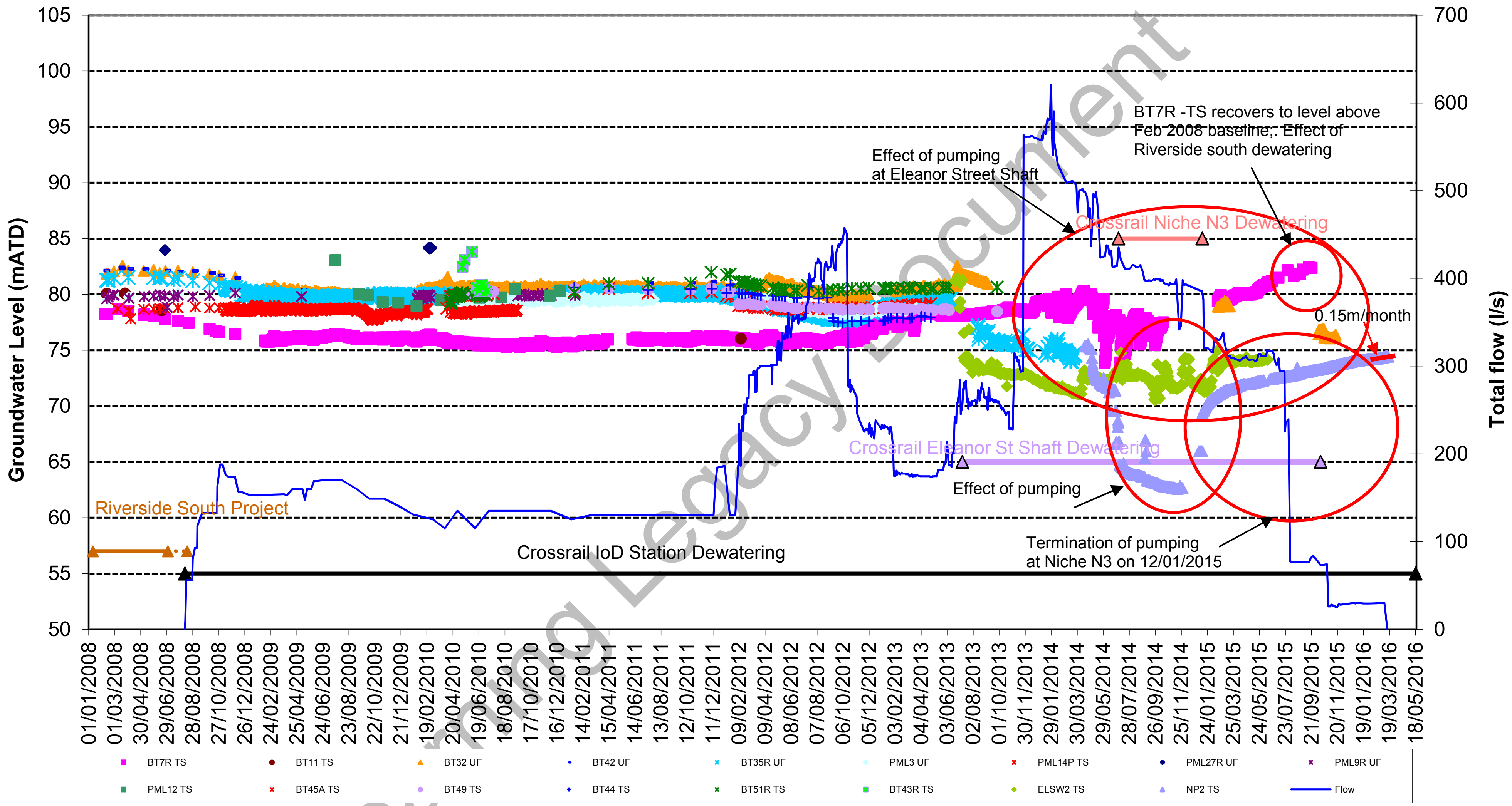
A.4b



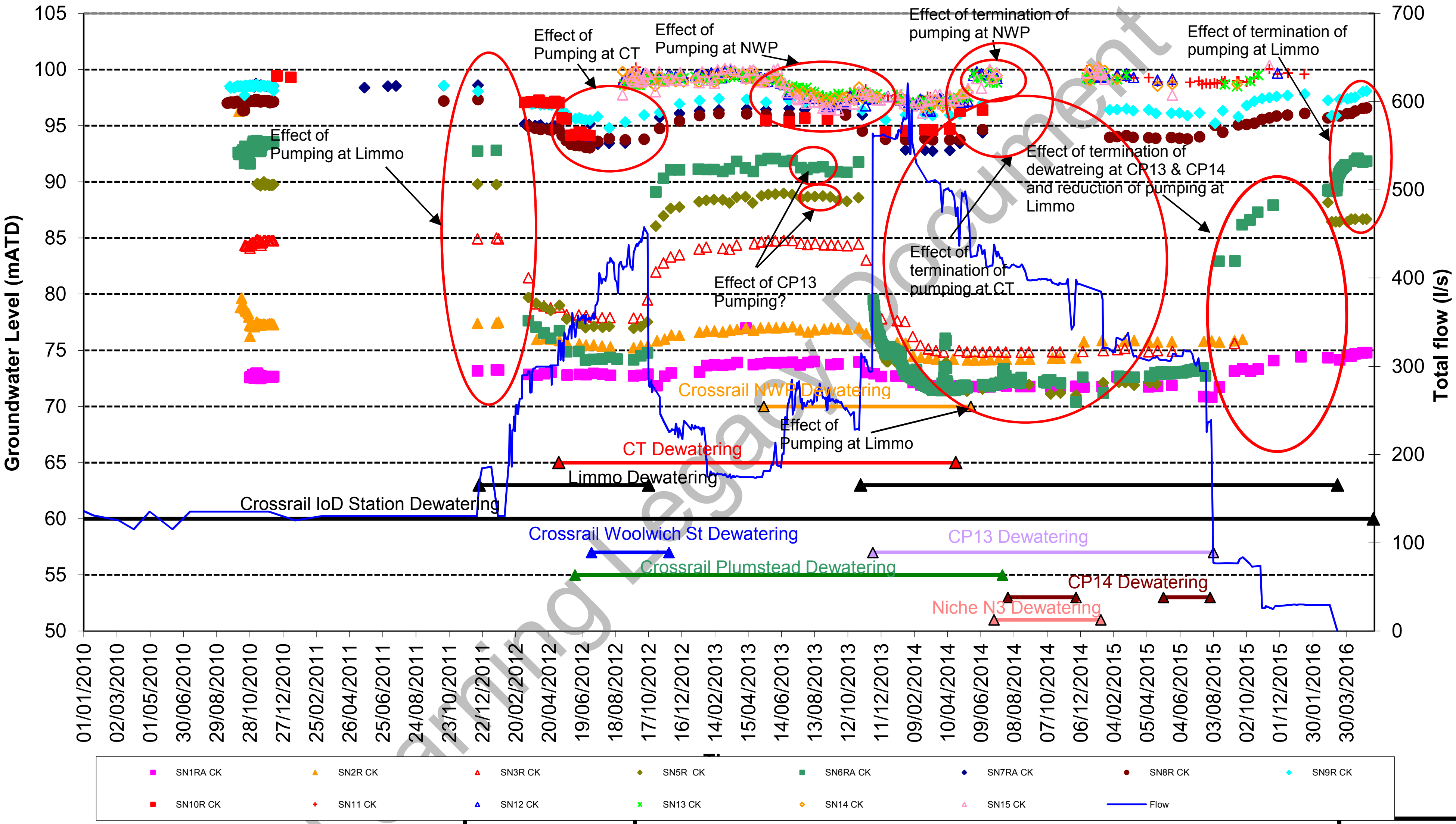
	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level Limmo Peninsula to North Woolwich	**A.5a**



	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level Limmo Peninsula to North Woolwich	**A.5b**



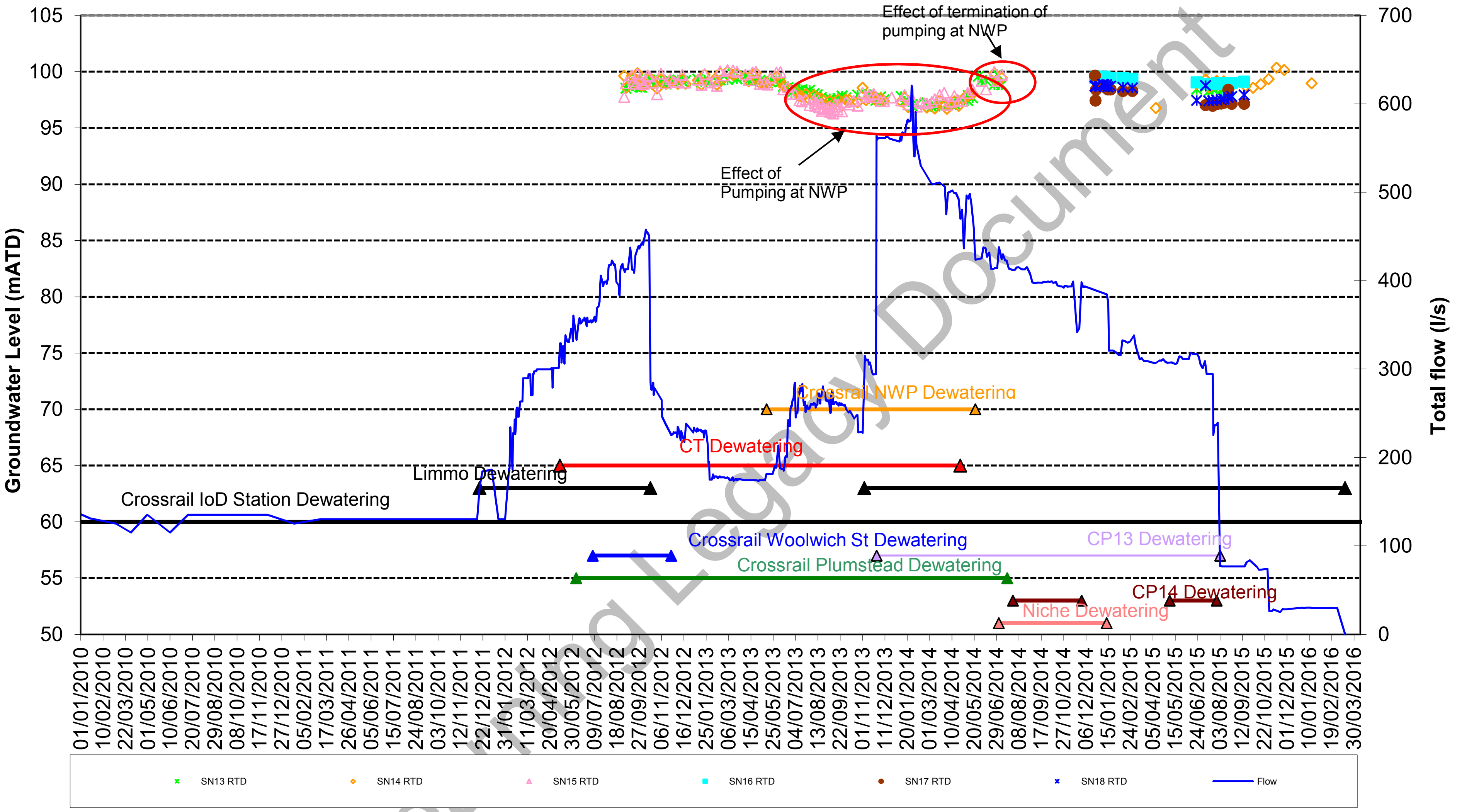
Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
Measured Piezometric Level Stepney Green to Pudding Mill Lane	**A.6**



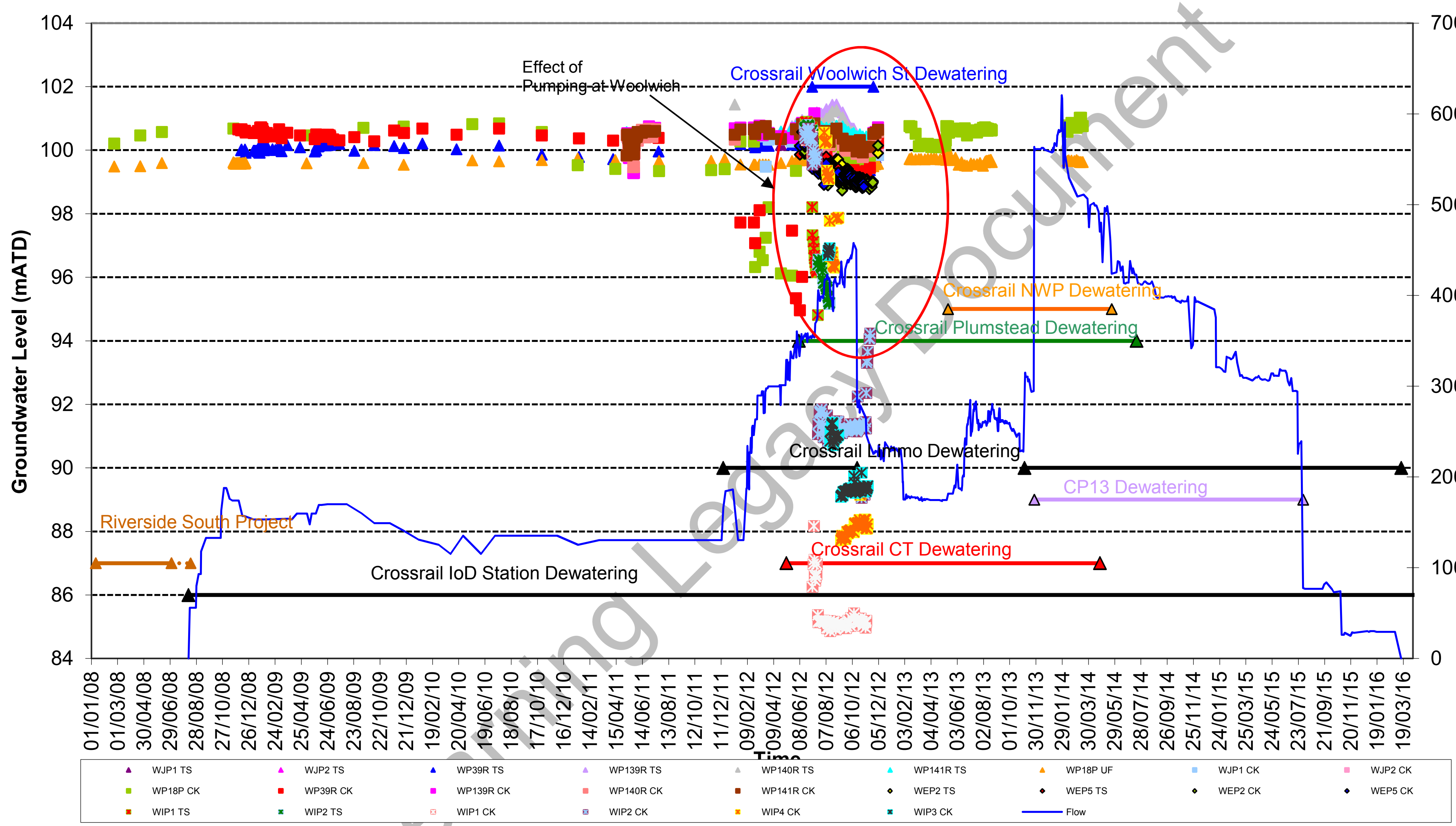
Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
Sentinel Wells in Chalk

Figure
A.7a



	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level Sentinel Wells in RTD	**A.7b**



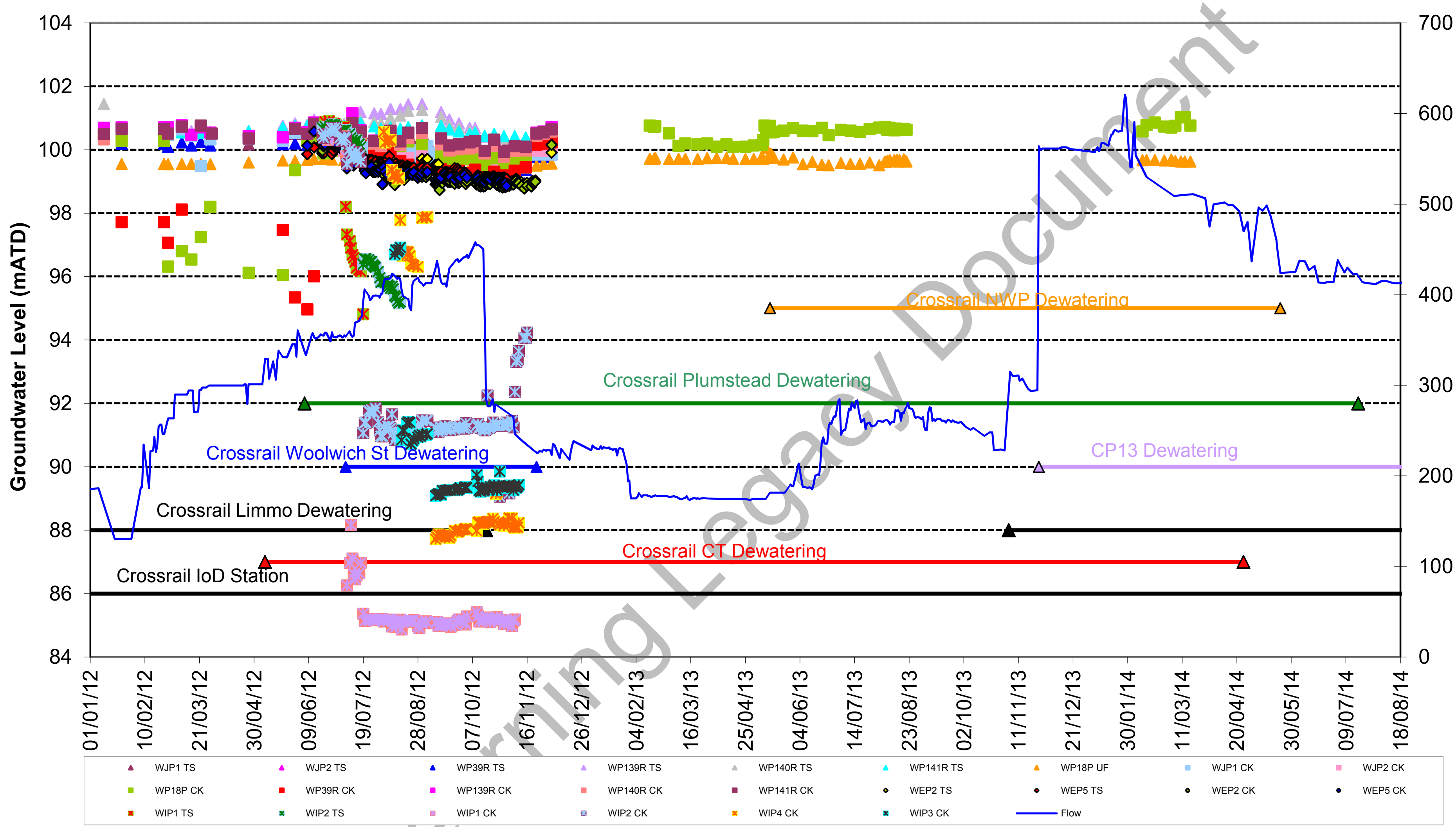
Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level

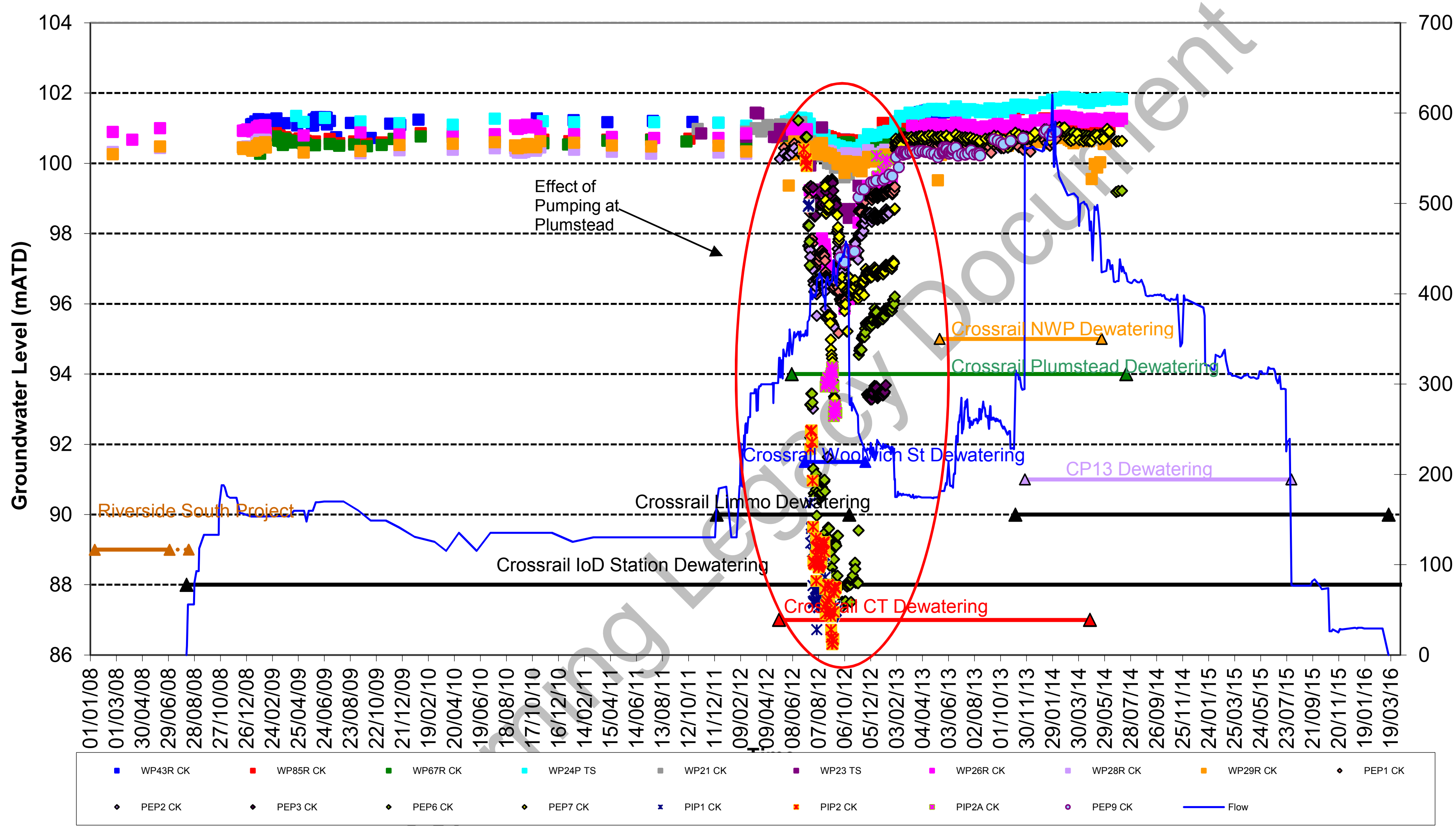
Woolwich Station

Figure

A.8a



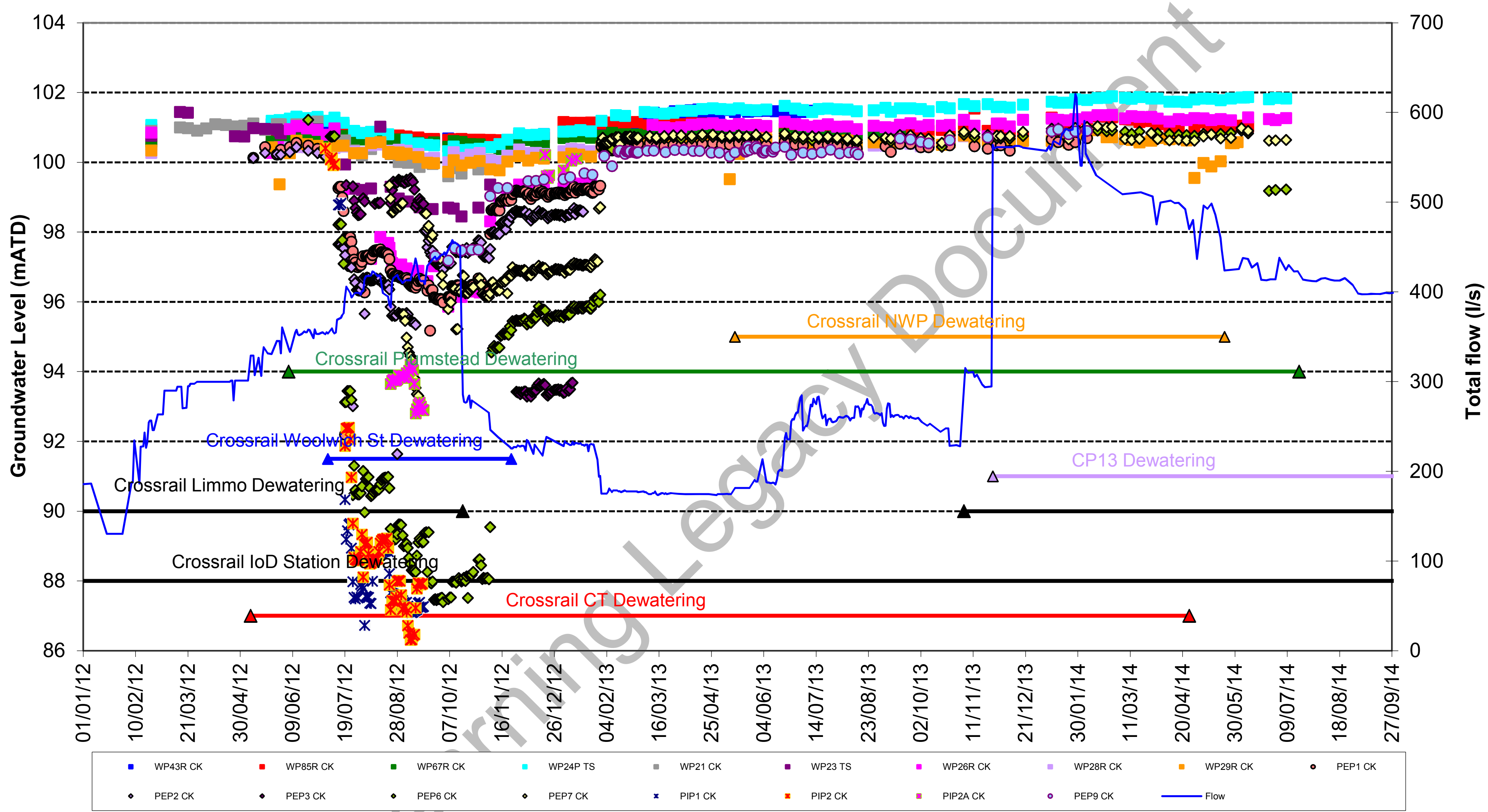
	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level Woolwich Station	**A.8b**



Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
Plumstead Portal (Chalk)

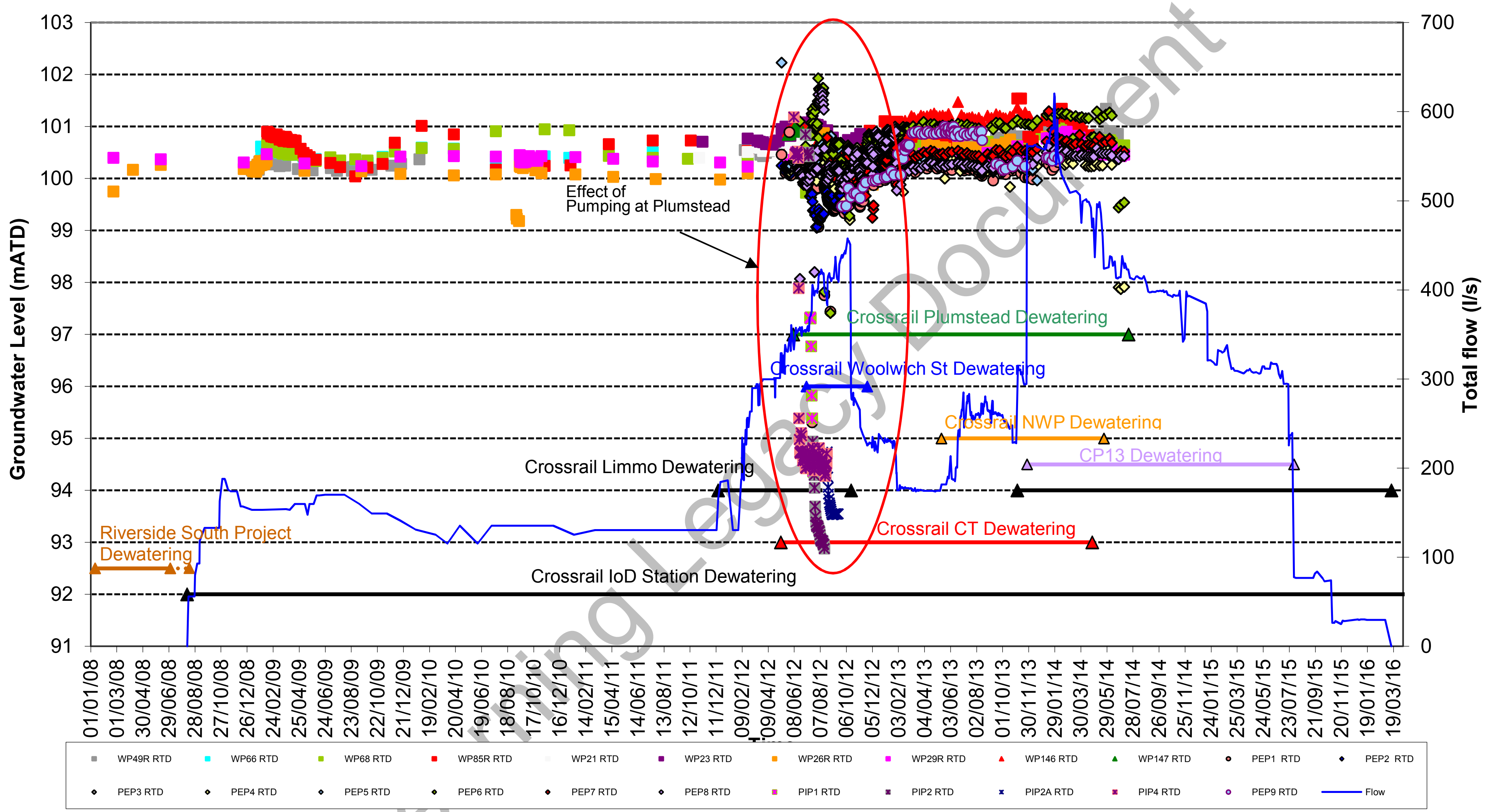
Figure
A.9a



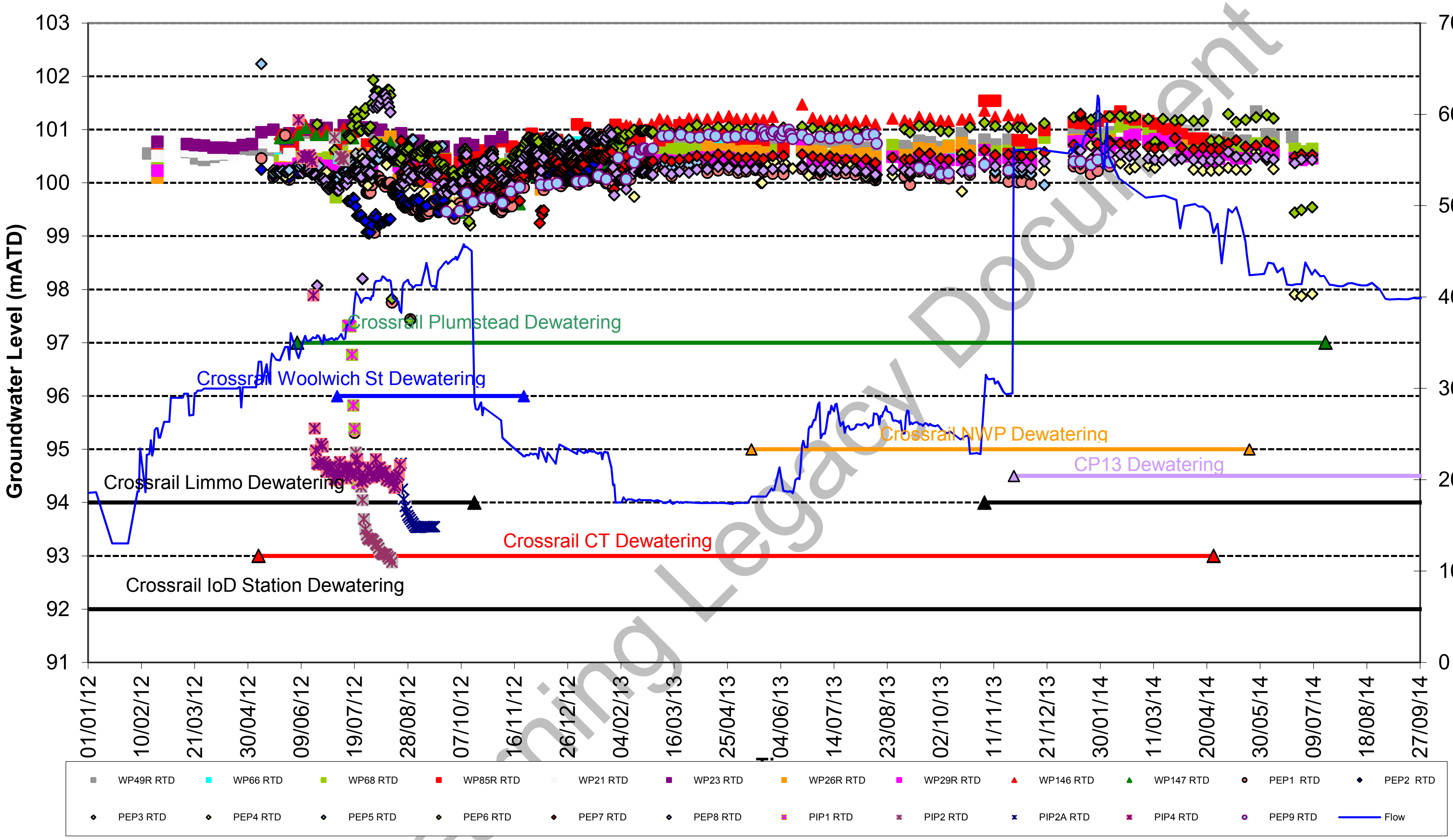
Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
Plumstead Portal (Chalk)

Figure
A.9b



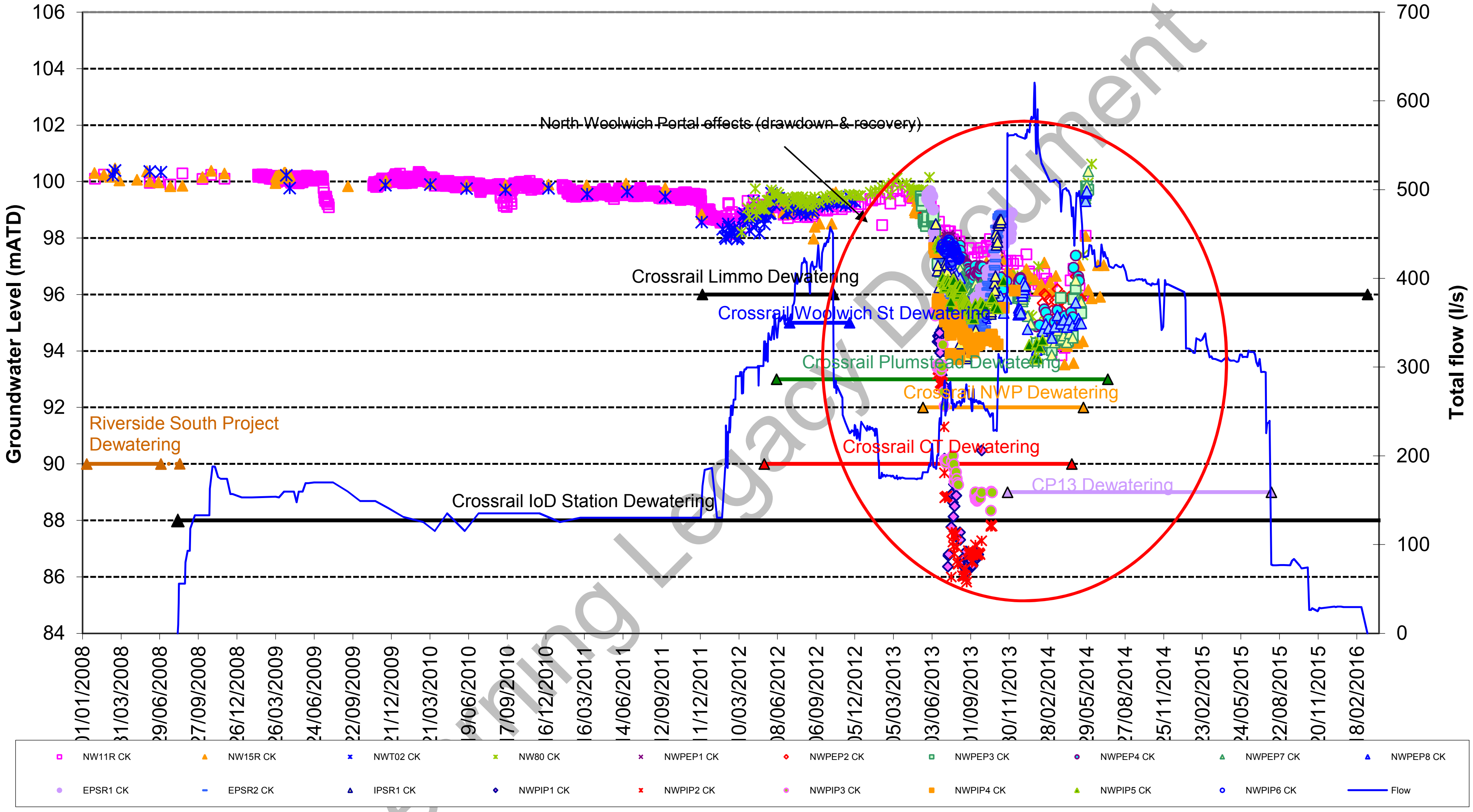
Crossrail Limited Crossrail Dewatering Works - Close out Report		**Figure**
Measured Piezometric Level Plumstead Portal (RTD)		**A.9c**



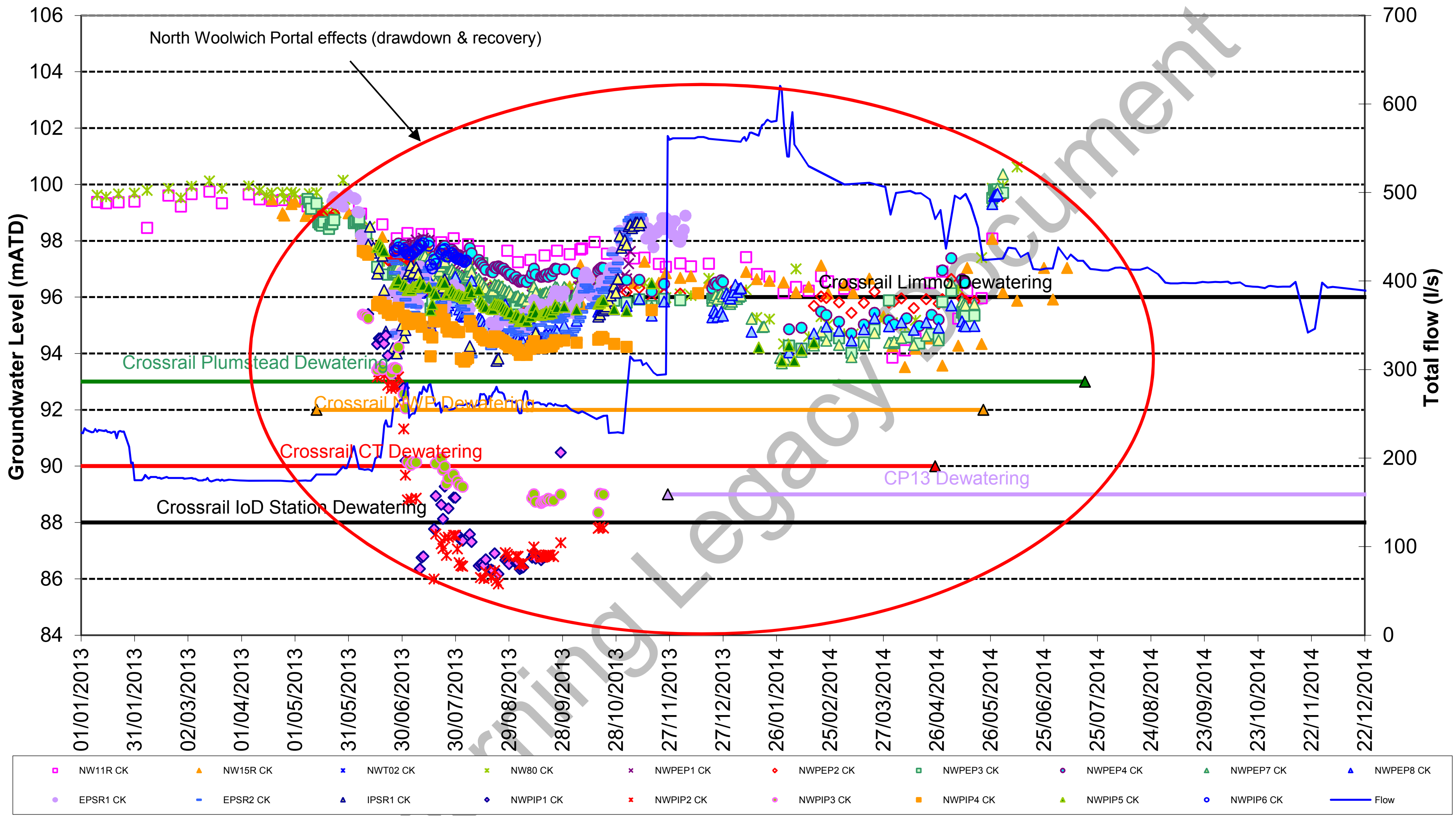
Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
Plumstead Portal (RTD)

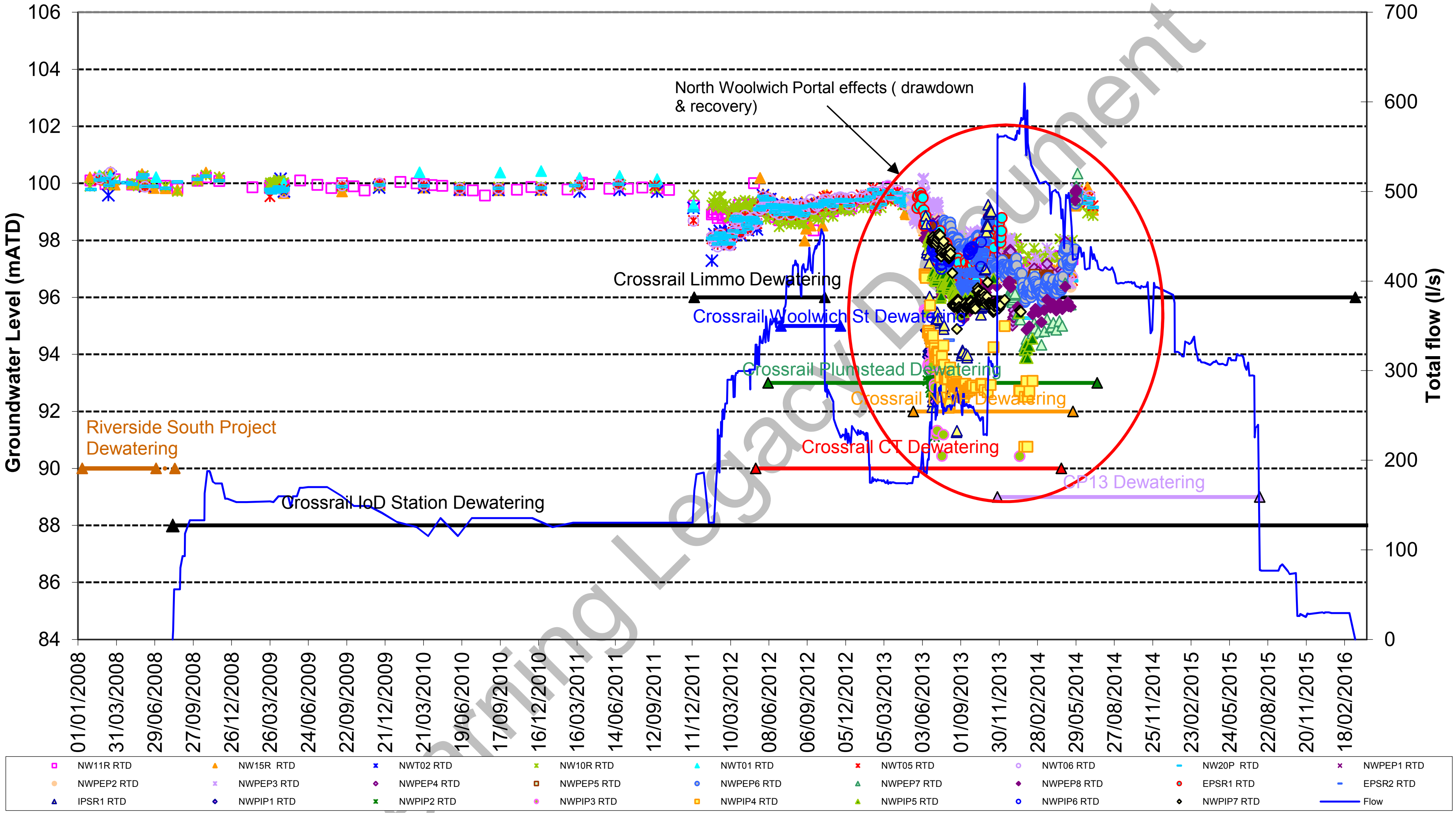
Figure
A.9d



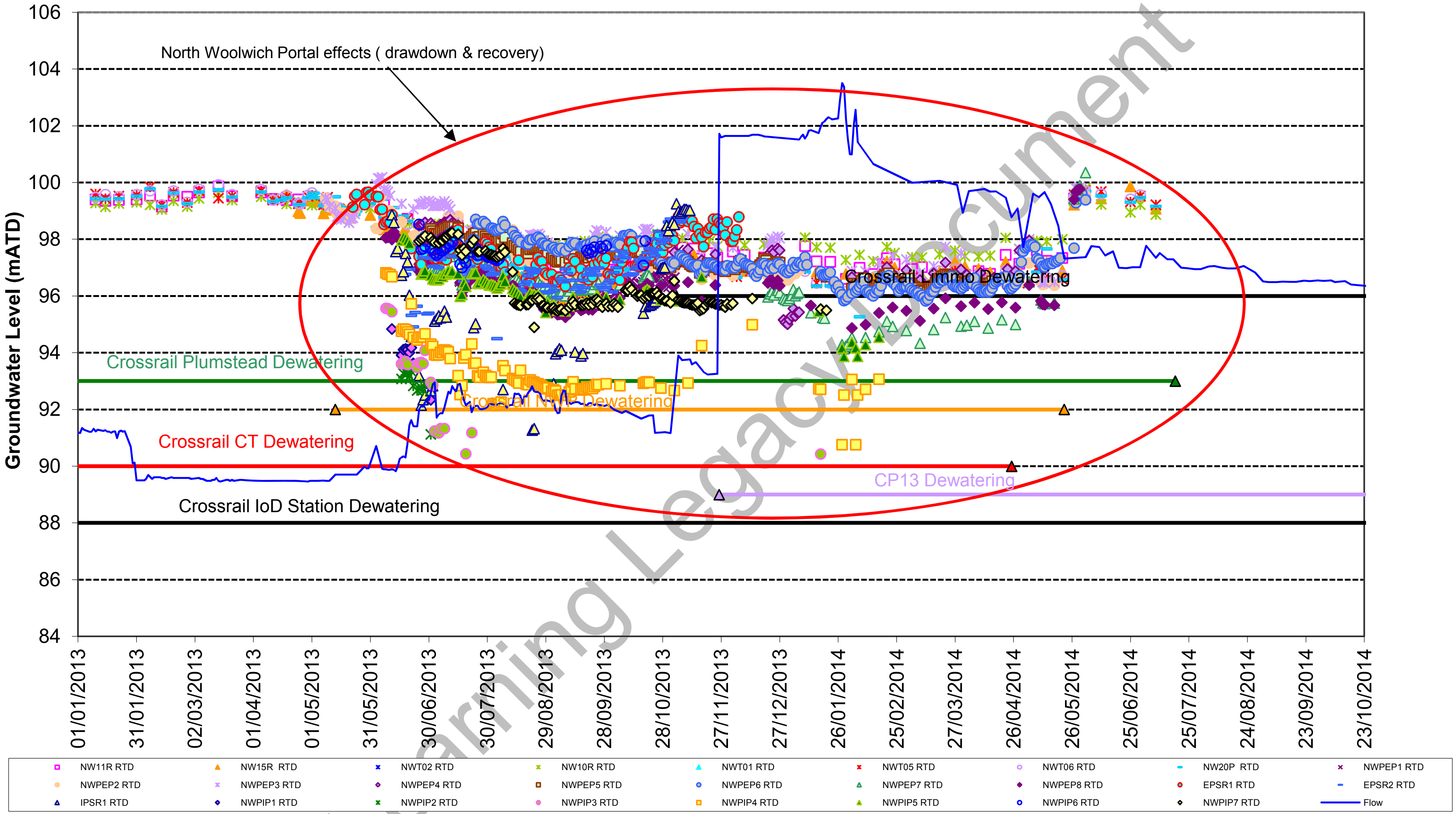
	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level North Woolwich Portal (Chalk)	**A.10a**



	Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
	Measured Piezometric Level North Woolwich Portal (Chalk)	**A.10b**



Crossrail Limited Crossrail Dewatering Works - Close out Report	**Figure**
Measured Piezometric Level North Woolwich Portal (RTD)	**A.10c**



Crossrail Limited
Crossrail Dewatering Works - Close out Report

Measured Piezometric Level
North Woolwich Portal (RTD)

Figure
A.10d