



C510 – Whitechapel and Liverpool Street Station Tunnels

Instrumentation and Monitoring Close Out Report Block 09 Liverpool Street CRL Document Number: C510-BBM-C2-RGN-C101-50225 Supplier Document Number: N/A Contract MDL reference: C13.014

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This document has been reviewed by the following individual for coordination, compliance, integration and acceptance and is acceptable for transmission to the above stakeholder for the above stated purpose.

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1 Purpose of Close out Report

Materials and Workmanship Specification - Instrumentation and Monitoring (C122-OVE-Z4-RSP-CR001-00007), section KX10.2114 specifies the requirement for a close out report prior to the decommissioning of monitoring sensors and instruments. It is therefore, the purpose of this close out report to gain acceptance to decommission identified monitoring sensors in Block 09 of Crossrails's C510 Liverpool St. Acceptance to decommission sensors will result in ceasing measurements, stopping the reporting and removing sensors.

To gain approval to decommission instrumentation and monitoring, the monitoring data will be analysed to demonstrate settlement does not breach specified rates after the minimum monitoring period is complete.

N.B. Monitoring sensors refers to all monitoring points; which includes BREs, road studs, extensometers, inclinometers, tilt meters, crack meters, retros (survey stickers) and prisms. Please note this is not an exhaustive list and does not include monitoring systems/equipment, such as communication boxes.

2 Scope of Monitoring Assessment for Close Out

Specification KX10.4103 of document C122-OVE-Z4-RSP-CR001-00007 states that to establish approval for decommissioning, the contractor is to produce a close out report which summarises the observations in correlation with the construction activities. The report is to demonstrate monitoring has reached acceptable settlement rates; whether to the specified rate, or where no rate is specified trigger values are evaluated against potential residual risks. I&M schedule C122-OVE-C2-DDJ-CR001-Z-31511 specifies the acceptable settlement rates with the requirements to monitor at different construction phases, and duration for completion. To summarise the I&M schedule states that the manual monitoring decommissioning specified rate is 2mm per year, following 16 months post construction monitoring (4 months step down and quarterly measurements for a minimum of 12 months long term monitoring). The I&M schedule does not identify the need for long term automated monitoring or specify a settlement rate requirement, it only states that monitoring must continue for 6 months post construction. At the 6 month juncture, agreement must be sought from the project manager to decommission automated monitoring programmes through a close out report or agreeing to cease the works with the project manager. In most cases decommissioning will be possible, as the residual risk will be captured through the remaining long term manual monitoring.

Contrary to the Specification for Instrumentation and Monitoring (C122-OVE-Z4-RSP-CR001-00007), the Project Managers Instruction (PMI) C510-PMI-01102 replaces long term monitoring with satellite interferometry (InSAR) for the areas agreed by the project manager. If long term monitoring responsibilities are removed from BBMV and covered by satellite interferometry, the specified settlement criteria may not be met by BBMV. If this occurs, reference to the agreement will be provided to state BBMV are no longer responsible for the sensors and consequently decommissioning acceptance will be proposed.

In some cases it may be agreed with the project manager to cease monitoring prior to meeting the specified rates. The close out report will be revised to incorporate these agreements prior to decommissioning. Due to multiple influencers and large construction monitoring zones, it may be prudent to submit successive document revisions for close out reports, where the specification is not met or the minimum post construction monitoring has not been achieved.

3 Close Out Report Block Description and Location Plan

3.1 Block 09 Location

Figure 1 shows the Liverpool St general location plan, C510 tunnel construction and where Block 09 is situated. Detailed location plans can be found within the installation reports and photomontages as listed in Section 3.2. Each monitoring sensor's location is shown within the assessment plans (Section 5.4).

The nearest Thames Water critical asset is a 16 inch cast iron water main, located on the southern side of Liverpool St adjacent to Hope Square. A ductile iron gas main is also located on Liverpool St. The location and detail of these assets can be found in Instrumentation and Monitoring Plan: Liverpool Street Station Ground Movement and Asset Protection C122-OVE-C2-RGN-C101-50013 or the relevant C122 prepared Damage Assessment Reports.

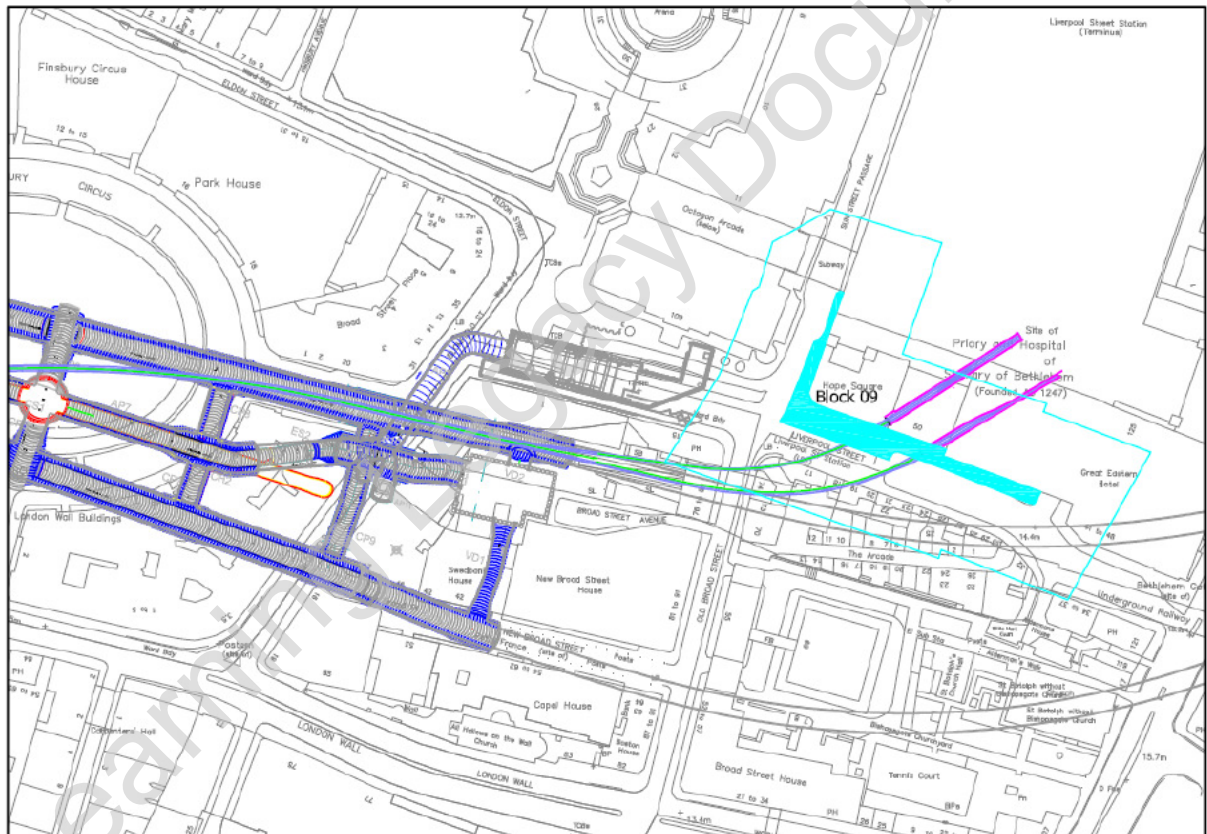


Figure 1- Liverpool St General Location Plan - including Block 09 monitoring area

3.2 Block 09 Description

Block 09 is located on the junction of Liverpool St and Old Broad Street - Sun St Passage. The Crossrail construction closest to Block 09 is the eastbound TBM which runs south of Block 09; additionally Broadgate Box construction is approximately 30 metres to the west of Block 09. Further detail of the construction programmes can be found in Section 4. Block 09 contains the following types of monitoring sensors:

- Road Studs (LP) - manual monitoring

Each monitoring assets details are listed within the Decommissioning Status Tracker (*Table 2*) and further relevant information can be sourced from the installation reports.

Block 09 Installation Report References:

- Monitoring Installation Report LIV-LP-09-Liverpool Street
CRL Document Number: C510-BBM-G-RGN-C101-50006

The Settlement Contour Drawing (C122-OVE-C2-DDA-CR001_Z-21313) predicts the Block 09 area to experience approximately 1-10mm of settlement.

4 Construction Programme Influencing Block 09

Extent of Influence (EOI) monitoring areas were established to record ground movements in relation to C510 construction. The EOI purpose is to ensure all assets and areas are adequately monitored for movement during construction, this is achieved by controlling when and how often monitoring occurs. The Asset Protection Instrument and Monitoring (I&M) Schedules (C122 –OVE-C2-DDJ-CR001_Z-31511) states the extent of influence (EOI) of an active tunnel is 2 x depth from the active tunnel face. The EOI is used to determine when monitoring sensors are no longer influenced by construction and can be considered for decommissioning.

The original specification received amendments to manual monitoring frequency within the EOI through several PMIs, with the latest PMI (C510-PMI-01103) establishing an Active ZOI (Zone of Influence) as 2 x tunnel diameter from the active tunnel face projected to the surface. The Active ZOI changed the rates of monitoring frequency, it did not replace EOI. The EOI is used to determine when a monitoring sensor is eligible for decommissioning. Whereas, active ZOI is used to analyse manual monitoring movement against construction.

To identify the tunnels that had the potential to significantly affect Block 09, a ZOI area was established by giving each monitoring sensor a radius of 2.0 x tunnel diameter. This area was then used to determine all the mining advances that occurred within its boundary, *Figure 2* shows this area (blue outline) and the tunnel constructions. Tunnel advances start and finish dates will be used in assessment of the monitoring data.

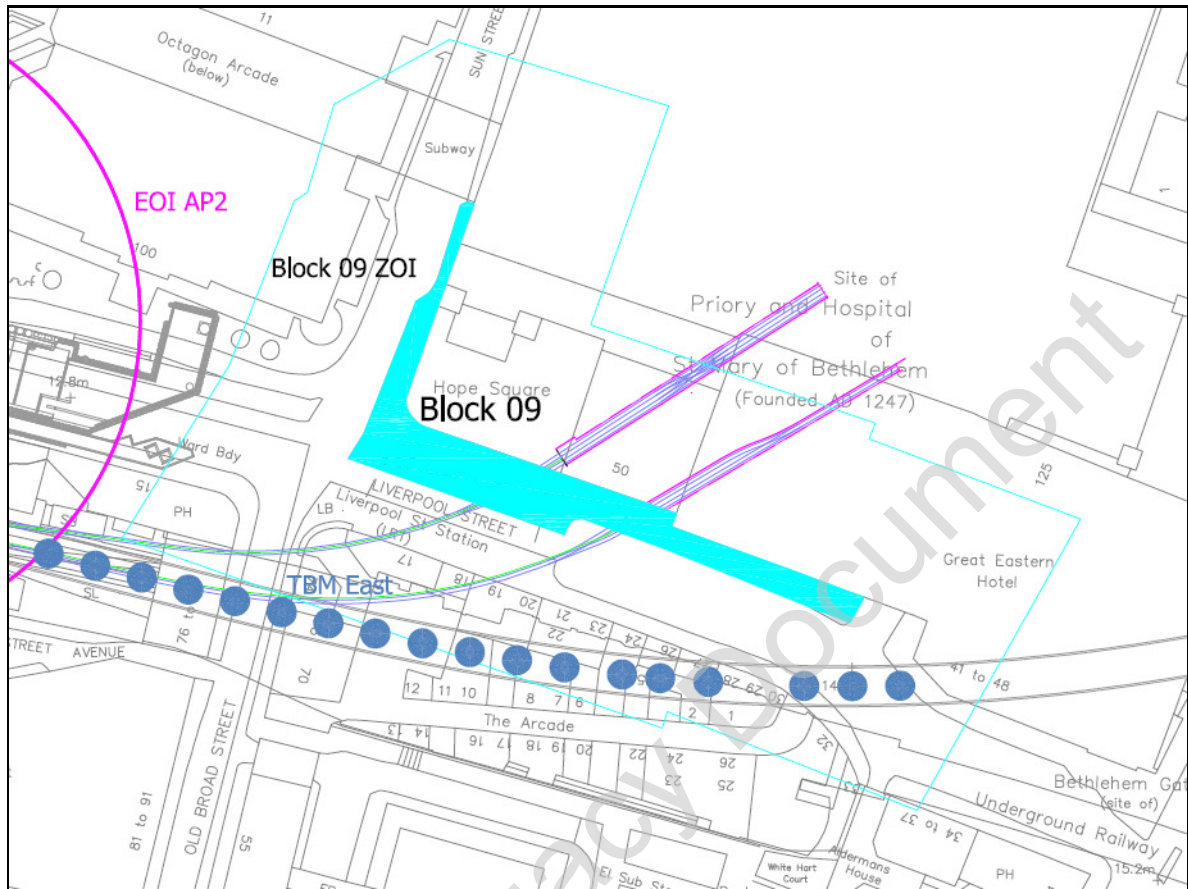


Figure 2 - Block 09 Active ZOI Construction

N.B. AP2 EOI is represented in Figure 2 to display that the ZOI for Block 09 is not affected by recent construction.

Figure 2 - Block 09 Active ZOI Construction shows that no C510 works are within 2 x tunnel diameter of Block 09 (active ZOI). Therefore, to assist the monitoring analysis of Block 09, the EOI of construction will be referenced against settlement. The construction advances EOI that have the potential to affect Block 09 are listed and summarised, which is shown in Table 1.

The last completed C510 advance, which had the potential to affect Block 09 through its EOI, is the RCE Enlargement advance 86, which was completed on the 5th of March 2014. As there is no further C510 construction that has the potential to affect Block 09 and the last construction advance within the EOI has surpassed 16 months of post construction monitoring, the entire Block 09 can be assessed for decommissioning.

The C305 Eastbound TBM construction may have influenced Block 09, and is included within the table and the graph to assess the monitoring data. Further evidence for construction dates can be seen in the decommissioning tracker Table 2, which lists the latest tunnel advances for each point.

N.B. Reference should be made to C502 and C503 close out reports for construction dates of Broadgate Box and associated excavations.

4.1.1 Tunnel Advances Affecting Block 09

The information presented in *Table 1* is used in the monitoring graph (Section 5.1), to show the ground movements in relation to construction. As no C510 construction's active ZOI affects Block 09, C510 construction's EOI has been used.

TUNNEL ADVANCES STARTS & ENDS FOR GRAPHS							
Tunnel Code	Tunnel Reference	Primary Layer Type	Start Date	End Date	Start Advance	End Advance	Zone
TBM-East-RC-Pilot	TBM-East-RC	Enlargement	22/01/2015	31/01/2015	3805	3909	C305
RCE-Enlargement	RCE	Enlargement	25/02/2014	05/03/2014	59	86	EOI
RCE-Pilot	RCE	Pilot	23/09/2013	26/09/2013	35	51	EOI

Table 1 - Tunnel Advances Affecting Block 09

N.B. The advance number for TBM headings, is the advance ring number.

Heading Index:

AP – Access Passage

CH - Chamber

CP - Cross Passage

ES – Escalator

GAD – Grout Adit

LCE - Launch Chamber East

LCW – Launch Chamber West

PTE – Platform Tunnel East

PTW – Platform Tunnel West

RCE – Reception Chamber East

RCW – Reception Chamber West

TBM – Tunnel Boring Machine

VD – Ventilation Drive

5 Monitoring Assessment of Block 09

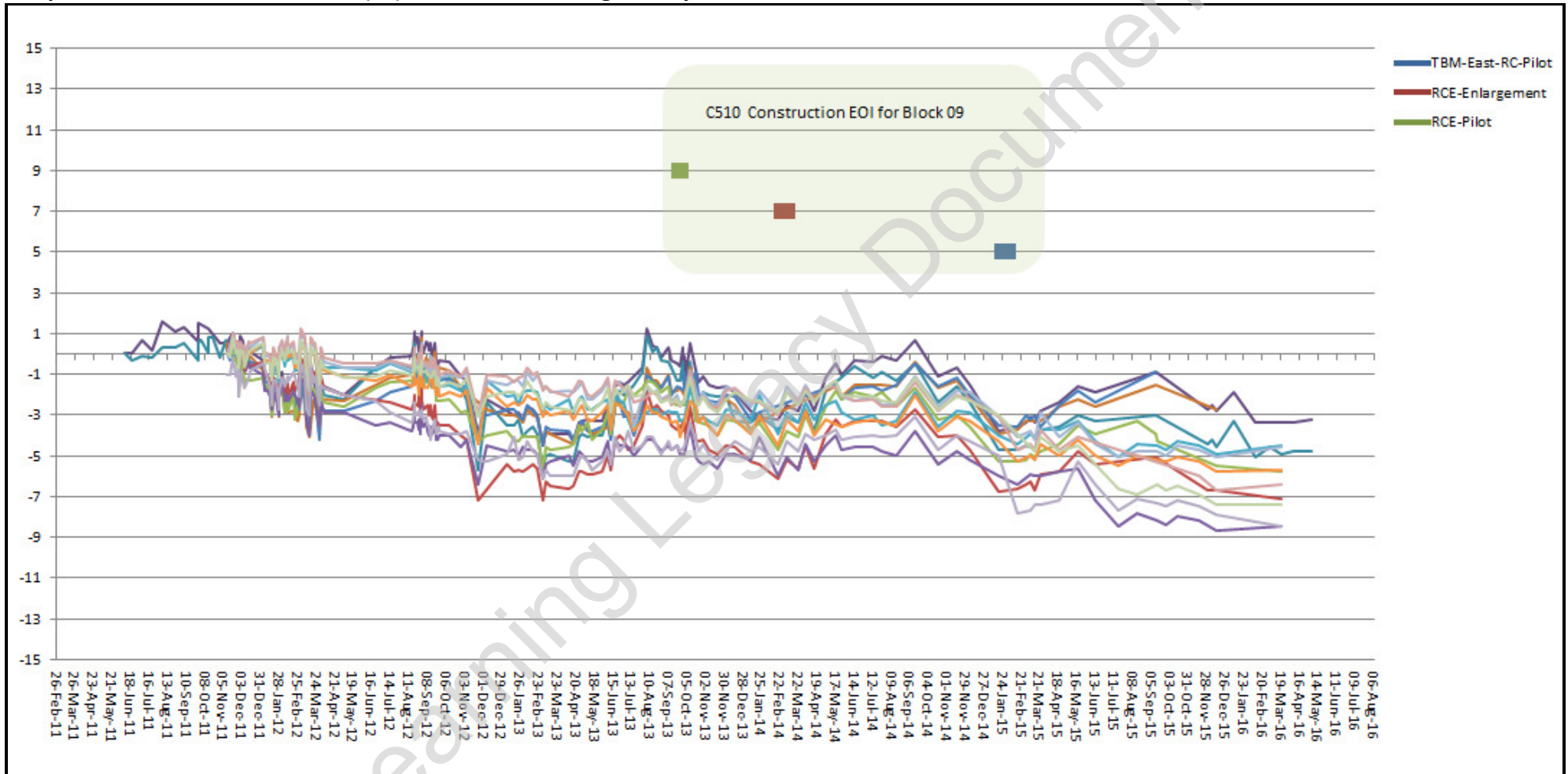
Evidence for decommissioning each monitoring sensor is shown through a graph, table (*Table 2*) and a plan. Each element of assessment compliments the other and is used together to determine acceptance of decommissioning. *Table 2 - Decommissioning Tracker* highlights the monitoring sensors to be considered for decommissioning and provides the supporting evidence for the decision. In some cases supplementary evidence is required to prove stability or provide reasoning for decommissioning.

5.1 Time Graphs Monitoring Full History and Construction Durations

To assess the movement of Block 09 monitoring sensors; each monitoring sensor data type is displayed in a line graph, with a gantt chart (bar) representing the construction identified in Section 4:

- *Graph 1 - All Block 09 Road Studs (LP) Manual Monitoring History in Relation to Construction*

Graph 1 - All Block 09 Road Studs (LP) Manual Monitoring History in Relation to Construction



5.2 Block 09 Decommissioning Status Tracker

The decommissioning tracker (*Table 2*) identifies each monitoring sensor and provides the critical information to enable decommissioning assessment for each sensor. The initial fields shown in the tracker are descriptors of the monitoring sensor, whilst the remaining fields are the assessment for decommissioning. The purpose of the tracker is to provide Crossrail reviewers with sufficient information in conjunction with construction movement graphs and plots, to accept BBMV's proposal to decommission sensors on an individual basis.

Detailed explanation of the tracker column headers:

Tracker Column Header – Last Construction Date and Traffic Lights

For each sensor the EOI parameter is used to determine the latest completed construction advance that had the potential to cause settlement. All construction tunnel advances that had the potential to affect a sensor through its EOI are listed for each sensor, from the list the latest advance is used as a construction completion indicator. A traffic light system is used to highlight when a sensor has surpassed defined monitoring time frames; 4 months (120 days), 6 months (180 days) and 16 months (480 days)

N.B. Each monitoring sensor's last affecting primary construction heading and advance number's completion date has been listed within the Decommissioning Status Tracker. The last construction heading listed, is not the closest to the monitoring sensor, but the last completed within the EOI radius (2 x depth).

If any Block 09 sensors are not within a distance of 2 x depth of any tunnel advance location, the last completed construction's EOI that had the potential to affect Block 09 is used as a reference.

Tracker Column Header – 120, 180 & 365 Days Average Settlement Trend

There are three average settlement trends, which tie into the defined monitoring time frames; 120, 180 and 365 days. The calculation used to determine the trend is the same for all three periods. It is a slope calculation (explained below) of the defined period, multiplied over one year. The trend is calculated from the latest reading and includes all readings within the defined period, which is averaged and then multiplied over 1 year. If there is no initial reading for the time frame date, the calculation will continue back to include the next available date. This is an important consideration when assessing the trend and to assist the reviewers, the time frame used within the calculation is included within the decommissioning tracker status table. Defined monitoring time frames:

- The 120 day average rate is used to show the completion of manual monitoring step down period, this is the minimum period of monitoring prior to InSAR taking monitoring responsibility.
- The 180 day average rate is the minimum monitoring period after construction for automated sensors.
- The 365 day average trend is a calculation to determine annual settlement rates using measurements taken across a full year. This measurement period is therefore the desired duration to be used to assess whether long term settlement meets the 2mm per annum specification.

Slope calculation Settlement Trend:

Description – The settlement trend calculates the slope of the linear regression line through data points in known_y's and known_x's. The slope is the vertical distance divided by the horizontal distance between any two points on the line, which is the rate of change along the regression line.

Calculation

$$b = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sum (x - \bar{x})^2}$$

Example - If the calculated trend for a 6 month period is 1.5mm, it is multiplied into 365 days, to equal a projected settlement trend of 3mm over 1 year.

Tracker Column Header – ERP Ceased date

ERP and CTC meetings have identified project efficiencies, by ceasing manual monitoring programmes early, or prior to reaching 2mm/yr. InSAR may have taken responsibility of monitoring or the perceived risk may be low enough to warrant ceasing the monitoring. In these situations the cease date is provided, along with a comment explaining the reasoning. Monitoring that has been ceased still requires approval to decommission and will be identified within the decommissioning status tracker as proposed to decommission.

Tracker Column Header – Decommissioning Status

The status is the decommissioning situation for each sensor within Block 09. The different statuses are as follows:

- Outstanding - Monitoring sensor has not met the close out requirements and approval to decommission will be sought in subsequent revisions of this close out report.
- Proposed - the sensor is proposed to be decommissioned. Crossrail to accept the sensor can be decommissioned.
- Agreed – Agreed to decommission through previous revision of the close out report. No further reporting or monitoring has taken place.
- Complete - Monitoring sensor has been removed and evidence gathered during decommissioning.

N.B. When monitoring sensors have not met the requirements, it may still be appropriate to decommission. In this scenario supplementary evidence will be provided to explain the reasoning for decommissioning.

Table 2 - Block 09 Decommissioning Status Tracker

21/10/2016

< 2.0 mm GREEN < 3.5 mm AMBER > 3.5 mm RED

C510 Sensor Name	Block	Section	Int / Ext	Measurement Type	Sensor Type	Sensor Description	Asset/Location	EOI Last Primary Layer Construction	Last Construction Date	Latest Surveyed Date	AVERAGE SETTLEMENT TREND					Ceased Date	General Comment	Decommissioning Status	
											120 Day Trend	120 Day Calculation Period	180 Day Trend	180 Day Calculation Period	365 Day Trend				365 Day Calculation Period
C510-LP10901	Block 09	S10901	External	Manual	LP	Road Stud	Sun St Passage	LIV_TBM-East-RC_Pilot_Adv-3909	31/01/2015	03/05/2016	-2.42	142	-3.47	234	-1.61	386	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10902	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3909	31/01/2015	03/05/2016	-2.06	142	-2.59	234	-1.78	386	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10903	Block 09	S10901	External	Manual	LP	Road Stud	Sun St Passage	LIV_TBM-East-RC_Pilot_Adv-3895	27/01/2015	13/12/2015	-0.21	183	-0.21	183	1.19	386	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10904	Block 09	S10901	External	Manual	LP	Road Stud	Sun St Passage	LIV_TBM-East-RC_Pilot_Adv-3895	27/01/2015	12/09/2015	3.69	146	4.61	182	-0.86	386	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10905	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3909	31/01/2015	19/03/2016	-1.38	189	-3.71	189	-1.14	379	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10906	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3895	27/01/2015	19/03/2016	-2.92	186	-2.92	186	-1.04	379	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10907	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3895	27/01/2015	19/03/2016	-0.45	125	-0.72	186	-3.27	379	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10908	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3890	27/01/2015	19/03/2016	0.39	125	-0.10	186	-1.02	379	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10909	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3880	26/01/2015	19/03/2016	-0.77	125	-1.16	186	-1.04	379	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10910	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3875	26/01/2015	19/03/2016	0.70	125	0.27	186	-1.37	379	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10911	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3870	26/01/2015	19/03/2016	-0.57	125	-3.03	307	-2.58	423	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10912	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3865	25/01/2015	19/03/2016	-1.08	125	-2.01	186	-3.42	368	14/04/2016	Ceased in ERP 14/04/2016	Proposed
C510-LP10913	Block 09	S10901	External	Manual	LP	Road Stud	Liverpool St	LIV_TBM-East-RC_Pilot_Adv-3860	25/01/2015	19/03/2016	-2.75	125	-2.42	186	-1.38	423	14/04/2016	Ceased in ERP 14/04/2016	Proposed

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5.3 Supplementary Evidence for Decommissioning

Revision 1 of Block 09 close out report does not require supplementary evidence.

5.4 Monitoring sensor Location Plan and Decommissioning Status

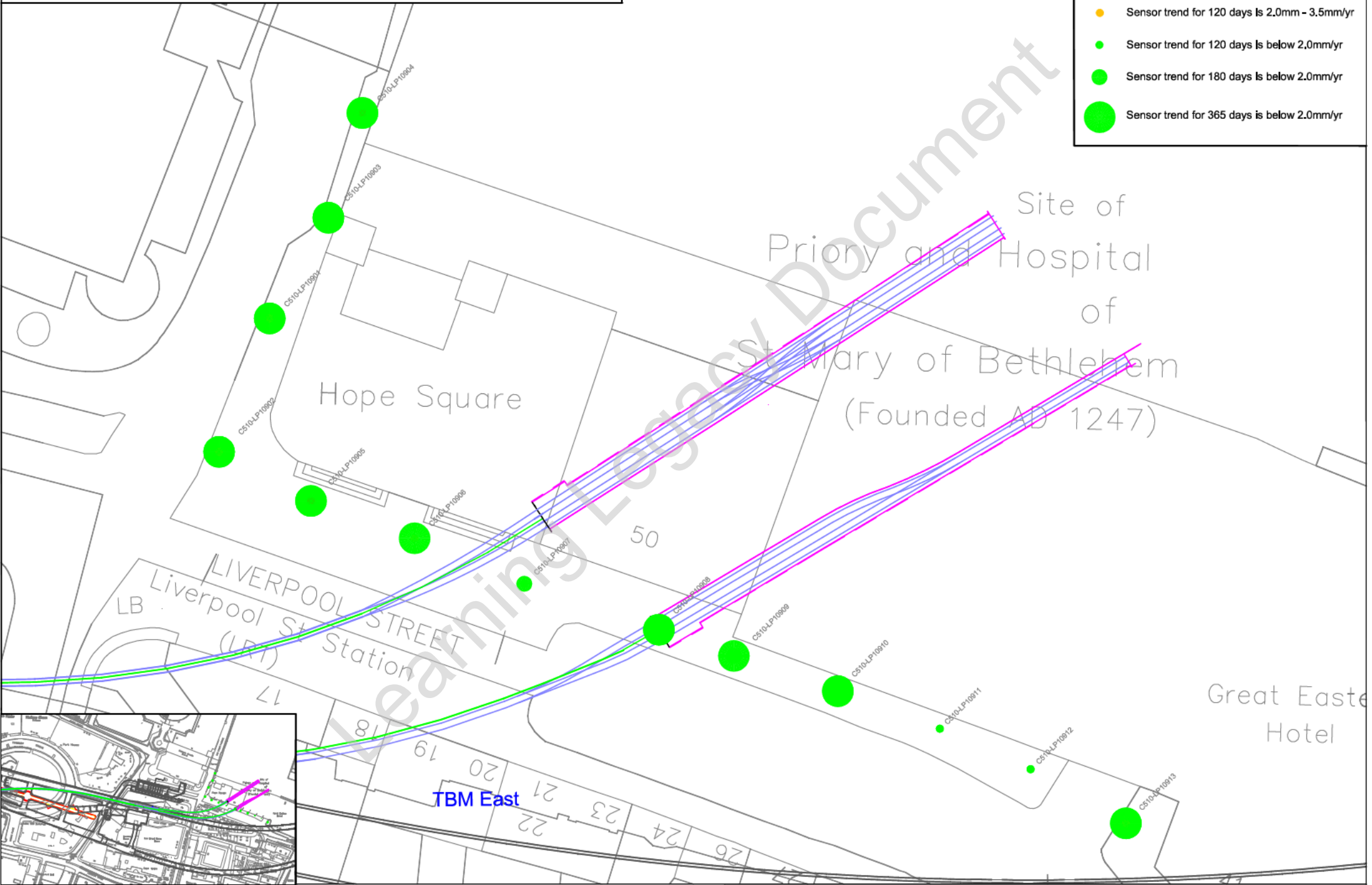
The following plots provide a visual representation of all Block 09 monitoring sensors with a colour circle that defines its settlement status. A green circle represents when a trend is below 2mm/yr and the larger the circle the greater the trend period. When a trend has not been met, a small red circle will represent the monitoring sensor. There is one plan for Block 09 LP monitoring sensors.

- *Figure 3 - LP Monitoring Sensor Settlement Status and Location Plan*

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Figure 3 - LP Monitoring Sensor Settlement Status and Location Plan

Legend	
●	Sensor has not met any trend requirements
●	Sensor trend for 120 days is 2.0mm - 3.5mm/yr
●	Sensor trend for 120 days is below 2.0mm/yr
●	Sensor trend for 180 days is below 2.0mm/yr
●	Sensor trend for 365 days is below 2.0mm/yr



6 Decommissioning Recommendations

Through the monitoring assessment process in Section 5, it is purposed that all Block 09 sensors are proposed to be decommissioned. *Table 2 - Decommissioning Tracker* lists all Block 09 monitoring sensor's decommissioning status and the supporting evidence. Most Block 09 sensors met the specification identified in Section 2 and all were ceased as part of an ERP meeting on the 14th of April 2016.

N.B. When required, decommissioning and re-instatement evidence will be collected during the removal of monitoring sensors, which will be included within the final report.

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