



C510 – Whitechapel and Liverpool Street Station Tunnels

Instrumentation and Monitoring Close Out Report Block 12 Liverpool Street

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(From General Document Template ref: BBMV-0)

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 12 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 12 Location

Figure 1 shows the Liverpool St general location plan, C510 tunnel construction and where Block 12 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).

Thames critical assets are located on Moorgate within Block 12, including 10 and 12 inch cast iron water mains, a 450mm ductile iron water main and London Bridge Sewer Main Line. The location and details 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.

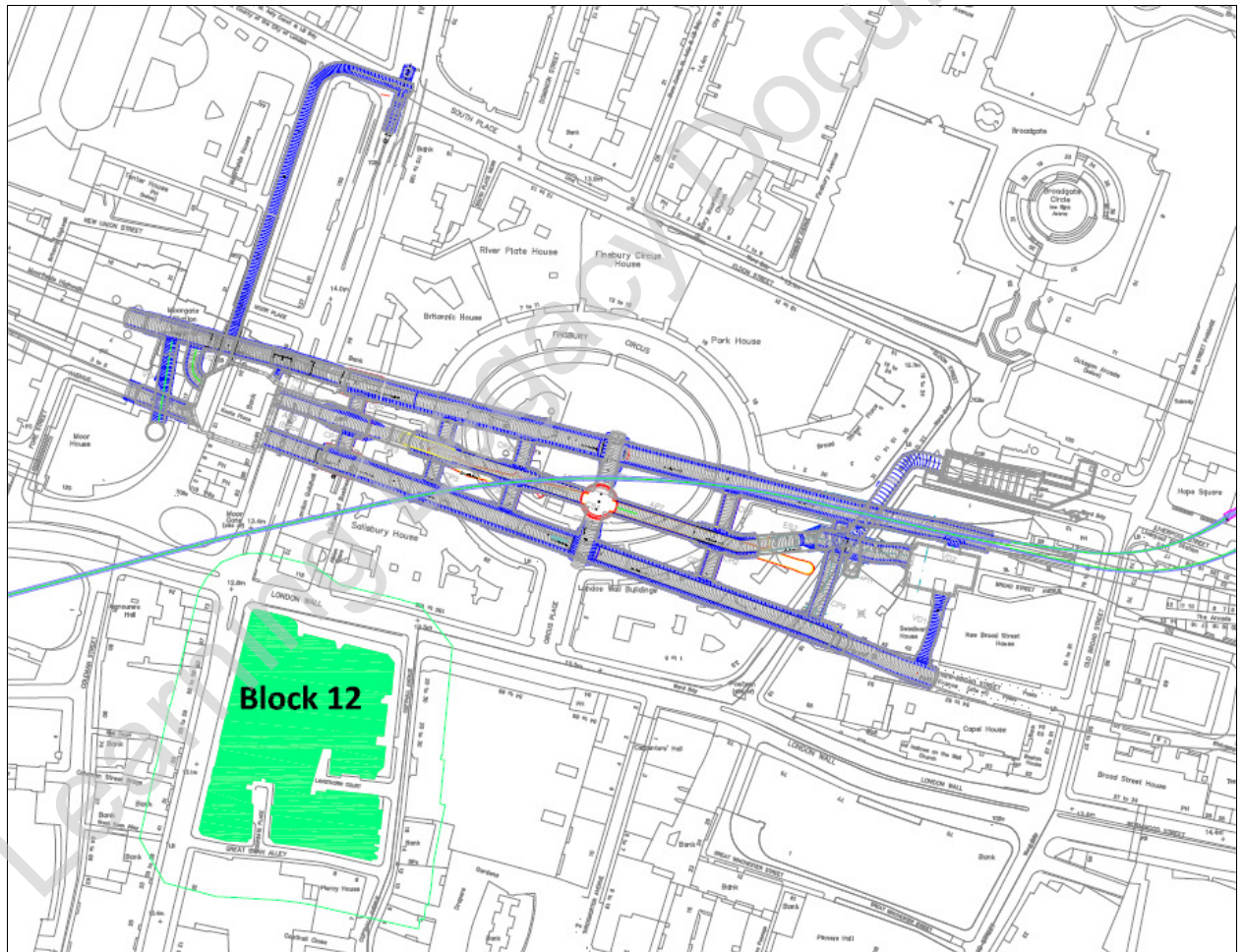


Figure 1 - Liverpool St General Location Plan - including Block 12 monitoring area

(From General Document Template ref: BBMV-0)

3.2 Block 12 Description

Block 12 is located on the south side of London Wall at the intersection of Moorgate. The block is approximately 60 metres south of the Platform Tunnel West (PTW). Further detail of the construction programmes can be found in Section 4. Block 12 contains the following types of monitoring sensors:

- Building (BREs) - manual monitoring
- 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 12 Installation Report References:

- Monitoring Installation Report LIV-LB-12-Liverpool Street
CRL Document Number: C510-BBM-C2-RGN-C101-50131
- Monitoring Installation Report LIV-LP-12-Liverpool Street
CRL Document Number: C510-BBM-C2-RGN-C101-50166
- Monitoring Installation Report (Block 12), Liverpool (ATS)
CRL Document Number: C510-BBM-C2-RGN-C101-50124

The Settlement Contour Drawing (C122-OVE-C2-DDA-CR001_Z-21313) predicts the Block 12 area to experience approximately 1-5mm of settlement.

4 Construction Programme Influencing Block 12

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 12, a ZOI area was established by giving each monitoring sensor a radius of 2.0 x tunnel diameter from the exposed face. This area was then used to determine all the mining advances that occurred within its boundary, *Figure 2* shows this area (green outline) and the tunnels. The tunnel advances start and finish dates will be used in assessment of the monitoring data.

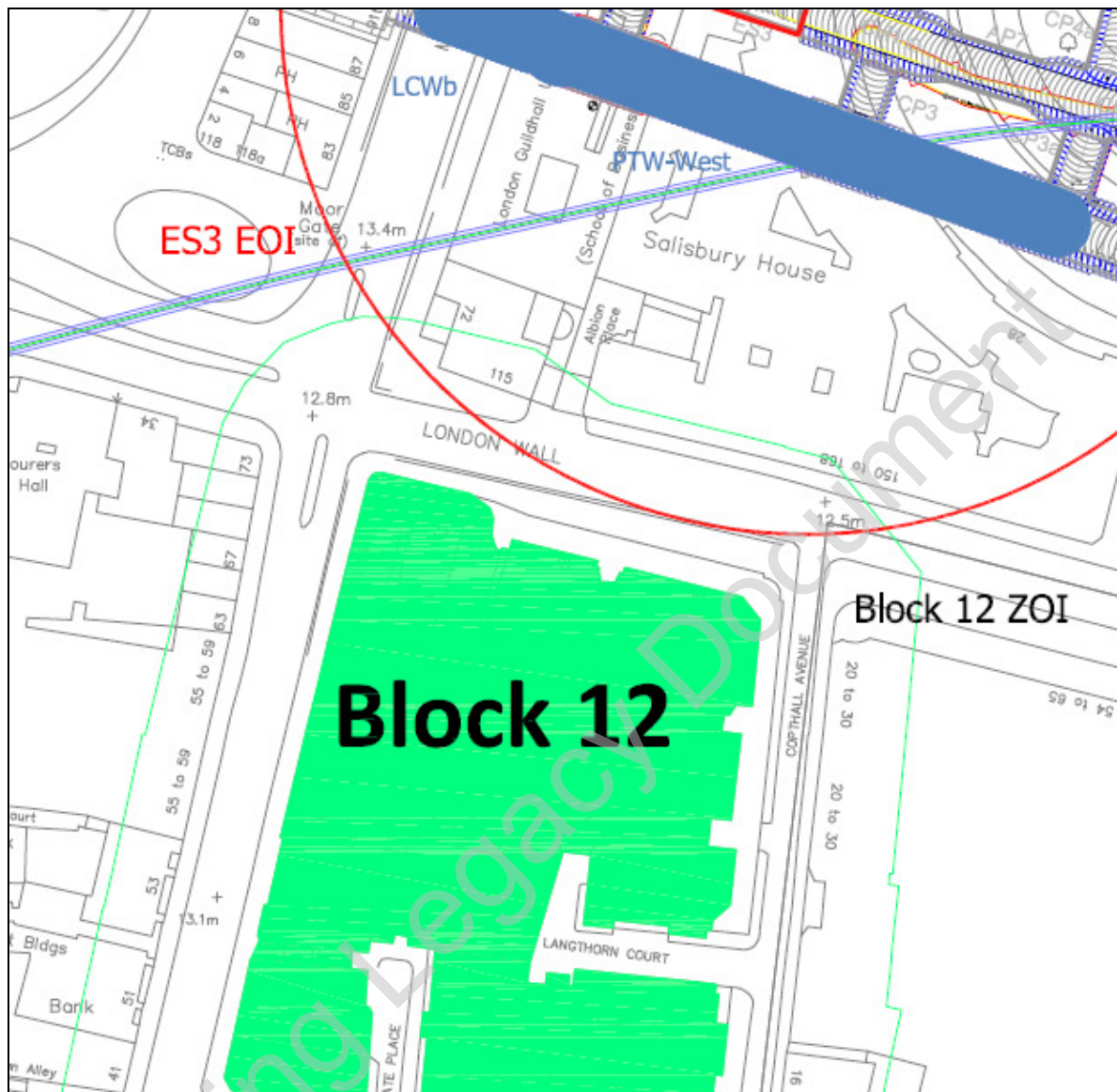


Figure 2 - Block 12 Active ZOI Construction

N.B. ES3 EOI is displayed in *Figure 2* to show that no current C510 constructions EOI should impact Block 12 sensors.

Figure 2 shows that no C510 works are within 2 x tunnel diameter of Block 12 (active ZOI). Therefore, to assist the monitoring analysis of Block 12, the EOI will be referenced against settlement. The construction advances EOI that have the potential to affect Block 12 are listed and summarised in *Table 1*.

The last completed C510 advance, which had the potential to affect Block 12 through its EOI, was the CP1 Enlargement, which was completed on the 28th of June 2014. As there is no further C510 construction that has the potential to affect Block 12 and the last construction advance within the EOI has surpassed 16 months of post construction monitoring, the entire Block 12 can be assessed for decommissioning. Further evidence for construction dates can be seen in *Table 2*, which lists the latest tunnel advances for each point

4.1.1 Tunnel Advances Affecting Block 12

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 construction's active ZOI affects Block 12, 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
CP1-Enlargement	CP1	Enlargement	24/06/2014	28/06/2014	3	13	EOI
CP1-Pilot	CP1	Pilot	07/06/2014	07/06/2014	5	9	EOI
CP3a-Enlargement	CP3a	Enlargement	29/05/2014	31/05/2014	10	end face	EOI
CP3-Enlargement	CP3	Enlargement	01/05/2014	06/05/2014	3	15	EOI
CP3-Pilot	CP3	Pilot	30/04/2014	01/05/2014	5	10	EOI
LCWb-Enlargement	LCWb	Enlargement	25/02/2014	05/03/2014	1	36	EOI
PTW-West-Enlargement	PTW-West	Enlargement	14/09/2013	24/02/2014	22	182	EOI
CP3a-Pilot	CP3a	Pilot	13/01/2014	14/01/2014	10	end face	EOI
LCWb-Pilot	LCWb	Pilot	20/10/2013	24/10/2013	1	19	EOI
PTW-West-Pilot	PTW-West	Pilot	07/06/2013	20/10/2013	21	130	EOI

Table 1 - Tunnel Advances Affecting Block 12

N.B. The advance number for TBM headings, is the advance ring number. Reference should be made to C501 close out report for excavation dates of the Moorgate shaft.

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 12

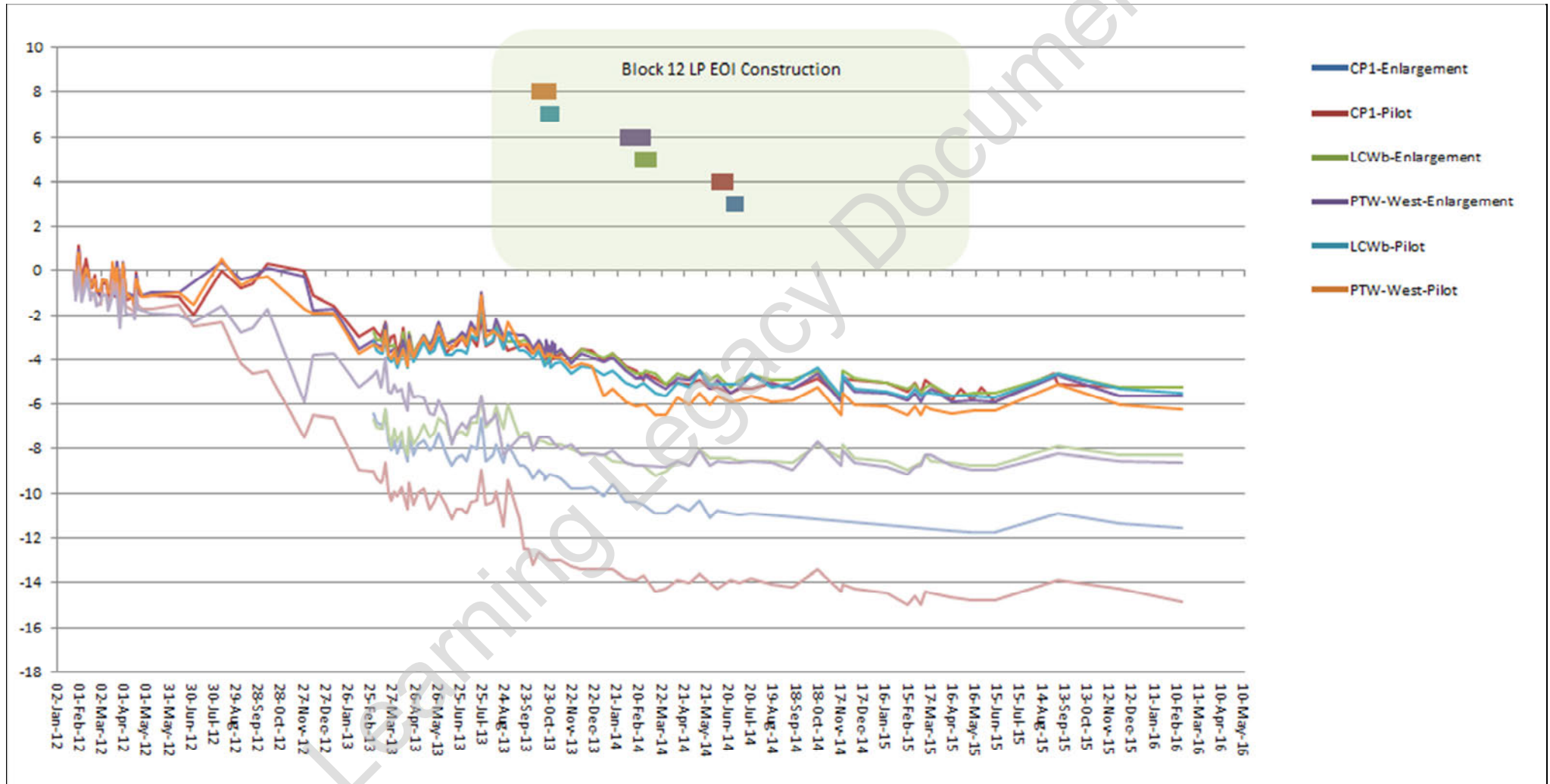
Evidence for decommissioning each monitored sensor is shown through graphs, tables (*Table 2*) and plans. Each element of assessment compliments the other and is used together to determine acceptance of decommissioning. *Table 2 - Decommissioning Tracker* highlights the monitoring sensors to be considered 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

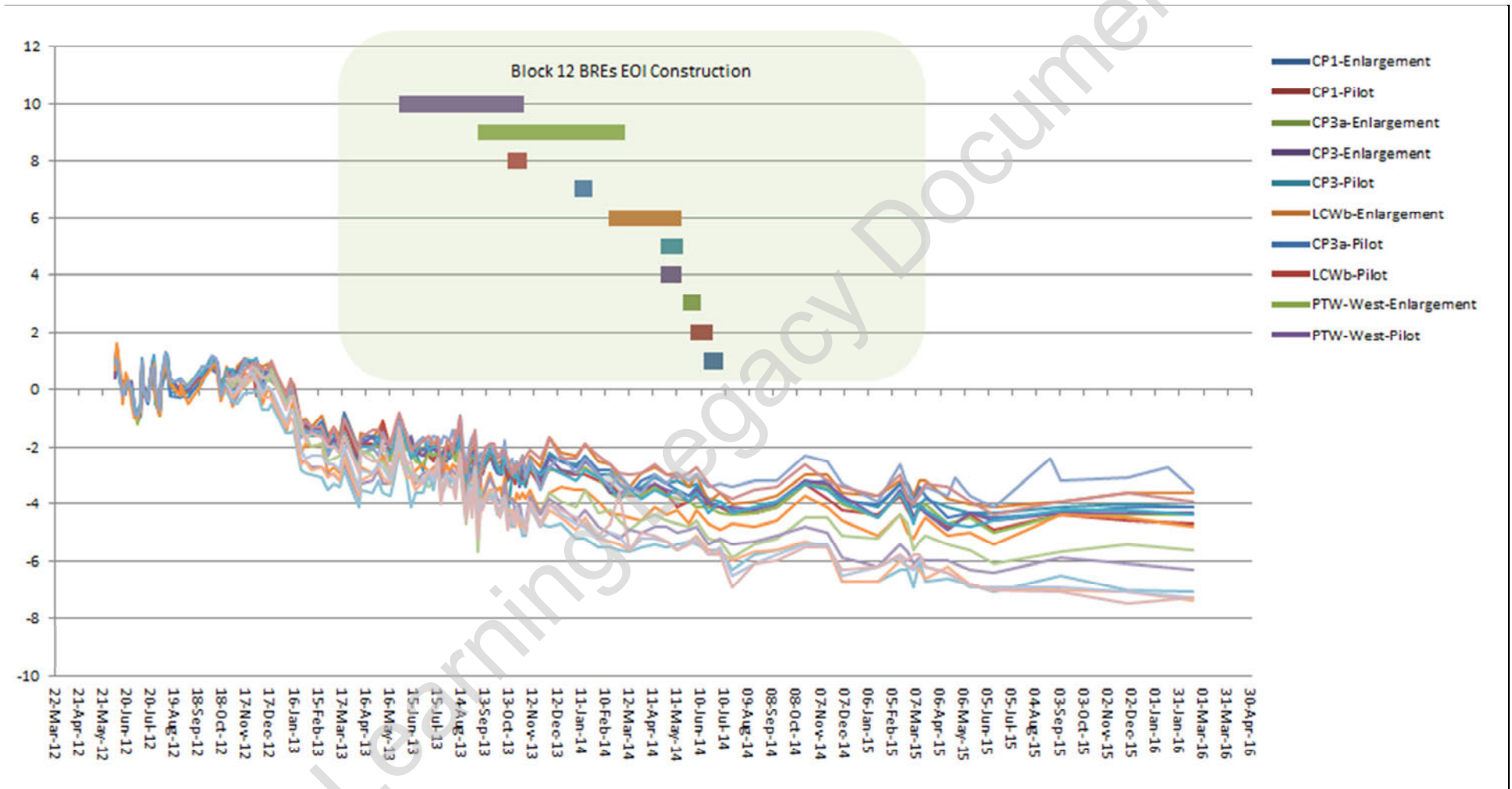
To assess the movement of Block 12 monitoring sensors; each monitoring sensor data type is displayed in a line graph, with a gantt chart (bar) representing the construction identified in Section 4:

- *Graph 1* - All Block 12 Road Studs (LP) Manual Monitoring History in Relation to Construction
- *Graph 2* - All Block 12 Building (BRE) Manual Monitoring History in Relation to Construction

Graph 1 - All Block 12 Road Studs (LP) Manual Monitoring History in Relation to Construction



Graph 2 - All Block 12 Building (BRE) Manual Monitoring History in Relation to Construction



5.2 Block 12 Decommissioning Status Tracker

The decommissioning tracker identifies (*Table 2*) 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 12 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 12 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 12. 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 12 Decommissioning Status Tracker

06/10/2016

< 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	Last Primary Layer Construction	Last Construction Date	Latest Surveyed Date	AVERAGE SETTLEMENT TREND				Ceased Date	General Comment	Decommissioning Status		
											120 Days	120 Day Calculation Period	180 Days	180 Day Calculation Period				365 Days	365 Day Calculation Period
C510-AT112127	Block 112		External	Automated	AT	Total Station	60 Moorgate				#N/A		#N/A		#N/A		Do not remove if required for the network, 09/08/2016	Proposed	
C510-LB11201	Block 12	S11201	External	Manual	LB	BRE	41-43 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.00	166	0.31	250	-0.33	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11202	Block 12	S11201	External	Manual	LB	BRE	41-43 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.66	166	0.79	250	-0.34	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11203	Block 12	S11201	External	Manual	LB	BRE	41-43 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.44	166	0.61	250	-0.65	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11204	Block 12	S11201	External	Manual	LB	BRE	41-43 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.66	166	0.18	250	-0.54	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11205	Block 12	S11201	External	Manual	LB	BRE	41-43 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.00	166	0.79	250	-0.39	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11206	Block 12	S11201	External	Manual	LB	BRE	62-64 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.00	166	0.40	250	-0.23	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11207	Block 12	S11201	External	Manual	LB	BRE	62-64 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.44	166	0.27	250	-0.15	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11208	Block 12	S11201	External	Manual	LB	BRE	62-64 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.88	166	0.75	250	0.22	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11209	Block 12	S11201	External	Manual	LB	BRE	62-64 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.06	166	0.65	250	0.44	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11210	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.00	166	0.79	250	-0.35	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11211	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	0.22	166	0.79	250	-0.65	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11212	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.88	166	0.05	250	-0.42	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11213	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-1.32	166	-0.22	250	-0.64	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11214	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.88	166	-0.57	250	-1.24	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11215	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.88	166	-0.61	250	-1.26	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LB11216	Block 12	S11202	External	Manual	LB	BRE	45-50 London Wall	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.44	166	-0.57	250	-1.71	367	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13201	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.22	166	0.56	250	0.23	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13202	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-1.32	166	0.13	250	0.24	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13203	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-1.99	166	0.00	250	0.26	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13204	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-1.98	166	-0.04	250	0.32	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13205	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-2.43	166	-0.26	250	0.45	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13206	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-1.54	166	0.05	250	-0.24	577	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13207	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-2.20	166	-0.30	250	0.25	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13208	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.88	166	0.35	250	0.49	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed
C510-LP13209	Block 12	S11201	External	Manual	LP	Road Stud	Moorgate	LIV_CP1_Enlargement_ADV_13	28/06/2014	16/02/2016	-0.88	166	0.27	250	0.24	368	10/03/2016	Ceased - ERP 10/03/2016	Proposed

Learning Legacy Doc

5.3 Supplementary Evidence for Decommissioning

Revision 1 of Block 12 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 12 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 12 BRE monitoring sensors.

- *Figure 3 - LP Monitoring Sensor Settlement Status and Location Plan*
- *Figure 4 - LB Monitoring Sensor Settlement Status and Location Plan*

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

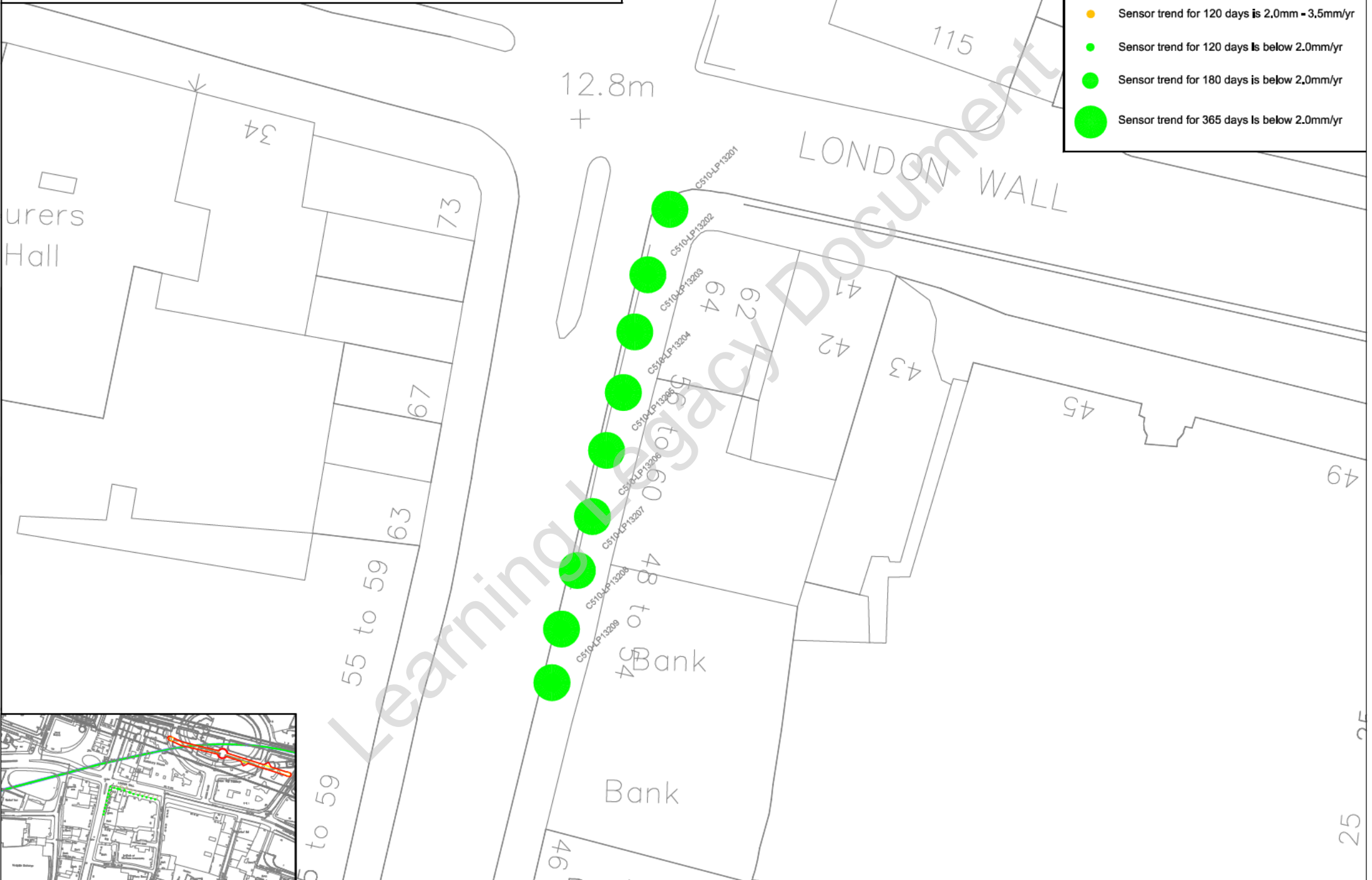
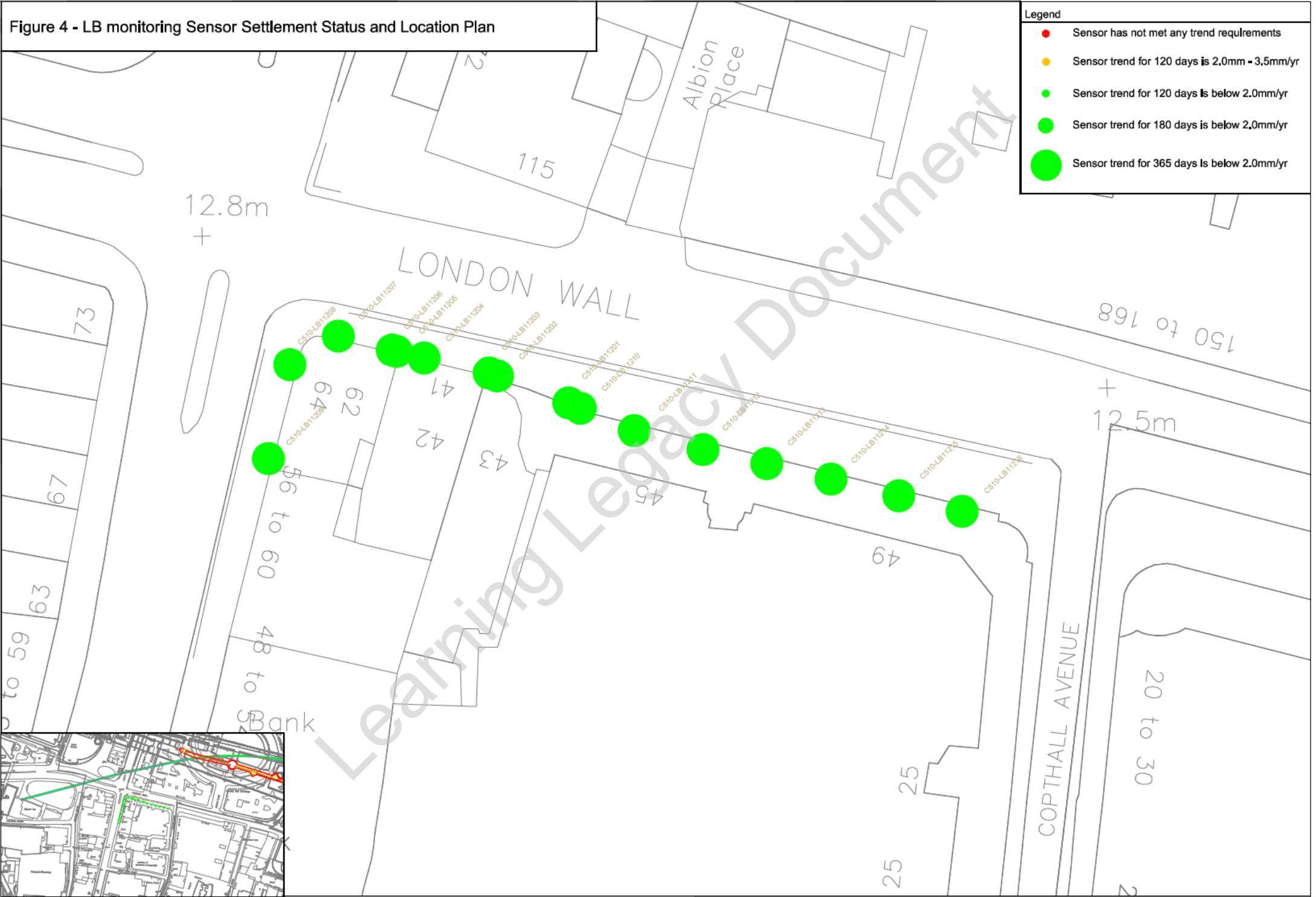


Figure 4 - LB monitoring Sensor Settlement Status and Location Plan

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 12 sensors have met the monitoring specifications and are proposed to be decommissioned. *Table 2 - Decommissioning Tracker* lists all Block 12 monitoring sensor's decommissioning status and the supporting evidence. All Block 12 sensors have met the specification identified in Section 2 and monitoring ceased as agreed at the ERP meeting on the 10th of March 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.

Learning Legacy Document