C510 – Whitechapel and Liverpool Street Station Tunnels

Instrumentation and Monitoring Close Out Report
Block 18 Liverpool Street
CRL Document Number: C510-BBM-C2-RGN-C101-50217
Supplier Document Number: N/A

Contract MDL reference: C13.014

1. Contractor Document Submittal History:

Revision:	Date:	Prepared by:	Checked by:	Approved by:	Reason for Issue:
1.0	03/10/2016	[redacted]			For Acceptance

2a. Stakeholder Review Required? YES ☐ NO ☒

Stakeholder submission required: LU ☐ RfL ☐ NR ☐ LO ☐ DLR ☐ Other: _____

Purpose of submission: For no objection ☐ For information ☐

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

Sign: _____ Role: _____ Name: _____ Date: _____

Sign: _____ Role: _____ Name: _____ Date: _____

2b. Review by Stakeholder (if required):

Stakeholder Organisation	Job Title	Name	Signature	Date	Acceptance
					☐
					☐

3. Acceptance by *Crossrail*:

	***Crossrail* Review and Acceptance Decal** This decal is to be used for submitted documents requiring acceptance by *Crossrail*.	
☒	Code 1.	Accepted. Work May Proceed
☐	Code 2.	Not Accepted. Revise and resubmit. Work may proceed subject to incorporation of changes indicated
	Code 3.	Not Accepted. Revise and resubmit. Work may not proceed
	Code 4.	Received for information only. Receipt is confirmed
[redacted]	Print Name: [redacted]	Position: [redacted] Date: 27/01/17

[redacted] does not relieve the designer/supplier from full compliance with their contractual obligations and does not constitute *Crossrail* approval of design, details, calculations, [redacted] materials developed or selected by the designer/supplier.

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

Document Revision History		
Revision	Date	Purpose
1.0	03/10/2016	For approval

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

TABLE OF CONTENTS

Tables and Figures

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

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 18 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.

Learning Legacy Document

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

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.

Learning Legacy Document

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

3 Close Out Report Block Description and Location Plan

3.1 Block 18 Location

Figure 1 shows the Liverpool St general location plan, C510 tunnel construction and where Block 18 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 water (sewers and water mains), NGG assets (gas utilities) and a BT tunnel are located in the vicinity of Block 18. 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.

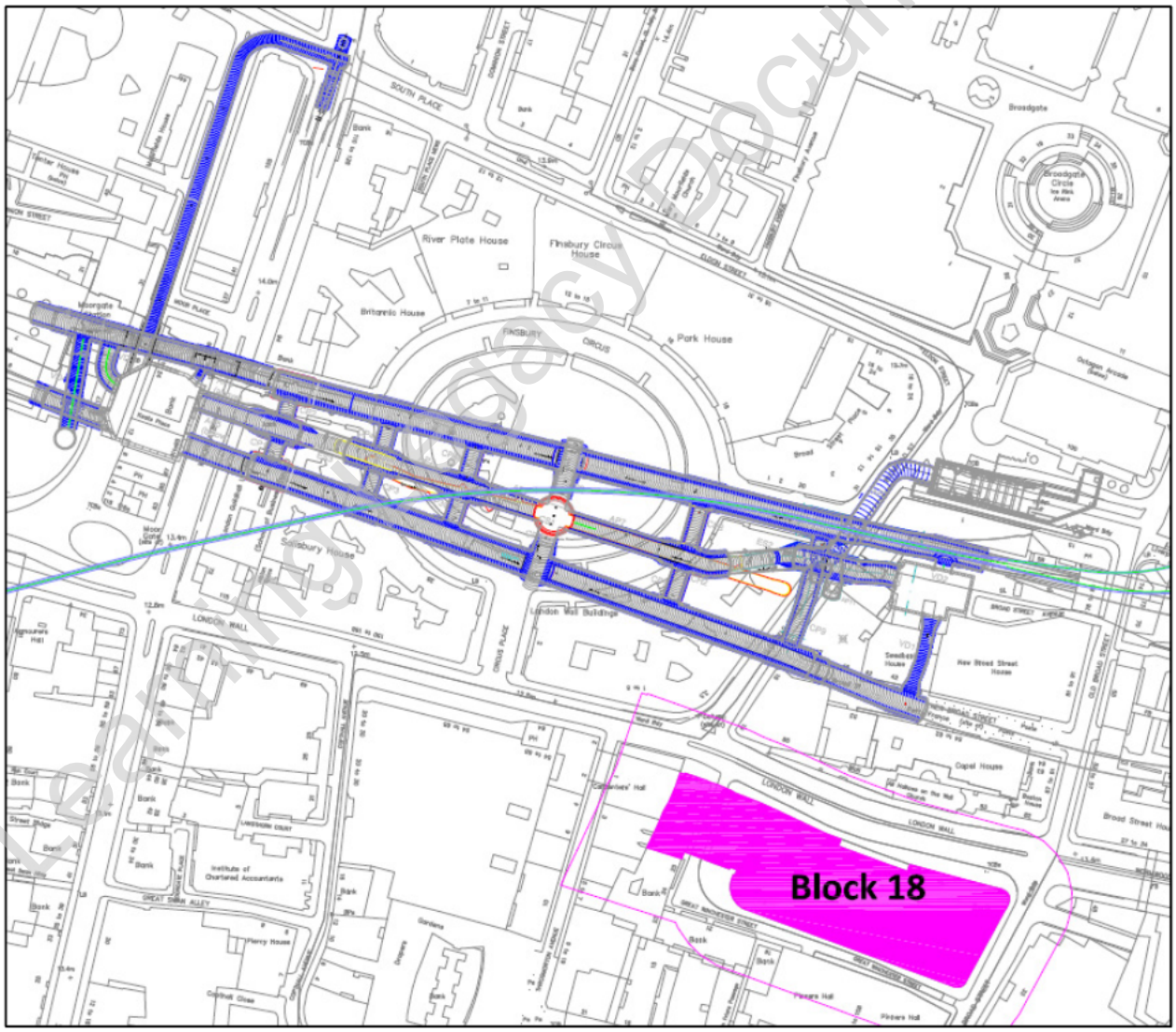


Figure 1 - Liverpool St General Location Plan - including Block 18 monitoring area

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

3.2 Block 18 Description

Block 18 is located on the South side of London Wall and the corner of Old Broad Street. The block is approximately 50 metres south and parallel to the Platform Tunnel West (PTW), further detail of the construction programmes can be found in Section 4. Block 18 contains the following types of monitoring sensors:

- Building (BREs) - 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 18 Installation Report References:

- Monitoring Installation Report LIV-LB-18-Liverpool Street
  CRL Document Number: C510-BBM-C2-RGN-C101-50159

The settlement Drawing C122-OVE-C2-DDA-CR001_Z-21313, predicts the Block 18 area to receive between 1-5mm of settlement.

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

4 Construction Programme Influencing Block 18

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 18, an area ZOI 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 (red outline) and the tunnels. The tunnel's advances start and finish date will be used in assessment of the monitoring data.

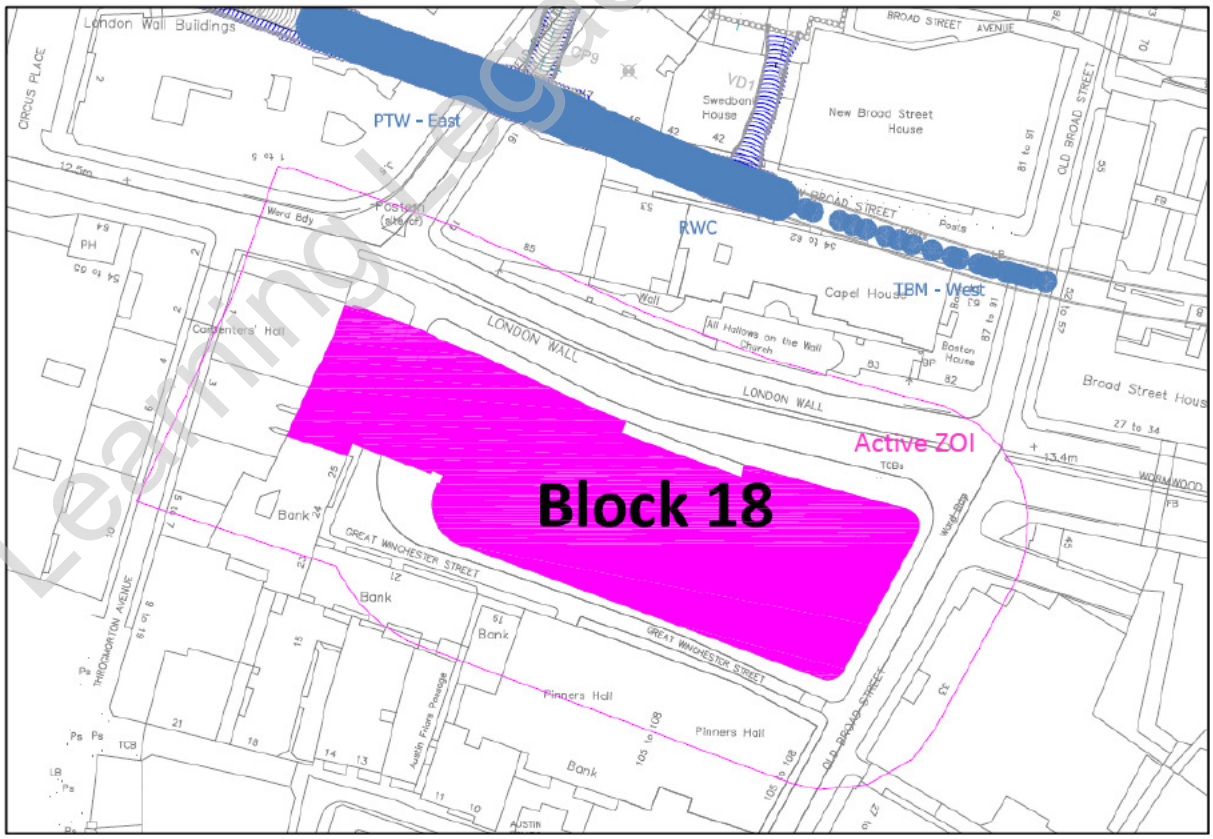


Figure 2 - Block 18 Active ZOI Construction

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

Learning Legacy Document

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Figure 2 - Block 18 Active ZOI Construction shows that no C510 works are within 2 x tunnel diameter of Block 18 (active ZOI). Therefore, to assist the monitoring analysis of Block 18, the EOI of construction will be referenced against settlement. The construction advances EOI that have the potential to affect Block 18 are listed and summarised in Table 1.

The last completed SCL advance, which had the potential to affect Block 18 through its EOI is CP9 Enlargement advance 32, which was completed on 23/08/2014. As there is no further C510's construction that has the potential to affect Block 18 and the last EOI advance that influenced Block 18 has surpassed 16 months of post construction monitoring, the entire Block 18 can be assessed for decommissioning. The TBM West construction may have influenced Block 18, 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.

Learning Legacy Document

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

4.1.1 Tunnel Advances Affecting Block 18

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 18, 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-West-RC-Pilot	TBM-West-RC	Pilot	04/03/2015	12/03/2015	3943	4008	C305
CP9-Enlargement	CP9	Enlargement	10/08/2014	23/08/2014	7	32	EOI
CP9-Pilot	CP9	Pilot	18/07/2014	23/07/2014	8	31	EOI
VD1-Enlargement	VD1	Enlargement	28/05/2014	05/06/2014	3	28	EOI
CP7-Enlargement	CP7	Enlargement	11/05/2014	06/07/2014	3	16	EOI
CP7-Pilot	CP7	Pilot	06/05/2014	09/05/2014	2	15	EOI
RCW-Enlargement	RCW	Enlargement	14/04/2014	07/05/2014	1	71	EOI
PTW-East-Enlargement	PTW-East	Enlargement	25/11/2013	14/04/2014	17	176	EOI
RCW-Pilot	RCW	Pilot	18/10/2013	28/10/2013	1	42	EOI
PTW-East-Pilot	PTW-East	Pilot	24/07/2013	18/10/2013	18	125	EOI
ES2-Pilot	ES2	Pilot	01/05/2013	23/03/2013	1	83	EOI
CH2-Enlargement	CH2	Enlargement	11/04/2013	01/05/2013	3	49	EOI
CH2-Pilot	CH2	Pilot	15/02/2013	18/03/2013	49	73	EOI

Table 1 - Tunnel Advances Affecting Block 18

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

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

5 Monitoring Assessment of Block 18

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 18 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:

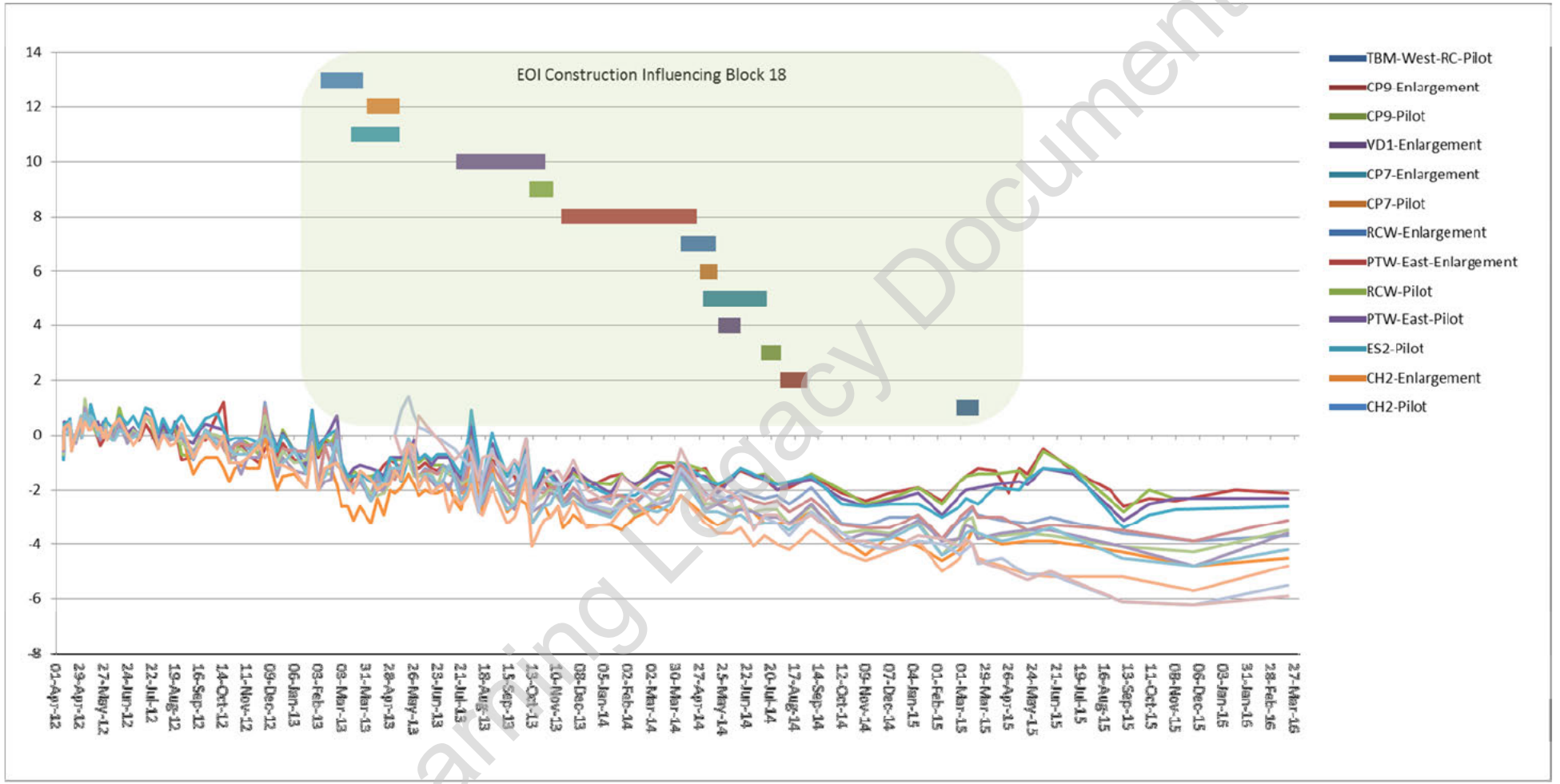
- Graph 1- All Block 18 Building (BRE) Manual Monitoring History in Relation to Construction

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

Graph 1- All Block 18 Building (BRE) Manual Monitoring History in Relation to Construction



Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

5.2 Block 18 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 closet 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 the desired period to be used if the long term monitoring has been completed for decommissioning evidence. The specification states that if the trend is below 2mm/yr, then the sensor is eligible for decommissioning.

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

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 18. 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.

Learning Legacy Document

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

5.2.1 Block 18 Decommissioning Status Tracker

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

18/03/2016

AVERAGE SETTLEMENT TREND

C510 Sensor Name	Block	Section	Int / Ext	Measurement Type	Sensor Type	Sensor Description	Asset	EOI Last Primary Layer Construction	Last Construction Date	Latest Surveyed Date	120 day	120 Day Trend	120 Day Calculation Period	180 day Past	180 Day Trend	180 Day Calculation Period	365 day Past	365 Day Trend	365 Day Calculation Period	Ceased Date	General Comment	Decommissioning Status
C510-LB11801	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.86	132		0.94	193		-1.12	378	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11802	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.00	132		0.39	193		-1.28	378	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11803	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.00	132		1.09	193		-0.84	378	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11804	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.28	132		1.18	193		-0.97	378	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11805	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		-0.31	194		-0.31	194		-1.08	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11806	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		-0.15	194		-0.15	194		-1.04	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11807	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.85	194		0.85	194		-0.53	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11808	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		1.21	194		1.21	194		-0.40	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11809	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		1.09	194		1.09	194		-0.58	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11810	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.64	194		0.64	194		-1.00	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11811	Block 18	S11801	External	Manual	LB	BRE	Winchester House, 75-77 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.87	194		0.87	194		-0.73	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11812	Block 18	S11801	External	Manual	LB	BRE	72 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		1.19	194		1.19	194		-1.58	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed
C510-LB11813	Block 18	S11801	External	Manual	LB	BRE	72 London Wall	CP9-Enlargement	23/08/2014	18/03/2016		0.41	194		0.41	194		-1.78	371	10/03/2016	ERP - Ceased. 10/03/2016	Proposed

Learning Legacy Document

5.3 Supplementary Evidence for Decommissioning

Revision 1 of Block 18 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 18 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 18 BRE monitoring sensors.

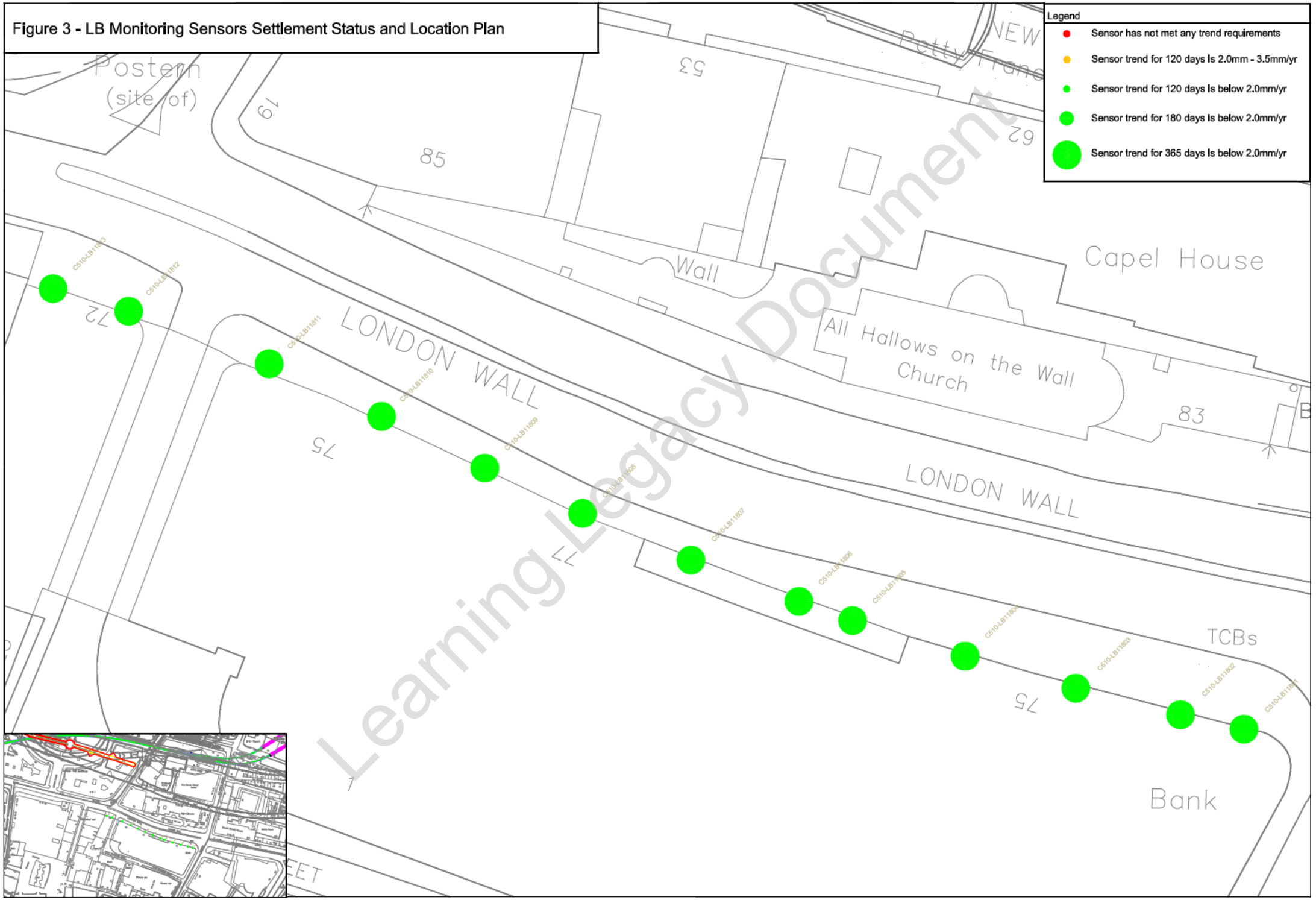
- Figure 3 - LB Monitoring Sensor Settlement Status and Location Plan

Learning Legacy Document

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC

Figure 3 - LB Monitoring Sensors Settlement Status and Location Plan



Learning Legacy Document

6 Decommissioning Recommendations

Through the monitoring assessment process in Section 5, it is purposed that all Block 18 sensors have met the monitoring specifications and are proposed to be decommissioned. Table 2 - Decommissioning Tracker lists all Block 18 monitoring sensor's decommissioning status and the supporting evidence. All Block 18 sensors have met the specification identified in Section 2 and monitoring ceased as agreed at the ERP meeting on 10/03/2016.

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

(From General Document Template ref: BBMV-Form-S9-04 rev 5.0)

Document uncontrolled once printed. All controlled documents are saved on the CRL Document System and BBMV BC