

C510 – Whitechapel and Liverpool Street Station Tunnels

Instrumentation and Monitoring Close Out Report

Block 07 Liverpool Street

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

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TABLE OF CONTENTS

1	Purpose of Close out Report	4
2	Scope of Monitoring Assessment for Close Out	5
3	Close Out Report Block Description and Location Plan	6
3.1	Block 07 Location	6
3.2	Block 07 Description.....	7
4	Construction Programme Influencing Block 07	8
4.1.1	Tunnel Advances Affecting Block 07	10
5	Monitoring Assessment of Block 07	11
5.1	Time Graphs Monitoring Full History and Construction Durations	11
5.2	Block 07 Decommissioning Status Tracker	15
5.3	Supplementary Evidence for Decommissioning.....	18
5.4	Monitoring sensor Location Plan and Decommissioning Status	19
6	Decommissioning Recommendations	23
7	Appendix 1	24

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

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Tables and Figures

<i>Figure 1- Liverpool St General Location Plan - including Block 07 monitoring area</i>	6
<i>Figure 2 - Block 07 ZOI Constructions.....</i>	9
<i>Figure 3- LP10714 Located on Unstable Pavement.....</i>	18
<i>Figure 4- LB Monitoring Sensor Settlement Status and Location Plan.....</i>	20
<i>Figure 5- LP Monitoring Sensor Settlement Status and Location Plan.....</i>	21
<i>Figure 6- RP Monitoring Sensor Settlement Status and Location Plan</i>	22
<i>Graph 1- All Remaining Block 07 BREs (LB) Manual Monitoring History in Relation to Construction</i>	12
<i>Graph 2- All Remaining Block 07 Road Studs (LP) Manual Monitoring History in Relation to Construction ..</i>	13
<i>Graph 3- All Remaining Block 07 3d Geodetic Prisms (RP) Automated Monitoring History in Relation to Construction</i>	14
<i>Table 1- Tunnel Advances Affecting Block 07.....</i>	10
<i>Table 2- Block 07 Decommissioning Status Tracker LB, LP and RP</i>	17

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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 07 of Crossrail'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 07 Location

Figure 1 shows the Liverpool St general location plan, C510 tunnel construction and where Block 07 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 critical assets include 200mm and 400mm Stainless Steel water mains located on Liverpool Street within close proximity to Block 07. Other utilities in the vicinity of Block 07 include plastic gas mains, various water mains and a brick sewer. 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.

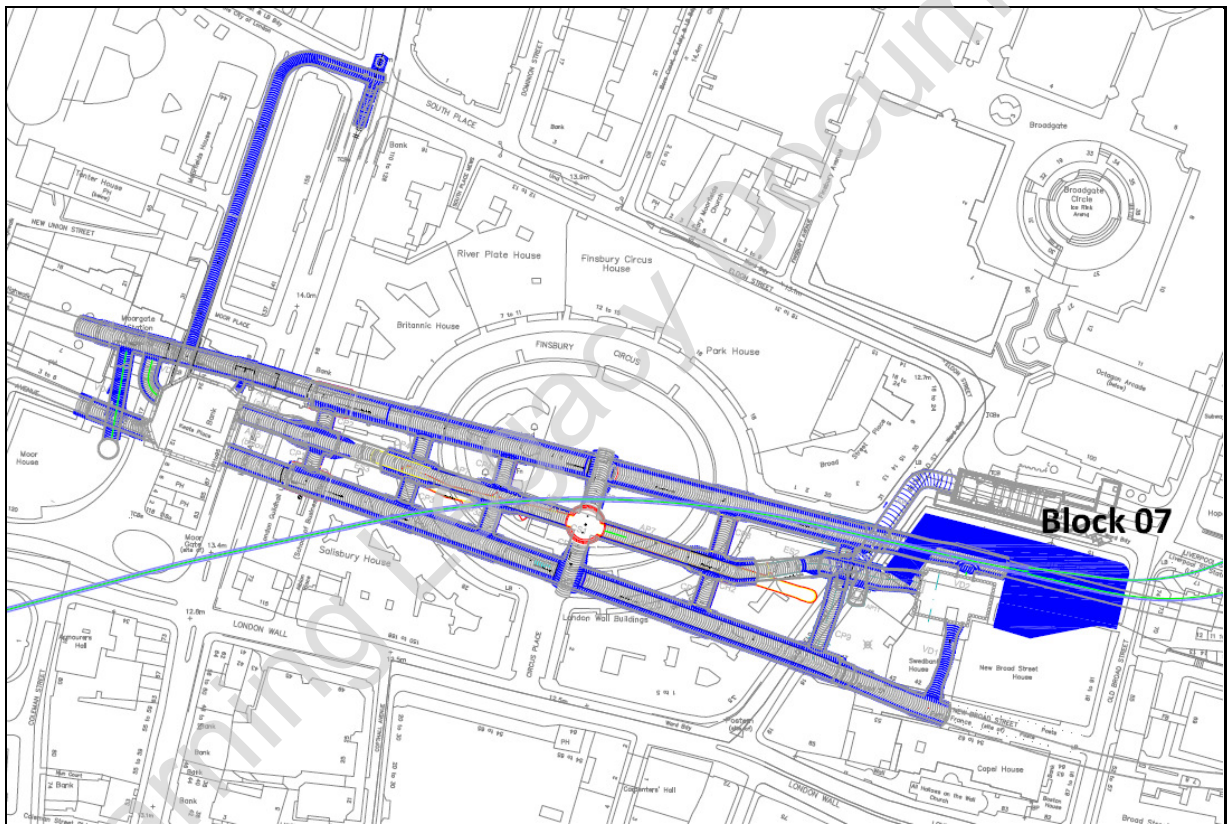


Figure 1- Liverpool St General Location Plan - including Block 07 monitoring area

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

3.2 Block 07 Description

Block 07 is located between Blomfield St and Old Broad St. The block is adjacent to C502's Broadgate Site and occupies The Railway Tavern and Crossrail's Blomfield St office. Block 07 contains the following types of monitoring sensors:

- Road Studs (LP) - manual monitoring
- 3D Geodetic Prism Monitoring (RP) – automated monitoring
- Tiltmeters (TB)- automated monitoring
- Building (BREs)- manual monitoring
- Water Settlement Cell- Electronic (SH)- automated monitoring

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

Block 07 Report References:

- Monitoring Installation Report External LIV-LB-07-Liverpool Street
CRL Document Number: C510-BBM-G-RGN-C101-50002
- Monitoring Installation Report Internal LIV-LB-07 Liverpool Street (1-14 Liverpool St)
CRL Document Number: C510-BBM-C2-RGN-C101-50156
- Monitoring Installation Report LIV-LP-07 – Liverpool Street
CRL Document Number: C510-BBM-G-RGN-C101-50001
- Installation Report- (Block-7), Liverpool Street
CRL Document Number: C510-BBM-G-RGN-C101-50008

The Settlement Contour Drawing (C122-OVE-C2-DDA-CR001_Z-21313) predicts the Block 07 area to experience approximately 20-120mm of settlement.

4 Construction Programme Influencing Block 07

Extent of Influence (EOI) monitoring areas were established to record ground movements in relation to Crossrail 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 07, 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 the ZOI boundary (blue outline) and the tunnel constructions. Tunnel advance start and finish dates will be used in assessment of the monitoring data.

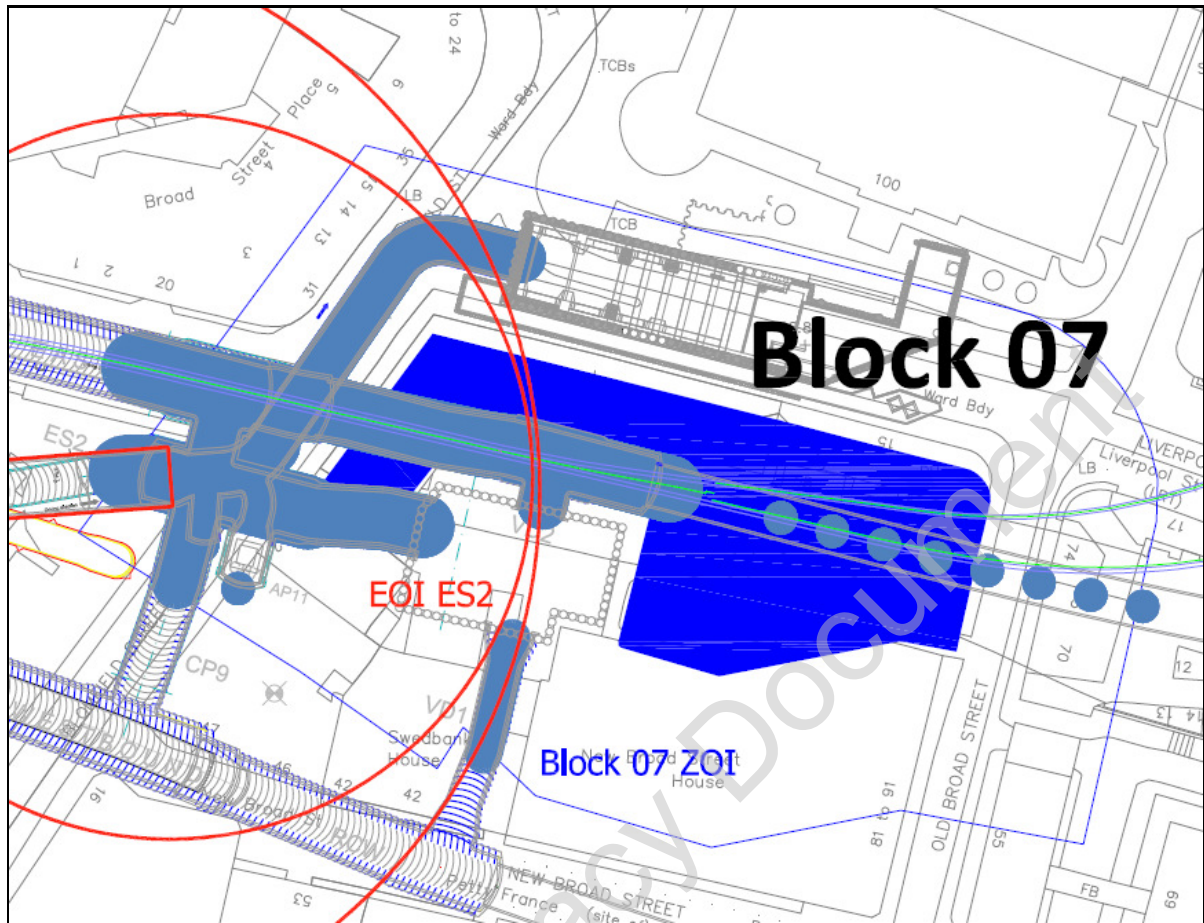


Figure 2 - Block 07 ZOI Constructions

N.B. ES2 EOI is represented in Figure 2 to show the area of Block 07 that is within its boundary.

Figure 2 shows the Block 07 ZOI and the tunnel advances that occurred within its boundary. The construction advances within the ZOI that have the potential to affect Block 07 are listed and summarised in Table 1. Further evidence for construction dates can be seen in Table 2, which lists the latest tunnel advances for each point.

As the ES2 safe stop was completed on the 24th of November 2016, post construction monitoring has been completed for all of Block 07 with regards to ES2 EOI. Therefore, all monitoring sensors are eligible to be decommissioned, subject to meeting required settlement trends. Grouting facilities within the GAD adits were agreed to be decommissioned at the ERP meeting on 27/07/2017, and as such, all remaining automated sensors were agreed to be decommissioned. Under ss. KC21.3220(c) of the Crossrail document C122-OVE-Z4-RSP-CR001-00010, it states that automatic monitoring can be decommissioned at the same time as the grouting facilities. Further evidence for Block 07 sensors decommissioning status can be found in the decommissioning tracker.

4.1.1 Tunnel Advances Affecting Block 07

The information presented in *Table 1* is used in the monitoring graph (Section 5.1), to show the ground movements in relation to construction.

TUNNEL ADVANCES STARTS & ENDS FOR GRAPHS					
Tunnel Code	Tunnel Reference	Primary Layer Type	Start Date	End Date	ZOI
ES2-Enlargement	ES2	Enlargement	24/09/2016	24/09/2016	ZOI
CH3-Enlargement	CH3	Enlargement	21/08/2016	28/08/2016	ZOI
AP11-Enlargement	AP11	Enlargement	06/08/2016	14/08/2016	ZOI
AP12-Enlargement	AP12	Enlargement	04/08/2016	04/08/2016	ZOI
AP2-Enlargement	AP2	Enlargement	28/06/2016	21/06/2016	ZOI
AP2-Pilot	AP2	Pilot	25/04/2016	31/05/2016	ZOI
ES2-Pilot	ES2	Pilot	09/03/2016	24/04/2016	ZOI
TBM-East-RC-Pilot	TBM-East-RC	Pilot	25/01/2015	31/01/2015	C305
CP10-Enlargement	CP10	Enlargement	15/08/2014	17/08/2014	ZOI
CP9-Enlargement	CP9	Enlargement	08/08/2014	12/08/2014	ZOI
CP9-Pilot	CP9	Pilot	17/07/2014	19/07/2014	ZOI
CP10-Pilot	CP10	Pilot	15/07/2014	16/07/2014	ZOI
VD1-Enlargement	VD1	Enlargement	28/05/2014	08/06/2014	ZOI
VD2-Enlargement	VD2	Enlargement	17/05/2014	17/05/2014	ZOI
RCW-Enlargement	RCW	Enlargement	26/04/2014	26/04/2014	ZOI
RCE-Enlargement	RCE	Enlargement	31/01/2014	05/03/2014	ZOI
PTE-East-Enlargement	PTE-East	Enlargement	17/01/2014	30/01/2014	ZOI
RCE-Pilot	RCE	Pilot	09/09/2013	26/09/2013	ZOI
PTE-East-Pilot	PTE-East	Pilot	01/09/2013	09/09/2013	ZOI
AP1a-Enlargement	AP1a	Enlargement	04/08/2013	14/08/2013	ZOI
AP1b-Enlargement	AP1b	Enlargement	16/07/2013	04/08/2013	ZOI
AP1a-Pilot	AP1a	Pilot	19/05/2013	07/06/2013	ZOI
AP1b-Pilot	AP1b	Pilot	05/05/2013	18/05/2013	ZOI

Table 1- Tunnel Advances Affecting Block 07

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 07

Evidence for decommissioning each monitoring sensor is shown through graphs, tables (decommissioning status tracker) and plans. Each element of assessment compliments the other and is used together to determine acceptance of decommissioning. The decommissioning status tracker (*Table 2*) highlights the monitoring sensors to be considered for decommissioning and provides supporting evidence for the decision. In some cases supplementary evidence is required to prove stability or provide reasoning for decommissioning.

ES2 was the final construction activity to affect Block 07. The final construction activity affecting Block 07 took place on 24/09/2016; therefore, all sensors were eligible for decommissioning from 24/03/2017 provided the specified sensor meets the <2mm/year settlement requirement. As discussed in section 4, KC21.3220(c) states, however, that all automated sensors can be decommissioned at the same time as grouting regardless of the automated sensor's settlement rate.

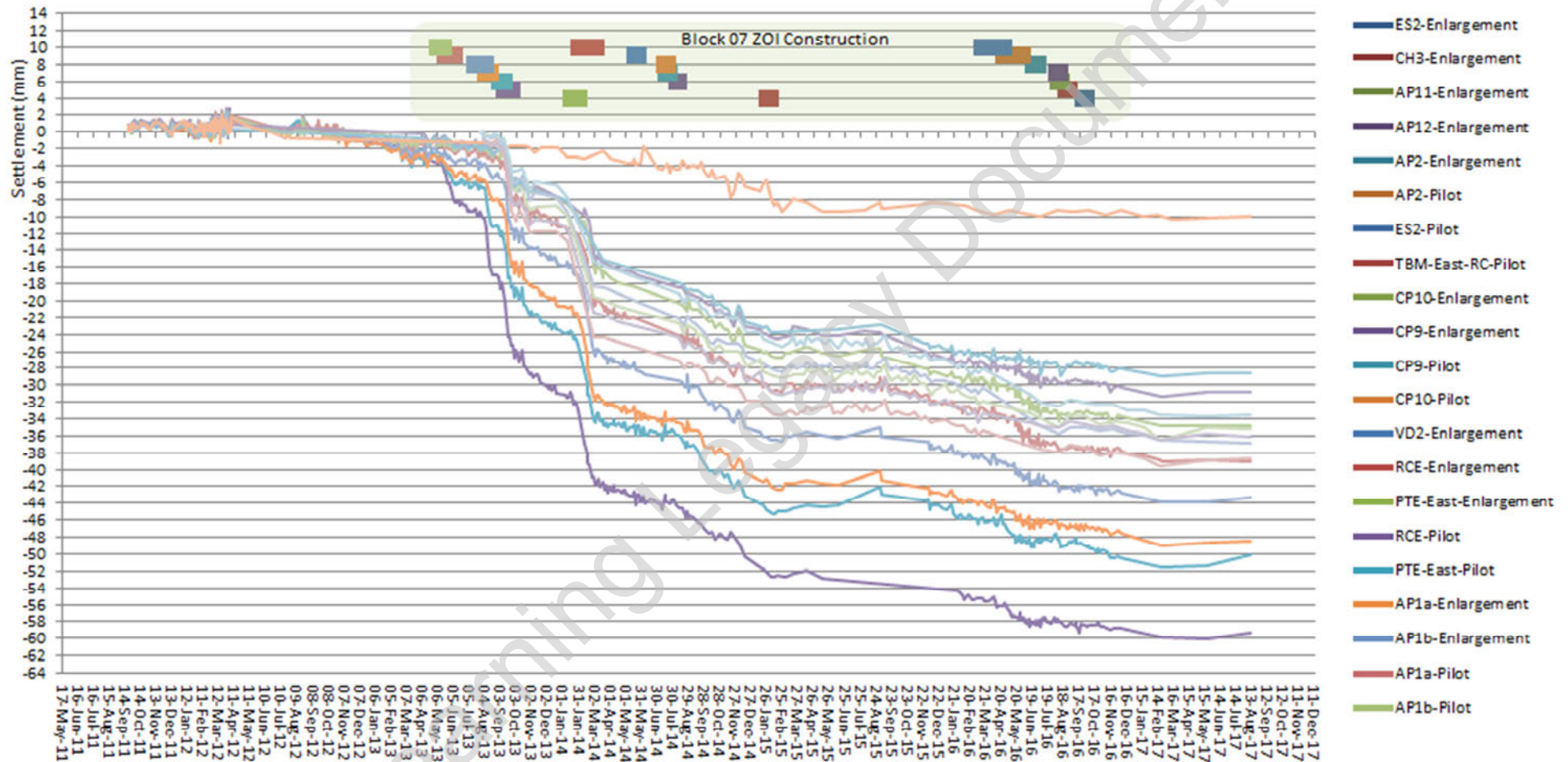
Crossrail agreed at the ERP meeting held on the 20/06/2017 to decommission that grouting facilities within GAD2 tunnel and Blomfield Grout Box. As such, this allowed for decommissioning of all automated sensors within the influence area. It is therefore proposed that all remaining automated sensors within Block 07 be removed. See graphs, tables and plans for further details on the automated sensors.

5.1 Time Graphs Monitoring Full History and Construction Durations

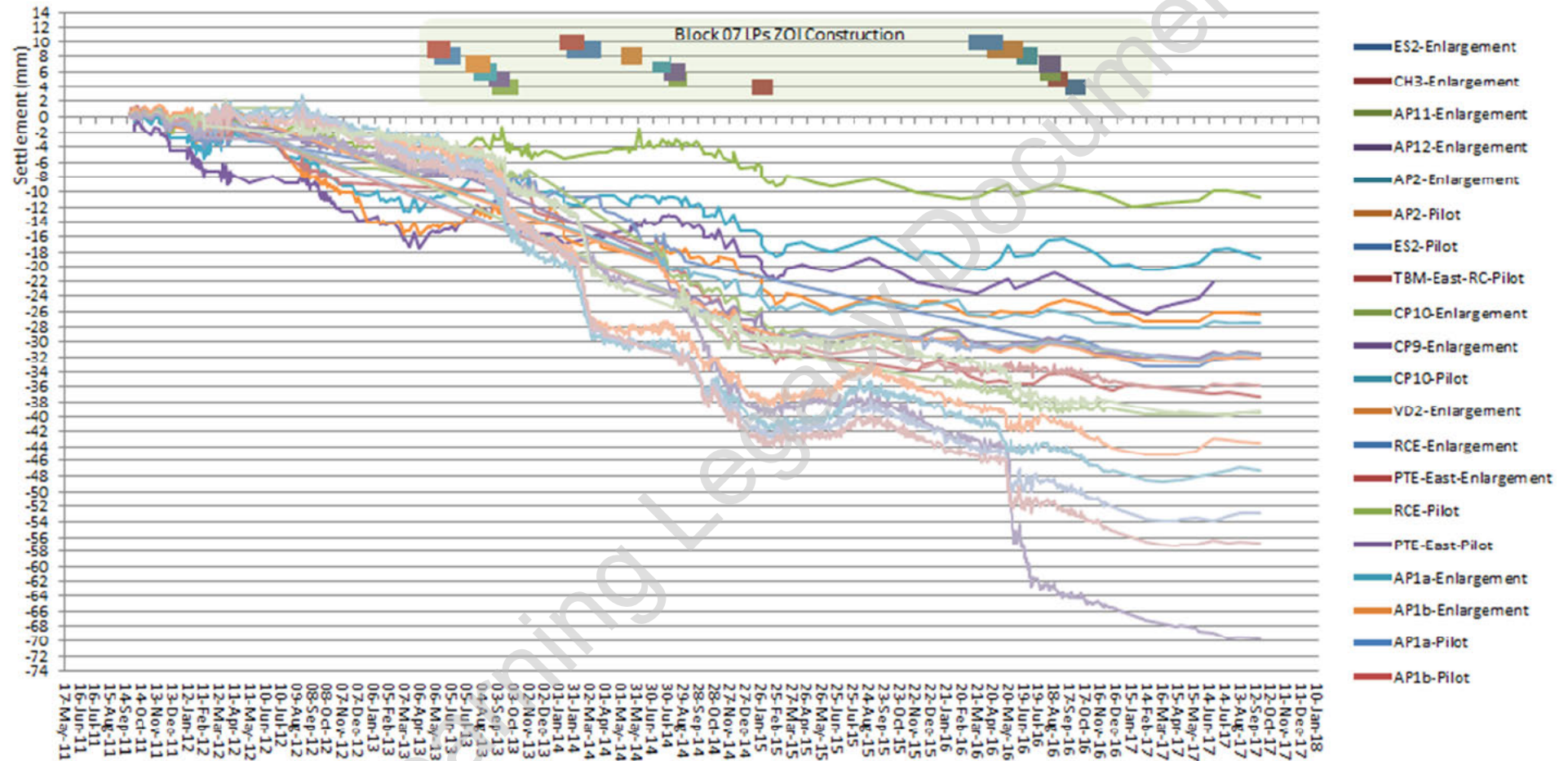
To assess the movement of Block 07 monitoring sensors; each monitoring sensor data type is displayed in a line graph, with a gantt chart (bar) representing the construction identified in Section 4:

- *Graph 1*- All Remaining Block 07 BREs (LB) Manual Monitoring History in Relation to Construction
- *Graph 2*- All Remaining Block 07 Road Studs (LP) Manual Monitoring History in Relation to Construction
- *Graph 3*- All Remaining Block 07 3d Geodetic Prisms (RP) Automated Monitoring History in Relation to Construction

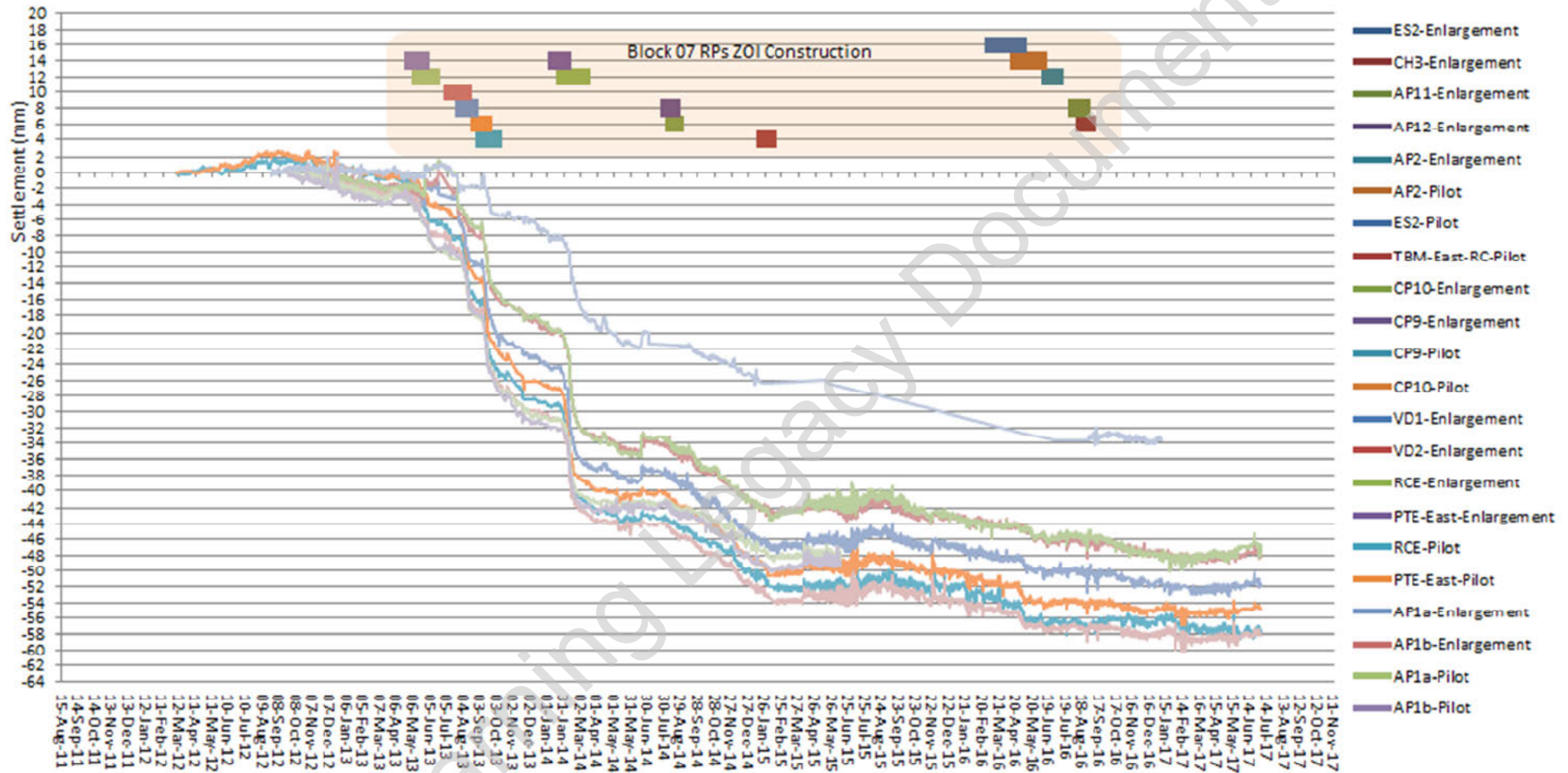
Graph 1- All Remaining Block 07 BREs (LB) Manual Monitoring History in Relation to Construction



Graph 2- All Remaining Block 07 Road Studs (LP) Manual Monitoring History in Relation to Construction



Graph 3- All Remaining Block 07 3d Geodetic Prisms (RP) Automated Monitoring History in Relation to Construction



5.2 Block 07 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 last 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 2 x diameter radius.

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 07. 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 07 Decommissioning Status Tracker LB, LP and RP

20/10/2017

Color-coded legend for settlement trends: < 2.0 mm GREEN, < 3.5 mm AMBER, > 3.5 mm RED.

Table with columns: 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, and settlement data for 120, 180, and 365 days. Includes General Comment and Decommissioning Status.

5.3 Supplementary Evidence for Decommissioning

In some cases supplementary evidence will be provided to support the decommissioning evidence.

Road Stud LP10714

LP10714 has not met any trend requirements; however, the surrounding studs have all met the allowable trend for a minimum of 180/365 days. It can be seen in *Figure 3* below that the circled road stud is located on a section of asphaltic concrete pavement. It is likely that the small area of differing pavement is within a vicinity of recent utility works, and in turn, may have led to greater settlement than the adjacent area (e.g. due to poor compaction). Therefore, the settlement trend may not be a true reflection of the absolute ground movement caused by Crossrail works in the area. It should be noted that the sensor has met stable trend requirements for 90 days.

Based on the adjacent road studs' settlement trends, it is proposed that LP10714 should be considered as unreliable with regards to settlement trends caused by tunnelling construction and that the sensor should be decommissioned.



Figure 3- LP10714 Located on Unstable Pavement

5.4 Monitoring sensor Location Plan and Decommissioning Status

The following plots provide a visual representation of all Block 07 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.

- *Figure 4- LB Monitoring Sensor Settlement Status and Location Plan*
- *Figure 5- LP Monitoring Sensor Settlement Status and Location Plan*
- *Figure 6- RP Monitoring Sensor Settlement Status and Location Plan*

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Figure 4 - BRE 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

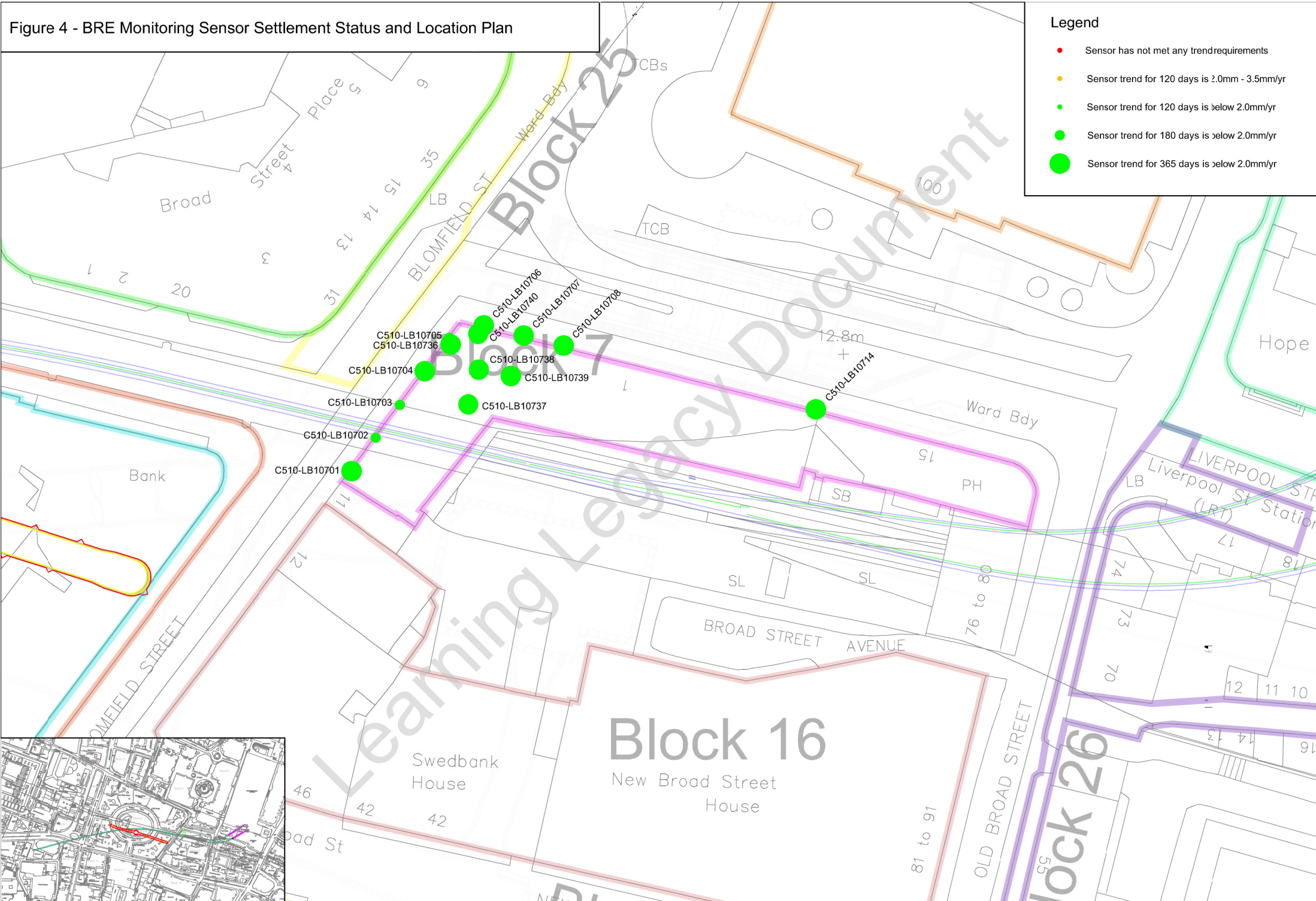


Figure 5 - LP Monitoring Sensor Settlement Status and Location Plan

- 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
 - Sensor trend Not Applicable

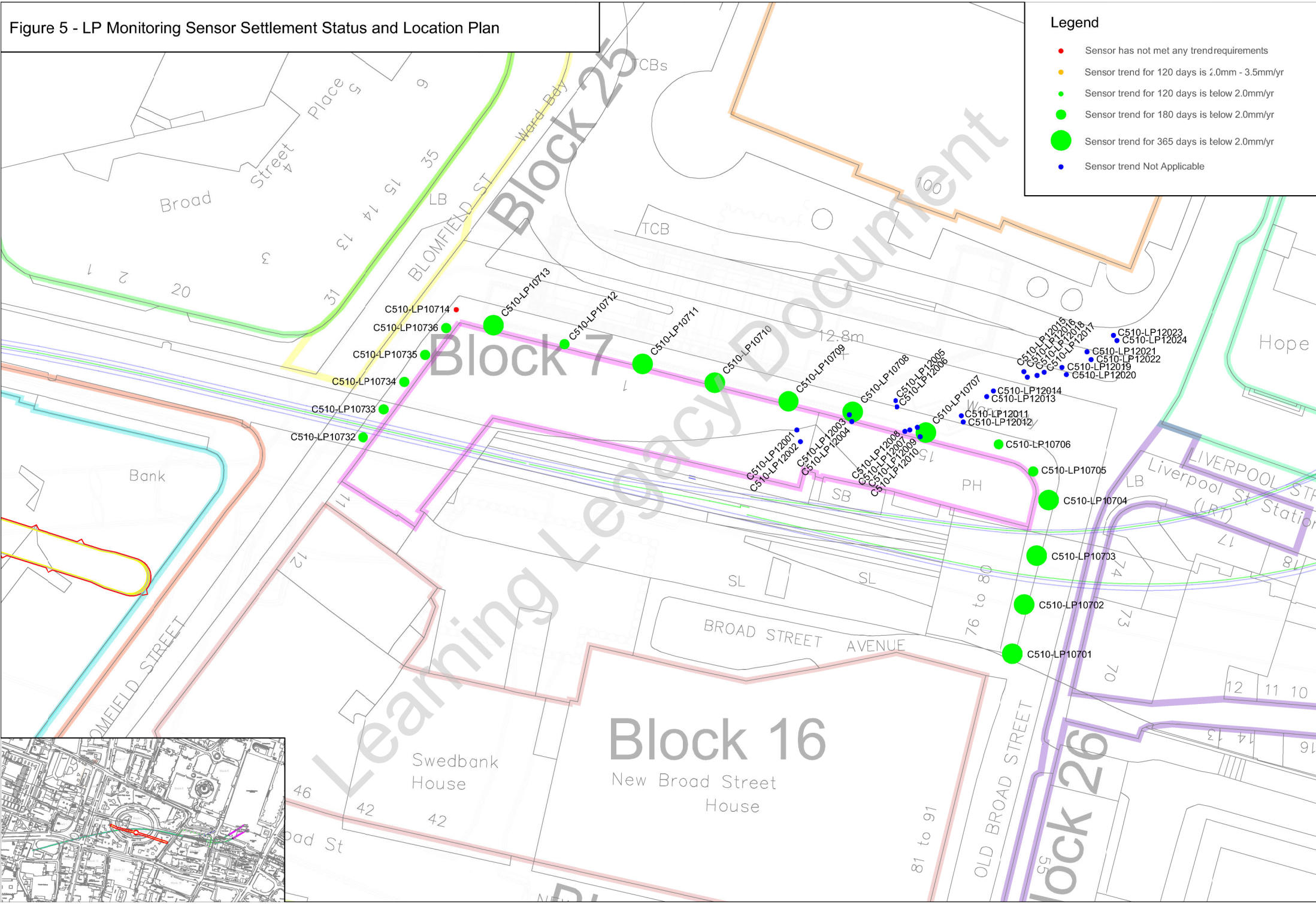
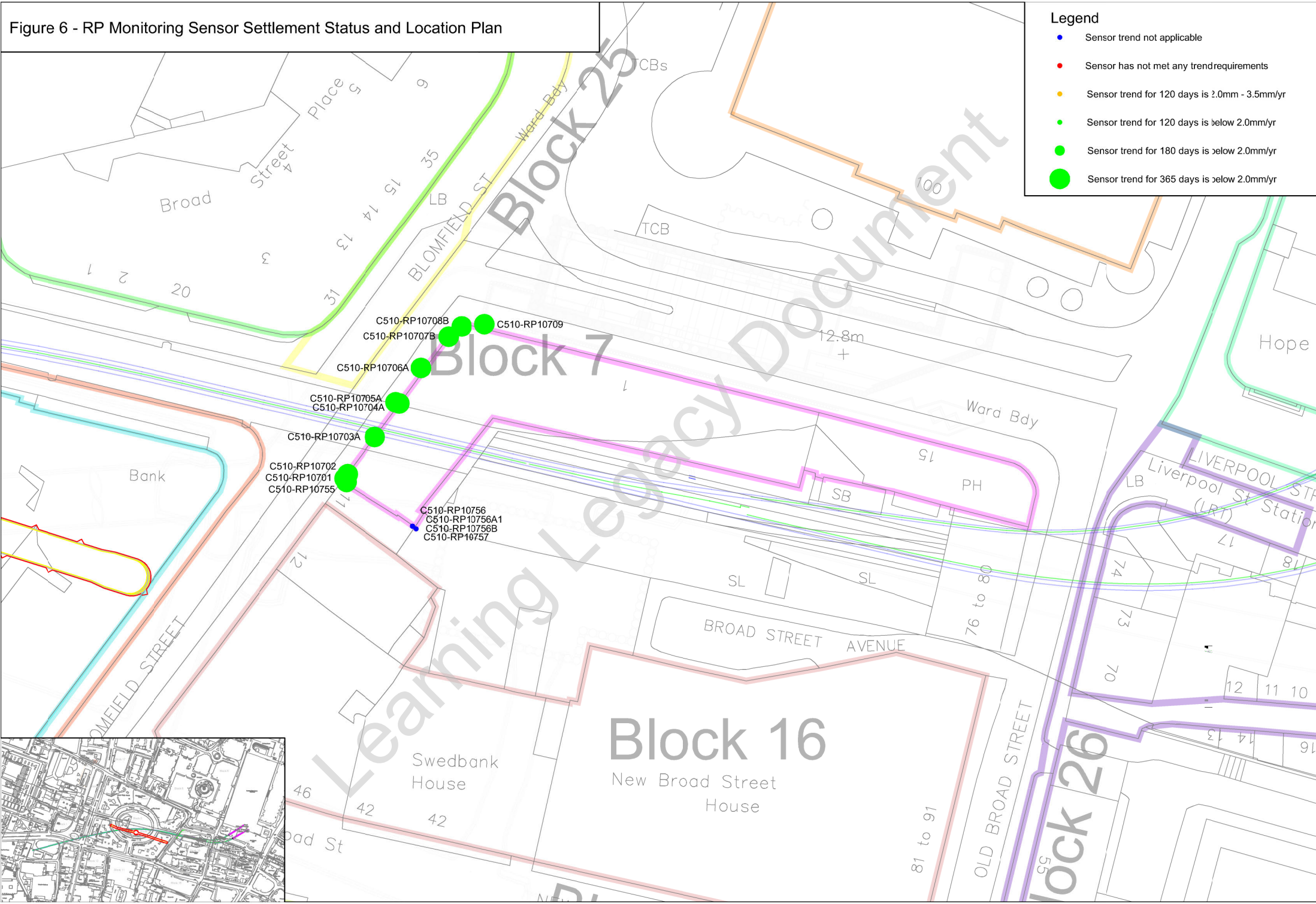


Figure 6 - RP Monitoring Sensor Settlement Status and Location Plan

- Legend**
- Sensor trend not applicable
 - 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

Revision 2 of Block 07 close out report requests all monitoring sensors to be decommissioned. The decommissioning status tracker (*Table 2*) identifies the monitoring sensors to be agreed for decommissioning.

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.

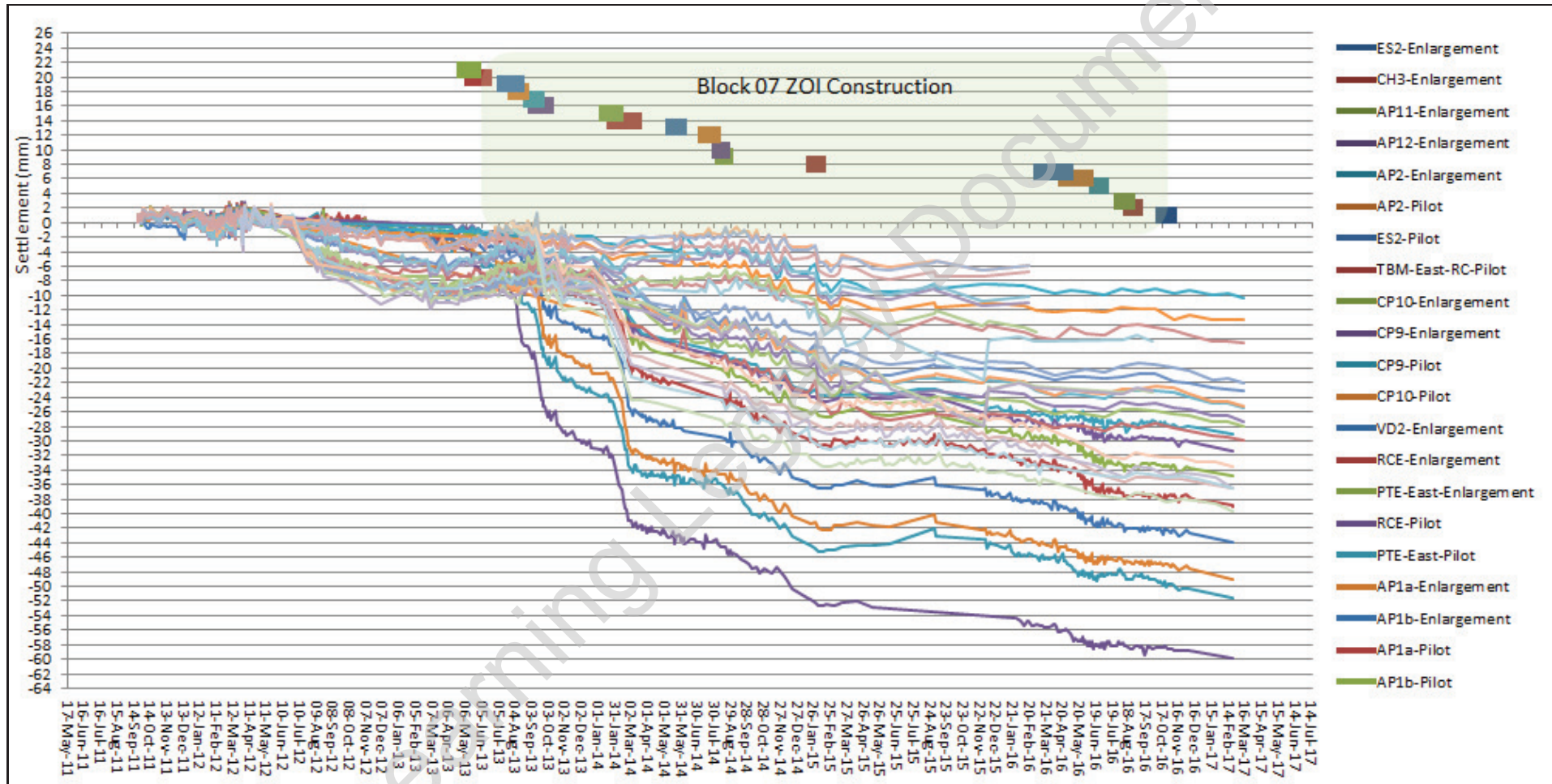
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7 **Appendix 1**

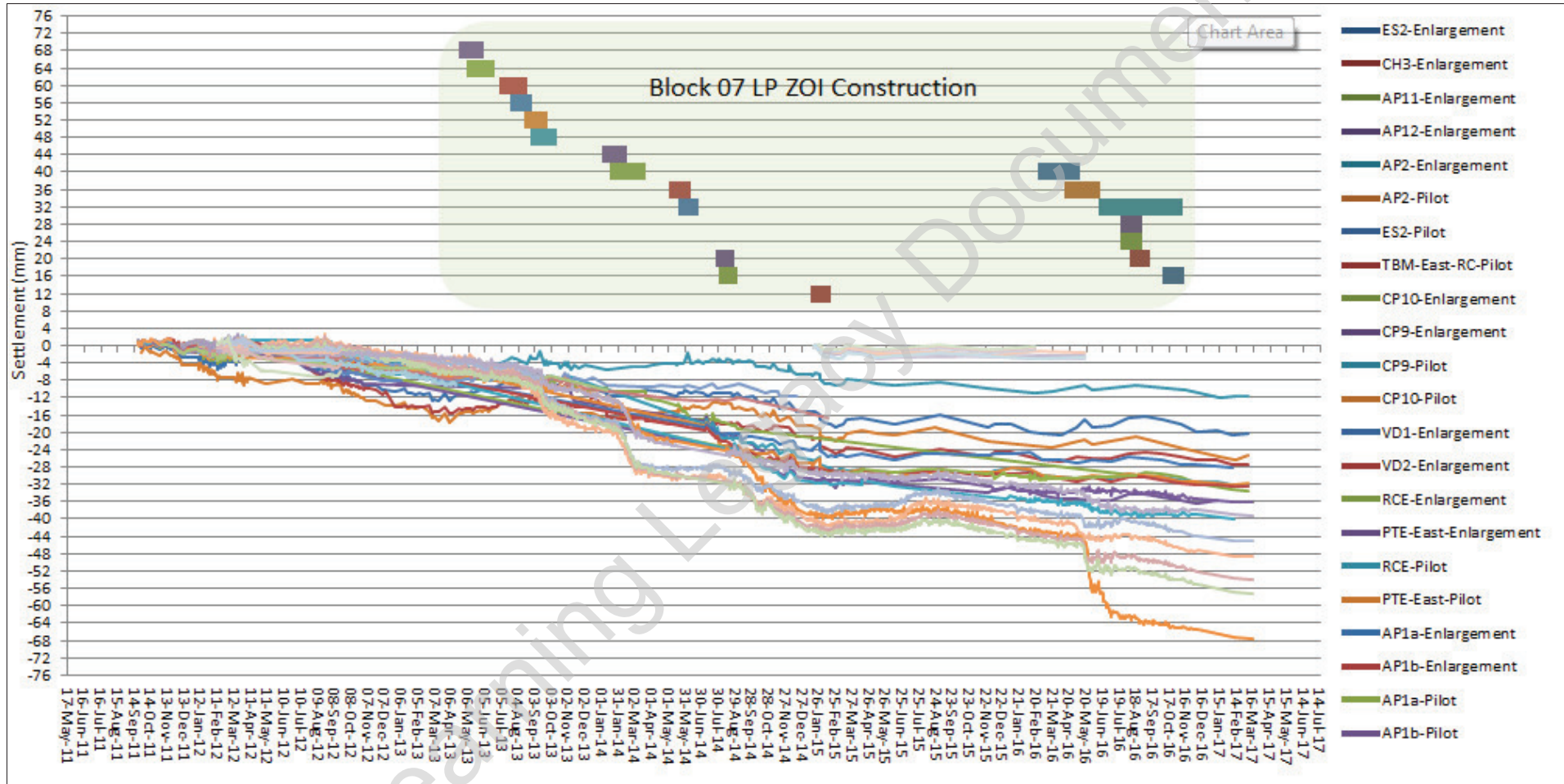
Appendix 1 includes the decommissioning tracker table, plots and graphs that were used as evidence to agree decommissioning in Revision 1 of Block 07 close out report.

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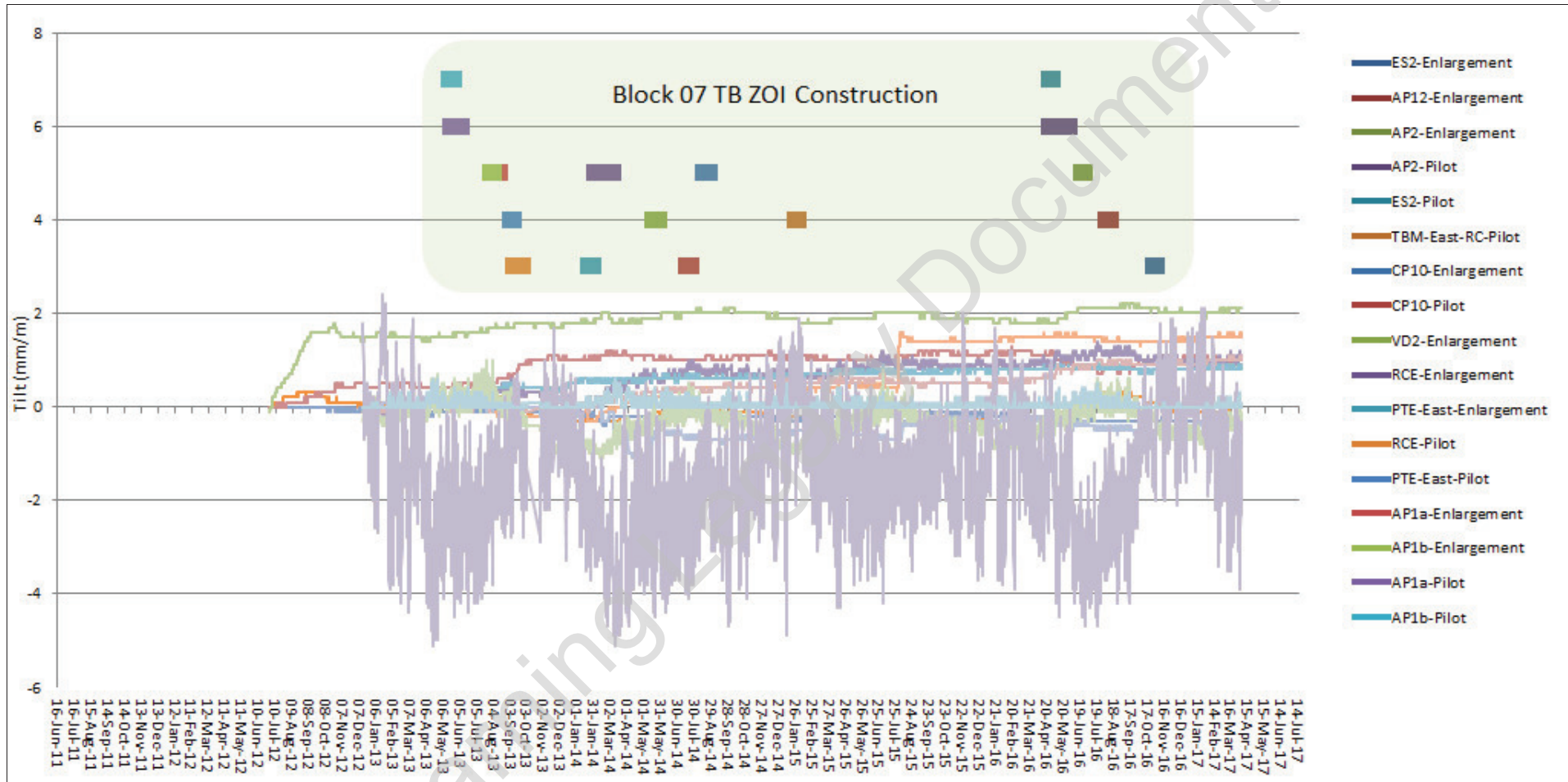
Graph 1- All Block 07 BREs (LB) Manual Monitoring History in Relation to Construction



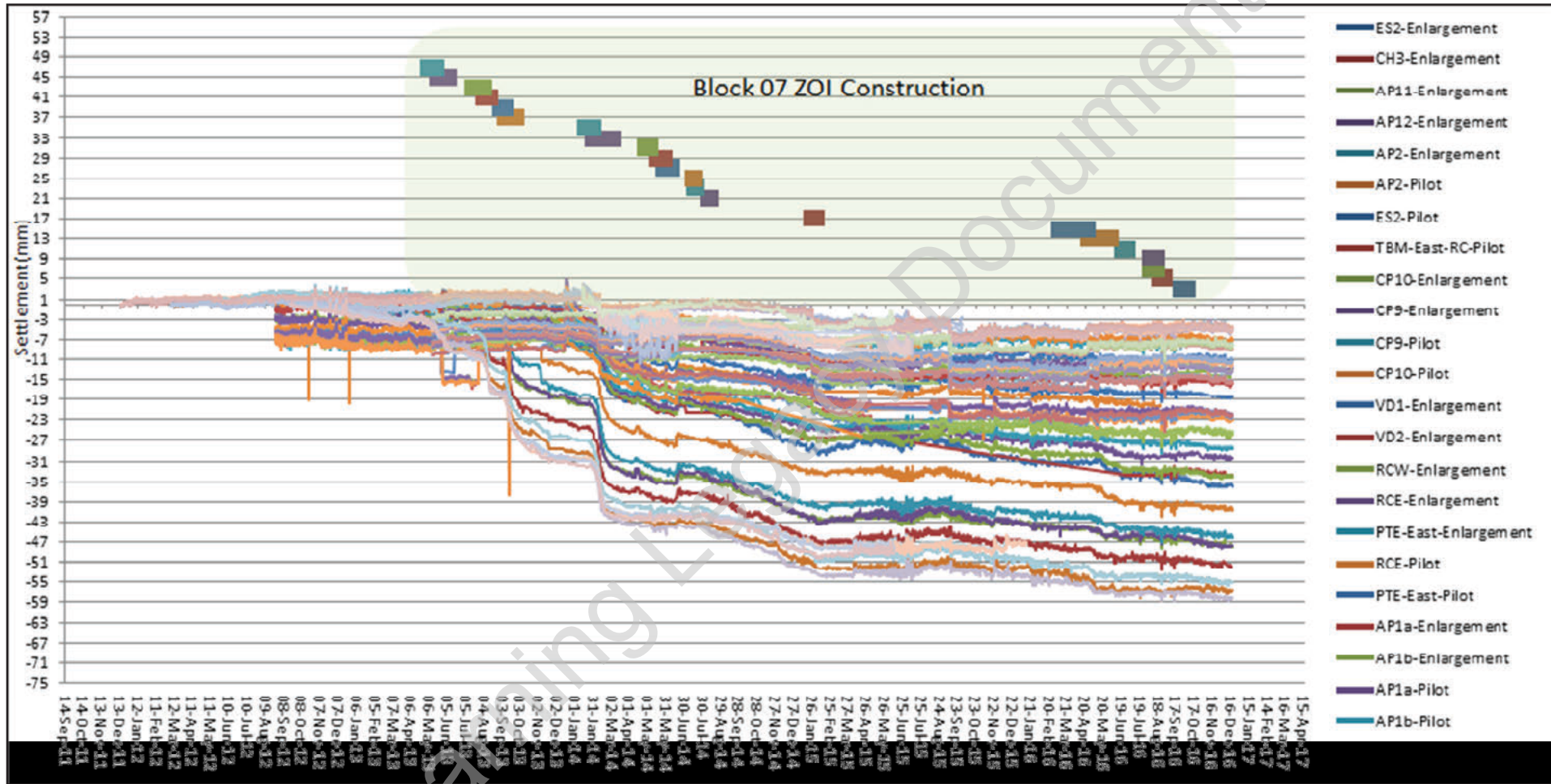
Graph 2- All Block 07 Road Studs (LP) Manual Monitoring History in Relation to Construction



Graph 3- All Block 07 Tiltmeters (TB) Automated Monitoring History in Relation to Construction



Graph 4- All Block 07 3d Geodetic Prisms (RP) Automated Monitoring History in Relation to Construction



Graph 5- All Block 07 Water Cells (SH) Manual Monitoring History in Relation to Construction

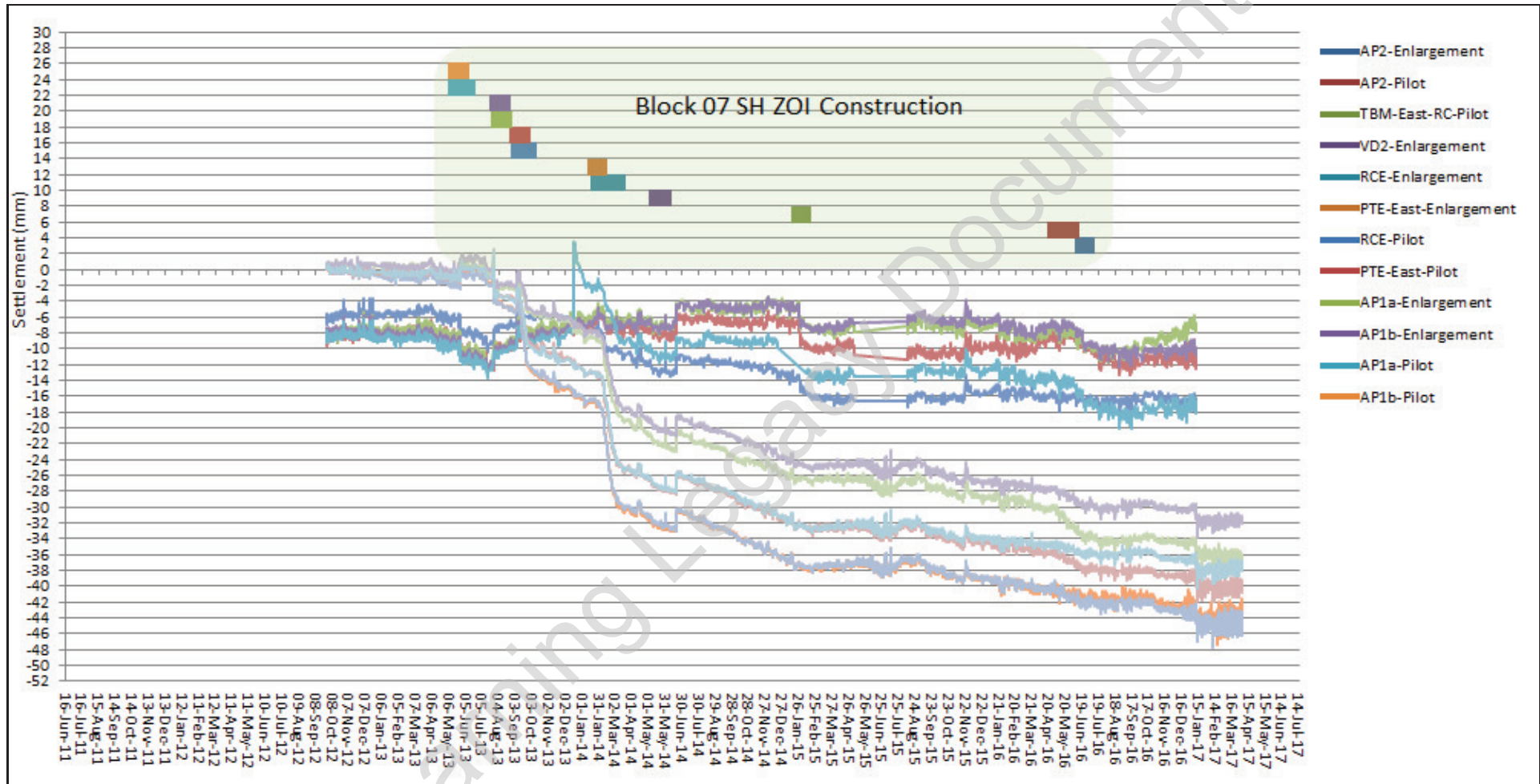


Figure 7- LB Monitoring Sensor Decommissioning Status and Location Plan

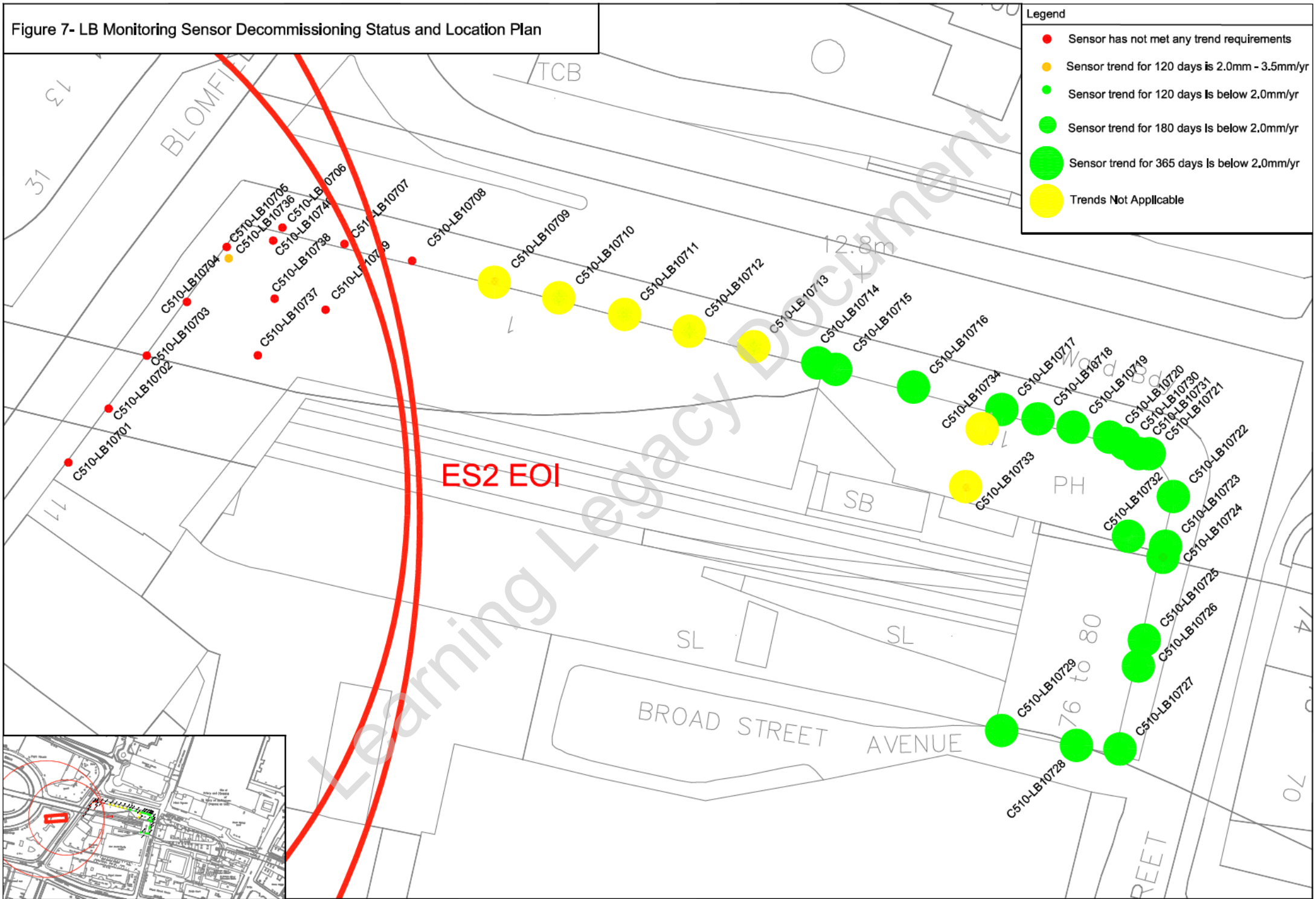


Figure 9- TB Monitoring Sensor Decommissioning Status and Location Plan

- 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

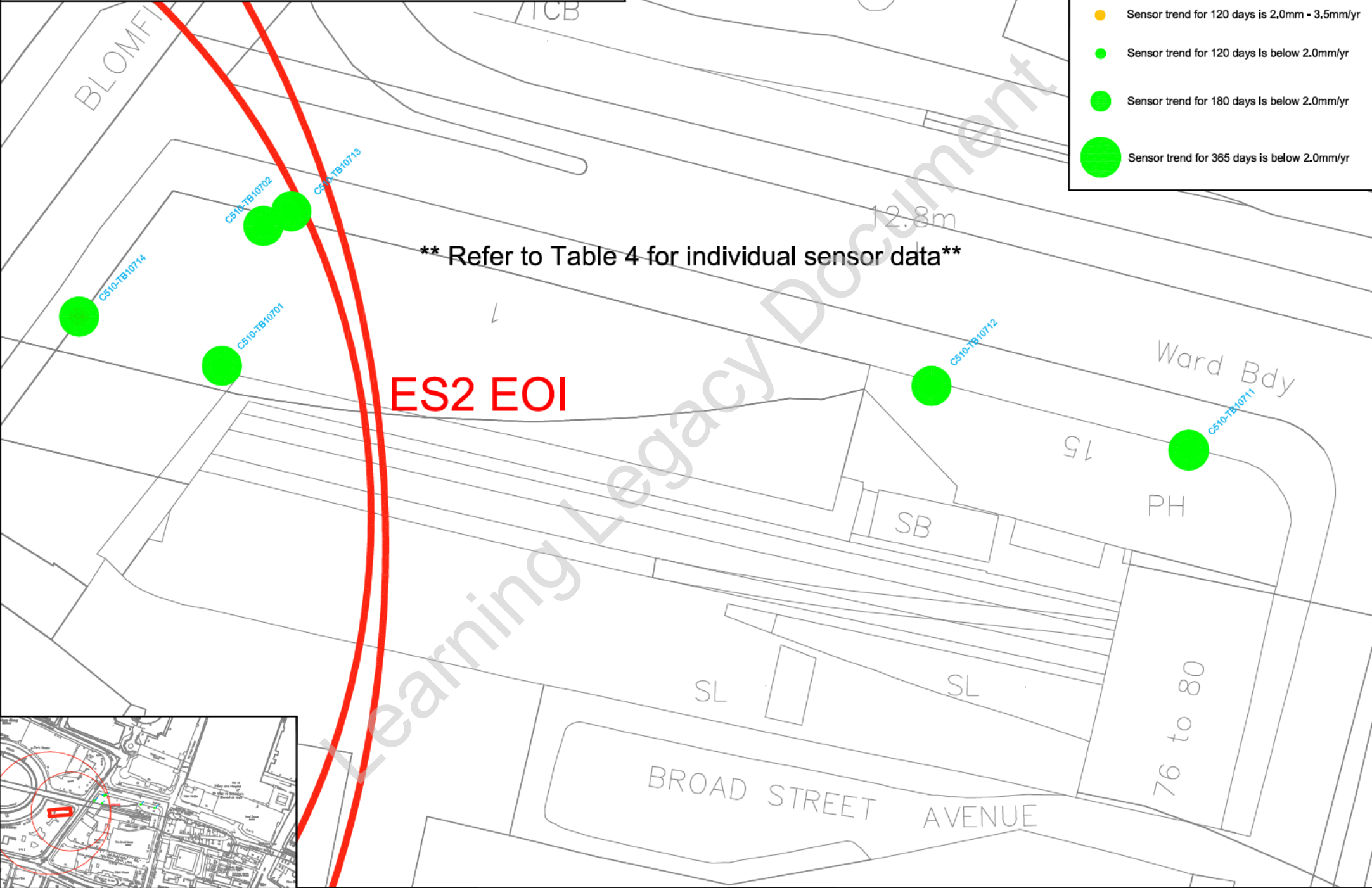


Figure 10- RP Monitoring Sensor Decommissioning Status and Location Plan

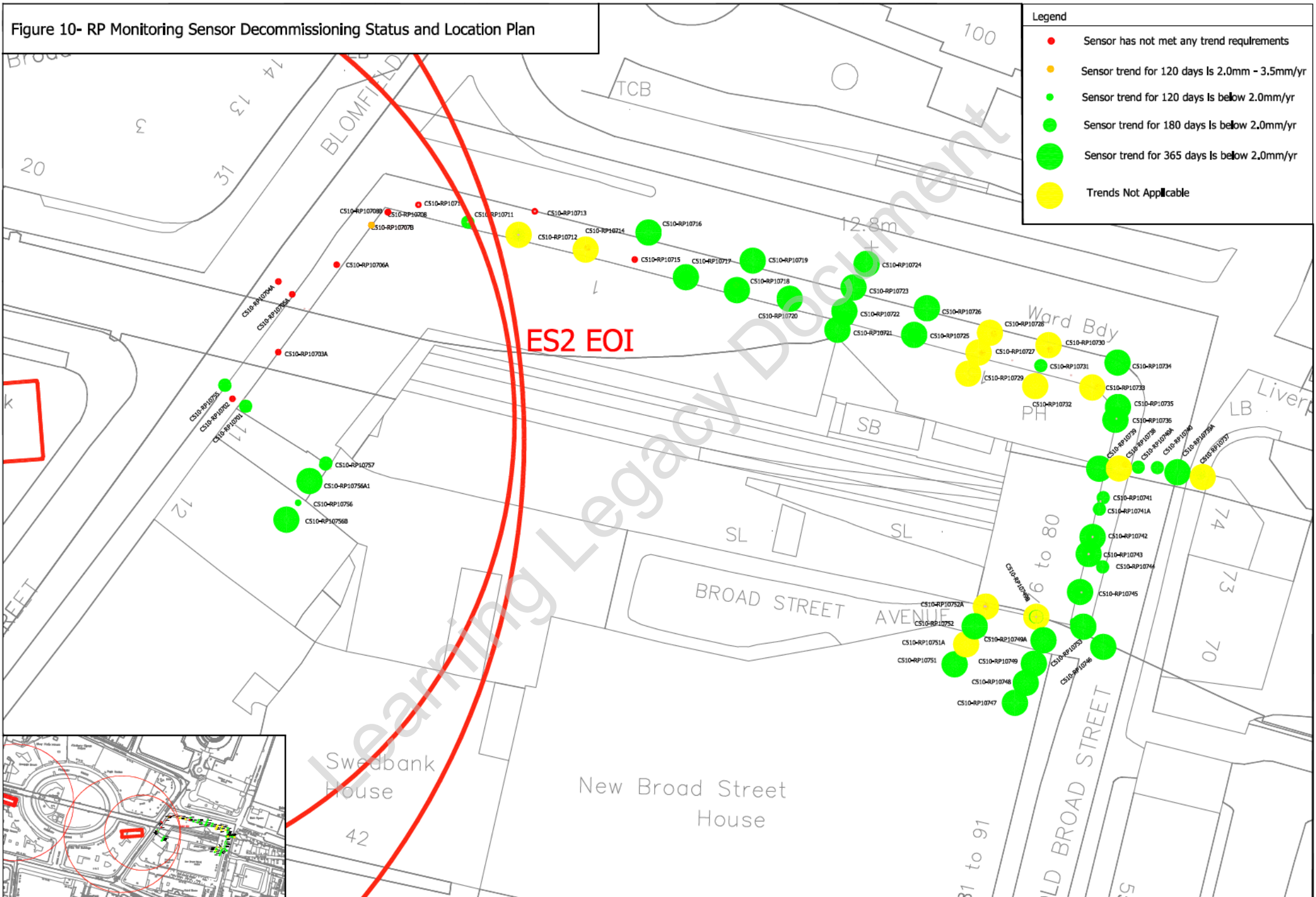


Figure 11- SH Monitoring Sensor Decommissioning Status and Location Plan

