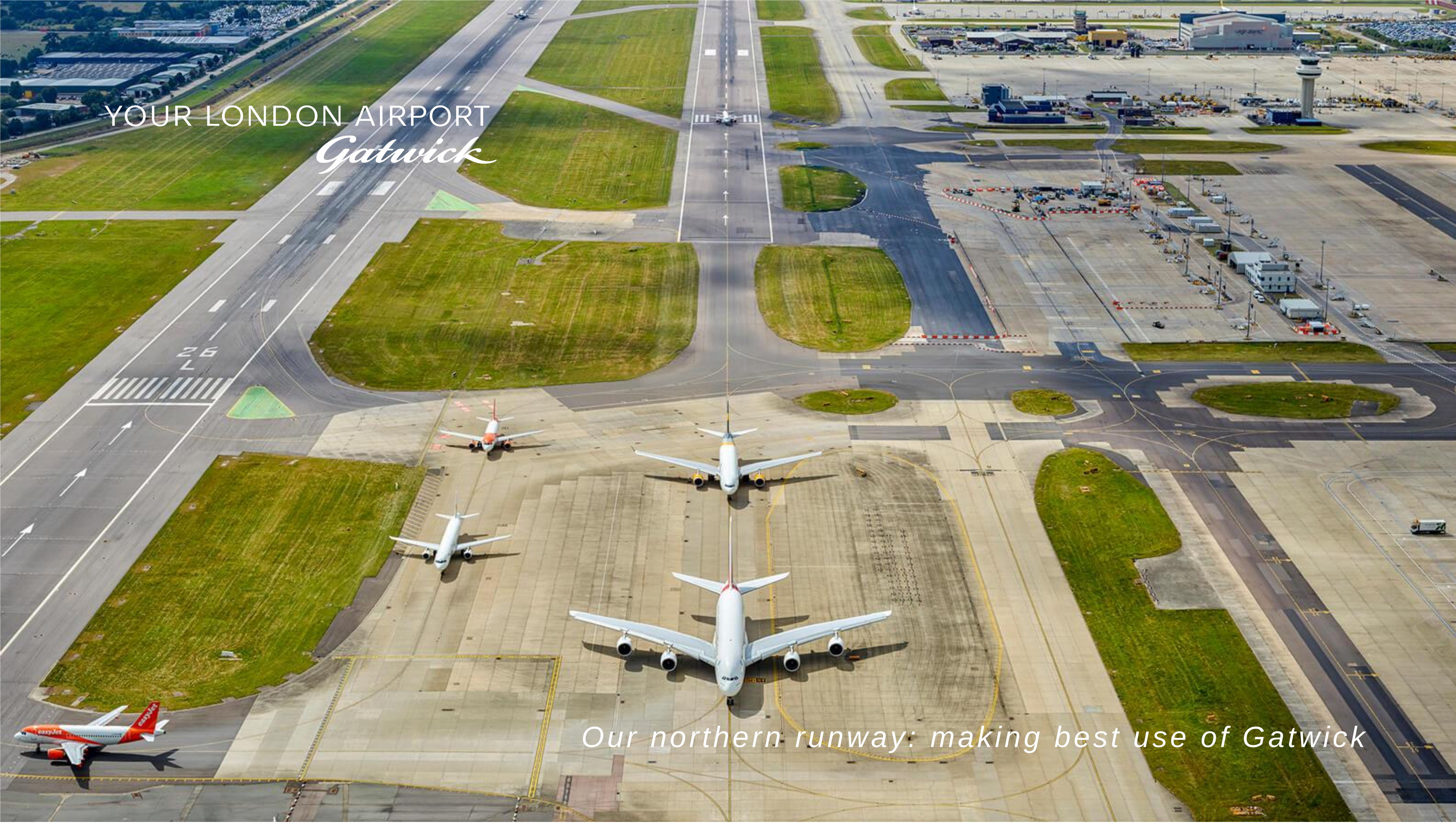

Preliminary Environmental Information Report
Appendix 13.4.1: Air Quality Assessment Methodology

September 2021

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1 Introduction

1.1.1 This document forms Appendix 13.4.1 of the Preliminary Environmental Information Report (PEIR) prepared on behalf of Gatwick Airport Limited (GAL). The PEIR presents the preliminary findings of the Environmental Impact Assessment (EIA) process for the proposal to make best use of Gatwick Airport's existing runways (referred to within this report as 'the Project'). The Project proposes alterations to the existing northern runway which, together with the lifting of the current restrictions on its use, would enable dual runway operations. The Project includes the development of a range of infrastructure and facilities which, with the alterations to the northern runway, would enable the airport passenger and aircraft operations to increase. Further details regarding the components of the Project can be found in the Chapter 5: Project Description.

2 Construction Dust Assessment Methodology

2.1 Methodology

2.1.1 There are five steps in the assessment process described in the Institute of Air Quality Assessment (IAQM) guidance (Guidance on the assessment of dust from demolition and construction) (Holman *et al.*, 2014). These are summarised in Diagram 2.1.1 and a further description is provided this section.

Step 1: Need for Assessment

2.1.2 The first step is the initial screening for the need for a detailed assessment. According to the IAQM guidance (Holman *et al.*, 2014), an assessment is required where there are sensitive receptors within 350 metres of the site boundary of the scheme (for ecological receptors that is 50 metres) and/or within 50 metres of the route(s) used by the construction vehicles on the public highway for up to 500 metres along the route from the site entrance(s).

Step 2: Assess the Risk of Dust Impacts

2.1.3 This step is split into three sections as follows:

- 2A: Define the potential dust emission magnitude;
- 2B: Define the sensitivity of the area; and
- 2C: Define the risk of impacts.

2.1.4 Each of the dust-generating activities is given a dust emission magnitude depending on the scale and nature of the works (step 2A) based on the criteria presented in Table 2.1.1.

2.1.5 The sensitivity of the surrounding area is then determined (step 2B) for each dust effect from the above dust-generating activities, based on the proximity and number of receptors, their sensitivity to dust, the local PM_{10} background concentrations and any other site-specific factors. Table 2.1.2 and Table 2.1.3 show the criteria for defining the sensitivity of the area to different dust effects.

2.1.6 The overall risk of the impacts for each activity is then determined (step 2C) prior to the application of any mitigation measures (Table 2.1.4) and an overall risk for the site is derived.

Table 2.1.1: Dust Emission Magnitude

Small	Medium	Large
Demolition		
▪ Total building volume <20,000 m³. ▪ Construction material with low potential for dust release (eg metal cladding or timber).	▪ Total building volume 20,000 m³ - 50,000 m³. ▪ Potentially dusty construction material. ▪ Demolition activities 10-20 metres above ground level.	▪ Total building volume >50,000 m³. ▪ Potentially dusty construction material (eg concrete). ▪ On-site crushing and screening, demolition activities >20 metres above ground level.
Earthworks		
▪ Total site area <2,500 m², soil type with large grain size (eg sand). ▪ <5 heavy earth moving vehicles active at any one time. ▪ Formation of bunds <4 metres in height. ▪ Total material moved <20,000 tonnes. ▪ Earthworks during wetter months.	▪ Total site area 2,500 m² - 10,000 m², moderately dusty soil type (eg silt). ▪ 5-10 heavy earth moving vehicles active at any one time. ▪ Formation of bunds 4 metres - 8 metres in height. ▪ Total material moved 20,000 - 100,000 tonnes.	▪ Total site area >10,000 m² potentially dusty soil type (eg clay, which will be prone to suspension when dry due to small particle size). ▪ >10 heavy earth moving vehicles active at any one time. ▪ Formation of bunds >8 metres in height. ▪ Total material moved >100,000 tonnes.
Construction		
▪ Total building volume <25,000 m³. ▪ Construction material with low potential for dust release (eg metal cladding or timber).	▪ Total building volume 25,000 m³ -100,000 m³. ▪ Potentially dusty construction material (eg concrete). ▪ Piling. ▪ On-site concrete batching.	▪ Total building volume >100,000 m³. ▪ Piling. ▪ On-site concrete batching. ▪ Sandblasting.
Trackout		
▪ <10 heavy duty vehicles (HDV) (>3.5 t) trips in any one day. ▪ Surface material with low potential for dust release. ▪ Unpaved road length <50 metres.	▪ 10-50 HDV (>3.5 t) trips in any one day. ▪ Moderately dusty surface material (eg high clay content). ▪ Unpaved road length 50 metres – 100 metres.	▪ >50 HDV (>3.5 t) trips in any one day. ▪ Potentially dusty surface material (eg high clay content). ▪ Unpaved road length >100 metres.

Table 2.1.2: Sensitivity of the Area to Dust Soiling Effects

Receptor Sensitivity	Number of Receptors	Distance from the Source (metres)			
		<20	<50	<100	<350
High	>100	High	High	Medium	Low
	10 – 100	High	Medium	Low	Low
	<10	Medium	Low	Low	Low
Medium	>1	Medium	Low	Low	Low
Low	>1	Low	Low	Low	Low

Table 2.1.3: Sensitivity of the Area to Human Health Impacts

Receptor Sensitivity	Annual Mean PM_{10} Concentrations	Number of Receptors	Distance from the Source (metres)				
			<20	<50	<100	<200	<350
High	>32 µg/m^3	>100	High	High	High	Medium	Low
		10-100		High	Medium	Low	
		1-10		Medium	Low		
	28-32 µg/m^3	>100	High	High	Medium	Low	Low
		10-100		Medium	Low		
		1-10					
	24-28 µg/m^3	>100	High	Medium	Low	Low	Low
		10-100					
		1-10	Medium	Low			
	<24 µg/m^3	>100	Medium	Low	Low	Low	Low
		10-100	Low				
		1-10					
Medium	>32 µg/m^3	>10	High	Medium	Low	Low	Low
		1-10	Medium	Low			
	28-32 µg/m^3	>10	Medium	Low	Low	Low	Low
		1-10	Low				
	24-28 µg/m^3	>10	Low	Low	Low	Low	Low
		1-10					
	<24 µg/m^3	>10	Low	Low	Low	Low	Low
		1-10					
Low	-	≥1	Low	Low	Low	Low	Low

Table 2.1.4: Risk of Dust Impacts

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
Demolition			
High	High Risk	Medium Risk	Medium Risk
Medium	High Risk	Medium Risk	Low Risk
Low	Medium Risk	Low Risk	Negligible
Earthworks			
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Medium Risk	Low Risk
Low	Low Risk	Low Risk	Negligible

Sensitivity of Area	Dust Emission Magnitude		
	Large	Medium	Small
Construction			
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Medium Risk	Low Risk
Low	Low Risk	Low Risk	Negligible
Trackout			
High	High Risk	Medium Risk	Low Risk
Medium	Medium Risk	Low Risk	Negligible
Low	Low Risk	Low Risk	Negligible

Step 3: Determine the Site-specific Mitigation

2.1.7 Once each of the activities is assigned a risk rating, appropriate mitigation measures are identified. Where the risk is negligible, no mitigation measures beyond those required by legislation are necessary.

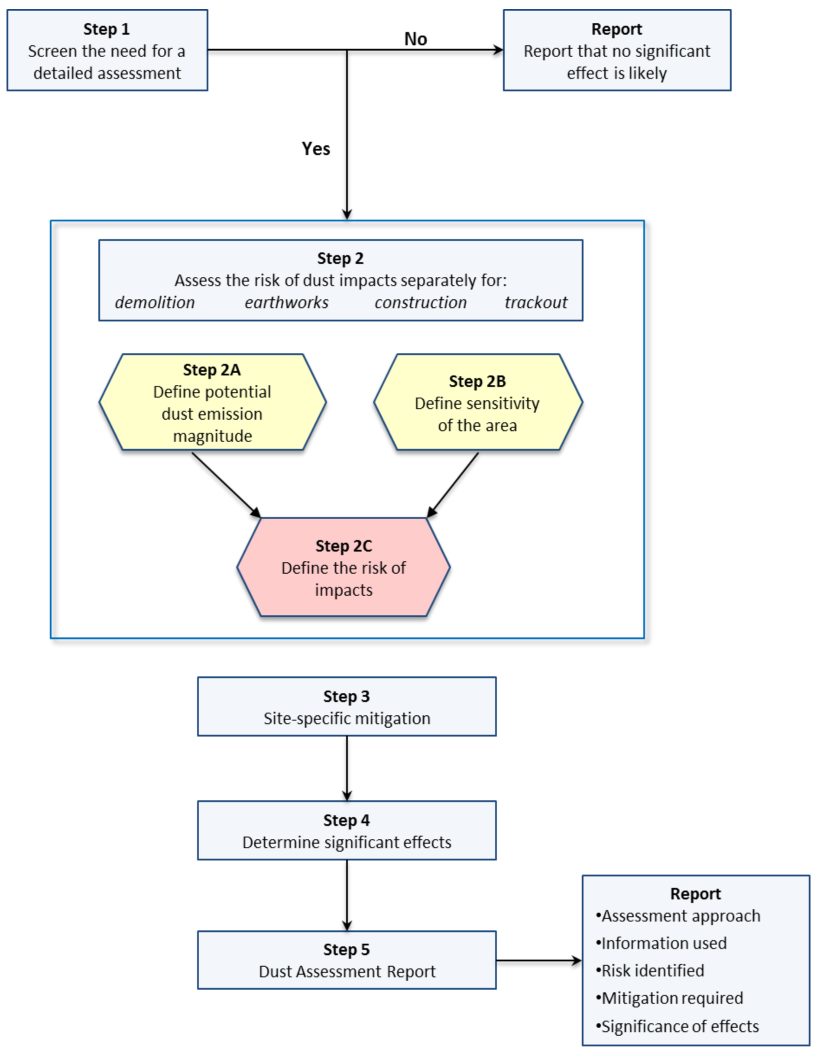
Step 4: Determine any Significant Residual Effects

2.1.8 Once the risk of dust impacts has been determined and the appropriate dust mitigation measures identified, the final step is to determine whether there are any residual significant effects. The IAQM guidance notes that it is anticipated that with the implementation of effective site-specific mitigation measures, the environmental effect would not be significant in most cases.

Step 5: Prepare a Dust Assessment Report

2.1.9 The last step of the assessment is the preparation of a Dust Assessment Report. For the Preliminary Environmental Information Report (PEIR), this is the assessment of construction dust emissions as detailed in Chapter 13 and Appendix 13.8.1.

Diagram 2.1.1: IAQM Dust Assessment Methodology



3 Emissions Methodology

3.1 Overview

3.1.1 This section describes the methodology used in this assessment which builds on that used for the previous air quality assessments for Gatwick Airport in 2002/3, 2005/6, 2010 and 2015, which in turn followed the recommendations of the Department for Transport (DfT) Project for the Sustainable Development of Heathrow (PSDH) (DfT, 2006). There have been updates to the methodology, specifically, accounting for reduced-engine taxiing and use of auxiliary power units (APU) off-stand for this analysis.

3.1.2 Operational air quality impacts from the airport arise as a result of emissions from aircraft traffic, other on-site activity and increased road traffic on the local road network.

3.1.3 The methodology is aimed at calculating pollutant concentrations averaged over a year for comparison with air quality standards. Concentrations over shorter averaging periods, for comparison with short-term objectives, are derived from the annual mean values using empirical relationships.

3.1.4 The airfield and road traffic contribution to air pollutant concentrations is calculated using a two-step process. The first step is the development of an emissions inventory to quantify the emissions arising from airport-related sources and road traffic, including the spatial distribution and temporal breakdown of the emissions. Dispersion modelling is then used to calculate the contribution to ground-level concentrations at selected receptors, based on the calculated emissions, having due regard to their spatial distribution. The temporal breakdown of the emissions ensures that meteorological conditions are applied properly.

3.1.5 The calculation of emissions involves the multiplication of an ‘activity’ statistic, for example fuel usage or distance travelled, by an emission factor (expressed as mass of pollutant emitted per unit of ‘activity’ such as kg of fuel burned or per km travelled). Emission factors are usually derived from measurements, but often a limited sample of measurements need to be generalised to a broad activity type. An optimum route to developing an emission inventory is to have ‘activity’ statistics broken down at the same level of detail as that available in the emission factors, but this is not always possible.

3.1.6 The aim of the inventory methodology is to generate a realistic best estimate of the emissions. Where possible, activity data for the calendar year 2018 were used. Where such activity data were not available, statistics for the nearest available period were used, and adjusted as necessary.

Pollutants Assessed

3.1.7 In common with most activities involving the combustion of fuel, activities associated with an airport release a wide variety of pollutants but, for most of the regulated pollutants, airport emissions (even from a large airport) do not have the potential to be a significant factor in whether or not current air quality standards can be met around the airport. The relevant evidence was previously reviewed by the air quality technical panels set for the PSDH (DfT, 2006). Based on the available monitoring and modelling data, it was concluded that benzene, 1,3-butadiene, carbon monoxide, lead, polycyclic aromatic hydrocarbons (PAHs) and sulphur dioxide were not priority pollutants at airports, leading to a focus on oxides of nitrogen (NOx), particulate matter (PM_{10} and $PM_{2.5}$) and ozone. Ozone is not a primary airport pollutant, although airports contribute precursors (volatile organic compounds and nitrogen dioxide (NO_2)) to the formation of ozone on a regional and trans-national scale. Therefore, ozone is not currently included in the regulations for local air quality management (The Air Quality Standards Regulations, 2016) and is not considered in this assessment. Although the PSDH (DfT, 2006) review of priority pollutants was carried out in the Heathrow Airport context, the reasoning is also transferable to Gatwick and has been applied in air quality assessments of other major airports in the United Kingdom (UK).

3.1.8 The main pollutants included in this assessment are therefore NOx, NO_2, PM_{10} and $PM_{2.5}$.

3.1.9 The NOx emitted from combustion sources is principally in the form of nitric oxide (NO), with usually only a small percentage of NO_2 directly emitted from the combustion source (ie primary NO_2). After release, further NO_2 is formed in the atmosphere by transformation of NO, principally as a result of the reaction with ambient ozone; the fraction of NO converted to NO_2 at various distances from the source depends on a number of climatological factors. Primary NO_2 (pNO_2) fractions for the aircraft sources were taken from the methodology of the PSDH (DfT, 2006) and are shown in Table 3.1.1.

Table 3.1.1: Primary NO_2 Fractions for Aircraft Emissions

Thrust Setting	Primary NO_2 Fraction
100%	4.5%
85%	5.3%
30%	15%
7%	37.5%

3.1.10 In relation to $PM_{2.5}$ emissions, the European Monitoring and Evaluation programme (EMEP) / European Environment Agency (EEA) Guidebook (EMEP/EEA, 2019) states that “*it is reasonable to assume that for aircraft, their PM emissions can be considered as $PM_{2.5}$*”. Therefore, it was assumed that all particulate matter emissions from aircraft engines were in the $PM_{2.5}$ fraction. For the road sources, emission factors for $PM_{2.5}$ are available so no assumption about the $PM_{2.5}$ fraction from road traffic was required.

3.1.11 Where different assumptions on the calculation of pNO_2 and $PM_{2.5}$ emissions from those given in paragraphs 3.1.9 and 3.1.10 have been made for other emissions sources, these are reported in the following sections.

3.2 Sources of Emissions

3.2.1 An inventory of NOx, pNO_2, PM_{10} and $PM_{2.5}$ emissions was built for the following pollution sources:

- aircraft main engines in the landing and take-off (LTO) cycle on the ground and up to a height of 3,000 ft (915 metres);
- aircraft auxiliary power units (APU);
- aircraft engine testing;
- ground support equipment (GSE);
- airport heating plant;
- fire training ground (FTG); and
- road vehicles on the local and strategic highway network around the airport and at car parks.

3.2.2 For PM_{10} and $PM_{2.5}$, the inventory includes not only exhaust emissions but also fugitive emissions from brake and tyre wear for aircraft.

3.3 Aircraft Emissions During the LTO Cycle

3.3.1 The dominant aircraft source of emissions is main-engine exhaust during the LTO flight phases (modes). Separate consideration is given to emissions from APUs and engine testing (engine ground runs).

3.3.2 The contribution to aircraft exhaust emissions (kg) arising from a given mode of aircraft operation from a single engine is given by the product of the duration (seconds) of the operation, the engine fuel flow rate at the appropriate thrust setting (kg fuel per second) and the emission factor for the pollutant of interest (kg pollutant per kg fuel). The annual emissions total for the mode (kg per year or tonnes per year) is obtained by summing contributions over all engines for all aircraft movements in the year.

LTO Flight Phases

3.3.3 The following ‘modes’ (phases) of the LTO cycle are considered for the purpose of emissions estimation:

- approach (from 3,000 ft altitude to runway threshold);
- landing roll (from runway threshold to runway exit);
- taxi-in;
- taxi-out;
- hold at runway head;
- take-off roll (from start-of-roll to wheels-off);
- initial climb (from wheels-off to throttle-back); and
- climb-out (from throttle-back to 3,000 ft altitude).

3.3.4 ‘Taxi-out’ commences at stand (including pushback) and ends when the aircraft joins the departure queue; ‘taxi-in’ commences when the aircraft leaves the runway and ends when the aircraft reaches the stand. There may be some overestimation of taxi-out emissions from assuming all engines are lit during pushback, but there is a lack of information on when engines are lit as a function of aircraft type and operator. It is assumed that all engines are shut down immediately when the aircraft reaches the stand[1]. It is judged that, on average, any potential underestimation of aircraft emissions from this assumption is compensated by the assumption that all engines are lit during pushback.

3.3.5 Helicopters do not have take-off roll or landing roll, and a single mode covers the climb from ground to an altitude of 3,000 ft.

Reduced-engine Taxiing

3.3.6 Reduced-engine taxiing is the practice of shutting down an engine during taxiing operations, which helps reduce fuel use, emissions, and noise. In theory, reductions of 20 to 40 per cent of the ground level fuel burn and carbon dioxide (CO_2), and 10 to 30 per cent of ground level NOx emissions, may be realised depending on aircraft type and operator technique. However, some of the reductions may be offset by the need to keep the APU running during taxiing.

3.3.7 For this assessment, a survey of the airlines was undertaken to identify the extent to which reduced-engine taxiing was used at the airport. Responses to the survey showed the practice of reduced-engine taxiing to be common at Gatwick and provided estimates of the frequency and duration for both arrivals and departures on an airline/aircraft fleet by fleet basis. These data have been included in the emission calculations, with suitably averaged data applied to those airline/aircraft fleets for which survey information was not available.

Movement Data and Fleet Mix

3.3.8 Detailed information on flight-by-flight records for the baseline year of 2018 was provided by Gatwick Airport Limited (GAL) from its aircraft movement database. This included:

- actual flight date and time;
- arrival or departure identifier;
- aircraft type;
- stand number;
- runway number;
- aircraft registration number;
- operator; and
- aircraft engine (in the form of a unique engine identifier (UID)).

Engine Assignment

3.3.9 GAL's aircraft movement database includes a UID, which, for jet aircraft, links directly to records in the International Civil Aviation Organisation (ICAO) databank of emission factors (European Union (EU) Aviation Safety Agency (EASA), 2021). For a small fraction of movements, the UID was unknown or erroneous; for these, a default engine was assigned based (where possible) on the most common engine for that aircraft type at Gatwick Airport. Where there was no instance in the Gatwick data giving an engine assignment for a particular aircraft type, a typical engine was chosen according to standard aircraft reference sources.

Exhaust Emission Factors

3.3.10 The emission factors for aircraft engines vary from one engine type to another, and, for a given engine, depend on thrust setting. The main source of emission factors (and fuel flow rates) used in the assessment is the ICAO databank, which gives certification test results for most of the jet engines in service at four thrust settings (7 %, 30 %, 85 % and 100 % of rated thrust) (EASA, 2021). Data for some engines not listed in the ICAO databank were obtained from the FOI (Swedish Defence Research Agency) compilation (FOI, 2002) for turboprops or Federal Office of Civil Aviation (FOCA) piston engine database and helicopter emissions table.

3.3.11 Certification data in the ICAO databank are based on tests carried out using new or nearly-new production engines, with certification data corrected to production standard (EASA, 2021). Thus, the applicability of certification data to in-service engines requires consideration. For reasons of safety and fuel efficiency, aircraft engines operate within closely-monitored ranges of tolerance and are subject to strict maintenance schedules. In the past, uncertainties in emission rates related to engine ageing were judged as small compared to other uncertainties and were not taken into account. However, at any particular time the engines in the fleet operating at an airport will be, on average, part-way through the maintenance cycle; in addition, there will be some longer-term degradation not restored by maintenance that will be restored only at refurbishment. Thus, there may be a systematic bias in emissions estimates based on certification data.

3.3.12 The available data on this issue were reviewed by QinetiQ for the PSDH (DfT, 2006), in particular distinguishing whole-flight deterioration values from LTO-only values, leading to a recommendation of a 4.3 per cent increase in fuel flow rates in the LTO cycle compared to certification values and a 4.5 per cent increase in NOx emission rates (the product of fuel flow rate and emission index) compared to certification values. Although there was some indication in the available data of variation with engine type, the data were not detailed enough to support engine-specific recommendations: the values given are appropriate averages for the fleet as a whole, bearing in mind the range of engine age in the fleet at any given time. These fleet-averaged values, applied to Heathrow in the PSDH work, were judged equally applicable to Gatwick.

3.3.13 The available data are also not detailed enough to make a distinction between the various phases of the LTO cycle (taxiing, take-off) so, in applying these values in the PSDH work, the percentage NOx increase was applied equally to the NOx emissions from all phases. It was recommended that the fuel increase be applied to PM_{10} emission rates, recognising the major uncertainties in PM_{10} emission indices (further detailed below). These recommendations were applied to this assessment.

3.3.14 The ICAO databank contains measured non-volatile PM_{10} emission factors for only a small number of newer engines. For older engines it only includes 'smoke number' (SN). This is an indirect measure of particulate emissions calculated from the reflectance of a filter paper measured before and after the passage of a known quantity of smoke-bearing gas. For the PSDH, methods and data for deriving aircraft exhaust PM_{10} emission indices were reviewed by QinetiQ, and recommendations were made for an interim methodology to be used while further data were being collected from various programmes in several countries. A closely similar methodology has been advocated in guidance by the ICAO Committee on Aviation Environmental Protection (CAEP) on the calculation of airport emission inventories (CAEP, 2004). This includes a means of deriving non-volatile PM_{10} emission factors from SN, which has been adopted for older engines for this assessment, and methodologies for estimating the volatile sulphate and organic PM_{10} component, which have also been adopted for this assessment.

3.3.15 The ICAO certification test results are given at the four standard thrust settings (7 %, 30 %, 85 % and 100 % of engine rating),

[1] It is recognised that some engines may have been shut down prior to arrival at stand if the aircraft is operating reduced-engine taxiing.

whereas recent airport inventories take account of differences between actual thrust settings and the ICAO set points, particularly for take-off thrust. The ICAO CAEP committee has issued a guidance note on the use of the ICAO databank in assessing airport emissions, which included advice on calculating emission indices at intermediate thrust settings (CAEP, 2004). If the fuel flow rate at the intermediate setting is known, the preferred method of interpolation is the 'Boeing fuel flow method' (Baughcum *et al.*, 1996), which interpolates the emission index as a function of the fuel flow rate; however, actual take-off fuel flow rates are not generally available for Gatwick operations. In this case, CAEP gives guidance on how to interpolate emission index on the basis of thrust value, suggesting a multi-order polynomial for NOx (but also noting that linear interpolation between 100 per cent and 85 per cent thrust has good accuracy in this range). The PSDH report (DfT, 2006) endorsed the multi-order polynomial approach for NOx in the absence of actual fuel flow rate data, and this approach was adopted for this assessment. The fuel flow rate and SN have therefore been calculated using interpolation.

Effect of Ambient Conditions

3.3.16 Aircraft engine emissions (NOx in particular) vary with ambient temperature, pressure and humidity. The certification test results in the ICAO databank are corrected to sea-level international standard atmosphere conditions (EASA, 2021). The CAEP guidance note considered the effect of variations in ambient conditions, noting that variations in ambient pressure and temperature are primarily reflected in changes in operating conditions and are therefore largely taken into account when actual thrust settings are used instead of notional ones; thus, no additional adjustment was recommended.

3.3.17 However, there will be some variation in NOx emission rates (ie the product of fuel flow rate and emission index) with hour-to-hour variations in ambient conditions because of the associated changes in engine operating point. This was examined by QinetiQ as part of the PSDH work, leading to a technical report (Horton, 2006) which recommends a method for adjusting NOx emission rates at a given thrust to ambient temperature and pressure. The sensitivity to ambient temperature and pressure variations was found to be significantly greater for the higher overall pressure ratio (OPR) engines (40:1 and above) that are now common on modern large jets (for example, the Rolls-Royce Trent 1000 engine as fitted to the Boeing 787 aircraft has OPR values of up to 49.4). QinetiQ estimated that the impact on total ground-level NOx emissions over the year, using weather data for Heathrow in 2002, is typically in the order of a few per cent. However, annual-average emission rate is not the only parameter of interest in air quality assessment, even when calculating annual-mean concentrations: the diurnal and seasonal variation in emissions is also important, given that the frequency of meteorological conditions leading to better (or worse) atmospheric dispersion varies with hour of day and month of year. QinetiQ found that, for the most sensitive type of engine, the hourly NO_x emission rate at a given thrust varied during a year by up to ±50 per cent from the value calculated assuming International Standard Atmosphere (ISA) conditions.

3.3.18 The QinetiQ report found that it was not possible to condense the results of their analysis into simple expressions applicable to a small number of engine type categories because of wide variations from one individual engine to another (Horton, 2006). Therefore, a calculation method that derives factors to apply to emissions of NOx, hydrocarbons (HC) and carbon monoxide (CO) for each engine type in the ICAO databank was implemented, covering a wide range of ambient pressures and temperatures (EASA, 2021). For the remainder of engines (principally turboprops) QinetiQ default parameters were used.

3.3.19 In light of the relatively poor characterisation of aircraft PM emissions, the PSDH report recommended that no adjustment for variations in ambient conditions be applied to PM emission rates (DfT, 2006).

3.3.20 The temperature and pressure variation with altitude will affect emission rates during climb and approach for an individual flight. As the aircraft climbs or descends, there are continuous changes in forward speed, temperature and pressure to which the engine control system will respond appropriately. However, emissions at increasing height have a decreasing impact on ground-level concentrations, which are the principal focus of interest in local air quality assessment. Even bearing in mind the potential impact of trailing vortices in transporting exhaust gases downwards, it is unlikely that emissions above 200 metres height have a significant impact on ground-level concentrations. For this reason, greater effort has been put into representing realistically the emission rates for the lowest few hundred metres in height than for greater heights.

3.3.21 To address this, the NOx emission rate during the initial-climb phase of the LTO cycle (from wheels-off to engine cut-back, typically at 1,000 ft to 1,500 ft) was calculated based on the ground-level temperature and pressure. This ensures that the emission rate in the lowest part of the initial climb is not underestimated, accepting that there will be some slight overestimation of the average emission in the initial climb taken over the whole year. For the climb-out phase (from cut-back height to 3,000 ft), the hourly surface temperature and pressure values were adjusted using simple representative profiles of temperature and pressure. Temperature was assumed to decrease with height from its surface value in line with the dry adiabatic lapse rate of −9.8°C per km (which would only strictly be the case for zero heat flux to/from the ground); the temperature adjustment to climb-out emissions was worked out using the mid-height temperature for the climb-out phase. Pressure was assumed to vary with height in a manner consistent with the adiabatic lapse rate for an atmosphere in hydrostatic equilibrium. This simpler procedure for climb-out emissions is judged adequate for emissions in this part of the LTO cycle, which have an insignificant impact on ground-level concentrations.

3.3.22 Similar simple procedures were used to account for the temperature/pressure variation with altitude during approach.

3.3.23 For correcting from NOx test results in the databank to actual humidity, the CAEP document advocates using in reverse the expression provided by ICAO Annex 16 Vol II (ICAO, 1993) to adjust test results to ISA conditions, albeit correcting a slight error in the reference specific humidity quoted in Annex 16 (ICAO, 1993). This adjustment is engine independent. Typically, this leads to hourly variations in the ground-level NOx emission rate over the year for a given thrust setting of around ±5 per cent, although the net effect on total annual emissions is much less. The adjustment for relative humidity is given by:

$$EI(NO_x)_{adjusted} = EI(NO_x)_{ICAO}\, exp\big(19(H_{ref} - H)\big)$$

3.3.24 For elevated emissions, it was assumed that the specific humidity is constant with height, which is strictly true only in the absence of condensation and evaporation.

3.3.25 The hourly surface temperature and humidity data was taken from meteorology data for 2018 at Gatwick Airport. Atmospheric surface pressure data, which is not included in this dataset, was obtained from the National Oceanic and Atmospheric Administration website (NOAA, 2019).

Forward-Speed Effect

3.3.26 Emission indices and fuel flow rates in the ICAO databank are measured on a stationary engine in a test cell. Generally, there will be a difference in the emission rate (the product of fuel flow rate and emission index) at a selected take-off thrust when the aircraft is moving at speed with respect to the air drawn into the engine compared to the emission rate for an aircraft that is stationary.

3.3.27 To estimate the effect of forward speed on NOx emission rate, the approach specified by QinetiQ was similar to that for estimating the effect of ambient temperature and pressure variations, with the key influence being the effect of forward velocity on the relative temperature and pressure at the engine inlet. The results of the analysis are given in the QinetiQ report (Horton, 2006). The principal effect of interest from a local air quality viewpoint is the change in emission rate during the take-off roll, although consideration was also given to the effect of forward speed on climb and approach emissions. The aircraft engine management system will respond to the inlet changes experienced. For example, QinetiQ assumed a representative 1.1 per cent increase in fuel flow over the roll, based on samples of Flight Data Recorder (FDR) data. Thus, the forward-speed adjustment to emission rates is the combined effect of changes in fuel flow rate and changes in emission indices.

3.3.28 The net impact of these changes is that the NOx emission rate increases with increasing speed during the take-off roll, with the fractional increase tending to be greater for engines with higher OPR. Table 3.3.1 presents the calculated ratio of emission rate at the end of the roll to the static emission rate at full thrust for a sample of common engine types. For engines with OPR around 40 the factor at the end of roll is around 1.15 (ie a 15 per cent higher emission rate).

Table 3.3.1: Mean and Final NOx Factors During Take-off, for a Range of Engine Types

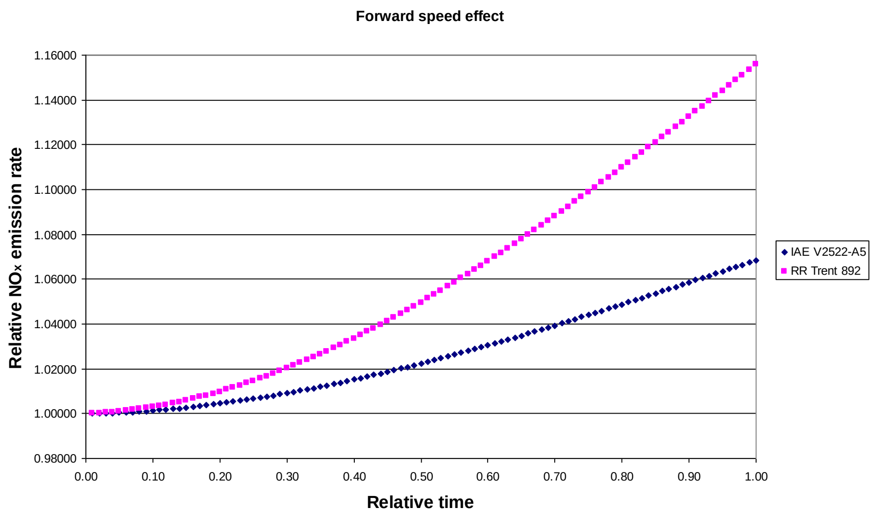
Engine	OPR[1]	Mean Factor[2]	Final Factor[2]
CFM56−3C−1	25.5	1.0251	1.0645
V2527-A5	27.2	1.0272	1.0700
CFM56−5B3/P	32.8	1.0367	1.0950
Trent 772	35.8	1.0505	1.1314
Trent 892	41.4	1.0590	1.1542

[1] OPR – overall pressure ratio

[2] 'Factor' is the ratio of NOx emission rate accounting for aircraft speed to that for stationary aircraft

3.3.29 The above approach was implemented for the impacts of forward speed on engine emissions in the same calculation tool as used for the ambient condition effects. For each engine type, the factors on emissions are calculated as coefficients of a cubic polynomial representing the emission rate as a function of time, with the emission rate expressed relative to the static emission rate at the selected take-off thrust and time expressed as a fraction of total roll time. In principle, this normalised emission profile depends on the actual take-off thrust selected, but the PSDH report found that the relevant factors for 85 per cent thrust were close to those for 100 per cent thrust. Thus, a single normalised profile is assumed to apply for a given engine to all take-off thrust values. For illustration, Diagram 3.3.1: Example of Forward Speed Effect for NOx Emissions During the Take-off Roll. NOx Emission Rate is Relative to the Value for a Stationary Aircraft; Time is Expressed as a Fraction of the Total Roll Time presents the profile for two common engines of widely different OPR.

Diagram 3.3.1: Example of Forward Speed Effect for NOx Emissions During the Take-off Roll. NOx Emission Rate is Relative to the Value for a Stationary Aircraft; Time is Expressed as a Fraction of the Total Roll Time[2]



3.3.30 Forward-speed effects are also considered during the initial climb, climb out and approach phases of the LTO cycle. For the initial climb phase, the forward-speed factor worked out for the end of the take-off roll was applied. The tool used for the calculation of the factors applied during take-off also derived those for the climb-out and approach phases, calculated using a representative speed and thrust level for each phase. Thus, the forward-speed adjustments for these phases are treated more approximately than for the take-off roll, with the same justification as that given in paragraph 3.3.20 in the context of adjustment for ambient conditions.

3.3.31 There was insufficient information available in the PSDH to quantify the effect of forward speed on PM_{10} emission rates and it recommended that the effect is ignored for this pollutant; correspondingly, the impact on $PM_{2.5}$ emissions was also ignored.

Engine Spool-Up

3.3.32 In the compilation of emission inventories prior to the PSDH work, it was assumed that the selected take-off thrust is applied immediately at the start of take-off roll. In practice, there is a period of engine 'spool-up' during which fuel flow rates and thrust levels are significantly less than the take-off values. The duration of this initial phase depends on aircraft type, and for large aircraft may be in the order of 10 seconds, which is a significant portion of the total roll time (around 40 seconds).

3.3.33 Although the engine thrust is significantly less than take-off thrust during this phase, the engine is not at equilibrium, and it is difficult to predict what the effective emission index (kg pollutant per kg fuel burned) will be, even if the fuel flow rate is known. Thus, the PSDH made an interim recommendation that the NOx emission index be held the same during the transient phase as that applicable at take-off thrust, so the net effect of spool-up on estimated emission rate derives solely from the lower fuel flow rate.

3.3.34 QinetiQ examined FDR data obtained during take-off for a number of aircraft types, and found that the data on fuel flow rate versus time collapsed reasonably well onto a single curve when fuel flow rate was expressed as a fraction of the flow rate at take-off thrust and time was expressed as a fraction of total roll time (Horton, 2006). For ease of implementation, this curve was fitted using a simple analytic expression of the form:

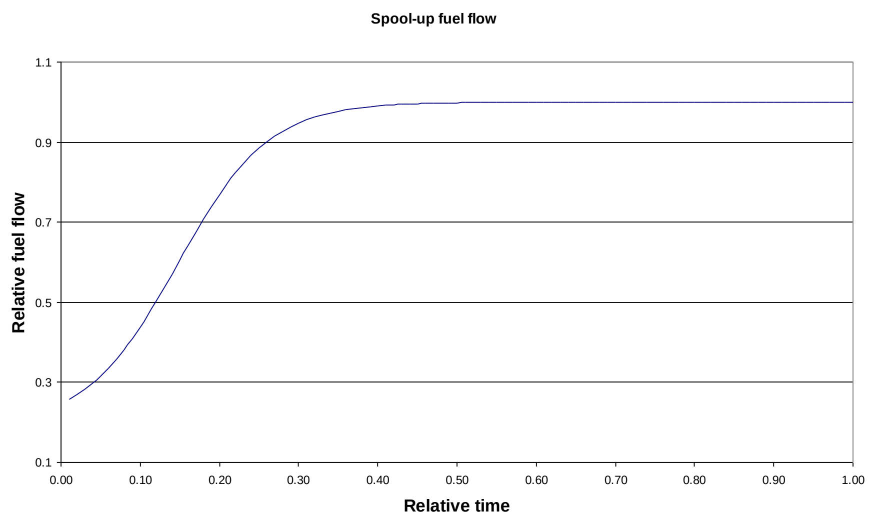
$$f(t) = a\tanh(bt + c) + d$$

3.3.35 where *f(t)* is the fuel flow rate expressed as a fraction of flow rate at take-off thrust and *t* is time expressed as a fraction of total roll

[2] The relative emission rates shown in the Diagram 3.3.1: Example of Forward Speed Effect for NOx Emissions During the Take-off Roll. NOx Emission Rate is Relative to the Value for a Stationary Aircraft; Time is Expressed as a Fraction of the Total Roll Timeaccount solely for the effect of forward speed and do not include the effect of engine spool-up (see later). In implementation, both effects are taken into account.

time. *tanh* denotes the hyperbolic tangent function; *a*, *b*, *c* and *d* are constant, with the values $a = 0.405$; $b = 8.720$; $c = -1.282$; $d = 0.595$. This form, which is shown in Diagram 3.3.2: Fuel Flow Variation due to Engine Spool-up During Take-off Rollwas adopted by the PSDH and has been applied to all engines and aircraft types in compiling the 2018 Gatwick Airport inventory of NO_x emissions.

Diagram 3.3.2: Fuel Flow Variation due to Engine Spool-up During Take-off Roll[3]



3.3.36 For PM_{10}, there are even greater uncertainties in SN during the transient spool-up phase than in the NOx emission index. Given the overall uncertainties surrounding the calculation of PM_{10} emission rates, the PSDH recommended that the effect of spool-up be ignored for this pollutant, ie take-off thrust is assumed to apply from the start of roll. This recommendation has been followed in this assessment and has also been applied to $PM_{2.5}$ emissions.

Thrust Settings

Approach

3.3.37 In the standard ICAO LTO cycle, approach thrust is set at 30 per cent throughout the descent from 3,000 ft to touchdown, as shown in Table 3.3.2. Although some FDR data analysed in the EU Aircraft Environmental Impacts and Certification Criteria (AEROCERT) programme (Middel, 2001) indicated that in practice thrust levels were often less than 25 per cent and were variable during the approach, it was considered adequate from a local air quality perspective to retain the 30 per cent value in airport emission inventories, given that most of the approach emissions are well above the ground.

3.3.38 However, in line with its intention of improving estimates of elevated LTO emissions as well as near-ground emissions, the PSDH defined a typical approach procedure at Heathrow as follows. Aircraft follow a 3° glide path (as in previous assessments) with power levels of 15 per cent of maximum thrust from 3,000 ft down to 2,000 ft and 30 per cent of maximum thrust from 2,000 ft to touchdown. This requires the approach to be treated in two sections with differing emission rates. Although devised for Heathrow, it was judged that this generic approach prescription is adequately representative of Gatwick operations, and has therefore been applied in this assessment.

Reverse Thrust on Landing

3.3.39 Some arriving aircraft deploy thrust reversers at thrust levels above idle on landing whereas other aircraft, although they may deploy the reversers, use only idle thrust and rely on the wheel brakes to slow down the aircraft. There are three key parameters determining the total annual emissions from landing roll: the fraction of aircraft of a given type that use reverse thrust on landing; the duration of reverse-thrust deployment; and the thrust level engaged.

3.3.40 For this Project, Gatwick undertook a survey of the airlines to identify the extent to which reverse thrust was used on landing at Gatwick. Responses to the survey provided estimates of the frequency and duration of reverse idle and reverse thrust above idle on an airline/aircraft fleet by fleet by fleet basis. These data have been included in the emission calculations with suitable averaged data applied to those airline/aircraft fleets for which data were not available.

Taxiing

3.3.41 Taxiing is assigned a thrust setting of 7 per cent in the standard ICAO LTO cycle. However, there is evidence that actual taxiing thrust settings are on average less than this. However, it is unclear how emission indices would behave at lower thrust settings. For the products of incomplete combustion, such as CO and HC, the emission indices (g pollutant per kg fuel burned) are likely to be higher for lower thrust settings, with the reverse likely to be true for NOx; the position for SN and PM_{10} emission indices is unclear. Lower taxiing thrust was partly taken into account in the 2002/3 Gatwick Airport emission inventory in that taxiing fuel flow rates were provided by British Airways (BA) for all the major aircraft types in their fleet, derived from information in their fuel management databases. These data confirmed that aircraft were on average taxiing at less than 7 per cent thrust. However, it was not clear if the BA dataset could be extended to other airlines, so it was applied only to BA movements. Emission indices (g per kg) were held at the values for 7 per cent thrust, recognising that this might lead to overestimation of NOx emissions.

3.3.42 The evaluation of taxiing emissions is made potentially more complex by the practice of reduced-engine taxiing, which is favoured by some operators for some aircraft types. For this Project, Gatwick undertook a survey of the airlines to identify the extent to which reduced-engine taxiing was used at the airport. Responses to the survey showed the practice of reduced-engine taxiing to be common at Gatwick and provided estimates of its frequency and duration for both arrivals and departures on an airline/aircraft, fleet by fleet by fleet basis.

3.3.43 For taxiing on all engines, the PSDH recommended that idle thrust settings lower than 7 per cent should be taken into account. FDR data compiled for the PSDH indicated that in most cases the ground-idle thrust setting used during most of taxiing and hold was around 5 per cent, except for aircraft fitted with Rolls-Royce engines, for which 3 per cent thrust was a closer approximation. Clearly, there will be brief periods of higher thrust (perhaps 10 to 15 per cent) to get the aircraft rolling or to negotiate sharp turns, but they are superimposed on much longer periods at the ground idle setting, so the average thrust level will be significantly below 7 per cent.

3.3.44 It is easier to estimate the impact of these lower thrust settings on fuel flow than on emission indices. Considering the available data as a whole, the PSDH recommended that fuel flow rates for engine types other than Rolls Royce be set 15 – 20 per cent lower than the ICAO 7 per cent value and for Rolls Royce engines be set 30 – 35 per cent lower than the ICAO 7 per cent value, and these recommendations were implemented for Heathrow by using the mid-point of the ranges, ie 17.5 per cent and 32.5 per cent respectively, with the values applied to all periods of taxiing and hold. The PSDH further recommended that the NOx and PM_{10} emission indices at the lower fuel flow rate be held the same as the value at 7 per cent thrust. As noted earlier, this is likely to yield a somewhat conservative estimate (ie

[3] Time is expressed as a fraction of total roll time; fuel flow is expressed relative to fuel flow when the engine has stabilised at take-off thrust.

overestimate) of taxiing NO_x emissions; current information (QinetiQ, 2006), albeit more uncertain, suggests that this assumption is also likely to be conservative for PM_{10}. These recommendations were adopted in this assessment.

3.3.45 Analysis of the impact of reduced-engine taxiing on emissions suggests that the engines that are in use generally have to be operated at higher thrust settings (and the APU may be running for longer). In light of this, the standard ICAO thrust setting of 7 per cent was assumed during reduced-engine taxiing. It is worth noting that the PSDH made no specific recommendation for taking account of reduced-engine taxiing for NOx and PM emissions.

Take-Off Thrust

3.3.46 The four thrust settings used in the ICAO databank were chosen to be representative of actual thrusts in the principal LTO flight phases, and early methodologies for calculating aircraft emissions simply assigned each LTO flight phase to one of the settings (with the exception of landing roll, where periods of reverse thrust were identified for some aircraft types), as shown in Table 3.3.2. However, more recent airport emission inventories recognise that large jets usually do not take off at 100 per cent thrust, with the actual thrust selected depending on take-off weight and air temperature. Typically, for large jets, actual take-off thrust lies between 75 per cent and 90 per cent of maximum thrust[4].

Table 3.3.2: Thrust settings used in early emission inventories[1]

Mode	Thrust
Taxi-out	7%
Holding at runway head	7%
Take-off roll	100%
Initial climb	100%
Climb-out	85%
Approach	30%
Landing roll[2]	7%
Taxi-in	7%

[1] These values have now been superseded by more detailed methodologies

[2] Periods of reverse thrust above idle were recognised even in early emission inventories

3.3.47 NOx emissions from take-off roll are a major component of the total ground-level NOx from aircraft at an airport, and the emission rate during take-off is strongly dependent on thrust, not only does fuel flow rate increase with thrust but the NO_x emissions index (g NOx per kg fuel burned) also increases with thrust. Furthermore, there is large variability in the NOx emission indices from one engine type to another. Thus, it is important to make realistic estimates of the thrust settings for those operator/aircraft type/engine combinations that have high utilisation at Gatwick Airport.

3.3.48 Actual take-off thrust settings are not routinely available on a flight-by-flight basis, although they can be extracted from FDR data. For PSDH, BA developed a methodology that enables information on take-off thrust to be derived from information on actual aircraft take-off weight. The methodology is based on their analysis of an extensive set of take-off thrust (derived from FDR data) and weight data for their fleet at Heathrow (Morris, 2002). BA found that, to a reasonable approximation, when flexible thrust[5] is being used the ratio of actual take-off thrust to maximum take-off thrust is given by the ratio of actual take-off weight (ATOW) to Performance Limited Take-Off Weight (PLTOW)[6], subject to a lower limit set by regulation, normally 75 per cent.

3.3.49 Prior to the compilation of the 2002/3 Gatwick Airport emission inventory, British Airports Authority (BAA) carried out a survey of the principal airlines operating at Gatwick, first to ascertain how commonly flexible thrust (via the Assumed Temperature Method) was used at Gatwick and then to ask for information on ATOW and PLTOW for those operators using it. Airlines do not normally release ATOW on a flight-by-flight basis, but many of the major operators at Gatwick were willing to release annual-average ATOW information and were also willing to give information on the average limiting take-off weight. Due to a problem of terminology in the survey questionnaire, however, the airlines actually provided the lower of the PLTOW and the structural limit on weight (termed the Maximum Take-Off Weight, MTOW). Most aircraft types operating at Gatwick in typical weather conditions are not performance limited, so generally MTOW is less than PLTOW, so using the limiting weight values as provided tended to give a conservative (ie over-) estimate of mean take-off thrust.

3.3.50 There was insufficient time to repeat the full airline survey before compiling the 2002/3 inventory, but it was possible to obtain specific $PLTOW_0$[7] values for the fleets of BA and Air2000 operating at Gatwick. Two values were supplied for each aircraft type, corresponding to runway directions 26L and 08R, although the differences were typically less than 2 per cent. For other airlines, the potentially conservative nature of the estimates of mean thrust was accepted. It is not possible to use $PLTOW_0$ values from one airline for another for the same aircraft type because $PLTOW_0$ depends on details of the aircraft configuration, in particular which engines are fitted. The indications from the BA and Air2000 data were that the degree of thrust overestimation would be generally less than 5 per cent.

3.3.51 Even if it is an airline's policy to use reduced thrust where possible, there are circumstances when 100 per cent thrust is mandated even if the aircraft is not at its limiting take-off weight, for example when the runway is icy or there is excessive low-level wind shear. Typically, the annual fraction of departures at 100 per cent thrust lies in the range of 2 to 10 per cent. Data on this fraction was requested in the BAA survey, and this fraction was treated separately in the emissions analysis.

3.3.52 In some instances, the airline indicated that for a given aircraft type a fixed thrust de-rate is used (sometimes called 'push-button de-rate'). In this case, the airline was asked to give the value of the de-rated thrust. De-rated thrust can be used in conjunction with the assumed temperature method, and if this was indicated in the survey response then the appropriate ATOW and limiting weight information was also requested.

3.3.53 Where survey results were not available for a given aircraft type[8] for a given airline, the value of mean take-off thrust was taken to be the average of the values obtained for the same aircraft type operated by other airlines (if possible with a similar type of business, ie scheduled or low-cost/charter). Small jets were assumed to take off at 100 per cent thrust.

3.3.54 For the 2005/6 inventory (Underwood *et al.*, 2008), major operators at Gatwick Airport were asked to update the

[4] All thrusts in the following text are expressed as a percentage of the rated output (F_{00}), the maximum thrust available for take-off under normal operating conditions at ISA sea level static conditions.

[5] 'Flexible' thrust is a term used to contrast with push-button de-rated thrust and is typically applied via the 'Assumed Temperature Method'. In the latter, the aircraft flight management system is supplied with the value of the maximum air temperature at which the aircraft could take off with its actual take-off weight, according to the flight manual. This is an approved method that maintains safety margins.

[6] PLTOW is the maximum take-off weight for a flight given by the aircraft flight manual, with due account taken of outside air temperature (OAT), wind speed/direction, runway characteristics (elevation, length, slope) and obstacle clearances. If it is higher than the maximum take-off weight (MTOW) determined by structural considerations, then MTOW would set the limiting take-off weight for the flight.

[7] $PLTOW_0$ is the value of PLTOW for 15°C OAT and zero wind. This is used in the BA thrust methodology if actual average values of PLTOW are not available.

[8] 'Aircraft type' in this context refers to main type and series (ie B747–400); data for one series were not automatically assumed to apply to other series.

information on average ATOW and PLTOW values for the principal aircraft types in their fleets operating at Gatwick in the relevant period (ensuring that the terminology problems of the earlier survey were not repeated) on the grounds that load factors and routes may have changed in the intervening period. BA, EasyJet, Ryanair and Great British (GB) Airways provided updated information for key aircraft types in their Gatwick fleets, and the corresponding thrust values were used for the inventory. The updated information covered around 50 per cent of the movements in the 2005/6 period. For other operators/aircraft types, the values used for the previous inventory were retained.

3.3.55 Ryanair indicated that it uses 'push-button de-rate' on its B737−800 aircraft (one of the two principal aircraft types operated by Ryanair during the period of interest, the other being the B737−200), and provided information that enabled the average amount of de-rate to be estimated. Ryanair also use flexible thrust on this aircraft, but previous Ryanair data indicated that this flexibility leads on average to little additional thrust reduction.

3.3.56 For the current study, Gatwick undertook a survey of the airlines to update the information on take-off thrust. The responses to the survey were patchy, but they did include sufficient information to update the assumptions for TUI, Thomas Cook, EasyJet and Virgin Atlantic. The take-off thrust assumptions for BA were retained from the 2005/6 inventory (Underwood *et al,* 2008).

3.3.57 Where no specific data were available from any of the surveys for a particular aircraft type, the average value over all jet aircraft types with the same number of engines was used. This procedure for filling data gaps is consistent with that advocated by the PSDH.

3.3.58 The above procedure gives thrust values based on annual average values of weight. In principle, PLTOW is influenced by ambient temperature, so that the take-off thrust for aircraft of a given take-off weight could show systematic diurnal and seasonal variations. However, modern commercial aircraft show little dependence of PLTOW on ambient temperature across the range of temperatures commonly experienced in the UK, so the influence of ambient temperature on take-off thrust for a given aircraft weight is not expected to be significant. Actual take-off weights for a given aircraft type operated by a given airline may also vary with time of day and season due to systematic variation in load factors or routes served, but the detailed ATOW data are not available to take this into account. The use of average weight data is unlikely to introduce significant error in the estimates of annual take-off emissions, but could influence the diurnal and seasonal profile of emissions.

Climb-Out

3.3.59 In the standard ICAO LTO cycle, the thrust after cut-back is 85 per cent, but in practice aircraft use a range of thrust settings, with the value for a particular flight linked in part to the take-off thrust. In particular, the aircraft will not climb out at a thrust setting higher than at take-off. In the 2002/3 Gatwick Airport inventory, the influence of reduced-thrust take-off was recognised simply in terms of a constraint that if the take-off thrust is less than 85 per cent the climb-out thrust is set at take-off thrust; otherwise it was set at 85 per cent. It was recognised that this procedure was likely to overestimate climb-out NO_x emissions, but emissions above the cut-back height have an insignificant influence on ground-level annual-mean concentrations (even when the potential influence of trailing vortices is taken into account), so the approximation was considered acceptable from a local air quality viewpoint.

3.3.60 However, the PSDH recognised that total emissions in the LTO cycle are also of interest beyond the local air quality perspective, for instance for the calculation of greenhouse gas emissions, and made recommendations aimed at improving estimates of elevated emissions, including recommendations on climb-out thrust, which are summarised below.

3.3.61 Large commercial jets usually have several pre-set climb thrust settings, typically the maximum climb setting (CLB) and two lower settings, CLB1 and CLB2 (nominally 10 and 20 per cent, respectively lower thrust than CLB). The actual climb settings depend on aircraft type and engine fit, but for most types CLB does indeed appear to be close to 85 per cent of the full engine rating, with CLB1 and CLB2 at around 78 and 70 per cent of full rating. Thus, the PSDH report recommends the following procedure for setting climb-out thrust:

- use 85 per cent for take-off thrust settings between 100 and 90 per cent;
- use 78 per cent for take-off thrust settings between 90 and 80 per cent;
- use 70 per cent for take-off thrust settings between 80 and 75 per cent (the normal lower limit on take-off thrust); and
- set climb-out thrust equal to take-off thrust if take-off thrust is less than 75 per cent (for particular cases where an aircraft type is specifically certificated for take-off at less than 75 per cent).

3.3.62 These recommendations were adopted for the 2005/6 Gatwick inventory and have been retained for the 2018 inventory.

Times-in-Mode

3.3.63 The PSDH report did not make any specific recommendations on how times-in-mode for the LTO flight phases should be assessed, but endorsed the AEA[9] approach of using ground-radar and Noise and Track-Keeping (NTK) data where available. An early version of this approach was used for the 2002/3 Gatwick inventory and further refinements to the methodology and the updating of data sources were made for the subsequent inventories.

Approach

3.3.64 Data for the approach mode were obtained from Gatwick's NTK system, which provides accurate positioning information every four seconds on a flight-by-flight basis. Sample NTK data, covering all arrivals for eight representative days from 2018, were used to derive average times in each phase of approach for a number of aircraft types. The sample data included both westerly and easterly operations from each season of the year. The data were available for the two approach segments (from 3000 ft to 2,000 ft and from 2,000 ft to the ground).

Landing Roll

3.3.65 For landing roll, GAL provided a sample of runway occupancy data from their ground radar system for August 2018. The data were flight-by-flight records including runway occupancy times (from threshold to runway exit to the nearest second) and an identification of the runway exit block. These times (and exit blocks) were matched to arrival records from GAL's aircraft movement database. The runway occupancy data were also used to calculate average landing roll times by runway, exit block and aircraft type and to give exit block frequency by runway and aircraft type. These average times from the August 2018 sample were assigned to the remaining arrival records.

Reverse Thrust

3.3.66 From the airline survey undertaken for this assessment, estimates were obtained of the frequency and duration of reverse idle and reverse thrust above idle on an airline/aircraft fleet by

[9] AEA Technology was acquired by Ricardo Group, forming Ricardo-AEA Ltd, in 2012.

fleet basis. These data have fed though to emission calculations, with suitable averaged data applied to those airline/aircraft fleets that detailed information was not available for.

Taxiing

3.3.67 Gatwick's airport operational management system (IDAHO) provides, on a flight-by-flight basis, the times (to the nearest minute) of a number of key 'events'; for example, for arrivals it gives the time the aircraft landed and the time it arrives at stand (On Chox); for departing aircraft, it gives the time the aircraft left the stand (Off Chox) and the time it became airborne. The IDAHO data align very closely with records from GAL's aircraft movement database, providing a match for 99.9 per cent of the movements.

3.3.68 Taxi-in times were calculated on a flight-by-flight basis, by subtracting landing-roll times from the total time from when the aircraft landed to the time it arrived at stand. Suitably averaged data were applied to the few unmatched records.

3.3.69 Taxi-out times were calculated on a flight-by-flight basis, by subtracting hold, line-up and take-off roll times from the total time from when the aircraft left the stand to the time it became airborne. Again, suitably averaged data were applied to the few unmatched records.

Hold, Line-Up and Take-Off Roll

3.3.70 In addition to providing runway occupancy times for arrivals, the sample runway occupancy data for August 2018 provided the runway holding time for departures, the time to line-up and the runway occupancy time (from lined-up to airborne). The data were provided to the nearest second and there was also an identification of the runway hold point (entry block). These times (and entry blocks) were matched to departure records from GAL's aircraft movement database. The data were used to calculate average holding, line-up and take-off roll times by runway, hold point and aircraft type and to give hold point frequency by runway and aircraft type. These average times from the August 2018 sample were assigned to the remaining departure records.

3.3.71 It is recognised that runway occupancy time may provide an over-estimate of take-off roll time, as there may be some delay at the runway head prior to the start of the take-off roll. However, the degree of over-estimation is considered to be negligible and does not affect the results of the assessment.

Initial Climb and Climb-Out

3.3.72 Data for the initial climb and climb-out modes were obtained from Gatwick's NTK system for a sample covering all departures for eight representative days in 2018. The data were used to derive average times in initial-climb and climb-out for a number of aircraft types and included both westerly and easterly operations from each season of the year.

3.3.73 It is understood that some operators/aircraft types normally cut back at 1,000 ft rather than 1,500 ft for noise-compliance reasons. Advice from the Civil Aviation Authority (CAA) during the PSDH work indicated that the lower cut-back was used by most aircraft in the 'Heavy' wake-vortex category (typically B777, B747, B767, A340, A310, A300, MD11) and by aircraft in the 'Medium' wake-vortex category (typically B737, A319, A320, A321) for particular operators. The NTK data were further analysed to derive for times and distances to 1,000 ft for these aircraft types. All the remaining departures were assumed to cut back at 1,500 ft.

3.4 Aircraft Auxiliary Power Unit Emissions

3.4.1 APU emissions (kg) from a given aircraft movement were calculated as the product of the APU running time (s), the fuel consumption (kg per s) and the emission factor (kg pollutant per kg fuel consumed) appropriate to the APU model fitted on the aircraft.

3.4.2 There are relatively few openly-available sources of information giving APU emission factors (kg pollutant per kg fuel burned) and fuel flow rates (kg per hour), principally because APUs are not included in the ICAO certification process. The (United States) Federal Aviation Administration (FAA) reviewed the information available in 2000 by persuading the principal manufacturer (Honeywell) to comment on the datasets being recommended at the time by the FAA. The resulting set of APU emission indices, which have been widely employed in the compilation of airport emission inventories, were used for the 2002/3 Gatwick Airport inventory and quoted in the corresponding inventory report. No PM_{10} emission factors were available, so a notional value of 0.1 g/kg fuel was used, based on the average value for main engines according to the methodology being used at the time.

3.4.3 Two limitations of the FAA data set were that (a) values are available for only a limited number of APU types that were common some years ago and that (b) the values given are averages for a typical APU cycle consisting of specified fractional amounts of various operational modes (such as providing electrical power only or providing air conditioning). This cycle (the details of which are not known for the FAA data) may differ from the actual cycle typical of Gatwick operations.

3.4.4 The release of detailed modal APU emission indices is controlled by the APU manufacturers, but data are released to aircraft operators for the purposes of generating emission inventories, provided the values for individual APU models are not published. For the work of the PSDH, a compromise was worked out whereby BA derived from the detailed manufacturer's data supplied to them a set of representative modal emission indices for general use in compiling inventories. This approach allowed greater realism to be reflected in the emission factors used for airport emission inventories whilst maintaining the level of confidentiality required by the manufacturers. The key elements of this methodology have been adopted in the CAEP guidance report on airport emission inventories referred to earlier (CAEP, 2007).

3.4.5 Potentially there is a wide range of APU operating conditions for which differing fuel flow rates and emission factors apply, ranging from 'no load' through to the starting of main engines with the provision of electrical power to the aircraft systems. Other load conditions include the supply of electrical power and/or the provision of air conditioning. However, inspection of the data revealed that it is adequate to characterise APU operations in terms of three modes: (a) no load; (b) air conditioning plus electrical power (labelled ECS – environmental control systems - for convenience below) and (c) main engine start plus electrical power (labelled main engine start (MES) below).

3.4.6 For NO_x emissions, BA defined six APU classes that adequately span the range of values found in the detailed data; each aircraft type was assigned to one of the six classes for the purpose of calculating APU NO_x emissions. The modal NO_x emission rates (product of fuel flow rate and emission index) for the six classes are given in Table 3.4.1 with the principal aircraft types assigned to the classes. It will be seen later that APU running times are dominated by the 'ECS' mode so overall emission indices are similar to those in this column of Table 3.4.1. As expected, these values span a similar range as the cycle-average values used in earlier inventories.

Table 3.4.1: APU NOx Emission Rates and Class Assignments

NOx Class	NOx Emission Rate (kg per hour)			Aircraft Types in Class
	NO Load	ECS	MES	
a	0.274	0.452	0.530	B727−100/200; BAe 146; A318; ERJ 135/145; F100, Tu 154M; Business Jets (with an APU)
b	0.364	0.805	1.016	B737-NG; CRJ; CRJ700; MD90
c	0.565	1.064	1.354	B737-CB757−2; A319/320/321; MD80; B767−2; B767−3
d	0.798	1.756	2.091	A300; A310; MD11; DC10; L1011−1/5/50/100
e	1.137	2.071	2.645	A330; B747−4; B747-SP; A340−3; B747−1; B747−2; B747−3
f	1.210	2.892	4.048	B777−2; B777−3; A340−6; A380

3.4.7 The detailed data on PM_{10} emission indices proved more difficult to generalise, but BA found that the large variability in modal PM_{10} emission rates could be reduced if the emission rates were expressed as a function of the corresponding NOx emission index. In this way, BA distinguished three classes of APU for which a different functional form of the relationship between PM_{10} emission rate and NOx emission rate was appropriate, with each aircraft type assigned to one of these classes. The forms of the relationships derived are shown in Table 3.4.2 with the principal aircraft types assigned to the classes. $PM_{2.5}$ emission indices were set equal to the corresponding PM_{10} indices.

Table 3.4.2: APU PM_{10} Emission Rates

PM_{10} Class	PM_{10} Emission Rate (kg per hour)[10]	Aircraft Types in Class
A	PM_{10}=0.0233 x (NO_x)0.0934	All types (with an APU) except those below
B	PM_{10}=0.379 x (NO_x)2.642	Business jets (with an APU); BAe146; ERJ 135/145; CRJ; CRJ700
C	PM_{10}=0.0630 x (NO_x)0.173	B757−2; B767−2; B767−3; A300; A310

3.4.8 The Gatwick Airport Directive: GAD/F:28/17 sets limits on the use of aircraft auxiliary power units. It sets separate constraints on wide-bodied and narrow-bodied aircraft. For wide-bodied types, APU running time prior to scheduled departure time is limited normally to 50 minutes; running time on arrival at stand is limited normally to 15 minutes. For narrow-bodied jets, the equivalent times are 10 minutes on departure and 10 minutes on arrival.

3.4.9 In the absence of statistical data specific to Gatwick Airport, APU running times for previous inventories were also based on the equivalent limits in force at the time.

3.4.10 For this Project, logs of compliance audits undertaken during 2018 were made available. These indicate that, broadly speaking, the limits set out in the directive are being observed. Furthermore, statistical analysis of the compliance logs and data on average turnaround times, suggest that, on-stand, APU are typically in operation for about 60 per cent of the limit times. This percentage is highly uncertain. However, it was judged reasonable to apply it to the calculations.

3.4.11 The above procedure leads to total APU running time, whereas the PSDH methodology distinguishes three operating modes, namely (a) no load; (b) air conditioning plus electrical power (labelled ECS) and (c) main engine start plus electrical power (labelled MES), so the total time needs to be partitioned amongst these three modes. BA provided estimates of the typical times for the no-load and MES modes, with the former given as 180 seconds (all aircraft types) and the latter as 35 seconds for two-engined aircraft or 140 seconds for four-engined aircraft. These times, which were applied to Heathrow in the PSDH work, have been adopted in the CAEP guidance report (CAEP, 2004), and were assumed to apply at Gatwick Airport. Thus, for arrivals, the time assigned to the ECS mode was set equal to the difference between total arrival running time and no-load time. For departures, the time assigned to the ECS mode was set equal to the time remaining after subtraction of no-load and MES times from the total departure running time.

3.4.12 With the increased use of reduced-engine taxiing there is a propensity for aircraft to operate their APUs during taxiing. In light of this, the survey that Gatwick undertook to identify the extent to which reduced-engine taxiing was used at the airport also asked about APU use during taxiing. The responses provided estimates of its frequency and duration for both arrivals and departures on an airline/aircraft fleet by fleet by fleet basis. These have fed though to emission calculations, with suitable averaged data applied to those airline/aircraft fleets that did not respond.

3.5 Engine Testing Emissions

3.5.1 An estimate of the emissions from engine testing on the airport was based on detailed logs of tests carried out during 2018 (total of 192 tests during the year). The logs provide information on the aircraft type, the aircraft registration number, the location of the test, the number of engines tested, an indication of the power setting of each engine tested and the total test duration. Emissions (g) for a given test were calculated as the product of a test time (s), the fuel flow rate of the relevant engine type (kg per s) at the appropriate thrust setting and the relevant emission factor (g pollutant per kg fuel consumed), summed over the engines involved in the test.

3.5.2 Power setting was specified using descriptive terms such as ‘ground idle’, ‘flight idle’, ‘full power’ etc., although for above-idle settings supplementary information was given on the actual thrust as a percentage of the engine rating (F_{00} – the maximum thrust (engine rating) at sea-level in standard atmospheric conditions).The great majority of tests were at ground idle or flight idle. For ground idle, the PSDH-recommended reductions in fuel flow have been applied. The PSDH report also notes that ‘flight idle’ is typically 10 − 15 per cent F_{00}, so a value of 15 per cent has been in this assessment.

3.5.3 From discussions with aircraft operators, it is expected that engines are run at high power for periods of only a few minutes even if the total duration of the test period is much longer, but there is no information in the test logs on what fraction of the total run time was at high power. However, given that there were only 7 runs at above-idle power in the 2018 period, it was assumed conservatively that the whole run time was at the above-idle setting for these runs. A sensitivity test indicated that restricting the high-power running to five minutes per engine per test reduced the total NOx from engine testing by 15 per cent.

[10] as function of NOx emission rate (kg per hour)

3.5.4 Engine type was assigned based on the aircraft registration number. For thrust settings intermediate between ICAO standard test thrust points (7 per cent, 30 per cent, 85 per cent and 100 per cent), the interpolation procedure described earlier in the context of reduced-thrust take-off was used. The PSDH factors for engine deterioration were also included.

3.6 Aircraft Brake and Tyre Wear

3.6.1 The 2002/3 Gatwick Airport emission inventory included an estimate of the contribution to PM_{10} emissions from aircraft brake and tyre wear, albeit based on sparse data. The estimate was based on the generalisation of information obtained from a single operator at Stansted airport giving the amount of material eroded from brakes and tyres per landing for Fokker 100 and BAe146 aircraft. In the absence of any specific data, it was assumed that all eroded material would end up as suspended particulate matter in the PM_{10} size range, recognising that this would almost certainly lead to an overestimation of PM_{10} mass (given the blackening of runways and aircraft undercarriages). In order to estimate emissions from the whole fleet at Gatwick Airport based on this limited information, it was assumed that the PM_{10} mass per landing would scale with the size of the aircraft, as represented by its MTOW, although there were no specific data to support this assumption.

3.6.2 More recently, additional information has become available to supplement the earlier data. Maintenance operators at Stansted airport have provided data on brake wear for the B737−300 and tyre wear for the B737 and A320, supplemented by data from the aircraft tyre manufacturers. Also, information on tyre wear has been compiled by BA for a number of the aircraft types in their fleet at Heathrow.

3.6.3 For the PSDH, QinetiQ reviewed the available data on brake and tyre wear and recommended a methodology for making best use of the information (Horton, 2006). For brake wear, the earlier assumption that all the eroded mass ends up as suspended PM_{10} particulate matter was retained, partly by analogy to road-vehicle data indicating that a significant fraction of the eroded mass can end up as PM_{10}, but with continuing recognition that this is likely to lead to an overestimation of the PM_{10} mass emitted. Similarly, the assumption that the emitted PM_{10} mass per landing, scales with aircraft weight was retained. Pooling the data for the B737−300 with the earlier data gave an emission factor of 2.5 x 10^{-7} kg PM_{10} per kg MTOW.

3.6.4 For tyre wear, the methodology was based principally on the BA information, which covered a wider range of aircraft size than previous data. This gave support to a linear dependence of mass eroded per landing on aircraft weight (represented as MTOW), and a linear regression of the data yielded the following relationship:

$$Amount\ lost\ per\ landing\ (kg) = 2.23\ x\ 10-6\ x10-6\ x\ (MTOW\ in\ kg) - 0.0879\ kg\ for\ MTOW\ greater\ than\ 50{,}000kg$$

3.6.5 The report gave no recommendation for modelling tyre wear for aircraft with MTOW less than 50,000 kg, and in implementing the above methodology in subsequent Heathrow emission inventories for the PSDH it was assumed that the eroded mass per landing varied linearly from the value at an MTOW of 50,000 kg given by the above to zero, at an MTOW of zero.

3.6.6 Judging by analogy to the road-vehicle data, QinetiQ considered it over-conservative to assume that all the eroded mass from tyre wear is suspended as particulate matter, and a PM_{10} fraction of 10 per cent was assumed, which is at the upper end of the range observed for road-vehicle tyres. This contrasts with the assumption made for the 2002/3 Gatwick inventory that all eroded tyre material contributes to suspended PM_{10} mass.

3.6.7 The above PSDH methodology (DfT, 2006) was adopted for the 2005/6 Gatwick emission inventory and has again been used for the 2018 inventory. It is recognised that there remain significant uncertainties in estimating PM_{10} emissions from brake and tyre wear, but these would only be reduced when more aircraft-specific data become available. The summed brake-wear and tyre-wear emission factor detailed above is around a factor of three, smaller than that used for the 2002/3 inventory, principally as a result of the less conservative assumption for the fraction of material suspended from tyre wear.

3.6.8 The mean size of particles from attrition processes such as brake and tyre wear tends to be much higher than from combustion processes, so in this case setting $PM_{2.5}$ emission factors equal to PM_{10} emission factors is likely to significantly overestimate $PM_{2.5}$ emissions. There are no specific data on the $PM_{2.5}/PM_{10}$ mass ratio for aircraft brake and tyres, so equivalent data for road vehicles were used, adding to the uncertainty in the $PM_{2.5}$ estimates. The road-vehicle values were taken from a review of brake and tyre wear carried out for the United Nations Economic Commission for Europe (UNECE, 2003). This estimates that the $PM_{2.5}/PM_{10}$ mass ratio for brake wear is 0.4 and for tyre wear is 0.7; these ratios were adopted for aircraft brake and tyre wear for the 2005/6 Gatwick inventory (Underwood *et al*., 2008) and have been retained for this current study.

3.7 Future Year Aircraft Emissions

Movement Data

3.7.1 For each of the future case options, GAL provided fleet data in the form of annual forecasts of aircraft movements broken down by aircraft type and time of day (Day, Evening and Night). The diurnal profile of movements was derived from these forecasts by assuming a uniform distribution of movements within each period (Day, Evening and Night). In the absence of movement data for each day of the year, the annual profile of movements was assumed to be flat; sensitivity modelling undertaken for previous work has shown this assumption to be conservative. A summary of these forecasts is shown in Table 3.7.1.

Table 3.7.1: Annual Aircraft Movements

Aircraft	2029		2032		2038	
	Without Project	With Project	Without Project	With Project	Without Project	With Project
319	18,393	19,279	8,177	8,520	0	0
320	76,554	81,115	46,780	52,402	0	0
321	5,895	6,281	0	0	0	0
73H	11,080	11,814	1,582	1,661	0	0
AT7	489	489	0	0	0	0
320neo	91,661	96,852	125,718	153,076	178,618	211,073
321neo	20,878	22,238	32,570	39,308	36,072	42,794
738Max	33,347	35,523	42,738	47,083	44,288	48,165
737Max 10	2,913	3,125	3,299	4,099	3,316	4,101
CS100	5,622	5,624	6,063	6,171	6,043	6,214
CS300	1,912	2,037	2,443	9,302	2,451	9,306
772	8,888	9,681	2,339	2,486	0	0
333	3,155	3,437	904	904	0	0
77W	235	256	0	0	0	0
788	5,074	5,504	6,201	9,201	6,521	9,199
789	17,959	19,560	26,772	34,026	31,896	39,575
359	4,203	4,578	5,208	7,703	5,716	8,092
350	1,450	1,580	806	806	1,827	1,871
77X	352	383	587	587	2,200	2,200

Aircraft	2029		2032		2038	
	Without Project	With Project	Without Project	With Project	Without Project	With Project
339neo	117	128	587	587	587	587
388	2,346	2,555	2,346	2,346	733	733
ER4	104	111	106	128	107	129
CJL	103	109	104	126	106	128
GS5	90	95	91	110	92	111
H28	62	66	63	76	64	77
CCJ	56	59	57	69	58	69
D2L	55	58	55	67	56	68
CJ1	45	47	45	55	46	55
HAP	60	63	60	73	61	74
EP3	35	37	35	43	36	43
Total	313,133	332,683	315,735	381,013	320,894	384,664

Engine Assignment

3.7.2 The movement data provided by Gatwick Airport for movements in future years included generic aircraft types. The majority of the aircraft types included in the list are already in production; however, one type (the Boeing 777-X) is not yet in production and so there was a need to define the engine characteristics for this aircraft.

3.7.3 For existing aircraft types, the movement data for 2018 were used to define the percentage split between the different engine types. In the case of the Airbus A320neo family, which entered service in recent years and hence has only few movements in 2018, the split between engine manufacturers on the previous generation of the type (the A320ceo family) was taken to indicate the likely engine preferences for airlines as they transition their fleets to the new variants. Thus, the percentage split between CFM International (the CFM56-5B engines) and Pratt & Whitney (the V2500-A5 engines) on the A320ceo family aircraft were maintained when defining the split between the CFM LEAP−1A and PW1100G engines on the A320neo aircraft.

3.7.4 For the aircraft type not yet in production, the Boeing 777-X (specifically the −9X variant) the engine type for this aircraft has been announced (as the General Electric GE9X) but certification-based emissions data are not yet available, (certification data are generally released for new engines once the aircraft and engine have entered service). Therefore, the emissions characteristics of the new engine were estimated using publicly-available data for this assessment:

- engine rated thrust: 470kN;
- engine OPR: 60:1; and
- engine specific fuel consumption (sfc): 10 per cent lower than the GE90-115B.

3.7.5 The engine was assumed to use a combustor based on the most advanced that General Electric (GE) currently has in production, that fitted to the GEnx engine. Therefore, the fuel flow rates at the four certification test points were set to be 18 per cent lower than the equivalent values for the GE90−115B (combining 10 per cent lower sfc and 8.5 per cent lower rated thrust), while the emission indices for NO_x were set to those for the GEnx−1B76/P2.

3.7.6 The analyses described in paragraphs 3.7.2 to 3.7.5 defined the engine types (existing and future) which would be fitted to the aircraft operating at the airport in the future years and the proportions of the aircraft types fitted with the relevant engine types.

Times in Mode

3.7.7 With the exception of taxiing and hold, the times-in-mode used for the 2018 baseline have been used for the future years. For reduced-engine taxiing and off-stand APU use the duration depended on the airline. The total duration for each aircraft type in 2018 was summed and pro-rated on the basis of the change in air transport movements (ATMs) for that aircraft type. The duration was then averaged across all aircraft for each aircraft type.

3.7.8 For the future cases, taxiing and hold times were obtained from airport simulation modelling. These gave times for westerly operations both with and without the northern runway in operation (cases with and without Project respectively). The taxi and hold times are shown in Table 3.7.2.

Table 3.7.2: Taxi and Hold Times – Westerly Operations

Mode	Time (minutes)	
	Without Project	With Project
Taxi-in[1]	8.25	9.37
Taxi-out	8.32	8.04
Hold	8.25	6.38

[1] from touchdown

3.7.9 The taxi-in times include the landing-roll times from touchdown to turn-off.

3.7.10 No airport simulation modelling was undertaken for easterly operations, so taxi and hold times were estimated from those for westerly operations. Hold times were assumed to be the same as for westerlies. Taxi-in and taxi-out times were assumed to be the same as taxi-out and taxi-in for westerlies, respectively. This assumption was made on the grounds that the taxiing distances would be similar.

Take-off Thrust

3.7.11 Settings for reduced thrust on take-off are based on the Gatwick and BAA survey data that have been used to derive mean aircraft take-off thrust for each main aircraft type. The mean taken over the calculated values of all movements of that type in the 2018 data.

3.7.12 New aircraft types were assigned suitable take-off thrusts based on averages of the 2018 data.

Ambient Conditions

3.7.13 Corrections for ambient conditions, forward-speed effects and engine spool-up are based on PSDH but updated with new data.

Runway Assignments

3.7.14 Runway assignments for a given hour of the year were the same as those used in the 2018 baseline in order to align with the meteorological conditions used in the dispersion modelling. The direction in which aircraft arrive and depart is largely determined by the wind direction, which of course also strongly affects the dispersion, so it is essential that the correlation between the two is preserved.

3.7.15 For two-runway options, movements also need to be assigned to the north or south runway. For all options with Project all arrivals are assigned to the southern runway. Departures are assigned to both runways, with all daytime departures of class C aircraft assigned to the northern runway and all other departures assigned to the southern runway.

3.8 Ground Support Equipment Emissions

3.8.1 This source category includes all vehicles and plant that generate exhaust emissions airside, principally vehicles associated with aircraft turn-around (vehicles operated by caterers, cleaners and fuel handlers, Ground Power Units and buses) but also vehicles associated with runway maintenance.

3.8.2 The Arup energy team provided forecasts of fuel consumption for GAL and third party vehicles. These included medium-ambition scenarios for the options with Project and baseline scenarios for the options without Project.

3.8.3 Emissions from ground support equipment were calculated from estimates of the annual amount of fuel used airside by various vehicle categories, with emission factors expressed as grams of pollutant per kg of fuel consumed.

3.8.4 For each of the future case options, the fuel consumption projections were used to scale activity data from 2018. The emission factors used for future year scenarios reflect the progression of the airside fleet with older vehicles being replaced by newer ones with tighter emissions standards.

3.8.5 The airport filling station, which supplies fuel to GAL, third party operators and staff, is the primary source of fuel used by vehicles operating airside, but it is also recognised that fuel obtained off-airport (for example brought in by caterers and cleaners with off-airport bases) is used airside. However, this additional source is assumed to be balanced out by GAL and third party fuel obtained from the airport filling station that is used off-airport. All staff fuel is assumed to be used off-airport.

Fuel Apportionment

3.8.6 Each vehicle in the airside vehicle permit (AVP) database was assigned to one of eight principal categories, five for road vehicles (Articulated heavy goods vehicle (HGV), Car, Coach, light goods vehicle (LGV) and Rigid HGV) and three for off-road vehicles (37−75 kW, 75−130 kW and 130−560 kW), determined from information on the vehicle manufacturer and model. Every non-electric vehicle was assumed to have used an equal share, weighted by vehicle size, of the fuel dispensed by the airport filling station, with the proviso of petrol only being apportioned to light duty vehicles (Cars and LGVs).

Emission Factors

Hot-Running Exhaust Emissions

3.8.7 Exhaust emission factors (g pollutant per kg fuel consumed) depend on vehicle category and the ‘Euro’ standard of the vehicle (ie the stage of EU emissions control to which the engine conforms). EU emission limits are different for road and off-road vehicles, both in terms of limit values and introduction dates.

3.8.8 Where possible, the Euro standard was derived from the vehicle registration number, assuming that the vehicle had the minimum Euro standard compatible with its year of registration. In practice, vehicles may be manufactured to a standard higher than the minimum and/or vehicles may be retrofitted with exhaust after-treatment that improves its emission performance over that at manufacture. On the whole, however, year of manufacture is an adequate indicator of Euro standard.

3.8.9 Where it was not possible to derive the year of registration from the vehicle registration number (commonplace for non-road vehicle categories) a weighted average emission factor was applied based on standards in place over the previous ten years (ie effectively assuming a uniform ten year age profile for each vehicle).

3.8.10 The emission-factor data set used takes account of Euro standards already included in EU Directives. For road vehicles, emission factors from COPERT 5 were used. The speed-emission curves include standards up to and including Euro 6 (Euro 6 is split into three stages: up to 2017, 2018−2020 and 2021+) for light duty vehicles (LDVs) and up to Euro VI for HDVs. Fuel consumption values and emission factors for NO_x and PM_{10} were worked out at 32 kph (corresponding to an airside speed limit of 20 mph); $PM_{2.5}$ emission factors were derived from the PM_{10} emission factors using $PM_{2.5}/PM_{10}$ ratios of 0.9 for catalyst-equipped petrol vehicles, 0.8 for non-catalyst petrol vehicles and 0.9 for diesel vehicles, as used in the National Atmospheric Emissions Inventory (NAEI) (Department for Business, Energy and Industrial Strategy (BEIS) and Defra, 2021).

3.8.11 For off-road (specialist) vehicles, exhaust emission factors for Uncontrolled, Stage I, Stage II, Stage IIIA, Stage IIIB and Stage IV diesel vehicles for NO_x and PM (taken to be PM_{10}) and $PM_{2.5}$ were taken from the latest issue of the European Monitoring and Evaluation programme (EMEP)/EEA Guidebook, available on the European Environment Agency website (EMEP/EEA, 2019). The values for Stages I to IV have been taken from the emission limits in the EU Directive 2004/26/EC (European Commission, 2004).

Cold Starts

3.8.12 For NO_x and PM_{10}, the NAEI emission factor compilation contains data on ‘cold starts’ for LDVs, expressed as a quantity of pollutant per trip (BEIS and Defra, 2021). This represents the additional (integrated) amount of pollutant generated near the start of a trip, incurred during the period when the engine (and catalyst if fitted) has not yet reached its normal operating temperature range; this is particularly significant for catalyst-equipped vehicles. There are currently no cold start emission factors for HGVs.

3.8.13 It is difficult to estimate the number of cold starts associated with airside fuel use because of the wide range of duty cycles for airside vehicles and plant. However, even if every airside LDV had two cold starts every day, the contribution to annual NO_x and PM emissions would be around 1 − 2 per cent of the total hot-running emissions. Thus, emissions from airside cold starts were ignored.

Fugitive PM_{10} and $PM_{2.5}$ Emissions

3.8.14 Four sources of fugitive PM_{10} and $PM_{2.5}$ emissions from road vehicles have been included in the 2018 inventory: brake wear, tyre wear, road abrasion and re-suspended road dust. It is worth noting that fugitive emissions are becoming a significant component of total PM_{10} and $PM_{2.5}$ emissions from road vehicles as exhaust emissions fall in response to tightening EU vehicle emission limits.

3.8.15 The fugitive-PM emission factors are expressed in terms of g per km and vary with vehicle category. For road vehicles operating airside, therefore, an estimate of the vehicle-km travelled for each vehicle was derived from the fuel consumed by the vehicle using the appropriate NAEI specific fuel consumption data at 32 kph. For off-road vehicles, it is expected that much of the fuel is used by stationary vehicles/plant so it is difficult to estimate corresponding fugitive-PM emissions. Rather than ignore the contribution, an upper bound on the contribution was included by converting all the fuel used into km travelled using the fuel consumption data for a road vehicle of comparable engine size. This is likely to overestimate the PM emissions from these vehicles by a significant factor, but in practice the resulting emissions contribution is not dominant.

Heating Plant Emissions

3.8.16 Emissions from a given heating plant (g per year) were calculated as the product of the total amount of fuel used, expressed as the energy equivalent of the fuel in MJ per year, and an emission factor (g per MJ).

3.8.17 GAL supplied the annual fuel consumption in (kW-hr) for their facilities for 2018, all the boilers run on natural gas. The facilities listed span a wide range of annual consumptions, with only the North Terminal Boiler House and South Terminal Boiler House having an annual consumption of more than 10^7 kW-hr. GAL also supplied annual fuel consumption (kW-hr) for the Hilton Hotel and estimates were made for other airport facilities including hotels and hangers.

3.8.18 No NO_x or PM stack emission measurement data were available for any of these boilers, so default emission factors (g per MJ) for NO_x and PM_{10} were taken from the EEA Guidebook (EMEP/EEA, 2019). Separate emission factors are given for various categories of fuel usage: for natural gas burning in boilers, the category 'other industrial combustion – natural gas' was selected.

3.8.19 The Arup energy team provided forecasts of natural gas consumption for GAL and third parties and, separately, for standalone third parties. These included medium-ambition scenarios for the future year scenarios with and without the Project. For each of the future year scenarios, the natural gas consumption projections were used to scale emissions from 2018.

3.8.20 Additionally, GAL supplied the total food tonnage processed by their energy from waste facility in 2018. For the future year with Project scenarios, the energy from waste plant would be relocated. The location of the source has been updated for the dispersion modelling using data provided by GAL.

3.8.21 Emission factors (g per MJ) for NO_x and PM_{10} were derived from stack emissions monitoring undertaken in 2017 by Environmental Scientifics.

Fire Training Ground Emissions

3.8.22 The Fire Training Ground (FTG) is included here for the sake of completeness, although the annual emissions of the pollutants of interest are expected to be negligible compared to those from other airport sources, based on previous emission inventories. GAL provided the information that 44,404 litres of liquefied. petroleum gas (LPG) was used in fire training activities during 2018.

3.8.23 LPG is usually a mixture of butane and propane predominantly, in varying proportions depending on the origin, but the emission factor data available are not detailed enough to vary with composition. There are no emission factors specific to the type of operation at the FTG, but it was judged that the NO_x and PM_{10}[11] emission factors from AP−42 (United States Environment Protection Agency, 1995) for the burning of LPG in commercial boilers (0.1 to 3.0 MW) would be reasonably appropriate.

3.8.24 There are no specific data on the $PM_{2.5}/PM_{10}$ ratio for open burning of these fuels, and it was conservatively assumed that the $PM_{2.5}$ mass is equal to the PM_{10} mass. Given the extremely small PM_{10} contribution from the FTG, this approximation has an insignificant impact on the estimate of the total airport-related $PM_{2.5}$ emissions.

3.8.25 Future year emissions from the fire training ground have been kept the same as in 2018 as it is an activity that is independent of the number of ATMs or passengers.

3.9 Road Traffic Emissions

Highway Network

3.9.1 Traffic data was provided by the Arup transport consultants in the form of annual average daily traffic (AADT) flows. The data comprised a fleet mix of cars, LGVs and HGVs split between airport related and non-airport related traffic. Airport-related traffic includes passenger cars, LGVs and HGVs related to the airport's operations, buses, coaches and staff cars.

3.9.2 Road traffic emissions for NOx, PM_{10} and $PM_{2.5}$ were calculated using the 2018, 2024, 2029 and 2030[12] factors from the Defra Emissions Factor Toolkit (EFT) version 10.1 (Defra, 2020) for the assessment of base, construction and operational traffic scenarios.

3.9.3 The primary NO_2 emissions were derived from NOx using the percentage stated in NAEI and presented in Table 3.9.1 (BEIS and Defra, 2021).

Table 3.9.1: Fraction of NOx Emitted by Vehicles as pNO_2

Year	pNO2 Fraction
2018	0.286
2024	0.272
2029	0.240
2030[12]	0.234

3.9.4 Emissions were calculated separately for each vehicle class and then added together for each road link split into airport and non-airport related traffic. Speed data in kilometres per hour were provided for all traffic links from the transport consultants. Junctions and roundabouts were modelled at a reduced speed (20 kph) in accordance with the Defra LAQM Technical Guidance (TG16) guidance (Defra, 2021).

3.9.5 Assumptions and limitations with regards to the road traffic data are discussed in section 5. The traffic data were the outputs of the Simulation and Assignment of Traffic to Urban Road Networks (SATURN) model, which used manual and automatic data count points as input. The geometry of the road network for the baseline, construction and operational traffic scenarios is presented in Appendix 13.4.1 Figure 4.1.1 to Figure 4.1.5.

Car Parks

3.9.6 Information on car park movements was provided by the Arup transport team in the form of daily number of vehicles (cars) entering and leaving each car park for the existing and future year scenarios. Assumptions and limitations of this data are presented in section 5. Emissions were calculated following the Cambridge Environmental Research Consultants (CERC) note on modelling car parks for both street-level and multi-storey car parks (CERC, 2017).

3.9.7 The 2018, 2029 and 2030[12] emission factors for vehicles were taken from Defra's EFT (version 10.1) (Defra, 2021), while cold start emissions were taken from the NAEI database (BEIS and Defra, 2021). The percentage of primary NO_2 emissions was also taken from the NAEI and is presented in Table 3.9.1 (BEIS and Defra, 2021). A speed of 5 kph was assumed in all car parks.

3.9.8 For the airport construction (2024) scenario, in absence of information on car park movements for 2024, the car park movements, emissions and percentage of primary NO_2 emissions for 2029 were used.

3.9.9 The location of car parks included in the assessment for the baseline and future year scenarios are presented in Appendix 13.4.1 Figure 4.1.6 to Figure 4.1.9.

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[11] The AP-42 value applies to 'filterable particulate matter', which is assumed to be all PM_{10}.

[12] 2030 is used as a representative year for 2032 as the Defra EFT currently only predicts up to 2030.The fraction of NOx emitted by vehicles as pNO_2 and value for the regional background oxidant for 2030 have been used for consistency with the year of road traffic emissions.

4 Model Setup

4.1 Model Setup Parameters

4.1.1 The Atmospheric Dispersion Modelling System (ADMS) ADMS-Airport (version 5.0.0.1) (CERC, 2020) was used for this assessment. The ADMS software is widely used for air quality assessments in the UK and ADMS-Airport was the software used for the assessments of both Heathrow and Gatwick airports for the Airports Commission.

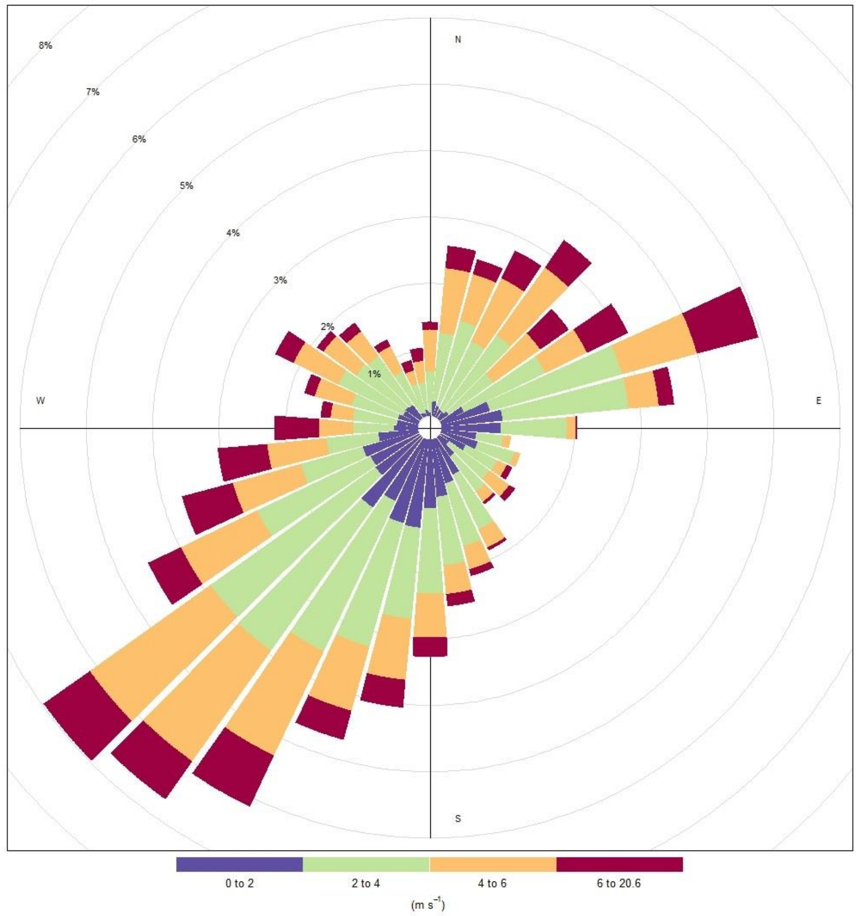
Meteorology

4.1.2 The air quality dispersion model uses hourly sequential meteorological data from which to calculate the boundary layer parameters. Meteorological data from Gatwick Airport were obtained for 2018 for use in this assessment.

4.1.3 Most dispersion models do not use meteorological data if they relate to calm wind conditions, as dispersion of air pollutants is more difficult to calculate in these circumstances. The ADMS-Airport model treats calm wind conditions by setting the minimum wind speed to 0.75 m/s. Defra's LAQM (TG16) guidance (Defra, 2021) states that the meteorological data file is tested by running the meteorological pre-processor of the dispersion model and the relevant output log checked to confirm the number of missing hours and calm hours that cannot be used by the dispersion model. This is important when considering predictions of high percentiles and the number of exceedances. The guidance recommends that meteorological data should only be used if the percentage of usable hours is greater than 75 per cent and preferably greater than 90 per cent.

4.1.4 The 2018 meteorological data from Gatwick Airport includes 97.6 per cent of usable data. This is above the 90 per cent threshold and these data therefore meet the requirement of the Defra guidance. Diagram 4.1.1: Windrose for Gatwick Airport 2018 presents the windrose for the 2018 meteorological data from Gatwick Airport. It can be observed that prevailing winds are south westerly.

Diagram 4.1.1: Windrose for Gatwick Airport 2018



Other Model Parameters

4.1.5 The extent of mechanical turbulence (and hence, mixing) in the atmosphere is affected by the surface/ground over which the air is passing. Typical surface roughness values range from 0.0001 metres (for water or sandy deserts) to 1.5 metres (for cities, forests and industrial areas). In this assessment, a surface roughness of 0.2 metres was used, which matches the conditions at the airport site.

4.1.6 Another model parameter is the Monin-Obukhov length, which describes the minimum level of turbulence in the atmosphere, which can be limited due to the urban heat island effect. For this model, a minimum length of 20 metres was used.

4.2 Spatial Representation

4.2.1 For some sources, for example taxiing, the emissions occur at well-defined spatial locations, in this example along taxiways. For other sources, such as airside vehicles, the location of the emissions is less well defined. For such sources, the total emissions have been calculated and have then been disaggregated over the area within which they typically occur using a surrogate parameter; for airside vehicles, the parameter is the product of aircraft movements and MTOW (see paragraph 4.2.17.

Aircraft-Related Emissions

Aircraft Jet Sources

4.2.2 For modelling purposes aircraft were grouped into modelling categories (MCATs) of aircraft-engine combinations with similar dispersion characteristics, primarily geometry and plume buoyancy. A lead aircraft and representative engine was selected for each aircraft category, the MCATs, lead aircraft and representative engines are presented in Table 4.2.1.

Table 4.2.1: Aircraft modelling categories

MCAT	Typical Aircraft Type	Representative Engine
0	Piston and turboprop aircraft	N/A[1]
1	A319	CFM56−5B5/P
2	A320	CFM56−5B4/3
3	A321	CFM56−5B3/P
4	B757-200	RB211−535E4
5	B787−900	Trent 1000-J2
6	B777−200	GE90−85B
7	B777−200	Trent 895
8	B747−400	CF6−80C2B1F
9	A380−800	GP7270
10	A320 neo	LEAP−1A26/26E1

[1]Piston and turboprop aircraft were modelled as passive releases (ie no jet buoyancy characteristic).

Taxiing and Hold

4.2.3 The taxiway system on the airport was represented by a network of nodes joined by straight-line links. Each taxiing route was composed of a series of straight-line segments.

4.2.4 For the purpose of modelling taxiing routes, taxi-out from all stands in a given stand group to a given hold point were represented by a single taxiing route, taken from a representative point within the stand group. Taxi-out emissions assigned to a given taxi-out route were then distributed uniformly along the route.

4.2.5 A similar approach was used for taxi-in emissions. Taxi-in routes were devised for each runway exit/stand group pair and are shown in Appendix 13.4.1 (Figures 5.2.1 to 5.2.3).

4.2.6 Similarly, holding emissions for a given hold point were assigned to a line source joining the taxiway to where aircraft would join the runway for the corresponding hold point (Figure 5.2.4 to 5.2.6 in Appendix 13.4.1).

Take-Off Roll and Landing Roll

4.2.7 Take-off roll emissions for a given flight were distributed along the runway between a start-of-roll point and a wheels-off point (Figure 5.2.7 in Appendix 13.4.1). As a result of engine spool-up and the forward-speed effect, the acceleration of the aircraft is not constant; this has been taken into account in the model using the data provided in the '.sec' file which spatially distributes the roll emissions.

4.2.8 Landing-roll emissions were distributed between the touchdown point and runway exit (Figure 5.2.8 in Appendix 13.4.1), assuming a constant deceleration from a touchdown speed of 130 knots to a taxiing speed of 15 knots.

Initial Climb, Climb-Out and Approach

4.2.9 Climb profiles were stylised as two straight-line segments: from the end of roll to throttle-back (at 1,000 ft or 1,500 ft) and from throttle-back to 3000 ft. Departure tracks were assumed to continue in the direction of the runway up to 3,000 ft (Figure 5.2.7 in Appendix 13.4.1). Aircraft may start to turn below this height, but the positional deviation caused by the approximation would only affect emission contributions that have an insignificant impact on ground-level concentrations.

4.2.10 The NTK data were analysed to give the average distances to reach throttle-back height and to reach 3,000 ft for each aircraft type. These were used to work out a mean initial climb angle and a mean climb-out angle for each aircraft group.

4.2.11 Approach emissions were represented as two co-linear line segments aligned with the runway (from 3,000 ft height to 2,000 ft height and then from 2,000 ft height to touch down) at a 3° angle to the horizontal. The total emissions for each segment were distributed uniformly along the corresponding line segment (Figure 5.2.8 in Appendix 13.4.1).

Brake and Tyre Wear

4.2.12 Brake and tyre wear during landing were represented in the model as volume sources on the runway. The modelled brake and tyre wear locations are shown in Appendix 13.4.1, Figure 5.2.9.

APU Emissions

4.2.13 On-stand APU emissions were calculated separately for each stand as GAL's aircraft movement database included flight-by-flight data on-stand used (including stands in the maintenance area). A volume source (50 metres × 50 metres × 12 metres) was located at each stand.

4.2.14 Off-stand APU emissions were assigned to the devised taxi-in and taxi-out routes.

4.2.15 The locations of the modelled APU emissions are shown in Appendix 13.4.1 (Figure 5.2.10 to 5.2.12).

Engine Testing

4.2.16 The test log used for calculating emissions from engine ground runs gave the location of individual tests, identified as particular named or numbered areas on the airport, as shown in Appendix 13.4.1 (Figure 5.2.13). A volume source (50 metres × 50 metres × 15 metres) was modelled at each location.

Airside Support Vehicles/Plant

Ground support equipment

4.2.17 Airside vehicle emissions were assigned to stands in proportion to the 'airside activity' at the stands. To calculate airside activity, each aircraft movement was assigned a 'weight' to represent its contribution to airside activity in terms of demand for airside services. The weighting factor was taken to be the MTOW for the aircraft. Emissions associated with a stand were assigned to a volume source (50 metres × 50 metres × 3 metres) at the stand. The locations of the modelled ground support equipment are shown in Appendix 13.4.1 (Figure 5.2.14 to 5.2.16).

Heating Plant

4.2.18 Emissions from the boiler houses and the energy from waste plant were treated as point sources. The boiler houses (one at the North Terminal and one at the South Terminal) are shown in Appendix 13.4.1 (Figure 5.2.17 and 5.2.18).

Fire Training Ground

4.2.19 Emissions from the fire training ground were assigned to a volume source (50 metres × 50 metres × 20 metres) located as shown on Figure 5.2.13 in Appendix 13.4.1.

Road Traffic

Highway Network

4.2.20 Emissions from road traffic are modelled as road sources. The ArcGIS geospatial software was used to assist in inputting road link information into the air quality model. The modelled roads are shown in Appendix 13.4.1 (Figure 4.1.1 to 4.1.5). Widths for the roads were calculated using the Ordnance Survey (OS) MasterMap layer or satellite imagery.

Car Parks

4.2.21 Emissions from street level car parks were modelled as area sources and emissions from multi-storey car parks were modelled as volume sources. The location of the modelled car parks are presented in Appendix 13.4.1 (Figure 4.1.6 to 4.1.9).

4.3 Temporal Variation

4.3.1 Temporal variation refers to variations during a day (diurnal variation) and/or between seasons. The temporal variation of emissions is represented in the dispersion model by use of temporal profiles. The level of detail needed in temporal profiles depends on the significance given to peak short-period concentrations and how these are estimated, which are matters to be considered at the dispersion modelling stage. Annual-mean concentrations are less sensitive to the details of the temporal profiles.

4.3.2 The highest resolution of temporal variation (shortest time period) that can be modelled in ADMS-Airport is the time resolution of the meteorological data, which is one hour.

Aircraft-Related Emissions

4.3.3 Aircraft exhaust emissions in the LTO flight phases were calculated at a time resolution of one hour based on the hourly data supplied in the 2018 baseline. This variation automatically incorporates diurnal and seasonal changes in the number and type of aircraft movements, systematic variations in ground-movement times-in-mode and the impact of diurnal and seasonal variations in ambient temperature and pressure. In the modelling of future years, the temporal variation was simplified as described in paragraph 3.7.1.

Airside Support Vehicles/Plant

4.3.4 Airside vehicles emissions were distributed among stands in proportion to the 'airside activity' (product of movements and aircraft MTOW), which is derived from the breakdown of aircraft movements by stand. These data were also used to provide temporal profiles of airside-vehicle emissions that vary with stand.

4.3.5 Other sources, such as the boiler-house emissions and the fire training ground, were assigned a uniform temporal profile.

Road Traffic

4.3.6 No temporal variation was applied to the highway network and car parks as the data were unavailable for this assessment.

4.4 Results Processing

NOx to NO_2 Conversion

4.4.1 The model predicts roadside NOx concentrations and therefore a suitable NOx to NO_2 conversion needs to be applied to the modelled concentrations. The method used for this conversion in the assessment follows the approach described by Clapp and Jenkin (2001), which takes account of the proportion of primary NO_2 in the balance between NO and NO_2 and derives total NO_2 concentrations as a function of distance from major sources.

4.4.2 The method requires a value for the regional background oxidant, which was taken to be 33.5 parts per billion (ppb) in 2008 (Clapp and Jenkin, 2001) and was projected to increase by +0.1 ppb/year for future years, giving a value of 34.5 ppb for 2018, 35.1 ppb for 2024, 35.6 ppb for 2029 and 35.7 for 2030[12].

Background concentrations

4.4.3 The Defra website (Defra, 2021) includes estimated background air pollution concentrations for each 1 km by 1 km OS grid square in the UK. The background concentrations for the modelled receptors are presented in Appendix 13.6.1.

5 Assumptions and Limitations

Table5.1.1: Assumptions and Limitations of the Air Quality Assessment

Project Item	Assumption/Limitation
Road traffic	No temporal profile has been applied to road traffic.
	For road links outside of London, vehicle emissions for 'England (not London)' have been used in the Defra EFT tool. For road links in London, vehicle emissions for 'London' have been used in the Defra EFT tool.
Car parks	No temporal profile has been applied to car parks.
	Cold start emissions have been calculated, assuming all cars are diesel, providing a conservative estimate.
	The BA car park is assumed to have the same number of movements as Car Park W for the 2018 Baseline scenario. It is assumed that the number of movements are the same, assuming no growth in future years. This is due to the similar size and category of the car park, as advised by Arup transport consultants.
	Vehicle speed is assumed to be 5 kph for all car parks.
	The higher number of daily in/out movements provided by Arup transport consultants was used for calculations of emissions to provide a conservative estimate for all car parks.
	If the in/out movements provided by the Arup transport consultants were for road links that may be entry/exit points for multiple car parks the number of movements were distributed across the car parks according to gross floor area.
	Car parks with decking were modelled as a multi-storey car park, represented in the ADMS model as a volume source.
Construction dust	Option 2 for central airfield maintenance and recycling (CARE) facilities has been used in the assessment as it has a larger surface area and is located closer to sensitive receptors, allowing for a conservative approach.
	Trackout has only been considered for access to contractor compounds as details about the route of HGVs within the Project have not been provided.
Heating plant emissions	It is assumed that the heating plant emissions would be dominated by those servicing the needs of on-airport buildings therefore only heating plants that are sited within the current airport perimeter are included in the airport inventory.
Airport construction sources	Any construction sources of PM_{10} or $PM_{2.5}$ on the airport during the period of interest are not included in the airport emissions inventory.
Taxi-out emissions	The assessment assumes all engines are lit during pushback due to lack of specific information on when engines are lit for each aircraft type and operator. It is assumed that all engines are shut down immediately when the aircraft reaches the stand. It is judged that each assumption would compensate the other.
Aircraft engine type	If there was no engine type identifier available a default engine based on the most common engine for that aircraft type was used. If there was no data providing an engine for a particular aircraft type, a typical engine according to standard aircraft reference sources was assigned to the aircraft.
Aircraft emission factors for PM_{10}	The ICAO databank contains measured non-volatile PM_{10} emission factors for only a small number of newer engines. For older engines, the methodology in CAEP guidance was used to derive non-volatile PM_{10} emissions. The guidance was also used to estimate volatile sulphate and organic PM_{10} emissions for all aircraft engines.
Aircraft $PM_{2.5}$ exhaust emissions	It was assumed that the mass of $PM_{2.5}$ in aircraft exhaust equals the mass of PM_{10} (for both volatile and non-volatile components).
Aircraft emissions of pNO_2	Aircraft emissions of pNO_2 were derived from the fractions presented in the PSDH methodology. These factors were 4.5 per cent pNO_2 at 100 per cent thrust, 5.3 per cent at 85 per cent thrust, 15 per cent at 30 per cent thrust and 37.5 per cent at

Project Item	Assumption/Limitation
	7 per cent thrust. Linear interpolation was used for intermediate thrust settings.
Aircraft Engine spool-up	NOx emission index for all engines and aircraft types was kept constant during the transient phase as that applicable at take-off thrust so the net effect of spool-up on estimated emission rate derives solely from the lower fuel flow rate.
	The effects of engine spool-up has been ignored for PM_{10} and $PM_{2.5}$ in line with the PSDH recommendation.
Aircraft taxiing	Fuel flow rates for engine types other than Rolls Royce were estimated to be set 17.5 per cent lower, and for Rolls Royce engines 32.5 per cent lower than the ICAO 7 per cent value because survey results suggested lower thrust settings were used. These values applied to all periods of taxiing and hold. The NOx and PM_{10} emission indices at the lower fuel flow rate were held the same as the value at 7 per cent thrust.
Aircraft take-off thrust	Take-off thrusts for BA used the 2055/6 inventory. Updated survey was undertaken for TUI, Thomas Cook, EasyJet and Virgin Atlantic data with aircraft using the average value over all jet aircraft types with the same number of engines was used.
Aircraft climb-out thrusts	The following thrusts were used in this assessment: 85 per cent for take-off thrust settings between 100 per cent and 90 per cent; 78 per cent for take-off thrust settings between 90 per cent and 80 per cent; 70 per cent for take-off thrust settings between 80 per cent and 75 per cent (the normal lower limit on take-off thrust) and set climb-out thrust equal to take-off thrust if take-off thrust is less than 75 per cent (for particular cases where an aircraft type is specifically certificated for take-off at less than 75 per cent).
Aircraft initial climb and climb-out	Sample NTK data from Gatwick, covering all departures for eight representative days from 2018, were used to derive average times in initial-climb and climb-out for a number of aircraft types. For defined 'Heavy' and 'Medium' aircraft types,

Project Item	Assumption/Limitation
	the NTK data were analysed for times and distances to 1,000 ft rather than 1,500 ft.
Aircraft brake and tyre wear	Brake and tyre wear was calculated using methodology from the Gatwick 2005/6 emissions inventory and used the same $PM_{2.5}$ fractions of PM_{10} (40 per cent for brake wear and 70 per cent of tyre wear).
GSE	All staff fuel is assumed to be used off-airport.
	The Euro standard was derived from vehicle registration number, assuming that the vehicle had the minimum Euro standard compatible with its year of registration. Where registrations were not available a uniform ten-year age profile for each vehicle was assumed.
FTG	It was conservatively assumed that the $PM_{2.5}$ mass is equal to the PM_{10} mass for open burning of LPG.
Aircraft take-off roll and landing roll	Landing-roll emissions were distributed between the touchdown point and runway exit, assuming a constant deceleration from a touchdown speed of 130 knots to a taxiing speed of 15 knots.
Aircraft departure tracks	Departure tracks were assumed to continue in the direction of the runway up to 3,000 ft.
Future aircraft diurnal profiles	The diurnal profile of movements was assumed using a uniform distribution of movements within each period (Day, Evening and Night). In the absence of movement data for each day of the year, the annual profile of movements was assumed to be flat as a conservative assumption.

6 References

6.1 Legislation

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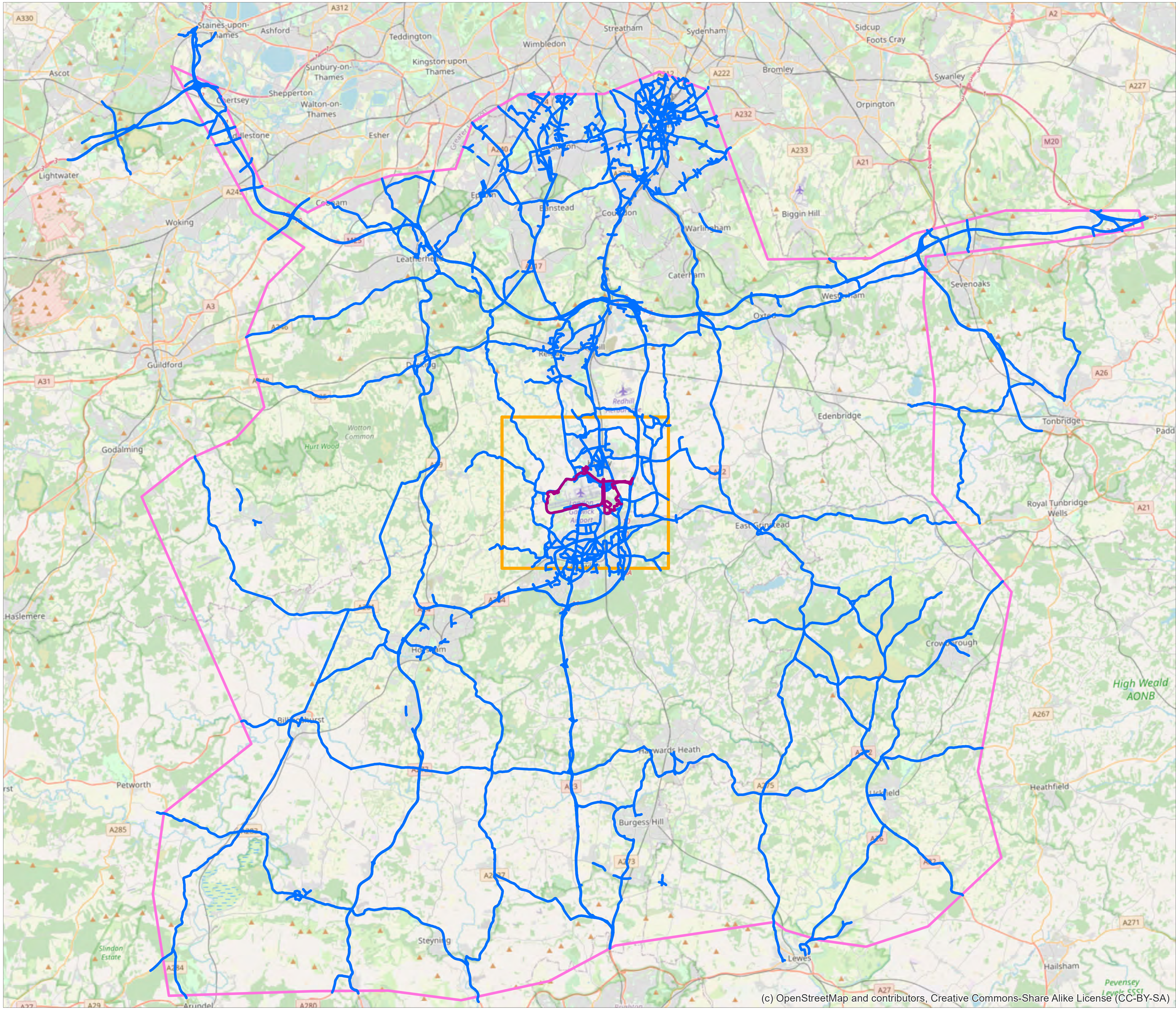
7 Glossary

7.1 Glossary of Terms

Table 7.1.1 Glossary

Term	Description
AADT	Annual Average Daily Traffic
ADMS	Atmospheric Dispersion Modelling System
AEROCERT	Aircraft Environmental Impacts and Certification Criteria
APU	Auxiliary Power Unit
ATM	Air Transport Movement
ATOW	Actual Take-off Weight
AVP	Airside Vehicle Permit
BA	British Airways
BAA	British Airports Authority
BEIS	Business, Energy and Industrial Strategy
CAA	Civil Aviation Authority
CAEP	Committee on Aviation Environmental Protection
CARE	Central airfield maintenance and recycling
CERC	Cambridge Environmental Research Consultants
CLB	Climb setting
CO	Carbon monoxide
CO_2	Carbon dioxide
CoCP	Code of Construction Practice
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
EASA	European Union Aviation Safety Agency
ECS	Environmental Control Systems
EEA	European Environment Agency
EEA	European Environment Agency
EFT	Emissions Factors Toolkit
EMEP	European Monitoring and Evaluation programme
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FOCA	Federal Office of Civil Aviation
FOI	Swedish Defence Research Agency
FTG	Fire Training Ground
GAL	Gatwick Airport Limited
GB	Great British
GE	General Electric
GIS	Geographic Information System
GSE	Ground Support Equipment
HC	Hydrocarbons
HDV	Heavy Duty Vehicles
HGV	Heavy Goods Vehicle
HRA	Habitats Regulations Assessment
IAQM	Institute of Air Quality Assessment
ICAO	International Civil Aviation Organisation
IDAHO	Gatwick's airport operational management system
ISA	International Standard Atmosphere
LDV	Light Duty Vehicle
LGV	Light Goods Vehicle
LPG	Liquefied petroleum gas
LTO	Landing and Take-off
MCATs	Modelling categories
MES	Main Engine Start
MTOW	Maximum Take-Off Weight
NAEI	National Atmospheric Emissions Inventory
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Oxides of nitrogen
NTK	Noise and Track-Keeping
OAT	Outside air temperature
Off-chox	The time an aircraft leaves a stand
On-chox	The time an aircraft arrives at a stand
OPR	Overall Pressure Ratio
OS	Ordnance Survey
PAHs	Polycyclic Aromatic Hydrocarbons
PEIR	Preliminary Environmental Information Report
PLTOW	Performance Limited Take-Off Weight
PM_{10} and $PM_{2.5}$	Particulate matter
pNO_2	Primary nitrogen dioxide
ppb	Parts per billion

Term	Description
PSDH	Project for the Sustainable Development of Heathrow
SATURN	Simulation and Assignment of Traffic to Urban Road Networks
sfc	Specific fuel consumption
SN	Smoke number
UID	Unique Engine Identifier
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe



YOUR LONDON AIRPORT
Gatwick

- Project Site Boundary (PEIR)
- 11 km x 10 km Domain
- Wider Study Area
- Modelled Road Network

DOCUMENT
Preliminary Environmental Information Report

DRAWING TITLE
Modelled Road Network for 2018 Baseline Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
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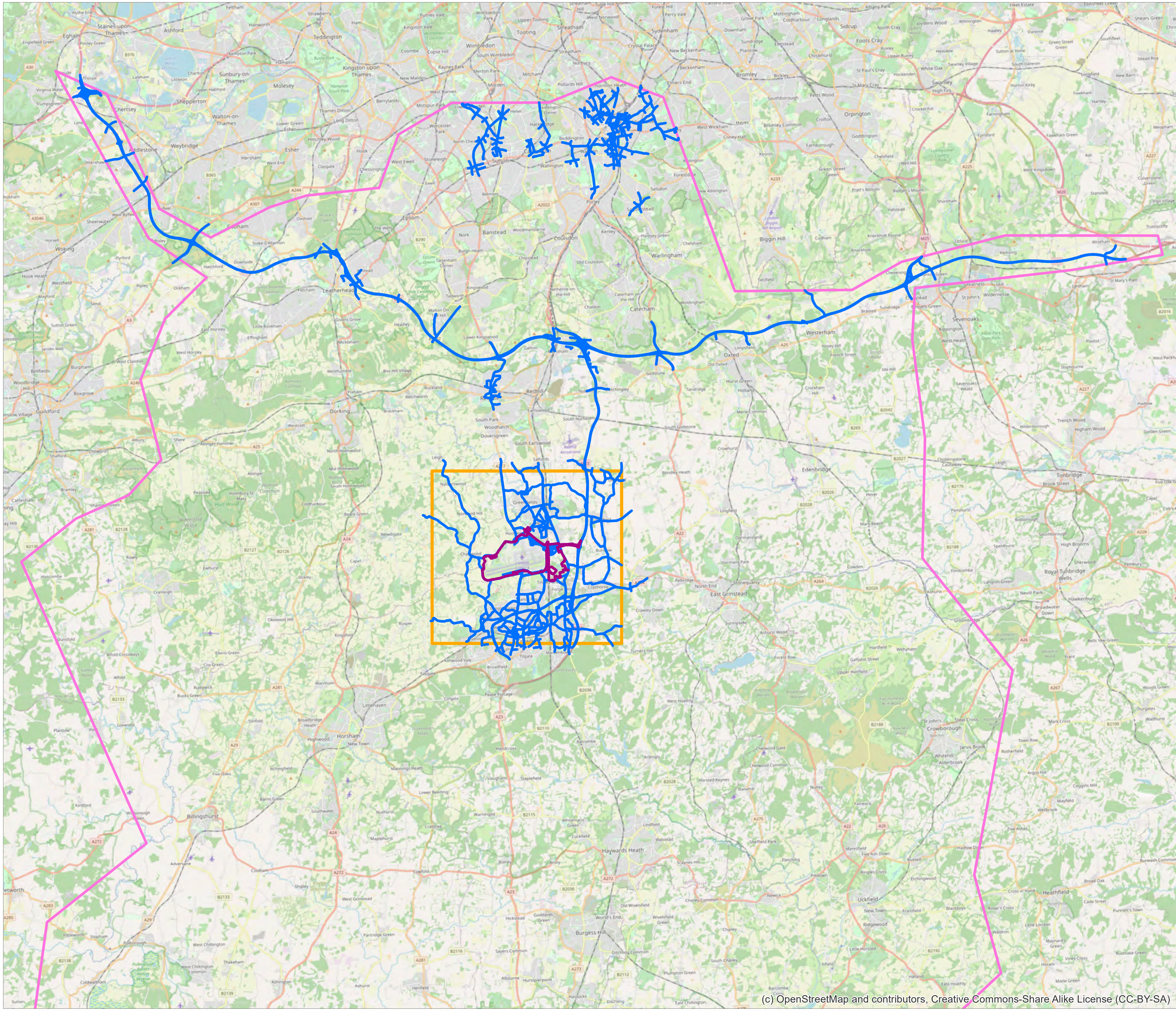

YOUR LONDON AIRPORT
Gatwick

- Project Site Boundary (PEIR)
- 11 km x 10 km Domain
- Wider Study Area
- Modelled Road Network

DOCUMENT
Preliminary Environmental Information Report

DRAWING TITLE
Modelled Road Network for Construction 2024 With and Without Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.2	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

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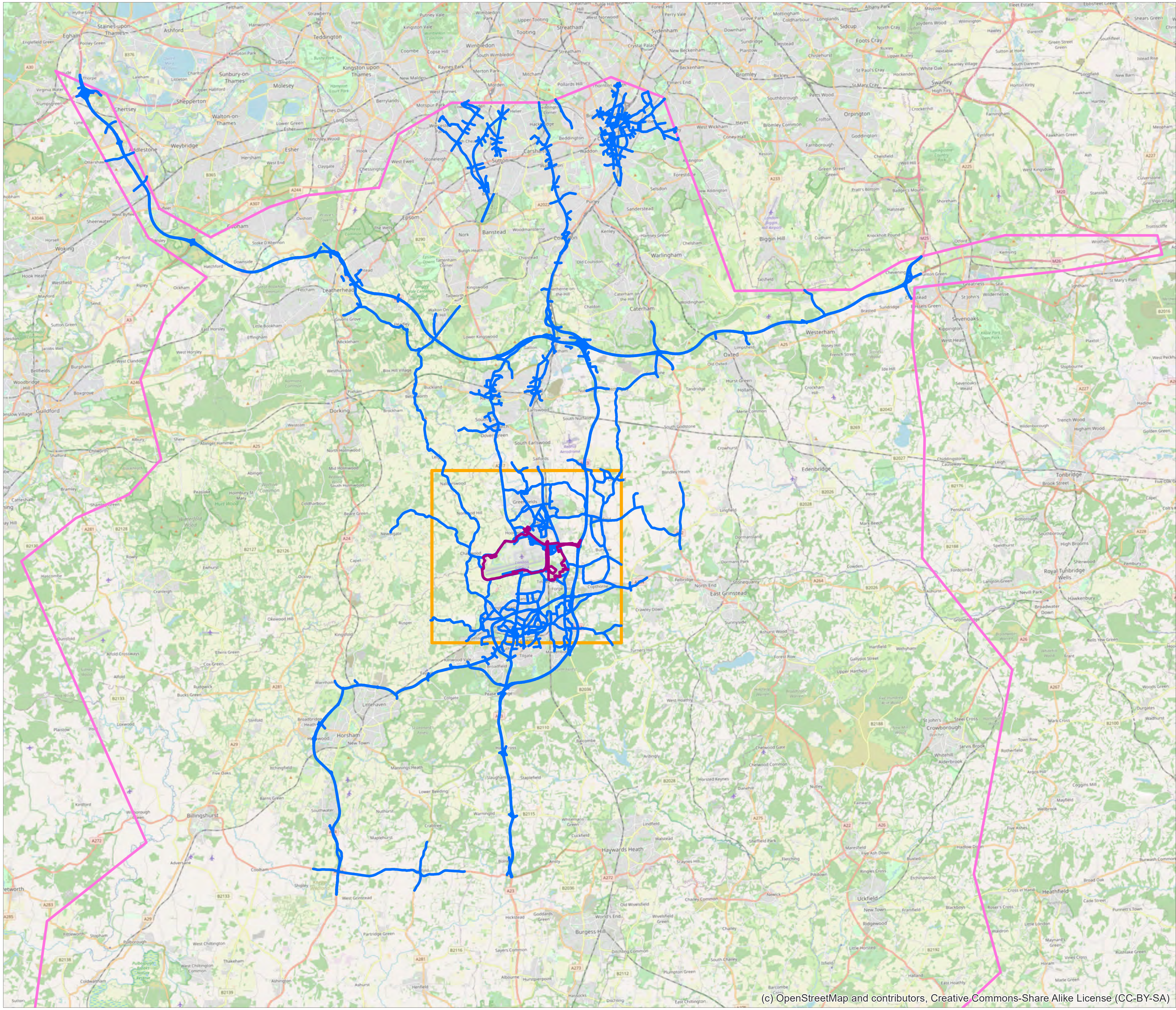

YOUR LONDON AIRPORT
Gatwick

- Project Site Boundary (PEIR)
- 11 km x 10 km Domain
- Wider Study Area
- Modelled Road Network

DOCUMENT

Preliminary Environmental Information Report

DRAWING TITLE

Modelled Road Network for Construction 2029 With and Without Project Scenarios

DATE

September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.3	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
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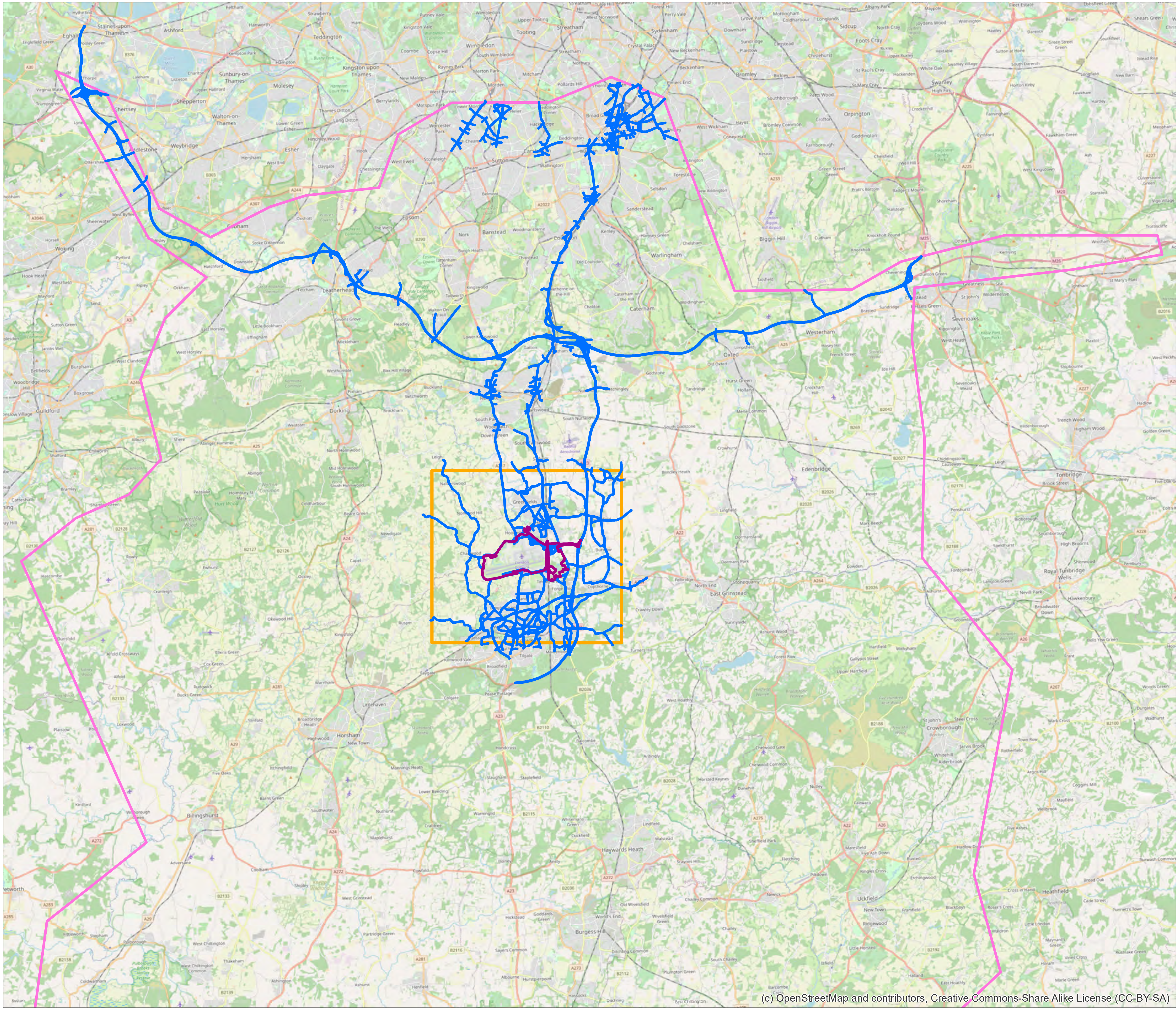

YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
11 km x 10 km domain
Wider Study Area
Modelled Road Network

DOCUMENT
Preliminary Environmental Information Report

DRAWING TITLE
Modelled Road Network for Operational 2029 With and Without Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
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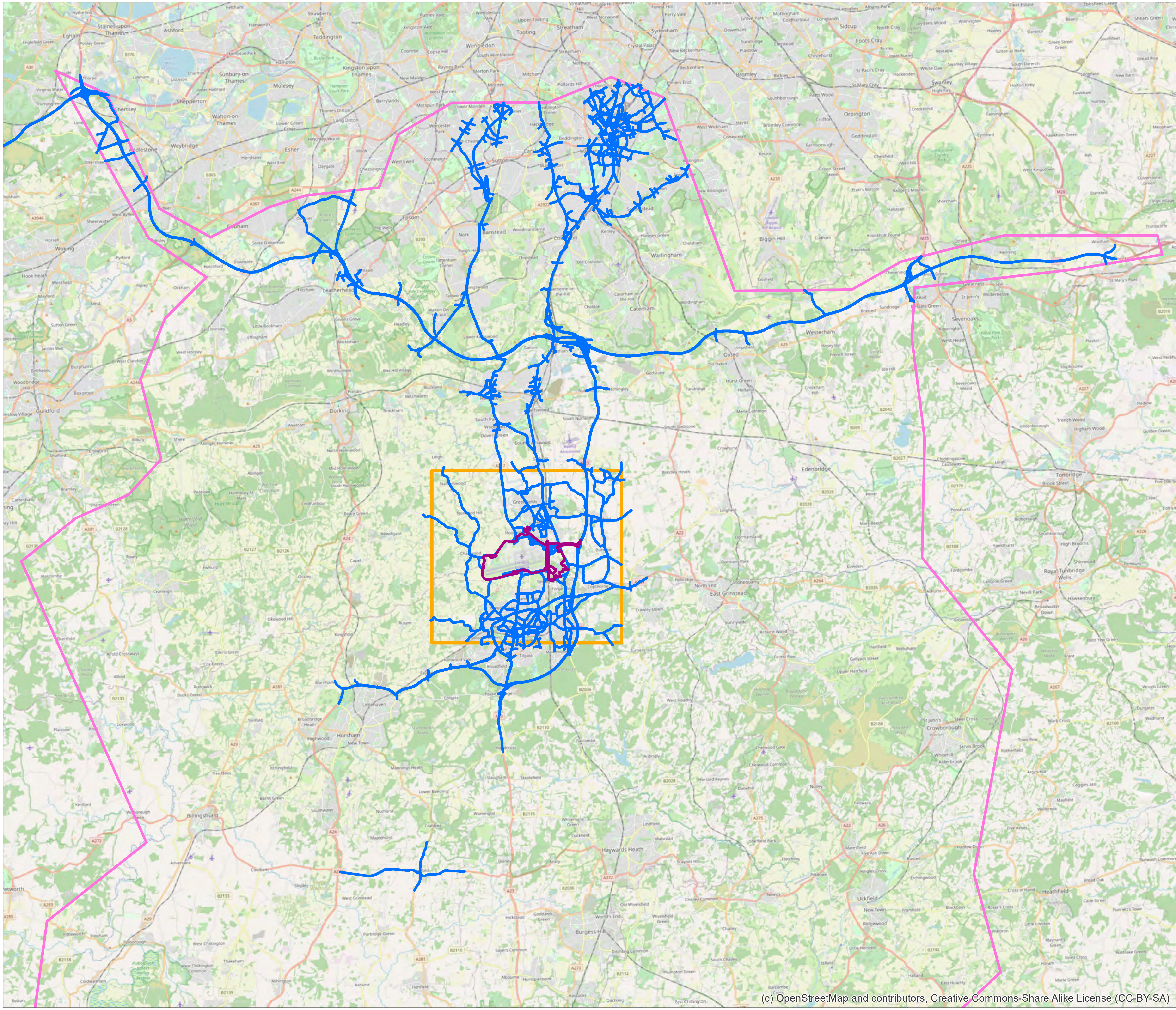

YOUR LONDON AIRPORT
Gatwick

- Project Site Boundary (PEIR)
- 11 km x 10 km Domain
- Wider Study Area
- Modelled Road Network

DOCUMENT
Preliminary Environmental Information Report

DRAWING TITLE
Modelled Road Network for Construction 2032 With and Without Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.5	For PEIR Issue
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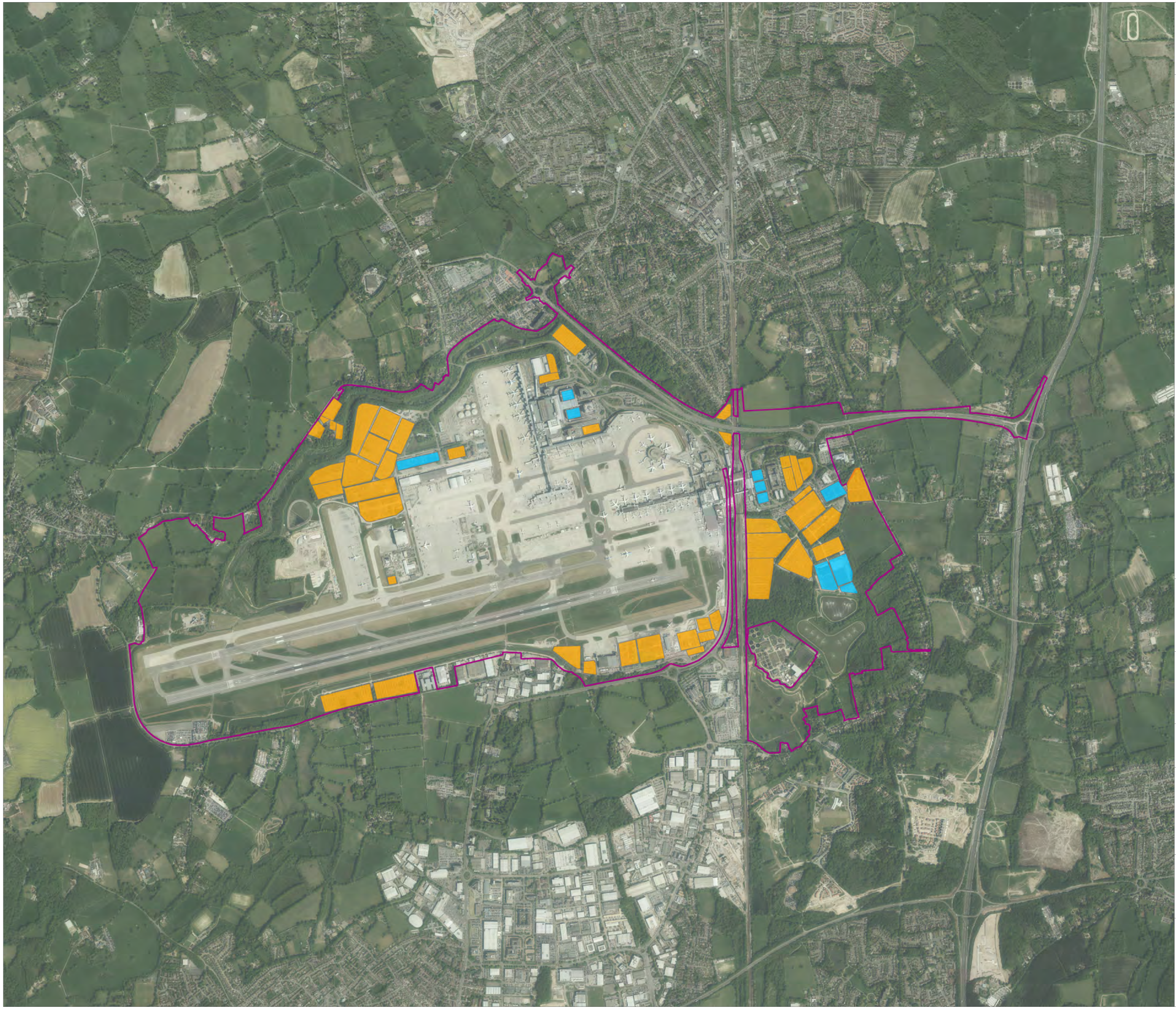


YOUR LONDON AIRPORT Gatwick

DOCUMENT

Preliminary Environmental Information Report

DRAWING TITLE

Location of Modelled Car Parks for the 2018 Baseline Scenario

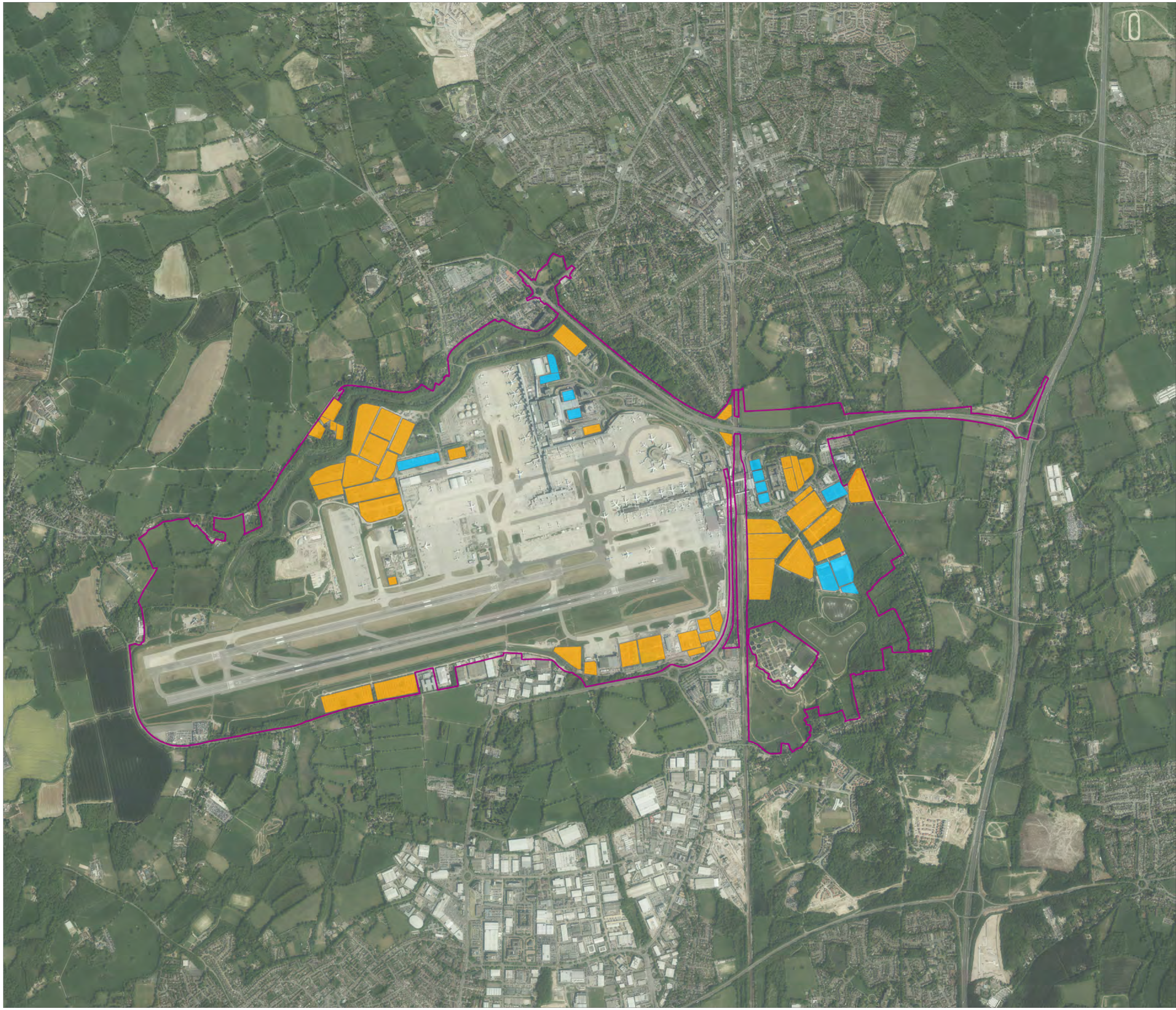
DATE

September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.6	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:22,625

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Modelled Surface Car Park
Modelled Multi-storey Car Park

DOCUMENT
Preliminary Environmental Information Report

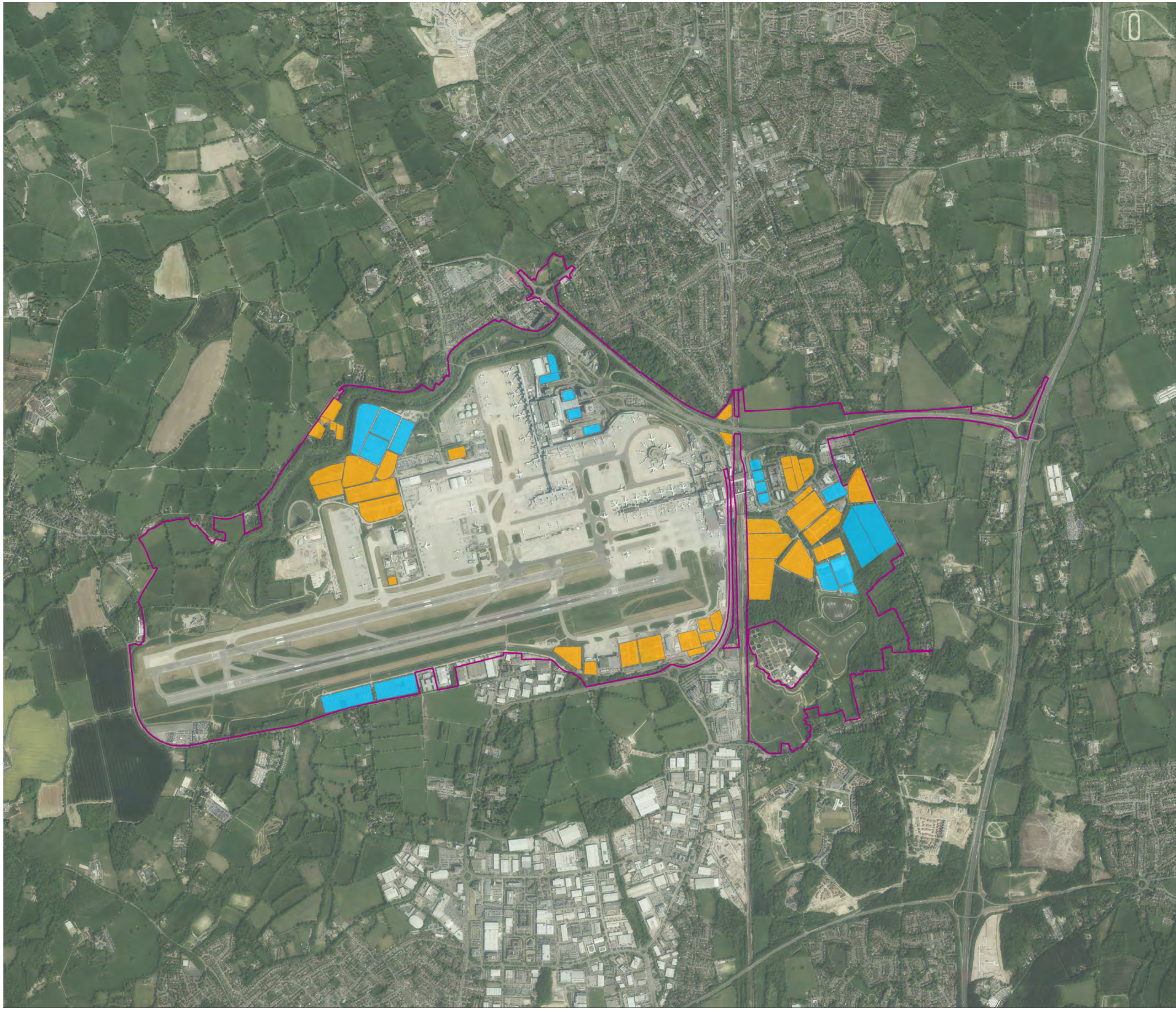
DRAWING TITLE
Location of Modelled Car Parks for the Without Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.7	For PEIR Issue
	DRAWN BY TC	PM / CHECKED BY MK

SCALE @ A3 1:22,625

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Modelled Surface Car Park
Modelled Multi-storey Car Park

DOCUMENT
Preliminary Environmental Information Report

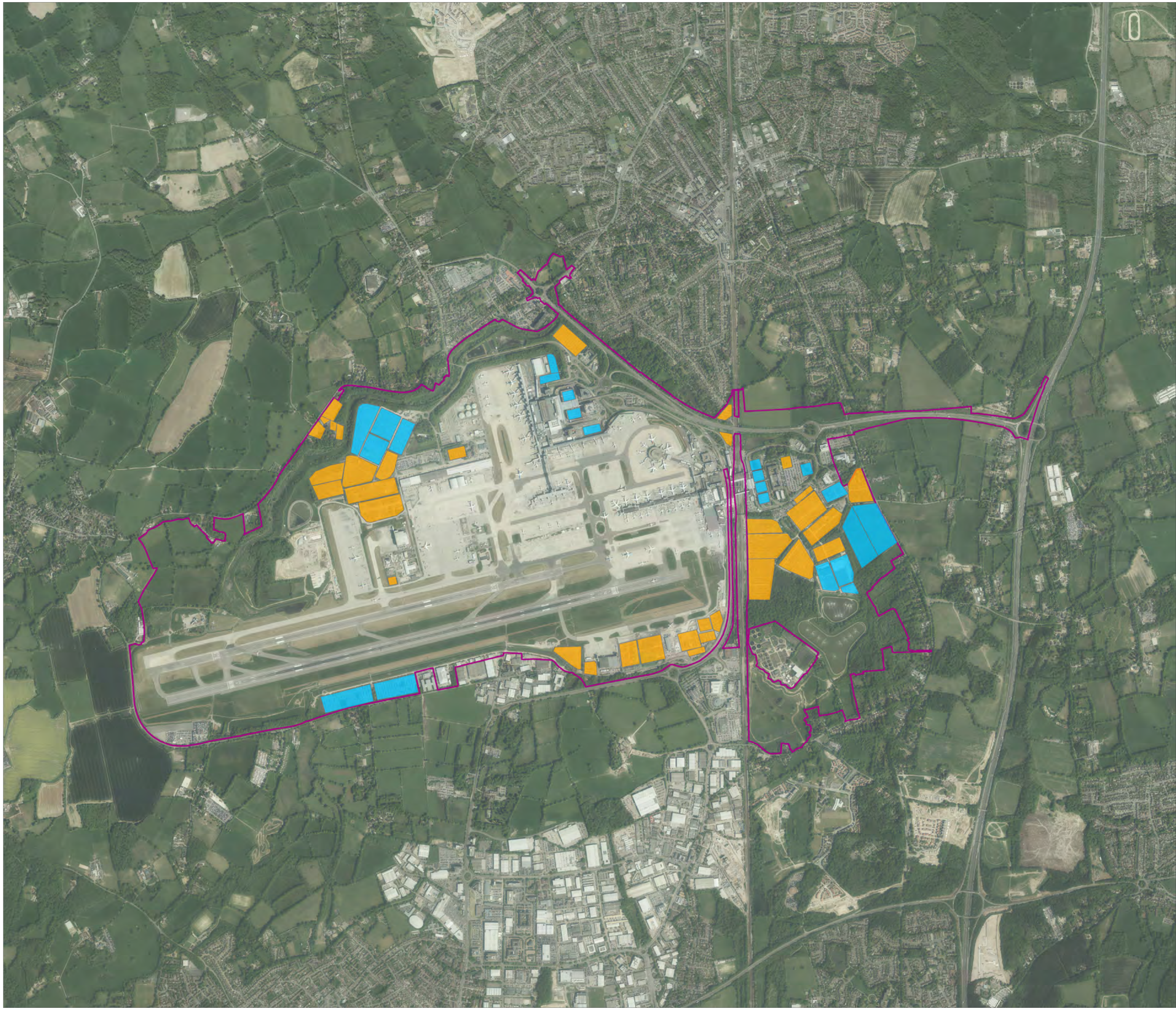
DRAWING TITLE
Location of Modelled Car Parks for the 2029 With Project Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.8	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:22,625

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Modelled Surface Car Park
Modelled Multi-storey Car Park

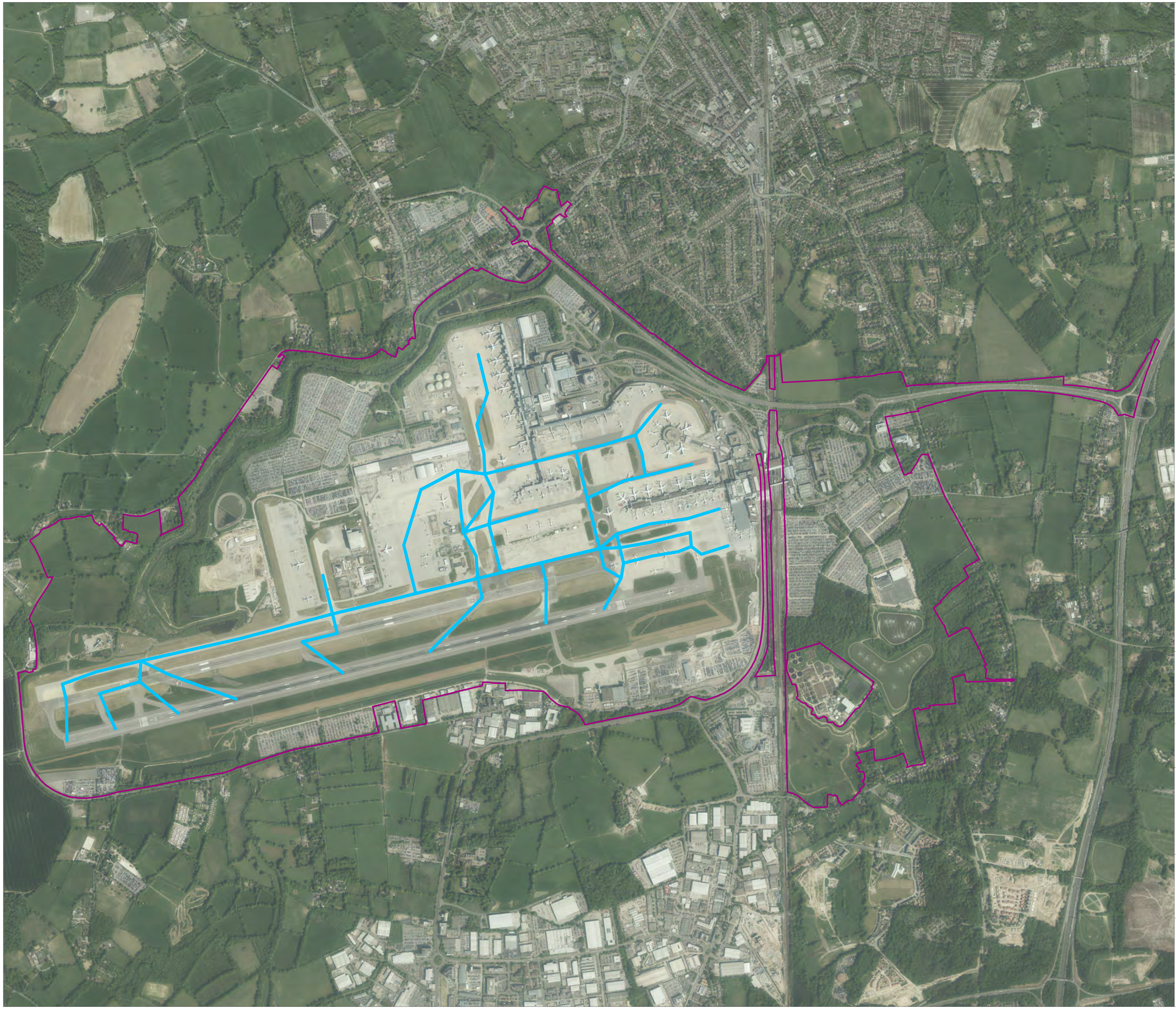
DOCUMENT
Preliminary Environmental Information Report

DRAWING TITLE
Location of Modelled Car Parks for the 2032 With Project Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 4.1.9	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:22,625



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Taxi In

DOCUMENT
Preliminary Environmental Information Report

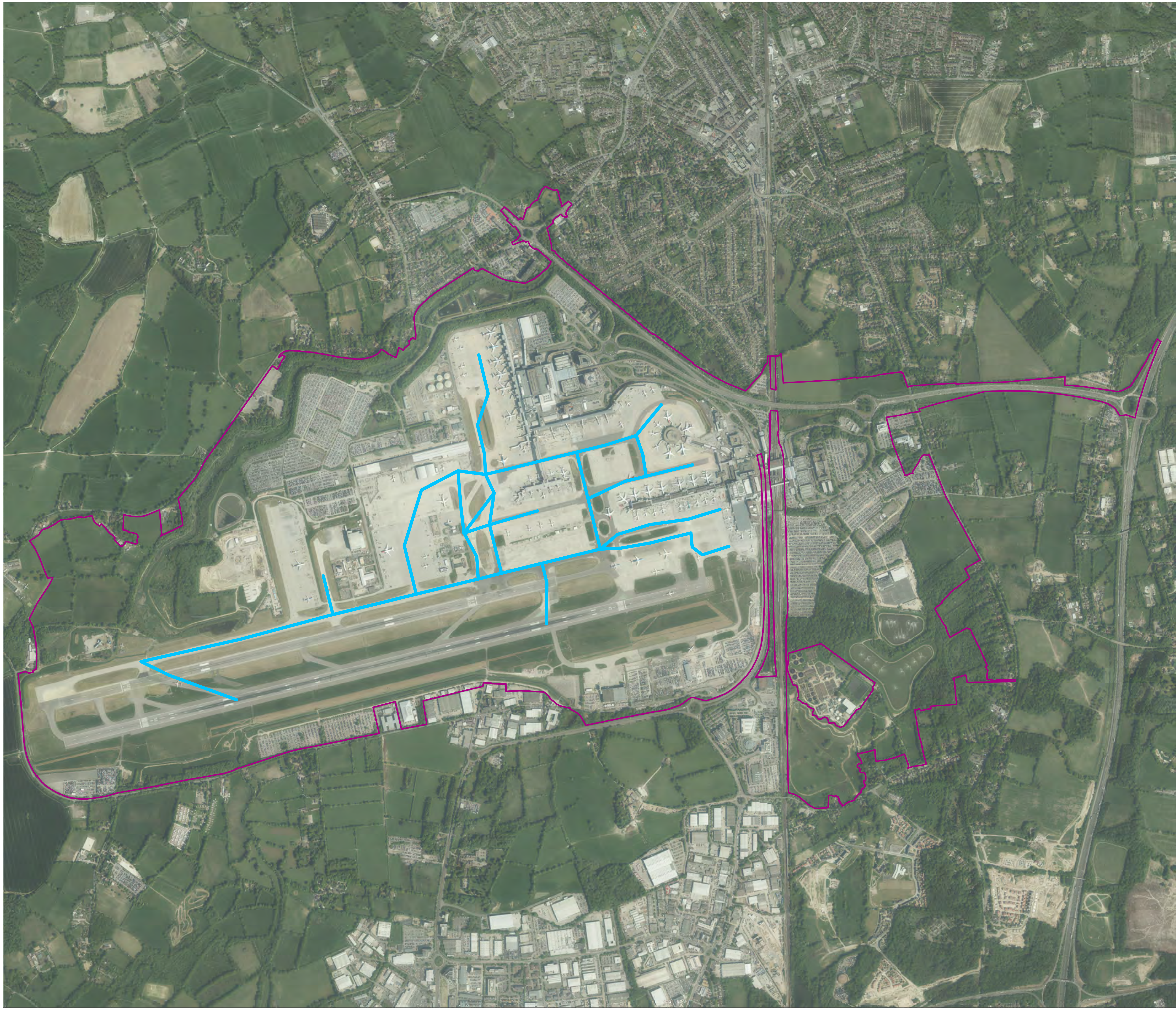
DRAWING TITLE
Modelled LTO Sources - Taxi In for 2018 Baseline Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.1	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Taxi In

DOCUMENT
Preliminary Environmental Information Report

DRAWING TITLE
Modelled LTO Sources - Taxi In for Without Project Scenarios

DATE
September 2021

ORIENTATION
N

DRAWING NO.
APPENDIX 13.4.1 FIGURE 5.2.2

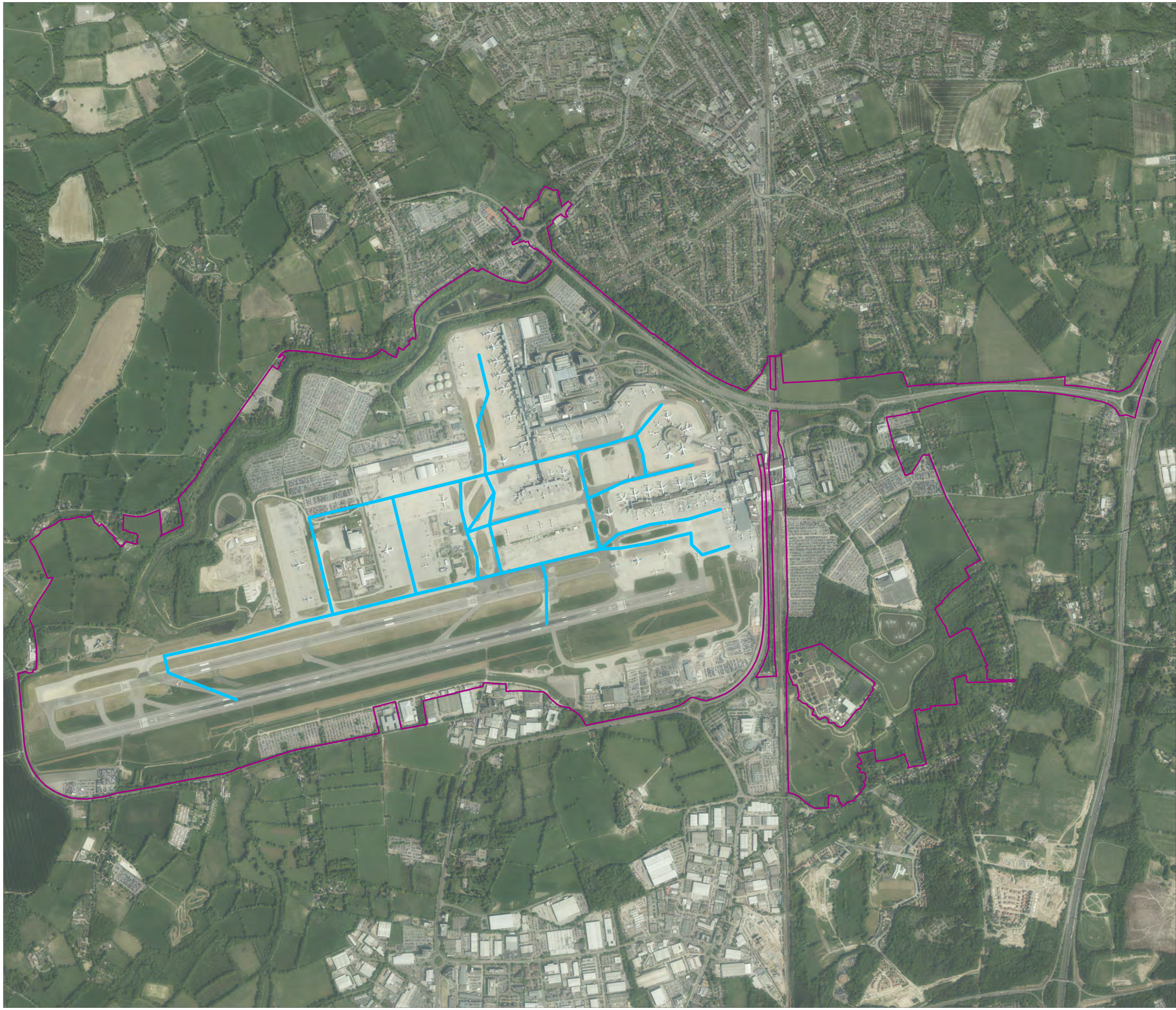
REVISION
For PEIR Issue

DRAWN BY
TC

PM / CHECKED BY
MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT Gatwick

Project Site Boundary (PEIR)

Taxi In

DOCUMENT

Preliminary Environmental Information Report

DRAWING TITLE

Modelled LTO Sources - Taxi In for With Project Scenarios

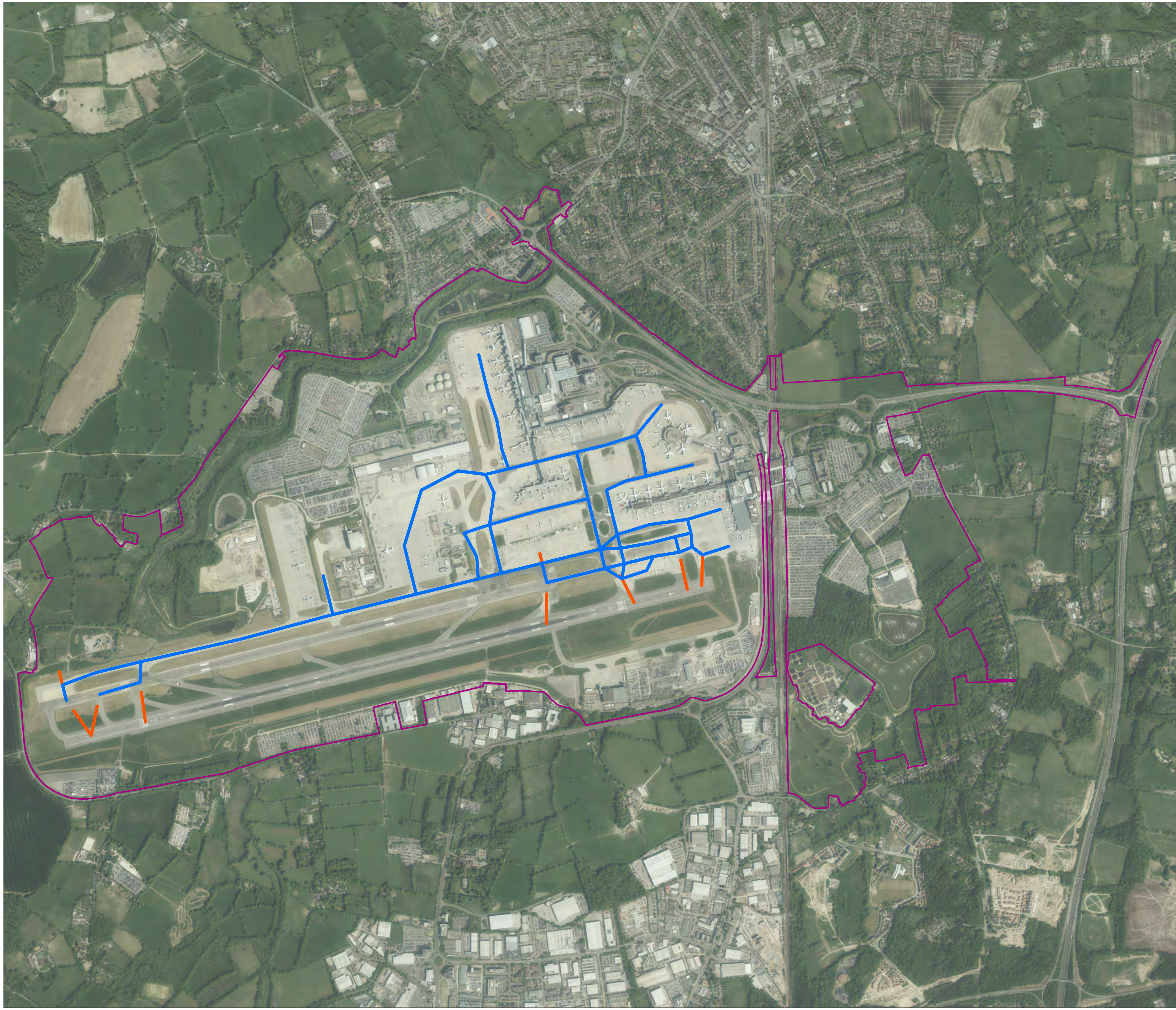
DATE

September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.3	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Taxi Out
Hold

DOCUMENT
Preliminary Environmental Information Report

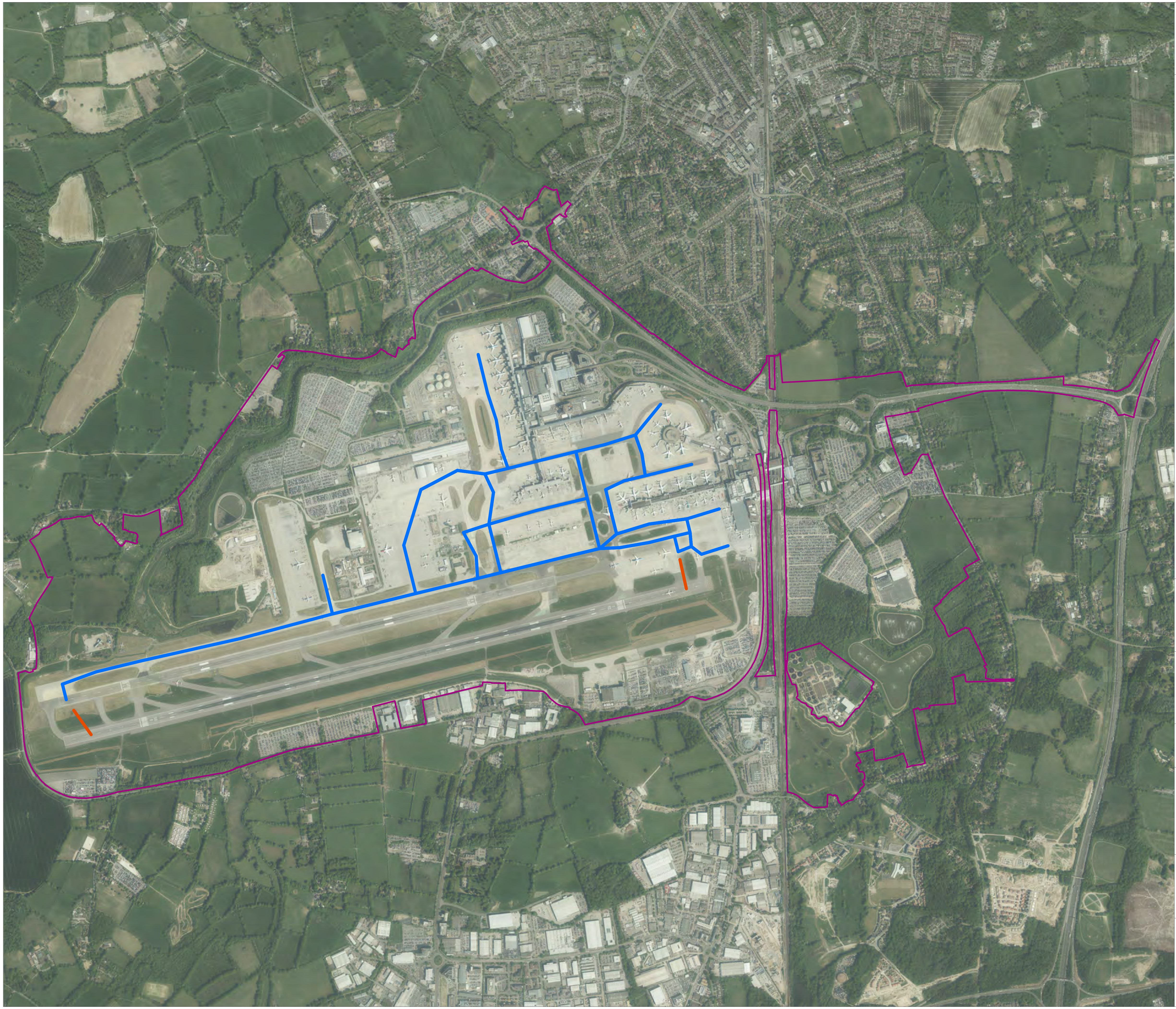
DRAWING TITLE
Modelled LTO Sources - Taxi Out and Hold for 2018 Baseline Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.4	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Taxi Out
Hold

DOCUMENT
Preliminary Environmental Information Report

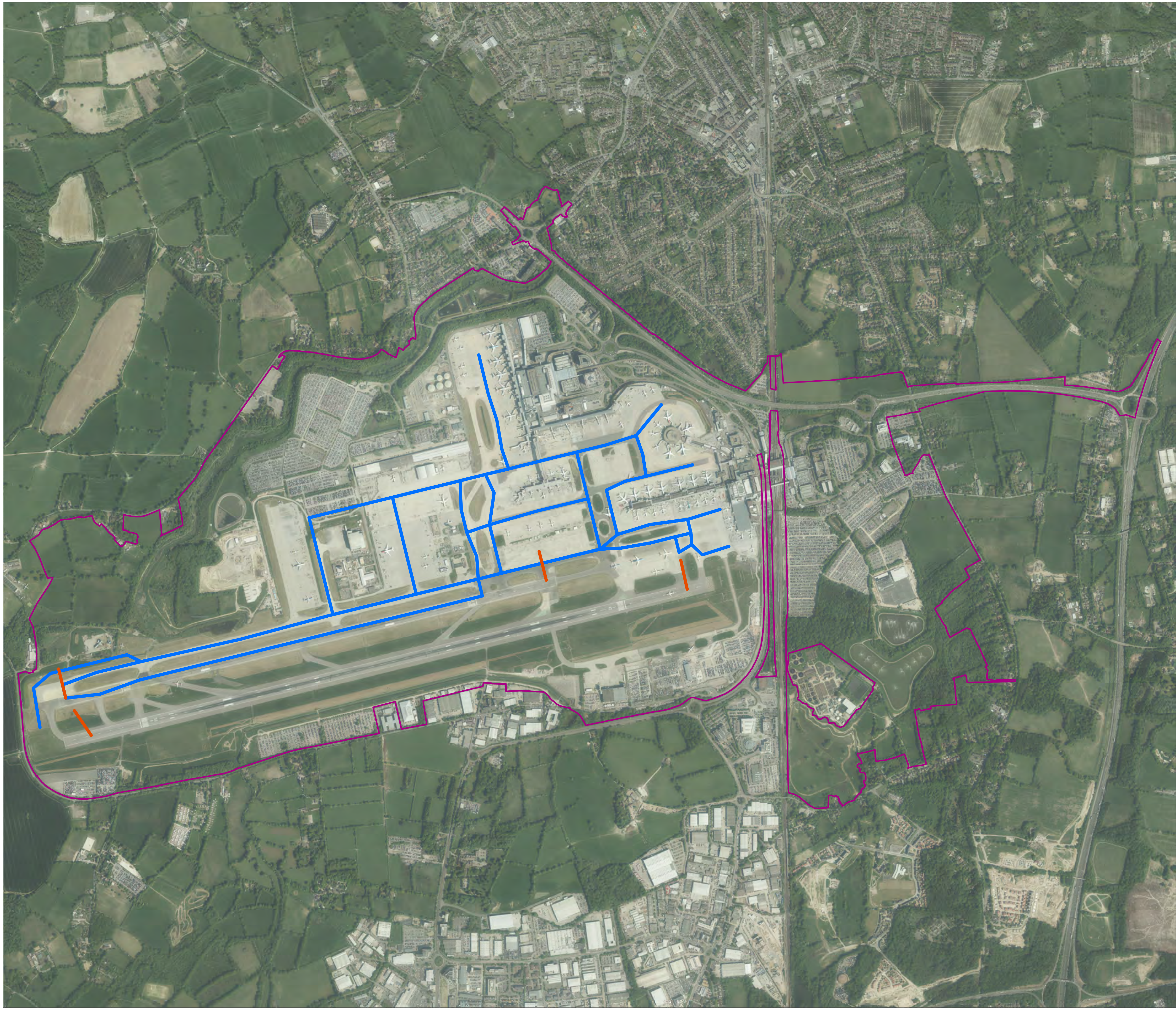
DRAWING TITLE
Modelled LTO Sources - Taxi Out and Hold for Without Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.5	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Taxi Out
Hold

DOCUMENT
Preliminary Environmental Information Report

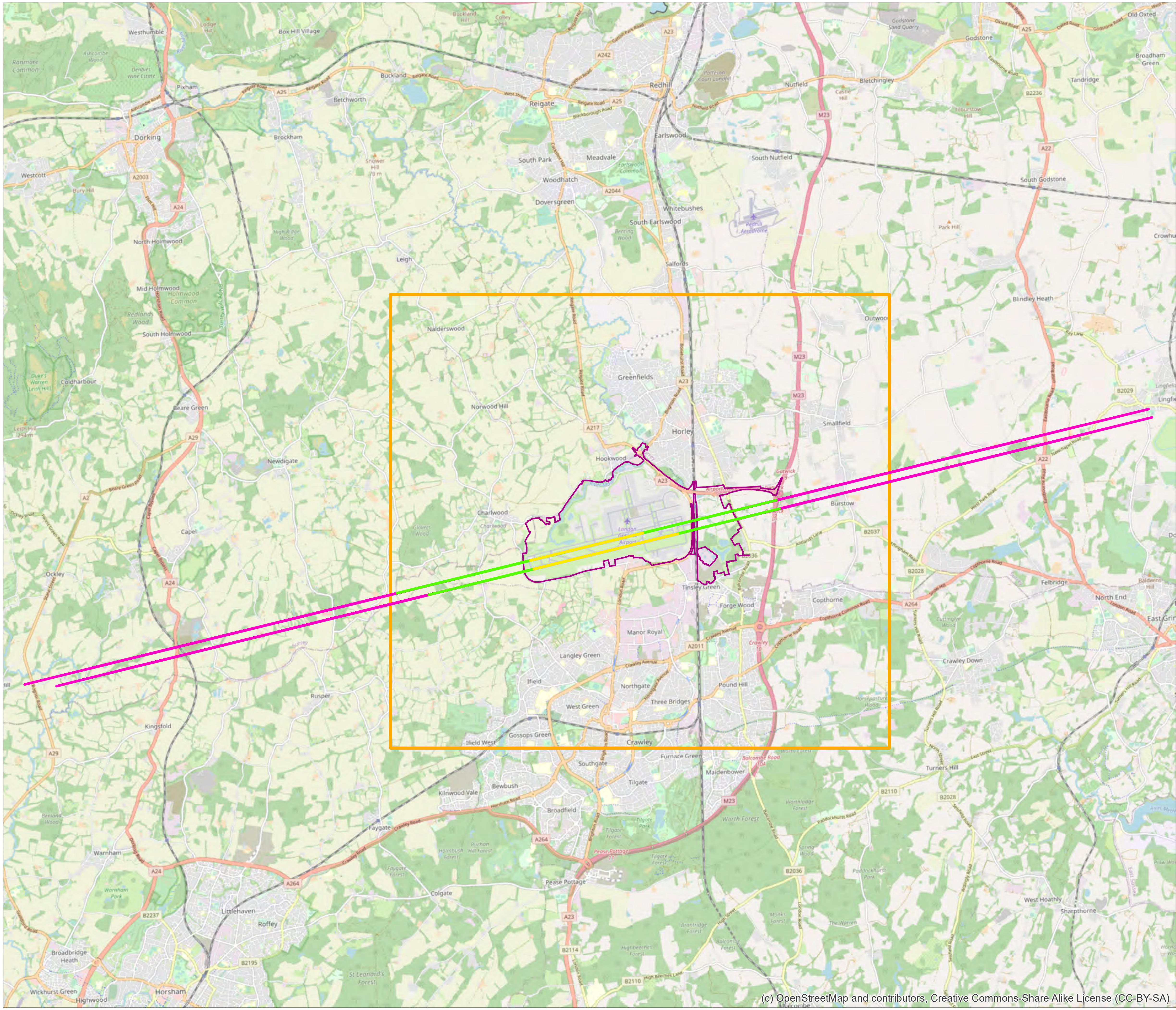
DRAWING TITLE
Modelled LTO Sources - Taxi Out and Hold for With Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.6	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
11 km x 10 km domain
Take Off Roll
Initial Climb
Climb Out

DOCUMENT
Preliminary Environmental Information Report

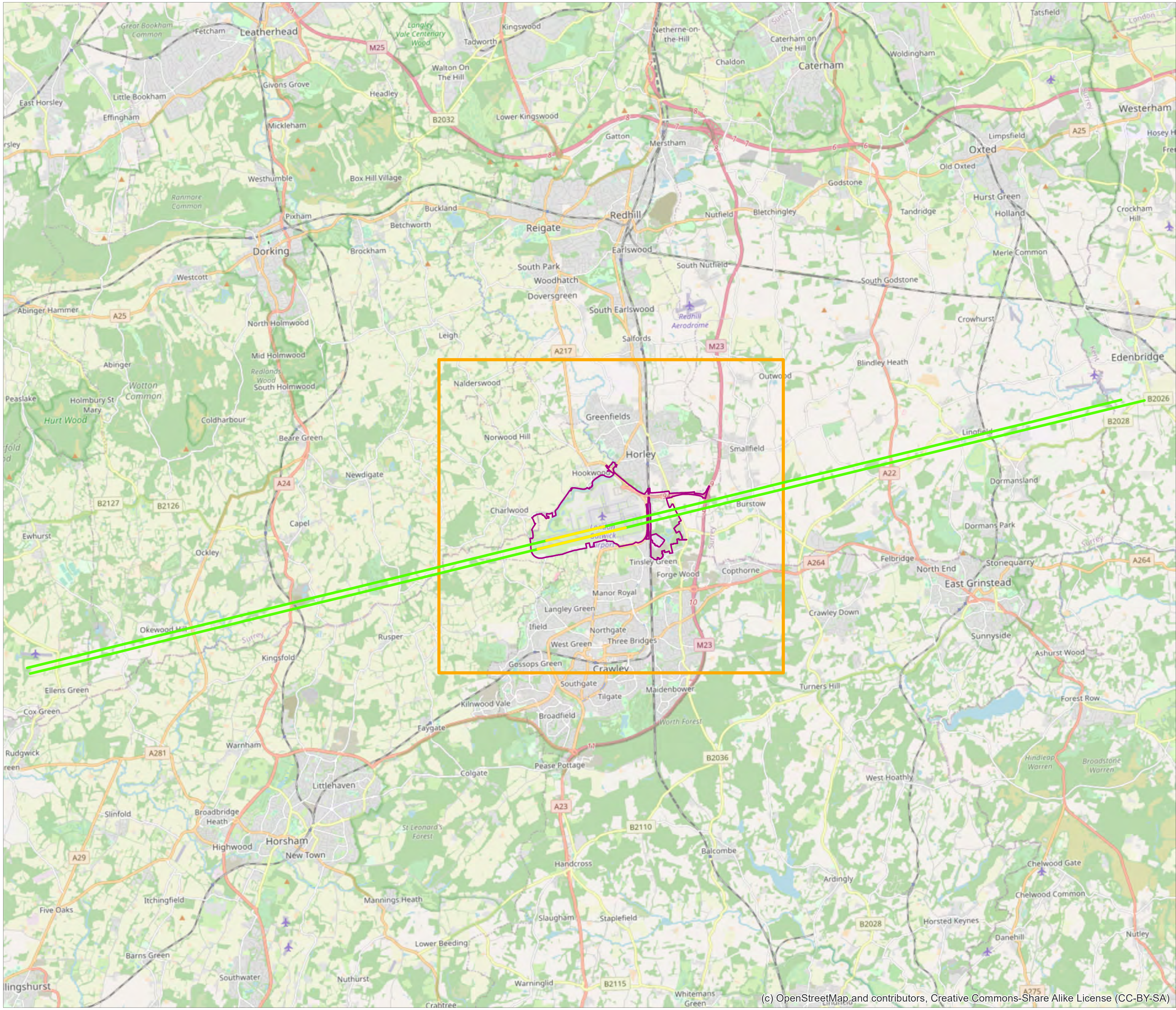
DRAWING TITLE
Modelled LTO Sources - Take Off Roll, Initial Climb and Climb Out

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.7	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:80,026

0 1,000 2,000 4,000 m



YOUR LONDON AIRPORT
Gatwick

- Project Site Boundary (PEIR)
- 11 km x 10 km domain
- Landing
- Approach

DOCUMENT
Preliminary Environmental Information Report

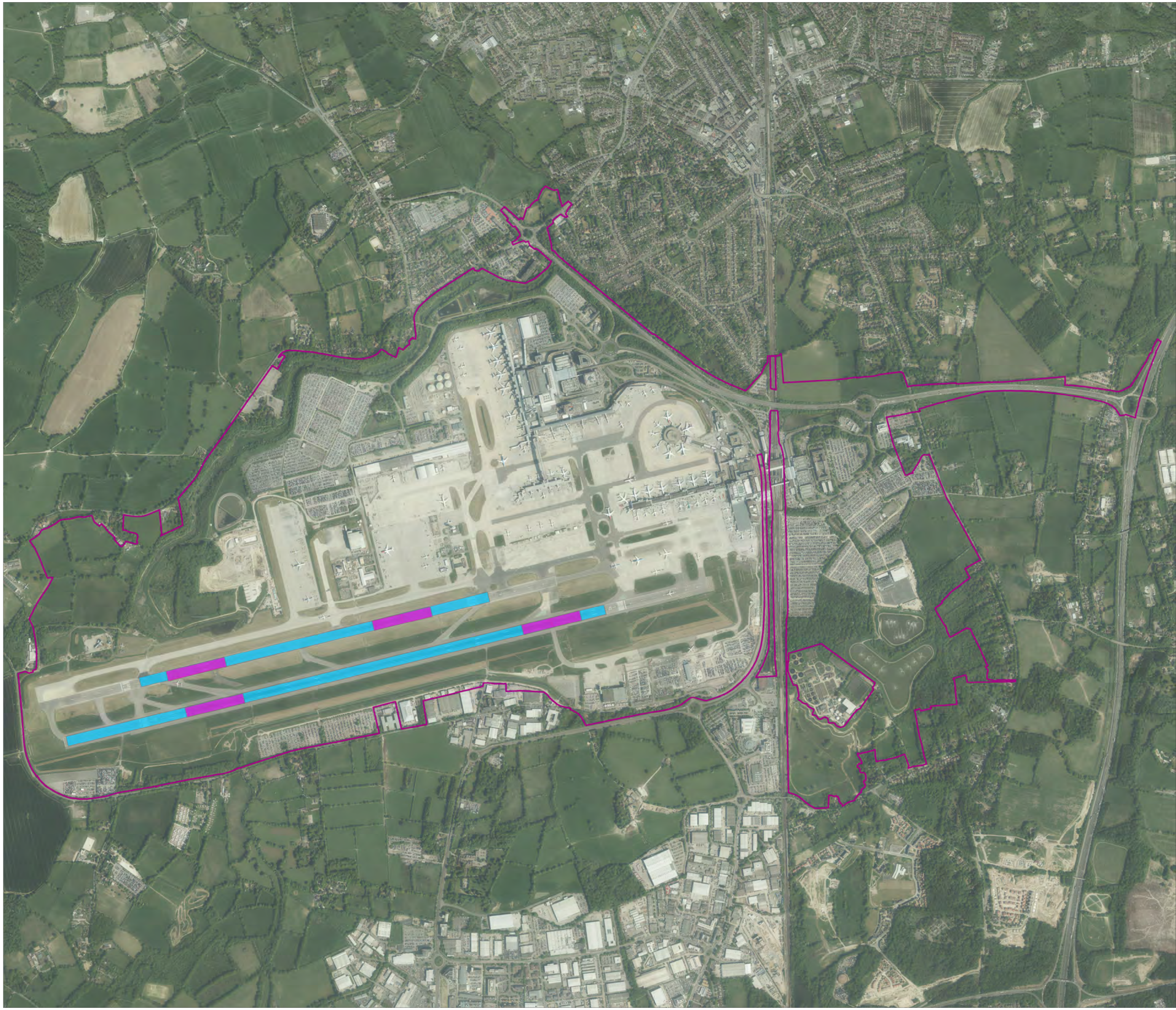
DRAWING TITLE
Modelled LTO Sources - Approach and Landing

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.8	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:115,894

0 1,500 3,000 6,000 m



YOUR LONDON AIRPORT Gatwick

DOCUMENT
Preliminary Environmental Information Report

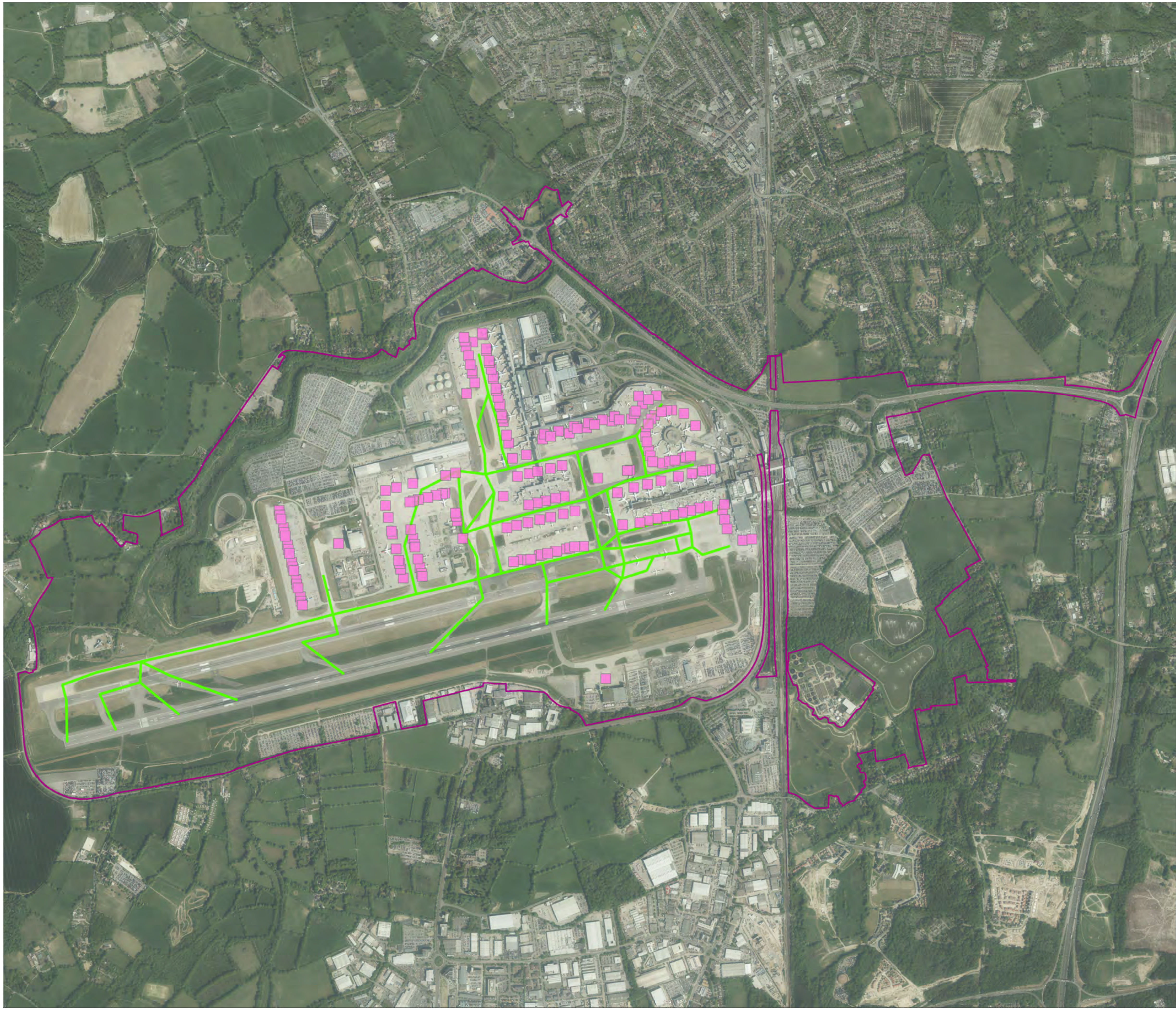
DRAWING TITLE
Modelled LTO Sources - Brake and Tyre Wear

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.9	For PEIR Issue
	DRAWN BY TC	PM / CHECKED BY MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
On-stand Auxiliary Power Unit
Off-stand Auxiliary Power Unit

DOCUMENT
Preliminary Environmental Information Report

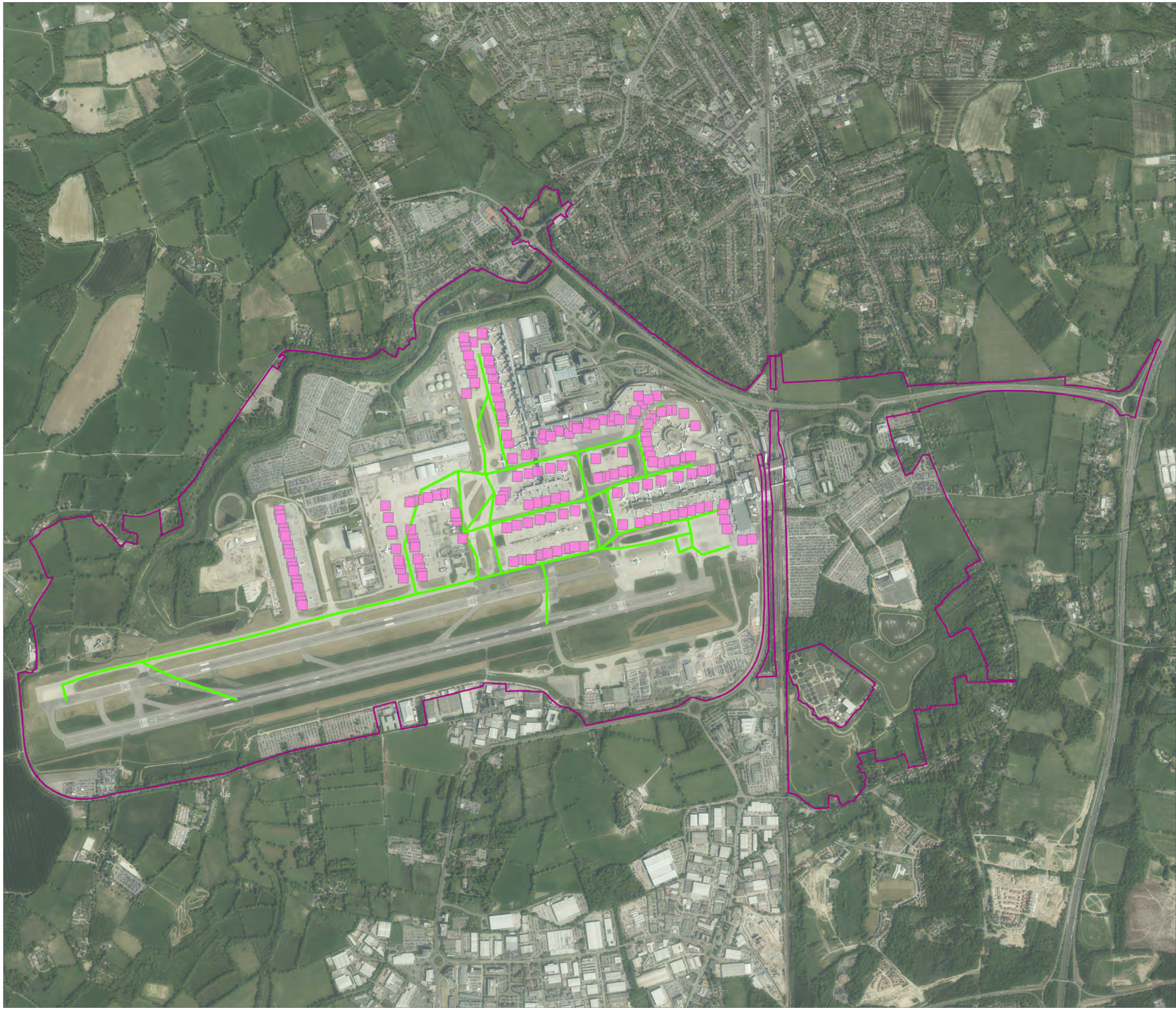
DRAWING TITLE
Modelled LTO Sources - Auxiliary Power Units for 2018 Baseline Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.10	For PEIR Issue
	DRAWN BY TC	PM / CHECKED BY MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
On-stand Auxiliary Power Unit
Off-stand Auxiliary Power Unit

DOCUMENT
Preliminary Environmental Information Report

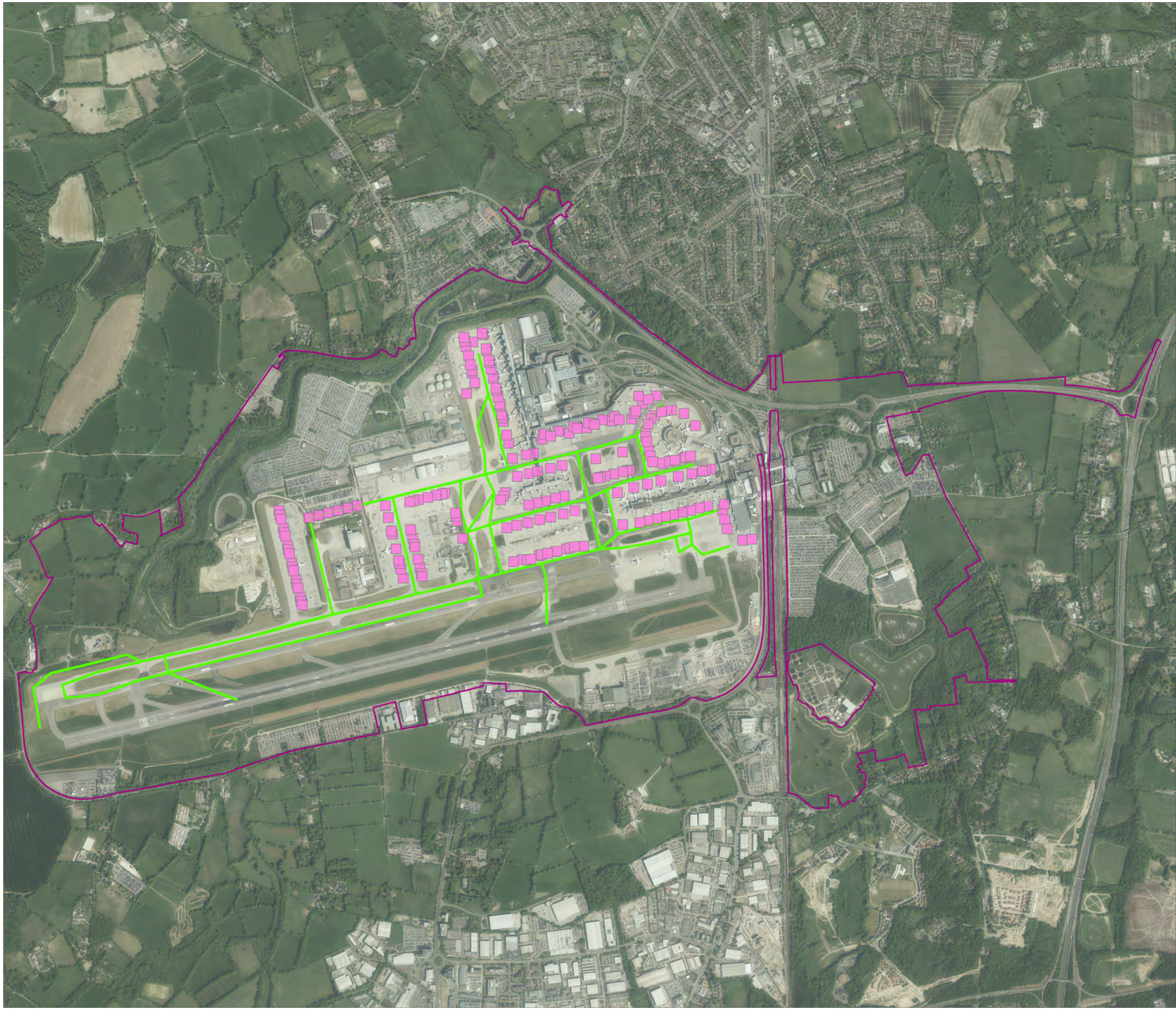
DRAWING TITLE
Modelled LTO Sources - Auxiliary Power Units for Without Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.11	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
On-stand Auxiliary Power Unit
Off-stand Auxiliary Power Unit

DOCUMENT
Preliminary Environmental Information Report

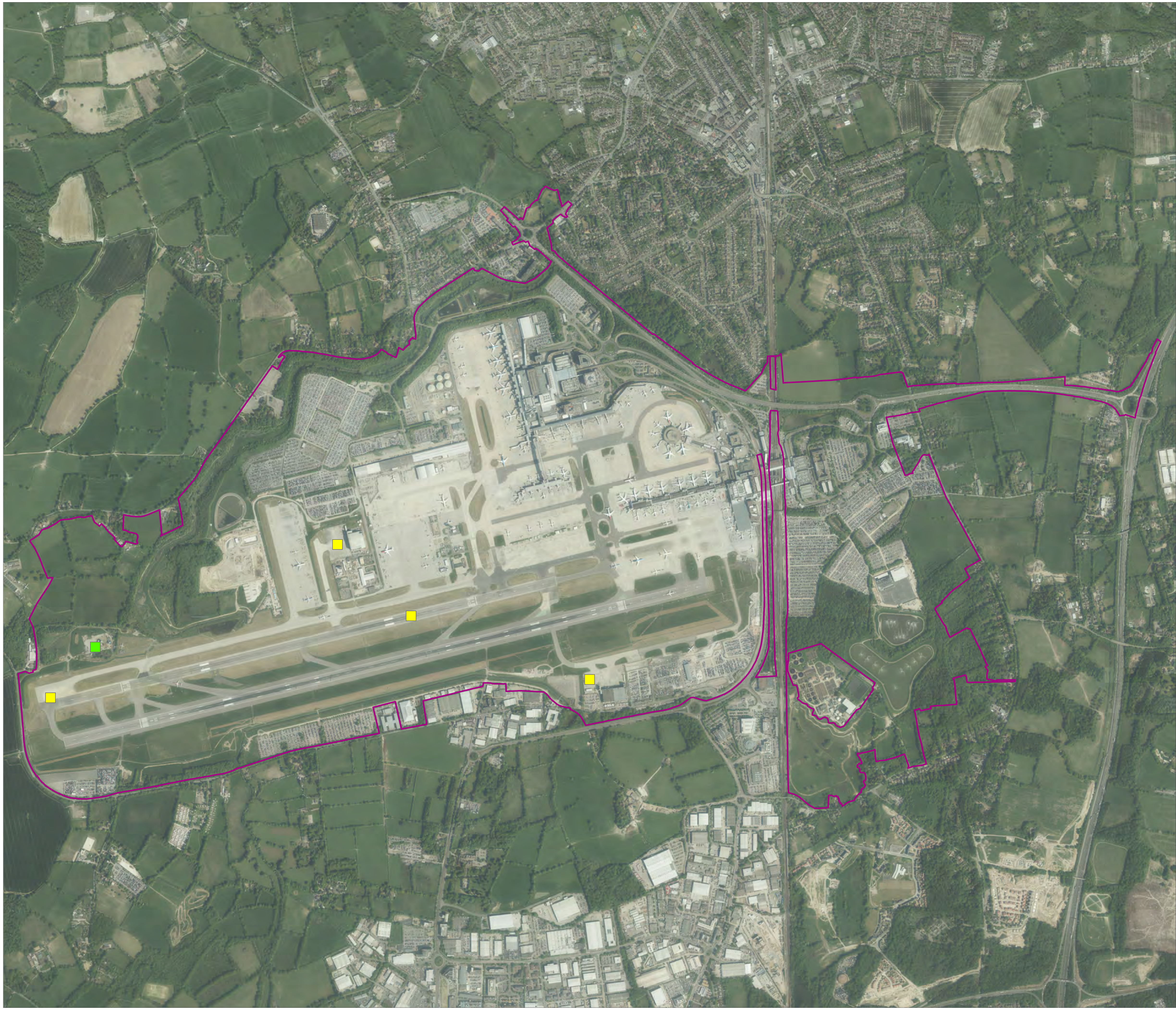
DRAWING TITLE
Modelled LTO Sources - Auxiliary Power Units for With Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.12	For PEIR Issue
	DRAWN BY TC	PM / CHECKED BY MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Engine Testing
Fire Training Ground

DOCUMENT
Preliminary Environmental Information Report

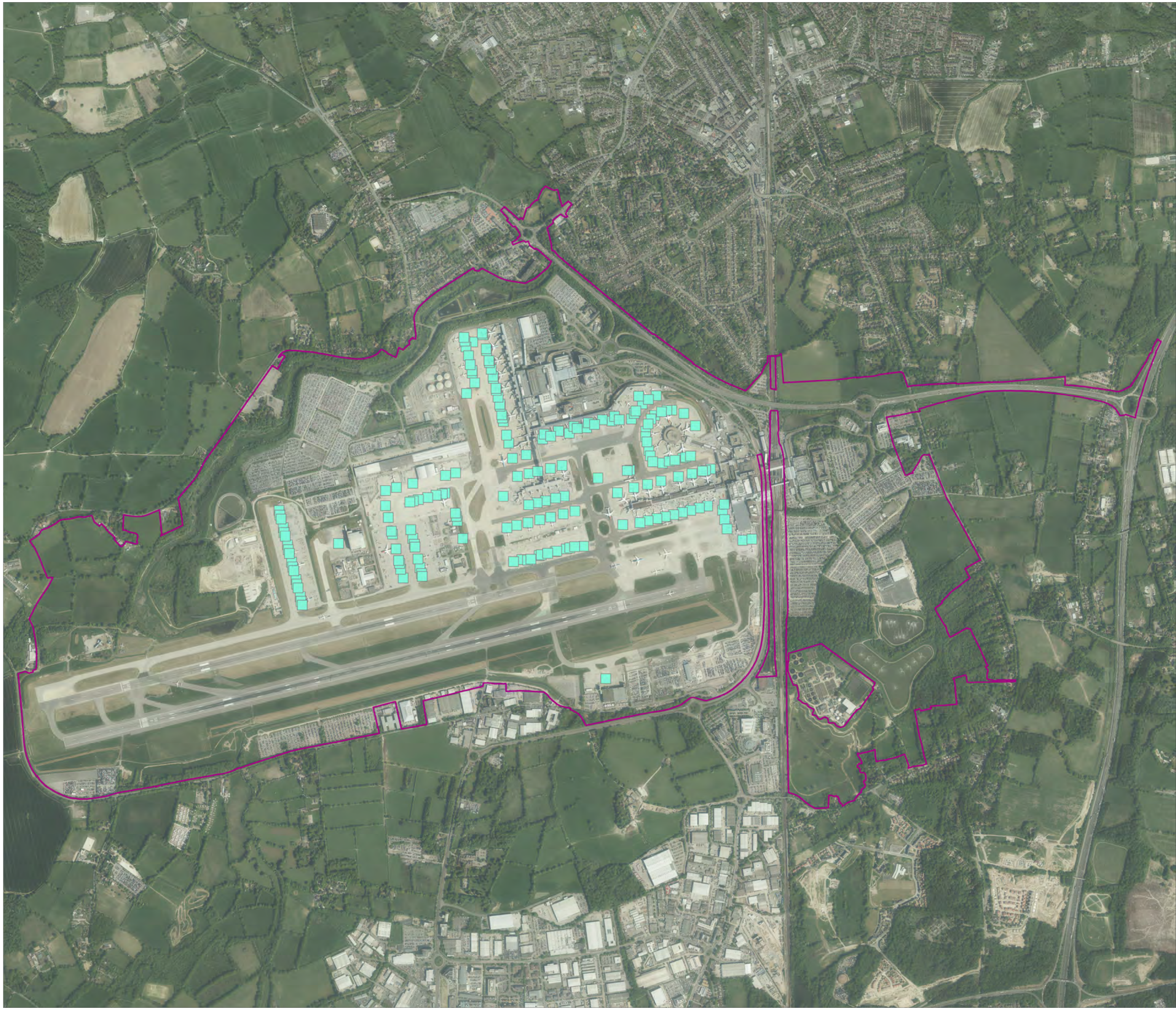
DRAWING TITLE
Modelled LTO Sources - Engine Testing and Fire Training Ground

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.13	For PEIR Issue
	DRAWN BY TC	PM / CHECKED BY MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)
Ground Support Equipment

DOCUMENT
Preliminary Environmental Information Report

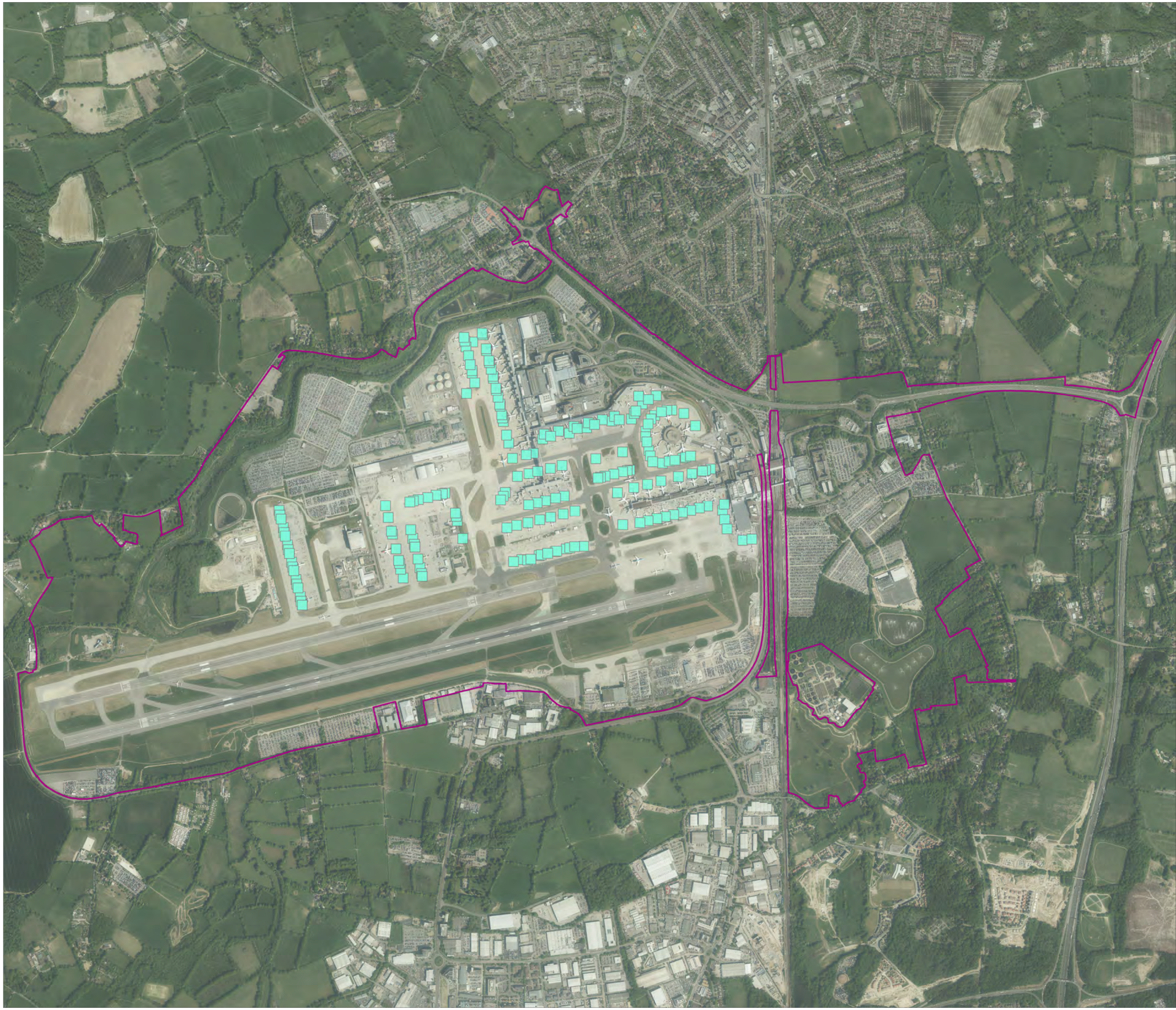
DRAWING TITLE
Modelled LTO Sources - Ground Support Equipment for 2018 Baseline Scenario

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.14	For PEIR Issue
	DRAWN BY TC	PM / CHECKED BY MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)

Ground Support Equipment

DOCUMENT

Preliminary Environmental Information Report

DRAWING TITLE

Modelled LTO Sources - Ground Support Equipment for Without Project Scenarios

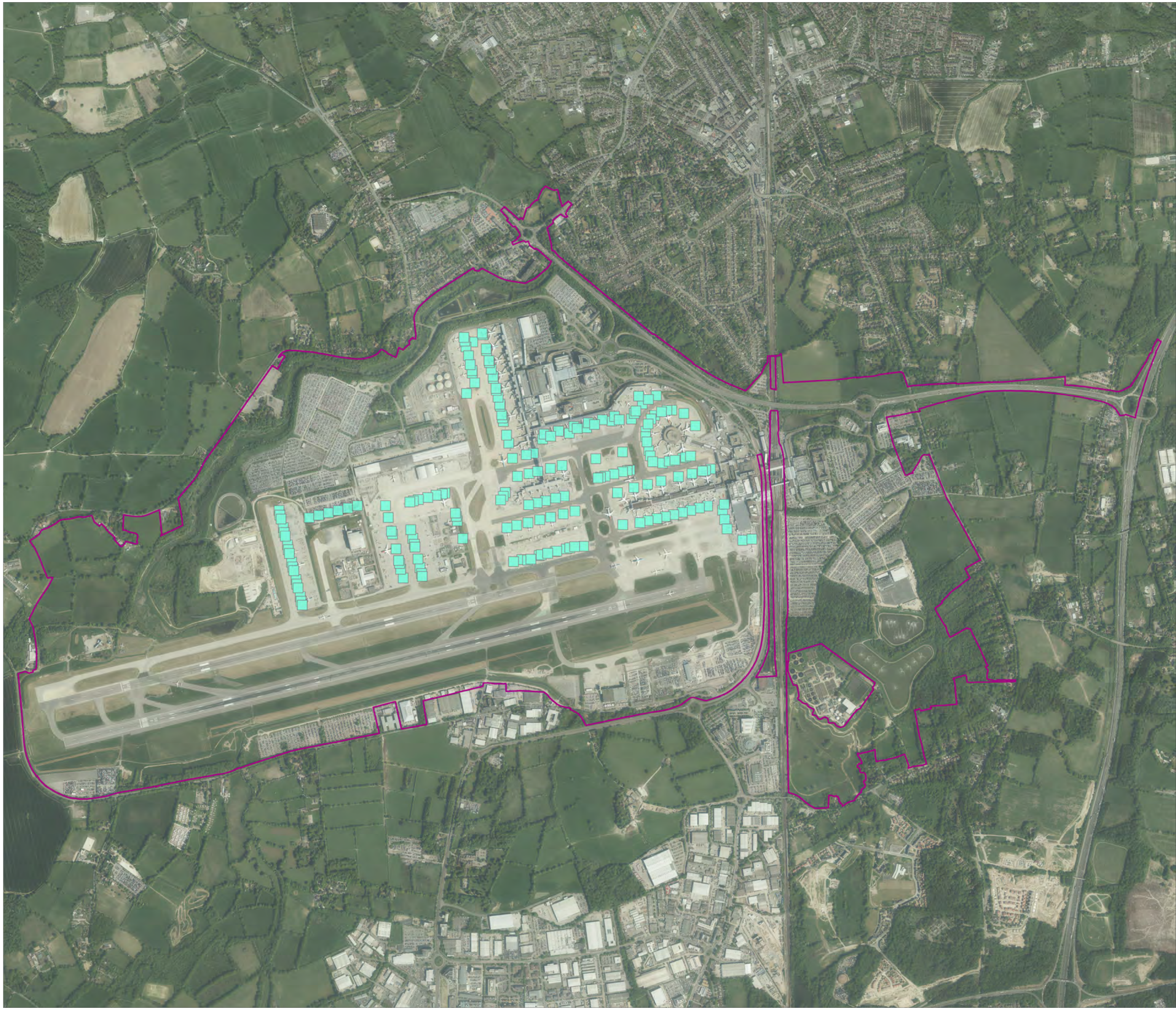
DATE

September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.15	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)

Ground Support Equipment

DOCUMENT
Preliminary Environmental Information Report

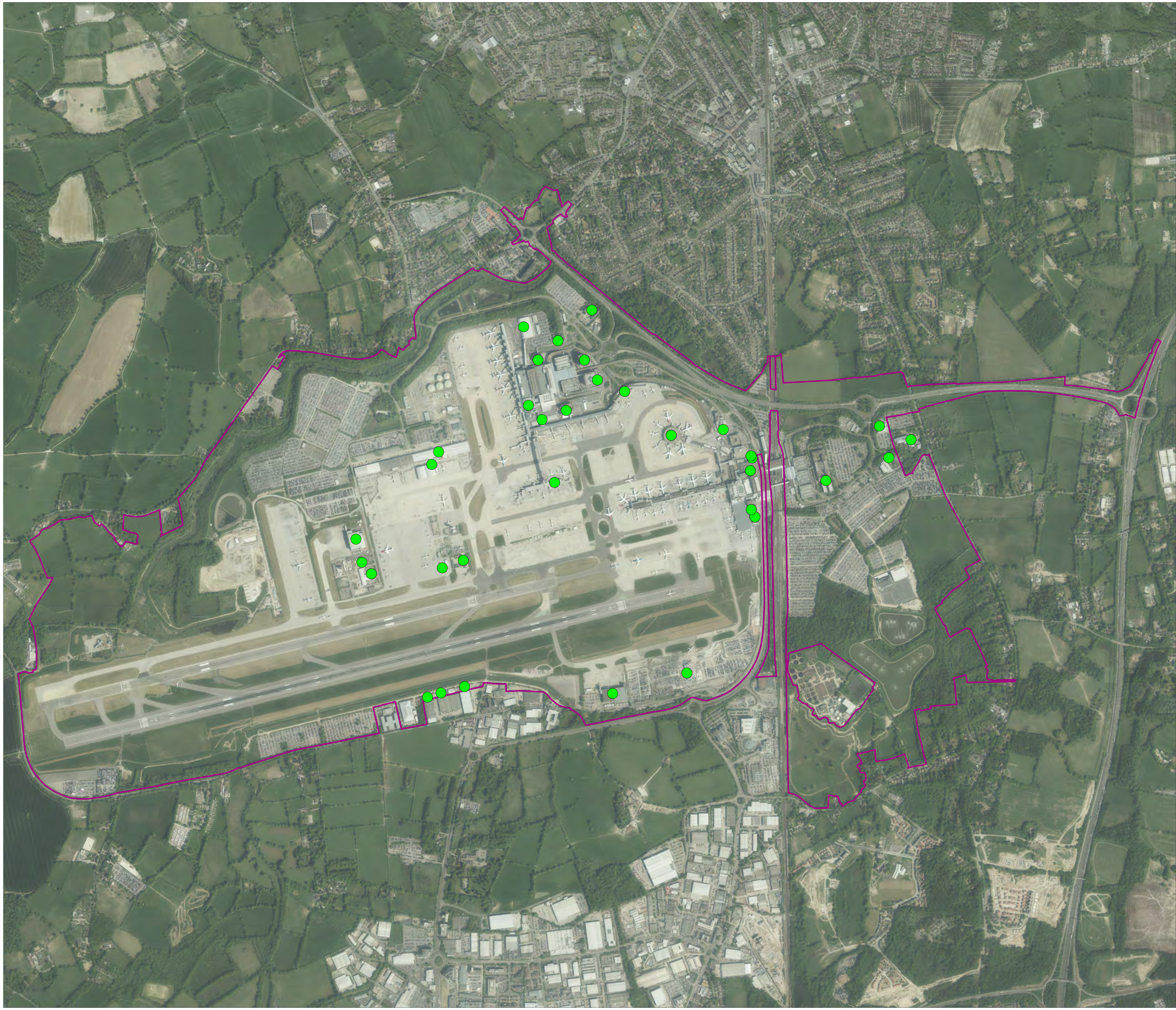
DRAWING TITLE
Modelled LTO Sources - Ground Support Equipment for With Project Scenarios

DATE
September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.16	For PEIR Issue
	DRAWN BY: TC	PM / CHECKED BY: MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)

Energy Plant

DOCUMENT

Preliminary Environmental Information Report

DRAWING TITLE

Modelled LTO Sources - Energy Plant for 2018 Baseline and Without Project Scenarios

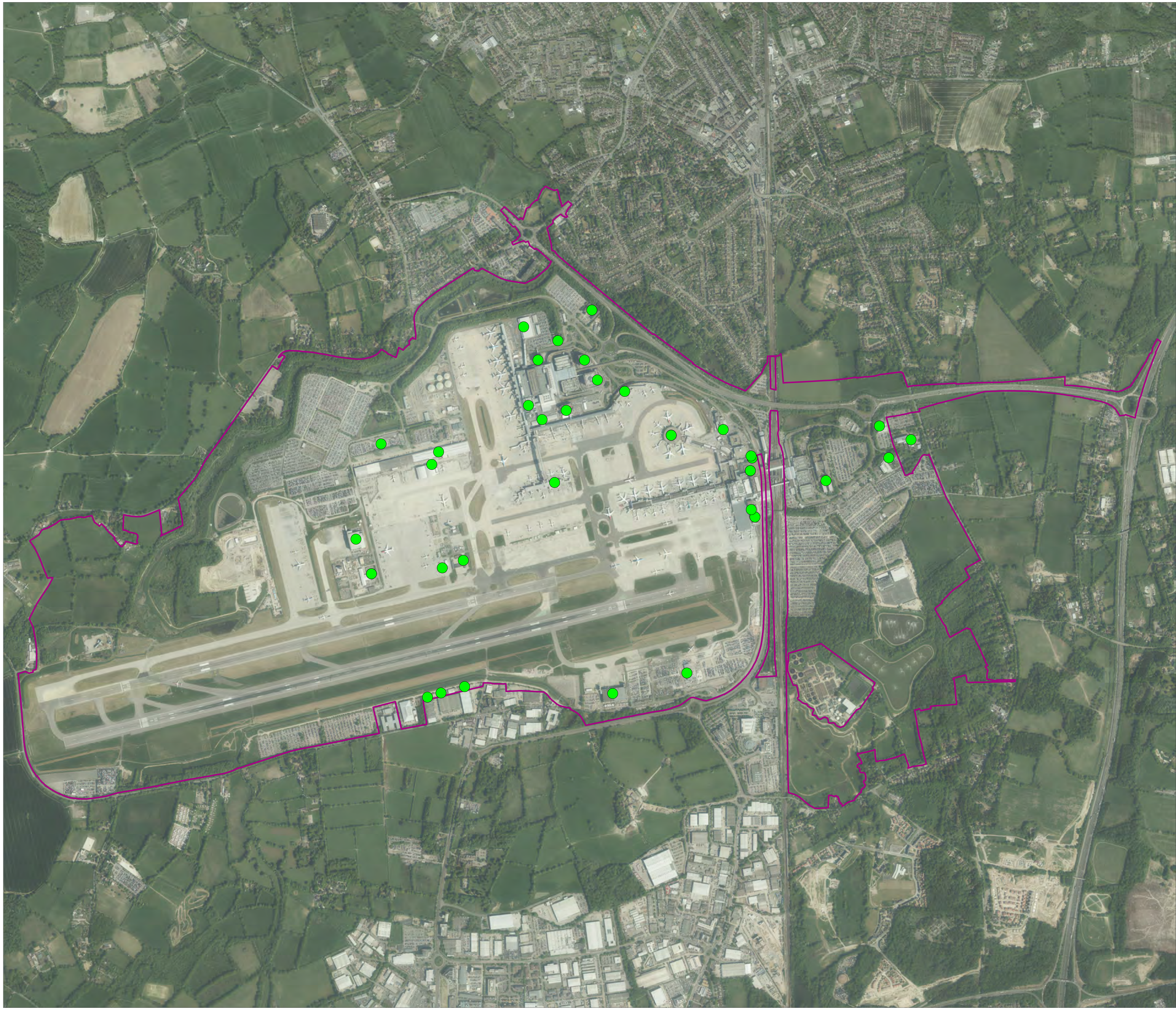
DATE

September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.17	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m



YOUR LONDON AIRPORT
Gatwick

Project Site Boundary (PEIR)

Energy Plant

DOCUMENT

Preliminary Environmental Information Report

DRAWING TITLE

Modelled LTO Sources - Energy Plant for With Project Scenarios

DATE

September 2021

ORIENTATION	DRAWING NO.	REVISION
N	APPENDIX 13.4.1 FIGURE 5.2.18	For PEIR Issue
	DRAWN BY	PM / CHECKED BY
	TC	MK

SCALE @ A3 1:18,193

0 250 500 1,000 m