East West Rail Phase 2

Technical Note: Culverts Hydraulic Assessment Technical Note

Discipline/Grip Stage: Culvert/GRIP5

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Document History

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Project:	**East West Rail Phase 2**	**To:**	**Environment Agency, Aylesbury Vale District Council, Buckinghamshire County Council, Central Bedfordshire Council, Milton Keynes Council, Oxfordshire County Council**
Discipline:	**Culvert**	**From:**	**East West Rail Alliance**
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Title:	**Culvert Hydraulic Assessment Technical Note**		

Introduction

The Environment Agency (EA), Internal Drainage Board (IDB) and the Lead Local Flood Authorities (LLFAs) have been consulted about the East West Rail Phase 2 (EWR2) scheme proposals during regular technical update meetings. During the meetings on the 6th October and 7th December 2017, authorities indicated that any significant change to existing culverts (and by definition, this would include replacement solutions) would need to accommodate an allowance for climate change.

In the meeting held on the 2nd February 2018, it was agreed that the application of climate change will be considered for the new culverts (including replacement culverts and brand new culverting of a watercourse to support a new highway earthworks) and the modified existing culverts where reasonably practicable, i.e. taking account of local site constraints or features, without altering the proposed permanent way alignment or increasing local flood risk.

Based upon the previous discussions referred to above, this document sets out the methodology and key design principles to be applied in the hydraulic design of culverts and the application of climate change during the GRIP 5 detailed design stage of the East West Rail Phase 2 (EWR2) project.

Scheme overview

The objective of the EWR2 project is the introduction of direct rail passenger services between Oxford, Milton Keynes and Bedford, and also between London Marylebone and Milton Keynes (via Aylesbury). This will be achieved by reconstructing and upgrading the partially disused Bicester – Bletchley – Bedford line and the Aylesbury – Claydon Junction routes.

A schematic of the project is given in Figure 1.

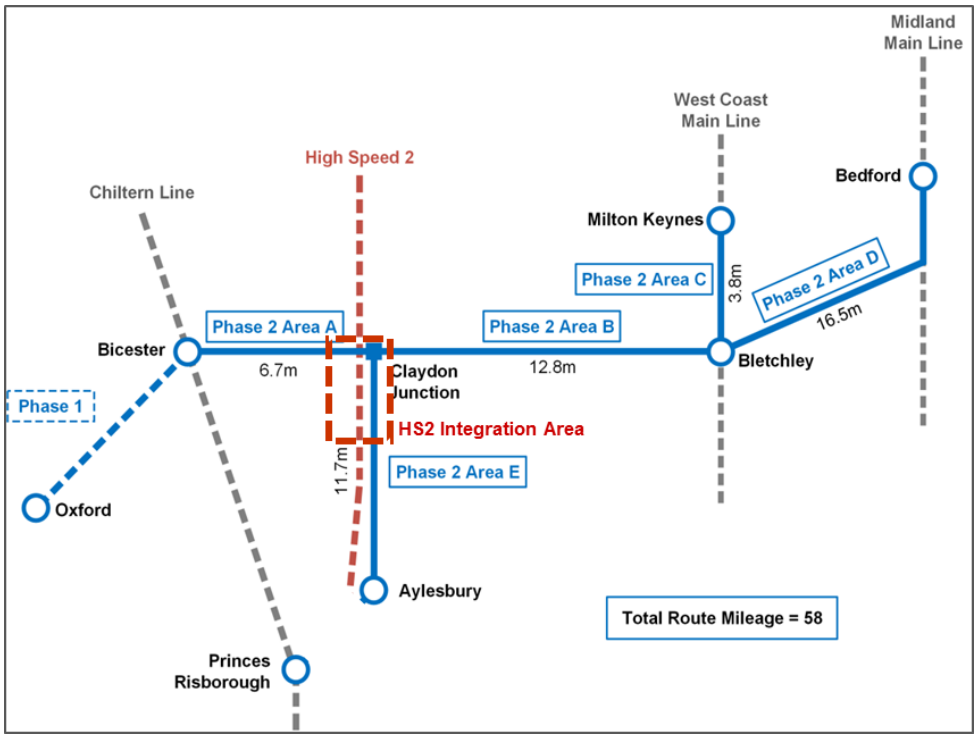


Figure 1 – Schematic drawing of EWR 2 project extents (Phases 1 & 2)

Culvert Overview

A total of 92 existing culverts have been identified within the project extents between the following chainages:

- Section 2A extends from east of Bicester (Phase 1 scheme end) OXD: 18mi 49Ch to OXD: 12mi 0Ch.
- Section 2B extends from OXD: 12mi 0Ch to OXD: 0mi 62Ch.
- Section 2C extends from OXD: 0m 62Ch to BFO:0m.
- Section 2E extends from MCJ2/3: 161mi 50Ch/ 44mi 28Ch to MCJ2 40mi 38Ch.

The assets vary both in size and construction from approximately 0.4m to 1.5m span/diameter and from materials including brick, concrete, clayware, and UPVC. Further details of each culvert are available within the Culvert Data Sheet (133735_RW-EWR-XX-XX-SH-DC-000012).

Proposed earthworks and Permanent Way designs have been assessed to determine changes to depth of cover and the structural condition of the existing culverts in accordance with NR/L1/CIV/032[1] and NR/L3/CIV/020[2]. The proposed improvement work required on each culvert and its associated headwalls can be categorised by the following;

- Replacement
- Extension
- Rehabilitation
- Removal

Notwithstanding this, no intervention has been proposed for existing culverts with a depth of cover greater than 3m[3] and where no existing structural defects or cracking has been identified, except for general consideration to regular maintenance of the assets in accordance with Network Rail standards.

Additionally, 24 No. culverts have been identified from the Network Rail Civils Asset Register and Reporting System (CARRS). Since there is no survey information or Network Rail Inspection reports available for these assets, they are referred to as “Risk Culverts”. At this stage it is assumed that these culverts will be replaced by the project. However, following the site clearance and de-vegetation, further investigation will be carried out to confirm the presence and operational state of these assets to subsequently validate the proposal.

Table 1 below summarises the quantity of each type of design solution required for the EWR2 project:

Table 0: Breakdown of culverts by design solution

Design proposal	Quantity
Rehabilitation only	9
Rehabilitation and Extension	4
Replacement	44
Risk Culvert	24
No Intervention	8
Removal	3

[1] NR/L1/CIV/032 -The Management of Structures. Compliance 05/12/09
[2] NR/L3/CIV/020- Design of Bridges. Compliance 04/06/11
[3] The structural assessment, based on BS EN 1295, shows that the FoS plateaus at an acceptable level, i.e. at a depth of 3m the rail surcharge load is counterbalanced by the soil surcharge.

Methodology

As set out in the project Flood Risk Assessment (FRA)[4] a proportionate approach to developing the hydrological and hydraulic modelling will be adopted, taking into account the availability of data, the scale of the proposed works and the receptors which are potentially affected.

In GRIP 4, where replacement, extension or rehabilitation has been proposed, the baseline hydraulic assessment of existing culverts was undertaken in their current form in accordance with CIRIA C689[5]. MicroDrainage Source Control software (version 17.1.2) was utilised to derive peak flow estimates for each culvert. Bentley CulvertMaster software (version 3.3) was then used to determine headwater elevations where topographical survey data was available. Climate change was applied to the model by increasing flow in line with the appropriate Environment Agency Climate Change Guidelines[6].

Appendix A summarises the process to decide which hydraulic modelling method (such as Integrated Catchment Modelling (ICM) or CulvertMaster) will be utilised in GRIP5. In principle, hydraulic modelling will be utilised where one of the following criteria is satisfied:

- Hydraulic capacity checks could not be undertaken due to insufficient topographical survey data.
- Hydraulic capacity checks demonstrated that the culvert does not perform in a free-flowing condition.
- There is an increased flood risk to sensitive receptors (for example residential properties) in the local area either upstream of the asset through backing-up of flows, or downstream through increasing the volume or flow-rate passing through the culvert.

If the above criteria is not met, then the MicroDrainage CulvertMaster combined with MicroDrainage Source Control software will be used to assess headwater elevation (HWE) as described above.

Once the HWE has been calculated using the hydraulic model or CulvertMaster method, the maximum allowable upstream headwater level (HWL) and culvert soffit level have been compared with the HWE to confirm whether the culvert capacity is sufficient to convey the relevant design flow. A Red Amber Green RAG system was applied to assess the culvert performance in line with the following definitions:

- Green - Culvert is performing in a free-flowing condition i.e. Max HWL>HWE.
- Amber - Culvert is likely to be performing in surcharged conditions as the HWL does not allow sufficient freeboard i.e. Max HWL < HWE < culvert soffit level.
- Red - Culvert is performing in surcharged conditions i.e. HWE > culvert soffit.

The following paragraphs describe the approach for considering the outcome of this assessment in determining the solution for each culvert:

Where culverts are proposed to be rehabilitated and / or extended using an internal liner, the impact of the proposed solution on the hydraulic capacity (both on cross-sectional area and pipe roughness) will be assessed. However, should the assessment indicate that the application of climate change requires a different construction solution, then the design will not take account of climate change.

Where the adverse effect of upsizing cannot be mitigated (e.g. where flood risk to a sensitive downstream receptor is increased), the principle of like-for-like replacement will be adopted. Should this approach be taken and depending on the scale of change and receptors at risk, provision for flood mitigation measures may be required to manage the potential impacts from climate change.

[4] Project Flood Risk Assessment (FRA). Reference: The Network Rail (East West Rail Bicester to Bedford Improvements) Order, Environmental Statement, Volume 3, Appendix 13.1.
[5] Culvert Design and Operation Guide, CIRIA C689, 2010
[6] Flood risk assessments: climate change allowances, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances, 2016

Design Criteria

Design Flows

As discussed the hydraulic modelling from either ICM or CulvertMaster will be utilised in GRIP5 to assess hydraulic performance of the proposed culverts. Table 2 summarises the process of undertaking the catchment analysis and flow calculation in respect to each hydraulic assessment method.

Table 0: Catchment and flow calculation methodology

Hydraulic Assessment Methodology	Catchment Assessment*	Flow Calculation
CulvertMaster	The Surface Watershed function in AutoCAD Civil 3D 2018 will be utilised to analyse the surface water flow paths and extent of catchment area attributed to each culvert. A combination of topographical survey, LiDAR and proposed earthworks modelling data will be used to generate flow paths.	Peak flow rates will be calculated using MicroDrainage Source Control (version 17.1.2) for 0.5%, 1%, 1% plus climate change and 2% annual probability rainfall events using the following methods: • IH124 method for catchment areas greater than 50 ha, or • ICP SuDS methods for catchments less than 50 ha
Integrated Catchment Modelling (ICM)	Dependent on the catchment characteristics and type, one of two forms of hydrological assessment will be undertaken: 1) For smaller catchments a direct rainfall approach will be utilised where the rainfall is distributed across the model domain allowing overland flow paths to be determined by the model (rather than specifying flow boundaries to provide a more accurate representation of the catchment flows and flow paths). 2) For larger catchments peak flow rates will be calculated using Flood Estimation Handbook (FEH) methods (ReFH, FEH Statistical).	Based on the appropriate hydrological method, dependent on the catchment type the following flood events will be simulated in the model: • 50% annual chance event; • 20% annual chance event; • 10% annual chance event; • 5% annual chance event; • 1% annual chance event; • 1% annual chance event plus climate change; • 0.5% annual chance event.

* Appendix B sets out the list of available information to be used in developing the hydraulic models and calculations.

It should be noted that peak discharge rates from the proposed railway and earthwork drainage systems will be taken into account during the GRIP 5 assessment where they are to pass through the culvert. Peak discharges from the railway drainage system will however not be any greater than the existing situation.

Application of Climate Change and Freeboard

The project will aim to achieve the Alliance requirements summarised in the Climate Change Resilience Review document (133735-EWR-REP-EEN-000024) where it is practicable to do so. Notwithstanding this, as a baseline requirement the design shall be checked to ensure it satisfies the NR standard as a minimum in all cases.

CIRIA Report C689 provides industry best practice guidelines and will be adhered to where practicable in culvert design. However, aligning with CIRIA is not a direct requirement of either the Network Rail or Alliance Standards and is therefore not considered critical where it is impracticable to apply.

The table below outlines the design parameters set out in the Alliance Climate Change Resilience Review, NR design standard and CIRIA Report C689.

Table 3: Hydraulic design requirements*

Relevant Standard	Document Reference	Design Return Period	Climate Change	Embedment	Freeboard
Alliance Climate Change Resilience Review	• EWR Climate Change Resilience Review (Ref: 133735-EWR-REP-EEN-000024) • Hydraulic Assessment Technical Note (Ref: 133735_RW-EWR-XX-XX-RP-DC-000007)	1% annual chance event	• 40% applied to rainfall intensities • 65% or 70% applied to peak river flows for Anglian and Thames catchments respectively	• D<600mm: lowering of invert by 100mm • 600mm<D<1200mm: embedment equivalent to D/4 • D>1200mm dia: 300mm embedment • For box culverts: 150mm embedment	• 300mm minimum • 600mm where no detailed modelling information is available.
Network Rail	NR/L3/CIV/005/2C	2% annual chance event	20% applied to rainfall intensities	N/A	D/4 (with minimum of 300mm) for culverts up to 2m
CIRIA C689	Culvert Design and Operation Guide, CIRIA Report C689, 2010	1% annual chance event	20% applied to rainfall intensities	• D<1200mm: embedment equivalent to D/4 • D>1200mm: 300mm embedment • For box culverts: 150mm embedment	• D>1200mm: freeboard allowance of 300mm • D<1200: freeboard allowance equivalent to D/4

*It should be noted that the climate change allowances are due to be updated in November 2018; these updated allowances will be tested in the modelling and design assessment.

Since the majority of the culvert works will be replacing existing assets along the existing railway, there may be locations where adherence to the guidance in Table 3 is not achievable. These instances are likely to fall into two categories:

1) Where existing site conditions or constraints (such as depth of cover over the culvert) prevent achieving the criteria set out above without significant implications for embankment and track design (i.e. track raising).

2) Where the analysis indicates that taking into account the freeboard requirements and revised climate change allowances would result in a requirement for a significant upsizing of the existing asset, which could impact on flood risk receptors downstream. Although the proposed works will seek to provide resilience to climate change, this needs to be balanced against the need to not substantially alter the hydraulic behaviour of the existing system, and not increase flood risk to downstream receptors.

In these cases, each site shall be evaluated to ensure a robust design is developed and approval for reduced climate change/ freeboard allowances shall be sought from the relevant regulatory authority.

Position of the invert

As set out in the project Water Framework Directive assessment (WFD)7, the invert of all new culverts will be designed to be below the natural bed level where this can be achieved. In some cases, the site constraints such as the SGN high pressure gas main may be prohibitive to lower the culvert invert level below the existing one. A depressed invert set slightly below the existing bed level allows for natural bed substrates to be installed to form the bed level, which helps reduce disruption of channel velocities, maintain habitat connectivity and fish passage; baffles (precast or otherwise) may be required to retain bed substrate if there is a risk of the natural sediment flushing through at high flows. Embedment depth will be in accordance with the Alliance requirements stated in Table 3. It should be noted that no allowance for embedment or lowering of invert levels have been made on culverts that only serve a land drainage catchment, i.e. there are no fluvial flows associated with a watercourse.

As with the freeboard allowance, since the majority of the culvert works will be replacing assets along the existing railway, the design will seek to be consistent with the embedment depth requirements but there may be locations where strict adherence to the guidance is not viable. Where this is the case these will be assessed on a site by site basis as part of the freeboard analysis to ensure a resilient design is developed, with approval sought from the relevant regulatory authority.

Risk of Blockage

The project FRA has undertaken a qualitative assessment in relation to the risk of blockage for the existing culverts where works are proposed as part of the Scheme, i.e. where no works are proposed a blockage assessment will not be undertaken.

Initially, a screening exercise will be undertaken to identify locations where the self-cleansing velocity cannot be achieved through the culvert during low flow conditions, likely to occur during the QBAR (50% probability of annual occurrence) event. Where blockage may increase the flood risk to a sensitive receptor, a hydraulic modelling assessment will be undertaken to determine the impact and inform any maintenance and operation requirements.

Exclusions

No hydraulic betterment will be provided for existing culverts where their structural condition is assessed to be adequate and therefore no intervention has been proposed. However, if any hydraulic capacity issues are shown to be caused by sedimentation/blockage, then these culverts will be cleaned out by the Alliance to restore their operational state.

Where culverts are proposed to be rehabilitated and / or extended using an internal liner, the impact of the proposed solution on the hydraulic capacity (both on cross-sectional area and pipe roughness) will be assessed. However, should the assessment indicate that the application of climate change requires a different construction solution, then the design will not take account of climate change.

Summary

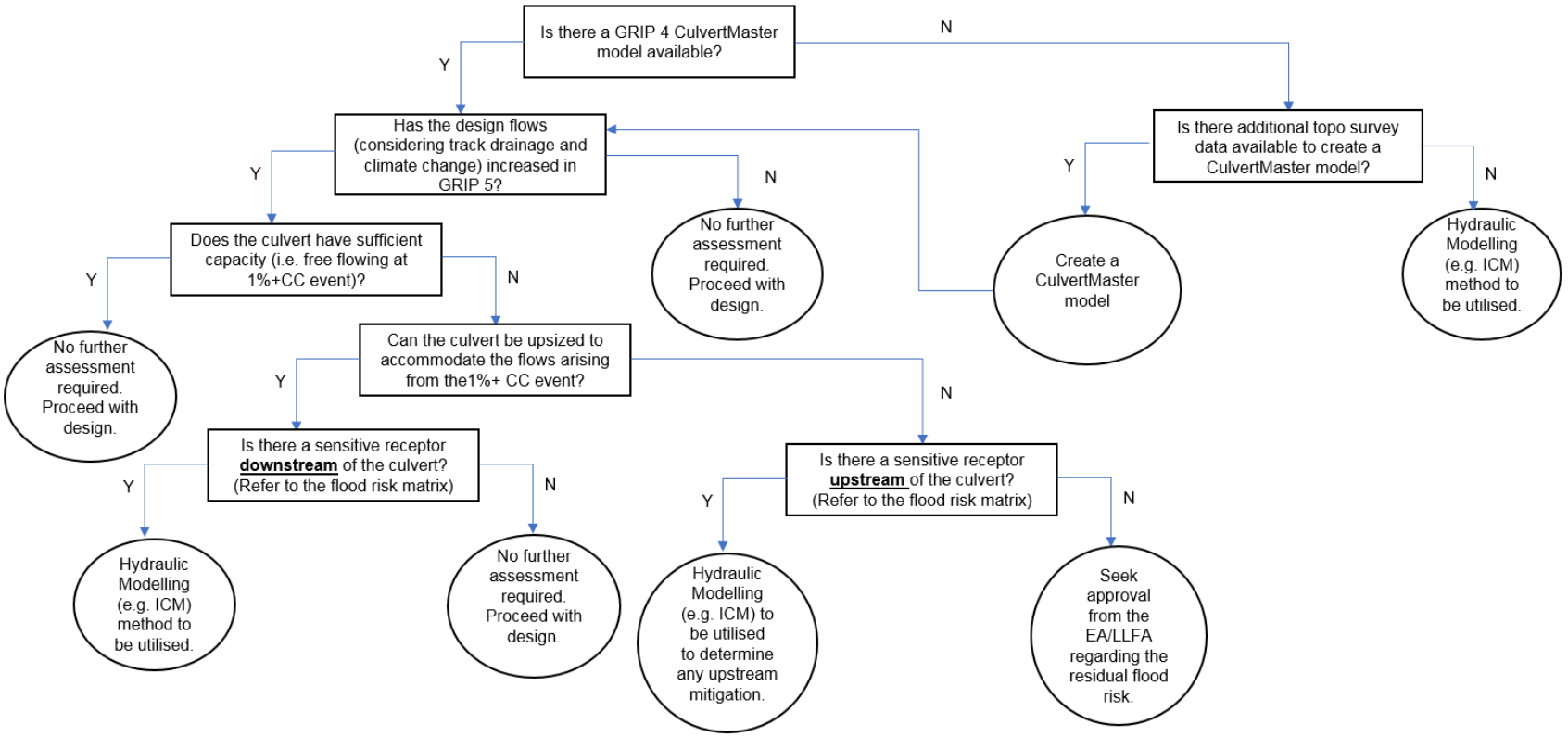
The procedure described in this document will be followed throughout GRIP 5 to ensure that current climate change allowances are applied to the new culverts. However, the impact of applying climate change allowances will be assessed on a case-by-case basis for existing railway culverts which are being modified by the project. It was agreed with regulators that in some cases it may not be viable to accommodate such allowances due to site conditions / constraints; therefore, some flexibility in approach is considered to be appropriate, taking into account potential impacts on sensitive receptors.

[7] Project Wide Water Framework Directive Assessment (WFD, reference: The Network Rail (East West Rail Bicester to Bedford Improvements) Order, Environmental Statement, Volume 3, Appendix 13.2)

Any variations required to this methodology for a particular culvert will be discussed and agreed with the relevant authority. It should be noted that the climate change allowances are due to be updated in November 2018, and at the time of writing were not available. When these values become available, we will undertake a sensitivity analysis using the updated allowances to understand the impact on the modelling and design of the proposed culverts.

Appendices

Appendix A- GRIP 5 Hydraulic Assessment Flowchart



Appendix B List of Information Used

Title	Model Reference	Purpose
EWR Civils Earthwork Models	• EWR2-EGE-MOF-PBL-231000 (P05) • EWR2-EGE-MOF-PBL-251000 (P03) • EWR2-EGE-MOF-PBL-271000 (P08)	To determine the length of required culvert extension.
P-Way Track Model- 2E	• 133735_RW-EWR-XX-XX-M3-RP-001000	To determine the proposed track level at the culvert location.
P-Way Track Model- 2A&B	• EWR2-ETR-MOD-PBL-270003(P06)	To determine the proposed track level at culvert location.
Culvert Location	• EWR2-ECV-MOD-PBL-210300 (P01) 2A • EWR2-ECV-MOD-PBL-220300 (P01) 2B • EWR2-ECV-MOD-PBL-250300 (P01) 2E	To obtain coordinates for the culvert ends.
Route-wide LiDAR Data	• EWRP2 Mapping Section 2a&2b OBB12 • EWRP2 Mapping Section 2e&2f OBB12	To determine the existing culvert invert level.
Route-wide Culvert Surveys	• 133735_RW-EWR-XX-XX-MC-G-000001	Determine existing culvert invert level

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