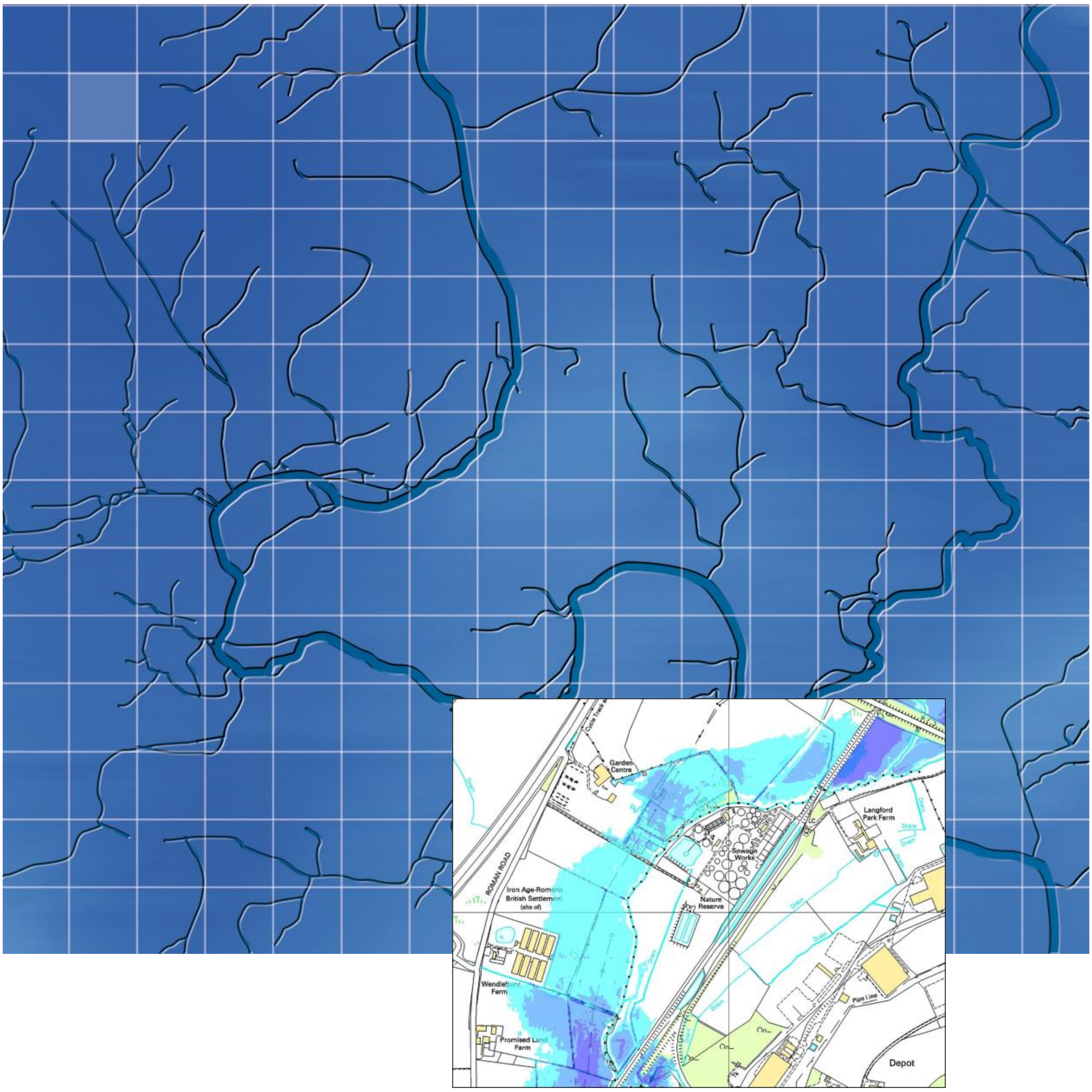
Network Rail and Chiltern Railways

January 2014

MOD Sidings Model Report



Wallingford HydroSolutions Limited

Network Rail and Chiltern Railways

MOD Sidings Model Report

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For and on behalf of Wallingford HydroSolutions Ltd.

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Position *Technical Director*

Date **28th January 2014**

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Contents

1 Introduction and Background

1.1 Purpose of the Report

Wallingford HydroSolutions (WHS) has been contracted to undertake flood modelling on behalf of Chiltern Railways and Network Rail, to inform a Level 3 Flood Risk Assessment for proposed essential infrastructure works along the Bicester to Oxford Railway line.

This report focuses on the proposed works at the MOD Sidings (NGR: 458160, 221195). The purpose of the report is to outline the hydraulic model development which allows analysis of flood risk to and as a result of any proposed development works in this location. The results will also allow consideration as to the requirements of any mitigation measures such as design of compensatory storage.

The proposed works in this location include the widening of a railway embankment and the partial infill of a surface water pond and ditches.

This report will only discuss elements of the model construction north of Langford Lane as this is the area that is relevant in the assessment of development implications at the MOD Sidings. The model extends a considerable distance downstream of Langford Lane and will be used within other flood risk assessment submissions related to access roads at Langford Lane and adjacent to the M40. Model construction south of Langford Lane is considered within the Langford Lane Hydraulic Model Report[1] which was submitted to the Environment Agency at the start of January 2014.

1.2 Background

1.2.1 Site Description

The proposed development is focused around the railway embankment adjacent to the MOD site, approximately 0.5km downstream of the edge of the Bicester urban boundary as highlighted by Figure 1. The surrounding catchment is rural despite the close proximity to Bicester town. Dominant land use is farmland, with a number of small building installations such as a water treatment works and MOD installations located close to the proposed development boundary.

Two watercourses are found within the study area. The Langford Brook is the dominant flow route. A tributary of the Langford Brook, the Bure Brook is also located close to the site, the confluence of the two being located approximately 100m to the east, as highlighted within Figure 1.

Current Environment Agency Flood Maps suggests that the area is at risk of flooding during both the 1 in 100 year and 1 in 1000 year event, as highlighted by Figure 2. There are no formal defences within the study area.

[1] WHS. 2013. Langford Lane Hydraulic Model Report.

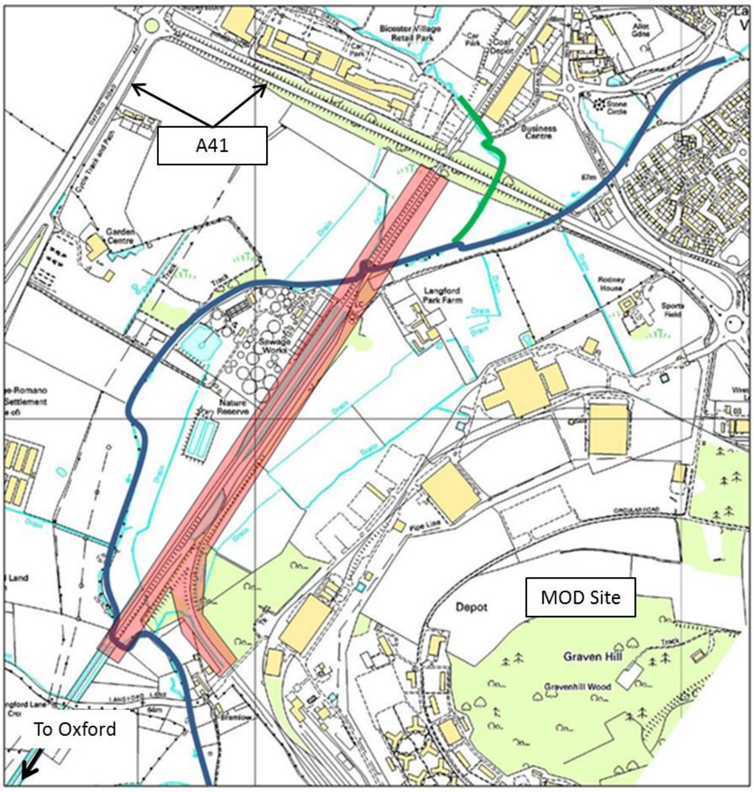

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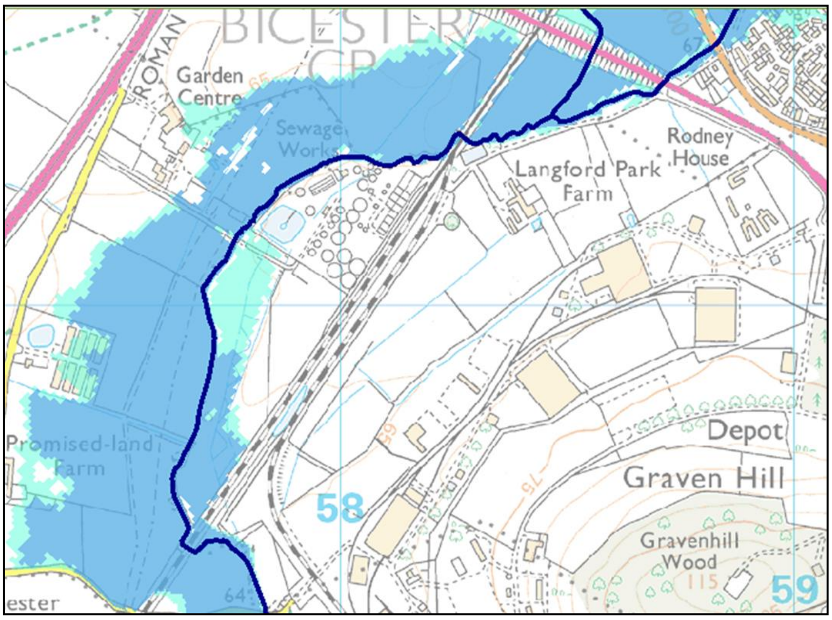
Figure 1 – MOD Sidings Development site location (Red shaded area). Bure Brook (Green Line) and Langford Brook (Blue Line) are the dominant watercourses influencing this site.



1 in 100 year event outline

1 in 1000 year outline

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Figure 2 – Extract from the Environment Agency Flood Map (showing extensive flood extent in the area).

1.2.2 Development Proposal

As part of the proposed railway upgrade works between Bicester and Oxford there is a requirement to widen the existing railway embankment along this section of the track. This route is currently single track and dual tracking is required to improve passenger services. Improved connectivity to the MOD site to the south will also be provided, involving provision of an additional railway track and further widening of the railway embankment. A basic overview of the proposed works is outlined within Figure 3. Figure 3 also highlights three distinct work areas, referred to as Eastern, Central and Western, within the report. More details of the development proposal are provided within the formal FRA submission[2] document.

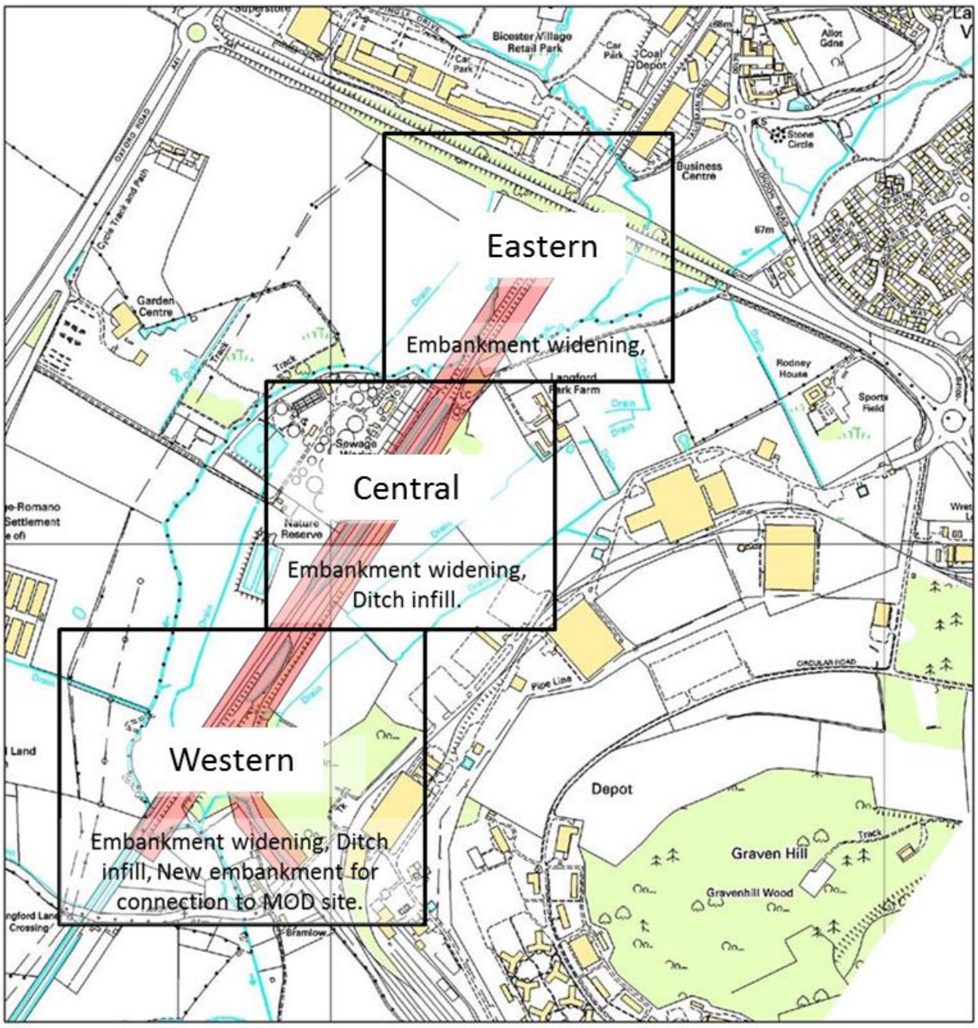

Figure 3 – Extent of Development and Proposed Works (identifying three key geographical areas of works referred to within the report).

[2] WHS. 2013. MOD Siding Flood Risk Assessment

1.3 Previous Model Study

The proposed development site partially falls within a current 1D-2D model extent, the modelling undertaken by Peter Brett Associates (PBA) LLP on behalf of the Environment Agency[3] in 2009. The Environment Agency has outlined that this modelling is suitable for use as a baseline model to aid in flood risk assessments. This modelling was undertaken under the Strategic Flood Risk Mapping framework, to create flood risk maps of Bicester and to gain a better understanding of the risk in this area.

The hydraulic model was a fully integrated 1D/2D model using ISIS-TUFLOW modelling software (ISIS version 3.1, TUFLOW version 2008-08-AH-isp). The project modelled a number of watercourses in the Cherwell Catchment; these were the Langford Brook, Pingle Stream and Bure/Back Brook. These watercourses run through Bicester, as highlighted in Figure 4.

The model was reviewed by the Environment Agency at the time of completion and was found to be appropriate for use in flood risk mapping. The mapping produced by this model is currently being used by the Environment Agency as flood risk mapping for the area.

The model grid size used within this model was 10m.

A full copy of the model and model report is available from the Environment Agency on request.

The current model extent does not include all of the development site boundary. The western area of development is outside the current flood model domain. In addition, the 2D domain is relatively coarsely defined at a 10m grid resolution. As a result additional hydraulic modelling is required to allow for modelling of the impact of engineering features.

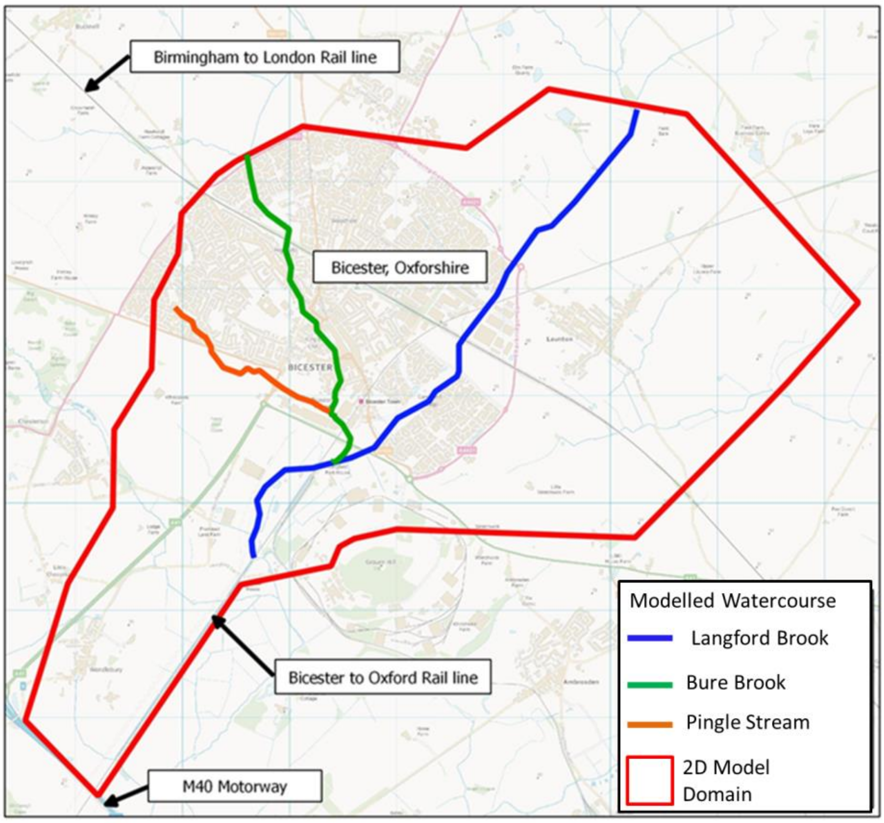

Figure 4 – Peter Brett Associates (2009) - Bicester Flood risk mapping study, model extent.

[3] Peter Brett Associates on behalf of Environment Agency. 2009. Bicester Flood Risk Mapping Study. Ref: R0/rev4.

1.4 Model Approach

As the current 1D-2D PBA model is considered suitable for use in flood risk assessments; this will form the baseline model for this study. The model will be extended downstream to include the area of development north of Langford Lane. The model will also be run with an improved 2D DTM, based on 2m resolution LiDAR, rather than the original 10m model grid.

In order to improve model run times, the original model will be trimmed at Gloucester Road and just downstream of the Bicester outlet village.

Model checks and improvements, where necessary, will be undertaken, including the checking of current modelled bank heights and link lines.

It is highlighted that the current model provided as part of this submission extends south of the required area of study. Other development proposals as part of the wider upgrade programme at Langford Lane and adjacent to the M40 will require flood risk assessments and therefore the model was extended downstream to the River Ray. Only modelling north of Langford Lane will be considered within this report although files provided cover a greater model extent. Details of modelling undertaken south of Langford Lane is considered in other submissions relating to the Langford Lane access road and a proposed access road adjacent to the M40.

2 Hydrological Model

Re-assessment of hydrological inputs has been undertaken as described with the hydrological report accompanying this model study[4]. The hydrological assessment was used as the basis of model 1D hydrological inputs.

The hydrological assessment has highlighted that the hydrology used in the existing PBA model is likely to be very conservative. The PBA model hydrology has however been adopted to provide a conservative assessment.

3 Hydraulic Model

3.1 Introduction and Methodology

The scope of modelling work was set out in a number of discussions and email communications with the Environment Agency. As outlined previously the current Environment Agency hydraulic model does not extend to the complete development site; rather its downstream boundary is set at the railway embankment upstream of Langford Lane (OXD40), NGR: 457673,220495.

As a portion of the development site is downstream of the current model boundary an extension to the existing model was required. The existing Environment Agency model is an ISIS-TUFLOW 1D-2D model, with a 10m cell resolution. It was considered appropriate to trim the existing model in order allow conversion to a 2m horizontal resolution and to reduce the model size and run times.

The chosen 2m horizontal grid resolution allows the development features (e.g. embankment widening) to be mapped and modelled more accurately. It will also allow more detailed consideration of floodplain flow routes.

As the current Environment Agency model consists of a 1D-2D hydraulic model, it was considered appropriate to use the same modelling software in order to undertake this assessment. ISIS – TUFLOW allows a detailed assessment of both 1D (in channel) flow patterns, levels, velocities but also allows greater analysis of 2D (floodplain) flow routes, flow patterns and flood depths. The combination of 1D-2D

[4] WHS. 2013. MOD Hydrology Report.

allows a better overall understanding to be gained of how the river catchment operates holistically, allowing the modelling of different parts of the catchment which could not be undertaken using only one type of model methodology. The combination of open-channel assessment alongside overland flow enables a more integrated approach to modelling.

3.2 Model Extent

The model is a combination of existing EA model and a new area extending the model downstream. As previously stated the Environment Agency model has been trimmed upstream. Figure 5 outlines the extent of the model and highlights the "new" and "existing" model areas.

This study covers two main watercourses, the Langford Brook and Bure Brook.Table 1 sets out the upstream and downstream grid reference of the watercourses to mark the model extent considered within this report. This excludes the reach downstream of Langford Lane.

To summarise, a 1D-2D hydraulic model has been constructed to allow consideration of the impacts of proposed development works at the MOD Sidings. ISIS version 3.6.0.156 will be used as the 1D modelling package. TUFLOW version 2012-05-AE-iDP-w64 will be used as the 2D component. The 1D element of TUFLOW (ESTRY) was used to model culverts within the flood plain at a number of locations; this is discussed in more detail within the structures section of the report.

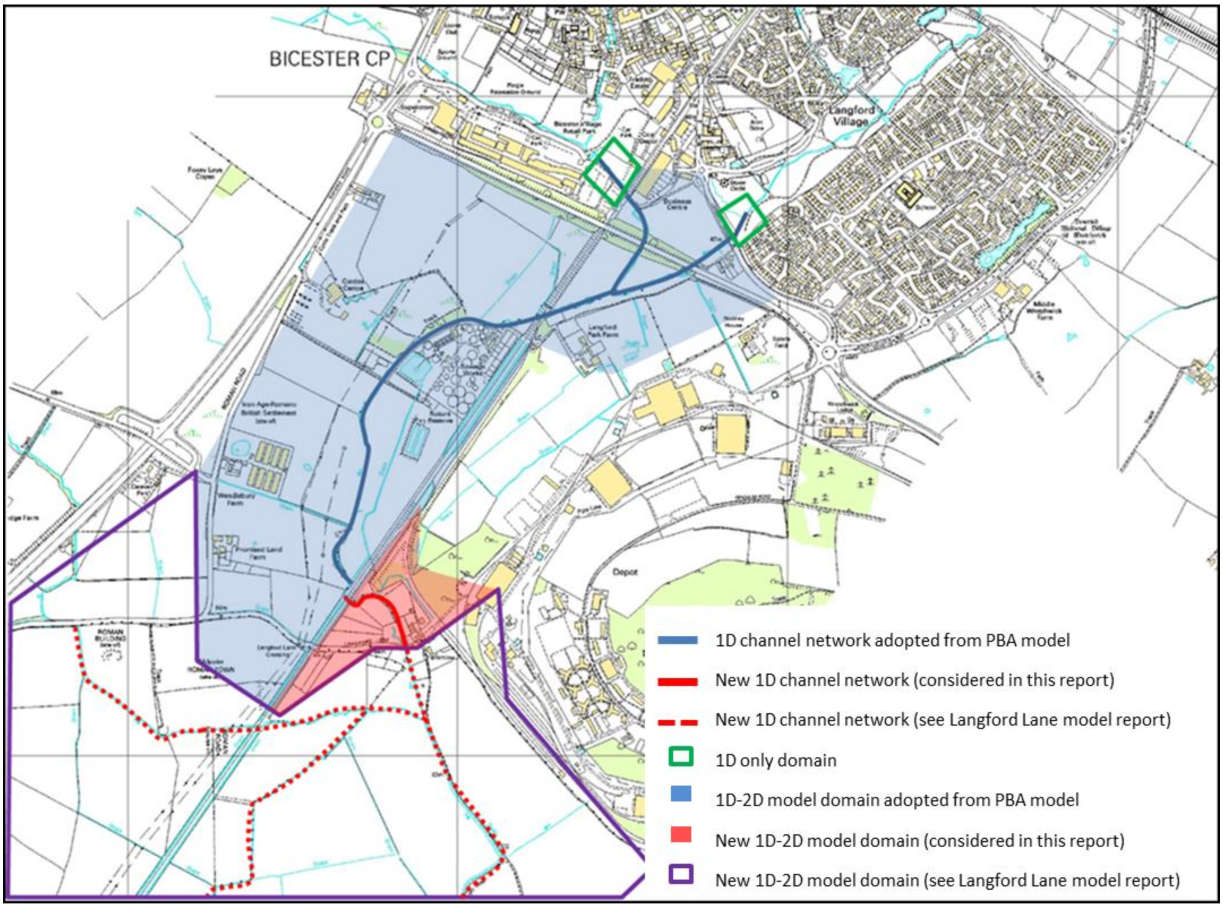

Figure 5 – WHS Model, Model Domain Schematic

Table 1 – Watercourse Extents Modelled by this Study.

Watercourse	Upstream	Downstream
Langford Brook (existing)	458879,221673	457674,220497
Langford Brook (extension)	457674,220497	457779,220313
Bure Brook (existing)	458414,221808	458444,221413

3.3 1D Modelling

As stated the assessment of fluvial flood risk was undertaken using ISIS (Halcrow, version 3.6.0.156) one dimensional unsteady state hydraulic model. The model comprised of survey sections adopted from the existing model, with the extension outside of the original boundary using new survey sections provided by Interlock Surveys Ltd (April, 2013). A 1D schematic of the model layout is presented in Figure 10. A model log outlining decisions and assumptions for each cross section within the model is presented within the model submission alongside these reports. As previously stated, the existing Environment Agency model was trimmed, with the new model upstream boundary located at ISIS node LA.2021 (Langford Brook) BU.472 (Bure Brook), this was considered to be appropriate located approximately 1.5km upstream of the development area.

Although the cross sections are relatively coarsely spaced this is not considered to represent a significant limitation. The catchment is rural and flat and the channel dimensions themselves are relatively consistent. As such the number and spacing of the cross sections was considered to be appropriate and this has been accepted as the basis for Environment Agency model.

3.3.1 Boundary conditions

Hydrological analysis was undertaken as outlined within the hydrology report[4]. The associated hydrographs for each watercourse were applied at the upstream boundary of each watercourse. The original PBA modelling did have a number of lateral inflows within the 1D domain to take into account increases in catchment area. However, this model has removed these lateral inflows and instead inserted the full hydrographs at the upstream boundary. This is considered further within the hydrological report which accompanies this report.

The downstream boundary of the larger model was located on the River Ray, on the downstream side of Fencott Bridge (NGR: 457001, 216192).The boundary was simulated as a normal depth boundary. Based on the slope of the River Ray the boundary was set to a slope value of 0.001 or 1:1000. As the downstream boundary is 4.5km downstream of the downstream limit of the MOD Sidings works, the results at the works location will be insensitive to the downstream boundary assumptions.

3.3.2 River Channel Cross Sections

River channel cross sections were input into ISIS based on survey data undertaken by Interlock Surveys (April, 2013). Cross sections were also adopted from the existing PBA model. To aid in model stability linkages between the 1D and 2D model domains, one interpolated section was added within the existing model extent. This is located at node LA.1350D.1. The original distance between nodes at this location was 393m and this was split into two to allow greater stability. The downstream cross section of the original model was also removed and replaced by more up to date survey data, entered as node LB2. This cross section was considered to better represent the upstream face of the railway embankment at the downstream end of the original PBA model (the original model did not represent this structure).

For more detail on the cross sections at each 1D node, please refer to the model log provided alongside this report with the hydraulic model files. This outlines any assumptions and the method behind representation in more detail for each 1D ISIS node. The channel sections were surveyed after a long period of rainfall and as such the water levels noted within the CAD files supplied alongside this report within the model files are not considered to be representative of base flow conditions.

Existing sections LA.1362 and LA.1350 have been deactivated to a width less than that previously represented. Originally the full floodplain width in this location had been represented in 1D and in order to better represent development proposals in this location the cross section was deactivated at left bank level. Flows were then connected to the 2D model via an HX link line. The reasoning behind this narrowing of these 1D sections is summarised in Figure 6.

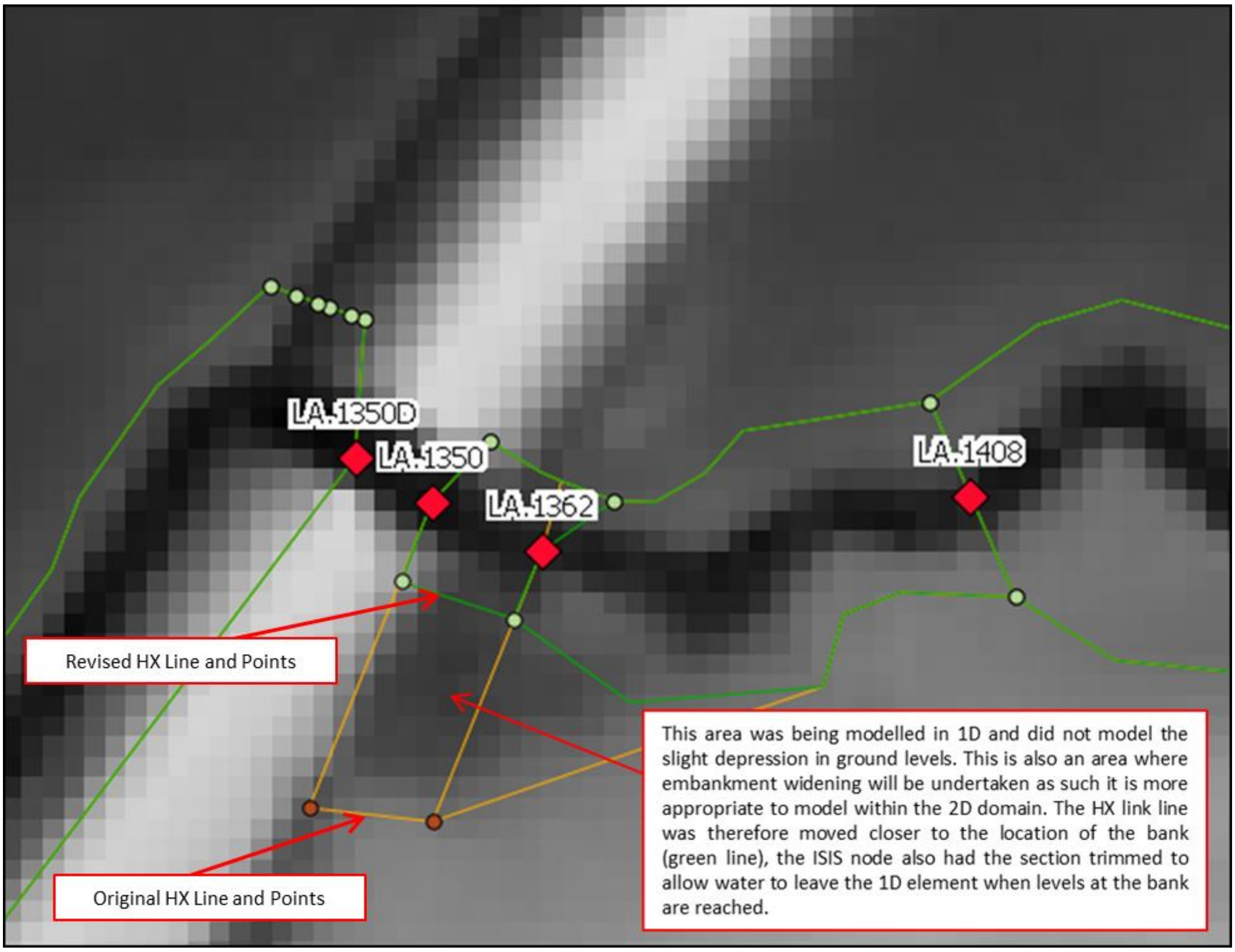

Figure 6 – Section Alteration at Node LA.1350 and LA.1362 (to allow more detailed analysis of flood levels and impacts as a result of development).

Section LA.1873 was also trimmed slightly on the left bank. LiDAR data in this location suggested an overland flow route from this section through the 2D domain to the downstream section which was not represented in the existing PBA model. The section was therefore trimmed to the left bank to allow flows across the left bank to be connected to the 2D domain to test whether a flow route existed. This is considered in more detail within section 3.4.3.

3.3.3 Mannings 'n'

The resistance to flow in the channel and over the floodplain is replicated in the hydraulic model by the use of a roughness co-efficient. In this study Manning's 'n' was used as the roughness coefficient. The Manning roughness coefficients applied to the modelled channels and floodplains have been estimated from the site visit observations using tables of recommended values[5].

A Manning's 'n' of 0.035 was considered appropriate for the majority of the channel. Guidance from Chow[5] describes this value as representative of a clean, relatively straight channel, with no rifts or deep pools, with some stones and weeds. This is considered representative of the channel network in this location. At a number of locations the in stream Manning's value was increased to 0.05 to reflect local changes in bed morphology.

The original ISIS model sections adopted from the Environment Agency model used Manning's n values of 0.05 to 0.06 for the channel sections. These values are considered to be relatively high for the channel type and its nature, in particular as the survey photos and site walkover confirmed that the bed and lower banks of the watercourses were relatively smooth with little or no cobbles.

A photograph of a typical cross section is provided as Figure 7. This photograph is taken downstream of ISIS node LB4. The bed material in the channel is made up of very fine material and therefore the Manning's n value of 0.035 is considered appropriate. The bank has been set to a slightly higher level of 0.04 to take into account the roughness of the intermittent vegetation.

Sections upstream of section LA.1350d retain the original PBA manning's values. Therefore, the reach of watercourse which runs adjacent to the site of interest uses the higher and more conservative Manning's values used within the original model study (PBA, 2009).

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[5] Ven Te Chow. 1959. Open-Channel Hydraulics. McGraw Hill. ISBN 0070107769

Figure 7 – Typical Channel Cross Section along the Langford Brook (This section is taken at LB4).

3.3.4 Structures

All structures represented within the original PBA model were maintained. Two new structures were added to the extension of the model. The first is the railway embankment bridge crossing at node LB2, which was not included within the original model. This structure was modelled as a standard USBPR bridge unit. No spill was attached as the flood level is not predicted to reach the top of the railway embankment. This is considered appropriate based on the photograph of the structure shown in Figure 8.

The second additional structure is Langford Lane crossing, which marks the downstream limit of the section of model considered by this report. Langford Lane is represented at ISIS node LB6. This structure was modelled as a culvert unit, considered appropriate based on the photograph of the structure shown in Figure 9. The Langford Lane structure has a significant drop in bed level on the downstream side of approximately 0.99m.

A number of surface water culverts are also present along the railway embankment, the input of these into the model is considered within section 3.4.3.

Figure 8 – Upstream Face of Railway Bridge Modelled as USBPR Bridge Unit at ISIS node LB2.

Figure 9 – Upstream Face of Langford Lane Road Bridge, Modelled as a Culvert Unit at ISIS node LB6

3.3.5 1D model schematic

Figure 10 shows the ISIS 1D model schematic, illustrating the construction of the 1D component of the model. Interpolated cross sections have been removed from the schematic for clarity. Junctions between structures and spills have also been removed; however the spills have been placed adjacent to their corresponding structure. To provide an indication of how the model extent considered within this report relates to the larger model used for other flood risk assessments the complete model extent has been shown within the figure. This report is only considering model elements upstream of LB7, the downstream section of Langford Lane bridge crossing (highlighted on Figure 10),.

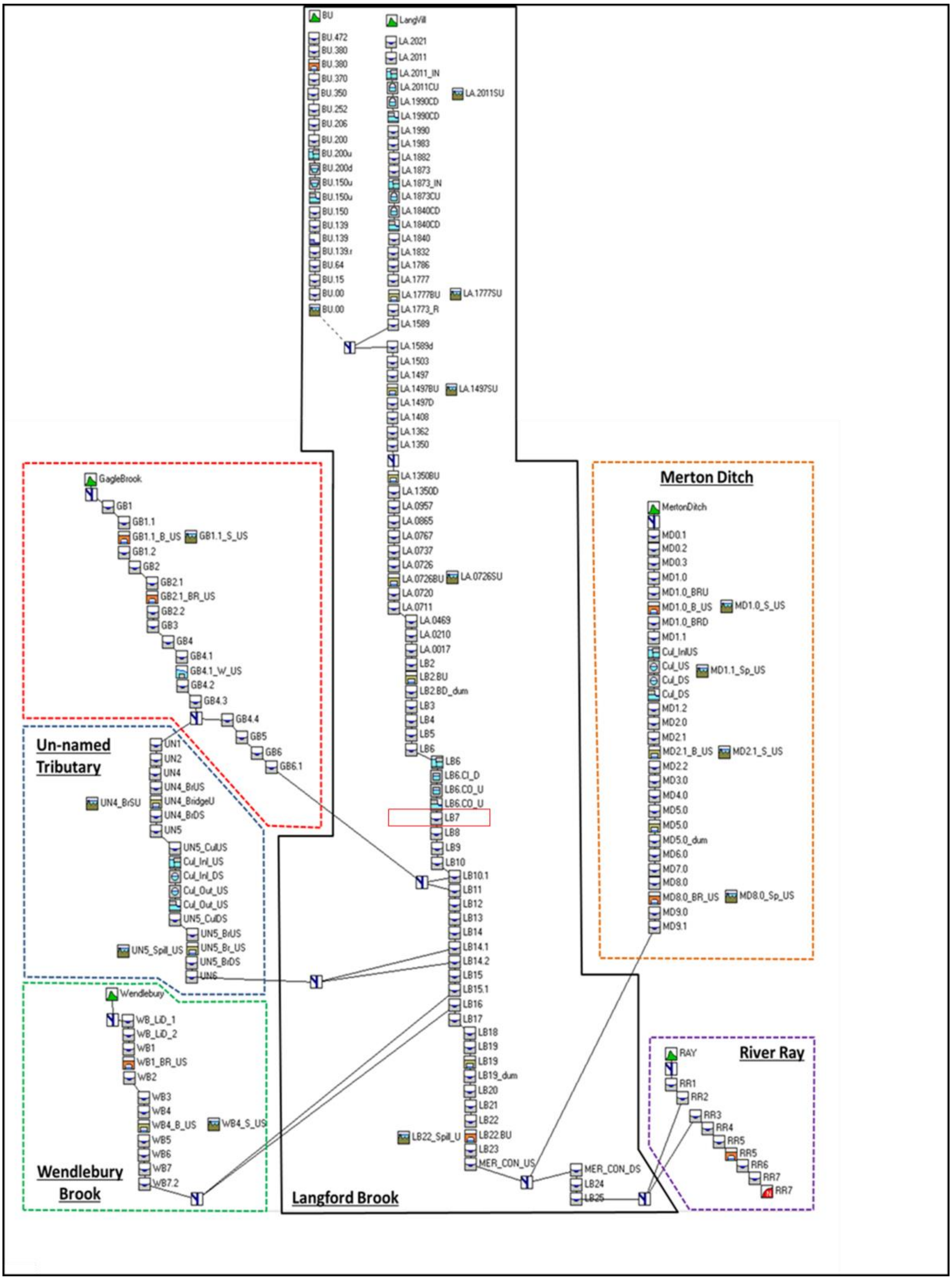

Figure 10 – Schematic of 1D ISIS Model (Nodes are referenced to correspond with the cross sectional reference assigned by surveyors. The model log and survey output has been provided within the appendices for further information).

3.4 2D Modelling

2D modelling allows the flow of flood waters across the floodplain to be considered. Using 2D modelling, features such as buildings or a change in topography can be incorporated into a DTM (digital terrain model) of the floodplain. This allows for consideration of impacts caused as a result of development works (which alter the ground levels across an area). This study used 2D modelling in order to assess the change in flood depths, velocities, water levels upstream and downstream of the proposed MOD Sidings development.

A number of files were used in order to build up a digital representation of the floodplain and the potential flood routes that exist. The construction of the 2D domain is considered in the following sections.

TUFLOW was used as the 2D model package. The 2D model component was run using a 2m grid cell size, which is small enough to allow for 2D flood plain features such as the proposed embankment works to be represented accurately.

3.4.1 Floodplain Topography

LiDAR data were used as the underlying topographic data for representation of the floodplain. A 2m resolution data set was used and converted to a 2m model grid. This was used both within the new and original model extents. Flood plain extent was considered to be relatively large in this area, as the topography is very flat. To ensure that glass walling did not occur, a larger than necessary 2D polygon was used to define the 2D model extent. Figure 11 highlights the area of 2D model extent within the vicinity of the MOD Sidings.

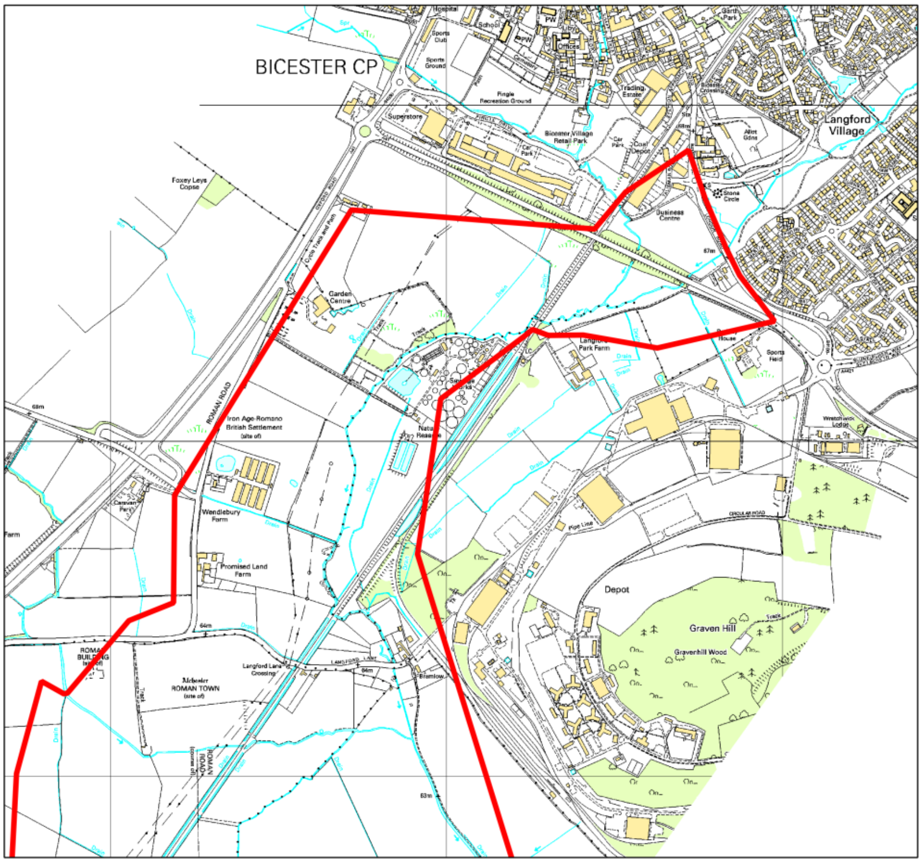

Figure 11 – Extent of Modelled 2D Domain Focussed Around the MOD Sidings Development.

3.4.2 Roughness Co-efficient

Roughness co-efficients for the existing model extent were adopted from the original PBA hydraulic model. This used Manning's 'n' roughness co-efficients applied to master map mapped polygons, which were grouped into specific land use types.

For the extended model domain, a baseline Manning's 'n' was applied. This was considered appropriate as a large proportion of the model domain was defined as rural, with the dominant land use being pastureland / agricultural land. As such a Manning's value of 0.045 was applied. This was considered suitable based on guidance from the conveyance estimator software published by HR Wallingford[Error! Bookmark not defined.]. A number of areas were categorised as "non-default" and a different Manning's 'n' was applied to shape files based on the categories identified within the original PBA model.

The 2d_mat_LLB_Mann_R_002.shp and 2d_mat_Bicester_001.mif provided within the model files allows analysis of the Manning's 'n' values used in the model. Table 2 summarises the Manning's 'n' values applied to those areas highlighted within the model files.

Table 2 – Mannings 'n' Values used within the 2D Floodplain.

Code in .tmf file	Description	Manning's n Value
1	Inland Water	0.03
2	Dense Vegetation	0.09
3	Roads	0.03
4	Dense Urban Areas / Individual large buildings	0.15
5	Rail	0.035
6	Default PBA (Now redundant)	0.05
7	General Land Surface (short grass)	0.035
8	Scrub woodland	0.05
9	Height varying grass (set as default)	0.045

3.4.3 Structures and Flow Routes

A number of hydraulic structures are modelled within the 2D domain, some of which are within this report's study area. These take the form of ESTRY 1D culvert units. These culverts have been modelled within ESTRY as they are modelled as dry at the start of a simulation. ISIS does not allow dry channels or structures, although dummy flows can be used. It was however considered appropriate for this study to represent these flow routes using ESTRY. Figure 12 shows the locations of a number of culverts and

Table 3 presents the dimensions of the culverts based on culvert condition reports and survey carried out by Atkins in January 2013.

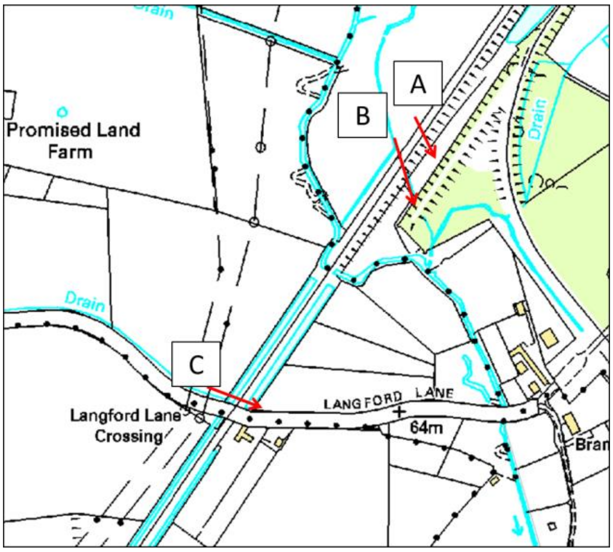

Figure 12 – Location of Culvert Units Represented in ESTRY (1D component of TUFLOW).

Table 3 – Culvert Dimensions used within ESTRY 1D units Considered within this Report.

Reference	Type	Dimensions
A	Box	0.91 x 0.91
B	Box	1.22 x 1.22
C	Box	1.22 x 1.22

Within the original PBA model, one potential over land flow route was found to have not been modelled. As such, it was considered important to represent this route to consider whether flows could travel through the floodplain and bypass a railway embankment in this location. Figure 13 highlights the location of this 2D flow route. In order to represent this, the 1D code and HX link lines were trimmed back to the left bank of the watercourse. The zpoints set along the HX line were also re-assigned with values more appropriate to the true left bank levels at this location.

Figure 13 – 2D Flow Route not Originally Modelled within the PBA Model shown as Red Arrow (This has been modelled within this updated model simulation, HX link lines were changed to allow consideration of this flow route).

At a number of locations, the interpolated bank level within the 2D domain was considered inappropriate when compared to LiDAR levels. Although there are errors associated with LiDAR data, the vertical accuracy is considered to be +/- 0.15m. Figure 14 highlights one of these locations within the original model. Here the bank levels interpolated based on the levels from the ISIS nodes were causing an artificial wall to be created within the 2D domain, preventing the movement of water between the channel and the 2D domain and vice versa. As such bank levels along the 2D HX line were reviewed, with a number of new zpts added to better represent the bank levels. This is an important consideration as it can potentially lead to large errors within the levels predicted both in the 1D and 2D domain.

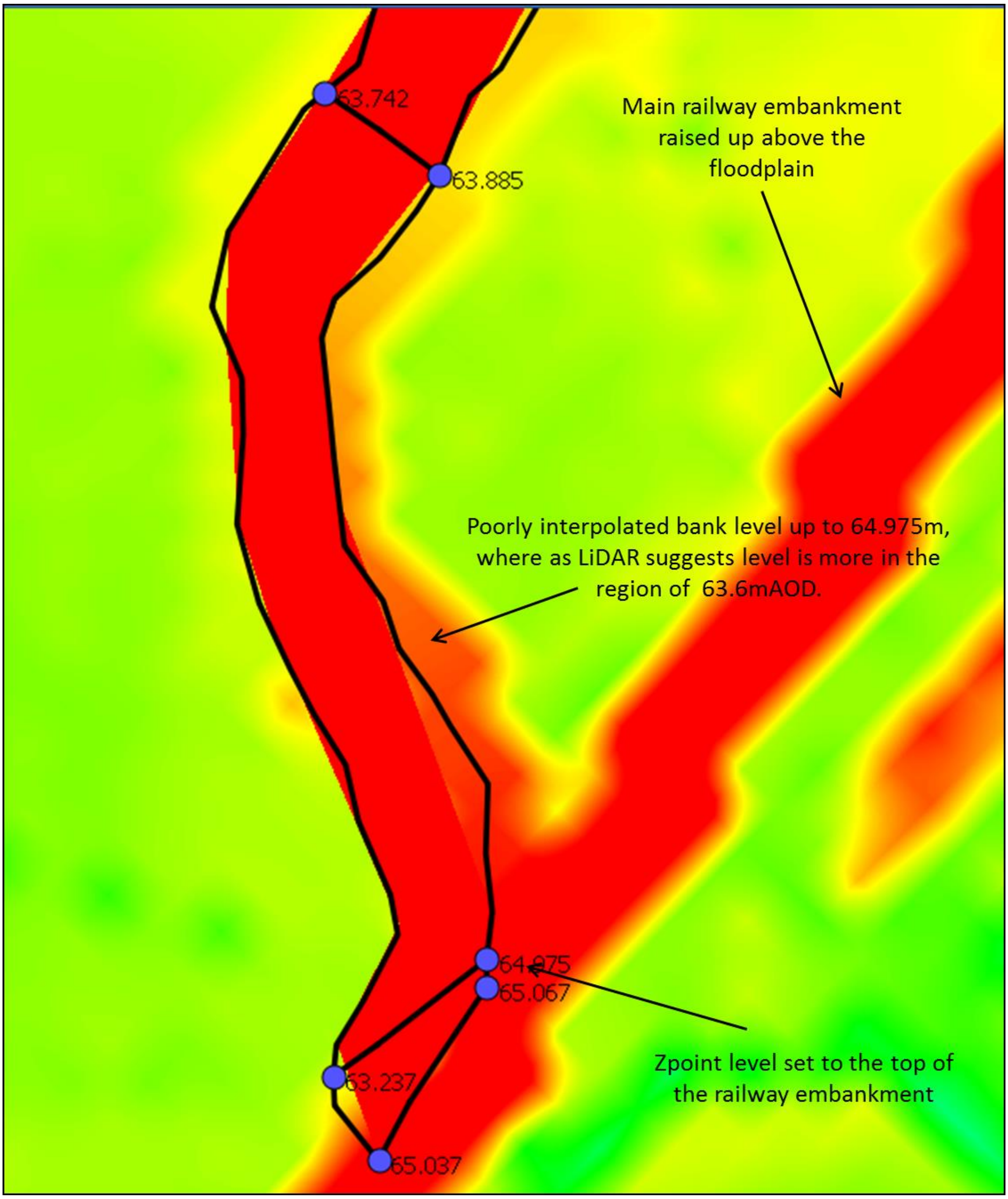

Figure 14 – Example of Where Poorly Interpolated Bank Levels have Raised the Level Causing a Potential Barrier Against Flows (The red bank levels indicate levels up to 65.00m AOD, interpolated poorly due to the point to south set to main railway embankment levels).

A number of stability issues were found when the model was run, which were primarily within the existing PBA model. The stability issues were caused as a result of using 2m resolution LiDAR, rather than the original 10m grid cell size. In order to reduce the number of unnecessary changes to the Environment Agency approved model, zshapes were added to smooth out the area causing instability. More detail on the location of these smoothed areas can be found within the model log supplied with the model files provided on USB as part of this submission.

3.4.4 Drainage Ditches Connected to Main Channel

A number of drainage ditches are found to connect to the main watercourse within this reach of the Langford Brook. LiDAR was used to confirm the connectivity between drainage ditches in the floodplain and the main channel, where connections were clear the 2D bank levels set on the HX boundary line were lowered to the bed level obtained from LiDAR (conservative level due to the inability of LiDAR to penetrate water). Bank levels were only lowered locally and then raised back to the main watercourse bank level based on LiDAR. Figure 15 shows the location of the drainage ditches considered to be connected and therefore needed to be represented. One particular drainage ditch is located immediately downstream of the proposed MOD Sidings embankment widening, as such it is critical for this flow path to be represented in order to present a more accurate prediction of the flow routes that may be in operation.

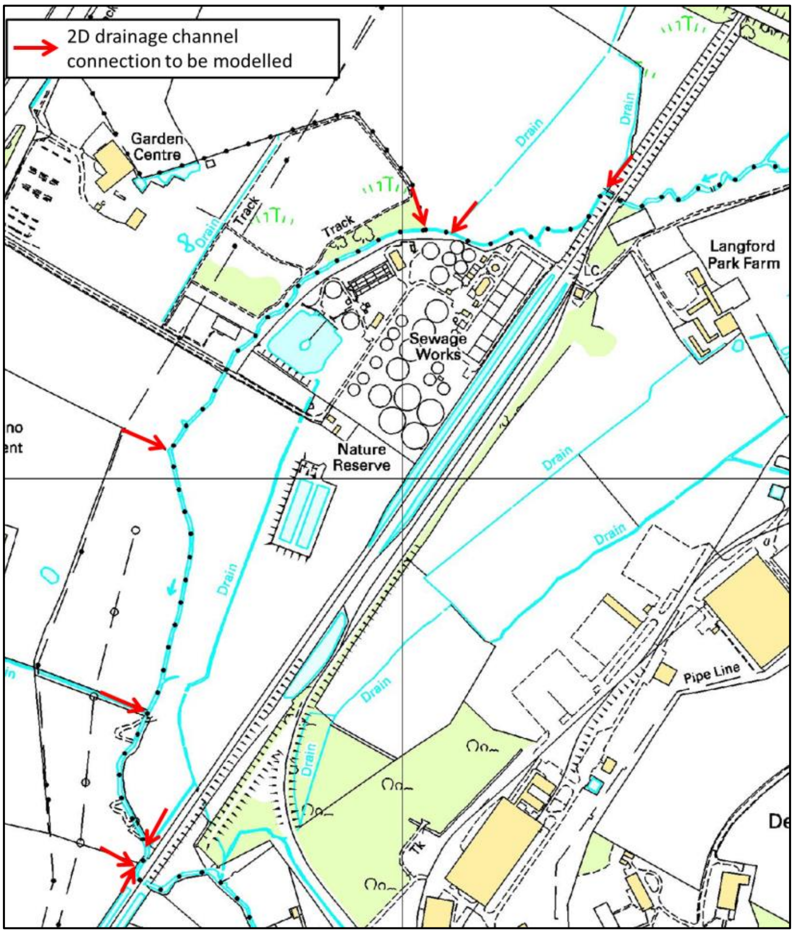

Figure 15 – 2D Drainage Channel Connections to Main Channel Represented as Lowered Bank Levels.

3.4.5 Downstream Boundary

The downstream boundary of the model is located 4km downstream of the site outside of the 2d domain of the model. The boundary is sufficiently far downstream of the site such that it does not influence flood levels at the MOD sidings. Please refer to the Langford Lane Hydraulic Model Report[1] for details of sensitivity testing of the boundary condition.

3.5 Post Development Model

The main Flood Risk Assessment report for the MOD Sidings provides further details of the proposed works and the development of mitigation measures for the proposed development. The key features are a widened embankment, retained on its south side by a retaining wall, in conjunction with the provision of a swale to provide additional compensatory storage on a volume for volume basis.

3.5.1 Embankment modification

The proposed width increase along the main railway embankment was input into the model using a zshape, as outlined within the model log supplied with the model files provided on USB as part of this submission.. This raised the area defined by the z shape above the flood level along the embankment. The alignment was based on AutoCAD designs provided to WHS by Atkins in November 2013.

3.5.2 Swale

The swale was inserted using a zshape. The swale was designed to accommodate approximately 700m^3 of flood storage within its main body and was entered into the model based on Atkins' preliminary design. A zshape was used to lower the grid cells within the swale area to those proposed by Atkins. A copy of the swale design is located within Appendix 4 of the main FRA document. The location of the swale was placed adjacent to the A41 embankment. Although this model does not represent the exact location of the swale, it does allow for the consideration of volume for volume storage to be undertaken at the levels proposed.

In order to allow for the swale inlet to operate as designed, the bank levels within the 1D-2D HXI spill line were modified to those of the proposed inlet.

3.6 Runs

The following simulations were run:

Baseline Simulations

- 1 in 100 year plus climate change (QMED on River Ray); and

Post-development Simulations

- 1 in 100 year plus climate change post development with swale feature.

3.7 Results

Model results are considered within the main Flood Risk Assessment report for the MOD Sidings. The baseline model results show a similar flood extent to that predicted within the original model study undertaken by PBA. Flood impacts and mitigations are covered within the main Flood Risk Assessment report.