MetroWest

Portishead Branch Line (MetroWest Phase 1)

TR040011

Applicant: North Somerset District Council
5.6, Flood Risk Assessment, Part 5 of 17
Appendices K to M
The Infrastructure Planning (Applications: Prescribed Forms and Procedure)
Regulations 2009, regulation 5(2)(e)
Planning Act 2008

Author: CH2M
Date: November 2019

Notice

© Copyright 2019 CH2M HILL United Kingdom. The concepts and information contained in this document are the property of CH2M HILL United Kingdom, a wholly owned subsidiary of Jacobs. Use or copying of this document in whole or in part without the written permission of Jacobs constitutes an infringement of copyright.

Limitation: This document has been prepared on behalf of, and for the exclusive use of Jacobs' client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this document by any third party.

Where any data supplied by the client or from other sources have been used, it has been assumed that the information is correct. No responsibility can be accepted by Jacobs for inaccuracies in the data supplied by any other party. The conclusions and recommendations in this report are based on the assumption that all relevant information has been supplied by those bodies from whom it was requested. Where field investigations have been carried out, these have been restricted to a level of detail required to achieve the stated objectives of the work. This work has been undertaken in accordance with the quality management system of Jacobs.

Document history

Project	Portishead Branch Line (MetroWest Phase 1) Development Consent Order Scheme
Planning Inspectorate Scheme Reference	TR040011
Volume and Application Document Reference	5, 5.6
Document title	Flood Risk Assessment, Part 5 of 17, Appendices K to M: Appendix K Hydraulic modelling of Drove Rhyne and Easton-in-Gordano Stream Appendix L Flood Zone review Appendix M Further development of Environment Agency coastal modelling
Regulation Number	Regulation 5(2)(e)
Applicant	North Somerset District Council
Lead Author	RB at CH2M

Version	Date	Status of Version
Rev: 01	12/11/19	Application Issue

MetroWest

Portishead Branch Line (MetroWest Phase 1)

TR040011

Applicant: North Somerset District Council
5.6, Flood Risk Assessment,
Appendix K Hydraulic modelling of Drove Rhyne and Easton-in-Gordano Stream
The Infrastructure Planning (Applications: Prescribed Forms and Procedure)
Regulations 2009, regulation 5(2)(e)
Planning Act 2008

Author: CH2M
Date: November 2019

TECHNICAL MEMORANDUM

Metro West Phase 1 FRA – Fluvial Modelling Technical Note

PREPARED FOR:	North Somerset Council
COPY TO:	
PREPARED BY:	Silvia Garattini/ Meloni Guido/Jonathan Hillaby
DATE:	16 November 2018
PROJECT NUMBER:	674946
REVISION NO.:	2
APPROVED BY:	Robert Bird/Silvia Garattini

1.0 Introduction

1.1 Study Background

CH2M HILL (now Jacobs) was appointed by North Somerset Council to undertake a Flood Risk Assessment (FRA) for the MetroWest Phase 1 Development Consent Order (DCO) application.

The exercise includes an investigation on the current fluvial flood risk and in the proposed scenario (re-opening of the railway line). This analysis was undertaken via the creation of two ISIS-TuFLOW 1D-2D models to compare pre- and post- development flood risk for various return periods.

1.2 Study Objectives

The primary study objectives are as follows:

i. Estimate flows at the railway line for several return periods;

ii. Create two 1D-2D models for the Drove Rhyne watercourse and the Easton-in-Gordano drain using the latest survey (AP Survey, 2015);

iii. Assess sensitivity of the model to downstream boundary, storm duration, Manning's n parameters, runoff percentage coefficient, structure representation.

iv. Run the model for baseline scenario.

v. Run post-scheme scenario (if appropriate) with watercourse modifications included for the same return periods referenced in (iv). Thus enabling an assessment of the pre- and post-development alterations to flood risk.

This technical note will focus on objectives ii, iii, iv and v, since the hydrology report is issued separately.

2.0 Model Data

2.1 Data List

A summary of all the data which was used during the creation of the model is provided in Table 1 below.

File name	Description	Format	Date	Comments
APLS_0401 Gordano.dwg	Topographic survey commissioned to support the MetroWest Phase 1 hydraulic modelling	AutoCAD drawings	November 2015	The surveys cover the area requested along the Drove Rhyne and the Easton-in-Gordano drain. Bed levels are reported for both hard and soft bed conditions.
Network Rail level survey	Topographic survey along the MetroWest Phase 1 railway alignment.	AutoCAD drawings	November 2015	The survey covers the embankments and the rails along the railway line.
MetroWest Phase 1 - culvert survey report (ARUP, 2015) W1097B-ARP-REP-ETR-000002.pdf	Desk study summary of available information Survey of railway Culverts	Pdf	September 2015	The document included position and approximate dimensions of culverts/ structures draining the railway line.
Various IDB annotated maps received by email	Maps of the area prepared by local IDB showing drain directions in the study area.	Pdf	November 2015	The maps show direction of drains in the study area. Maps were used to derive watershed areas North of the M5 and connections between drains which were not surveyed.
AIMS information for the study area	Maps of the high-ground and flood defences in the study area.	Pdf	Sept 2015	The maps are provided together with related table showing levels of defences and accuracy in the measurement.
-	Operational models of tidal structure along the two watercourses modelled.	Communication via email.	November 2015	EA confirmation of operational models of tidal structures within the study area.
2m LiDAR for the area	LiDAR of the study area	ASCII grid	Downloaded in Sept 2015	2m resolution LiDAR for the area used to update the 2d domain, downloaded from Geomatics. Lower resolutions were not available.
MasterMap for the area	MasterMap tiles used for the 2d domain roughness layer	Shapefile	Downloaded in Sept 2015	Downloaded as 1sqkm tiles.

Table 1: Summary of data used to update the model

2.2 Data Quality and Implications

2.2.1 Topography Review

The 2015 surveys cover the area indicated in Figure 1 along the Drove Rhyne and the area in Figure 2 along the Easton-in-Gordano watercourse. The survey included both information on the morphology of the watercourses and dimensions of key culverts/ structures.

Given the high level of silt present in the channel, soft bed levels were used to build models as this was deemed more suitable to represent the current flood risk.

Survey data was unavailable for a section of the Easton in Gordano watercourse. As can be seen in Figure 2, the reach between the railway line and the pond downstream from it were not surveyed. The downstream end of the culvert under the railway line was not available either, so the length of this culvert was not known. The assumptions made for the missing data are explained in the hydraulic modelling section.

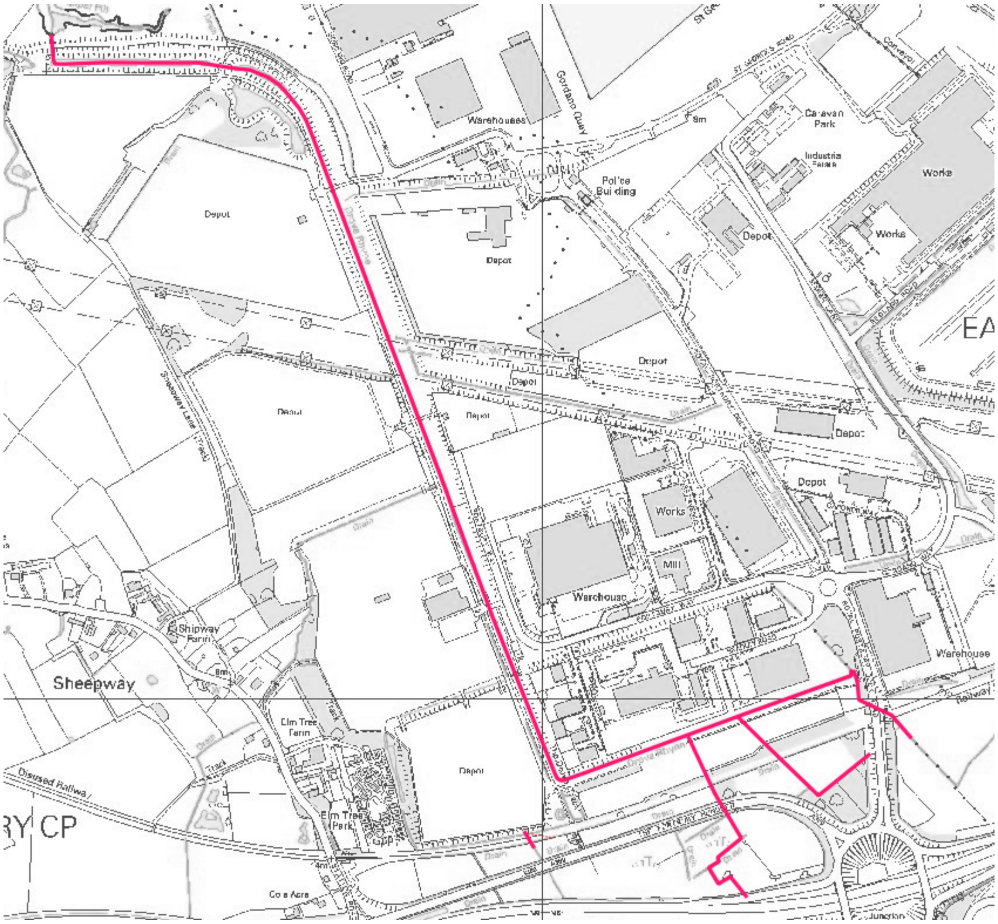


Figure 1: 2015 AP survey along the Drove Rhyne

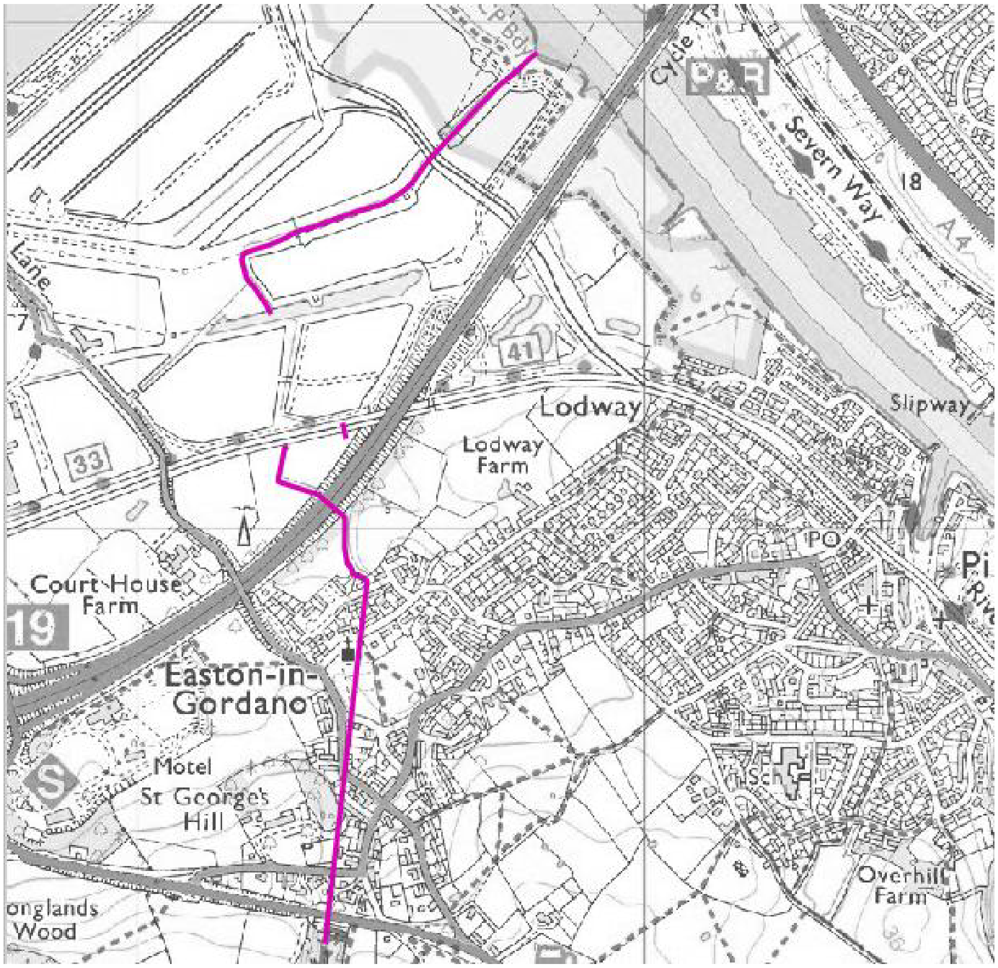


Figure 2: 2015 AP survey along the Easton-in-Gordano

An automated topography check tool compared all the out of bank elevations from the 2015 survey with the latest available 2m resolution LiDAR. The results show that overall there is an acceptable fit between levels in the LiDAR and in the model for the Drove Rhyne watercourse (Table 1 and Figure 3). The comparison does not show any geographical trend in the level difference (e.g. no reach is consistently lower/ higher than the DTM).

Table 1: Results from inspection with most recent composite LiDAR data (model- LiDAR) for the Drove Rhyne model

Metric	(m)
Min	-1.168
Max	0.681
Average	-0.099
Median	-0.052
Root Mean Square Error	0.299
Root Median Square Error	0.101

Figure 3: Results from comparison between Drove Rhyne model and with most recent LiDAR data

2.2.2 Structure Review

Culverts cross-sectional area and invert levels were also adjusted to take into account silt deposition where present as the possibility of the sediments being flushed away during a high-flow event was considered negligible.

3.0 Technical Method and Implementation

3.1 Hydrological Assessment

The final design flood estimates for the two catchments were derived as follows:

- The sub-catchment schematization was derived as detailed in the hydrology report with inflows from the catchments south of the M5 modelled using FEH RR1999 methodology, whilst direct rainfall (from the same design storm) was applied for catchments north of the M5. This approach is deemed appropriate for the low lying catchments north of the M5 where the diffuse drain network makes the routing model from catchment descriptors of the FEH RR model not applicable.
- Runoff coefficients for areas where direct rainfall was applied were consistent with values used for surface flood modelling (70% for concrete and manmade surfaces and 30% for natural environment).
- A critical storm duration of 6.25 hours was initially identified for the Drove Rhyne catchments at the culverts running underneath the railway line (Figure 4).

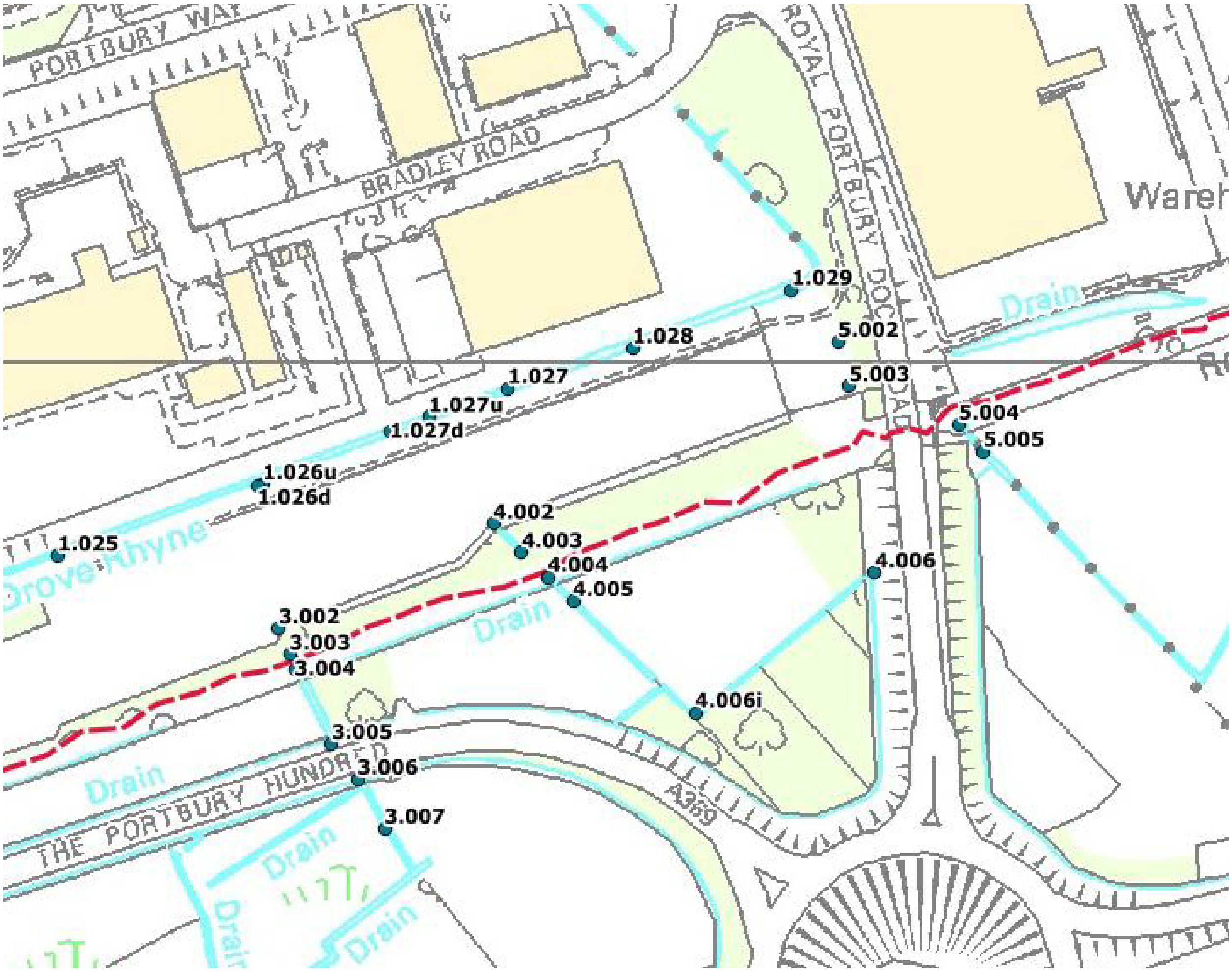


Figure 4: Culverts connecting the Drove Rhyne to its tributaries running underneath the existing MetroWest railway line represented by the red line (3.004, 4.004 and 5.004 nodes are the inlet of the culverts).

- As no information was available for the culverts running underneath the M5, it was assumed (using a conservative approach) that all the flow from the catchments drains directly into the culverts underneath the Portbury Hundred Road.
- To include the potential effects of climate change flows and rainfall were scaled by 130% and sea level was increased following current guidelines (the downstream model boundary was taken from the MetroWest project coastal model). Climate change allowances have been applied for the future year 2115.

3.2 Downstream Boundary Condition

For fluvial events, both the Drove Rhyne and the Easton-in-Gordano stream model downstream boundaries are tidal. However the natural tidal limits have been modified by the presence of flapped outlets on both watercourses. Mean high water spring levels downstream of the tidal structures were extracted from results of the Bristol City Council CAFRA model (2015) at an appropriate model node.

The Easton-in-Gordano model was also run for higher return period tidal events. In this case the tidal levels used as downstream boundary conditions were also extracted from the same model.

3.3 Baseline Hydraulic Modelling

3.3.1 Drove Rhyne Model

Construction of the 1D-2D Drove Rhyne model commenced from the available 2015 AP channel survey. Levels along the top of the banks were modelled as z-lines along the watercourse using 2015 data consistently with overtopping levels from the cross sections.

The watercourse floodplain north of the M5 was modelled in a 2D hydrodynamic environment using a 4m cell resolution in TuFLOW software. Levels along the railway line were modelled as polygons (z-shape) along the path using 2015 ARUP survey data. The level of the railway ballast was chosen as the onset of flooding. Existing coastal defences in the AIMS database were also included in the 2D domain. Culverts running through the railway were modelled using TuFLOW 1D component (ESTRY) with levels and dimensions estimated from photos or survey data (where available). A standard size of 600mm in diameter was assumed for structures where no other information was available.
The drainage network in the area was represented using z-lines (or polygons where considered more appropriate) as were not accurately represented in the DTM (i.e. not representing a continuous flow path). The flow direction was established looking at IDB maps (where available) or by looking at terrain gradient in the LiDAR data. Drains and structures connecting them were modelled making best use of available data and engineering judgement (culverts were assumed to have a 600mm diameter).

Connection between the 1D and the 2D parts of the model was achieved using HX lines (level connections) as opposed to SX lines (flow connections).

The surface roughness Manning's coefficients values of 0.040 and 0.060 for the channel and the floodplain respectively is considered appropriate given channel and floodplain characteristics. Buildings were represented following latest EA recommendation using a very high roughness coefficient and increasing the LiDAR level by 300mm.

3.3.3 Easton in Gordano

The model built to represent the Easton-in-Gordano watercourse is composed of 3 parts with different characteristics.

- Upstream (south) of the M5
- Between the M5 and the railway
- Downstream (north) of the railway.

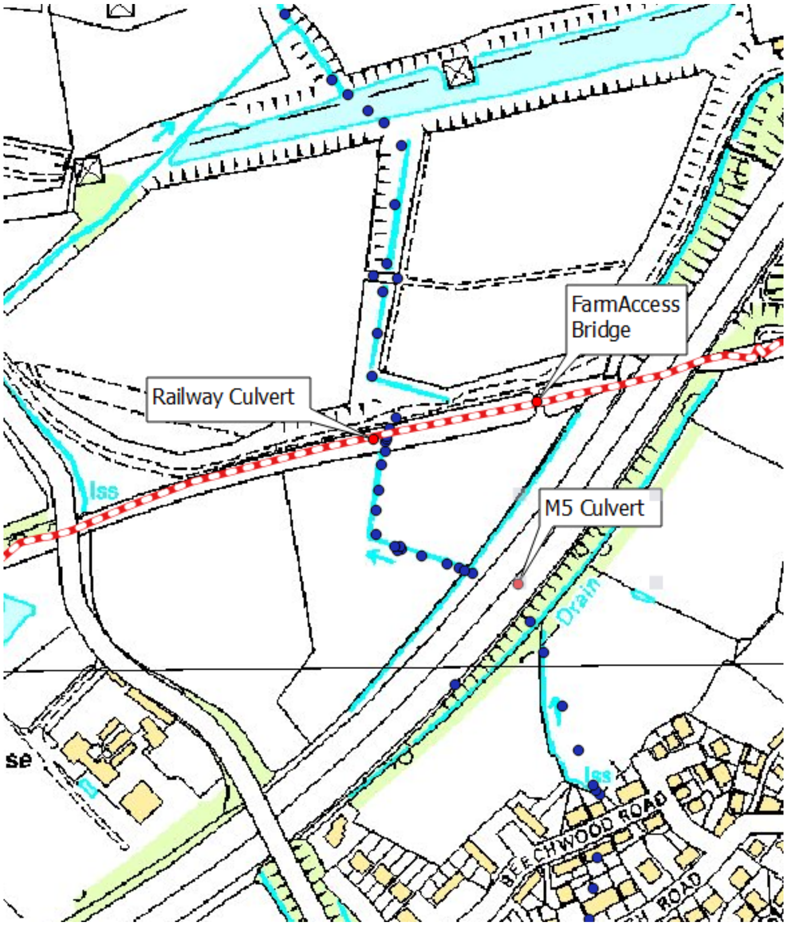


Figure 5: Location of water course (dots in blue represent cross sections in model), railway and M5.

The main area of interest with regards to the risk of flooding to the railway is the reach between the M5 and the railway line. Water enters this reach through a culvert under the M5 and exits through a culvert under the railway during low flows. During flooding it also flows under a railway bridge which serves as a farm access 120m from the culvert, and could flow over the railway if the water level is high enough. Due to the culvert under the railway being relatively small, this area floods easily. When this happens the water level in this zone is relatively constant, and given mainly by the inflow under the M5 and the outflows through the railway culvert and bridge.

The model in this area is a 1D-2D linked model. It has the following characteristics:

- 1D part of the model based on survey, which includes one structure in this reach.
- 2D model based on 2m LiDAR data
- Direct rainfall is applied on the 2D domain.
- HX lines form the 1D-2D link. The levels that determine this link are given by the LiDAR.

- The cross sections of the 1D model were extended for model stability purposes.
- The length of the culvert under the railway, or the location of the downstream exit, were not given by the survey. The length of the culvert under the railway was assumed as being the embankment's width plus an extra 10m as the culvert may not cross perpendicularly.
- The railway bridge's cross section is given by the survey. Ground levels at its entrance and exit were lowered to coincide with survey.
- The Network Rail level survey was used to correct embankment levels given by the LiDAR

The area upstream of the M5 is important mainly because its components affect the flow reaching the railway line. These flows are primarily affected by: the M5 culvert's capacity and the water that accumulates upstream of it, and the culvert under Easton in Gordano and the water that may accumulate upstream of it.

This section of the model also represents the impacts of any changes to the drainage system under the railway on this area. Higher water levels downstream of the M5 produce higher levels and larger areas affected by flooding upstream of the motorway.

The model in this section of the watercourse is a 1D model:

- Is based on survey data
- FEH units produce the inflows from the upstream catchment.
- The culvert under the M5 is represented as an orifice for model stability purposes.
- A reservoir unit allows for the representation of the impoundment of water upstream of the M5.
- Survey data for the culvert under Easton in Gordano shows different culvert cross sections on its upstream and downstream sides (0.95m and 0.65m respectively). The culvert was split into several shorter sections in the model. It was assumed all but the last had the upstream diameter, the larger one, thus taking the more conservative assumption which allows more water to reach the railway area.
- A reservoir unit allows for the representation of the impoundment of water upstream of the culvert under Easton in Gordano

The reach downstream of the railway defines the water levels downstream of the railway. These are significant to the study as they affect water levels upstream of the railway and because it enables the effects of the changes to the railway drainage elements to be understood.

Of particular interest in this reach is the propagation of tides from the Avon estuary and the effect these may have on flood characteristics at the railways location.

This reach was modelled in 1D-2D, and has the following characteristics:

- 1D part of the model based on survey, which includes several structures in this reach. Several sections of this section of the watercourse however were not covered by the survey, mainly the reach between the 'pond' and the railway. The following assumptions were made:
    - Several sections had to be copied from similar looking sections of the channel as seen in satellite images.
    - Levels for these sections were interpolated between the 'pond' and the section upstream of the railway.
    - Bank levels for these sections were made to coincide with LiDAR data.

  - Dimensions of structures copied from similar looking structure as seen in satellite images.
- Outfall is modelled as a flapped orifice
- Downstream boundary conditions are given by the Avon estuary tidal levels (taken from the River Avon tidal model results used during this project).
- 2D model based on 2mx2m LiDAR data
- Direct rainfall is applied on the 2D domain.
- HX lines form the 1D-2D link. The levels that determine this link are given by the LiDAR.
- 'Pond' modelled in the 2D domain. Levels taken from LiDAR

3.4 Post-development Hydraulic Modelling

Drove Rhyne

The proposed railway design includes minor changes as increasing the railway line level between 100-200mm along the stretch represented in the Drove Rhyne hydraulic model. To simulate the proposed scheme, the existing model was therefore modified by increasing the level of the railway line by 150mm in the 2D domain. An additional sensitivity run was also undertaken to understand changes to flood extents with a 200mm increase in railway level. No changes were made to the 1D part of the model.

Easton in Gordano

The proposed scheme includes the following changes in the Easton in Gordano area.

- Elevation of railway embankment. Its lowest level increases from 8.65mAOD to 9mAOD for the post-development case. As flood levels do not reach the top of the embankment for any of the fluvial scenarios run, raising its level has no influence on fluvial flood risk.
- A slight increase in railway embankment footprint within the Easton-in-Gordano Stream floodplain, between the M5 Motorway crossing and Marsh Lane, by approximately 3 m on average along the southern edge of the DCO Scheme. This change is too small to represent accurately in the hydraulic model grid.

As the proposed changes in railway elevation are above modelled flood levels, and the slight increase in embankment footprint is too small to be represented in the hydraulic model, no post development model is required. The impact of the increase in railway embankment on floodplain storage is considered in the scheme Flood Risk Assessment.

3.5 Flood Mapping and post-processing

Drove Rhyne

Maximum water levels calculated for each location/model node along the watercourse were extracted for the critical storm duration/ tide phase and used to create flood extents in conjunction with LiDAR. Results were processed using QGIS software.

Output from direct rainfall inflows shows the whole domain as wet. As such a threshold of 0.05m was chosen when showing flood depth grids.

Easton-in-Gordano Stream

Maximum water depths given by the 2D (TUFLOW) component of the model were extracted to present flood extents and depths in the area surrounding the railway (the maps produced show flood depths north of the M5).

Output from direct rainfall inflows shows the whole domain as wet. Flooding due to surface water only was removed from the maps. The resulting figures therefore only show flooding from the river.

4.0 Model Runs

4.1 Sensitivity runs

4.1.1 Drove Rhyne Model

Tests were undertaken to understand the sensitivity of the Drove Rhyne model to:

- Tidal phase sensitivity (tide shifted by 3/6/9 hrs). A different range of storm durations (6.25, 12.25, 18.25, 24.25 hrs) were applied to verify that the combination chosen was the probable worst case scenario.
- Channel roughness (+/- 20%) for the 1% AEP event. Storm durations and tidal phasing were selected from the most critical scenario from the sensitivity test above.
- Interaction with tidal event (50% AEP tidal event applied)
- Blockage at railway culverts (50% reduction in cross section area)
- Sensitivity on inflows/ percentage runoff (+/- 20% variation in rainfall depth and flows)
- Sensitivity of results to invoking orifice equations for a modelled bridge (1.015Br) when submerged for the 1% and 0.1% AEP events in the future (2115) scenario.
- Floodplain roughness (+/- 20%) for the 1% AEP event.

Results from sensitivity tests show the followings:

- From the matrix of storm durations and tide phase, the worst tidal phase scenario was identified for each storm duration. Results from this selection are collected in Table 2. Results show that there is limited variation between the different scenarios and that a 6hrs storm duration combined with 9hrs tide phase shift was the worst case scenario at two of the three structures. A comparison between flood extents for the different scenarios showed that differences could be considered negligible.

Table 2: Results from sensitivity test (1% AEP) on combined effect of storm duration and tidal phase at key culverts

Culvert Node	Phase Tide (hrs)	Storm Duration (hrs)	Peak Level (mAOD)
5.004	Baseline	24.25	6.26
5.004	+3	18.25	6.27
5.004	+6	12.25	6.25
5.004	+9	6.25	6.29
4.004	Baseline	24.25	6.31
4.004	+3	18.25	6.33
4.004	+6	12.25	6.34
4.004	+9	6.25	6.33
3.004	Baseline	24.25	6.29
3.004	+3	18.25	6.31
3.004	+6	12.25	6.31

3.004	+9	6.25	6.32

Since undertaking sensitivity runs on storm duration the model has been further refined by adjusting railway levels and spill levels over the railway according to latest NR surveys. Peak levels at the railway culverts are therefore slightly different from those presented in Table 2.

- Results from the sensitivity runs on Manning's roughness coefficients are summarised in Table 3. The choice of Manning's roughness parameter is considered robust as there is limited variation in peak levels with a 20% increase or decrease.

Table 3: Results from sensitivity runs (1% AEP) on Manning's n roughness coefficient at key culverts

Culvert Node	Scenario	Peak Level (mAOD)
3.004	+20% Manning's roughness	6.16
4.004	+20% Manning's roughness	5.97
5.004	+20% Manning's roughness	6.15
3.004	Baseline	6.16
4.004	Baseline	5.92
5.004	Baseline	6.13
3.004	-20% Manning's roughness	6.15
4.004	-20% Manning's roughness	5.92
5.004	-20% Manning's roughness	6.11

- Results from sensitivity runs on percentage runoff/ inflow are shown in Table 4. Structure 3.004 shows little sensitivity to flow increase as the water is constrained by an upstream structure.

Table 4: Results from sensitivity runs (1% AEP) on increased/ decreased flow magnitude

Culvert Node	Scenario	Peak Level (mAOD)
3.004	Baseline	6.16
4.004	Baseline	5.97
5.004	Baseline	6.15
3.004	+20% inflow	6.24
4.004	+20% inflow	6.27
5.004	+20% inflow	6.41
3.004	-20% inflow	5.99
4.004	-20% inflow	5.62
5.004	-20% inflow	5.82

Results from the sensitivity runs using a 50% AEP tide level, show a limited increase in peak levels as a result of the slight increase in tidal lock time at the downstream outfall. Differences in peak levels at the railway culverts are summarized in

- Table 5.

Table 5: Results from sensitivity runs (1% AEP) on 50% AEP tidal boundary at key culverts

Culvert Node	Scenario	Peak Level (mAOD)
3.004	Baseline	6.16
4.004	Baseline	5.97
5.004	Baseline	6.15
3.004	50% AEP tide event	6.17
4.004	50% AEP tide event	6.00
5.004	50% AEP tide event	6.16

- Results from the blockage simulations run show that structures 3.004 and 4.004 show little sensitivity to variation in bore area.

Table 6: Results from sensitivity runs (1% AEP) on 50% blockage key culverts

Culvert Node	Scenario	Peak Level (mAOD)
3.004	Baseline	6.16
4.004	Baseline	5.97
5.004	Baseline	6.15
3.004	50% Blockage	6.16
4.004	50% Blockage	5.94
5.004	50% Blockage	6.46

- Results from the sensitivity simulation on the bridge unit 1.015Bu show minimal change to the peak flood levels at the culverts beneath the railway line for the 1% AEP event in 2115 (less than 0.01m, i.e. below the 1D model convergence tolerance value, as shown in Table 7). The differences are higher for the 0.1% AEP event in 2115, with the baseline levels in Table 7 being 0.14m to 0.2m higher than those of the sensitivity runs. Given the limited difference (within model uncertainty for such a low AEP event) and the more conservative estimates provided by the baseline model, the baseline results are considered acceptable.

Table 7: Results from sensitivity runs on orifice representation at node 1.015Bu.

Culvert Node	Scenario	Peak Level (mAOD)
3.004	Baseline – 1% AEP, 2115	6.34
3.004	Baseline – 0.1% AEP, 2115	6.60
4.004	Baseline – 1% AEP, 2115	6.41
4.004	Baseline – 0.1% AEP, 2115	6.60
5.004	Baseline – 1% AEP, 2115	6.50
5.004	Baseline – 0.1% AEP, 2115	6.85
3.004	Orifice – 1% AEP, 2115	6.34
3.004	Orifice – 0.1% AEP, 2115	6.40
4.004	Orifice – 1% AEP, 2115	6.41
4.004	Orifice – 0.1% AEP, 2115	6.46
5.004	Orifice – 1% AEP, 2115	6.50
5.004	Orifice – 0.1% AEP, 2115	6.71

- Results from the sensitivity runs for the floodplain roughness show no significant changes to the peak water levels on the 2D domain. The results shown below (Figure 6, Figure 7) show differences are within +/- 20mm along the railway line.

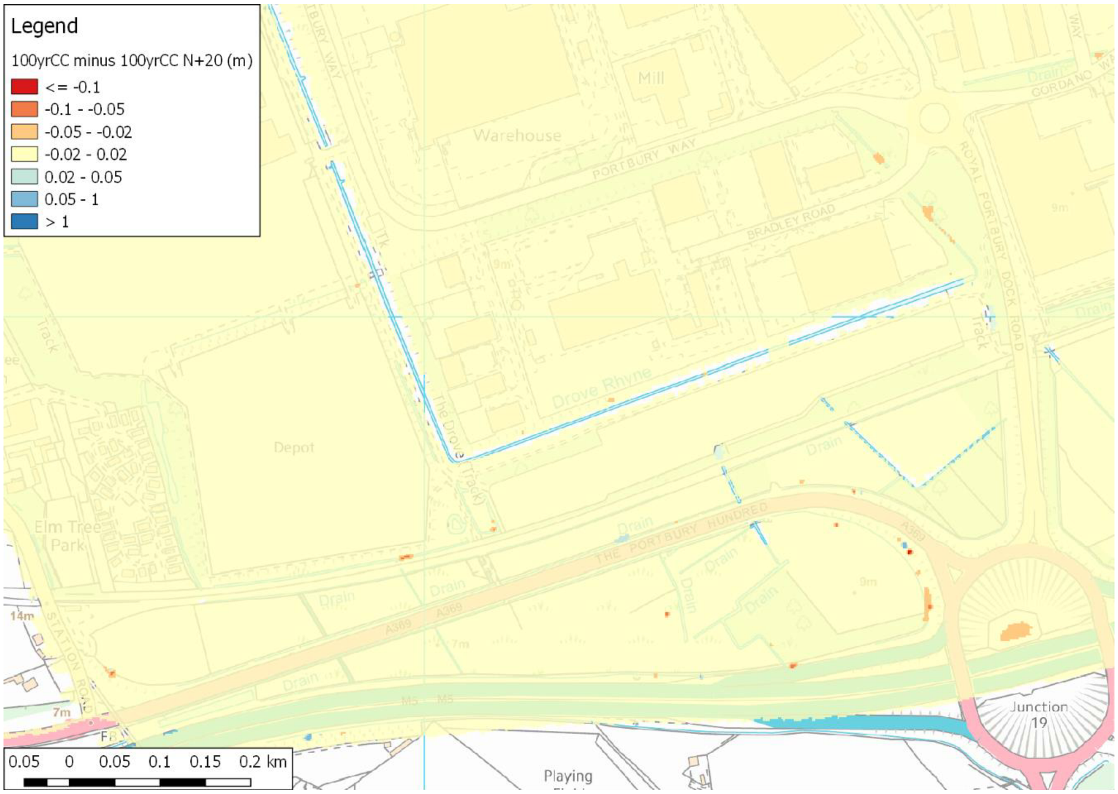


Figure 6: Difference in peak water levels between the 1% AEP (2115) baseline and 20% increase on Manning's n roughness coefficient on the floodplain.

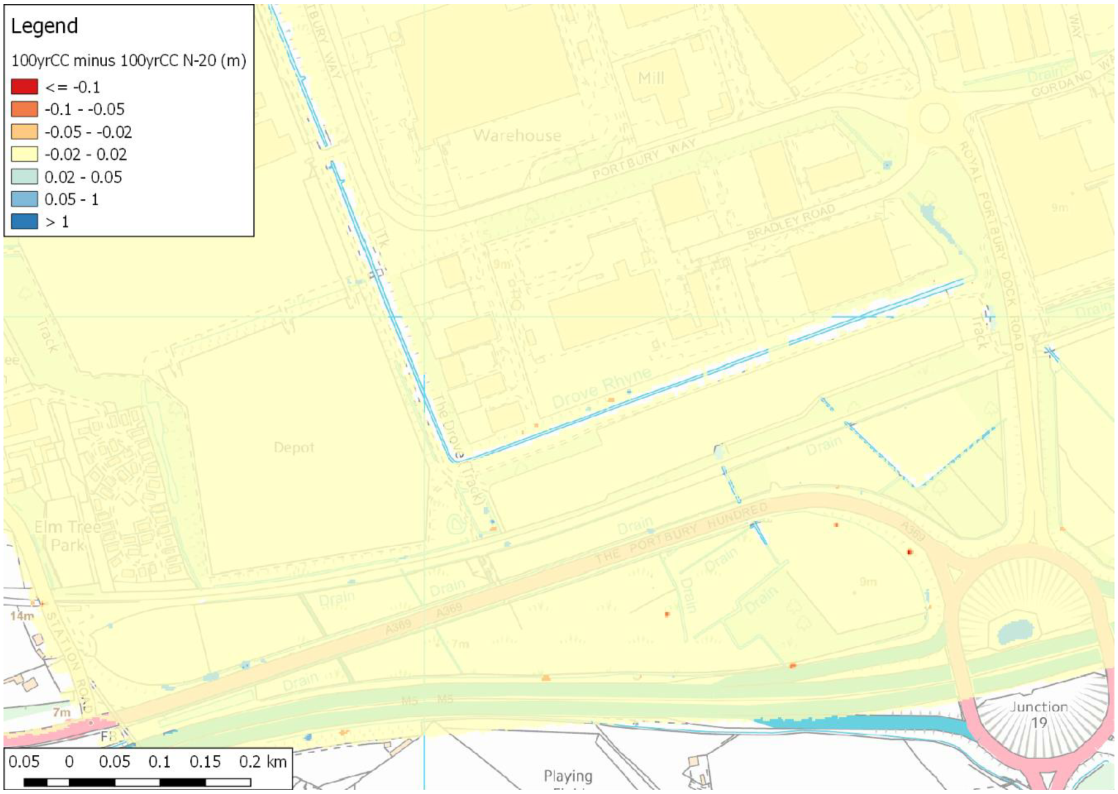


Figure 7: Difference in peak water levels between the 1% AEP (2115) baseline and 20% decrease on Manning's n roughness coefficient on the floodplain.

Key findings from the sensitivity runs include:

- The worst case scenario in terms of storm duration and tide phase is 6hrs storm duration and 9hrs shift in tide phase
- The choice of Manning's roughness parameter is considered robust as there is limited variation in peak levels with a 20% increase or decrease (both in channel and on the floodplain)
- Representation of the bridge 1.015Bu has little influence for the 1% AEP event in 2115 at the railway line. The current baseline representation results in more conservative water levels in the most extreme AEP (0.1% in 2115).
- Influence of high AEPs coastal events on fluvial flood risk at the railway is considered negligible.
- Peak levels from all simulations exceed the culvert soffit levels but are well within bank, and below the railway level of approximately 7.20mAOD

Easton in Gordano

The sensitivity tests carried out for the Easton in Gordano model were the following:

- Tidal phase sensitivity (tide shifted by 3/6/9 hrs). A different range of storm durations (6.25, 12.25, 15.25, 18.25, 24.25 hrs) were applied to verify that the combination chosen was the probable worst case scenario.
- Channel roughness (+/- 20%) for the 1% AEP event. Storm durations and tidal phasing were selected from the most critical scenario from the sensitivity test above.
- Interaction with tidal event (50% AEP tidal event applied)
- Blockage at railway culverts (assumed 50% area reduction)

- Blockage at farm access bridge (100% blockage)

Results from sensitivity tests are shown below. The levels given in the tables are for the cross section upstream of the railway line.

- The different tide phases had no effect on the water levels upstream of the railway. The effects were limited to the section of the watercourse downstream of the railway. The tide phase selected for the analysis was the one that produced the highest water levels at the point closest to the railway were changes were noticeable.
- Levels were not very sensitive to storm duration. The storm duration that produced the highest water levels upstream of the railway is 18hrs. The difference between the 15hr and 18hr storms was very small and cannot be seen in the table due to the rounding up of the results.

Table 8: Results from sensitivity test (1% AEP) on effect of storm duration

Duration	Peak Level (mAOD)
6	8.18
12	8.19
15	8.20
18	8.20
24	8.16

Since doing sensitivity runs on storm duration the model has been further refined. Peak levels at the railway culvert are therefore slightly different from the ones presented in Table 8.

All other tests carried out except the farm access blockage show little sensitivity to the change in the parameters, as seen in

- Table 9
- The response to the increase in the tide event is consistent with the results observed for the changes in tide phase. The effects of the tide on this test however reached a point closer to the railway. Higher return period tide events were run as events without any rainfall events and have an impact on water levels upstream of the railway. The run details and results can be seen in the corresponding sections of this report.
- The effects of blocking the culvert are limited due to the presence of the farm access bridge a short distance away from the watercourse. When water levels are high most of the flow goes through this railway bridge. The effects of blocking this bridge were tested in the post-development runs.
- Blocking the farm access bridge produces a high increase in water level. Even though it is over 100m away from the channel, a significant proportion of the water flowing downstream presently goes through the farm access bridge during high return period events due to it being on the floodplain and the railway culvert being relatively small.

Table 9: Results from sensitivity tests (1% AEP). Lowest point in channel is at 6.40m and flood plain at approximately 7.20m.

Scenario	Peak Level (mAOD)
Base	8.24
+20% Manning's roughness	8.26
- 20% Manning's roughness	8.20
50% Culvert Blockage	8.29
50% AEP tide event	8.24
100 % Farm access blockage	8.54

Key findings from the sensitivity runs include:

- The storm duration producing maximum water levels is 18hs.
- Tides with a return period of up to at least 50% AEP have no effect on water levels upstream of the railway.
- The farm access bridge has a strong effect on water levels for out of bank events.
- The lowest point of the existing embankment being 8.65, the effects of all other sensitivity tests carried out are not significant to flood risk to the railway.

4.2 Model simulations

4.2.1 Drove Rhyne Model

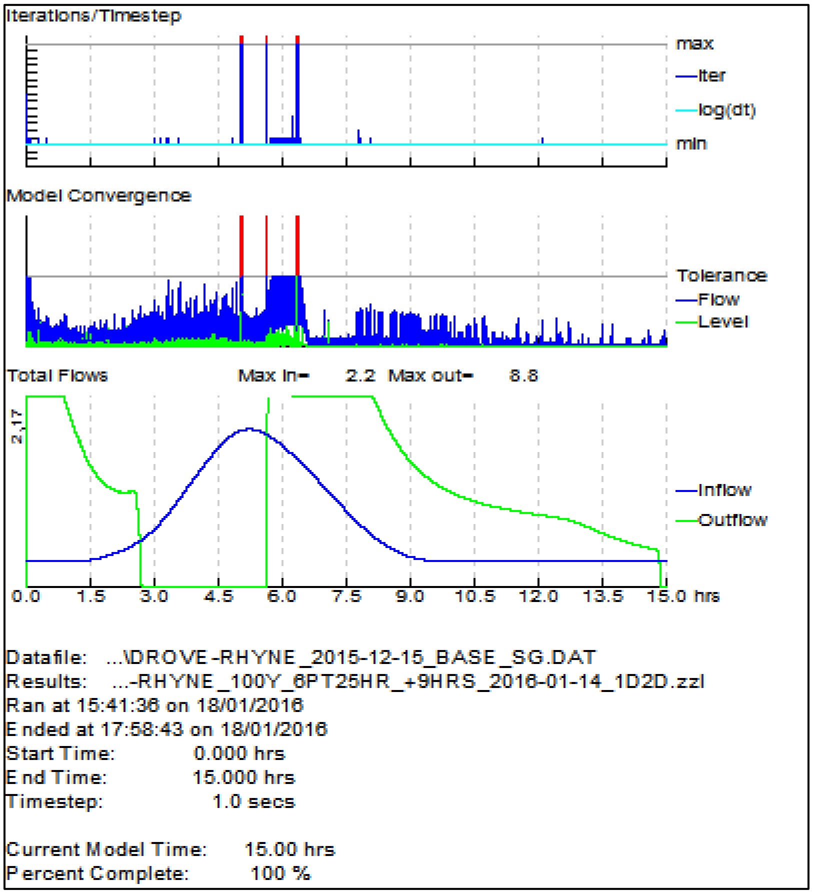
The model was run with the railway line in its present state for the following AEP events: 3.33%, 1%, 0.5%, and 0.1% for the present day (2015) and future (21150 sceanrio.

The only aspect of the post development design with potential to impact Drove Rhyne flood risk is the proposed increase in levels along the MetroWest railway alignment (by between approximately 100mm and 200mm within the Drove Rhyne study area). To test whether further post-development runs would be required, a representative post-development model was run as a sensitivity test with levels increased by 150mm along the MetroWest railway alignment. This model was run for the 1% AEP event in 2115, as there was no out of bank flow for the Drove Rhyne model for lower magnitude events. An additional sensitivity test was also run with levels increased by 200mm along the MetroWest railway alignment.

For each AEP, the worst combination of tide phase and storm duration identified in the sensitivity runs section was run. Peak results were extracted for each node. Model outputs provided electronically include maximum waters levels, flood depth and hazard grids.

All the model simulations completed satisfactorily with limited non-convergence as shown in Figure 8. The model was run for 15hrs using a 1s timestep in the 1D domain and 2s timestep in the 2D domain. The theta value was increased from the default value of 0.7 to 0.8 and the number of maximum iterations was increased to 17 to improve stability. Run parameters are considered acceptable. Despite the efforts to achieve a suitable compromise between physical realism and model stability, the cumulative mass error in the 2D element is 3.99% in the 1% AEP event. This is higher than the recommended threshold of 1%, however higher mass balance errors are common in direct rainfall models and the current runs can be considered conservative estimates owing to the additional water 'created' by the model.

Run parameters were further relaxed for the 0.1% AEP event in 2115 in order to achieve an acceptable level of numerical noise. The theta value was increased from the default value to 0.99 and the number of maximum iteration was increased to 25 to improve stability.



```
Datafile:   ...\DROVE-RHYNE_2015-12-15_BASE_SG.DAT
Results:    ...-RHYNE_100Y_6PT25HR_+9HRS_2016-01-14_1D2D.zzl
Ran at 15:41:36 on 18/01/2016
Ended at 17:58:43 on 18/01/2016
Start Time:            0.000 hrs
End Time:              15.000 hrs
Timestep:                 1.0 secs

Current Model Time:      15.00 hrs
Percent Complete:         100 %
```

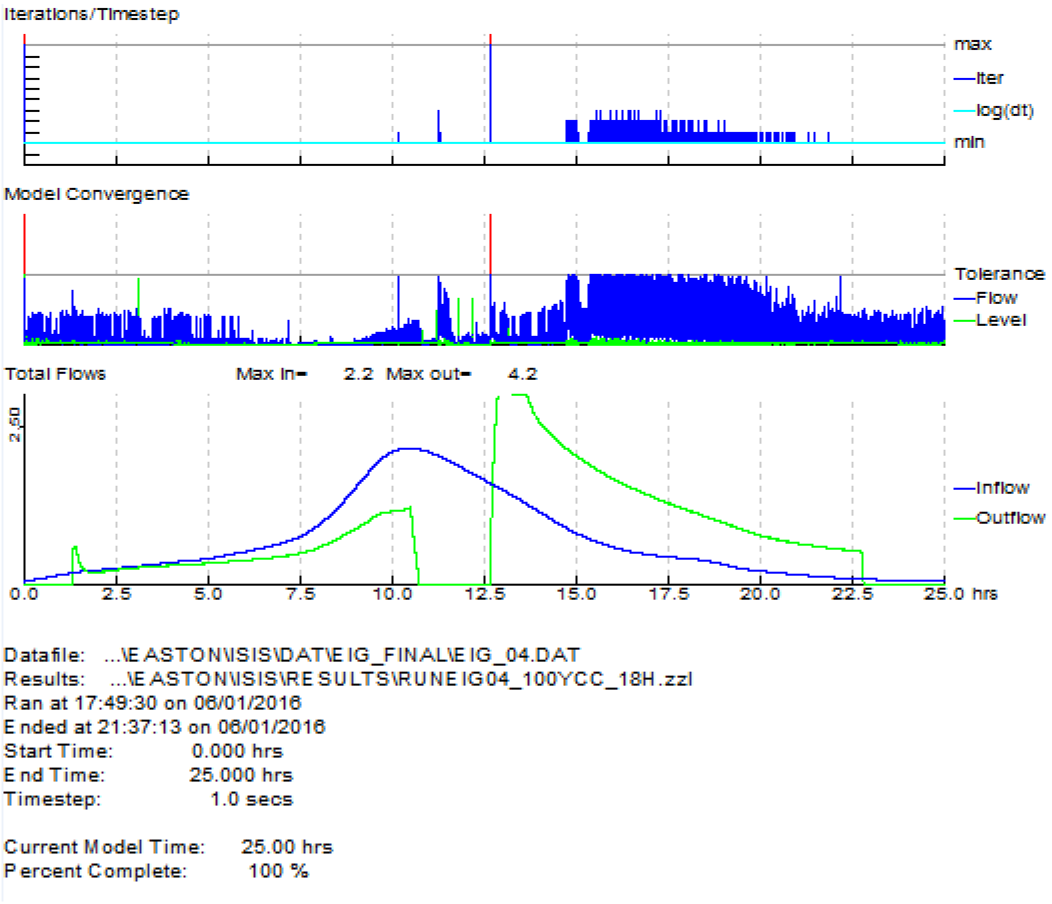
Figure 8: Model convergence plot (1% AEP event)

Easton in Gordano Runs

The model was run with the railway line in its present state (no post-development simulation was required, see Section 3.4) for the following AEP events:

- Fluvial events: 3.33%, 1%, 0.5%, 0.1%, for the present day (2015) and future (2075 and 2115) years.
- Tidal events (with only baseflow in the rivers and no direct rainfall applied to the 2D domain): 5%, 2%, 0.5% and 0.1%, for the present day (2015) and future (2075 and 2115) years.

The model was run using a timestep of 1s and 2s for the 1D and 2D domains for a duration of 25 hours. The model run-time is approximately 4 hours but can be reduced to less than 1 hour if run without the direct rainfall applied on the 2D domain. All simulations parameters remained at their default values except dflood which was increased to 10 for the 1000 year future runs and to 5 for all other runs.



```
Datafile:   ...\EASTON\ISIS\DAT\EIG_FINAL\EIG_04.DAT
Results:    ...\EASTON\ISIS\RESULTS\RUNEIG04_100YCC_18H.zzl
Ran at 17:49:30 on 06/01/2016
Ended at 21:37:13 on 06/01/2016
Start Time:          0.000 hrs
End Time:           25.000 hrs
Timestep:              1.0 secs

Current Model Time:     25.00 hrs
Percent Complete:        100 %
```

Figure 9: Model convergence plot (1% AEP event)

5.0 Model Results and Interpretation

5.1.1 Drove Rhyne

Results from the current scenario runs show that fluvial flood risk at the railway from the Drove Rhyne is limited, with levels at the critical railway culverts below the threshold of flooding at the railway for the 3.33%, 1%, 0.5% and 0.1% AEP and the same return period in 2115 (excluding the 0.1% AEP). The limited amount of overtopping is consistent with the lack of recorded flood history (see accompanying FEH proforma). The model shows however the presence of two low spots where the railway could be subject to flooding from surface water:

- Cut underneath Station Road: flooding at this location is evident at all tested AEPs. Water accumulates in the railway cut from the direct rainfall inflow.
- Cut underneath the Royal Portbury Dock Road: flood at this location is evident all tested AEPs. Similarly, to what happens underneath Station Road flooding occurs following water accumulation directly from the rainfall input.

As the purpose of this modelling is to assess fluvial flood risk from Drove Rhyne, there is uncertainty in the areas shown to be potentially at risk of surface water flooding. Confidence could be further improved at the low spots identified along the railway by incorporating new survey data of the complex drain network in the area to confirm onset of flooding at the railway cuts

Peak flood levels from the post-development sensitivity run with elevation of the MetroWest railway line increased by 150mm, and the additional sensitivity test with elevation of the MetroWest railway line increased by 200mm (1% AEP event in 2115 was run as lower magnitude events do not give out of bank fluvial flooding) are very similar to results from the baseline scenario. Differences in peak flood levels (in-channel) at selected locations are approximately 0.01m or below (Table 10), which is considered to be within model tolerance (the 1D convergence limit is 0.01m). Maximum flood extents at the low spots identified above are also similar for the pre and post development cases (Figure 12-15).

Figures 16 and 17 and the figure in Appendix A show limited differences between peak flood levels of the baseline run and the additional post development sensitivity run (with elevation of the MetroWest railway line increased by 200mm). Differences are located mainly along the railway line (as this is the location where the DTM was modified) and are generally between 100mm and 200mm along the railway. Figure 16, Figure 17 and Appendix A show that there is no increase in flood levels away from the railway line with the exception of some isolated spots, which can be attributed to model convergence/stability (rather than to the development). The identified spots are located away from the railway line, are small in extent and are not hydraulically connected to the Drove Rhyne watercourse. Appendix A includes the difference maps for the whole extent of the model.

It is therefore reasonable to conclude that the proposed increase in railway levels will not affect flood risk elsewhere, and no further assessment of the post-development scenario is required.

Table 10: Differences in peak water levels at selected locations for proposed and baseline scenario (1% AEP in 2115)

	Difference in peak levels between baseline and proposed scenario (m)*						
	culvert node 3.004		culvert node 4.004 **		culvert node 5.004		Drove Rhyne
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	1.024
+150mm	0.000	0.000	-0.003	0.010	0.002	0.003	0.002
+200mm	0.000	0.000	0.001	0.011	0.008	0.008	0.003

* Positive differences indicate an increase in peak flood level in the post development scenario

** Limited numerical stability

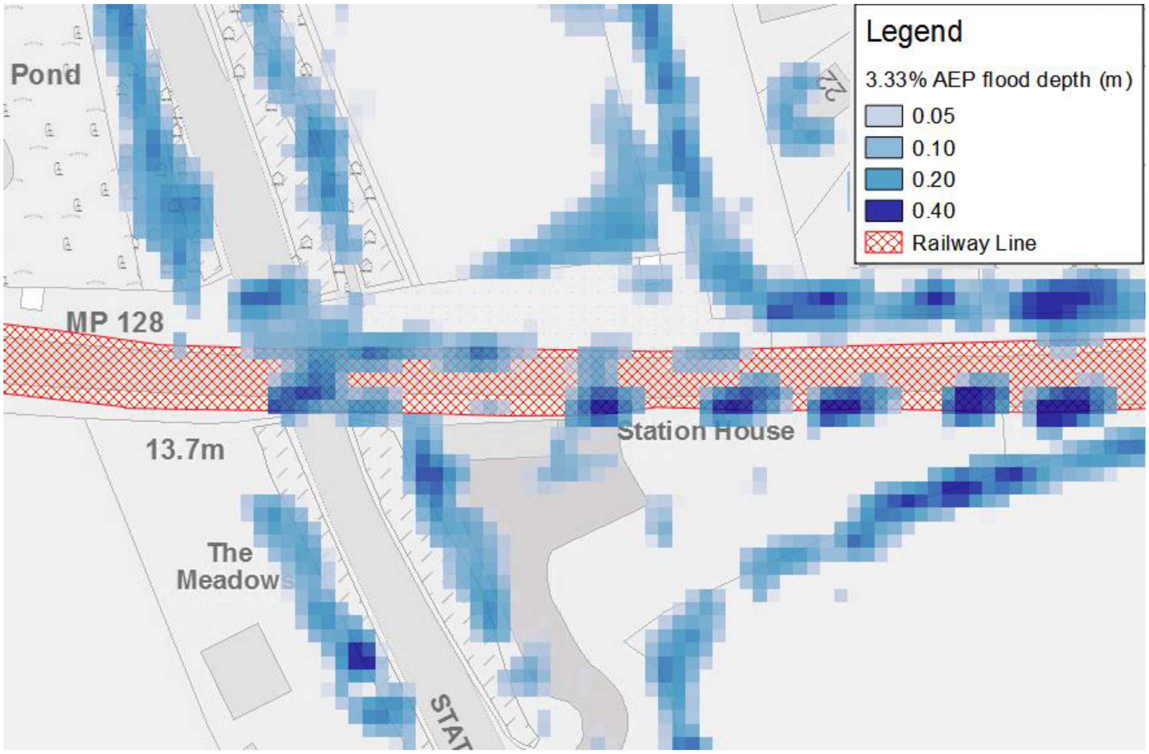


Figure 10: Flood depth map at railway cut underneath Station Road for the 3.33% AEP

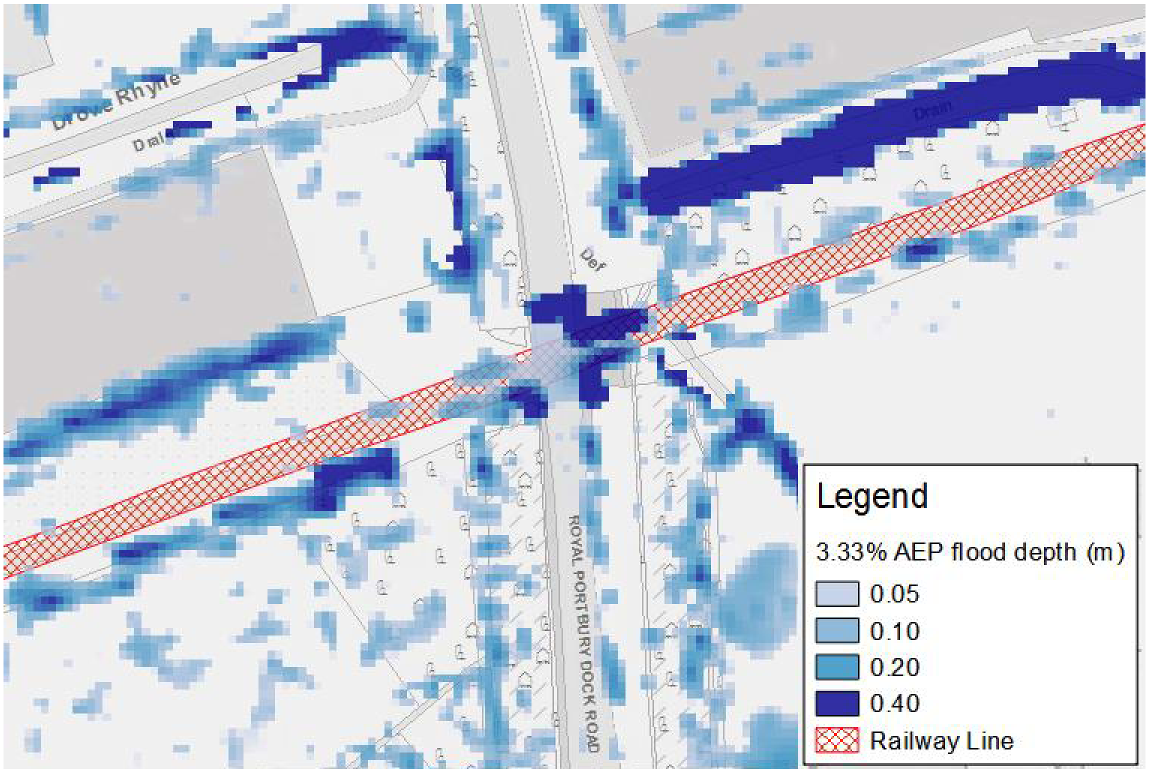


Figure 11: Flood depth map at railway cut underneath Royal Portbury Dock Road for the 3.33% AEP

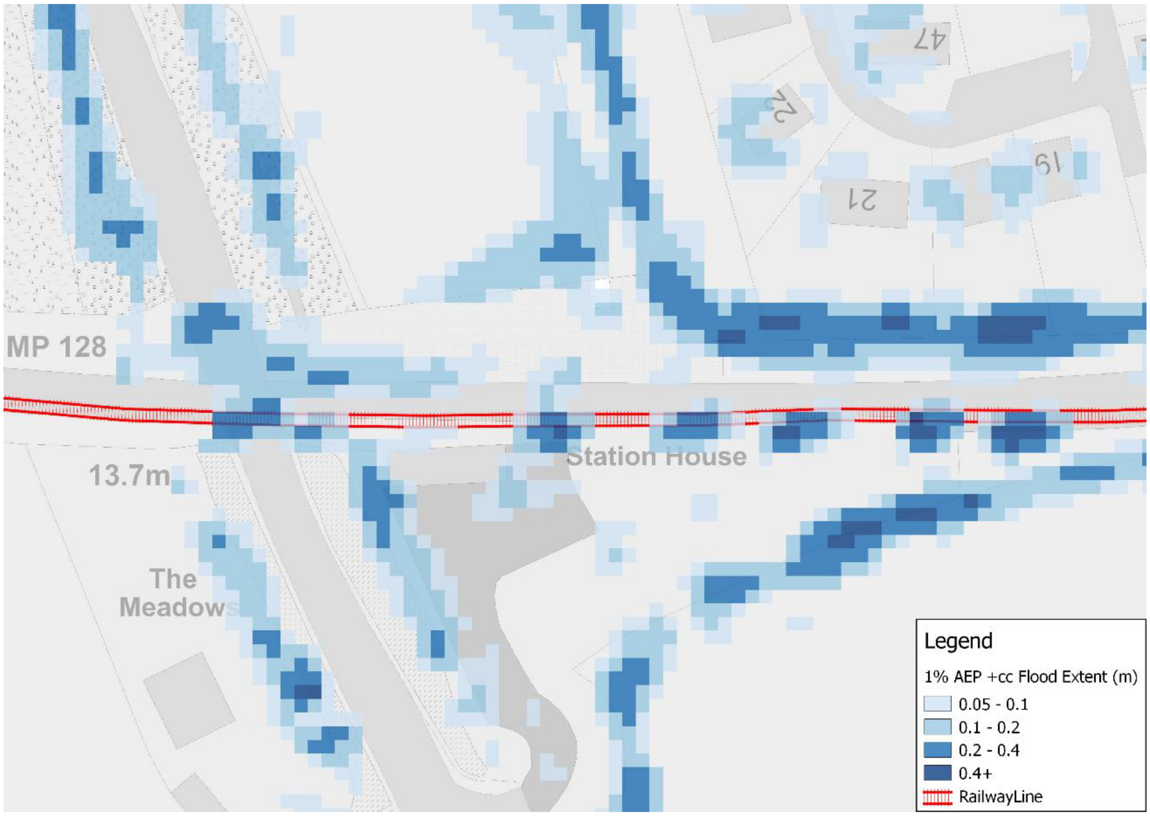


Figure 12: Flood depth map for the 1% AEP in 2115 event at the railway cut at Station Road.

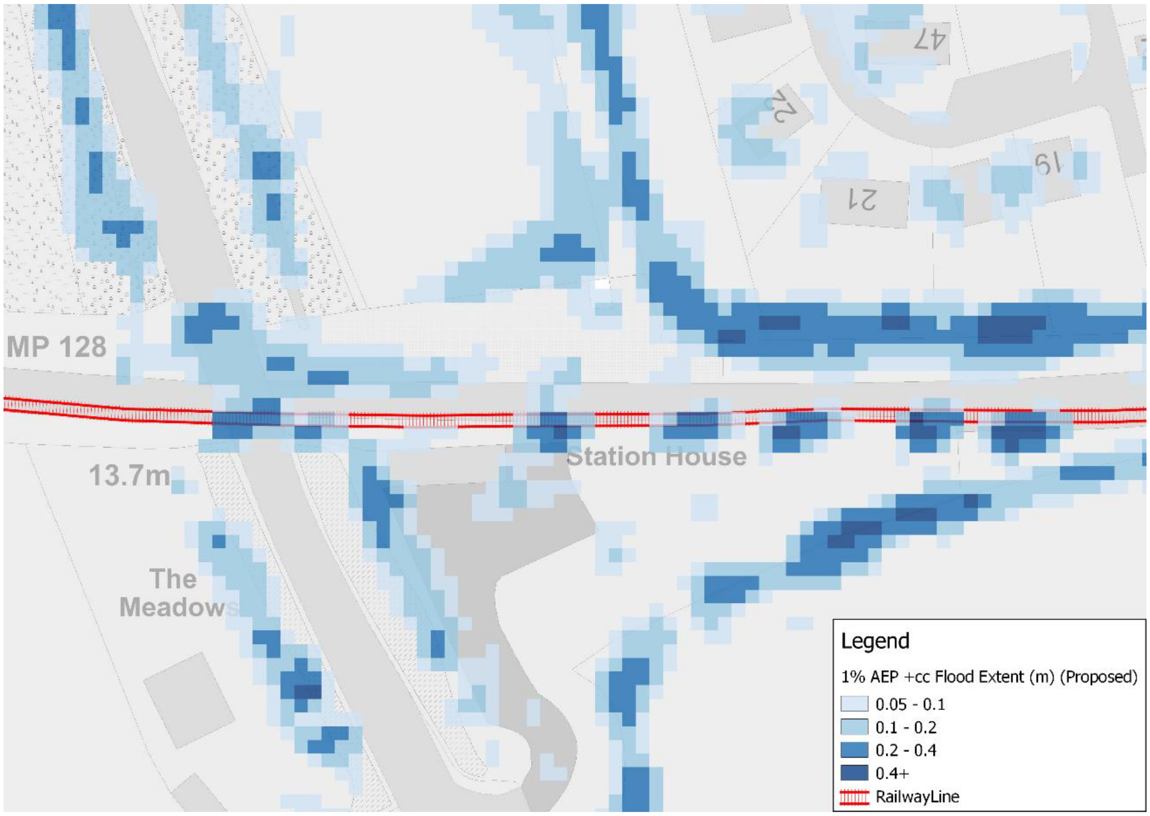


Figure 13: Flood depth map for the 1% AEP in 2115 proposed scenario at the railway cut at Station Road.

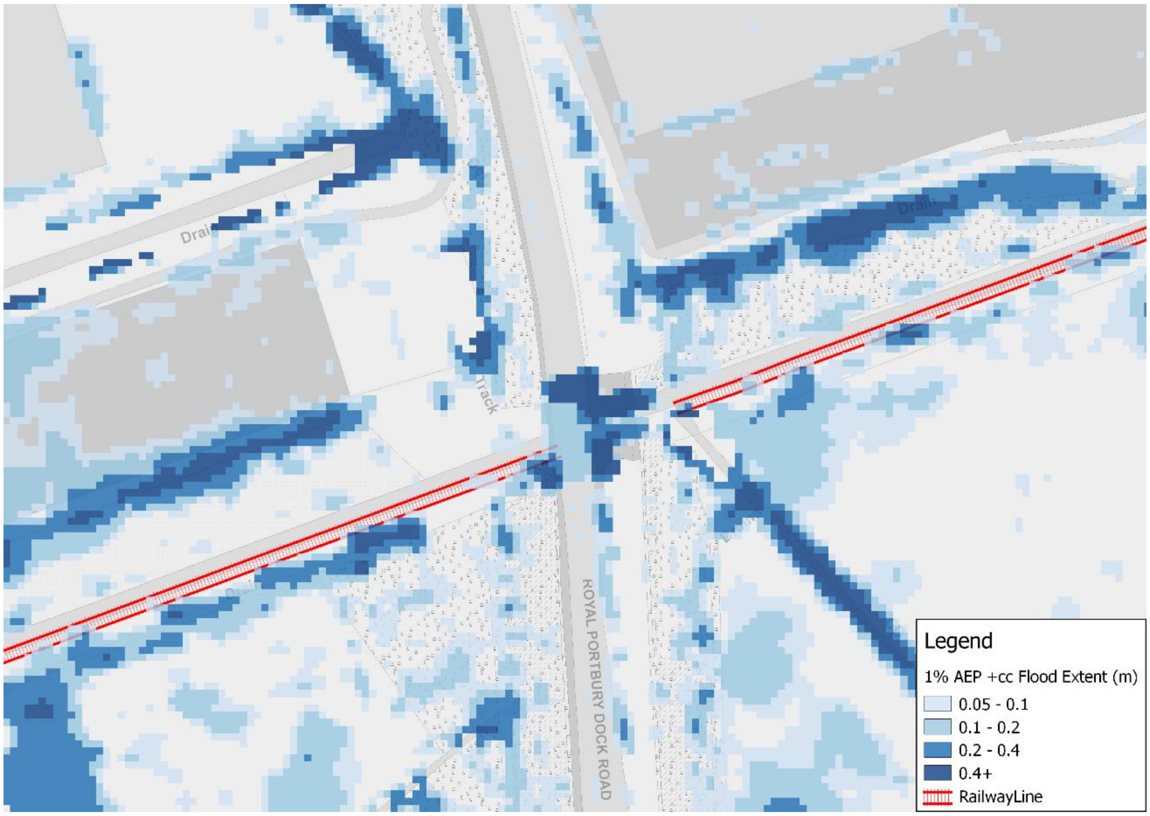


Figure 14: Flood depth map for the 1% AEP in 2115 event at the railway cut at Royal Portbury Dock Road.

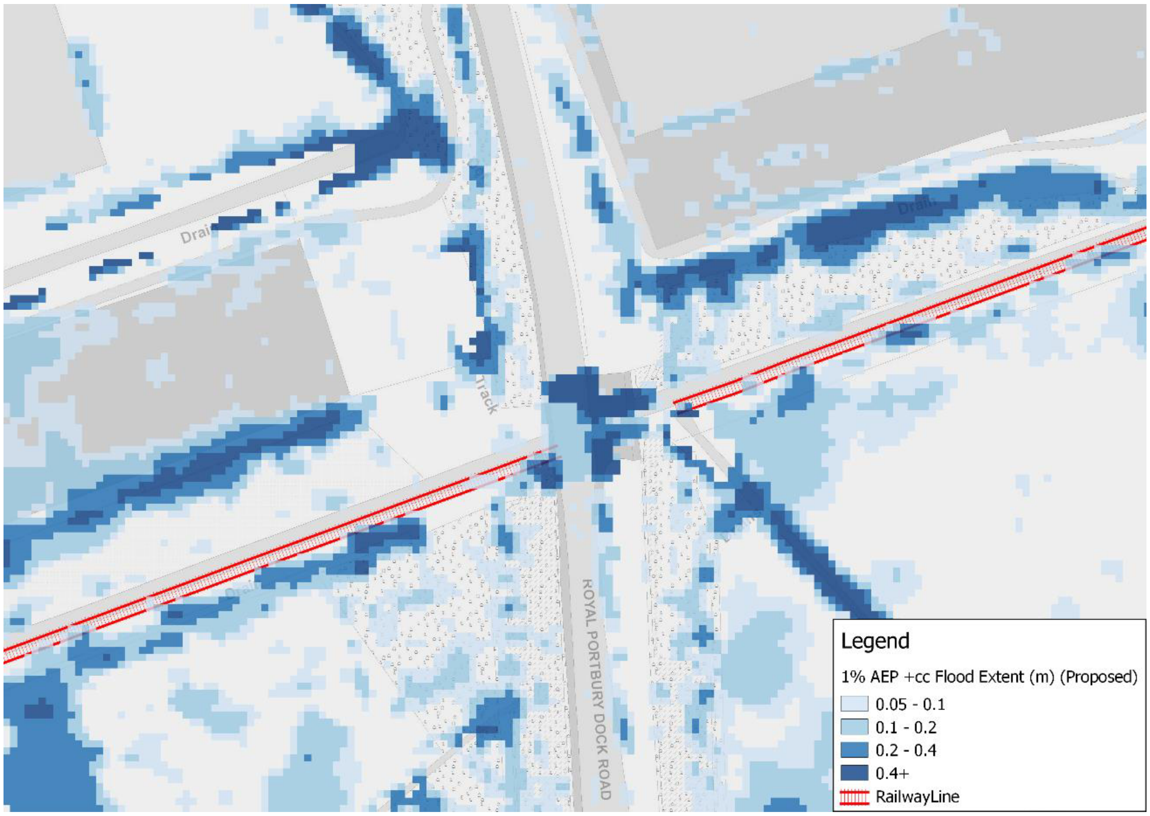


Figure 15: Flood depth map for the 1% AEP in 2115 proposed scenario at Royal Portbury Dock Road.

Figure 16: Flood level difference map for comparison between the Baseline run and the 200mm railway level sensitivity run at Royal Portbury Dock Road (1% AEP in 2115).

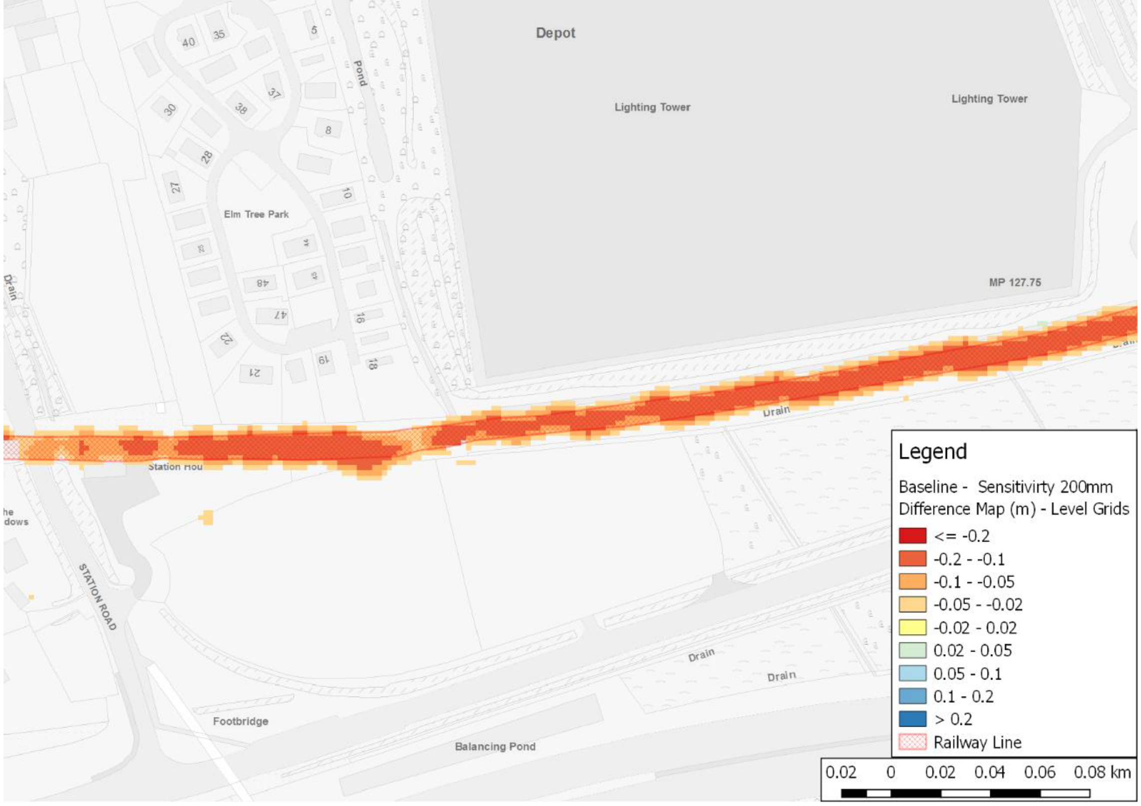


Figure 17: Flood level difference map for comparison between the Baseline run and the 200mm railway level sensitivity run at Station Road (1% AEP in 2115).

5.1.2 Easton in Gordano

Fluvial Events

Results for the existing railway layout show that there is no flooding on the railway for any of the fluvial events simulated (3.33%, 1%, 0.5% and 0.1% AEP).

Flooding does occur however on the floodplain upstream of the railway. Water accumulates in the area between the railway and the M5 due to the limited capacity of the railway culvert. Levels in this area are relatively constant (spatially) when this happens, with water entering through the M5 culvert and leaving through the railway culvert and the farm access bridge. For high water levels, more water flows through this bridge than through the railway culvert. For example, there is more than twice the peak flow through the farm access bridge than through the railway culvert for the 1% AEP storm. Figure 18 shows flood extents in this area.

Water also accumulates upstream of the M5 for high return periods. This impoundment of water is partly due to the M5 culvert capacity and partly due to high water levels between the M5 and the railway bridge.

The effect of the tides modelled as downstream boundary conditions for the fluvial events can be observed in the section of the watercourse downstream of the railway. However, they don't affect flow or levels at the crossing of the railway over the watercourse. In fact, levels downstream of the railway don't have a significant influence on flooding for the events modelled in this section.

Water levels upstream and downstream of the railway on the main channel are shown in the Table 11.

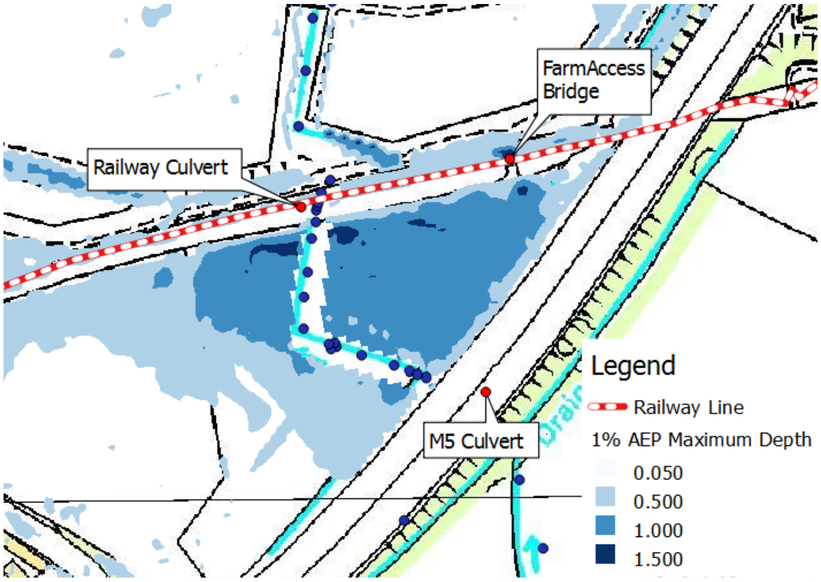


Figure 18: Maximum flood depth between the railway and the M5 for the present railway layout for the 1% AEP (flood depths upstream of the M5 not shown in this figure- only 2D domain results shown).

Table 11: Easton-in-Gordano Stream fluvial flooding results.

Fluvial Events Levels (mAOD)			
		Upstream of Railway	Downstream of Railway
Min Railway Level		8.65	
Present (2015) Events	30y	8.09	6.62
	100y	8.19	6.76
	200y	8.24	6.90
	1000y	8.36	7.31
Future (2115) Events	30y	8.17	6.78
	100y	8.26	7.09
	200y	8.31	7.30
	1000y	8.42	7.75

Tidal Events

Results for the tidal events show that the railway is above modelled flood levels for all events simulated.

In these events, water flows from the River Avon through the channel system towards the railway, filling up the low lying pond on its way. Initially, water is stopped from flowing inwards by a flap valve, but the structure with the flap valve is overtopped on all events modelled. The area around the channels to the north of the railway is raised, so only floods during the more extreme events (200 and 1000 year return period events in 2115). The flood plain between the railway and the M5, as for fluvial events, floods more easily. Water levels rise above bank levels for present tidal events with a return period of 50 years or above, and for all the 2115 tidal events modelled.

Water levels upstream and downstream of the railway on the main channel are shown in the table below.

Table 12: Easton-in-Gordano Stream tidal flooding results.

Tidal Events Levels (mAOD)			
		Upstream of Railway	Downstream of Railway
Min Railway Level		8.65	
Present (2015) Events	20y	7.07	7.05
	50y	7.36	7.39
	200y	7.47	7.74
	1000y	7.59	8.01
Future (2115) Events	20y CC	7.80	8.16
	50y CC	7.93	8.22
	200y CC	8.20	8.32
	1000y CC	8.45	8.46

6.0 Conclusions

The current model exercise shows that risk from fluvial flooding to the railway by the Drove Rhyne and the Easton-in-Gordano Stream is limited for the current scenario.

Drove Rhyne

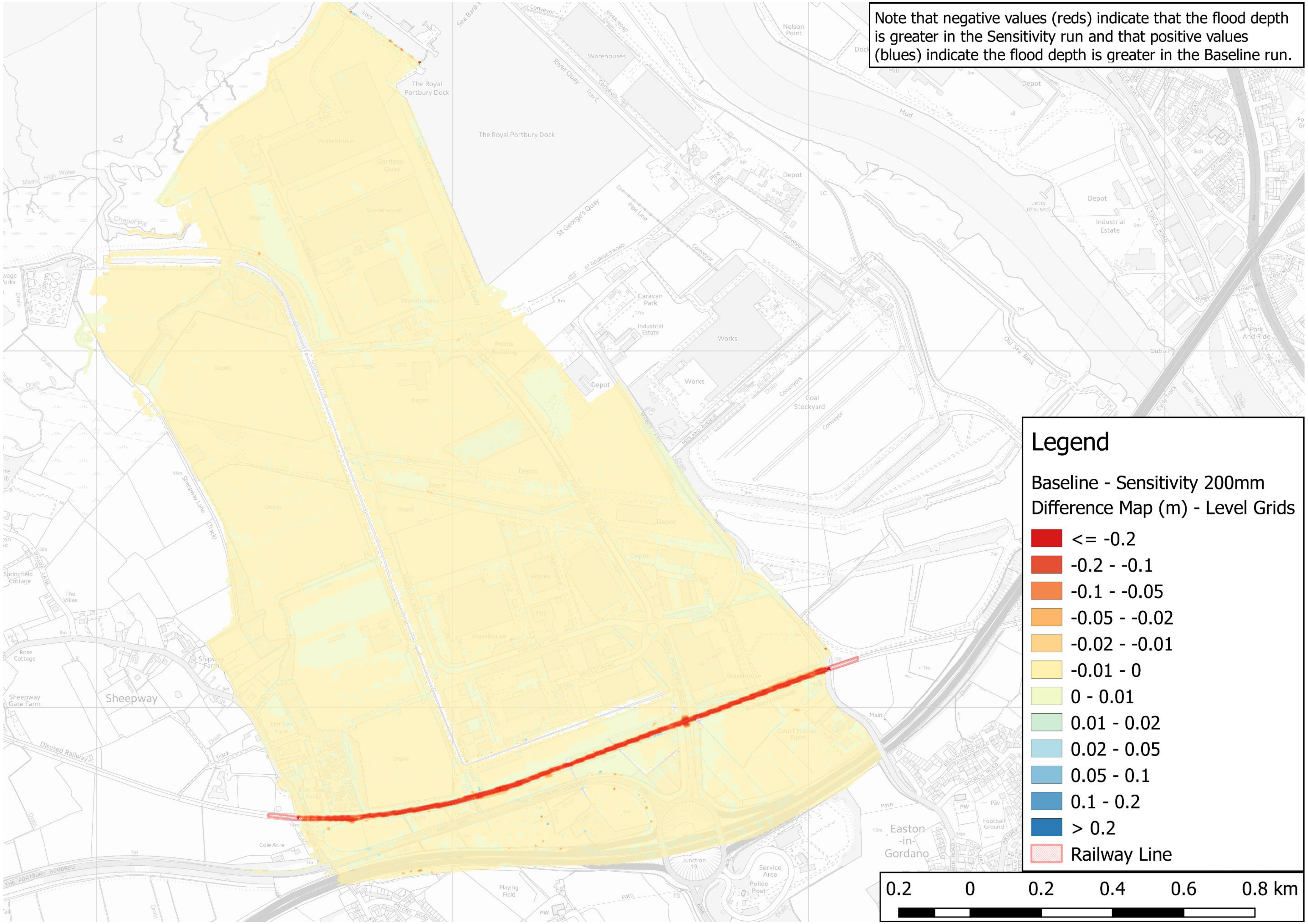
Two low spots were identified to be potentially at risk of flooding from surface water with onset of flooding being 3.33% AEP. The flooding mechanism at these locations is the accumulation of flood water from direct rainfall inflow. Given the sparsity of data on drain networks and structure dimensions at these locations, the presence and location of these surface water flood risk low spots is uncertain. The proposed scheme does not have a significant impact on existing fluvial flood risk from the Drove Rhyne.

Easton-in-Gordano Stream

Simulated fluvial and tidal Easton-in-Gordano Stream flood levels are below the Portishead to Pill railway level, including the simulated 1000 year future (2115) fluvial and tidal events.

As the proposed changes in railway elevation are above modelled flood levels, and the slight increase in embankment footprint is too small to be represented in the hydraulic model, no post development model is required. The impact of the increase in railway embankment on floodplain storage is considered in the scheme Flood Risk Assessment.

Appendix A: Difference map between the baseline run and the sensitivity run (railway level increased by 200mm).



Note that negative values (reds) indicate that the flood depth is greater in the Sensitivity run and that positive values (blues) indicate the flood depth is greater in the Baseline run.

HYDROLOGY REPORT

Portishead Branch Line - Metrowest Phase 1

Prepared for

North Somerset Council

July 2016
1.0

Burderop Park
Swindon, SN4 0QD
GB

Document Control

This document has been issued and amended as follows:

Version	Date	Description	Created by	Checked by	Approved by
0.1	9/10/2015	First draft	Silvia Garattini		
1.0	8/7/2016	Draft	Silvia Garratini	Robert Bird	Robert Bird

Contents

Acronyms and Abbreviations

AEP	Annual Exceedance Probabiltiy
AMAX	Annual Maximum (flow)
FAS	Flood Attenuation Scheme
FEH	Flood Estimation Handbook
FFC	Flood Frequency Curve
PDM	Probability Distribution Model
PG	Pooling Group
PUM	Pooling Uncertainty Measure
QMED	Median flow
ReFH	Revitalised Flood Estimation Handbook
RP	Return Period

SECTION 0

Introduction

Background

This hydrological analysis was carried out as part of the flood risk assessment for MetroWest Phase 1 led by North Somerset Council on behalf of Bristol City Council, Bath and North East Somerset Council and Gloucestershire council. The derived hydrological inflows will be used to develop two hydraulic fluvial models (Drove Rhyne and Easton in Gordano) which will be used to compare flood risk for the current situation and for a post-development scenario for a range of return periods.

MetroWest Phase 1 involves providing a new train service between Portishead, Pill and Bristol Temple Meads, an upgraded train service for the Severn Beach line to Avonmouth, and local stations between Bristol and Bath. Some of the MetroWest Phase 1 works can be undertaken under Network Rail's permitted development rights and the remainder will require Development Consent Order (DCO) approval. The works requiring DCO approval include:

- Restoration of disused passenger railway line between Portishead and Pill
- Construct new station and car park at Portishead
- Reinstate Pill platform and construct associated new station building and car park
- New pedestrian and farm track crossings of railway between Portishead and Pill

Scope

The current study hydrology will:

- Identify inflow boundaries for Drove Rhyne and Easton in Gordano models respectively
- Derive appropriate model inflows for the selected catchment and design events for a range of design event

Study area

The proposed extent of the models is represented in Figure 1 and Figure 2. The models include the Drove Rhyne watercourse (and tributaries) and the drain system in Easton-in-Gordano. The study area is located in the urban areas of Easton in Gordano and Portbury (North Somerset, UK). The area borders the tidal river Avon. The southern part of the study area is mainly rural and relatively hilly whilst urban settlements and impermeable cover associated with docks are concentrated in the low lying Northern part.

Based on British Geological Survey maps, the bedrock geology underlying the catchments is predominantly limestone and sandstone in the South of the catchments and Mudstone in the proximity of the M5. No superficial deposit is present in most of the subject area. Head (clay, silt, sand and gravel) is present in the proximity of the M5. As a result, the area is characterized by modest permeability overall with the Northern part of the catchment being more impermeable than the South.

The drain network in the subject area crosses the M5 and the disused railway line through a series of culverts. Most of the drains are also culverted when running through the urban areas of Portbury and Easton in Gordano. Storage in the channel is therefore a key factor to be considered when assessing flood risk.

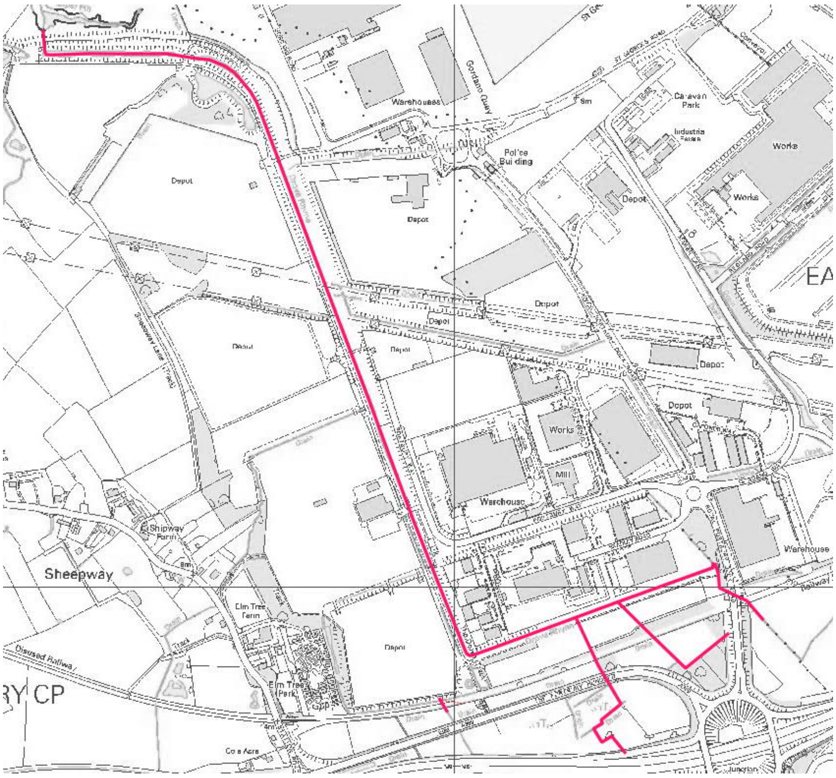


Figure 1: Extent of the Drove-Rhyne hydraulic model

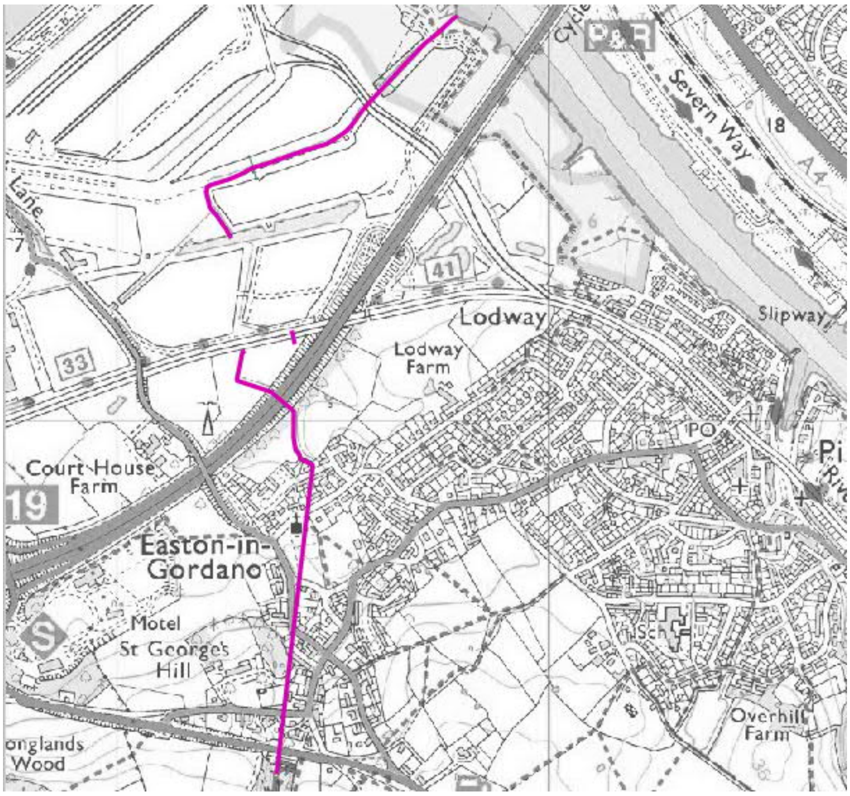


Figure 2: Extent of the Easton in Gordano hydraulic model

Flood data and flood history

We requested from the EA details of all hydrological data to inform the FRA. No flow or level gauges were identified by the EA in the Drove Rhyne or Easton-in-Gordano Stream study areas. The EA consultation response letter (EA ref WX/2014/125769/01-L01, July 2014) states:

" …… Unfortunately, we do not hold any flood level data for any of the above watercourses (i.e. Drove Rhyne, Portbury Ditch and Markham Brook) other than the historic flood data included in the Product 4 request………."

Since thi shydrology was completed, the Ea has referred to a Drove Rhyne level gauge at te htidal outfall. However, as this level gauge is located at the tidal outfall, it is unlikely a reliable stage-discharge rating could be derived and so it is unlikely to improve peak flow estimation.

The only available flood history data was the EA Product 4 data. This does not show any historic flood extents in the Drove Rhyne study area. Due to the nature of the catchment (small, ungauged, subject to significant change in the last few decades e.g. M5 Motorway, Ports land use) historic flooding may not be representative of flood risk in the catchment in its current form.

Hydrological schematisation and inflows

Catchment schematisation

The proposed model schematisation identifies two different groups of catchments North and South of the M5.

Given the low lying nature of the catchments North of the M5 and the diffuse network of channels present, catchment boundaries at this location have been derived looking at LiDAR data, survey and IDB network maps. Inflows from this part of the catchment will be modelled using direct rainfall methodology.

Subcatchments corresponding to the tributaries of the Drove Rhyne drain and Easton in Gordano Drain South of the M5 were extracted from the FEH CD ROM (version 3) – see Figure 3. The FEH CD-ROM catchments were compared against the OS mapping to check the catchment boundaries. This resulted in the following adjustments being made:

- E2 and D2 catchments were reduced South to the M5. Areas North of the M5 will in-fact be included in the model using direct rainfall inflows.
- Part of E1 was included in E2 as considered more hydrologically similar to the second (low lying and urban)
- D2 was extended to incorporate additional catchment areas south of the M5 not included in the FEH CD Rom

DPLBAR was modified using the appropriate method in FEH volume 5 chapter 7. URBEXT values were calculated using the FEH expansion formulas. Note that catchment D2 is considered heavily urbanized ($URBEXT_{1990}$= 0.262). Catchment D1 and E1 are also permeable (SPRHOST below 20%). As catchments considered are small in size and adjacent to each other, individual DDF parameters were kept for each catchment. Catchment descriptors are shown in Table 1.

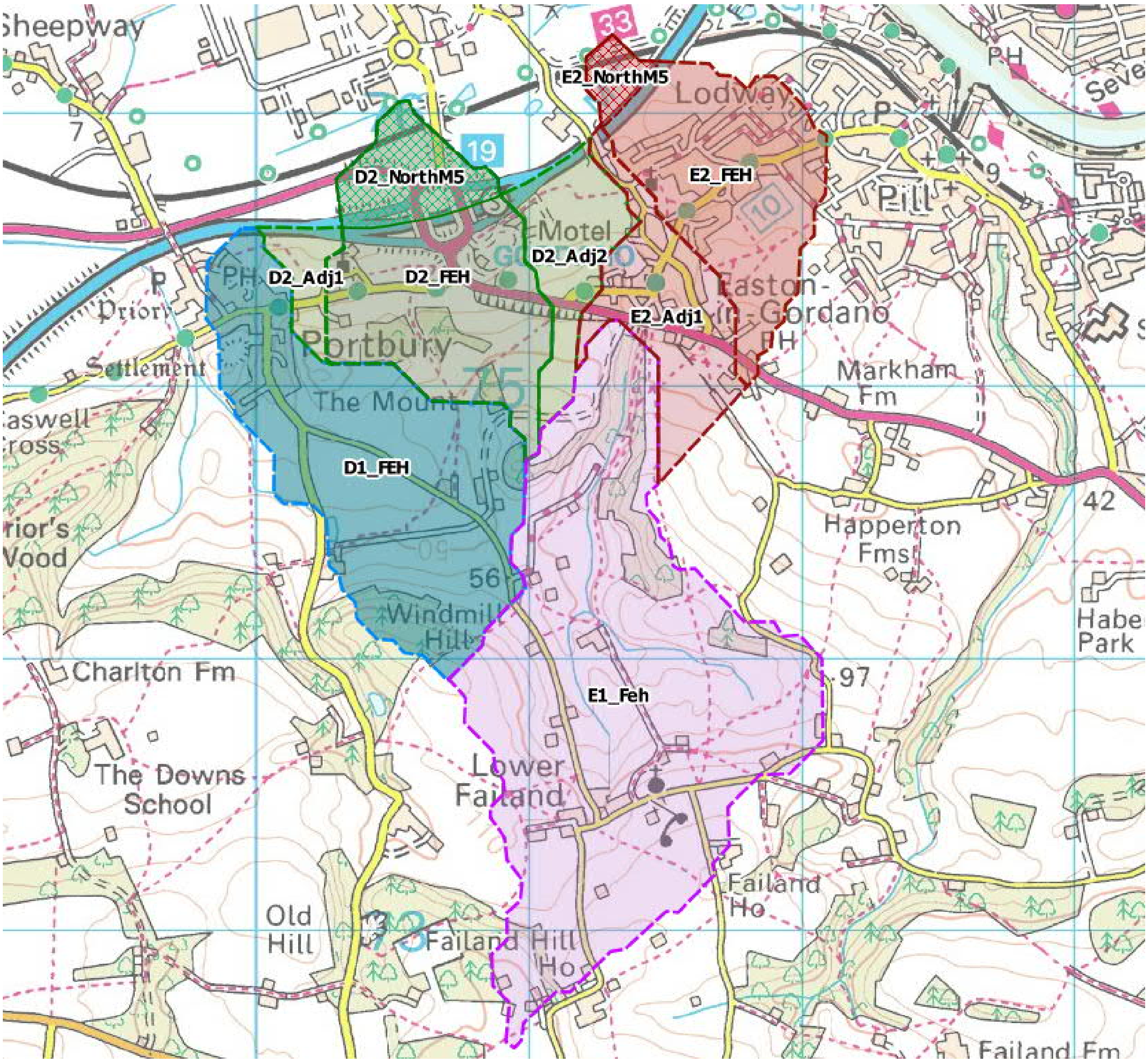


Figure 3: Drove Rhyne model subcatchments (D1 and D2) and Easton-in-Gordano model subcatchments (E1 and E2) South of the M5.

Table 1: FEH parameters for E1, E2, D1 and D2.

	E1	E2	D1	D2
AREA	1.73	0.82	0.89	0.79
BFIHOST	0.749	0.62	0.739	0.675
DPLBAR	1.64	0.90	1.25	0.88
DPSBAR	114.8	30.8	96.8	59.8
FARL	1	1	1	1
FPEXT	0.0115	0.0833	0.0197	0.246
PROPWET	0.35	0.35	0.35	0.35
SAAR	882	820	856	835
SPRHOST	11.9	30.24	14.98	24.69
URBEXT1990	0.0014	0.2623	0.0379	0.0099
URBEXT2000	0.0007	0.2598	0.0674	0.004
C(1 km)	-0.027	-0.027	-0.027	-0.027
D1(1 km)	0.339	0.334	0.337	0.332
D2(1 km)	0.445	0.444	0.446	0.441
D3(1 km)	0.282	0.285	0.279	0.279
E(1 km)	0.295	0.294	0.295	0.294
F1 (1 km)	2.423	2.414	2.411	2.405
Outlet easting	351400	351300	349550	350500
Outlet northing	175150	176250	175550	175950

Model inflows

Given the low-lying nature of the catchments North of the M5 and the presence of a diffuse network of drains (rather than a single watercourse), model inflows for these catchments were modelled in the form of direct rainfall. Extent of the catchments contributing to the Drove-Rhyne and the Easton-in-Gordano drain respectively was checked using latest available LiDAR and maps provided by the IDB network. Extent of direct rainfall inflows is shown in Figure 4 and Figure 5 respectively.

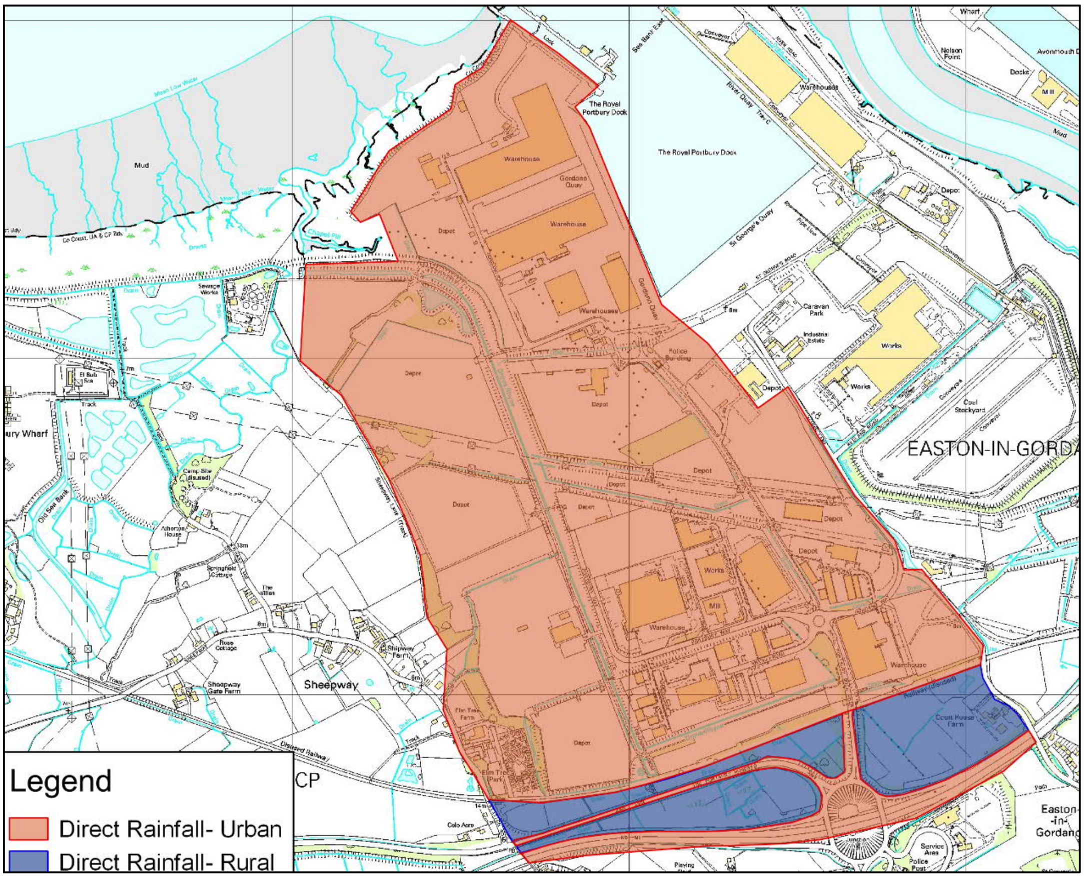


Figure 4: Direct rainfall catchment extents for the Drove-Rhyne hydraulic model

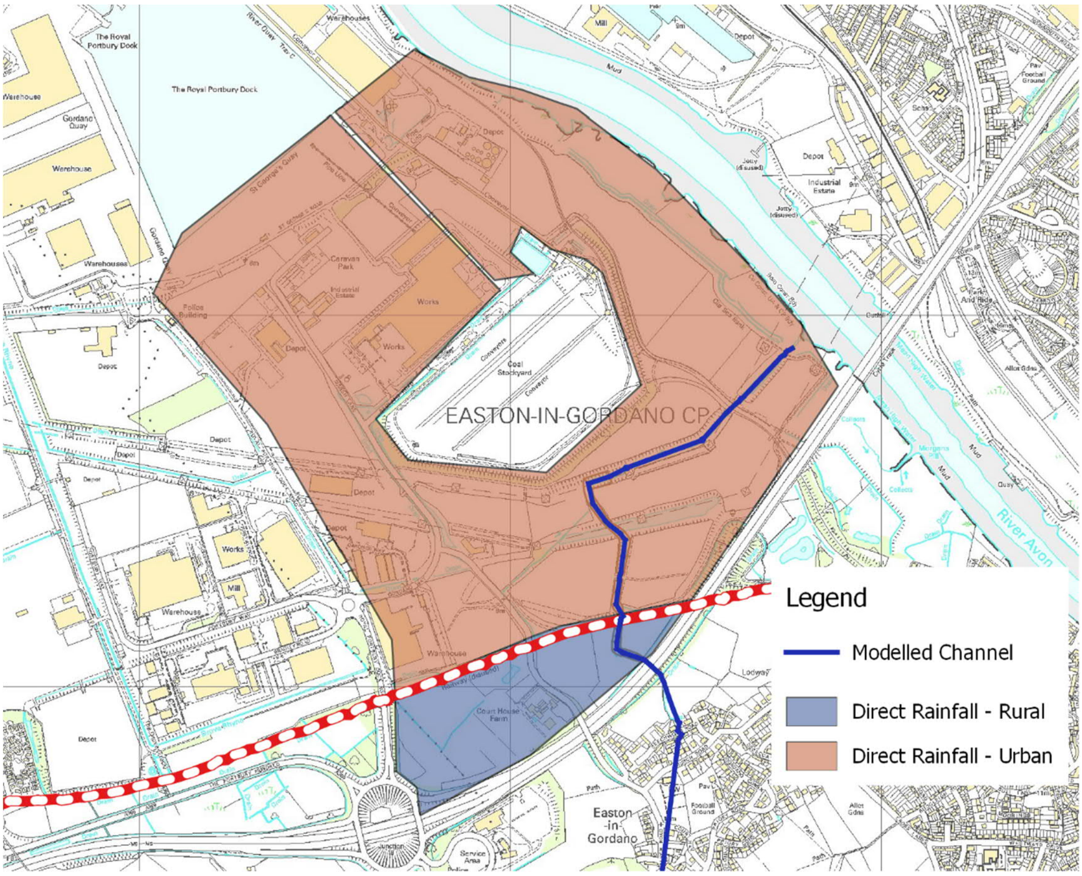


Figure 5: Direct rainfall catchment extents for the Easton-in-Gordano hydraulic model

Design hyetograph were extracted from FEH units of catchments D1, D2, E1, E2, assuming a uniform storm across the whole catchment area. Runoff percentages were established according to the surface material (Table 2). Land use was gathered from OS maps and aerial photography (Google Maps/ Bing Maps were used to support this decision).

This approach is considered appropriate as the routing model from catchment descriptors from the FEH RR model is not applicable.

Table 2: Percentage runoff for different materials

Material	Runoff %
Concrete and manmade hard surfaces	70
Natural environment and gardens	30

For catchments South of the M5 (D1, D2, E1, E2), the FEH approach was considered appropriate to produce design hydrographs. This approach is considered suitable also for the more permeable catchments (D1 and E1) given their small dimension and relative steepness. Runoff for these catchments infact is mainly in the form of rainfall runoff (rather than groundwater seepage).

Given the vicinity of the tidal Avon and the complex network of culverts running in the system, channel storage is considered a key parameter to be assessed in the FRA. The RR1999 model was therefore considered a more suitable approach than the ReFH model, for its more transparent way of conserving volumes. Furthermore, FEH guidance recommends to avoid using the ReFH model for catchments with high BFIHOST (subject catchments have BFIHOST above 0.62)

Flood frequency curves

Analysis location

Flood frequency curves (FFC) were constructed applying the RR1999 model and the current FEH statistical method for the purpose of scaling design hydrograph inflows to the hydraulic model. Flood frequency analysis was carried out at points in Figure 2. FEH catchment descriptors for the analysis are reported in Table 1.

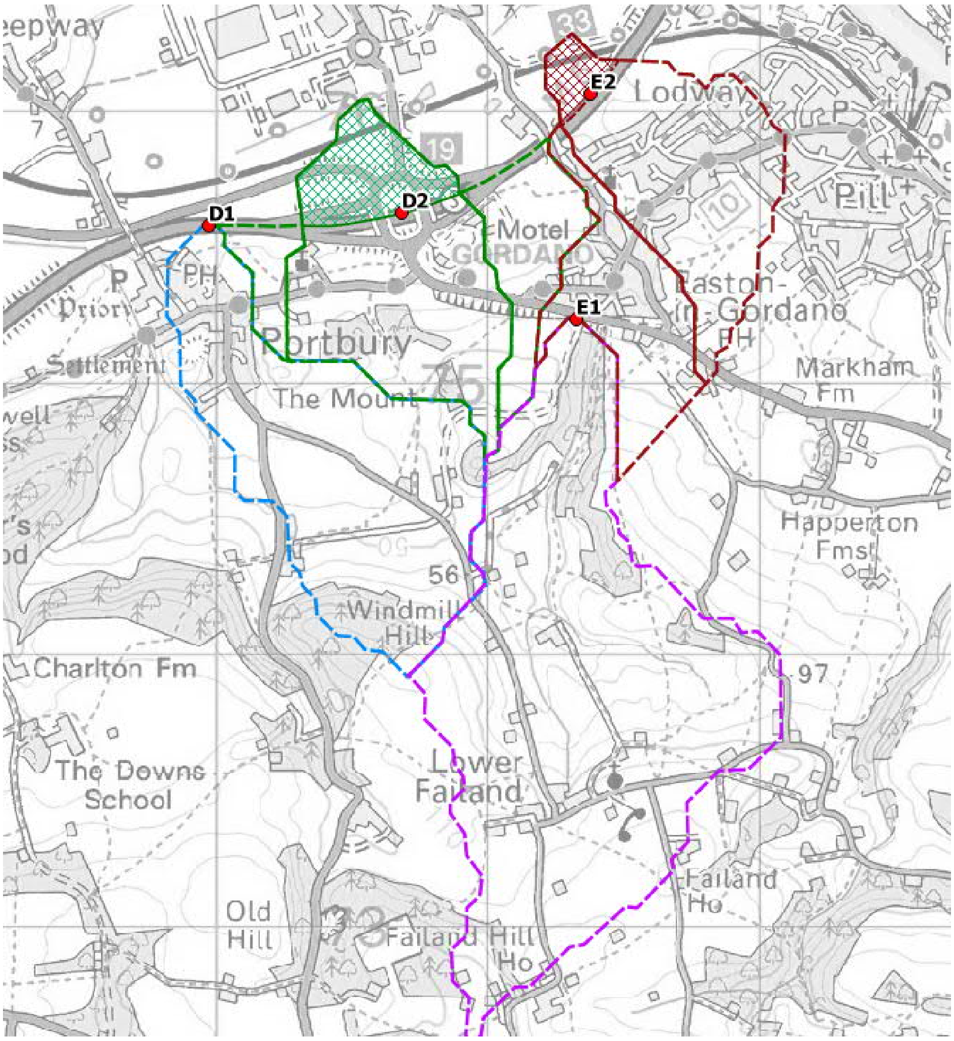


Figure 6: Points selected for flow estimate and respective FEH catchments

FEH statistical method

QMED estimation

The FEH Statistical Method calculates peak flows by fitting statistical distributions to observed annual maximum flow data. For ungauged sites a pooling group method is used whereby the distribution is fitted to observed flood data from a number of gauged sites which are judged similar to the subject site based on catchment descriptor information.

The index flood for the four catchments, Qmed [or a 50% (1 in 2 year) Annual Exceedance Probability (AEP) flow], calculated using the RR1999 model, based on catchment descriptors and following donor adjustment is reported in Table 2.

Table 2: Qmed estimate for E1, E2, D1 and D2.

	CD Q_{med} (m^3/s)	CD- Donor Adjustment Q_{med} (m^3/s)	RR1999 Qmed (m^3/s)*	95% confidence interval on CD estimate
E1	0.28	0.29	0.32	0.14- 0.60
E2	0.36	0.37	0.74**	0.18- 0.76
D1	0.19	0.20	0.26	0.10- 0.41
D2	0.18	0.18	0.31	0.09- 0.38

*2.33years RP

** Tp multiplied by 1.6. Qmed value with default Tp 0.92

Results from Qmed calculation shows the followings:

- Donor adjustment does no have a significant impact on catchment descriptors derived Qmed for any of the four catchments
- Estimates from the RR1999 model are consistently higher than estimates from catchment descriptors but still within 95% confidence interval for all catchments but E2, if using default Tp value. Multiplying E2 Tp by 1.6, the Qmed estimate using RR1999 is 0.74, which is within the 95% confidence interval. This adjustment is considered legitimate as within 68% confidence interval of the RR1999 estimate.

Given the lack of observed data, there is significant uncertainty in Qmed estimates.

Growth curve estimation

The FEH Statistical Method estimates a flood growth curve by fitting statistical distributions to observed annual maximum flow data. For ungauged sites, a pooling group method is used whereby the distribution is fitted to observed flood data from a number of gauged sites which are judged similar to the subject site based on catchment descriptor information. The standard procedure would be to require a pooling group with 500 station-years of AMAX records. However, given the small size of the catchments (i.e. the limited number of representative stations in the HiFlows-UK database), pooling groups with approximately 300 station-years of AMAX records were considered satisfactory. This is not considered to have a detrimental impact on the final results as the Pooled Uncertainty Measure (PUM) does not vary significantly for growth curves estimated by 300 station-year and 500 station-year pooling groups (EA Science Report SC050050).

To scale the Qmed flows to other AEP events, a flood growth curve was estimated for each point in Figure 2 using the pooling group method. Pooling groups were created for catchments D1 and D2 and the resulting rural growth curves were applied to E1 and E2 respectively. The approach is considered legitimate as D1-E1 and D2-E2 have similar catchment charasteristics and (given the paucity of similar catchments in HiFlows) using the single cathcments is unlikely to give different pooled groups.

The default pooling groups for D1 and D2 were reviewed to check if the pooled stations were representative of the subject sites. Given the permeable nature of the catchments, the most impermeable sites were discarded. AMAX records were also discarded if available information (National Rivers Flow Archive website) indicated the rating of high flows may be uncertain.

The default pooling groups for site D1 and D2 are reported in Appendix A. The final pooling groups and the catchment descriptors for both sites are shown in Table 3a, Table 3b, Table 4a and Table 4b respectively. The similarity distance is an indication of how similar the pooling group catchment is to the subject site in terms of the catchment descriptors AREA, SAAR, FARL and FPEXT. L-cv and L-skew are the parameters used to calculate the growth curve. Discordancy shows how consistent each station's L-cv and L-skew values are compared with the rest of the pooling group. As permeable stations were present in both PGs, permeable adjustment was applied at both sites. Urban adjustment was applied using each of the four catchments' URBEXT value.

Growth curves for the four catchments were also estimated using the RR1999 model.

Table 5, 6, 7 and 8 report the growth curves obtained for both sites using the methods described above. Results show estimates from the RR1999 method to be generally higher but within the same range of the ones obtained using the statistical approach.

Table 3a: D1 reviewed PG

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
45816 (Haddeo @ Upton)	2.921	19	3.456	0.324	0.434	0.452
28033 (Dove @ Hollinsclough)	3.18	33	4.666	0.266	0.415	0.689
91802 (Allt Leachdach @ Intake)	3.486	34	6.35	0.153	0.257	1.978
47022 (Tory Brook @ Newnham Park)	3.928	19	7.331	0.257	0.071	0.822
27073 (Brompton Beck @ Snainton Ings)	3.938	32	0.813	0.197	-0.022	1.414
25019 (Leven @ Easby)	3.954	34	5.538	0.347	0.394	0.452
26802 (Gypsey Race @ Kirby Grindalythe)	4.033	13	0.109	0.261	0.199	0.737
44008 (South Winterbourne @ Winterbourne Steepleton)	4.373	33	0.42	0.395	0.332	0.792
51002 (Horner Water @ West Luccombe)	4.507	19	8.354	0.409	0.343	2.134
48004 (Warleggan @ Trengoffe)	4.787	43	9.799	0.268	0.287	0.531

Table 3b: D1 reviewed PG catchment parameters

Station	Distance	AREA (km2)	SAAR	FPEXT	FARL	URBEXT 2000
45816 (Haddeo @ Upton)	2.921	6.81	1210	0.011	1	0.005
28033 (Dove @ Hollinsclough)	3.18	7.93	1346	0.007	1	0
91802 (Allt Leachdach @ Intake)	3.486	6.52	2555	0.003	0.992	0
47022 (Tory Brook @ Newnham Park)	3.928	13.45	1403	0.023	0.942	0.014
27073 (Brompton Beck @ Snainton Ings)	3.938	8.06	721	0.237	1	0.008
25019 (Leven @ Easby)	3.954	15.07	830	0.019	1	0.004
26802 (Gypsey Race @ Kirby Grindalythe)	4.033	15.85	757	0.03	1	0
44008 (South Winterbourne @ Winterbourne Steepleton)	4.373	20.17	1012	0.015	1	0.004
51002 (Horner Water @ West Luccombe)	4.507	20.38	1485	0.003	0.978	0
48004 (Warleggan @ Trengoffe)	4.787	25.26	1445	0.035	0.978	0.003

Table 4a: D2 reviewed PG

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	3.26	32	0.813	0.197	-0.022	0.714
45816 (Haddeo @ Upton)	4.055	19	3.456	0.324	0.434	0.67
28033 (Dove @ Hollinsclough)	4.282	33	4.666	0.266	0.415	1.111
47022 (Tory Brook @ Newnham Park)	4.797	19	7.331	0.257	0.071	0.518
25019 (Leven @ Easby)	4.837	34	5.538	0.347	0.394	0.587
26802 (Gypsey Race @ Kirby Grindalythe)	4.838	13	0.109	0.261	0.199	0.475
203046 (Rathmore Burn @ Rathmore Bridge)	5.085	30	10.934	0.136	0.091	1.262
20002 (West Peffer Burn @ Luffness)	5.107	41	3.299	0.292	0.015	1.802
44008 (South Winterbourne @ Winterbourne Steepleton)	5.226	33	0.42	0.395	0.332	0.844
72014 (Conder @ Galgate)	5.401	45	17.703	0.193	0.059	1.057
51002 (Horner Water @ West Luccombe)	5.409	19	8.354	0.409	0.343	1.959

Table 4b: D2 reviewed PG catchment parameters

Station	Distance SDM	AREA (km^2)	SAAR	FPEXT	FARL	URBEXT 2000	SPRHOST
27073 (Brompton Beck @ Snainton Ings)	3.26	8.06	721	0.237	1	0.008	8.06
45816 (Haddeo @ Upton)	4.055	6.81	1210	0.011	1	0.005	6.81
28033 (Dove @ Hollinsclough)	4.282	7.93	1346	0.007	1	0	7.93
47022 (Tory Brook @ Newnham Park)	4.797	13.45	1403	0.023	0.942	0.014	13.45
25019 (Leven @ Easby)	4.837	15.07	830	0.019	1	0.004	15.07
26802 (Gypsey Race @ Kirby Grindalythe)	4.838	15.85	757	0.03	1	0	15.85
203046 (Rathmore Burn @ Rathmore Bridge)	5.085	22.51	1043	0.073	1	0	22.51
20002 (West Peffer Burn @ Luffness)	5.107	26.31	616	0.128	0.996	0.002	26.31
44008 (South Winterbourne @ Winterbourne Steepleton)	5.226	20.17	1012	0.015	1	0.004	20.17
72014 (Conder @ Galgate)	5.401	28.99	1183	0.082	0.975	0.006	28.99
51002 (Horner Water @ West Luccombe)	5.409	20.38	1485	0.003	0.978	0	20.38

Table 5: Growth curve estimates for D1 (selected option in bold)

RP (years)	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	GF- FEH RR1999, 3.8hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.382	1.485	1.465	1.479	1.484
10	1.672	1.867	1.836	1.869	1.801
25	2.105	2.457	2.416	2.491	2.465
50	2.49	2.998	2.953	3.077	3.121
100	2.939	3.646	3.601	3.794	3.789
200	3.466	4.424	4.386	4.677	4.621
1000	5.074	6.908	6.933	7.607	7.570

Table 6: Growth curve estimates for E1 (selected option in bold)

RP (years)	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	GF- FEH RR1999, 5.7 hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.382	1.485	1.485	1.501	1.433
10	1.672	1.867	1.867	1.904	1.774
25	2.105	2.457	2.458	2.538	2.563
50	2.49	2.998	3.000	3.129	3.245
100	2.939	3.646	3.648	3.846	3.950
200	3.466	4.424	4.428	4.720	4.839
1000	5.074	6.908	6.918	7.578	7.997

Table 7: Growth curve estimates for D2 (selected option in bold)

RP (years)	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	GF- FEH RR1999, 6.9hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.383	1.457	1.456	1.448	1.468
10	1.673	1.793	1.791	1.780	1.779
25	2.107	2.280	2.278	2.269	2.380
50	2.493	2.703	2.701	2.697	2.890
100	2.943	3.185	3.183	3.191	3.399
200	3.471	3.738	3.736	3.761	4.023

1000	5.083	5.366	5.367	5.465	6.136

Table 8: Growth curve estimates for E2 (selected option in bold)

RP (years)	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	GF- FEH RR1999, 1.7hrs storm duration, summer profile, 2015 URBEXT$_{1990}^{*}$
2	1.000	1.000	1.000	1.000	1.000
5	1.383	1.457	1.391	1.383	1.284
10	1.673	1.793	1.693	1.681	1.573
25	2.107	2.280	2.152	2.140	2.038
50	2.493	2.703	2.566	2.558	2.469
100	2.943	3.185	3.054	3.055	3.123
200	3.471	3.738	3.634	3.650	3.906
1000	5.083	5.366	5.440	5.530	6.558

* Tp multiplied by 1.6

Flood frequency curves

Results from the statistical pooled group (following urban and permeabled adjustment) are reported in Table 9.

The final choice for the flood frequency curves for each of the above analyses are shown in Table 10. The final choice of method is the FEH RR1999 method as this is the most reliable method to assess the sensitivity of the system to flood volumes. This choice of method is considered appropriate as results using this methodology were proven to be higher but consistent with estimates from the statistical method.

Table 9: FFC obtained using statistical PG approach and CD Qmed with donor adjustment.

Return Period (T) (years)	E1 FFC (cumecs) CD Qmed, donor adjustment, reviewed PG with permeable adj.	E2 FFC (cumecs) CD Qmed, donor adjustment, reviewed PG with permeable adj.	D1 FFC (cumecs) CD Qmed, donor adjustment, reviewed PG with permeable adj.	D2 FFC (cumecs) CD Qmed, donor adjustment, reviewed PG with permeable adj.
2	0.29	0.37	0.20	0.18
5	0.44	0.51	0.30	0.27
10	0.56	0.62	0.38	0.33
25	0.74	0.79	0.50	0.42
50	0.91	0.95	0.62	0.50
100	1.12	1.13	0.76	0.59
200	1.38	1.35	0.94	0.69
1000	2.21	2.05	1.53	1.00

Table 10: Final FFC using RR1999 methodology

Return Period (T) (years)	E1 FFC (cumecs) FEH, SD 5.7hrs summer profile	E2 FFC (cumecs) FEH, SD 1.7hrs summer profile, Tp multiplied by 1.6	D1 FFC (cumecs) FEH, SD 3.8hrs summer profile	D2 FFC (cumecs) FEH, SD 6.9hrs summer profile
2.33	0.32	0.74	0.26	0.31
5	0.46	0.95	0.38	0.45
10	0.57	1.16	0.46	0.55
25	0.83	1.50	0.63	0.73
50	1.05	1.82	0.80	0.89
100	1.28	2.30	0.97	1.05
200	1.56	2.88	1.18	1.24
1000	2.58	4.83	1.94	1.89

References

Flood Estimation Handbook, Duncan Reed, Duncan Faulkner, Alison Robson, Helen Houghton-Carr, Adrian Bayliss, Institute of Hydrology, 1999

Revitalisation of the FSR/FEH rainfall runoff method, R&D Technical Report FD1913/TR, TR Kjeldsen, EJ Stewart, JC Packman, SS Folwell and AC Bayliss, Environment Agency and Defra, July 2005

URBEXT2000 – A new FEH catchment descriptor; Calculation, dissemination and application, R&D Technical Report FD1919/TR, AC Bayliss, KB Black, A Fava-Verde and TR Kjeldsen, Environment Agency and Defra, March 2006

Improving the FEH statistical procedures for flood frequency estimation, Science report SC050050, TR Kjeldsen, DA Jones and AC Bayliss, Environment Agency and Defra, June 2008

Modelling the impact of urbanisation on flood frequency relationships in the UK, TR Kjeldsen, Hydrology Research, 2010

Flood Estimation Guidelines, Operational Instruction 197_08, Environment Agency, 21 January 2015

Appendices

Appendix A: Default and reviewed pooling groups

D1- Default Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	1.141	35	1.84	0.169	0.333	1.161
45816 (Haddeo @ Upton)	2.921	19	3.456	0.324	0.434	0.602
27051 (Crimple @ Burn Bridge)	3.096	40	4.539	0.222	0.149	0.292
28033 (Dove @ Hollinsclough)	3.18	33	4.666	0.266	0.415	0.434
91802 (Allt Leachdach @ Intake)	3.486	34	6.35	0.153	0.257	1.119
54022 (Severn @ Plynlimon Flume)	3.781	37	15.031	0.155	0.168	1.509
49006 (Camel @ Camelford)	3.856	6	8.832	0.11	-0.293	3.072
25011 (Langdon Beck @ Langdon)	3.864	26	15.878	0.241	0.326	1.337
25003 (Trout Beck @ Moor House)	3.892	39	15.164	0.176	0.291	0.646
47022 (Tory Brook @ Newnham Park)	3.928	19	7.331	0.257	0.071	0.567
27073 (Brompton Beck @ Snainton Ings)	3.938	32	0.813	0.197	-0.022	0.644
25019 (Leven @ Easby)	3.954	34	5.538	0.347	0.394	0.85
26802 (Gypsey Race @ Kirby Grindalythe)	4.033	13	0.109	0.261	0.199	0.41
206006 (Annalong @ Recorder)	4.045	48	15.33	0.189	0.052	1.683
27010 (Hodge Beck @ Bransdale Weir)	4.276	41	9.42	0.224	0.293	0.138
44008 (South Winterbourne @ Winterbourne Steepleton)	4.373	33	0.42	0.395	0.332	1.849
22003 (Usway Burn @ Shillmoor)	4.495	26	19.22	0.303	0.303	0.687
Total		515				
Weighted means				0.233	0.237	

D1- Reviewed Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
45816 (Haddeo @ Upton)	2.921	19	3.456	0.324	0.434	0.452
28033 (Dove @ Hollinsclough)	3.18	33	4.666	0.266	0.415	0.689
91802 (Allt Leachdach @ Intake)	3.486	34	6.35	0.153	0.257	1.978
47022 (Tory Brook @ Newnham Park)	3.928	19	7.331	0.257	0.071	0.822
27073 (Brompton Beck @ Snainton Ings)	3.938	32	0.813	0.197	-0.022	1.414
25019 (Leven @ Easby)	3.954	34	5.538	0.347	0.394	0.452
26802 (Gypsey Race @ Kirby Grindalythe)	4.033	13	0.109	0.261	0.199	0.737
44008 (South Winterbourne @ Winterbourne Steepleton)	4.373	33	0.42	0.395	0.332	0.792
51002 (Horner Water @ West Luccombe)	4.507	19	8.354	0.409	0.343	2.134
48004 (Warleggan @ Trengoffe)	4.787	43	9.799	0.268	0.287	0.531
Total		279				
Weighted means				0.286	0.274	

D2- Default Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
76011 (Coal Burn @ Coalburn)	2.238	35	1.84	0.169	0.333	1.048
27073 (Brompton Beck @ Snainton Ings)	3.26	32	0.813	0.197	-0.022	0.47
45816 (Haddeo @ Upton)	4.055	19	3.456	0.324	0.434	1.003
27051 (Crimple @ Burn Bridge)	4.172	40	4.539	0.222	0.149	0.385
28033 (Dove @ Hollinsclough)	4.282	33	4.666	0.266	0.415	0.534
91802 (Allt Leachdach @ Intake)	4.544	34	6.35	0.153	0.257	1.01
25003 (Trout Beck @ Moor House)	4.658	39	15.164	0.176	0.291	0.551
54022 (Severn @ Plynlimon Flume)	4.748	37	15.031	0.155	0.168	1.379
47022 (Tory Brook @ Newnham Park)	4.797	19	7.331	0.257	0.071	0.619
49006 (Camel @ Camelford)	4.802	6	8.832	0.11	-0.293	2.968
25011 (Langdon Beck @ Langdon)	4.807	26	15.878	0.241	0.326	1.483
25019 (Leven @ Easby)	4.837	34	5.538	0.347	0.394	1.333
26802 (Gypsey Race @ Kirby Grindalythe)	4.838	13	0.109	0.261	0.199	0.355
206006 (Annalong @ Recorder)	4.896	48	15.33	0.189	0.052	1.303
203046 (Rathmore Burn @ Rathmore Bridge)	5.085	30	10.934	0.136	0.091	0.678
20002 (West Peffer Burn @ Luffness)	5.107	41	3.299	0.292	0.015	1.744
27010 (Hodge Beck @ Bransdale Weir)	5.172	41	9.42	0.224	0.293	0.135
Total		527				
Weighted means				0.219	0.204	

D2- Reviewed Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	3.26	32	0.813	0.197	-0.022	0.714
45816 (Haddeo @ Upton)	4.055	19	3.456	0.324	0.434	0.67
28033 (Dove @ Hollinsclough)	4.282	33	4.666	0.266	0.415	1.111
47022 (Tory Brook @ Newnham Park)	4.797	19	7.331	0.257	0.071	0.518
25019 (Leven @ Easby)	4.837	34	5.538	0.347	0.394	0.587
26802 (Gypsey Race @ Kirby Grindalythe)	4.838	13	0.109	0.261	0.199	0.475
203046 (Rathmore Burn @ Rathmore Bridge)	5.085	30	10.934	0.136	0.091	1.262
20002 (West Peffer Burn @ Luffness)	5.107	41	3.299	0.292	0.015	1.802

44008 (South Winterbourne @ Winterbourne Steepleton)	5.226	33	0.42	0.395	0.332	0.844
72014 (Conder @ Galgate)	5.401	45	17.703	0.193	0.059	1.057
51002 (Horner Water @ West Luccombe)	5.409	19	8.354	0.409	0.343	1.959
Total		318				
Weighted means				0.278	0.207	

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

Contents

Page

Approval

	Signature	Name and qualifications	For Environment Agency staff: Competence level (see below)
Calculations prepared by:	SG	Silvia Garattini, BSc, MSc	1
Calculations checked by:	RB	Robert Bird, BSc, MSc, MCIWEM	3
Calculations approved by:	RB	Robert Bird, BSc, MSc, MCIWEM	3

Environment Agency competence levels are covered in Section 2.1 of the flood estimation guidelines:

- Level 1 – Hydrologist with minimum approved experience in flood estimation
- Level 2 – Senior Hydrologist
- Level 3 – Senior Hydrologist with extensive experience of flood estimation

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations • Approx. time available	Inflows were required for two adjacent models: Drove Rhyne (Portbury) and Easton-in-Gordano, North Somerset UK. The models will be used as part of a FRA study to assess flood risk along the alignment of a disused railway north of the M5 motorway. The model will compare flood risk for the current situation and for a post-development scenario (restoration of the railway) for a range of return periods between 2 years and 1000 years. Full hydrographs are required for the model boundary nodes to model interaction with the downstream tidal boundary and test the impact of different storm duration events on the system storage.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The study catchments include the urban areas of Easton in Gordano and Portbury on the Southern side of the M5. The area borders the tidal river Avon. The Southern area of both catchments is mainly rural whilst the urban areas of Pill, Easton in Gordano and Portbury are located in the North of the study area. Based on British Geological Survey maps, the bedrock geology underlying the catchment is mainly limestone and sandstone in the South of the catchments and Mudstone in the proximity of the M5. No superficial deposit is present in most of the subject area. Head (clay, silt, sand and gravel) in the proximity of the M5. As a result, the area is characterized by modest permeability overall with the Northern part of the catchment being more impermeable than the South. The area is ungauged and most of the watercourses in the area are culverted and flows through the urban settlements. Given the tidal downstream boundary of the catchment, storage in the channel is a key factor to be considered when assessing flood risk.

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.3.4 No changes made.

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
Land Yeo	Wraxall Bridge		52015	ST48371 5	23.3	Crump Weir	1971-2014

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	**Other comments on station and flow data quality** – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
Wraxall Bridge	1971-2014	No	Yes	No	No	Triangular profile Crump weir, crest 5m wide, then rated section within wing walls. All flows contained. Closed from September 1979 to May 1985. Reopened following installation of telemetry. River weedy but weir cleared regularly. Rating confirmed by gaugings to 0.3 m; validity does not extend beyond 0.4 m, where reasonable extrapolation would end. Uncertain rating at high flows. Barrow Gurney reservoirs in catchment (approximately 0.75 km2).
Give link/reference to any further data quality checks carried out						

1.6 Rating equations

Station name	**Type of rating** e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	**Reasons** – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Wraxall Bridge	One rating applied across period of record. Existing rating confirmed by gaugings to 0.3 m. Validity does not extend beyond 0.4 m where reasonable extrapolation would end.	No	Estimates of Qmed are thought to be reasonable.
Give link/reference to any rating reviews carried out			

1.7 Other data available and how it has been obtained

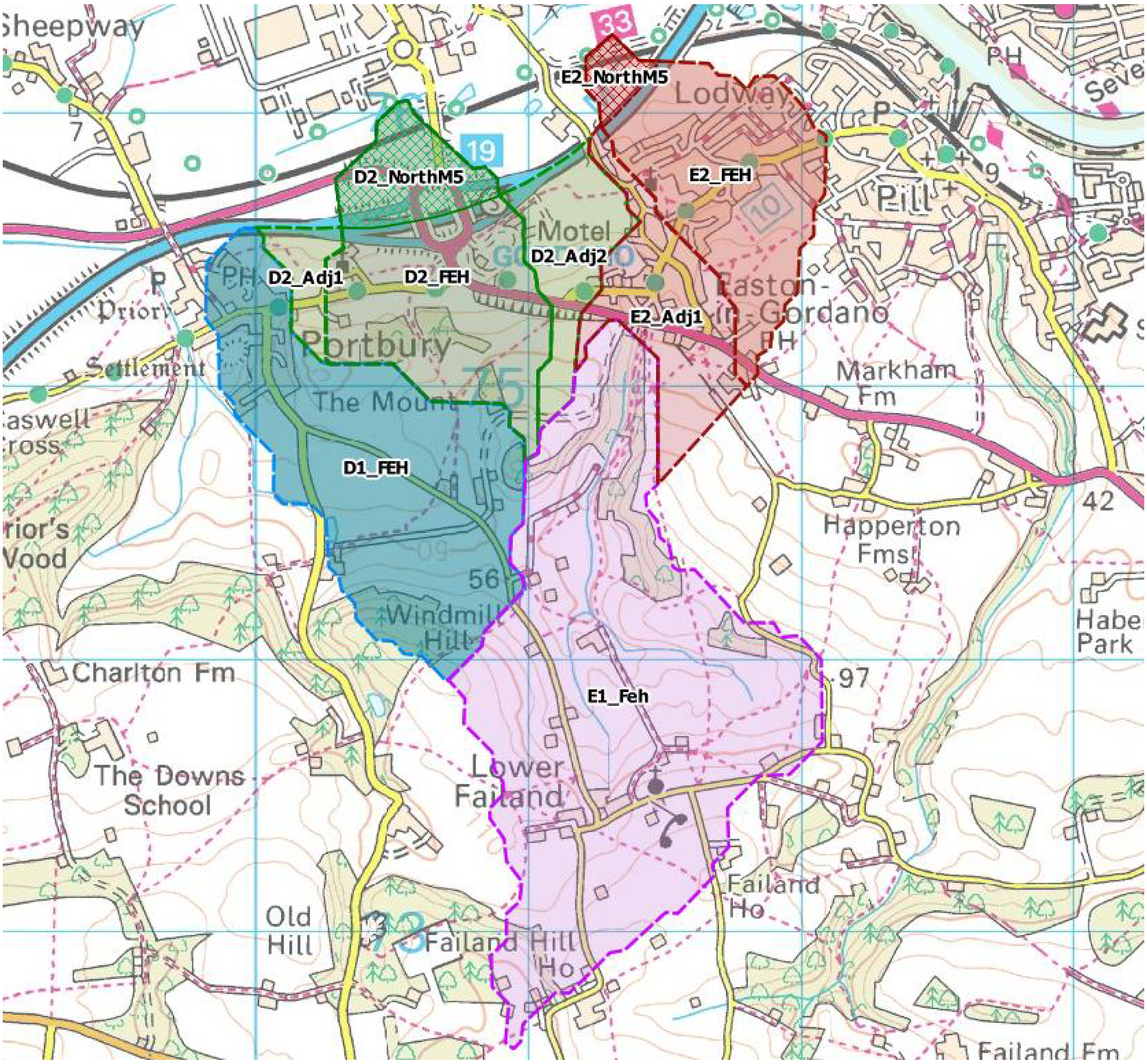
Type of data	Data relevant to this study?	Data available ?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)					
Historic flood data – give link to historic review if carried out.	N/A	No			
Flow data for events	N/A	No			
Rainfall data for events	N/A	No			

Potential evaporation data					
Results from previous studies	N/A	No			
Other data or information (e.g. groundwater, tides)	Level at tidal Avon used for downstream boundary conditions	Yes	Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelling	Nov 2015	Modelling data and accompanying model report

1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Overall the catchment areas are not too urbanised or permeable and the catchment sizes are small but still above the 0.5km^2 recommended threshold. The FEH method is therefore considered an appropriate approach to derive hydrographs and flood estimates in the area.
Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	The main aim of the study is to evaluate the change in flood risk in the area of Easton-in-Gordano and Drove (North Somerset, UK) following restauration work at the disused railway line close to the M5. Culverted drains flow south of the M5 to the railway line through urban areas. Given the tidal border of the subject area and the presence of culverts, flood volumes is the more likely cause of flood. There are small lakes but no reservoirs in the catchment. Temporary dams not in consideration.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing • extensive floodplain storage – consider choice of method carefully	One of the sub-catchments for the Easton-in-Gordano model is highly urbanised (URBEXT1990 = 0.263). Two sub-catchments (one from Easton in Giordano and one from Drove) are permeable with SPRHOST values below 20%. A permeable adjustment has been applied at the locations analysed. All the sub-catchments have high BFIHOST (over 0.62).
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	It was anticipated that the ReFH methodology would not be suitable for this study as the ReFH is known to give unreliable hydrograph volumes for event durations significantly longer than the default design duration, which may be the case here due to the influence of tide locking on flood storage. The FEH rainfall-runoff approach is therefore considered a preferable option to derive the hydrograph profiles, as

	there is a more direct relationship between event rainfall volume and hydrograph volume. To estimate the FFC curve at the selected sites, the FEH rainfall runoff model and the statistical method have been explored. Given the lack of data at the subject site and the scarcity of small and permeable catchments in HiFlows, it is also important to understand the uncertainty in the estimates obtained. The catchments will be split into sub-catchments for the model boundary inflows (see image below for schematisation). Growth curves using the statistical method have been derived for catchments D1 and D2; D1 was used as a donor for E1 and D2 for E2. Qmed has been estimated for all the subcatchments using FEH RR model and the catchment descriptor statistical method including with a donor adjustment from a nearby station.
Software to be used (with version numbers)	FEH CD-ROM v3.0[1] WINFAP-FEH v3.0.002[2] / ISIS 3.7



---

[1] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

[2] WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
E1	Easton Drain	Easton in Gordano-South	351400	175150	1.73	-
E2	Easton Drain	Easton in Gordano-North	351300	176250	0.51	0.824
D1	Drove Drain	Portbury South	349550	1175550	0.89	-
D2	Drove Drain	Portbury North	350500	175950	0.63	0.786
Reasons for choosing above locations		Catchments in the models have been divided to reflect differences in land-use/ hydrological characteristics.				

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT	FPEXT
E1	1	0.35	0.749	1.64	114.8	882	11.9	URBEXT1990: in 1990 = 0.0014, in 2015 = 0.015 URBEXT2000: in 2000 = 0.0007, in 2015 = 0.0007	0.0115
E2	1	0.35	0.620	0.90	30.8	820	30.24	URBEXT1990: in 1990 = 0.262, in 2015 = 0.2822 URBEXT2000: in 2000 = 0.2598, in 2015 = 0.2693	0.083
D1	1	0.35	0.739	1.25	96.8	856	14.98	URBEXT1990: in 1990 = 0.038, in 2015 = 0.0408 URBEXT2000: in 2000 = 0.067, in 2015 = 0.0696	0.020
D2	1	0.35	0.675	0.88	59.8	835	24.69	URBEXT1990: in 1990 = 0.0099, in 2015 = 0.0106 URBEXT2000: in 2000 = 0.0040, in 2015 = 0.0041	0.246

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Additional areas have been added to E2 and D2. Areas North of the M5 were also excluded as model inflows for these areas will be derived using direct rainfall method.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	High BFIHOST is consistent with the limestone bedrock geology. Relatively low SPRHOST is also consistent with the geology. DPLBAR has been adjusted for E2 and D2 following the area adjustment specified in FEH vol 5 ($AREA^{0.548}$).
Source of URBEXT	URBEXT2000 for statistical method, URBEXT1990 for FEH RR1999
Method for updating of URBEXT	CPRE formula from FEH Volume 4 for URBEXT1990 / Urban expansion model – Defra/EA R&D technical Report FD1919/TR

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	The catchments have a very small area, have high BFIHOST and are relatively permeable. This type of catchment is not very well represented in HiFlows and there is a scarcity of available donors as a result. The NRFA was consulted to look for nearby stations with acceptable areas and quality of records that could be used as donors.

Note- when Qmed was estimated from catchment descriptors the 2008 revised equation was considered.

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjust-ment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)
52015	- Close to subject site - Confidence in Qmed estimates - Key catchment descriptors (PROPWET, SAAR, BFIHOST, and SPRHOST) are consistent with subject sites.	AM	No	3.40	3.26	1.04
Which version of the urban adjustment was used for QMED at donor sites, and why? Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).				The subject catchments have BFIHOST under the recommended threshold. Urban adjustment using WINFAP-FEH v3.0.003 / Kjeldsen (2010)		

Given the scarcity of available stations, 52015 has been used as a donor station for D1, D2, E1 and E2.

3.3 Overview of estimation of QMED at each subject site

Qmed (equivalent to 2.33years) using the RR1999 has been estimated for the four sites analysed and results are reported below. Tp pf the hydrograph for E2 has been multiplied by 1.6 to achieve Qmed estimates closer to the catchment descriptors method. Given the uncertainty of Qmed at the location, this approach is considered legitimate and with the upper 68% confidence limit of the RR model estimate.

Site code	Method	Initial estimate of QMED (m^3/s)	Data transfer					Final estimate of QMED (m^3/s)
			NRFA numbers for	Distance between centroids	Power term, a	Moderated QMED adjustment	If more than one donor	

			donor sites used (see 3.3)	**d_{ij} (km)**		**factor, $(A/B)^a$**	**Weight**	**Weighted average adjustment factor**	
E1	DT	0.28	52015	4.58	0.4799	1.034	-	-	0.29
E1	CD	0.28	-	-					0.28
E1	RR 1999	0.320							0.32
E2	DT	0.36	52015	6.49	0.4280	1.030			0.37
E2	CD	0.36	-	-					0.36
D1	DT	0.20	52015	5.52	0.4503	1.031			0.20
D1	CD	0.20	-	-					0.20
D2	DT	0.18	52015	6.15	0.4350	1.030			0.18
D2	CD	0.18	-	-	-	-	-	-	0.18
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?						N/A			
Which version of the urban adjustment was used for QMED, and why?						Kjeldsen (2010)			

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.

When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added.

When QMED is estimated from catchment descriptors, the revised 2008 equation from Science Report SC050050**Error! Bookmark not defined.** should be used. If the original FEH equation has been used, say so and give the reason why.

The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8). The adjustment method used in WINFAP-FEH v3.0.003 is likely to overestimate adjustment factors for such catchments. In this case the only reliable flood estimates are likely to be derived from local flow data.

The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is $(A/B)^a$ times the initial estimate from catchment descriptors.

If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

3.4 Derivation of pooling groups

The composition of the pooling groups is given in the Annex. Several subject sites may use the same pooling group.

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
D1_PG	D1	NO	49006 was discarded for having only 6 years of records. 76011, 25003, 25011, 22003, 27051, 54022, 206006, 27010 were rejected for low BFIHOST. 51002, 48004 were added for having BFIHOST/ SPRHOST similar to the subject catchment and to replace discarded station. AMAX data between 1979 and 1992 were discarded for station 51002, as came from mean daily flow rather than peak flow data.	L-CV: 0.286 L-SKEW: 274
D2_PG	D2	NO	49006 was discarded for having only 6 years of records. 76011, 25003, 25011, 27051, 54022, 206006, 27010 were rejected for low BFIHOST. 51002, 48004 were added for having BFIHOST/ SPRHOST similar to the subject catchment and to replace discarded station. AMAX data between 1979 and 1992 were discarded for station 51002, as came from mean daily flow rather than peak flow data. 91802 was rejected for high BFIHOST, 72014 was added to replace the station.	L-CV: 0.28 L-SKEW: 0.207

Notes

Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

3.5 Derivation of flood growth curves at subject sites

Site code	**Method** (SS, P, ESS, J)	**If P, ESS or J, name of pooling group (3.4)**	**Distribution used and reason for choice**	**Note any urban adjustment or permeable adjustment**	**Parameters of distribution** (location, scale and shape) after adjustments	**Growth factor for 100-year return period**
E1	P	**D1_PG**	GL l-median as FEH recommended	Permeable adjustment	Location: 1 Kappa: -0.294 Beta 0.293	3.846
E2	P	**D2_PG**	GL l-median as FEH recommended	Permeable adjustment	Location: 1 Kappa: -0.266 Beta: 0.228	3.191
D1	P	**D1_PG**	GL l-median as FEH recommended	Permeable adjustment	Location: 1 Kappa: -0.306 Beta: 0.277	3.794
D2	P	**D2_PG**	GL l-median as FEH recommended	Permeable adjustment	Location: 1 Kappa: -0.219 Beta: 0.277	3.055

Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Growth curves were derived using the revised procedures from Science Report SC050050 (2008).

Growth curves obtained with the statistical and the FEH methods obtained for the different sites are reported below.

Growth Curve estimates for site D1 (using general logistic):

RP	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	FEH RR1999, 3.8hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.382	1.485	1.465	1.479	1.484
10	1.672	1.867	1.836	1.869	1.801
20	1.993	2.302	2.262	2.326	#N/A
25	2.105	2.457	2.416	2.491	2.465
30	2.201	2.591	2.547	2.634	N/A
50	2.49	2.998	2.953	3.077	3.121
75	2.744	3.363	3.316	3.479	#N/A
100	2.939	3.646	3.601	3.794	3.789
200	3.466	4.424	4.386	4.677	4.621
500	4.306	5.704	5.692	6.168	#N/A
1000	5.074	6.908	6.933	7.607	7.570

Growth Curve estimates for site E1 (using general logistic):

RP	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	FEH RR1999, 5.7 hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.382	1.485	1.485	1.501	1.433
10	1.672	1.867	1.867	1.904	1.774
20	1.993	2.302	2.302	2.370	#N/A
25	2.105	2.457	2.458	2.538	2.563
30	2.201	2.591	2.591	2.683	#N/A
50	2.49	2.998	3.000	3.129	3.245
75	2.744	3.363	3.364	3.531	#N/A
100	2.939	3.646	3.648	3.846	3.950
200	3.466	4.424	4.428	4.720	4.839
500	4.306	5.704	5.711	6.181	#N/A
1000	5.074	6.908	6.918	7.578	7.997

Growth Curve estimates for site D2 (using general logistic):

RP	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	FEH RR1999, 6.9hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.383	1.457	1.456	1.448	1.468
10	1.673	1.793	1.791	1.780	1.779
20	1.994	2.155	2.153	2.143	N/A
25	2.107	2.280	2.278	2.269	2.380
30	2.203	2.386	2.384	2.376	N/A

50	2.493	2.703	2.701	2.697	2.890
75	2.748	2.977	2.975	2.977	N/A
100	2.943	3.185	3.183	3.191	3.399
200	3.471	3.738	3.736	3.761	4.023
500	4.313	4.599	4.598	4.657	N/A
1000	5.083	5.366	5.367	5.465	6.136

Growth Curve estimates for site E2 (using general logistic):
Please note that Tp was adjusted for E2 as described in section 3.3

RP	GF- unreviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Rural	GF-reviewed PG without permeable adj. Urban adjustment	GF-reviewed PG with permeable adj. Urban adjustment	FEH RR1999, 1.7hrs storm duration, summer profile, 2015 URBEXT$_{1990}$
2	1.000	1.000	1.000	1.000	1.000
5	1.383	1.457	1.391	1.383	1.284
10	1.673	1.793	1.693	1.681	1.573
20	1.994	2.155	2.032	2.020	N/A
25	2.107	2.280	2.152	2.140	2.038
30	2.203	2.386	2.255	2.243	N/A
50	2.493	2.703	2.566	2.558	2.469
75	2.748	2.977	2.842	2.838	N/A
100	2.943	3.185	3.054	3.055	3.123
200	3.471	3.738	3.634	3.650	3.906
500	4.313	4.599	4.572	4.621	N/A
1000	5.083	5.366	5.440	5.530	6.558

3.6 Flood estimates from the statistical method

Site code	Method	Flood peak (m^3/s) for the following return periods (in years)								
		2	**5**	**10**	**20**	**50**	**75**	**100**	**200**	**1000**
		CD-Qmed								
E1	P	0.28	0.42	0.54	0.67	0.88	1.00	1.08	1.33	2.14
E2	P	0.36	0.50	0.60	0.73	0.92	1.02	1.10	1.31	1.99
D1	P	0.19	0.29	0.36	0.45	0.60	0.68	0.74	0.91	1.48
D2	P	0.18	0.26	0.32	0.38	0.48	0.53	0.57	0.67	0.97
		CD-Qmed with donor adjustment								
E1	P	0.29	0.44	0.55	0.69	0.91	1.03	1.12	1.38	2.21
E2	P	0.37	0.51	0.62	0.75	0.95	1.05	1.13	1.35	2.05
D1	P	0.20	0.30	0.38	0.47	0.62	0.70	0.76	0.94	1.53
D2	P	0.18	0.27	0.33	0.39	0.50	0.55	0.59	0.69	1.00

4 FEH rainfall-runoff method

4.1 Parameters for FEH rainfall-runoff model

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

Site code	**Method:** OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	**Tp (hours)** Time to peak	**C_{max} (mm)** Maximum storage capacity	**BL (hours)** Baseflow lag	**BR** Baseflow recharge
N/A	N/A	N/A	N/A	N/A	N/A
Brief description of any flood event analysis carried out (further details should be given below or in a project report)					

The ReFH method has not been tested as part of this hydrological analysis as not suitable for the purpose of the study (relatively long duration simulations may be required). The FEH approach has been used instead (please see Section 1.8, Initial choice of approach).

The parameters for the FEH unit have been estimated from catchment descriptors for catchments D1, D2 and E1. For catchment E1, Tp was multiplied by 1.6 to obtain results closer to the FEH statistical estimate of Qmed. This reconciliation with the FEH statistical estimate is considered reasonable as the Tp adjustment is within the uncertainty of the Tp regression equation (factorial standard error = 1.85) and gives a Qmed estimate within the FEH statistical estimate 95% confidence interval (please refer to section 3.3).

Site code	**Method:** OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	**Tp (hours)** Time to peak	**C_{max} (mm)** Maximum storage capacity	**BL (hours)** Baseflow lag	**BR** Baseflow recharge
E2		Multiplied by 1.6			
Brief description of any flood event analysis carried out (further details should be given below or in a project report)					

4.2 Design events for ReFH method

Site code	**Urban or rural**	**Season of design event (summer or winter)**	**Storm duration (hours)**	**Storm area for ARF** (if not catchment area)
N/A	N/A	N/A	N/A	N/A
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?				

Parameters used for the FEH units are reported in the table below:

Site code	**Urban or rural**	**Season of design event (summer or winter)**	**Storm duration (hours)**	**Storm area for ARF (if not catchment area)**
E1	-	Summer	5.7	
E2	-	Summer	1.7	
D1	-	Summer	3.8	
D2	-	Summer	6.9	

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			Yes – tide locking of channel outfall may be significant.	

4.3 Flood estimates from the FEH rainfall-runoff method

Flood estimates from FEH method:

Site code	Flood peak (m^3/s) for the following return periods (in years)								
	2 (2.33 year)	5	10	25	50	100	200	1000	
E1	0.32	0.46	0.57	0.83	1.05	1.28	1.56	2.58	
E2	0.74	0.95	1.16	1.50	1.82	2.30	2.88	4.83	
D1	0.26	0.38	0.46	0.63	0.80	0.97	1.18	1.94	
D2	0.31	0.45	0.56	0.73	0.89	1.05	1.24	1.89	

5 Discussion and summary of results

5.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code		Ratio of peak flow to FEH Statistical peak					
	Return period 2 years				Return period 100 years		
	FEH statistical	FEH RR1999		Other method	FEH statistical	FEH RR1999	Other method
E1	0.29	0.32			1.12	1.28	
E2 (Tp multiplied by 1.6)	0.37	0.74			1.13	2.30	
D1	0.20	0.26			0.76	0.97	
D2	0.18	0.31			0.59	1.05	

5.2 Final choice of method

<table>
<tr>
<td>Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.</td>
<td>The final FFC selected for the site is the FEH RR1999 approach. The method as been chosen for the following reason:
• For this study design event volume may be important in the assessment of flood risk as there is potential for tide locking of flood flows. The final choice of method is therefore the FEH RR1999 method as this will provide inflow hydrographs with realistic volumes (design rainfall volumes with losses applied according to the rainfall runoff models) and peak flows generally higher than but within the uncertainty of the statistical estimates.
• The flood growth factors of the FEH rainfall runoff method are consistent with those derived by the statistical analysis pooled growth curves.</td>
</tr>
</table>

5.3 Assumptions, limitations and uncertainty

<table>
<tr>
<td>List the main assumptions made (specific to this study)</td>
<td>It is assumed that the FEH method can be used to derive hydrograph shape at the subject location.</td>
</tr>
<tr>
<td>Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed</td>
<td>Given the high BFIHOST of the catchment and the importance of flood volumes the ReFH method was not tested.
The catchments analysed are small and are permeable. Pooling group cumulative number of years was reduced to approx. 300years as using the 500 station-year PG may introduce sites that may not be representative of the site.</td>
</tr>
<tr>
<td>Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH **3** 12.5 or the factorial standard error from Science Report SC050050 (2008).</td>
<td>Estimates for Qmed and confidence limits for Qmed from CD catchment descriptors are indicated below:
<table>
<tr><th>Site</th><th>Qmed from RR1999 (cumecs)</th><th>CD Qmed (cumecs)</th><th>CD descriptors-Donor Adjustment (cumecs)</th><th>95% confidence interval on CD estimate</th><th>95% confidence interval on CD estimate</th></tr>
<tr><td>E1</td><td>0.32</td><td>0.28</td><td>0.29</td><td>0.14</td><td>0.60</td></tr>
<tr><td>E2</td><td>0.74</td><td>0.36</td><td>0.37</td><td>0.18</td><td>0.76</td></tr>
<tr><td>D1</td><td>0.26</td><td>0.19</td><td>0.20</td><td>0.10</td><td>0.41</td></tr>
<tr><td>D2</td><td>0.31</td><td>0.18</td><td>0.18</td><td>0.09</td><td>0.38</td></tr>
</table>
</td>
</tr>
<tr>
<td>Comment on the suitability of the</td>
<td>The analysis carried out is based on the latest methodology and</td>
</tr>
</table>

results for future studies, e.g. at nearby locations or for different purposes.	AMAX data available at this time. Future studies should consider whether there have been improvements in methodology or significant additional data since this time. The results have been developed for a particular purpose and should be reviewed for suitability before applying for other purposes.
Give any other comments on the study, for example suggestions for additional work.	Further information to improve confidence in the flow estimates in the subject area would be beneficial (e.g. spot gaugings in the subject area).

5.4 Checks

<table>
<tr><td>Are the results consistent, for example at confluences?</td><td>N/A</td></tr>
<tr><td>What do the results imply regarding the return periods of floods during the period of record?</td><td>N/A</td></tr>
<tr><td>What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)</td><td>All sites are within realistic range:
E1: 3.95
E2: 3.12
D1: 3.79
D2: 3.40</td></tr>
<tr><td>If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?</td><td>E1: 2.02
E2: 2.10
D1: 2.00
D2: 1.81</td></tr>
<tr><td>What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?</td><td>For the final choice flood frequency curve, the specific runoff flows (l/s/ha) are:
<table>
<tr><th>RP (years)</th><th>E1 (l/s/ha)</th><th>E2 (l/s/ha)</th><th>D1 (l/s/ha)</th><th>D2 (l/s/ha)</th></tr>
<tr><td>2.33</td><td>1.9</td><td>8.9</td><td>2.9</td><td>3.9</td></tr>
<tr><td>5</td><td>2.7</td><td>11.5</td><td>4.3</td><td>5.7</td></tr>
<tr><td>10</td><td>3.3</td><td>14.1</td><td>5.2</td><td>7.0</td></tr>
<tr><td>25</td><td>4.8</td><td>18.2</td><td>7.1</td><td>9.3</td></tr>
<tr><td>50</td><td>6.1</td><td>22.1</td><td>9.0</td><td>11.3</td></tr>
<tr><td>100</td><td>7.4</td><td>27.9</td><td>10.1</td><td>13.3</td></tr>
<tr><td>200</td><td>9.0</td><td>34.9</td><td>13.3</td><td>15.8</td></tr>
<tr><td>1000</td><td>14.9</td><td>58.6</td><td>21.8</td><td>24.0</td></tr>
</table></td></tr>
<tr><td>How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.</td><td>No previous studies are available.</td></tr>
<tr><td>Are the results compatible with the longer-term flood history?</td><td>There is no available long term flood history.</td></tr>
<tr><td>Describe any other checks on the results</td><td>Subsequent hydraulic model results will be reviewed by the EA.</td></tr>
</table>

5.5 Final results

Return Period (T) (years)	E1 FFC (cumecs) FEH, SD 5.7hrs summer profile	E2 FFC (cumecs) FEH, SD 1.7hrs summer profile, Tp multiplied by 1.6	D1 FFC (cumecs) FEH, SD 3.8hrs summer profile	D2 FFC (cumecs) FEH, SD 6.9hrs summer profile
2.33	0.32	0.74	0.26	0.31

5	0.46	0.95	0.38	0.45
10	0.57	1.16	0.46	0.55
25	0.83	1.50	0.63	0.73
50	1.05	1.82	0.80	0.89
100	1.28	2.30	0.97	1.05
200	1.56	2.88	1.18	1.24
1000	2.58	4.83	1.94	1.89

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	-

6 Annex - supporting information

6.1 Pooling group composition

D2 PG

Station	Years of data
27073 (Brompton Beck @ Snainton Ings)	32
45816 (Haddeo @ Upton)	19
28033 (Dove @ Hollinsclough)	33
47022 (Tory Brook @ Newnham Park)	19
25019 (Leven @ Easby)	34
26802 (Gypsey Race @ Kirby Grindalythe)	13
203046 (Rathmore Burn @ Rathmore Bridge)	30
20002 (West Peffer Burn @ Luffness)	41
44008 (South Winterbourne @ Winterbourne Steepleton)	33
72014 (Conder @ Galgate)	45
51002 (Horner Water @ West Luccombe)	19
Total	318

D1 PG

Station	**Years of data**
45816 (Haddeo @ Upton)	19
28033 (Dove @ Hollinsclough)	33
91802 (Allt Leachdach @ Intake)	34
47022 (Tory Brook @ Newnham Park)	19
27073 (Brompton Beck @ Snainton Ings)	32
25019 (Leven @ Easby)	34
26802 (Gypsey Race @ Kirby Grindalythe)	13
44008 (South Winterbourne @ Winterbourne Steepleton)	33
51002 (Horner Water @ West Luccombe)	19
48004 (Warleggan @ Trengoffe)	43
Total	279

Flood maps

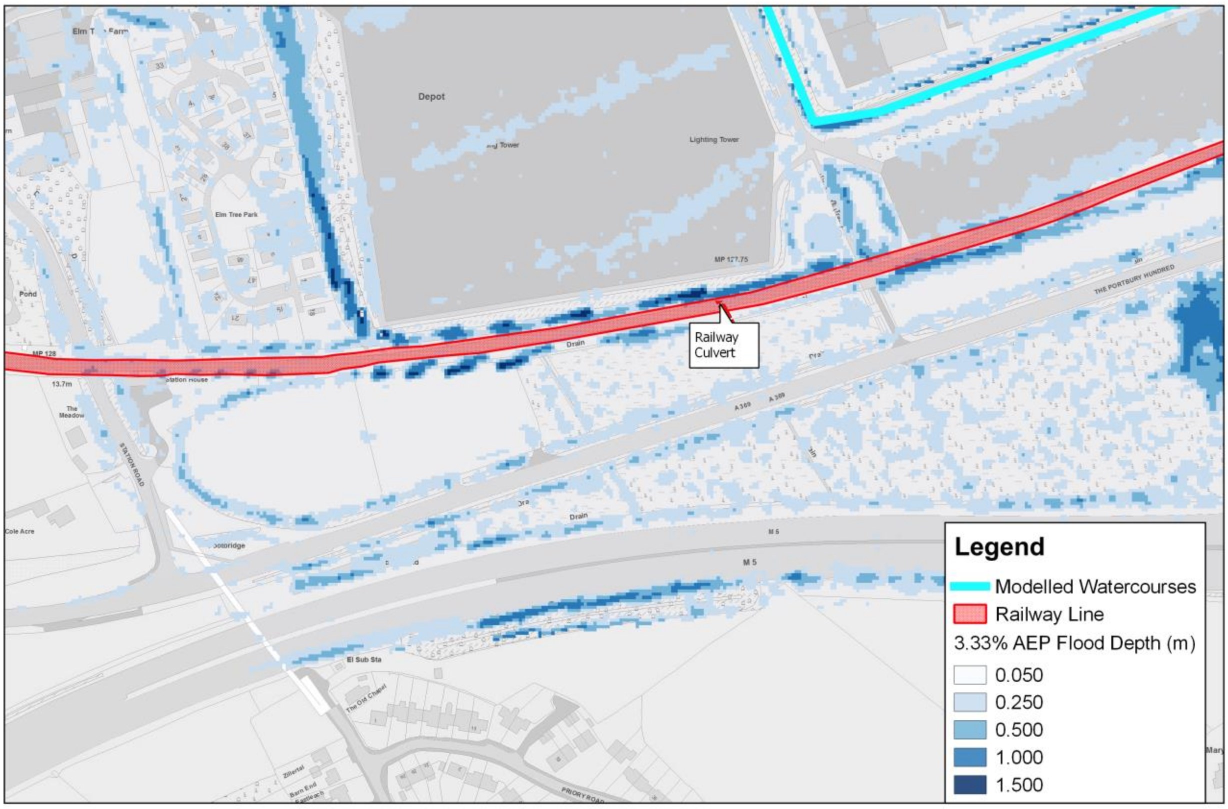


Figure K-1: Drove Rhyne 30 year return period- 1

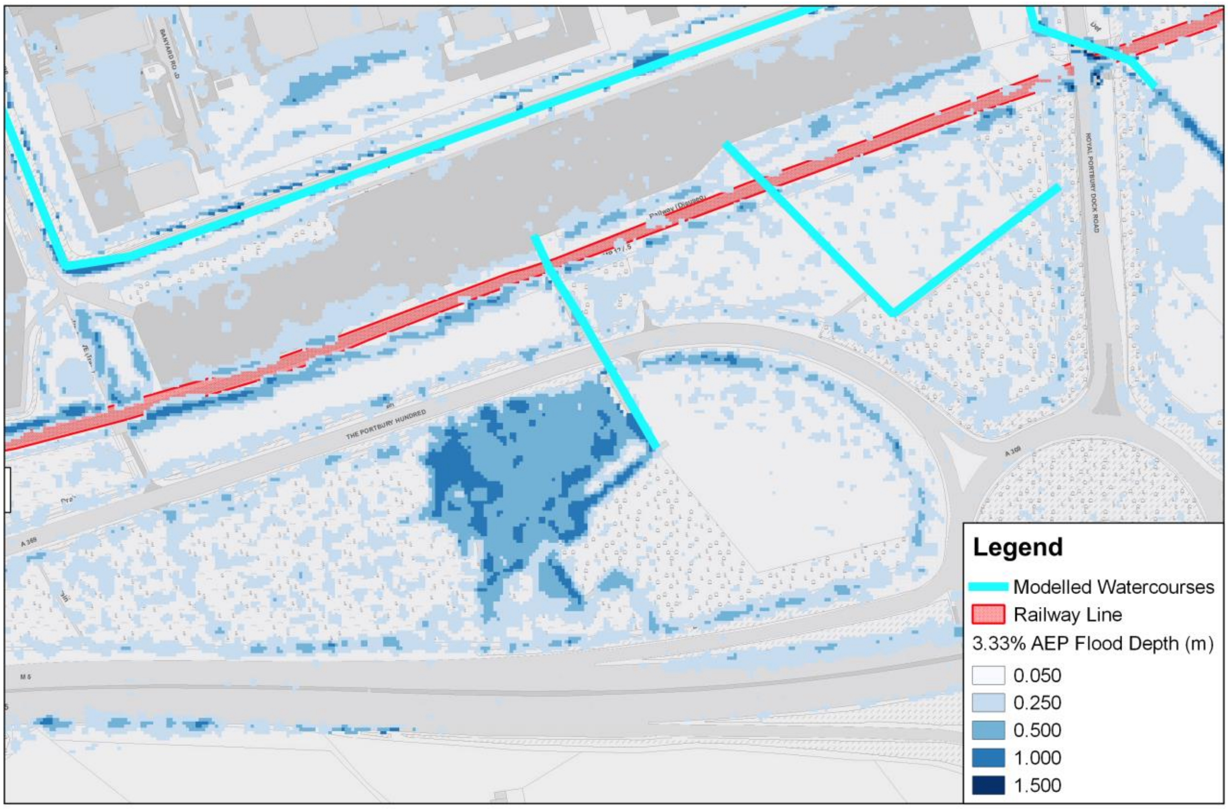


Figure K-2: Drove Rhyne 30 year return period- 2

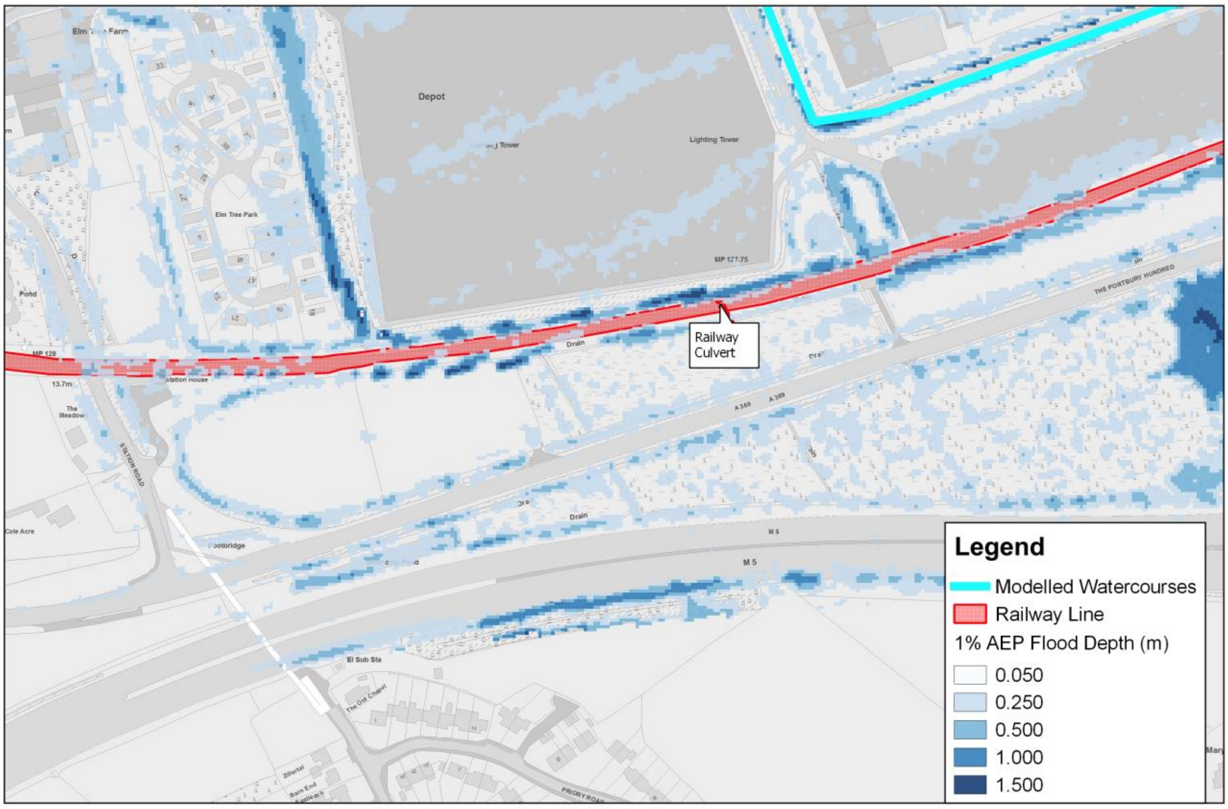


Figure K-3: Drove Rhyne 100 year return period- 1

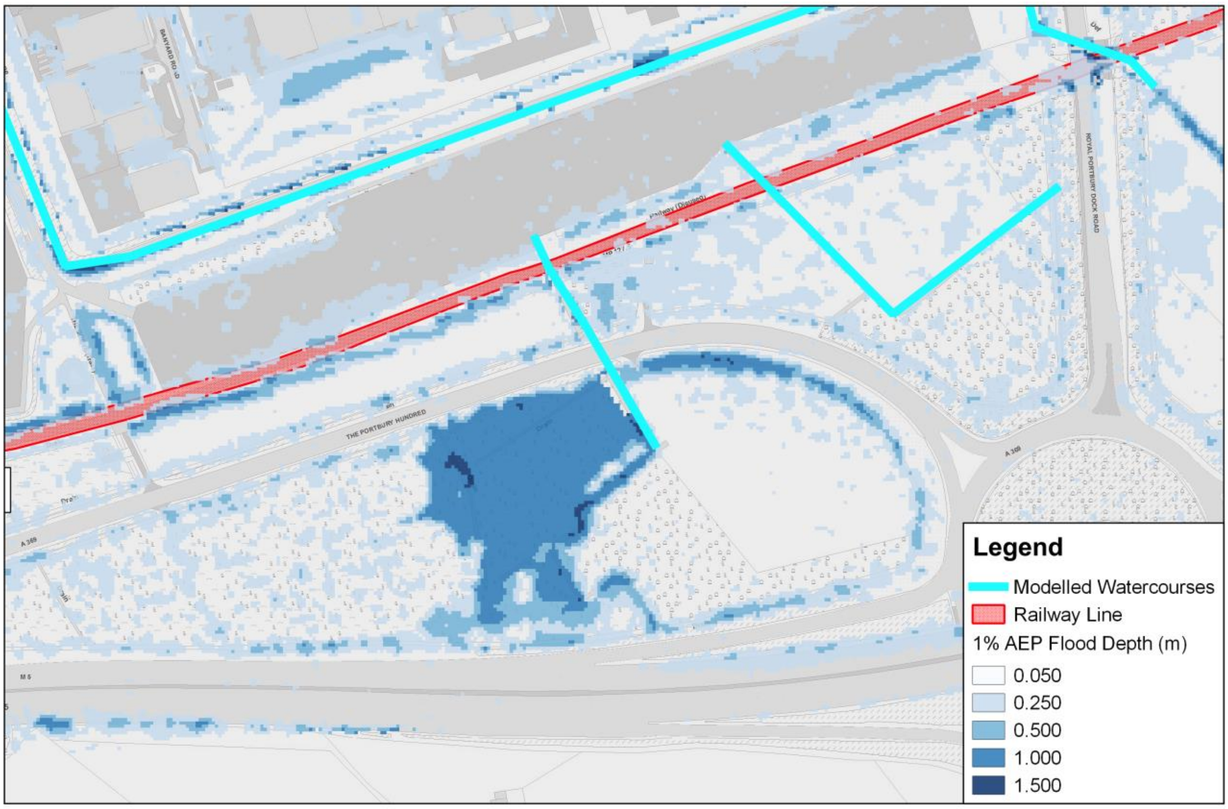


Figure K-4: Drove Rhyne 100 year return period- 2

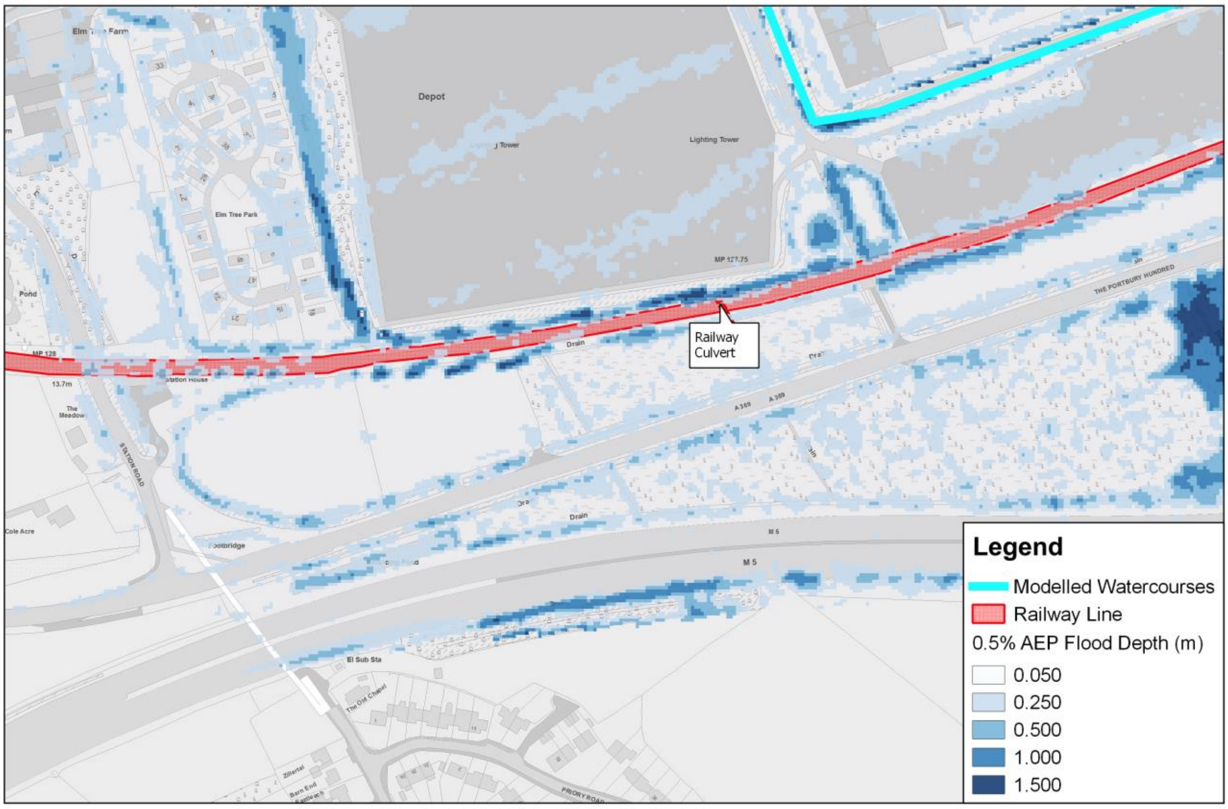


Figure K-5: Drove Rhyne 200 year return period- 1

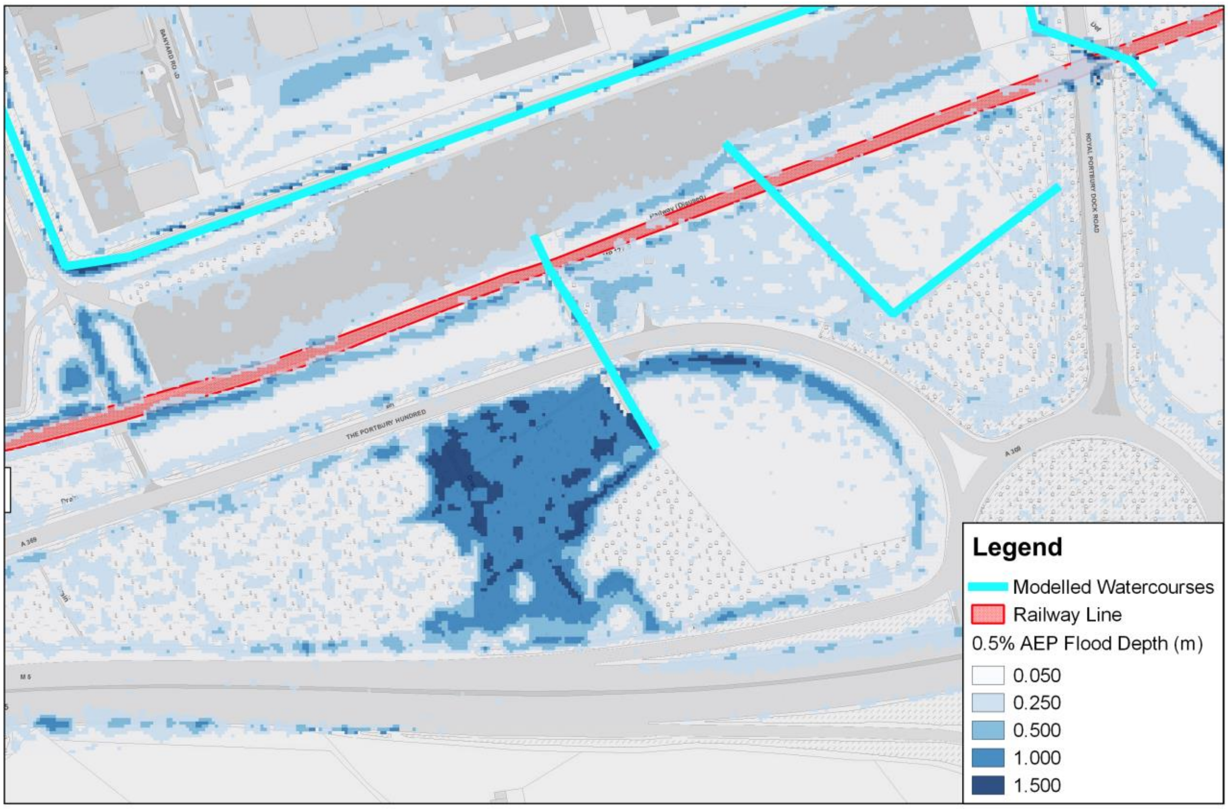


Figure K-6: Drove Rhyne 200 year return period- 2

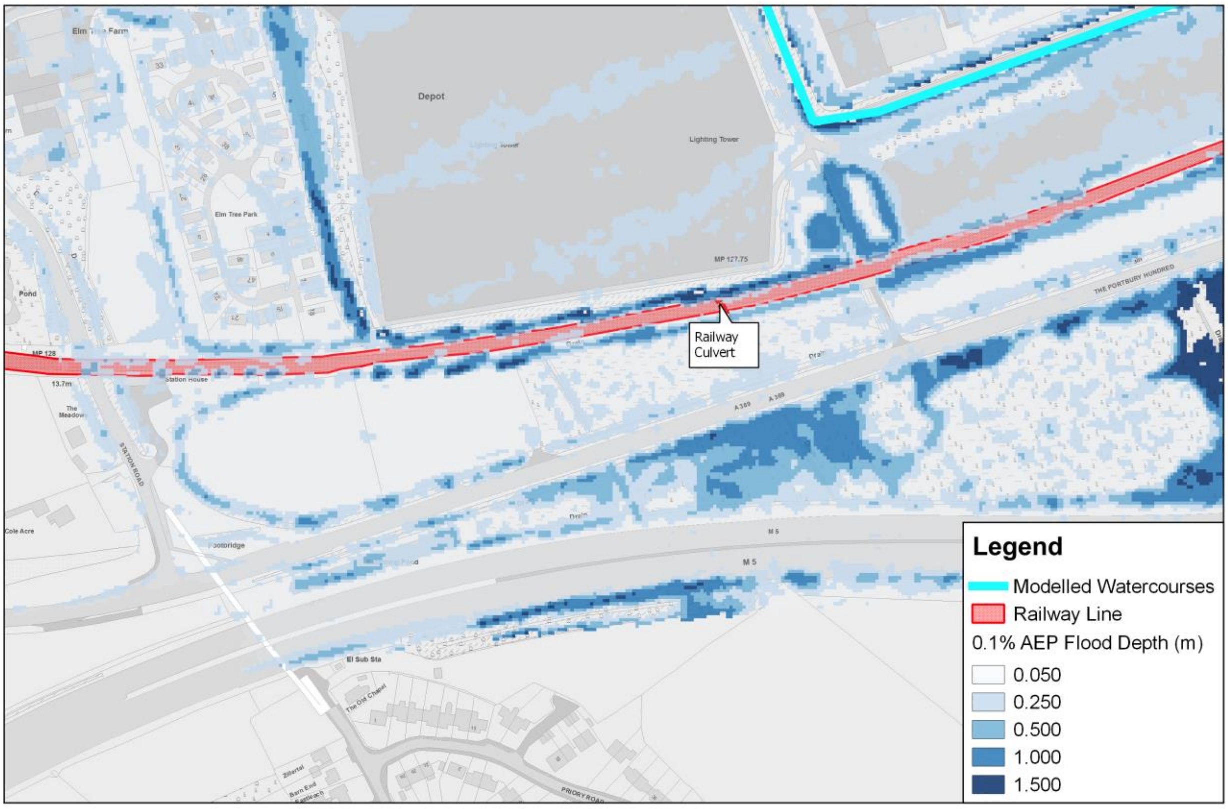


Figure K-7: Drove Rhyne 1000 year return period- 1

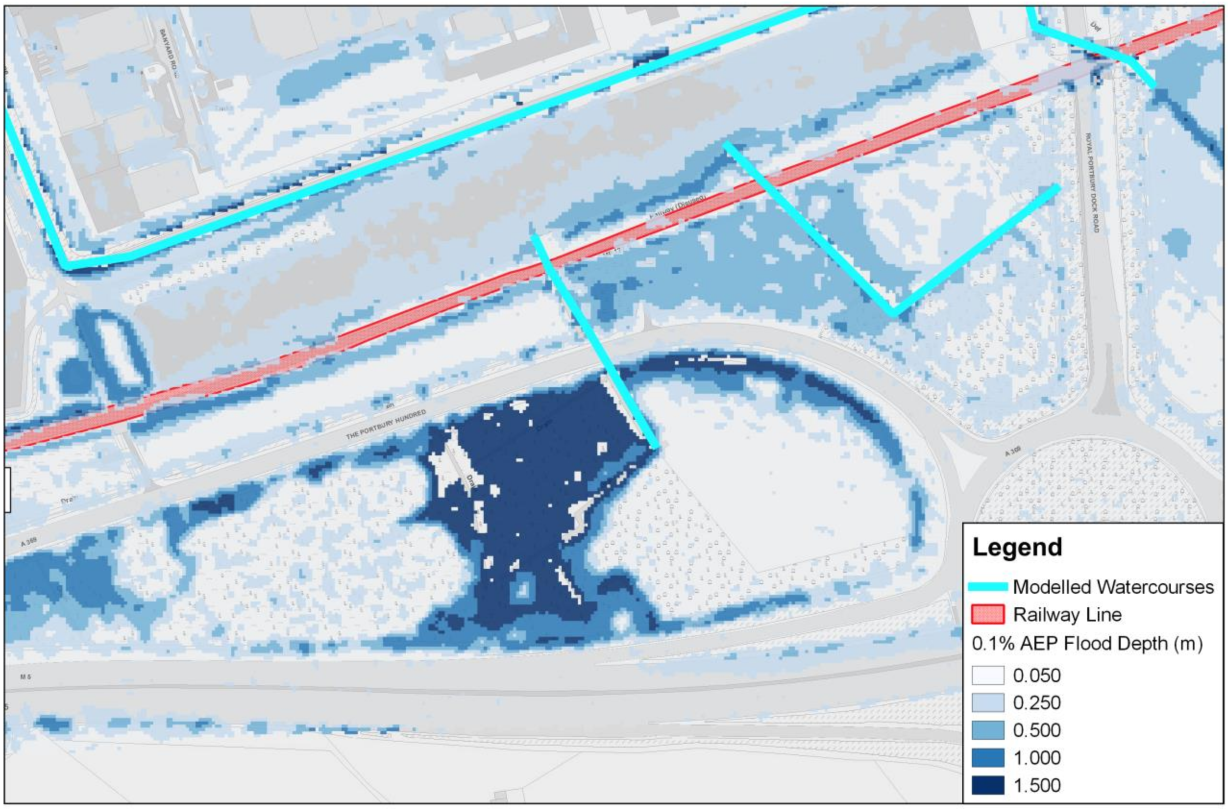


Figure K-8: Drove Rhyne 1000 year return period- 2

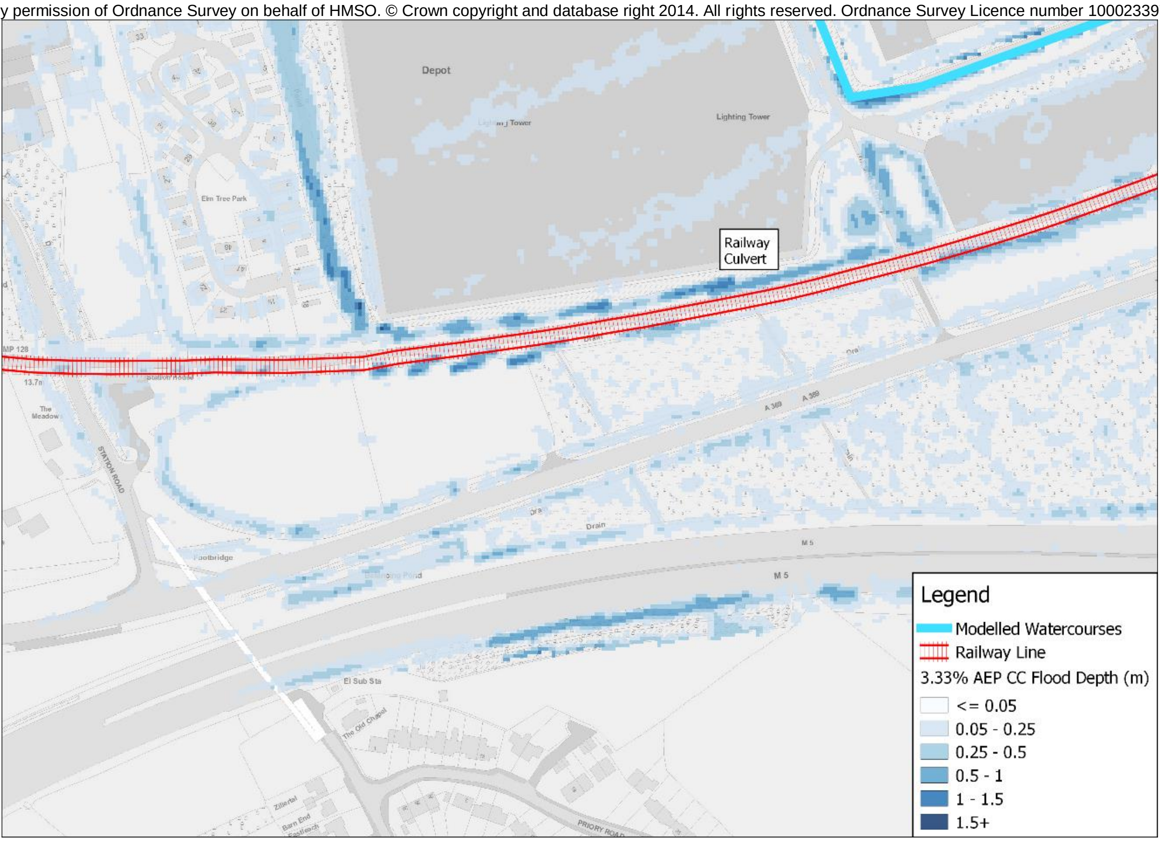


Figure K-9: Drove Rhyne 30 year return period, 2115 - 1

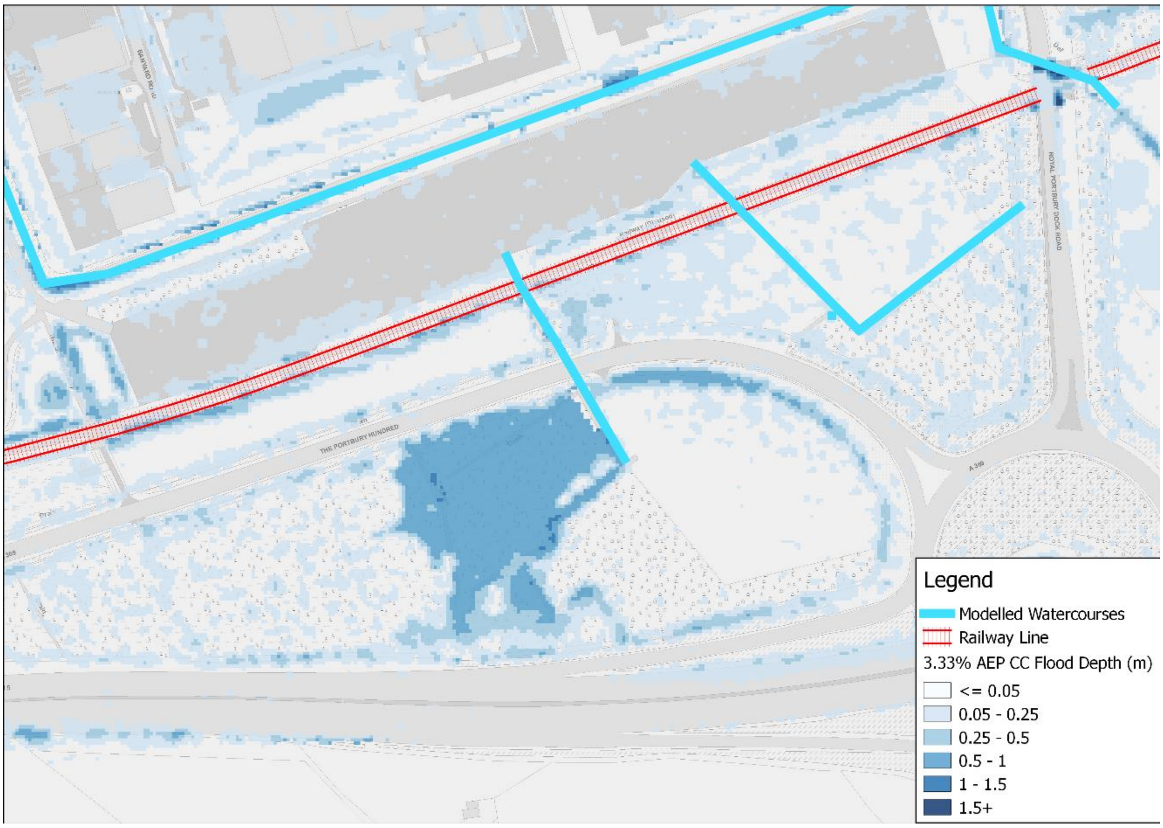


Figure K-10: Drove Rhyne 30 year return period, 2115 - 2

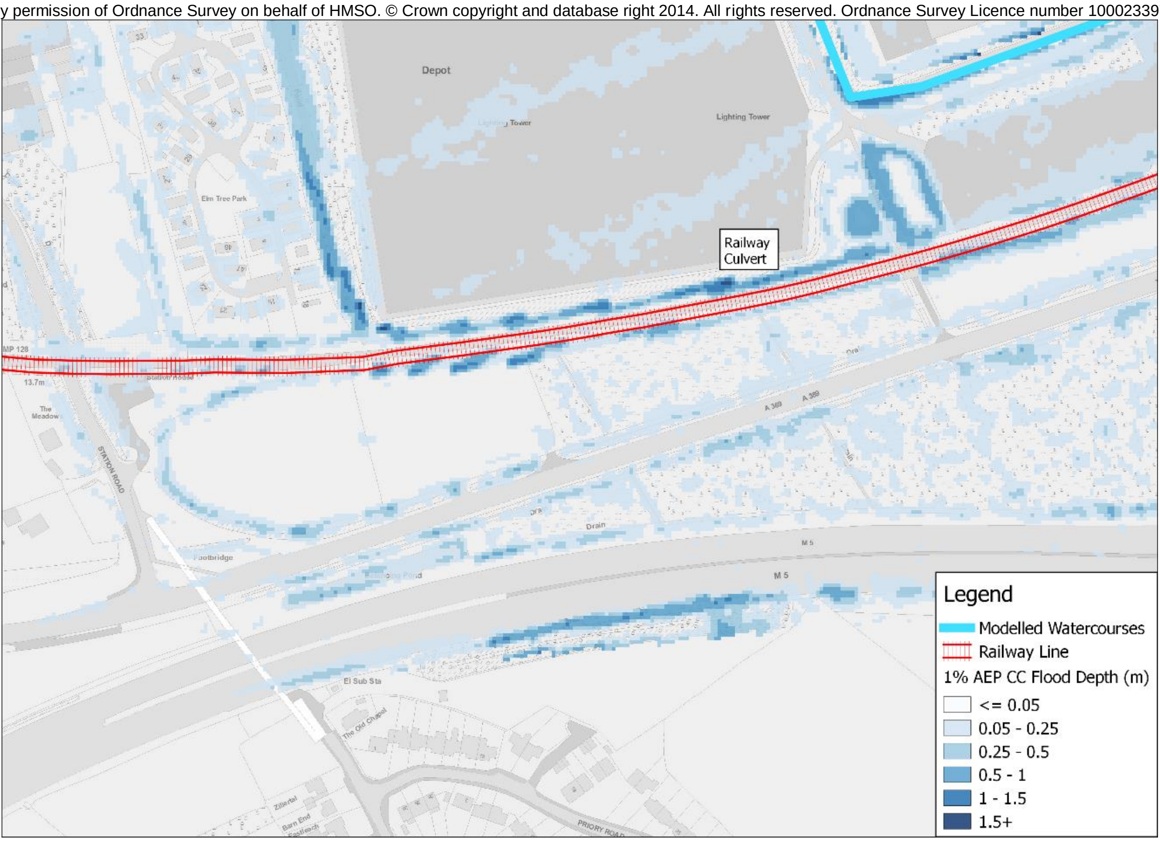


Figure K-11: Drove Rhyne 100 year return period, 2115 - 1

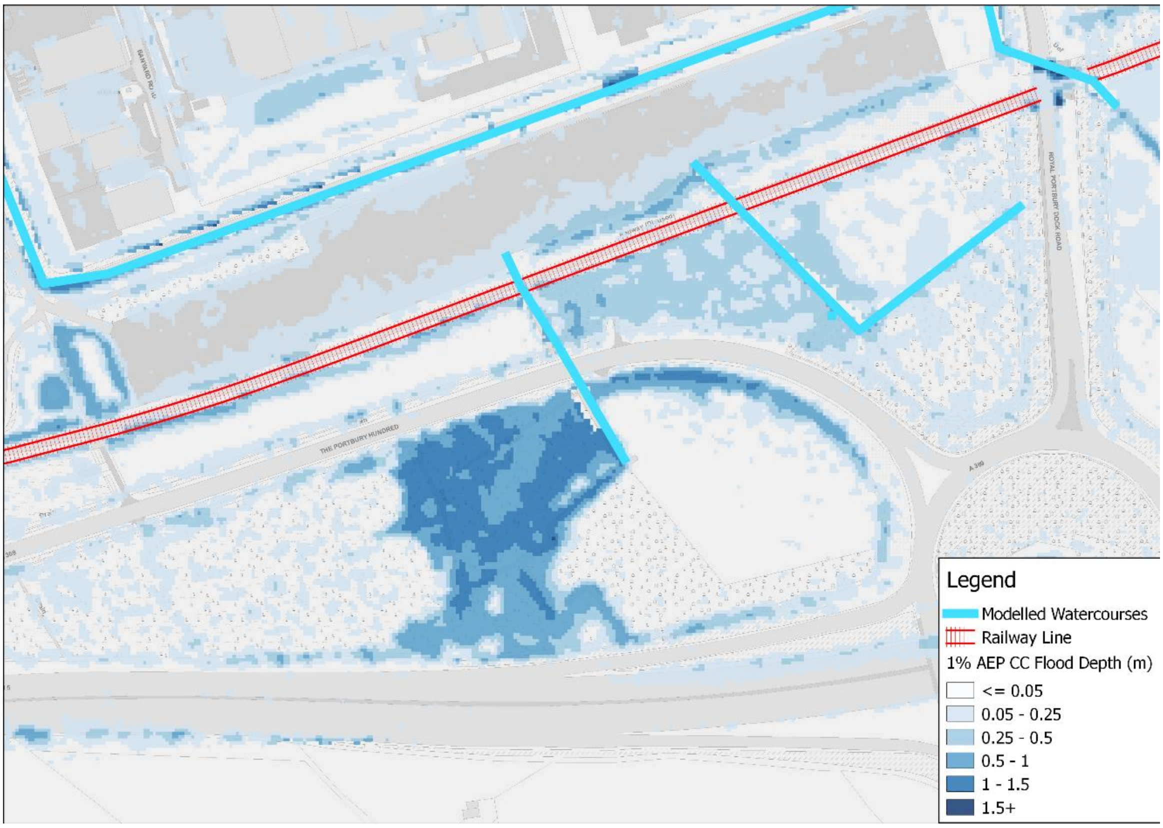


Figure K-12: Drove Rhyne 100 year return period, 2115 - 2

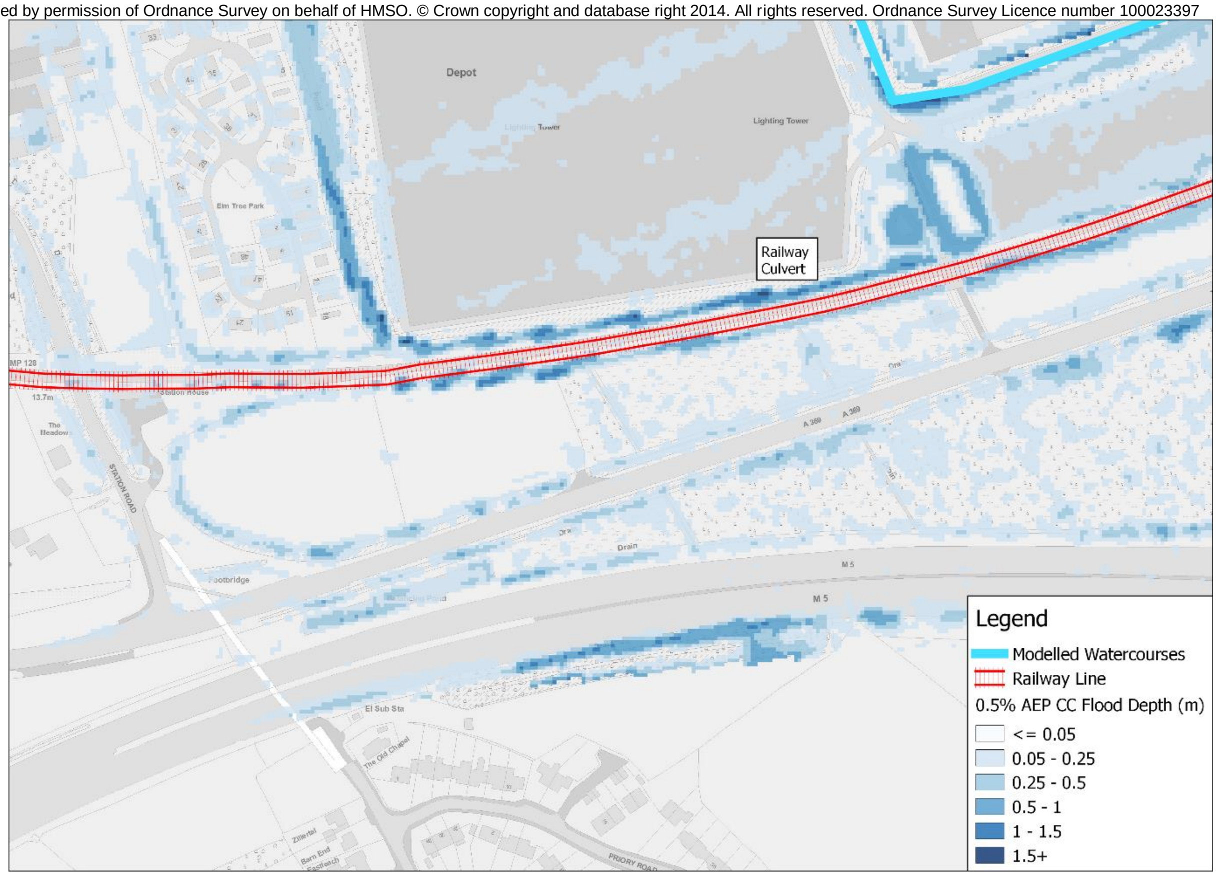


Figure K-13: Drove Rhyne 200 year return period, 2115 - 1

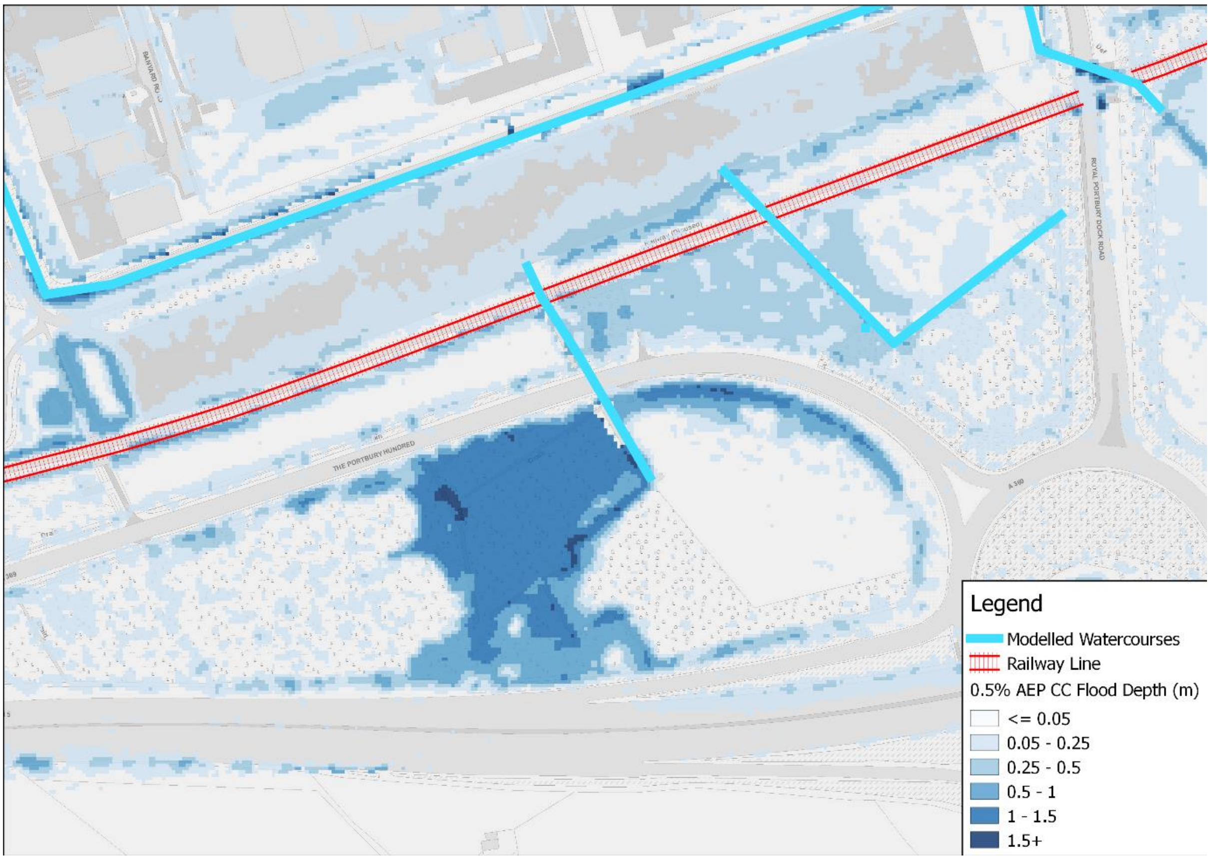


Figure K-14: Drove Rhyne 200 year return period, 2115 - 2

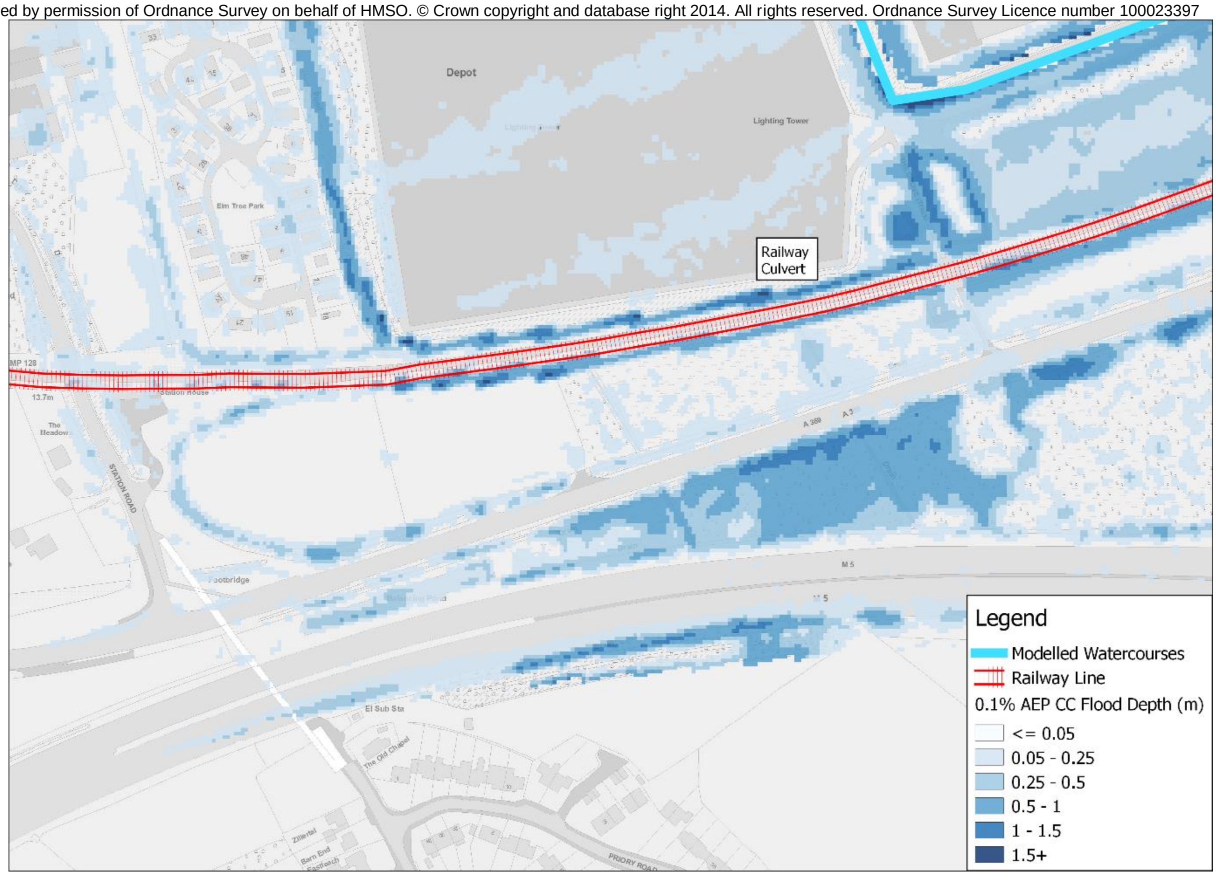


Figure K-15: Drove Rhyne 1000 year return period, 2115 - 1

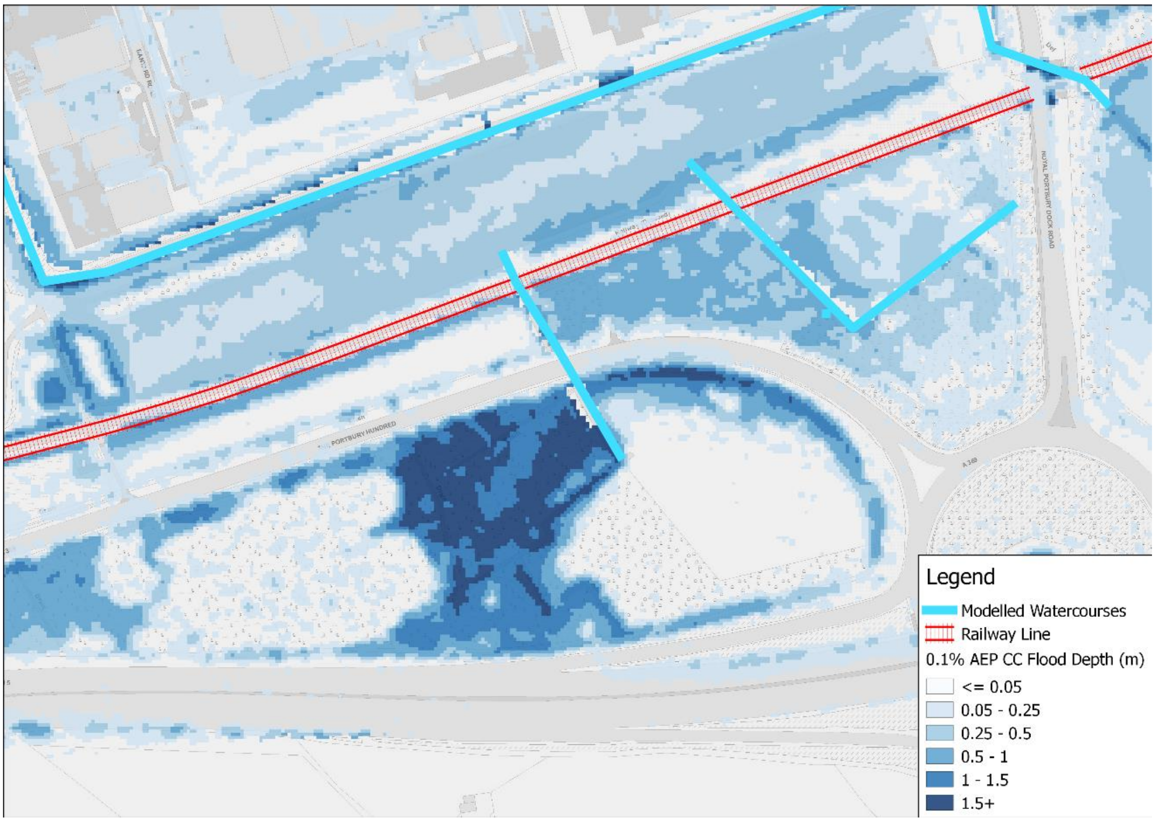


Figure K-16: Drove Rhyne 1000 year return period, 2115 - 2

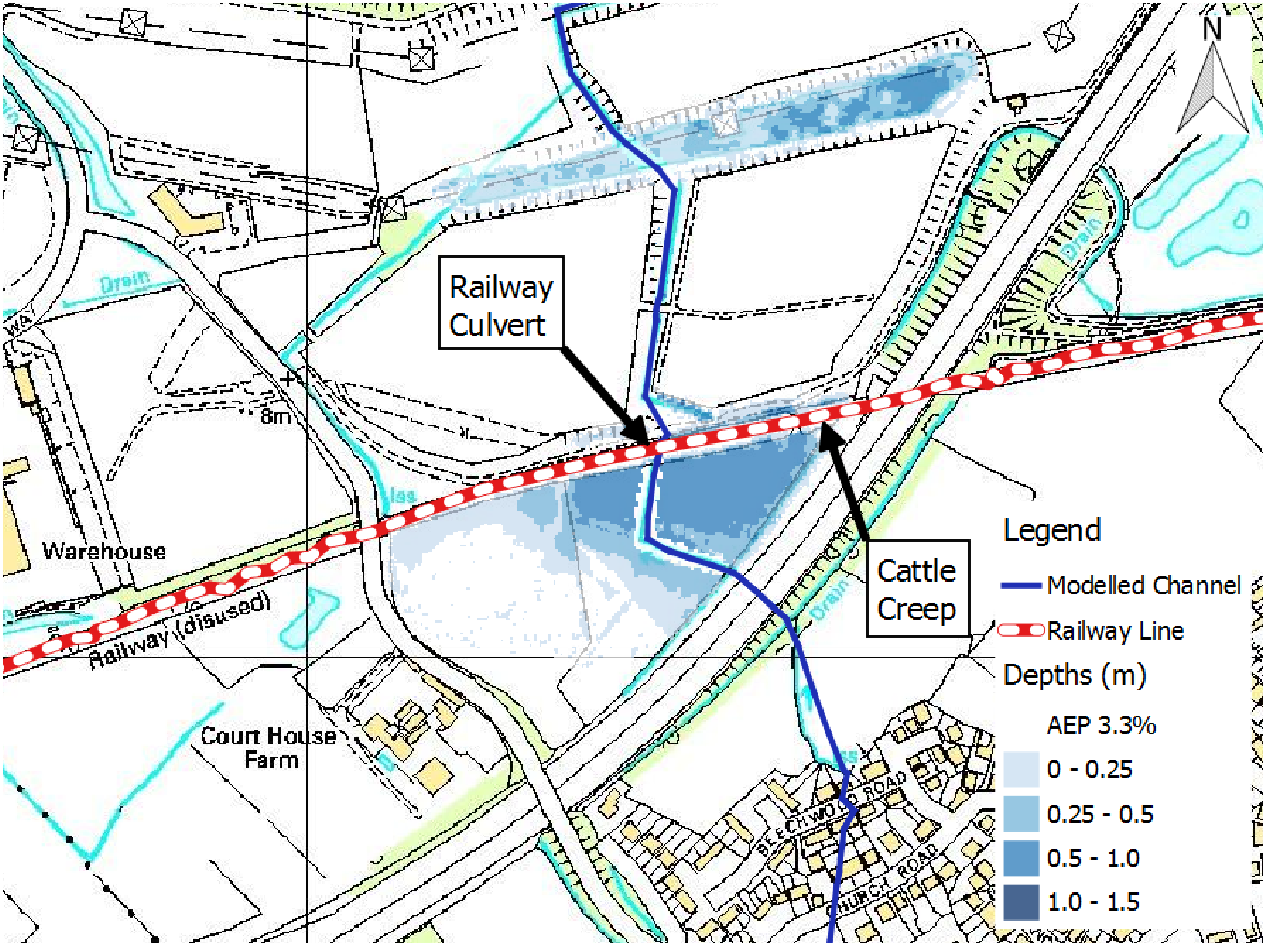


Figure K-101: Easton-in-Gordano - Fluvial event - 30 year return period – Depths in 2D Model Domain

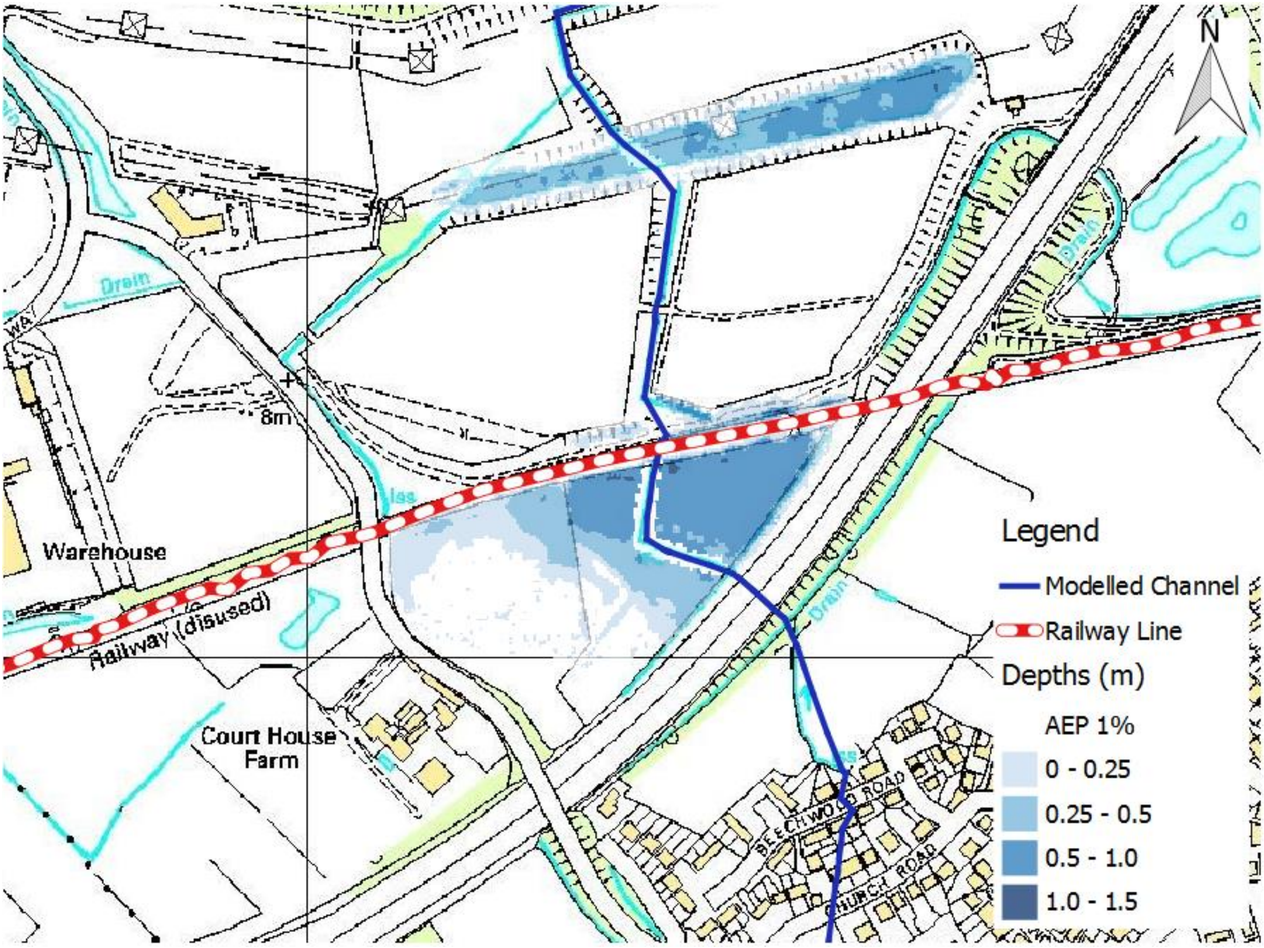


Figure K-102: Easton-in-Gordano - Fluvial event - 100 year return period – Depths in 2D Model Domain

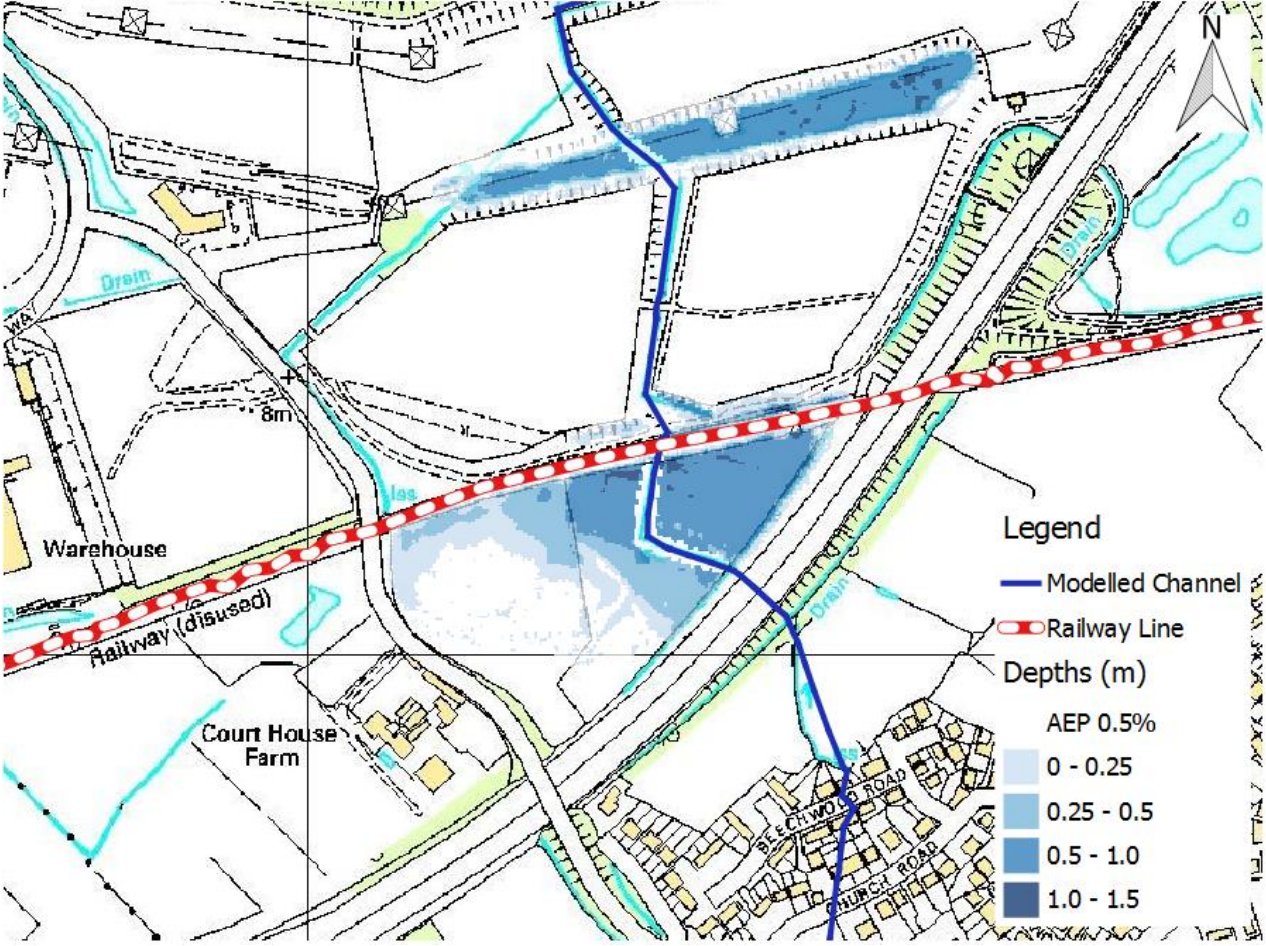


Figure K-103: Easton-in-Gordano - Fluvial event - 200 year return period – Depths in 2D Model Domain

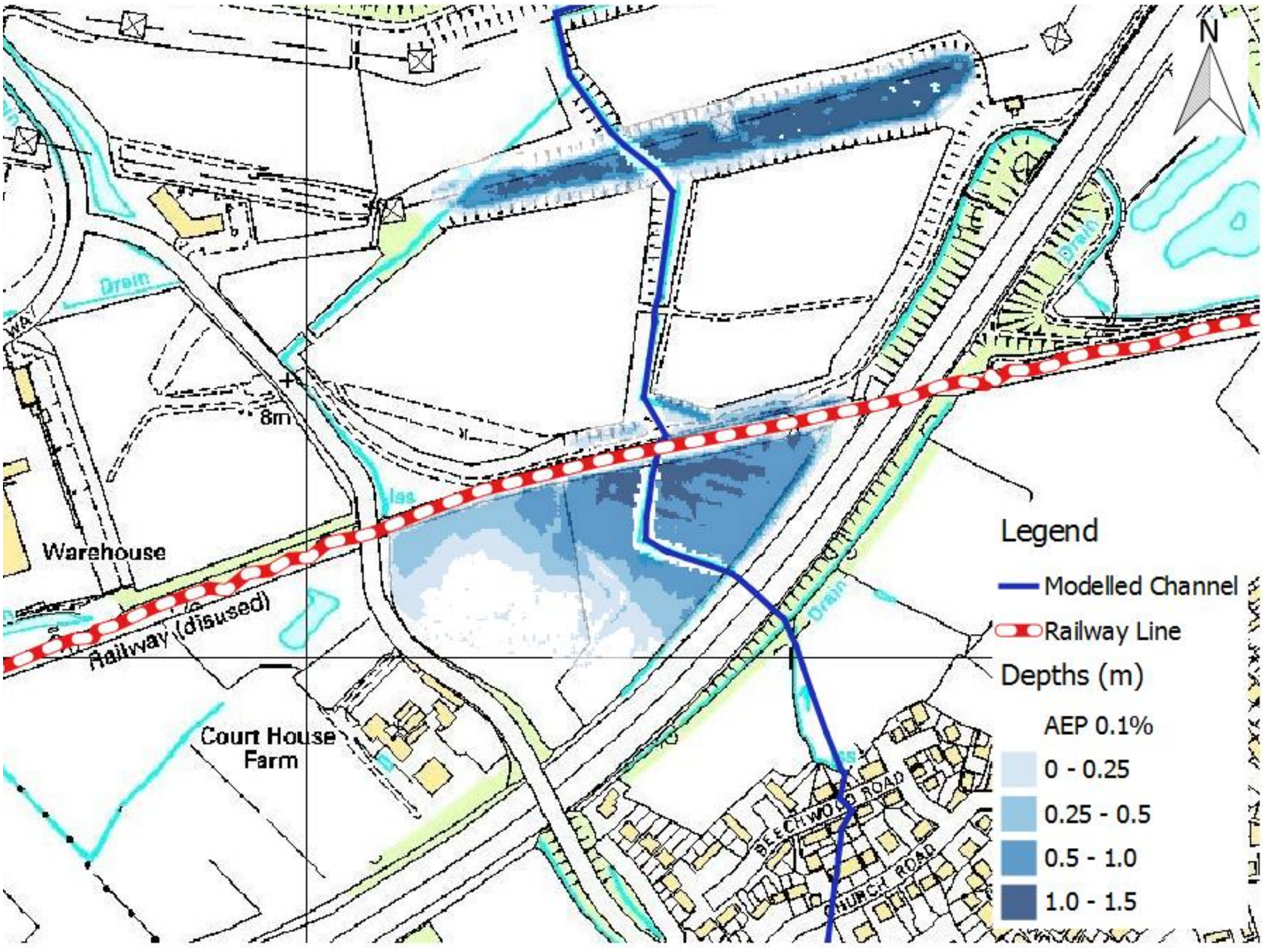


Figure K-104: Easton-in-Gordano - Fluvial event - 1000 year return period – Depths in 2D Model Domain

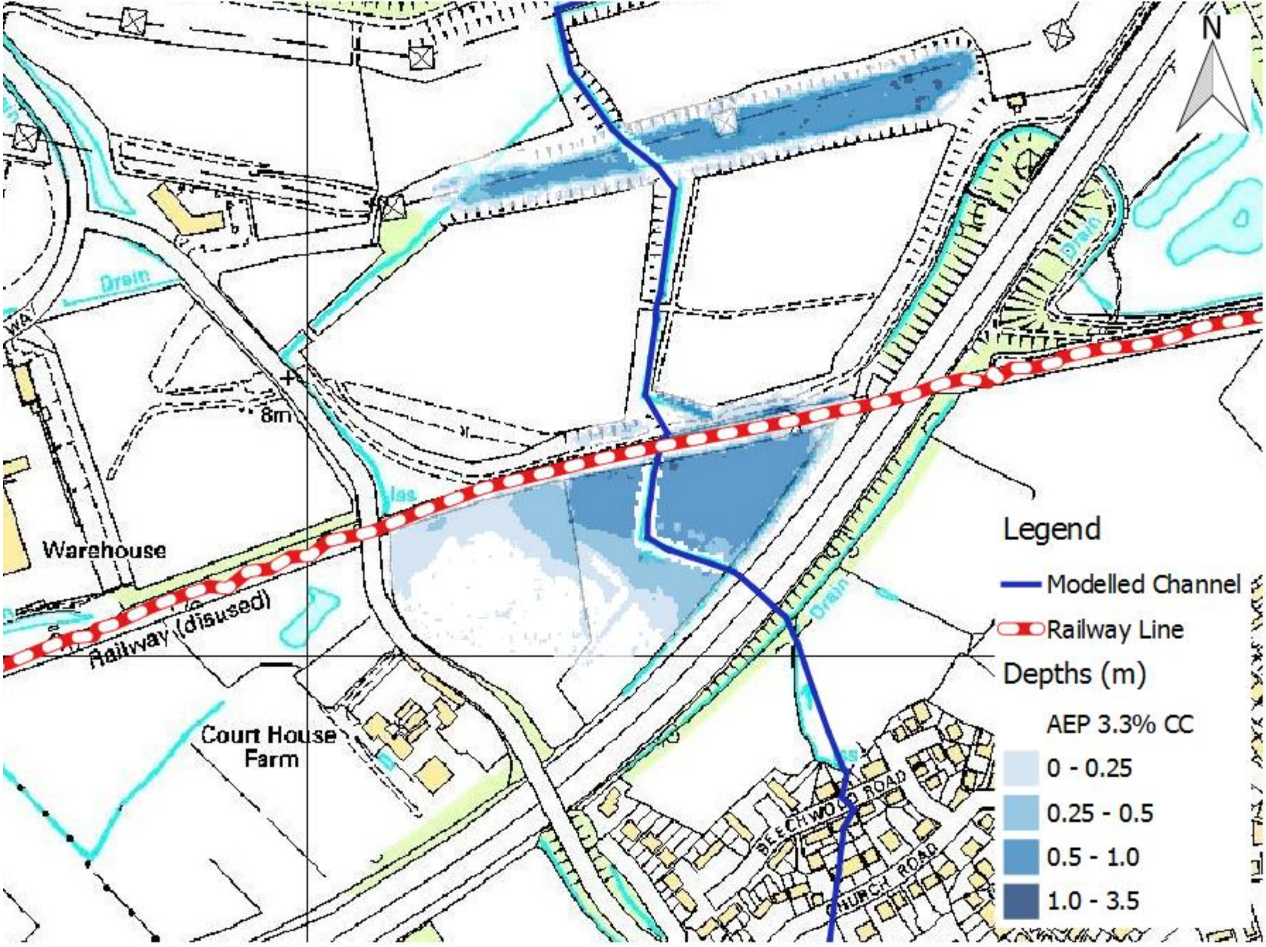


Figure K-105: Easton-in-Gordano - Fluvial event - 30 year return period, 2115 – Depths in 2D Model Domain

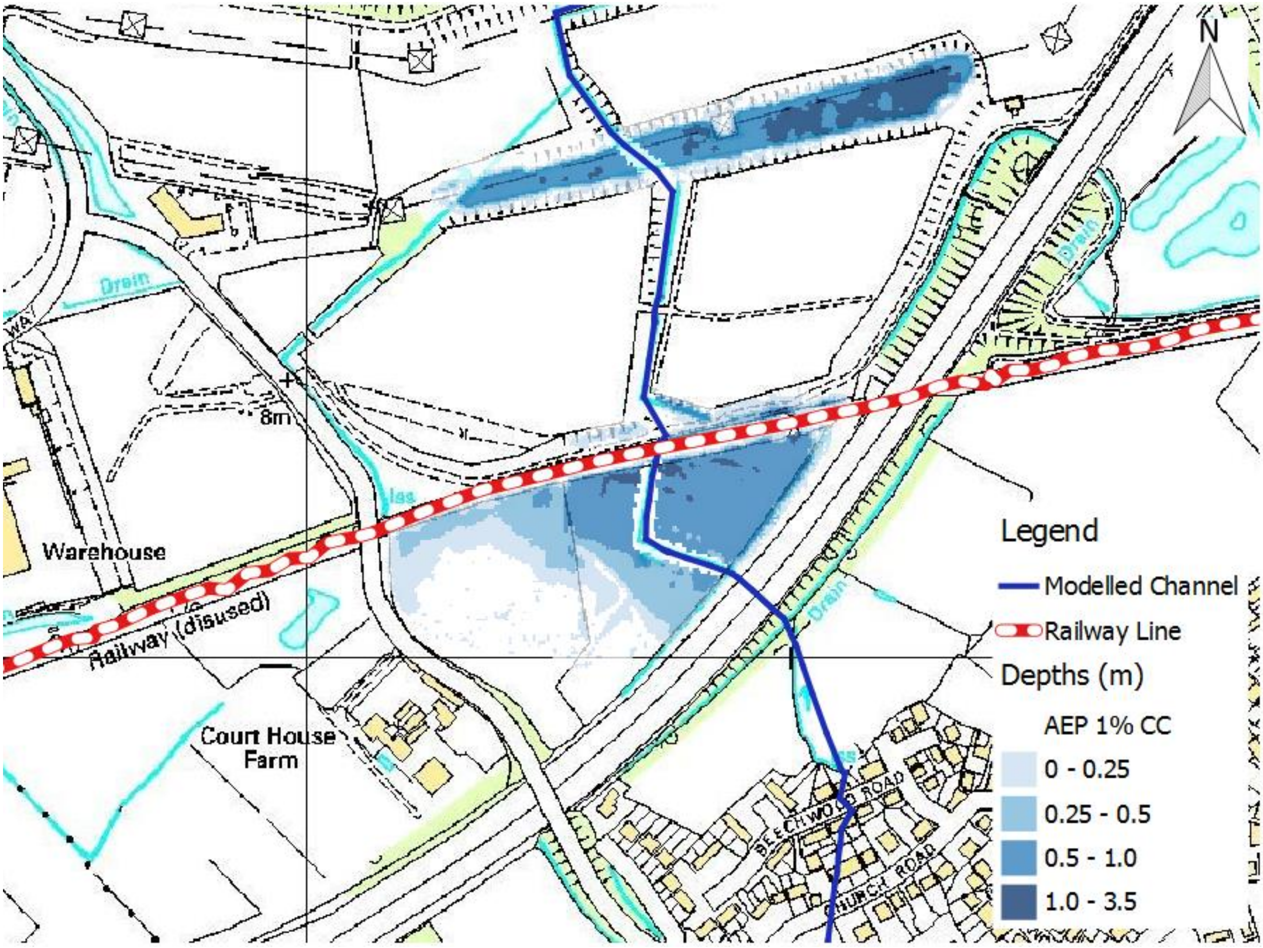


Figure K-106: Easton-in-Gordano - Fluvial event - 100 year return period, 2115 – Depths in 2D Model Domain

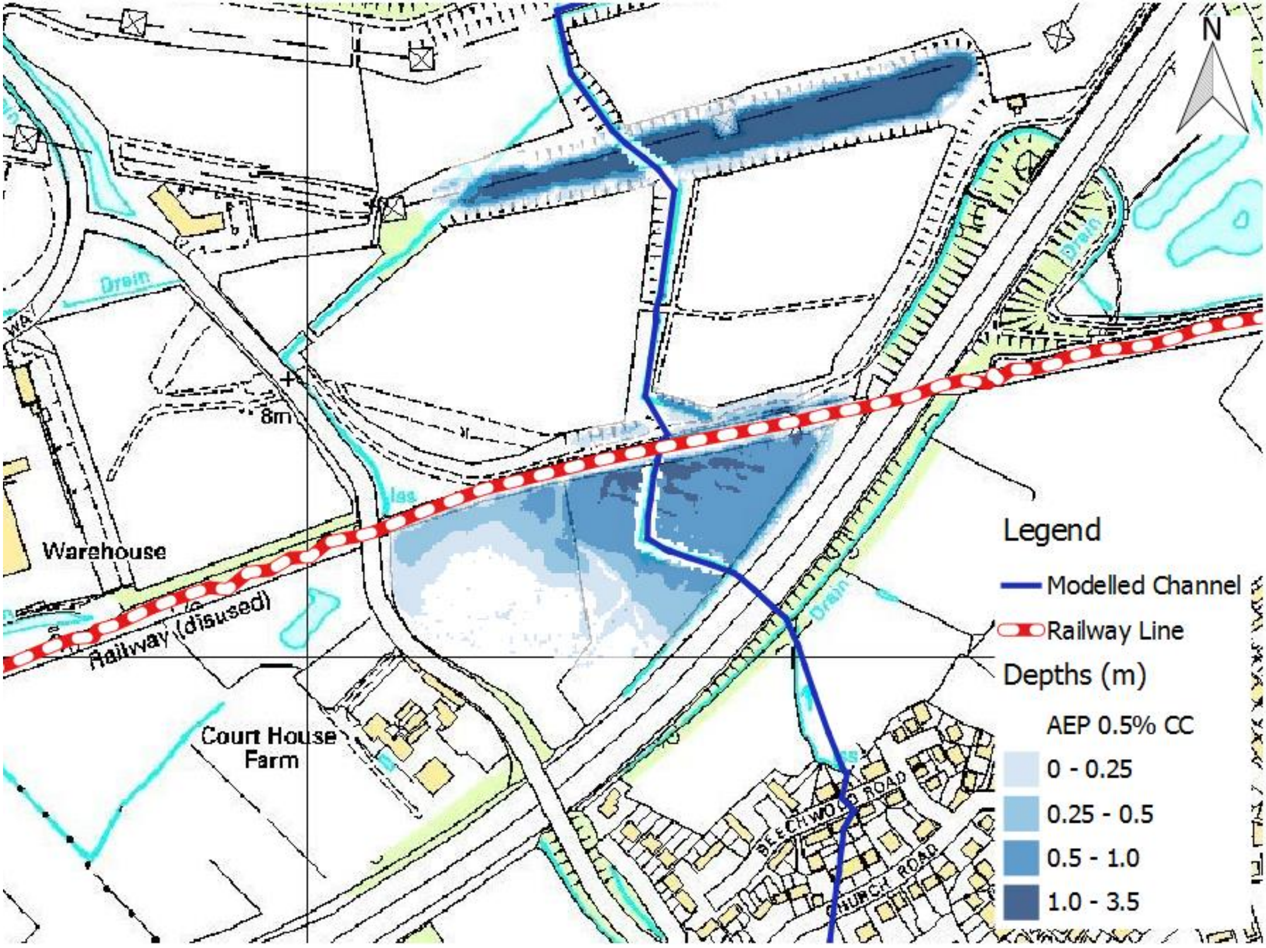


Figure K-107: Easton-in-Gordano - Fluvial event - 200 year return period, 2115 – Depths in 2D Model Domain

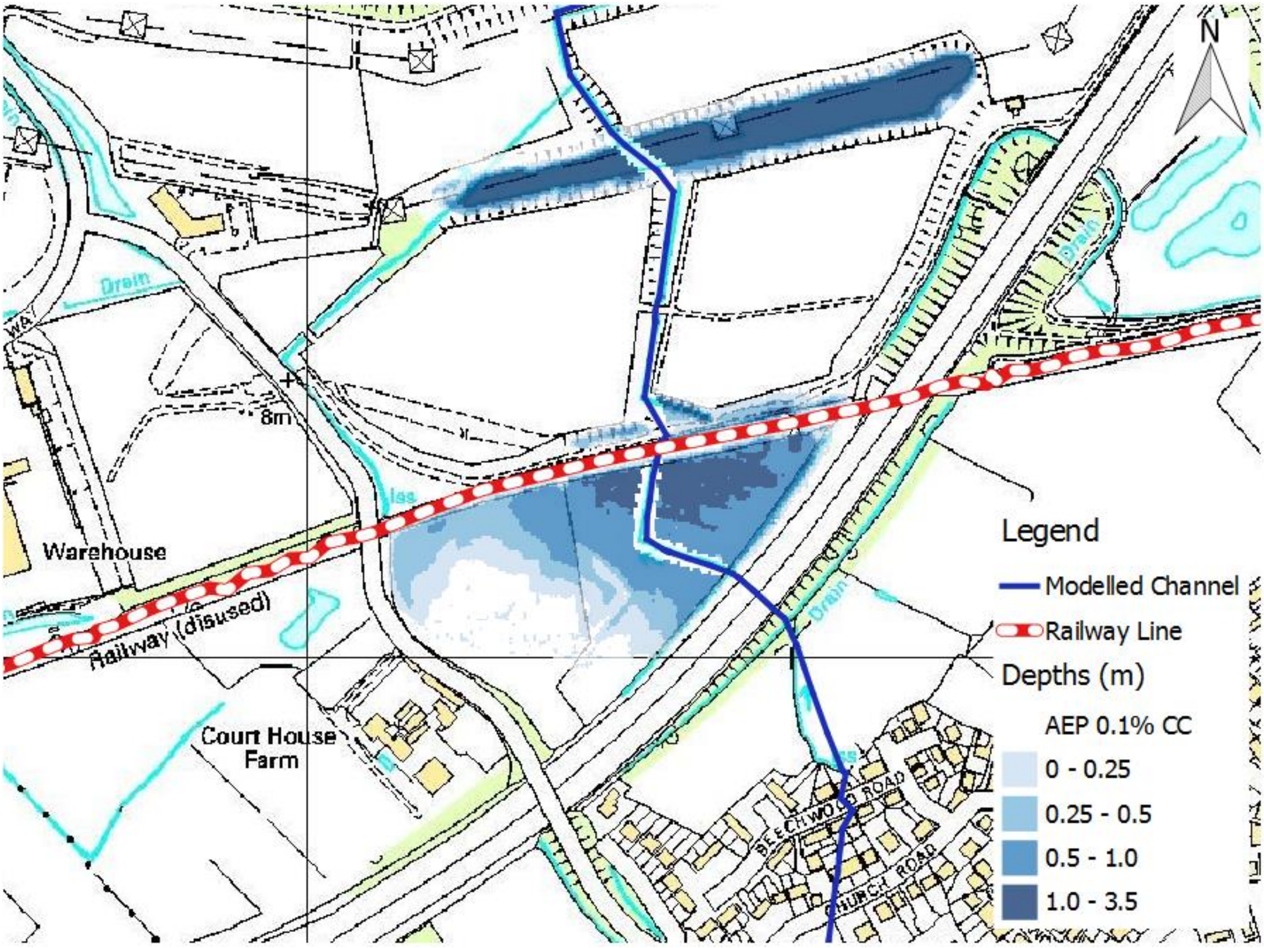


Figure K-108: Easton-in-Gordano - Fluvial event - 1000 year return period, 2115 – Depths in 2D Model Domain

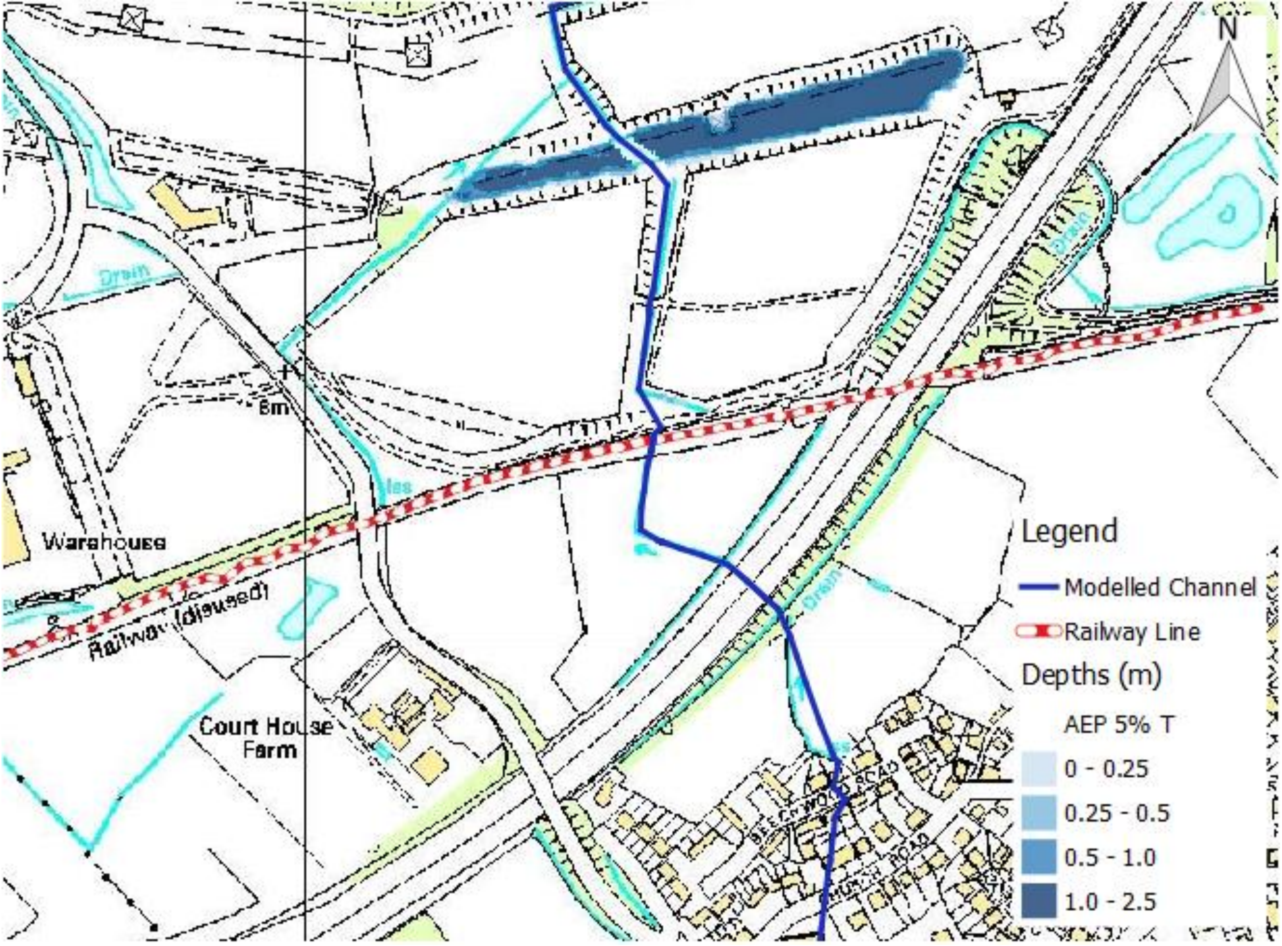


Figure K-109: Easton-in-Gordano - Tidal event - 20 year return period – Depths in 2D Model Domain

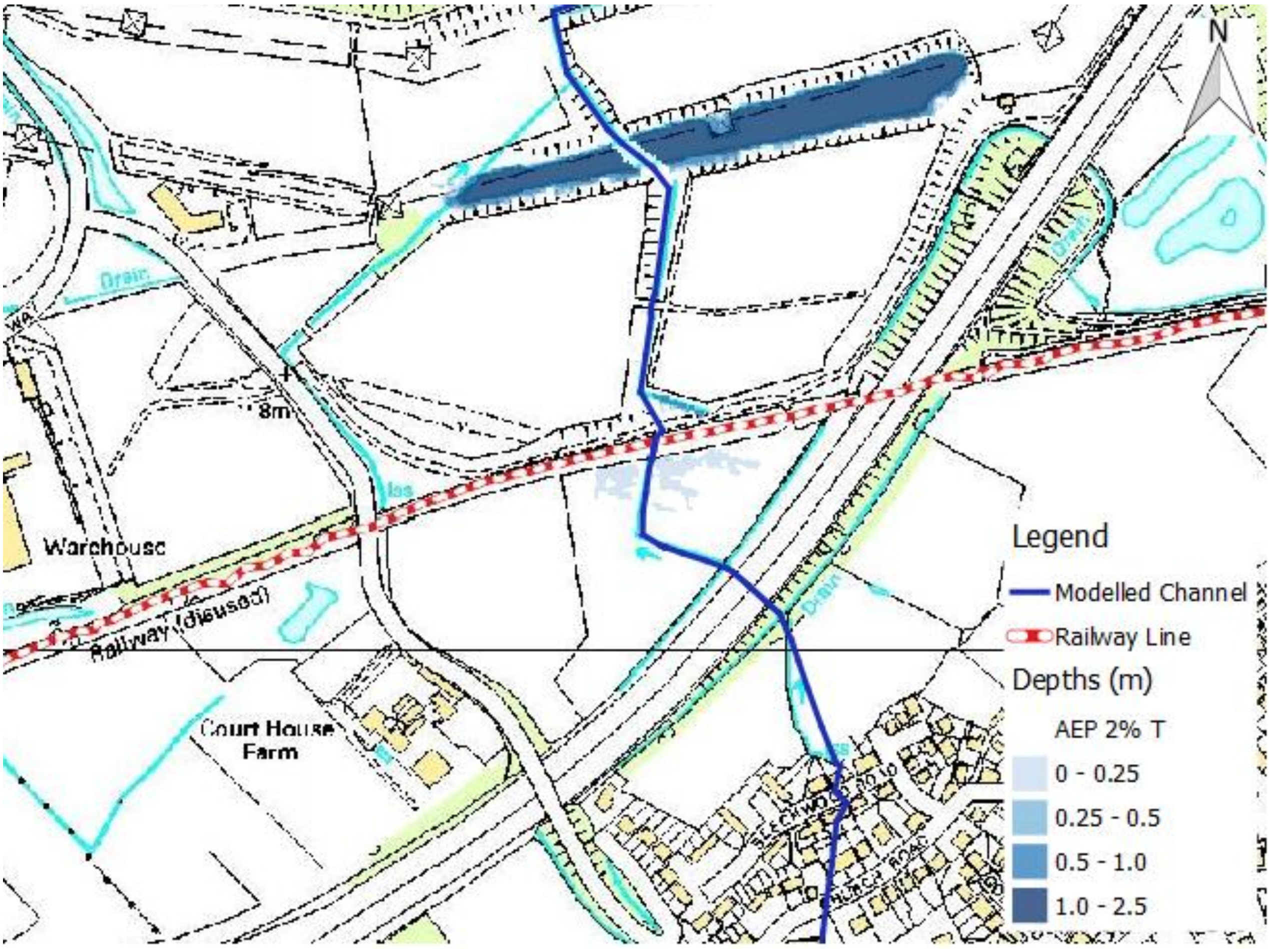


Figure K-110: Easton-in-Gordano - Tidal event - 50 year return period – Depths in 2D Model Domain

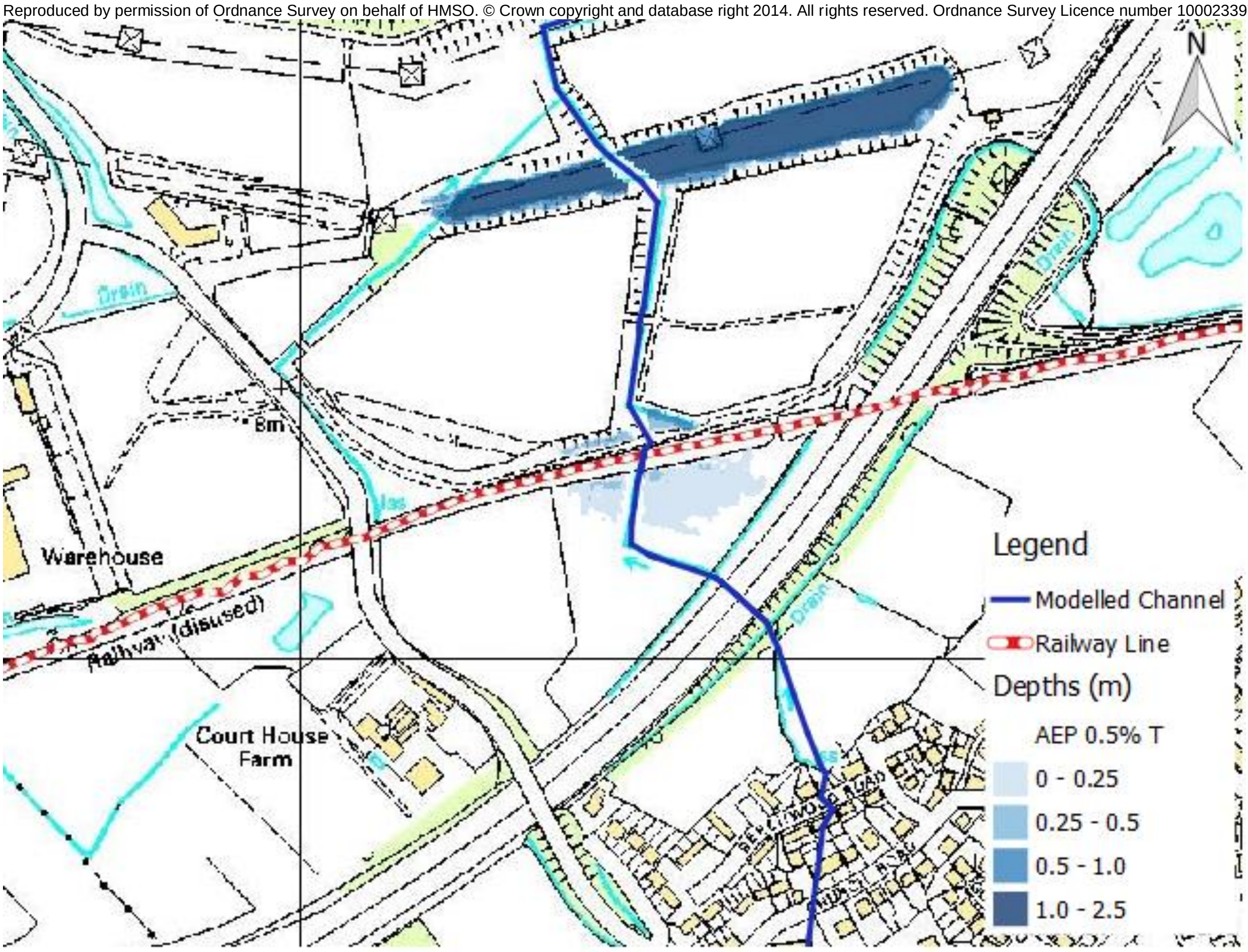


Figure K-111: Easton-in-Gordano - Tidal event - 200 year return period – Depths in 2D Model Domain

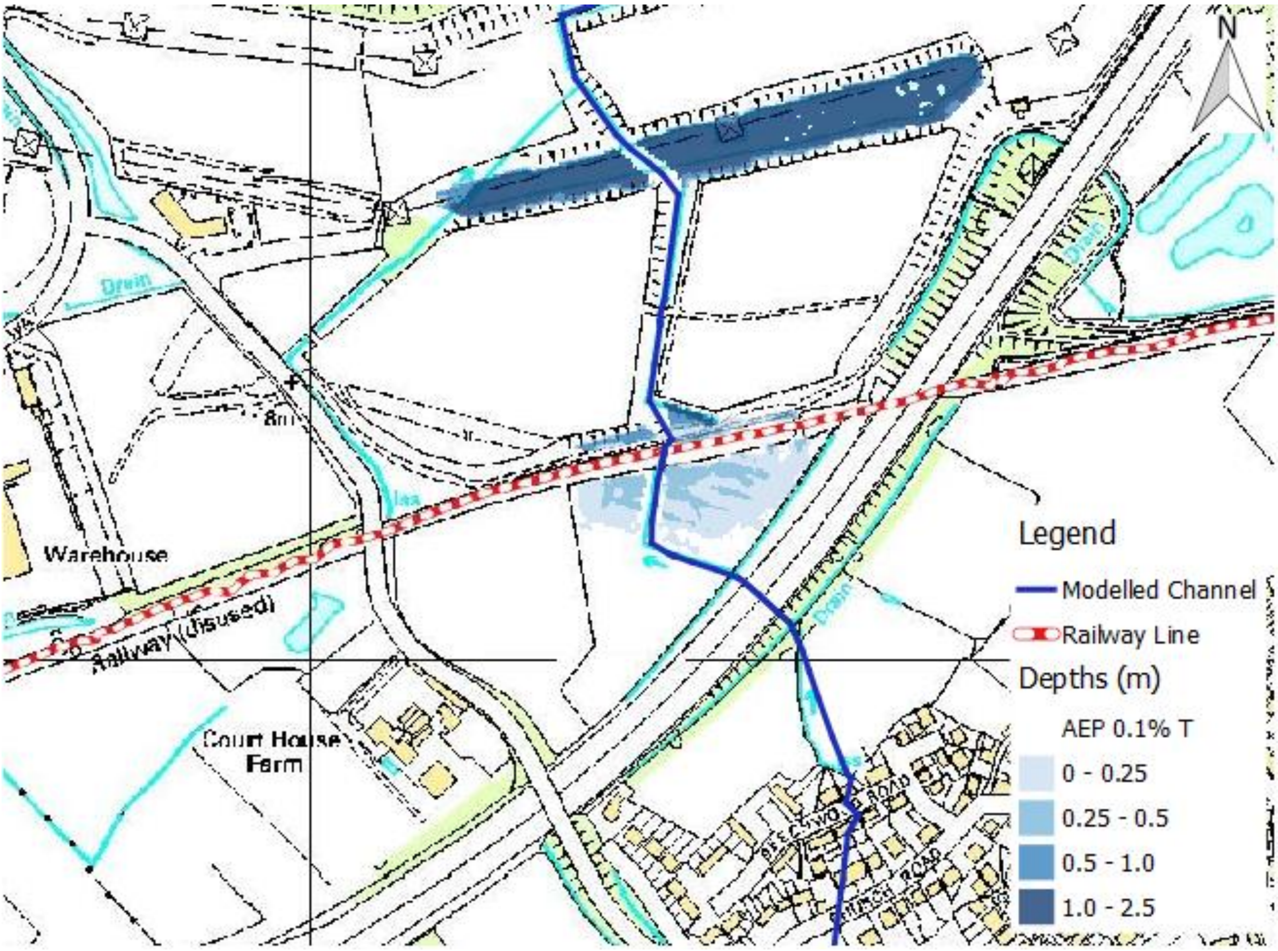


Figure K-112: Easton-in-Gordano - Tidal event - 1000 year return period – Depths in 2D Model Domain

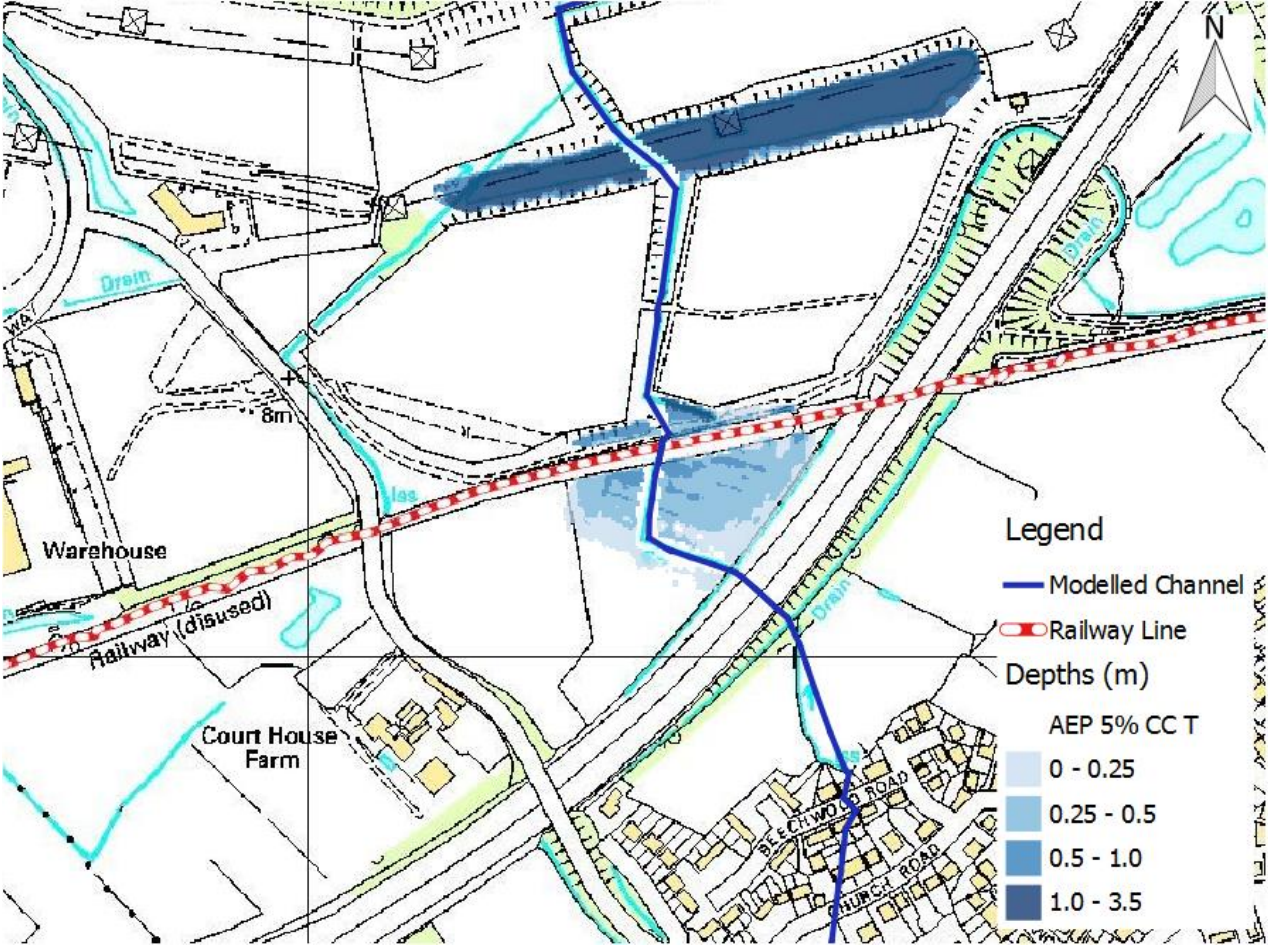


Figure K-113: Easton-in-Gordano - Tidal event - 20 year return period, 2115– Depths in 2D Model Domain

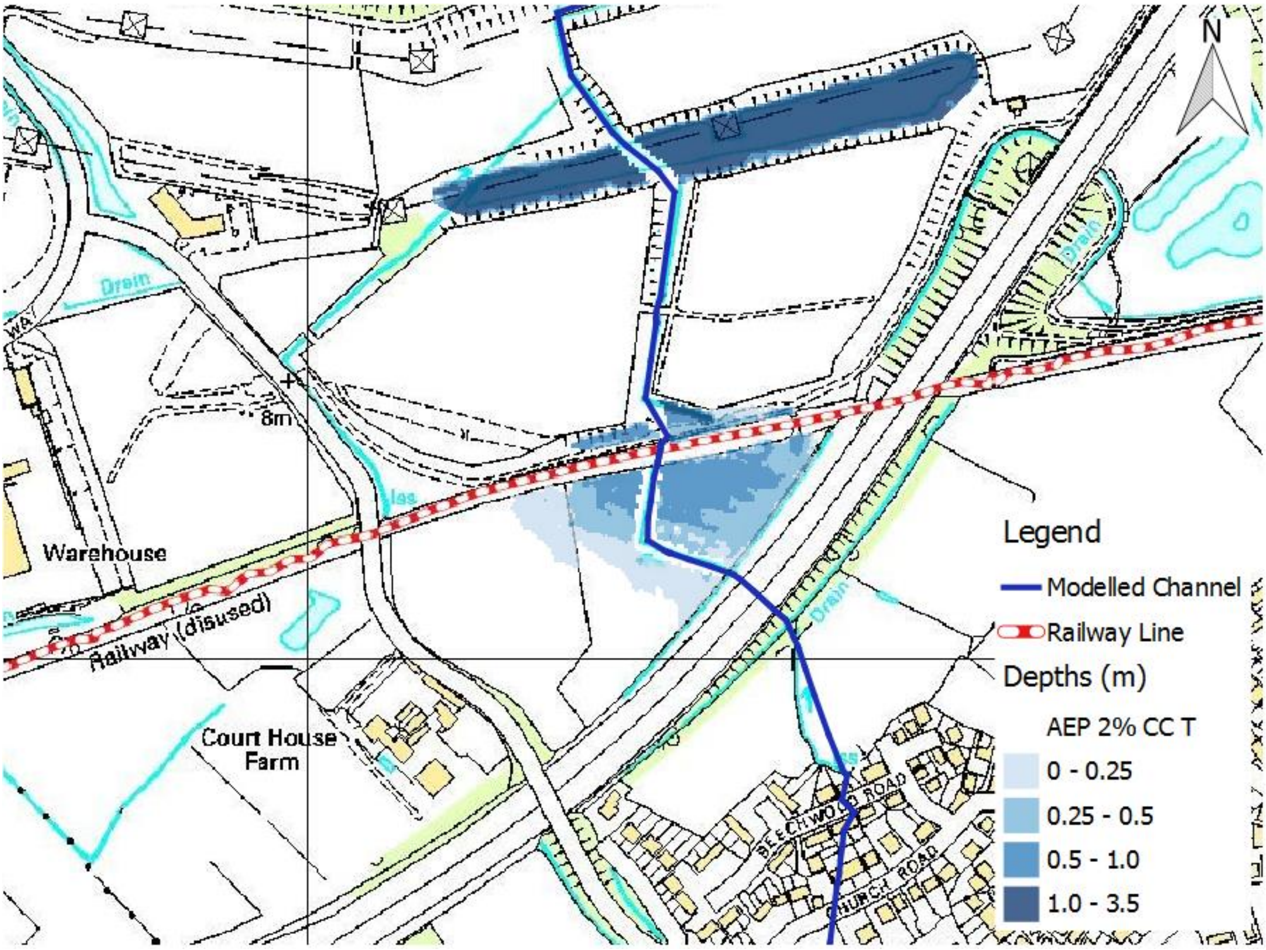


Figure K-114: Easton-in-Gordano - Tidal event - 50 year return period, 2115 – Depths in 2D Model Domain

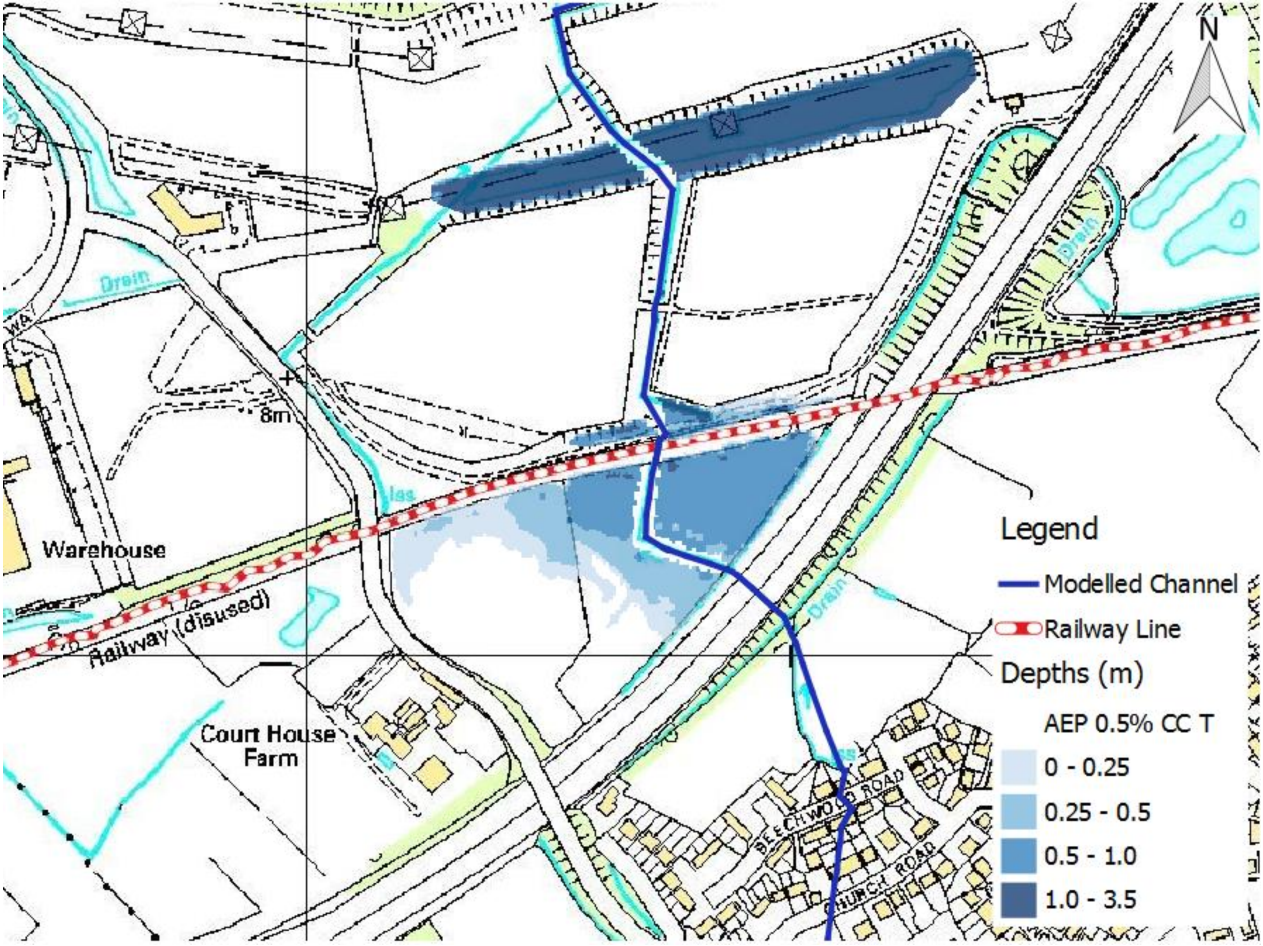


Figure K-115: Easton-in-Gordano - Tidal event - 200 year return period, 2115 – Depths in 2D Model Domain

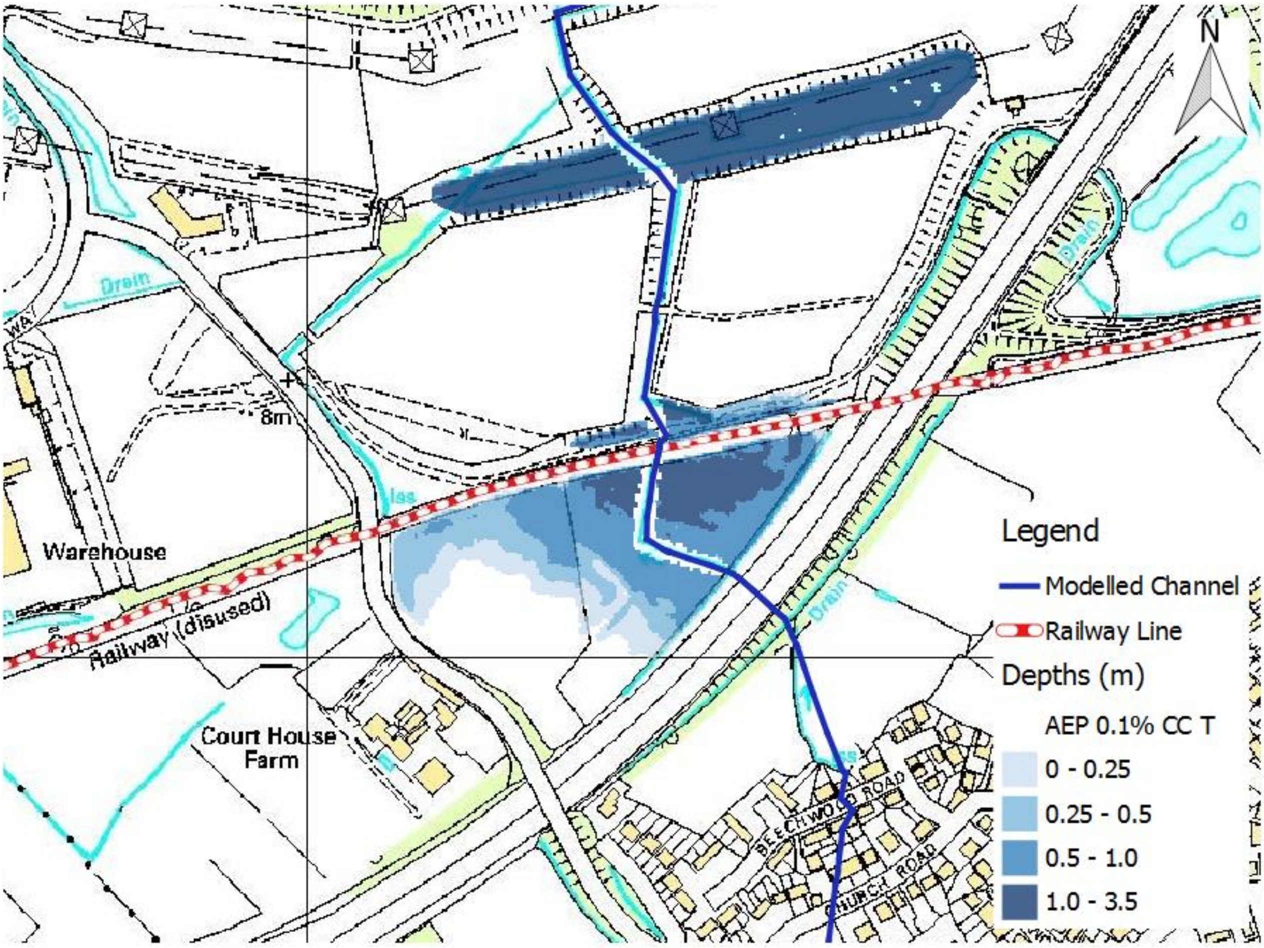


Figure K-116: Easton-in-Gordano - Tidal event - 1000 year return period, 2115 – Depths in 2D Model Domain

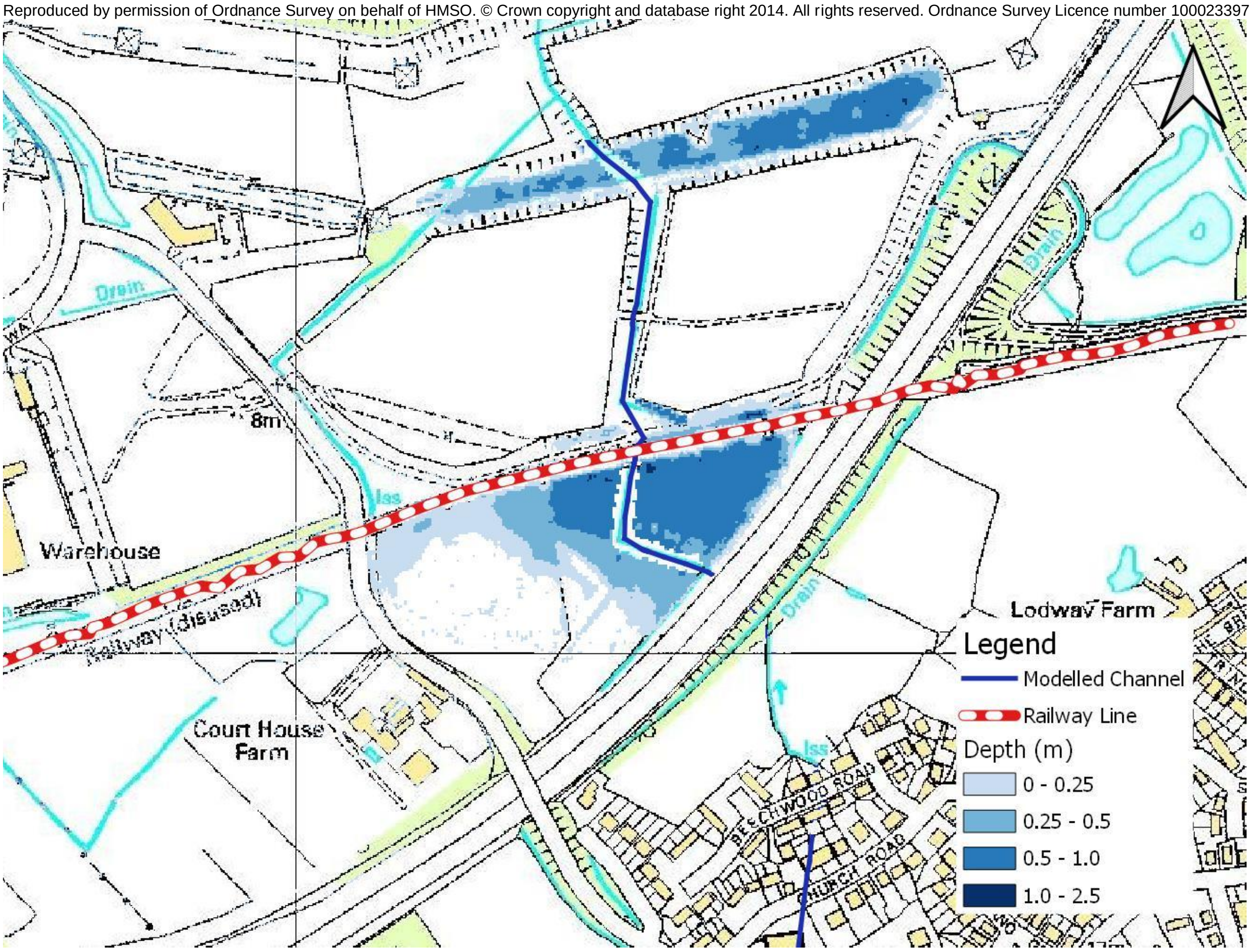


Figure K-117: Easton-in-Gordano - Fluvial event - 30 year return period, 2075 – Depths in 2D Model Domain

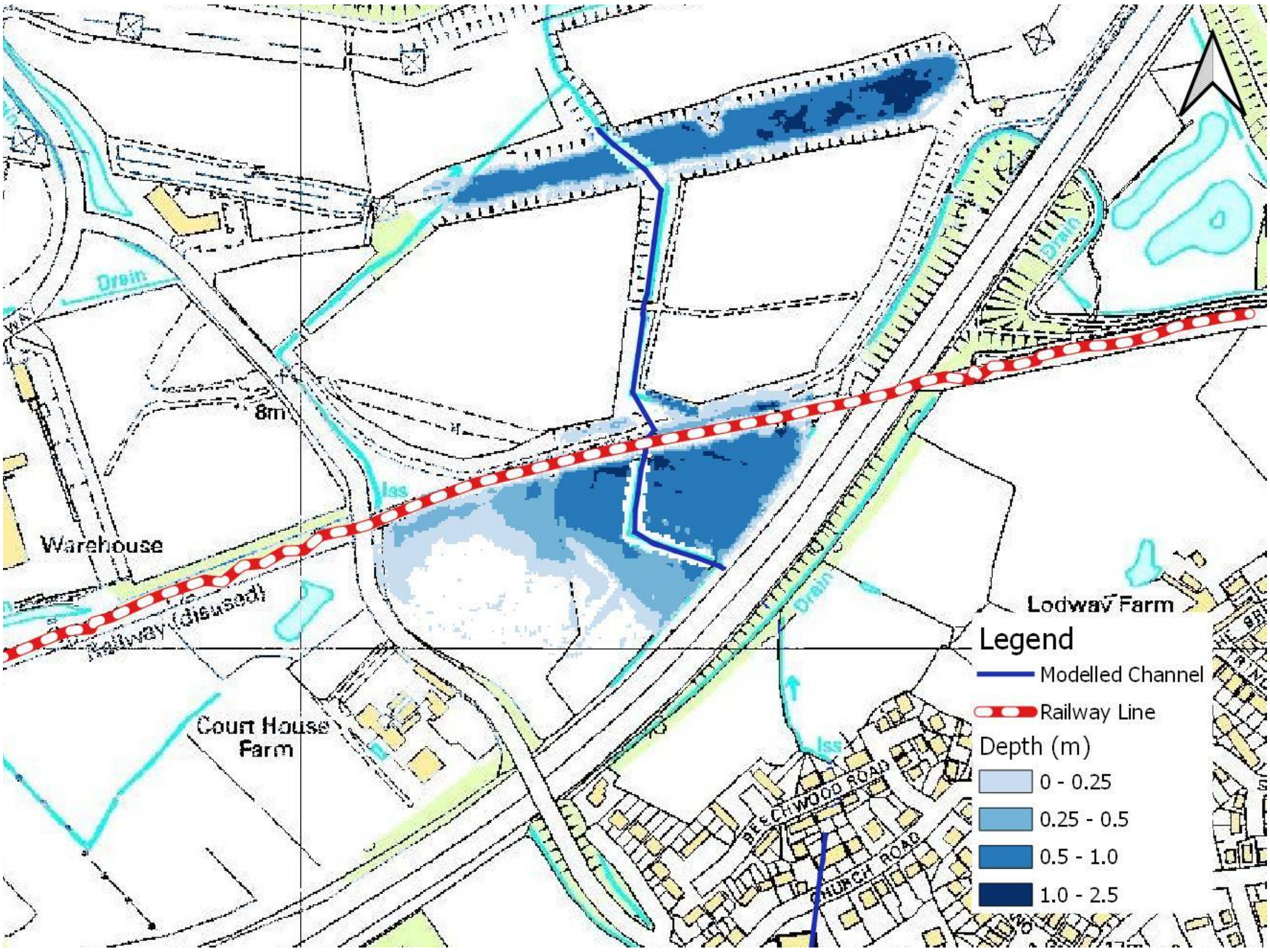


Figure K-118: Easton-in-Gordano - Fluvial event - 100 year return period, 2075 – Depths in 2D Model Domain

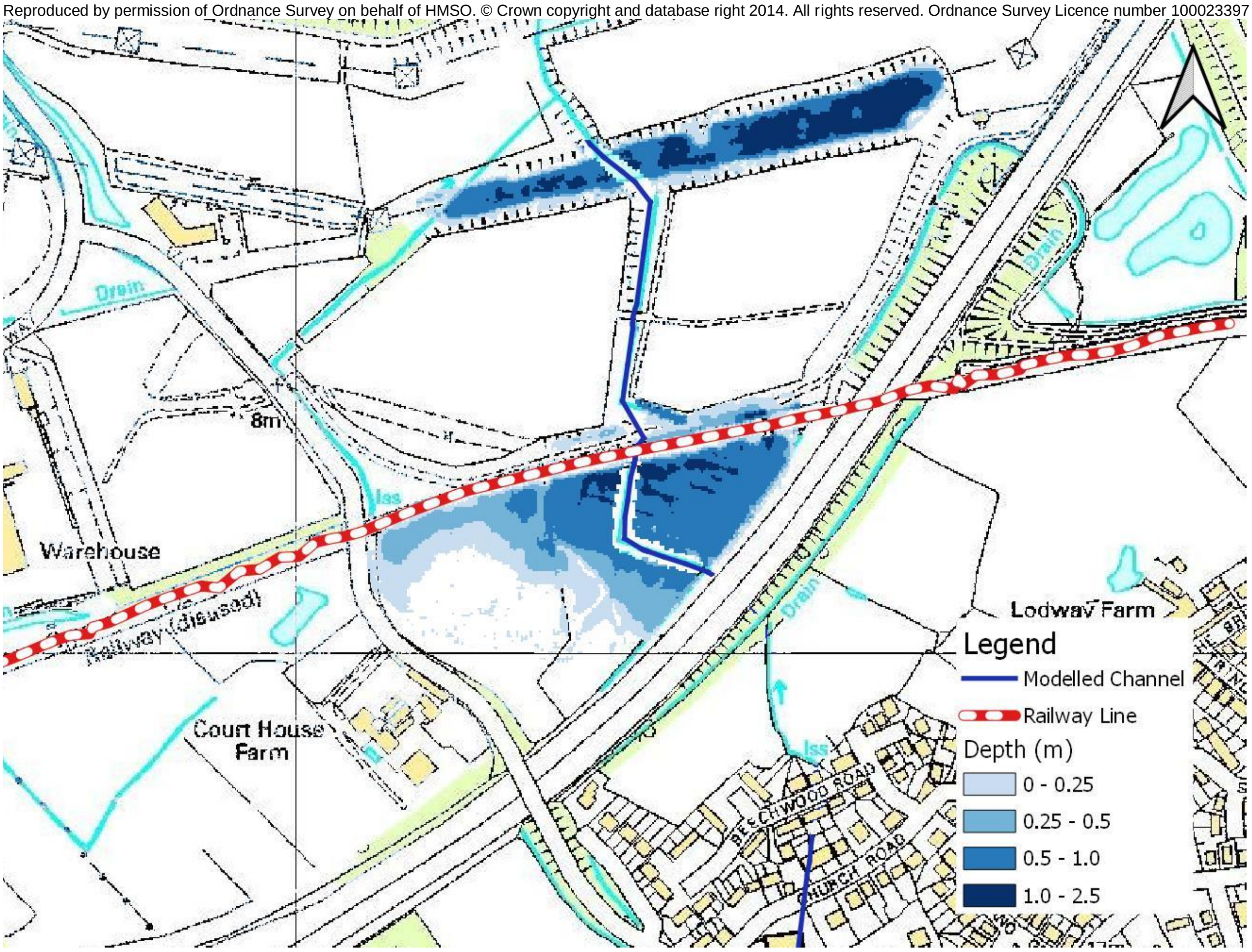


Figure K-119: Easton-in-Gordano - Fluvial event - 200 year return period, 2075 – Depths in 2D Model Domain

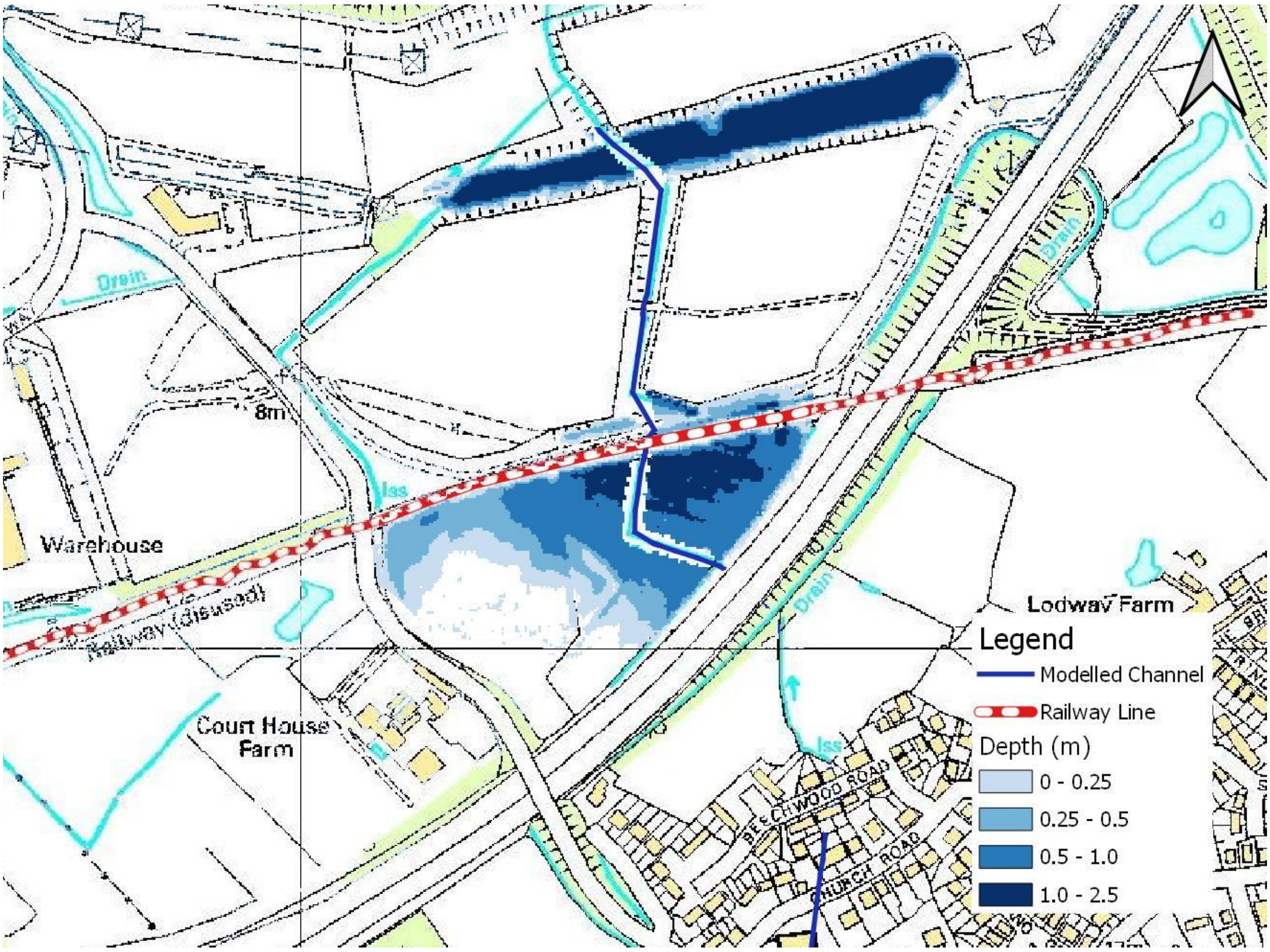


Figure K-120: Easton-in-Gordano - Fluvial event - 1000 year return period, 2075 – Depths in 2D Model Domain

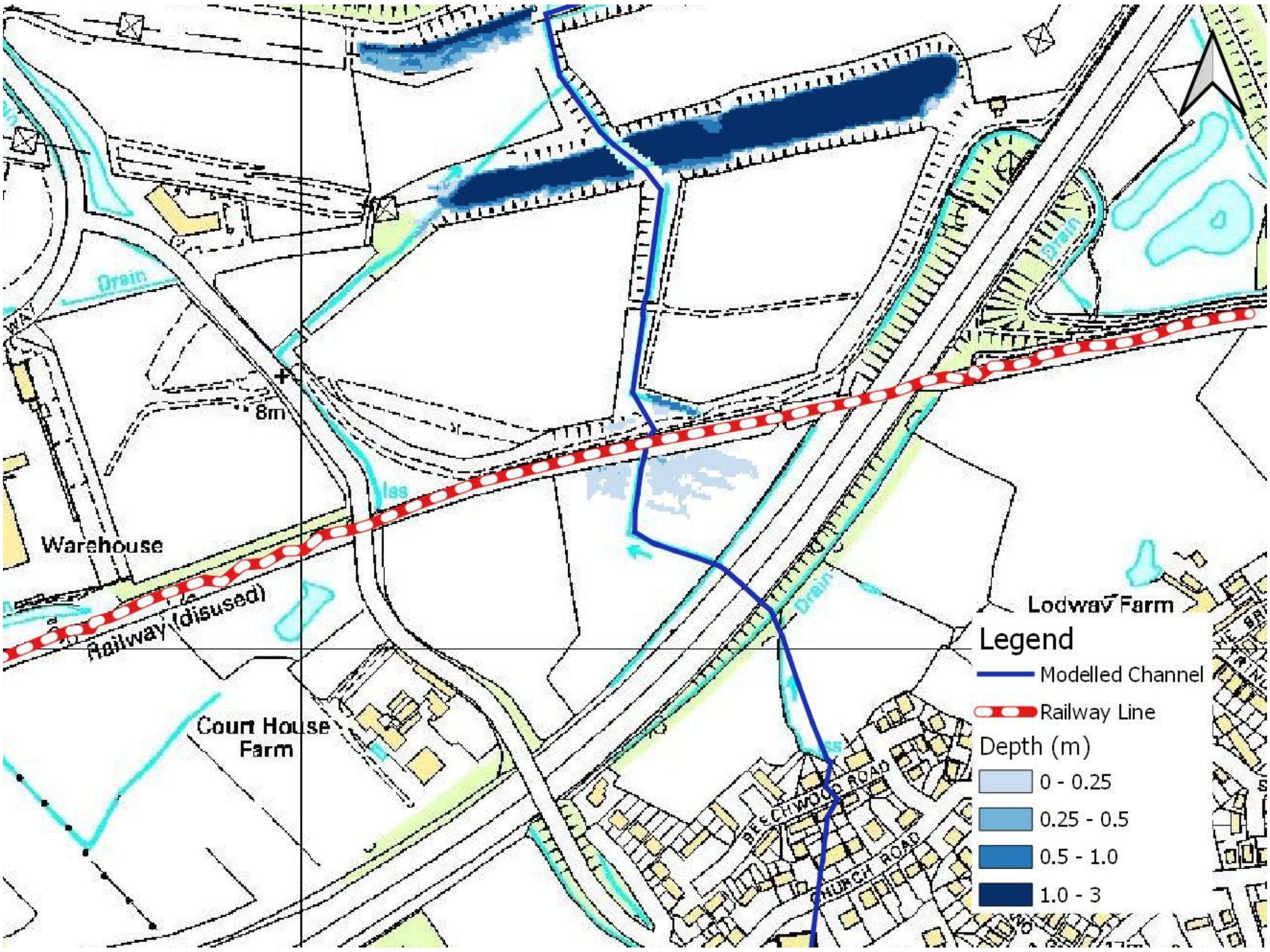


Figure K-121: Easton-in-Gordano - Tidal event - 20 year return period, 2075 – Depths in 2D Model Domain

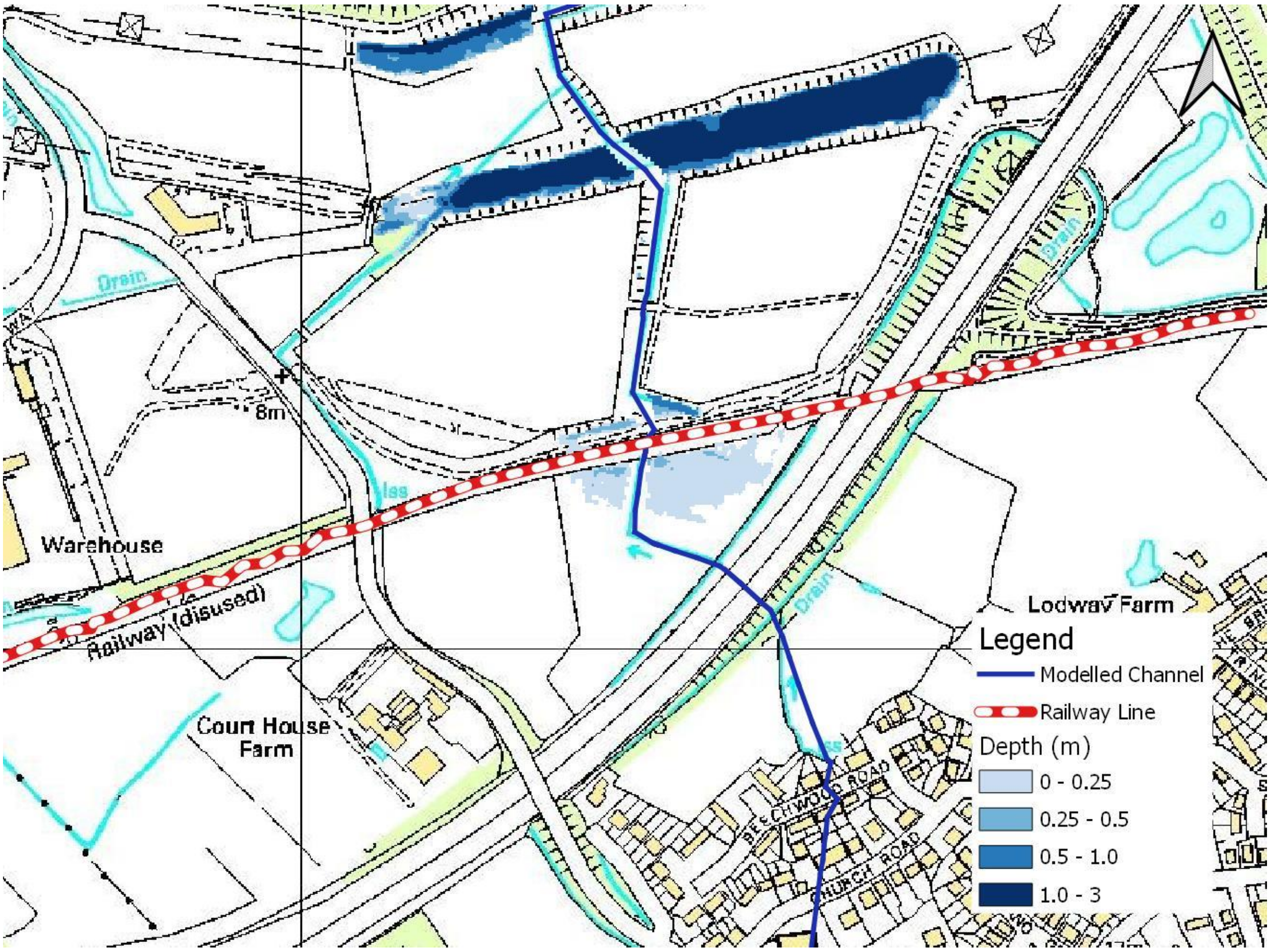


Figure K-122: Easton-in-Gordano - Tidal event - 50 year return period, 2075 – Depths in 2D Model Domain

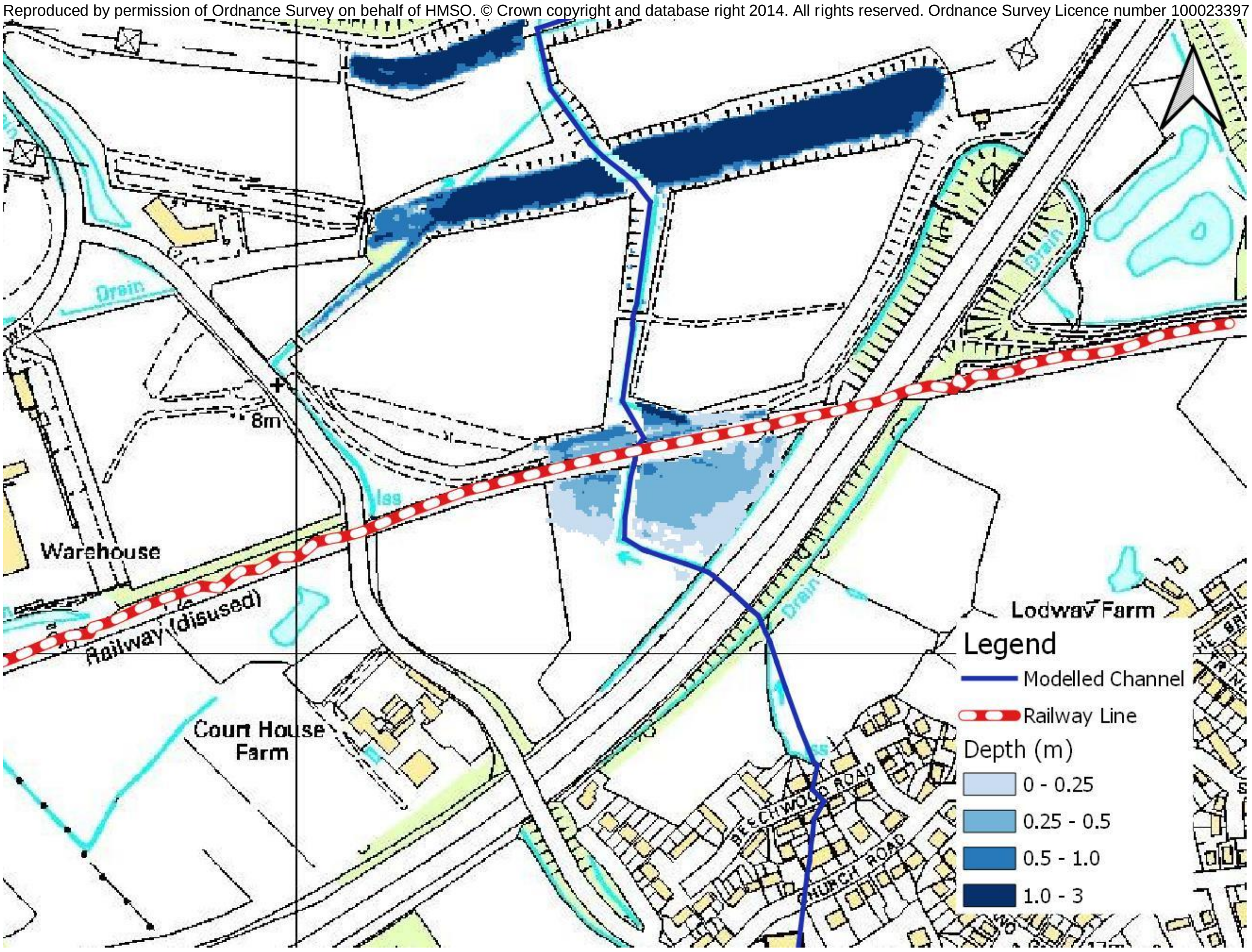


Figure K-123: Easton-in-Gordano - Tidal event - 200 year return period, 2075 – Depths in 2D Model Domain

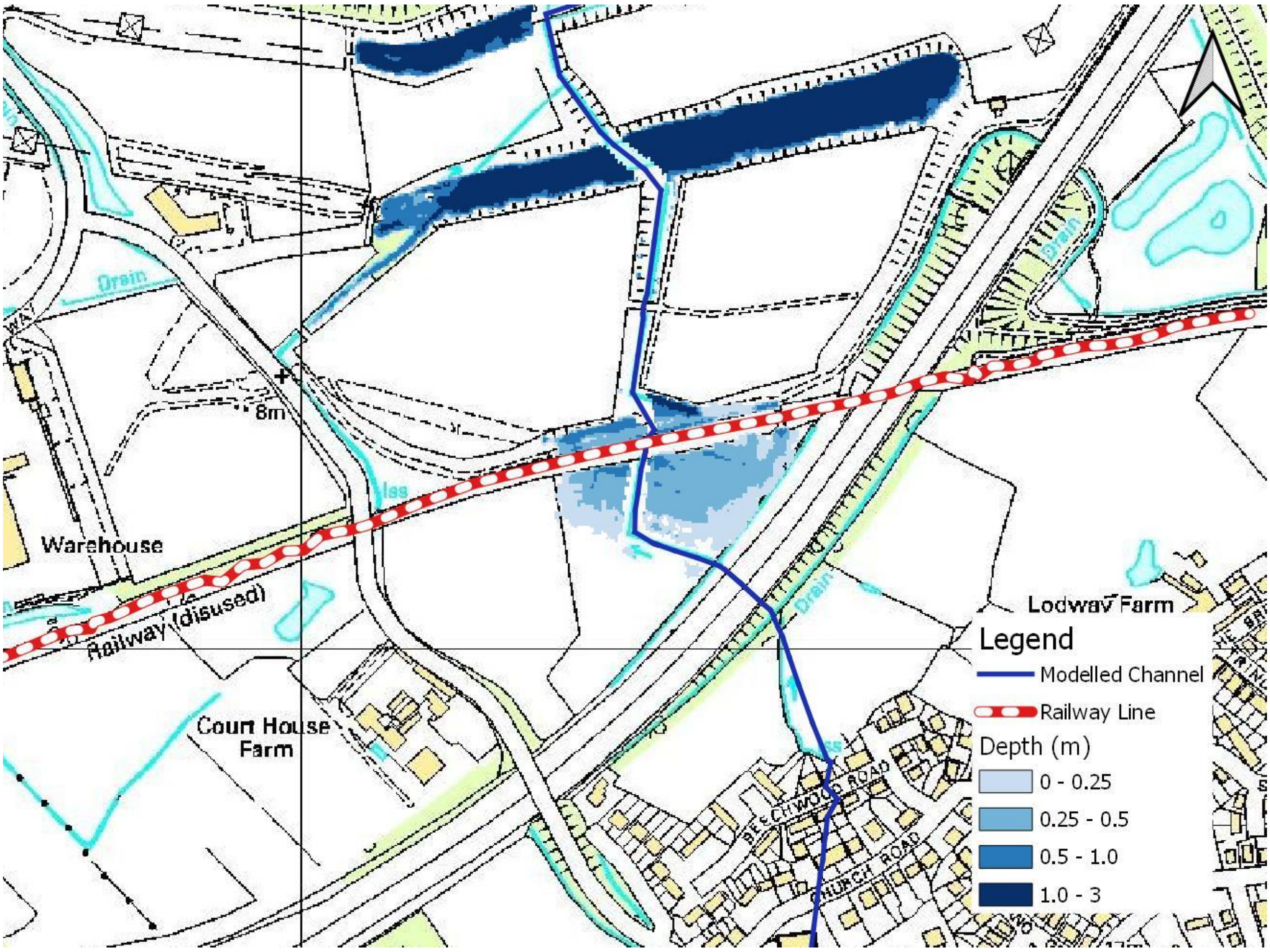


Figure K-124: Easton-in-Gordano - Tidal event - 1000 year return period, 2075 – Depths in 2D Model Domain

MetroWest

Portishead Branch Line (MetroWest Phase 1)

TR040011

Applicant: North Somerset District Council
5.6, Flood Risk Assessment,
Appendix L Flood Zone review
The Infrastructure Planning (Applications: Prescribed Forms and Procedure)
Regulations 2009, regulation 5(2)(e)
Planning Act 2008

Author: CH2M
Date: November 2019

	Proposed DCO Scheme Works No.	Description	Permanent or Temporary	EA Flood Zone (FZ)	More detailed assessment of Flood Zone (interpretation of results MetroWest Phase 1 hydraulic modelling and other available infromation)	Revised Flood Zone (FZ) based on more detailed information (hydraulic model results)
	The Nationally Significant Infrastructure Project					
	1	A railway of 2,264 metres in length, shown on sheets 1, 1A, 2, and 3 of the works plans commencing at a point 96 metres north of the junction of Quays Avenue and Galingale Way, Portishead, using the track bed of the former Portishead Branch Line railway, and terminating at a junction with Work 1A at a point 57 metres to the east of the bridge carrying Station Road (Portbury) over the former Portishead Branch Line railway;	Permanent	All within FZ1, FZ2, and defended FZ3 except: Within Easton-in-Gordano Stream tidal FZ3 between Marsh Lane and the M5 motorway Pill viaduct crosses FZ3 (but proposed works are signifcantly higher than the flood level)	**Between Portishead and Royal Portbury Dock Road** Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show parts of the Portishead Branch Line (MetroWest Phase 1) Project between Portishead and Royal Portbury Dock Road to be within the undefended 200-year and 1000-year coastal flood extents (see EA coastal flood model depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf). Results of hydraulic modelling of Drove Rhyne undertaken for The Project show that the Portishead Branch Line level is above the 1000-year return period Drove Rhyne flood level (Appendix M). **Between Royal Portbury Dock Road and the M5 motorway** Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show the Portishead Branch Line (MetroWest Phase 1) Project between Royal Portbury Dock Road and M5 motorway to be outside the undefended 1000-year coastal flood extent (see EA coastal flood model depth map provided in Appendix B - SW6012 0.1% Undef Tidal Depth data.pdf). The EA Flood Zones show the part of the disued railway between Royal Portbury Dock Road and the M5 motorway to cross River Avon FZ2 and FZ3 due to the projection of Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelled (tidally dominated) flood levels in this area. However, hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project has provided a more refined estimate of flood risk in this area by applying CAFRA modelled level time series as a downstream boundary to the Easton-in-Gordano Stream model and hence assessing a more realistic propogation of River Avon flood levels up the Easton-in-Gordano Stream. These simulations indicate this part of the disused railway is within the simulated 200-year flood extent but outside of the 20yr tidal flood extent (Figures K.109 and K.111 in Appendix K). Hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project indicates the Portishead to Pill (disused section) between Portbury Royal Dock Road and the M5 motorway crossing is partly within the fluvial 30-year flood extent i.e within FZ3b. **Between the M5 motorway and junction with the operational Portbury Freight Line** n/a **Between DCO boundary north of M5 motorway and Pill viaduct** n/a **Pill viaduct crossing of Markham Brook** Pill viaduct crosses FZ2 and FZ3 but the railway is at a signifcantly higher level. All proposed works are at railway track/ballast level i.e. above FZ2 and FZ3.	**Between Portishead and Royal Portbury Dock Road** Defended FZ2 and defended FZ3 **Between Royal Portbury Dock Road and the M5 motorway** Partly within FZ3b **Between the M5 motorway and junction with the operational Portbury Freight Line** FZ1 **Between DCO boundary north of M5 motorway and Pill viaduct** FZ1 **Pill viaduct crossing of Markham Brook** FZ3a (but works are actually above FZ2 and FZ3 flood levels)
	1A	A railway of 2,498 metres in length, shown on sheets 3, 4, 5 and 6 of the works plans commencing at a point 57 metres to the east of the bridge carrying Station Road (Portbury) over the former Portishead Branch Line railway, using the track bed of the former Portishead Branch Line railway and terminating at the junction of the former Portishead Branch Line railway and the Bristol Port Company's railway, at a point 49 metres to the west of the bridge carrying the railway over public footpath LA8/5/40 between Avon Road and Lodway Close Pill;	Permanent			
	1B	A railway of 871 metres in length, shown on sheets 6 and 7 of the works plans commencing at the junction of the former Portishead Branch Line railway and Bristol Port Company's railway at a point 49 metres west of the bridge carrying the railway over public footpath LA8/5/40 between Avon Road and Lodway Close, Pill, terminating at a new junction with the Parson Street to Royal Portbury Dock Railway, at a point 53 metres to the north-east of the junction of the highways of Ham Green and Westward Drive, Pill; and	Permanent			
	1C	A railway of 871 metres in length, being a realignment of the Parson Street to Royal Portbury Dock railway, shown on sheets 6 and 7 of the works plans, commencing at a point 49 metres west of the bridge carrying the railway over public footpath LA8/5/40 between Avon Road and Lodway Close, Pill and terminating at a new junction with Work No. 1B, at a point 53 metres to the north-east of the junction of the highways of Ham Green and Westward Drive, Pill.	Permanent			
	Associated Development					
	2	Diversionof the highway of Quays Avenue, Portishead, of 181 metres in length, shown on sheets 1 and 1A of the works plans, from the junction of Quays Avenue and Galingale Way to a point west of the existing gyratory junction of Quays Avenue, Harbour Road and Phoenix Way, Portishead, together with connections to existing highways, widening of the southern footway of Harbour Road, landscaping, new bus waiting facilities, signage, lighting, pedestrian crossing facilities, pipes, drains, cables, ducts, troughs, telecommunications apparatus, conduits and apparatus for utilities as well as footways, and a connection to the pedestrian and cycle track forming part of Work No. 4;	Permanent	FZ2 and defended FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show parts of the Portishead Branch Line (MetroWest Phase 1) Project between Portishead and Royal Portbury Dock Road to be within the undefended 200-year and 1000-year coastal flood extents (see EA coastal flood model depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf).	Defended FZ2 and defended FZ3.
	2A	Surface water drain, of 27 metres in length, shown on sheets 1 and 1A of the works plans north from Phoenix Way, Portishead into the watercourse known as the Cut;	Permanent	Defended FZ3		

	3	A foot and cycle track, of 63 metres in length, shown on sheet 1 of the works plans, commencing at a junction with Work No. 4 east of the watercourse known as the Portbury Ditch, to a point west of Portbury Ditch, together with associated landscaping, signage, fencing, lighting, cables, ducts, troughs, telecommunication apparatus, conduits and apparatus for utilities;	Permanent	Defended FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show parts of the Portishead Branch Line (MetroWest Phase 1) Project between Portishead and Royal Portbury Dock Road to be within the undefended 200-year and 1000-year coastal flood extents (see EA coastal flood model depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf). The DCO boundary western extent crosses Portbury Ditch to allow for works above an existing culverted crossing of Portbury Ditch. The proposal retains the existing structure and all works are to the top of the crossing. Raised flood levels in Portbury Ditch would be a result of tide locked fluvial flows. Topographic survey undertaken for The Project shows the existing crossing has a top level of approximately 7.5mAOD. There is significant storage in the upstream Portbury Ditch catchment with large flat areas between the M5 motorway and B3124 road, north-east of Clevedon, shown to have levels of approximatley 6m to 7m in Ordance Survey mapping. Due to the significant low lying floodplain storage availble, it is considered ulikley that fluvial flood levels in Portbury Ditch would reach 7.5mAOD and the proposed Portbury Ditch works are considerd to be in FZ3a rather than FZ3b.	Defended FZ3, except FZ3a over existing culvert structure on Portbury Ditch.
	4	A car park of 4841 square metres in area, foot and cycle track of 275 metres in length and a new vehicular access to the highway of Harbour Road, shown on sheets 1 and 1A of the works plans, south of Harbour Road, Portishead and east of the Portbury Ditch, together with landscaping, lighting, signage, fencing, drainage in to the adjacent Portbury Ditch, to the west of Quays Avenue, Portishead;	Permanent	FZ2 and defended FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show parts of the Portishead Branch Line (MetroWest Phase 1) Project between Portishead and Royal Portbury Dock Road to be within the undefended 200-year and 1000-year coastal flood extents (see EA coastal flood model depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf).	FZ1, defended FZ2 and defended FZ3.
	5	Railway station, of 396 metres in area, shown on sheets 1 and 1A of the works plans, to the south of Phoenix Way, Portishead, comprising platform, shelter, office, waiting area, storage and refuse area, seating, ticket vending machine, closed circuit television equipment, passenger help point, customer toilet, utilities connections, telecommunications equipment, public address system, information boards and displays, signage, lighting columns, fencing, acoustic barrier, landscaping, railway communications mast and surface water drain in to the adjacent watercourse known as the Cut;	Permanent	FZ2 and defended FZ3		
	6	Car park, of 4419 metres in area, shown on sheets 1 and 1A of the works plans, to the south of Phoenix Way, Portishead, including mobility impaired spaces, drainage, lighting, fencing, landscaping, signage, cycle parking facilities and utilities apparatus, together with access from the highway of Phoenix Way;	Permanent	FZ2 and defended FZ3		
	7	Public foot and cycle track bridge over Work No. 1, shown on sheets 1 and 1A of the works plans, to the south west of Trinity School, Portishead, together with connections to cycle tracks, lighting, signage, fencing and hardstandings;	Permanent	FZ2 and defended FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show parts of the Portishead Branch Line (MetroWest Phase 1) Project between Portishead and Royal Portbury Dock Road to be within the undefended 200-year and 1000-year coastal flood extents (see EA coastal flood model depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf).	FZ1, defended FZ2 and defended FZ3.
	7A	Public foot and cycle track, of 273 metres in length, shown on sheets 1 and 1A of the works plans, from Phoenix Way, Portishead to connect with Works Nos.7 and 7C, to the south of Tansy Lane and north of Work No. 1, together with signage, drainage, lighting, fencing and landscaping;	Permanent	Defended FZ3		
	7B	Public foot and cycle track, of 150 metres in length, shown on sheets 1 and 1A of the works plans, from Quays Avenue, Portishead, to connect with Work No. 7, to the north of Galingale Way and to the south of Work No. 1, together with signage, drainage, lighting, fencing and landscaping;	Permanent	FZ2 and defended FZ3		

	7C	Public foot and cycle track, of 18 metres in length, shown on sheets 1 and 1A of the works plans, from Work No. 7 north to Tansy Lane, Portishead, together with signage, drainage, lighting, fencing and landscaping;	Permanent	Defended FZ3	depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf). The EA Flood Map for Planning shows parts of the railway corridor in the vicinity of The Cut culvert to be in FZ2 (based on coastal model simulations i.e. coastal flood risk, which is discussed above). The EA Likelihood of Flooding from Rivers and the Sea maps shows the railway corridor in the vicinity of The Cut culvert to have a Low risk of flooding (between 1 in 100yr and 1 in 1000yr). Levels along the railway corridor in the vicinity of The Cut culvert are approximately 0.5m to 1m above ground levels south of the railway corridor. The Cut catchment area is relatively small (approx. 1.1km2). The risk of inundation of the railway corridor due to flows from The Cut is therefore considered insignificant.	
	7D	Temporaryconstruction compound, of 2876 square metres in area, shown on sheet 1 of the works plans, to the south of Tansy Lane, Portishead and to the north of Work No. 1;	Temporary	FZ2 and defended FZ3		
	7E	Underground electrical supply cables of 294 metres in length connecting from Work No. 7 to Tansy Lane, Portishead, shown on sheet 1 and 1A of the works plans;	Permanent	FZ1		
	8	Temporary construction haul road of 486 metres in length, shown on sheets 1 and 2 of the works plans, on south side of, and parallel to, Work No. 1, between a point south of Fennel Road, Portishead, and the highway known as Sheepway, Portbury;	Temporary	Defended FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Results of EA simulations without coastal flood defences show parts of the Portishead Branch Line (MetroWest Phase 1) Project between Portishead and Royal Portbury Dock Road to be within the undefended 200-year and 1000-year coastal flood extents (see EA coastal flood model depth maps provided in Appendix B - SW6012 0.5% Undef Tidal Depth data.pdf and SW6012 0.1% Undef Tidal Depth data.pdf).	Defended FZ3
	9	Permanent vehicular compound of 1862 square metres, road/rail vehicle access point and access road from the highway of Sheepway, shown on sheet 2 of the works plans, to the north of the bridge carrying the highway of Sheepway over Work No.1, a permanent diversion of the existing permissive cycle path and works to the existing public car park to the west of Sheepway, together with fencing, drainage, communications apparatus, ducts, troughs, utilities apparatus, hardstanding and means of access to the highway of Sheepway;	Permanent	Defended FZ3		FZ1, defended FZ2 and defended FZ3.
	10	Temporary diversion of the existing permissive cycle path, of 156 metres in length shown on sheet 2 of the works plans, on the north west side of the highway of Sheepway, opposite Shipway Gate Farm, Portbury;	Temporary	FZ1		FZ1, defended FZ2 and defended FZ3.
	10A	Temporary construction compound of 2179 metres in area shown on sheet 2 of the works plans, to the north-west of the highway of Sheepway at Shipway Gate Farm, Portbury;	Temporary	Defended FZ3		FZ1, defended FZ2 and defended FZ3.
	10B	Temporary construction haul road to the north of the highway of Sheepway of 125 metres in length shown on sheet 2 of the works plans, at Shipway Gate Farm, Portbury;	Temporary	FZ1		FZ1
	10C	Pond, of 586 metres in area, shown on sheet 2 of the works plans, within the Portbury Wharf Nature Reserve, Portbury;	Permanent	Defended FZ3		Defended FZ3
	11	Improvements to the existing agricultural access from Shipway Gate Farm, Portbury to the highway of Sheepway, shown on sheet 2 of the works plans, south of the former Portishead branch line;	Permanent	Defended FZ3		Defended FZ3
	11A	Temporary construction haul road, of 590 metres in length, shown on sheet 2 of the works plans, east from the highway of Sheepway, to the south of and parallel to former Portishead Branch Line to Work No. 12A;	Temporary	FZ2 and defended FZ3		FZ1, defended FZ2 and defended FZ3.

	11B	Temporary construction haul road of 269 metres in length, shown on sheet 2 of the works plans, to the south of the highway of Sheepway at Shipway Gate Farm, Portbury;	Temporary	FZ2 and defended FZ3		Defended FZ3
	12	Permanent new access to the A369 classified road known as Portbury Hundred, shown on sheet 3 of the works plans;	Permanent	Defended FZ3		Defended FZ3
	12A	Temporary construction compound, of 113467 square metres in area, shown on sheets 2, 2B and 3 of the works plans, to the north of the A369 classified road known as Portbury Hundred and to the south of the former Portishead Branch line;	Temporary	FZ2 and defended FZ3		FZ1, defended FZ2 and defended FZ3.
	12B	Pond and associated ecological works, shown on sheet 3 of the works plans, to the north of Work No.1 and south of the highway of Sheepway, Portbury;	Permanent	FZ1		FZ1
	13	Improvement of the existing access and parking area, shown on sheet 4 of the works plans, at The Drove, Portbury, to the north of the A369 classified road known as Portbury Hundred, including additional permanent car parking spaces and improvement of existing car parking area;	Permanent	Defended FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Simulations without coastal flood defences show the Portishead Branch Line (MetroWest Phase 1) Project between Royal Portbury Dock Road and M5 motorway to be outside the undefended 1000-year coastal flood extent (see EA coastal flood model depth map provided in Appendix B - SW6012 0.1% Undef Tidal Depth data.pdf). Hydraulic modelling of Drove Rhyne undertaken for The Project indicate there is potential for localised surface water flooding under the Royal Portbury Dock road bridge. However, the modelling does not include a detailed representation of surface water drainage processes. The drainage design considers the local drainage of surface water further.	Defended FZ3
	13A	Temporary vehicle turning circle, shown on sheet 4 of the works plans, south of the former Portishead branch line, Portbury;	Temporary	Defended FZ3		Defended FZ3
	14	Improvement to bridleway LA15/21/20, shown on sheet 4 of the works plans, at its junction with the highway of Royal Portbury Dock Road, Portbury;	Permanent	FZ1		FZ1
	14A	Improvement to bridleway LA8/66/10, shown on sheet 4 of the works plans, at its junction with the highway of Royal Portbury Dock Road, Portbury;	Permanent	FZ1		FZ1
	14B	Realignment of the existing permissive cycling route, shown on sheet 4 of the works plans, under Royal Portbury Dock Road, Portbury;	Permanent	FZ1 and defended FZ3		FZ1 and defended FZ3
	15	Temporary path to connect bridleway LA8/66/10 with the highway of Marsh Lane, shown on sheet 5 of the works plans, on the western side of Marsh Lane, Easton in Gordano, and north of the former Portishead branch line;	Temporary	FZ3	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Simulations without coastal flood defences show the Portishead Branch Line (MetroWest Phase 1) Project between Royal Portbury Dock Road and M5 motorway to be outside the undefended 1000-year coastal flood extent (see EA coastal flood model depth map provided in Appendix B - SW6012 0.1% Undef Tidal Depth data.pdf). The EA Flood Zones show the parts of temporary path and parts of the cycle way to be within the River Avon FZ3 due to the projection of Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelled (tidally dominated) flood levels in this area. However, hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project has provided a more refined estimate of flood risk in this area by applying CAFRA modelled level time series (for design events) as a downstream boundary to the Easton-in-Gordano Stream model and hence assessing a more realistic propogation of River Avon flood levels up the Easton-in-Gordano Stream. These simulations indicate the propsoed temporary path and cycleway works are outside of the 1000-year fluvial and tidal flood extents.	FZ1
	16	Realignment path of 11 metres in length to connect bridleway LA8/66/10 with the highway of Marsh Lane, shown on sheet 5 of the works plans, on the western side of Marsh Lane, Easton in Gordano, and north of the former Portishead branch line;	Permanent	FZ3		FZ1
	16A	Temporary construction compound of 7509 square metres in area shown on sheet 5 of the works plans, beneath the M5 Special Road Avonmouth Bridge, Easton in Gordano;	Temporary	FZ2	The EA Flood Zones show the construction compound to be within River Avon FZ2, due to the projection of Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelled (tidally dominated) flood levels in this area. Hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project has provided a more refined estimate of flood risk in this area by applying CAFRA modelled level time series as a downstream boundary to the Easton-in-Gordano Stream model and hence assessing a more realistic propogation of River Avon flood levels up the Easton-in-Gordano Stream. These simulations indicate the temporay construction compound is outside of the Easton-in-Gordano Stream fluvial and tidal 1000-year flood extents. (Figures K104 and K.112 in Appendix K).	FZ1

	16B	Pond and associated ecological works, shown on sheet 5 of the works plans, to the south of the former Portishead branch line and west of the M5 Special Road, Easton in Gordano;	Permanent	FZ2 and FZ3	The EA Flood Zones show the proposed pond to be within River Avon FZ2 and FZ3, due to the projection of Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelled (tidally dominated) flood levels in this area. Hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project has provided a more refined estimate of flood risk in this area by applying CAFRA modelled level time series as a downstream boundary to the Easton-in-Gordano Stream model and hence assessing a more realistic propogation of River Avon flood levels up the Easton-in-Gordano Stream. These simulations indicate the propsoed pond is partly within the Easton-in-Gordano Stream tidal 200-year and 1000-year flood extents, (Figures K111 and K.112 in Appendix K) and within the fluvial 30-year, 100-year and 1000-year flood extents (Figures K101, K102 and K.104 in Appendix K).	FZ3b
	16C	Road rail access point shown on sheet 5 of the works plans, west of the Avonmouth Bridge of the M5 Special Road, Easton in Gordano;	Permanent	FZ1	n/a	FZ1
	16D	Flood water storage area of 4078 square metres in area, shown on sheet 5 of the works plans, to the south of the former Portishead branch line railway and west of the M5 Special Road, Easton in Gordano;	Permanent	FZ2 and FZ3	The EA Flood Zones show the proposed floodplain compensation area to be within River Avon FZ2 and FZ3, due to the projection of Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelled (tidally dominated) flood levels in this area. Hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project has provided a more refined estimate of flood risk in this area by applying CAFRA modelled level time series as a downstream boundary to the Easton-in-Gordano Stream model and hence assessing a more realistic propogation of River Avon flood levels up the Easton-in-Gordano Stream. These simulations indicate the propsoed floodplain compensation area is partly within the Easton-in-Gordano Stream fluvial 30-year, 100-year and 1000-year flood extents (Figures K101, K102 and K.104 in Appendix K).	FZ3b, FZ3a and FZ2
	17	Temporary construction compound of 89293 square metres in area shown on sheets 5 and 6 of the works plans, at Lodway Farm, Pill, together with access to the highway of the Breaches, Easton in Gordano;	Temporary	FZ1	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M.	FZ1
	17A	Temporary construction haul road, of 1078 metres in length shown on sheet 6 of the works plans, between Work No. 17 and footpath LA8/5/40, Pill;	Temporary	FZ1		FZ1
	18	Bridleway, of 211 metres in length shown on sheet 5 of the works plans, commencing at a point to the west of the M5 Special Road and passing under the Avonmouth Bridge of the M5 to join National Cycle Way Network Route 41 between the Avonmouth Bridge of the M5 Special Road and Pill;	Permanent	FZ2	Coastal flood model simulations undertaken for The Project indicate the entire Portishead to Pill (disused section) is outside of the 1000-year return period coastal flood extent when coastal flood defences are accounted for in the modelling (not accounted for in the EA FZ2 modelling) - see Figure M1 in Appendix M. Simulations without coastal flood defences show the Portishead Branch Line (MetroWest Phase 1) Project between Royal Portbury Dock Road and M5 motorway to be outside the undefended 1000-year coastal flood extent (see EA coastal flood model depth map provided in Appendix B - SW6012 0.1% Undef Tidal Depth data.pdf). The EA Flood Zones show parts of the bridleway to be within the River Avon FZ2 due to the projection of Bristol City Council Central Area Flood Risk Assessment (CAFRA) modelled (tidally dominated) flood levels in this area. However, hydraulic modelling of Easton-in-Gordano Stream undertaken for The Project has provided a more refined estimate of flood risk in this area by applying CAFRA modelled level time series (for design events) as a downstream boundary to the Easton-in-Gordano Stream model and hence assessing a more realistic propogation of River Avon flood levels up the Easton-in-Gordano Stream. These simulations indicate the proposed bridleway works are outside of the 1000-year fluvial and tidal flood extents.	FZ1
	19	Installation of new and alteration of existing railway signal equipment, troughs and cables, as shown on sheets 5 and 6 of the works plans, on the Bristol Port Company's railway from Portbury Junction and a new railway signal at the Bristol Port Company's Royal Portbury Dock;	Permanent	FZ1	n/a	FZ1
	20	Temporary diversion of part of National Cycle Network Route 41 of 83 metres in length shown on sheet 6 of the works plans, north from its existing alignment on the street north of the Portishead Branch Line, west of Avon Road, Pill, to connect with the western turning head of Avon Road, Pill;	Temporary	Mostly FZ1. Partly FZ2 and FZ3.	CAFRA model results (2015) at this location confirm the proposed works are mostly FZ1 and partly FZ2 and FZ3.	Mostly FZ1. Partly FZ2 and FZ3.
	20A	Demolition of existing bridge carrying the Portishead Branch Line over footpath LA8/5/40 and construction of new bridge and abutments, shown on sheet 6 of the works plans, south of Avon Road, Pill and north of Lodway Close, Pill;	Permanent	FZ1	n/a	FZ1

	20B	Demolition of existing garages and temporary construction compound of 1990 square metres in area, as shown on sheet 6 of the works plans, Avon Road, Pill;	Permanent	FZ1	n/a	FZ1
	21	Car park of 2004 square metres in area, as shown on sheet 6 of the works plans, to the south of Severn Road and Monmouth Road, Pill, including landscaping, accesses to highway, drainage and attenuation tanks, signage, lighting, fencing, drainage ducts, troughs, communications apparatus and utilities apparatus;	Permanent	FZ1	n/a	FZ1
	21A	Road/rail access point, permanent railway maintenance compound of 820 square metres in area and principal supply point building, as shown on sheet 6 of the works plans, south of Severn Road, Pill, including landscaping, lighting, fencing, drainage, ducts, troughs, communications apparatus, utilities apparatus, bat accommodation and associated access;	Permanent	FZ1	n/a	FZ1
	22	New railway station, shown on sheet 6 of the works plans, comprising platform, ramp, signage, seating, ticket vending machine, closed circuit television equipment, passenger help point, information boards and displays, passenger refuge area, car park (including mobility impaired spaces) drop off point, and cycle parking facilities, demolition of No. 7 Station Road, lighting, fencing, landscaping, ground strengthening and stability works, communications apparatus, drainage and utilities apparatus, to the north west of Station Road, Pill;	Permanent	FZ1	n/a	FZ1
	22A	Improved bus waiting facility, shown on sheet 6 of the works plans, on the highways of Lodway and Heywood Road, Pill, north of the Pill Memorial Club, Pill, together with retaining wall, lighting, drainage and utilities apparatus;	Permanent	FZ1	n/a	FZ1
	22B	Temporary construction compound of 1067 square metres in area, shown on sheet 6 of the works plans, within the car park of Pill Memorial Club, Lodway, Pill;	Temporary	FZ1	n/a	FZ1
	23	Temporary construction compound of 151 square metres in area, as shown on sheet 6 of the works plans, beneath and to the north of Pill Viaduct, Underbanks, Pill;	Temporary	FZ3	CAFRA model results at this location indicate ground levels at the compound (approximately 8.6mAOD) are below adjacent River Avon flood levels for the 20 year tidal flood in 2015 (8.78mAOD). However, the compound location is protected by flood defences which are above the 20 year flood level but below the 200 year flood level.	FZ3a
	24	Permanent vehicular compound of 2011 square metres in area, shown on sheet 8 of the works plans, south of Ham Green Lake, together with a road/rail vehicle access point, permanent access south from the highway of Chapel Pill Lane to the compound and new fencing, lighting, landscaping, utilities connections, laying of electricity, water, drainage and communications conduits and apparatus together with a new access to Ham Green Lake and improvements to Chapel Pill Lane;	Permanent	FZ1	n/a	FZ1
	24A	Temporary construction compound of 6653 square metres in area, shown on sheet 8 of the works plans, accessed from the highway of Chapel Pill Lane, Ham Green, Pill; and	Temporary	FZ1	n/a	FZ1
	25	Reconstruction of accommodation bridge known as Quarry Bridge No. 2, temporary construction compound and temporary ramp for construction access to the railway, shown on sheet 12 of the works plans, to the east of the Portishead Branch Line.	Permanent	FZ1	n/a	FZ1

	26	Permanent vehicular access, ramp, flood attenuation works and railway maintenance compound, of 2948 square metres in area shown on sheet 15 of the works plans, east of the highway of the A369 classified road known as Clanage Road, Ashton, north of the Bedminster Cricket Club;	Permanent	FZ3	The CAFRA model detail in the vicinity of the Portbury Freight Line/River Avon near Bower Ashton has been updated for this project. The updated CAFRA model results indicate that the permanent vehicular access, ramp and railway maintenance compound, and the temporary construction compound, are mostly within the modelled 20 year flood extents (River Avon tidal event). Simulated tidal River Avon flood maps are shown in Appendix N. However, a consideration of historic flooding and uncertainty in CAFRA model results (FRA Section 4.2.12 to 4.2.19) concludes the modelling is likely to overestimate flooding and assigning FZ3b is precautionary.	FZ3b
	26A	Temporaryconstruction compound of 3346 square metres in area, shown on sheet 15 of the works plans, east of the highway of the A369 classified road known as Clanage Road, Ashton, north of the Bedminster Cricket Club,	Temporary	FZ3		FZ3b
	26B	Permanent vehicular access to the highway of the A369 classified road known as Clanage Road, Ashton from the land to the north of the Bedminster Cricket Club, shown on sheet 15 of the works plans;	Permanent	FZ3	The CAFRA model detail in the vicinity of the Portbury Freight Line/River Avon near Bower Ashton has been updated for this project. The updated CAFRA model results indicate that the maintenance road/access point is mostly within the 200 year flood extent, and partly within the 20 year flood extent (River Avon tidal event) Simulated tidal River Avon flood maps are shown in Appendix N. However, a consideration of historic flooding and uncertainty in CAFRA model results (FRA Section 4.2.12 to 4.2.19) concludes the modelling is likely to overestimate flooding and assigning FZ3b is precautionary.	Mostly FZ3a, partly FZ3b
	27	Foot and cycle track and ramp of 140 metres in length, shown on sheets 15 and 16 of the works plans, from the A370 classified road known as Ashton Road to Ashton Vale Road to the west of the Portishead Branch Line, Ashton, together with works to utilities apparatus, drainage, fencing, lighting and landscaping;	Permanent	FZ2	The CAFRA model detail in the vicinity of the Portbury Freight Line/River Avon near Bower Ashton has been updated for this project. The updated CAFRA model results indicate that the ramp is within the 1000 year longmoor/Colliters Brooks fluvial flood extent but outside the 100-year flood extent. Simulated flood maps for the 100-year and 1000-year return periods are shown in Appendix N.	FZ2
	28	Improvementof the highway of Winterstoke Road at its junction with Ashton Vale Road, Ashton, as shown on sheet 16 of the works plans, including extension of existing left turn lane in to Ashton Vale Road, works to divert and install utility apparatus and installation of a new traffic signal control system, Ashton; and	Permanent	FZ2	The CAFRA model detail in the vicinity of the Portbury Freight Line/River Avon near Bower Ashton has been updated for this project. The updated CAFRA model results indicate that the proposed highway works are within the 1000 year longmoor/Colliters Brooks fluvial flood extent but outside the 100-year flood extent. Simulated flood maps for the 100-year and 1000-year return periods are shown in Appendix N.	FZ2
	29	Temporary compound of 3176 square metres within the rail freight facility at Liberty Lane, Bristol, shown on sheet 17 of the works plans.	Temporary	FZ1	n/a	FZ1

MetroWest

Portishead Branch Line (MetroWest Phase 1)

TR040011

Applicant: North Somerset District Council
5.6, Flood Risk Assessment,
Appendix M Further development of Environment Agency coastal modelling
The Infrastructure Planning (Applications: Prescribed Forms and Procedure)
Regulations 2009, regulation 5(2)(e)
Planning Act 2008

Author: CH2M
Date: November 2019

TECHNICAL MEMORANDUM

Metro West Phase 1 FRA – Coastal Modelling Technical Note

PREPARED FOR:	North Somerset Council
COPY TO:	
PREPARED BY:	Kostya Vasilyev
DATE:	September 2019
PROJECT NUMBER:	
REVISION NO.:	3
APPROVED BY:	Robert Bird

1.0 Introduction

1.1 Purpose of this note

This note provides background information and details on hydraulic modelling work carried out as part of a Flood Risk Assessment Study using the already available tidal coastal TUFLOW (2D) model for the project, which is described in Section 1.2 of this note.

1.2 Study background

CH2M HILL (now Jacobs) was appointed by North Somerset Council to undertake a Flood Risk Assessment (FRA) for the MetroWest Phase 1 Development Consent Order (DCO) application.

The exercise includes adapting and re-running with appropriate boundary conditions (present day and future scenarios) an available Environment Agency TUFLOW (2D) coastal model. This analysis was undertaken to compare pre- and post- development water levels for various return periods for the present day (2015) scenario and future (2115) scenario with allowances for projected future climate change and sea level rise.

1.3 Study objectives

The primary study objectives are as follows:

i. Specify design tidal flows into the 2D inundation model for the present day (2015) and future (2115) scenarios;

ii. Specify design overtopping flows of the tidal sea defences for the present day (2015) and future (2115) scenarios;

iii. Review the 2D coastal model data using available topographic survey data (AP Land Survey and Network Rail survey, both undertaken in 2015) and improve model detail if required for this study;

iv. Undertake simulations for the pre-development scenario;

v. Develop a post-development model and undertake simulations. Thus enabling an assessment of flood risk to the proposed development and the impact of the proposed development on flood risk elsewhere.

This technical note will focus on objectives iii, iv, and v, since the wave transformation and overtopping modelling undertaken to derive model boundary conditions is reported separately.

2.0 Existing EA coastal model overview

The modelling exercise described in this technical note has been carried out using an existing TUFLOW (2D) coastal model representing the coastal area relevant to the MetroWest Phase 1 Development Consent Order application.

This model was developed as part of the hydraulic modelling project for the larger area in 2010-2012. This project was commissioned by the Environment Agency's South West Region Wessex Area, Flood Incident Management team to Jeremy Benn Associates (JBA) under Commission Number SW024a of 01 September 2010.

The project title was "Somerset North Coast Flood Warning Improvements". The overall aim of the project was to improve the coastal flood warning procedures. More details about the modelling work for this project can be found in JBA Consulting's Final Model Development Report "Somerset North Coast Flood Warning Improvements" dated June 2012.

The part of the model from this 2010-2012 project that was relevant to the modelling exercise described in this note was Som4. This is the model covering Portbury. The model extents for the Coastal TUFLOW (2D) model are shown on Figure 1.

The boundary conditions used in this Som4 model were tidal boundary conditions specifying the tidal levels, and overtopping inflow boundary conditions at Sea Commissioner's Defence.

The baseline date used in the JBA's model was 2011. In 2010-2012 the hydraulic simulations were run for the following return periods: 10 year, 25 year, 50 year, 75 year, 100 year, 200 year and 1000 year return periods as well as 200 year and 1000 year return periods undefended and 100 year return period breach for the present date situation (baseline date as described above). No climate change/sea level rise runs were undertaken.

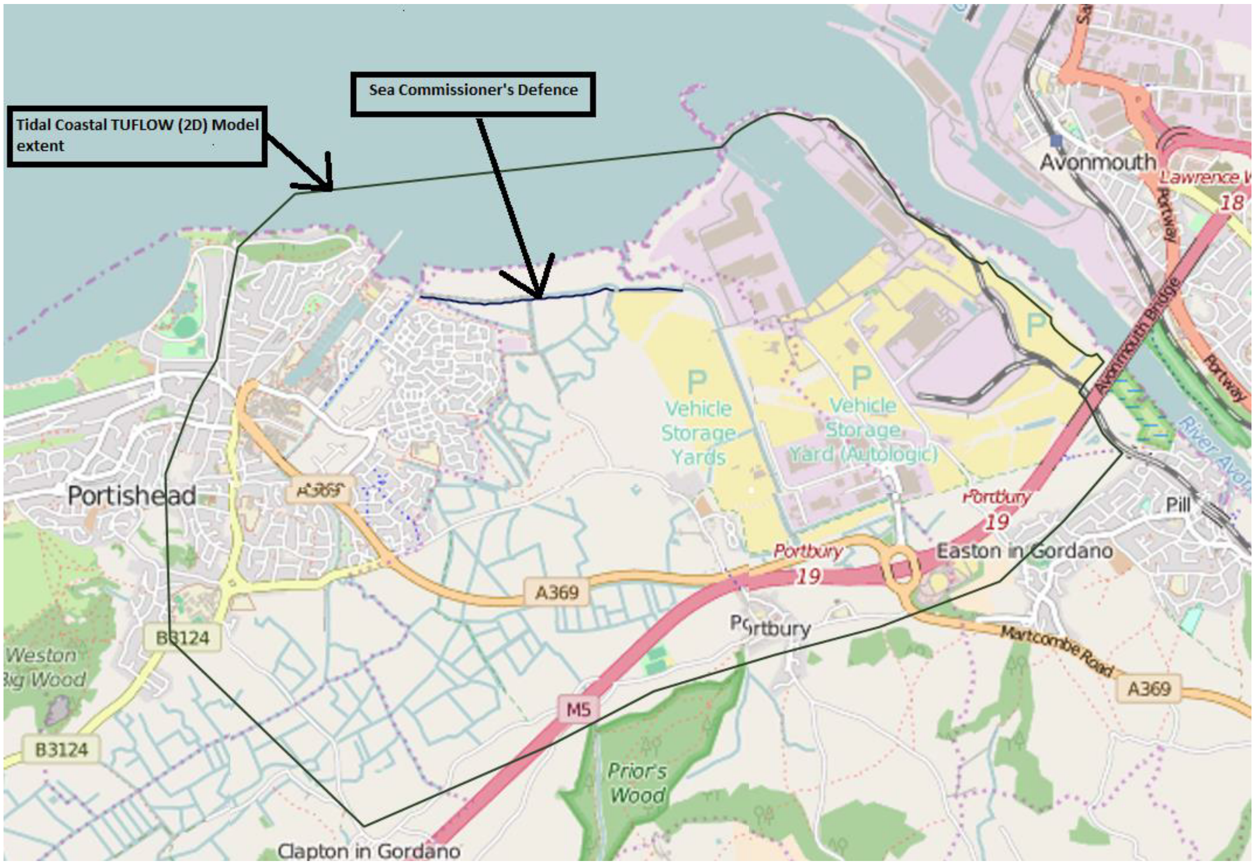


Figure 1. TUFLOW Coastal TUFLOW (2D) Model extent and Sea Commissioner's Defence line.

The grid size of the Som4 TUFLOW model (as used in this hydraulic modelling exercise) is 10m.

JBA's Som4 model already included some roads (those with width approximately greater than or equal to the 10m grid size), flood defences, and urban areas (applying Manning's n values of 0.1 in urban areas, to represent an average value for buildings and gardens). Small fluvial channels are represented using 1d network layers in ESTRY.

The representation of the existing railway in JBA's hydraulic model was not at a sufficient level of detail for this FRA, as it was represented in the DTM based on LiDAR data, rather than based on the more accurate topographic survey available for the MetroWest study.

3.0 Available data

3.1 Data list

A summary of all the data which was used during development of the model is provided in Table 1.

Table 1: Summary of data used to update the model.

File name	Description	Format	Date	Comments
AP Survey	Cross section surveys along the Drove-Rhyne and the Easton-in-Gordano drain	AutoCAD drawings	November 2015	The surveys cover the area requested along Drove-Rhyne and Easton-in-Gordano Stream. Bed levels are reported for both hard and soft bed conditions.
Network Rail level survey	Survey of the embankments along the railway line.	AutoCAD drawings	November 2015	The survey extent includes the embankments and the rails along the railway line within the coastal model extent.
Metrowest Phase 1 - Culvert Survey Report - W1079B-ARP-REP-ETR-000002 (ARUP)	Culvert details along railway alignment	Pdf	September 2015	The document included position and approximate dimensions of culverts/ structures draining the railway line.
2m LiDAR for the area	LiDAR of the study area	ASCII grid	Downloaded in Sept 2015	2m resolution LiDAR for the area used to update the 2d domain, downloaded from Geomatics. Lower resolutions were not available.
MasterMap for the area	MasterMap tiles used for the 2d domain roughness layer	Shapefile	Downloaded in Sept 2015	Downloaded as 1sq km tiles.
Somerset North Coast Flood Warning Improvements (Final Model Development Report) by JBA	Report that contains information about the TUFLOW model developed for the Somerset North Coast	PDF	June 2012	This is the report which describes the model in the line below, i.e. the model which was used during this project
TUFLOW Model Som4	The model used/developed further for this project	TUFLOW model files	2011	
Information supplied as part of the wave transformation and overtopping modelling undertaken for this project	Model boundary data and Technical Note reporting development of the tidal and overtopping boundary conditions to be used for the Coastal Tidal model runs	PDF and Excel files	2015	
MetroWest Phase 1 design drawings	MetroWest Phase 1 design drawings	PDFs	December 2015	

3.2 Topography review - data quality and implications

The 2015 AP Land Survey topographic survey covers the area indicated in Figure 2 along Drove-Rhyne and the area in Figure 3 along Easton-in-Gordano Stream. The survey included both information on the morphology of the watercourses and dimensions of key culverts/structures. See Metro West Phase 1 FRA - Fluvial Modelling Technical Note for more information on the limitations of this survey data.

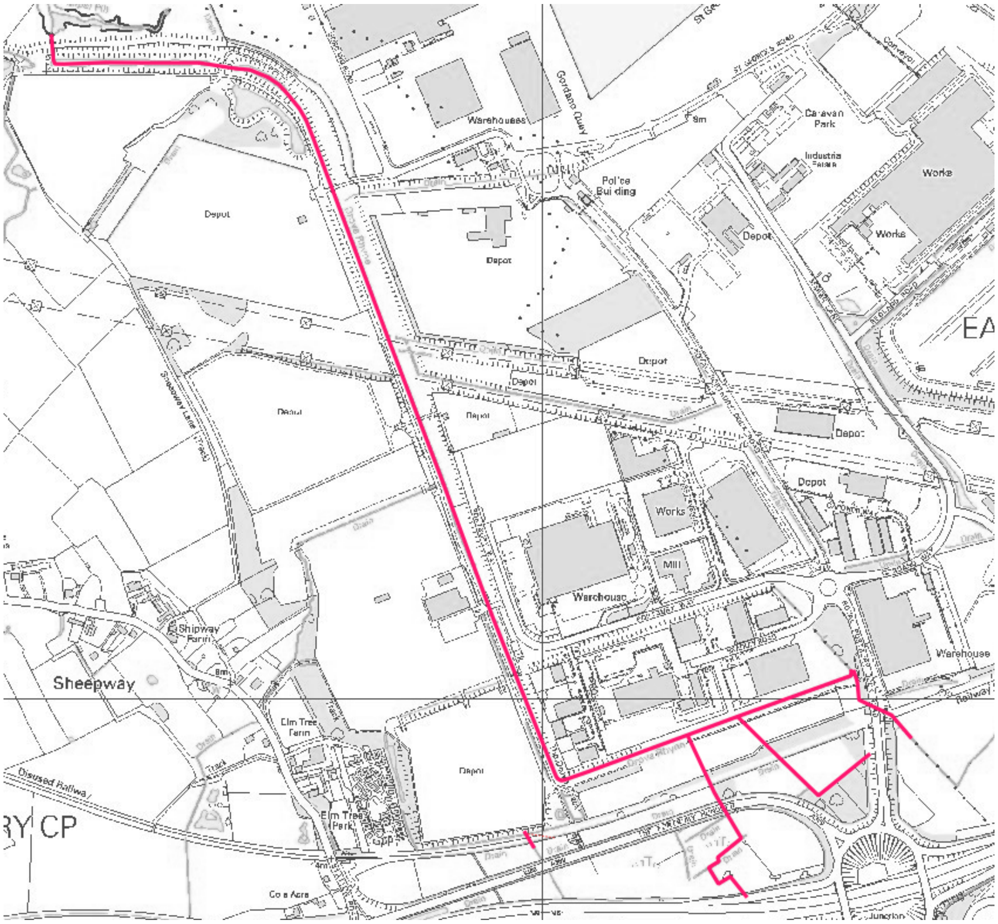


Figure 2. Extent of 2015 AP survey along the Drove-Rhyne

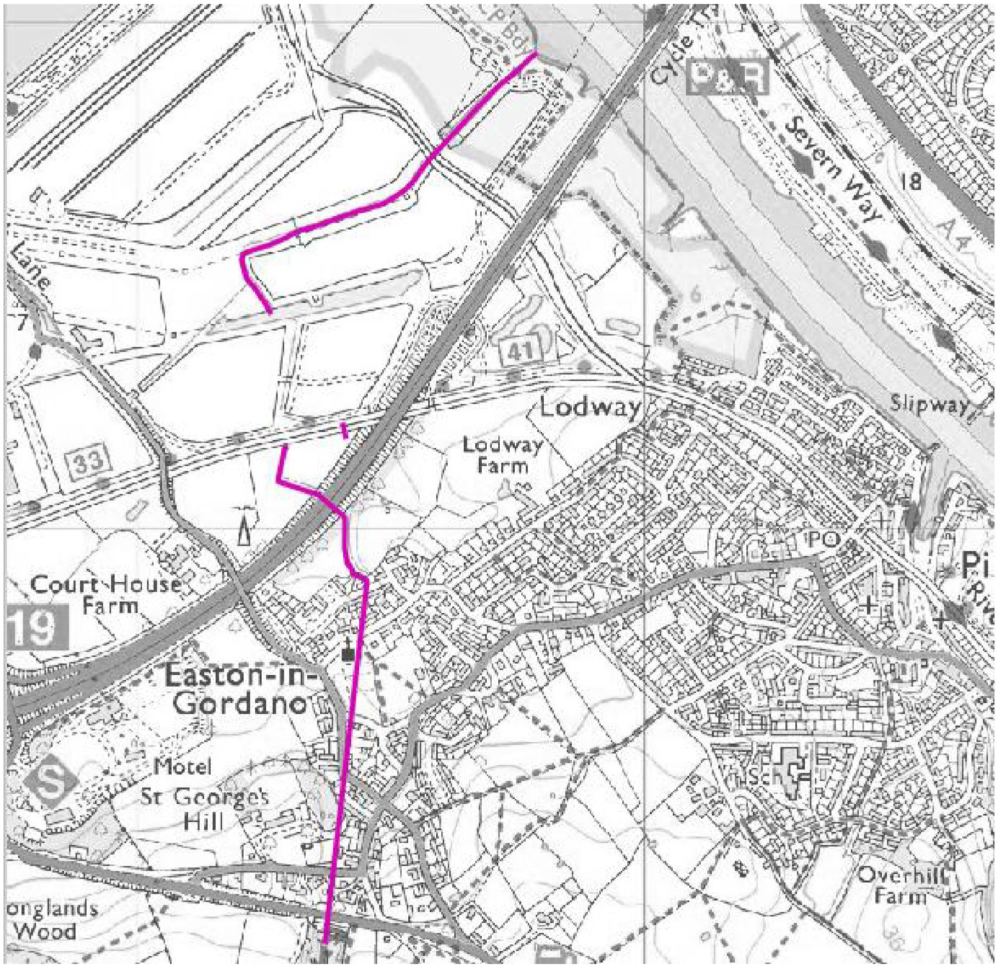


Figure 3. Extent of 2015 AP survey along the Easton-in-Gordano

The Network Rail survey includes level information along the railway in its current state (Autumn 2015) including the rail levels and the embankment levels. The information was provided with a vertical elevation offset of +100m initially in Snakegrid format and later in OS grid coordinates.

Ground level information in the form of a Digital Terrain Model was available. This data was already incorporated in JBA's 2010-2012 model. JBA's Somerset North Coast Flood Warning Improvements Final Model Development Report confirms most of the study area is represented by 1m LIDAR data. Data gaps were in-filled with 2m LIDAR data (by JBA). For the offshore areas, bathymetry data has been used. Each of these data sources are read in as a separate zpt layer in TUFLOW.

A comparison of LiDAR-derived levels in the model with topographic survey levels (AP Land Survey and Network Rail survey data) at locations where LiDAR data is expected to perform well, e.g. tarmac roads, open areas with grass, indicates the datasets are consistent with no systematic differences, and with level differences between the datasets typically within approximately 0cm to 7cm).

In addition, in 2015 Arup surveyed culverts along the MetroWest Phase 1 railway extent. This survey includes photos and dimensions of the culverts and ditches, including at culverts requested by the MetroWest Phase 1 modelling team (culvert numbers in the Arup report Metrowest Phase 1 - Culvert Survey Report - W1079B-ARP-REP-ETR-000002: 3, 15, 57, 70, 72, 73, 75, 76). Where dimensions in their report are not included it was due to insufficient access or overgrown vegetation.

4.0 Modifications to the model

4.1 Overview

During this project the following modifications were done to the model TUFLOW Model Som4 (produced by JBA in 2011):

- Tidal boundaries changed as per the tidal flows estimation for the present day (2015) and future (2075 and 2115) scenarios
- Extended tidal boundary along River Avon upstream as far as the M5 motorway crossing of the River Avon (where high ground levels are above the tidal design levels)
- Calculated overtopping and overflow flows applied for the tidal sea defences
- Topographic Feature line added representing the proposed MetroWest railway (using Network Rail survey from Autumn 2015)
- Topographic Feature line added representing the proposed MetroWest railway (using the PDFs such as w1097B-ARP-DRG-ETR-000247.pdf and others dated December 2015)
- 8 culverts located along the railway alignment added into the ESTRY 1D domain of the model
- Other minor modifications enabling the simulations of the model for certain return periods to run to completion

4.2 Overtopping and overflow calculations

Details of the overtopping calculations are in the appended technical note “Wave transformation and overtopping modelling – MetroWest Phase 1 FRA: Coastal flood risk modelling”. Overtopping (of the Sea Commissioner’s Bank) inflows for the present day (2015) and future (2135) scenarios were calculated. For the future (2075 and 2115) scenarios, overtopping inflows were taken as those derived for 2135 (i.e. the overtopping inflows are slightly overestimated, and hence the assessment is conservative).

4.3 Topographic Feature Line representing the MetroWest railway.

A comparison between the Network Rail survey (of the top of rails and the railway ballast or embankment level) and the LiDAR data showed that the railway was not represented well in the LiDAR ground grids. It was therefore decided that the ground representation used in the TUFLOW model should be improved by creating a Topographic Feature Polyline to represent the railway level, applying the highest ballast levels near and along the railway from Network Rail survey. The Polyline created has been snapped to the relevant model points using MapInfo. The frequency of vertices in the resulting Polyline file was the same as the points representing the railway in the Network Rail survey (approximately one point per 8 – 10 meters). This polyline has been included in the relevant *.tgc files for the pre-development scenario runs.

For the post-development case a similar process has been adopted except that the polyline has been created in a shapefile format, with level information based on the MetroWest Phase 1 design drawings (December 2015).

4.4 Culverts

Several additional culverts were inserted into the Coastal model. These are listed in Table 2.

Table 2. Information about culverts inserted into the Coastal model domain.

Model ID	Type	Length	Roughness	Upstream Invert	Downstream Invert	Width	Height	Diameter	Entry Loss	Exit Loss	No in the Arup report
MDH_20	C	14.2	0.016	7.9	8.36			0.61	0.5	1	70
MDH_21	R	68.7	0.016	5.46	6.65	1	1		0.5	1	76
MDH_22	C	12	0.016	4.76	4.76			1.3	0.5	1	66
MDH_23	R	8	0.016	5.88	5.71	0.8	0.4		0.5	1	67
MDH_24	C	18.3	0.016	5	4.95			1	0.5	1	65
MDH_25	C	64	0.016	5.37	5.37			0.68	0.5	1	63/64
MDH_26	R	8.31	0.016	7.12	7.12	2.76	1.78		0.5	1	60
MDH_27	C	36	0.016	6.41	6.41		0	0.44	0.5	1	61

Note that culvert no 62 (as numbered in Arup's report) was not represented in the TUFLOW model modified as part of this exercise as this is a water mains culvert and flood waters are unlikely to get into this culvert.

The culverts already in the JBA's 2010-2012 TUFLOW model were cross-checked against data in the Drove-Rhyne and Easton in Gordano Stream models developed for the MetroWest Phase 1 FRA (and the information in these models was based on the 2015 AP Land Survey).

Figures 5 and 6 show the locations of culverts in the Tidal Coastal TUFLOW (2D) model as modified and developed for this FRA.

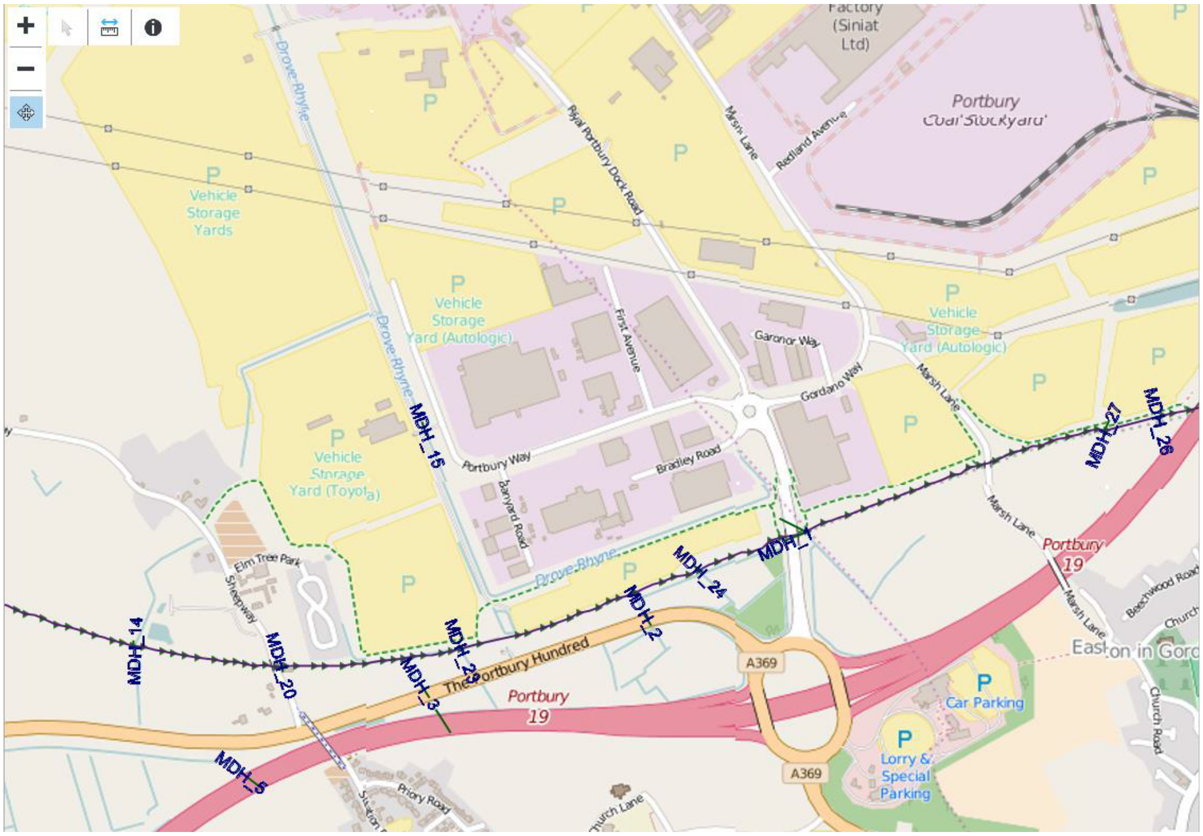


Figure 5. The locations of culverts in the eastern part of Tidal Coastal TUFLOW (2D) model

Figure 6. The locations of culverts in the western part of Tidal Coastal TUFLOW (2D) model

4.5 Other changes to the model

Stability patch

In order to improve stability for climate change runs the following topographic feature was added to the relevant .tgc files:

Read MI Z Shape == mi\2d_zsh_cul12_pgn.mif ! Raising of ground levels in the vicinity of MDH_12 Culvert to prevent flows from going above the culvert; the ground levels were raised to 6.5 m.

This is a stability patch, which raises ground levels slightly in order to prevent double counting of flows for climate change runs for the Coastal model near the culvert MDH_12.

Removal of dock entrance structure

The dock entrance structure as specified in relevant .tgc files by the line:

> Read MI Z Line [RIDGE | THICK] == mi\2d_zlr_Portbury_dock_entrance.MIF ! Level either side of Portbury Dock entrance and of entrance gates (set to maintained level)

has been removed from the future (2115) scenario runs apart from 100 year return period (100_year_cc). The reason for this was that this structure would cause the model to be unstable for higher boundary condition values (apart from the 100 year return period climate change runs). This dock entrance is far from the rail line. The test runs have shown that its presence does not have an effect on the extent of flooding near the railway.

Placing a flap on one of the culverts at the downstream side of Drove-Rhyne river

A flap was placed on the culvert at MDH_19, in accord with the 2015 AP Land Survey.

5.0 Model runs

For the present day (2015) scenario the model was run for the following return periods: 10, 25, 200 and 1000 year return periods. No post-development runs were required as there was no flooding simulated on the railway for the present day scenario.

For the future (2075) scenario the simulations for the following return periods were run:

200, 1000 year (same results pre and post development as flood levels do not overtop the railway)

For the future (2115) scenario the simulations for the following return periods were run:

25, 50, 75, 100, 200, 1000 year (both pre- and post-development).

Additionally the 200 year return period breach simulations for the present day (2015) and future (2115) scenarios were run. For these runs a 200m long breach was assumed along the outer defence line (there are two lines of defences between the estuary and the railway line). The breach was placed in a position that would maximise its effect on flood levels inland. Figure 7 shows the location of the breach, in the middle of the low lying land through which flood waters have potential to reach the railway. The breach was in place throughout the whole run (i.e. it doesn't happen at a specific point in the run, the defence has a gap there from the start of the run).

The models were run using the 2016-03-AD-iDP-w64 build of TUFLOW.

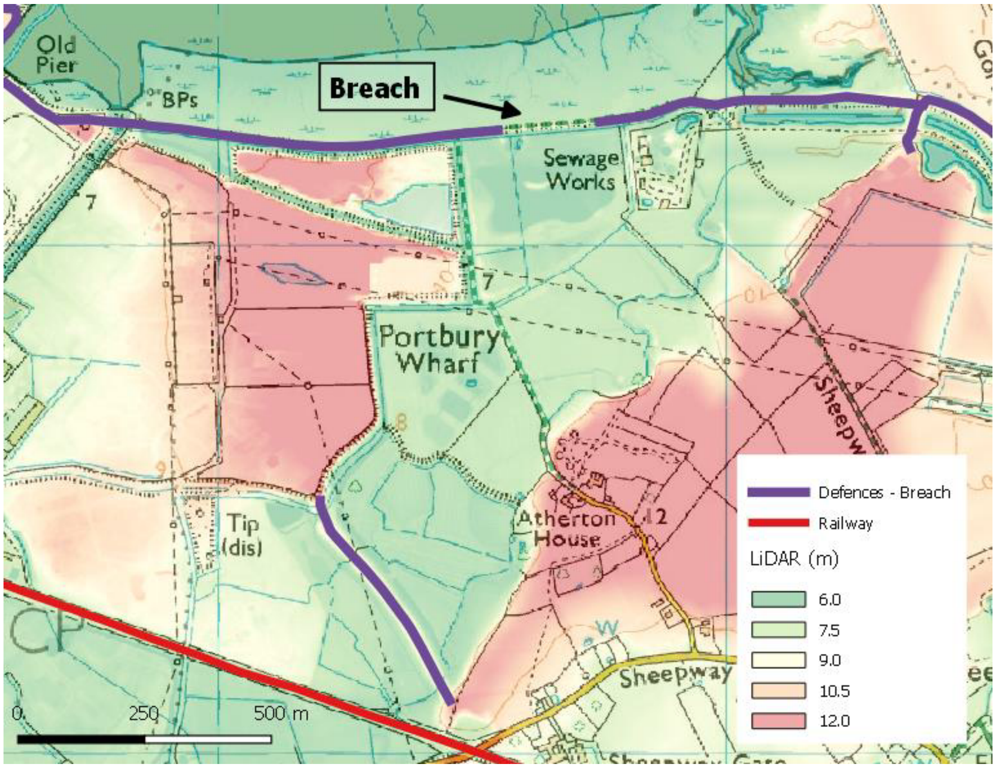


Figure 7. Breach location. Railway, defenses and ground level can be seen in this image.

6.0 Model results and interpretation

The model runs produced results for the return periods listed in Section 5.0. Flood maps showing modelled flood depth, velocity and hazard score for the return periods simulated above are presented in as an appendix. Depth difference plots (i.e. differences in pre-development and post-development flood depths) were also produced for the 100 year and 200 year return period future (2115) scenarios.

The model results show that no flooding is observed on the railway for the present day (2015) scenario simulations. For the future (2075 and 2115) scenarios simulated flood levels increase due to the projected future sea level rise.

For the future (2075) simulations, simulated 200 year flood extents do not reach the railway and 100 year peak flood levels are below the railway level. For the future (2115) simulations, the lowest return periods with simulated inundation of the railway is 200 years pre-development case and 1000 years post-development.

The breach simulations show no difference in maximum water levels compared to the simulations with the full defence in place, as during the 200 year return period event, both with and without climate change, water levels rise high enough (and for long enough) above the defence level for this defence to have no impact on water levels on either side of it. Thus the breach in the defence has no impact on maximum water levels on the inland side of the defence. However water does, as would be expected, flood the land behind the defence earlier in the scenarios with the breach in place.

Model results are discussed further in the MetroWest Phase 1 FRA.

7.0 Conclusions

The Environment Agency North Somerset Flood Warning Improvements model has been developed for use in the MetroWest Phase 1 FRA.

Model results indicate insignificant coastal flood risk to the project for present day (2015) and inundation of the railway (post development) approximately once every 200 to 1000 years for the future (2115) scenario, due to significant projected future sea level rise.

TECHNICAL NOTE

Wave transformation and overtopping modelling - MetroWest Phase 1 FRA: Coastal flood risk modelling

Prepared for

North Somerset Council

23 November 2015

Document history

Wave transformation and overtopping modelling - MetroWest Phase 1 FRA: Coastal flood risk modelling

North Somerset Council

This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified by	Approved by
1	23 November 2015	Draft for comment	Apostolos Kalpias	Bin Li	
2					
3					

Contents

1 Introduction

This technical note provides a summary of the wave transformation modelling and wave overtopping modelling undertaken for the MetroWest Phase 1 FRA Coastal flood risk modelling.

Coastal flood modelling was required to assess flood risk to the MetroWest railway line. More specifically, the modelling was required to assess current and future standard of operation of the proposed railway line and the impact of the proposed railway restoration between Portishead and Pill (South West of Bristol) on flood risk elsewhere.

The presented study was built on a previous study, i.e. Somerset North Coast Flood Warning Improvements - Model Development Report (*JBA Consulting, 2012*).

2 Objective

The aim of the previous study was to improve the coastal flood warning service to the coastal communities. Several scenarios were modelled from different extreme still water levels, wind directions and wind speeds.

The current study undertook additional simulations for a 2135 future scenario. To this end, the climate change and the associated sea level rise was applied.

2.1 Climate change parameters

The projection of impacts of climate change on extreme rainfall, flood flows and wind/waves is very uncertain. The estimated adjustments for climate change up to 2115 (i.e. 100 year horizon) were applied that are consistent with the Defra 2011 approach. For the estimate of the rate of sea level rise beyond 2115, it was assumed that the rate of increase is the same as for the period 2085 to 2115. Consequently, sea level rise and uplift to wind speed and wave height were applied. Table 1 summarises the climate change parameters that were implemented in the wave transformation model.

Table 1: Climate change parameters implemented in the wave transformation model.

Offshore wind speed	+10%
Extreme wave height	+10%
Sea level rise	+1.432m (relative to a base year 1990)

3 Methodology

The followed process was the same as described in the Somerset North Coast Flood Warning Improvements - Model Development Report (*JBA Consulting, 2012*).

The wave transformation model SWAN was used to consider the changing nature of waves as they travel from the offshore environment into the nearshore zone. More specifically, it was used to provide wave height, period and direction information at the toe of the coastal flood defences (i.e. fifty-seven output locations), from a range of offshore driving conditions (extreme sea-level, wind direction, wave direction and wind-speed).

These wave parameters were used to calculate wave overtopping rates for the different scenarios at one of the fifty-seven output locations, i.e. Portbury (348821m Easting, 177288m Northing). The defences at breach risk are the Commissioner’s Bank, which is between the dock gates in Portishead and Pill village (refer to Figure 1). The amount of overtopping was calculated using the methods outlined in the European Overtopping Manual (EurOtop). These overtopping results were inputs to the flood inundation model TUFLOW which is described in another technical note.

Summaries of the wave transformation modelling and the wave overtopping modelling are provided in Chapter 4 and Chapter 5 respectively. A more detailed description of the models and the data that have been used can be found in the Somerset North Coast Flood Warning Improvements - Model Development Report (*JBA Consulting, 2012*).

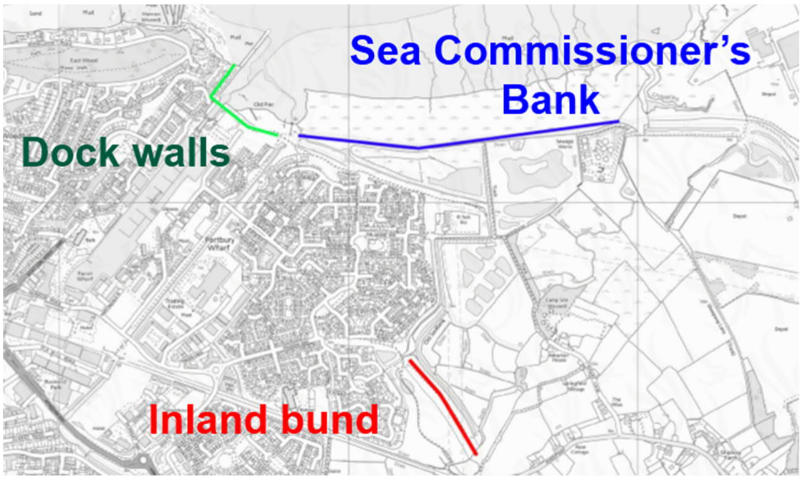


Figure 1. The defences at breach risk, i.e. the Commissioner's Bank, in Portbury.

4 Wave transformation modelling

Wave transformation modelling was undertaken using SWAN (Simulating WAves Nearshore). SWAN is a third-generation wave model, developed at Delft University of Technology, that computes random, short-crested wind-generated waves in coastal regions and inland waters.

The previous study used seven extreme still water levels, three wind directions (for each extreme still water level) and four wind speeds (for each wind direction), i.e. eighty-four different combinations for the offshore driving conditions. They are summarized in Table 2.

Table 2: The different offshore driving conditions that were used in the Somerset North Coast Flood Warning Improvements - Model Development Report (*JBA Consulting, 2012*).

Extreme Still Water Levels Return Periods (Years)	Wind Direction (Degrees)*	Wind Force (Beaufort Scale)
10	240 (Hs = 5.64m, Tz = 8.34m)	4
25	270 (Hs = 5.86m, Tz = 8.50m)	6
50	300 (Hs = 5.28m, Tz = 8.07m)	8
75		10
100		
200		
1000		

*** The corresponding wave boundary conditions are in parenthesis.**

It was decided that Wind Force 6 (i.e. Wind speed = 14m/s) should be used for the current study. For the climate change considerations, an uplift 10% in wind speed was applied (refer to Table 1).

The worst case wind direction (from 240, 270 or 300 degrees) was determined in terms of overtopping flows for the 200yr design event. Most overtopping (both cumulatively and as a peak value) was calculated for 300° in the previous study, as it is shown in Table 3. It is noted that wave overtopping was calculated for two locations (i.e. 7e00698 and 7e00720) representing two sections of the Commissioner's Bank defences in Portbury, as it is explained in the next chapter (i.e. 5 Wave overtopping modelling).

Table 3: Calculated overtopping discharges for 240, 270 and 300° (200yr extreme water level, Wind Force 6) for the locations 7e00698 and 7e00720.The peak values are shown in red. Source: data files from the previous study.

7e00698

Time (hrs)	OT_q(m3/s/m)_240	OT_q(m3/s/m)_270	OT_q(m3/s/m)_300
56.5	0	0	0
56.75	0	0	0
57	0	0	0
57.25	0	0	0.00003
57.5	0	0.00003	0.0003
57.75	0	0.00021	0.00133
58	0.00001	0.00048	0.0025
58.25	0.00001	0.00043	0.0023
58.5	0	0.00015	0.00103
58.75	0	0.00002	0.0002
59	0	0	0.00001
59.25	0	0	0
60	0	0	0
167.75	0	0	0
SUM	0.00002	0.00132	0.0077

7e00720

Time (hrs)	OT_q(m3/s/m)_240	OT_q(m3/s/m)_270	OT_q(m3/s/m)_300
56.5	0	0	0
56.75	0	0	0
57	0	0.00001	0.00002
57.25	0.03178	0.0712	0.10683
57.5	0	0	0
58.25	0	0	0
58.5	0	0	0
58.75	0	0	0
59	0.00531	0.01914	0.02844
59.25	0	0	0
60	0	0	0
167.75	0	0	0
SUM	0.03709	0.09035	0.13529

This direction, i.e. 300°, was adopted for the simulations. The corresponding boundary wave condition (as it had the same direction as the wind) was a JONSWAP type spectrum imposed at a segment of the ocean boundary with significant wave height Hs = 5.28m, mean zero-crossing period Tz = 8.07s and wave direction 300°. For the climate change considerations, an uplift 10% in wave height was applied (refer to Table 1).

The seven extreme still water levels that were used in the previous study (refer to Table 2) were applied. For the climate change considerations, +1.432m were added to account for sea level rise (refer to Table 1).

Table 4 summarises the different offshore driving conditions that were used in the simulations. In total seven combinations were applied: seven extreme still water levels, one wind direction and one wind speed for each extreme still water level.

The final model results for each defence site (i.e. fifty-seven output location points) are listed in Appendix A Wave transformation results.

Table 4: The different offshore driving conditions adjusted for the climate change considerations that were used.

Extreme Still Water Levels Return Periods (Years)	Wind Direction (Degrees) and Wave Boundary Condition	Wind Force (Beaufort Scale)
10, with +1.432m 25, with +1.432m 50, with +1.432m 75, with +1.432m 100, with +1.432m 200, with +1.432m 1000, with +1.432m	300° Hs = 1.1 x 5.28m = 5.808m Tz = 8.07m (T mean = 8.63s)*	6, uplifted 10% Equivalent Wind Speed: 1.1 x 13.8 = 15.18 m/s

*** The simulation files of previous study (that were used as basis) used T mean (not Tz).**

5 Wave overtopping modelling

Wave overtopping was calculated for one of the fifty-seven wave transformation modelling output locations, i.e. Portbury (348821m Easting, 177288m Northing). More specifically, it was calculated for the following two cross-sections representing different parts of the Commissioner's Bank defences in Portbury (refer to Figure 1):

- 7e00698 (347775m Easting, 177114m Northing).
- 7e00720 (348863m Easting, 177118m Northing).

These overtopping results were required as inputs to the flood inundation model TUFLOW and were the same cross-section locations as the ones provided in the data files from the previous study.

The wave overtopping was calculated using the methods outlined in the European Overtopping Manual (EurOtop). The amount of overtopping is quantified by the parameter 'q', which represents the mean overtopping discharge in m^3/s/m.

A set of input parameters was required for the calculations:

- The still water level at the toe of the defence to be overtopped.
- The incident wave conditions at the defence toe.

- The defence profile shape.

The still water levels comprised the seven extreme still water levels including sea level rise (refer to Table 4) and the astronomical tide. It is noted that the data files from the previous study used tidal data from two locations (namely "Level 376" and "Level 380"). The worst from the two was used for the calculations (i.e. highest level): "Level 380". There was the requirement the models to run for three tidal cycles.

The incident wave conditions (i.e. height Hs and period Tp) at the defence toe were obtained from the wave transformation model at the Portbury output location, for the seven combinations (i.e. seven extreme still water levels, one wind direction and one wind speed for each extreme still water level, refer to Table 4). Table 5 summarises them. The following should be noted:

- The spectral wave height H_{m0} (i.e. wave transformation modelling output which is equal to the significant wave height H_s according to the SWAN user manual) was used for the overtopping calculations. Depth limited wave breaking was taken into account using **max H_{m0} = 0.6 x depth**, because the water levels varied significantly.
- The wave period used for overtopping formulae in the EurOtop is the spectral period $T_{m-1.0}$. The peak period T_p (i.e. SWAN output) was coverted using **$T_p = 1.1\ T_{m-1.0}$** (refer to the EurOtop manual).

Table 5: Summary of the wave input parameters for the overtopping calculations.

Extreme Still Water Levels return periods (years)	significant wave height H_{m0} (m)	spectral wave period $T_{m-1.0}$ (s)
10	0.84	3.4
25	0.85	3.4
50	0.86	3.4
75	0.86	3.4
100	0.86	3.4
200	0.87	3.4
1000	0.88	3.4

The defence profile shapes of the two different locations (7e00698 and 7e00720) were provided from cross-shore measurements from the Channel Coastal Observatory. The defences are earth embankment seawalls as it can be observed from the profile shapes. Therefore, the empirical equations Eq. 5.9 & Eq. 5.10 from the European Overtopping Manual (EurOtop) were used to estimate the mean overtopping discharge. It is noted that the previous study used the PC Overtopping method for the earth embankment sections and the Neural Network method for the hard defences (refer to the Somerset North Coast Flood Warning Improvements - Model Development Report - *JBA Consulting, 2012*).

Figure 2 shows the cross-section of the 7e00698 location. The upper panel shows a 2009 beach survey and the lower panel shows a 2003 LIDAR survey (used to obtain an overview of the location).

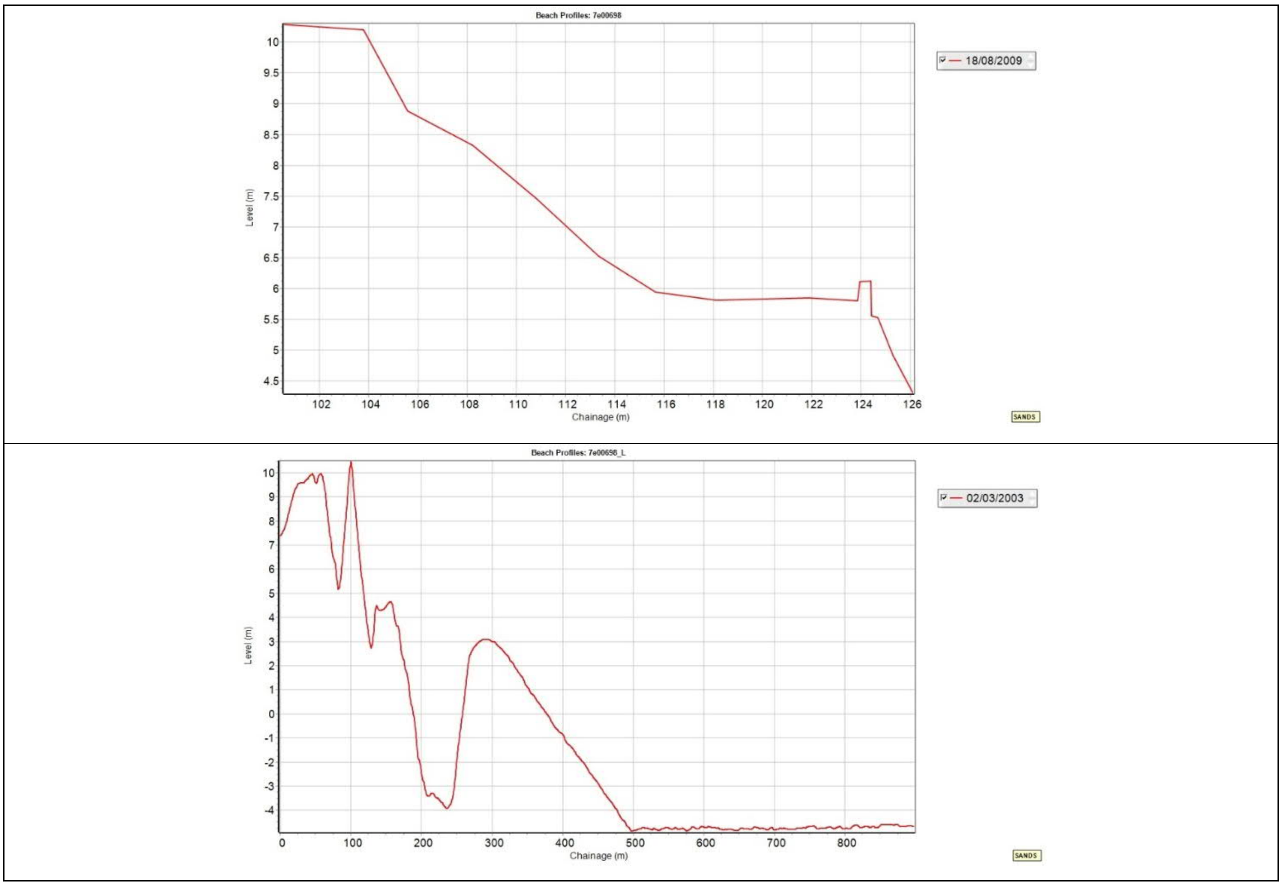


Figure 2. Cross-sections of the 7e00698 location. Upper panel: beach survey in 2009. Lower panel: LIDAR survey (Data courtesy of Channel Coastal Observatory).

The following profile shape parameters for 7e00698 were used for the overtopping calculations:

- Crest level = 10.29m AOD
- Defence slope = 1 : 3
- Toe level = 6.01m AOD (same as in wave transformation model, where output was required).
- Surface roughness factor $\gamma_f = 1$ (used for concrete, asphalt, grass – refer to EurOtop).
- Influence factor for oblique wave attack $\gamma_\beta = 1$ (assuming that waves attack perpendicularly the defence).

Figure 3 shows the cross-section of the 7e00720 location. The upper panel shows a 2011 beach survey and the lower panel shows a 2003 LIDAR survey (used to obtain an overview of the location).

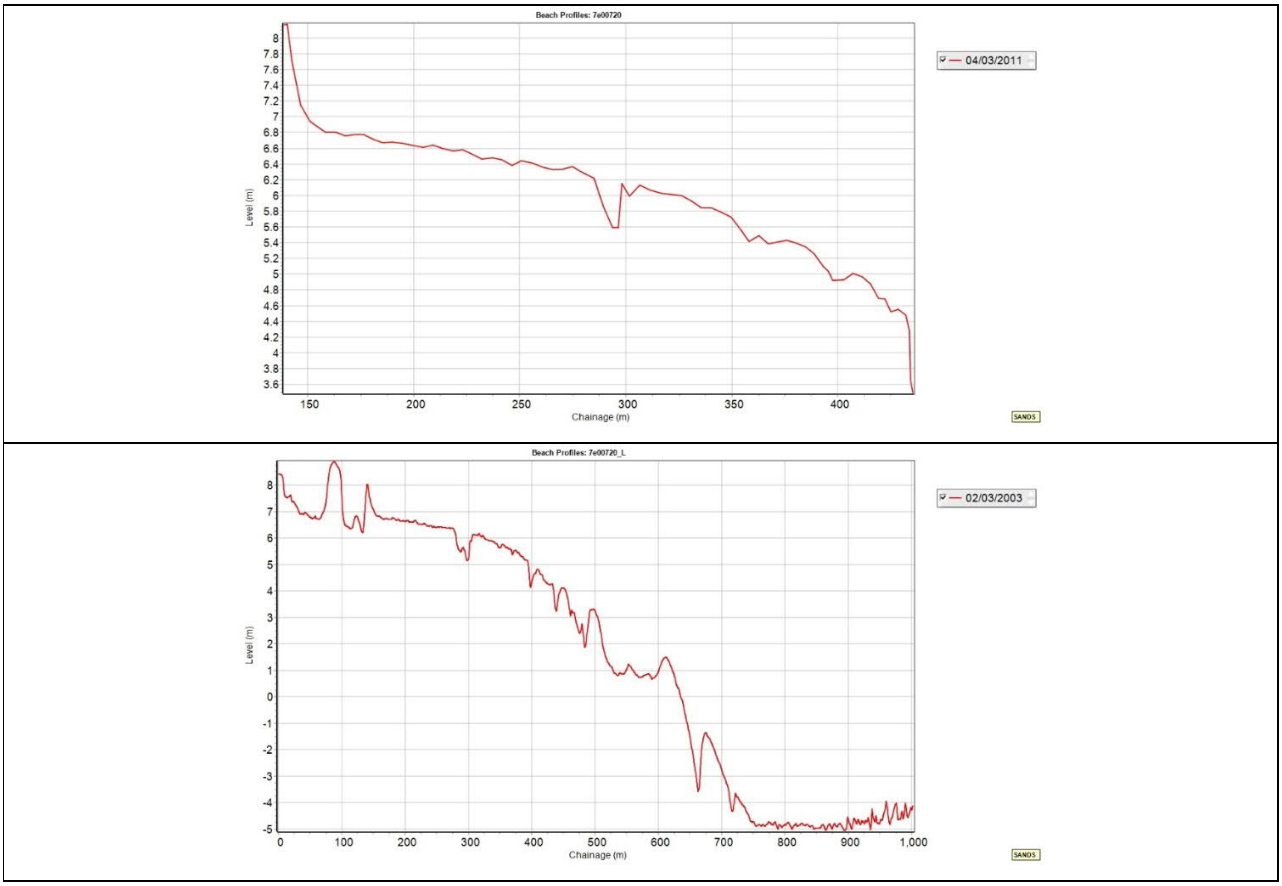


Figure 3. Cross-sections of the 7e00720 location. Upper panel: beach survey in 2011. Lower panel: LIDAR survey (Data courtesy of Channel Coastal Observatory).

The following profile shape parameters for 7e00720 were used for the overtopping calculations:

- Crest level = 8.18m AOD
- Defence slope = 1 : 6
- Toe level = 6.9m AOD. As it is shown in Figure 3, a foreshore exists at 6.01 (i.e. where wave information is given). The toe is at 6.9 AOD and therefore, wave breaking occurring across this (i.e. depth limiting the wave due to this) was taken into account.
- Surface roughness factor $\gamma_f = 1$ (used for concrete, asphalt, grass – refer to EurOtop).
- Influence factor for oblique wave attack $\gamma_\beta = 1$ (assuming that waves attack perpendicularly the defence).

The final results for both locations are listed in Appendix B Wave overtopping results. It is noted that overflow was calculated in several cases, especially for the 7e00720 location: the water levels were higher than the defence crest level (i.e. negative freeboard). The overtopping calculation methods become redundant in those circumstances as we are then looking at an entirely different problem (e.g. weir overflow equation could be used to calculate the discharges). Therefore, overtopping discharge values were not presented in those cases. The difference between the water levels and the defence crest level were provided for the subsequent TUFLOW calculations instead.

Appendices

A Wave transformation results

Table A1 – Water Level 10yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.08	3	10.3	2.88	8.38	5.51
Minehead_2	297218	146805	1.08	357	10.2	6.80	8.40	1.60
Minehead_3	297426	146366	0.79	3	10.3	1.62	8.40	6.78
Minehead_4	298071	146352	1.07	340	10.3	2.04	8.43	6.38
Minehead_5	298700	146567	1.89	335	10.2	5.95	8.44	2.50
Minehead_6	298866	146506	1.67	337	10.2	4.36	8.45	4.09
Minehead_7	299094	146444	1.63	343	10.2	4.55	8.47	3.92
Minehead_8	299321	146265	1.31	351	10.2	4.59	8.49	3.91
Minehead_9	299385	145958	1.01	1	10.2	3.16	8.50	5.34
Dunster Beaches_1	299718	145618	0.98	13	10.2	3.93	8.50	4.57
Dunster Beaches_2	299894	145257	0.89	2	10.2	3.16	8.51	5.35
Dunster Beaches_3	300212	144806	0.88	19	10.2	2.67	8.52	5.85
Dunster Beaches_4	300482	144600	0.89	4	10.2	3.00	8.52	5.52
Dunster Beaches_5	300622	144395	0.87	8	10.1	4.72	8.52	3.80
Dunster Beaches_6	301028	144206	1.07	350	10.1	5.46	8.53	3.07
Blue Anchor_1	301254	143762	0.88	359	10.1	4.29	8.54	4.24
Blue Anchor_2	301796	143598	1.13	347	10.1	4.71	8.54	3.83
Blue Anchor_3	302269	143533	1.33	339	5.5	5.59	8.54	2.95
Blue Anchor_4	302660	143594	1.45	334	5.6	7.65	8.55	0.90
Blue Anchor_5	303044	143640	1.39	334	5.7	7.01	8.55	1.54
Hinkley_1	321934	146057	1.34	338	6.7	5.72	8.87	3.15
Hinkley_2	322505	145975	1.64	326	6.6	5.98	8.88	2.90
Stolford_1	323018	146077	1.53	317	6.6	5.32	8.89	3.58
Stolford_2	323248	145952	1.37	336	10.0	4.22	8.90	4.67
Steart	327470	146224	1.10	308	10.0	2.14	8.96	6.82
Burnham_1	330199	148682	1.63	294	6.6	4.74	9.00	4.26
Burnham_2	330334	149608	1.40	276	6.5	3.45	9.01	5.56
Berrow	329157	154127	1.55	286	10.1	2.87	9.12	6.25
Brean_1	329666	157314	1.28	277	6.6	2.59	9.18	6.58
Brean_2	329676	158047	1.56	273	6.5	3.60	9.20	5.59
Brean_3	329527	158635	1.39	257	6.6	3.80	9.22	5.43
Brean_4	330402	158380	0.53	352	4.1	3.19	9.23	6.04
Kewstoke	333001	163741	1.04	279	5.9	2.20	9.47	7.27
Sand Bay_1	333076	165577	1.07	263	6.2	2.44	9.54	7.10
Sand Bay_2	332903	165870	0.94	252	5.9	3.00	9.53	6.53
Kingston Seymour_1	337157	167184	1.22	301	4.6	5.30	9.75	4.45
Kingston Seymour_2	337970	168588	1.50	288	4.9	6.86	9.78	2.92
Kingston Seymour_3	338670	169557	1.09	280	5.1	2.77	9.81	7.04
Kingston Seymour_4	338577	169717	1.52	284	4.9	5.98	9.82	3.84
Clevedon_1	339059	170245	1.07	299	4.7	3.97	9.84	5.87
Clevedon_2	339842	171283	1.38	294	4.7	5.68	9.86	4.18
Portbury	348821	177288	0.84	316	3.8	3.97	9.98	6.01
Avonmouth_1	351958	180878	1.22	281	4.5	9.43	10.03	0.60
Avonmouth_2	353189	182652	1.08	283	4.5	5.70	10.09	4.39
Severn Beach_1	353877	184506	0.91	266	4.5	2.37	10.13	7.76
Severn Beach_2	353815	185353	1.08	269	4.5	7.70	10.14	2.44
Redwick	354045	186224	1.08	271	4.5	8.69	10.16	1.47
Northwick_1	354913	186950	0.94	282	3.8	6.69	10.19	3.50
Northwick_2	355475	187701	0.83	284	3.6	5.71	10.21	4.50
Aust	356335	188714	0.73	283	3.6	2.47	10.23	7.76
Oldbury_1	359165	191663	0.79	300	3.2	4.73	10.37	5.64
Oldbury_2	360916	195570	0.75	293	3.1	4.92	10.52	5.60
Nupdown	361716	196634	0.71	293	3.1	7.12	10.57	3.45
Berkeley_1	364898	198645	0.73	290	3.1	10.34	10.70	0.36
Berkeley_2	365225	198980	0.74	285	3.2	12.15	10.72	-1.44
Berkeley_3	366092	199899	0.67	290	3.1	6.50	10.76	4.26
Sharpness	366666	201037	0.71	279	3.0	12.28	10.80	-1.48

Table A2 – Water Level 25yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.11	3	10.3	3.00	8.50	5.51
Minehead_2	297218	146805	1.08	357	10.2	6.92	8.52	1.60
Minehead_3	297426	146366	0.83	3	10.3	1.74	8.52	6.78
Minehead_4	298071	146352	1.11	340	10.3	2.16	8.55	6.38
Minehead_5	298700	146567	1.90	335	10.2	6.07	8.56	2.50
Minehead_6	298866	146506	1.69	337	10.2	4.48	8.57	4.09
Minehead_7	299094	146444	1.64	342	10.2	4.67	8.59	3.92
Minehead_8	299321	146265	1.31	351	10.2	4.71	8.61	3.91
Minehead_9	299385	145958	1.03	1	10.2	3.28	8.62	5.34
Dunster Beaches_1	299718	145618	0.99	13	10.2	4.05	8.62	4.57
Dunster Beaches_2	299894	145257	0.90	2	10.2	3.28	8.63	5.35
Dunster Beaches_3	300212	144806	0.90	19	10.2	2.79	8.64	5.85
Dunster Beaches_4	300482	144600	0.92	4	10.2	3.12	8.64	5.52
Dunster Beaches_5	300622	144395	0.87	7	10.1	4.84	8.64	3.80
Dunster Beaches_6	301028	144206	1.09	350	10.1	5.58	8.65	3.07
Blue Anchor_1	301254	143762	0.88	358	10.1	4.41	8.66	4.24
Blue Anchor_2	301796	143598	1.15	347	10.1	4.83	8.66	3.83
Blue Anchor_3	302269	143533	1.34	339	5.5	5.71	8.66	2.95
Blue Anchor_4	302660	143594	1.46	333	5.6	7.77	8.67	0.90
Blue Anchor_5	303044	143640	1.40	334	5.7	7.13	8.67	1.54
Hinkley_1	321934	146057	1.35	338	6.7	5.85	9.00	3.15
Hinkley_2	322505	145975	1.65	326	6.6	6.11	9.01	2.90
Stolford_1	323018	146077	1.55	317	6.6	5.45	9.02	3.58
Stolford_2	323248	145952	1.40	336	10.0	4.35	9.03	4.67
Steart	327470	146224	1.15	308	10.0	2.27	9.09	6.82
Burnham_1	330199	148682	1.65	294	6.6	4.87	9.13	4.26
Burnham_2	330334	149608	1.43	276	6.5	3.58	9.14	5.56
Berrow	329157	154127	1.60	286	10.1	3.00	9.25	6.25
Brean_1	329666	157314	1.32	277	6.6	2.72	9.31	6.58
Brean_2	329676	158047	1.60	273	6.5	3.73	9.33	5.59
Brean_3	329527	158635	1.40	258	6.6	3.93	9.35	5.43
Brean_4	330402	158380	0.54	352	4.1	3.33	9.37	6.04
Kewstoke	333001	163741	1.09	279	5.9	2.34	9.61	7.27
Sand Bay_1	333076	165577	1.11	263	6.1	2.58	9.68	7.10
Sand Bay_2	332903	165870	0.96	252	5.9	3.14	9.67	6.53
Kingston Seymour_1	337157	167184	1.23	301	4.6	5.45	9.90	4.45
Kingston Seymour_2	337970	168588	1.51	288	4.9	7.01	9.93	2.92
Kingston Seymour_3	338670	169557	1.13	279	5.1	2.92	9.96	7.04
Kingston Seymour_4	338577	169717	1.52	284	4.9	6.13	9.97	3.84
Clevedon_1	339059	170245	1.09	299	4.7	4.12	9.99	5.87
Clevedon_2	339842	171283	1.38	294	4.7	5.83	10.01	4.18
Portbury	348821	177288	0.85	315	3.8	4.14	10.15	6.01
Avonmouth_1	351958	180878	1.23	281	4.5	9.61	10.21	0.60
Avonmouth_2	353189	182652	1.09	283	4.5	5.88	10.26	4.39
Severn Beach_1	353877	184506	0.95	266	4.5	2.55	10.31	7.76
Severn Beach_2	353815	185353	1.09	269	4.5	7.88	10.32	2.44
Redwick	354045	186224	1.08	271	4.5	8.87	10.34	1.47
Northwick_1	354913	186950	0.95	282	3.8	6.87	10.37	3.50
Northwick_2	355475	187701	0.84	284	3.5	5.89	10.39	4.50
Aust	356335	188714	0.75	282	3.6	2.65	10.41	7.76
Oldbury_1	359165	191663	0.79	300	3.3	4.92	10.56	5.64
Oldbury_2	360916	195570	0.76	293	3.1	5.11	10.71	5.60
Nupdown	361716	196634	0.72	293	3.1	7.31	10.76	3.45
Berkeley_1	364898	198645	0.73	290	3.1	10.52	10.89	0.36
Berkeley_2	365225	198980	0.74	285	3.2	12.34	10.91	-1.44
Berkeley_3	366092	199899	0.68	290	3.1	6.69	10.95	4.26
Sharpness	366666	201037	0.71	279	3.0	12.47	10.99	-1.48

Table A3 – Water Level 50yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.14	3	10.3	3.08	8.58	5.51
Minehead_2	297218	146805	1.08	357	10.2	7.00	8.60	1.60
Minehead_3	297426	146366	0.85	3	10.3	1.82	8.60	6.78
Minehead_4	298071	146352	1.14	340	10.3	2.24	8.63	6.38
Minehead_5	298700	146567	1.90	335	10.2	6.15	8.64	2.50
Minehead_6	298866	146506	1.70	337	10.2	4.56	8.65	4.09
Minehead_7	299094	146444	1.65	342	10.2	4.75	8.67	3.92
Minehead_8	299321	146265	1.31	350	10.2	4.79	8.69	3.91
Minehead_9	299385	145958	1.05	1	10.2	3.36	8.70	5.34
Dunster Beaches_1	299718	145618	1.00	12	10.2	4.13	8.70	4.57
Dunster Beaches_2	299894	145257	0.91	1	10.2	3.36	8.71	5.35
Dunster Beaches_3	300212	144806	0.91	18	10.2	2.87	8.72	5.85
Dunster Beaches_4	300482	144600	0.94	4	10.2	3.21	8.72	5.52
Dunster Beaches_5	300622	144395	0.88	7	10.1	4.93	8.73	3.80
Dunster Beaches_6	301028	144206	1.09	350	10.1	5.66	8.73	3.07
Blue Anchor_1	301254	143762	0.89	358	10.1	4.49	8.74	4.24
Blue Anchor_2	301796	143598	1.16	347	10.1	4.91	8.74	3.83
Blue Anchor_3	302269	143533	1.34	338	5.6	5.80	8.75	2.95
Blue Anchor_4	302660	143594	1.46	333	5.5	7.85	8.76	0.90
Blue Anchor_5	303044	143640	1.41	334	5.7	7.22	8.76	1.54
Hinkley_1	321934	146057	1.36	338	6.7	5.95	9.10	3.15
Hinkley_2	322505	145975	1.65	325	6.6	6.21	9.11	2.90
Stolford_1	323018	146077	1.56	317	6.6	5.55	9.12	3.58
Stolford_2	323248	145952	1.42	336	10.0	4.46	9.13	4.67
Steart	327470	146224	1.18	308	10.0	2.37	9.19	6.82
Burnham_1	330199	148682	1.67	294	6.6	4.97	9.23	4.26
Burnham_2	330334	149608	1.46	276	6.5	3.68	9.24	5.56
Berrow	329157	154127	1.64	286	10.1	3.11	9.36	6.25
Brean_1	329666	157314	1.36	277	6.6	2.83	9.42	6.58
Brean_2	329676	158047	1.62	273	6.5	3.84	9.44	5.59
Brean_3	329527	158635	1.41	258	6.5	4.04	9.46	5.43
Brean_4	330402	158380	0.54	352	4.1	3.44	9.48	6.04
Kewstoke	333001	163741	1.12	279	5.9	2.46	9.73	7.27
Sand Bay_1	333076	165577	1.14	263	6.1	2.70	9.80	7.10
Sand Bay_2	332903	165870	0.96	252	5.8	3.26	9.79	6.53
Kingston Seymour_1	337157	167184	1.24	301	4.6	5.57	10.01	4.45
Kingston Seymour_2	337970	168588	1.51	288	4.9	7.13	10.05	2.92
Kingston Seymour_3	338670	169557	1.15	279	5.1	3.05	10.09	7.04
Kingston Seymour_4	338577	169717	1.53	284	4.9	6.26	10.10	3.84
Clevedon_1	339059	170245	1.12	299	4.7	4.25	10.12	5.87
Clevedon_2	339842	171283	1.39	293	4.7	5.96	10.14	4.18
Portbury	348821	177288	0.86	315	3.8	4.26	10.27	6.01
Avonmouth_1	351958	180878	1.24	282	4.5	9.74	10.34	0.60
Avonmouth_2	353189	182652	1.10	282	4.5	6.01	10.39	4.39
Severn Beach_1	353877	184506	0.97	266	4.5	2.68	10.44	7.76
Severn Beach_2	353815	185353	1.10	269	4.5	8.01	10.45	2.44
Redwick	354045	186224	1.09	270	4.5	9.00	10.47	1.47
Northwick_1	354913	186950	0.95	281	3.9	7.00	10.50	3.50
Northwick_2	355475	187701	0.85	283	3.6	6.02	10.52	4.50
Aust	356335	188714	0.76	282	3.6	2.78	10.54	7.76
Oldbury_1	359165	191663	0.80	300	3.3	5.05	10.69	5.64
Oldbury_2	360916	195570	0.76	293	3.1	5.24	10.85	5.60
Nupdown	361716	196634	0.72	293	3.1	7.45	10.90	3.45
Berkeley_1	364898	198645	0.74	289	3.1	10.66	11.03	0.36
Berkeley_2	365225	198980	0.75	285	3.2	12.48	11.04	-1.44
Berkeley_3	366092	199899	0.68	290	3.1	6.83	11.09	4.26
Sharpness	366666	201037	0.71	279	3.0	12.61	11.13	-1.48

Table A4 – Water Level 75yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.15	3	10.3	3.13	8.63	5.51
Minehead_2	297218	146805	1.08	357	10.2	7.05	8.65	1.60
Minehead_3	297426	146366	0.87	3	10.3	1.87	8.65	6.78
Minehead_4	298071	146352	1.16	340	10.3	2.29	8.68	6.38
Minehead_5	298700	146567	1.90	335	10.2	6.20	8.69	2.50
Minehead_6	298866	146506	1.71	337	10.2	4.61	8.70	4.09
Minehead_7	299094	146444	1.65	342	10.2	4.80	8.72	3.92
Minehead_8	299321	146265	1.32	350	10.2	4.84	8.74	3.91
Minehead_9	299385	145958	1.06	1	10.2	3.41	8.75	5.34
Dunster Beaches_1	299718	145618	1.00	12	10.2	4.18	8.75	4.57
Dunster Beaches_2	299894	145257	0.91	1	10.2	3.41	8.76	5.35
Dunster Beaches_3	300212	144806	0.92	18	10.2	2.92	8.77	5.85
Dunster Beaches_4	300482	144600	0.95	4	10.2	3.26	8.77	5.52
Dunster Beaches_5	300622	144395	0.88	6	10.1	4.98	8.78	3.80
Dunster Beaches_6	301028	144206	1.10	350	10.1	5.71	8.78	3.07
Blue Anchor_1	301254	143762	0.89	358	10.1	4.54	8.79	4.24
Blue Anchor_2	301796	143598	1.16	347	10.1	4.96	8.79	3.83
Blue Anchor_3	302269	143533	1.34	338	5.6	5.85	8.80	2.95
Blue Anchor_4	302660	143594	1.46	333	5.6	7.90	8.81	0.90
Blue Anchor_5	303044	143640	1.42	334	5.7	7.27	8.81	1.54
Hinkley_1	321934	146057	1.36	338	6.7	6.01	9.16	3.15
Hinkley_2	322505	145975	1.66	325	6.6	6.27	9.17	2.90
Stolford_1	323018	146077	1.58	317	6.6	5.61	9.18	3.58
Stolford_2	323248	145952	1.44	336	10.0	4.52	9.19	4.67
Steart	327470	146224	1.20	308	10.0	2.43	9.25	6.82
Burnham_1	330199	148682	1.68	294	6.6	5.04	9.30	4.26
Burnham_2	330334	149608	1.47	276	6.5	3.75	9.31	5.56
Berrow	329157	154127	1.67	286	10.1	3.17	9.42	6.25
Brean_1	329666	157314	1.38	277	6.6	2.90	9.49	6.58
Brean_2	329676	158047	1.64	273	6.5	3.91	9.51	5.59
Brean_3	329527	158635	1.41	258	6.5	4.11	9.53	5.43
Brean_4	330402	158380	0.54	352	4.1	3.51	9.55	6.04
Kewstoke	333001	163741	1.14	279	5.9	2.53	9.80	7.27
Sand Bay_1	333076	165577	1.16	263	6.1	2.77	9.87	7.10
Sand Bay_2	332903	165870	0.97	252	5.8	3.33	9.86	6.53
Kingston Seymour_1	337157	167184	1.24	301	4.6	5.64	10.09	4.45
Kingston Seymour_2	337970	168588	1.52	288	4.9	7.20	10.12	2.92
Kingston Seymour_3	338670	169557	1.17	279	5.1	3.12	10.16	7.04
Kingston Seymour_4	338577	169717	1.53	284	4.9	6.33	10.17	3.84
Clevedon_1	339059	170245	1.13	299	4.7	4.32	10.19	5.87
Clevedon_2	339842	171283	1.39	293	4.7	6.03	10.21	4.18
Portbury	348821	177288	0.86	315	3.8	4.34	10.35	6.01
Avonmouth_1	351958	180878	1.25	282	4.5	9.81	10.41	0.60
Avonmouth_2	353189	182652	1.11	282	4.5	6.08	10.46	4.39
Severn Beach_1	353877	184506	0.98	267	4.5	2.75	10.51	7.76
Severn Beach_2	353815	185353	1.10	269	4.5	8.08	10.52	2.44
Redwick	354045	186224	1.09	270	4.5	9.07	10.54	1.47
Northwick_1	354913	186950	0.96	281	3.8	7.07	10.57	3.50
Northwick_2	355475	187701	0.86	283	3.5	6.09	10.59	4.50
Aust	356335	188714	0.76	282	3.6	2.86	10.62	7.76
Oldbury_1	359165	191663	0.80	300	3.3	5.13	10.77	5.64
Oldbury_2	360916	195570	0.76	293	3.1	5.33	10.93	5.60
Nupdown	361716	196634	0.73	293	3.1	7.53	10.98	3.45
Berkeley_1	364898	198645	0.74	289	3.1	10.75	11.12	0.36
Berkeley_2	365225	198980	0.75	285	3.2	12.57	11.13	-1.44
Berkeley_3	366092	199899	0.69	290	3.1	6.92	11.18	4.26
Sharpness	366666	201037	0.71	279	3.0	12.70	11.22	-1.48

Table A5 – Water Level 100yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.16	3	10.3	3.16	8.66	5.51
Minehead_2	297218	146805	1.08	357	10.2	7.08	8.68	1.60
Minehead_3	297426	146366	0.88	3	10.3	1.90	8.68	6.78
Minehead_4	298071	146352	1.17	340	10.3	2.32	8.71	6.38
Minehead_5	298700	146567	1.90	335	10.2	6.23	8.73	2.50
Minehead_6	298866	146506	1.71	337	10.2	4.64	8.73	4.09
Minehead_7	299094	146444	1.66	342	10.2	4.83	8.75	3.92
Minehead_8	299321	146265	1.32	350	10.2	4.87	8.77	3.91
Minehead_9	299385	145958	1.06	1	10.2	3.44	8.78	5.34
Dunster Beaches_1	299718	145618	1.00	12	10.2	4.21	8.78	4.57
Dunster Beaches_2	299894	145257	0.92	1	10.2	3.44	8.79	5.35
Dunster Beaches_3	300212	144806	0.92	18	10.2	2.95	8.80	5.85
Dunster Beaches_4	300482	144600	0.96	4	10.2	3.29	8.80	5.52
Dunster Beaches_5	300622	144395	0.88	6	10.1	5.01	8.81	3.80
Dunster Beaches_6	301028	144206	1.10	350	10.1	5.74	8.81	3.07
Blue Anchor_1	301254	143762	0.89	358	10.1	4.57	8.82	4.24
Blue Anchor_2	301796	143598	1.17	346	10.1	4.99	8.82	3.83
Blue Anchor_3	302269	143533	1.35	338	5.6	5.88	8.83	2.95
Blue Anchor_4	302660	143594	1.46	333	5.6	7.93	8.84	0.90
Blue Anchor_5	303044	143640	1.42	334	5.7	7.30	8.84	1.54
Hinkley_1	321934	146057	1.37	338	6.7	6.05	9.20	3.15
Hinkley_2	322505	145975	1.66	325	6.6	6.31	9.21	2.90
Stolford_1	323018	146077	1.58	317	6.6	5.65	9.22	3.58
Stolford_2	323248	145952	1.45	336	10.0	4.56	9.23	4.67
Steart	327470	146224	1.22	308	10.0	2.48	9.30	6.82
Burnham_1	330199	148682	1.69	294	6.6	5.08	9.34	4.26
Burnham_2	330334	149608	1.48	276	6.5	3.79	9.35	5.56
Berrow	329157	154127	1.68	286	10.1	3.21	9.47	6.25
Brean_1	329666	157314	1.40	277	6.6	2.95	9.54	6.58
Brean_2	329676	158047	1.65	273	6.5	3.96	9.56	5.59
Brean_3	329527	158635	1.42	258	6.5	4.16	9.58	5.43
Brean_4	330402	158380	0.54	352	4.1	3.56	9.60	6.04
Kewstoke	333001	163741	1.16	279	5.9	2.58	9.85	7.27
Sand Bay_1	333076	165577	1.17	263	6.1	2.82	9.92	7.10
Sand Bay_2	332903	165870	0.97	252	5.8	3.38	9.91	6.53
Kingston Seymour_1	337157	167184	1.24	301	4.6	5.70	10.14	4.45
Kingston Seymour_2	337970	168588	1.52	288	4.9	7.26	10.17	2.92
Kingston Seymour_3	338670	169557	1.18	279	5.1	3.17	10.21	7.04
Kingston Seymour_4	338577	169717	1.53	284	4.9	6.38	10.22	3.84
Clevedon_1	339059	170245	1.13	299	4.7	4.37	10.24	5.87
Clevedon_2	339842	171283	1.39	293	4.7	6.08	10.26	4.18
Portbury	348821	177288	0.86	315	3.8	4.39	10.40	6.01
Avonmouth_1	351958	180878	1.25	282	4.5	9.87	10.47	0.60
Avonmouth_2	353189	182652	1.11	282	4.5	6.14	10.53	4.39
Severn Beach_1	353877	184506	0.99	267	4.5	2.82	10.58	7.76
Severn Beach_2	353815	185353	1.10	268	4.5	8.15	10.59	2.44
Redwick	354045	186224	1.09	270	4.5	9.13	10.60	1.47
Northwick_1	354913	186950	0.96	281	3.9	7.13	10.63	3.50
Northwick_2	355475	187701	0.86	283	3.5	6.15	10.65	4.50
Aust	356335	188714	0.77	282	3.6	2.91	10.67	7.76
Oldbury_1	359165	191663	0.80	300	3.3	5.18	10.82	5.64
Oldbury_2	360916	195570	0.76	293	3.1	5.38	10.98	5.60
Nupdown	361716	196634	0.73	292	3.1	7.58	11.03	3.45
Berkeley_1	364898	198645	0.74	289	3.1	10.80	11.17	0.36
Berkeley_2	365225	198980	0.75	285	3.2	12.62	11.18	-1.44
Berkeley_3	366092	199899	0.69	289	3.1	6.97	11.23	4.26
Sharpness	366666	201037	0.71	279	3.0	12.75	11.27	-1.48

Table A6 – Water Level 200yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.18	4	10.3	3.24	8.74	5.51
Minehead_2	297218	146805	1.08	357	10.2	7.16	8.76	1.60
Minehead_3	297426	146366	0.90	3	10.3	1.99	8.76	6.78
Minehead_4	298071	146352	1.19	340	10.3	2.40	8.79	6.38
Minehead_5	298700	146567	1.90	335	10.2	6.31	8.81	2.50
Minehead_6	298866	146506	1.72	336	10.2	4.72	8.81	4.09
Minehead_7	299094	146444	1.66	342	10.2	4.91	8.83	3.92
Minehead_8	299321	146265	1.32	350	10.2	4.95	8.85	3.91
Minehead_9	299385	145958	1.08	0	10.2	3.52	8.86	5.34
Dunster Beaches_1	299718	145618	1.01	11	10.2	4.29	8.86	4.57
Dunster Beaches_2	299894	145257	0.93	1	10.2	3.52	8.87	5.35
Dunster Beaches_3	300212	144806	0.93	17	10.2	3.03	8.88	5.85
Dunster Beaches_4	300482	144600	0.97	4	10.2	3.37	8.88	5.52
Dunster Beaches_5	300622	144395	0.89	6	10.1	5.09	8.89	3.80
Dunster Beaches_6	301028	144206	1.11	350	10.1	5.82	8.89	3.07
Blue Anchor_1	301254	143762	0.90	357	10.1	4.66	8.90	4.24
Blue Anchor_2	301796	143598	1.18	346	10.1	5.08	8.91	3.83
Blue Anchor_3	302269	143533	1.35	338	5.6	5.96	8.91	2.95
Blue Anchor_4	302660	143594	1.47	333	5.6	8.01	8.92	0.90
Blue Anchor_5	303044	143640	1.43	334	5.7	7.38	8.92	1.54
Hinkley_1	321934	146057	1.38	337	6.8	6.15	9.30	3.15
Hinkley_2	322505	145975	1.66	325	6.6	6.42	9.32	2.90
Stolford_1	323018	146077	1.60	317	6.6	5.75	9.33	3.58
Stolford_2	323248	145952	1.47	335	10.0	4.66	9.34	4.67
Steart	327470	146224	1.26	308	10.0	2.59	9.41	6.82
Burnham_1	330199	148682	1.71	294	6.6	5.22	9.48	4.26
Burnham_2	330334	149608	1.51	276	6.5	3.92	9.49	5.56
Berrow	329157	154127	1.73	286	10.1	3.33	9.59	6.25
Brean_1	329666	157314	1.44	277	6.6	3.07	9.65	6.58
Brean_2	329676	158047	1.68	273	6.5	4.08	9.68	5.59
Brean_3	329527	158635	1.42	258	6.5	4.28	9.70	5.43
Brean_4	330402	158380	0.53	352	4.1	3.68	9.72	6.04
Kewstoke	333001	163741	1.20	279	6.0	2.71	9.98	7.27
Sand Bay_1	333076	165577	1.20	263	6.0	2.94	10.04	7.10
Sand Bay_2	332903	165870	0.97	252	5.8	3.50	10.03	6.53
Kingston Seymour_1	337157	167184	1.25	301	4.6	5.82	10.27	4.45
Kingston Seymour_2	337970	168588	1.52	288	4.9	7.38	10.30	2.92
Kingston Seymour_3	338670	169557	1.20	279	5.1	3.30	10.34	7.04
Kingston Seymour_4	338577	169717	1.53	284	4.9	6.51	10.35	3.84
Clevedon_1	339059	170245	1.15	299	4.7	4.50	10.37	5.87
Clevedon_2	339842	171283	1.39	293	4.7	6.21	10.39	4.18
Portbury	348821	177288	0.87	315	3.8	4.52	10.53	6.01
Avonmouth_1	351958	180878	1.25	281	4.5	9.99	10.59	0.60
Avonmouth_2	353189	182652	1.12	282	4.5	6.25	10.64	4.39
Severn Beach_1	353877	184506	1.00	267	4.5	2.92	10.68	7.76
Severn Beach_2	353815	185353	1.10	268	4.5	8.26	10.70	2.44
Redwick	354045	186224	1.09	270	4.5	9.25	10.72	1.47
Northwick_1	354913	186950	0.97	281	3.9	7.25	10.75	3.50
Northwick_2	355475	187701	0.87	283	3.5	6.27	10.77	4.50
Aust	356335	188714	0.78	281	3.6	3.04	10.80	7.76
Oldbury_1	359165	191663	0.81	299	3.3	5.31	10.95	5.64
Oldbury_2	360916	195570	0.77	292	3.1	5.51	11.12	5.60
Nupdown	361716	196634	0.73	292	3.1	7.72	11.17	3.45
Berkeley_1	364898	198645	0.74	289	3.1	10.94	11.31	0.36
Berkeley_2	365225	198980	0.75	285	3.2	12.76	11.32	-1.44
Berkeley_3	366092	199899	0.69	289	3.1	7.11	11.37	4.26
Sharpness	366666	201037	0.71	279	3.0	12.89	11.41	-1.48

Table A7 – Water Level 1000yr, with sea level rise and uplift to wind speed and boundary waves applied

Location	Easting (m)	Northing (m)	Hs (m)	Dir (degr)	Tp (s)	Water Depth (m)	Water Level (m AOD)	Toe Level (m AOD)
Minehead_1	296941	147282	1.23	4	10.3	3.46	8.97	5.51
Minehead_2	297218	146805	1.08	356	10.2	7.39	8.98	1.60
Minehead_3	297426	146366	0.95	3	10.3	2.21	8.99	6.78
Minehead_4	298071	146352	1.25	340	10.3	2.62	9.01	6.38
Minehead_5	298700	146567	1.91	334	10.2	6.52	9.02	2.50
Minehead_6	298866	146506	1.75	336	10.2	4.93	9.02	4.09
Minehead_7	299094	146444	1.69	341	10.2	5.13	9.04	3.92
Minehead_8	299321	146265	1.33	349	10.2	5.16	9.07	3.91
Minehead_9	299385	145958	1.11	360	10.2	3.73	9.07	5.34
Dunster Beaches_1	299718	145618	1.03	10	10.2	4.50	9.07	4.57
Dunster Beaches_2	299894	145257	0.94	360	10.2	3.73	9.08	5.35
Dunster Beaches_3	300212	144806	0.95	16	10.2	3.24	9.09	5.85
Dunster Beaches_4	300482	144600	1.02	4	10.2	3.58	9.09	5.52
Dunster Beaches_5	300622	144395	0.90	5	10.1	5.30	9.10	3.80
Dunster Beaches_6	301028	144206	1.13	350	10.1	6.03	9.10	3.07
Blue Anchor_1	301254	143762	0.91	357	10.1	4.87	9.11	4.24
Blue Anchor_2	301796	143598	1.20	346	10.1	5.29	9.11	3.83
Blue Anchor_3	302269	143533	1.36	338	5.6	6.17	9.12	2.95
Blue Anchor_4	302660	143594	1.48	333	5.6	8.23	9.13	0.90
Blue Anchor_5	303044	143640	1.46	334	5.7	7.59	9.14	1.54
Hinkley_1	321934	146057	1.41	337	6.8	6.40	9.55	3.15
Hinkley_2	322505	145975	1.68	324	6.6	6.67	9.57	2.90
Stolford_1	323018	146077	1.64	317	6.6	6.01	9.59	3.58
Stolford_2	323248	145952	1.52	335	10.0	4.92	9.59	4.67
Steart	327470	146224	1.36	308	10.0	2.86	9.68	6.82
Burnham_1	330199	148682	1.77	294	6.6	5.50	9.76	4.26
Burnham_2	330334	149608	1.57	277	6.5	4.20	9.76	5.56
Berrow	329157	154127	1.83	286	10.1	3.63	9.88	6.25
Brean_1	329666	157314	1.54	277	6.6	3.39	9.97	6.58
Brean_2	329676	158047	1.74	273	6.5	4.41	10.00	5.59
Brean_3	329527	158635	1.43	258	6.5	4.61	10.03	5.43
Brean_4	330402	158380	0.62	351	3.6	4.00	10.04	6.04
Kewstoke	333001	163741	1.29	279	6.0	3.03	10.30	7.27
Sand Bay_1	333076	165577	1.27	263	5.9	3.27	10.37	7.10
Sand Bay_2	332903	165870	0.99	252	5.8	3.83	10.36	6.53
Kingston Seymour_1	337157	167184	1.26	301	4.6	6.14	10.59	4.45
Kingston Seymour_2	337970	168588	1.53	288	4.9	7.71	10.62	2.92
Kingston Seymour_3	338670	169557	1.27	279	5.1	3.62	10.66	7.04
Kingston Seymour_4	338577	169717	1.54	284	4.9	6.83	10.67	3.84
Clevedon_1	339059	170245	1.18	299	4.7	4.82	10.69	5.87
Clevedon_2	339842	171283	1.41	293	4.7	6.53	10.71	4.18
Portbury	348821	177288	0.88	314	3.8	4.84	10.85	6.01
Avonmouth_1	351958	180878	1.26	281	4.5	10.32	10.92	0.60
Avonmouth_2	353189	182652	1.14	282	4.5	6.59	10.97	4.39
Severn Beach_1	353877	184506	1.04	268	4.5	3.26	11.02	7.76
Severn Beach_2	353815	185353	1.12	268	4.5	8.59	11.03	2.44
Redwick	354045	186224	1.10	269	4.5	9.57	11.05	1.47
Northwick_1	354913	186950	0.98	280	4.0	7.57	11.07	3.50
Northwick_2	355475	187701	0.88	282	3.5	6.59	11.09	4.50
Aust	356335	188714	0.80	280	3.6	3.35	11.11	7.76
Oldbury_1	359165	191663	0.82	299	3.3	5.63	11.27	5.64
Oldbury_2	360916	195570	0.78	292	3.1	5.83	11.43	5.60
Nupdown	361716	196634	0.74	292	3.1	8.04	11.49	3.45
Berkeley_1	364898	198645	0.75	289	3.1	11.26	11.62	0.36
Berkeley_2	365225	198980	0.75	284	3.2	13.08	11.64	-1.44
Berkeley_3	366092	199899	0.70	288	3.1	7.43	11.69	4.26
Sharpness	366666	201037	0.71	279	3.0	13.22	11.74	-1.48

B Wave overtopping results

Table B1 – Water Level 10yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00005
44.75	0.00040
45	0.00298
45.25	0.01188
45.5	0.02973
45.75	0.04523
46	0.03521
46.25	0.01313
46.5	0.00395
46.75	0.00071
47	0.00009
47.25	0.00000
56.5	0.00000
56.75	0.00006
57	0.00068
57.25	0.00503
57.5	0.02843
57.75	0.09332
58	0.16163
58.25	0.15729
58.5	0.08601
58.75	0.02481
59	0.00414
59.25	0.00055
59.5	0.00006
59.75	0.00000
69	0.00000
69.25	0.00004
69.5	0.00042
69.75	0.00272
70	0.01121
70.25	0.02426
70.5	0.02960
70.75	0.02182
71	0.00795
71.25	0.00207
71.5	0.00028
71.75	0.00004
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00027
44.75	0.27838
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	0.00360
47.25	0.00000
56.5	0.00000
56.75	0.00062
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	0.00061
59.75	0.00000
69	0.00000
69.25	0.00019
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	0.11814
71.75	0.00007
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.
Note2: Overflow is referred where the water levels were higher than the defence crest level.

Table B2 – Water Level 25yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00007
44.75	0.00059
45	0.00445
45.25	0.01782
45.5	0.04503
45.75	0.06935
46	0.05480
46.25	0.02081
46.5	0.00640
46.75	0.00118
47	0.00015
47.25	0.00000
56.5	0.00000
56.75	0.00011
57	0.00132
57.25	0.00950
57.5	0.05249
57.75	0.16895
58	0.28796
58.25	0.27673
58.5	0.14993
58.75	0.04302
59	0.00717
59.25	0.00095
59.5	0.00010
59.75	0.00000
69	0.00000
69.25	0.00006
69.5	0.00054
69.75	0.00348
70	0.01416
70.25	0.03042
70.5	0.03695
70.75	0.02721
71	0.00994
71.25	0.00260
71.5	0.00035
71.75	0.00005
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00120
44.75	overflow
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	0.01785
47.25	0.00000
56.5	0.00000
56.75	0.00714
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	0.00428
59.75	0.00000
69	0.00000
69.25	0.00051
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	0.18641
71.75	0.00018
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.
Note2: Overflow is referred where the water levels were higher than the defence crest level.

Table B3 – Water Level 50yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00010
44.75	0.00081
45	0.00607
45.25	0.02438
45.5	0.06198
45.75	0.09630
46	0.07696
46.25	0.02967
46.5	0.00928
46.75	0.00175
47	0.00023
47.25	0.00001
47.5	0.00000
56.5	0.00000
56.75	0.00019
57	0.00220
57.25	0.01549
57.5	0.08391
57.75	0.26565
58	0.44703
58.25	0.42554
58.5	0.22914
58.75	0.06559
59	0.01094
59.25	0.00145
59.5	0.00015
59.75	0.00000
69	0.00000
69.25	0.00007
69.5	0.00067
69.75	0.00423
70	0.01702
70.25	0.03632
70.5	0.04397
70.75	0.03236
71	0.01187
71.25	0.00312
71.5	0.00043
71.75	0.00006
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00326
44.75	overflow
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	0.05164
47.25	0.00000
56.5	0.00000
56.75	0.03237
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	0.01501
59.75	0.00000
69	0.00000
69.25	0.00104
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	0.26057
71.75	0.00036
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.

Note2: Overflow is referred where the water levels were higher than the defence crest level.

Table B4 – Water Level 75yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00011
44.75	0.00093
45	0.00703
45.25	0.02839
45.5	0.07263
45.75	0.11354
46	0.09123
46.25	0.03536
46.5	0.01112
46.75	0.00212
47	0.00028
47.25	0.00002
47.5	0.00000
56.5	0.00000
56.75	0.00025
57	0.00283
57.25	0.01979
57.5	0.10664
57.75	0.33583
58	overflow
58.25	overflow
58.5	0.28518
58.75	0.08120
59	0.01347
59.25	0.00178
59.5	0.00018
59.75	0.00000
69	0.00000
69.25	0.00008
69.5	0.00073
69.75	0.00459
70	0.01847
70.25	0.03938
70.5	0.04761
70.75	0.03499
71	0.01282
71.25	0.00336
71.5	0.00046
71.75	0.00006
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00536
44.75	overflow
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	0.08742
47.25	0.00000
56.5	0.00000
56.75	0.06673
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	0.02768
59.75	0.00000
69	0.00000
69.25	0.00149
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	overflow
71.75	0.00051
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.
Note2: Overflow is referred where the water levels were higher than the defence crest level.

Table B5 – Water Level 100yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00013
44.75	0.00105
45	0.00797
45.25	0.03235
45.5	0.08321
45.75	0.13076
46	0.10555
46.25	0.04109
46.5	0.01299
46.75	0.00248
47	0.00033
47.25	0.00002
47.5	0.00000
56.25	0.00000
56.5	0.00001
56.75	0.00031
57	0.00350
57.25	0.02441
57.5	0.13095
57.75	0.41056
58	overflow
58.25	overflow
58.5	0.34399
58.75	0.09751
59	0.01610
59.25	0.00211
59.5	0.00022
59.75	0.00001
60	0.00000
69	0.00000
69.25	0.00009
69.5	0.00078
69.75	0.00493
70	0.01982
70.25	0.04220
70.5	0.05096
70.75	0.03742
71	0.01370
71.25	0.00359
71.5	0.00049
71.75	0.00007
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00804
44.75	overflow
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	0.13431
47.25	0.00001
47.5	0.00000
56.5	0.00000
56.75	0.11912
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	0.04539
59.75	0.00000
69	0.00000
69.25	0.00201
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	overflow
71.75	0.00068
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.
Note2: Overflow is referred where the water levels were higher than the defence crest level.

Table B6 – Water Level 200yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.00017
44.75	0.00143
45	0.01082
45.25	0.04402
45.5	0.11391
45.75	0.18056
46	0.14740
46.25	0.05825
46.5	0.01873
46.75	0.00365
47	0.00049
47.25	0.00005
47.5	0.00000
56.25	0.00000
56.5	0.00003
56.75	0.00053
57	0.00578
57.25	0.03947
57.5	0.20766
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	0.14760
59	0.02439
59.25	0.00321
59.5	0.00033
59.75	0.00001
60	0.00000
69	0.00000
69.25	0.00011
69.5	0.00096
69.75	0.00597
70	0.02374
70.25	0.05024
70.5	0.06046
70.75	0.04437
71	0.01630
71.25	0.00430
71.5	0.00060
71.75	0.00008
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.01831
44.75	overflow
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	overflow
47.25	0.00011
47.5	0.00000
56.25	0.00000
56.5	0.00002
56.75	overflow
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	0.12227
59.75	0.00000
69	0.00000
69.25	0.00371
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	overflow
71.75	0.00123
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.

Note2: Overflow is referred where the water levels were higher than the defence crest level.

Table B7 – Water Level 1000yr, with sea level rise and uplift to wind speed and boundary waves applied. Overtopping discharges for three tidal cycles.

Location 7e00698

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44	0.00000
44.25	0.00001
44.5	0.00033
44.75	0.00282
45	0.02169
45.25	0.08983
45.5	0.23780
45.75	0.38647
46	0.32363
46.25	0.13161
46.5	0.04368
46.75	0.00884
47	0.00124
47.25	0.00013
47.5	0.00000
56.25	0.00000
56.5	0.00013
56.75	0.00176
57	0.01856
57.25	0.12242
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	0.39437
59	0.06431
59.25	0.00836
59.5	0.00086
59.75	0.00007
60	0.00000
69	0.00000
69.25	0.00017
69.5	0.00147
69.75	0.00902
70	0.03538
70.25	0.07413
70.5	0.08861
70.75	0.06478
71	0.02380
71.25	0.00629
71.5	0.00088
71.75	0.00012
72	0.00000
77.5	0.00000

Location 7e00720

Time (hrs)	OT_q(m3/s/m)
40.25	0.00000
44.25	0.00000
44.5	0.10678
44.75	overflow
45	overflow
45.25	overflow
45.5	overflow
45.75	overflow
46	overflow
46.25	overflow
46.5	overflow
46.75	overflow
47	overflow
47.25	0.00584
47.5	0.00000
56.25	0.00000
56.5	0.00554
56.75	overflow
57	overflow
57.25	overflow
57.5	overflow
57.75	overflow
58	overflow
58.25	overflow
58.5	overflow
58.75	overflow
59	overflow
59.25	overflow
59.5	overflow
59.75	0.00043
60	0.00000
69	0.00000
69.25	0.01440
69.5	overflow
69.75	overflow
70	overflow
70.25	overflow
70.5	overflow
70.75	overflow
71	overflow
71.25	overflow
71.5	overflow
71.75	0.00455
72	0.00000
77.5	0.00000

Note1: The time steps with 0 calculated discharges were omitted.
Note2: Overflow is referred where the water levels were higher than the defence crest level.

Flood maps

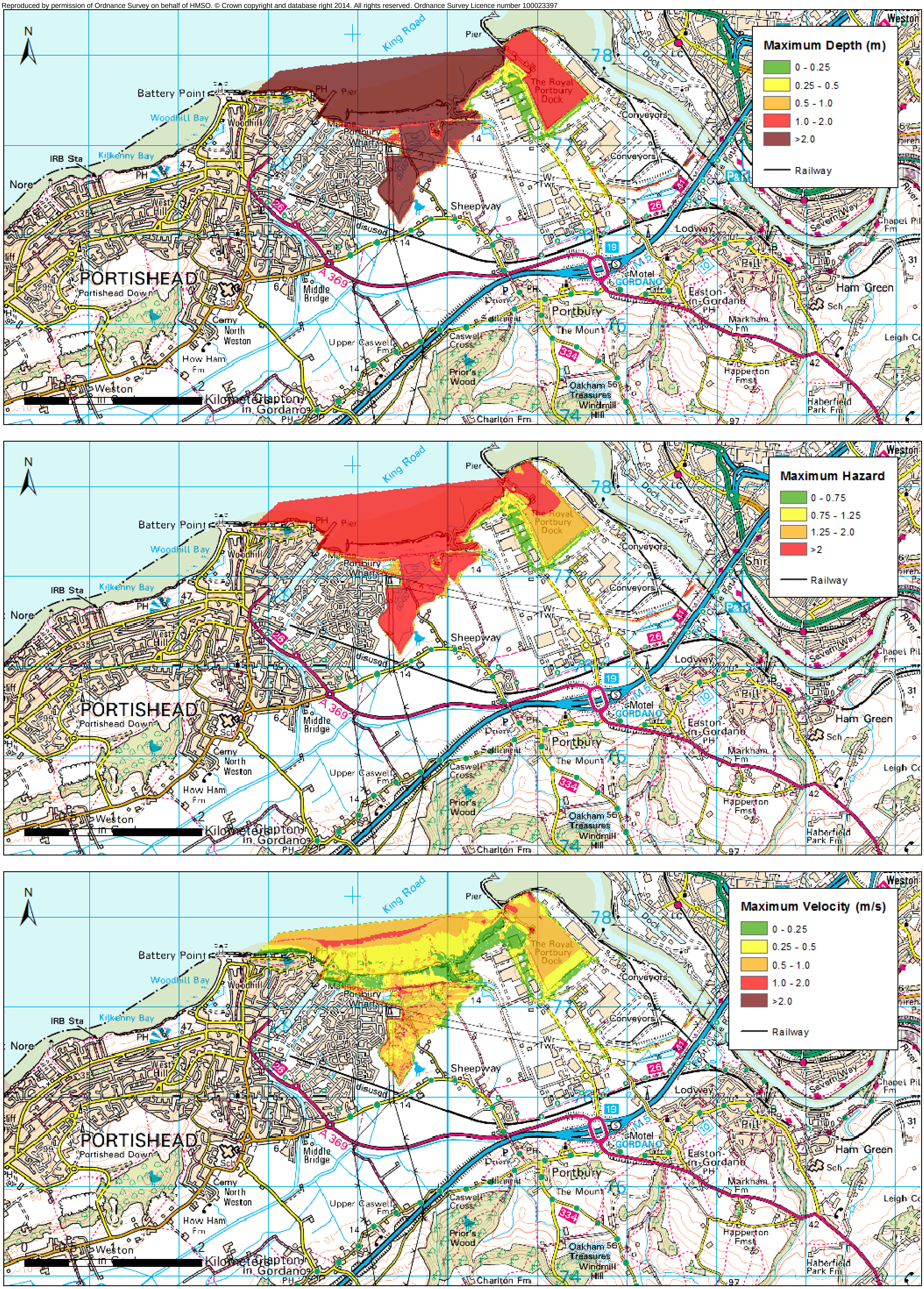


Figure M-1: 1000 year return period

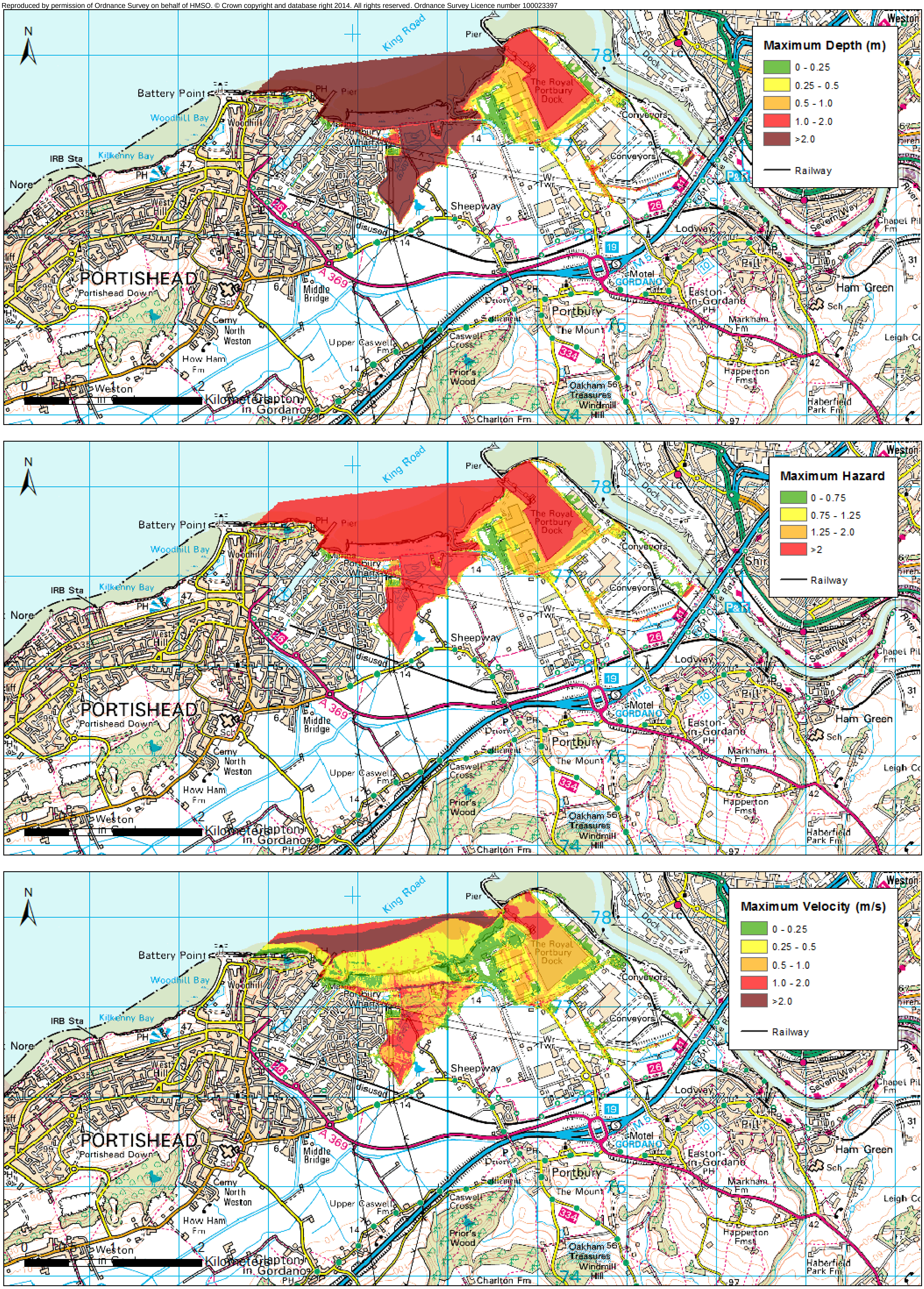


Figure M-2: Existing Railway, 25 year return period - 2115

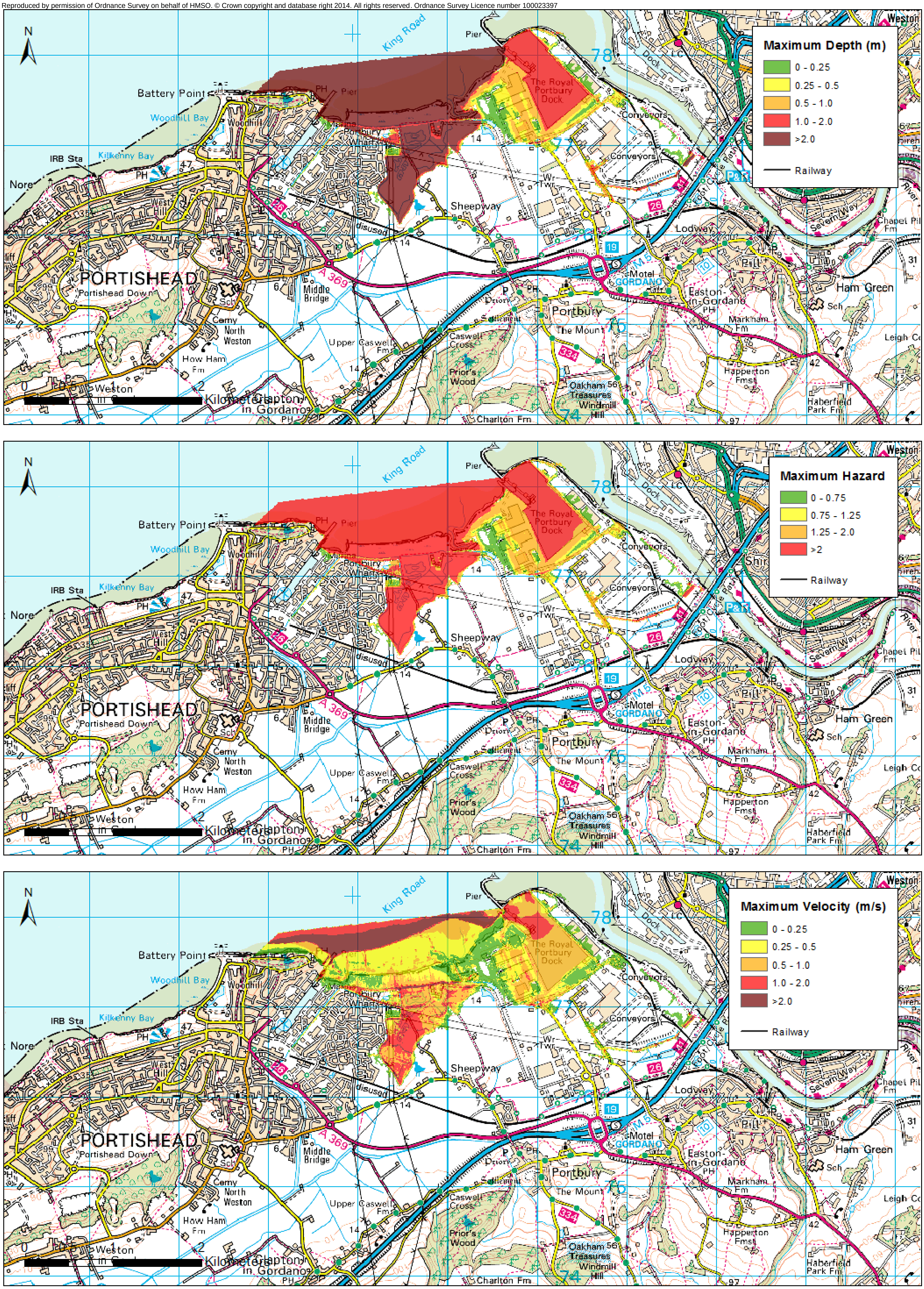


Figure M-3: Post Development Railway, 25 year return period - 2115

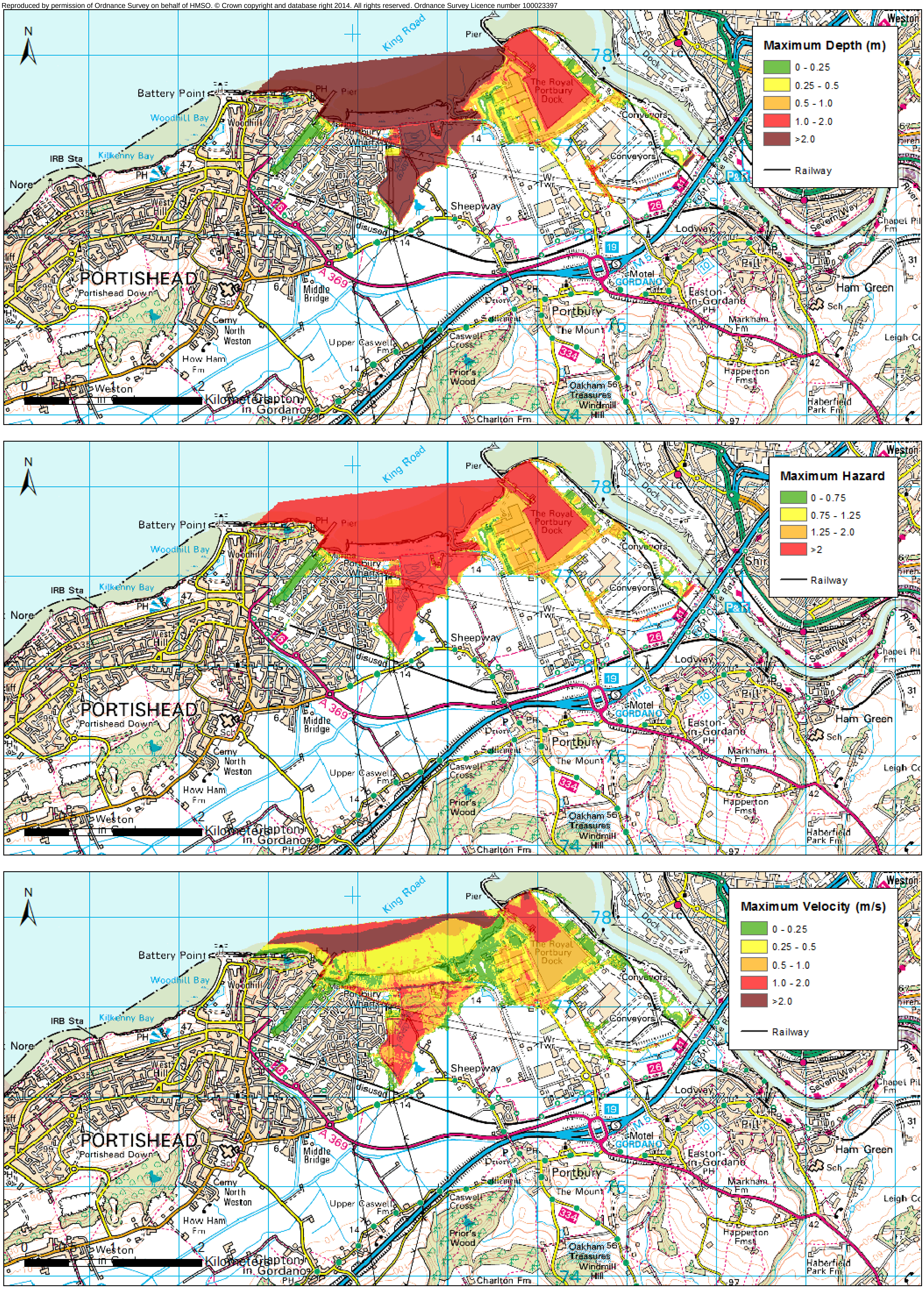


Figure M-4: Existing Railway, 50 year return period - 2115

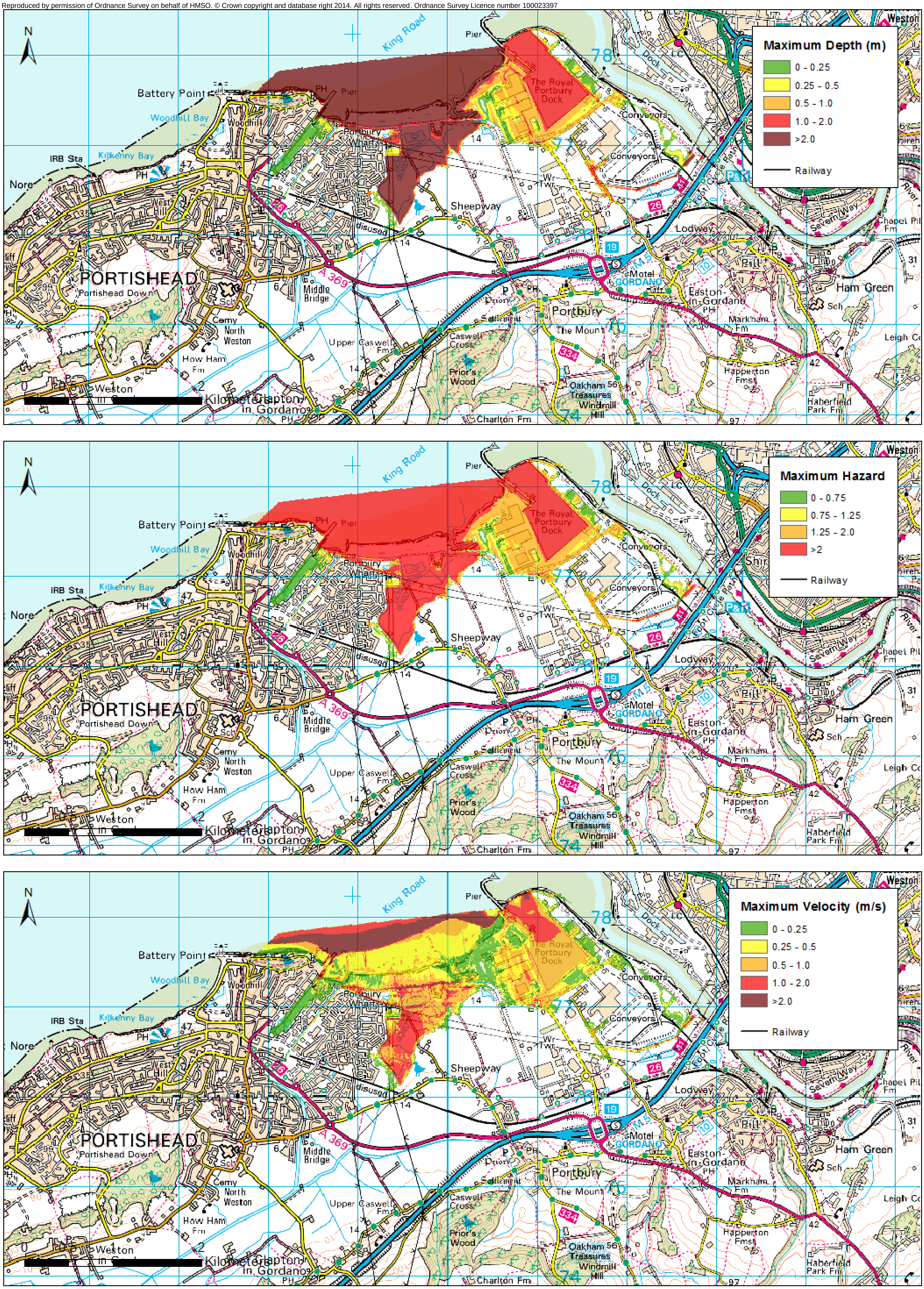
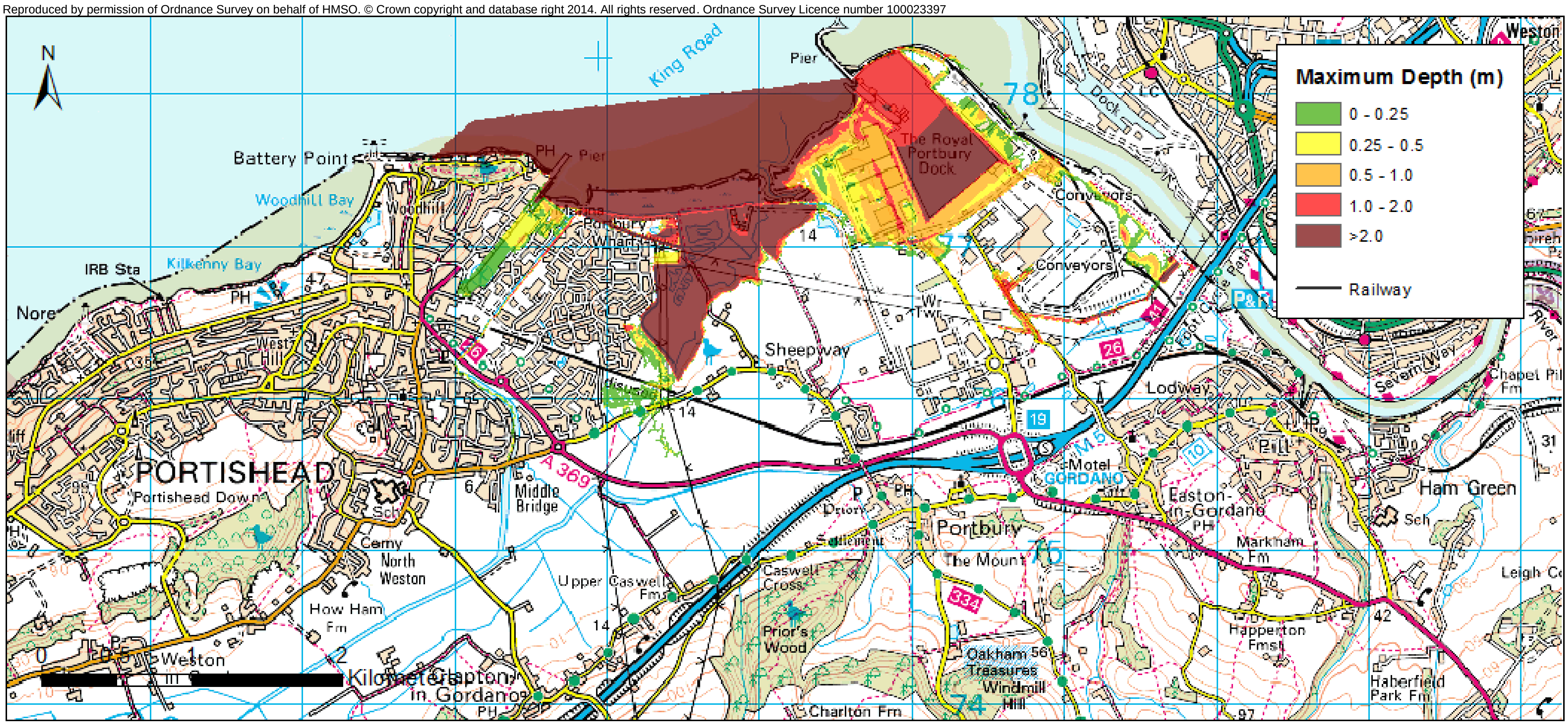
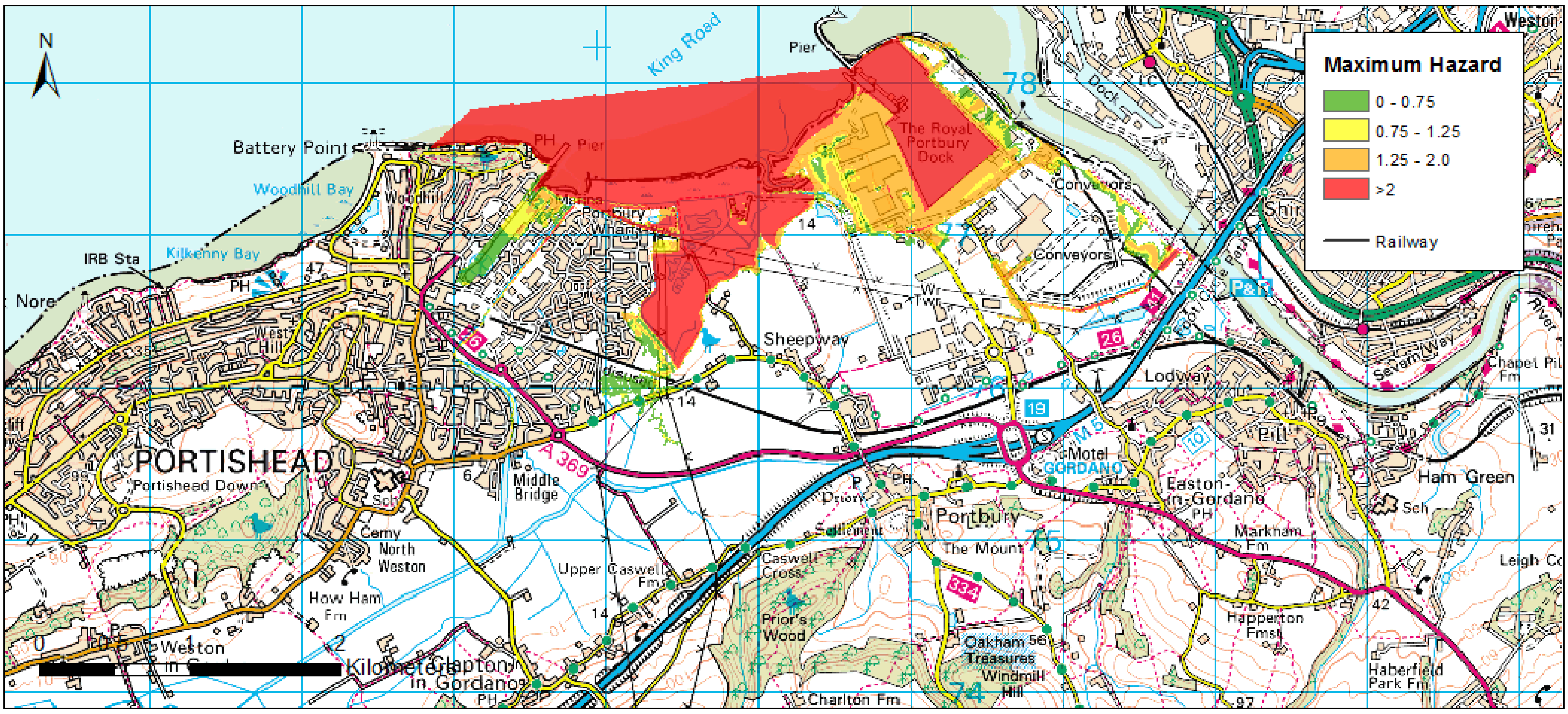


Figure M-5: Post Development Railway, 50 year return period - 2115





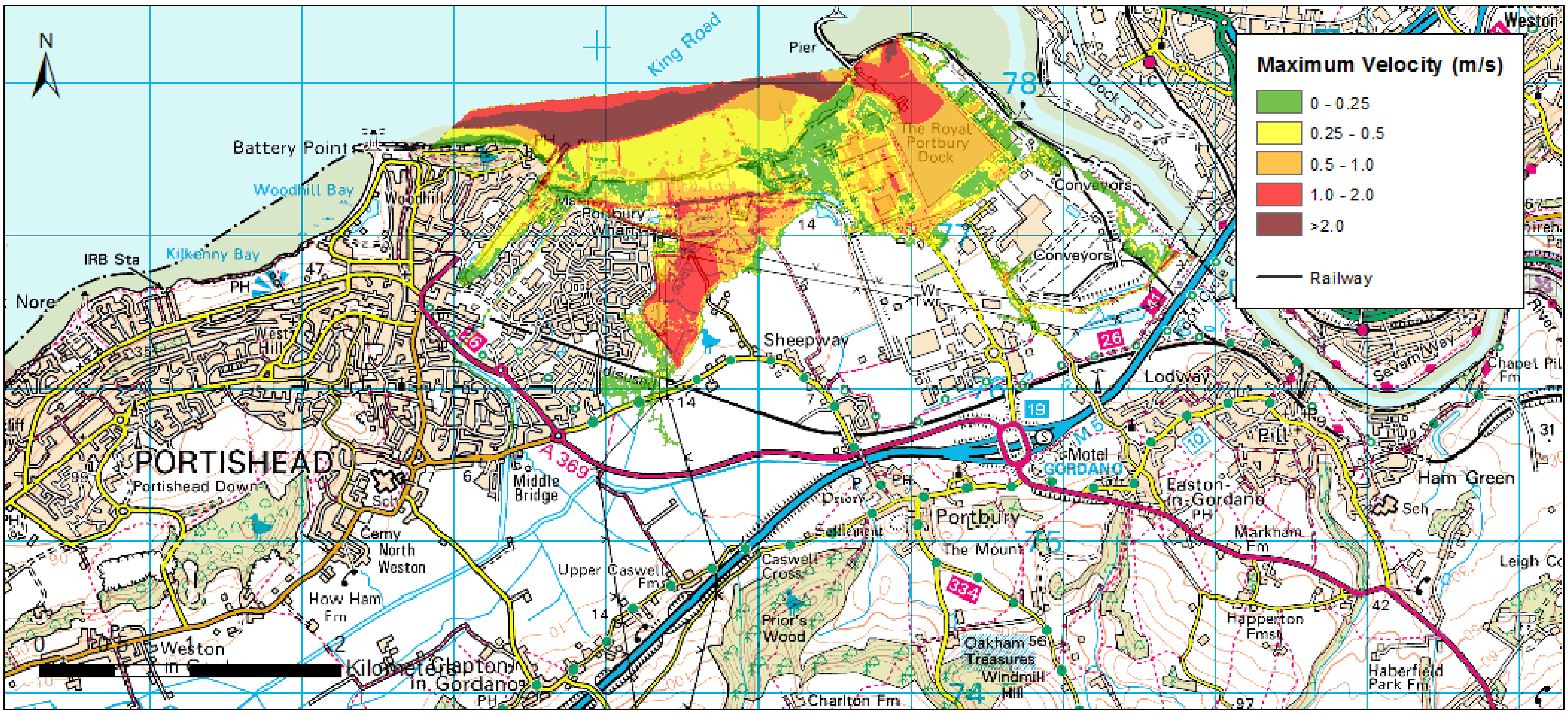


Figure M-6: Existing Railway, 75 year return period - 2115

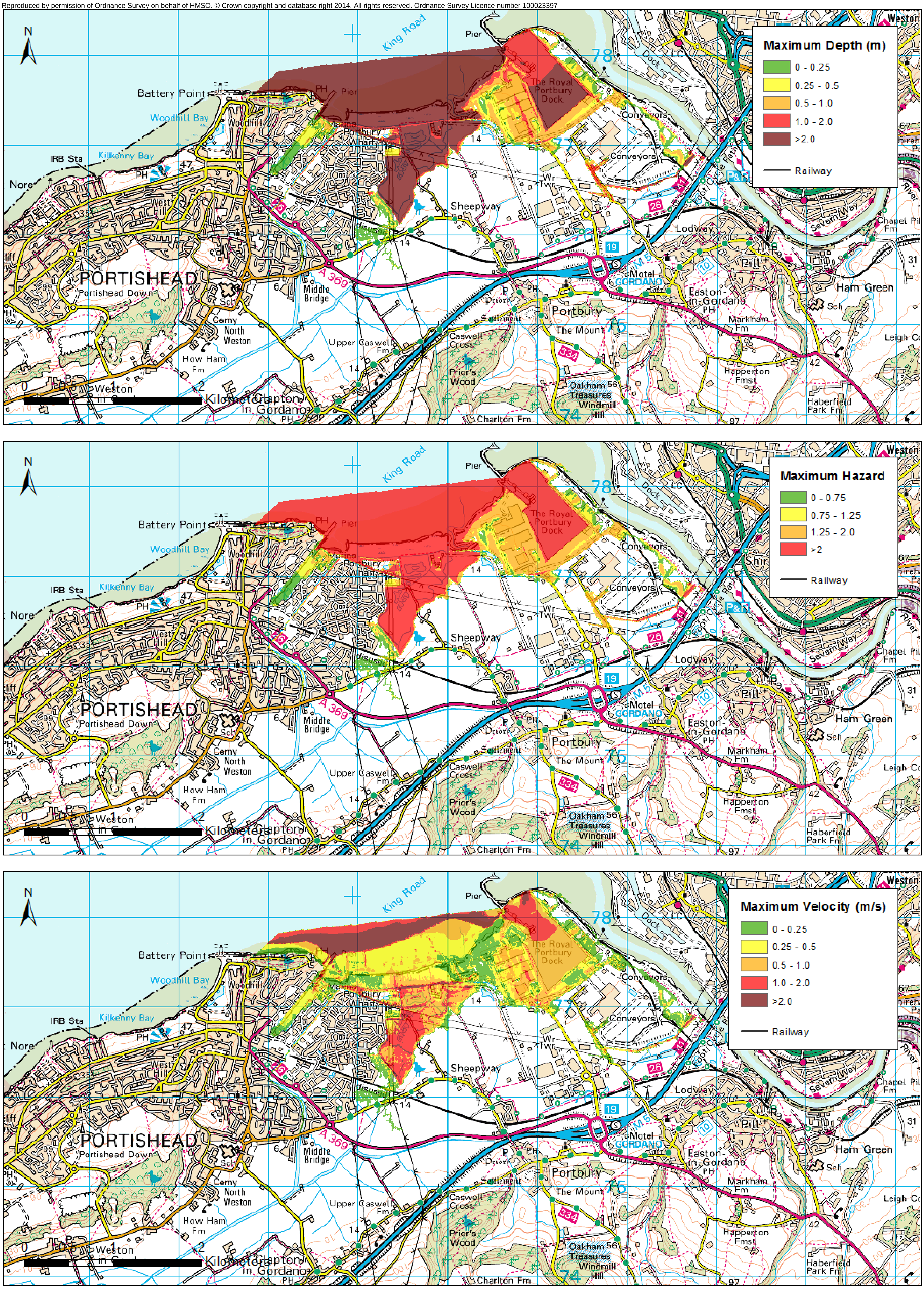


Figure M-7: Post Development Railway, 75 year return period - 2115

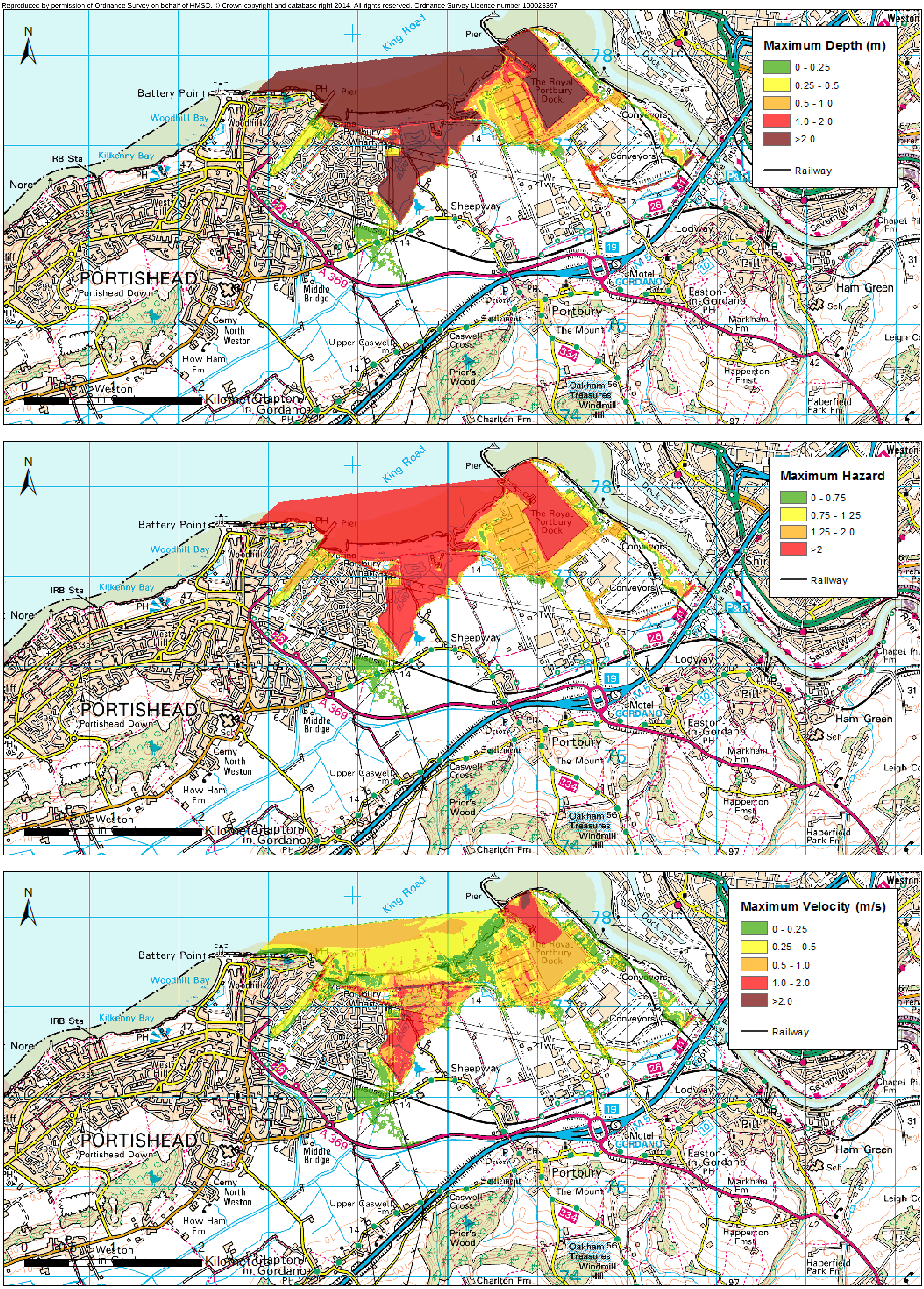


Figure M-8: Existing Railway, 100 year return period - 2115

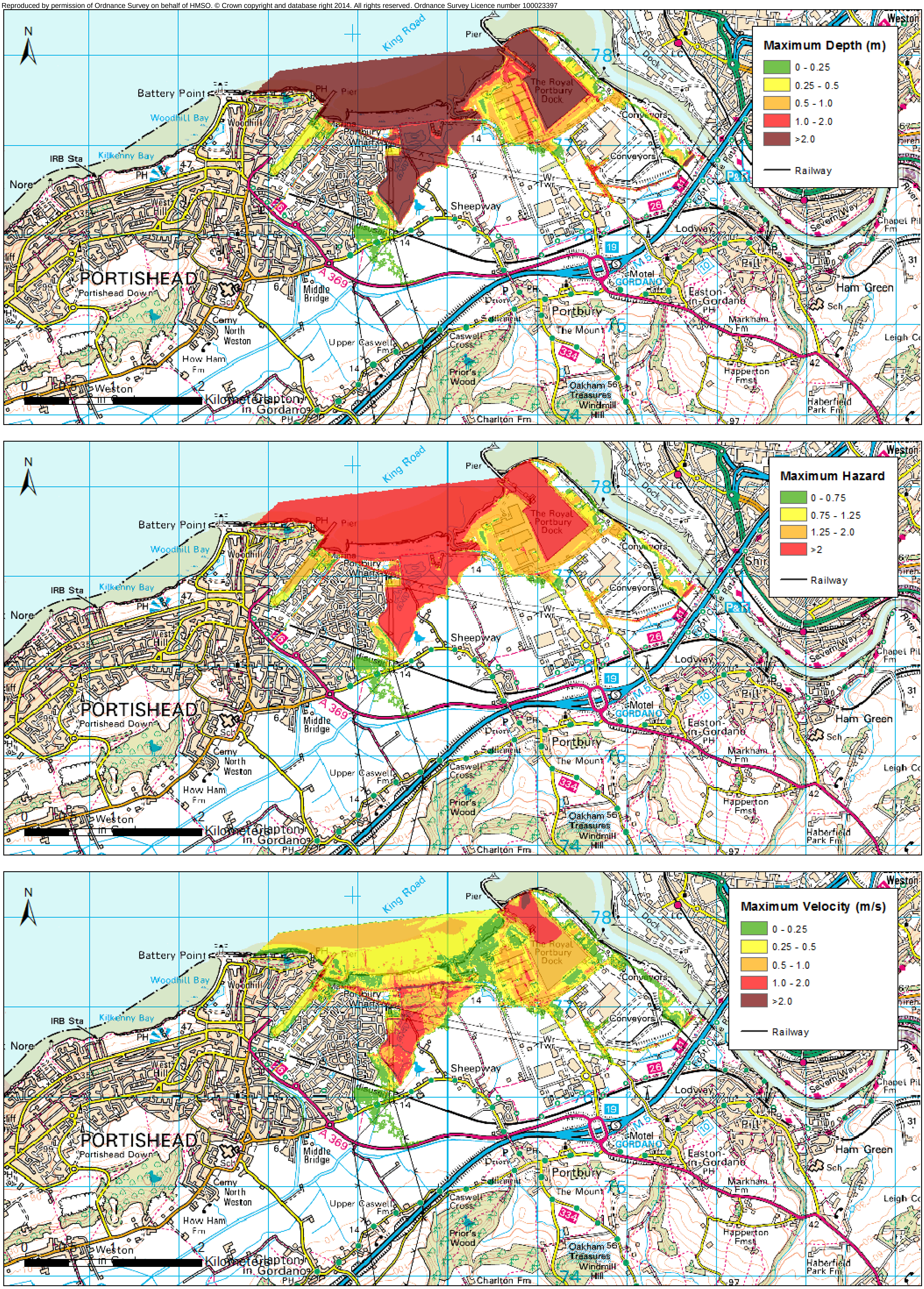


Figure M-9: Post Development Railway, 100 year return period - 2115

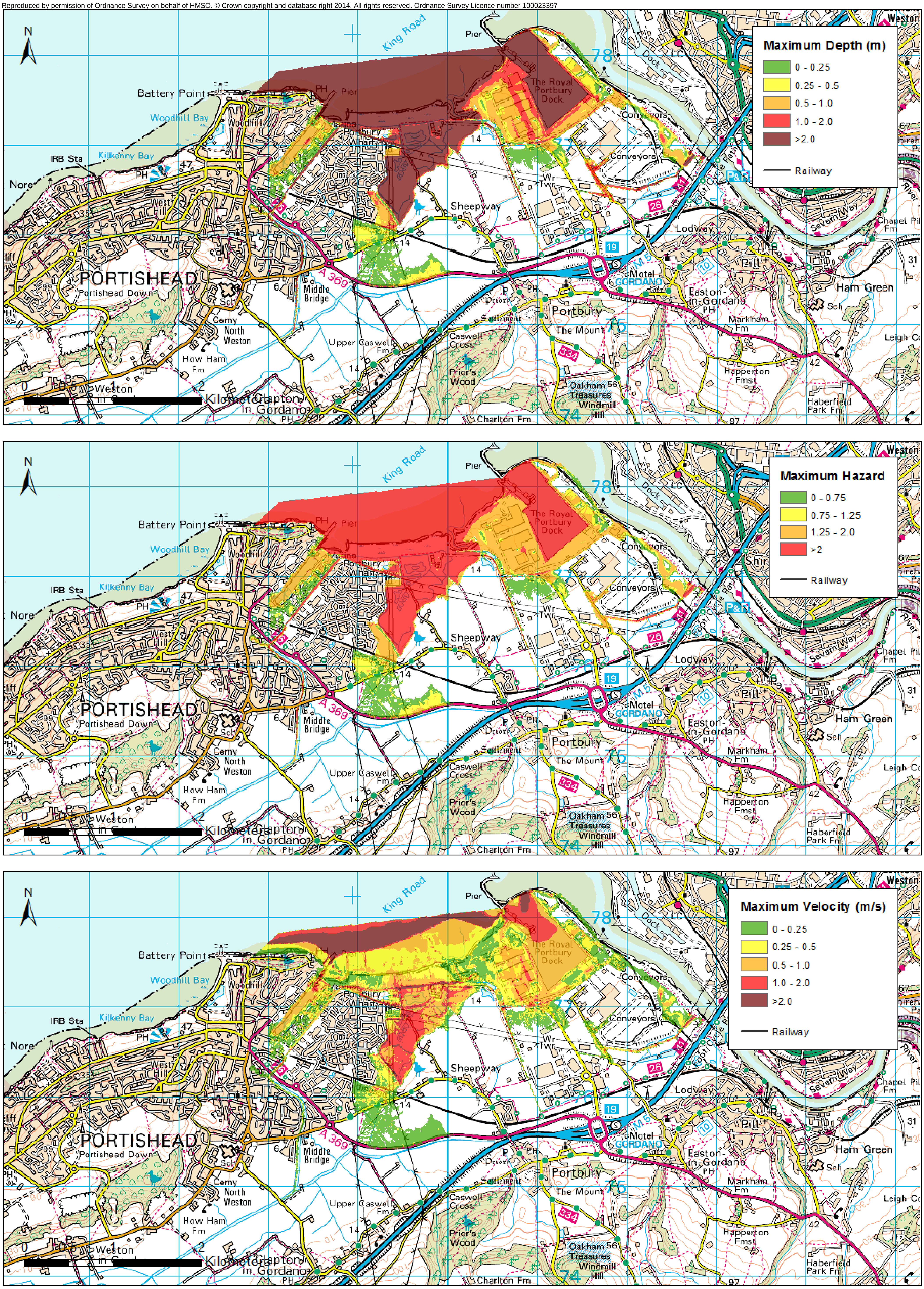


Figure M-10: Existing Railway, 200 year return period - 2115

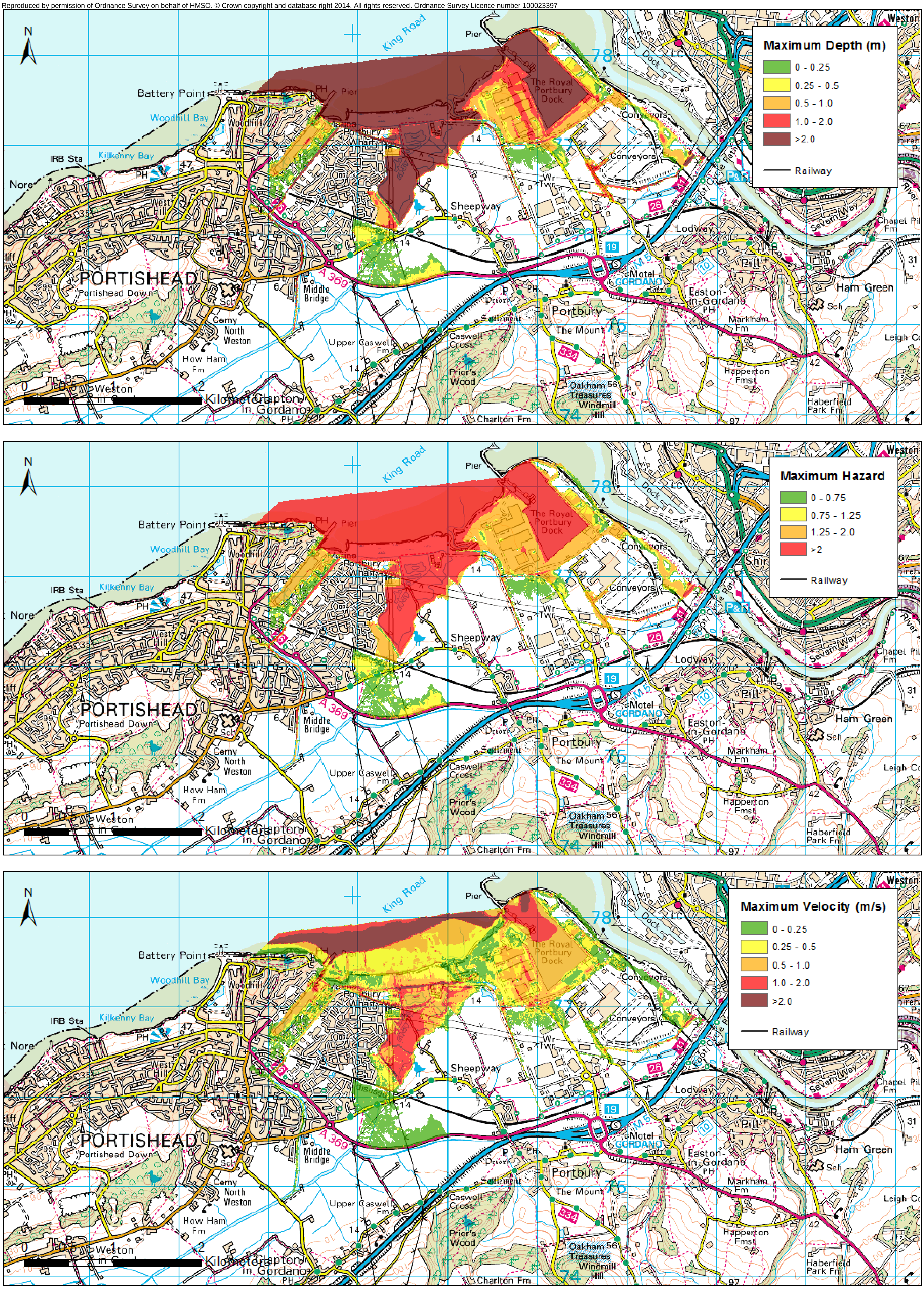


Figure M-11: Post Development Railway, 200 year return period - 2115

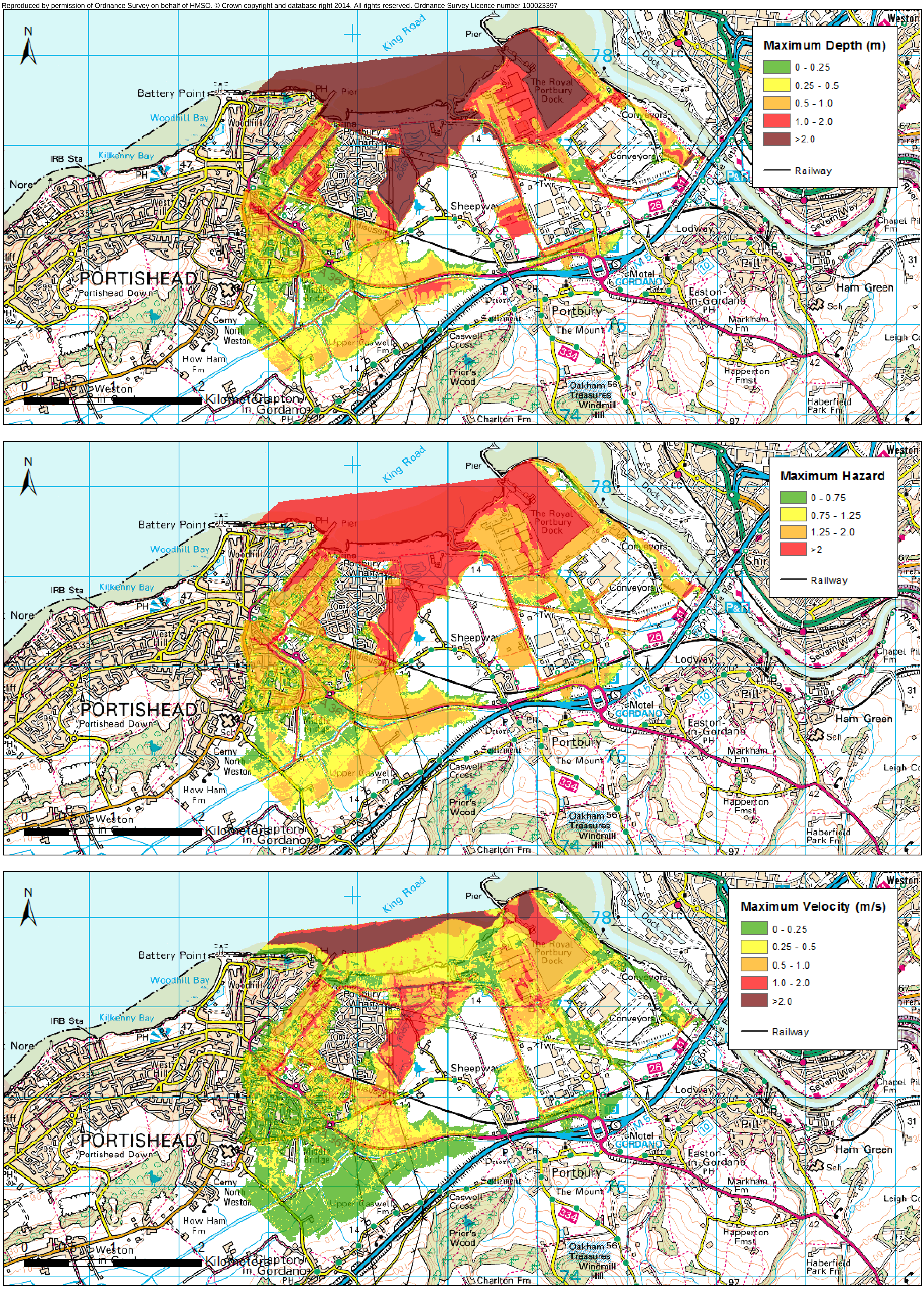


Figure M-12: Existing Railway, 1000 year return period - 2115

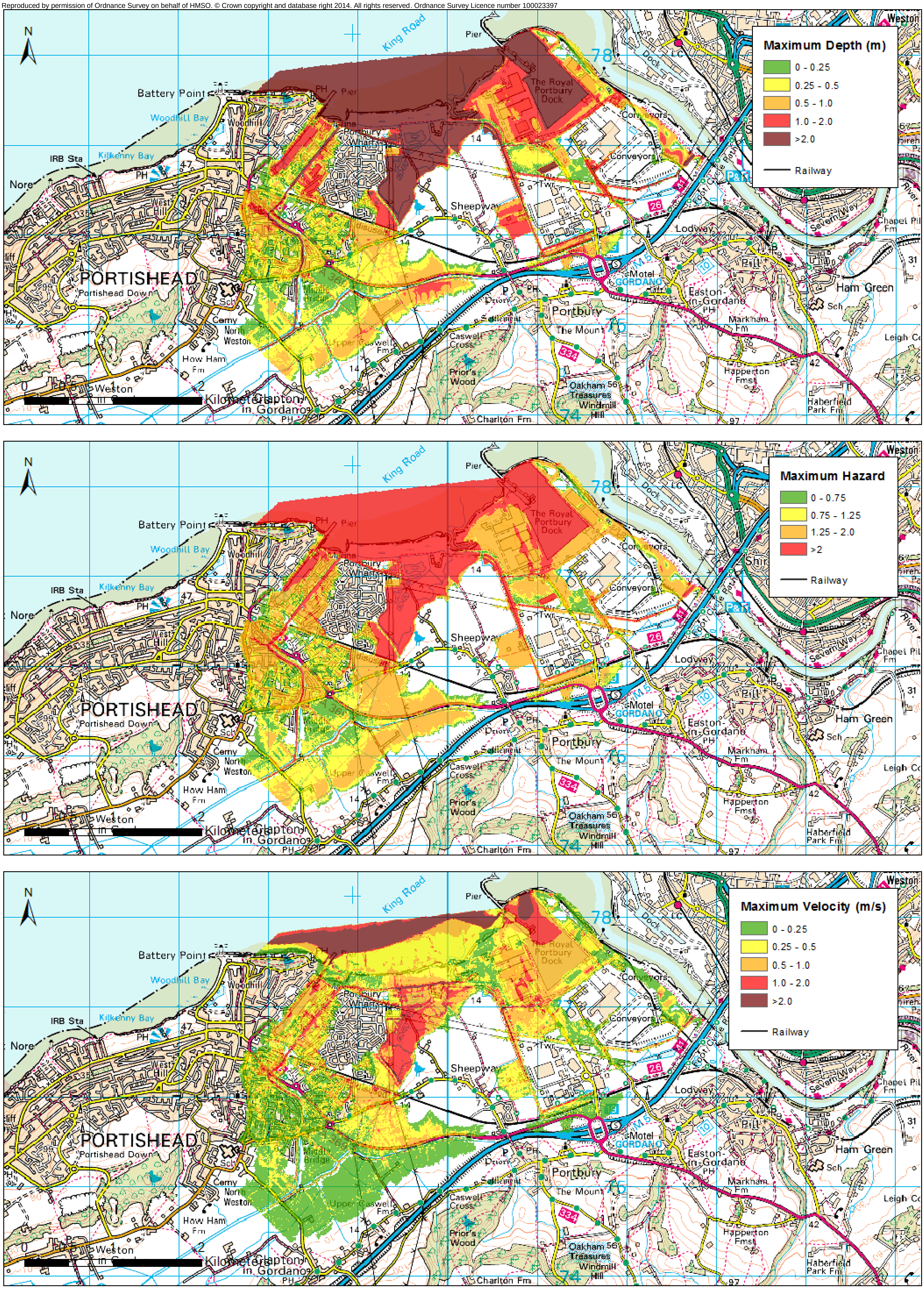


Figure M-13: Post Development Railway, 1000 year return period - 2115

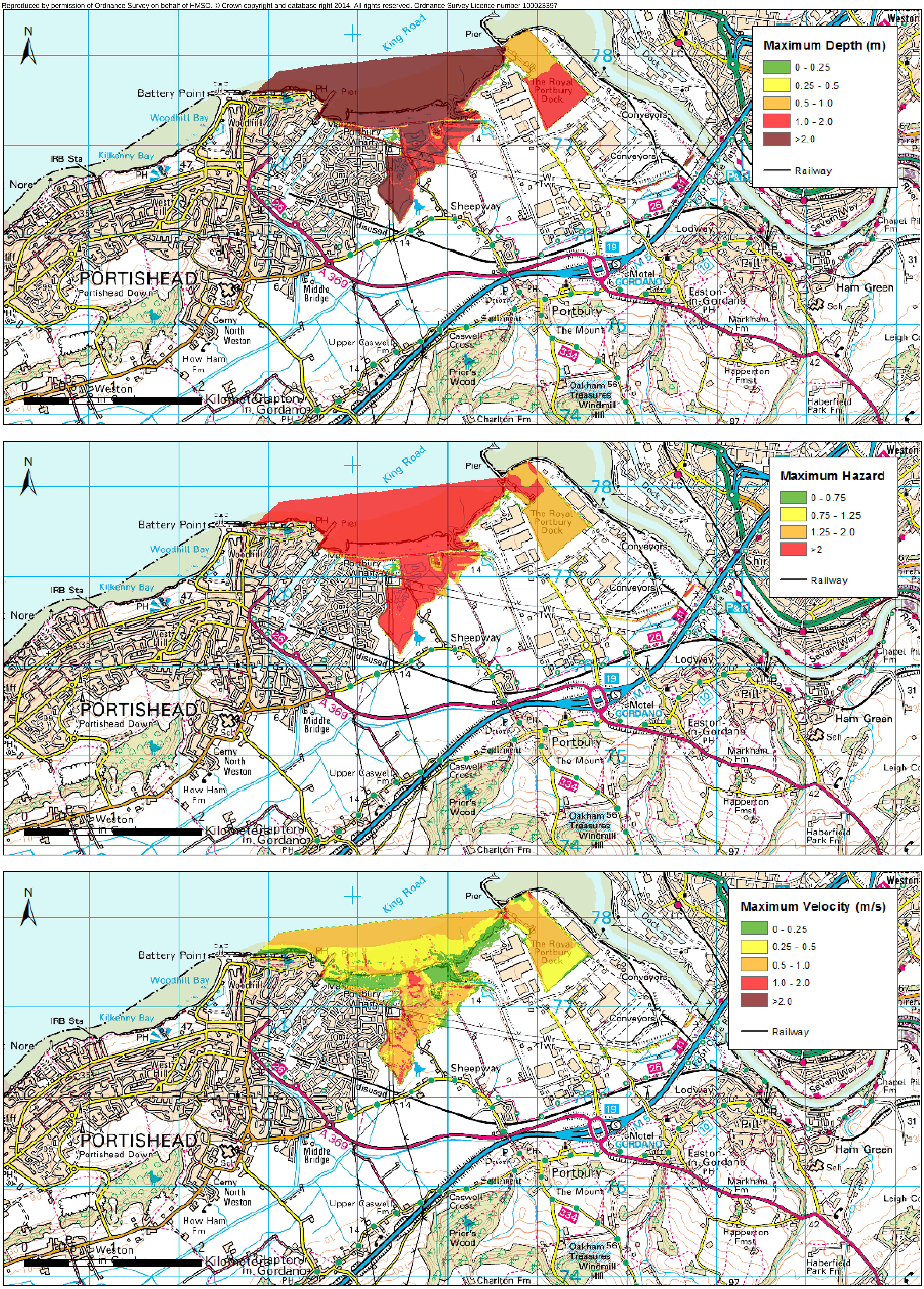


Figure M-14: Existing Railway, Breach on outer defence, 200 year return period - 2015

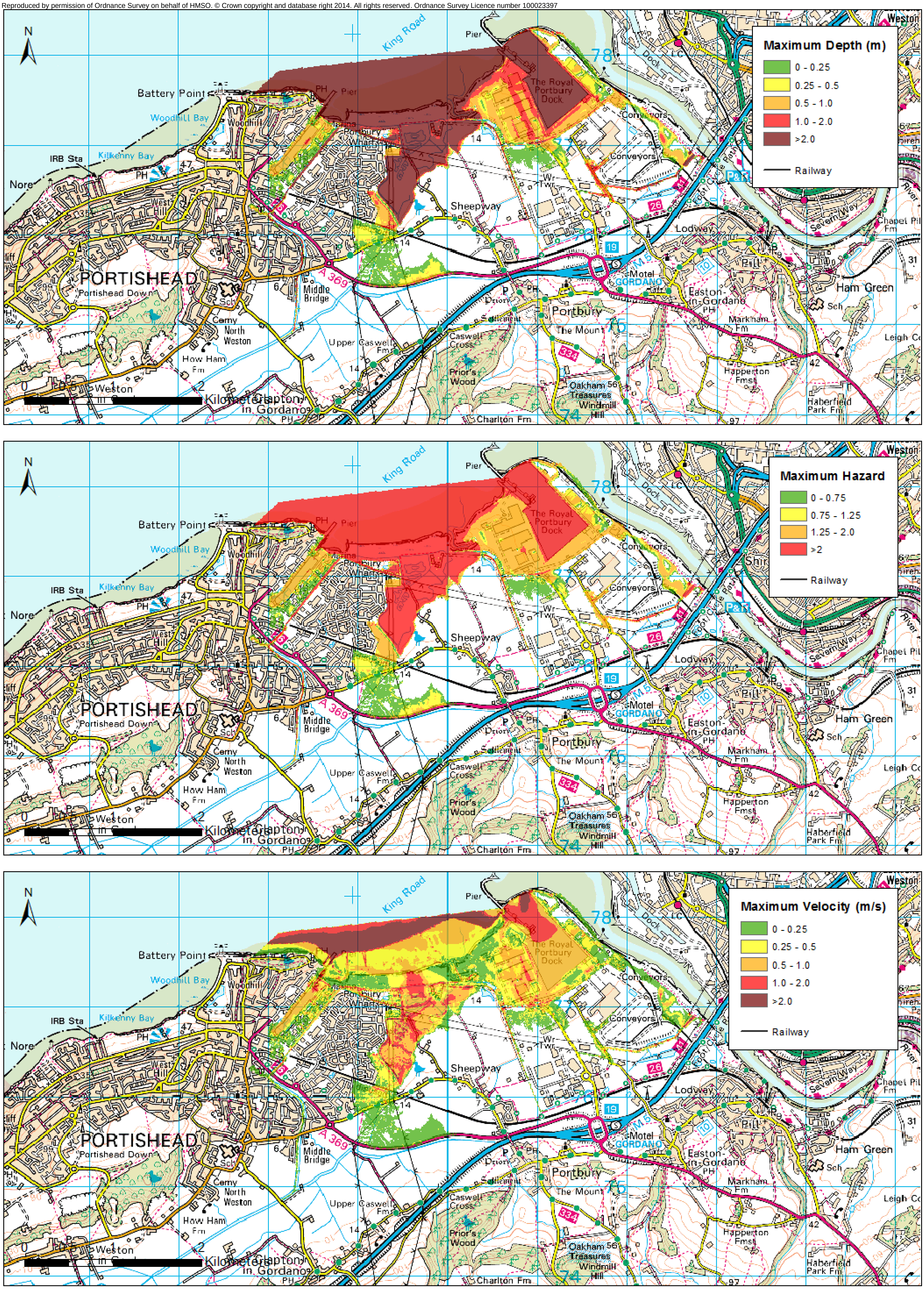


Figure M-15: Existing Railway, Breach on outer defence, 200 year return period - 2115

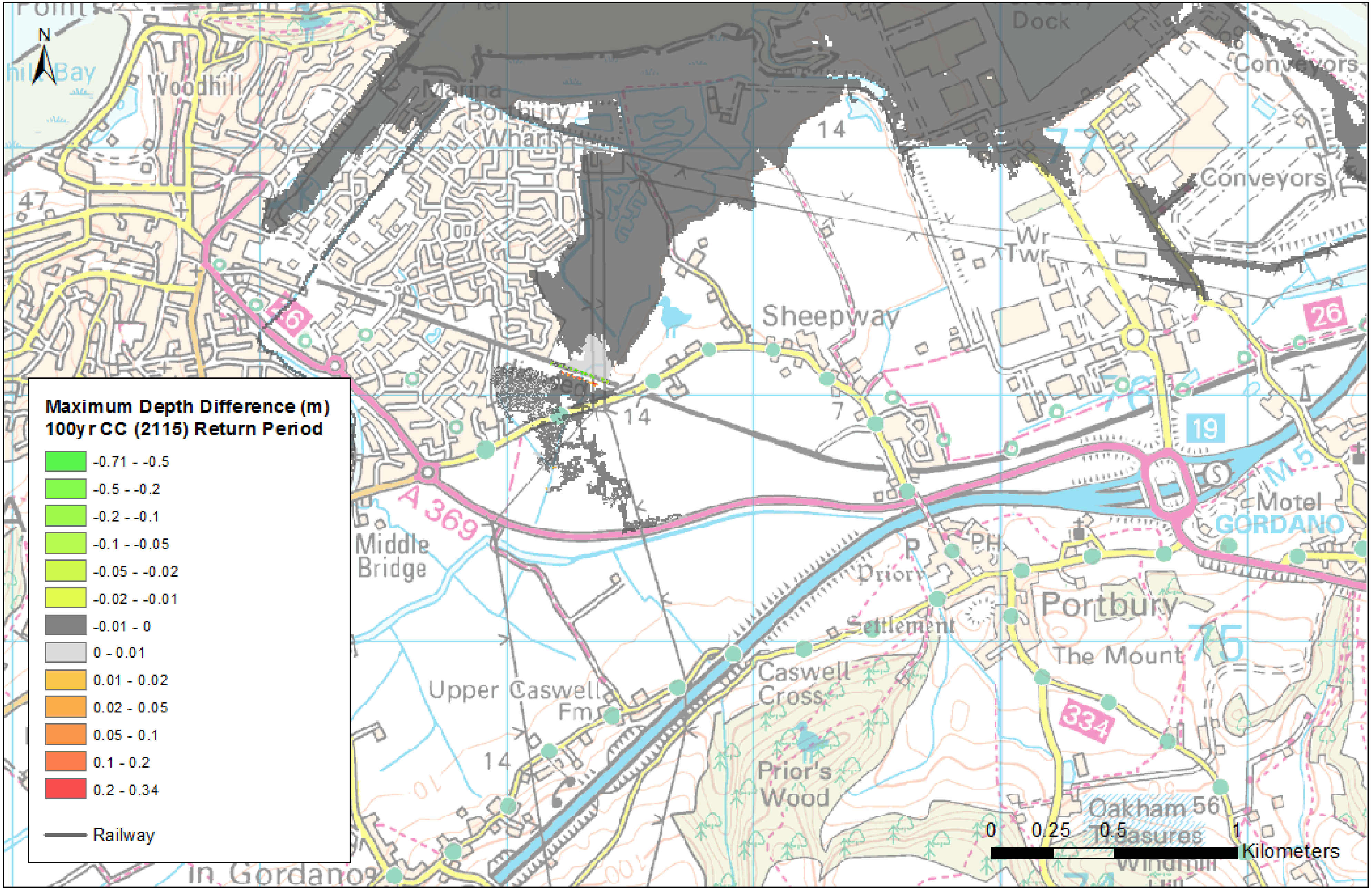


Figure M-16: Post Development - Pre Development difference, 100 year return period - 2115

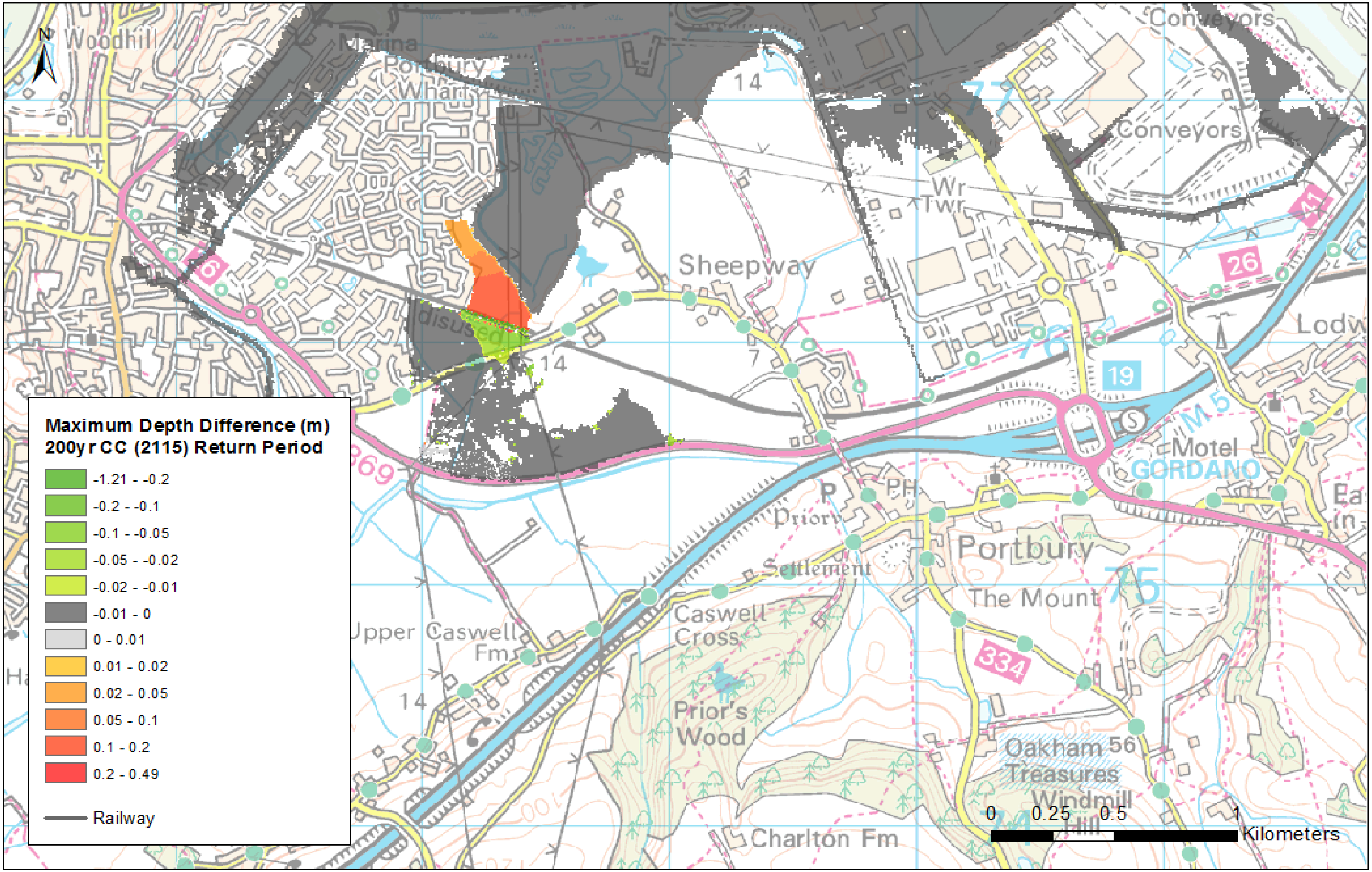


Figure M-17: Post Development - Pre Development difference, 200 year return period - 2115

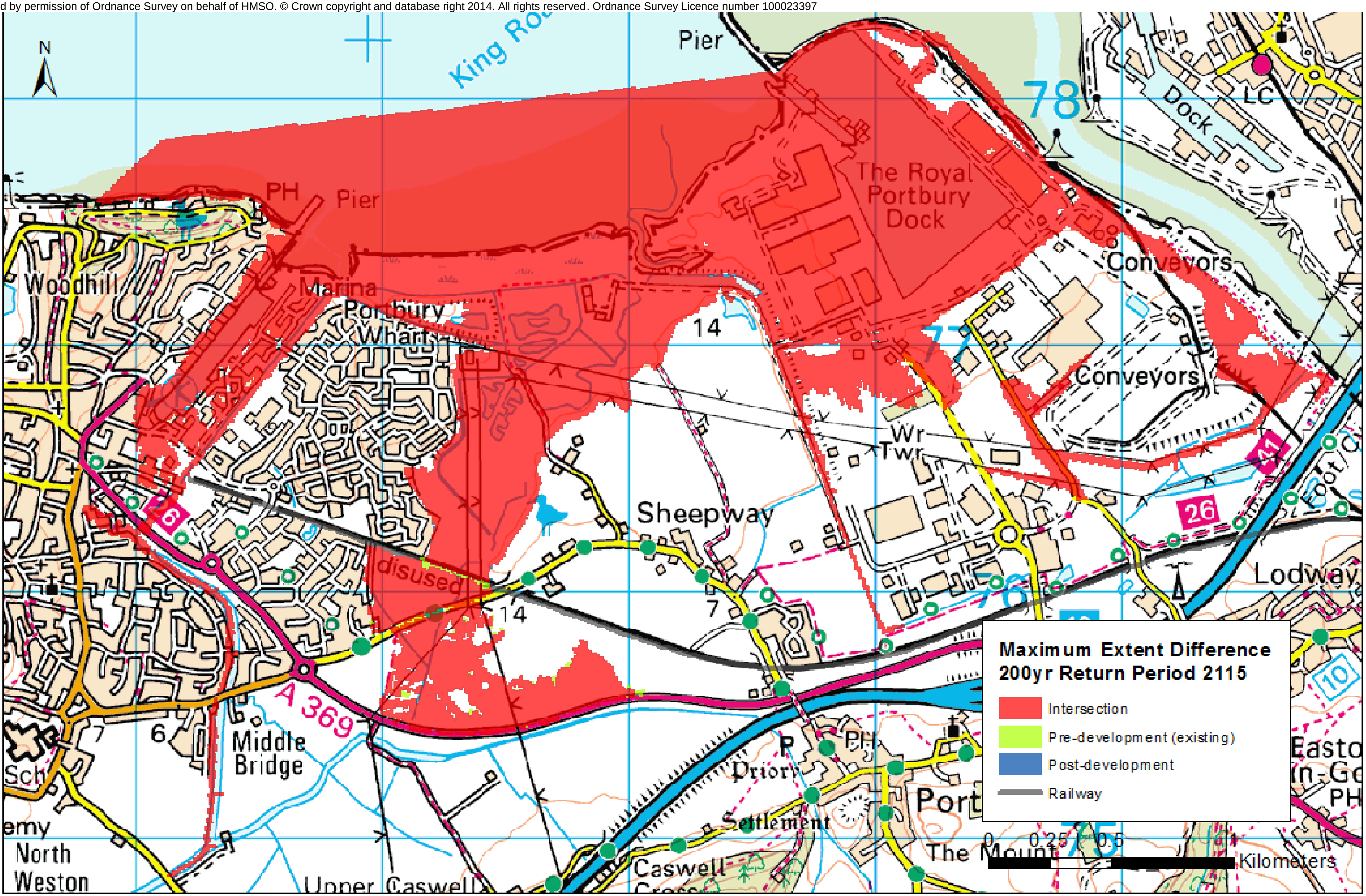


Figure M-18: 200 years return period – 2115 - maximum extent difference (areas classified as pre only, post only, both - intersection).

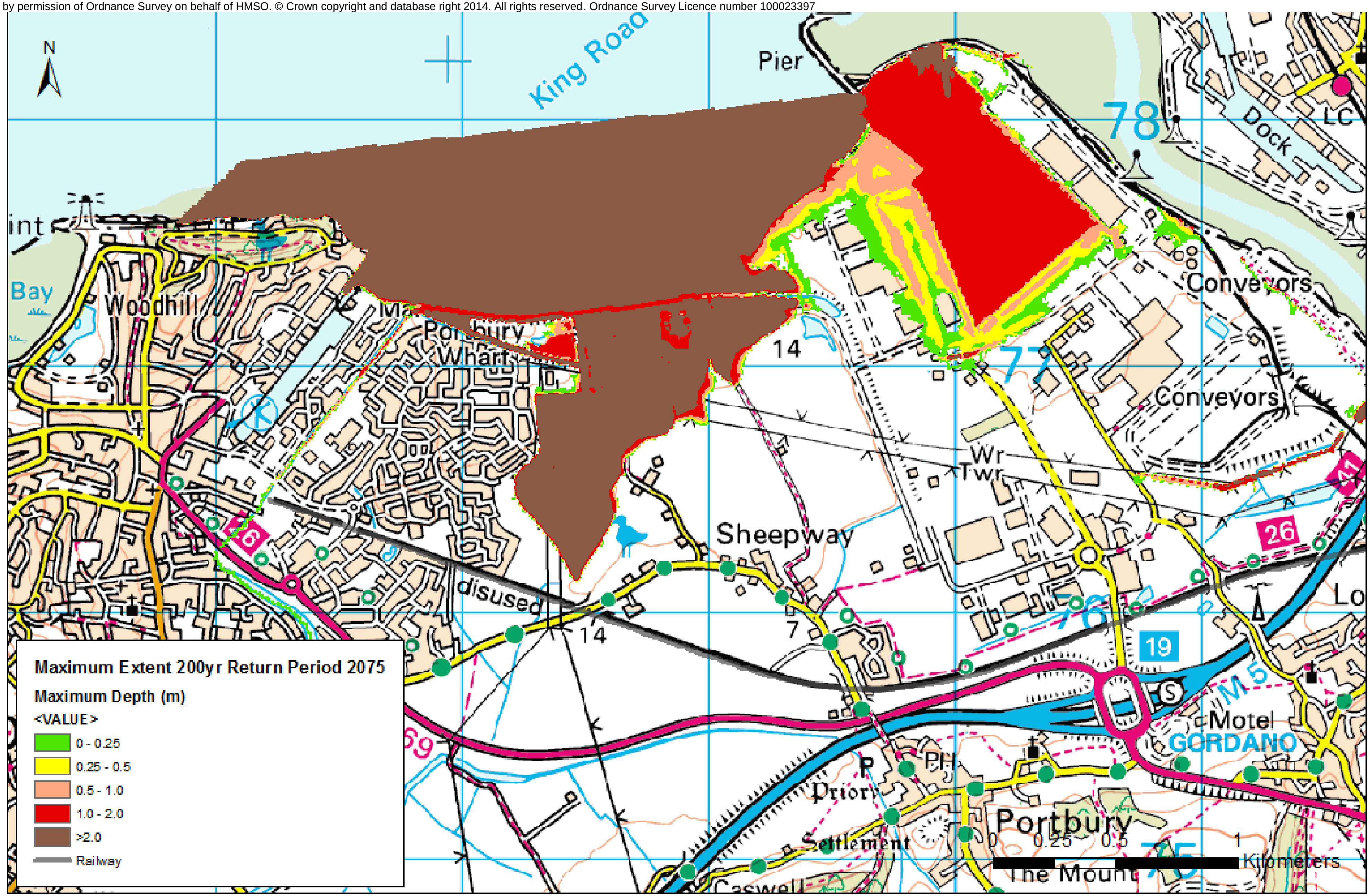


Figure M-19: 200 year return period maximum depth grid - 2075

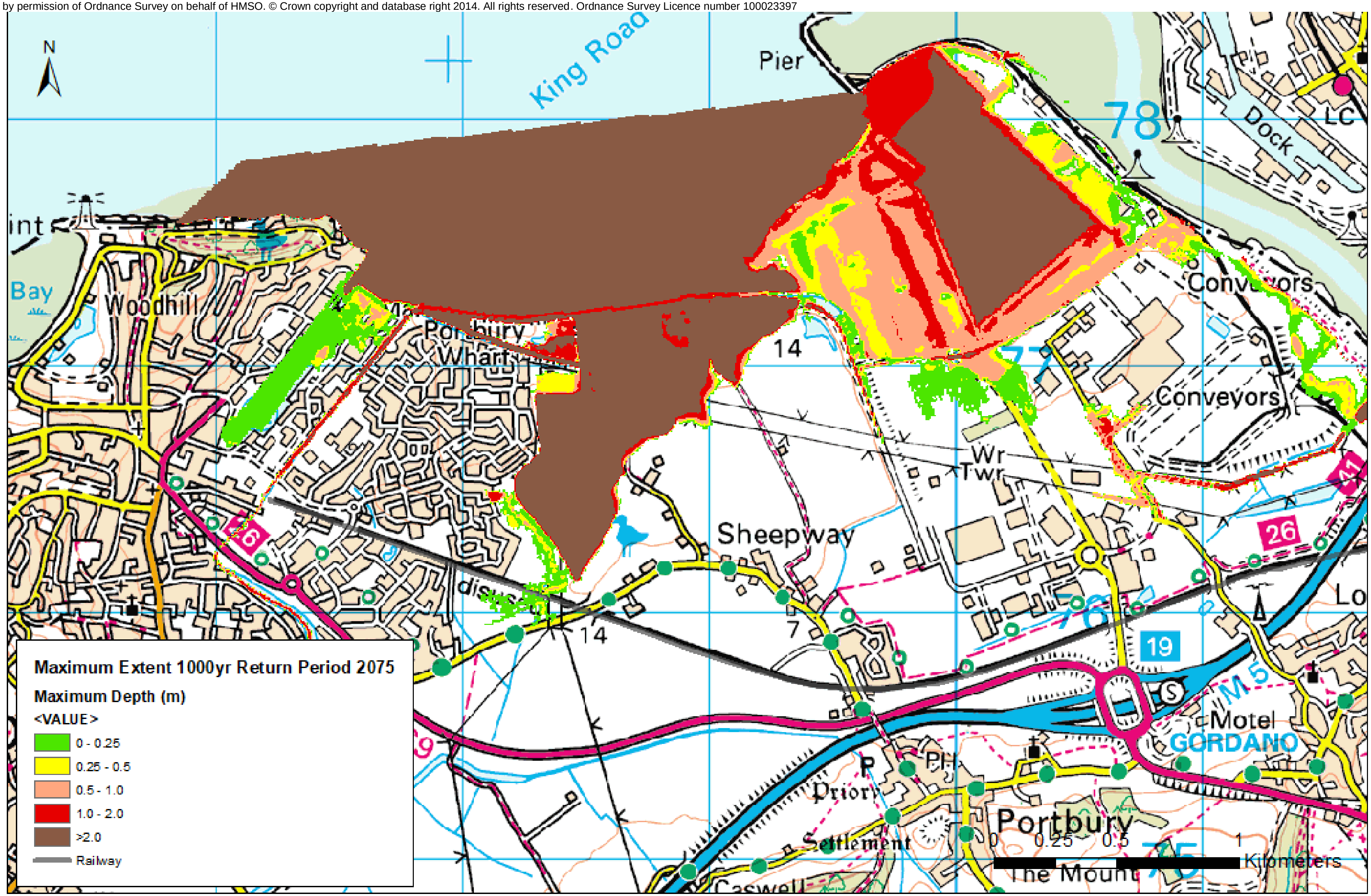


Figure M-20: 1000 year return period maximum depth grid - 2075