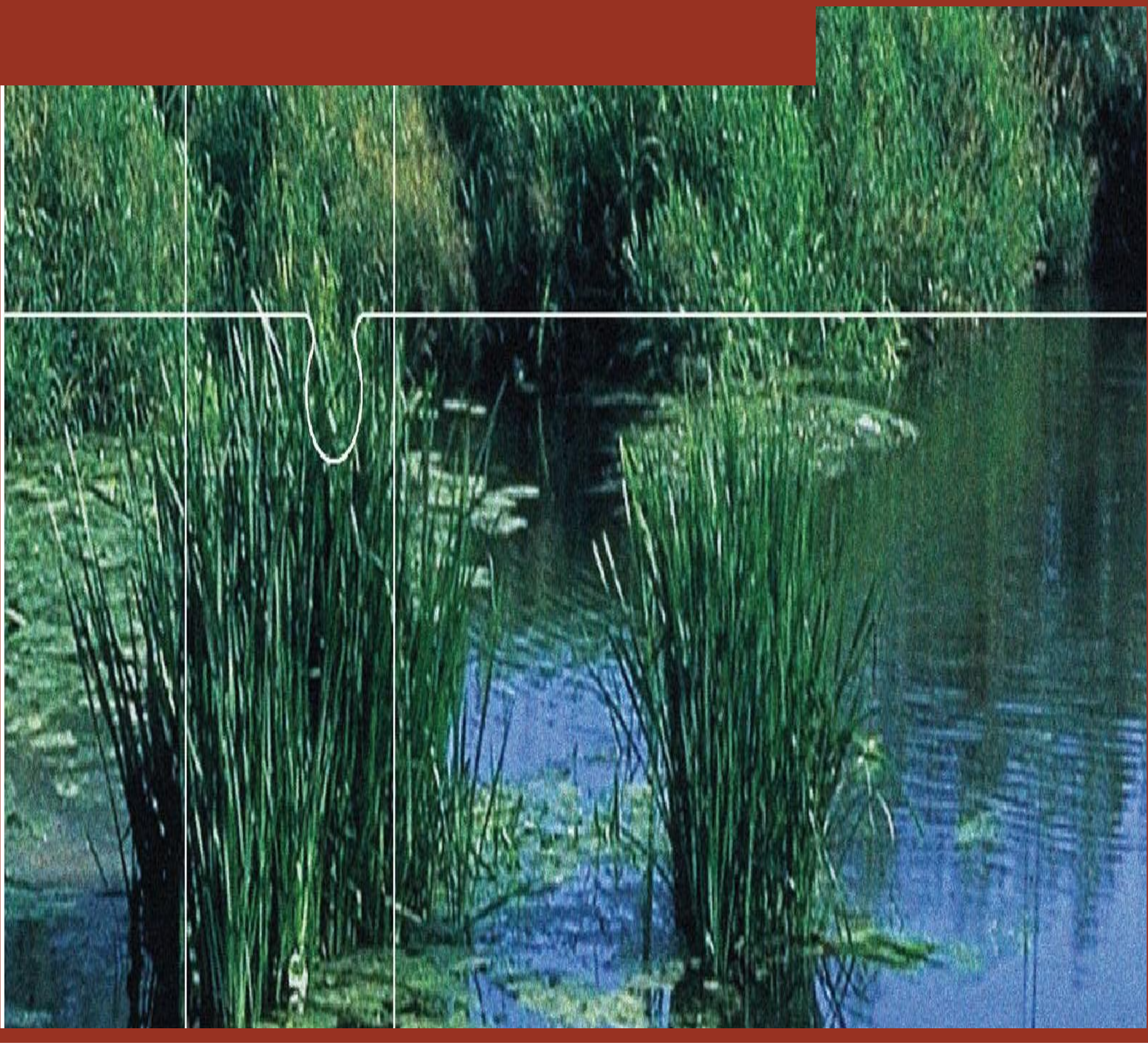
CAPITA

Rother Valley Railway

Modelling Report

June 2016



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Executive Summary

1. Capita Property and Infrastructure Ltd (Capita) has been commissioned by Rother Valley Railway Limited to undertake a Flood Risk Assessment (FRA) for the proposed reinstatement of the Rother Valley Railway between Robertsbridge and Udiam (Bodiam). The route is approximately 3.5 km and will link the existing railway between Bodiam and Robertsbridge. The proposed scheme includes reinstating the historic railway line with a new embankment and the addition of culverts, bridges and viaducts along its route.

2. The FRA is detailed in a separate report. This report provides additional detail about the modelling that was undertaken as part of the FRA. There is an existing Environment Agency hydraulic model of the River Rother. This report focuses on the amendments made to the hydraulic model as part of the FRA. These include a number of improvements to the existing model and the development of a new version of the model which includes the proposed railway.

3. The site is located in the Rother catchment. The River Rother flows in an easterly direction for approximately 30 km before flowing into the English Channel, at Rye. The Darwell Stream is a tributary of the Rother that joins the main channel at Robertsbridge. The area has been subjected to quite severe flooding over the last 20 years and a flood defence scheme was put in place for Robertsbridge in 2004.

4. The site has been modelled using Flood Modeller (previously known as ISIS) and TUFLOW which are established software packages used for modelling rivers and floodplains. The modelling covered a number of flooding scenarios and compared the “without railway” baseline (i.e. the existing condition) with the Rother Valley Railway constructed, ‘with railway’ scenario.

5. The work was carried out in close liaison with the Environment Agency and the key results are based on a 1% AEP (100 year) with climate change design flood event. The modelling undertaken for this FRA (2016) and by the Environment Agency in 2011 shows that overtopping of the existing flood protection scheme occurs at some locations for a 1% AEP and larger flood events. The river modelling techniques currently available are more advanced than those available when the flood defence scheme was designed and built.

6. The modelling found that the construction of the railway would not increase flood risk to properties during a 1% AEP with climate change design flood event in Northbridge Street and Robertsbridge. The impact across the floodplain varies with some areas benefiting from reduced flood levels and others experiencing potential increases in flood levels of up to 50mm. There are a few small isolated areas, immediately adjacent to the proposed railway where predicted increases in water levels are greater.

7. To investigate future flood risk, modelling was undertaken for the 1% AEP with climate change flood event (this includes a 20% increase in the 1% AEP flood event flows). The majority of the FRA work and consultation with the Environment Agency was undertaken prior to the latest climate change allowances being published (February 2016) and therefore the Environment Agency has agreed to base its advice on the previous allowances.

8. To manage the consequences of flooding to the railway the train operators will sign up to the Environment Agency’s Flood Warnings Direct service and cease any services when there is a risk of flooding.

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1 Introduction

1.1 Study Background

1.1.1 Capita Property and Infrastructure Ltd (Capita) has been commissioned by Rother Valley Railway Limited to undertake a Flood Risk Assessment (FRA) for the proposed reinstatement of the Rother Valley Railway between Robertsbridge and Udiam (near Bodiam). The route is approximately 3.5 km and will link the existing railway between Bodiam and Robertsbridge (**Figure 1**). The proposed scheme includes reinstating the old railway line with raised embankments, culverts and bridges along the route. The propose railway scheme also includes sections of track lowered close to ground level and a number of viaducts to maintain floodplain flow routes and minimise the impact on flood levels.

1.1.2 The FRA forms a separate report. This modelling report provides additional detail about the modelling that was undertaken as part of the FRA. There is an existing Environment Agency hydraulic model of the River Rother and details of this are given below. This report focuses on the amendments made to the hydraulic model as part of the FRA. The Environment Agency Final Modelling Report[1] should be referenced for further details about the original model.

1.1.3 It should be noted at the outset that the historic route of the railway is through the Rother floodplain. Therefore the proposed reinstated route, which links two existing sections of railway, is also through the floodplain.

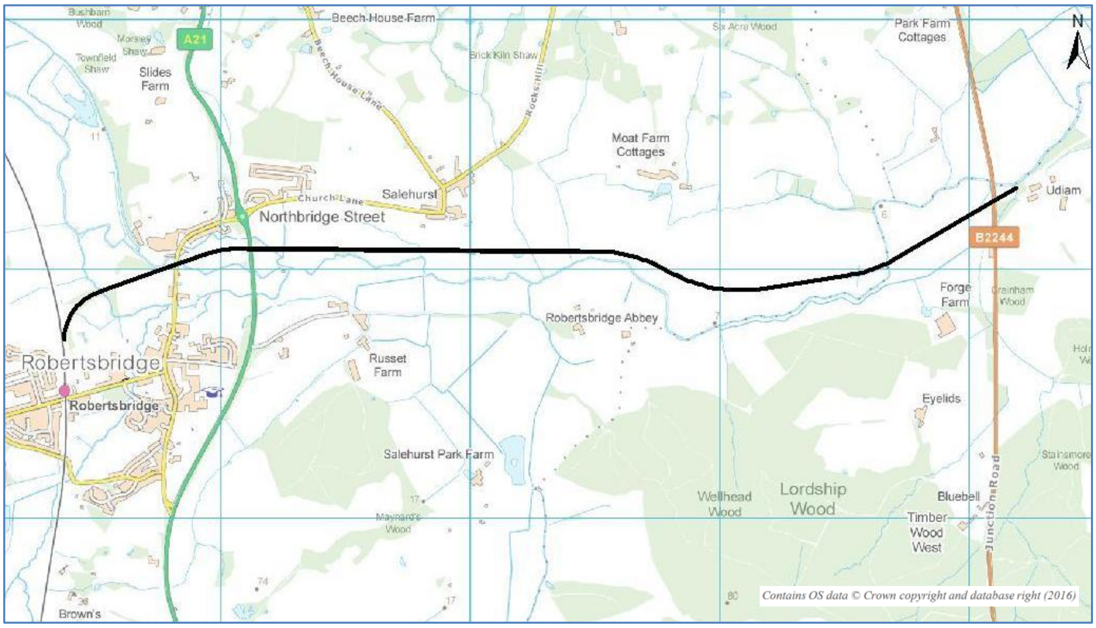

Figure 1 - Proposed Route of Railway

[1] Environment Agency, 2011, River Rother Final Hydraulic Modelling, ABD, and Hazard Mapping Report, Hyder.

1.2 Catchment and Flooding Background

1.2.1 In order to assess the risk of flooding to the reinstated railway, and the wider area of Robertsbridge, it is important to understand the existing catchment characteristics, flow patterns and flooding history.

1.2.2 The site is located in the Rother catchment. The River Rother flows in an easterly direction for approximately 30 km before flowing into the English Channel, at Rye (NGR TQ 95700 17400). The Darwell Stream is a tributary of the Rother that flows through Robertsbridge.

1.2.3 Table 1-1 provides information on historic fluvial flood events in the Robertsbridge area based on information provided in the Rother SFRA. Historic flooding from other sources is detailed in the FRA report.

Table 1-1 Historic flood events at Robertsbridge

Date	Description and Source
1946. 1960, 1979, 1985, 1999, 2001	Fluvial - Insufficient storage capacity. Very intense rainfall on an already wet soil leading to rapid runoff. Recent development in the floodplains, debris in the river channel.
1993	Fluvial - Intense rainfall, properties flooded by sewage contaminated water
12th October 2000 (greater than 1% event) 31st October 2000 5th November 2000	Fluvial - Very intense rainfall on an already wet soil leading to rapid runoff. Recent development in the floodplains, debris in the river channel, backing up from road drains and surcharging of combined sewerage system (indirect source), backing up behind culverts and bridges, overtopping of low flood embankment, back up of floodwater from the floodplains, reduced storage capacity due to repeat events

1.3 Existing Flood Risk Management Infrastructure

1.3.1 After the autumn 2000 floods, a major flood defence scheme was implemented in Robertsbridge, consisting of raised permanent flood walls/bunds along the river, and a number of movable gates that can be used to create temporary flood walls. This scheme was completed in 2004 (Atkins, 2007). Pumps were also added to the scheme to deal with runoff resulting from incident rainfall within the defended area which was no longer able to connect directly back into the river due to the flood defences blocking flow. These pumps facilitate removal of water from within the defended area back into the river. Pumps on the Mill Stream also convey high flows over the defences and back into the Rother[1].

1.3.2 Robertsbridge and Northbridge Street both benefit from defences on the River Rother and Darwell Stream.

1.3.3 The modelling undertaken for this FRA (2016) and by the Environment Agency in 2011 shows that overtopping of the existing flood protection scheme occurs at some locations for a 1% AEP and larger flood events. The river modelling techniques currently available are more advanced than those available when the flood defence scheme was designed and built.

1.3.4 The topographical survey shows the crest level of the defences are between 12.4 m AOD (upstream) and 11.2 m AOD (downstream) at Northbridge Street, and between 12.7 m AOD and 11.5 m AOD at Robertsbridge.

1.4 Existing Flood Model

1.4.1 There is an existing hydraulic model of the River Rother which has been used to assess flood risk and the impact of the proposed reinstatement of the railway. The model was developed by Hyder for the Environment Agency in 2011. The model includes the River Rother and its tributaries between Turk's Bridge at Bivelham Farm and a point 0.4 km downstream of Kent Ditch's confluence with the Rother.

1.4.2 The aim of the 2011 hydrological and hydrodynamic modelling was to quantify predicted flooding of the Rother and its tributaries for flood events ranging from the 20% AEP (1 in 5 year) to 0.1% AEP (1 in 1000 year). The study defined flood extents, areas benefiting from defences and produced flood hazard mapping.

1.4.3 Three models had been constructed of the Rother and its tributaries prior to the 2011 study; the details of these are provided in the 2011 report[1]. However, these models were considered unsuitable for the purposes of the 2011 study.

1.4.4 The 2011 River Rother model was constructed as a linked 1D-2D hydraulic model using ISIS and TUFLOW software. The versions of modelling software used in the 2011 study were ISIS 3.1.1.38 and TUFLOW version 2008-08-DB-iSP. The model was based on survey undertaken in 2001 and 2009. A channel Manning's *n* value of 0.045 was applied in the model based on the channel being typically natural, with a pebbled bed including a small amount of debris and some aquatic vegetation. The 2D model domains were based on 1m filtered LiDAR. The model included multiple domains to manage runs times. A 5m grid was applied in the key areas of interest (around Robertsbridge), and a 20m grid was used in more rural areas. OS MasterMap data was used to define Manning's *n* values across the floodplain. The raised defences around Northbridge Street and Robertsbridge are included in the model. The 2011 report[1] also states that the pump in the Mill Stream which pumps water over the defence bund has been included in the model. The pair of Penstock Sluice Gates (grid ref. 573676, 124095) on the Mill race in Northbridge Street are designed to close during a flood event. This was represented in the model by disconnecting the 1D channel between the main Rother and the Mill Stream, although flow is still transmitted to the Mill Stream via overland routes.

1.4.5 The 2011 report[1] details the model calibration, which was based on three events, 12th October 2000, 30th October 2000 and 6th November 2000. The report states that the outputs of the study agree very well with the historic flood outline from the flood events in October 2000 as well as hydrometric data at Udiam and photographic evidence at Robertsbridge. In addition to the calibration the original study also included a sensitivity analysis. The maximum change in stage was reported for changes to model inflows. Changes in Manning's *n* resulted in changes in stage of up to 0.2m. The sensitivity analysis also indicated that the flood extents in Robertsbridge are sensitive to changes in Manning's *n* and inflow.

1.4.6 The 2011 model (defended version) is considered suitable for assessing flood risk in the Robertsbridge area. The 2011 report recommends the model is reviewed prior to its use in Flood Risk Assessments. Capita reviewed the model to assess its suitability for use in the FRA. The model was considered a suitable baseline model for use in the Rother Valley Railway FRA subject to the changes detailed in this report.

1.4.7 While reviewing the model for use in this flood risk assessment a number of opportunities for improvements were noted. The improvements made to the model included the following and further details are given in Chapter 2:

- improvements to the 2d_2d boundary between the middle and lower domains, where an unrealistic water surface profile was observed in the 1% AEP design event;
- changes to the Darwell Stream and downstream of the A21 to improve model stability including changes to weir coefficients and modular limits in the spill units, changes to spill widths, removal of a minor footbridge, improvements to floodplain Manning's *n* values, and changing some SX boundaries between Flood Modeller (previously ISIS) and TUFLOW to HX connections;
- amendments to the defences layer in the model which included removing a defence along The Clappers which doesn't exist, raising the defence to the north of the Museum/Bridge bungalow which was set 100mm to low, and raising the defence to the east of The Clappers Flood Gate which was too low for approximately 10m;
- the application of HX loss coefficients (relatively new feature), which improves the representation of energy losses as water flows out of bank and model stability; and
- the addition of zshapes to enforce road elevations at key locations and enforce the existing historic railway embankment, which is picked up in the LiDAR, but due to the model grid resolution is not fully represented in the model grid.

1.4.8 Chapter 2 of this report describes the amendments made to the original Environment Agency model to develop the FRA baseline model. The FRA baseline model was used to assess the current flood risk in the study area.

1.4.9 Chapter 3 of this report describes the amendments made to the FRA baseline model to develop a scenario model that represent the proposed reinstated railway.

2 Improvements to the 2011 model

2.1 Introduction

2.1.1 A description of the Environment Agency's 2011 model has been provided in section 1.4 of this report. This chapter describes the amendments made to the original Environment Agency model to develop a baseline 'current' scenario for the FRA. The baseline FRA model was used to assess the current flood risk in the study area.

2.1.2 The FRA model was run using Flood Modeller version 4.1 (previously known as ISIS) and TUFLOW version 2013-12-AD-isp. The 1% AEP results from the 2011 model and FRA 2016 baseline model were compared to make sure that the results were similar and that significant differences could be explained (section 2.7).

2.2 2d_2d boundary

2.2.1 The review of the existing Environment Agency 2011 model identified that there was a significant head loss at some points along the 2d_2d boundary near Robertsbridge Abbey (TQ 73500 23970), giving an unrealistic water surface profile. The 2d_2d boundary "stitches" two 2D domains together by a series of water level control points. Momentum across the link is preserved provided the Zpt elevations along the selected cells in both 2D domains are the same or similar[2]. In order to improve the water surface profile across the boundary the zline along the boundary was edited to improve the smoothing of the Zpt elevations along the boundary.

2.2.2 Based on previous research we have undertaken on 2d_2d boundaries to determine suitable 'a' and 'd' attributes we also adjusted these attributes in the 2d_2d boundary line. The "a" attribute default value is 2. Increasing this value from the default of 2 may improve stability, but may unacceptably attenuate results. The "d" attribute is the minimum distance between 2d_2d water level control points between vertices along the 2D line. If set to zero, only the vertices along the 2D polyline are used. This value should not be less than the larger of the two 2D domains' cell sizes[2]. The 'a' and 'd' attributes were amended from 0 to 2, and from 20 to 30 respectively.

2.2.3 The graph in **Figure 2** illustrates the difference in water surface profile between the set up of the 2d_2d boundary as included in the Environment Agency 2011 model and the FRA baseline model (with amended Zpts and attributes at the 2d_2d boundary). It should be noted that although the transition across the boundary was improved, there remains a relatively large head loss across some sections of the boundary in the amended model. However given that the FRA baseline and proposed scenario models include identical 2d_2d boundary configurations, the comparison of results remains valid (i.e. consistency across the versions of the model, like for like comparison).

[2] BMT WBM, 2010, TUFLOW Manual.2010-10-AB,.

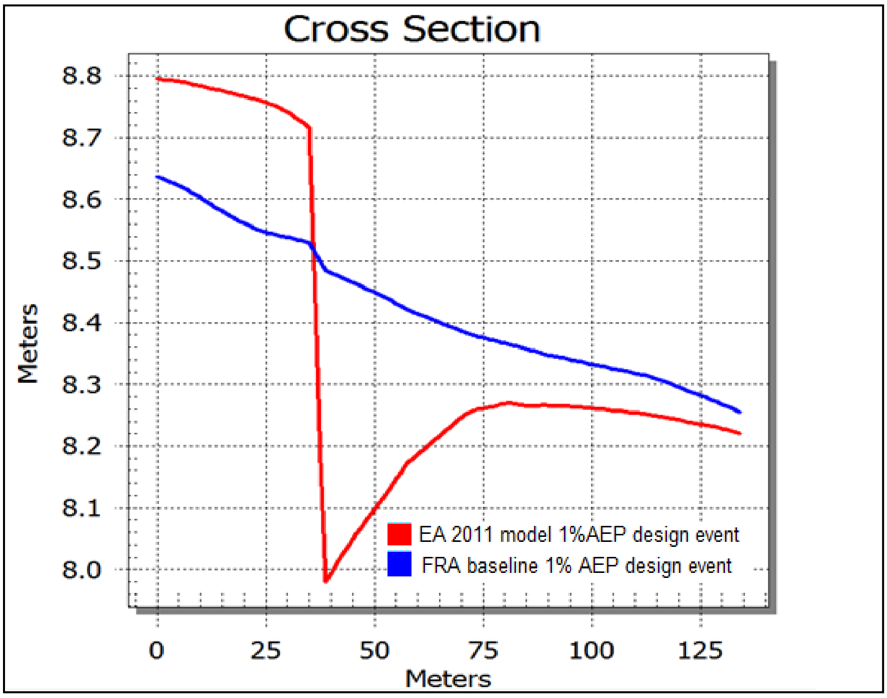

Figure 2 - Impact of amendments to 2d_2d boundary

2.3 1D-2D links

2.3.1 **Darwell Stream** - A review of model results identified that some sections of defences were predicted to overtop around Robertsbridge. At some locations in channel flood levels were marginally lower than the defence crest heights suggesting they should not be overtopping. The cause of this was identified as the method of 1D-2D linking between the Flood Modeller and TUFLOW domains; SX boundaries had been used. When SX connections are used the flow interaction of the Flood Modeller and TUFLOW domains are controlled by Flood Modeller spill units rather than via the TUFLOW domain via HX connections. Relatively small oscillations caused by model instabilities in the Flood Modeller were resulting in flow into the 2D domain. The right bank 1D-2D links between node DA4995 and DA4780 were changed from SX to HX connections and this rectified the issue.

2.3.2 The inline spill widths and coefficients were reviewed along the Darwell Stream. The widths of spills over structures were compared to the null area in TUFLOW i.e. the width of the watercourse that should be represented in Flood Modeller. The width of spill unit sp5226u was reduced from 28.766m to approximately 15m and the width of sp5181u was reduced from 151.049m to approximately 15m. The flow over the bridges at these locations is represented in Flood Modeller, however either side of the structures overland flow is represented in TUFLOW. The spill coefficient was set very low (0.3) at sp5046u, this was increased to 0.7 which is more appropriate for flow over a track.

2.3.3 Just downstream of the confluence between the Darwell Stream and the main channel, spill unit PS4728h was reduced in width from 30.699m to approximately 20m wide to match the null area width in TUFLOW. The spill coefficient was also adjusted from 1.7 to 1.2, which was considered more appropriate for the flow over the road at this location. To the south of this structure a row of TUFLOW cells were amended to set the Manning's *n* value to 0.05 (consistent with the Manning's *n* specified at adjacent cells downstream of the road). This was to address a model instability which was resulting in an over estimate of flooding behind defences in the baseline 1% AEP with climate change scenario.

2.3.4 To improve the representation of floodplain flow paths at the Darwell Stream confluence, changes were made to the HX line configuration between the Darwell Stream (right bank) and The Clappers (Figure 5). An interpolate was also added, 'PS4737i', between PS4737 and PS4737a to improve the water surface profile and stability. To reflect the HX line location change the width of sections NDA4809n and DA4780 were amended.

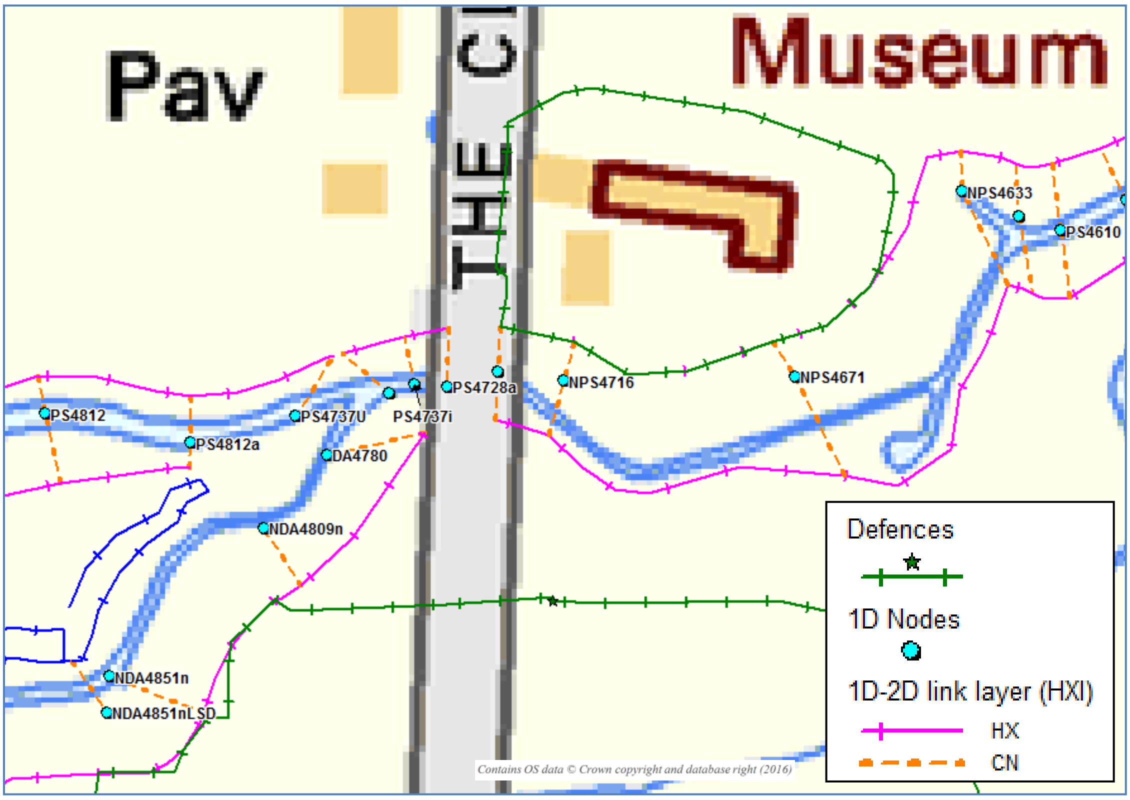

Figure 3 – Improved 1D-2D link and representation of flow paths at the Darwell Stream confluence.

2.3.5 Manning's *n* was refined behind the left bank defences in Robertsbridge. This was to improve the representation of the vegetation and fences/walls in the area. The modelled flood extent in this area was shown to be quite sensitive to Manning's *n* in the original 2011 study.

2.3.6 **Downstream of A21** – In the 2011 model SX connections were used downstream of the A21 to link the Flood Modeller and TUFLOW domains. An area of instability was identified between Flood Modeller node PS4381 and PS4234arbd. In addition to this the difference in floodplain water levels either side of the river channel was not realistic and the SX connections were replaced by HX connections between the A21 and model node RO3825.

2.3.7 The river channel represented in 1D from RO4187 to RO4341u was not connected to the 2D domain. The hxi layer was updated to include new HX lines and CN connections at this location.

2.3.8 **Downstream of The Clappers -** An interpolate was added between model nodes RO4673 and RO4649 to increase stability and improve the water surface profile.

2.3.9 The width of spill unit sp4649u was amended from 61m to 13.2m wide, to match the width of the watercourse modelled in 1D.

2.3.10 **Upstream of the B2244 at Udiam** - Interpolates and associated links to the 2D were added to improve stability and the water surface profile between ROT1746 and RO0425.

2.3.11 **Other -** A loss coefficient of between 0.1 and 0.5 was applied to the HX line along the study reach. This was to improve the representation of energy losses as water flows out of bank and improve model stability.

2.4 Defences

2.4.1 The review of the existing Environment Agency 2011 model included comparing the drawings of the defences around Northbridge Street and Robertsbridge with those represented in the model. A number of inconsistencies were identified between the drawings and the representation of defences in the model. These were initially investigated using Google Street View and a site visit was deemed necessary. Based on site visit observations, which confirmed the drawings were correct, the following amendments were made to the zlines representing the defences in the model.

2.4.2 The zline in the model representing the defence to the east and adjacent to the demountable defence north of Robertsbridge (TQ 73819 23818) was raised to a level of 12.1 m downstream of the road for approximately 10 m.

2.4.3 The defence zline in the model along the High Street between the demountable defence north of Robertsbridge and the Fireplace shop/museum (TQ 73813 23836) was removed.

2.4.4 The Bridge Bungalow/Museum (TQ 73820 23900) defence zline was amended to raise a section of low model cells which had been set to 12 m AOD rather than 12.1 m AOD.

2.4.5 The model grid upstream of the Mill area (TQ 73673 24080) in Northbridge Street was amended to remove a low grid cell and to tie in the defence and ground levels.

2.5 Topography

2.5.1 The following zshapes were added or amended to make sure that the correct elevations were represented in the 2D model grid.

2.5.2 A zshape was added (2d_zsh_road_274.TAB) to enforce the road elevations along Northbridge Street.

2.5.3 The zshape enforcing elevations along a section of The Clappers wasn't applying correctly. This was rectified (2d_zsh_road_v39.3_297.TAB).

2.5.4 Sections of the dismantled railway embankment still exist downstream of Salehurst and are shown in the LiDAR. However particularly within the 20m model domain, the top of the embankment is not picked up by the grid, due to the resolution. Therefore a zshape has been added to the model to make sure the crest of the embankment is represented by the model grid. (2d_zsh_ExistingRailEmbankment_276.TAB).

2.5.5 **Forge Farm -** A zshape was added (2d_zsh_embankment_327.TAB) to represent the raised land (intermittent embankment) north of Forge Farm and the elevation of the building footprints at Forge Farm (design floor levels should be above 6.41 mAOD based on the recommendations in the FRA[3]).

[3] Rother District Council Planning Portal references RR/2013/343/P and RR/2013/342/P

2.5.6 A zshape (2d_zsh_ditch_327.TAB) was added to make sure the model grid represented the flow path north of Forge Farm to the B2244 and from downstream of the B2244 to the railway at Udiam. Structures under the road were added (see section 2.6).

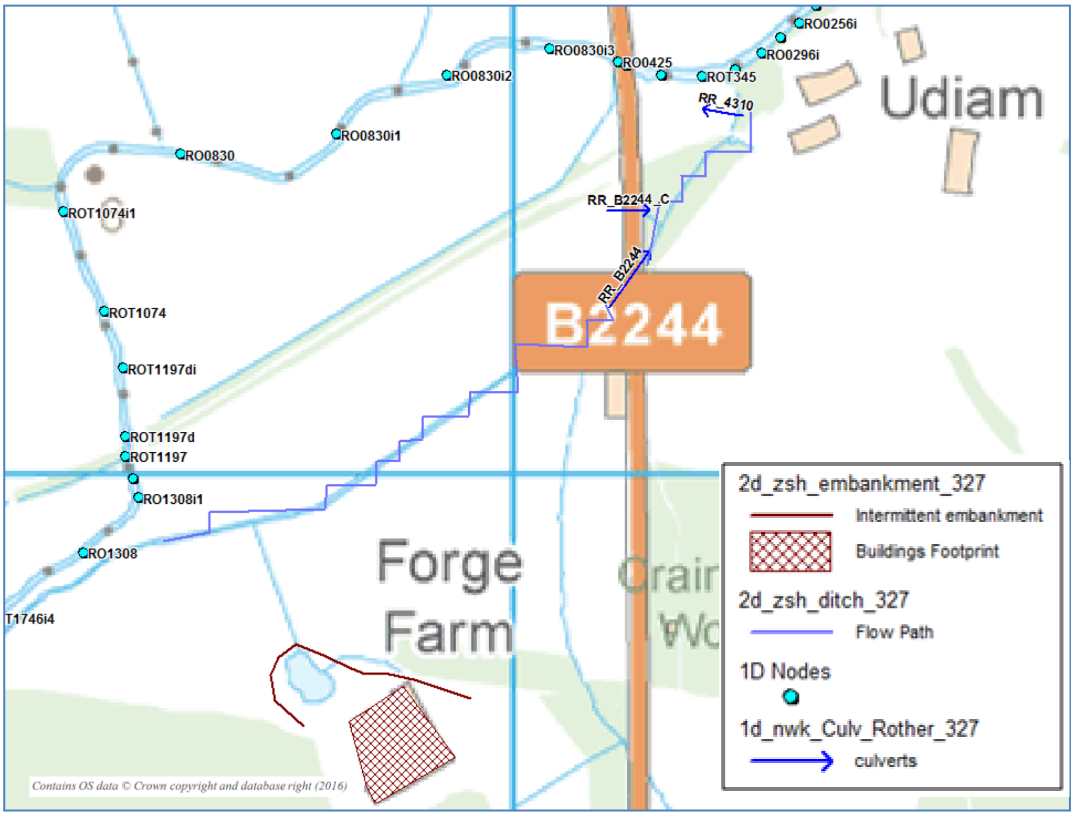

Figure 4 – Amendments to the model in the Forge Farm area, near Udiam

2.6 Structures

2.6.1 **Forge Farm –** There are two flow paths under the B2244 and one under the existing reinstated railway that were not included in the 2011 model. These have been added using ESTRY 1D elements linked to the 2D model domain. The location of the culverts (RR_4310, RR_B2244, and RR_B2244_C) is shown in Figure 4. The dimensions of the culverts are provided in Table 2-1.

Table 2-1 - Culvert Dimensions

Reference	Description	Dimensions	Invert
RR_4310	Circular Culvert	1.4 m diameter	2.1 mAOD
RR_B2244_C	Circular Culvert	0.9 m diameter	3.1 mAOD
RR_B2244	Bridge (modelled using rectangular culvert)	Cross sectional area 11 m^2 (Width 3.14 m, Height 3.5 m)	1.1 mAOD (estimated), Bridge soffit 4.6 mAOD

2.6.2 **Downstream of A21** – The head loss at structures and water surface profiles were reviewed to identify areas where they were unrealistic. One location identified for further consideration was immediately downstream of the A21. The following model nodes were removed: Footbridge ROT4257 is clear spanning, with open handrails and is not a significant structure; River section RO4262 has a short chainage length and inconsistent channel shape**.**

2.7 Comparison of Results

2.7.1 Comparisons of the model results and flood extents were made between the Environment Agency 2011 model and the amended FRA 2016 baseline model.

2.7.2 The long section in Figure 5, extracted from Flood Modeller, illustrates there are no significant differences in water level along the majority of the reach between Robertsbridge and Udiam. The greatest difference in water level, shown by the long section, is located between The Clappers and 400m downstream of the A21. The difference between the two models results at this location can be explain by the amendments to the 1D-2D linking method and the connection of a short reach of 1D not previously connected to the 2D domain. For the majority of the stretch of river between Robertsbridge and Udiam the difference in water levels is less than 100 mm.

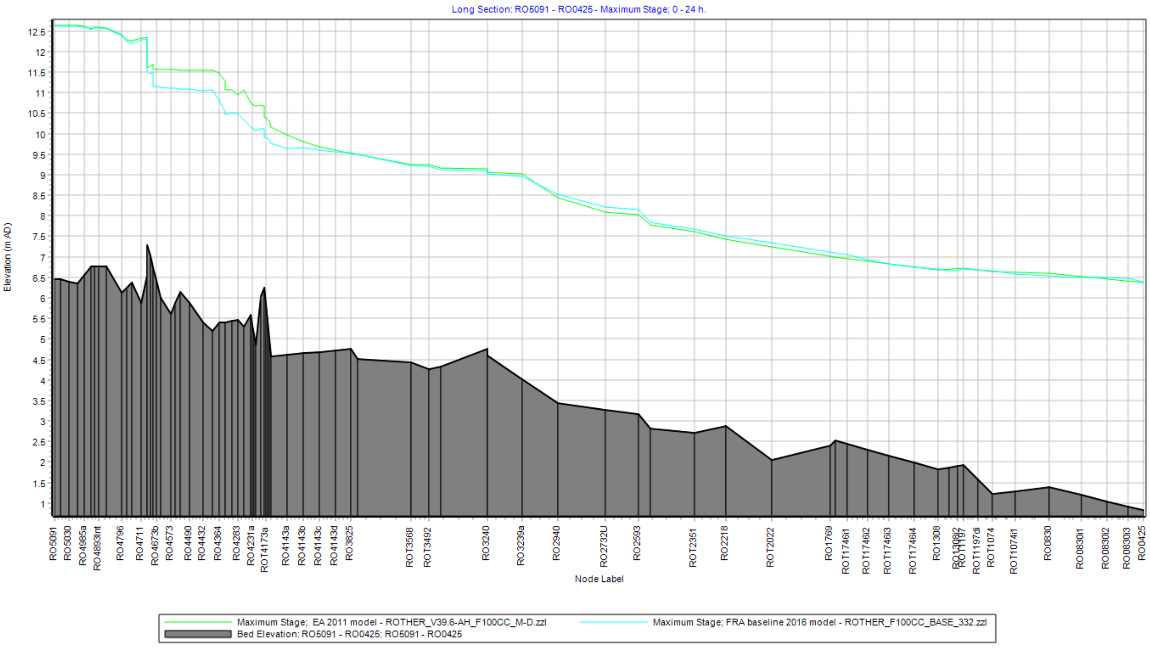

Figure 5 - Comparison of 1% AEP with climate change modelled water levels

2.7.3 The 1% AEP with climate change flood extents were compared for the Environment Agency 2011 model and the amended FRA 2016 baseline model (**Figure 6**). Overall the flood extents are similar, although there are some differences in the predicted flood extent at Robertsbridge and near Robertsbridge Abbey.

2.7.4 The amendments to the defences and 1D-2D linking along the Darwell Stream had the greatest impact on flood extent. The Environment Agency 2011 1% AEP with climate change flood extent is larger behind the defences in Robertsbridge, with the exception of one small area on the right bank upstream of Station Road, where the FRA 2016 modelled flood extent is larger.

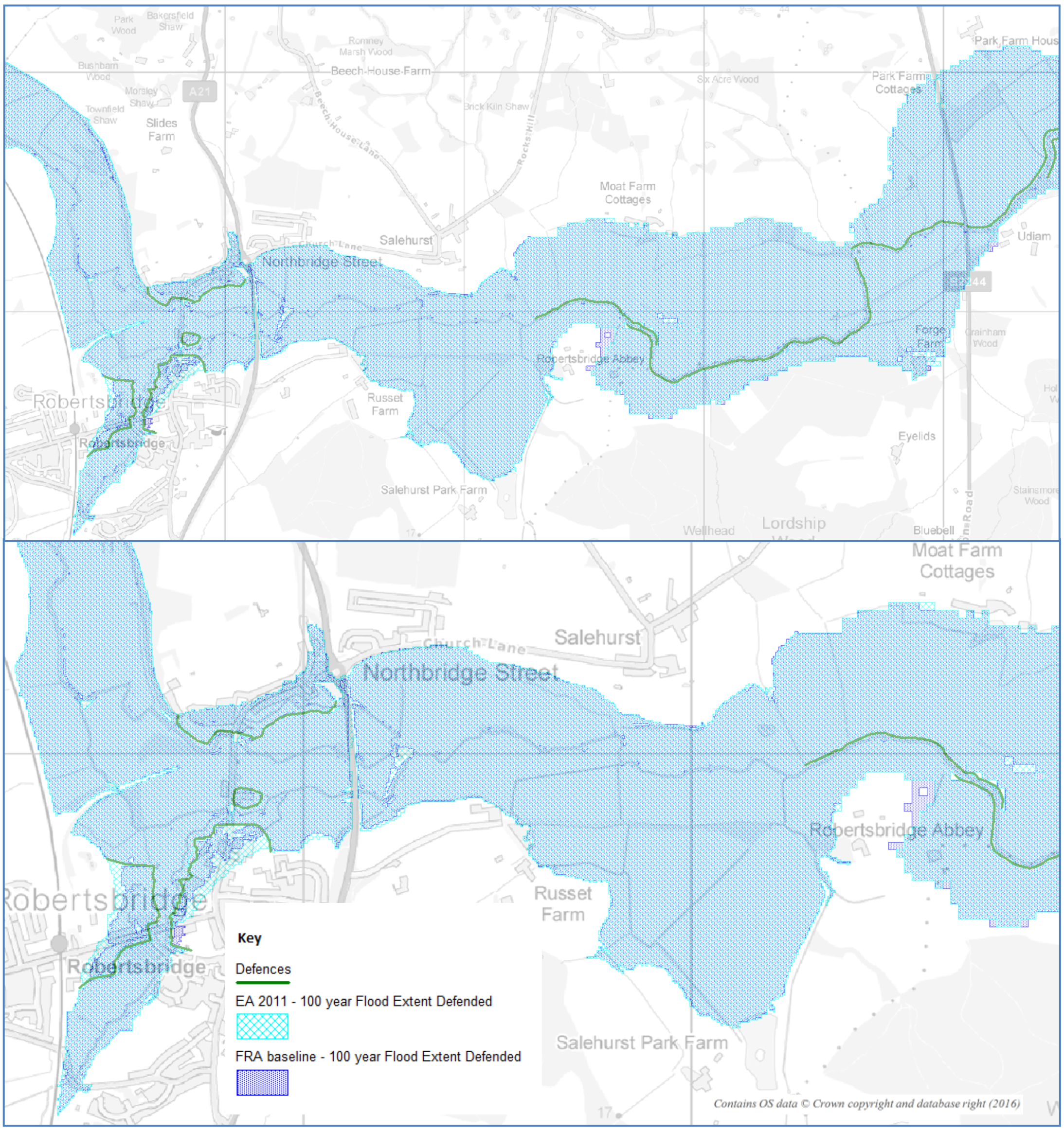

Figure 6 - Comparison of 1% AEP with climate change flood extents

2.7.5 The FRA baseline model was used to provide the ‘current’ baseline scenario for comparison with the proposed railway scenario.

3 Proposed scenario modelling

3.1 Summary of design

3.1.1 The representation of the reinstated railway has been based on drawings RVR-G-001 to RVR-G-006. Subsequent amendments were made to the railway elevations, flood relief culverts and viaducts in consultation with Rother Valley Railway to minimise the impact of the proposed railway on flood risk. These changes to the model are detailed below.

3.1.2 Existing ground levels along the route of the proposed railway vary from 11.7 m AOD to 4.4 m AOD generally falling from the west towards the east. The embankment levels for the proposed railway vary along its length to accommodate floodplain flow paths (Figure 7). The railway embankment elevation is 11.53 m AOD near Northbridge Street and 5.86 m AOD where it meets the existing Kent and East Sussex railway.

3.2 Methodology for modelling

3.2.1 The updated baseline model (as described in Chapter 2) was used as the basis for the ‘with railway’ model which includes the proposed reinstated railway. The initial modelling of the proposed reinstated railway included a number of iterations to optimise the railway elevations, number of viaducts, and proposed culverts through the railway embankment. The aim was to retaining connectivity across the existing floodplain and minimise the impact on flood risk. Once this initial modelling was completed and the revised scheme agreed with Rother Valley Railway the ‘with railway’ model was taken forward for assessment in the FRA.

3.2.2 Further details of the amendments made to the baseline model in developing the ‘with railway’ scenario are given in section 3.3.

3.2.3 The model was run for a range of design flood events including the 5%, 2%, 1.33%, 1% and 1% with climate change AEP design flood events. The results are summarised in chapter 4, and further discussion of the results is presented in the FRA report.

3.3 Amendments to model

3.3.1 **Reinstated Railway Line –** Zlines have been used to represent the reinstated railway line within the 2D domain (TUFLOW). A series of specified elevation points have been placed along the line to ensure the grid cells are either raised or lowered to the required levels. The railway elevations are required to tie in to the existing road crossings and the existing railway at Robertsbridge and Udiam. The elevation of the railway therefore varies along its length to meet these requirements, utilise existing sections of embankment and to allow floodplain connectively (Figure 7).

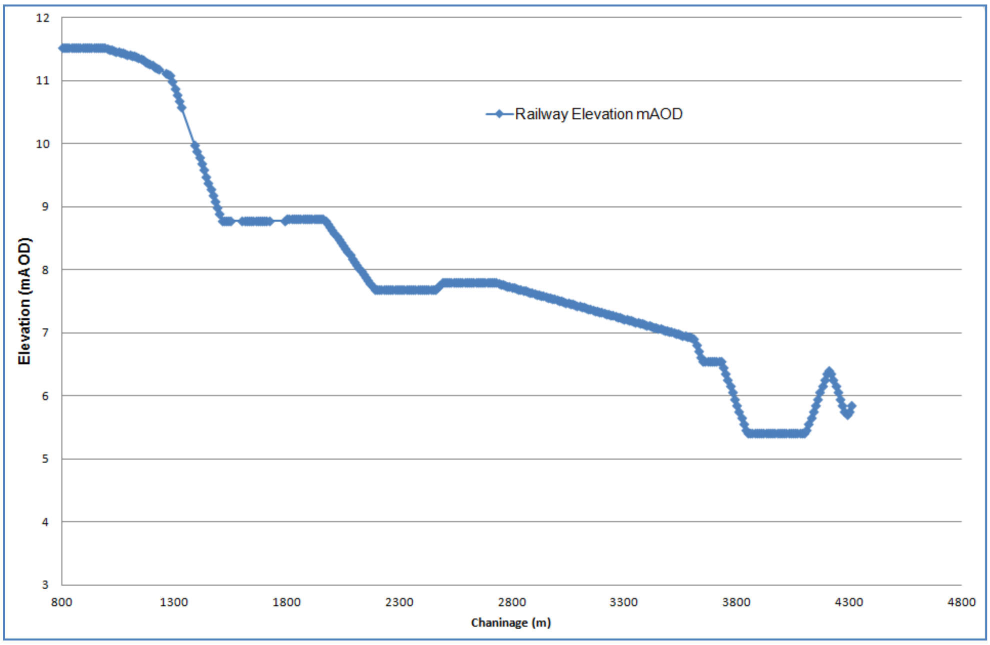

Figure 7 - Plot of the proposed railway elevations

3.3.2 The modelled scenario includes breaks in the zline to represent viaducts (Figure 8, green). Minimal headloss has been assumed through the viaducts. The viaducts and sections of railway where proposed elevations are close to ground levels aim to maintain floodplain flow paths and allow water to transfer across the floodplain.

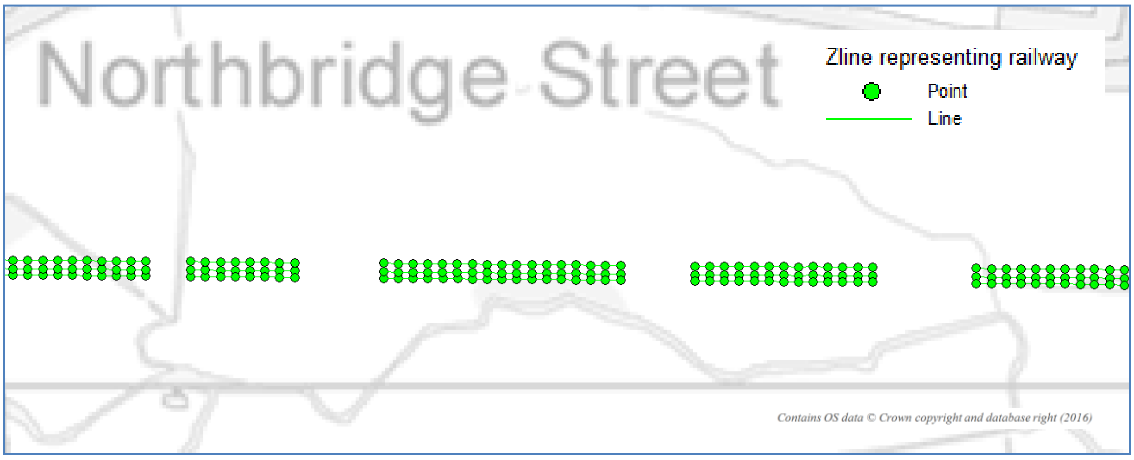

Figure 8 - Image of the 2d Zline used to represent the reinstated railway line

3.3.3 **Flood Relief Culverts –** A combination of rectangular and circular culverts were included in the model to represent the flood relief structures through the embankment. The culverts allow flood waters to transfer across the floodplain under the railway.

3.3.4 The culverts have been modelled using ESTRY as 1D network features and are connected to the 2D domain via 2d_bc SX connections.

3.3.5 The model includes 45 circular culverts and 4 rectangular box culverts under the reinstated railway. Default loss coefficients were applied to the culverts based on square/sharp edged openings and Manning's *n* values of 0.015 were applied along the length of the culverts.

3.3.6 **Other Structures –** In addition to the flood relief culverts a number of structures were edited or added in Flood Modeller to represent the bridges crossing the watercourse. These included:

3.3.7 Bridge at chainage 840 – Model node RO4649u was amended initially based on drawing RVR-G-001 in the 'with railway' model. It was then updated again to incorporate the latest design information in June 2013 (including soffit level 10.863 mAOD, width of opening at soffit 10.573m).

3.3.8 Bridge at chainage 1200 – Model node MS4311 was included in Flood Modeller as an orifice unit.

3.3.9 A list of structures included in the model along the propose railway is provided in Appendix A.

4 Model Results

4.1 Flood Extents

4.1.1 The model results are discussed in detail in the main FRA report. In summary the model results illustrate that the proposed railway has a relatively small impact on water levels in the study area and in some locations reduces the level of flooding compared to the baseline.

4.1.2 The flood extents are very similar for all the flood events up to and including the 1% AEP with climate change (Figure 9).

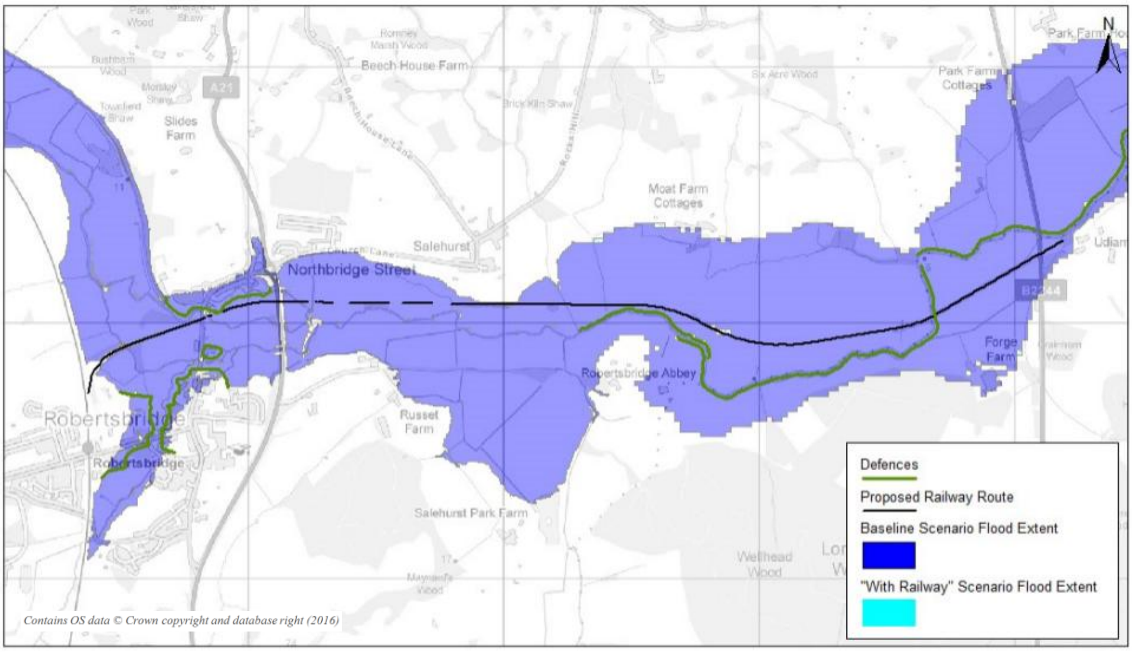

Figure 9 - 1% AEP with climate change flood extent for the 'baseline' and 'with railway' scenario.
(Note the 'with railway' scenario flood extent is drawn below the baseline flood extent shown and therefore it is only visible on the map where its extent is greater than the baseline flood extent).

4.1.3 The section of the railway between Salehurst and Robertsbridge Abbey and near Udiam between Austins Bridge and the B2244 are at risk in all the flood events modelled. The proposed railway elevations between Salehurst and Robertsbridge Abby have been lowered to maintain floodplain flow paths and connectivity.

4.1.4 The flood extents for the baseline and the 'with railway' scenario are provided in Appendix A (Figures A-1 to A-5) of the Rother Valley Railway FRA report (2016). The difference in predicted water depth between the 'with railway' and baseline scenarios are also in Appendix A (Figures B1 to C5) of the Rother Valley Railway FRA report (2016). The figures illustrate the proposed railway has a negligible impact on flood levels across the majority of the floodplain.

5 Model Accuracy and Limitations

5.1.1 Model accuracy and limitations can be understood through considering the underlying hydraulic equations used by the model, the accuracy of the input data, through model calibration and sensitivity analysis. The original 2011 study included sensitivity analysis and therefore further sensitivity testing was not undertaken as part of the FRA. The sensitivity analysis undertaken in 2011 indicated that the largest changes in modelled water levels were caused by changes in flow and Manning's *n*.

5.1.2 The 2011 modelling report[1] explains model accuracy in terms of the calibration results and accuracy of the input data, specifically the LiDAR, which has a vertical accuracy of 150 mm. The modelled peak stage for the 12th October 2000 event was within 60 mm of the recorded.

5.1.3 The 2011 modelling report[1] states the following assumptions:

- That there will be no blockages at the structures which might impede flow and elevate flood levels.
- That flood water levels may exceed structure capacity and hence the model allows flow bypassing/overflowing units at all structure locations.
- That the structural survey, channel survey and digital terrain model represent the correct data and terrain levels for each of the calibration events and the current conditions. Furthermore that there have been no major earthworks or construction in the channel or floodplain subsequent to measuring of any ground data used.

5.1.4 The 2011 modelling report[1] details the limitations associated with the study and are summarised as:

- The model provides a representation of the river and floodplain and a balance was required between the representation of certain structures and model stability.
- The size of the study area required the floodplain to be represented at a 5m and 20m grid cells in the model. (It should be noted that the FRA falls primarily within the more detailed 5m grid).
- It is recognised that studies on smaller reaches may be able to improve the estimates produced by the 2011 study.

5.1.5 The following assumptions should also be noted with respect to the FRA modelling:

- It was assumed that the hydrological inflows developed for the 2011 model were suitable for use in this study and provide the best estimate of design flows.
- Following a review of the 2011 modelling report and model, it was assumed that the 2011 study provided a good baseline from which to develop the FRA model.
- The drawings of the railway embankment that the model is based on are current at time of modelling and the proposed locations of flood relief culverts and viaducts (based on the modelling) will be included in the final plans.
- Minimal head loss is assumed in the method used to represent viaducts in the model.
- A roughness value of 0.5 has been selected for Buildings which allows for some storage of water and flow through the buildings and is appropriate at the grid resolution of the model.

5.1.6 Three _MB.csv files are output by TUFLOW reporting on the various inflows and outflows, volume, predicted volume error and the mass and cumulative mass errors as a percentage a. These give an indication of the health of the model. The graphs in Figure 10 and Figure 11 are based on the _MB.csv file, which is for the overall model (all 1D and 2D domains).

5.1.7 The Cumulative Mass Balance (%) reported for the 1% AEP with climate change model runs are shown in Figure 10. The values are within +/- 1% and indicate the model is healthy.

5.1.8 The dVol reported for the 1% AEP with climate change model runs are shown in Figure 10. The initial spike in dVol is related to the initial water levels in the 1D model upstream of Etchingham. This is outside the FRA study area and does not impact on the FRA results.

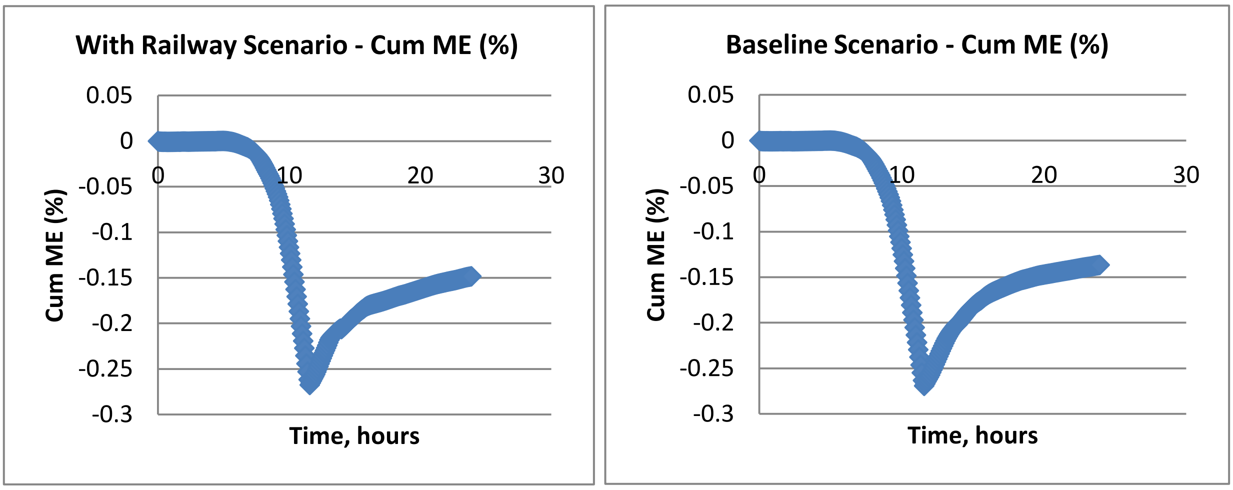

Figure 10 - Cumulative Mass Balance (%) for 1% AEP with climate change scenarios

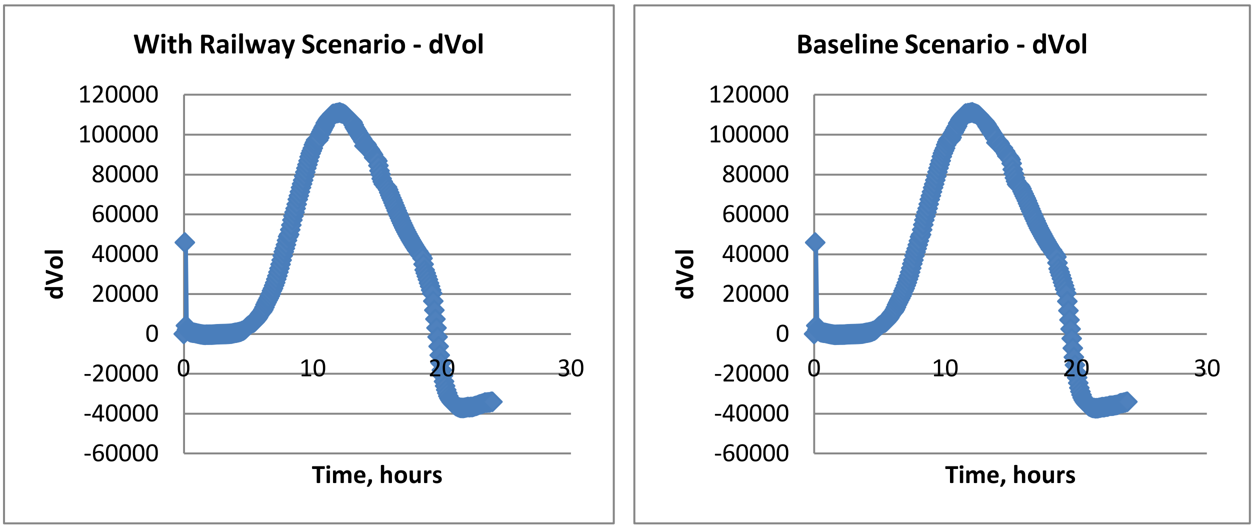

Figure 11 - dVol for 1% AEP with climate change scenarios

5.1.9 The check and warning messages reported by the model are documented in Appendix B.

6 Conclusion

6.1.1 Capita have been commissioned by Rother Valley Railway Limited to undertake a Flood Risk Assessment (FRA) for the proposed reinstatement of the Rother Valley Railway between Robertsbridge and Udiam (NGR TQ 73807 24014 to TQ 77186 24322). The route is approximately 3.5 km and will link the existing railway between Bodiam and Robertsbridge.

6.1.2 This report has detailed the amendments made to the Environment Agency 2011 model to produce an improved FRA baseline model. The amendments made to the FRA baseline model to create the 'with railway' scenario model have also been described. This report has provided a summary of the model results. Further analysis of the results is presented in the FRA report (2016).

6.1.3 The modelling results have shown the flood extents between the baseline scenario and the proposed 'with railway' scenario have not changed significantly. The modelling indicates that there is a reduction in flood depths behind the Robertsbridge and Northbridge Street defences in the 1% AEP with climate change design flood events. The 'with railway' scenarios indicates some areas where water levels increase by up to 50mm, however there are also areas where the flood levels are lower in the 'with railway' scenario. The small areas where a larger increase in flood levels is predicted in the 'with railway' scenario are adjacent to the proposed railway, where no property is located.

6.1.4 In low lying areas where the reinstated railway line is close to existing ground levels flooding is likely to inundate the track and impact on its operation. The risk from flooding to the public associated with the operation of the railway will be managed through restricting operation during times of severe flooding. If there is a risk of flooding to the railway line it is proposed that services along the railway between Bodiam and Robertsbridge are cancelled.

Appendix A - Structures

The proposed railway embankment includes a series of viaducts, bridges and culverts to allow water to flow across the surrounding floodplain. The table below provides details of these structures:

Model ID	Approx. chainage along railway	Type	Number of culverts	US Invert, mAOD	DS Invert, mAOD	Width or Diameter of culverts, m	Height of rectangular culverts only, m	Soffit, mAOD
	820 to 830	Viaduct/ bridge	-	-	-	-	-	-
br4649u	840	Bridge downstream of The Clappers	-	6.996	6.996	-	-	10.863
	850 to 860	Viaduct/ bridge	-	-	-	-	-	-
RR_C0920	920	Circular culvert	6	9.43	9.43	1.5	-	-
RR_C1070	1070	Circular culvert	6	9.198	9.198	1.5	-	-
RR_C1085	1085	Circular culvert	6	9.198	9.198	1.5	-	-
RR_C1150	1150	Circular culvert	8	9	9.2	1.5	-	-
MS4311u	1200	Bridge downstream of A21	-	6.5	6.5	-	-	10.563
	1230 to 1260	Viaduct	-	-	-	-	-	-
RR_C1280	1280	Circular culvert	8	8.8	8.8	1.5	-	-
	1330 to 1390	Viaduct	-	-	-	-	-	-
	1550 to 1600	Viaduct	-	-	-	-	-	-
	1720 to 1790	Viaduct	-	-	-	-	-	-
RR_C1800	1800	Rectangular culvert	1	6.977	6.977	6	1	-
RR_C1845	1845	Circular culvert	3	7.5	7.5	0.75	-	-
RR_C2245	2245	Circular culvert	3	6.8	6.8	0.4	-	-
RR_C2400	2400	Circular culvert	2	6	6	0.75	-	-
RR_C3045	3045	Circular culvert	1	5.8	5.8	0.75		
RR_C3585	3585	Rectangular culvert	1	5.164	5.164	13.397	1.051	
RR_C3675	3675	Rectangular culvert	2	5.1	5	3	1	
ROT1197bru				1.927	1.927			5.79

The manning's 'n' coefficient has been set to 0.015 for all of the above structures which is reasonable value for a standard culvert structure.

Appendix B - Check/ Warning Messages

BASE 100CC – Check/ Warning Messages		
Check/ Warning ID	**Message**	**Comment**
Check 2099	Ignored repeat application of boundary to 2D cell. BC Type = HX or SX	This message indicates a repeat application of a boundary to a 2D cell. This can occur when multiple SX or HX lines select a model grid cell. Spot checks indicate no changes are required.
Check 2108	2D HX link applied more than once at cell.	Occurs at 2D-2D boundary and indicates a repeat application of a boundary to a 2D cell (not within FRA study extents). No amendment required.
Check 2109	Raised HX ZC Zpt by 0.09m to 1D bed level.	No amendment required.
Warning 2117	Inactive 2D cell made active by 2D SX link.	This warning occurs where the inactive cells along the channel have been activated by an SX connection along the river banks. Spot checks of the 2D SX lines indicate no changes are required.
Check/ Warning 2118	Lowered SX ZC Zpt by XXm to 1D node bed level.	Lowered SX ZC Zpt to 1D node bed level. The use of a "Z" flag for the SX connector adjusts the elevation at each grid cell on the 2D SX object. This message indicates the cells have been lowered as the original grid cell elevations were higher. The elevations at the 1D node and 2D cells were spot checked to identify any inconsistencies. The elevations were appropriate.
Warning 2444	ZU of -9999.000 outside Zpt Range Check	All warnings are located outside of flood extent and will not impact results.
Warning 2991	Negative U depth at [0726;0454]	A 2D negative depth has occurred at the cell which indicates the solution failed to converge at this point in the 2D domain. The messages layer was imported and the duration of the negative depths were checked. The negative depths at this location will not impact on the FRA results. The location of this warning is outside of the FRA study area.

RAIL 100CC – Check/ Warning Messages		
Check/ Warning ID	**Message**	**Comment**
Check 2099	Ignored repeat application of boundary to 2D cell. BC Type = HX or SX	This message indicates a repeat application of a boundary to a 2D cell. This can occur when multiple SX or HX lines select a model grid cell. Spot checks indicate no changes are required.
Check 2108	2D HX link applied more than once at cell.	Occurs at 2D-2D boundary and indicates a repeat application of a boundary to a 2D cell (not within FRA study extents). No amendment required.
Check 2109	Raised HX ZC Zpt by 0.09m to 1D bed level.	No amendment required.
Warning 2117	Inactive 2D cell made active by 2D SX link.	This warning occurs where the inactive cells along the channel have been activated by an SX connection along the river banks. Spot checks of the 2D SX lines indicate no changes are required.
Check/ Warning 2118	Lowered SX ZC Zpt by XXm to 1D node bed level.	Lowered SX ZC Zpt to 1D node bed level. The use of a "Z" flag for the SX connector adjusts the elevation at each grid cell on the 2D SX object. This message indicates the cells have been lowered as the original grid cell elevations were higher. The elevations at the 1D node and 2D cells were spot checked to identify any inconsistencies. The elevations were appropriate.
Warning 2444	ZU of -9999.000 outside Zpt Range Check	All warnings are located outside of flood extent and will not impact results.
Warning 2991	Negative U depth at [0726;0454]	A 2D negative depth has occurred at the cell which indicates the solution failed to converge at this point in the 2D domain. The messages layer was imported and the duration of the negative depths were checked. The negative depths at this location will not impact on the FRA results. The location of this warning is outside of the FRA study area.

Warning 2991	WARNING 2991 - Negative V depth at [0429;0700].	A 2D negative depth has occurred at the cell which indicates the solution failed to converge at this point in the 2D domain. The messages layer was imported and the locations of the negative depths were checked. This warning occurs once as floodplain cells wet. The negative depths at this location will not impact on the FRA results. From a healthy model perspective, the occasional negative depth is not necessarily a concern, but repeat occurrences at the same location are an indication of poor topography or a difficult location in the model to solve.
Warning 2991	WARNING 2991 - Negative U depth at [0716;0491].	A 2D negative depth has occurred at the cell which indicates the solution failed to converge at this point in the 2D domain. The messages layer was imported and the locations of the negative depths were checked. This warning occurs once. The negative depths at this location will not impact on the FRA results. From a healthy model perspective, the occasional negative depth is not necessarily a concern, but repeat occurrences at the same location are an indication of poor topography or a difficult location in the model to solve.
Warning 2991	WARNING 2991 - Negative V depth at [0279;1102].	A 2D negative depth has occurred at the cell which indicates the solution failed to converge at this point in the 2D domain. The messages layer was imported and the locations of the negative depths were checked. This warning occurs twice as floodplain cells wet. This is the only negative depth warning within the FRA study area, however the negative depths at this location will not impact on the FRA results. From a healthy model perspective, the occasional negative depth is not necessarily a concern, but repeat occurrences at the same location are an indication of poor topography or a difficult location in the model to solve.

Appendix C – Model Log Summary

Baseline Model

Design Event	ief files	dat	tcf/ecf	Results File Name
5% AEP	Rother_F020_BASE_332	Rother_F0000_BASE_332	Rother_~e1~_BASE_332	Rother_F0020_BASE_332
2% AEP	Rother_F050_BASE_332			Rother_F0050_BASE_332
1.33% AEP	Rother_F075_BASE_332			Rother_F0075_BASE_332
1% AEP	Rother_F100_BASE_332			Rother_F100_BASE_332
1% AEP + CC	Rother_F100CC_BASE_332			Rother_F100CC_BASE_332

'With Railway' Model

Design Event	ief files	dat	tcf/ecf	Results File Name
5% AEP	Rother_F020_RAIL_333	Rother_F0000_RAIL_333	Rother_~e1~_RAIL_333	Rother_F0020_RAIL_333
2% AEP	Rother_F050_RAIL_333			Rother_F0050_RAIL_333
1.33% AEP	Rother_F075_RAIL_333			Rother_F0075_RAIL_333
1% AEP	Rother_F100_RAIL_333			Rother_F100_RAIL_333
1% AEP + CC	Rother_F100CC_RAIL_333			Rother_F100CC_RAIL_333

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