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Real-time flood impacts mapping:

Appendix 5a: Simplified fluvial modelling

SC120023/A5

Flood and Coastal Erosion Risk Management Research and Development Programme

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Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH

http://www.gov.uk/government/organisations/environment-agency

ISBN: 978-1-84911-444-8

Email: fcerm.evidence@environment-agency.gov.uk

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Dissemination Status:
Publicly available

Keywords:
Flood, impacts, inundation, mapping, real-time, forecasting

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Project Number:
SC120023/A5

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

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1 Pro-forma summary

This appendix presents results from testing fast two-dimensional (2D) models accelerated using graphics processing units (GPUs) based on the 2D shallow water equations to derive real-time inundation extents and depths. It explains how this option could work operationally and considers important points for its implementation.

The proof of concept (PoC) was tested using in-channel flow or level results from existing 1D–2D models (details of the models are given in Appendix 4, the pro-forma for fully dynamic fluvial modelling). These flow or level estimates are adjusted, as shown Figure 1.1, using the standard of protection (SoP) or crest levels for every asset whose details are held in the Environment Agency's Asset Information Management System (AIMS). For flows, this becomes the inflow onto the floodplain. Where in-channel levels are used, a simplification of the broad-crested weir equation is used to calculate inflows to the floodplain.

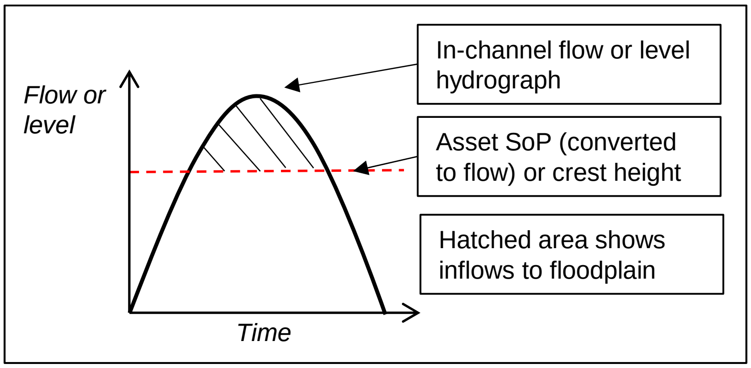


Figure 1.1 Adjustment of flow or level estimates

Individual models are run for each asset using a fast 2D hydraulic model where there is a net inflow to the floodplain. The results are mosaicked together to produce a flood map.

As discussed in the main report, 3 events were run through the model:

- Morpeth 2008
- Cockermouth 2009
- Thames 2014

Model results are compared with observed data using a suite of evaluation tests. Grid-to-Grid (G2G) ensembles are also evaluated as a means of understanding how the uncertainty in forecast boundary conditions propagates to variability in flood extents. Findings from these tests are presented in this pro-forma.

1.1 Key findings

Overall, the models accurately reproduce observations of flood extent. The key findings are summarised below.

- The quality of the results is heavily dependent on the accuracy with which boundary conditions and asset SoP or crest levels are specified.
- In the PoC, models driven by in-channel flow or asset SoP generally reproduce observed outlines more accurately than those driven by in-

channel level or asset crest level. A number of discrepancies were found between asset information held in the AIMS, with bank heights in 1D–2D hydraulic models (based on survey) and light detection and ranging (LIDAR) Digital Terrain Models (DTMs). Future implementation of this option should make use of accurate, up-to-date information on asset crests or SoP.

- Higher grid resolutions incorporated greater topographic detail into the modelling and resulted in longer run times. However, general predictions of flood extent were comparable at all the grid resolutions tested.
- GPU acceleration is required to achieve run times that are feasible for real-time use. Given the appropriate hardware, however, the models tested in this PoC ran in times that would allow this option to be used operationally. Coarser grid resolutions (10m) provide modelled depths and extents that could provide useful information to support flood incident management during an event.
- G2G outputs can be downscaled to guide a local, tactical response by using G2G flow grids as the boundary conditions to 2D hydraulic models.
- Uncertainty in forecast boundary conditions is a much greater source of variability in flood outlines predicted using this method than differences in grid resolution. In this PoC, this was demonstrated by running the model with different G2G ensemble members as inputs.
- Different return periods can be applied to different assets within a Flood Area.
- The simplified fluvial modelling option allows asset return period to vary within a Modelling and Decision Support Framework (MDSF2) Flood Area and so reflect the local return periods interpolated along the river network. This is in contrast to the simulation library approach (see Appendix 6), which assumes a single return period across an entire Flood Area. The ability to apply different return periods to different assets within a Flood Area is an important distinction between the 2 PoCs and a benefit of the simplified fluvial modelling approach.

1.2 Implementation

Operationally, this option could be implemented as follows:

1. Forecast levels or flows at a gauge are converted to a return period based on pre-computed frequency analysis at the location.
2. Return periods are interpolated along the river network and linked to a look-up which returns local flow/level at each asset.
3. SoP and crest levels are used as a threshold for obtaining floodplain inflows for a fast 2D flood spreading model (as in the testing of this PoC).
4. The results are mosaicked together to produce a flood footprint, which can be provided to Area Incident Rooms and Gold/Silver Command.

One of the main benefits of implementing this option is that it makes use of GPU-accelerated models. This provides faster run times than fully dynamic 1D–2D models, which is a requirement for real-time use. Where run times are prohibitive, a hybrid approach could be adopted where outputs from this option are combined with pre-computed return periods.

However, an important limitation of this approach is that it does not represent the dynamic link between channel and floodplain. This results in the potential for overprediction of flood extents (water is unable to drain into the channel on the recession of the event). It also means that the method requires accurate specification of in-channel conditions and bank heights or SoP; the latter is heavily dependent on data quality in AIMS. The significance of this limitation will vary with location.

Future development could incorporate the assessment of flood risk from defence breaches into the simplified fluvial modelling option. This would be relatively straightforward to implement by adjusting defence SoP/crest level or using fragility curve models such as Risk Assessment for Strategic Planning (RASP).

Section 5 of this appendix provides detailed descriptions of considerations for implementing this option.

2 Proof of concept overview

2.1 About this option

Name in Technical Options Report (Appendix 2): Real-time RASP for fluvial and coastal inundation modelling

Number in Technical Options Report: Option 5

This option considers the use of suitably fast flood spreading models to derive real-time inundation extents and depths. Predictions would be driven by in-channel flows and levels.

Forecasting models in the National Flood Forecasting System (NFFS) provide predictions at discrete nodes in the river network of river flow and, where hydraulic models and rating curves are present, level. G2G also provides estimates of river flow on a national scale, routed through the river network using kinematic wave flow routing.

This option uses these predictions of in-channel flows and levels to calculate inflow volumes to the floodplain. Inflow volumes could then be combined with a suitable inundation model to derive depths and extents.

River gauges do not, by themselves, provide sufficient spatial density to accurately represent the in-channel flow or level at each location where flows would overtop onto the floodplain. This PoC is therefore driven by detailed 1D-2D hydraulic models with observed boundary conditions, which were used to predict flow and level at each asset location. Operationally, interpolation of in-channel conditions between forecast locations in the NFFS, or G2G, could be used to drive this option. The provision of boundary conditions is something common to all the PoCs tested by this study; see the main report for further discussion.

Inflow volumes were derived using the RASP framework. In this approach, inflow volumes are derived on a per defence basis, or along lengths of high ground in undefended areas. The volumes are calculated using a simplified form of the broad-crested weir equation and a number of simplifying relationships that vary with asset type (derived from AIMS). Inflow volumes can be calculated for both breached and non-breach cases, which is a particular advantage of reapplying this method for real-time forecasting. The full set of equations is described in Environment Agency (2005) and can be easily implemented outside the MDSF2 software.

Operationally, a number of suitable fast 2D flood spreading models could be used to make predictions of inundation extent and depths. This study used JFlow, a GPU-based 2D hydraulic model to demonstrate the chosen approach.

2.2 Functional requirements

The Technical Options Report summarised the user requirements identified during the consultation exercise at the outset of this project. These were then presented as an evaluation matrix for each PoC. Figure 2.1 reproduces the one for this option.

- Each row of the table presents the detail required by different user groups. For example, spatial coverage may be local, regional or national scale.
- The user groups are shown as coloured bars along each row of the table. In this case, the user groups are Area Incident Rooms (green bars) and

Gold/Silver Command (silver bars). A shaded bar implies that the particular user requires the given functionality.

- If the option meets a given acceptability criteria, it is assigned a ‘Y’.

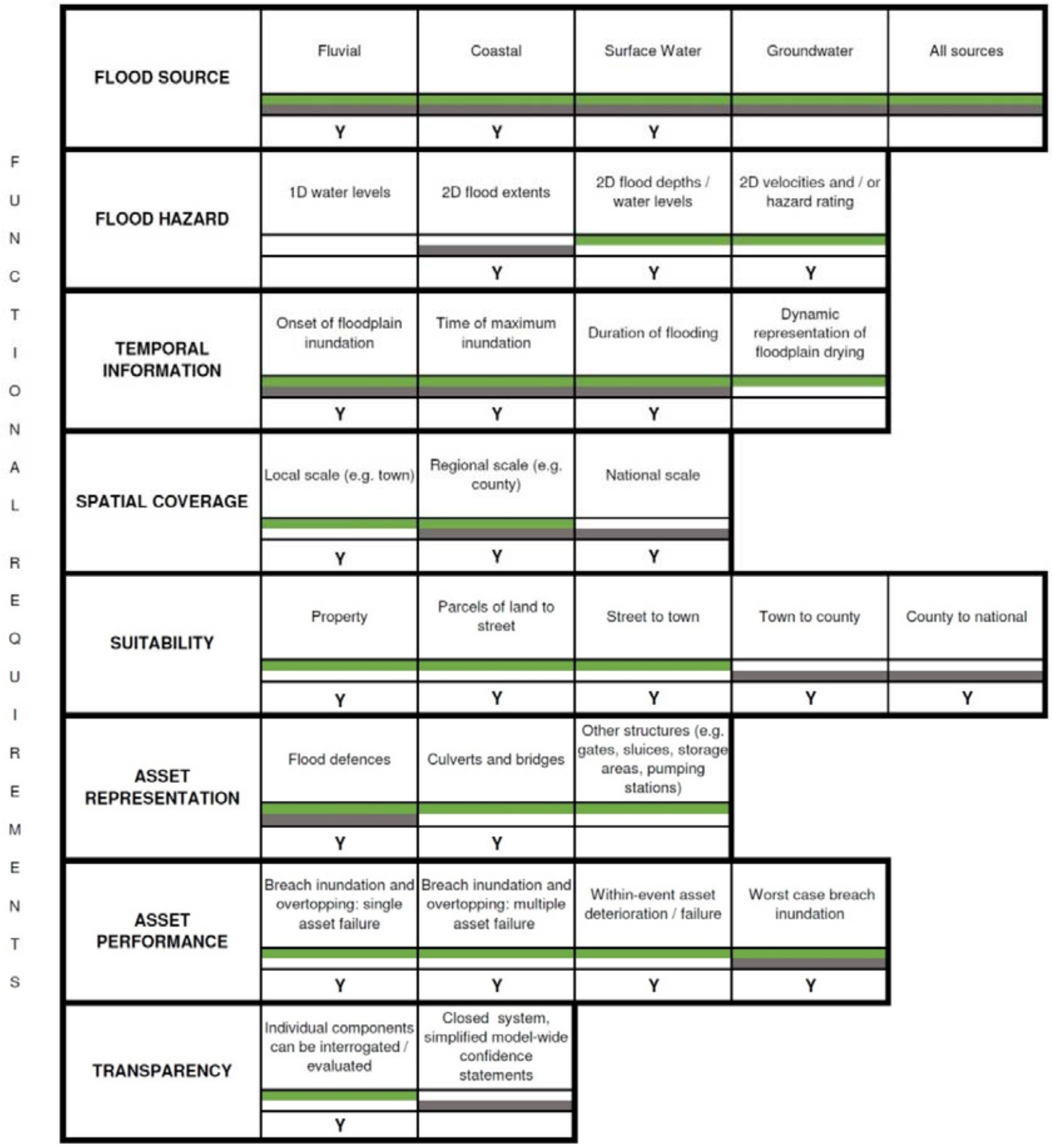


Figure 2.1 Evaluation matrix: simplified fluvial modelling

2.3 Workflow

The flow chart presented in Figure 2.2 shows, in generalised terms, how this option works. Subsequent sections of this appendix refer to the reference numbers in the flow chart to give:

- specific information about how the option was tested, and the data and software used in this project (Section 3)
- considerations for operational implementation (Section 5)

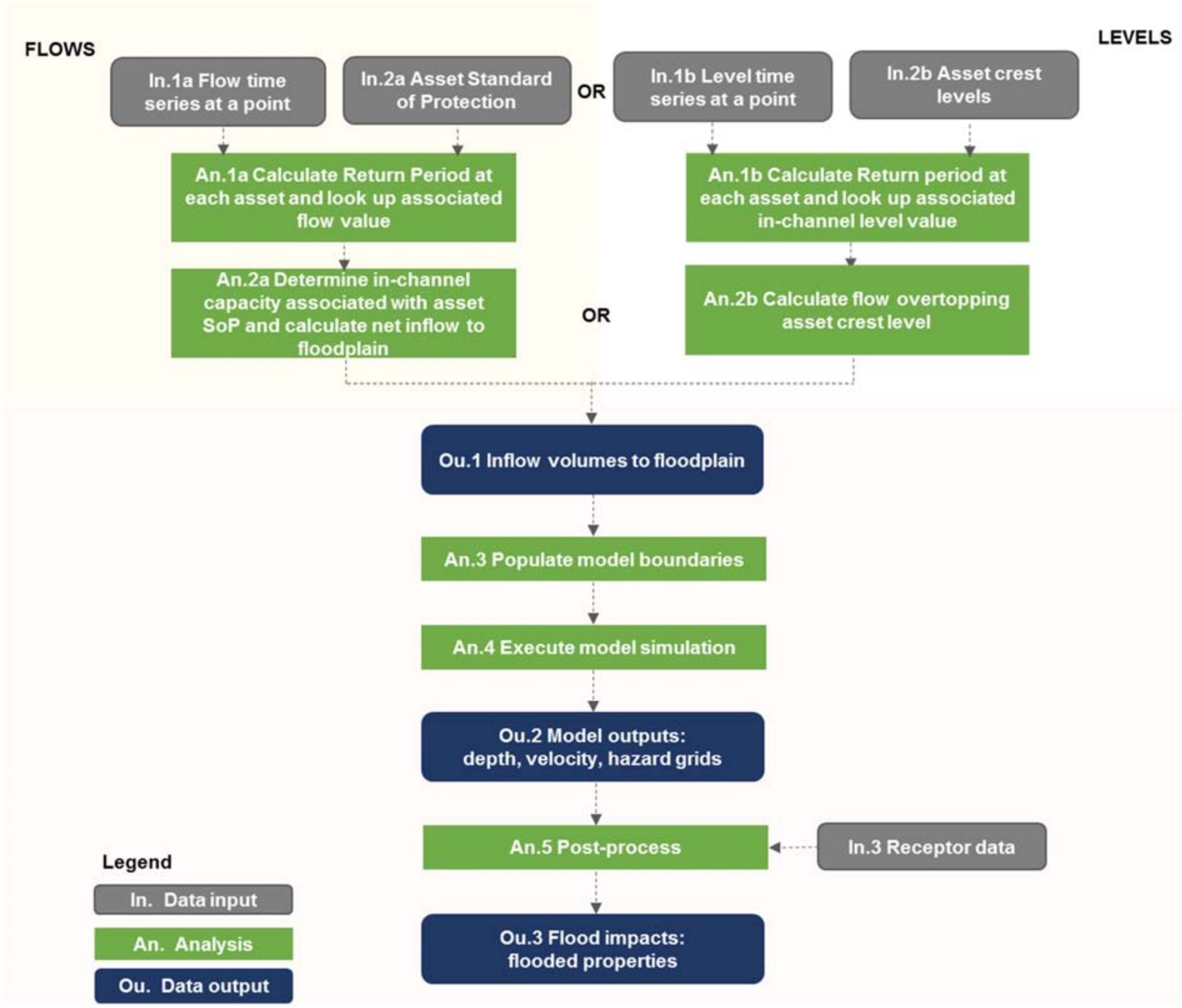


Figure 2.2 Flow chart showing PoC workflow for the simplified fluvial modelling option

3 Proof of concept testing

3.1 Case studies

This section describes the case studies and data (boundary conditions, evaluation data and model outputs) available to this PoC test. Full descriptions of each case study and dataset are given in Section 5 of the main report.

Table 3.1 Summary of available case study data

	Morpeth	**Cockermouth**	**Thames**
Event	5–7 September 2008	12–30 November 2009	6–17 February 2014
Inputs (grid resolutions of model scenarios tested are given in brackets)[1]	Observed (10m) Sensitivity test (+10%, -20% at 10m) G2G simulated and sample of ensemble (10m) Observed (5m) Observed (2m)	Observed (10m) Sensitivity test (±20% at 10m) G2G simulated and sample of ensemble (10m) Observed (2m) Observed (5m)	Observed Sensitivity test (±20% at 10m) G2G simulated and sample of ensemble (10m) Observed (2m) Observed (5m)
Evaluation data	7 flood depth maps at hourly intervals Georeferenced photographs Morpeth flood summary report (Parkin 2010) Flood Warnings issued	Aerial photographs Recorded Flood Outline Flood Warnings issued	Aerial photographs Recorded Flood Outline Flood Warnings issued
Evaluation tests[2]	A1, A2, B1, B2, C1	A1, A2, B1, B2, C1	A1, A2, B1, B2, C1
Outputs	Flood extents, depth, water level, velocity, hazard		
Comments	Input data were provided by a 1D–-2D model which was run with observed flows +10% (rather than +20%) for model stability	Aerial photographs were only available at the peak of the event, so Test B2 (property counts over time) was not performed	Aerial photographs for the full model domain were only available at the peak of the event, so Test B2 (property counts over time) was not performed. The Thames model was not run with G2G data due to time constraints.

Notes: [1] Inputs are valid for both the flows and levels case.
[2] See Section 4.1.5 of the main report for a description of each evaluation test.
Tests shown in light grey were not available or were not considered by this option.

3.2 Testing the PoC option

Details of how the PoC option was implemented in this study are given here for reference. The flow chart for this option is shown in Figure 2.2.

As described in Section 2, 2 different model set-ups were considered, based on either flow or level time series as boundary conditions. This section provides details of how the PoC was implemented for the flows case. The general approach and model set-up is common to both the flows and levels cases, but important differences between the model set-up for the 2 cases are noted where relevant.

3.2.1 Input data

Table 3.2 Flow chart: In.1, In.2, An.1, An.2, Ou.1, An.3

Model files	DTM – 10, 5, 2m resolution; unedited Bare Earth Model Asset lines (AIMS) from continuous defence line. Each asset is simulated separately. 1D–2D model nodes – each node has corresponding flow or level time series from a 1D–2D model. Asset lines are assigned flows or levels from the nearest node in order to calculate floodplain inflows. Flood Areas from MDSF2 used to define the active model area.
Required inputs	The PoC uses data from detailed 1D–2D models as inputs to JFlow. Flow and level time series are used to calculate floodplain inflows that become the input hydrograph to JFlow. The flows case uses 1D in-channel flows plus 2D floodplain inflows. The levels case uses the 1D in-channel level. Model software used to generate the input data: • Morpeth: ESTRY–TUFLOW • Cockermouth: ISIS–TUFLOW • Thames: ISIS–TUFLOW for Kingston, Walton, Staines, Windsor, Maidlow,[1] Reading
File formats	Flow and/or level time series obtained using tabular csv for Cockermouth and Thames, and plot output lines digitised along HX for Morpeth. *.csv format was used to populate the JFlow model. The JFlow model itself is set up within a Microsoft® Access database.
Data overheads	See model files below

Notes: [1] A combination of flows from the Maidenhead and Taplow sluices

3.2.2 Intermediate processing

Table 3.3 Flow chart: An.4

<table>
<tr><td colspan="2">Software</td></tr>
<tr><td colspan="2">Detailed 1D-2D model for input data
ISIS–TUFLOW (Thames, Cockermouth)
ESTRY–TUFLOW (Morpeth)
Requires licences for use of ISIS, TUFLOW and ISIS–TUFLOW linking.
Simplified fluvial model
JFlow: a fast and robust 2D numerical flow model designed to simulate a variety of flood risks. The model is not specifically designed for simulating in-bank river flows, but rather the movement of water over floodplains.
Details below are for the JFlow model.</td></tr>
<tr><td colspan="2">Hardware</td></tr>
<tr><td>Description</td><td>Runs were made on PCs with between 3.0GHz and 3.6GHz processors and 4–32GB of RAM. Each PC had 2–4 GPU devices to run simulations, mainly Nvidia GTX 690.</td></tr>
<tr><td>Size of model files (excluding outputs)</td><td>For JFlow models, the constituent files include model geometry (DTM, GIS files) and run files (Microsoft Access .accdb format).
Each Asset Raster is between 1KB and 100KB (10m resolution) and 3KB to 1.5MB (2m resolution).
Each active grid area (multiple flood areas) is between 300KB and 12.5MB (10m resolution) and 6.5–250MB.
Each database varies depending on the number of assets modelled (Morpeth and Cockermouth around 1MB, Thames approximately 25.MB).
The DTM is stored on an ArcSDE server.
Uncompressed size of DTM:
• 2m: 356.51GB
• 5m: 57.04GB
• 10m: 14.26GB</td></tr>
<tr><td>Network logistics</td><td>Intermediate run files were stored on the local hard drive of each PC and then transferred to a network location.</td></tr>
</table>

Run times	The times quoted below are for the flows case. The levels case tended to have longer run times than flows, but this was generally because the models have higher inflows to the floodplain. The total run time depends on the number of GPU cards available; the figures quoted here assume all assets are run on a single card, consecutively. The average run time per asset is given in brackets. **Morpeth 10m** 1.5 hours total simulation time (1.86 minutes per asset) **Morpeth 5m** 5.4 hours total simulation time (5.50 minutes per asset) **Morpeth 2m** 21.8 hours total simulation time (22.97 minutes per asset) **Cockermouth 10m** 6.8 hours total simulation time (4.79 minutes per asset) **Thames 10m** 1,720.3 hours total simulation time (77.55 minutes per asset) In reality, the models were implemented across multiple GPU cards simultaneously, significantly reducing the run times. For example, in Morpeth case study at 10m resolution: • run times <30 minutes would require 3 GPU cores • run times <20 minutes would require 5 GPU cores • run time <10 minutes requires 9 GPU cores
Size of model domain	There are multiple model domains, one per asset. All models use a grid cell size of 10m × 10m, although for the Morpeth case study, smaller grid resolutions of 2m and 5m were tested. Although asset lengths vary, most are <300m long.
Intermediate analysis required	A GIS routine was used to cap the model outputs, as follows, to avoid spurious high values skewing the results. • Depths capped to 10m. • Velocity capped to 10m per second. • Hazard rating capped to 100. Section 4 discusses the reasons for unreasonably high model depths and velocities within the context of the results.

3.2.3 Output data

Table 3.4 Flow chart: Ou.2

Outputs provided	Maximum and intermediate outputs in file geodatabase format (tables, raster datasets, mosaic datasets and feature classes). Outputs include: • Depths – maximum mosaic of all asset simulations • Velocity – maximum mosaic of all asset simulations • Extent – polygon extent of data • Hazard – maximum mosaic of asset simulations • Hour – intermediate hour at which the maximum depth occurs • Initial inundation – water depth at time of initial inundation • Rise time – time elapsed between initial inundation and maximum depth • Asset source – gives the individual asset simulation relating to maximum depth for each cell	
File sizes	**Depth results in file GDB format (using flows as input)**	**Final depth data in a single ASCII grid (using flows as input)**
Morpeth 10m	191MB	2.07MB
Morpeth 5m	257MB	8.25MB
Morpeth 2m	556MB	51.52MB
Cockermouth 10m	773MB	7.09MB
Thames 10m	10.7GB	198.17MB

3.2.4 Post-processing

Flow chart: In.3, An.5, Ou.3

Flood impacts were assessed in a generic way for each PoC option as described in Section 4 of the main report. The outcomes of these evaluation tests are presented in Section 4 of this appendix.

4 Proof of concept evaluation

This section provides detailed information on the outputs of the PoC. Its purpose is to provide supporting information for each case study event to demonstrate:

- the outputs available from the option
- the technical feasibility of the option
- the simulation performance of the option against observed data

The cases for flows and levels inputs are presented separately for the 3 case study events; for Morpeth, flows inputs are considered for 2, 5 and 10m resolution and levels input at 10m resolution. The findings are summarised in Table 4.1.

Table 4.1 Summary of PoC findings

Case study	Findings
Morpeth	Flow inputs to the simplified fluvial model produce results that generally correspond well to the observed flood outline, although there are some areas of overprediction and underprediction. Using levels as the input to the model leads to large areas of overprediction, particularly at the upstream extent of the model domain. This is largely caused by discrepancies in the crest levels used to specify bank heights. Model results from earlier time-steps give a much larger flood extent than that observed, suggesting that the model overpredicts earlier in the event. Reducing the grid resolution of the model decreases the flood extent (in this case, it matches better with the observed outline as a result). It also provides greater detail in the model outputs. However, overall depths are not particularly sensitive to grid resolution and future implementation could consider an appropriate level of topographic detail for real-time planning.
Cockermouth	Flood extent is accurately predicted for both flows and levels inputs. Recorded depths are not available; only the maximum recorded flood extent is available to aid assessment. Nonetheless, the levels input produces much greater depth results at the peak than the flows input, and produces a large flood extent from an earlier point in the hydrograph – as early as 36 hours before the peak.
Thames	Predictions of flood extent demonstrate bias towards overprediction throughout. This may be associated with uncertainties in the observed outline, which was digitised from satellite radar. Other possible explanations for the apparent overprediction include: • uncertainties in the model input data • the model not allowing return of flow to the channel • no explicit modelling of surface water drainage in this PoC – potentially significant over the duration of the event Overprediction is more pronounced when the model is driven with levels rather than flows. This highlights the significance of input data on model

Case study	Findings
	results and should be considered if this option were to be implemented operationally.

4.1 Case study 1: Morpeth, September 2008 – flows input (10m resolution)

4.1.1 Location

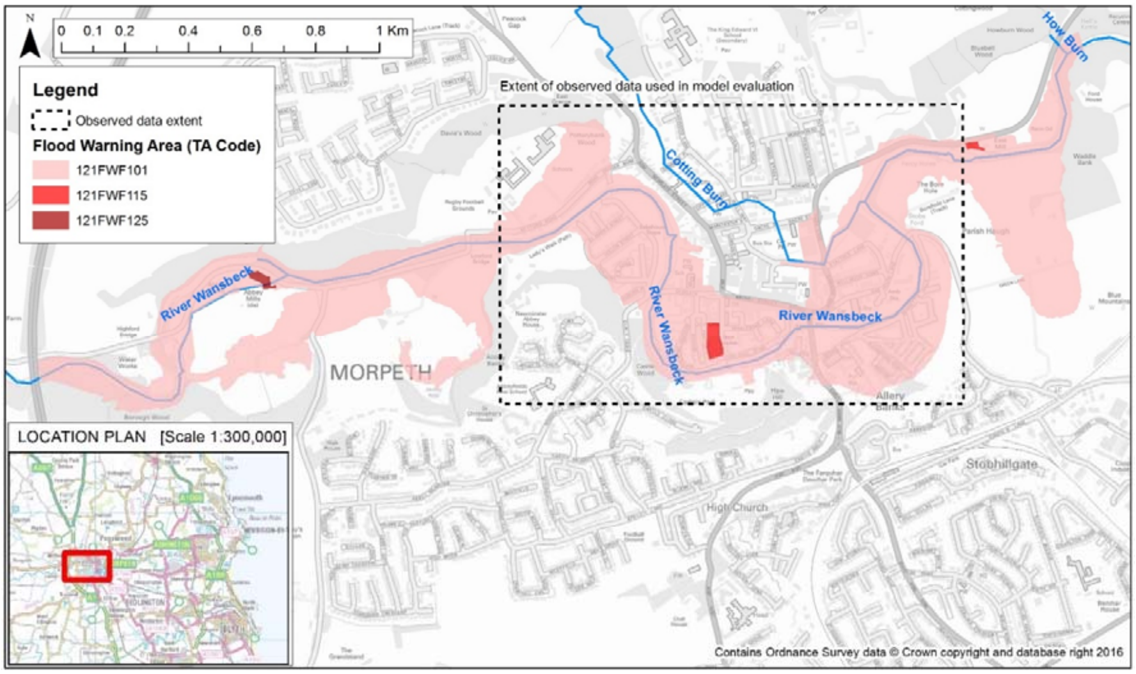


Figure 4.1 Location of Morpeth case study

Table 4.2 Description of Flood Warning Areas featured in the Morpeth case study

Flood Warning Target Area Code	Name
121FWF101	River Wansbeck at Morpeth
121FWF115	River Wansbeck at East Mill and Morpeth Riverside Leisure Centre
121FWF125[1]	River Wansbeck at Abbey Mills

Notes: [1] This is outside the extent of the observed flood outline data.

4.1.2 Model depths (10m resolution using flows as input)

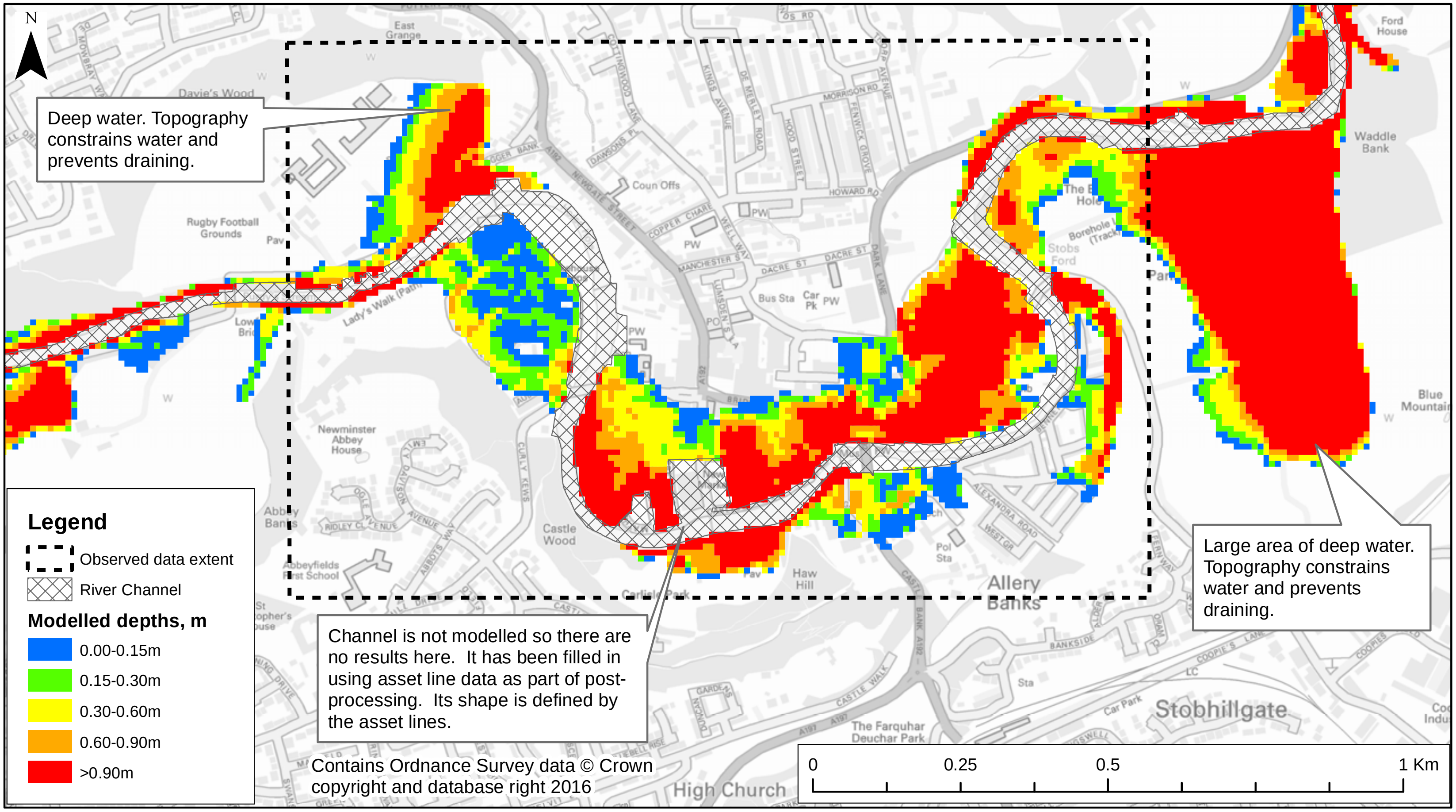


Figure 4.2 Model outputs for Morpeth event: flows input (10m resolution)

4.1.3 Extent flooded (Test A1)

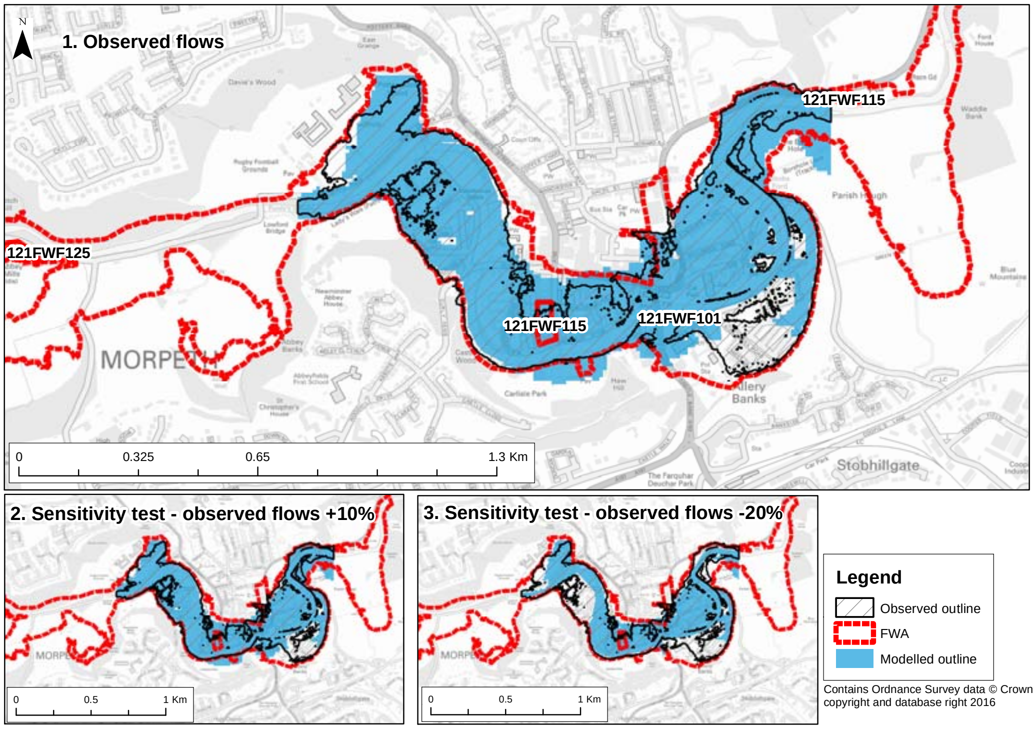


Figure 4.3 Maximum modelled and observed extent flooded: flows input (10m resolution)

Table 4.3 Comparison of modelled and observed area flooded for each Flood Warning Area for Morpeth event: flows input (10m resolution)

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	**587,038**	**464,766**	**79.2**	**439,788**	**74.9**
121FWF101	582,300	460,028	79.0	436,094	74.9
121FWF115	4,738	4,738	100	3,849	81.2
121FWF125	–	–	–	–	–

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

Overall, model performance is relatively good. The observed flood extent is well replicated in most areas; note that the model results have been trimmed to the extent of observed data for display purposes.

The modelled flood outline is sensitive to a 20% decrease in flows (although a 10% increase makes little difference to the extent). This demonstrates the need for accurate flow inputs in order to achieve an accurate prediction of flood extent.

Inflows for the simplified fluvial model were taken from the fully dynamic 1D–2D model for Morpeth. Initially, an increase of 20% was tested but this resulted in model instability. Instead, the model's sensitivity was tested by increasing flows to 10%. Implementing this option in real-time (discussed in Section 5) should therefore consider the robustness of existing models that provide inputs for the simplified fluvial model.

4.1.4 Model performance (Test A2)

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

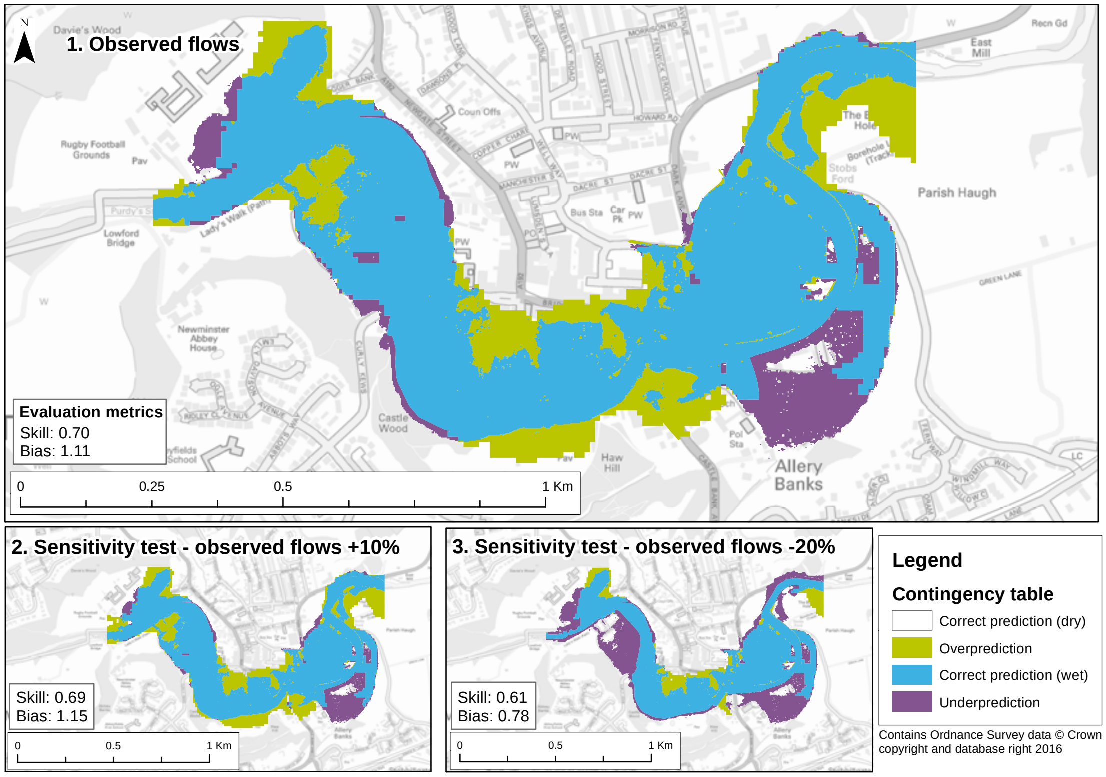


Figure 4.4 Model performance in predicting flooded extent at Morpeth: flows input (10m resolution)

Table 4.4 Model performance metrics for Morpeth event: flows input (10m resolution)

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
Modelled outline (all)	69.7	19.6	10.7	0.70	1.11
Modelled flood outline (within area covered by Flood Warning Areas only)					
121FWF101	73.0	15.8	11.2	0.73	1.05
121FWF115	81.2	18.8	0	0.81	1.23
121FWF125	–	–	–	–	–

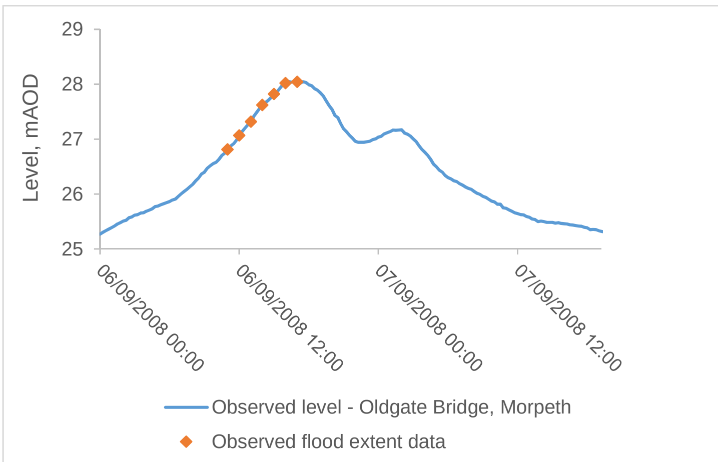
Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain and performance in locations where there is known to be flood risk to property.

Interpretation

The model accurately predicts the observed extent in most areas. However, there is a large area of underprediction in the south-east (Allery Banks/Middle Greens) of Morpeth where surface water flooding is known to have occurred during the 2008 event. This water contributes to the observed extent; the simplified fluvial model only simulates river flooding. The model also overpredicts in the centre of town and downstream into Parish Haugh at the eastern extend of the map. This is likely to be due to an incorrect SoP associated with the asset lines at these locations. A lower SoP in the model will lead to a greater volume of water on the floodplain.

Model performance – temporal

Seven observed depth maps were available for 6 September 2008, at one-hourly intervals from 11:00 to 17:00. The hydrograph (observed levels at Oldgate Bridge in Morpeth town centre) in Figure 4.5 shows the times of each depth map observations in the context of the event.



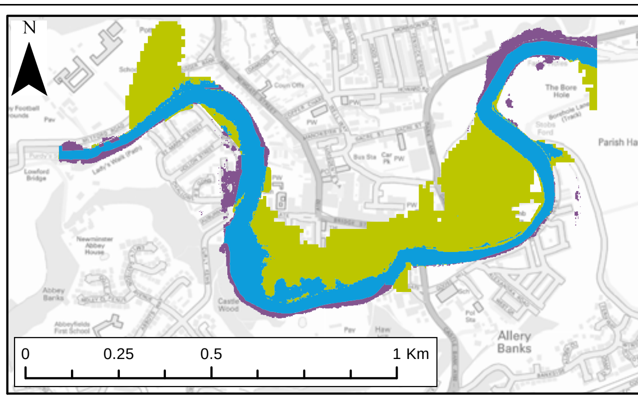
Seven observed depth maps available, at one-hourly intervals:

6 September 2008 11:00
6 September 2008 12:00
6 September 2008 13:00
6 September 2008 14:00
6 September 2008 15:00
6 September 2008 16:00
6 September 2008 17:00

Figure 4.5 Available data for evaluation of model's temporal performance for Morpeth flood event

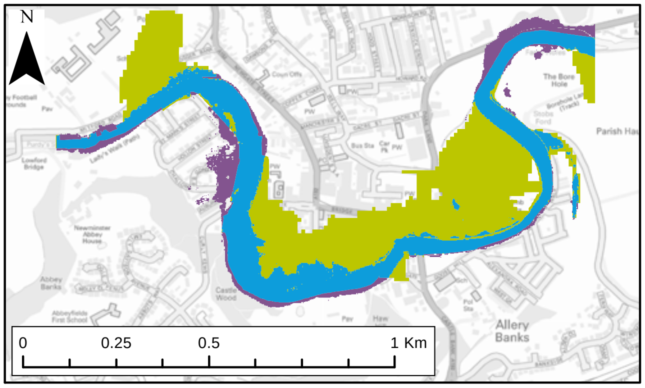
Table 4.5 Temporal evaluation of model performance at Morpeth on 6 September 2008: flows input (10m resolution)

11:00



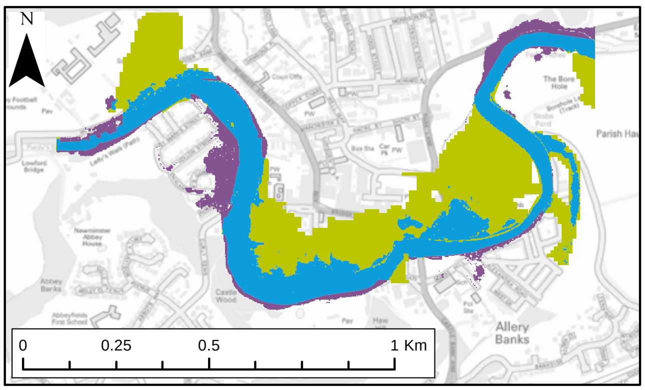
	Correct wet (%)	36.1
	Overprediction (%)	53.6
	Underprediction (%)	10.3
–	Skill	0.36
–	Bias	1.93

12:00



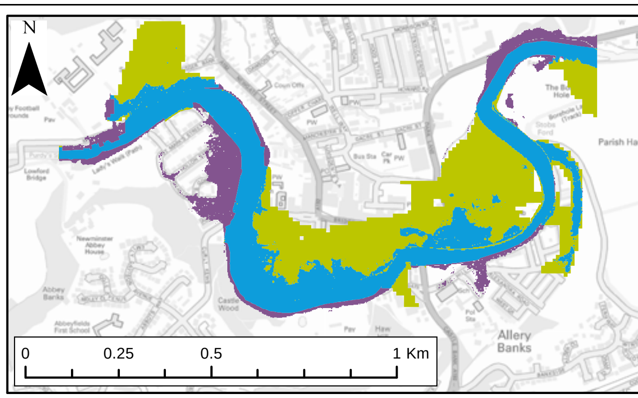
	Correct wet (%)	37.0
	Overprediction (%)	51.6
	Underprediction (%)	11.4
–	Skill	0.37
–	Bias	1.83

13:00

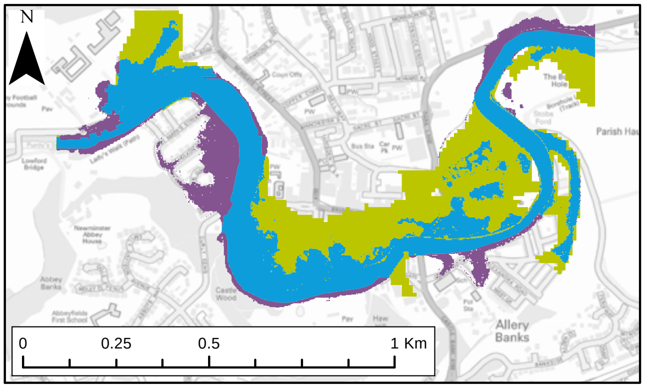
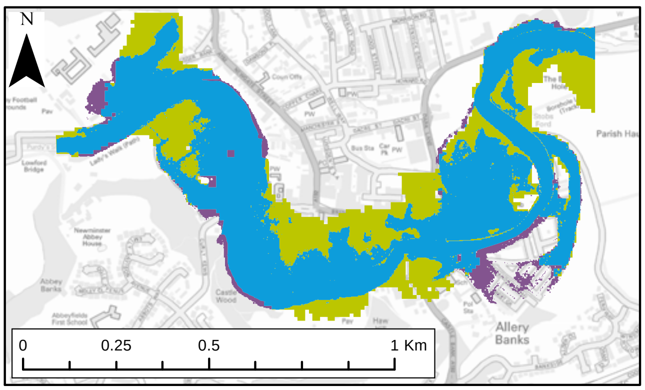
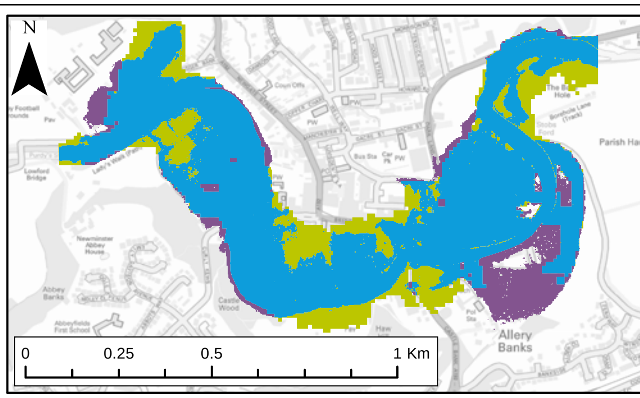


	Correct wet (%)	40.9
	Overprediction (%)	46.0
	Underprediction (%)	13.1
–	Skill	0.41
–	Bias	1.61

14:00



	Correct wet (%)	42.0
	Overprediction (%)	43.5
	Underprediction (%)	14.5
–	Skill	0.42
–	Bias	1.51

15:00			
		Correct wet (%)	46.8
		Overprediction (%)	37.7
		Underprediction (%)	15.5
	–	Skill	0.47
	–	Bias	1.36
16:00			
		Correct wet (%)	65.0
		Overprediction (%)	29.0
		Underprediction (%)	6.0
	–	Skill	0.65
	–	Bias	1.32
17:00 (observed maximum)			
		Correct wet (%)	70.0
		Overprediction (%)	18.4
		Underprediction (%)	11.7
	–	Skill	0.70
	–	Bias	1.08

4.1.5 Property counts (test B)

Properties within flood extent

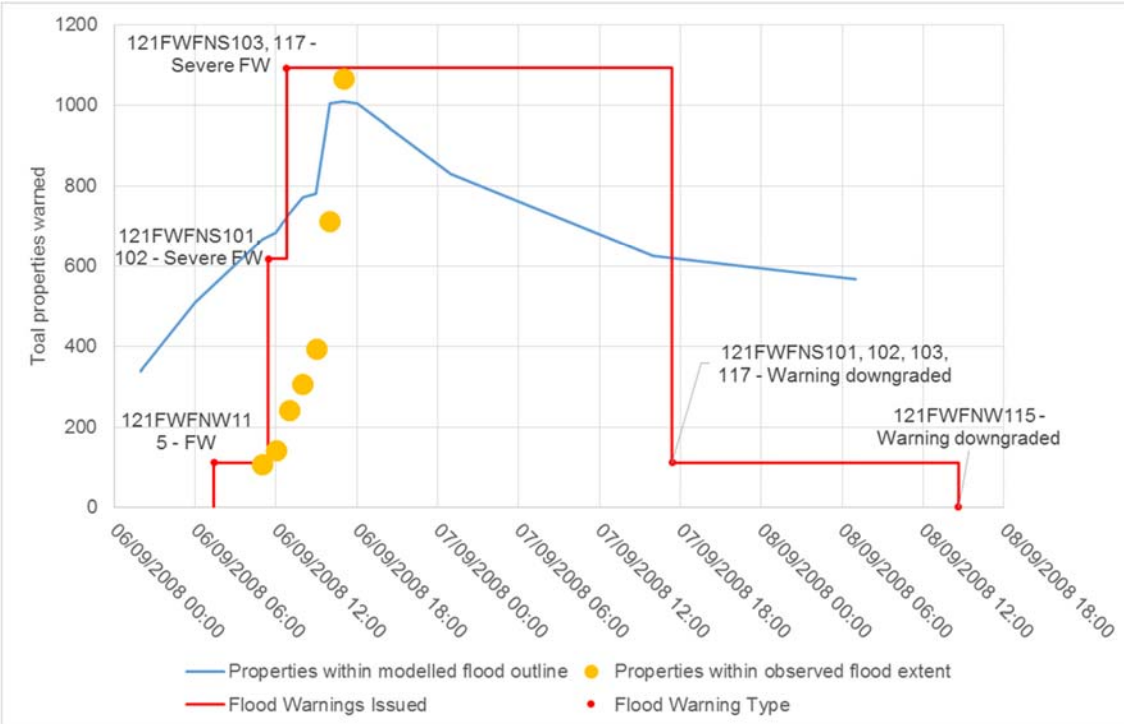


Figure 4.6 Properties within flood extent for Morpeth event: flows input (10m resolution)

Notes: Properties are mapped below.

Table 4.6 Maximum number of flooded properties for Morpeth event: flows input (10m resolution)

Flood Warning Area	Properties warned[1]	Observed[2]	Predicted[3]
All	–	1,066	1,015
121FWF101	–	1,061	1,010
121FWF115	–	5	5
121FWF125	–	–	–

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event. For this study, these were not available for Morpeth.
[2] Observed is based on the intersection of National Receptor Dataset (NRD) property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.

Interpretation

Over the onset of the event (11:00 to 15:00 on 6 September 2008), the number of properties in the modelled outline is significantly greater than the number of properties in the observed outline. The maps earlier in this appendix show that there are large areas of overprediction leading up to the peak.

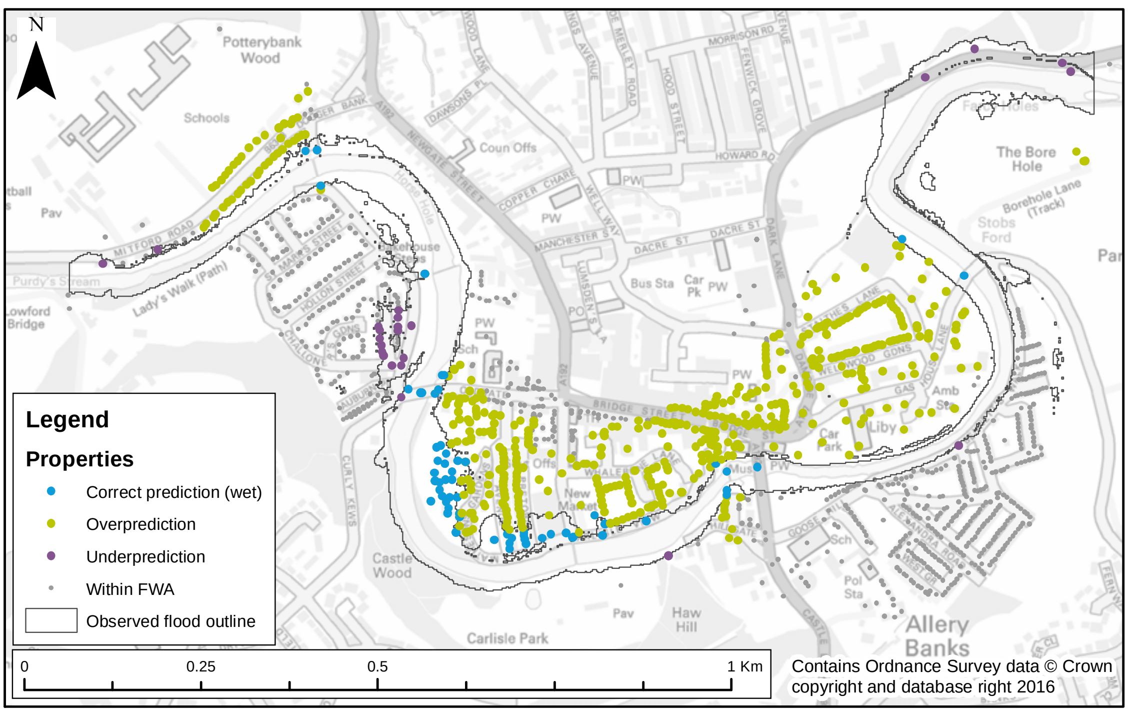
Closer to the peak of the event, the flood outlines better matches the observed and the number of properties flooded are similar. At the peak, there are more properties in the observed outline than the modelled outline – 51 properties are underpredicted by the model.

Although the number of properties within the observed and modelled flood outlines broadly matches, the spatial distribution of properties varies. The maps in the next section show that there are areas that are significantly overpredicted and underpredicted by the simplified fluvial model.

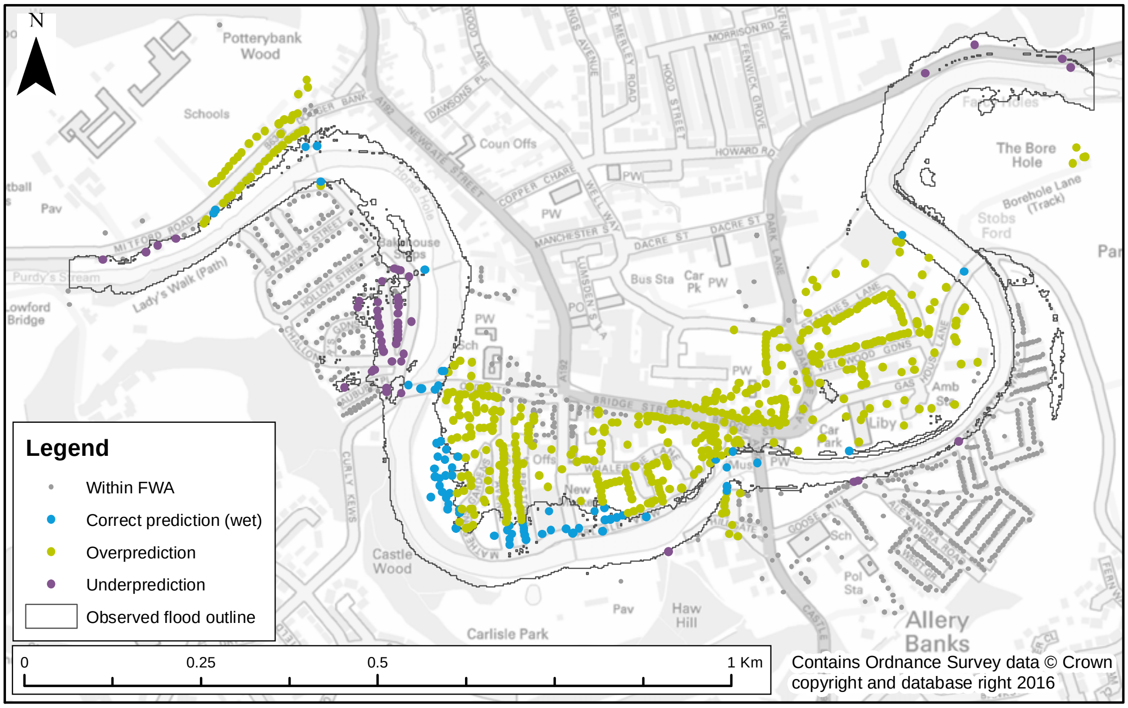
Properties mapped by model prediction

The maps presented in Figure 4.7 show NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline.

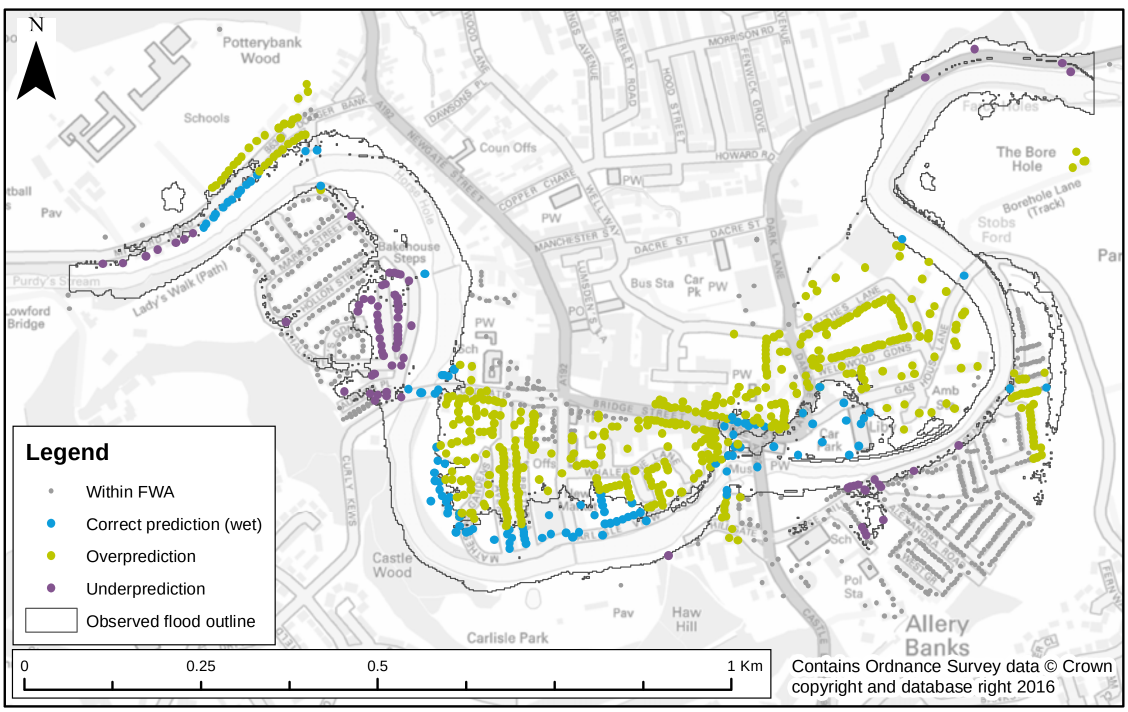
11:00



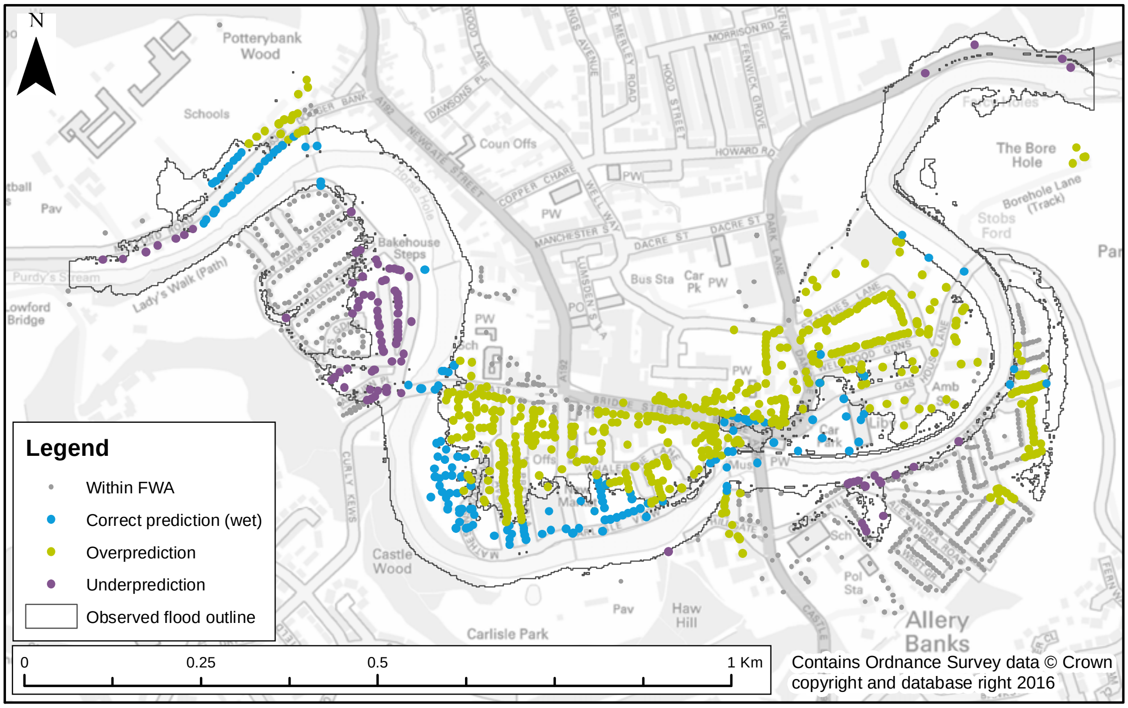
12:00


Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

13:00

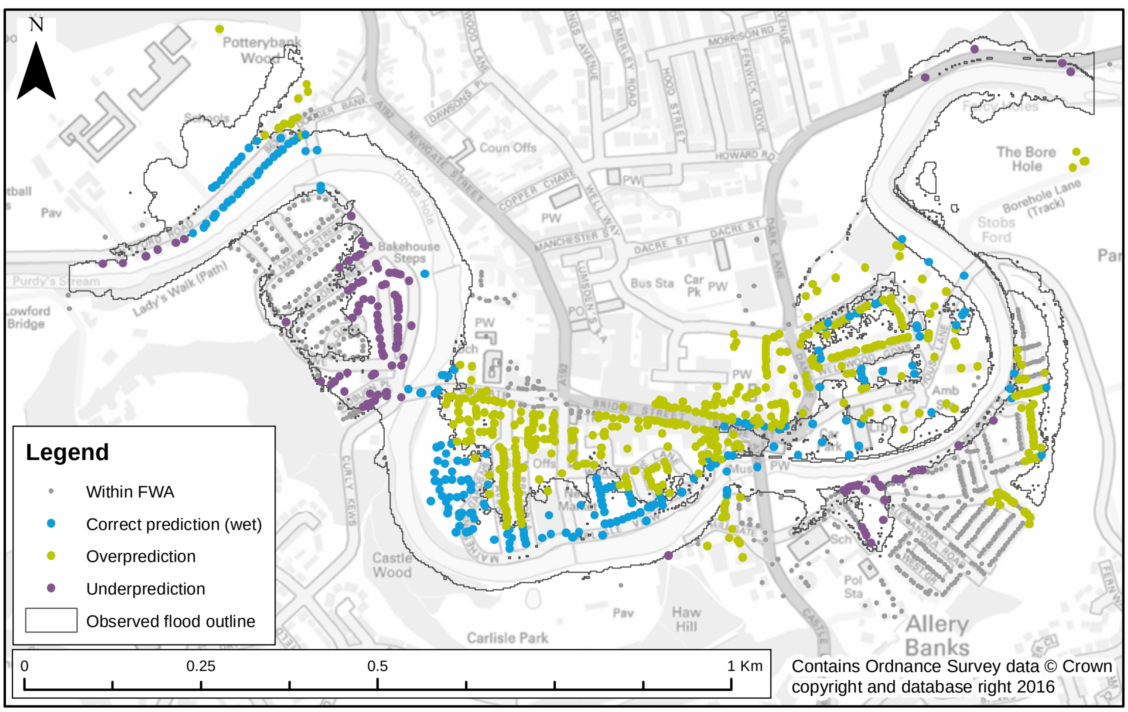

Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

14:00



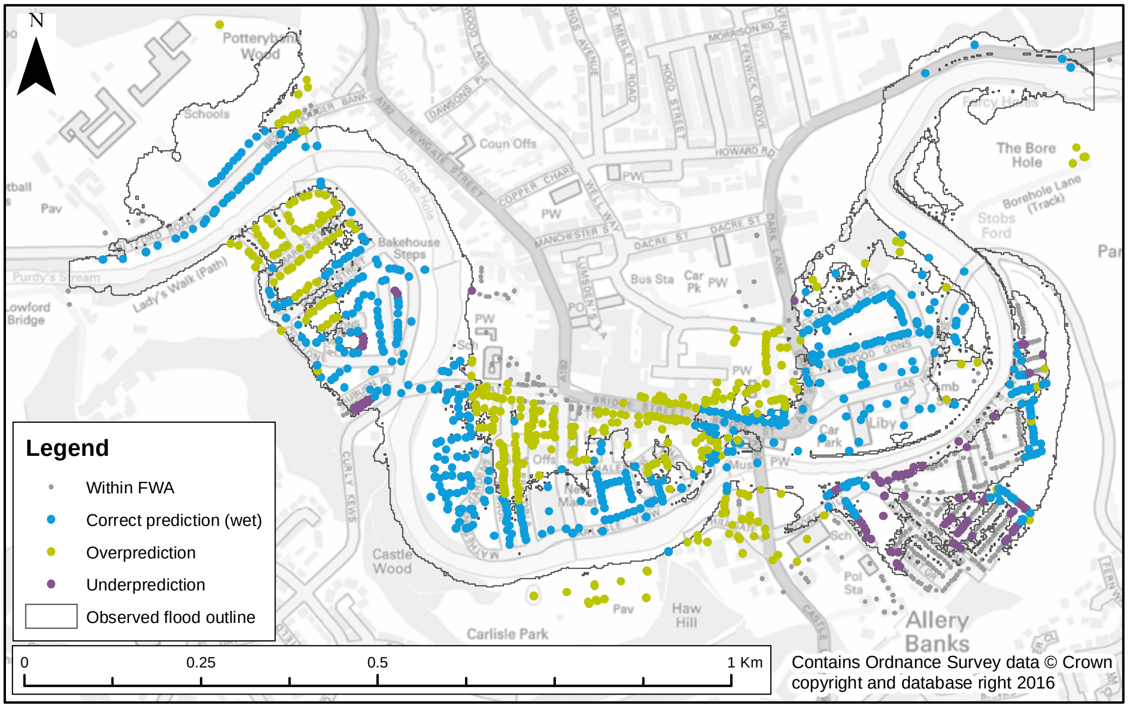
N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

15:00



N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

16:00



17:00

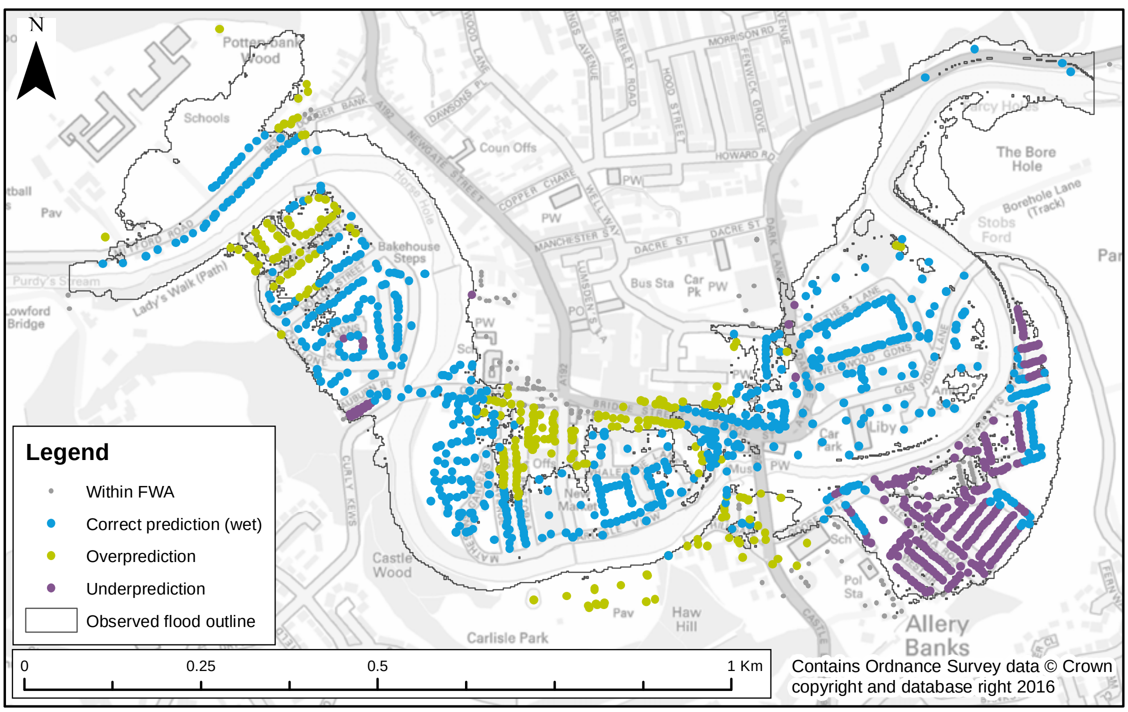


Figure 4.7 Model performance in predicting extent of flooding at Morpeth between 11:00 and 17:00 on 6 September 2008: flows input (10m resolution)

4.1.6 Depth analysis (Test C)

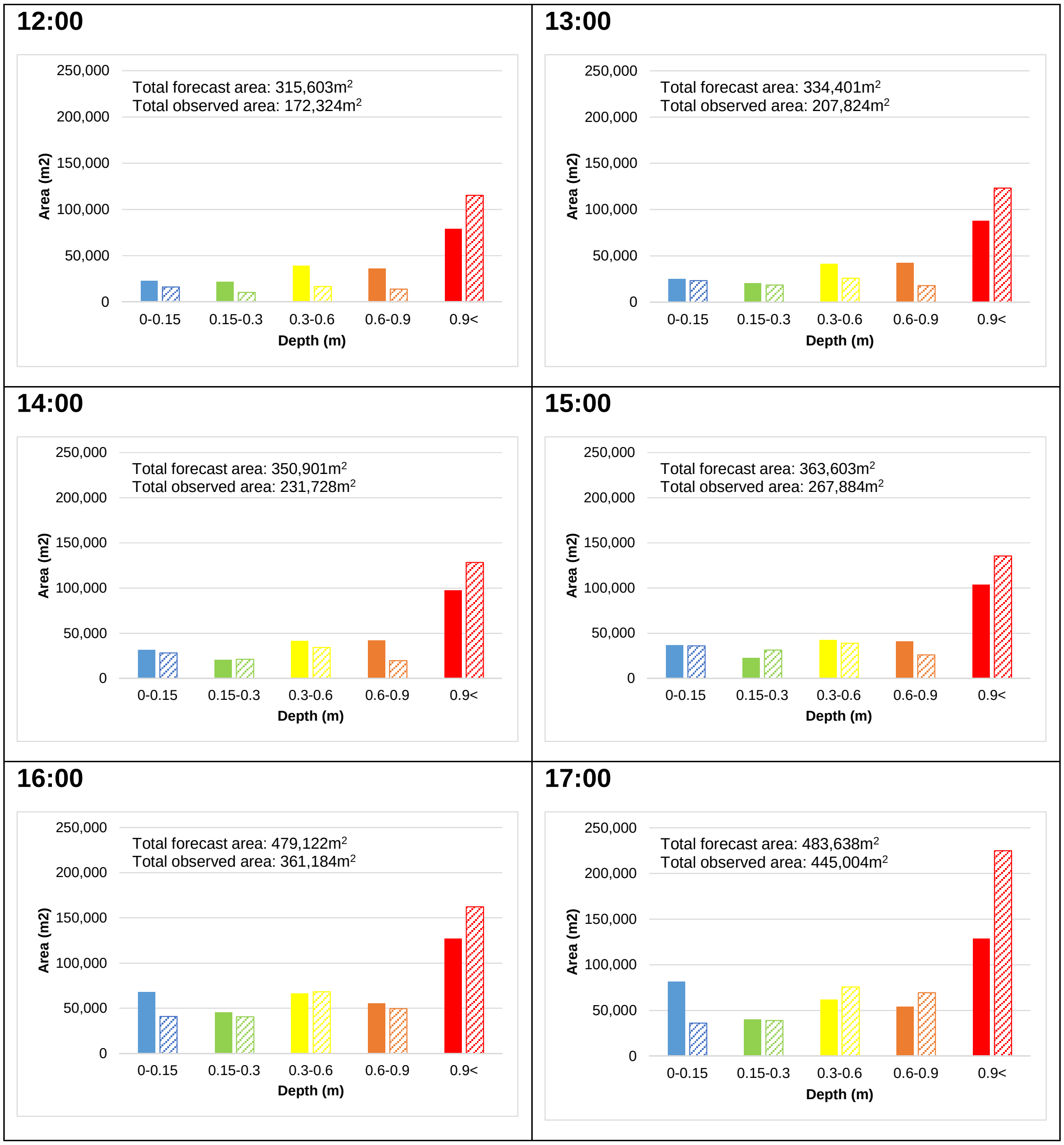


Figure 4.8 Modelled and observed flooded depths at Morpeth between 11:00 and 17:00 on 6 September 2008: flows input (10m resolution)

Notes: Solid bars show modelled depths (from the PoC option).
Dashed bars show observed depths (based on data supplied by Newcastle University).
Channel depths are not included in the modelled results and so the observed area would be expected to be greater for depths (especially for depths >0.9m). Channel area = 117,304m^2
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

Overall, the distribution of modelled depths is relatively consistent with the observed, based on surveyed depths.

The forecast area is greater than the observed area at each time-step. However, the differences decrease over time, shown by the forecast and observed areas (quoted on the plots in Figure 4.7). This reflects earlier maps in this appendix, which show large areas of overprediction earlier on in the event that become less significant closer to the peak.

In general, the model predicts a larger flooded area at depths <0.9m. However, for depths >0.9m, the observed area consistently exceeds the modelled area. Note that the modelled area does not include the channel area.

This is also the case at the peak of the event, where there is a substantial area deeper than 0.9m in the observed. However, the model tends to overpredict for the smallest depths.

4.1.7 Total water level

Figure 4.9 presents the total modelled water level on the floodplain (modelled depth plus land elevation from a LIDAR DTM). The maximum water level at in-channel nodes are also presented and are based on a 1D–2D hydrodynamic model which provided the inputs to this PoC. The channel itself is not represented by this PoC option and the nature of the simplified fluvial model means that there is no dynamic link between the channel and the floodplain during the model run. Annotations on the map explain the model results.

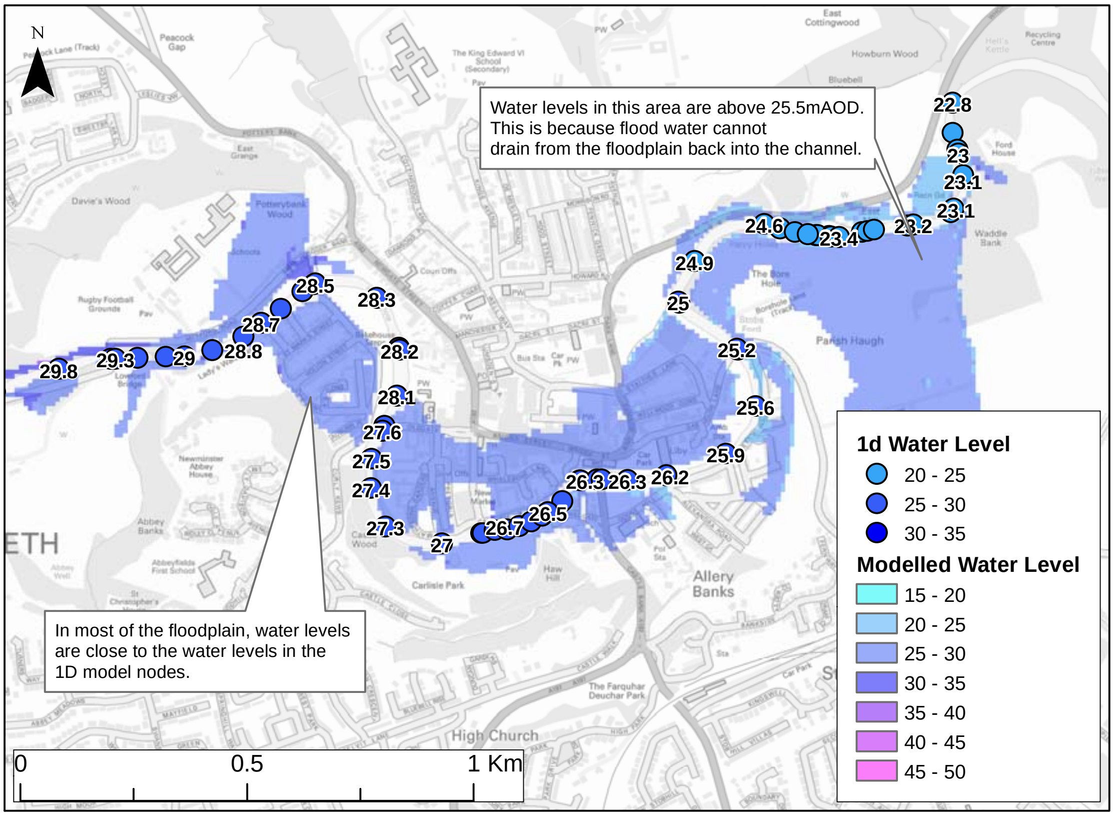


Figure 4.9 Total modelled water level on the floodplain and maximum water level at in-channel nodes for Morpeth event: flows input (10m resolution)

4.1.8 G2G simulation

Table 4.7 Details of available G2G data for Morpeth event

Simulation data	Start	5 September 2008 00:00GMT	End	7 September 2008 23:45GMT
Forecast data	UKV ensemble rainfall forecast 2km resolution, 24 ensemble members, 15-minute rainfall totals Lead times: 30 hours			
Forecast origins available	5 September 2008 12:00GMT			
Forecast origins tested	5 September 2008 12:00GMT			
Ensembles tested	All 24 available forecast ensemble members were tested. The centroid of the 1km grid square corresponding to the main river model inflow on the River Wansbeck is 417500,585500.			

Comparison of G2G simulated and observed inflows on River Wansbeck

Inflows on the River Wansbeck at the upstream extent of the model are plotted in Figure 4.10. The start time of the G2G data provided is midnight on 5 September 2008. The start time of the observed data is midnight on 6 September 2008.

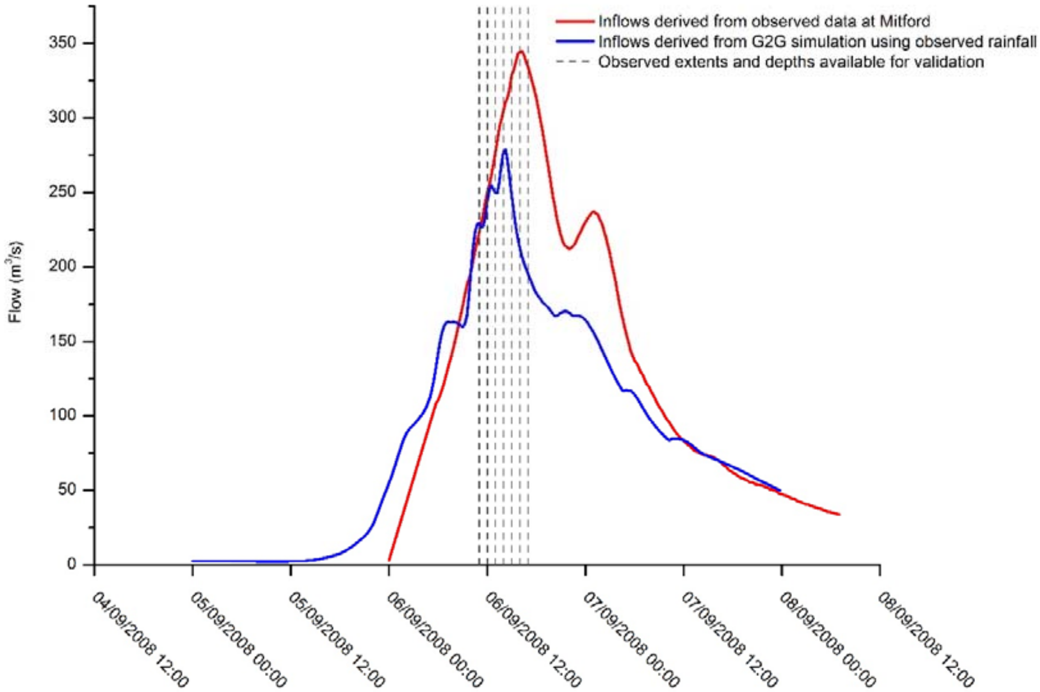


Figure 4.10 Hydrograph for the River Wansbeck: flows input (10m resolution)

Flood extent – maximum

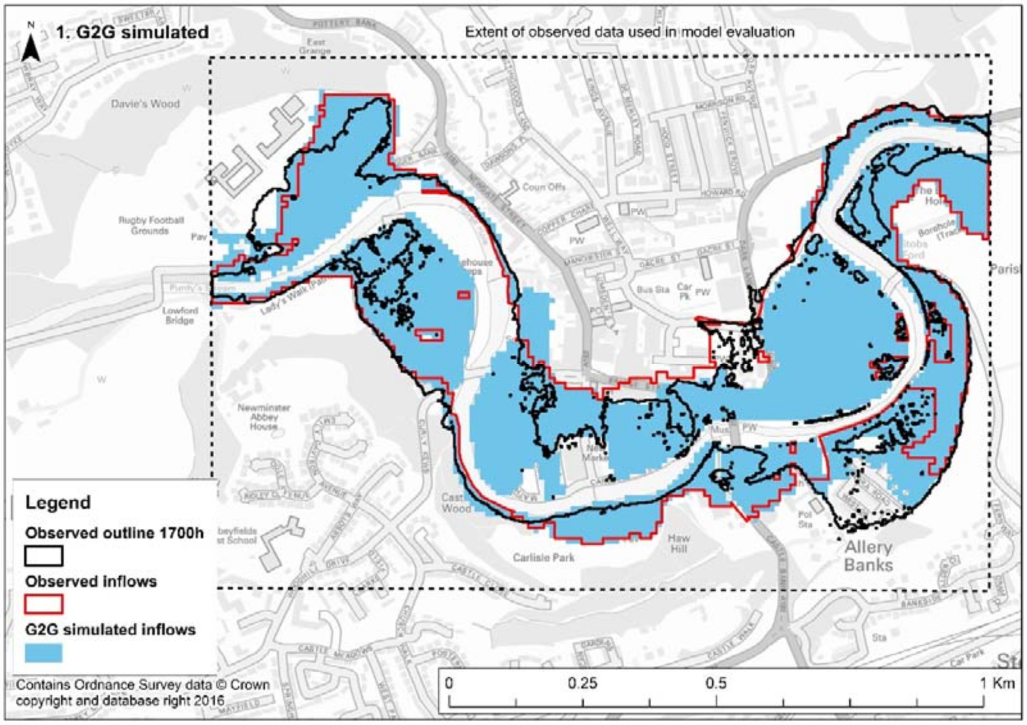


Figure 4.11 Observed and G2G simulated maximum flood extent for Morpeth event: flows input (10m resolution)

The hydrograph (Figure 4.10) shows that simulated flows from G2G (driven using observed rainfall) are notably smaller than observed flows at the upstream model boundary during the event peak and recession. Overall, the volume under the G2G simulated hydrograph is also substantially lower.

Consquently, the modelled flood extent from G2G simulated flows is underestimated compared with that modelled from observed flows, with some localised exceptions. One such exception is in the Allery Banks area. This could be associated with differences in the rising limbs of the observed and simulated hydrographs. The volume under the rising limb of the simulated hydrograph prior to the peak is greater than that under the observed hydrograph. The nature of the simplified fluvial model means there is no return of water to the channel, which allows water to accumulate on the floodplain for longer in the simulated run as flows approach the peak.

Both modelled extents overestimate flood impacts compared with the observed event outline. This is also due to the model not allowing the return of water to the channel or dynamic floodplain flow

G2G ensemble members

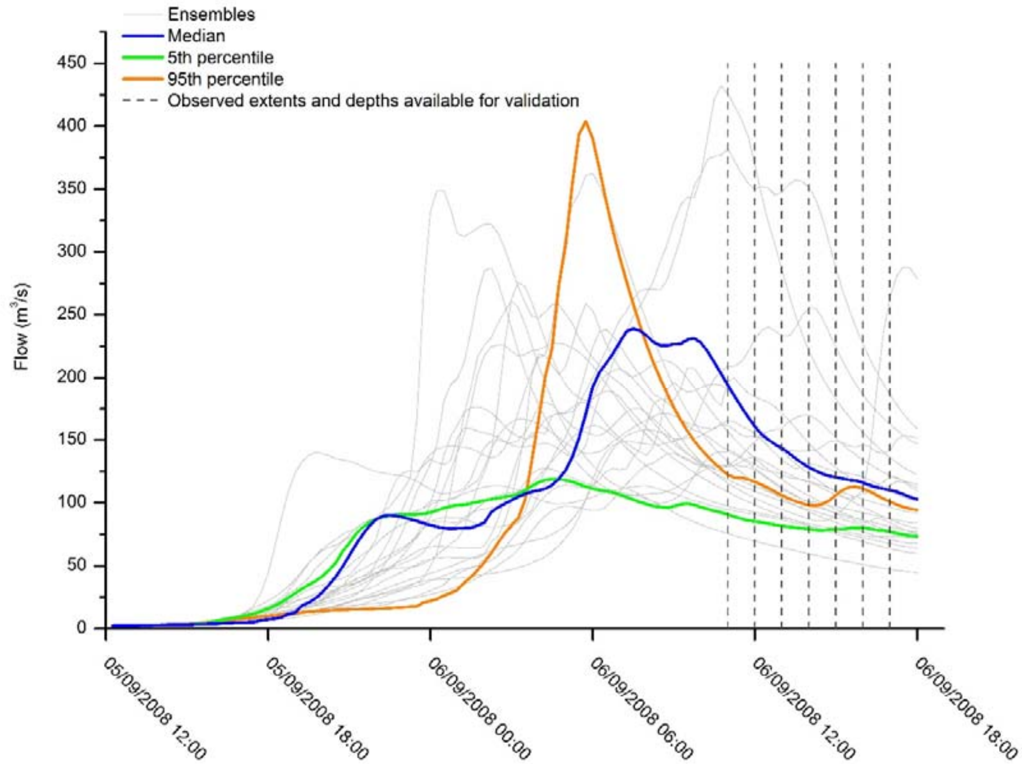


Figure 4.12 Inflows to hydraulic model for Morpeth event: flows input (10m resolution)

Flood extent – maximum observed and maximum G2G

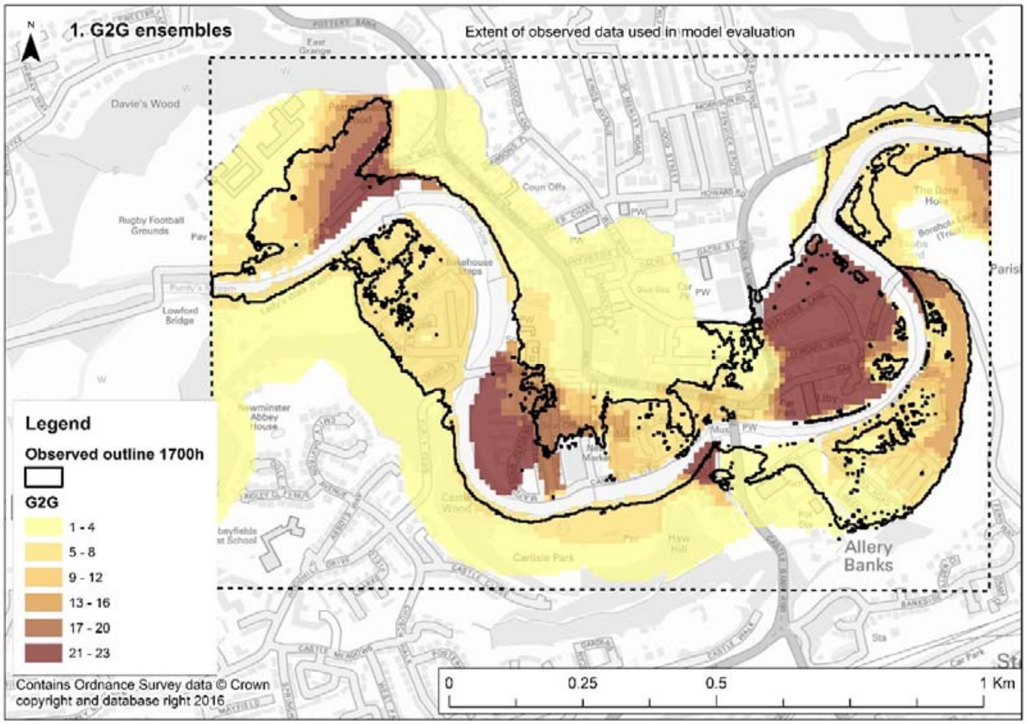


Figure 4.13 Maximum observed and maximum G2G simulation of flood extent for Morpeth event: flows input (10m resolution)

Notes: The map shows the maximum observed outline (black outline) against the maximum extent of all ensemble G2G runs (yellow-brown shading). Darker colours on the map show where greater numbers of ensemble members predict the same location as flooded, while the lightest colour shows areas predicted to flood by fewer ensemble members.

The G2G results shown in Figure 4.13 are trimmed to the extent of observed data. Flows from one ensemble run were not sufficient to overtop assets and cause flooding therefore only results from 23 ensemble runs can be presented. Darker colours on the map show where greater numbers of ensemble members predict the same location as flooded, while the lighter colours show areas predicted to flood by fewer ensemble members.

The observed peak was recorded at 17:00 on 6 September 2008. However, for the selected forecast origin, all the tested G2G ensemble members forecast an earlier peak. The flood extents shown in Figure 4.13 show the maximum extent from each model run, irrespective of where it occurs during the event.

The next section presents maps of modelled and observed flood extent at hourly intervals throughout the event. These are all on the recession of the G2G simulation, hence their similarity to each other.

Property counts - maximum

For comparison, the number of properties in observed flood extent is 1.065. Table 4.8 shows the properties in the modelled flood outlines. In this case, the model underpredicts in some locations. The final row of the table shows the number of properties within the observed outline that appear in none of the ensemble members.

Table 4.8 Number of NRD property points within the flood outlines for Morpeth event: flows input (10m resolution)

Flood outlines	Number of properties[1]	Cumulative property count[2]	Notes
21–23 × ensemble overlap	265	265	Area shown as flooded in 21 to 23 of all tested ensemble members
17–20 × ensemble overlap	128	393	–
13–16 × ensemble overlap	61	454	–
9–12 × ensemble overlap	86	540	–
5–8 × ensemble overlap	673	1,213	–
1–4 × ensemble overlap	978	2,191	–
Within observed outline but not forecast	32	–	Area not shown as flooded in any tested ensemble member

Notes: [1] This column shows the number of properties within each separate zone of the modelled outlines, ordered from the area where all ensembles coincide, to properties that appear in one ensemble member only.
[2] This column lists the cumulative number of properties within the modelled outlines, ordered by areas predicted to flood in the most ensemble members to the least ensemble members. For example, at this lead time, the models predict that there is a higher likelihood that 265 properties will flood and a lower likelihood that 978 properties will flood.

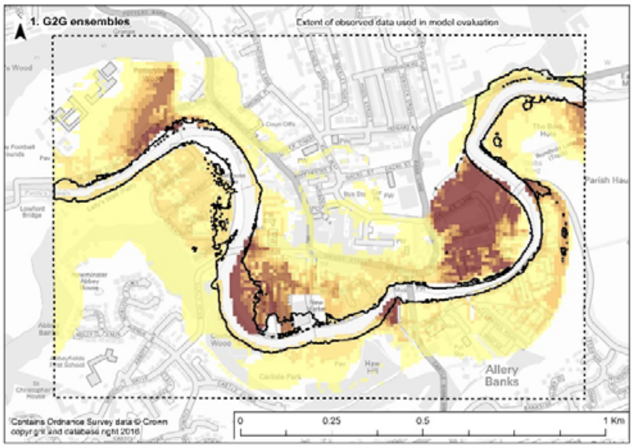
Flood extent and property counts – time slices

The numbers of properties in each separate zone of the modelled flood outlines are listed in Table 4.9, with the cumulative number of properties shown in brackets.

This section presents maps of modelled and observed flood extent at hourly intervals throughout the event. From the selected forecast origin, G2G forecast an earlier peak than was observed. The modelled flood extent at 17:00 is therefore dissimilar to the maximum modelled flood extent mapped previously.

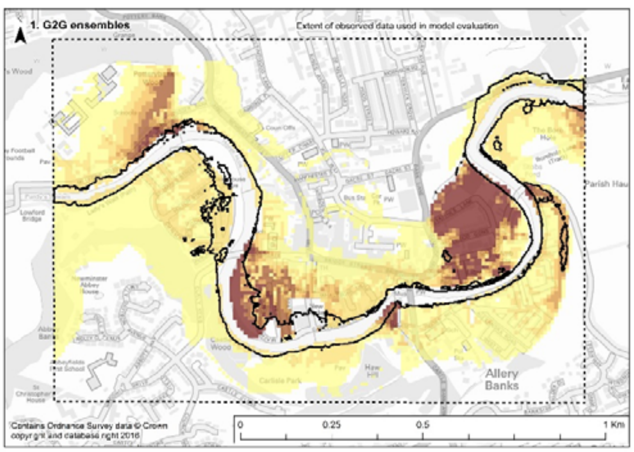
Table 4.9 Temporal evolution of observed and G2G modelled flood extent and property counts for 6 September 2008: flows input (10m resolution)

11:00



Flood outlines		Number of properties (cumulative)
	Observed	109
Number of overlapping ensembles		–
	21 to 23	141 (141)
	17 to 20	122 (263)
	13 to 16	101 (364)
	9 to 12	65 (429)
	5 to 8	479 (908)
	1 to 4	977 (1,885)
	Within observed outline but not forecast	21

12:00

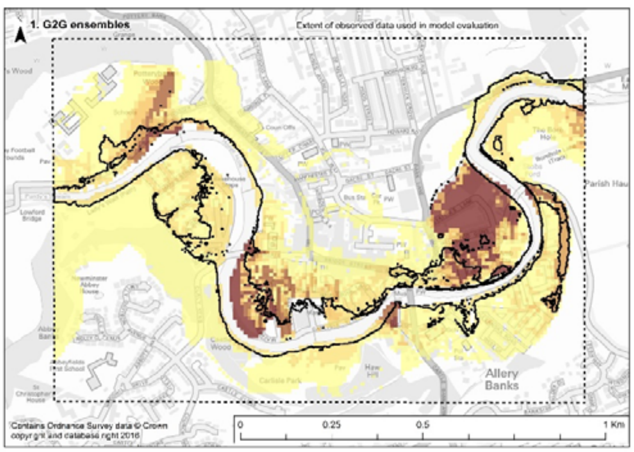


Flood outlines		Number of properties
	Observed	144
Number of overlapping ensembles		–
	21 to 23	134 (134)
	17 to 20	117 (251)
	13 to 16	62 (313)
	9 to 12	98 (411)
	5 to 8	444 (855)
	1 to 4	1,025 (1,880)
	Within observed outline but not forecast	0

13:00

Flood outlines		Number of properties
–	Observed	254
Number of overlapping ensembles		–
	21 to 23	133 (133)
	17 to 20	106 (239)
	13 to 16	45 (284)
	9 to 12	111 (395)
	5 to 8	435 (830)
	1 to 4	1,032 (1,862)
	Within observed outline but not forecast	24

14:00



Flood outlines		Number of properties
–	Observed	318
Number of overlapping ensembles		–
	21 to 23	128 (128)
	17 to 20	102 (230)
	13 to 16	42 (272)
	9 to 12	76 (348)
	5 to 8	457 (805)
	1 to 4	1,017 (1,822)
	Within observed outline but not forecast	25

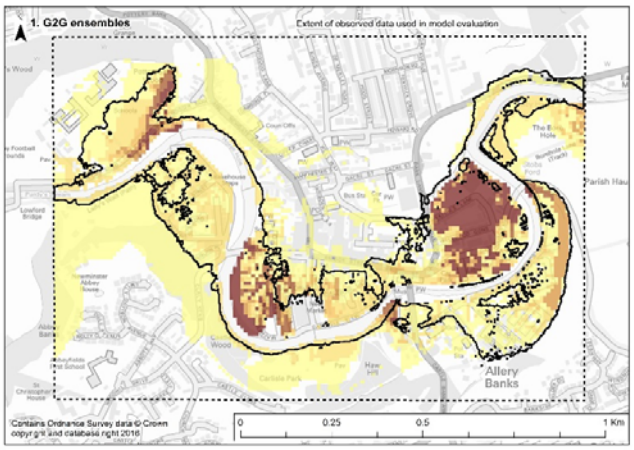
15:00

Flood outlines		Number of properties
–	Observed	397
Number of overlapping ensembles		–
	21 to 23	86 (86)
	17 to 20	119 (205)
	13 to 16	37 (242)
	9 to 12	52 (294)
	5 to 8	280 (574)
	1 to 4	1,132 (,706)
	Within observed outline but not forecast	26

16:00

Flood outlines		Number of properties
–	Observed	730
Number of overlapping ensembles		–
	21 to 23	116 (116)
	17 to 20	94 (210)
	13 to 16	38 (248)
	9 to 12	45 (293)
	5 to 8	434 (727)
	1 to 4	994 (1,721)
	Within observed outline but not forecast	35

17:00



Flood outlines		Number of properties
–	Observed	1,065
Number of overlapping ensembles		–
	21 to 23	115 (115)
	17 to 20	86 (201)
	13 to 16	33 (234)
	9 to 12	59 (293)
	5 to 8	449 (742)
	1 to 4	952 (1,694)
	Within observed outline but not forecast	113

4.2 Case study 1: Morpeth, September 2008 – flows input (5m resolution)

4.2.1 Location

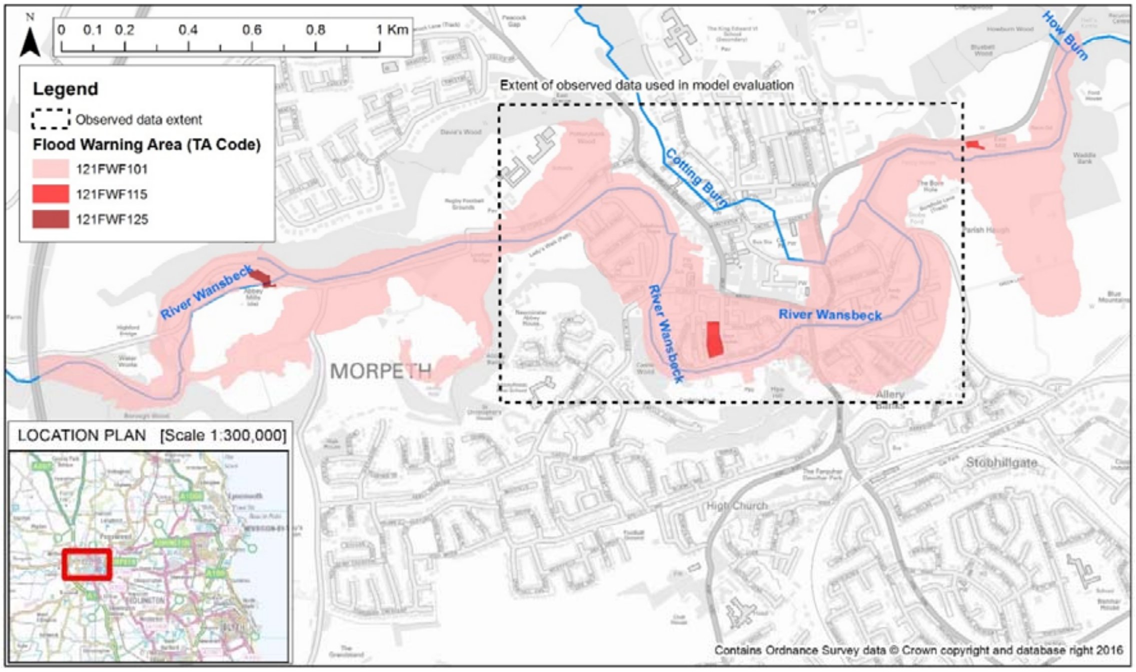


Figure 4.14 Location map for Morpeth case study

Table 4.10 Description of Flood Warning Areas featured in the Morpeth case study

Flood Warning Target Area Code	Name
121FWF101	River Wansbeck at Morpeth
121FWF115	River Wansbeck at East Mill and Morpeth Riverside Leisure Centre
121FWF125 [1]	River Wansbeck at Abbey Mills

Notes: [1] This is outside the extent of the observed flood outline data.

4.2.2 Model depths (5m resolution using flows as input)

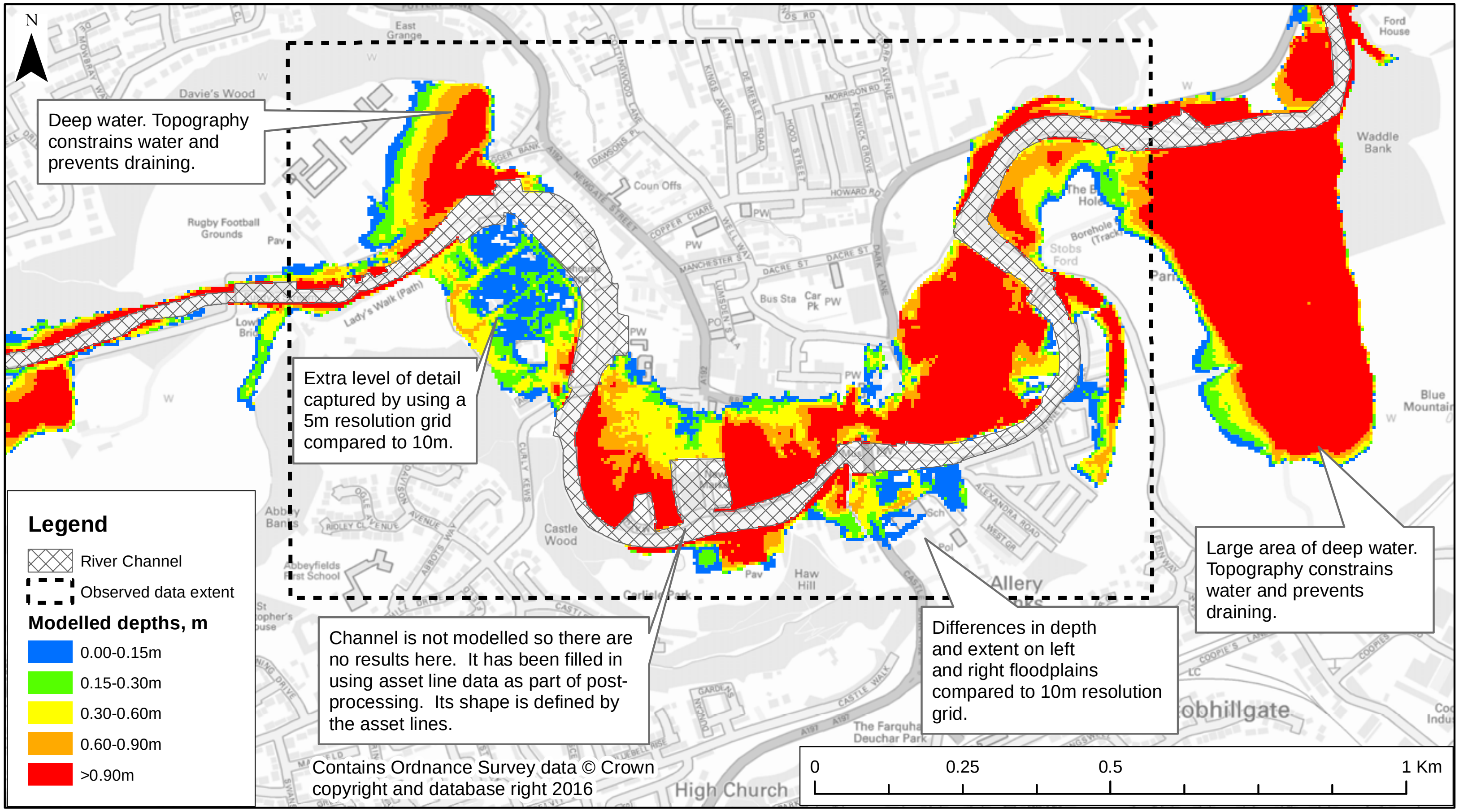
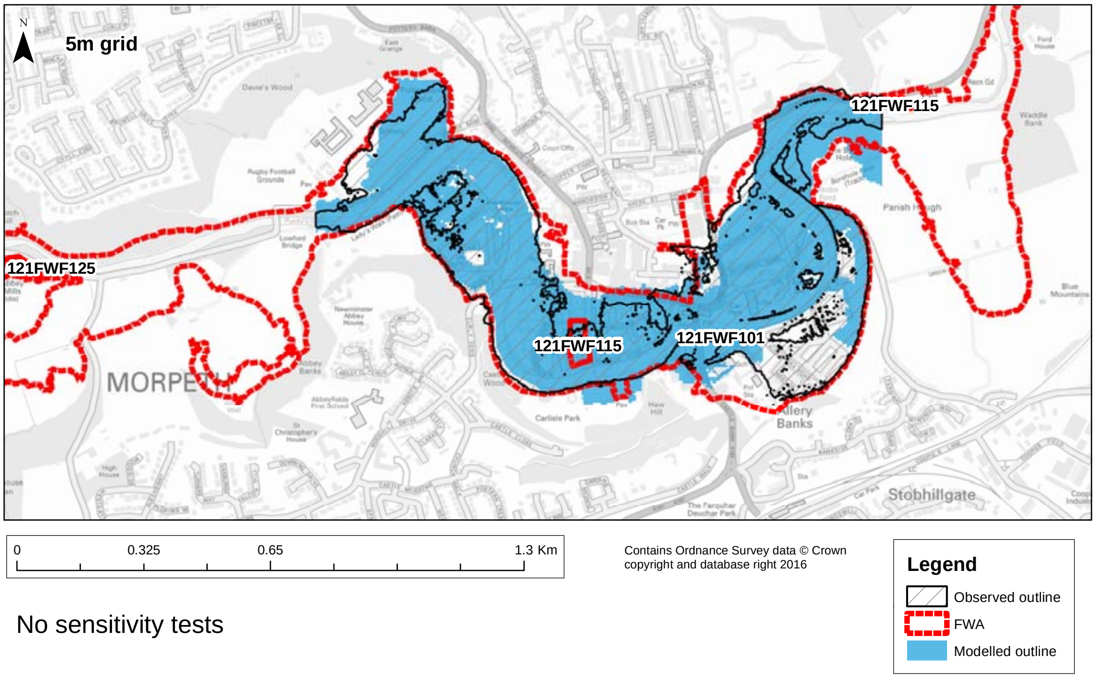


Figure 4.15 Model outputs for the Morpeth case study: flows input (5m resolution)

4.2.3 Extent flooded (Test A1)



No sensitivity tests

Figure 4.16 Maximum modelled and observed extent flooded (17:00 on 6 September 2008): flows input (5m resolution)

Table 4.11 Comparison of modelled and observed area flooded for each Flood Warning Area for Morpeth event: flows input (5m resolution)

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	**587,038**	**449,897**	**76.6**	**439,788**	**74.9**
121FWF101	582,300	445,159	76.4	436,094	74.9
121FWF115	4,738	4,738	100	3,849	81.2
121FWF125	–	–	–	–	–

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

Detailed discussion of results using a finer resolution is included in Section 4.3, which compares the results of using a 5m and 2m resolution to a 10m resolution grid. Much of the interpretation is common to the different grid resolutions tested.

4.2.4 Model performance (Test A2)

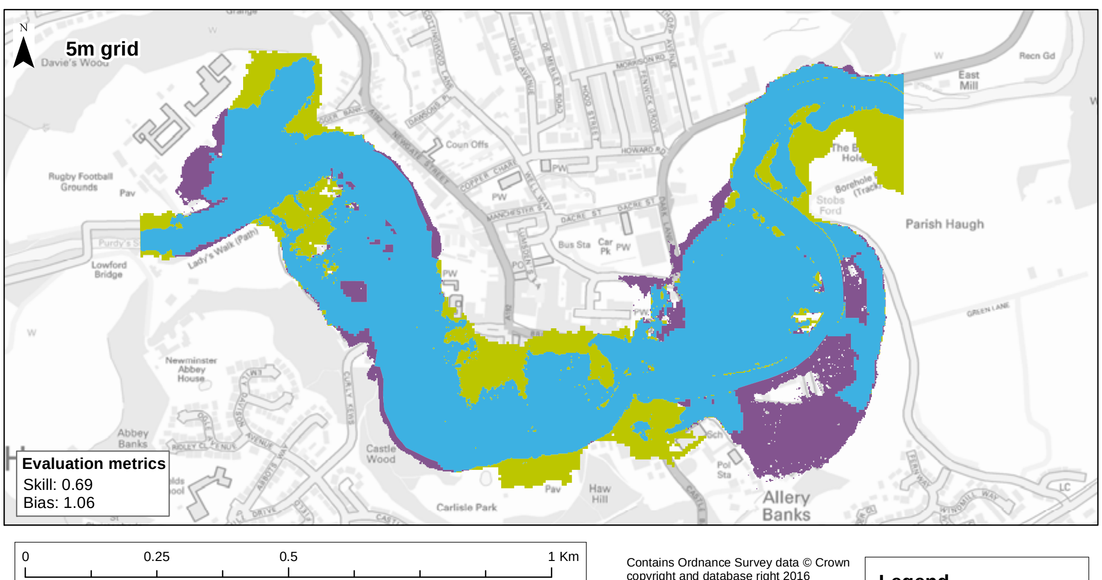
Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

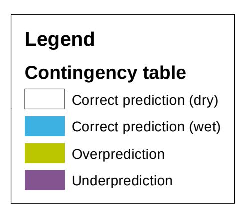
- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$





No sensitivity tests required

Figure 4.17 Model performance in predicting flooded extent at Morpeth: flows input (5m resolution)

Table 4.12 Model performance metrics for Morpeth event: flows input (5m resolution)

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
Modelled outline (all)	**69**	**17.8**	**13.2**	**0.69**	**1.06**
Modelled flood outline (within area covered by Flood Warning Areas only)					
121FWF101	71.3	15.2	13.5	0.71	1.02
121FWF115	81.2	18.8	0	0.81	1.23
121FWF125	–	–	–	–	–

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain and performance in locations where there is known to be flood risk to property.

Interpretation

Detailed discussion of results using a finer resolution is included in Section 3.44.3, which compares the results of using a 5m and 2m resolution to a 10m resolution grid. Much of the interpretation is common to the different grid resolutions tested.

Model performance – temporal

Seven observed depth maps were available for 6 September 2008, at one-hourly intervals from 11:00 to 17:00. The hydrograph (observed levels at Oldgate Bridge in Morpeth town centre) in Figure 4.18 shows the times of each depth map observations in the context of the event.

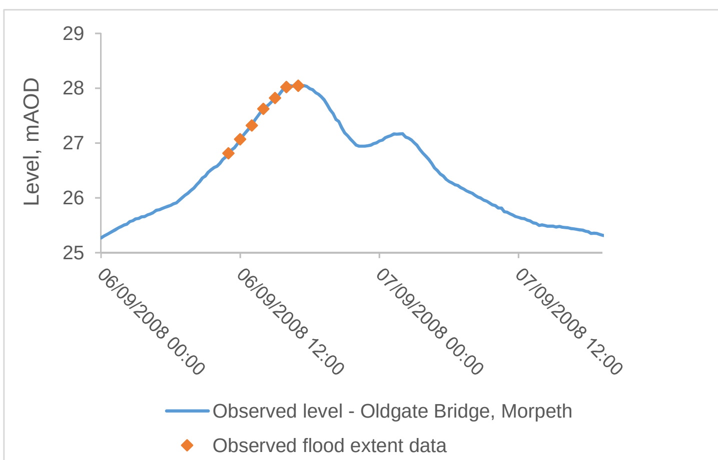
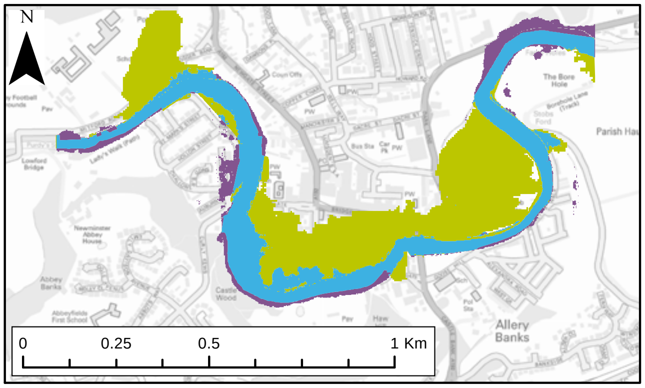


Figure 4.18 Available data for evaluation of model's temporal performance for Morpeth flood event

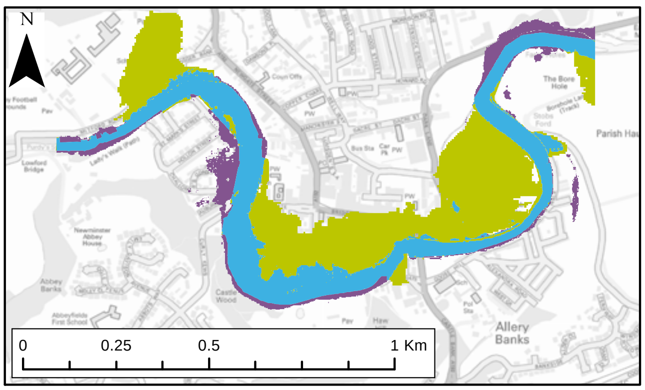
Table 4.13 Temporal evaluation of model performance at Morpeth on 6 September 2008: flows input (5m resolution)

11:00



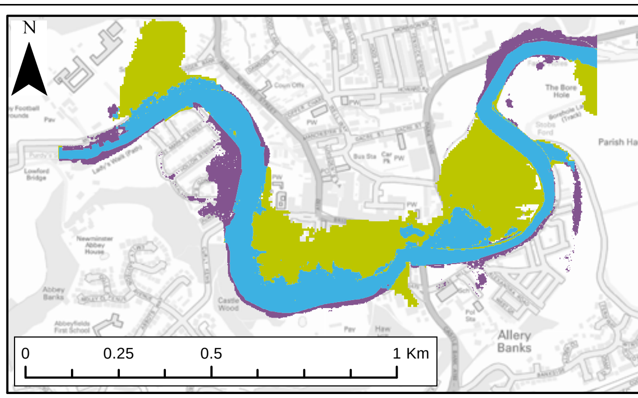
	Correct wet (%)	36.2
	Overprediction (%)	53.4
	Underprediction (%)	10.4
–	Skill	0.36
–	Bias	1.92

12:00



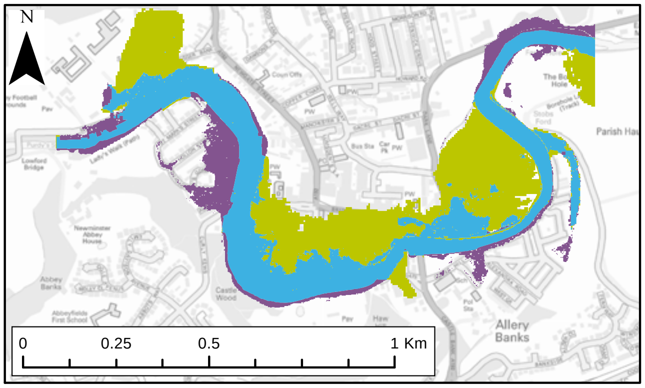
	Correct wet (%)	37.1
	Overprediction (%)	50.8
	Underprediction (%)	12.1
–	Skill	0.37
–	Bias	1.79

13:00



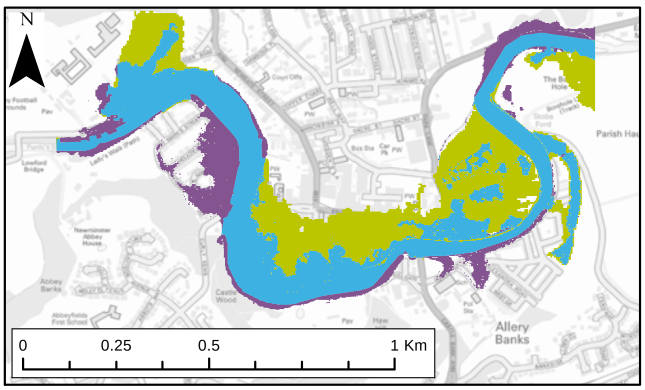
	Correct wet (%)	41.6
	Overprediction (%)	43.9
	Underprediction (%)	14.6
–	Skill	0.42
–	Bias	1.52

14:00



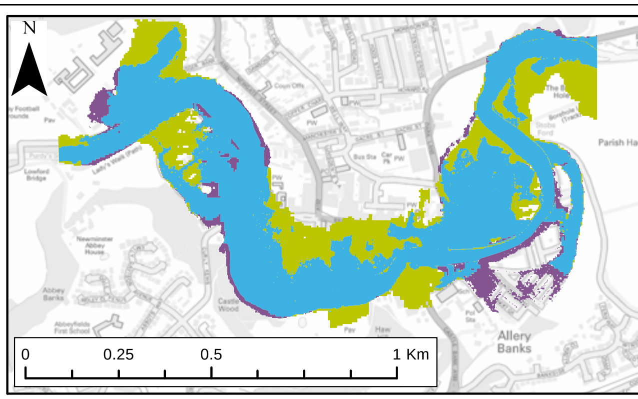
	Correct wet (%)	43.5
	Overprediction (%)	40.9
	Underprediction (%)	15.7
–	Skill	0.43
–	Bias	1.43

15:00

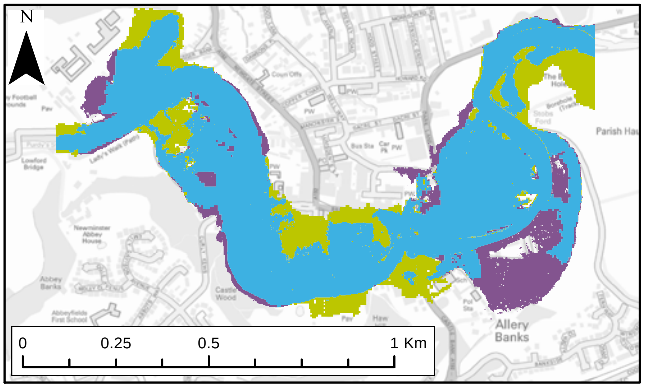


	Correct wet (%)	48.2
	Overprediction (%)	34.9
	Underprediction (%)	16.9
–	Skill	0.48
–	Bias	1.28

16:00



	Correct wet (%)	65.7
	Overprediction (%)	26.8
	Underprediction (%)	7.5
–	Skill	0.66
–	Bias	1.26

17:00 (observed maximum)			
		Correct wet (%)	68.8
		Overprediction (%)	17.6
		Underprediction (%)	13.6
	–	Skill	0.69
	–	Bias	1.05

4.2.5 Property counts (Test B)

Properties within flood extent

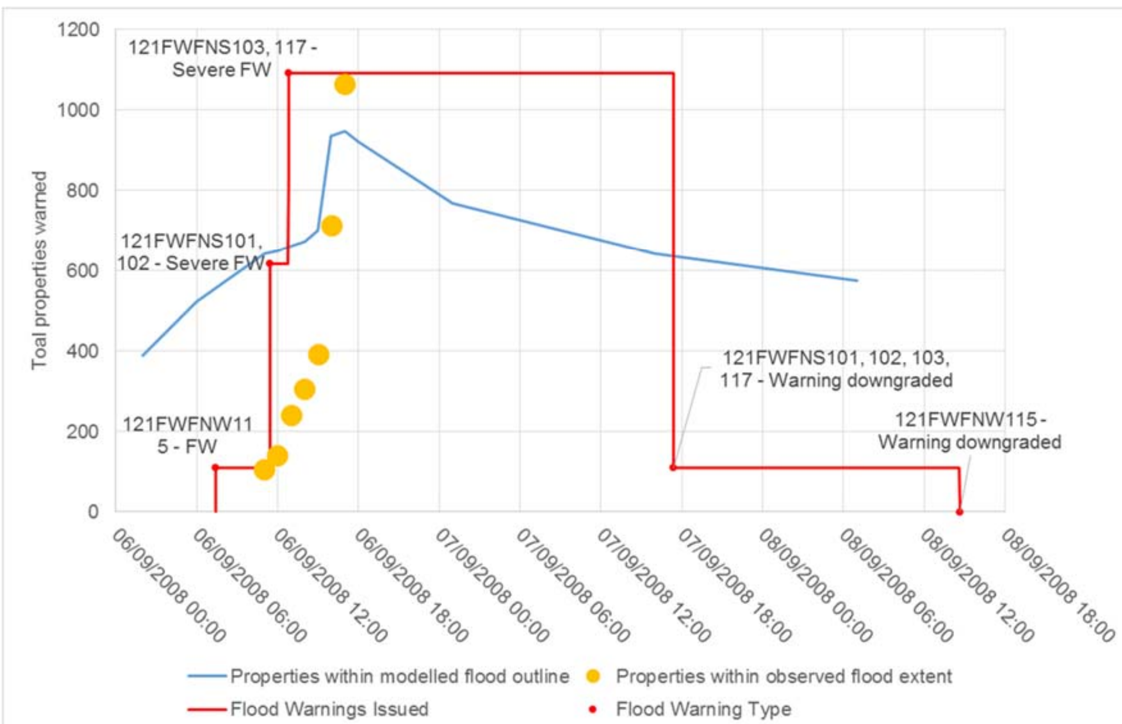


Figure 4.19 Properties within flood extent for Morpeth event: flows input (5m resolution)

Notes: Properties are mapped below.

Table 4.14 Maximum number of flooded properties for Morpeth event: flows input (5m resolution)

Flood Warning Area	Properties warned[1]	Observed[2]	Predicted[3]
All	–	1,066	960
121FWF101	–	1,061	955
121FWF115	–	5	5
121FWF125	–	–	–

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event. For this study, these were not available for Morpeth.
[2] Observed is based on the intersection of NRD property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.

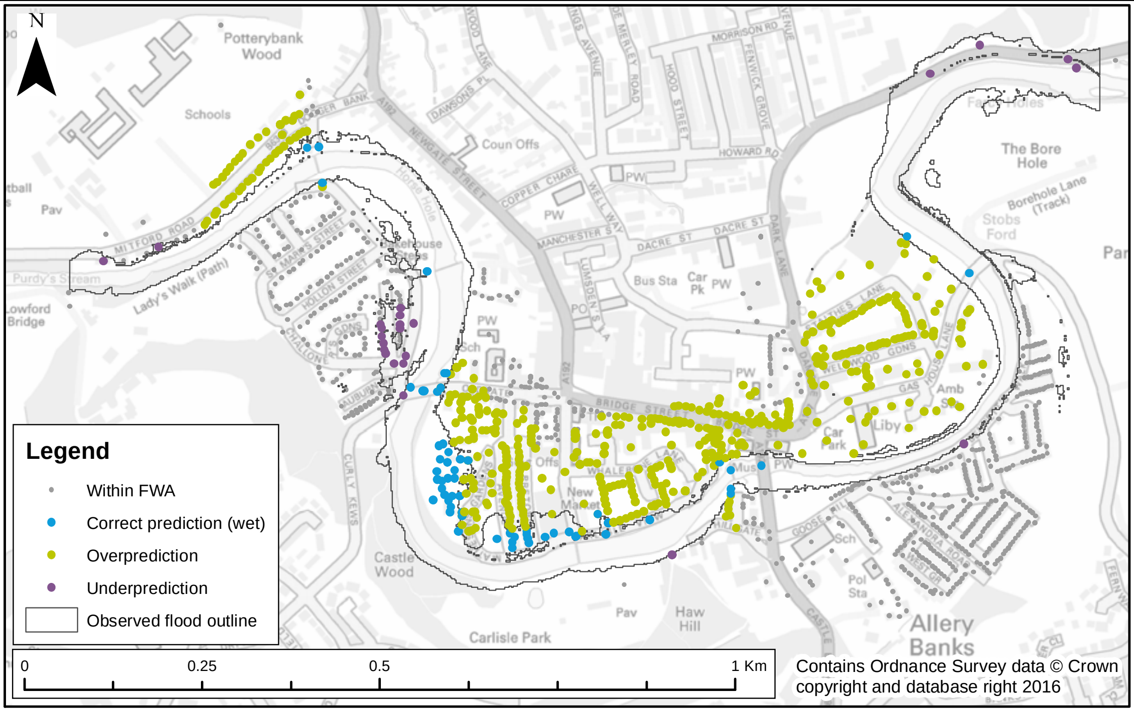
Interpretation

Detailed discussion of results using a finer resolution is included in Section 3.44.3, which compares the results of using a 5m and 2m resolution to a 10m resolution grid. Much of the interpretation is common to the different grid resolutions tested.

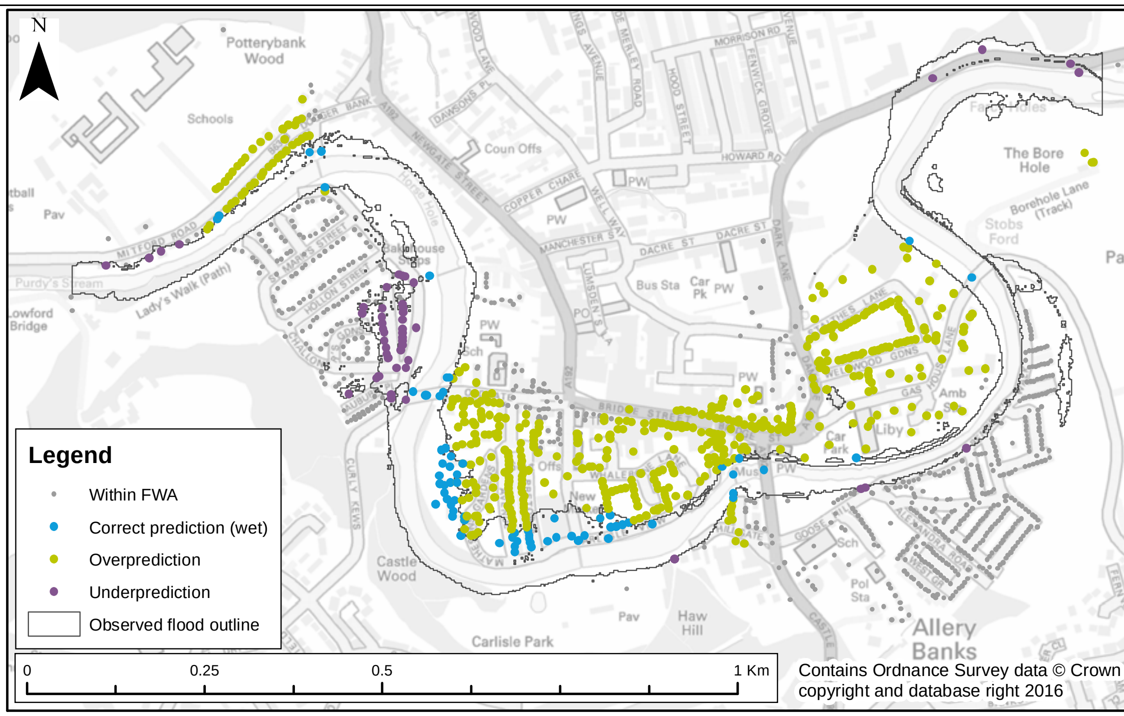
Properties mapped by model prediction

The maps presented in Figure 4.20 show NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline.

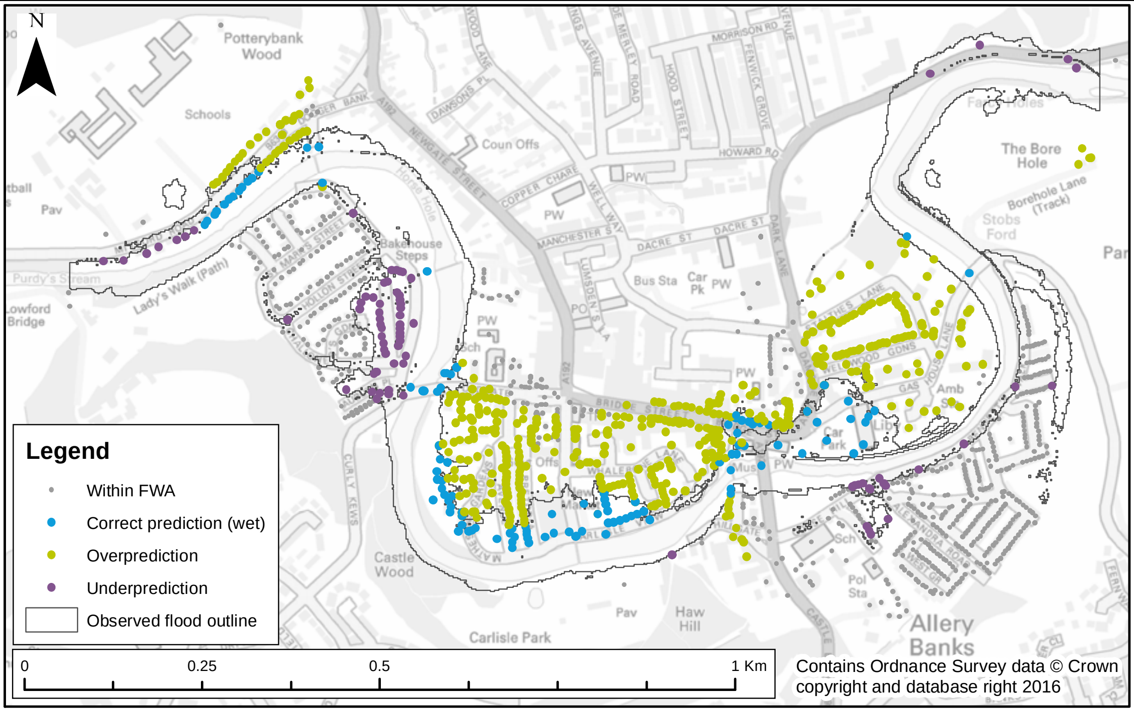
11:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

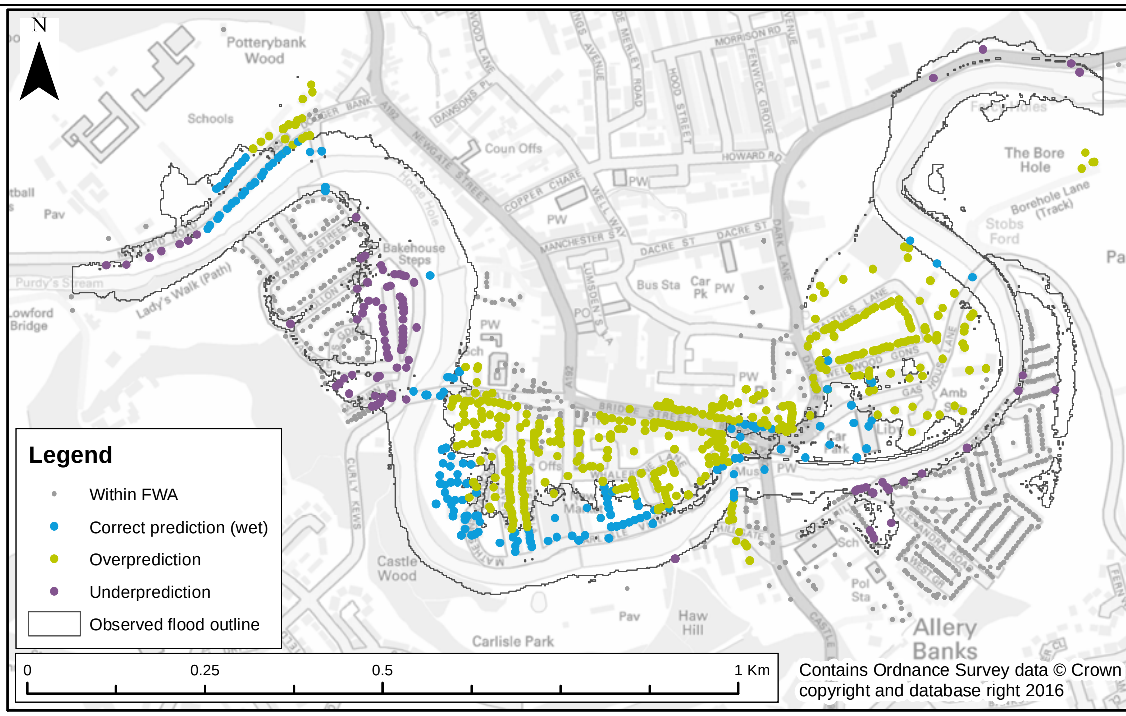
12:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

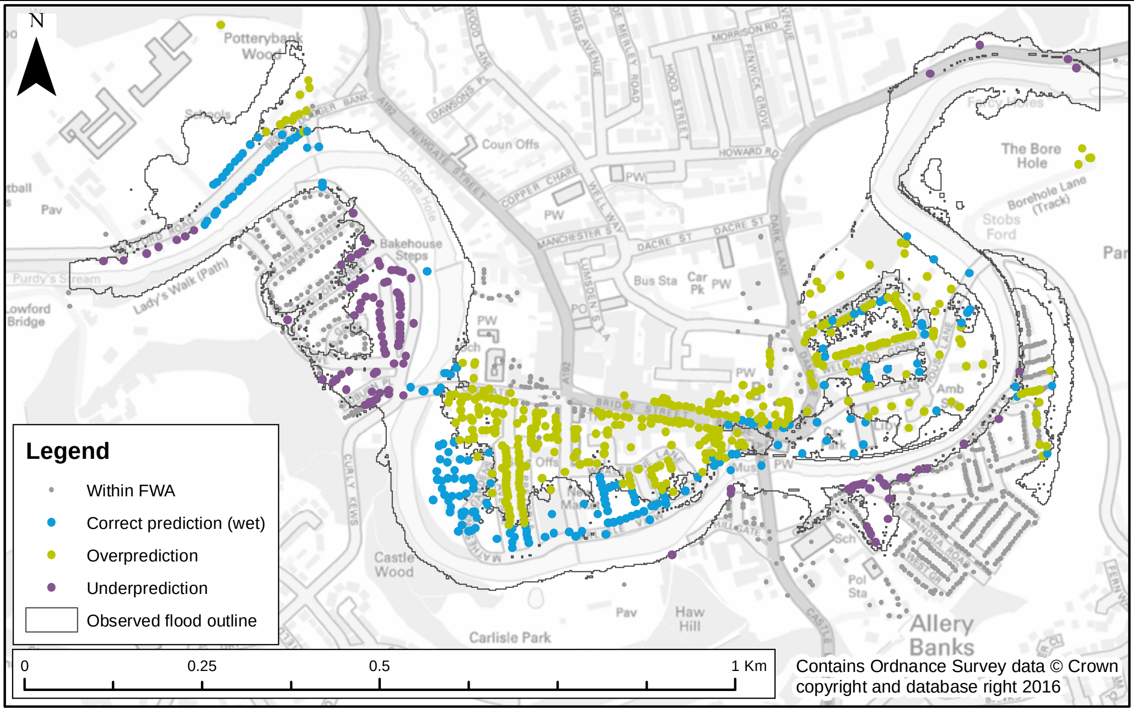
13:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

14:00

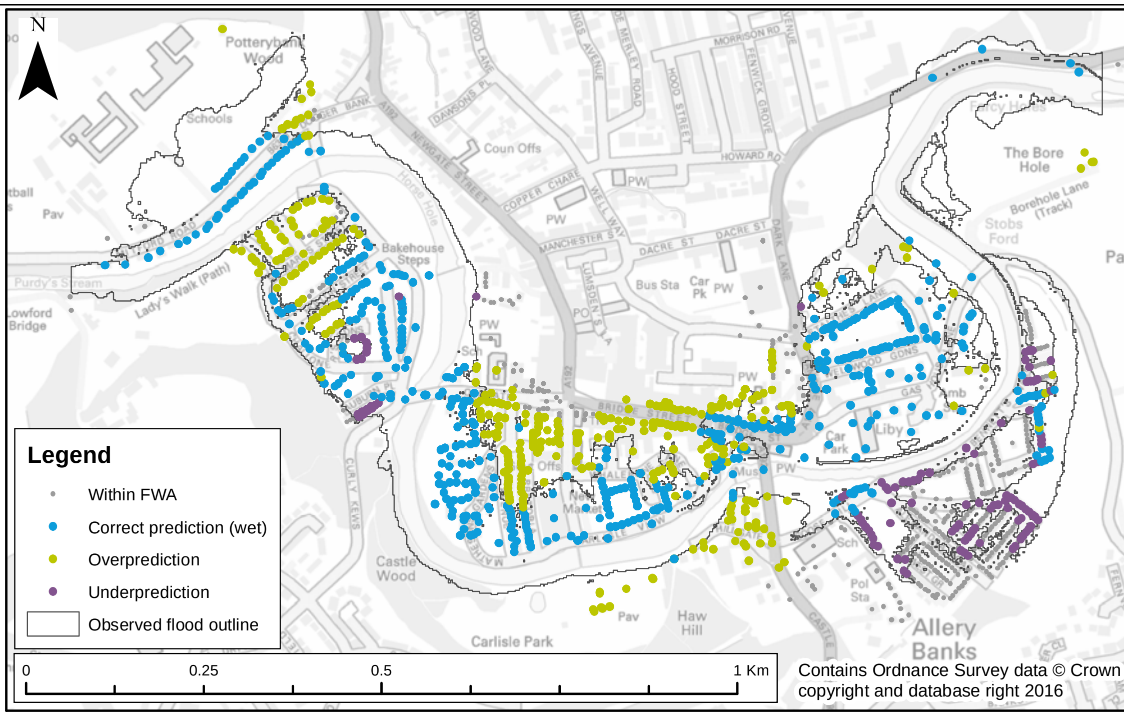

N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

15:00



N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

16:00



N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

17:00

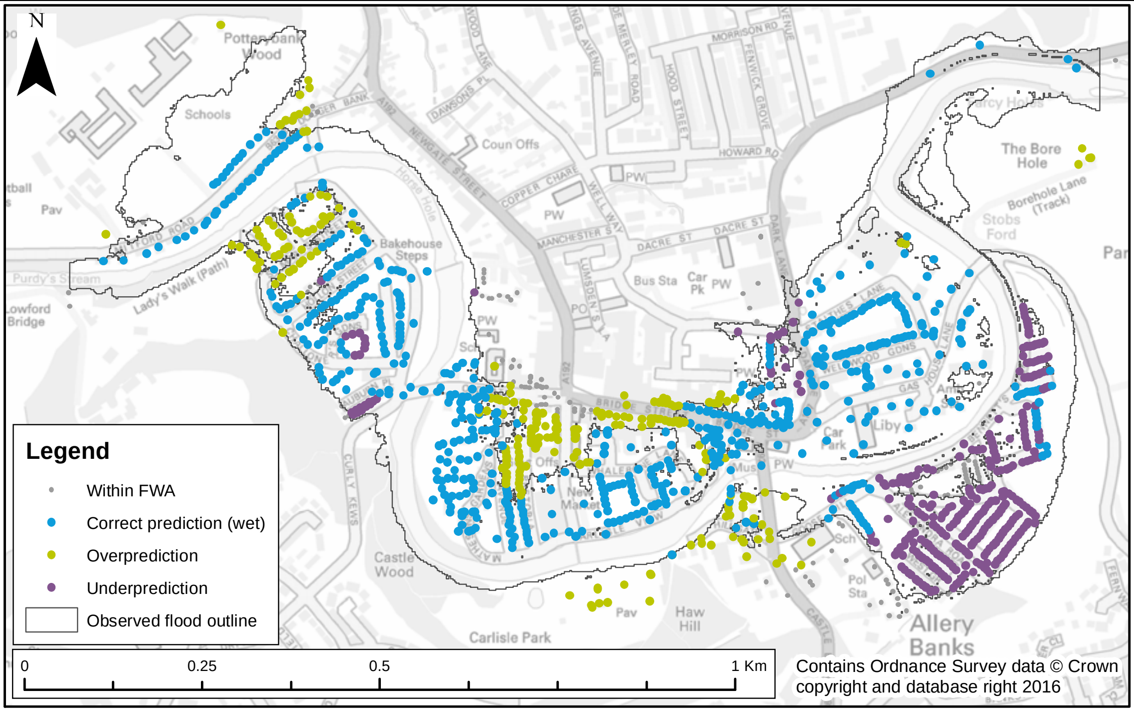
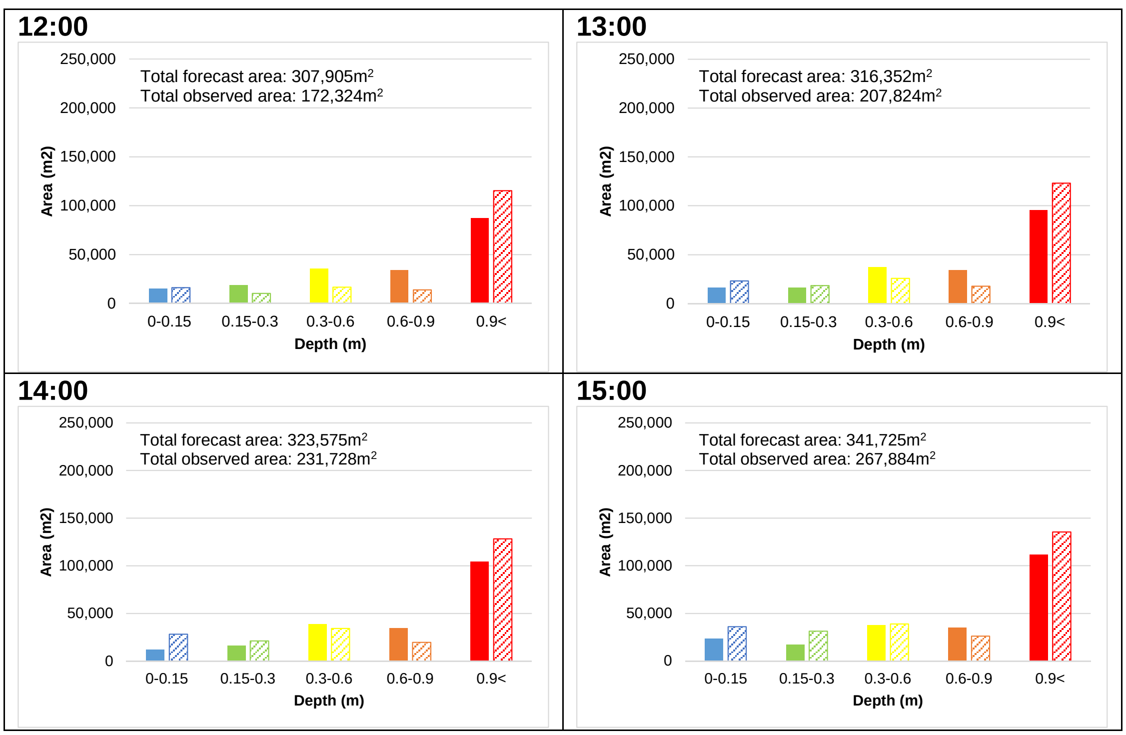


Figure 4.20 Model performance in predicting extent of flooding at Morpeth between 11:00 and 17:00 on 6 September 2008: flows input (5m resolution)

4.2.6 Depth analysis (Test C)

Flooded depths



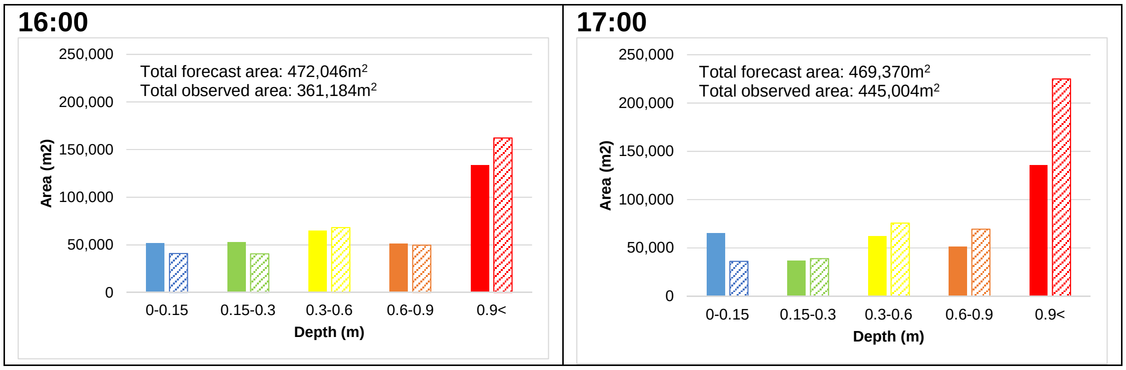


Figure 4.21 Modelled and observed flooded depths at Morpeth between 11:00 and 17:00 on 6 September 2008: flows input (5m resolution)

Notes: Solid bars show modelled depths (from the PoC option).
Dashed bars show observed depths (based on data supplied by Newcastle University).
Channel depths are not included in the modelled results and so the observed area would be expected to be greater for depths (especially for depths >0.9m). Channel area = 117,304m^2
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

Detailed discussion of results using a finer resolution is included in Section 3.4, which compares the results of using a 5m and 2m resolution to a 10m resolution grid. Much of the interpretation is common to the different grid resolutions tested.

4.3 Case study 1: Morpeth, September 2008 – flows input (2m resolution)

4.3.1 Location

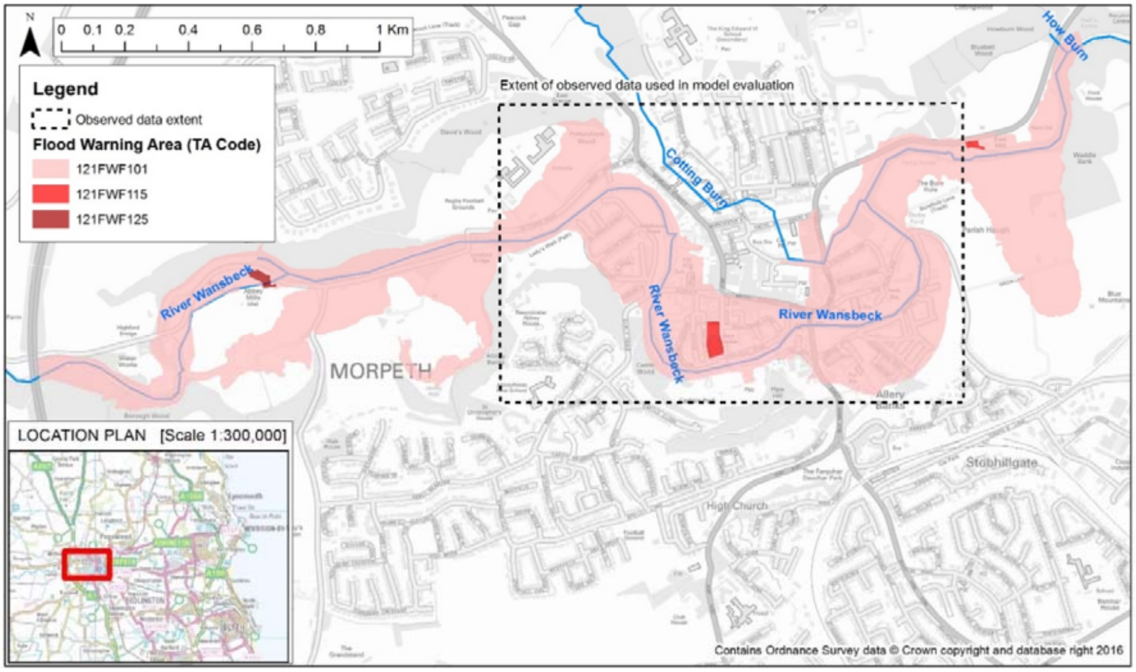


Figure 4.22 Location map for Morpeth case study

Table 4.15 Description of Flood Warning Areas featured in the Morpeth case study

Flood Warning Target Area Code	Name
121FWF101	River Wansbeck at Morpeth
121FWF115	River Wansbeck at East Mill and Morpeth Riverside Leisure Centre
121FWF125 [1]	River Wansbeck at Abbey Mills

Notes: [1] This is outside the extent of the observed flood outline data.

4.3.2 Model depths (2m resolution using flows as input)

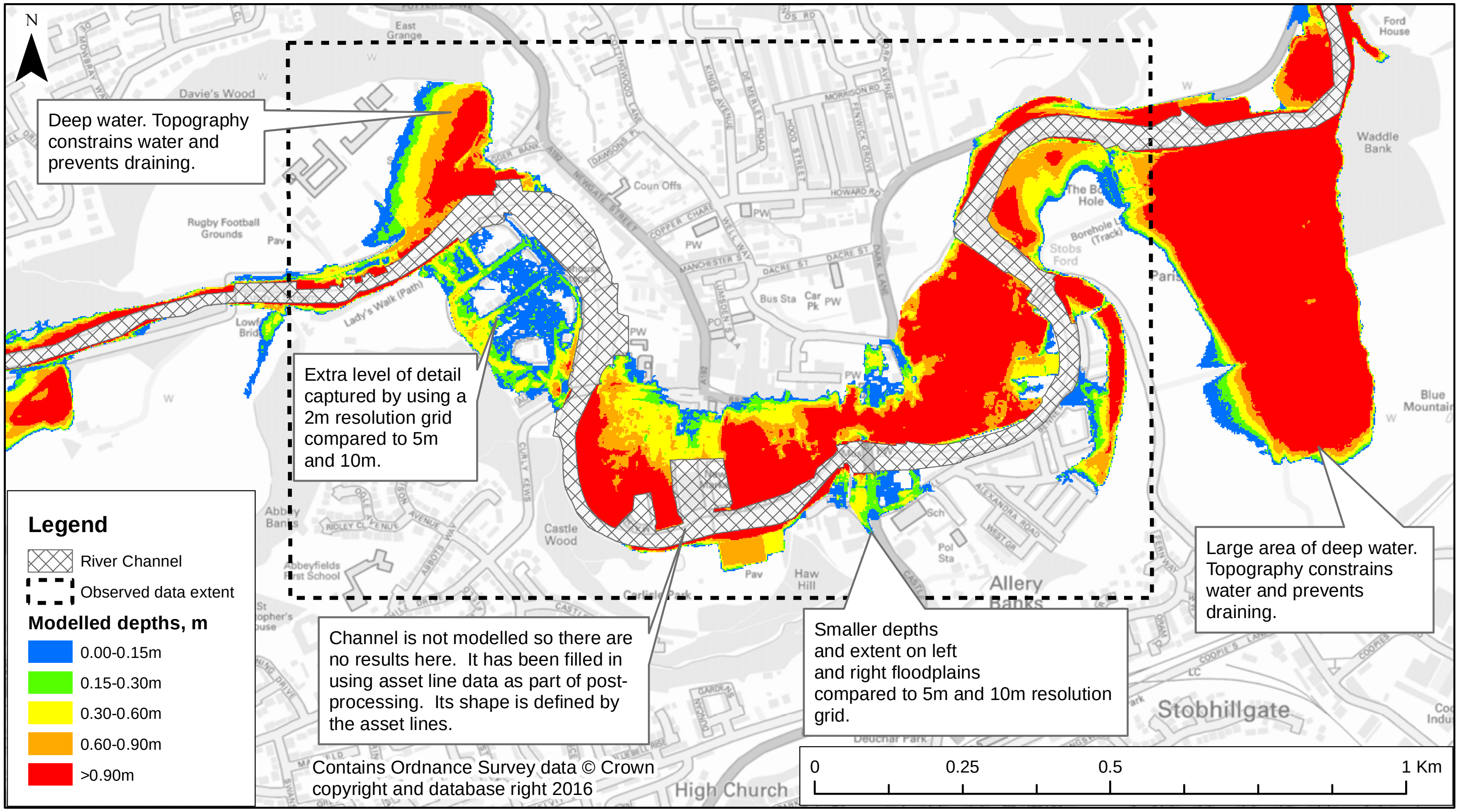


Figure 4.23 Model outputs for Morpeth event: flows input (2m resolution)

4.3.3 Extent flooded (Test A1)

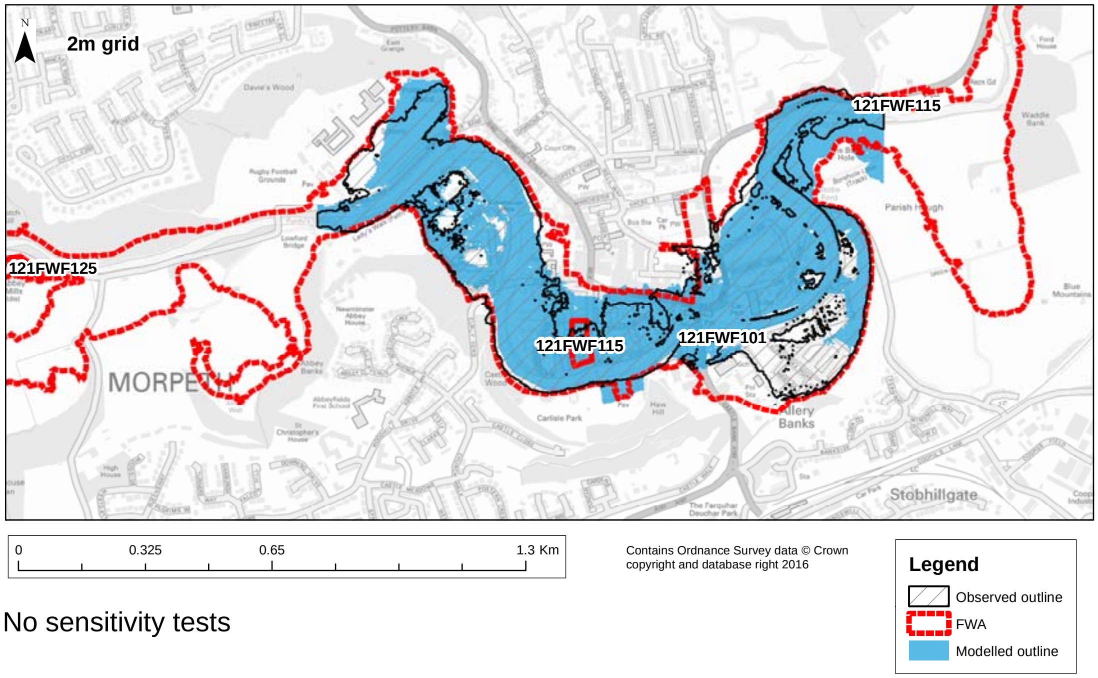


Figure 4.24 Maximum modelled and observed extent flooded (17:00 on 6 September 2008): flows input (2m resolution)

Table 4.16 Comparison of modelled and observed area flooded for each Flood Warning Area for Morpeth event: flows input (2m resolution)

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	587,038	428,568	73.0	439,788	74.9
121FWF101	582,300	423,830	72.8	436,094	74.9
121FWF115	4,738	4,738	100	3,849	81.2
121FWF125	–	–	–	–	–

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

This section compares the model outputs for a 10m grid to a finer resolution (2m and 5m) grid. Visually, finer resolution provides greater detail in modelled flood extents. However, overall predictions of flood extent are similar between the different grid resolutions – 10m grids provide similar predictions of the patterns of flooding.

The maximum flood extent decreases with a finer resolution. At 10m, the area flooded by the model, as a percentage of the Flood Warning Area, is 79.2%. At 5m and 2m resolutions, the flooded area decreases to 76.6% and 73.0% respectively. The results from using the smaller grid line up better with the observed flooded area (74.9%).

Surface water flooding is known to have occurred in the Allery Banks/Middle Greens area during the 2008 event, contributing to the observed flood extent. Since the hydraulic model only simulates fluvial flooding, the modelled flood extent would be expected to be smaller than the observed extent.

4.3.4 Model performance (Test A2)

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

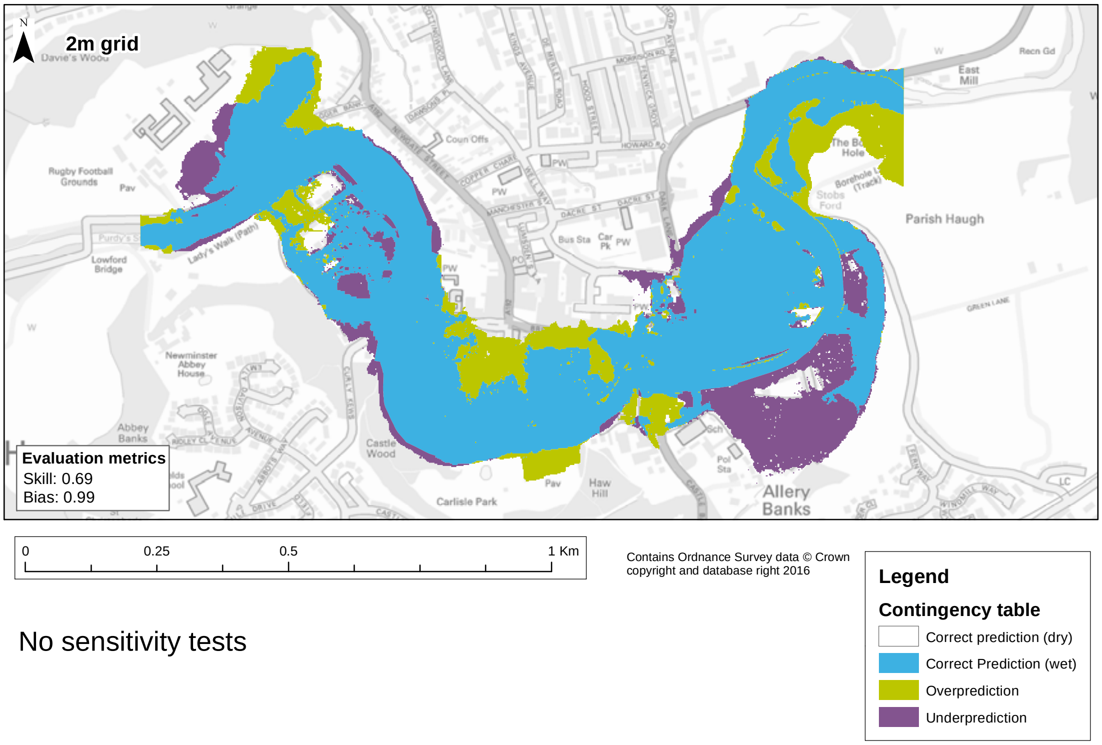


Figure 4.25 Model performance in predicting flooded extent at Morpeth: flows input (2m resolution)

Table 4.17 Model performance metrics for Morpeth event: flows input (2m resolution)

Location	**Correct wet (%)**	**Over-prediction (%)**	**Under-prediction (%)**	**Skill**	**Bias**
Modelled outline (all)	**69.4**	**15**	**15.6**	**0.69**	**0.99**
Modelled flood outline (within area covered by Flood Warning Areas only)					
121FWF101	71.0	13.3	15.8	0.71	0.97
121FWF115	81.2	18.8	0	0.81	1.23
121FWF125	–	–	–	–	–

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain and performance in locations where there is known to be flood risk to property.

Interpretation

There is very little difference in model skill between the 10m grid and a finer resolution (5m and 2m); 69% of the flood extent is correctly predicted at all grid sizes. However, as resolution decreases from 10m to 2m, overprediction decreases (from 19.6% to 15%) but underprediction increases (from 10.7% to 15.6%). Overall bias decreases from 1.11 to 0.99 (10m to 2m).

Model performance – temporal

Seven observed depth maps were available for 6 September 2008, at one-hourly intervals from 11:00 to 17:00. The hydrograph (observed levels at Oldgate Bridge in Morpeth town centre) in Figure 4.26 shows the times of each depth map observations in the context of the event.

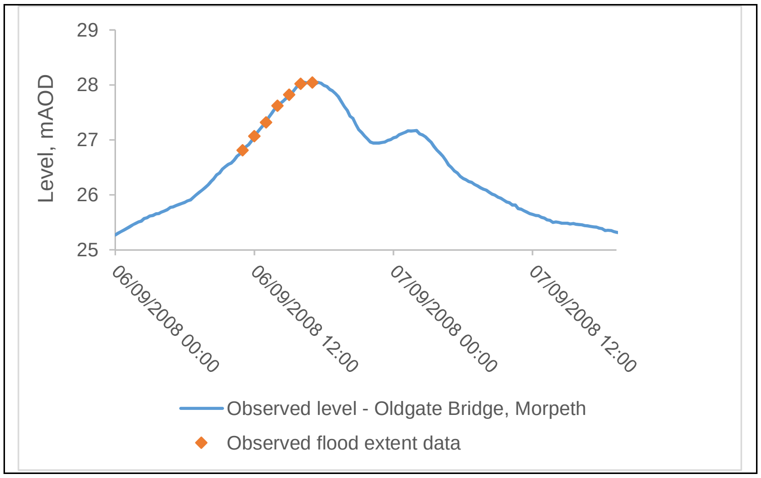
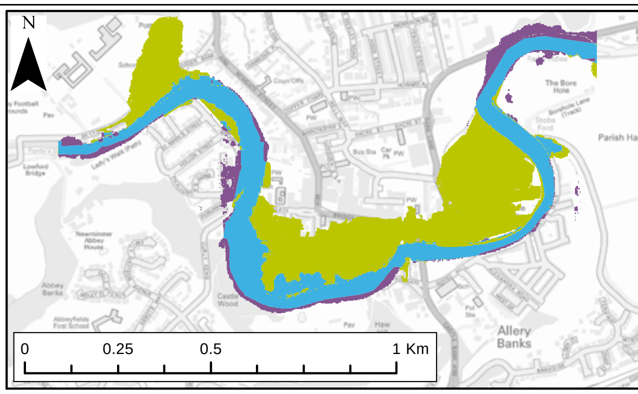
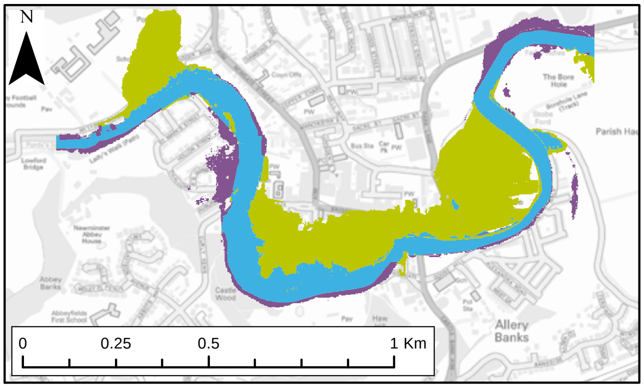


Figure 4.26 Available data for evaluation of model's temporal performance for Morpeth flood event

Table 4.18 Temporal evaluation of model performance at Morpeth on 6 September 2008: flows input (2m resolution)

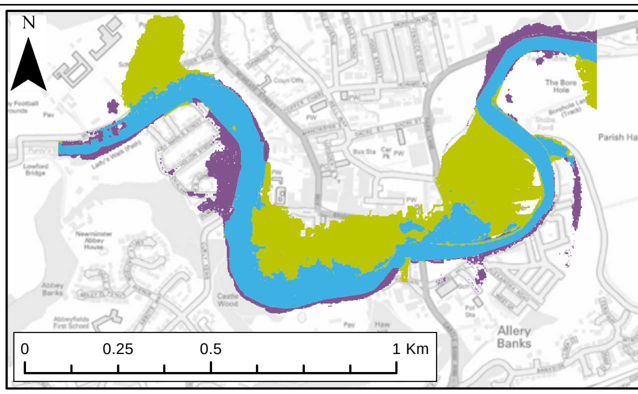
11:00			
		Correct wet (%)	36.7
		Overprediction (%)	52.5
		Underprediction (%)	10.8
	–	Skill	0.37
	–	Bias	1.88

12:00



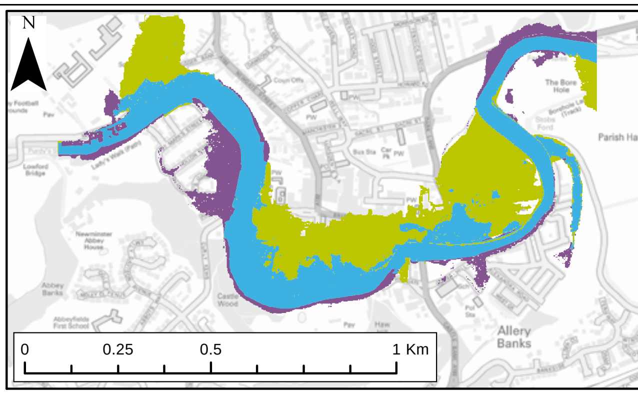
	Correct wet (%)	37.7
	Overprediction (%)	49.8
	Underprediction (%)	12.5
–	Skill	0.38
–	Bias	1.74

13:00



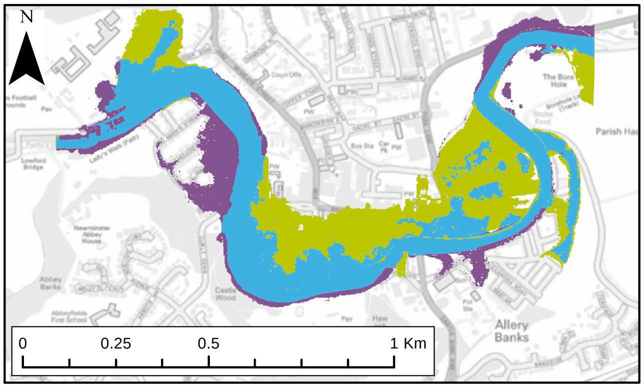
	Correct wet (%)	42.2
	Overprediction (%)	42.9
	Underprediction (%)	15.0
–	Skill	0.42
–	Bias	1.49

14:00



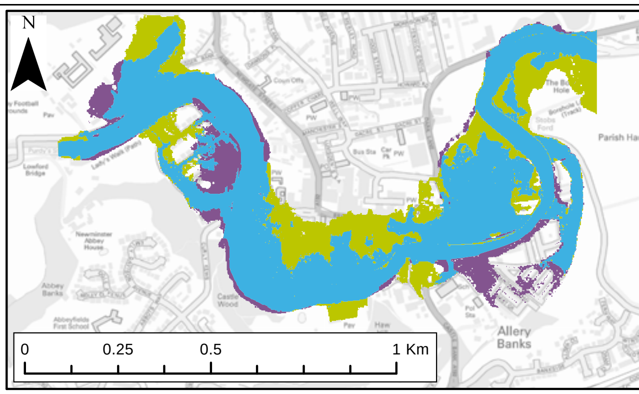
	Correct wet (%)	44.0
	Overprediction (%)	39.8
	Underprediction (%)	16.2
–	Skill	0.44
–	Bias	1.39

15:00



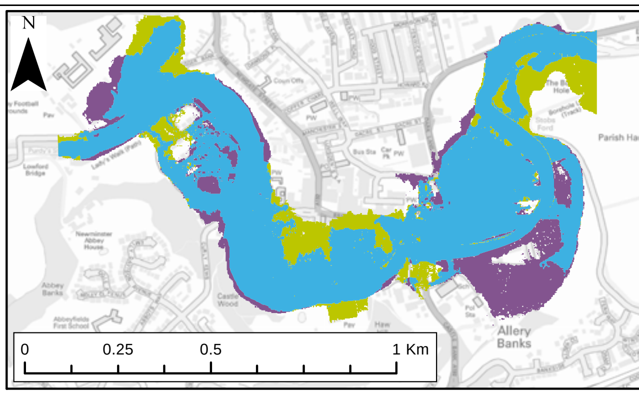
	Correct wet (%)	48.3
	Overprediction (%)	34.5
	Underprediction (%)	17.2
–	Skill	0.48
–	Bias	1.26

16:00



	Correct wet (%)	64.7
	Overprediction (%)	24.3
	Underprediction (%)	11.0
–	Skill	0.65
–	Bias	1.18

17:00 (observed maximum)



	Correct wet (%)	69.3
	Overprediction (%)	14.5
	Underprediction (%)	16.2
–	Skill	0.69
–	Bias	0.98

4.3.5 Property counts (Test B)

Properties within flood extent

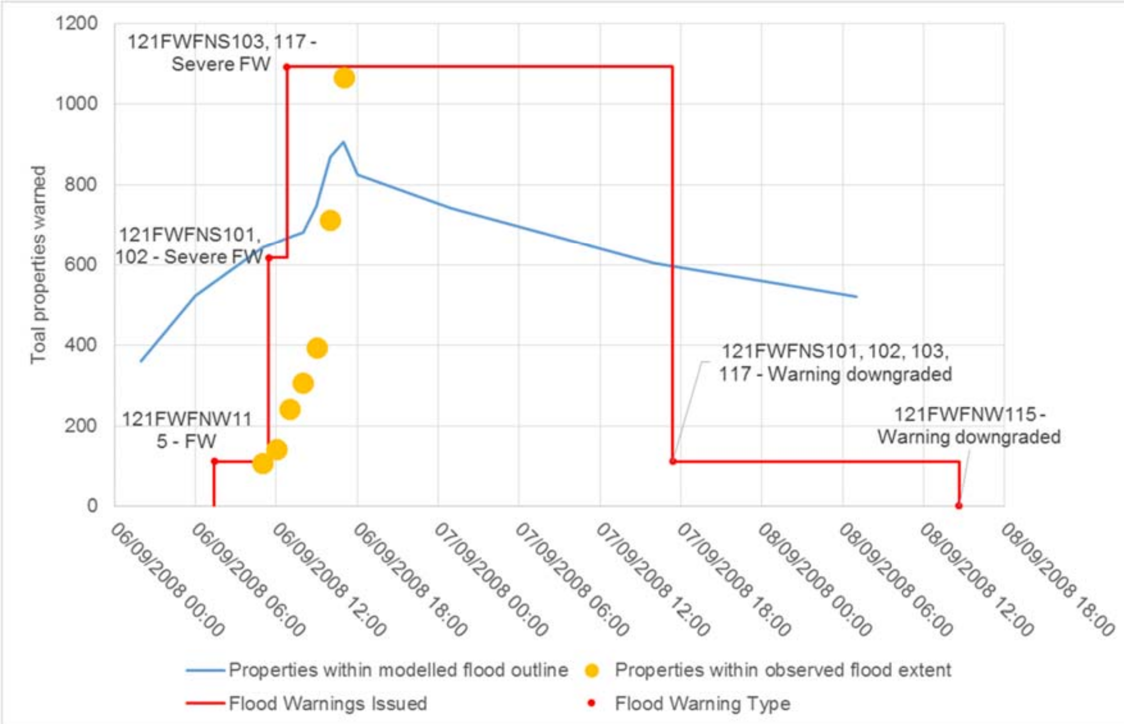


Figure 4.27 Properties within flood extent for Morpeth event: flows input (2m resolution)

Notes: Properties are mapped below.

Table 4.19 Maximum number of flooded properties for Morpeth event: flows input (2m resolution)

Flood Warning Area	Properties warned[1]	Observed[2]	Predicted[3]
All	–	1,066	916
121FWF101	–	1,061	911
121FWF115	–	5	5
121FWF125	–	–	–

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event. For this study, these were not available for Morpeth.
[2] Observed is based on the intersection of NRD property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.

Interpretation

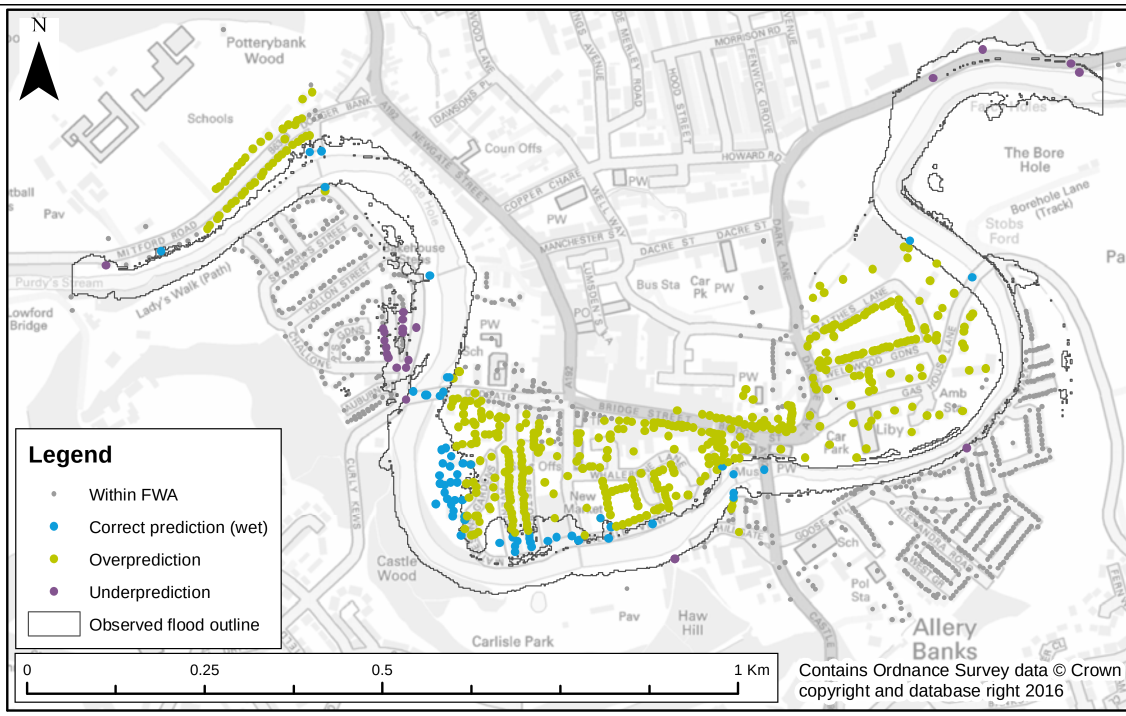
Overall, the number of properties in the modelled flood extent decreases as grid resolution becomes finer.

Across all grid sizes tested, the number of properties in the modelled outline is significantly greater than the number of properties in the observed outline during the first 5 hours of the event (11:00 to 17:00 on 6 September 2008). At the peak of the event, the number of properties in the modelled flood extent falls with grid size. A total of 1,015 properties are in the 10m resolution model extent compared with 916 properties at a 2m resolution. Fewer properties would be expected in the modelled flood extent compared with the observed extent due to the contribution of surface water flooding in the Allery Banks/Middle Greens in the observed outline.

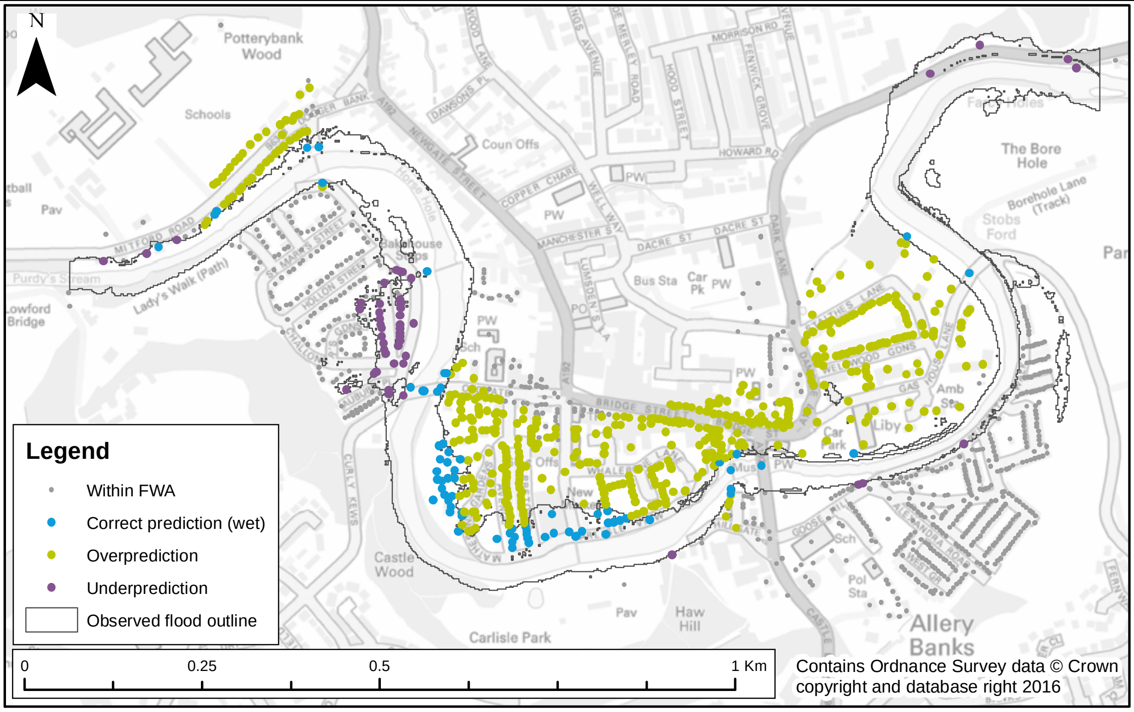
Properties mapped by model prediction

The maps presented in Figure 4.28 show NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline.

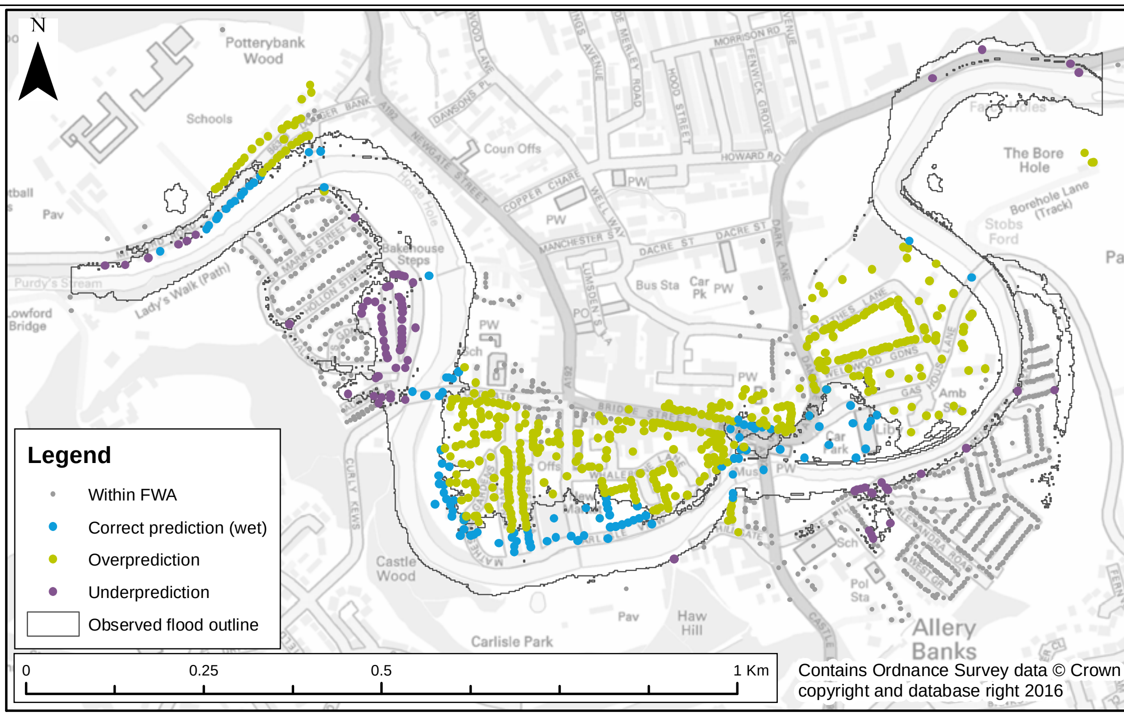
11:00



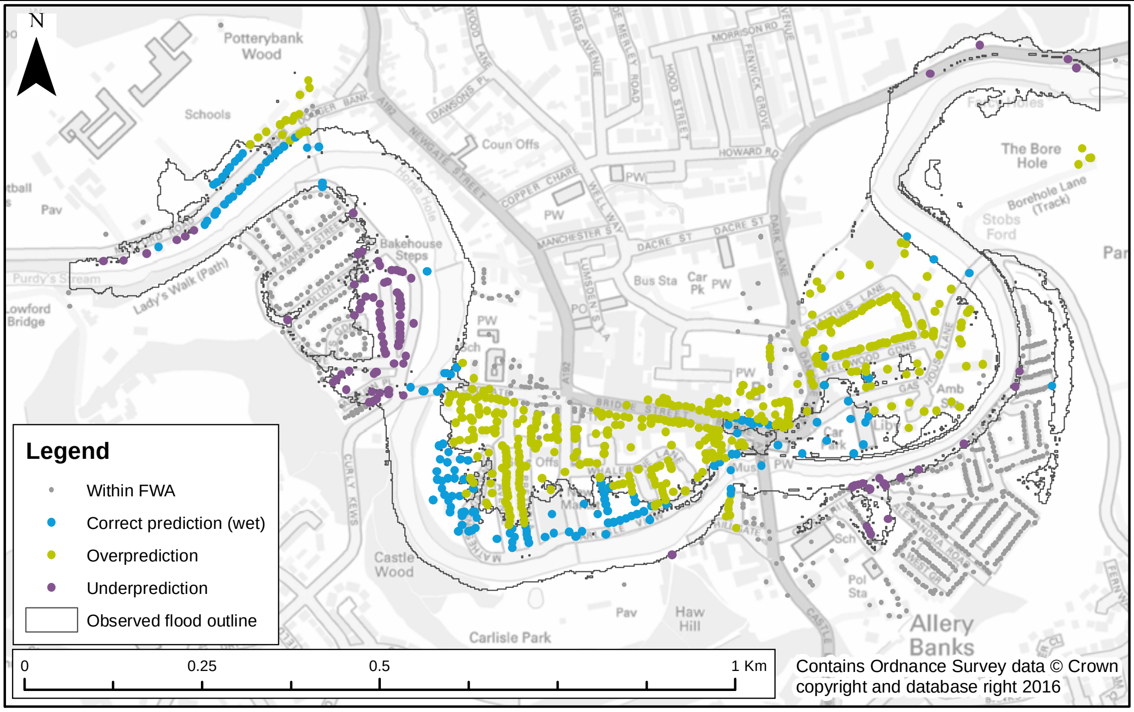
12:00


N
Potterybank Wood
Schools
Castle Wood
Carlisle Park
The Bore Hole
Allery Banks
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

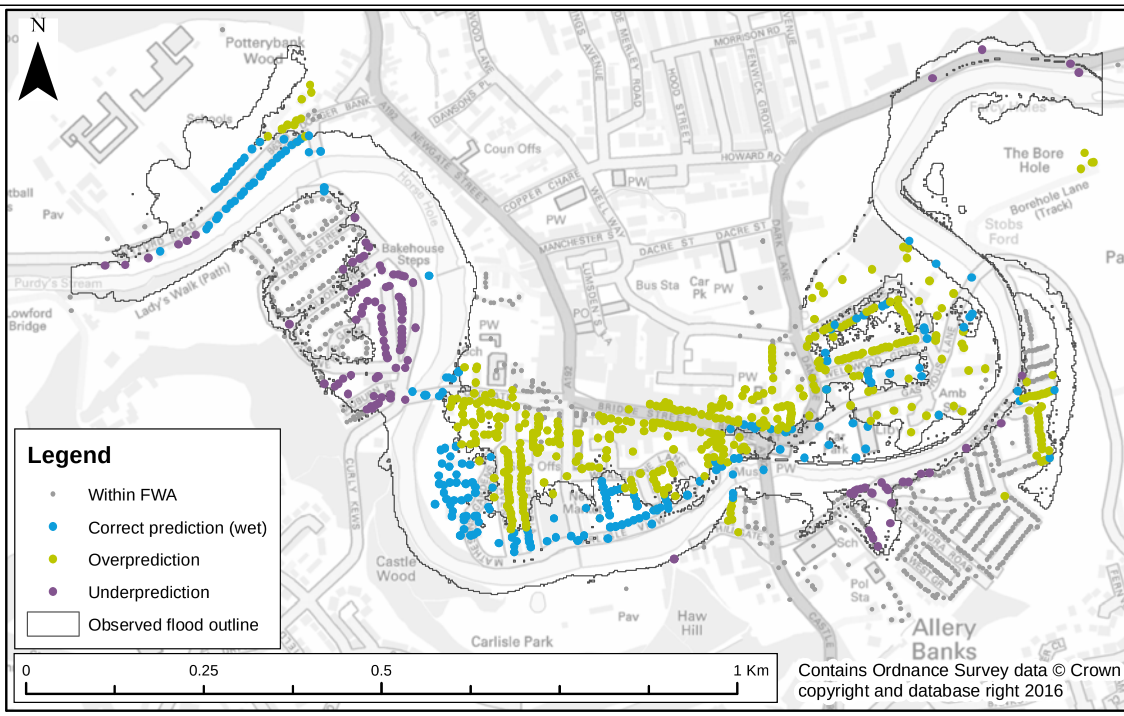
13:00


N
Potterybank Wood
Schools
Castle Wood
Carlisle Park
The Bore Hole
Allery Banks
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

14:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

15:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

16:00

17:00

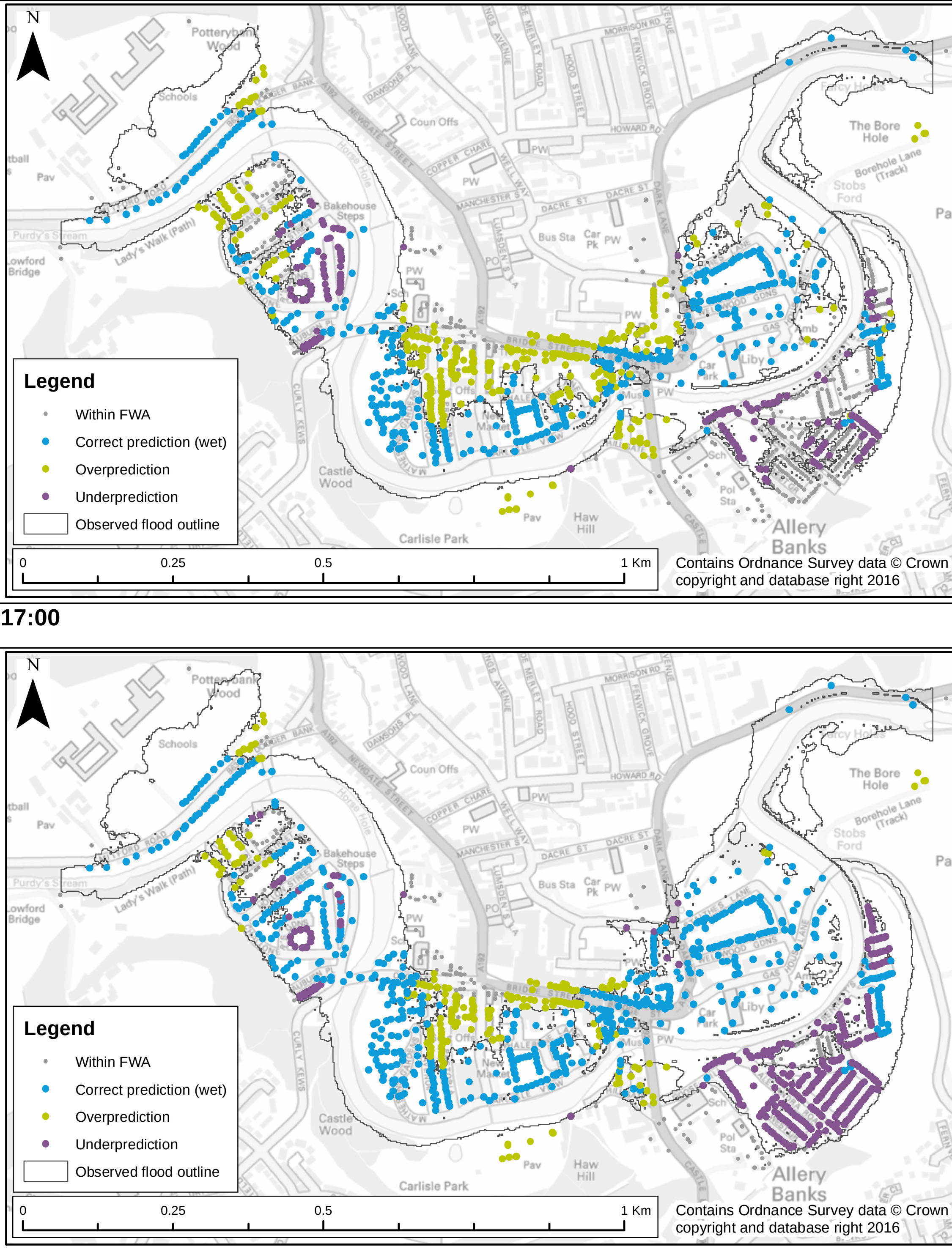


Figure 4.28 Model performance in predicting extent of flooding at Morpeth between 11:00 and 17:00 on 6 September 2008: flows input (2m resolution)

4.3.6 Depth analysis (Test C)

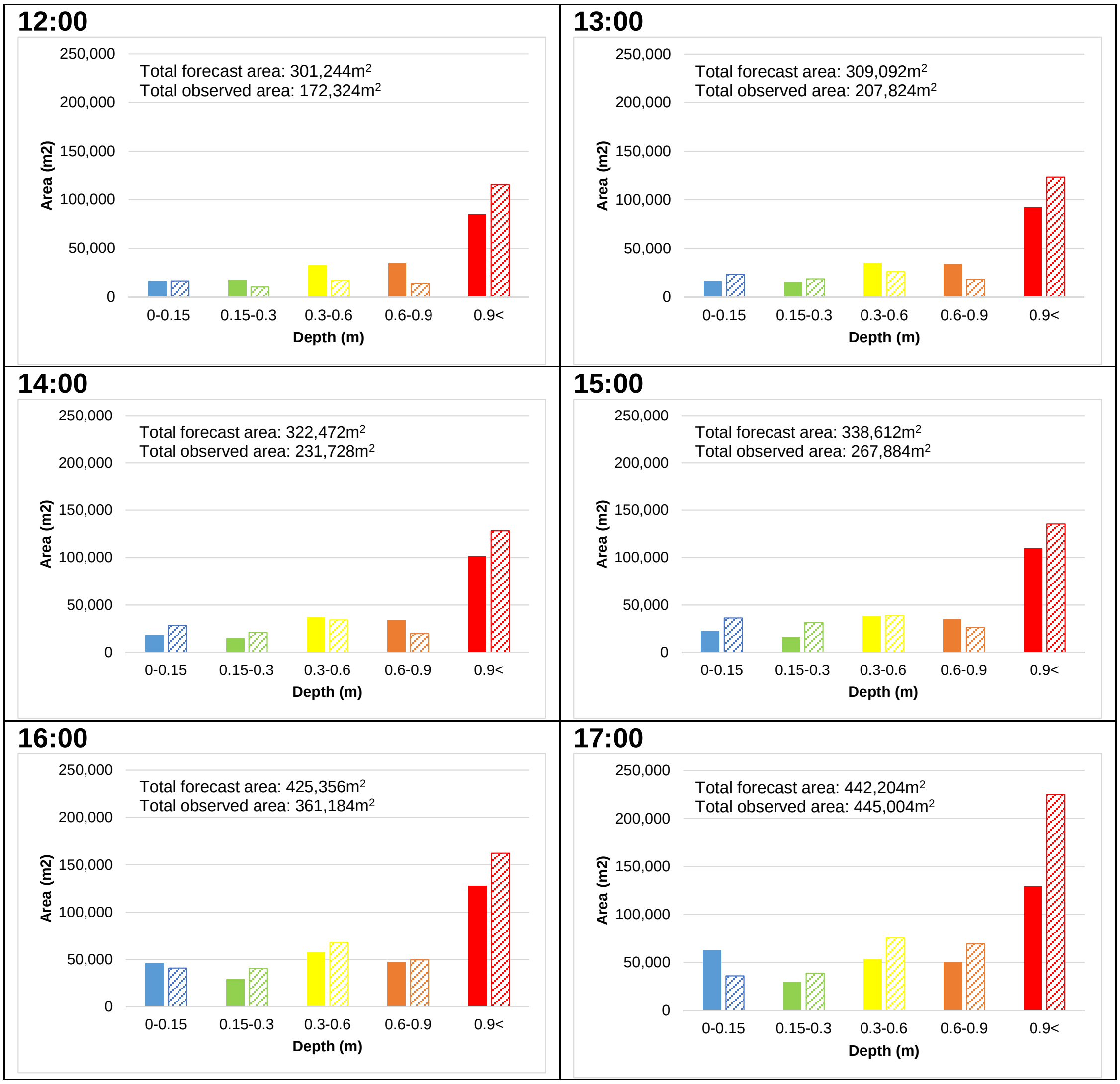


Figure 4.29 Modelled and observed flooded depths at Morpeth between 11:00 and 17:00 on 6 September 2008: flows input (2m resolution)

Notes: Solid bars show modelled depths (from the PoC option).
Dashed bars show observed depths (based on data supplied by Newcastle University).
Channel depths are not included in the modelled results and so the observed area would be expected to be greater for depths (especially for depths >0.9m). Channel area = 117,304m^2
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

The forecast area is greater than the observed area at each time-step for all grid resolutions. This finding does not change significantly with grid resolution. However, all resolutions show a decreasing difference between forecast and observed areas (quoted on the plots) at time progresses closer to the peak. A smaller grid size does lead to a smaller modelled flood extent, which matches better with the observed extent.

Generally, the distribution of flood depths is similar for different resolutions and this does not appear especially sensitive to grid resolution.

4.4 Case study 1: Morpeth, September 2008 – levels input (10m resolution)

4.4.1 Location

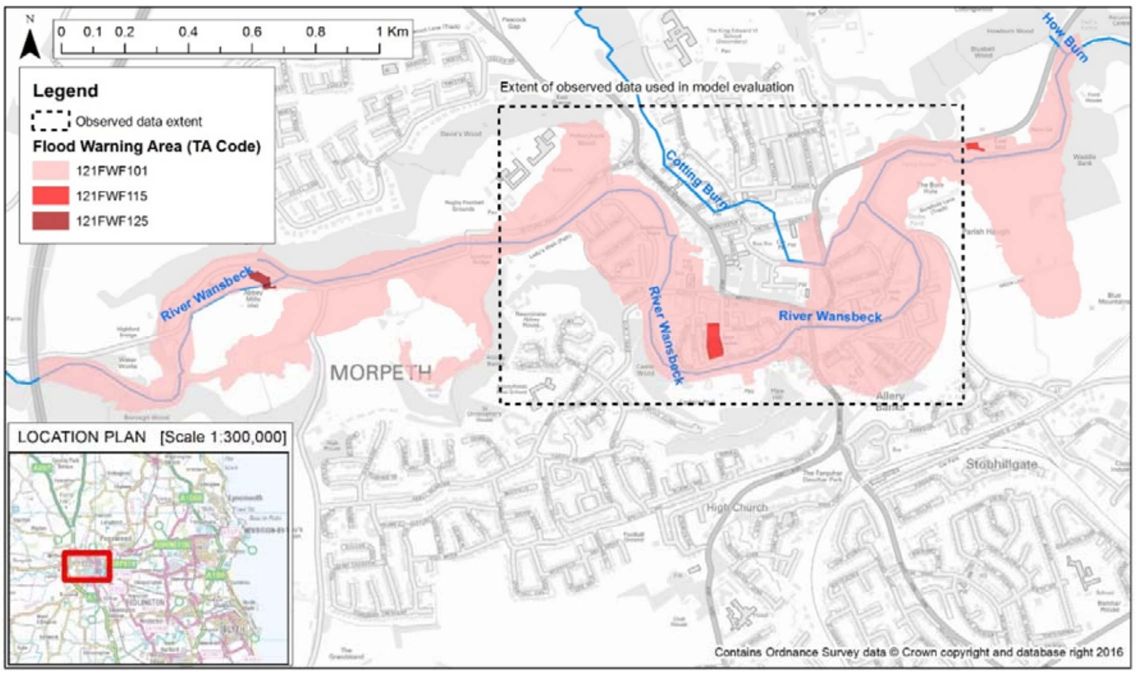


Figure 4.30 Location map for Morpeth case study

Table 4.20 Description of Flood Warning Areas featured in the Morpeth case study

Flood Warning Target Area Code	Name
121FWF101	River Wansbeck at Morpeth
121FWF115	River Wansbeck at East Mill and Morpeth Riverside Leisure Centre
121FWF125 [1]	River Wansbeck at Abbey Mills

Notes: [1] This is outside the extent of the observed flood outline data.

4.4.2 Model depths (10m resolution using levels as input)

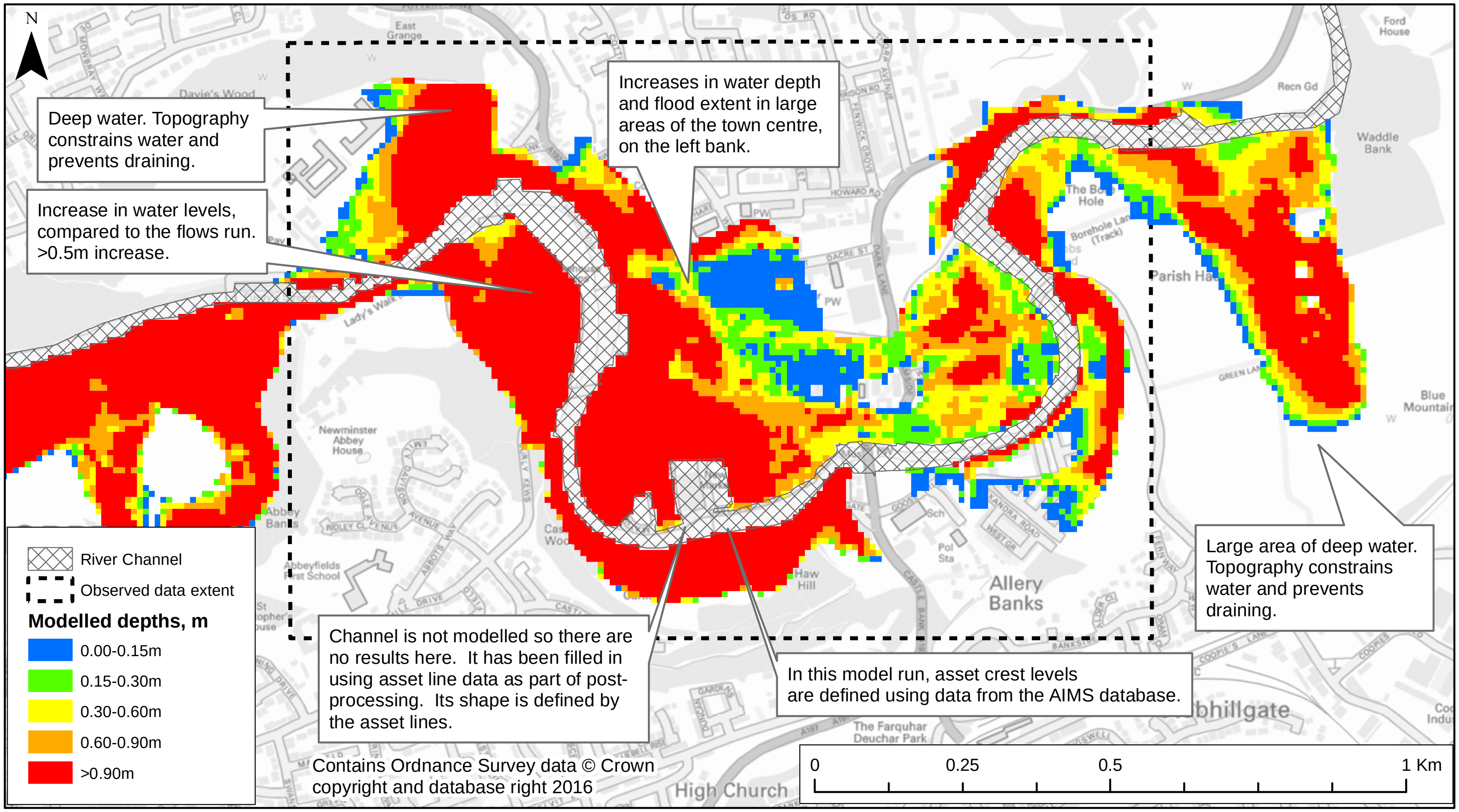


Figure 4.31 Model outputs for Morpeth event: levels input (10m resolution)

4.4.3 Extent flooded (Test A1)

Extent flooded

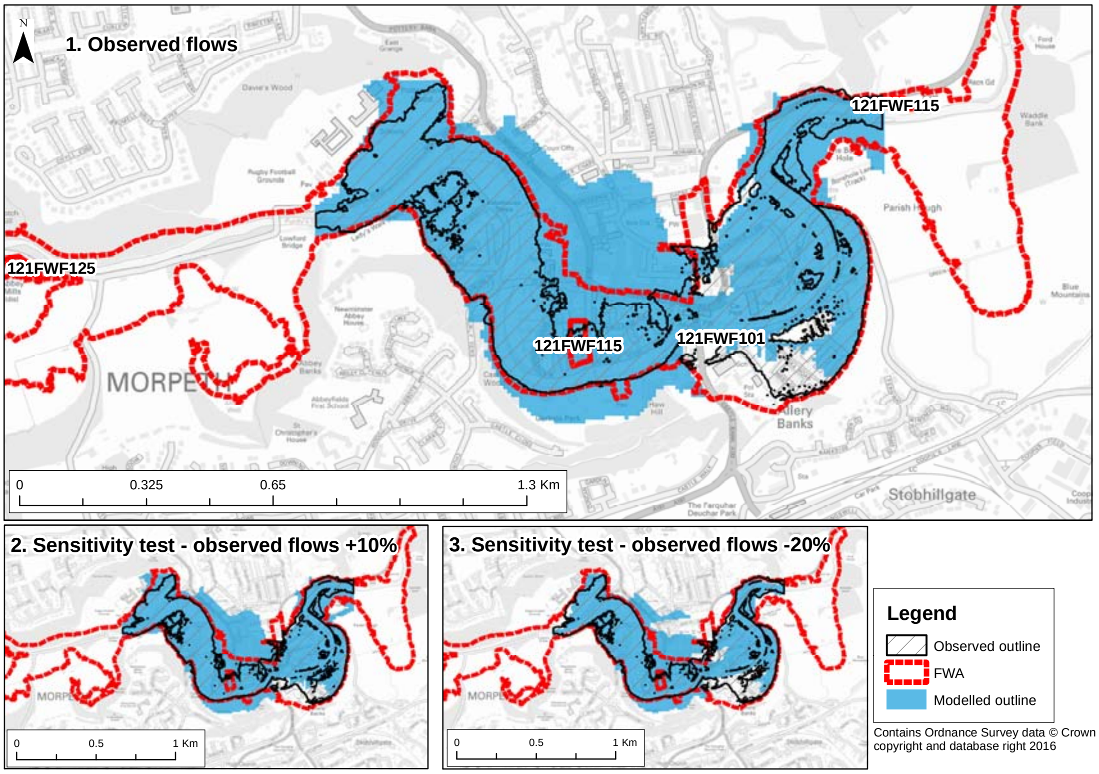


Figure 4.32 Maximum modelled and observed extent flooded (17:00 on 6 September 2008): levels input (10m resolution)

Table 4.21 Comparison of modelled and observed area flooded for each Flood Warning Area for Morpeth event: levels input (10m resolution)

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	587,038	505,281	86.1	439,788	74.9
121FWF101	582,300	500,543	86.0	436,094	74.9
121FWF115	4,738	4,738	100	3,849	81.2
121FWF125	–	–	–	–	–

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

The model reproduces the flooded area shown in the observed flood outline, although there are areas of significant overprediction. Note that the model results have been trimmed to the extent of observed data for display purposes.

The modelled flood outline demonstrates some sensitivity to variations in the input data (see sensitivity tests). Accurately quantifying inputs to the system is therefore a requirement for accurate prediction of flood extent.

4.4.4 Model performance (Test A2)

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

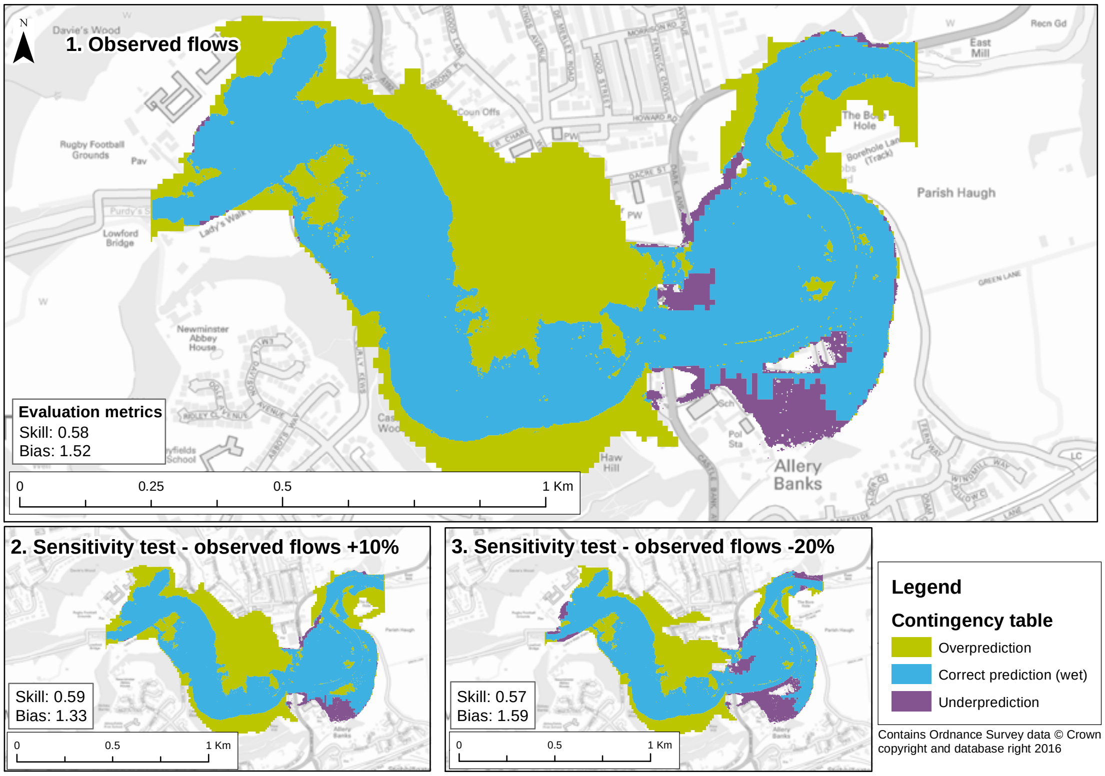


Figure 4.33 Model performance in predicting flooded extent at Morpeth: levels input (10m resolution)

Table 4.22 Model performance metrics for Morpeth event: levels input (10m resolution)

Location	**Correct wet (%)**	**Over-prediction (%)**	**Under-prediction (%)**	**Skill**	**Bias**
Modelled outline (all)	57.6	37.4	5.0	0.58	1.52
Modelled flood outline (within area covered by Flood Warning Areas only)					
121FWF101	75.1	18.5	6.4	0.75	1.15
121FWF115	81.2	18.8	0	0.81	1.23
121FWF125	–	–	–	–	–

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain and performance in locations where there is known to be flood risk to property.

Interpretation

There is significant overprediction in this model run. This might have occurred for 2 reasons.

First, there is no dynamic connection to the river channel, so water in the floodplain cannot drain into the river, particularly on the recession of the event.

Second, inaccuracies in the specification of in-bank heights (derived from AIMS) result in overprediction of the inflows to the 2D hydraulic model. This is likely to have a significant impact, given that such significant overprediction was not shown when the model was driven by in-channel flows (from the same source – a 1D–2D hydraulic model) and asset SoP.

However, the model still underpredicts in the Allery Banks area of the town (in the south0east); the flooding which was observed here is known to have been caused primarily by surface water, which is not modelled by this fluvial model.

Model performance – temporal

Seven observed depth maps were available for 6 September 2008, at one-hourly intervals from 11:00 to 17:00. The hydrograph (observed levels at Oldgate Bridge in Morpeth town centre) in Figure 4.34 shows the times of each depth map observations in the context of the event.

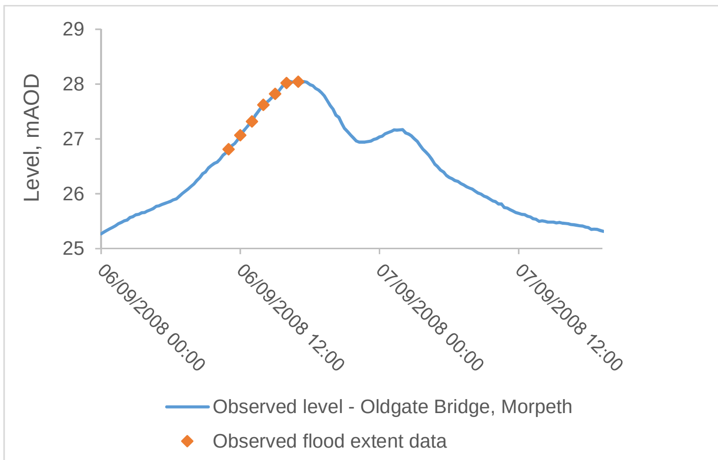
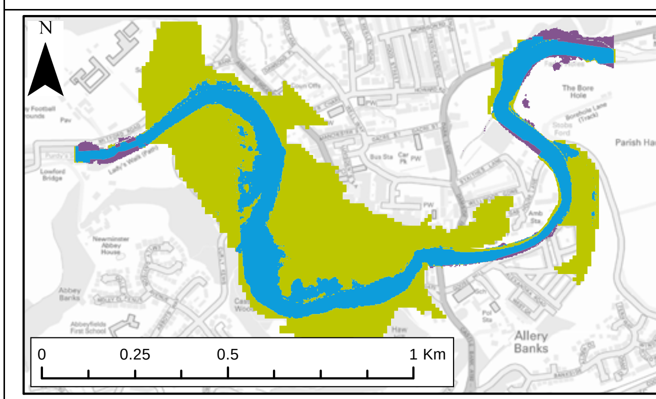
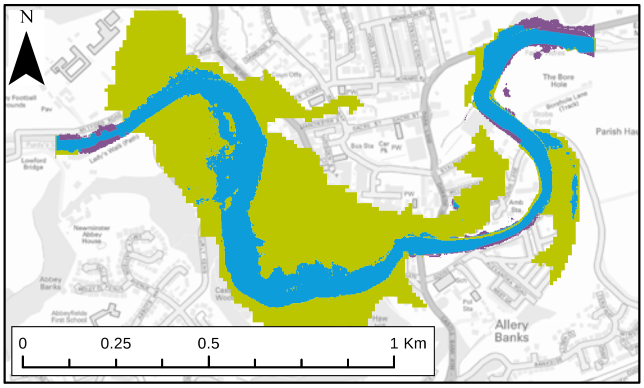


Figure 4.34 Available data for evaluation of model's temporal performance for Morpeth flood event

Table 4.23 Temporal evaluation of model performance at Morpeth on 6 September 2008: levels input (10m resolution)

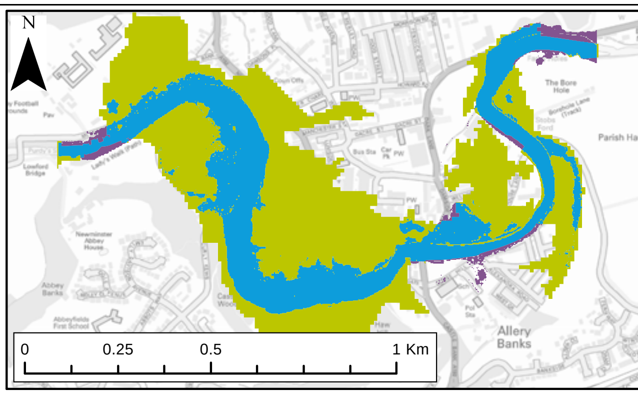
11:00			
		Correct wet (%)	31.8
		Overprediction (%)	65.0
		Underprediction (%)	3.2
	–	Skill	0.32
	–	Bias	2.77

12:00



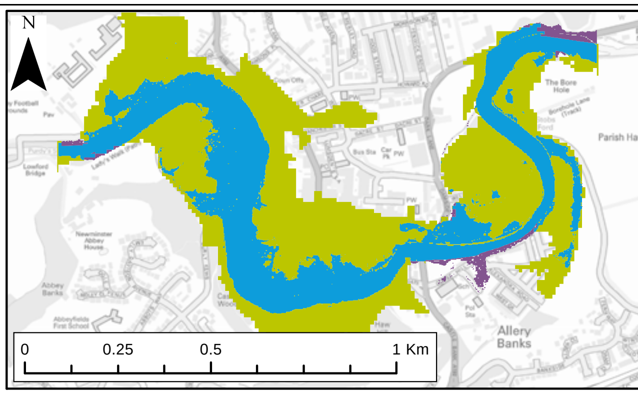
	Correct wet (%)	32.2
	Overprediction (%)	64.7
	Underprediction (%)	3.1
–	Skill	0.32
–	Bias	2.75

13:00



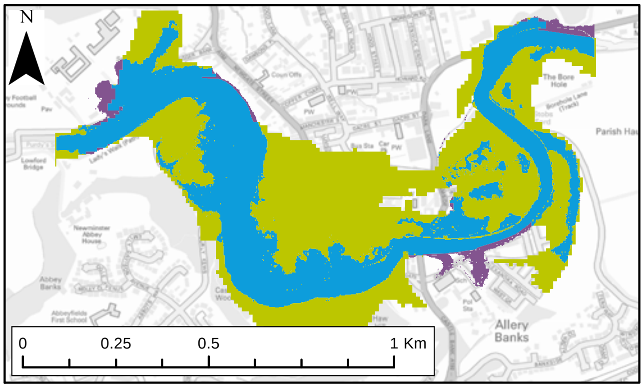
	Correct wet (%)	35.1
	Overprediction (%)	62.0
	Underprediction (%)	2.9
–	Skill	0.35
–	Bias	2.56

14:00



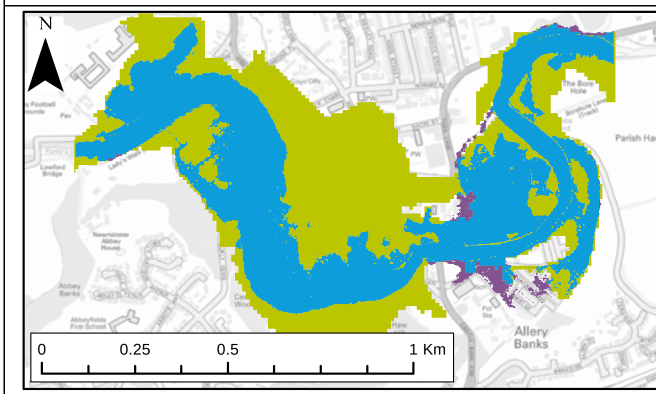
	Correct wet (%)	38.1
	Overprediction (%)	59.8
	Underprediction (%)	2.1
–	Skill	0.38
–	Bias	2.44

15:00



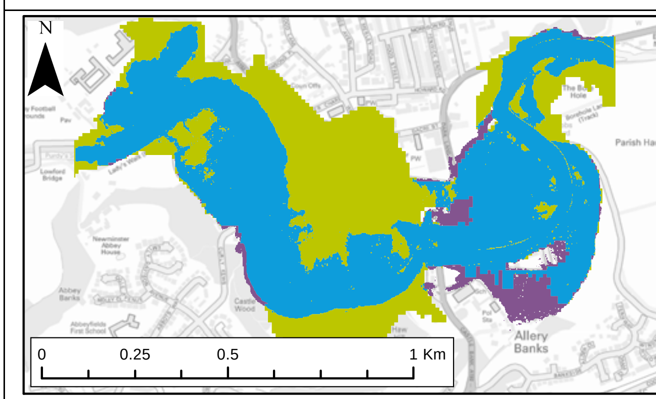
	Correct wet (%)	42.7
	Overprediction (%)	54.2
	Underprediction (%)	3.1
–	Skill	0.43
–	Bias	2.12

16:00



	Correct wet (%)	50.8
	Overprediction (%)	47.1
	Underprediction (%)	2.1
–	Skill	0.51
–	Bias	1.85

17:00 (observed maximum)



	Correct wet (%)	58.0
	Overprediction (%)	36.5
	Underprediction (%)	5.5
–	Skill	0.58
–	Bias	1.49

4.4.5 Property counts (Test B)

Properties within flood extent

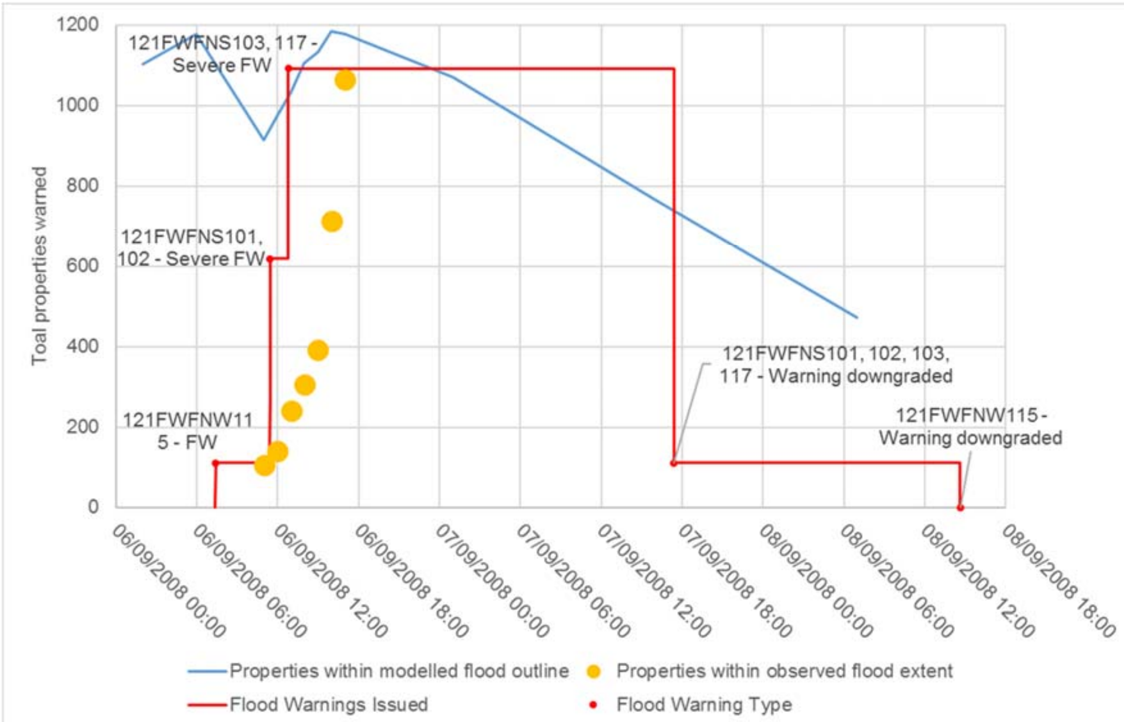


Figure 4.35 Properties within flood extent for Morpeth event: levels input (10m resolution)

Notes: Properties are mapped below.

Table 4.24 Maximum number of flooded properties for Morpeth event: levels input (10m resolution)

Flood Warning Area	Properties warned[1]	Observed[2]	Predicted[3]
All	–	1,066	1,184
121FWF101	–	1,061	1,179
121FWF115	–	5	5
121FWF125	–	–	–

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event. For this study, these were not available for Morpeth.
[2] Observed is based on the intersection of NRD property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.

Interpretation

The model overpredicts throughout the event and significantly more properties are within the modelled flood extent than the observed extent. This difference is large at the start of the event, although the peak of the event is more accurately predicted.

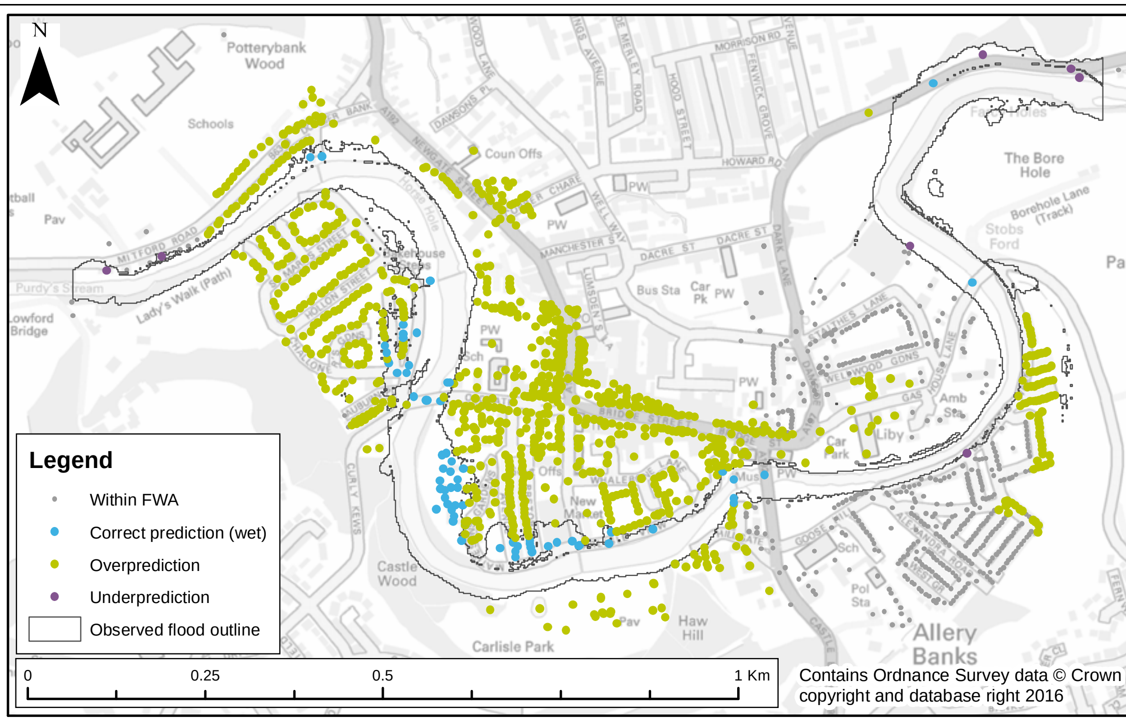
There is a double peak at the start of the event, resulting in a large error in the number of properties flooded in early time-steps.

The total number of properties warned at the peak is a product of large areas of overprediction (discussed earlier). However, the model appears to underpredict in the Allery Banks area of the town – a result of surface water contributing to flooding in this location. Figure 4.36 maps the properties by overprediction and underprediction during the course of 6 September 2008.

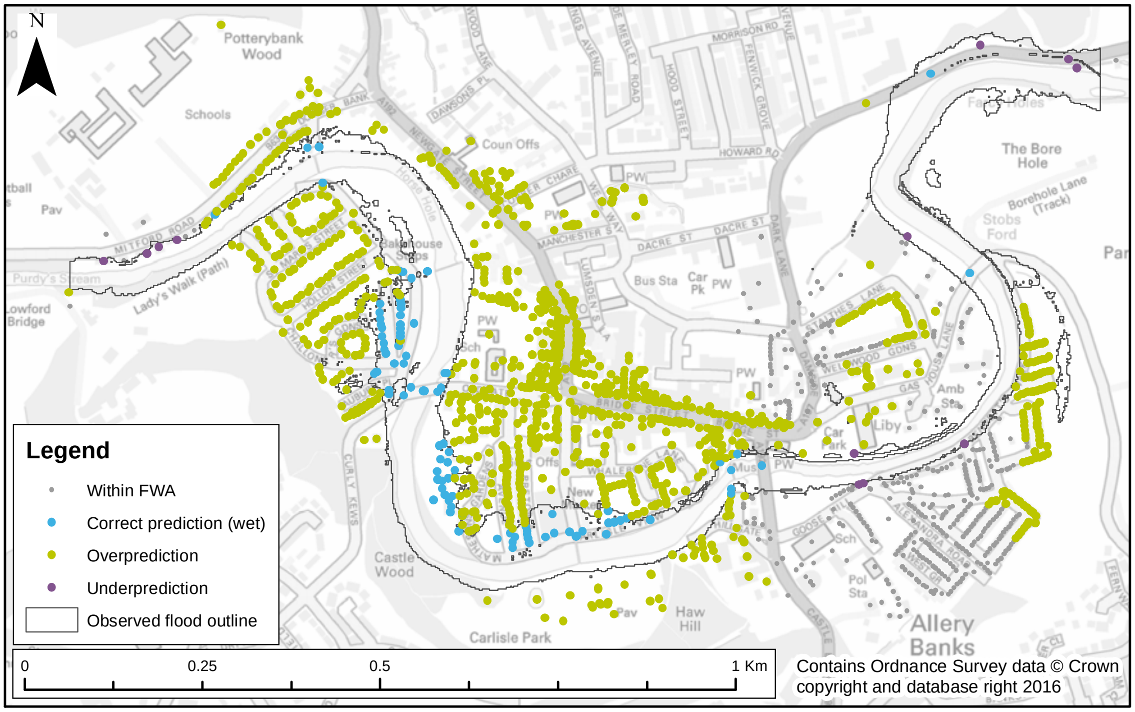
Properties mapped by model prediction

The maps presented in Figure 4.36 show NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline.

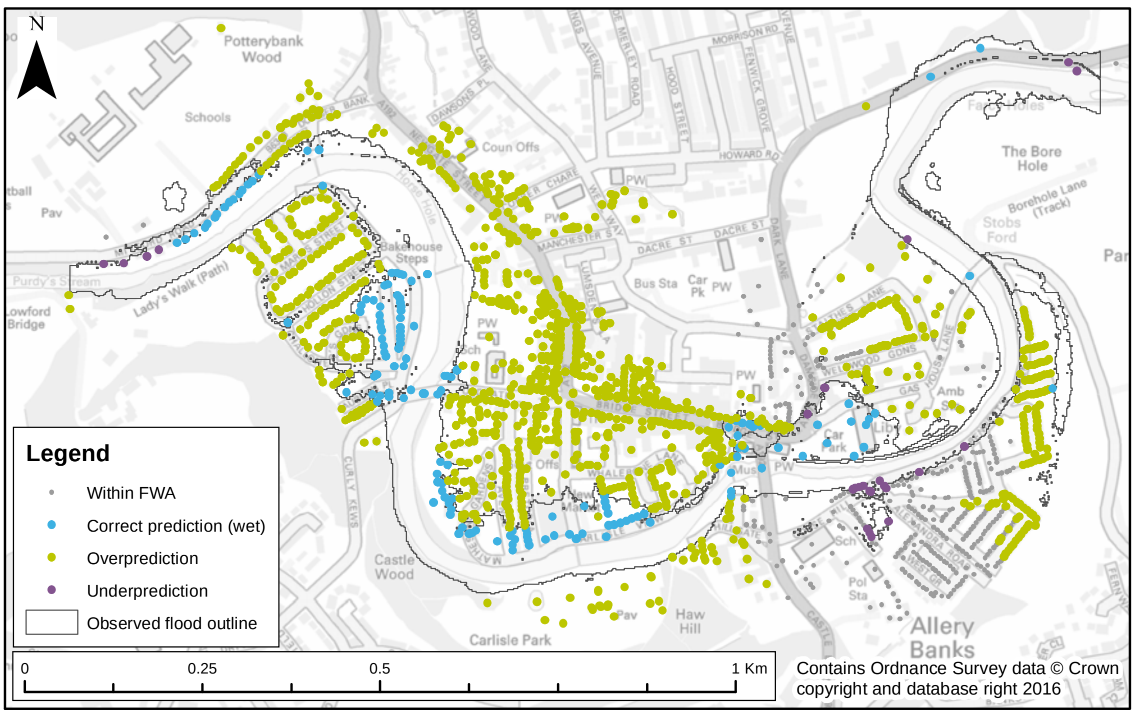
11:00



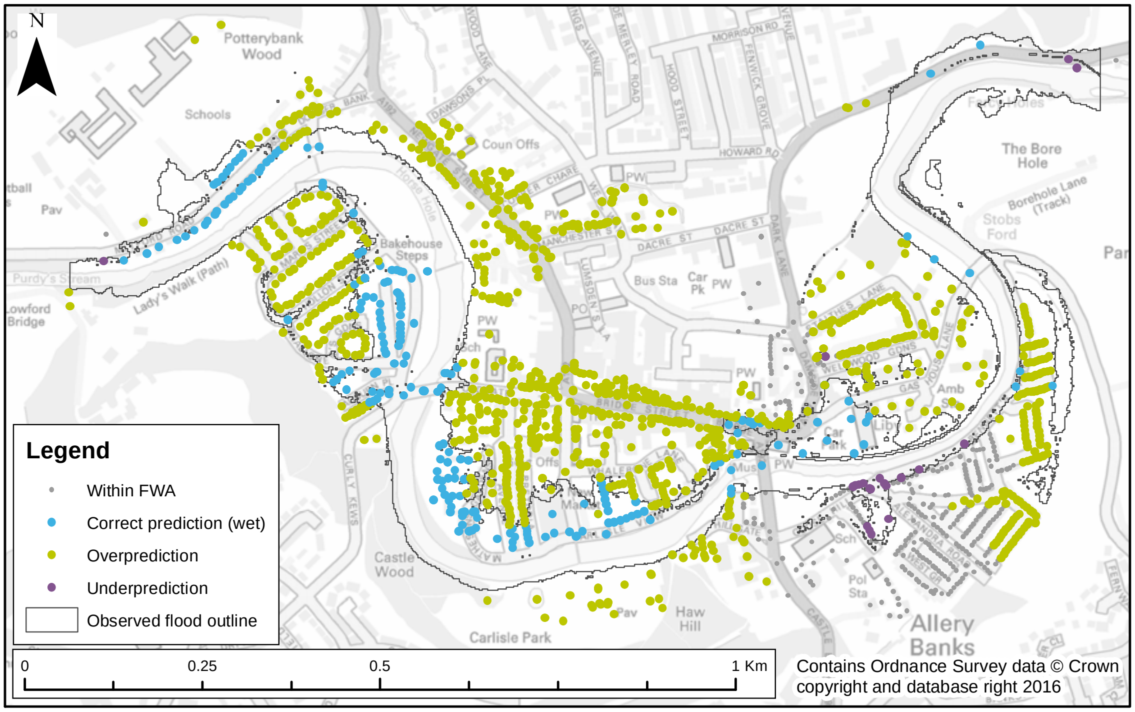
12:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

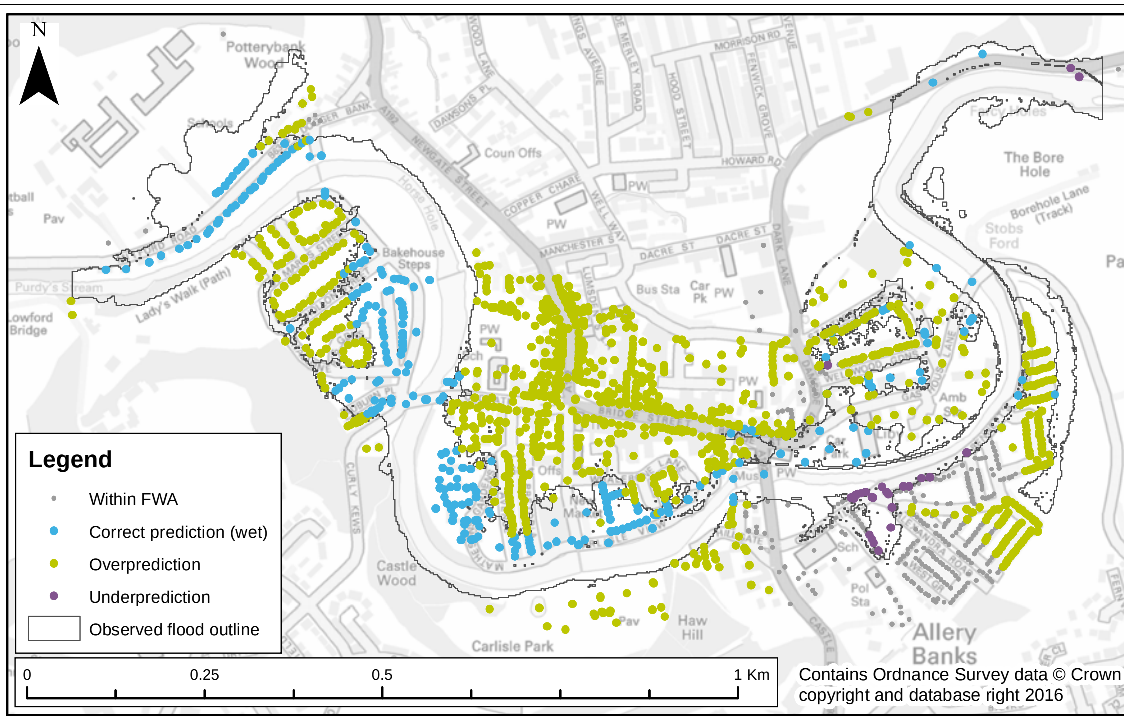
13:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016

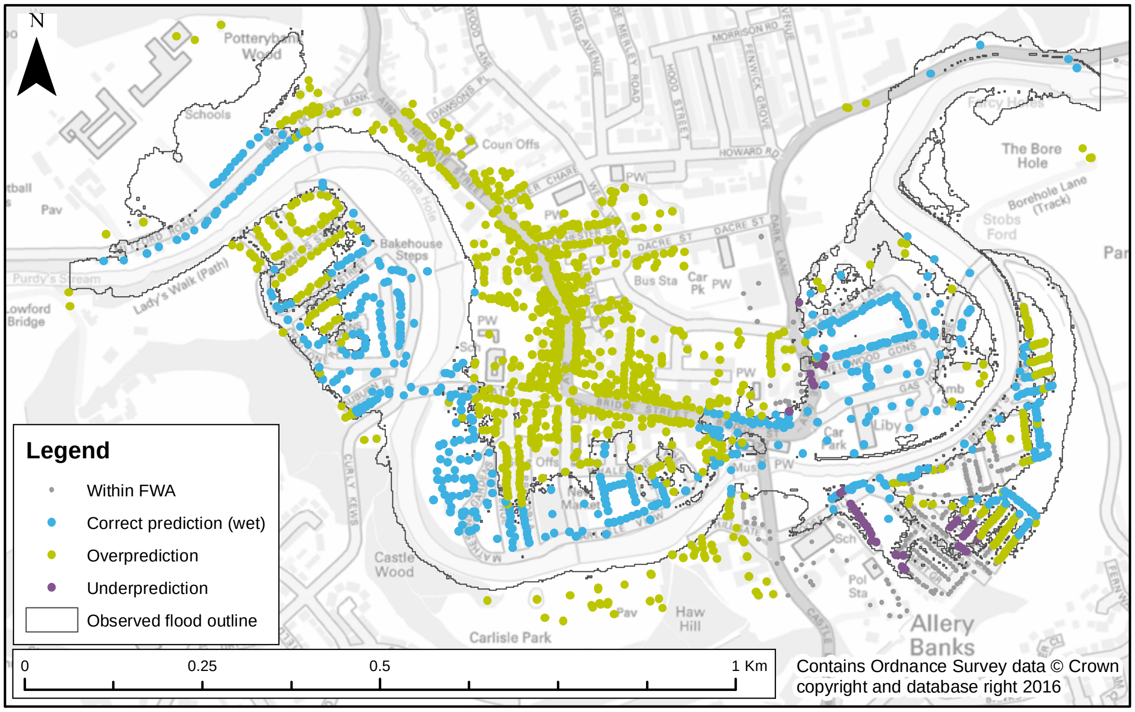
14:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016
Potterybank Wood
Schools
Coun Offs
The Bore Hole
Borehole Lane (Track)
Stobs Ford
Bakehouse Steps
Bus Sta
Car Pk
PW
Lady's Walk (Path)
Purdy's Stream
Lowford Bridge
Pav
Castle Wood
Carlisle Park
Haw Hill
Allery Banks
Pol Sta
Amb Sta
Sch

15:00


N
Legend
Within FWA
Correct prediction (wet)
Overprediction
Underprediction
Observed flood outline
0
0.25
0.5
1 Km
Contains Ordnance Survey data © Crown copyright and database right 2016
Potterybank Wood
Coun Offs
The Bore Hole
Borehole Lane (Track)
Stobs Ford
Bakehouse Steps
Bus Sta
Car Pk
PW
Lady's Walk (Path)
Purdy's Stream
Lowford Bridge
Pav
Castle Wood
Carlisle Park
Haw Hill
Allery Banks
Pol Sta
Amb Sta
Sch

16:00



17:00

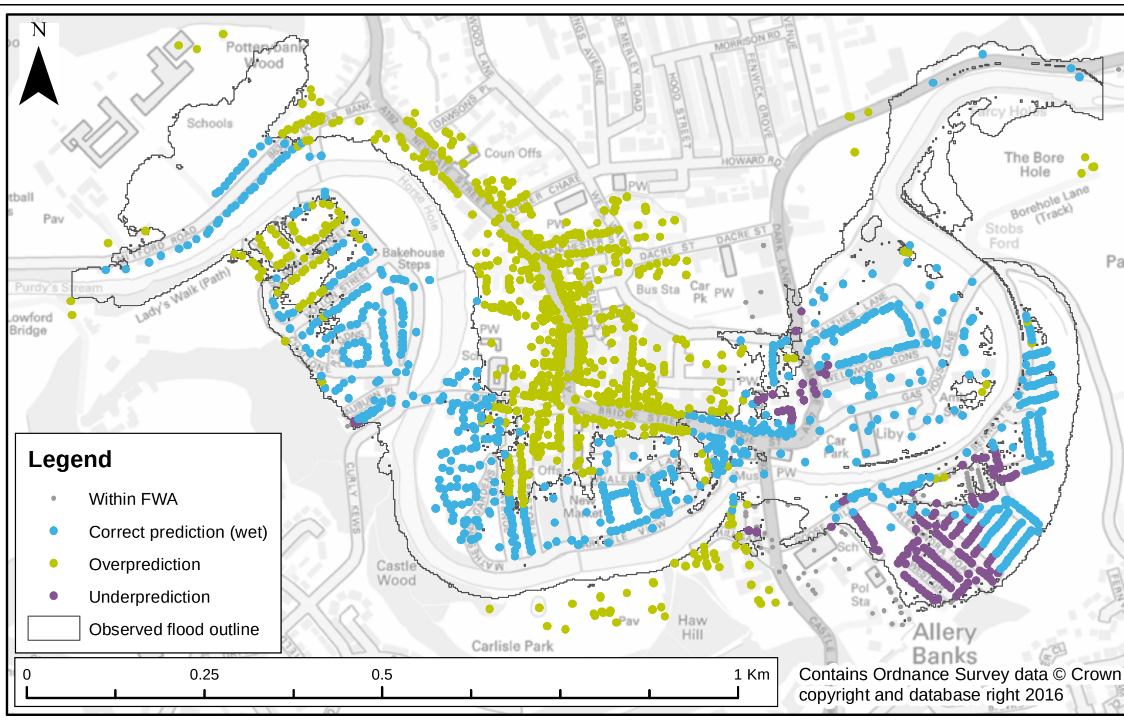


Figure 4.36 Model performance in predicting extent of flooding at Morpeth between 11:00 and 17:00 on 6 September 2008: levels input (10m resolution)

4.4.6 Depth analysis (Test C)

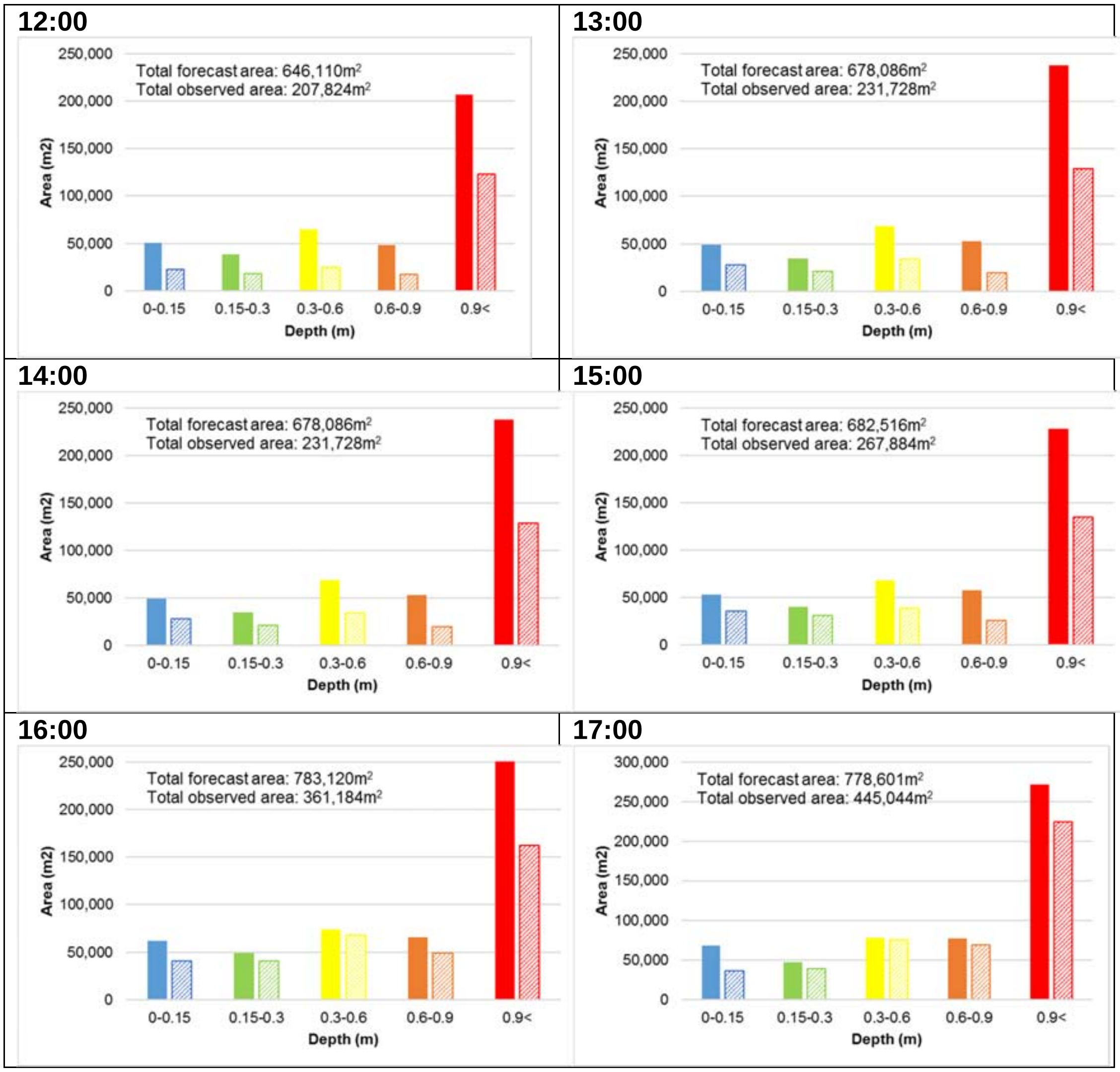


Figure 4.37 Modelled and observed flooded depths at Morpeth between 11:00 and 17:00 on 6 September 2008: levels input (10m resolution)

Notes: Solid bars show modelled depths (from the PoC option).
Dashed bars show observed depths (based on data supplied by Newcastle University).
Channel depths are not included in the modelled results and so the observed area would be expected to be greater for depths (especially for depths >0.9m). Channel area = 117,304m^2
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

A substantial area is deeper than 0.9m in both the modelled and observed extends, although the model significantly overpredicts, particularly at earlier time-steps.

The distribution of flood depths in the model run broadly matches the observed data, but the significant overprediction of flooded area makes it difficult to assess the distribution of depths in more detail.

4.4.7 Total water level

Figure 4.38 presents the total modelled water level on the floodplain (modelled depth plus land elevation from a LIDAR DTM). The maximum water levels at in-channel nodes are also presented based on a 1D–2D hydrodynamic model, which provided the inputs to this PoC. The channel itself is not represented by this PoC option, and the nature of the simplified fluvial model means that there is no dynamic link between the channel and the floodplain during the model run. Annotations on the map explain the model results.

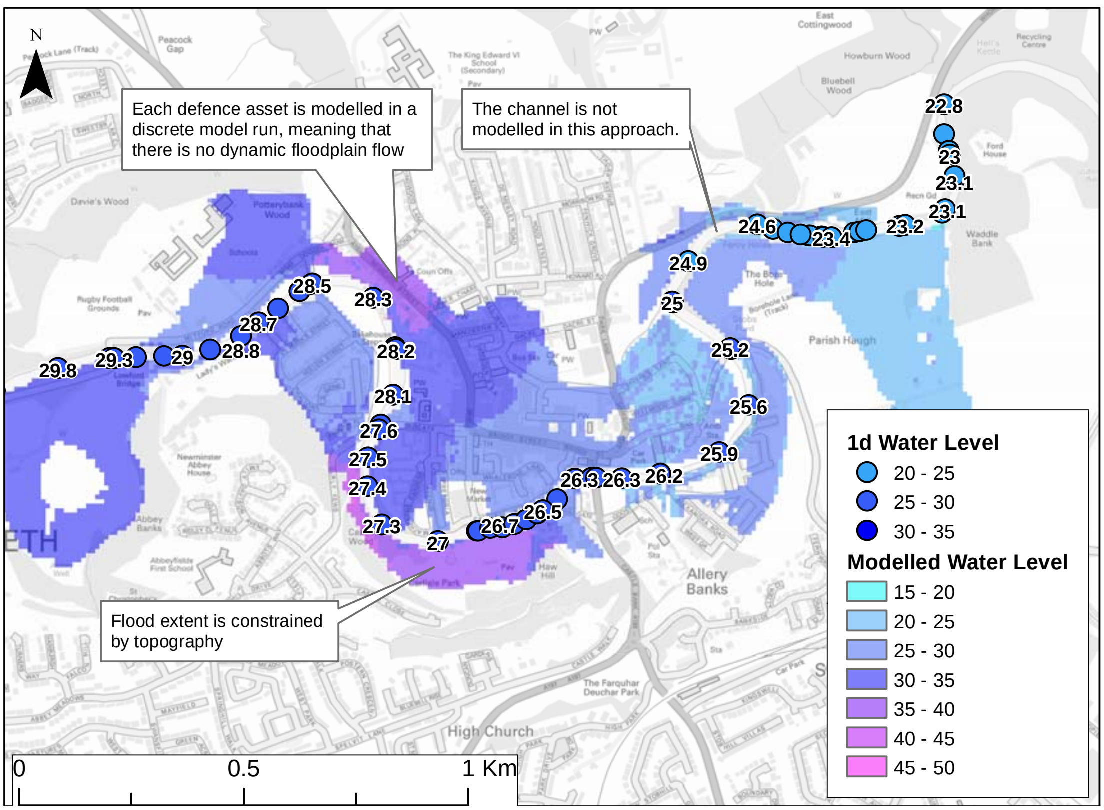


Figure 4.38 Total modelled water level on the floodplain and maximum water level at in-channel nodes for Morpeth event: levels input (10m resolution)

4.5 Comparing flows input with levels input

Figure 4.39 shows the difference in depth between the 2 model runs, driven by:

- in-channel flows and asset SoP
- in-channel levels and asset crest level

Results are shown for the peak of the event.

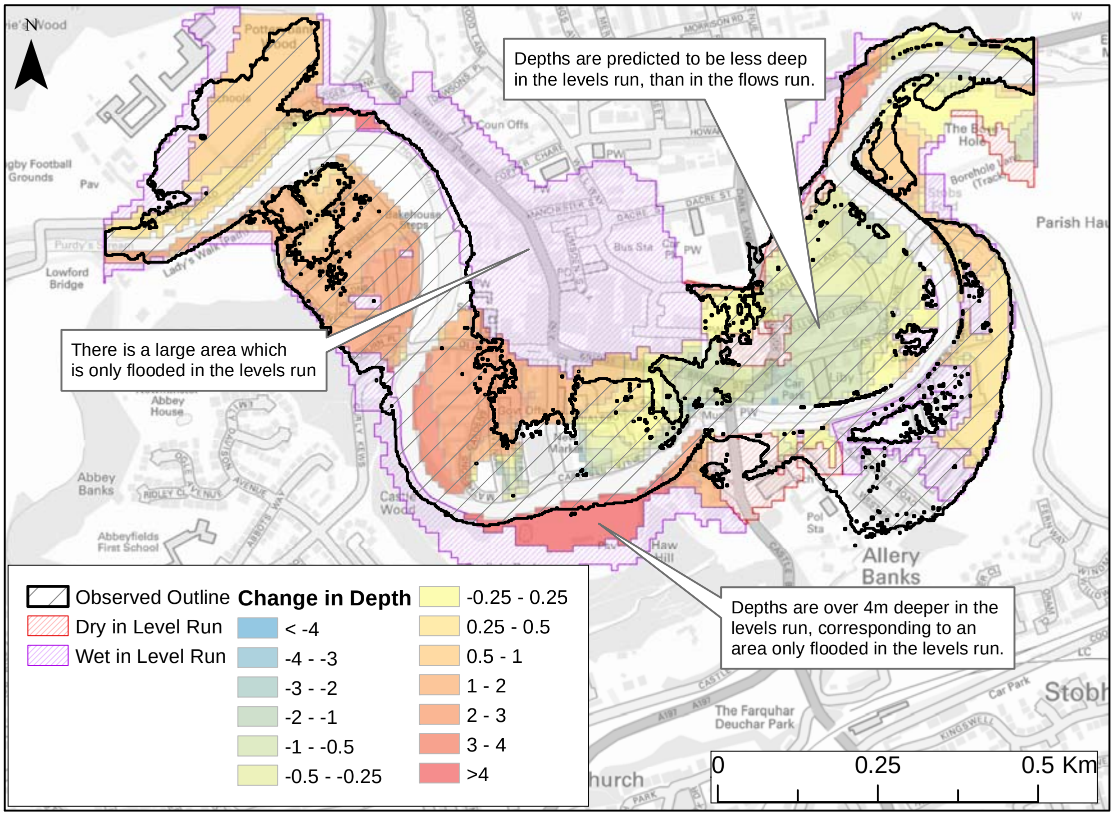


Figure 4.39 Flood outline changes in flow and level runs for Morpeth event

Notes: Positive numbers on the plot show areas where the levels case is deeper.

4.6 Case study 2: Cockermouth, November 2009 – flows input

4.6.1 Location

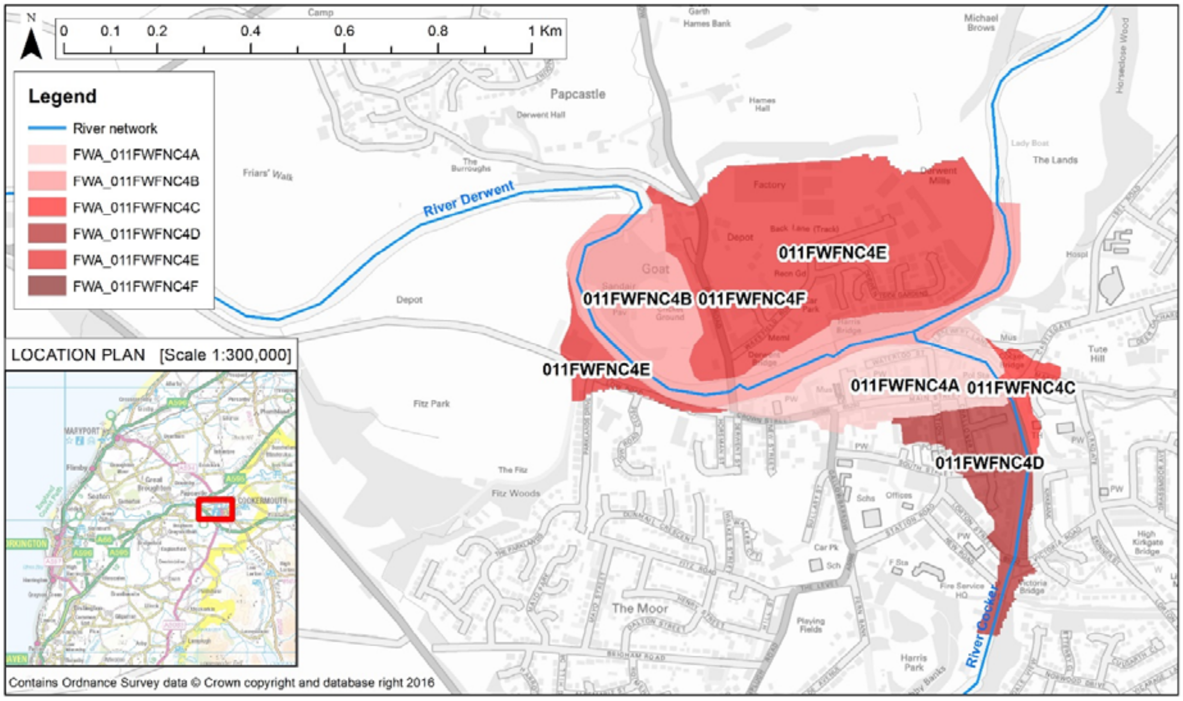


Figure 4.40 Location map for Cockermouth case study

Table 4.25 Description of Flood Warning Areas featured in the Cockermouth case study

Flood Warning Target Area Code	Name
011FWFNC4A	Rivers Cocker and Derwent at Cockermouth, Bridge St, Crown St, High Sand Lane and Main St
011FWFNC4B	Rivers Cocker and Derwent at Cockermouth, Cricket Ground and Trout Hotel Car Park
011FWFNC4C	River Cocker at Cockermouth, The Old Courthouse and Market Place Area
011FWFNC4D	River Cocker at Cockermouth, Challoner St, Croft Terrace, Jubilee Court and Rubbybanks Road
011FWFNC4E	River Derwent at Cockermouth, Gote Road to Derwent Mills Area and Low Road
011FWFNC4F	Cockermouth Gote Road and St Leonards

4.6.2 Model depths (10m resolution, flows input)

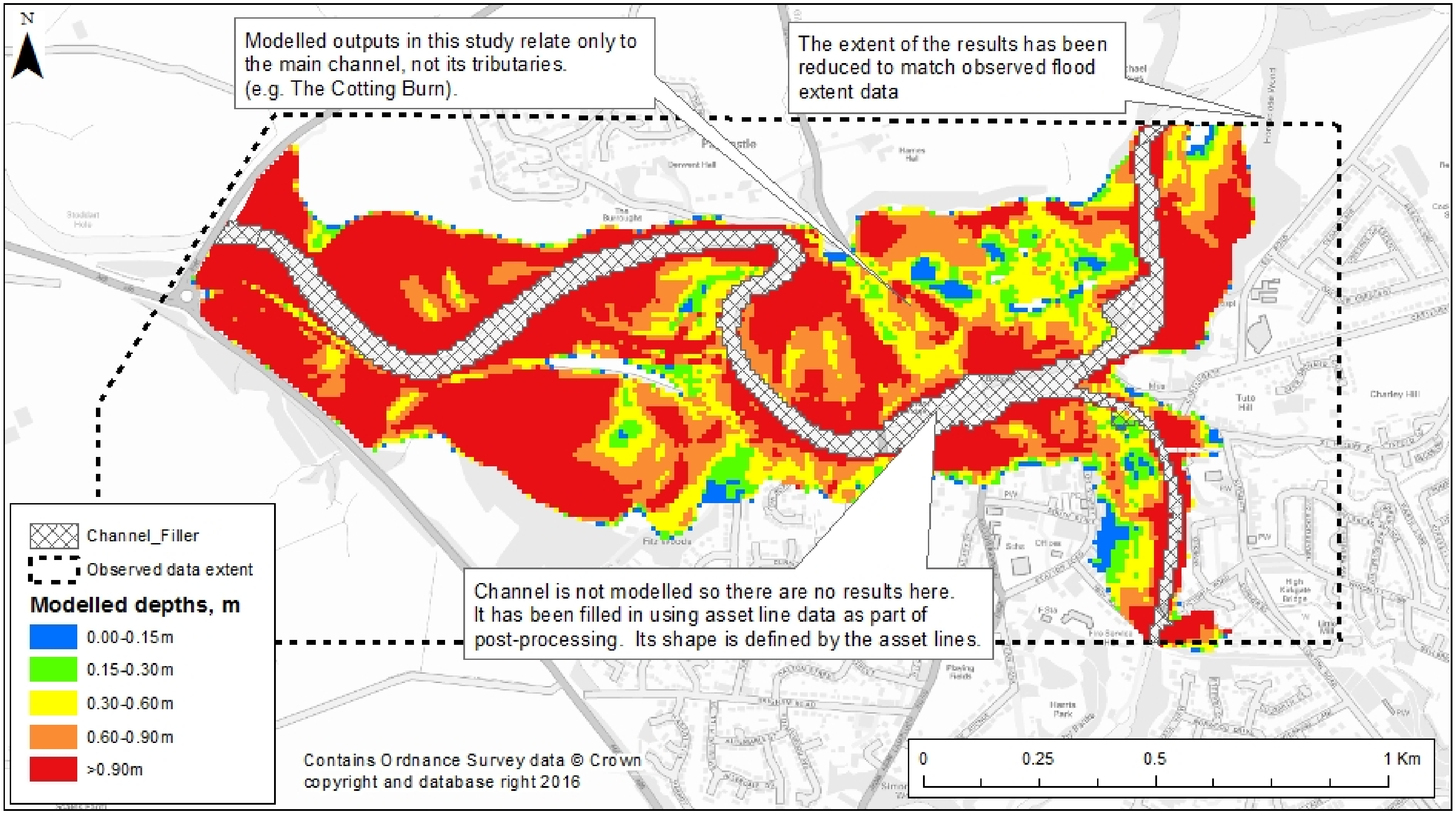


Figure 4.41 Model outputs for Cockermouth event: flows input (10m resolution)

4.6.3 Extent flooded (Test A1) – flows input

Extent flooded

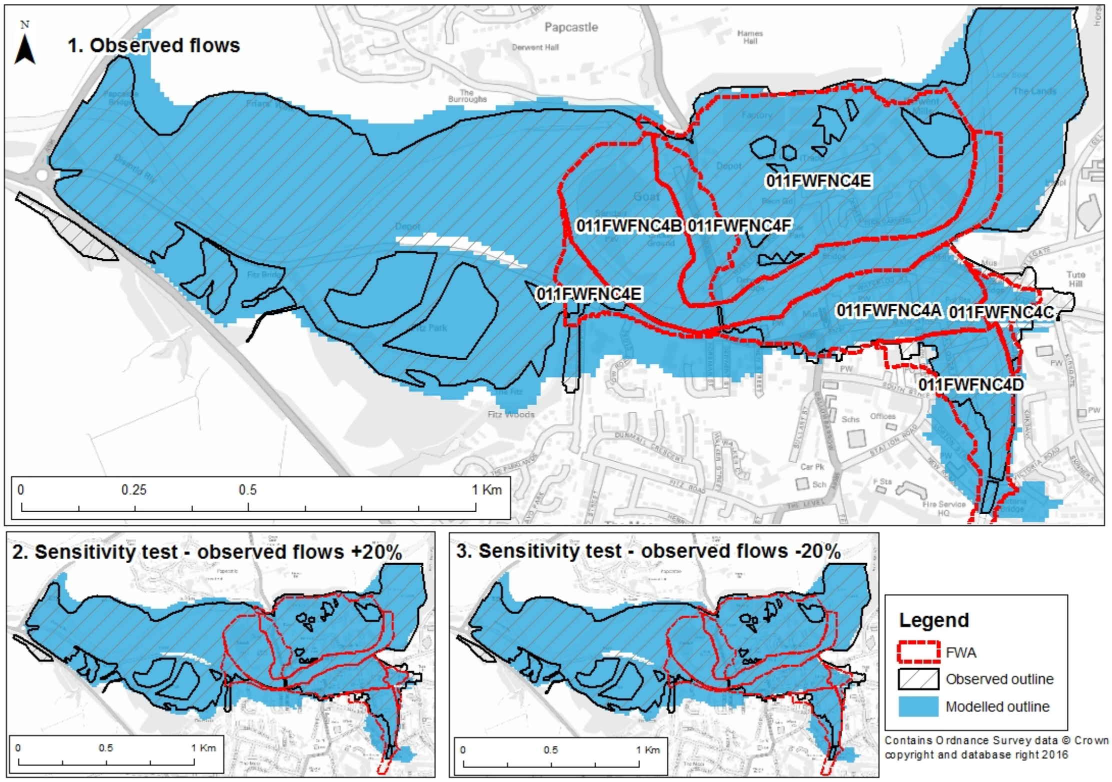


Figure 4.42 Maximum modelled and observed extent flooded for Cockermouth event: flows input (10m resolution)

Table 4.26 Comparison of modelled and observed area flooded for each Flood Warning Area for Cockermouth event: flows input (10m resolution)

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	560,039	545,449	97.4	508,774	90.9
011FWFNC4A	73,728	71,686	97.2	70,731	95.9
011FWFNC4B	134,289	134,288	100.0	133,541	99.4
011FWFNC4C	13,362	11,615	86.9	12,788	95.7
011FWFNC4D	57,177	46,737	81.7	37,810	66.1
011FWFNC4E	252,013	251,655	99.9	224,436	89.1
011FWFNC4F	29,469	29,469	100.0	29,469	100.0

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

Overall, the model accurately replicates the observed flood extent. However, the modelled flood outline is not very sensitive to variations in flow (see sensitivity tests). Nonetheless, accurately quantifying flow inputs to the system is a requirement for accurate prediction of flood extent.

4.6.4 Model performance (Test A2) – flows input

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. 'Correct dry' areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

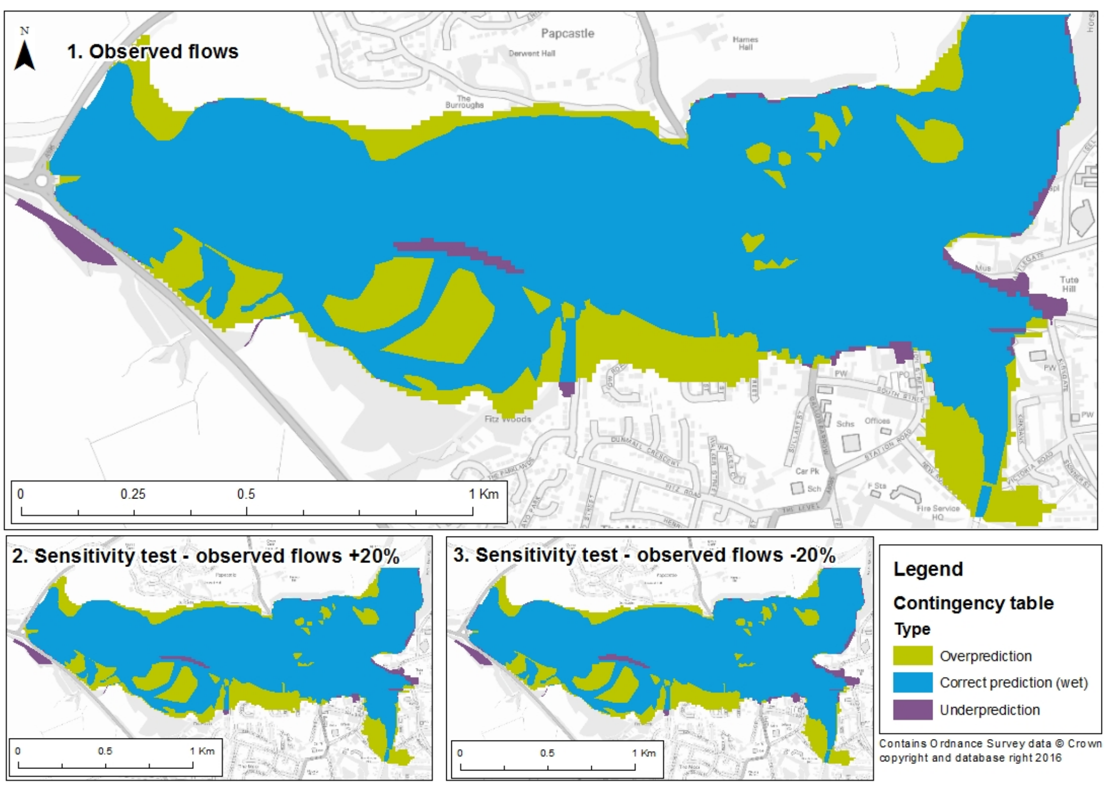


Figure 4.43 Model performance in predicting flooded extent at Cockermouth: flows input (10m resolution)

Table 4.27 Model performance metrics for Cockermouth event: flows input (10m resolution)

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
All	**78.2**	**19.3**	**2.5**	**0.78**	**1.21**
011FWFNC4A	94.6	3.3	2.0	0.95	1.01
011FWFNC4B	99.4	0.6	0.0	0.99	1.01
011FWFNC4C	82.6	4.3	13.1	0.83	0.91
011FWFNC4D	74.2	22.1	3.7	0.74	1.24
011FWFNC4E	89.0	10.9	0.1	0.89	1.12
011FWFNC4F	100.0	0.0	0.0	1.00	1.00

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain and performance in locations where there is known to be flood risk to property.

Interpretation

Overall, there is a large proportion of correct prediction within the model domain. Skill metrics improve when only the Flood Warning Areas are considered (that is, where there are known to be flood receptors), although there is significant overprediction (22%) in Flood Warning Area D.

In terms of bias, the model tends to slightly overpredict, as shown by the positive bias scores. However, areas of underprediction are observed at the eastern and western extremes of the model domain. In the west, a culvert beneath the road (which is not modelled by this PoC option) contributes to underprediction; in reality, this would allow flow to continue spreading beyond the road. Floodplain structures or editing the DTM should therefore be considered were this option to be implemented in the future.

4.6.5 Property counts (Test B) – flows input

Properties within flood extent

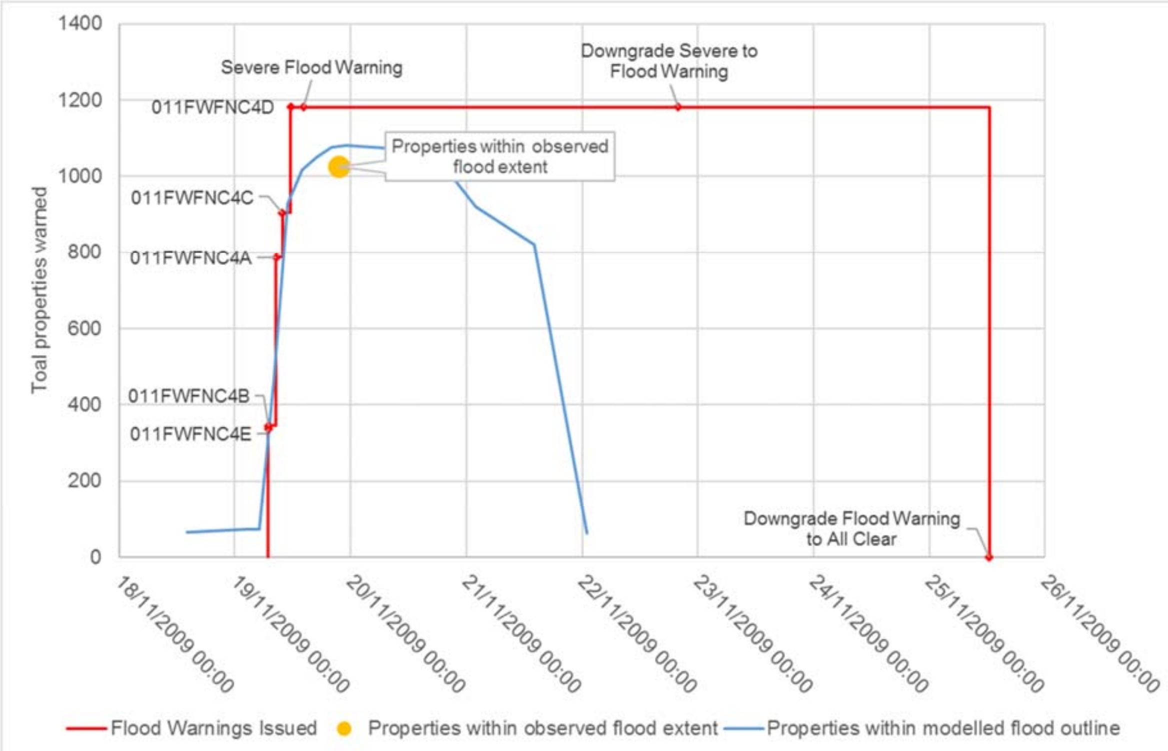


Figure 4.44 Properties within flood extent for Cockermouth event: flows input (10m resolution)

Notes: Properties are mapped below.

Table 4.28 Maximum number of flooded properties for Cockermouth event: flows input (10m resolution)

Flood Warning Area	Properties warned[1]	Observed[2]	Predicted[3]
All	1,180	1,036	1,099
011FWFNC4A	442	416	431
011FWFNC4B	9	8	9
011FWFNC4C	117	105	107
011FWFNC4D	278	185	218
011FWFNC4E	336	312	334
011FWFNC4F	119	119	119

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event. For this study, these were not available for Morpeth.
[2] Observed is based on the intersection of NRD property points and observed flood outline.

[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.
Flood Warning Area F is nested within Flood Warning Area E.

Interpretation

At the peak, the modelled results compare well with the observed data. There is a good match to total properties in the observed extent (+7% error). In all of the Flood Warning Areas there is a close fit between modelled and observed – the maximum error is +18% in Flood Warning Area D.

There is a slight positive bias shown in these results; however, the distribution of overpredicted and underpredicted properties is spatially variable (see Figure 4.46).

Properties mapped by model prediction

Figure 4.45 shows NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline.

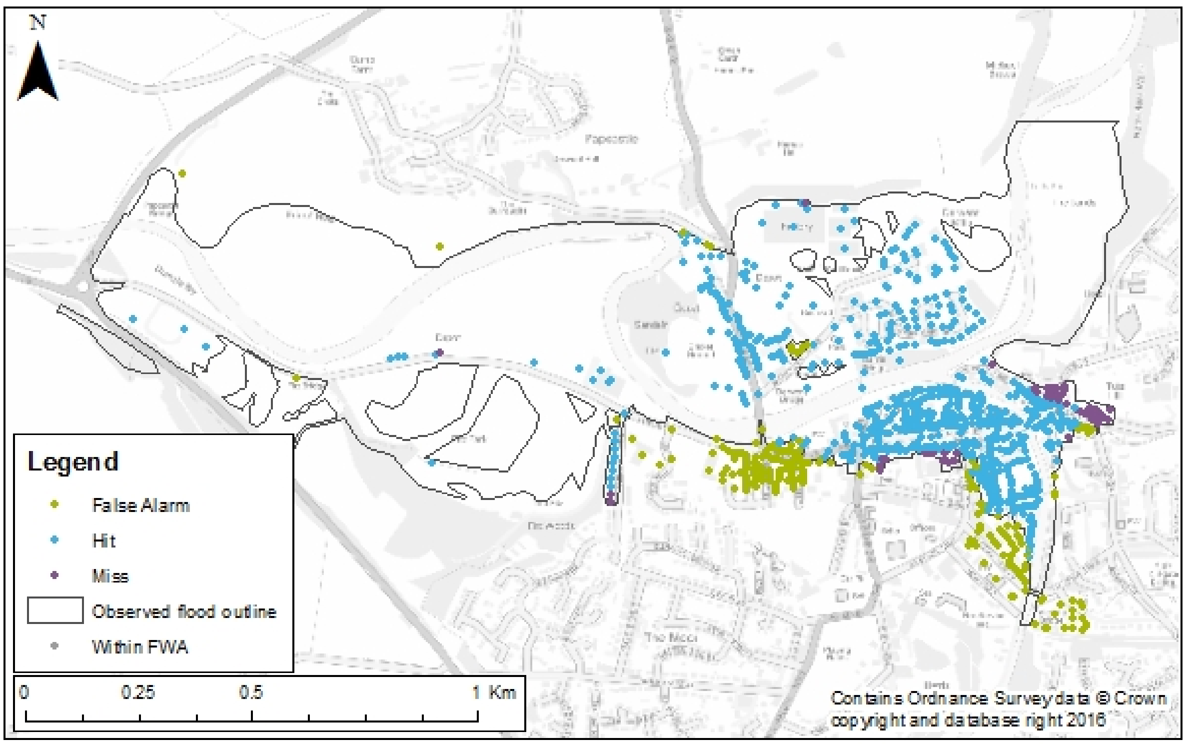


Figure 4.45 Model performance in predicting extent of flooding for Cockermouth event: flows input (10m resolution)

4.6.6 Depth analysis (Test C) – flows input

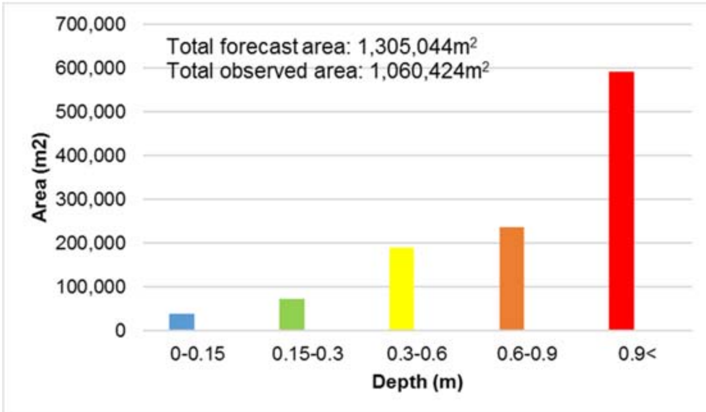


Figure 4.46 Modelled and observed flooded depths at Cockermouth on 20 September 2009 at 02:15 (peak): flows input (10m resolution)

Notes: Solid bars show modelled depths (from the PoC option). No observed depths are available.
Channel depths are not included in the modelled results and so the observed area would be expected to be greater for depths (especially for depths >0.9m). Channel area = 178,608m^2
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

Observed depths were not available for this case study, which limits detailed assessment. However, the distribution shown in Figure 4.47 (flows input) shows a contrasting distribution of depths with the levels run, in which depths are skewed to the deepest category (see Section 4.7.6).

4.6.7 G2G simulation

Table 4.29 Details of available G2G data for Cockermouth event

Simulation data	Start	18 November 2009 00:00GMT	End	28 November 2009 23:45GMT
Forecast data	MOGREPS ensemble rainfall forecast 24km resolution, 24 ensemble members, 3 hour rainfall totals Lead times: 54 hours Note that the MOGREPS product was that available at the time of the event. The MOGREPS data available now are a significant improvement (see Section 6).			
Forecast origins available	11:00 on 18 November 2009 to 23:00 on 25 November 2009 at 12 hourly intervals A total of 16 sets of ensemble forecasts were produced			
Forecast origins tested	19 November 2009 11:00 (results displayed) 19 November 2009 23:00			
Ensembles tested	All 24 ensembles are tested			

Comparison of G2G simulated and observed flows on the River Derwent

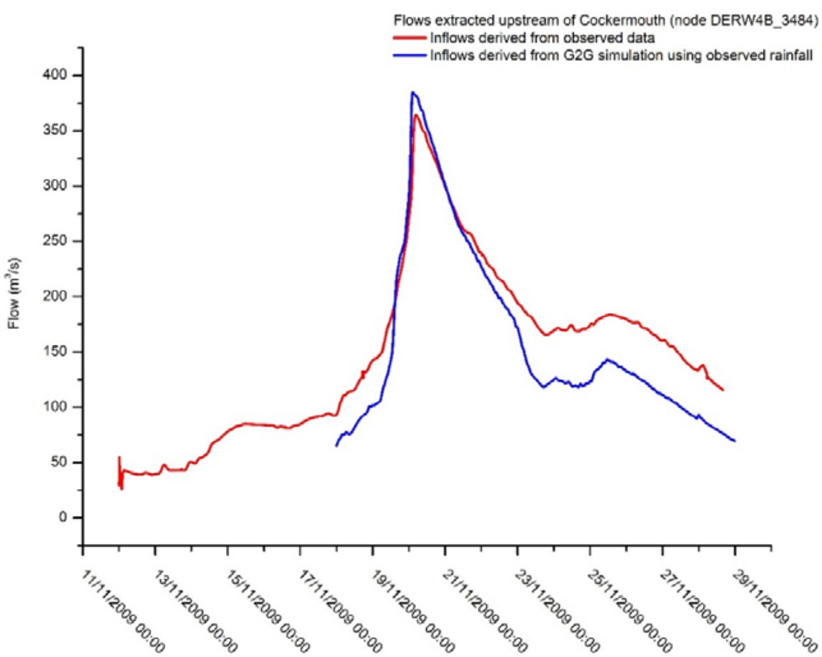


Figure 4.47 River Derwent hydrograph: flows input (10m resolution)

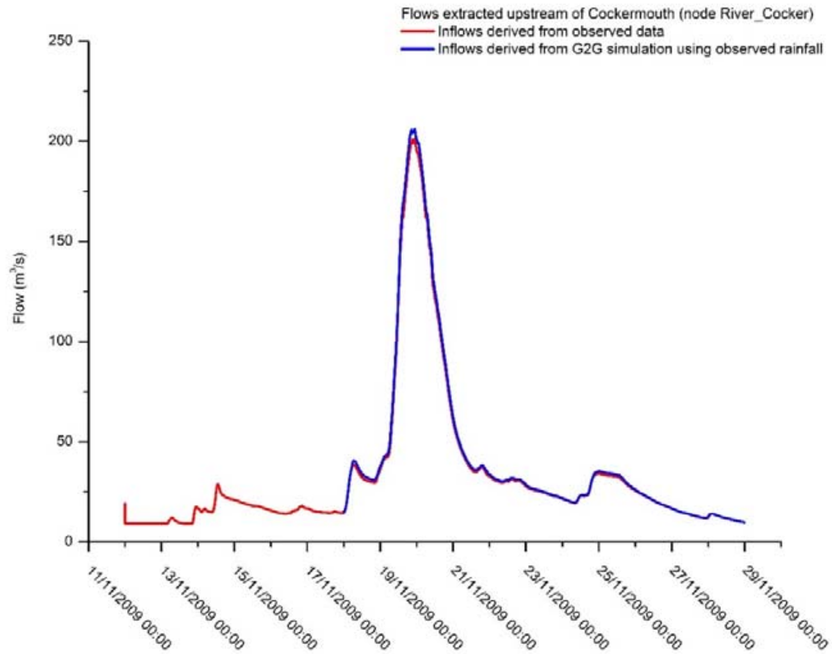


Figure 4.48 River Cocker hydrograph: flows input (10m resolution)

The hydrographs show flows on the Derwent approximately 2.75km upstream of the extent of the observed outline. The start date of the G2G simulated data provided is midnight on 18 November 2009. This is well before the peak of the event and there is no flooding at this time.

Flood extent – maximum

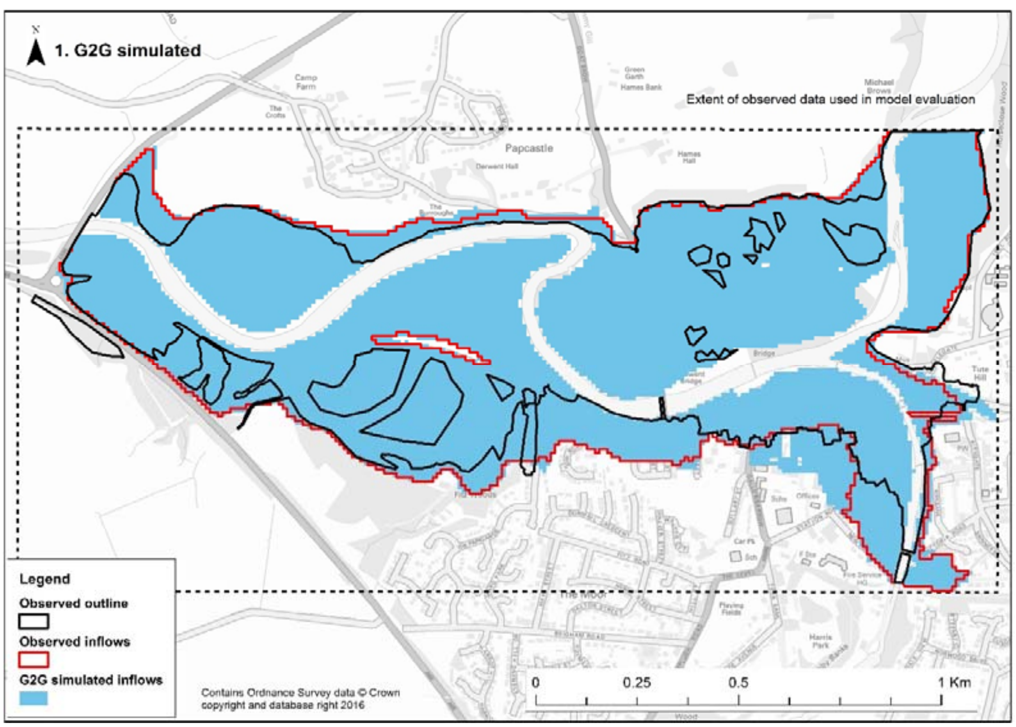


Figure 4.49 Observed and G2G simulated maximum flood extent for Cockermouth event: flows input (10m resolution)

The hydrographs show that simulated flows from G2G (driven using observed rainfall) are very similar to the observed flows at the upstream model boundary. The volume under the G2G simulated hydrograph is also comparable.

The extent modelled from G2G is larger than when observed inflows are used. However, both modelled extents are larger than the observed outline.

G2G to grid ensembles

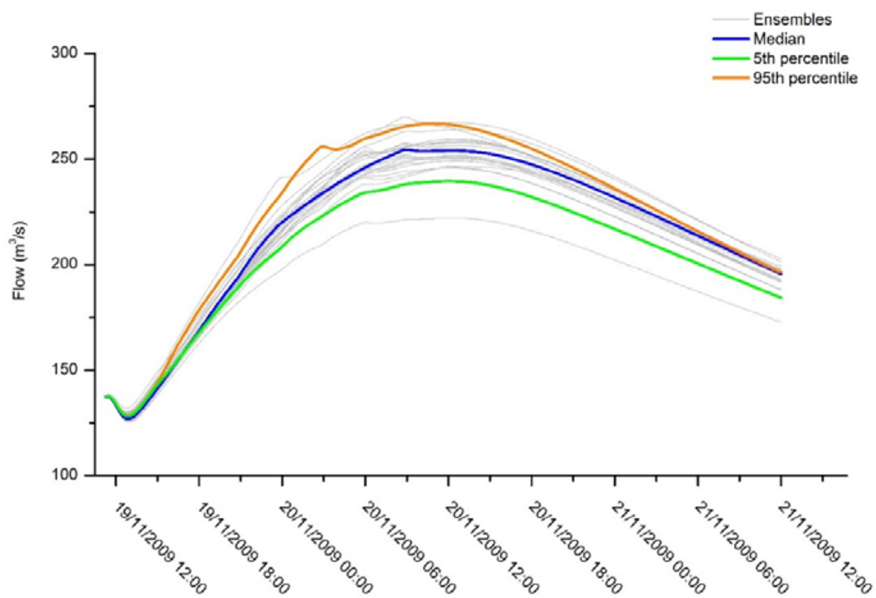


Figure 4.50 River Derwent inflows to hydraulic model

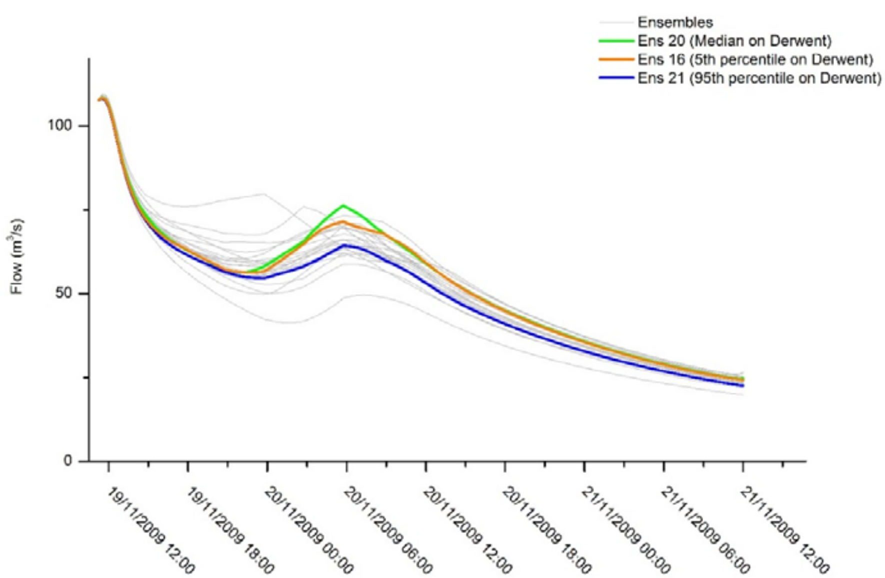


Figure 4.51 River Cocker inflows to hydraulic model

The ensemble plots above show the initial flow for the River Cocker is greater than the peak later in the run. Although initial flows on the River Cocker are high, flows on the River Derwent are consistently greater and it is still the River Derwent that drives flood risk through Cockermouth in this event.

Flood extent – maximum

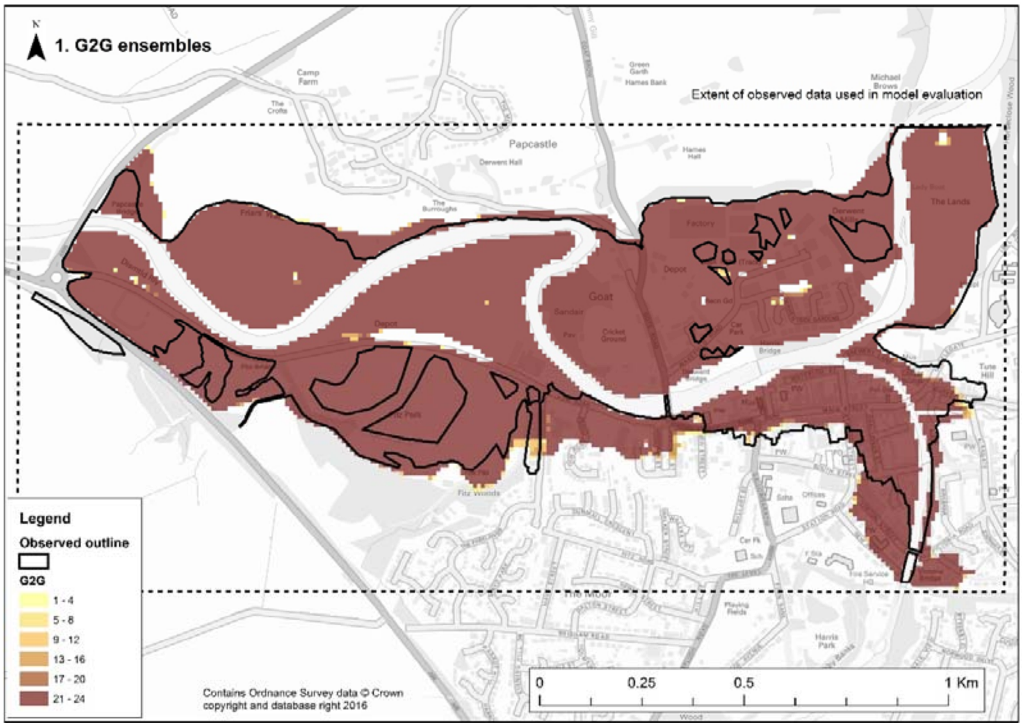


Figure 4.52 Maximum observed and maximum G2G simulation of flood extent for Cockermouth event: flows input (10m resolution)

Property counts – maximum

For comparison, number of properties in observed flood extent is 1,036. Table 4.30 shows the number of properties in the modelled flood outlines.

In this case, the model overpredicts. The final row of the table therefore shows there are no properties within the observed outline that do not appear in the ensemble members.

Table 4.30 Number of NRD property points within the flood outlines for Cockermouth event

Flood outlines	Number of properties[1]	Cumulative property count[2]	Notes
21–24 × ensemble members	1,263	1,263	Area shown as flooded in all tested ensemble members
17–20 × ensemble members	15	1,273	–
13–16 × ensemble members	10	1,283	–
9–12 × ensemble members	21	1,309	–
5–8 × ensemble	0	1,309	–

Flood outlines	Number of properties[1]	Cumulative property count[2]	Notes
members			
1–4 × ensemble members	30	1,339	–
Within observed outline but not forecast	0	–	Area not shown as flooded in any tested ensemble member

Notes: [1] This column shows the number of properties within each separate zone of the modelled outlines, ordered from the area where all ensembles coincide, to properties that appear in one ensemble member only.
[2] This column lists the cumulative number of properties within the modelled outlines, ordered by areas predicted to flood in the most ensemble members to the least ensemble members. For example, at this lead time, the models predict that there is a likelihood that 1,263 properties will flood and a lower likelihood that 923 properties will flood.

4.7 Case study 2: Cockermouth, November 2009 – levels input

4.7.1 Location

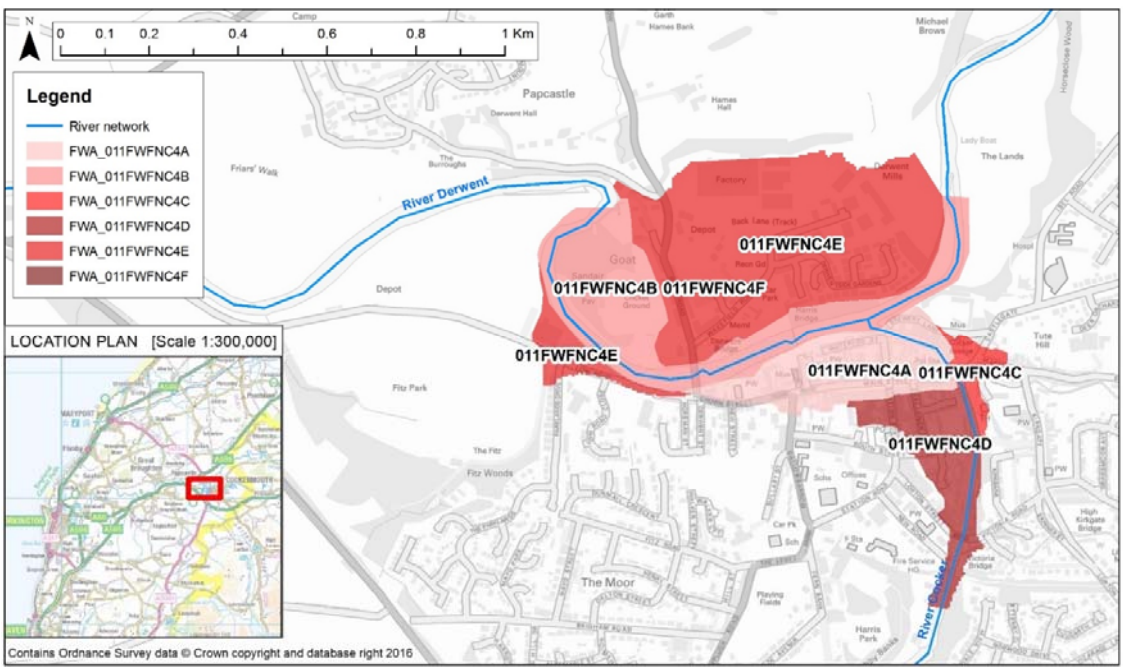


Figure 4.53 Location map for Cockermouth case study

Table 4.31 Description of Flood Warning Areas featured in the Cockermouth case study

Flood Warning Target Area Code	Name
011FWFNC4A	Rivers Cocker and Derwent at Cockermouth, Bridge St, Crown St, High Sand Lane and Main St
011FWFNC4B	Rivers Cocker and Derwent at Cockermouth, Cricket Ground and Trout Hotel Car Park
011FWFNC4C	River Cocker at Cockermouth, The Old Courthouse and Market Place Area
011FWFNC4D	River Cocker at Cockermouth, Challoner St, Croft Terrace, Jubilee Court and Rubbybanks Road
011FWFNC4E	River Derwent at Cockermouth, Gote Road to Derwent Mills Area and Low Road
011FWFNC4F	Cockermouth Gote Road and St Leonards

4.7.2 Model depths (10m resolution, levels input)

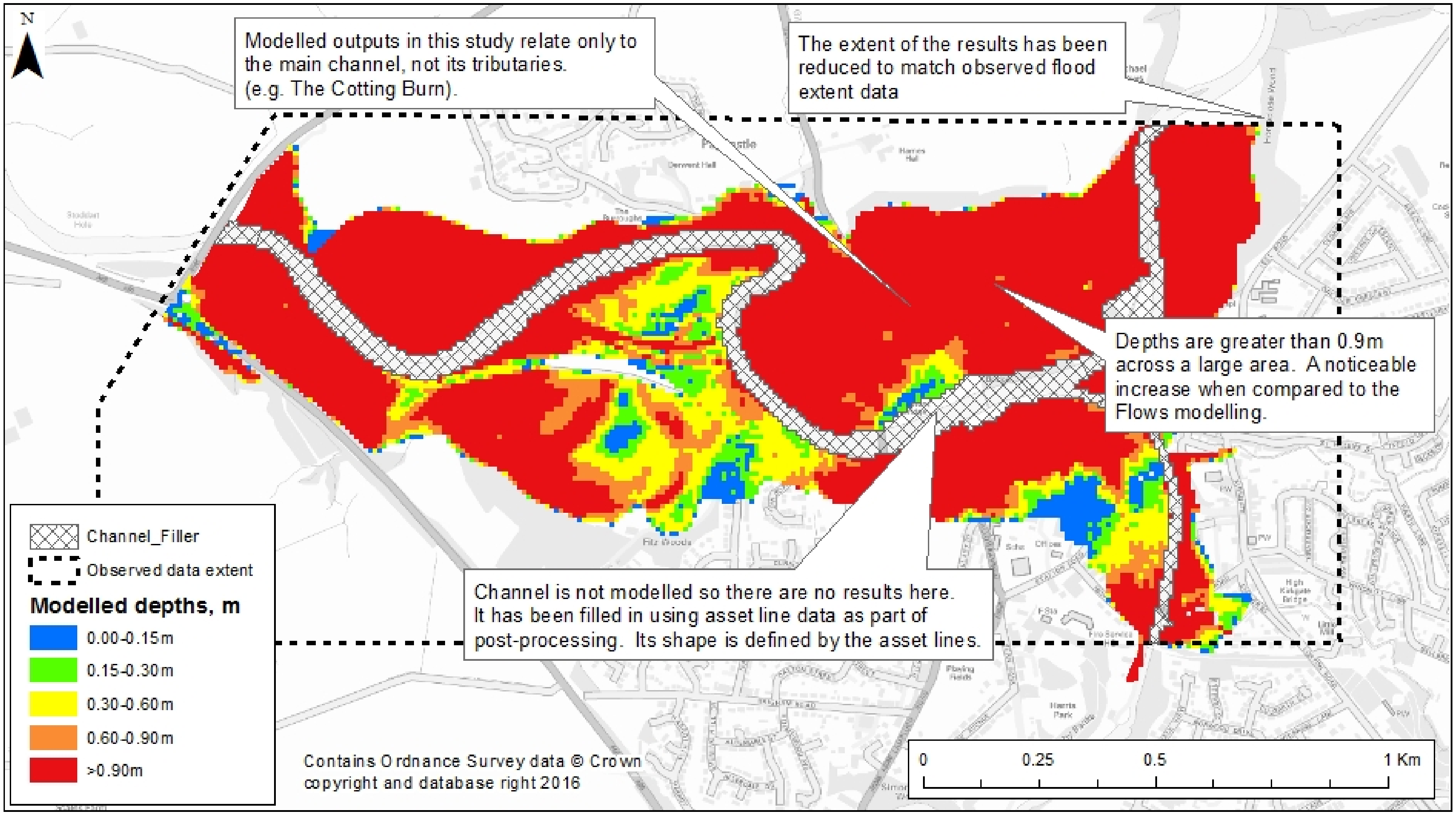


Figure 4.54 Model outputs for Cockermouth event: levels input (10m resolution)

4.7.3 Extent flooded (Test A1) – levels input

Extent flooded – maximum

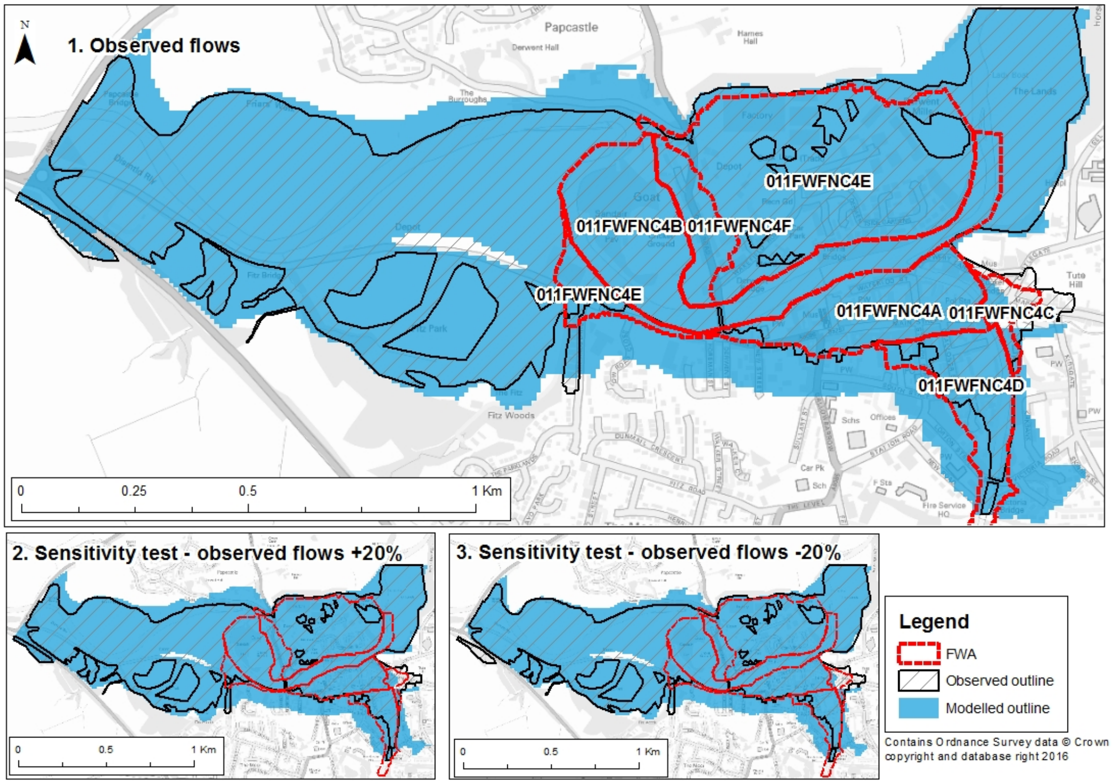


Figure 4.55 Maximum modelled and observed extent flooded for Cockermouth event: levels input (10m resolution)

Table 4.32 Comparison of modelled and observed area flooded for each Flood Warning Area for Cockermouth event: levels input (10m resolution)

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	**560,039**	**549,822**	**98.2**	**508,774**	**90.9**
011FWFNC4A	73,728	73,634	99.9	70,731	95.9
011FWFNC4B	134,289	134,289	100.0	133,541	99.4
011FWFNC4C	13,362	7,541	56.4	12,788	95.7
011FWFNC4D	57,177	52,877	92.5	37,810	66.1
011FWFNC4E	252,013	252,013	100.0	224,436	89.1
011FWFNC4F	29,469	29,469	100.0	29,469	100.0

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

The overall flood extent is overpredicted by the model to a greater extent than when flows were used as model inputs. Inaccuracies in specifying crest levels of assets, which are used to calcuate inflows to the floodplain, may contribute to the overprediction.

There are also small areas of underprediction within the area covered by the Flood Warning Areas, shown by percentage area flooded (for example, Flood Warning Area C).

4.7.4 Model performance (Test A2) – levels input

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

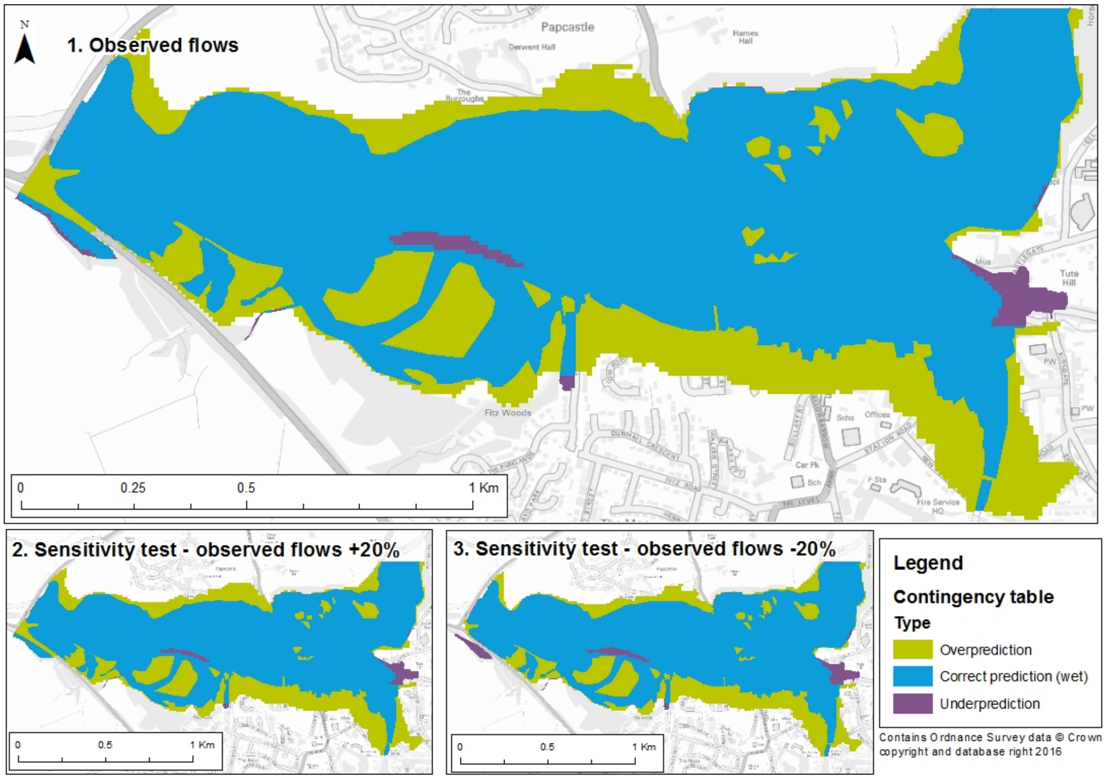


Figure 4.56 Model performance in predicting flooded extent at Cockermouth: levels input (10m resolution)

Table 4.33 Model performance metrics for Cockermouth event: levels input (10m resolution)

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
All	**73.1**	**25.1**	**1.8**	**0.73**	**1.31**
011FWFNC4A	95.8	4.1	0.1	0.96	1.04
011FWFNC4B	99.4	0.6	0.0	0.99	1.01
011FWFNC4C	52.1	4.3	43.6	0.52	0.59
011FWFNC4D	71.3	28.6	0.1	0.71	1.40
011FWFNC4E	89.0	10.9	0.1	0.89	1.12
011FWFNC4F	100.0	0.0	0.0	1.00	1.00

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain and performance in locations where there is known to be flood risk to property.

Interpretation

Although the metrics show that a large proportion of the model domain is correctly predicted, this is largely because the model overpredicts the observed flood extent. Overall, there is a significant bias towards overprediction (bias score of 1.31). The overprediction is more pronounced than in the run that used flows as inputs (see Section 4.6.4), indicating that the results are dependent on accurate specification of boundary conditions and crest heights.

However, when only the areas within the Flood Warning Areas are considered (that is, areas known to contain flood receptors), the model performs relatively well. Flood Warning Areas A, B, E and F have model skill scores of 0.89 or above.

As in the run that used flows as inputs, there is a significant area of underprediction in the area of Flood Warning Area C (at the east end of the model domain). The bias score demonstrates this, with underprediction in Flood Warning Area C resulting in a bias score of 0.59.

4.7.5 Property counts (Test B) – levels input

Properties within flood extent

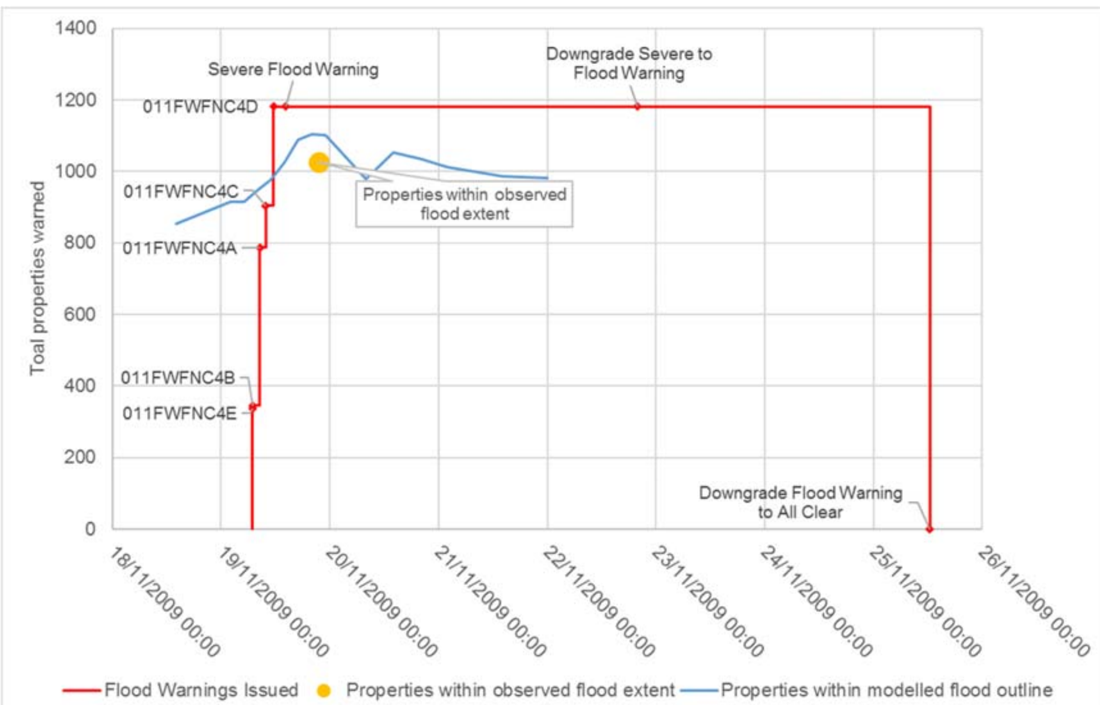


Figure 4.57 Properties within flood extent for Cockermouth event: levels input (10m resolution)

Notes: Properties are mapped below.

Table 4.34 Maximum number of flooded properties for Cockermouth event: levels input (10m resolution)

Flood Warning Area	Properties warned[1]	Observed[2]	Predicted[3]
All	1,180	1,036	1,120
011FWFNC4A	442	416	442
011FWFNC4B	9	8	9
011FWFNC4C	117	105	60
011FWFNC4D	278	185	273
011FWFNC4E	336	312	336
011FWFNC4F	119	119	119

Notes: 1 Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event.
[2] Observed is based on the intersection of NRD property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.
Flood Warning Area F is nested within Flood Warning Area E.

Interpretation

At the peak, the number of properties flooded is relatively accurate (9% difference between properties within the observed and modelled flood extent). A similar pattern is found within each individual Flood Warning Area. However, the number of properties flooded is overpredicted by the model, which is consistent with the maps shown above.

Properties mapped by model prediction

Figure 4.58 shows NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline.

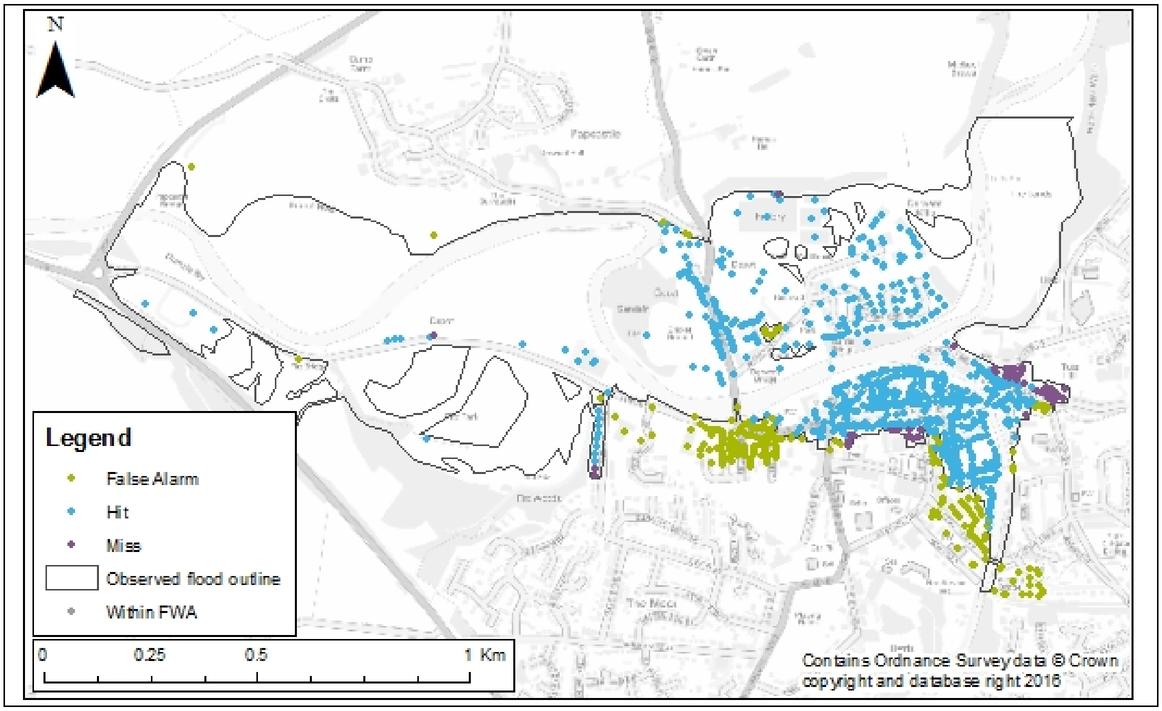


Figure 4.58 Model performance in predicting extent of flooding for Cockermouth event: levels input (10m resolution)

4.7.6 Depth analysis (Test C) – levels input

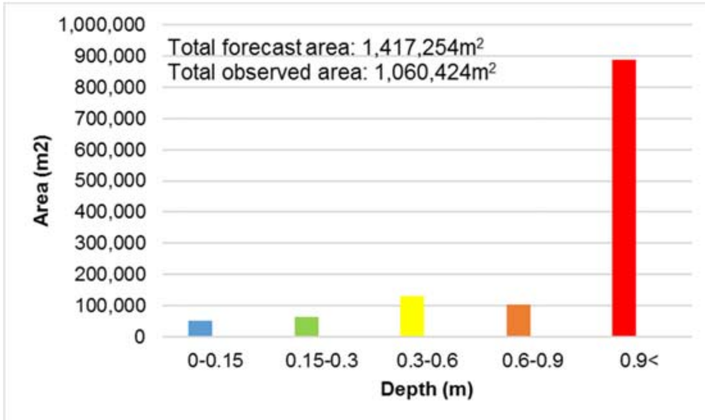


Figure 4.59 Modelled and observed flooded depths at Cockermouth on 20 September 2009 at 02:15 (peak): levels input (10m resolution)

Notes: Solid bars show modelled depths (from the PoC option). No observed depths are available.
Channel depths are not included in the modelled results and so the observed area would be expected to be greater for depths (especially for depths >0.9m). Channel area = 178,608m^2
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

A substantial area is shown to be deeper than 0.9m (over half the modelled flood extent). The distribution of depths is skewed to the deepest category, making assessment of the other categories of limited value.

This is in contrast to the results shown for the flows case (see Section 4.6.6) where a wider distribution of depths was found. As discussed previously, the results are dependent on the quality of input data (predictions of in-channel level and asset crest heights).

Observed depths were not available for this case study.

4.8 Cockermouth event: comparing flows input with levels input

Figure 4.60 shows the difference in depth between the 2 model runs driven by:

- in-channel flows and asset SoP
- in-channel levels and asset crest level

Results are shown for the peak of the event.

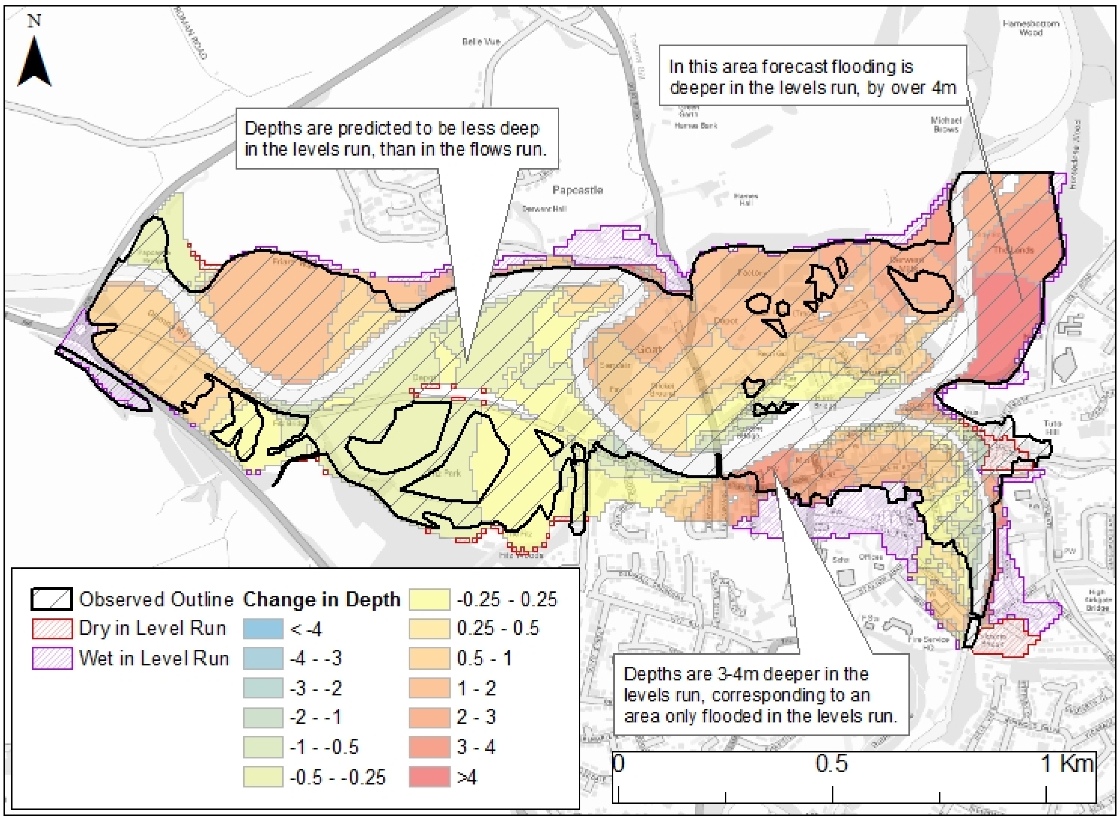


Figure 4.60 Changes in flood extent and depth flow and level runs for Cockermouth event

Notes: Positive numbers on the plot show areas where the levels case is deeper.

4.9 Case study 3: Thames, February 2014 – flows input

4.9.1 Location

The location map provided in Appendix 5b shows the entire Thames reach considered for analysis in this study.

Inputs to the simplified fluvial model were provided by a detailed 1D–2D hydrodynamic model, which is fully documented in Appendix 4 – the fully dynamic fluvial modelling pro-forma. The model, however, was in an interim stage of development at the time of this study. In particular, results from the 1D–2D model were only available to the peak of the event and the assessment therefore compares the latest available model outputs with the closest available observed outline (after the peak). Figure 4.61 shows the modelled and observed outlines in relation to the flow hydrograph, recorded at Walton gauge, towards the downstream extent of the model domain.

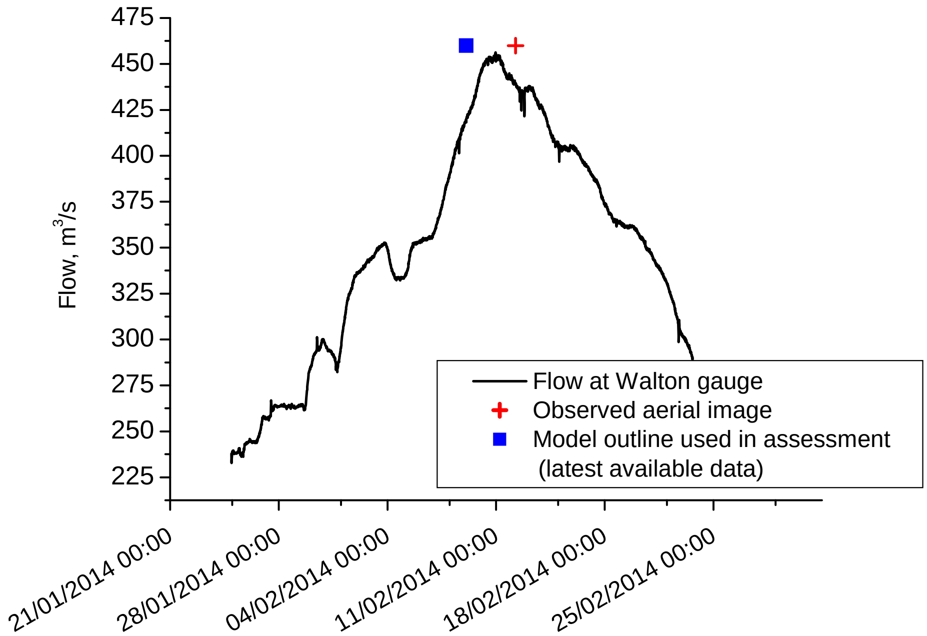


Figure 4.61 Observed flow hydrograph at the Walton gauge

In addition, sensitivity tests (increasing and decreasing model inflows by 20%) were not available within the time constraints of the project.

Although the full extent of model outputs was analysed, for consistency with other PoCs, the pro-forma presents detailed findings from 4 selected insets (highlighted in red on the map shown in Figure 4.62). These were chosen according to availability of observed and modelled data, and high concentration of receptors.

Table 4.35 Description of Flood Warning Areas featured in the Thames case study

Flood Warning Target Area Code	JBA code[1]	Name
061FWF23BrneEnd	101	River Thames at Bourne End
061FWF23Chertsey	102	River Thames at Chertsey
061FWF23Cookham	103	River Thames at Cookham
061FWF23Datchet	104	River Thames at Datchet
061FWF23HammCrt	105	River Thames at Hamm Court
061FWF23Horton	106	River Thames at Horton
061FWF23Laleham	107	River Thames at Laleham
061FWF23LHalifrd	108	River Thames at Shepperton and Lower Halliford
061FWF23Mdnhead	109	River Thames at Maidenhead to Windsor and Eton

Flood Warning Target Area Code	JBA code[1]	Name
061FWF23OldWndsr	110	River Thames at Old Windsor
061FWF23ShepGrn	111	River Thames at Shepperton Green
061FWF23Staines	112	River Thames at Staines and Egham
061FWF23Sunbury	113	River Thames at Sunbury
061FWF23Walton	114	River Thames at Walton
061FWF23Wraysbry	115	River Thames at Wraysbury
061FWF23XDatcht	116	Properties closest to the River Thames at Datchet, between Black Potts Bridge and Albert Bridge
061FWF23XLHalif	117	Properties closest to the River Thames from Shepperton Lock to Beasley's Ait
061FWF23XMhead	118	Moorings and properties closest to the River Thames between Maidenhead, Windsor and Eton
061FWF23XOldWnd	119	Properties closest to the River Thames at Old Windsor, from Friday Island to Magna Carta Island
061FWF23XShepG	120	Properties closest to the River Thames between Littleton Lane (Shepperton Green) and Shepperton Lock
061FWF23XStaines	121	Properties closest to the River Thames between Runnymede Pleasure Grounds, Staines and Penton Hook
061FWF23XWrysbry	122	Properties closest to the River Thames at Wraysbury from Old Windsor Weir to Magna Carta Island
061FWF26Binghams	123	Cut at the Binghams
061FWF29Addstne	124	Addlestone Bourne at Addlestone
061FWF29Chertsey	125	Chertsey Bourne at Chertsey
061FWF29ThorpGrn	126	Chertsey Bourne at Thorpe Green
061FWF29XAddstne	127	Properties closest to the Addlestone Bourne at Addlestone
061FWF29XChrtsy	128	Areas of Chertsey closest to the Chertsey Bourne
062FWF28Colnbrk	129	Colne Brook at Colnbrook
062FWF28WDrayton	130	River Colne and Frays River at West Drayton and Stanwell Moor
062FWF31Ashford	131	River Ash at Ashford and Staines
061FWF23Marlow	132	River Thames at Bisham village and Marlow town
061FWF23XMarlow	133	Properties closest to the River Thames from All Saints Church, Bisham to Little Marlow
061FWF23Hurley	134	River Thames at Hurley and Harleyford
061FWF23XSunbry	135	Properties closest to the River Thames at Sunbury

Flood Warning Target Area Code	JBA code[1]	Name
061FWF30Weybrdge	136	River Wey at Weybridge
061FWF23HenMed	137	River Thames for Henley, Remenham, and Medmenham

Notes: [1] Due to the size of the reach being analysed, a short three-digit code was assigned by JBA Consulting to all Flood Warning Areas to aid interpretation in later figures.

4.9.2 Context for model outputs

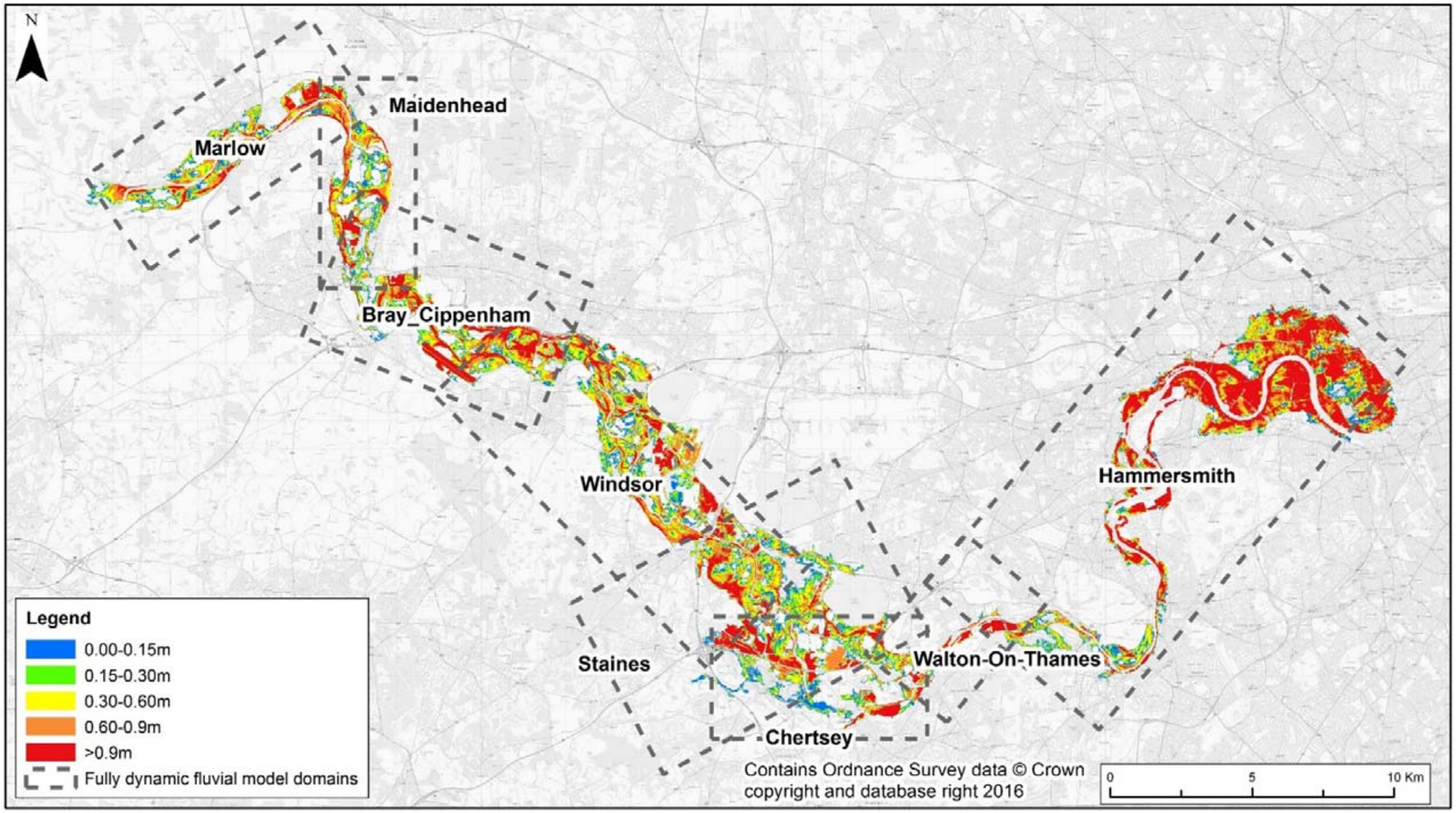


Figure 4.62 Context for model outputs for Thames case study: flows input

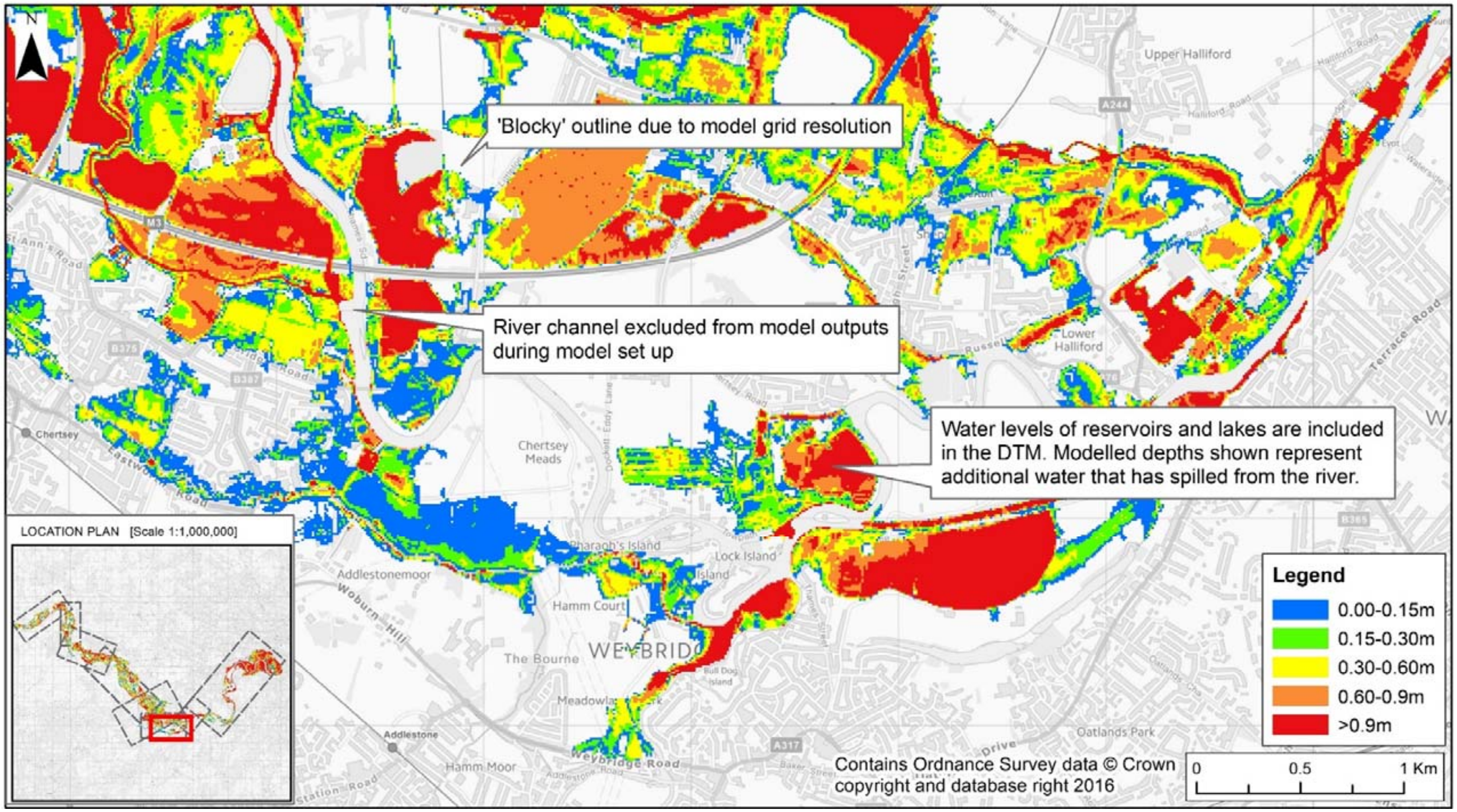


Figure 4.63 Context for model outputs in Chertsey domain: flows input

4.9.3 Extent flooded (Test A1)

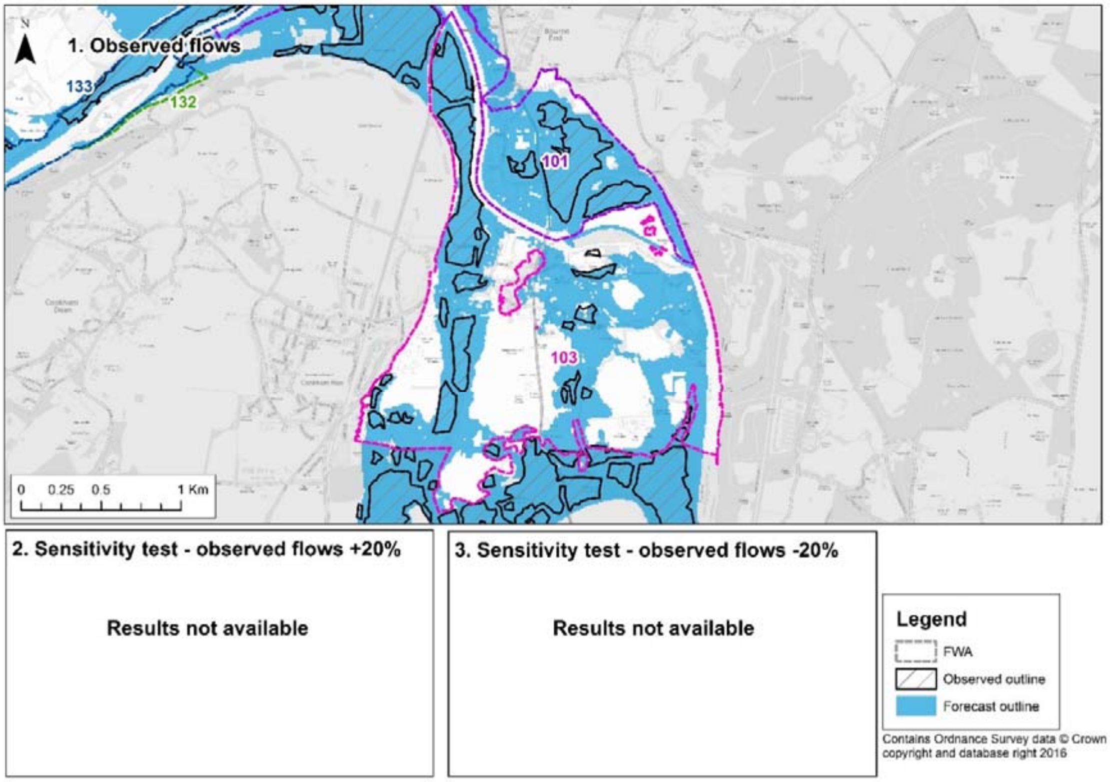


Figure 4.64 Maximum modelled and observed extent flooded for Maidenhead domain (inset 1): flows input

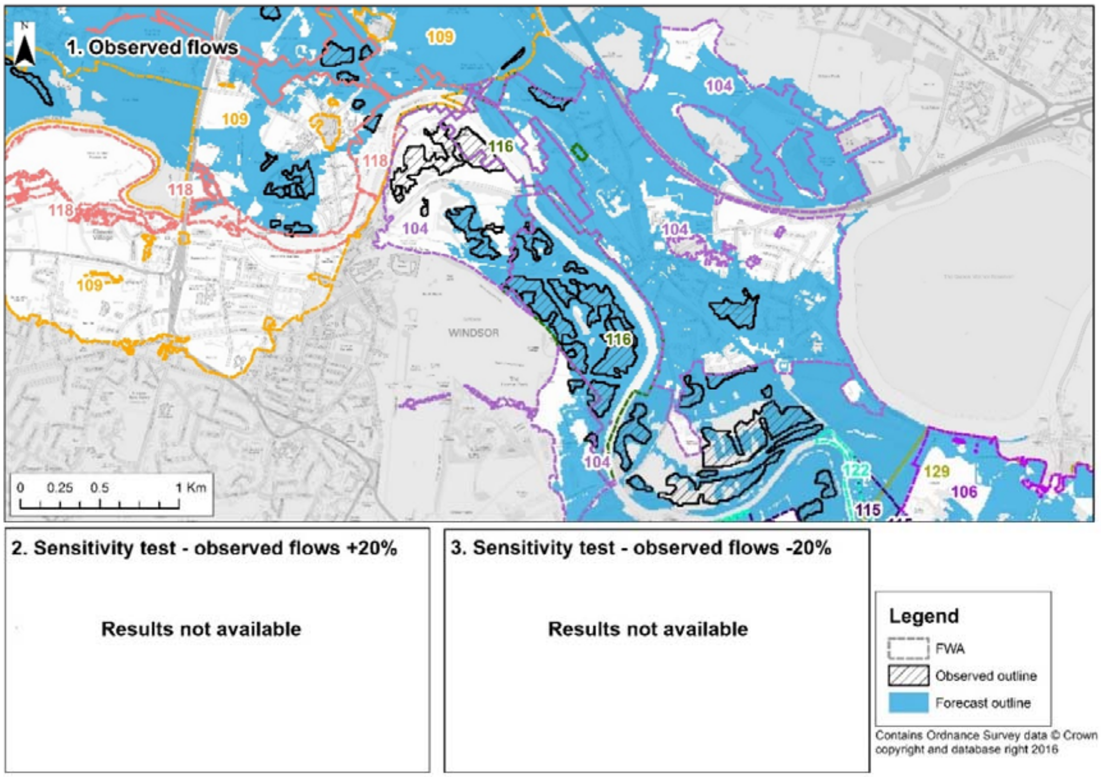


Figure 4.65 Maximum modelled and observed extent flooded for Bray, Cippenham and Windsor domains (inset 2): flows input

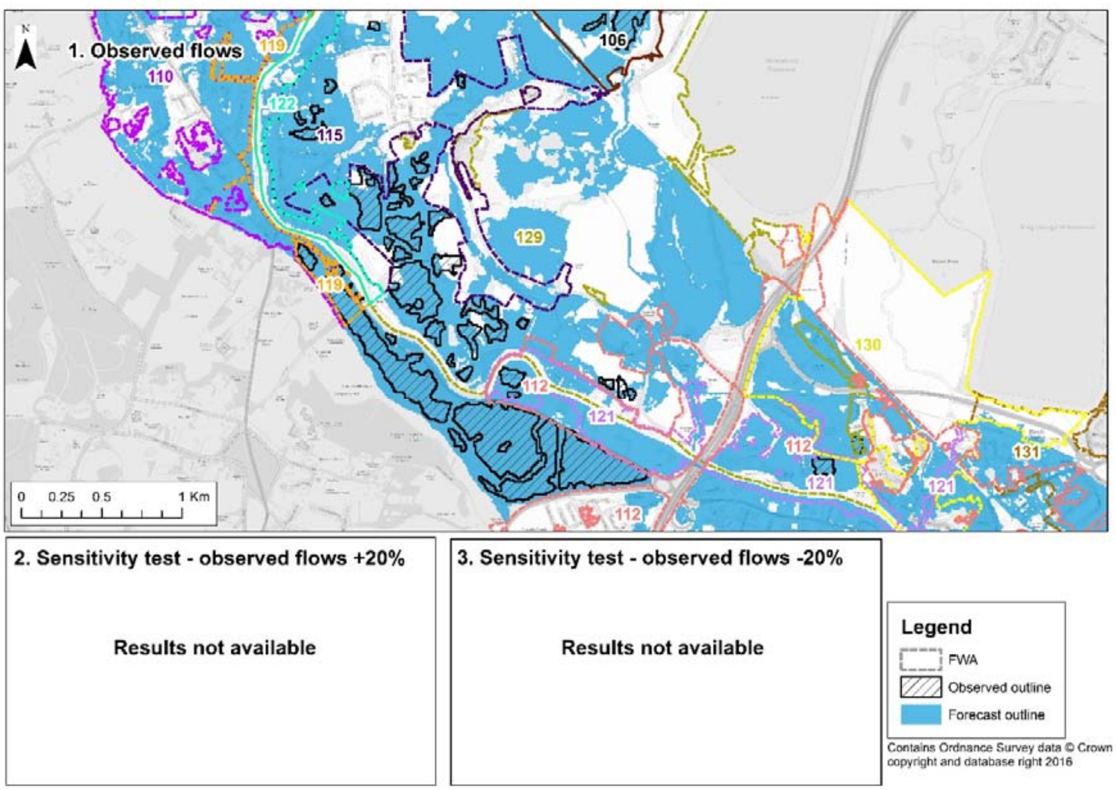


Figure 4.66 Maximum modelled and observed extent flooded for Windsor and Staines domains (inset 3): flows input

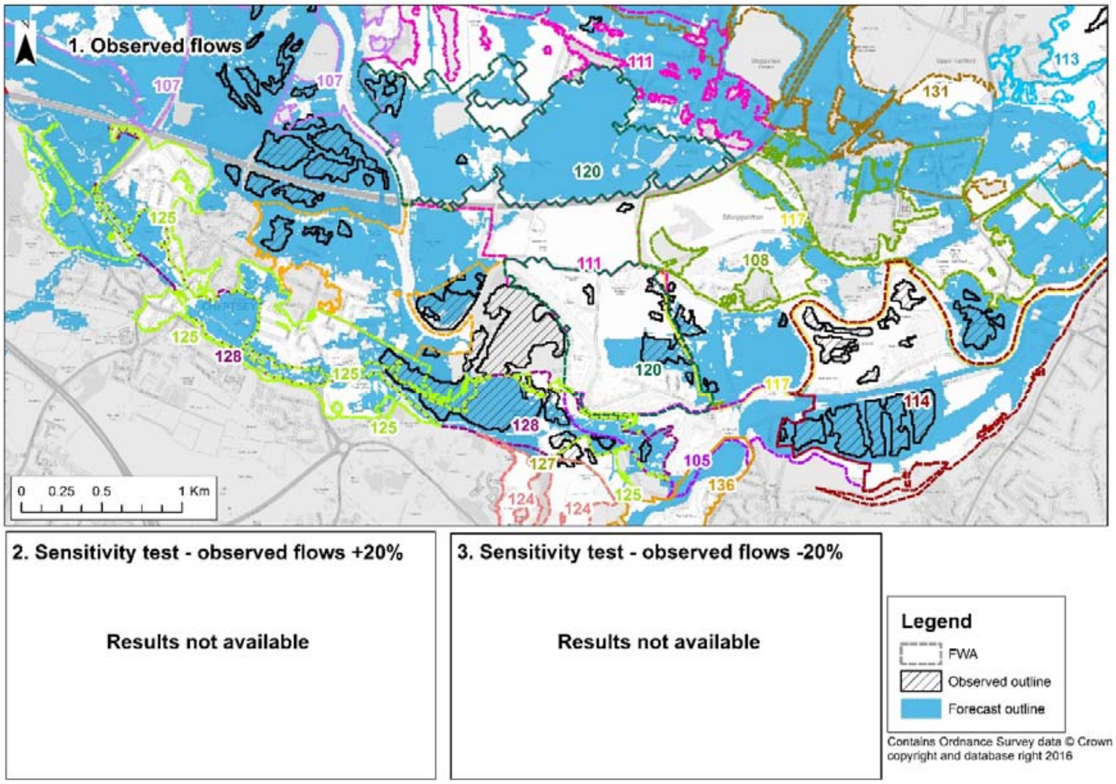


Figure 4.67 Maximum modelled and observed extent flooded for Windsor and Chertsey domains (inset 4): flows input

Table 4.36 Comparison of modelled and observed area flooded for each Flood Warning Area for Thames event: flows input

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	90,666,789	48,701,669	53.72	3,833,599	4.23
101	1,435,750	1,126,590	78.47	218,584	15.22
102	820,307	561,977	68.51	35,655	4.35
103	3,040,090	1,560,980	51.35	368,451	12.12
104	3,749,480	2,363,200	63.03	190,325	5.08
105	476,208	202,584	42.54	6,007	1.26
106	1,577,960	1,032,690	65.44	53,153	3.37
107	2,701,220	1,907,310	70.61	33,819	1.25
108	1,231,600	336,249	27.30	0	0.00
109	17,815,300	8,931,620	50.13	118,934	0.67
110	1,268,770	891,468	70.26	2,317	0.18

Flood Warning Area (FWA)	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
111	1,609,120	622,569	38.69	9,253	0.58
112	10,035,800	6,640,800	66.17	87,325	0.87
113	2,064,880	253,034	12.25	30,295	1.47
114	2,208,480	785,466	35.57	280,953	12.72
115	1,684,260	812,783	48.26	34,100	2.02
116	1,065,900	796,703	74.74	254,917	23.92
117	1,271,140	797,231	62.72	72,523	5.71
118	1,431,340	292,795	20.46	36,738	2.57
119	212,519	149,664	70.42	50,135	23.59
120	2,020,080	1,106,130	54.76	93,569	4.63
121	1,272,310	836,086	65.71	31,703	2.49
122	409,355	218,317	53.33	0	0.00
123	160,184	41	0.03	0	0.00
124	401,553	2,027	0.50	3,779	0.94
125	1,115,270	380,709	34.14	71,237	6.39
126	527,197	91,794	17.41	0	0.00
127	20,383	63	0.31	0	0.00
128	728,015	542,796	74.56	191,146	26.26
129	8,776,290	5,050,010	57.54	383,117	4.37
130	1,918,490	591,673	30.84	5,747	0.30
131	7,773,590	4,341,660	55.85	12,656	0.16
132	3,661,670	1,844,220	50.37	63,320	1.73
133	2,439,350	1,896,780	77.76	755,003	30.95
134	1,957,330	806,321	41.19	124,854	6.38
135	438,652	226,054	51.53	14,451	3.29
136	385,253	150,656	39.11	0	0.00
137	961,693	550,619	57.26	199,533	20.75

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

The simplified fluvial model provides detailed modelling of flow routes on the floodplain and flood extents. Generally, the results demonstrate a tendency towards overprediction (discussed further in Section 4.10.4). Inputs to the simplified fluvial model were provided by the 1D–2D fully dynamic fluvial model (developed by JBA Consulting for the Lower River Thames Flood Modelling Study). The 1D–2D results also demonstrate overprediction of flood extents, reasons for which may, in turn, be applicable to the simplified fluvial results. Further details are given in Appendix 4a.

Contributing factors to variations in overprediction and underprediction may also include the simplified fluvial model not allowing dynamic flow along the floodplain between discrete assets and not permitting return of flow to the channel. There may also be discrepancies in asset SoPs from AIMS which are used to define how much water spills onto the floodplain. A lower SoP will result in a greater volume of water on the floodplain.

An additional source of uncertainty may result from the observed outline, which was derived from satellite radar and taken some time after the peak. There may be inaccuracies in the digitisation of the outline, particularly in built-up or wooded areas, and therefore uncertainties in its extent. This may contribute to the marked differences between modelled and observed outlines. In addition, satellite radar may pick up surface water flooding or flooding driven by other fluvial sources excluded from the model. Furthermore, lakes and other water bodies in the floodplain may have been excluded from the observed outline but are included in the model, such as Abbeyfield Park near Chertsey. Here, the model appears to overpredict. The model also does not explicitly model surface water drainage which may have alleviated flooding in part in built-up areas during the 2014 event.

The period of time that elapses between modelled and observed outlines could also explain the disparities.

4.9.4 Model performance (Test A2)

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

Figure 4.68 Model performance in predicting flooded extent for Maidenhead domain (inset 1): flows input

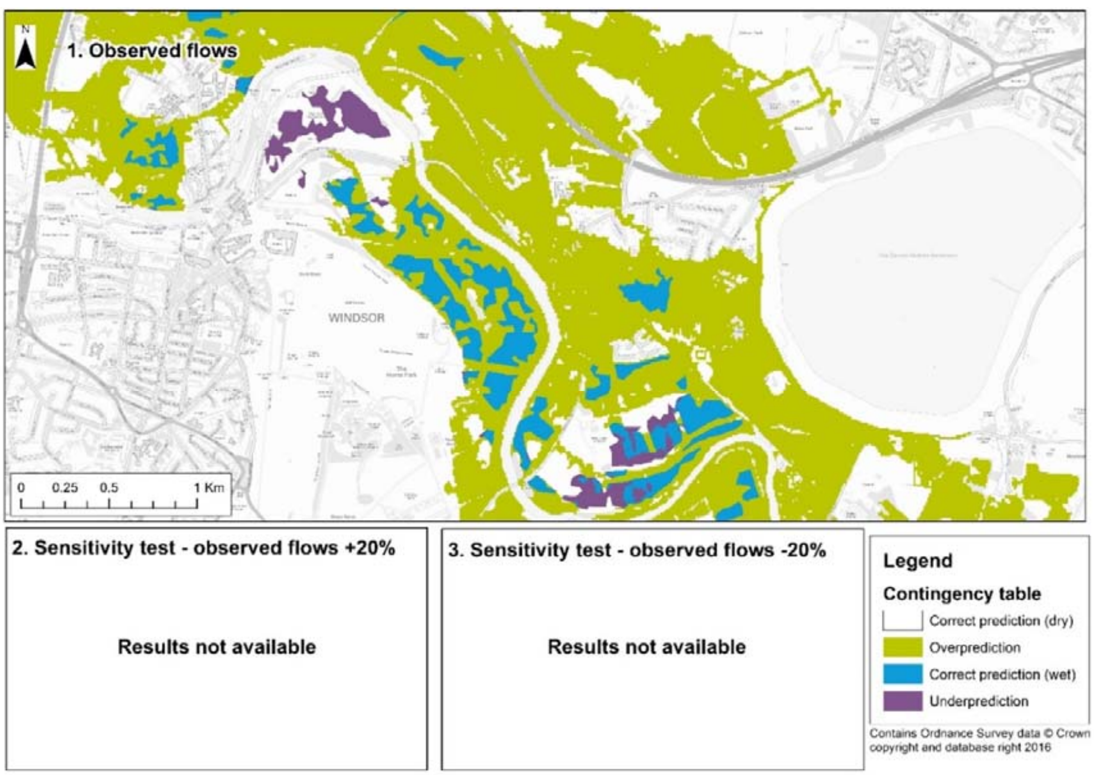


Figure 4.69 Model performance in predicting flooded extent for Bray, Cippenham and Windsor domains (inset 2): flows input

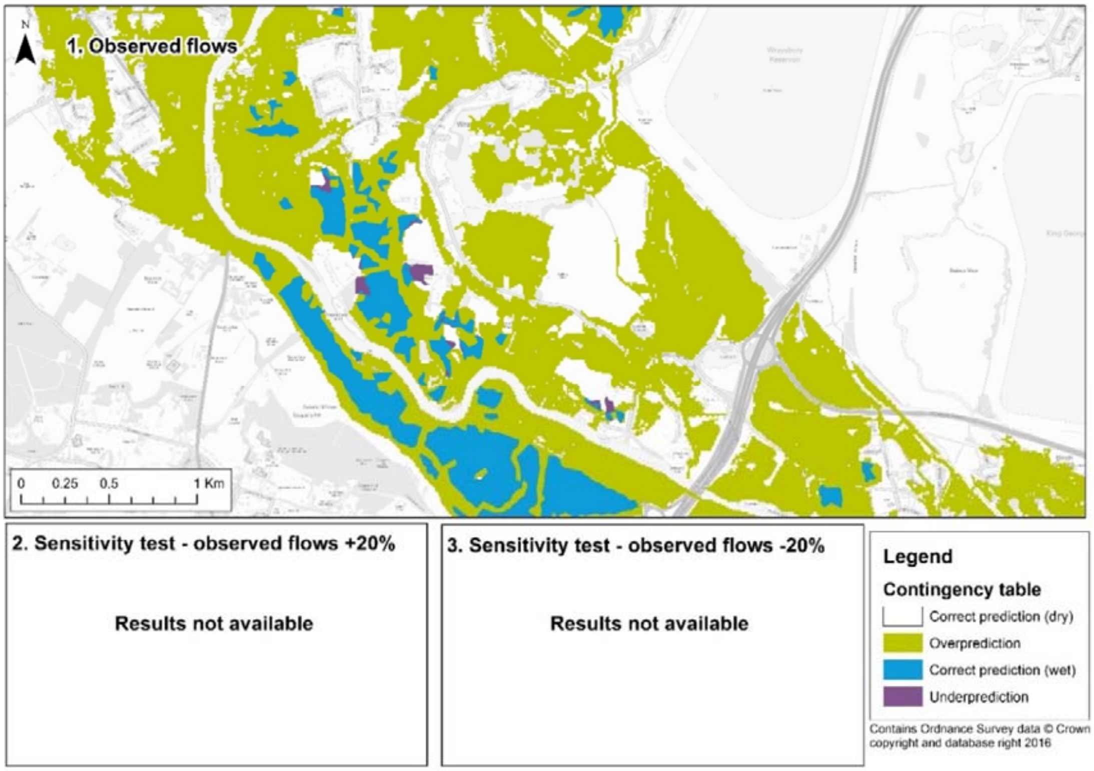


Figure 4.70 Model performance in predicting flooded extent for Windsor and Staines domains (inset 3): flows input

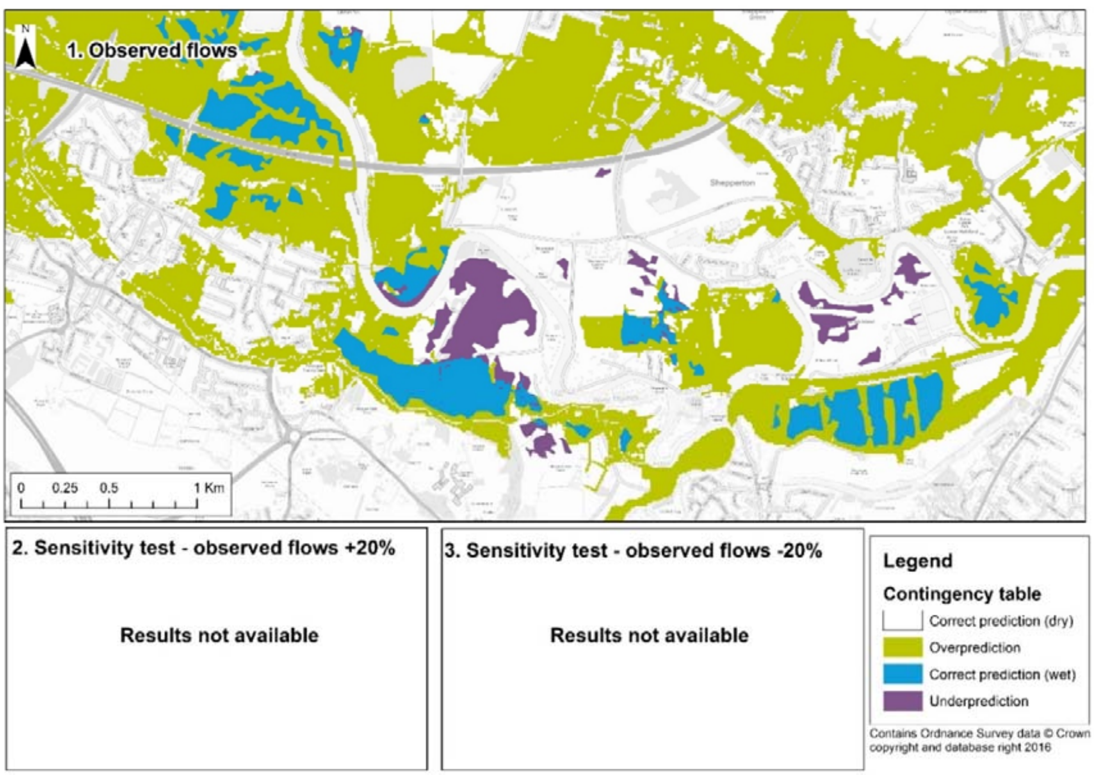


Figure 4.71 Model performance in predicting flooded extent for Staines and Chertsey domains (inset 4): flows input

Table 4.37 Model performance metrics for Thames event: flows input

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
Modelled outline (all)	**10.26**	**88.34**	**1.40**	**0.10**	**8.46**
Modelled outline (within area covered by Flood Warning Areas only)	6.93	92.19	0.88	0.07	12.69
101	19.33	80.61	0.06	0.19	5.15
102	6.33	93.66	0.01	0.06	15.76
103	22.82	76.55	0.63	0.23	4.24
104	4.05	92.24	3.71	0.04	12.42
105	2.89	97.04	0.07	0.03	33.72
106	5.15	94.85	0.00	0.05	19.43
107	1.55	98.23	0.22	0.02	56.40
108	0.00	100.00	0.00	0.00	0.00
109	1.32	98.67	0.02	0.01	75.10
110	0.26	99.74	0.00	0.00	384.78
111	0.68	98.53	0.80	0.01	67.29
112	1.26	98.69	0.05	0.01	76.05
113	8.08	88.44	3.48	0.08	8.35
114	23.29	67.52	9.19	0.23	2.80
115	4.02	95.81	0.16	0.04	23.84
116	26.95	69.23	3.82	0.27	3.13
117	7.80	91.01	1.19	0.08	10.99
118	12.16	87.50	0.34	0.12	7.97
119	33.35	66.54	0.11	0.33	2.99
120	6.18	91.72	2.11	0.06	11.82
121	3.79	96.21	0.00	0.04	26.37
122	0.00	100.00	0.00	0.00	0.00
123	0.00	100.00	0.00	0.00	0.00
124	0.00	34.91	65.09	0.00	0.54

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
125	13.27	82.15	4.58	0.13	5.34
126	0.00	100.00	0.00	0.00	0.00
127	0.00	100.00	0.00	0.00	0.00
128	29.79	66.20	4.01	0.30	2.84
129	6.97	92.36	0.67	0.07	13.00
130	0.97	99.03	0.00	0.01	102.95
131	0.08	99.71	0.21	0.00	343.05
132	2.52	96.60	0.88	0.03	29.13
133	38.87	60.46	0.67	0.39	2.51
134	12.61	84.90	2.49	0.13	6.46
135	6.39	93.61	0.00	0.06	15.64
136	0.00	100.00	0.00	0.00	0.00
137	30.64	65.25	4.11	0.31	2.76

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain, and performance in locations where there is known to be flood risk to property.

Interpretation

Overall the model significantly overpredicts, although there are some small, localised areas where the model underpredicts. An example where the model underpredicts is towards the centre of inset 4 at Chertsey Meads. This may be attributed to flows being insufficient to overtop asset lines along the Thames in this location. Contributing factors to variations in overprediction and underprediction may also include the model not allowing dynamic flow along the floodplain between discrete assets and not permitting return of flow to the channel. There may also be discrepancies in asset SoPs from AIMS which determines how much water spills onto the floodplain. A lower SoP will result in greater volume of water on the floodplain.

The calibration report from the 2015 Lower Thames modelling study carried out by JBA Consulting also highlights the significance of a number of factors on model performance which may in turn have an impact on results from the simplified fluvial model. These factors are discussed further in Appendix 4a.

An additional reason for the model overpredicting and underpredicting is uncertainty in the observed outline, which was derived from satellite radar and taken some time after the peak. There may be inaccuracies in the digitisation of the outline, particularly in built-up areas, and therefore uncertainties in its extent – which may contribute to the marked differences between modelled and observed outlines. Overprediction in built-up areas may also be attributed to the model not explicility modelling surface water drainage, which may have reduced flood extent during the 2014 event. A notable period of time elapses between modelled and observed outlines; although this is relatively low, it goes some way to explaining the differences between them – given the slow responding nature of the catchment and duration of this event.

4.9.5 Property counts (Test B)

Properties within flood extent

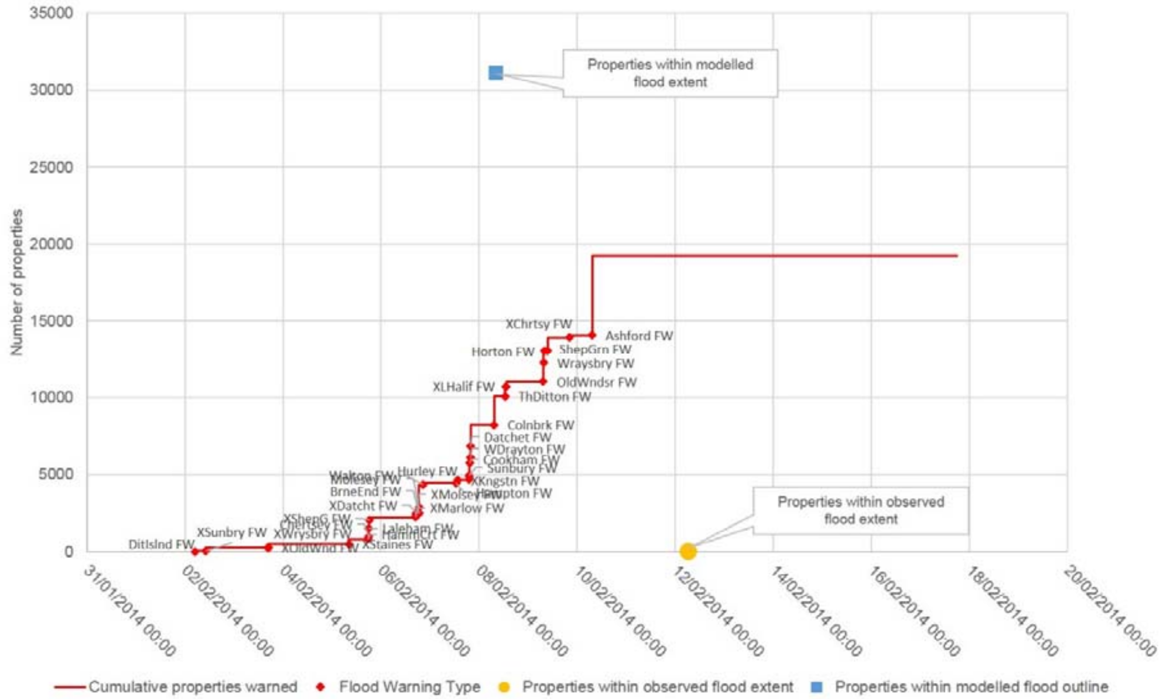


Figure 4.72 Properties within flood extent for Thames event: flows input

Notes: Properties are mapped below.

Table 4.38 Maximum number of flooded properties for Thames event: flows input

Flood Warning Area	Properties warned[1]	Observed[2] 06:09 on 12 February 2014	Predicted[3] 02:00 on 9 February 2014
All	**16,827**	**45**	**33,951**
101	376	4	569
102	530	0	497
103	304	4	184
104	1,378	2	1,791
105	171	0	122
106	10	0	47
107	548	2	1,018
108	0	0	511
109	0	1	4,218
110	1,240	1	1,394
111	860	1	1,024
112	0	3	11,512
113	838	0	107
114	120	5	44
115	785	0	469
116	11	0	33
117	315	1	265
118	0	0	23
119	26	2	58
120	169	0	62
121	325	3	561
122	218	0	227
123	0	0	0
124	0	0	0
125	0	0	643
126	0	0	13
127	0	0	0
128	147	1	146

Flood Warning Area	Properties warned[1]	Observed[2] 06:09 on 12 February 2014	Predicted[3] 02:00 on 9 February 2014
129	1,850	2	1,242
130	771	0	577
131	5,184	0	4,575
132	0	2	1,028
133	179	5	378
134	278	1	121
135	194	0	270
136	0	0	192
137	0	5	30

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event.
[2] Observed is based on the intersection of NRD property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.
Some Flood Warning Areas overlap and, as a result, some properties are double-counted in the totals on the first line of the table. Also some Flood Warning Areas have been trimmed to the modelled extent for display purposes and their dimensions may differ compared with the same Flood Warning Areas in other PoCs.

Interpretation

There are significantly more properties within the modelled flood outline than in the observed outline (33,951 compared with 45). As discussed in Section 4.9.4, there may be uncertainties in the observed outline, particularly in built-up areas. This possibility is supported by the maps shown in Figure 4.74 illustrating high concentrations of receptors where the model is shown to overpredict. Overprediction in built-up areas may also be attributed to the model not explicility modelling surface water drainage.

There are also a number of reasons associated with model schematisation detailed in Sections 4.9.3 and 4.9.44.9.4 which may, in part, explain the apparent overprediction. As discussed earlier, the observed flood outlines are based on remotely sensed imagery taken after the peak of the event, resulting in some discrepancies in the flood outlines and number of properties within the flood extent.

Properties mapped by model prediction

Figures 73 to 76 shows NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline. Only properties within the existing Flood Warning Area are considered.

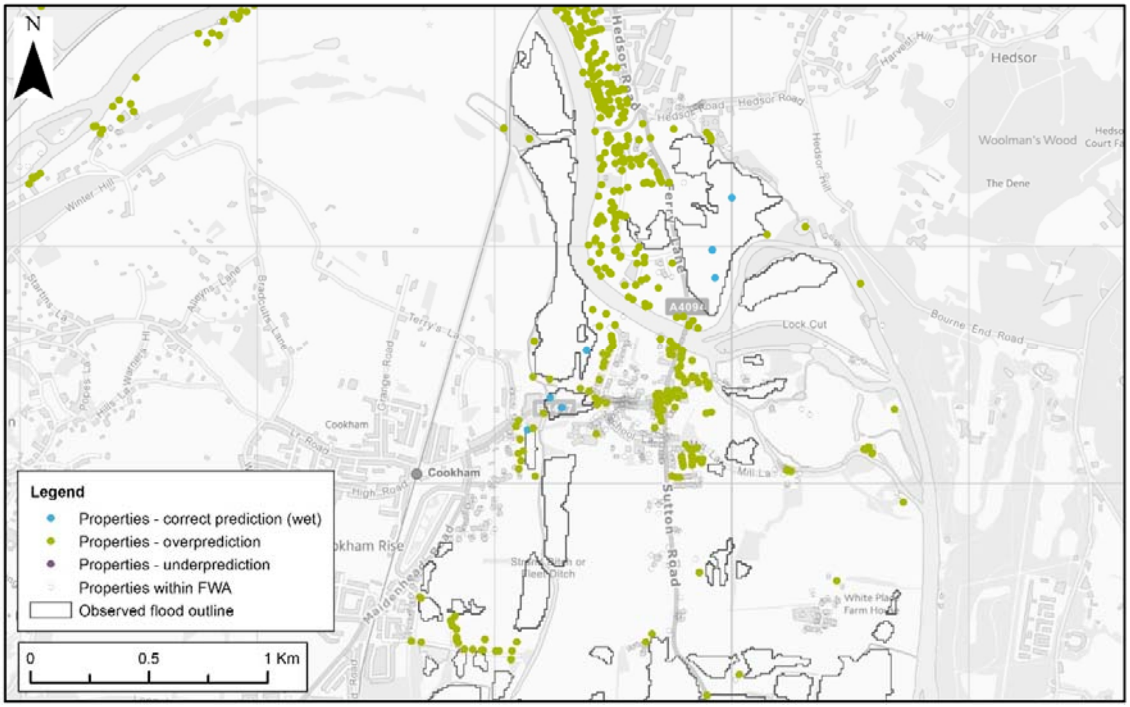


Figure 4.73 Closest modelled time-step to validation data for Maidenhead domain (inset 1): flows input

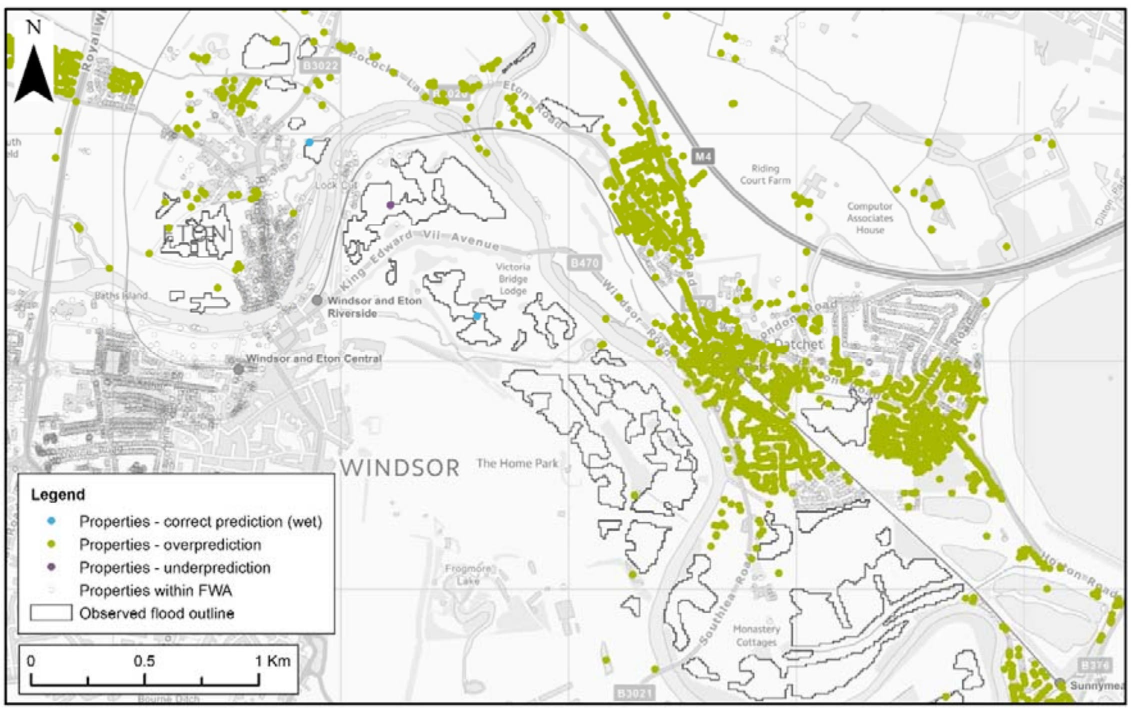


Figure 4.74 Closest modelled time-step to validation data for Bray, Cippenham and Windsor domains (inset 2): flows input

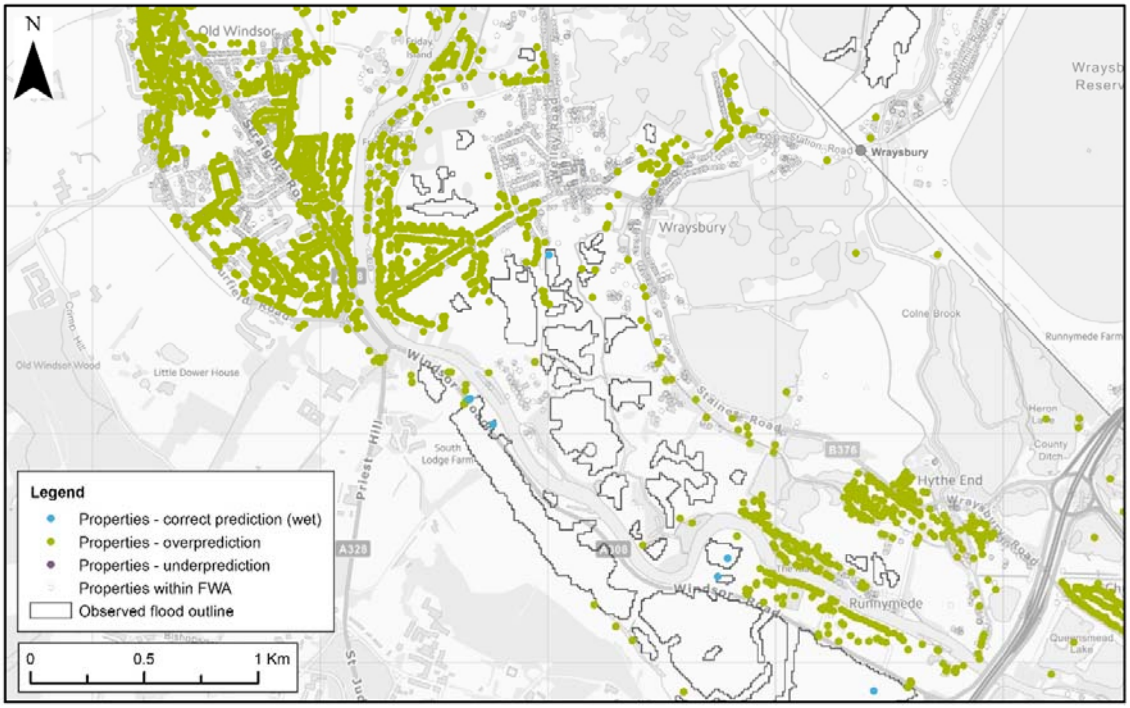


Figure 4.75 Closest modelled time-step to validation data for Windsor and Staines domains (inset 3): flows input

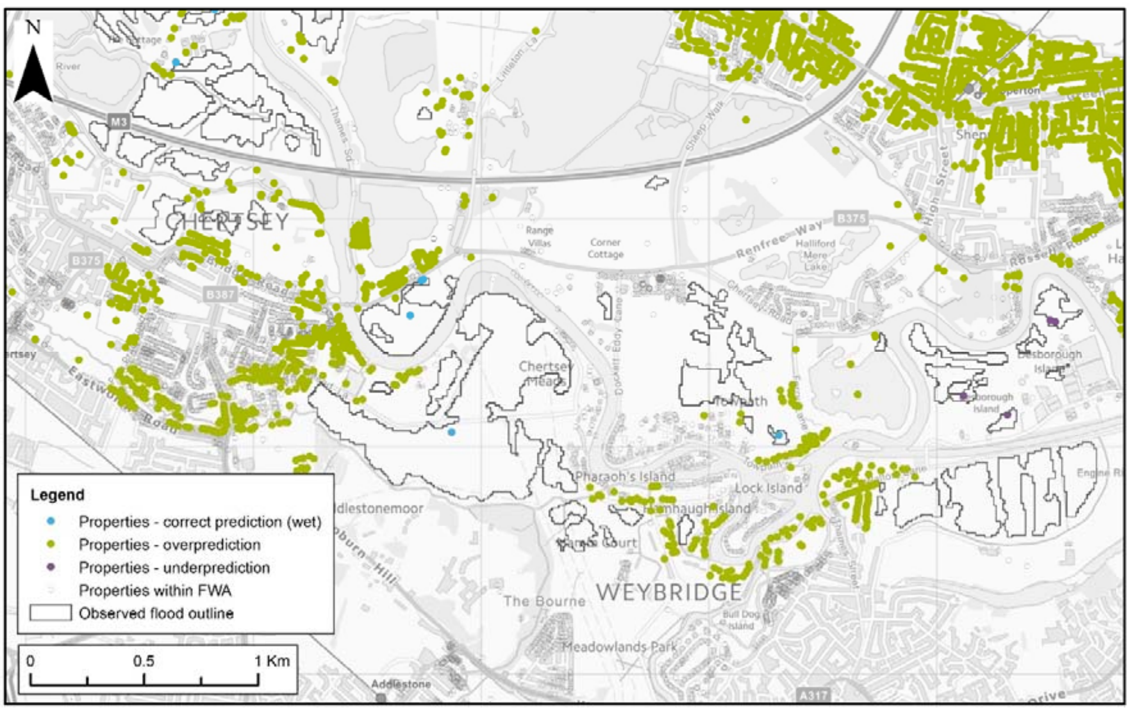


Figure 4.76 Closest modelled time-step to validation data for Staines and Chertsey domains (inset 4): flows input

4.9.6 Depth analysis (Test C)

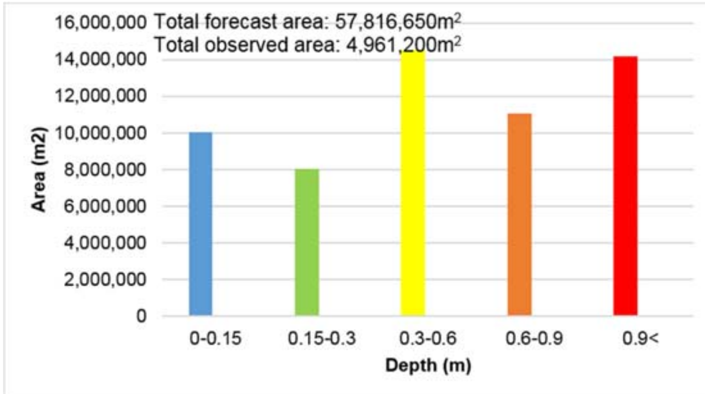


Figure 4.77 Distribution of flooded depths at 01:15 (peak) on 10 February 2014: flows input

Notes: Solid bars show modelled depths (from the PoC option); no observed depths are available.
Channel depths are not included in the modelled results.
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

Observed depths were not available for this case study, limiting the validation of the model results. Modelled depths are distributed across a range of depths. This is in contrast to the levels run (see Section 4.10.6), where depths are skewed towards deeper categories. This approach is therefore heavily influenced by accurate specification of in-channel conditions and asset information.

4.9.7 Total water level

Figure 4.78 presents the total modelled water level on the floodplain (modelled depth plus land elevation from a LIDAR DTM). The maximum water levels at in-channel nodes are also presented, based on a 1D–2D hydrodynamic model, which provided the inputs to this PoC. The channel itself is not represented by this PoC option, and the nature of the simplified fluvial model means that there is no dynamic link between the channel and the floodplain during the model run. This location in Staines-upon-Thames was chosen as there are numerous examples of locations where water levels on the floodplain differ from those in-channel. There is also a high density of receptors. Annotations on the map explain the model results.

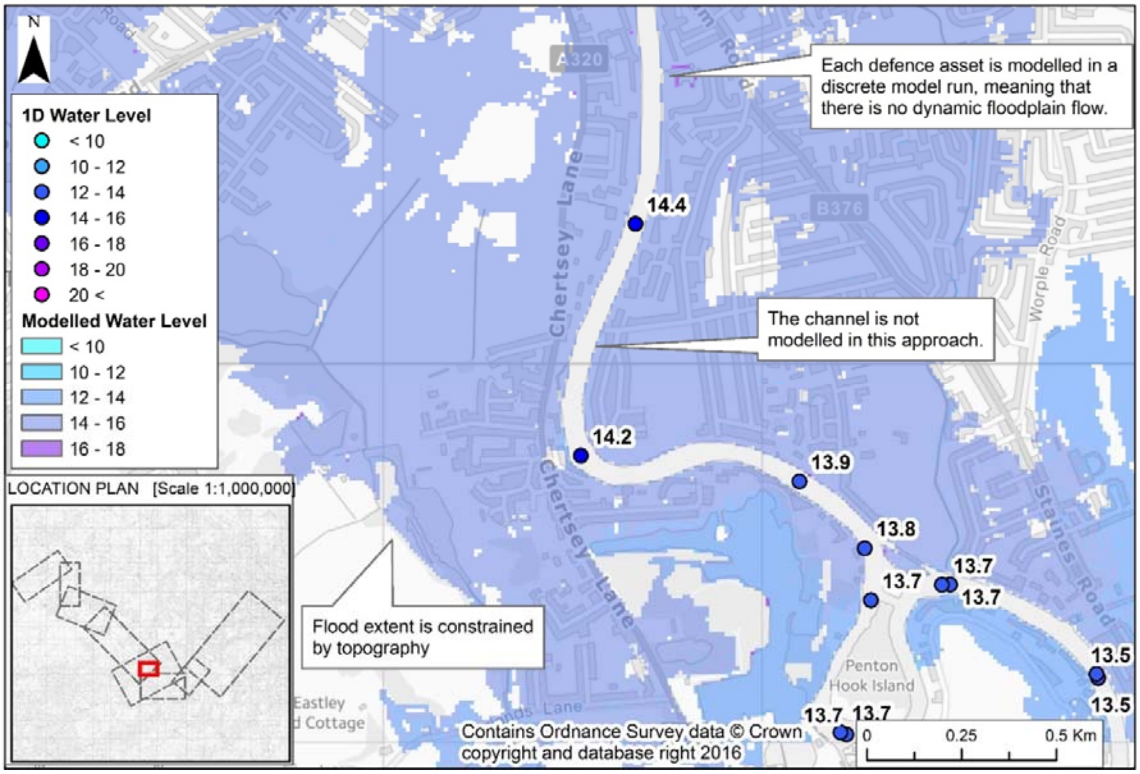


Figure 4.78 Total modelled water level on the floodplain and maximum water level at in-channel nodes at Staines: flows input

4.10 Case study 3: Thames, February 2014 – levels input

4.10.1 Location

See Section 4.9.1 for discussion of the location map and inputs used for this PoC.

Table 4.39 Description of Flood Warning Areas featured in the Thames case study

Flood Warning Target Area Code	JBA code[1]	Name
061FWF23BrneEnd	101	River Thames at Bourne End
061FWF23Chertsey	102	River Thames at Chertsey
061FWF23Cookham	103	River Thames at Cookham
061FWF23Datchet	104	River Thames at Datchet
061FWF23HammCrt	105	River Thames at Hamm Court
061FWF23Horton	106	River Thames at Horton
061FWF23Laleham	107	River Thames at Laleham
061FWF23LHalifrd	108	River Thames at Shepperton and Lower Halliford

Flood Warning Target Area Code	JBA code[1]	Name
061FWF23Mdnhead	109	River Thames at Maidenhead to Windsor and Eton
061FWF23OldWndsr	110	River Thames at Old Windsor
061FWF23ShepGrn	111	River Thames at Shepperton Green
061FWF23Staines	112	River Thames at Staines and Egham
061FWF23Sunbury	113	River Thames at Sunbury
061FWF23Walton	114	River Thames at Walton
061FWF23Wraysbry	115	River Thames at Wraysbury
061FWF23XDatcht	116	Properties closest to the River Thames at Datchet, between Black Potts Bridge and Albert Bridge
061FWF23XLHalif	117	Properties closest to the River Thames from Shepperton Lock to Beasley's Ait
061FWF23XMhead	118	Moorings and properties closest to the River Thames between Maidenhead, Windsor and Eton
061FWF23XOldWnd	119	Properties closest to the River Thames at Old Windsor, from Friday Island to Magna Carta Island
061FWF23XShepG	120	Properties closest to the River Thames between Littleton Lane (Shepperton Green) and Shepperton Lock
061FWF23XStaines	121	Properties closest to the River Thames between Runnymede Pleasure Grounds, Staines and Penton Hook
061FWF23XWrysbry	122	Properties closest to the River Thames at Wraysbury from Old Windsor Weir to Magna Carta Island
061FWF26Binghams	123	Cut at the Binghams
061FWF29Addstne	124	Addlestone Bourne at Addlestone
061FWF29Chertsey	125	Chertsey Bourne at Chertsey
061FWF29ThorpGrn	126	Chertsey Bourne at Thorpe Green
061FWF29XAddstne	127	Properties closest to the Addlestone Bourne at Addlestone
061FWF29XChrtsy	128	Areas of Chertsey closest to the Chertsey Bourne
062FWF28Colnbrk	129	Colne Brook at Colnbrook
062FWF28WDrayton	130	River Colne and Frays River at West Drayton and Stanwell Moor
062FWF31Ashford	131	River Ash at Ashford and Staines
061FWF23Marlow	132	River Thames at Bisham village and Marlow town
061FWF23XMarlow	133	Properties closest to the River Thames from All

Flood Warning Target Area Code	JBA code[1]	Name
		Saints Church, Bisham to Little Marlow
061FWF23Hurley	134	River Thames at Hurley and Harleyford
061FWF23XSunbry	135	Properties closest to the River Thames at Sunbury
061FWF30Weybrdge	136	River Wey at Weybridge
061FWF23HenMed	137	River Thames for Henley, Remenham, and Medmenham
061FWF23XMolsey	138	Properties closest to the River Thames between Platts Eyot to Hampton Court Bridge
061FWF23Molesey	139	River Thames at East and West Molesey
064FWF32Esher	140	River Mole at Esher and East Molesey

Notes: [1] Due to the size of the reach being analysed, a short three-digit code was assigned by JBA Consulting to all Flood Warning Areas to aid interpretation in later figures.

4.10.2 Context for model outputs

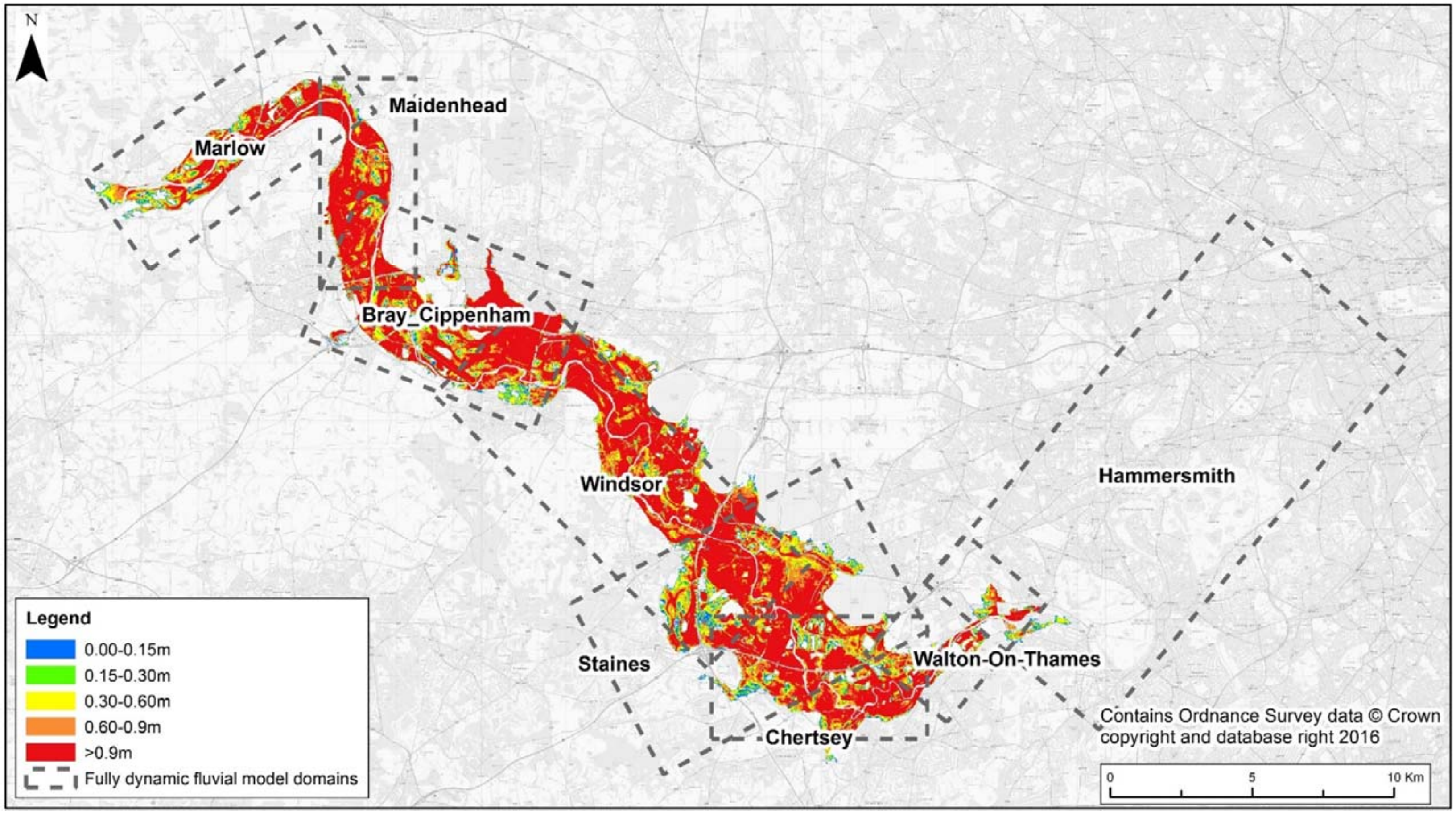


Figure 4.79 Context for model outputs for Thames case study: levels input

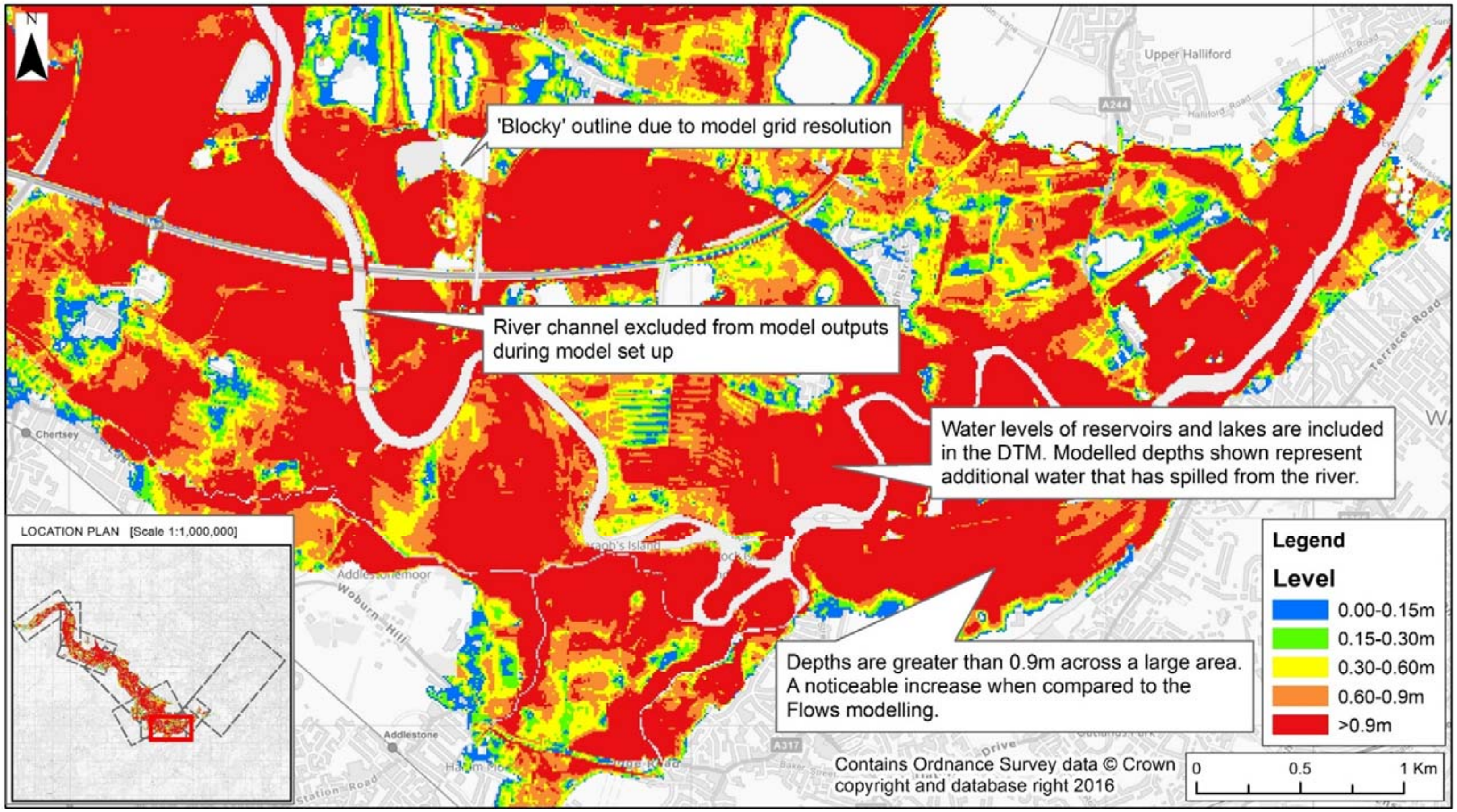


Figure 4.80 Context for model outputs for Chertsey domain: levels input

4.10.3 Extent flooded (Test A1)

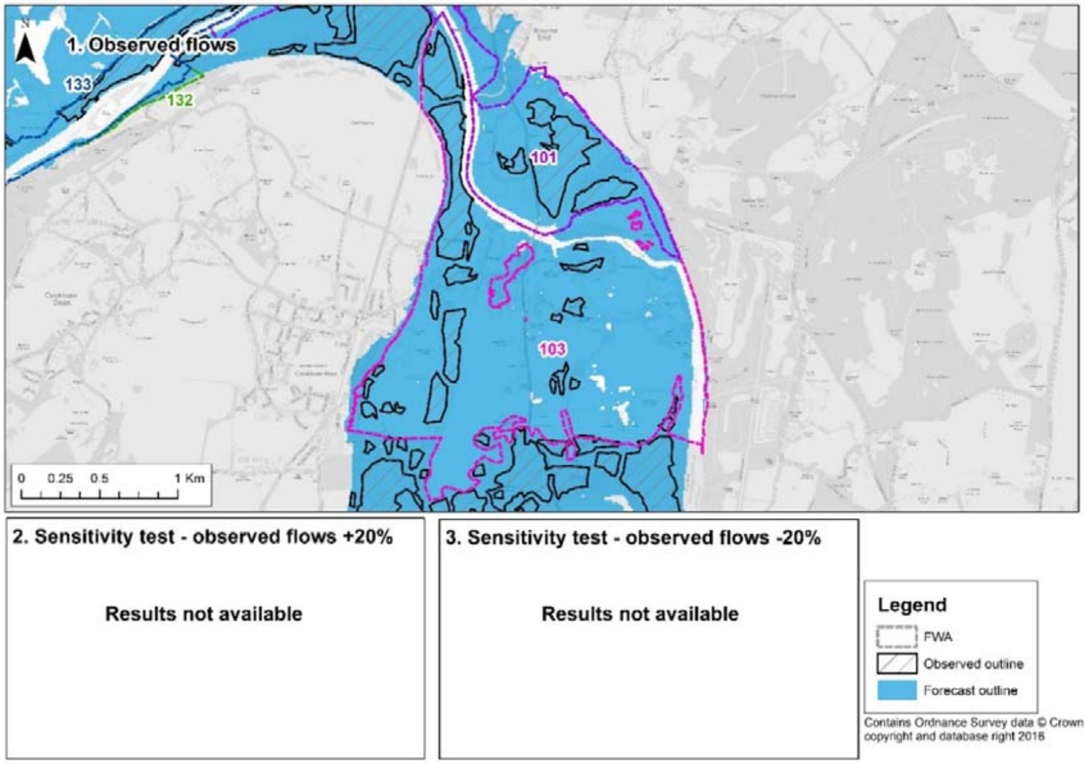


Figure 4.81 Maximum modelled and observed extent flooded for Maidenhead domain (inset 1): levels input

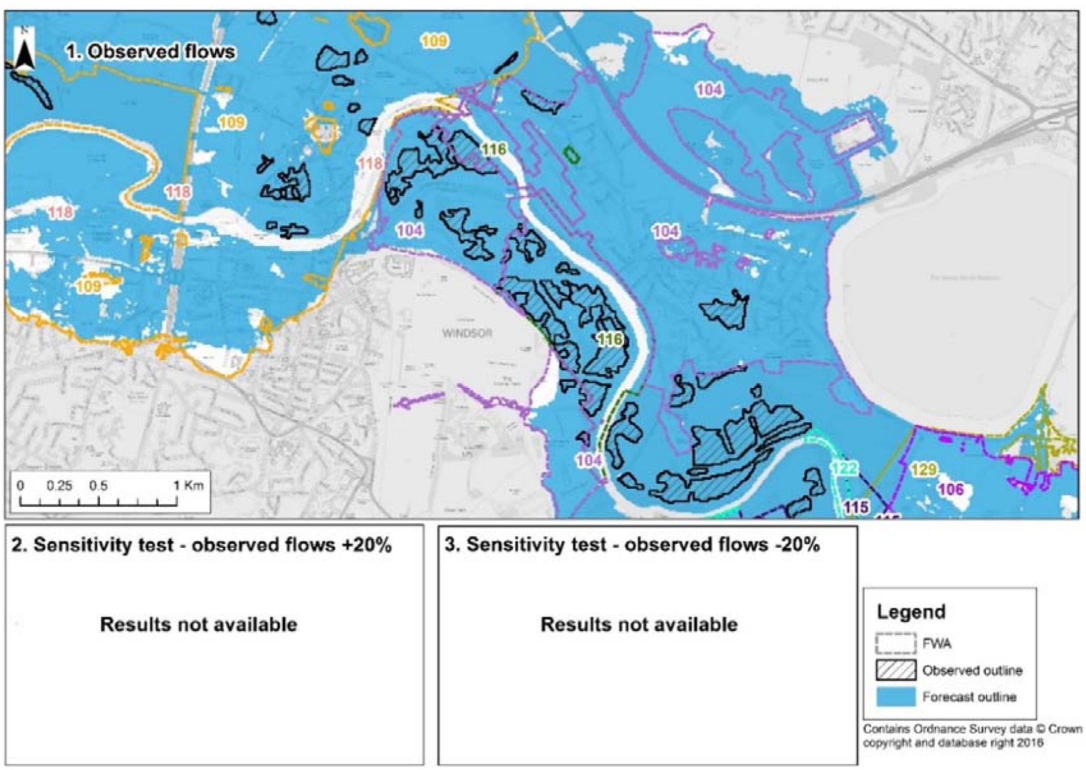


Figure 4.82 Maximum modelled and observed extent flooded for Bray, Cippenham and Windsor domains (inset 2): levels input

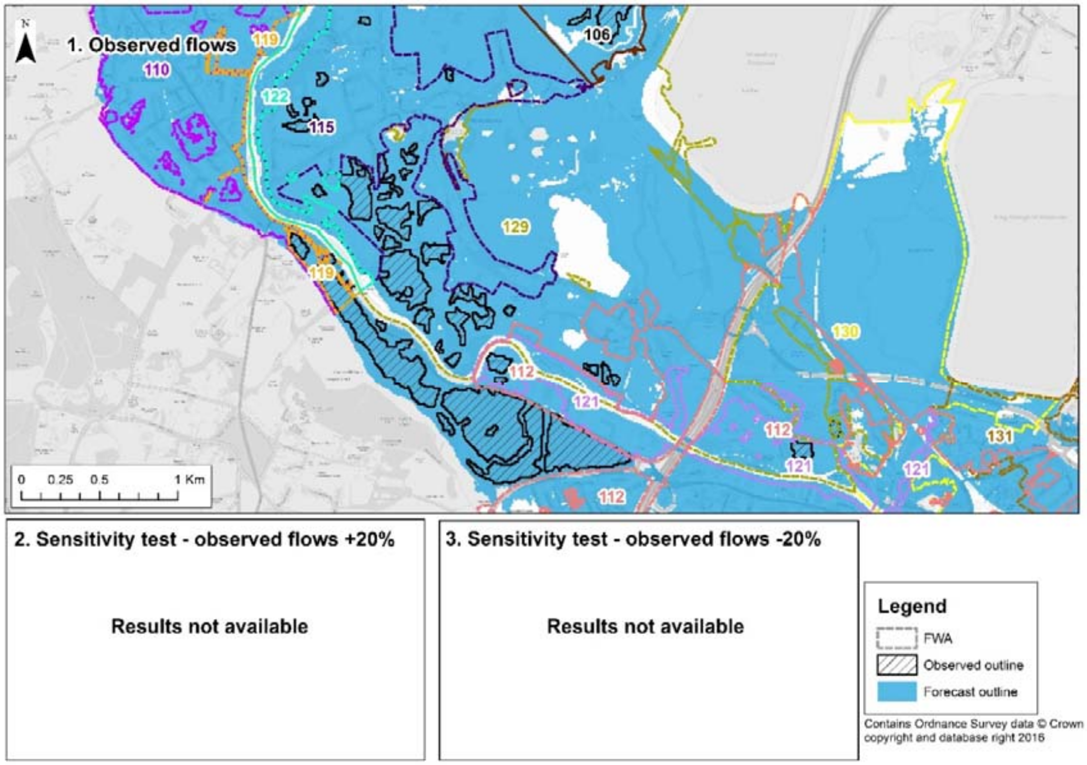


Figure 4.83 Maximum modelled and observed extent flooded for Windsor and Staines domains (inset 3): levels input

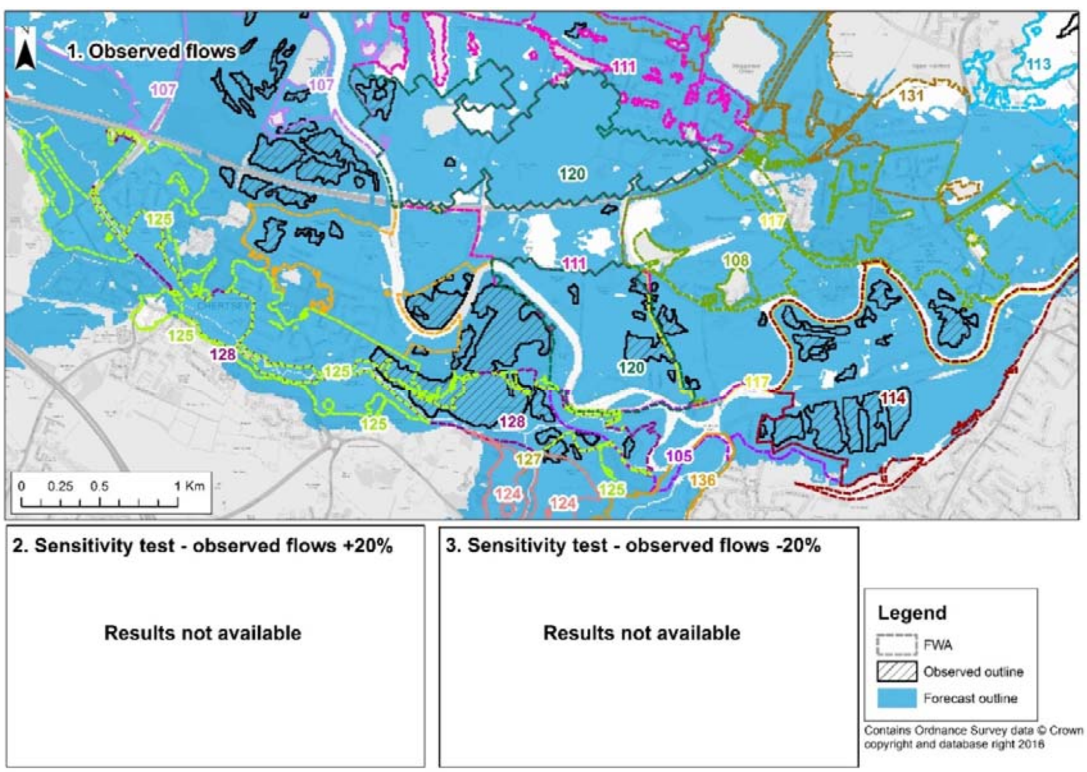


Figure 4.84 Maximum modelled and observed extent flooded for Staines and Chertsey domains (inset 4): levels input

Table 4.40 Comparison of modelled and observed area flooded for each Flood Warning Area for Thames event: levels input

Flood Warning Area	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
All	94,968,758	77,801,916	81.92	3,833,599	4.04
101	1,435,750	1,233,450	85.91	218,584	15.22
102	820,307	750,747	91.52	35,655	4.35
103	3,040,090	2,815,480	92.61	368,451	12.12
104	3,749,480	3,575,990	95.37	190,325	5.08
105	476,208	356,411	74.84	6,007	1.26
106	1,577,960	1,358,410	86.09	53,153	3.37
107	2,701,220	2,458,360	91.01	33,819	1.25
108	1,231,600	1,104,430	89.67	0	0.00
109	17,815,300	15,167,600	85.14	118,934	0.67
110	1,268,770	1,258,220	99.17	2,317	0.18
111	1,609,120	1,324,550	82.32	9,253	0.58
112	10,035,800	9,216,720	91.84	87,325	0.87
113	2,106,330	878,289	41.70	30,295	1.44
114	2,233,730	1,740,550	77.92	280,953	12.58
115	1,684,260	1,656,100	98.33	34,100	2.02
116	1,065,900	902,890	84.71	254,917	23.92
117	1,271,140	1,094,900	86.14	72,523	5.71
118	1,431,340	562,565	39.30	36,738	2.57
119	212,519	149,843	70.51	50,135	23.59
120	2,020,080	1,807,200	89.46	93,569	4.63
121	1,272,310	943,303	74.14	31,703	2.49
122	409,355	285,221	69.68	0	0.00
123	160,184	74,748	46.66	0	0.00
124	569,160	488,446	85.82	3,779	0.66
125	1,115,270	1,045,460	93.74	71,237	6.39
126	527,197	250,326	47.48	0	0.00
127	27,923	20,958	75.06	0	0.00
128	728,015	688,181	94.53	191,146	26.26

Flood Warning Area	Area (m^2)	Area flooded			
		Modelled		Observed	
		m^2	% of FWA	m^2	% of FWA
129	8,813,330	7,820,620	88.74	383,117	4.35
130	2,608,220	2,220,320	85.13	5,747	0.22
131	7,773,590	6,524,870	83.94	12,656	0.16
132	3,661,670	3,142,410	85.82	63,320	1.73
133	2,439,350	1,947,070	79.82	755,003	30.95
134	1,957,330	994,773	50.82	124,854	6.38
135	438,652	273,901	62.44	14,451	3.29
136	1,844,100	405,012	21.96	0	0.00
137	961,693	517,521	53.81	199,533	20.75
138	377,500	14,645	3.88	0	0.00
139	982,085	477,365	48.61	0	0.00
140	514,920	254,062	49.34	0	0.00

Notes: For the purposes of comparison, the areas of the Flood Warning Areas have been trimmed to the extent of the available observed data.

Interpretation

The simplified fluvial model provides detailed modelling of flood extents and flow routes on the floodplain. Like the flows case, the results demonstrate a tendency towards overprediction (see Section 4.9.3)4.9.4. The 1D–2D fully dynamic fluvial model (developed by JBA Consulting for the Lower River Thames Flood Modelling Study) provided inputs to the simplified fluvial model in this PoC. Results from the 1D–2D model also demonstrate overprediction of flood extents, reasons for which may, in addition, be applicable to the simplified fluvial results. Further details are given in Appendix 4.

Contributing factors to variations in overprediction and underprediction may also include discrepancies in asset crest heights from AIMS which are used to define how much water spills onto the floodplain. A lower crest height will result in a greater volume of water on the floodplain. In addition, the simplified fluvial model does not allow dynamic flow along the floodplain between discrete assets and does not permit return of flow to the channel, both of which may contribute to apparent overprediction.

A further source of uncertainty may be found in the observed outline, which was derived from satellite radar and does not coincide precisely with the model outputs (in terms of time). Further discussion is provided in Section 4.9.3.

The simplified fluvial model overpredicts to a greater extent when driven by levels than by flows. This could be associated with the accuracy of asset crest heights (used in the level driven approach) compared with asset SoPs (used in the flows driven approach) in AIMS.

4.10.4 Model performance (Test A2)

Model performance scores were derived by comparison of modelled and observed flood outlines. Percentages were calculated as follows.

- Correct wet: proportion of flood extent that is correctly predicted by the model. Modelled extent = observed extent (blue)
- Overprediction: proportion of flood extent that is overpredicted by the model. Modelled extent > observed extent (green)
- Underprediction: proportion of flood extent that is underpredicted by the model. Modelled extent < observed extent (purple)

Skill and bias scores were calculated using the equations given below. ‘Correct dry’ areas are never included in the scores, as this is heavily dependent on the extent of the model domain.

$$SKILL = \frac{Correct\ Wet}{Correct\ Wet + Overprediction + Underprediction}$$

$$BIAS = \frac{Correct\ Wet + Overprediction}{Correct\ Wet + Underprediction}$$

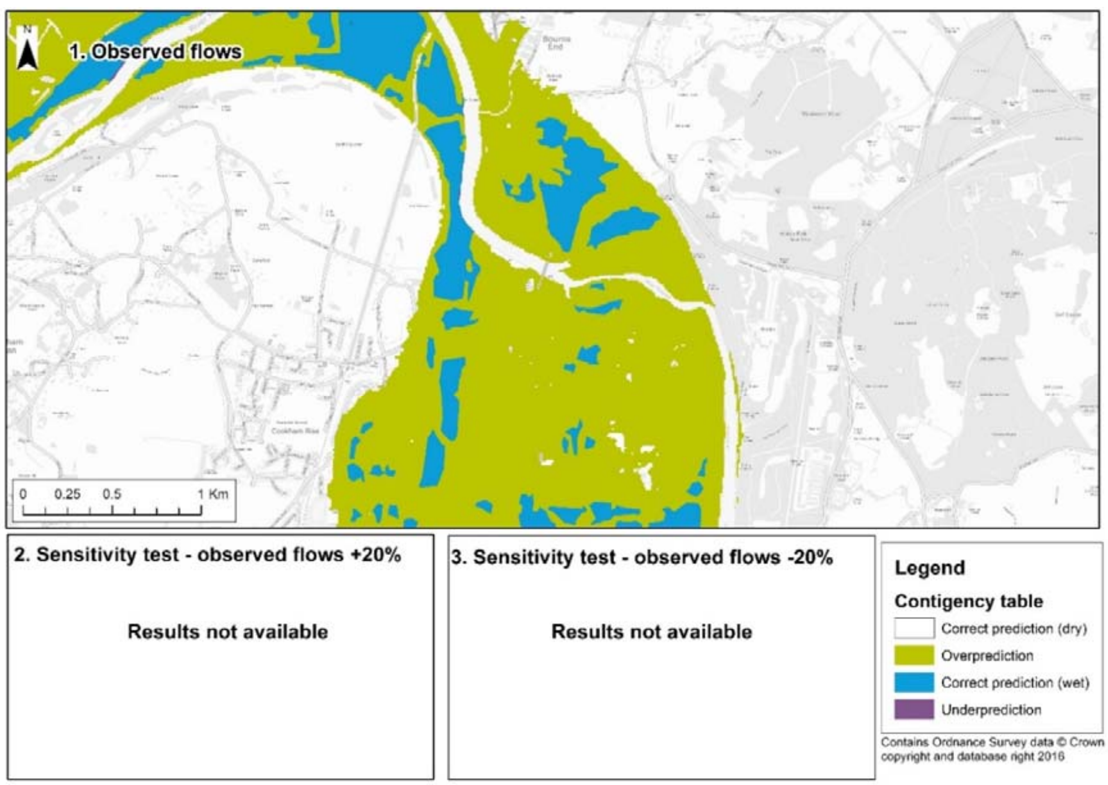


Figure 4.85 Model performance in predicting flooded extent for Maidenhead domain (inset 1): levels input

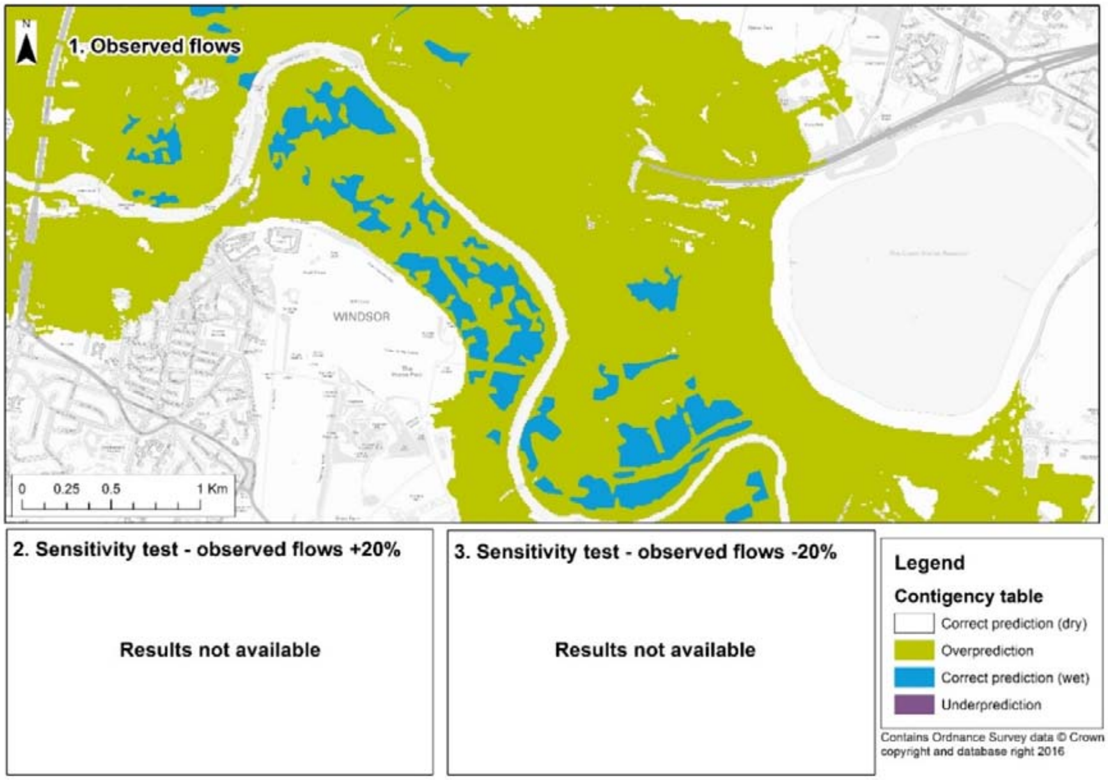


Figure 4.86 Model performance in predicting flooded extent for Bray, Cippenham and Windsor domains (inset 2): levels input

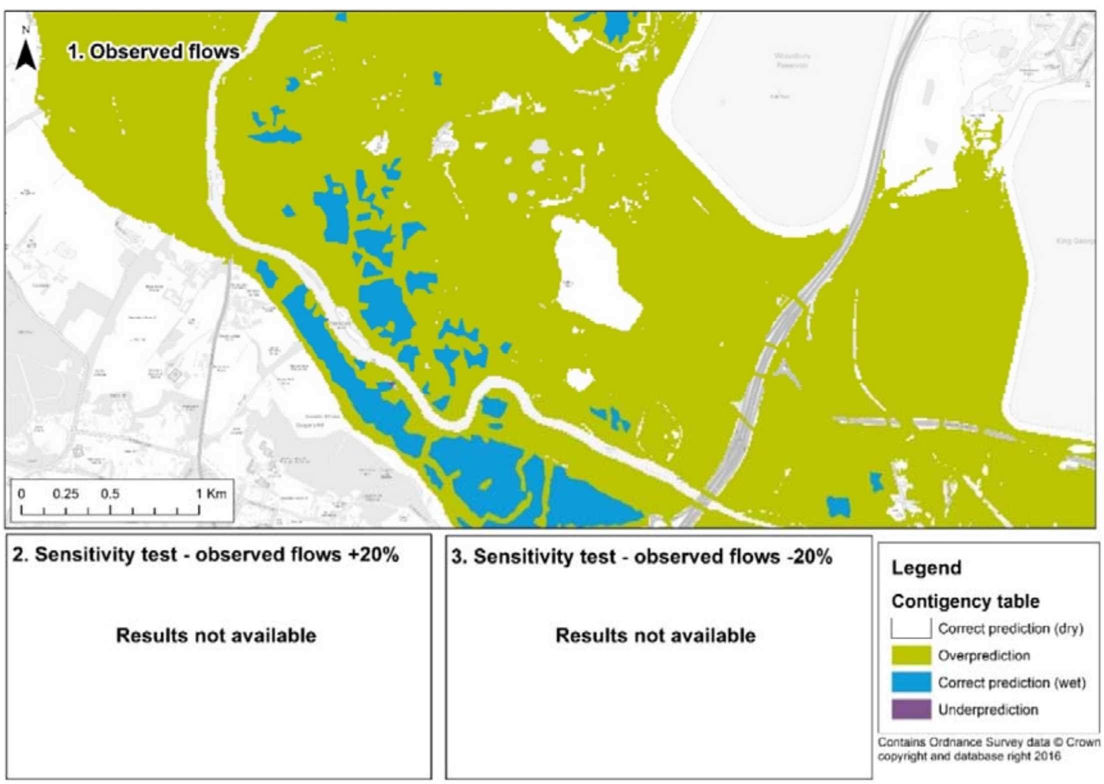


Figure 4.87 Model performance in predicting flooded extent for Windsor and Staines domains (inset 3): levels input

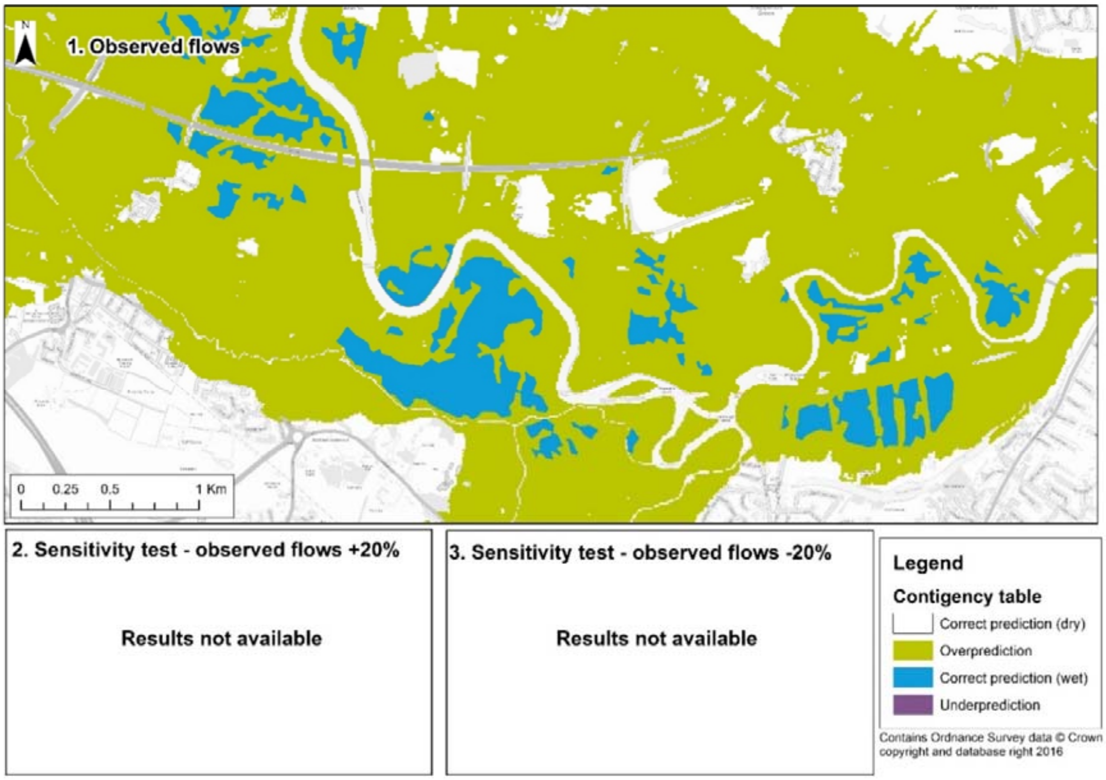


Figure 4.88 Model performance in predicting flooded extent for Staines and Chertsey domains (inset 4): levels input

Table 4.41 Model performance metrics for Thames event: levels input

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
Modelled outline (all)	**6.69**	**93.13**	**0.18**	**0.07**	**14.54**
Modelled outline (within area covered by Flood Warning Areas only)	**4.82**	**95.07**	**0.11**	**0.05**	**20.26**
101	17.66	82.29	0.05	0.18	5.64
102	4.75	95.25	0.00	0.05	21.06
103	13.02	86.92	0.06	0.13	7.64
104	5.32	94.68	0.00	0.05	18.79
105	1.65	98.32	0.04	0.02	59.33
106	3.91	96.09	0.00	0.04	25.56
107	1.38	98.62	0.00	0.01	72.69
108	0.00	100.00	0.00	0.00	0.00
109	0.78	99.22	0.00	0.01	127.53
110	0.18	99.82	0.00	0.00	543.07
111	0.70	99.30	0.00	0.01	143.15
112	0.95	99.05	0.00	0.01	105.55
113	2.39	96.59	1.02	0.02	28.99
114	16.14	83.86	0.00	0.16	6.20
115	2.06	97.94	0.00	0.02	48.57
116	28.23	71.77	0.00	0.28	3.54
117	6.61	93.38	0.01	0.07	15.10
118	6.44	93.48	0.08	0.06	15.31
119	33.32	66.58	0.11	0.33	2.99
120	5.18	94.82	0.00	0.05	19.31
121	3.36	96.64	0.00	0.03	29.75
122	0.00	100.00	0.00	0.00	0.00
123	0.00	100.00	0.00	0.00	0.00
124	0.77	99.23	0.00	0.01	129.25
125	6.81	93.19	0.00	0.07	14.68
126	0.00	100.00	0.00	0.00	0.00

Flood Warning Area	Correct wet (%)	Over-prediction (%)	Under-prediction (%)	Skill	Bias
127	0.00	100.00	0.00	0.00	0.00
128	27.74	72.23	0.03	0.28	3.60
129	4.97	95.03	0.00	0.05	20.11
130	0.26	99.74	0.00	0.00	386.32
131	0.05	99.81	0.14	0.00	515.55
132	1.79	97.99	0.22	0.02	49.63
133	38.14	61.40	0.46	0.38	2.58
134	10.99	87.62	1.39	0.11	7.97
135	5.28	94.72	0.00	0.05	18.95
136	0.00	100.00	0.00	0.00	0.00
137	30.42	63.71	5.87	0.30	2.59
138	0.00	100.00	0.00	0.00	0.00
139	0.00	100.00	0.00	0.00	0.00
140	0.00	100.00	0.00	0.00	0.00

Notes: Metrics are reported for the full modelled flood outline first. Subsequent rows of the table report the metrics for the model flood outline within given Flood Warning Areas. This distinguishes between performance across the full model domain, and performance in locations where there is known to be flood risk to property.

Interpretation

Overall the model significantly overpredicts, although there are some small, localised areas where the model underpredicts. Contributing factors to variations in overprediction and underprediction may also include the model not allowing dynamic flow along the floodplain between discrete assets and not permitting the return of flow to the channel.

Many of the potential reasons for model overprediction are common to the flows driven approach (see Section 4.9.4). However, it is worth re-iterating that differences in the timing of the observed data, relative to model results, introduce uncertainties into the assessment.

An additional source of uncertainty is in the accuracy of asset crest levels, which are used to calculate inflows to the floodplain. In a hydraulically complex catchment, such as this reach of the Thames, inaccuracies in the specification of crest levels may result in apparent inaccuracies in model extent.

4.10.5 Property counts (Test B)

Properties within flood extent

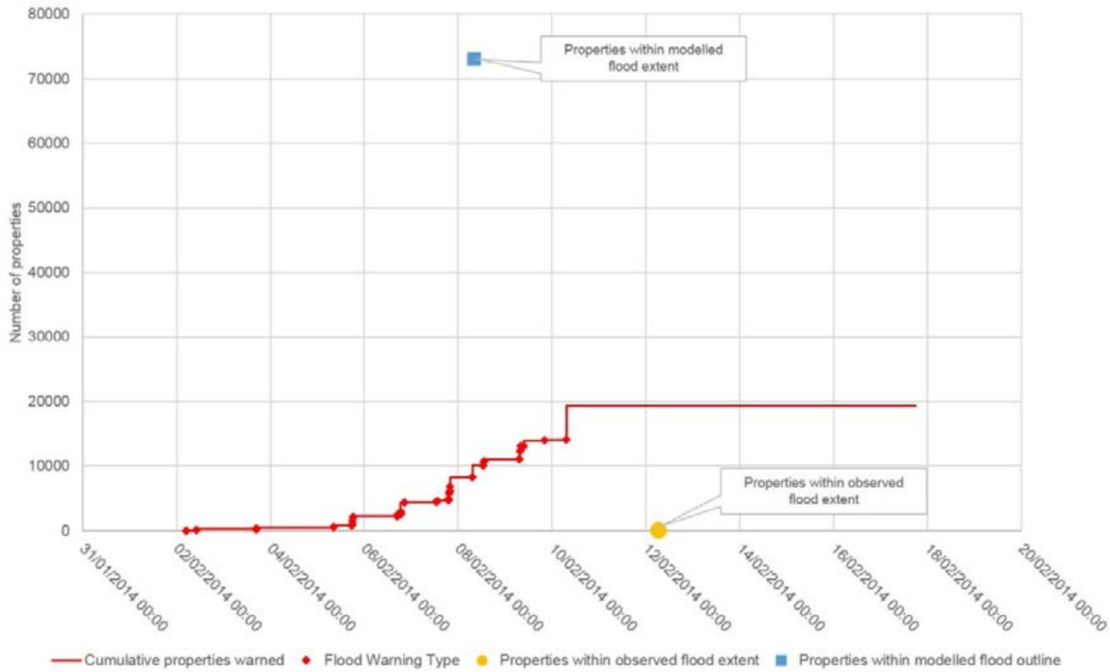


Figure 4.89 Properties within flood extent for Thames event: levels input

Notes: Properties are mapped below.

Table 4.42 Maximum number of flooded properties for Thames event: levels input

Flood Warning Area	Properties warned[1]	Observed[2] 06:09 on 12 February 2014	Predicted[3] 02:00 on 9 February 2014
All	**18,362**	**45**	**64,690**
101	376	4	711
102	530	0	1,013
103	304	4	616
104	1,378	2	2,678
105	171	0	268
106	10	0	87
107	548	2	1,202
108	0	0	1,228
109	0	1	13,212
110	1,240	1	2,176
111	860	1	1,285
112	0	3	17,121
113	838	0	373
114	120	5	266
115	785	0	1,498
116	11	0	37
117	315	1	421
118	0	0	122
119	26	2	58
120	169	0	418
121	325	3	632
122	218	0	334
123	0	0	95
124	0	0	414
125	0	0	2,285
126	0	0	107
127	0	0	6
128	147	1	248

129	1,850	2	2,919
130	771	0	1,083
131	5,184	0	7,675
132	0	2	1,471
133	179	5	399
134	278	1	178
135	194	0	293
136	0	0	777
137	0	5	22
138	87	0	1
139	1,448	0	364
140	0	0	597

Notes: [1] Properties warned: counts of properties within each Flood Warning Area that received a flood warning during the event.
[2] Observed is based on the intersection of NRD property points and observed flood outline.
[3] Predicted is based on the intersection of NRD property points with maximum modelled flood outline.
Some Flood Warning Areas overlap and, as a result, some properties are double-counted in the totals on the first line of the table. Also some Flood Warning Areas have been trimmed to the modelled extent for display purposes and their dimensions may differ compared with the same Flood Warning Areas in other PoCs.

Interpretation

There are significantly more properties within the modelled flood outline than in the observed (64,690 compared with 45). This is a significant increase on properties within the modelled flood outline predicted when using flows as inputs (see Section 4.9.5). The approach is heavily dependent on accurate specification of asset crest levels, in this case provided by AIMS.

Many of the reasons for these apparent discrepancies between properties within the modelled and observed outlines are discussed in relation to the flows case (see Section 4.9.5) and are also relevant here.

Properties mapped by model prediction

Figures 90 to 93 show NRD property points, colour-coded according to whether the model overpredicts, underpredicts or correctly predicts the observed flood outline. Only properties within the existing Flood Warning Area are considered.

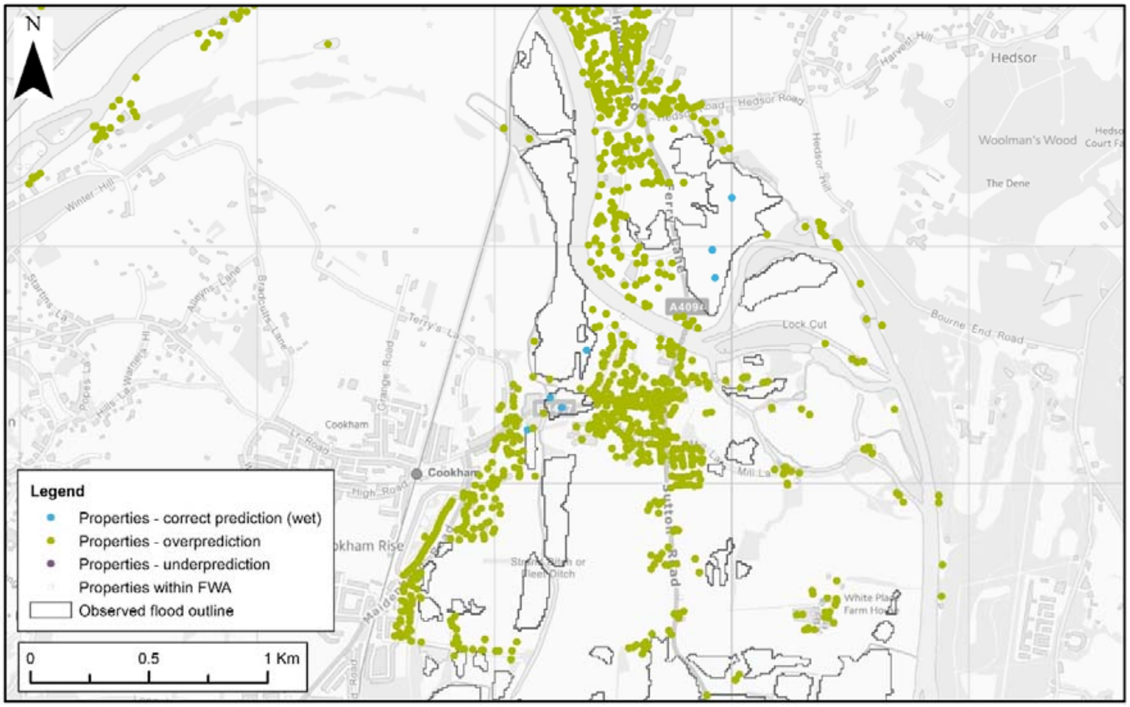


Figure 4.90 Closest modelled time-step to validation data for Maidenhead domain (inset 1): levels input

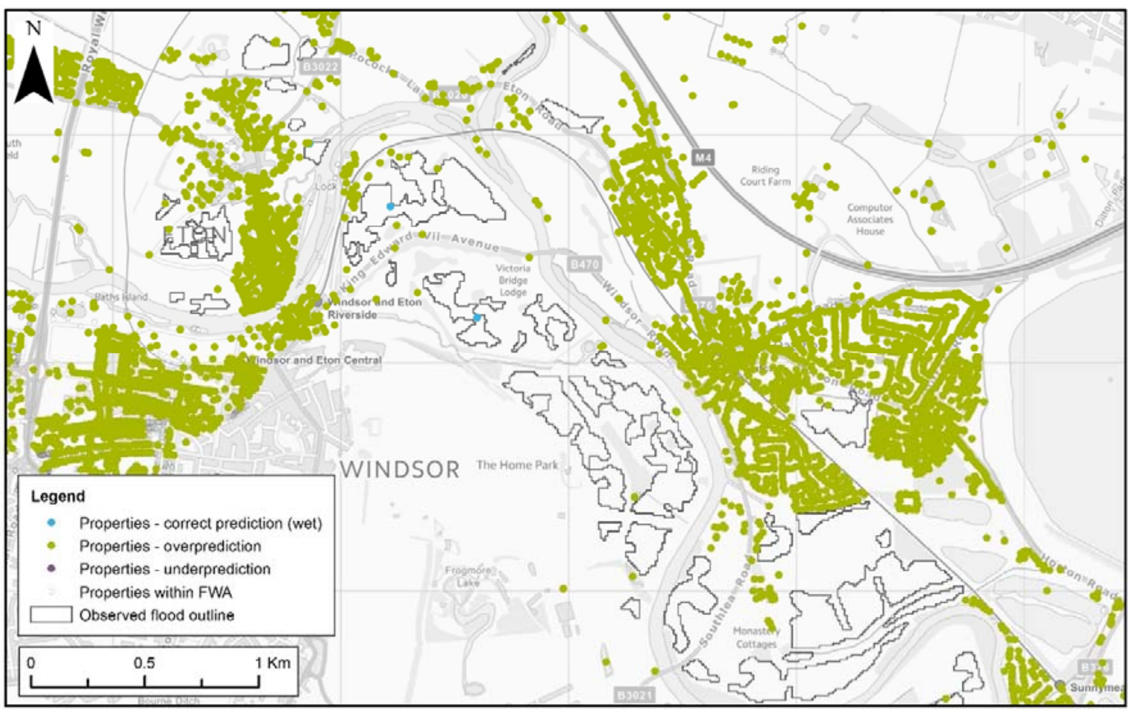


Figure 4.91 Closest modelled time-step to validation data for Bray, Cippenham and Windsor domains (inset 2): levels input

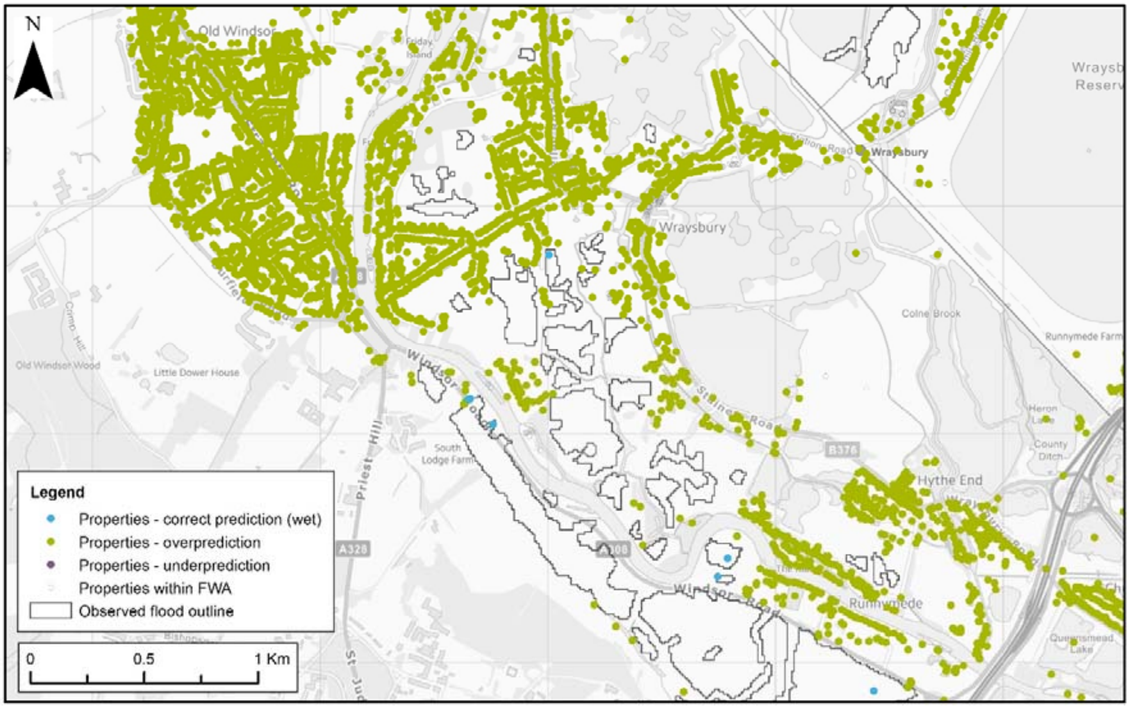


Figure 4.92 Closest modelled time-step to validation data for Windsor and Staines domains (inset 3): levels input

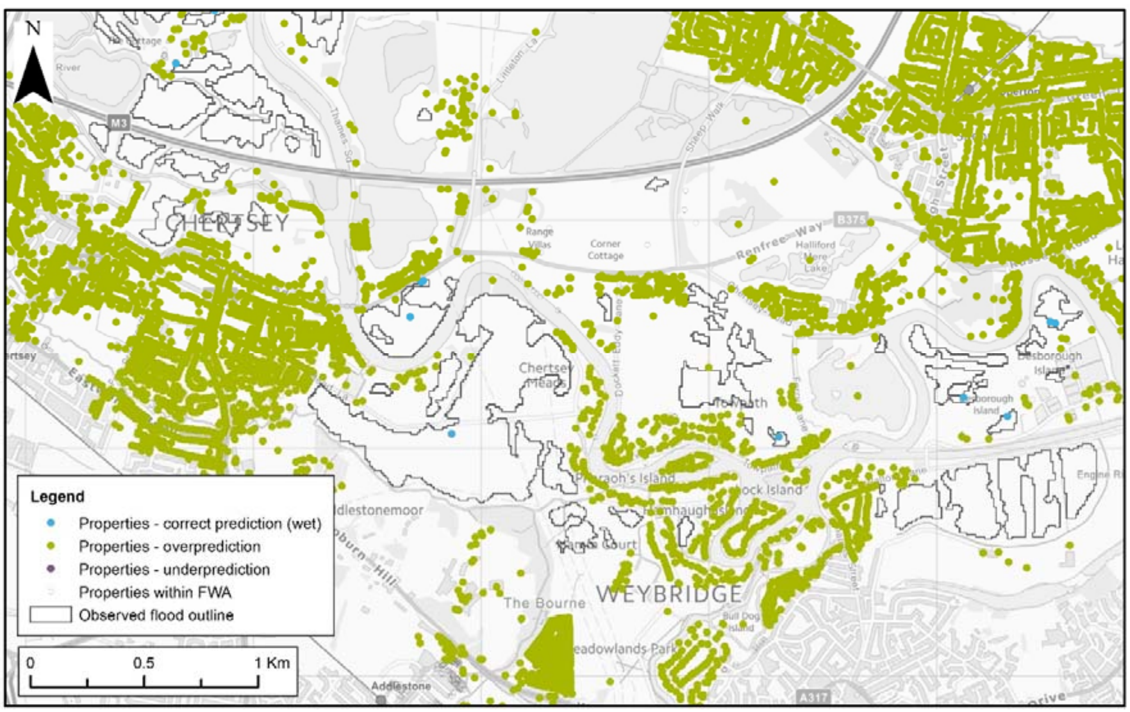


Figure 4.93 Closest modelled time-step to validation data for Staines and Chertsey domains (inset 4): levels input

4.10.6 Depth analysis (Test C)

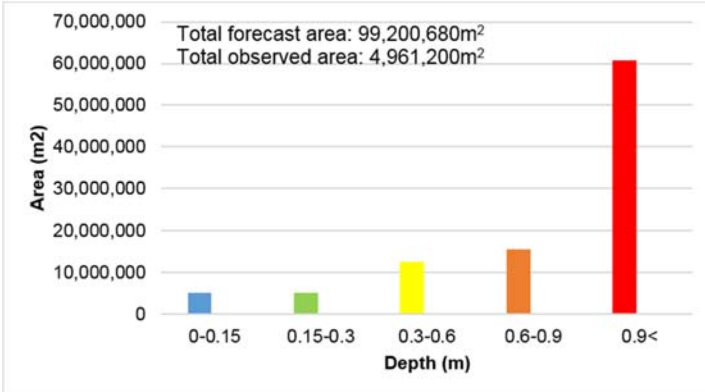


Figure 4.94 Distribution of flooded depths at 01:15 (peak) on 10 February 2014: levels input

Notes: Solid bars show modelled depths (from the PoC option); no observed depths are available.
Channel depths are not included in the modelled results.
Total areas quoted on each plot include the channel area for both forecast and observed results.

Modelled	Observed	Depth (m)
		0.00–0.15
		0.15–0.30
		0.30–0.60
		0.60–0.90
		>0.90

Interpretation

A substantial proportion of the modelled flood extent is deeper than 0.9m (nearly two-thirds of the modelled area). The distribution of depths is skewed to the deepest category, suggesting that the levels case predicts higher depths, as well as significant increases in flood extent, over the model driven with in-channel flows and asset SoP.

Further assessment of the distribution is not possible because there is no observed data on depths in this case study.

4.10.7 Total water level

Figure 4.95 presents the total modelled water level on the floodplain (modelled depth plus land elevation from a LIDAR DTM). The maximum water levels at in-channel nodes are also presented, based on a 1D–2D hydrodynamic model which provided the inputs to this PoC. The channel itself is not represented by this PoC option, and the nature of the simplified fluvial model means that there is no dynamic link between the channel and the floodplain during the model run. This location in Staines-upon-Thames was chosen as there are numerous examples of locations where water levels on the floodplain differ from those in-channel. There is also a high density of receptors. Annotations on the map explain the model results.

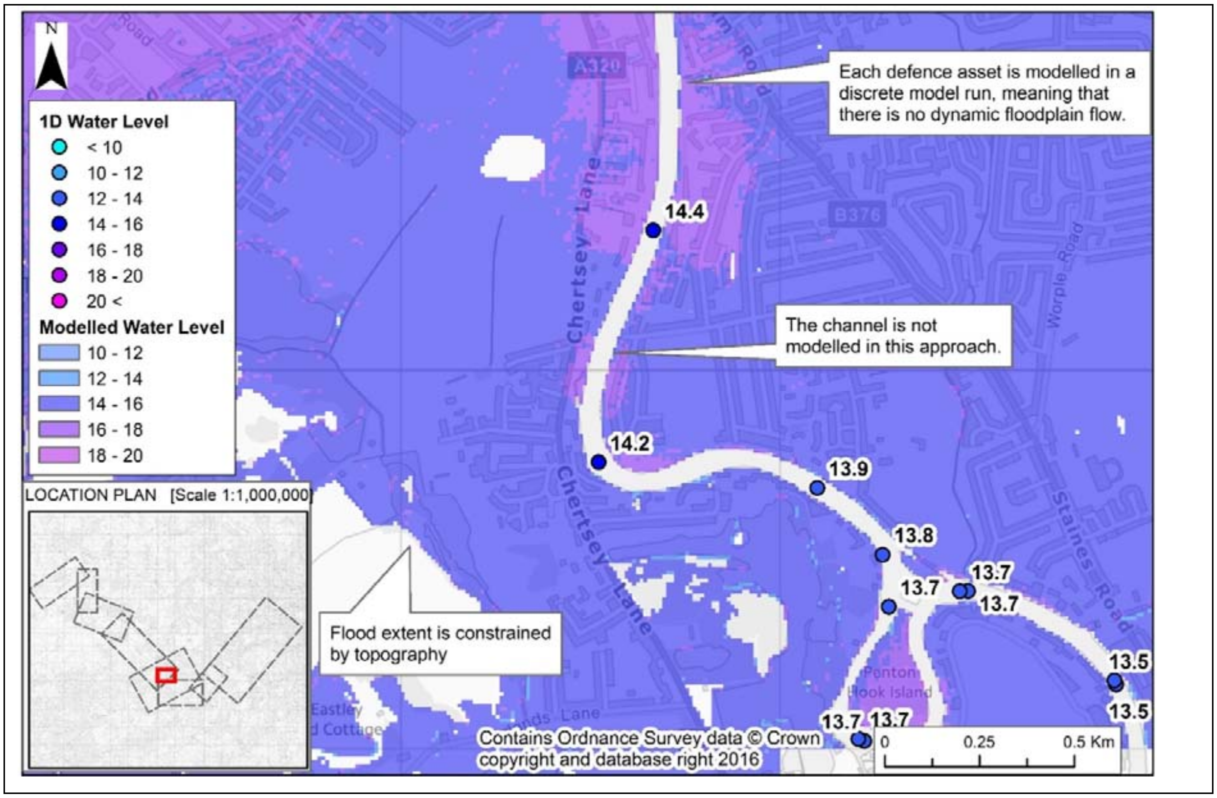


Figure 4.95 **Total modelled water level on the floodplain and maximum water level at in-channel nodes at Staines: levels input**

5 Implementation considerations

This section presents items to be considered by the Environment Agency if this PoC option is developed further towards operational use.

Section **Error! Reference source not found.** details technical considerations (input data, intermediate processing and outputs provided) beyond the specifics of the PoC testing undertaken by this project. The flow chart from Section 2 showing the steps involved in running the system is reproduced as Figure 5.1. Each step is discussed in turn.

Section **Error! Reference source not found.** discusses the skills, cost and effort that might be required to implement and maintain the system.

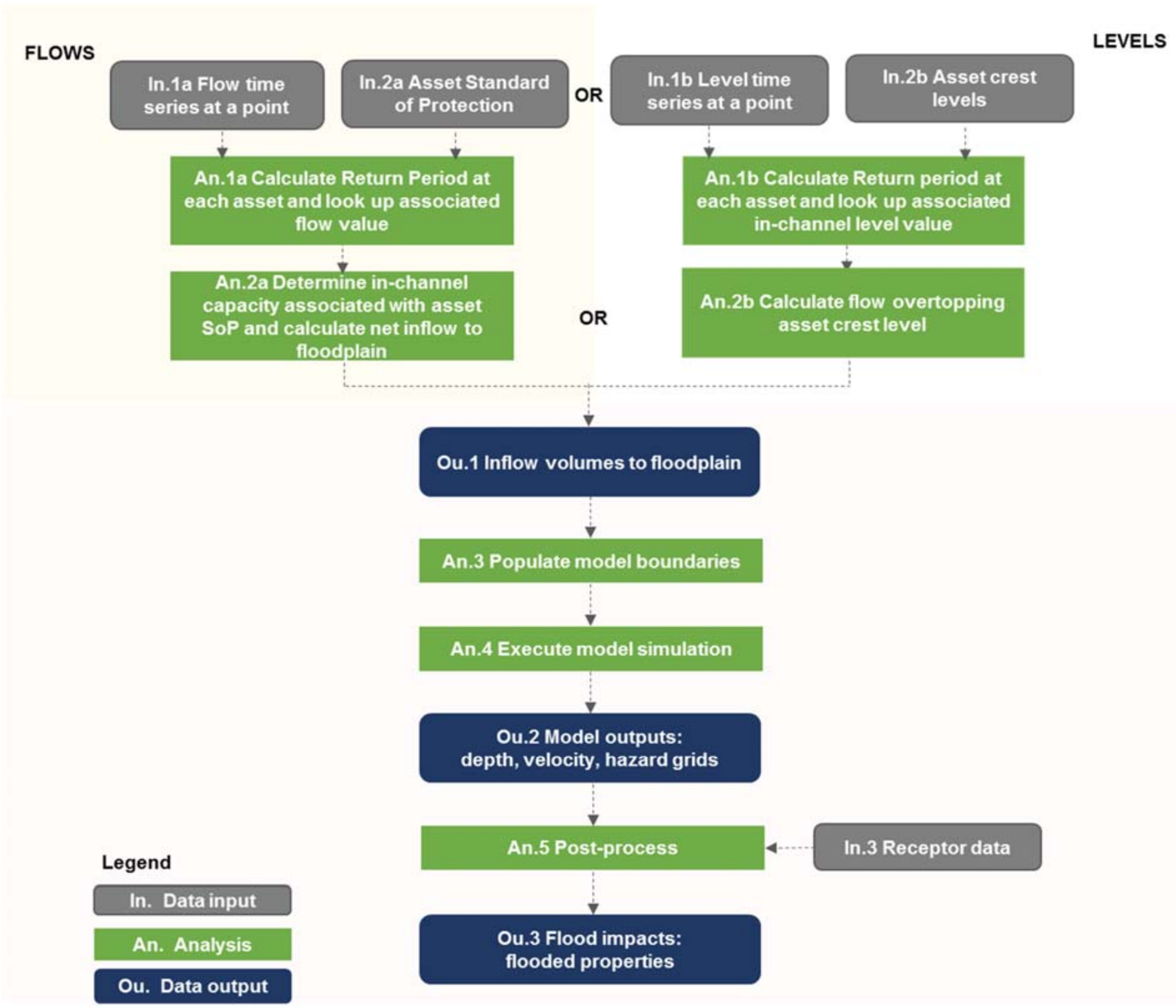


Figure 5.1 Flow chart showing PoC workflow for simplified fluvial modelling

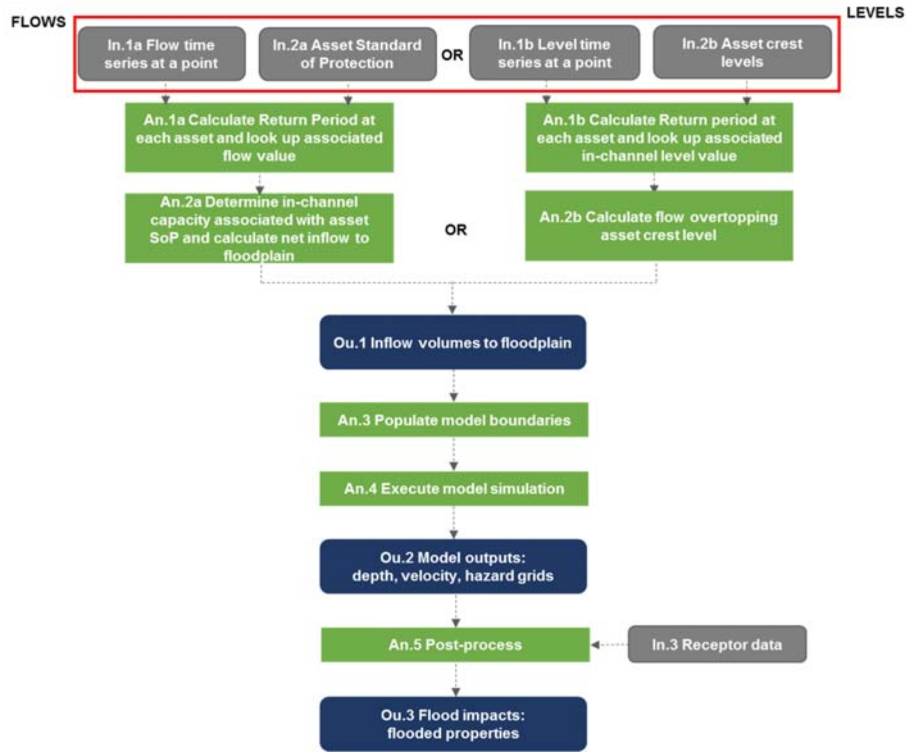
5.1 Operating the system

Table 5.1 Key considerations in using this option within an operational forecasting system

Description	**Priority**
Acceptable model run times for use in operational forecasting. Larger and more complex models will take longer to run.	High
Software and hardware requirements to run model. Non-standard hardware (for example, GPUs) may be required to run models based on the shallow water equations.	High
Transfer of model results – output files can be large (depending on size of model) and might require the transfer of large volumes of data across networks.	High
Appropriate sources of real-time boundary conditions (flow or level time series)	Medium
Mechanisms by which the model boundaries are populated and the model is executed	Medium
Integration within forecasting systems (for example, general adapters or application programming interfaces, APIs) is required to populate model boundaries are populated and execute the model run).	Medium
Post-processing of model runs will require GIS routines to intersect modelled flood outlines/depths with receptors (for example, properties). These routines may be time-consuming to run for large and/or higher resolution models.	Medium

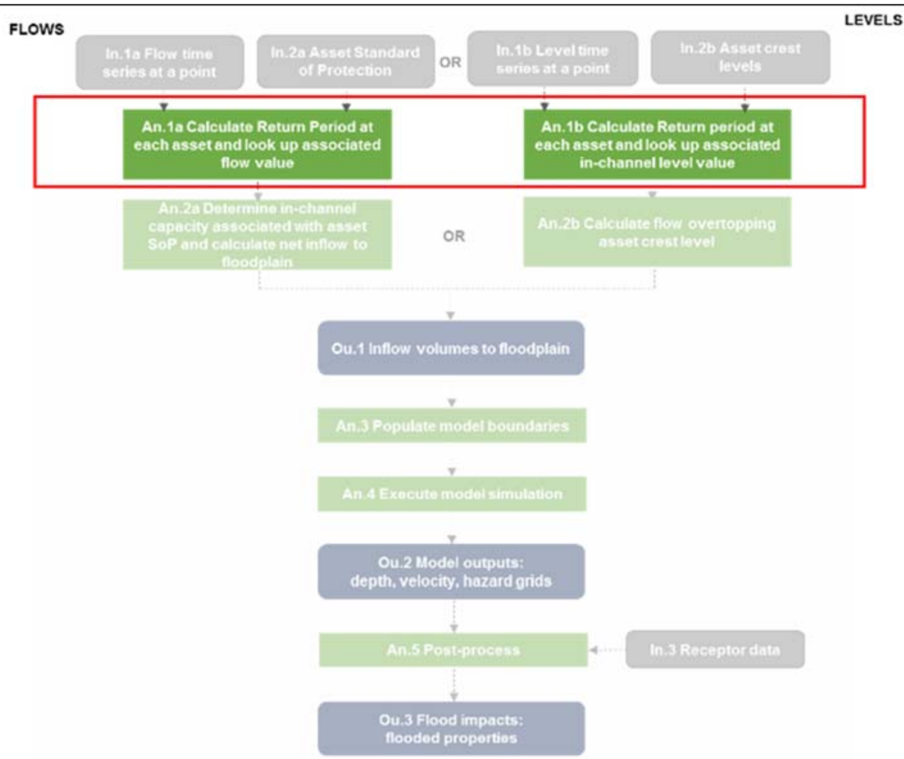
Table 5.2 Detailed considerations

In.1 Input flows/levels data (observed/forecast) and In.2 Input asset data

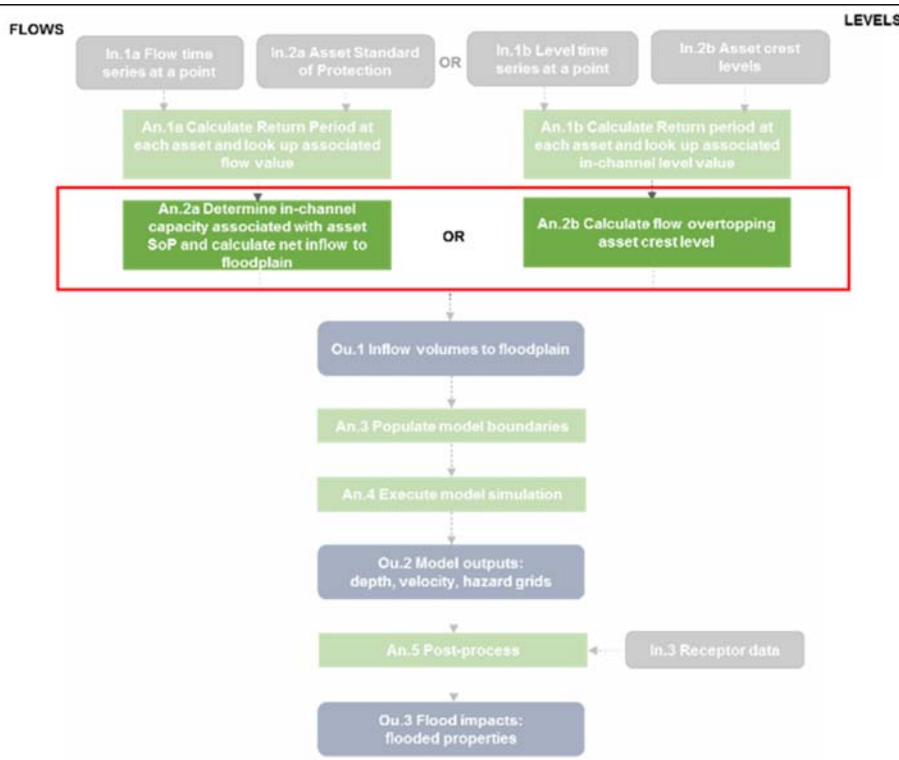
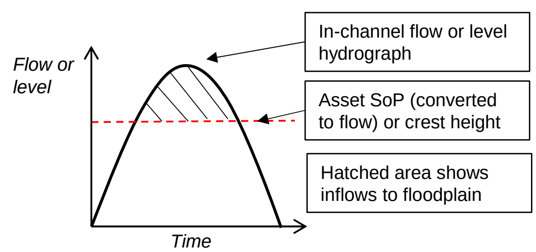


Description	Flow time series or level time series at a gauge are required as the main input for this PoC. Asset SoPs/crest levels (held in AIMS) are needed to calculate inflows to the simplified fluvial model. Consideration should be given to the most appropriate source of real-time flows/levels – their accuracy has a significant impact on the performance of this PoC.
Data overheads	Medium – files containing flow and level data tend to be small. AIMS data are much larger as it is a national dataset, but each model would only require access to data for a specific location of interest.
Run times	Flows/level inputs may be derived from another model. Run times are dependent on the type and size of the model.
Software	May be additional requirements depending on types of inputs.
Hardware	May be additional requirements depending on types of inputs.

An.1. Calculate Return Period and flow look-up

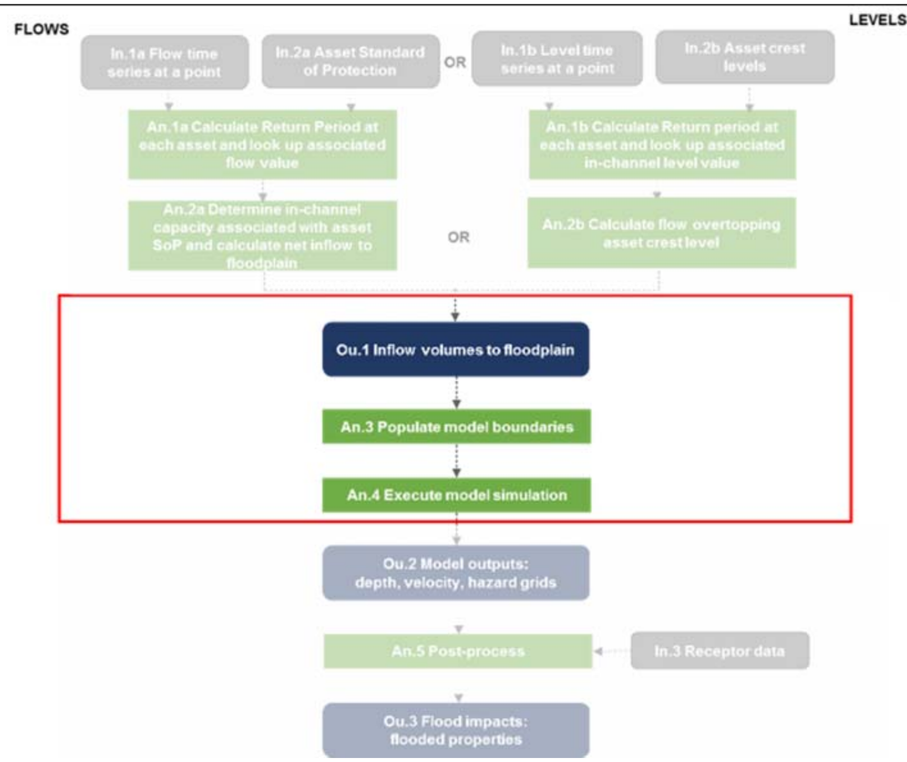


Description	Levels or flows at a gauge or NFFS forecast location are converted to a return period based on a pre-computed frequency analysis at the location. Return periods are then interpolated along the river network using outputs from the following. • National Fluvial Flows Database – estimates of flow for 9 return periods throughout the river network, based on Flood Estimation Handbook methods. The H21 Evidence Update for National Risk Assessment 2016 provides national coverage. • National Fluvial Levels Database – estimates of level for 39 return periods, at 100m intervals along Environment Agency designated Main Rivers. The dataset is currently being updated by the ongoing State of the Nation project. Return periods are linked to flow or level return period look-up at each asset. A local flow or level value is obtained.
Data overheads	Pre-computed standard flood frequency techniques are not widely used for converting flows/levels at a gauge to a return period.
Run times	Quick to compute once look-up is established.
Software	Not applicable
Hardware	Not applicable

<table>
<tr><th colspan="2">An.2. Calculate inflow to floodplain</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Description</td><td>In-channel capacity at an asset is associated with the SoP for flows and crest height for levels. Using this information, inflows to the floodplain are calculated on a per asset basis. The figure below shows the full hydrograph obtained from other model (black line). Separation of flow above the asset SoP or crest height (red line) gives the floodplain inflow to simplified model (black shading).


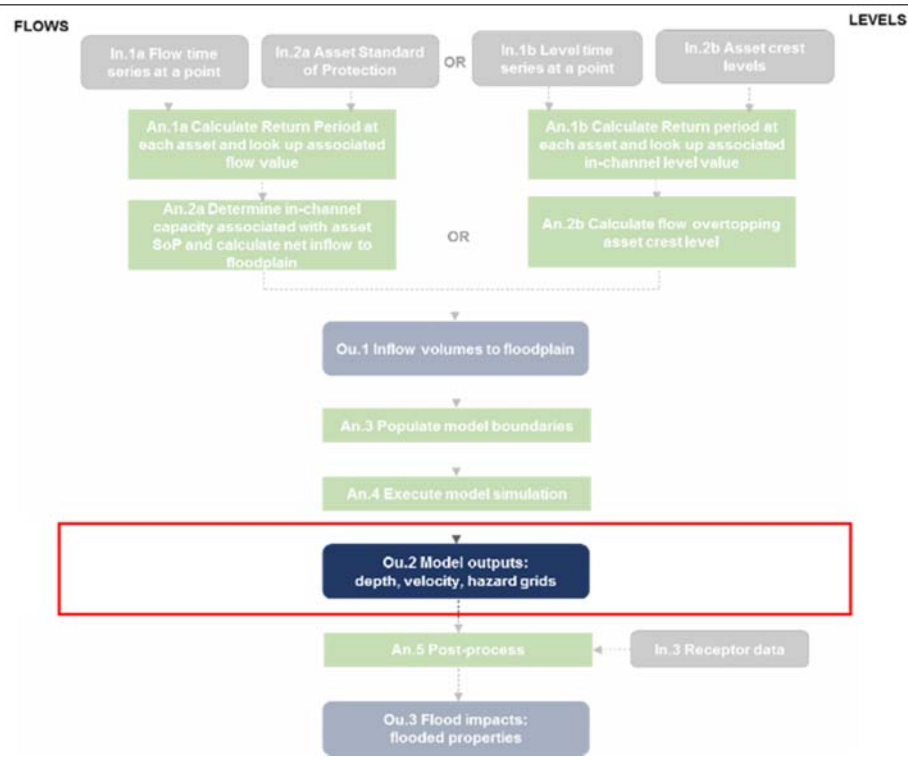
G2G flow outputs can be used instead of hydrograph separation by adjusting for the SoP offered by local flood defence assets. If using G2G data, the flow return period look-ups would be used to calculate the threshold (as shown in the dashed red line in the figure); flows are provided directly by G2G.</td></tr>
<tr><td>Data overheads</td><td>Low – calculation of inflows is simple with small overheads.</td></tr>
<tr><td>Run times</td><td>Low - calculation of inflows is quick can be automated.</td></tr>
<tr><td>Software</td><td>Not applicable</td></tr>
<tr><td>Hardware</td><td>Not applicable</td></tr>
</table>

Ou.1 Inflows to floodplain, An.3 populate model boundaries, An.4 execute model simulation



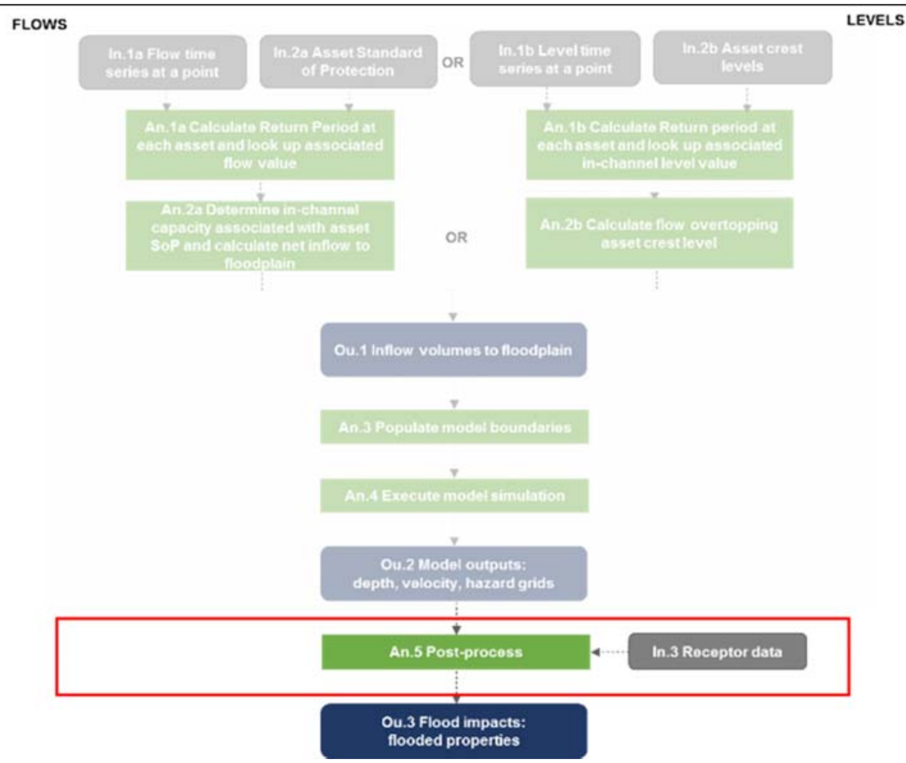
Description	In the NFFS, an adapter (a standalone executable) is used to populate the boundary conditions of the fast spreading model at each asset. The model is executed once populated with floodplain inflows. The model then runs in its native environment.
Data overheads	Low – setting up the model and populating the boundaries can be automated and overheads are small.
Run times	Medium – size of model domain, number of grid cells, number of assets and number of time-steps will all contribute to model run times. Model instability may also further increase run times. Implementation of this PoC option might need to consider a targeted approach to only running models in areas, or at times, of high flood risk.
Software	Fast 2D flood spreading model
Hardware	Non-standard hardware (for example, GPUs) may be required to run models based on the shallow water equations.

Ou. 2 Model outputs



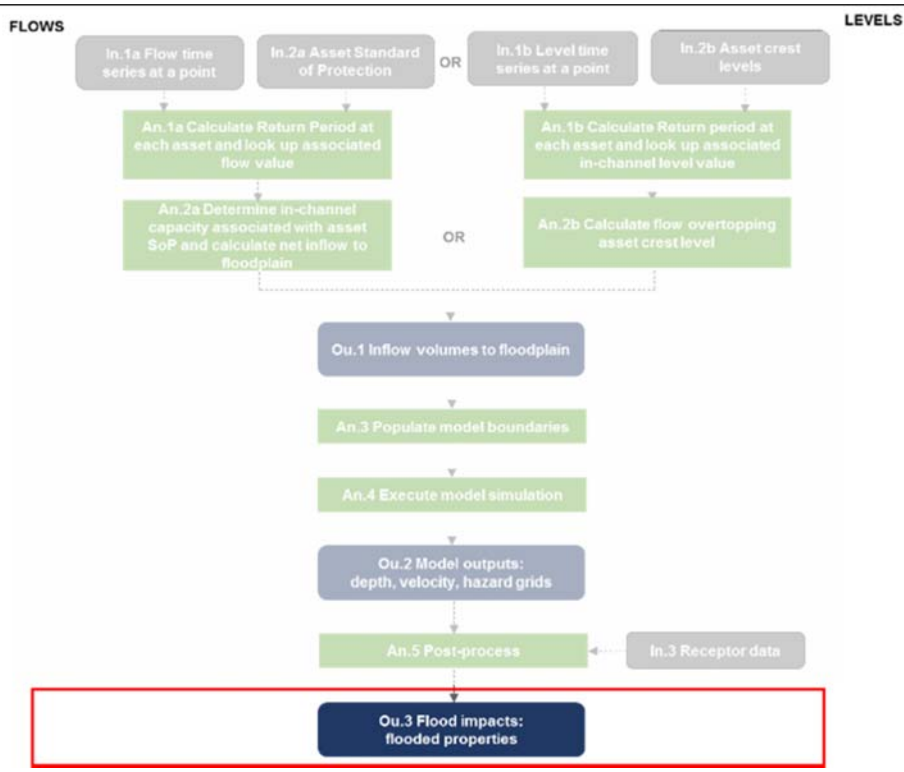
Description	Model outputs are typically raster grids of depth, velocity and hazard for each asset. Results are mosaicked together to produce a flood footprint.
Data overheads	High – file sizes can be large. Factors that will influence this include model domain size, grid resolution and frequency of outputs. There may be opportunities to compress data.
Run times	High – bandwidth required to transmit model results across a network has the potential to be high.
Software	GIS software may be required to view model outputs. Some model output data formats may be more readily accessible than others: .asc files can be read by most GIS packages (ArcGIS, MapInfo, QGIS) Data feeds could be provided to Easimap2, Resilience Direct, NFFS Viewer
Hardware	Dissemination to other systems – network logistics Would require reliable internet connections to transmit large volumes of model results to other systems.

In.3 Receptor data, An.5 Post-process



Description	Post-processing to create outlines and banded depth grids. Intersecting outlines and depth grids with receptor data (for example, properties).
Data overheads	Low – for a single time interval. Has potential to be higher for multiple time intervals and larger grids.
Run times	High – model domain size and grid resolution may influence processing time. It has the potential to be higher for multiple time intervals
Software	GIS software is required to post-process model outputs with receptor data. .shp files can be read, processed and analysed by ArcGIS
Hardware	Fast central processing unit (CPU) card

Ou.3 Flood impacts: flooded properties



Description	Flood outlines and property datasets, typically in GIS format
Data overheads	Low – for a single time interval. Has potential to be higher for multiple time intervals. Transmitting information on flooded properties may require transfer of smaller volumes of data than model results (for example, gridded data of flood depth).
Run times	Low – for post-processed outputs
Software	Data feeds could be provided to Easimap2, Resilience Direct, NFFS Viewer.
Hardware	Transmitting information on flooded properties may require transfer of smaller volumes of data than model results (for example, gridded data of flood depth).

5.2 Implementation and ongoing maintenance of an operational system

Table 5.3 Summary of implementation and maintenance issues for an operational system

<table>
<tr><td colspan="4">Overview</td></tr>
<tr><td colspan="4">This option uses data from existing models or methods to populate the boundaries of the simplified fluvial model. Some additional skills or training may be required to implement and maintain the system.</td></tr>
<tr><td colspan="4">Implementation</td></tr>
<tr><td rowspan="2">Change required</td><td>Low</td><td>Moderate</td><td>Significant</td></tr>
<tr><td colspan="3">This option could be introduced into existing forecasting systems. Adapters for the Flood Early Warning System (FEWS, the forecasting software that underpins the NFFS) are already available for GPU-based models (for example, JFlow, TUFLOW).

Some changes may be required to:

• set up and run simplified fluvial models in existing systems

• to process and disseminate real-time flood mapping and impact information</td></tr>
<tr><td rowspan="2">Cost to implement</td><td>Low</td><td>Moderate</td><td>Significant</td></tr>
<tr><td colspan="3">Setting up new forecasting models may be costly. However, reuse of MDSF2 models and data from the State of the Nation project would allow this option to be implemented relatively efficiently. Configuring models into a forecasting system has a relatively low cost.

This option assumes that inflows are derived from another model or method, and therefore the cost associated with this aspect would be relatively low.</td></tr>
<tr><td>Skills required to implement</td><td colspan="3">Some additional training or skills would be required. Although this option is likely to use software that is already used by the Environment Agency, limited additional training/skills would be required.</td></tr>
<tr><td>Time/effort to implement</td><td colspan="3">This option can be implemented efficiently on a national scale by reusing State of the Nation MDSF2 models and data.

Models required to provide boundary conditions to this option may already exist in the NFFS. If not, some time and effort may need to be spent implementing them into the system.

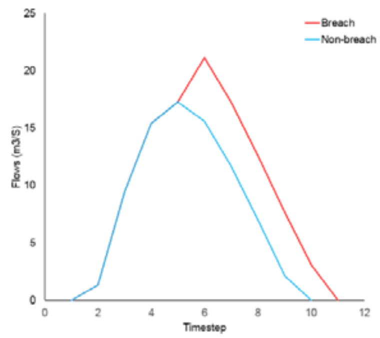
Time and effort will also need to be spent configuring the simplified fluvial model in the system, but this should be relatively straightforward, given that FEWS adapters already exist for a number of hydraulic modelling packages.</td></tr>
</table>

<table>
<tr><th colspan="4">Ongoing maintenance</th></tr>
<tr><td rowspan="2">Difficulty in accommodating change</td><td>Low</td><td>Moderate</td><td>Significant</td></tr>
<tr><td colspan="3">This option would need to accommodate:
updates to existing models and new commissions that may be used to update the simplified fluvial model, or provide boundary conditions
changes in datasets needed to run the simplified fluvial model (for example, asset lines from AIMS)
For practicalities in terms of staff availability and computing resources, this may need to be undertaken at set times (for example, quarterly intervals), which may result in difficulties in accommodating rapid change.</td></tr>
<tr><td rowspan="2">Cost to maintain</td><td>Low</td><td>Moderate</td><td>Significant</td></tr>
<tr><td colspan="3">Cost to update/license the software to run models, if required</td></tr>
<tr><td>Skills required to maintain</td><td colspan="3">Some additional training or skills would be required. However, the approach is conceptually straightforward – the option uses existing models as inputs to a 2D flood spreading model.</td></tr>
<tr><td>Time/effort to maintain</td><td colspan="3">Some time and effort would be needed to maintain the system if datasets (such as asset information or DTMs) are updated.</td></tr>
</table>

6 Scope for further development

Table 6.1 Future data and model improvements that may benefit this option

Description	Impact	Recent examples
Dynamic link between channel and floodplain (as the 1D–2D) not represented	May affect results more in locations not analysed as part of this PoC	
Hybrid approaches that combine outputs from real-time flood modelling and interpolations between pre-computed return periods may offer a solution where run times are prohibitive in real time.	Long run times can be reduced where Flood Areas are large, the hydrographs are long and the forecast return periods are large.	Flood maps for each return period in the look-ups could be pre-computed and then a flood map could be interpolated or extrapolate for the forecast return period. These interpolated maps could then be mosaicked with maps calculated in real time to provide the flood footprint.
Increases to computer processing speed	Faster model run times, particularly for larger models	Thames simplified fluvial run times could be shortened.
Updates to, or higher resolution geometry data, allowing improvements to accuracy of how topography is modelled	Improved model accuracy (although inclusion of higher resolution detail may increase model run times)	Some LIDAR datasets are periodically re-flown.
Recognition and maintenance of national flow look-ups (National Fluvial Flows Database and National Fluvial Levels Database)	Option to run the Rapid Flood Spreading Model (RFSM) with flows or levels at all locations	
Updates to AIMS asset data	Improved calculation of inflows to floodplain using SoP or crest height	
Improvements to accuracy of flow prediction (for example, driven by improvements to rainfall forecasts)	Model boundary conditions specified with greater accuracy, resulting in improved model performance	This project made use of G2G outputs, driven by the MOGREPS data that was available at the time of the Cockermouth event (November 2009). At that time, MOGREPS had 24km resolution and produced 3 hour rainfall totals. The current MOGREPS product now has 2.2km resolution and produces 15 minute rainfall totals.
Breaching can be incorporated through	Option to run a breach scenario in real time	The graph below shows hydrographs for a baseline case

Description	Impact	Recent examples
simple adjustments in defence SoP, crest level or fragility curve models such as RASP		and a breach scenario at a single asset with an SoP of 20 years. The breach occurs at the peak of the baseline hydrograph. The SoP is lowered from 20 years to 5 years to simulate the breach. More volume is added to the floodplain and the time of inundation is increased. 

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