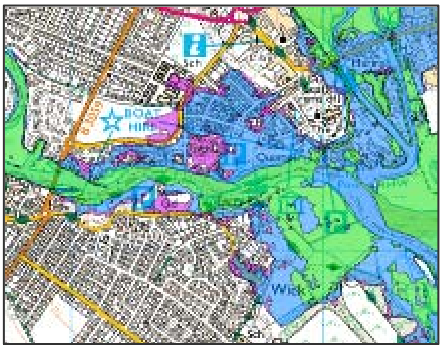
Christchurch Borough Council

Strategic Flood Risk Assessment

Level 2 SFRA – Modelling Report (Volume III)

May 2009

Halcrow Group Limited



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Burderop Park Swindon Wiltshire SN4 0QD
Tel +44 (0)1793 812479 Fax +44 (0)1793 812089
www.halcrow.com

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May 2009

Contents Amendment Record

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Signed
1	Draft	Modelling report	25 Feb 2009	C Wood C Grice
2	Final draft for approval		21 May 2009	O Snowden C Weeks D Wilson PS Rayner

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List of Abbreviations

AMAX	Annual Maximum (Flow) Series
AREA	Catchment drainage area (km^2)
BFIHOST	Base flow index derived using the HOST classification*
FARL	Index of flood attenuation due to reservoirs and lakes*
FEH	Flood Estimation Handbook
FRA	Flood Risk Area
PROPWET	Index of proportion of time that soils are wet*
QMED	Median Flow *
ReFH	Revitalised rainfall-runoff method
SAAR	1961-90 standard-period average annual rainfall (mm) *
SFRA	Strategic Flood Risk Assessment
SPR	Standard percentage runoff (%)*
Tp	Time to peak
SPRHOST	SPR derived using the HOST classification*
$URBEXT_{1990}$	FEH index of fractional urban extent for 1990*
$URBEXT_{2000}$	FEH index of fractional urban extent for 2000

*For more detailed explanation, reference can be made to the FEH 130-page Volume 5: Catchment descriptors.

1 Introduction

In June 2008, Christchurch Borough Council (CBC) commissioned Halcrow to produce a Level 2 Strategic Flood Risk Assessment (SFRA) for all populated areas at risk of flooding and locations being considered for future development (identified by Level 1 SFRA).

This Level 2 SFRA is in accordance with Planning Policy Statement 25: Development and Flood Risk (PPS25) and its accompanying practice guide. The areas investigated are shown in Figure 1.1.

This Level 2 SFRA refines and builds upon the recent Level 1 SFRA (February 2008), providing more detailed information on all forms of flood risk: fluvial (rivers), tidal, surface water, groundwater, sewer and from impounded water bodies (reservoirs), both now and in the future given the likely impacts of climate change. The Level 2 SFRA is presented in the main report (***Volume I***), and this modelling report provides the technical detail that supports this.

A series of detailed hydraulic models have been developed for flood risk areas that had only previously been modelled by the Environment Agency using a national generalised computer model (JFlow). Where appropriate, 2-D modelling software (TUFLOW) has been used to produce peak flood extents, depths and flow velocities and this information has been used to produce flood hazard classifications and flood simulations to illustrate the rate of onset of flooding.

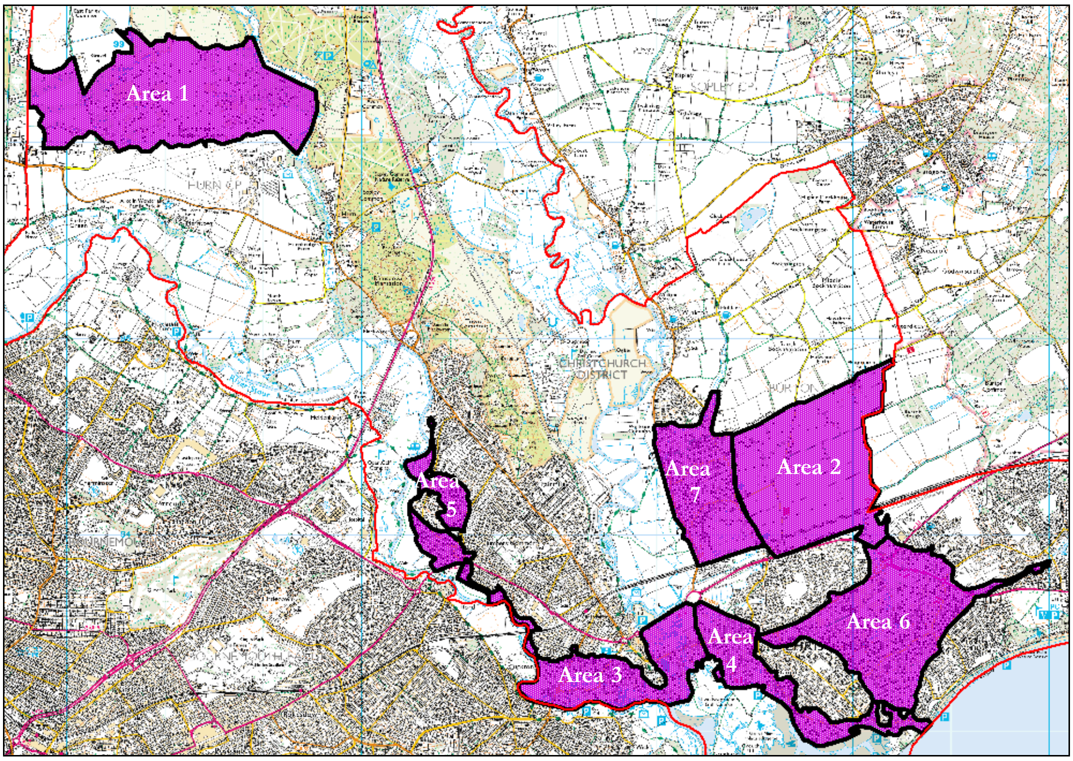


Figure 1.1 Level 2 SFRA areas

2 Assessment Methodology

2.1 Overview

The assessment methodology to improve the flood risk mapping for the seven areas under review involved: review of data and existing models (Section 3), hydrological assessment (Sections 4 to 7), hydraulic assessment (Sections 8 to 10) and flood mapping (Section 11). The approach is consistent with that specified by the Environment Agency for flood mapping commissions under their Strategic Flood Risk Management framework.

Further details of the methodology adopted are given below.

2.2 Review of data/models

There are significant data sets available for the areas under study, including existing hydraulic models, LiDAR topographic data, OS maps and FloodZone/historic flood limits.

The original models used for the study have been previously approved by the Environment Agency, therefore no form of model review/checking has been undertaken for this study.

The flood limits and LiDAR data were used to review the data requirements for FRA's with no existing hydraulic models and inform the survey requirement to build a model suitable for a SFRA assessment.

2.3 Hydrological assessment

The hydrological assessment provides an analysis of flood frequencies (20, 100 and 1000 year) for the sites of interest not modelled previously. The assessment is based on the latest FEH methods of analysis and some earlier methodologies as agreed with the Environment Agency.

Seven approaches were considered for deriving flood flow estimates for catchments to the downstream boundary of each area (except for Area 2 – see section 5.1). Flood flow estimates at key locations within each catchment for input into the hydraulic models, were then derived by scaling the ReFH hydrograph at each inflow point based on the total catchment hydrograph.

A separate hydrology report was issued in November 2008 with the results approved by the Environment Agency before modelling proceeded.

2.4 *Hydraulic assessment*

This flood mapping output will update the Level 1 SFRA Flood Zone maps and provide modelling/mapping data and tools that are state-of-the-art, appropriate to flood hazard mapping and other requirements.

The selected modelling method is ISIS (1D modelling) and ISIS-TUFLOW (2D modelling). ISIS provides accurate simulation of in-channel hydraulics for a river system, coupled with TUFLOW that gives detailed out-of-bank representation of the flooding routes, depths and velocities, and relies on accurate floodplain data to give accurate results.

Outputs from the TUFLOW include hazard mapping (by calculating the depth and velocity index for each point within the grid), flow routes, velocity vectors and flood depths at different timesteps.

The detailed modelling/mapping involved the use of several programmes:

- ISIS for the in-bank 1D model (and out of bank if not coupled to TUFLOW)
- MapInfo to display model inputs, such as the river line, 2D domain boundaries, spills, embankments, topography (LiDAR), etc.
- Text file programme (Ultra Edit recommended) to create the instruction files for the input data, joining models and data, and output information required.
- ESTRY 1D model – a 1D 'DOS-type' model that allows for pipes, culverts and other watercourses to be modelled in the 2D domain.
- TUFLOW (dos programme) to run the flows and depths into the 2D domain from the ISIS model outputs.
- ISIS Mapper to view flood extents, flood depths, flow velocities and to create flood simulations.

2.5 *Flood mapping outputs*

SFRA flood zones, flood depths (to the year 2126 with defences only) and flood hazard have been mapped and are available as hard copes (***Volume II***) as detailed in (***Volume I, Appendix B***). All maps are A1 size and are provided at the 1:25,000 scale, except for the airport and coastal area only maps (Map 5a, and Map Set 12) which are provided at the 1:10,000 scale.

GIS (ArcGIS and Mapinfo) files of the SFRA flood zones, depth, velocity and hazard mapping also accompany the SFRA reports on DVD.

3 Review of survey data / models

3.1 *Overview*

The review included site assessments of the rivers under study, and technical review of the available flood defences data, survey data including channel cross sections and LiDAR floodplain survey, and original models used for flood mapping. These models cover the Hampshire Avon, Lower Stour, Mudeford and Stanpit, and tidal areas through Christchurch. This review work is important as it establishes the most appropriate data for improving the original models and developing the new models where required.

3.2 *Site assessments*

Site assessments were undertaken on the 11 June and 1 July 2008 by the Environment Agency and Halcrow, involving walkover surveys to assess river conditions and agree the river/culvert survey requirements for Area 1 (Bournemouth International Airport), Area 2 (River Mude) and Area 7 (Clockhouse Stream and Burton Brook). Site photographs are supplied on DVD with the site photograph locations detailed in Appendix A. The survey specification detailing the location of cross sections for survey is provided in Appendix B.

A further site assessment was conducted in January 2009 to examine all flood defences, assess their condition and scope for raising and extending to increase the standard of protection.

3.3 *Flood defences data*

All formal flood defences are identified for areas where modelling/mapping is required.

- Data has been obtained from the Environment Agency's NFCDD database and CBC.
- All defences have been mapped (***Volume II, Maps 1 and 4***) with details of these defences provided in ***Volume I, Appendix E***.
- Flood defences have been included in the GIS mapping, and any future schemes can be added to this GIS layer.
- The condition of key defences was assessed in a site visit in January 2009.

For modelling/mapping purposes the Environment Agency require assessment of only formal flood defence schemes, designed and constructed to a specific standard of protection based on past experience and standards. Other informal or defacto defences are not considered as they have not been formally recognised as providing flood protection.

Further details on flood defences are included in the Main Report (***Volume I***).

3.4 *Survey data*

The river/culvert surveys (July 2008) involved surveying river cross sections and obtaining details of culverts in the area of Bournemouth International Airport (Area 1), River Mude (Area 2) and in the village of Burton (Area 6 – Clockhouse Stream and Burton Brook).

Surveys were carried out to a previously installed control, with the vertical control established relative to Ordnance Datum at Newlyn, and horizontal control orientated to the Ordnance Survey National Grid. A series of temporary survey stations were installed along the channel reaches, and data then collected by either total station or manual levelling.

All major surface features and levels were included in the survey where health and safety implications and access restrictions allow. Silt depths built-up in the pipes and culverts were also recorded (varied up to 0.1m) as detailed in the Main Report (***Volume I, Appendix C***).

The precision of heights on hard surfaces may be taken, to a 96% confidence level, to be within ±20mm relative to the control station height. Every effort was made to survey the cross sections at the locations specified on the survey technical note (7 July 2008). However, due to extensive vegetation cover and other site restrictions some river cross section positions were relocated or omitted.

The survey method and results are presented in a separate survey report (Halcrow, July 2008), and the survey data provided in a format appropriate for model development (compatible with Halcrow's ISIS modelling software). Graphs comparing the surveyed cross sections to the LiDAR DTM are included in Appendix C.

River Mude Channel Survey

A river channel survey (Ref EA111SVY05299) was commissioned by the Environment Agency in 2007, which consisted of 36 sections from the ford at Watery Lane to Christchurch harbour. The survey was commission due to inaccuracies in the LiDAR data as the Mude valley is mainly wooded. Sections to the north of the wooded areas have been compared to LiDAR

LiDAR floodplain survey

LiDAR surveys cover all FRA zones, where multiple grids are encountered they are treated as a stack, where levels retained from highest grid in the stack. Two LiDAR detailed DTM's were constructed for the study covering Area 1 and Areas 2, 6 and 7, the files used to create these DTM's are detailed in Tables 3.1 and 3.2. Due to the locations of Areas 2, 6 and 7 the LiDAR DTM has been merged - the area includes 1m and 2m resolution LiDAR.

Table 3.1: Area 1 - LiDAR

Stack	Polygon	Resolution	Filename	Date Flown
1	P_3346	1m	v0043116, v0043117, v0043119, v0043120, v0043124, v00431250	9th March 2005

Table 3.2: Areas 2, 6 and 7 - LiDAR

Stack	Polygon	Resolution	Filename	Date Flown
1	P_3903	1m	v0068027, v0068028, v0068025	16th Nov 2006
1	P_4865	2m	v0068855, v0068856, v0068861, v0068862, v0068863, v0068864, v0068865, v0068870, v0068871, v0068872, v0068873, v0068874, v0068876, v0068877, v0068878, v0068879, v0068882, v0068883, v0068884, v0068887, v0068888, v0068892	2nd Dec 2006
2	P_3850	1m	v0048176, v0048177, v0048181, v0048182, v0048185	27th Oct 2005
3 *	P_3060	2m	v0038830, v0038831, v0038833, v0038834, v0038835, v0038838, v0038839, v0038842, v0038843, v0038846	14th Feb 2005
3 *	P_3577	2m	v0050918, v0050920, v0050921, v0050924, v0050925, v0050929	7th Dec 2005

** not used overlapped by more recent LiDAR*

3.5 Original hydraulic models

The original models used for the study have been previously approved by the Environment Agency, therefore no form of model review/checking has been undertaken for this study

Hampshire Avon – Christchurch Model

The ISIS-TUFLOW model covering Christchurch developed for the Hampshire Avon Flood Mapping Study (built by Halcrow, April 2008) was used for this study. No changes were made to any topographic features of the model e.g. 1D cross sections or the 2D DTM. However, updates were made to the inflow and tidal boundaries to incorporate a revised inflow hydrograph and tidal boundary which impact the original model results. This is explained further in Section 9.

Lower Stour

The TUFLOW model developed for the September 2006 Lower Stour Hydraulic Model and Flood Study (built by Capita Symonds, SW697) was used for this study. No changes were made to any topographic features of the model or original inflows and tidal boundaries.

Mudeford and Stanpit

The TUFLOW model developed for the Mudeford & Stanpit Pre feasibility report (built by Haskoning, February 2008) was not used for this study. As recommended by the Environment agency the Christchurch tidal model DTM was extended to incorporate the area covered by the Stanpit and Mudeford model.

Christchurch Tidal Model

The TUFLOW model developed for the South Wessex Tidal Flood Zones Compliance Main Stage (built by Haskoning, Nov 2007) was used for this study. The 2D domain was extended to include the area covered by the Mudeford and Stanpit model. The domain was extended using filtered LiDAR used in the original study.

Bure Brook

The ISIS model developed for the Bure Brook (built by Capita Symonds, Sept 2008) was used for this study. No changes were made to any topographic features of the model or original inflows. Tidal boundaries were updated to include a peak water level of 1.2mAOD. This is representative of the mean spring tide cycle extracted from the data measured at Priory Quay in 2005 (Capita Symonds, 2006).

The model contains the watercourse of Bure Brook, Chewton Common Stream and formal flood defence at Nea Meadows (flood storage area, located upstream of the study limit). The model contains a 2D domain at Terrington Avenue culvert (upstream of study limit), it was agreed with the Environment Agency that flows from the ISIS only model could be used for this study, as there are only minor differences in flow at the area of interest.

4 Hydrological Assessment: Approach

4.1 *Overview*

The overall objective of the hydrological assessment is to derive flood flow estimates to be used as inputs to the hydraulic models. Standard methods were followed consistent with guidance of the Environment Agency. This section of the report outlines the approach and methods used in the hydrological assessment.

4.2 *SFRA catchments*

Christchurch encompasses the lower reaches of the Hampshire Avon and the Stour catchments. These major rivers join in Christchurch town centre, before flowing into Christchurch Harbour a short distance downstream.

4.3 *Flood risk areas for Level 2 SFRA*

The key flood risk areas of interest to be modelled for this project (Figure 1.1) are:

- Area 1 - Bournemouth International Airport
- Area 2 – RSS Area of Search M, east of Burton
- Area 3 - Town Centre
- Area 4 - Stanpit, Mudeford, Purewell – fluvial and tidal
- Area 5 – West Christchurch
- Area 6 – River Mude and Bure Brook
- Area 7 – Burton

Hydrological assessment has been undertaken for the following sites: Area 1 (subdivided into north and south), Area 2, Area 6 and Area 7 (subdivided as Clockhouse Stream and Burton Stream) – see Figure 4.1 for the locations of these catchments.

Some of the sites have been modelled previously (i.e. Areas 3, 4, 5 and 6 - Bure Brook only) and so where models and hydrological data (and hydraulic model results) are available, these have been used in this Level 2 SFRA work, e.g. Hampshire Avon model (Area 3), Lower Stour model (Area 5) and Bure Brook model (Area 6).

4.4 *Objectives for hydrological analysis*

The objectives agreed for this hydrological analysis are to provide:

- Background and understanding of the catchment's flood mechanisms
- Assessment of flood frequencies at key gauging stations and ungauged sites
- Set of design flood hydrographs needed for the river modelling.

Flood frequencies (20, 100 and 1000 year) have been computed for all sites of interest using the latest Flood Estimation Handbook (FEH) methods of analysis and some earlier methodologies as agreed with the Environment Agency. The seven methods considered for flood frequency estimation are listed below:

- Single site analysis
- Statistical Pooling Group analysis
- Revitalised rainfall-runoff model (ReFH)
- Rainfall-runoff model (superseded by ReFH)
- Small catchment method (superseded by FEH)
- Rational and modified rational methods – not applicable to the subject sites
- Automated FEH method used to generate inflows for Jflow modelling

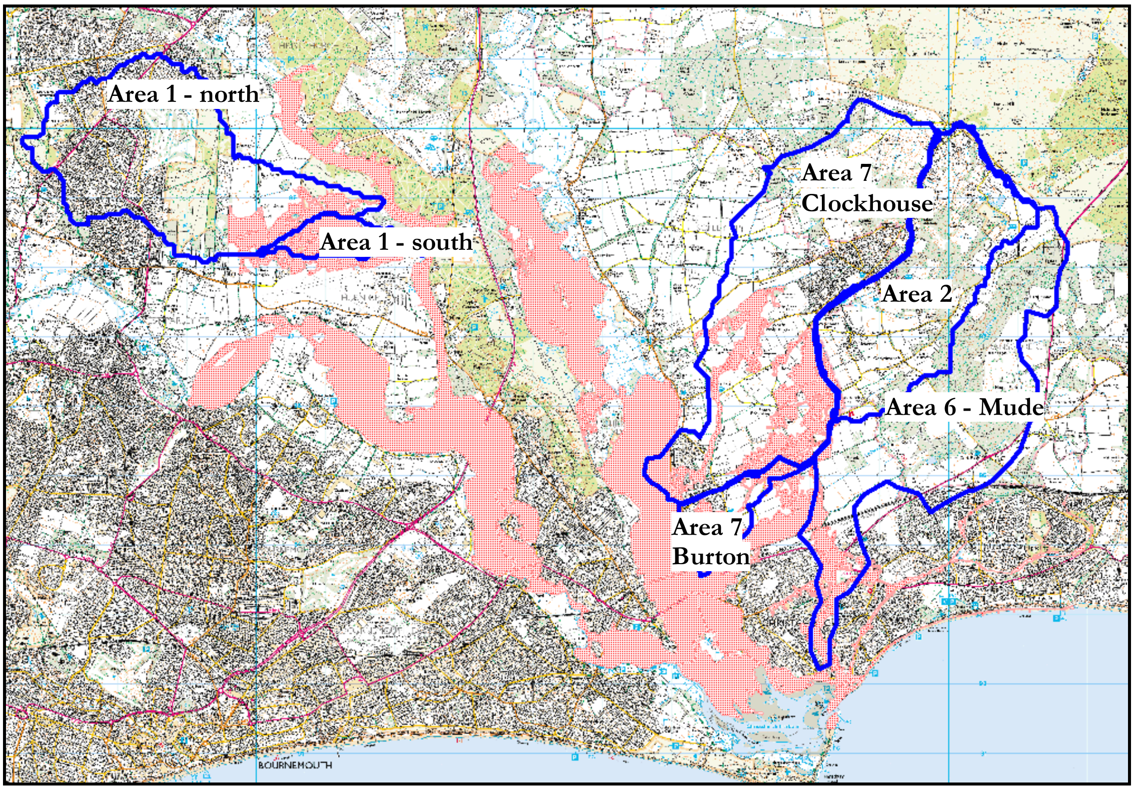


Figure 4.1: Catchments assessed

5 Hydrological Assessment: Flood Hydrology

5.1 *Catchment areas*

Critical to generating design flood hydrographs are catchment areas for the sites of interest. The catchment areas adopted in this study (Table 5.1) were obtained from the FEH CD-ROMv2 and verified using OS maps. The catchment boundary and descriptors for Area 1_South and Burton Brook (Area 7) were amended to reflect the areas shown on the OS map.

Flood estimates have been derived for catchments to the downstream boundary of each area, except for Area 2 since the catchment area to the downstream extent of Area 6 is only 0.83km² greater in area. However, as a reach of 3.8km of the River Mude is being modelled flood estimates to the top of Area 2 were also derived to help refine the flood estimates used in this study. Inflows into each model were then determined by scaling the ReFH hydrograph at each inflow point based on the total catchment hydrograph.

5.2 *Catchment flood mechanism*

As SPRHOST is greater than 20% at all sites (see Table 5.2) it shows that all sites are impermeable and have a high surface water response to storm rainfall. This is in contrast to the permeable chalk catchment of the Hampshire Avon upstream.

Table 5.1: Catchment areas

Site Ref	Description	Easting to catchment outlet	Northing to catchment outlet	Area (km²)
Area 1_North	Catchment for the northern area of Bournemouth airport	411850	98950	7.51
Area 1_South	Catchment for the southern area of Bournemouth airport	412450	98250	1.13
Area 2*	River Mude catchment to the upstream extent of FRA 2	418200	93900	6.08
Area 6_Mude	River Mude catchment	418200	92300	13.65
Area 7_Clockhouse	Clockhouse stream the downstream extent of FRA 7	416000	94650	10.71
Area 7_Burton	Burton Brook to the downstream extent of FRA 7	416200	93500	1.11

Table 5.2: Catchment descriptors at each subject site

Site Ref	FARL	PROPWET	BFIHOST	DPLBAR	DPSBAR	SAAR	SPRHOST	URBEXT*
Area 1_North	0.97	0.35	0.617	4.56	9.6	806	26.46	0.1935 (2000 value)
Area 1_South	1	0.35	0.613	1.38	7.9	799	26.56	0.3273 (2000 value)
Area 2*	0.966	0.33	0.620	3.59	38.7	789	29	0.0327 (2000 value)
Area 6_Mude	0.951	0.33	0.672	6.33	29.7	781	27.49	0.0451 (2000 value)
Area 7_Clockhouse	0.989	0.35	0.651	4.35	21.4	783	26.99	0.0662 (2000 value)
Area 7_Burton	0.99	0.35	0.845	1.25	6.833	766	18.49	0.145 (2000 value)

* Area 2 represents the catchment to the upstream extent of Area 2

5.3 River flow data

The Environment Agency provided observed discharges at quarter-hourly intervals and mean daily flows for Somerford (grid ref. SZ 18350 93600) on the River Mude. Quarter-hourly data recorded at this gauge are only available for a five year period (2003-2008), but mean daily data are available for the period 1971-1983.

The Somerford gauge is not HiFlows approved and therefore these flows need to be used with caution. Hiflows stations classed as acceptable for pooling, means that their discharge ratings should be acceptably reliable, notably in the range of higher flows.

The selection of suitable historic flood periods for calibration is based on well-known recent floods. Figure 5.1 (a & b) shows the daily mean flow hydrograph for Somerford on the River Mude, and demonstrates that in terms of flood peak:

- December 1974 was the greatest flood on record
- Winter of 2003/04 is the next largest flood
- December 1982 is the next largest flood peak

The above ranking of flood events, taken over 18 years of record, is fairly typical for stations in the Hampshire Avon catchment. Three events selected from this period of record (Quarter-hourly data required) were used to calibrate the ReFH inflows derived for Area 2 and 6 (as this gauge is located on the watercourse being modelled).

No other data are available for the watercourses being modelled, but there is a recently (Nov 2007) installed gauge on the adjacent Bure brook. However, the FEH (Vol. 3 and 4) only recommends data transfer from essentially rural-catchments and as the Bure Brook catchment is heavily urbanised in some parts ($URBEXT_{2000}$ = 0.26) it is not appropriate to use this gauge for donor transfer. Given the limited flow records local knowledge of flood history has been collated (Appendix D) which has been used to aid selection of the preferred flood frequencies (Section 7).

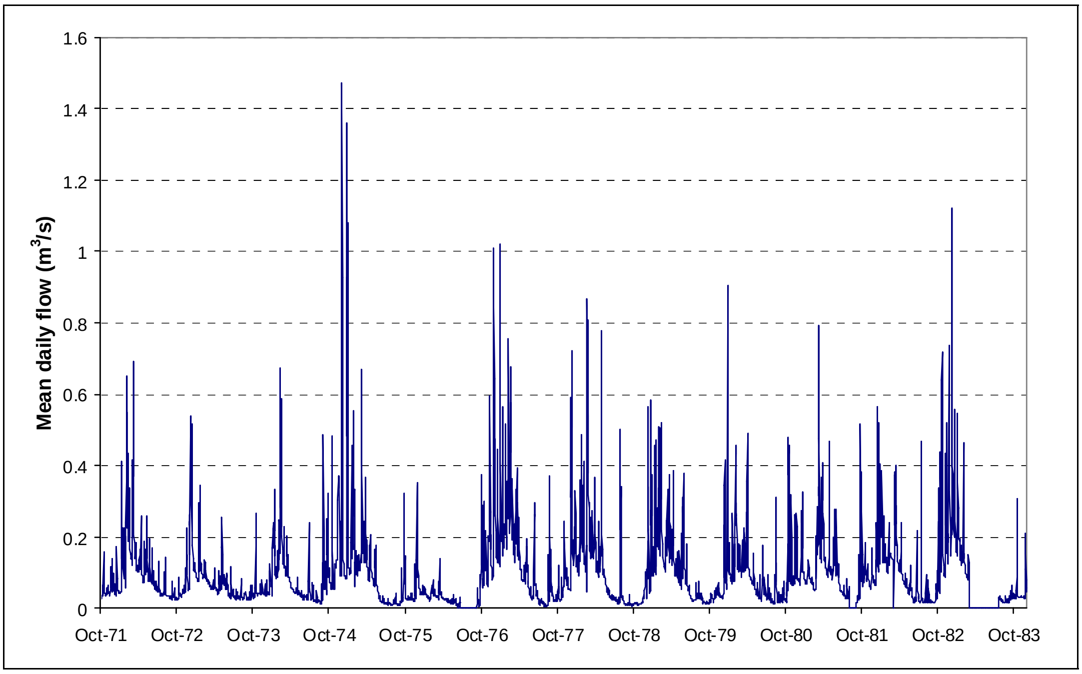


Figure 5.1a: Daily Mean Flows for the River Mude at Somerford 1971-83

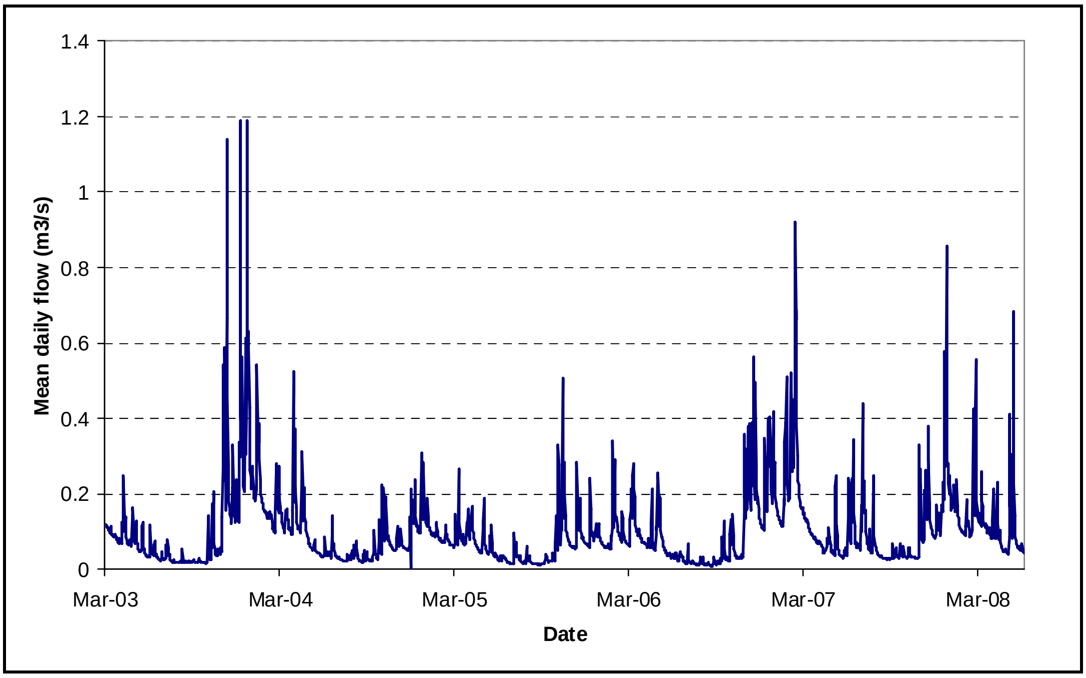


Figure 5.1b: Daily Mean Flows for the River Mude at Somerford 2003-08

6 Hydrological Assessment: FEH methodologies

6.1 Approach

The hydrological assessment derives, flood flow hydrographs at key locations within the catchment (Table 5.1), which are input to the hydraulic models. These hydrographs are developed for the schematised catchment for the following return periods that correspond to the PPS25 Flood Zones (FZ):

- 1 in 20-year (current FZ3b)
- 1 in 100-year (current FZ3a)
- 1 in 1000-year (current FZ2)
- 1 in 20-year +20% with climate change for the period 2025 to 2126 (future FZ3b)
- 1 in 100-year +20% with climate change for the period 2025 to 2126 (future FZ3a)
- 1 in 1000-year +20% with climate change for the period 2025 to 2126 (future FZ2)

Flood flow hydrographs (typically a bell-shaped profile of changing flows during a flood event) are required in order to assess the impact of flood attenuation and any floodplain storage within the river reaches modelled. On these reaches only flow data are available for Somerford on the River Mude.

As the Somerford gauge is not considered acceptable for pooling (i.e. the validity of the rating curve in the high flow range is unknown), pooling groups (for Area 2 and Area 6_Mude because the gauge is on the same watercourse) were derived with and without the inclusion of this gauge. The record was also used to improve estimates of Qmed, Tp and Cmax for the same sites of interest. Flood frequencies for sites on ungauged reaches were estimated using the most hydrologically similar sites contained within the Hiflows database.

Downstream boundary flow/tidal conditions are also considered – Sections 6.10 and 9.3.

6.2 Qmed

The FEH statistical approach comprises of two elements; an index flood (Qmed) and a growth curve. The growth curve is multiplied by Qmed to provide the final flood frequency curve of design peak flows.

Qmed for the Mude@Somerford was derived using observed annual maxima series (Table 6.1). Within the Amax series there is one flow record (1.67m^3/s observed on the 29/12/03) flagged as suspect, but a review of the rainfall (Holdenhurst rain gauge) and flow record suggests the flow peak is real. Therefore this value has been retained in the Amax series and has been used to provide an initial estimate of Qmed for the catchment to Somerford (Table 6.1).

However, as the Amax series for the gauge is short (six years) the series has been extended by establishing the relationship between the annual maximum mean flow and the Amax series (using the six years of record; Figure 4). This relationship was then used to extend the Amax series for the period 1971-83 as detailed in Table 6.2. Using this extended Amax series the value for Qmed was revised to 1.03m^3/s.

This later value for Qmed was transposed to the subject sites Area 2 and Area 6_Mude using the revised donor transfer procedure (Table 6.3) as detailed in recent guidance from the Environment Agency (2008b). This new method incorporates a distance term to take into account the geographical distance between the subject site and donor catchment.

Table 6.1: Amax series and Qmed values of the gauge at Somerford

Water year	**Date**	**Time**	**Amax** (m^3/s)	**Qmed** (m^3/s)
2002/03	28/04/2003	08:30	0.53	Qmed = 0.84 (derived only from the Amax series detailed in this table)
2003/04	29/12/2003	15:45	1.67*	
2004/05	10/01/2005	21:15	0.47	
2005/06	03/11/2005	06:00	0.60	
2006/07	05/03/2007	00:45	1.25	
2007/08	15/01/2008	16:00	1.09	

*Flow peak flagged as suspect on the Environment Agency's database

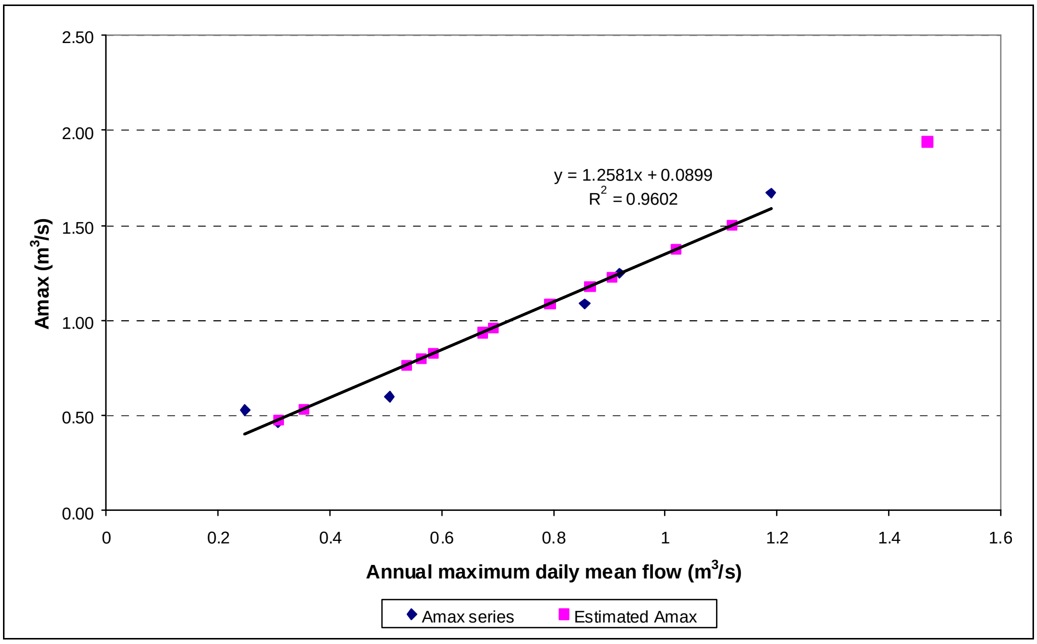


Figure 6.1 Relationship between Amax and annual maximum mean daily flow

Table 6.2: Estimated Amax values for Somerford based on gauged daily mean flows

Water year	**Annual max daily mean flow** (m^3/s)	**Amax** (m^3/s)
1971/72	0.692	0.961
1972/73	0.537	0.765
1973/74	0.673	0.937
1974/75	1.47	1.939
1975/76	0.353	0.534
1976/77	1.02	1.373
1977/78	0.866	1.179
1978/79	0.585	0.826
1979/80	0.906	1.230
1980/81	0.794	1.089
1981/82	0.564	0.799
1982/83	1.12	1.499

Table 6.3: Qmed adjustment ratio for the Mude@Somerford

Station	Watercourse	Qmed from data (A)	Qmed from CDs (B)	Adjustment ratio for Qmed (A/B)
43013	Mude@Somerford	1.03	1.58	0.65

Transposition of Qmed to the subject sites:

- Qmed for FRA2 (distance between subject and donor sites is 3.61km) = 0.82m³/s
- Qmed for FRA6 (distance between subject and donor sites is 3.38km) = 1.26m³/s

6.3 FEH single site analysis

Single site analysis can be used to derive flood frequency curves at a gauging station, such as at Somerford on the River Mude. However, the FEH recommends relying on pooled growth curves unless there is a flood peak record twice as long as the return period of interest (Environment Agency, 2008).

For the gauge at Somerford there are 18 years (six years of amax data and 12 years of derived amax) of record are available. The station record has been used to derive flood estimates up to the 1000 year return period, but is only recommended to use results up to the 10 year return period. This is because a single-site growth curve is very vulnerable to the limited period of record that the gauging station covers.

The generalised logistic curve has been used for estimation of the growth curve parameters using the L-moment method, as recommended for UK flood data (FEH, Vol.3). Table 6.4 shows the flood estimates derived using FEH single-site analysis.

Table 6.4 Flood frequencies derived using FEH single site analysis

Site code	Flood peak (m³/s) for following return periods (years)									
	2	5	10	20	25	50	100	200	500	1000
Somerford	1.02	1.42	1.70	1.99	2.09	2.41	2.77	3.17	3.78	4.29
Area 2*	0.48	0.66	0.79	0.93	0.98	1.13	1.30	1.49	1.77	2.01
Area 6_Mude*	1.07	1.49	1.78	2.09	2.19	2.54	2.92	3.34	3.97	4.52

*Flows estimated by scaling the single-site FFC derived using the flow record at Somerford

6.4 FEH statistical pooling group analysis

Flood frequencies were computed for sites based on pooling groups of Hiflows approved stations for a fixed pooling group of 500 station-years (Environment Agency, 2008b), with and without the inclusion of Somerford (none HiFlows approved) as the Rank 1 station. Details of the pooling groups are provided in Appendices E to I.

As all sites are ungauged, Qmed was estimated using catchment descriptors (Table 6.5) and adjusted using donor sites, where available (Table 6.6). The new Qmed equation (Environment Agency, 2008b) which accounts for the distance between the subject and donor site has been used.

Donor sites are selected based on the availability of a gauged site on the river reach or the similarity of catchment descriptors (where a nearby site is not available). The $URBEXT_{2000}$ values for each site were updated to the 2007/08 water year using the urban expansion factor detailed in

Baylis *et al*., 2006. Qmed was also updated using the urban adjustment factor (Baylis *et al*., 2006) to account for the sites being urbanised.

As all sites are urbanised an urban adjustment was applied to URBEXT and the statistically derived flood frequency curves. The flood frequency estimates are detailed in Table 6.7 below, with the flood frequency curves illustrated in Appendix J. To allow for climate change, an additional 20% is added to these values to represent the situation currently anticipated from 2025 to 2115, i.e. this additional 20% is adopted for both year 2086 and 2126.

The statistical pooling group flood frequency curve exceeds the flood estimates derived using single-site analysis (Appendix J) for Area 2, but are similar to those derived for Area 6_Mude.

Table 6.5: Estimation of Qmed at each subject site

Site code	**Initial estimate of QMED** (m^3/s) based on catchment descriptors	**Data transfer station**	**Final estimate of QMED** (m^3/s)
Area 1_North	1.755	44801	1.55
Area 1_South	0.471	45817	0.48
Area 2	1.032	Somerford	0.82
Area 6_Mude	1.583	Somerford	1.26
Area 7_Clockhouse	1.676	54034	1.69

Table 6.6: Donor sites for the FEH pooling group approach

Station	**Watercourse**	**Qmed from data** (A)	**Qmed from CDs** (B)	**Adjustment ratio for Qmed** (A/B)
44801	Hooke@Hooke	1.215	2.779	0.44
45817	RHB trib to Haddeo @ Upton	1.317	0.920	1.43
54034	Dowles Brook	9.022	4.218	2.14
43013	Mude@Somerford	1.03	1.58	0.65

Table 6.7: Flood Frequency Estimates *(target 100-yr pooling group, extrapolated to 1000-yr)*

Site code	**Flood peak** (m^3/s) **for the following return periods** (in years)									
	2	**5**	**10**	**20**	**25**	**50**	**100**	**200**	**500**	**1000**
Area 1_North	1.550	2.083	2.476	2.905	3.054	3.558	4.136	4.803	5.849	6.788
Area 1_South	0.480	0.615	0.712	0.814	0.850	0.968	1.103	1.256	1.491	1.700
Area 2	0.82	1.20	1.47	1.78	1.88	2.23	2.64	3.10	3.83	4.48
Area 2 (with Somerford Rank 1)	0.82	1.20	1.47	1.77	1.87	2.22	2.63	3.09	3.81	4.45
Area 6_Mude	1.26	1.80	2.19	2.63	2.78	3.30	3.89	4.58	5.66	6.64
Area 6_Mude (with Somerford Rank 1)	1.26	1.79	2.18	2.61	2.76	3.27	3.85	4.52	5.58	6.53
Area 7_Clockhouse	1.690	2.436	2.955	3.471	3.639	4.168	4.713	5.276	6.050	6.659

6.5 ReFH – revitalised rainfall-runoff model

The 'Revitalised Flood Hydrograph (ReFH)' release in 2006 (Kjeldsen et al, 2005) was developed to address several problems in the FEH rainfall-runoff method. ReFH has now superseded the FEH rainfall-runoff method for most applications (Environment Agency, 2008), which includes the types of sites being considered in this SFRA.

Tables 6.8 and 6.9 detail the parameters used in the ReFH model, and Table 6.10 details the design events modelled. In all cases the storm area was set to the catchment area, to simulate the effect of a storm centred over the catchment. The $URBEXT_{1990}$ values for each site were updated to the 2007/08 water year using the urban expansion factor detailed in FEH Volume 5.

For Area 2 and Area 6_Mude, Tp and Cmax were adjusted using the Mude@Somerford as a donor site. Values for the parameters Tp and Cmax at Somerford were estimated using the ReFH design flood modelling software (released by Wallingford Hydrosolutions in 2007).

Table 6.11 details the flood frequencies derived using ReFH. When compared with the flood frequencies detailed within Table 6.7 (the flood frequency curves are illustrated in Appendix J) this shows that the ReFH derived flow peaks tend to exceed the statistically derived flow peaks for all return periods (except for Area 1).

Table 6.8: Parameters for ReFH model

Site code	**Method:**	**Tp** (hours) Time to peak	**C_{max}** (mm) Maximum storage capacity	**BL** (hours) Baseflow lag	**BR** Baseflow recharge
Area 1_North	Catchment descriptors	4.369	485.477	34.160	1.525
Area 1_South	Catchment descriptors	1.742	482.487	21.017	1.515
Area 2	Flood Event analysis	5.26	383.85	45.788	1.501
Area 6_Mude	Flood Event analysis	7.58	414.37	51.255	1.638
Area 7_Clockhouse	Catchment descriptors	4.314	510.858	43.062	1.616
Area 7_Burton	Catchment descriptors	2.084	654.503	28.618	2.142

Table 6.9: Donor Transfer of Tp and Cmax parameters

Station	**Watercourse**	**Tp from data** (A)	**Tpfrom CDs** (B)	**Adjustment ratio for Tp** (A/B)	**Cmax from data** (C)	**Cmaxfrom CDs** (D)	**Adjustment ratio for Cmax** (C/D)
43013	Mude@Somerford	6.84	5.01	1.365	372.01	479.40	0.776

Table 6.10: Design events for the ReFH model

Site code	**Urban or rural (URBEXT)**	**Season of design event** (summer or winter)	**Storm duration** (hours)
Area 1_North	Urban (0.125)	Summer	14.25
Area 1_South	Urban (0.215)	Summer	8.75
Area 2	Rural (0.015)	Winter	11.75
Area 6_Mude	Rural (0.030)	Winter	24.75
Area 7_Clockhouse	Rural (0.047)	Winter	12.25
Area 7_Burton	Rural (0.096)	Winter	0.25

Table 6.11: Flood frequencies derived using ReFH

Site code	**Flood peak** (m^3/s) **for following return periods** (years)						
	2	**20**	**100**	**1000**	**20 +20%**	**100 +20%**	**1000 +20%**
Area 1_North	1.441	2.534	3.712	7.686	4.296	4.454	9.223
Area 1_South	0.359	0.644	0.948	2.008	0.773	1.138	2.410
Area 2	1.103	1.933	2.820	5.314	2.320	3.384	6.377
Area 6_Mude	1.733	3.035	4.450	8.402	3.642	5.340	10.082
Area 7_Clockhouse	2.094	3.559	5.078	9.238	4.270	6.094	11.086
Area 7_Burton	0.019	0.047	0.094	0.295	0.056	0.113	0.354

The ReFH approach results in flood peaks that overestimate the statistically-derived frequencies significantly less than those derived using the FEH rainfall-runoff approach (see Section 6.6). Hence when the hydrographs are scaled by the peak ratios, the volumes in ReFH hydrographs retain their theoretical volumes much more closely than those derived using the FEH rainfall-runoff approach.

For heavily or very heavily urbanised catchments ($0.125 \leq URBEXT_{2000} \leq 0.600$), such as the airport site (Area 1), ReFH should not currently be used because its summer design event was only calibrated on seven urban catchments. The statistical method's urban adjustment was calibrated using many more heavily urbanised catchments and for this reason should be preferred on such catchments (Environment Agency, 2008).

6.6 FEH – rainfall-runoff model

Although the FEH rainfall-runoff model has been superseded by the ReFH approach, the FEH rainfall-runoff method was used to derive flood estimates for comparison with those derived using the other approaches.

Tables 6.12 and 6.13 detail the parameters used in the FEH rainfall-runoff model. The Tp and SPR parameters for the donor site 25019 was obtained from the results of flood event analysis as detailed in the FEH Vol.4 (Tp and SPR were derived from the analysis of 16 and 13 flood events, respectively). Estimates of Tp for both Area 2 and Area 6_Mude an assessment of catchment lag ($Tp = 0.879LAG^{0.951}$) has been undertaken using the flow gauge at Somerford and the rain gauge at Holdenhurst.

Three events were analysed: 01 December 2003, 22 February 2007 and 02 March 2007.

Table 6.12: Parameters for the FEH rainfall-runoff model

Site code	Type	Tp(0): method	Tp(0): value (hours)	SPR: method	SPR: value (%)	Donor sites used (see Table 15)
FRA1_North	Urban	Donor transfer	3.56	Donor transfer	20.83	25019
FRA1_South	Urban	Catchment descriptors	1.11	Catchment descriptors	26.56	No suitable donors
FRA2	Urban	Catchment lag	6.44	Catchment descriptors	22.83	Mude@Somerford (Tp) 25019 (SPR)
FRA6_Mude	Rural	Catchment lag	8.91	Donor transfer	27.49	Mude@Somerford (Tp) No suitable donors (SPR)
FRA7_Clockhouse	Rural	Donor transfer	4.97	Donor transfer	21.25	25019 (SPR)
FRA7_Burton	Urban	Catchment descriptors	2.607	Catchment descriptors	18.49	No suitable donors

Table 6.13: Donor sites for the FEH rainfall-runoff parameters

Station	Watercourse	Tp(0) from data (A)	Tp(0) from CDs (B)	Adjustment ratio for Tp(0) (A/B)	SPR from data (C)	SPR from CDs (D)	Adjustment ratio for SPR (C/D)
25019	Leven @ Easby	3.9	4.163	0.937	38.58	30.2	0.783
54034	Dowles Brook	-	-	-	33.1	19.18	1.726

Baseflow derived using catchment descriptors to the gauge at Somerford is estimated to equal 0.257 m^3/s, which is representative of the observed baseflow recorded at the gauge. As baseflow represents only a small proportion of the total hydrograph (approximately 5.1% of the total hydrograph for the 20 year return period and less for the 100 (3.3%) and 1000 (1.8%) year return periods), no further refinement of estimated baseflow has been undertaken.

As for the ReFH approach, in all cases the storm area was set to the catchment area and the $URBEXT_{1990}$ values for each site were updated to the 2007/08 water year using the urban expansion factor detailed in the FEH Volume 5.

Table 6.14 details the flood frequencies derived using the FEH rainfall-runoff approach. When compared with the flood frequencies detailed within Tables 6.4, 6.7 and 6.11 (also see the FFC's in Appendix J) this shows that the FEH rainfall-runoff derived flow peaks significantly exceed the flood estimates derived using the FEH statistical and ReFH approaches.

Table 6.14: Flood frequencies derived using the FEH rainfall-runoff approach

Site code	**Critical storm duration** (hours)	**Flood peak** (m^3/s) **for following return periods** (years)						
		2	**20**	**100**	**1000**	**20 +20%**	**100 +20%**	**1000 +20%**
Area 1_North	9.25	2.367	4.546	7.831	14.925	5.455	9.397	17.910
Area 1_South	4.25	0.663	1.234	2.067	4.264	1.480	2.480	5.117
Area 2	12.75	1.167	2.742	4.109	7.388	3.290	4.931	8.866
Area 6_Mude	17.25	2.591	5.882	8.578	14.858	7.058	10.294	17.830
Area 7_Clockhouse	11.25	2.332	5.579	8.45	15.408	6.695	10.140	18.490
Area 7_Burton	6.25	0.274	0.659	1.030	1.953	0.791	1.236	2.344

6.7 Small catchment method (Institute of Hydrology Report 124)

Accurate estimation of flood parameters on small lowland catchments is known to be difficult, since small catchments (<25km²) with good quality data are few in number. FEH or ReFH methods will usually be the best choice for catchments larger than 2km², and often also for catchments between 0.5 and 2km², but alternatives such as the small catchment method are worth considering (Environment Agency, 2008a).

The small catchment method (Institute of Hydrology, 1994) was developed five years prior to the FEH, by examining the response to rainfall of such catchments to help derive improved flood estimate equations. Three models were considered to estimate Tp(0), but the compromise model was recommended for general use and has been used in this study (Table 6.15). These Tp (0) estimates have been used together with the FEH design rainfall for each catchment to derive flood estimates.

Table 6.16 shows the flood estimates derived using the small catchment method. When compared with Tables 6.4, 6.7, 6.11 and 6.14 (also see FFC curves in Appendix J) this shows that the small catchment derived flow peaks tend to be intermediate to those derived using the other methods. Although for the River Mude catchment (FRA2 and FRA6_Mude) flows derived using the small catchment method exceed those derived using all other methods.

Table 6.15: Tp(0) as estimated using the small catchment method

Site code	Tp(0): value (hours)
Area 1_North	6.49
Area 1_South	6.35
Area 2	5.75
Area 6_Mude	7.67
Area 7_Clockhouse	6.49
Area 7_Burton	3.01

Table 6.16: Flood frequencies derived using the small catchment method

Site code	Critical storm duration (hours)	Flood peak (m^3/s) for following return periods (years)						
		2	20	100	1000	20 +20%	100 +20%	1000 +20%
Area 1_North	12.25	1.68	3.22	5.12	10.12	3.86	6.15	12.15
Area 1_South	12.25	0.34	0.64	0.99	1.90	0.77	1.19	2.28
Area 2	12.25	1.25	2.95	4.43	7.99	3.54	5.31	9.58
Area 6_Mude	14.75	2.83	6.46	9.49	16.61	7.75	11.39	19.93
Area 7_Clockhouse	14.25	2.00	4.74	7.10	12.73	5.69	8.51	15.28
Area 7_Burton	6.75	0.34	0.65	1.09	2.25	0.78	1.30	2.70

6.8 *Rational and modified rational methods*

The rational and modified rational methods have been used from time to time in small catchment studies. However, the Rational Method is not recommended for use on small lowland catchments by the FEH (Vol. 4) as it gives peak flows typically twice as large as those from the FEH rainfall-runoff method for small lowland catchments (Institute of Hydrology, 1978). For this reason flood estimates in this study have not been derived using the rational method.

The Modified Rational Method (National Water Council, 1981) was developed for sewer design. The method is not suitable for flood frequency estimation in either urban or rural surface water catchments as it is designed for sewered urban areas (Environment Agency, 2008a). For this reason flood estimates in this study have not been derived using the modified rational method.

6.9 *Flood estimates derived for JFlow using an automated FEH statistical procedure*

The Environment Agency Flood Zone maps (available from: www.environment-agency.gov.uk) show the areas at risk of flooding from rivers and the sea, ignoring the presence of flood defences. For each of the catchments being considered the maps were produced from a National generalised computer model (JFlow), but are being improved as detailed hydraulic modelling studies are undertaken and more flood data and information becomes available.

The 100 year return period flood estimates for each of the catchments being considered (as provided by the Environment Agency) are detailed in Table 6.17. When compared with Tables 6.4, 6.7, 6.11, 6.14 and 6.16 (also see FFC's in Appendix J) this shows that the flow peaks derived using the automated FEH procedure (Morris, 2003) for input into Jflow tend to be intermediate to those derived using the other methods, with these estimates being most similar to those derived using the (manual) FEH Statistical pooling group (as expected) and ReFH methods.

Table 6.17: Flood frequencies derived using JFlow (100 year return period)

Site code	Flood peak (m^3/s) for 100 year return period
Area 1_North	4.28
Area 1_South	n/a*
Area 2	3.21
Area 6_Mude	4.91
Area 7_Clockhouse	4.78
Area 7_Burton	n/a*

*Jflow inflows are only generated for catchments with areas greater than $3km^2$.

6.10 Downstream tidal/fluvial boundaries

The downstream boundaries used in the hydraulic modelling are detailed in Section 9.3.

For the airport streams (Area 1, north and south), the Clockhouse stream and Burton Brook (both Area 7), the downstream boundaries are representative of a Qmed flood on both the Moors River and the Hampshire Avon. This represents the scenario of a local storm centred over each Area. The flood limits from catchment wide storms centred over the Hampshire Avon catchment were considered using the existing Hampshire Avon model.

For the airport streams the flood estimates for Area 1 close to the confluence with the Moors River will be less certain, as a catchment wide storm over the Moors catchment has not been considered. However, GeoStandards (2007) undertook a flood risk assessment for the Bournemouth airport passenger terminal extension and refurbishment which found flooding from the Moors river to be limited in aerial extent in the vicinity of the airport (including the area being considered in Area 1) for the 100 (with climate change) and 1000 year flood events.

The model results for the Moors River are also consistent with the memories of flooding history as detailed in Appendix D. This suggests that water levels in the Moors River has limited influence on the flood risk to the area of Area 1, nevertheless the model's sensitivity to the downstream boundary condition is considered in Section 10.6.

7 Hydrological Assessment: Recommended Flood Frequencies

7.1 Recommended flood frequencies at key locations

The flood frequencies derived for each site using the FEH single site, FEH pooling group, ReFH, FEH rainfall-runoff, small catchment method and Jflow approaches (where applicable) are illustrated in Appendix J. The recommended flood frequencies for the key flood risk areas of interest to be modelled for this project are set out in Table 7.1. For Area 1_North and Area 2, the hydrograph obtained using the ReFH approach will be used and scaled to the FEH pooling group flood frequencies.

Table 7.2 compares peak flood flow estimates (1 in 100-year) from the FEH methods of analysis, with the estimates recommended for the hydraulic assessment highlighted (in bold).

7.2 Flood hydrographs for modelling purposes

The design flood hydrographs for use in each of the Area models will be determined by scaling the ReFH hydrograph at each inflow point based on the adopted total catchment hydrograph.

Table 7.1: Recommended flood frequencies

Site code	Recommended approach	Key Reasons
Area 1_North	IoH 124 Small catchment method	- ReFH should not be used for heavily or very heavily urbanised catchments (Environment Agency, 2008a) - Flood estimates derived using the small catchment method represent a compromise between those derived using the various approaches
Area 1_South	IoH 124 Small catchment method	
Area 2	ReFH	ReFH model parameters refined using event analysis
Area 6_Mude	ReFH	ReFH model parameters refined using event analysis
Area 7_Clockhouse	ReFH	- Flood estimates derived using the ReFH and FEH pooling group approach are similar. However, ReFH is slightly more conservative at longer return periods for which statistical estimates are extrapolated and therefore the ReFH approach is recommended. - Flood estimates derived using the small catchment method are more conservative, but limited flooding has been observed (Appendix D) and FEH methods are often the best choice for catchments >2km² (Environment Agency, 2008a).
Area 7_Burton	IoH 124 Small catchment method	ReFH approach has now superseded the FEH rainfall-runoff approach (Environment Agency, 2008a) and is often the best choice for catchments between 0.5 and 2km². However, as the catchment descriptors have been derived (since the catchment is not recognised by the FEH CDROM) the more conservative estimates obtained using the small catchment method are recommended.

Table 7.2: Peak flood flow estimates (1 in 100-year) from the various methods of analysis

Catchment area	**1 in 100-year peak flood flow estimates (m^3/s)**					
	FEH single site	FEH Statistical Pooling Group	FEH Revitalised rainfall-runoff model (ReFH)	FEH Rainfall-runoff model	IoH 124 small catchment method	JFlow
Area 1_North	n/a	4.14	3.71	7.83	**5.12**	4.28
Area 1_South	n/a	1.10	0.95	2.07	**0.99**	n/a
Area 2	1.30*	2.03	**2.82**	4.11	4.43	3.21
Area 6_Mude	2.92*	3.00	**4.45**	8.58	9.49	4.91
Area 7_Clockhouse	n/a	4.71	**5.08**	8.45	7.10	4.78
Area 7_Burton	n/a	n/a	0.09	1.03	**1.09**	n/a

*Flows estimated by scaling the single-site FFC derived from the flow record at Somerford

7.3 Hydrology conclusion

This hydrological assessment has been undertaken for the areas not previously investigated: Area 1 (subdivided into north and south), Area 2, Area 6 and Area 7 (subdivided as Clockhouse Stream and Burton Brook). The previously modelled areas have been assessed based on existing hydrological data, e.g. Stour (Area 3), Hampshire Avon (Area 5) and Bure Brook (Area 6).

This assessment considers the catchment's flood mechanisms, the analysis of flood frequencies at key gauging stations and ungauged sites, and provides a set of design flood hydrographs needed for the river modelling. Flood flow estimation is based on the latest FEH methods of analysis and some earlier methodologies as agreed with the Environment Agency.

8 Hydraulic Assessment: Approach

8.1 Overview

The overall objective of the hydraulic modelling exercise was to develop models that could be used to produce an updated and accurate set of flood risk maps and associated data for the flood risk areas identified for the SFRA. This section of the report outlines the approach and methods used during the development of the model.

8.2 Modelling approach

Selected as the optimal modelling method, the project used **ISIS** for all 1D components and **TUFLOW** for all 2D components, both employing a hydrodynamic (unsteady) solution.

ISIS: ISIS for 1D modelling is developed by Halcrow. It is in an advanced state of development of coupling with a number of established 2-D floodplain models including ISIS-2D, DIVAST and TUFLOW. This enables the modeller to enhance the extensive capabilities of ISIS with the more complex intricacies and effects of 2-D modelling. ISIS integrates with, ISIS Mapper, DSF and other flood management system tools that add considerable value.

ISIS-TUFLOW: ISIS-TUFLOW is jointly developed by Halcrow and WBM, Australia. It is a two-dimensional, depth-integrated, time-variant model which has particular strengths for modelling overland flow routing and rapid inundation modelling (i.e. breach analysis and dam failure). It has recently been proven as a best approach method on the River Thames Embayment projects.

For this study, models were developed to the current Environment Agency SFRM specification for risk mapping (SFRM Specification Part B: Delivery) that provides guidance on 1D modelling but not 2D river modelling software.

The modelling process linked TUFLOW with a detailed 'in-bank' ISIS model. The alternative, TUFLOW linked to ESTRY for 1D which is the package that comes with TUFLOW, was not considered suitable for this study as ISIS can better represent the in-channel hydraulics.

The models were all run with default parameters and were ensured to be stable throughout the simulations.

ISIS-TUFLOW modelling packages
ISIS-TUFLOW is a joining of two software packages for managing overland flow and rapid inundation modelling. It provides a flexible and comprehensive range of tools for designing cost effective engineering schemes flood forecasting, flood risk mapping and developing catchment management strategies.

ISIS is a 1D open channel and culverted flow simulation engine which includes a wide range of hydraulic structures including all common types of bridges, culverts, sluices and weirs. Logical rules are also available which can be added to moveable structures to accurately model how they operate during flood event e.g. automated structures.

The project used the following version of ISIS:

- ISIS Version 3.0
- Computational Engine Version 6.0.0.12

TUFLOW is a modelling package for simulating depth averaged 2D free-surface flows, and was developed as a joint research and development project WBM Oceanics Australia and the University of Queensland, from 1990.

An ISIS -TUFLOW link has been developed as a joint research and development project between WBM Oceanics Australia and Halcrow. This link allows the ISIS 'in bank' model to be directly linked to a 2D domain, which allows for better representation of urban areas focussing the computational time on the most complex flow paths.

The project used the following version of TUFLOW and ISIS-TUFLOW link:

- Computational Engine Version 2007-07-BF (TUFLOW)
- Computational Engine Version 6.0.1.15 (ISIS-TUFLOW)

The Figure 8.1 below illustrates at a basic level the model representation.

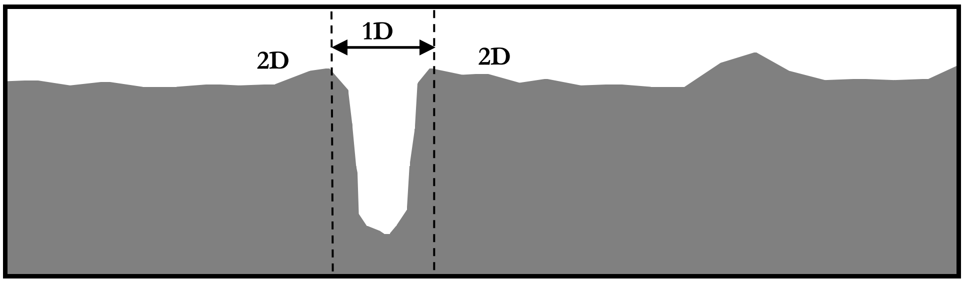


Figure 8.1 - Modelling a river channel in 1D & floodplain in 2D

TUFLOW model construction is undertaken in a GIS environment using MapInfo (outside of the TUFLOW programme), enabling direct geo-referenced visualisation of all model elements. This facilitates the identification of model elements as well as visual inspection of model schematisation. This is particularly useful when a model is handed over. The 2D domain is based on a grid of data from a topographic survey e.g. LIDAR.

8.3 *Model development – ISIS 1D integrated with TUFLOW 2D*

The basic steps to building an ISIS\TUFLOW model components are set out below.

1D model component:

- Typical 1D schematisation detailed in Figure 8.2
- Create model from channel survey to represent 'In Bank' conditions
- Incorporate structures
- Run "steady direct method" to generate initial conditions and stabilise model.
- Check model runs at low flows to match water levels observed in channel survey

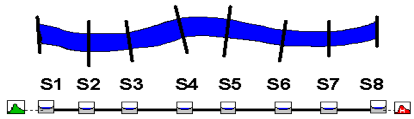
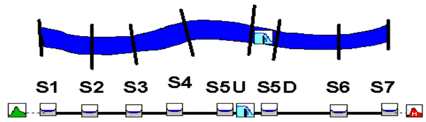
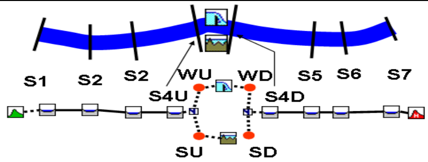
Simple river reach with no structures	
Simple river reach with a single structure, e.g. weir, sluice, or bridge	
Simple river reach with structures in parallel e.g. combinations of weir, sluice, bridges and spills around structures	

Figure 8.2 - Overview of 'typical' 1D model development

2D model component:

- Typical model schematisation detailed in Figure 8.3
- Collate all available ground level data (LiDAR, SAR, topo surveys)
- Collate all available GIS data (Landline, aerial photos, etc)
- Determine the extent of the area of interest for the project
- Determine the extent of the 2D domain
- Identify locations for boundary conditions
- Identify areas of 2D domain that can be made 'inactive' (e.g. high ground)
- Identify elements that can be modelled in 1D and create 1D model
- Select appropriate grid orientation and cell size
- Create grid & base elevations, e.g. embankments, lakes & other features not in base DEM
- Review the 2D 'mesh' created by TUFLOW
- Assign appropriate Manning's roughness values
- Determine the timestep required for the simulation

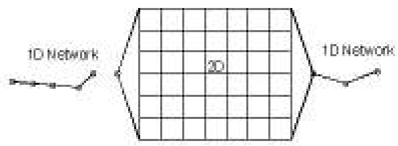
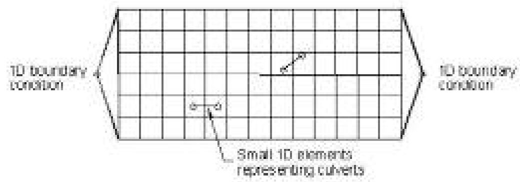
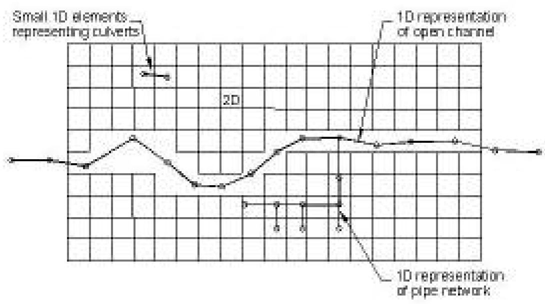
2D domain linked in between 1D networks	
2D domain, including 1D elements, linked between 1D networks,	
River network modelled as 1D, fully linked to 2D domains for floodplain	

Figure 8.3 - Overview of 'typical' 2D model development

8.4 *Topographic datasets*

The topographic datasets derive from surveys from various sources, of differing age and levels of accuracy, and are required to represent the channel, structures and floodplain in the hydrodynamic models. Table 8.1 presents details of the datasets referenced for each model component.

Table 8.1: Model construction

Model component	Topographic Survey
Channel cross section (1D)	Channel survey
Structures (1D)	Channel survey
Extended Cross Sections (1D)	LiDAR DTM
Floodplain/ditches modelled as ISIS cross sections (1D)	LiDAR DTM
Reservoir stage/area profile (1D)	LiDAR DTM
Bank Spills (1D)	Bank Marker from Channel survey or Bank Top survey
Floodplain Spills (1D)	LiDAR DTM
TUFLOW domain (2D)	LiDAR DTM
TUFLOW HX Lines (2D)	Bank top survey (if available) or LiDAR DTM

8.5 *Digital terrain model (DTM)*

The floodplain within the hydrodynamic models, either 1D cross sections or the 2D domains were defined by a DTM created using LiDAR (**Li**ght **D**etection **A**nd **R**anging) data provided by the Environment Agency. The LiDAR data used is detailed in Section 3.

8.6 *Channel survey*

The channel survey defines the river cross sections, the survey data is provided as an AutoCAD drawing and as ISIS EEBY survey format, to be directly imported in ISIS. As well as detailing the cross sections the AutoCAD drawings also contain all the information required to model structures, such as weir, sluice and bridges within ISIS. Figure 8.4 shows an example of a cross section and structures from a typical survey.

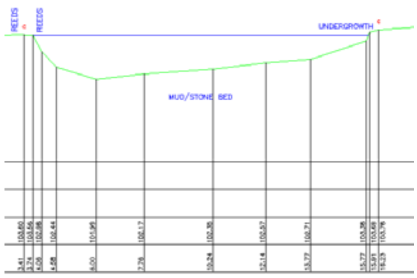
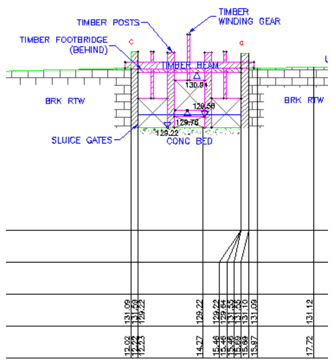
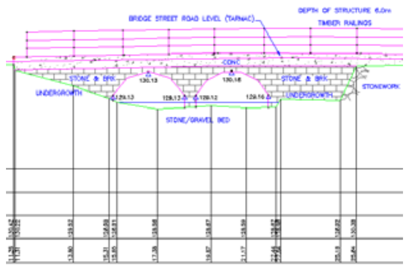
Example Cross Section	Example Weir/Sluice	Example Bridge
		

Figure 8.4: Example Channel Survey Data

9 Hydraulic Assessment: 1D/2D Model Schematisation, Boundaries and Parameters

9.1 Schematisation

The model extents detailed in Table 9.1 cover the 1D/2D ISIS-TUFLOW models developed for Areas 1, 2 and 7. For the River Mude (Area 6), due to the accuracy of LiDAR in the lower reaches of the tree covered floodplain the 1D/2D model was not considered and a 1D ISIS model was developed. The model was still linked to the 1D/2D model of Area 2 reach of the Mude, so accurate outflows could pass into the Area 6 model.

The 1D component of the 1D/2D ISIS-TUFLOW models were developed from new 1D models using survey collected for this study. The model developed for Area 6 used an Environment Agency survey undertaken in October 2007. The TUFLOW domain is defined to extend outside the floodplain, in order to avoid any 'glass wall' effects in the modelling process.

The only exception to the use of ISIS as the 1D model component was in Area 1 (Bournemouth International Airport). It was decided to use ESTRY to model the south channel, as the use of ISIS reservoir units (representing the storage areas between culverts) was unstable when linking to TUFLOW. The hydraulics of the channel is dictated by the culverts and these are represented in ESTRY.

The methodology adopted for model development is described in Section 8. The overriding aim is that project outputs can be obtained with the specified accuracy; and the model is able to work accurately at low to bank-full flow, and at floodplain flow.

When schematising the model all river channel cross sections were examined closely and where embankments are higher than the floodplain, the channel cross section was curtailed. Structures have been modelled using appropriate ISIS structure types according to their hydraulic behaviour.

The extent of the TUFLOW domains are detailed in Figure 9.1 and a breakdown of the components of each model is detailed in Tables 9.2. Figure 9.2 details the extent of the TUFLOW domains for the existing models.

Table 9.1: 1D or 1D/ 2D ISIS-TUFLOW Models

Flood Risk Area (model Name)	Model Type	Model Upper Limit		Model Lower Limit	
		Location	Co-ordinates	Location	Co-ordinates
Area 1: Airport Bournemouth Int.	1D/2D ISIS/TUFLOW	d/s Barrack Lane	409600 98370	Confluence with Moors River	411900 98930
Area 2*: RSS Area of Search M	1D/2D ISIS/TUFLOW	River Mude d/s Waterditch Road	418420 95780	A337 Somerford	418200 93890
Area 6* River Mude	1D ISIS	A337 Somerford	418200 93890	Raven Way, Mudeford	418220 92300
Area 7 Clockhouse Stream	1D/2D ISIS/TUFLOW	Salisbury Road	416530 95290	B3347 Stony Lane	416075 94715
Area 7 Burton Brook	1D/2D ISIS/TUFLOW	Burton Playing fields	416560 94500	B3347 Stony Lane	416420 93830

*Models linked

Table 9.2: Key Features of New Models

Model Features	Area 1	Areas 2 + Area 6	Area 7 Clockhouse	Area 7 Burton
Total Number of Nodes	75	118	40	18
River Sections (RIVER)	17	46	14	10
Flow/Time inflow boundaries (QTBDY)	2	5	2	1
Interpolated Sections (INTERPOLATE)	7	10	0	1
Downstream Boundaries (HTBDY or QHBDY)	1	1	1	1
Weirs (RNWEIR, SCWEIR, WEIR, CRUMP)	0	1	0	0
Sluice Structures (SLUICE, GATED,ORIFICE)	0	0	0	0
Bridges (BRIDGE)	0	2	0	0
Bridges/Restrictions (BERNOULLI)	4	0	1	1
Variable weirs e.g. bank tops (SPILLS)	0	9	1	0
Conduits	14	11	6	2
Culvert inlets/outlets	14	10	6	2
Junctions (JUNCTION)	12	17	9	5
Other (REPLICATE, ABSTRACTION etc)	0	0	0	0

Appendix K, lists the structures (culverts/bridges/weirs etc) which are included in the models, and the hydraulic unit used to represent them.

9.2 Digital terrain model (DTM)

The DTM is constructed from filtered LiDAR, so both the flow paths (mainly on the streets) and the storage (mainly within the houses) are considered. From the LiDAR DTM, the following TUFLOW cell sizes (Table 9.3) were considered optimal for all models, sufficient to reproduce the hydraulic behaviour in urban areas, e.g. flow paths in streets.

Table 9.3: TUFLOW cell sizes for each of the new models

TUFLOW Model	Cell Size
Area 1	3 m
Area 2	4 m
Area 7 – Clockhouse Stream	2 m
Area 7 – Burton Brook	2 m
Christchurch Tidal (existing model)	10 m
Hampshire Avon, Christchurch (existing model)	4 m
Lower Stour (existing model)	5 m

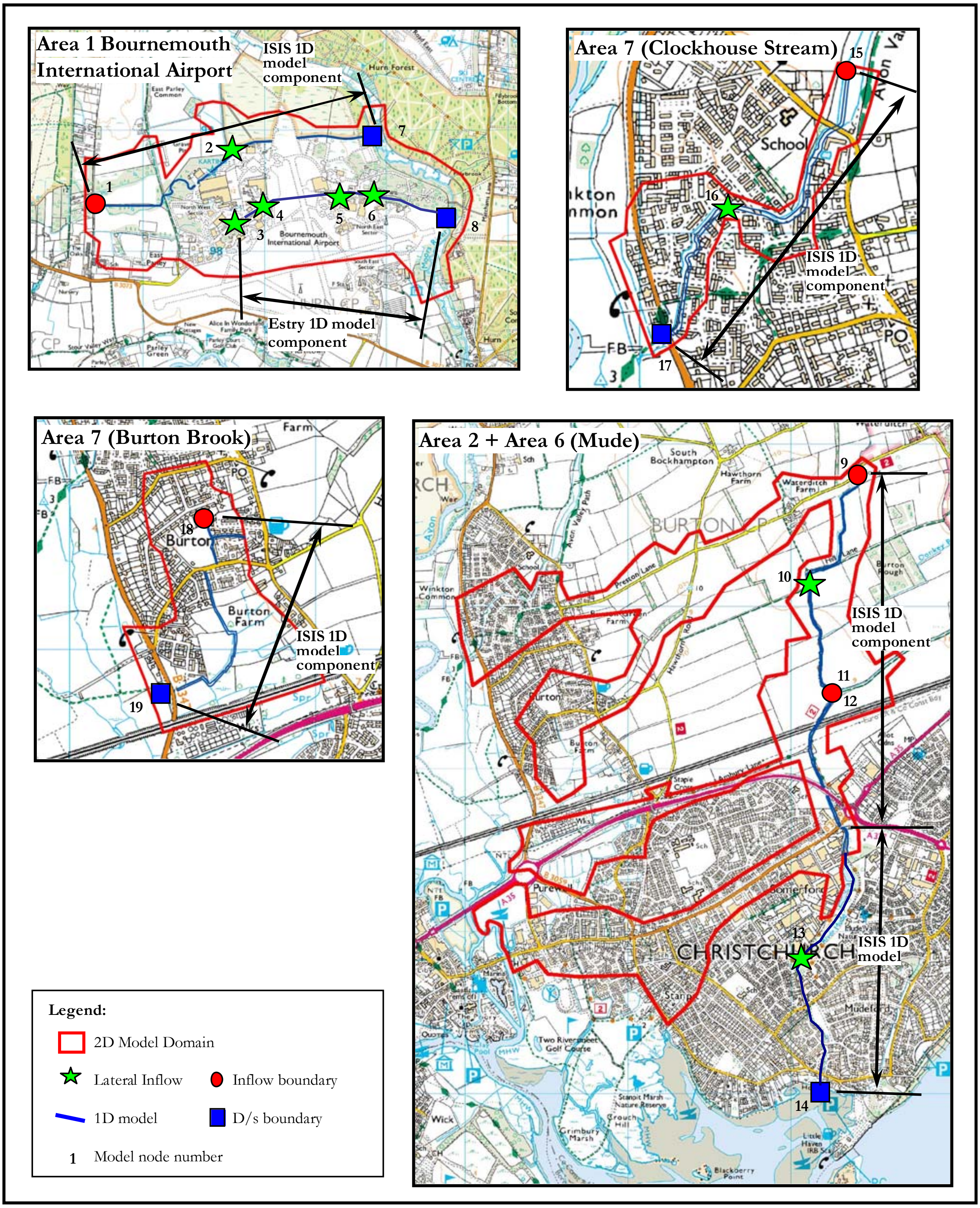


Figure 9.1: Areas of study - model boundary – new models

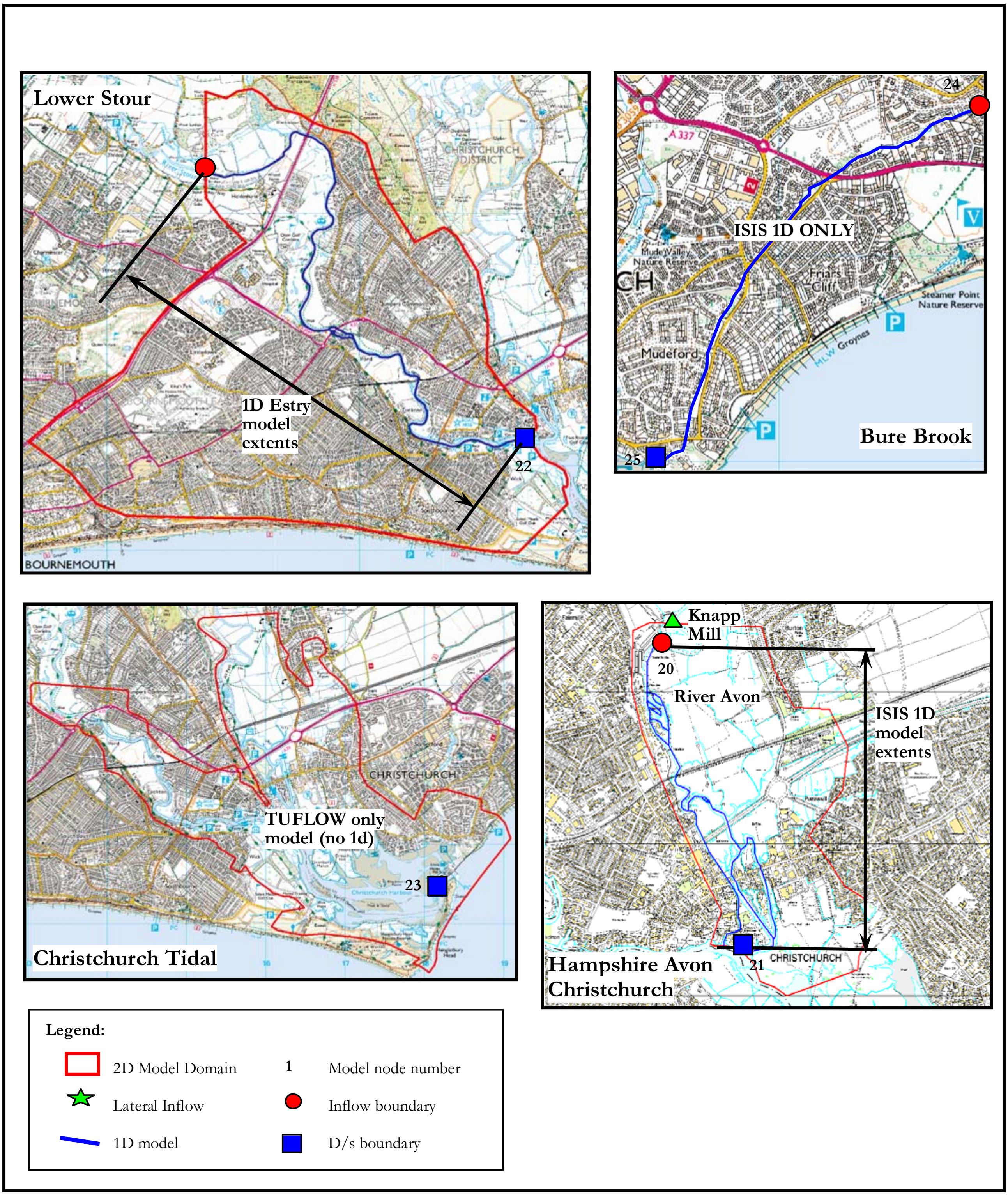


Figure 9.2: Areas of study - model boundary – existing models

9.3 Boundaries - inflows / downstream

This section describes the inflow and downstream boundaries used in the modelling, it includes details on the updates to the Hampshire Avon model boundaries and the boundaries used for the new model builds.

In modelling coastal conditions, the tidal boundary water level of 1.2mAOD was adopted. This is representative of the mean spring tide cycle extracted from the data measured at Priory Quay in 2005 (Capita Symonds, 2006).

For modelling the climate change scenarios, the factors applied to the hydrological data, was based on the predictions advised in PPS25, this included:

- Fluvial flood flows increased by 20% from 2025
- Sea level rise to increase the tidal boundary to 1.87mAOD (+0.67m) in year 2086 and 2.45mAOD (+1.25m) in year 2126

Hampshire Avon – Christchurch Model Updates

The previous fixed inflows and tidal levels were updated to use the recorded inflows at Knapp Mill for December 2000. This hydrograph shape was then scaled to match the flow peak for the design return periods stated in the Hampshire Avon Flood Mapping Study (April 2008). The tidal boundary was updated to use a level of approximately 1.20mAOD (as detailed above)

The inflow hydrograph and tidal boundary are detailed in Figure 9.3. The design boundaries used are detailed in Table 9.4 and Table 9.5 for the climate change scenarios

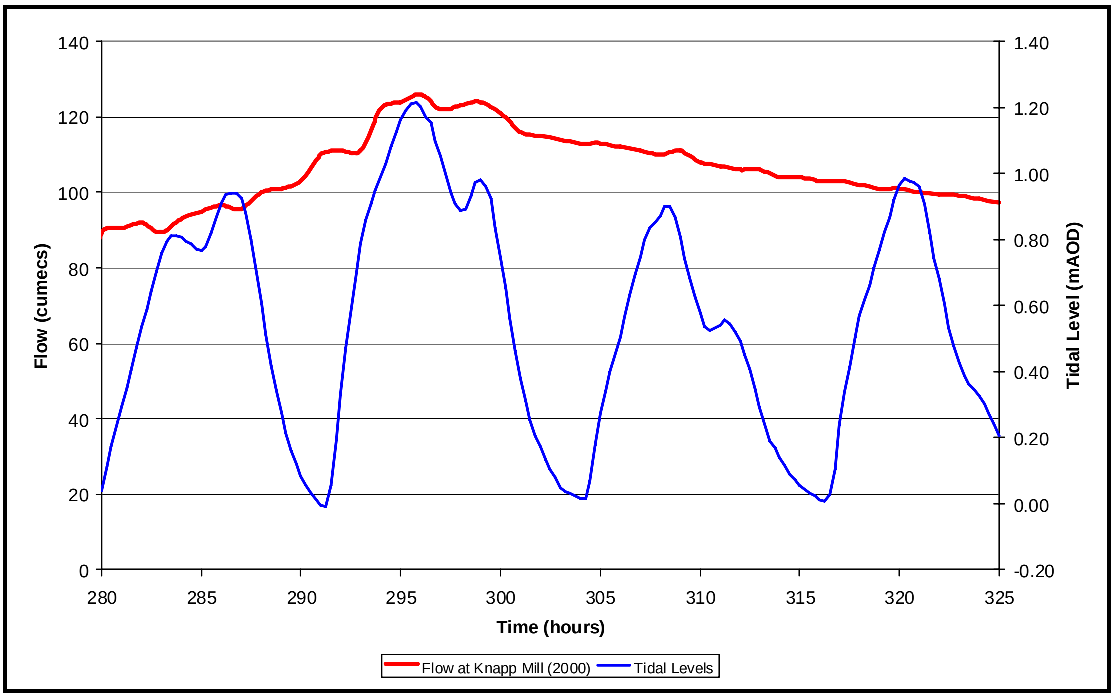


Figure 9.3 – Hampshire Avon, Christchurch model boundaries

Table 9.4: Hampshire Avon design inflows and downstream boundaries – current situation

Ref (Figure 9.2) & Model Node		Inflow Type	Model Inflows (m3/s) for Return Period		
			20-yr	100-yr	1000-yr
Area 3	**Hampshire Avon**				
20	01.042	In-line	137.47	175.39	258.05
21	Downstream Boundary – Tidal boundary peaks at 1.22mAOD				

Table 9.5: Hampshire Avon design inflows and downstream boundaries – climate change

Ref (Figure 9.2) & Model Node		Inflow Type	Model Inflows (m3/s) for Return Period		
			20-yr + 20%	100-yr + 20%	1000-yr +20%
Area 3	**Hampshire Avon**				
20	01.042	In-line	164.93	210.42	309.71
21	Downstream Boundary – Tidal boundary sea level rise, peaks at 1.87mAOD (year 2086)				
21	Downstream Boundary – Tidal boundary sea level rise, peaks at 2.45mAOD (year 2126)				

<u>New model builds</u>

Inflows to the models are included as ReFH boundaries which produces a flow/time data set. The ReFH boundaries were taken from the hydrological assessment. These boundaries were either input as point inflows, i.e. in-line to main river or outflow from a tributary or lateral inflows which are distributed over a river reach. The models are constructed with downstream boundaries based on either normal depth rating curves, fixed level or tidal boundaries. The design boundaries used are detailed in Table 9.6 and Table 9.7 for the climate change scenarios

Table 9.6: Design inflows and downstream boundaries – current situation

Ref (Figure 9.1) & Model Node		Inflow Type	Model Inflows (m3/s) for Return Period		
			20-yr	100-yr	1000-yr
Area 1	**Bournemouth International Airport**				
1	North_top	In-line	3.11	4.94	9.76
2	North_lats	Lateral	0.88	1.39	2.73
3	Flow_South_top_U	Lateral	0.34	0.65	1.01
4	Flow_South_top_D	Lateral	0.23	0.44	0.67
5	Flow_South_lats_U	Lateral	0.11	0.21	0.33
6	Flow_South_lats_D	Lateral	0.11	0.21	0.33
7	Downstream Boundary - Normal depth boundary at Moors River				
8	Downstream Boundary - set at 0.8m				
Area 2	**+ FRA 6 River Mude**				
9	Mude_1	In-line	1.96	2.82	5.17
10	Mude_2	Lateral	0.23	0.33	0.58
11	Mude_3	In-line	1.01	1.44	2.63
12	Mude_4	In-line	0.64	0.93	1.75
13	Mude_5	Lateral	0.10	0.18	0.42
14	Downstream Boundary - Tidal boundary peaks at 1.22mAOD				
Area 7	**Clockhouse Stream**				
15	Clock_top	In-line	3.36	4.75	8.50
16	Clock_lats	Lateral	0.42	0.67	1.47
17	Downstream Boundary - Fixed level of 2.33mAOD d/s of Stony lane bridge (bridge modelled as orifice and acts a control)				
Area 7	**Burton Brook**				
18	FRA7Burton	In-line	0.66	1.20	2.58
19	Downstream Boundary - Fixed level of 1.67mAOD d/s of Stony lane bridge (bridge modelled as orifice and acts a control)				

Table 9.7: Design inflows and downstream boundaries – climate change

Ref (Figure 9.1) & Model Node		Inflow Type	Model Inflows (m3/s) for Return Period		
			20-yr + 20%	**100-yr + 20%**	**1000-yr +20%**
Area 1	**Bournemouth International Airport**				
1	North_top	In-line	3.73	5.93	11.71
2	North_lats	Lateral	1.06	1.67	3.28
3	Flow_South_top_U	Lateral	0.41	0.78	1.21
4	Flow_South_top_D	Lateral	0.27	0.52	0.80
5	Flow_South_lats_U	Lateral	0.13	0.25	0.40
6	Flow_South_lats_D	Lateral	0.13	0.25	0.40
7	Downstream Boundary – Normal depth boundary at Moors River				
8	Downstream Boundary – set at 0.8m				
Area 2	**+ FRA 6 River Mude**				
9	Mude_1	In-line	2.35	3.38	6.20
10	Mude_2	Lateral	0.28	0.39	0.70
11	Mude_3	In-line	1.21	1.73	3.16
12	Mude_4	In-line	0.77	1.12	2.10
13	Mude_5	Lateral	0.12	0.21	0.51
14	Downstream Boundary – Tidal boundary sea level rise, peaks at 1.87mAOD (year 2086)				
14	Downstream Boundary – Tidal boundary sea level rise, peaks at 2.45mAOD (year 2126)				
Area 7	**Clockhouse Stream**				
15	Clock_top	In-line	4.04	5.70	10.20
16	Clock_lats	Lateral	0.50	0.81	1.76
17	Downstream Boundary - Fixed level of 2.33mAOD d/s of Stony lane bridge (bridge modelled as orifice and acts a control)				
Area 7	**Burton Brook**				
18	FRA7Burton	In-line	0.79	1.44	3.09
19	Downstream Boundary - Fixed level of 1.67mAOD d/s of Stony lane bridge (bridge modelled as orifice and acts a control)				

Lower Stour

The Lower Stour model extends from Sturminster Marshall (NGR 395770, 100540) to Christchurch where the model contains a tidal boundary. The TUFLOW model in Christchurch represents the lower reaches of this model and contains a tidal boundary of approximately 1.2mAOD, which is representative of the mean spring tide cycle extracted from the data measured at Priory Quay in 2005. The tidal levels adopted for the study are detailed in Table 9.8

Christchurch Tidal Model

The Christchurch Tidal Model contains a boundary which simulates a tidal curve for the 1:200 and 1:1000 year events. The tidal levels adopted for the study are detailed in Table 9.8.

Table 9.8: Tidal levels

Ref (Figure 9.2) & Model Node		Tidal Boundary Peak Level (mAOD)		
		Current	**2086**	**2126**
Area 3	**Lower Stour**			
22	Ls000000	1.22	1.87	2.45
Area 4	**Christchurch Tidal Model**			
23	1:200 year boundary	1.99	2.66	3.24
23	1:1000 year boundary	2.17	2.84	3.42

Bure Brook

The Bure Brook model extends from the South Coast Mainline Railway (NGR 420951, 091934 to it's outfall in Christchurch Harbour. The area of interest extends from Smugglers Lane South (NGR 420007, 093744), design flows in the Bure Brook at this location are detailed in Table 9.9. Flows for the defended and undefended scenarios are included as the defence (Nea Meadows flood storage area) is located upstream of the area of interest and impacts the flows.

The downstream boundary at Christchurch harbour is represented by a tidal boundary, with a water level of 1.2mAOD. This is representative of the mean spring tide cycle extracted from the data measured at Priory Quay in 2005 (Capita Symonds, 2006). The tidal levels adopted for the study are also detailed in Table 9.9.

Table 9.9: Bure Brook design inflow and downstream boundary

Ref (Figure 9.2) & Model Node		**Inflow Type**	**Model Inflows** (m3/s) **for Return Period**					
			20-yr	**100-yr**	**1000-yr**	**20-yr + 20%**	**100-yr + 20%**	**1000-yr +20%**
Area 6	**Bure Brook – Defended**							
24	BB102709	In-line	1.44	1.83	4.06	1.66	2.17	5.13
25	Downstream Boundary		Tidal boundary peaks at 1.22mAOD			Tidal boundary sea level rise, peaks at 2.45mAOD (year 2126)		
Area 6	**Bure Brook – Undefended**							
24	BB102709	In-line	2.00	2.79	4.83	2.37	3.33	5.51
25	Downstream Boundary		Tidal boundary peaks at 1.22mAOD			Tidal boundary sea level rise, peaks at 2.45mAOD (year 2126)		

9.4 *Model parameters 1D*

Roughness parameters for the ISIS cross sections are specified using Manning's n friction parameters. The roughness values are a means of representing the channel and floodplain conveyance based on the vegetation, composition and sinuosity.

The roughness values selected derive from site inspection, survey photos and a combination of modelling experience and information from Open Channel Hydraulics - states typical roughness in the range of 0.025 to 0.045 for natural streams with varying degree of stones and weeds (Chow V.T., McGraw-Hill).

Table 9.10 gives the roughness coefficients adopted. Without any additional flood data (recorded levels etc) there seems no justification for using more varied roughness values. However, the roughness parameter could be refined in site specific flood risk assessments using additional survey and informed by site inspection.

Thus for the 1D component, roughness is set at 0.035 and for the TUFLOW domain an averaged global roughness is set at 0.050. Given the manageable size of the TUFLOW domains the roughness was further broken down to represent individual floodplain components based on Master Map data.

Based on ISIS modelling experience and the guidelines within ISIS, the spill coefficients representing spilling over banks or between floodplain flood cells is in the range of 0.3 to 1.2. Typical spill coefficients are given in Table 9.11.

Area1: Bournemouth International Airport

Area 2: East of Burton

Area 7: Clockhouse Stream

Area 7: Burton Brook

Table 9.10: Manning's n values

Land Use	Description	Manning's n Value
Channel	Typical channel	0.035
Floodplain	Rural areas, scrub etc	0.050

Table 9.11: Spill coefficients

Description	Spill Coefficient	Description	Spill Coefficient
Sharp crested weir	1.85	Good quality bank	1.00 – 1.75
Round nosed weir	1.70	Poor quality banks/ rough ground	<1.00

9.5 Model prameters 2D

The floodplain roughness has been broken down to represent individual floodplain components using Master Map data, the roughness coefficients adopted are detailed in Table 9.12

Table 9.12: Master Map Manning's n values

TUFLOW material ref.	Description	Manning's n value
1	Building. Very high Manning's n - allow storage but no water movement	1.000
2	Foreshore	0.030
3	Manmade Surfaces and Steps	0.035
4	Multi Surface (primarily people's gardens, high value to take into account fences etc)	0.100
5	Natural roadside (Verges)	0.035
6	Natural surfaces (Primarily fields)	0.050
7	Path	0.035
8	Rail	0.035
9	Regions non Manmade Land (generally pavements)	0.020
10	Road or Track	0.020
11	Scrub ("medium to dense brush value, in winter")	0.070
12	Water	0.010
99	Other areas (default value)	0.050
999	Stability patch	0.100

9.6 Model run parameters - new models

The ISIS run parameters for the four new ISIS/TUFLOW models are detailed in Table 9.13. All parameters are stored in the "ief" file. It was not necessary to modify any other parameters, i.e. default values used. This reflects how well the models are constructed, representing 'real' conditions at site

It should be noted that relative path names are used in the "ief" files, which relate to directory structure where the model was developed and run. To re-run the model the same file structure should be adopted by simply copying the DVD to c:\. Otherwise the relative path names in the "ief" file will need to be modified.

Table 9.13: ISIS run parameters

Run Form Tab	Description	ISIS Data File (dat)			
		Area 1 FRA1_top.dat	Area 2+6 FRA2_FRA6.DAT	FRA7 Burton.DAT	FRA7 clockhouse.DAT
Files	Initial conditions	Data file	Data file	Data file	Data file
	Use of event data files	✓	✓	✓	✓
Times	Run type	Unsteady	Unsteady	Unsteady	Unsteady
	Timestep 1D (s)	0.75	2	1	1
	Timestep 2D (s)	1.50	2	1	1
	Save interval (s)	900	900	900	900
	Start time (hrs)	Dependant on run scenario and saved in the ief. Start and end times vary based on timings of inflow hydrographs			
	End time (hrs)				
Options	Automated Preissmann slot for river sections	×	×	×	×
Parameters	Various	default	default	default	default

The stability of these models is illustrated in Figure 9.4, which shows the model convergence for the 1 in 100-year flood event simulations. This shows the models are fit for purpose (convergence for other simulations is similar).

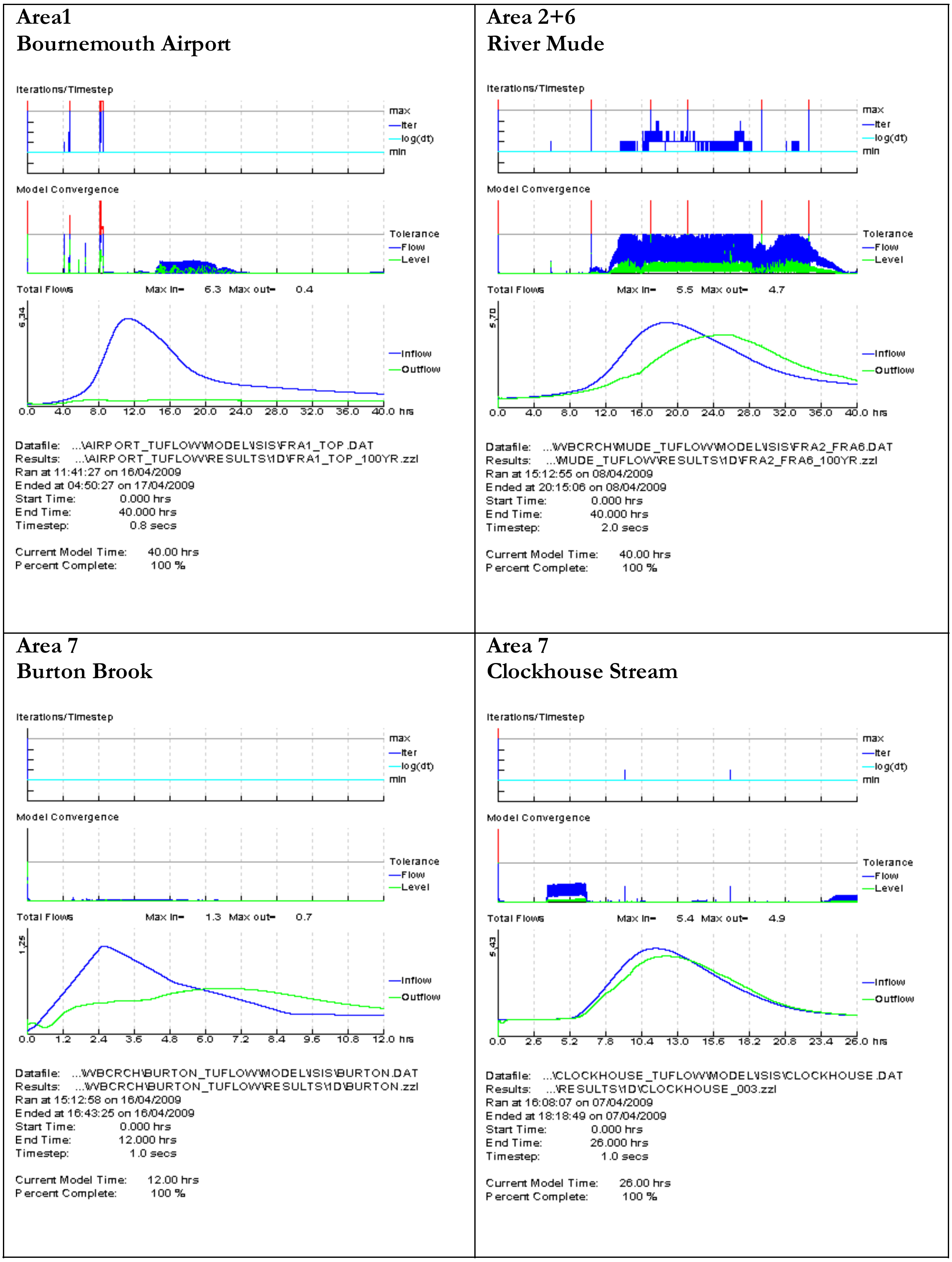


Figure 9.4: ISIS model convergence plots

10 Hydraulic Assessment: Calibration/Design Event Simulations

10.1 General

The aim and approach of the calibration process is to confirm the accuracy of the model before the modelling of design simulations. For the new build models (Areas 1, 2, 6 and 7) there is no available calibration event data, therefore the output mapping has been reviewed by those that know the areas and with the memories of flooding history as detailed in Appendix D.

The original models for the lower Stour and Hampshire Avon (Area 5 and 3) were calibrated in previous studies, with no additional calibration required for this latest modelling.

Design flood events have been run for the 1:20, 1:100 and 1:1000-year events (5%, 1%, 0.1% annual probability). For climate change scenarios the flows have been increased by 20% and for the models with tidal boundaries, sea level rise applied to represent years 2086 and 2126 (River Mude, Hampshire Avon Christchurch and Lower Stour).

All models are run without defences. However, the Hampshire Avon Christchurch model and the Lower Stour the design simulations have also been run with flood defences (there are no defences in other areas).

As a results summary, peak flood flows/levels at selected model nodes are tabulated, with these nodes located in Figure 10.1 and 10.2. Results for all model nodes and all return periods can be referenced from model output in Appendix L (also saved to DVD's accompanying this report).

For the Christchurch Tidal model only tidal simulations have been run, for the with defences scenarios the defences datasets used within the TUFLOW Hampshire Avon, Christchurch and Lower Stour models were added as the Christchurch Tidal modelling only ran undefended simulations

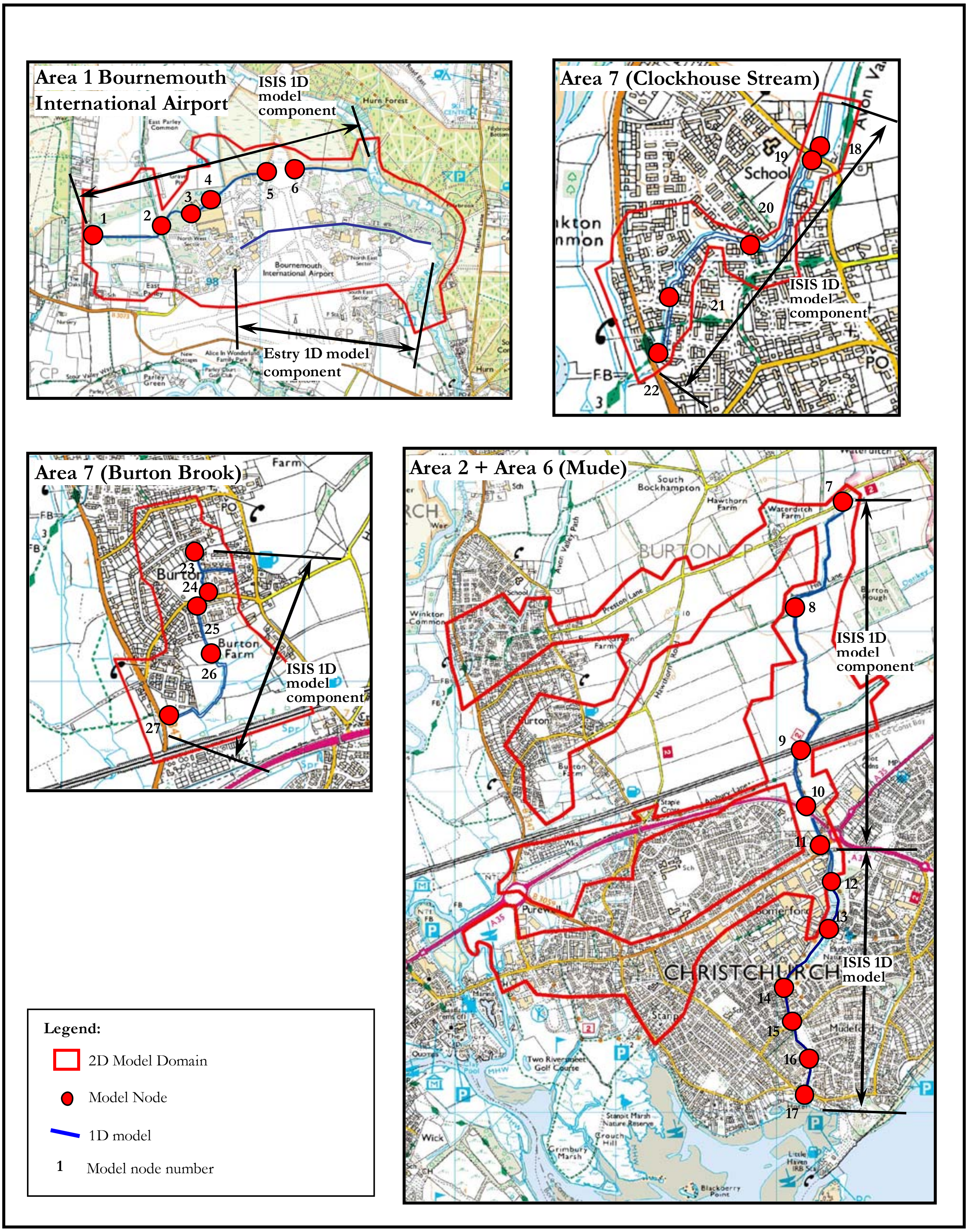


Figure 10.1 Selected model nodes – new models

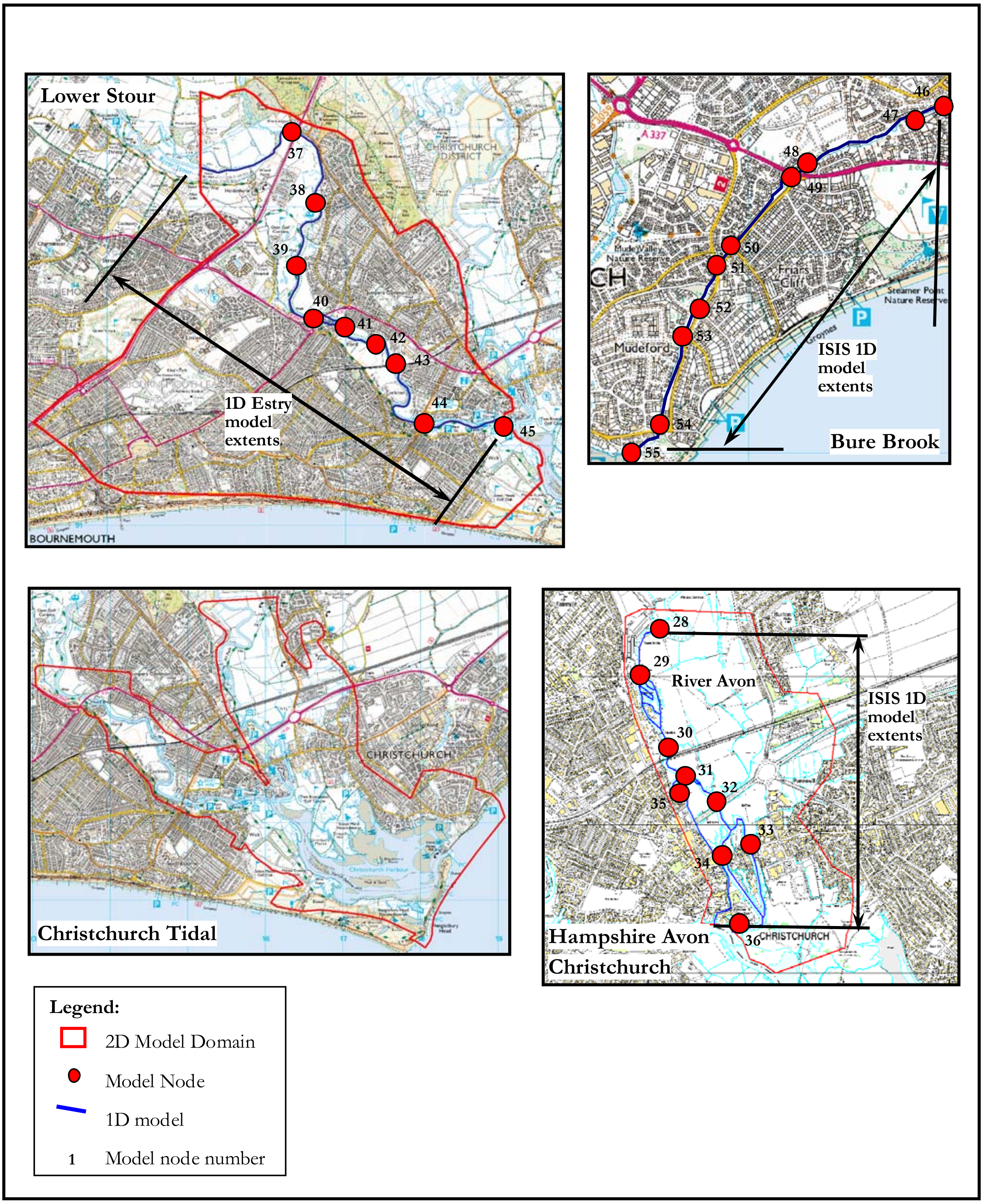


Figure 10.2 Selected model nodes – existing models

10.2 Design flood events – new model builds

As a results summary, peak flood flows/levels at selected model nodes are detailed in Tables 10.1 and Table 10.2 for Climate Change. For the River Mude only, sea level rise applied to represent years 2086 and 2126.

Table 10.1: New models, peak flows and water levels – current situation

Ref	Node	Co-ordinates		20-yr	100-yr	1000-yr	Description
		E	N	Level	Level	Level	
Area 1 – Bournemouth International Airport							
1	BA.001	409603	98374	11.40	11.50	11.64	u/s extent of model
2	BA.044	410190	98464	11.09	11.16	11.26	d/s Chapel Lane
3	BA.005	410413	98530	11.07	11.16	11.25	u/s culvert
4	BA.011	410576	98665	10.46	10.85	11.00	d/s culvert
5	BA.013	411051	98910	10.12	10.76	10.91	u/s Airfield Culvert
6	BA.051	411280	98935	9.44	9.59	9.61	d/s Airfield Culvert
Area 2 and Area 6 – River Mude							
7	M021	418420	95776	9.97	10.18	10.47	u/s extent of model
8	M023	418116	95103	9.13	9.28	9.34	River Mude
9	M025	418171	94282	7.92	8.09	8.71	Railway Bridge
10	m2127	418202	93886	7.19	7.52	8.03	u/s A35 road
11	m1867	418300	93651	6.90	7.25	7.71	u/s B3059 road
12	m1582	418362	93395	6.39	6.60	7.06	u/s Somerford Weir
13	m1265	418344	93106	5.42	5.77	6.81	u/s culvert
14	m736	418069	92709	3.85	4.30	5.85	u/s culvert
15	m567	418100	92544	2.60	2.82	2.97	u/s De Havilland Way
16	m291	418213	92306	1.68	1.83	2.06	u/s Raven Way
17	m97	418197	92125	1.22	1.22	1.22	u/s Mudeford Road
Area 7 Clockhouse Stream							
18	C026	416538	95289	6.64	6.86	7.22	u/s Salisbury Road
19	C_Lidar2	416509	95274	6.62	6.82	7.13	d/s Salisbury Road
20	C029	416348	95050	4.68	4.88	5.28	u/s Priory View Road
21	C033a	416125	94873	4.10	4.25	4.32	u/s Burnham Road
22	C036	416090	94727	2.63	2.74	3.02	u/s Stony Lane
Area 7 Burton Brook							
23	B_Lidar1	416561	94508	4.25	4.45	4.59	u/s extent of model
24	B1.041	416600	94348	4.22	4.42	4.49	u/s Martins Hill Lane
25	B1.044	416552	94312	3.53	3.62	3.80	d/s Martins Hill Lane
26	B1.045	416603	94150	3.05	3.22	3.52	Burton Brook
27	B1.047	416440	93834	2.09	2.23	2.41	u/s Stony Lane

Table 10.2: New models, peak flows and water levels – climate change

Ref	Node	20-yr +20% Tide 2086 *	20-yr +20% Tide 2126 *	100-yr +20% Tide 2086 *	100-yr +20% Tide 2126 *	1000-yr +20% Tide 2086 *	1000-yr+20% Tide 2126 *
		Level	Level	Level	Level	Level	Level
Area 1 – Bournemouth International Airport							
1	BA.001	11.44	N/A	11.54	N/A	11.67	N/A
2	BA.044	11.11	N/A	11.19	N/A	11.29	N/A
3	BA.005	11.10	N/A	11.18	N/A	11.28	N/A
4	BA.011	10.57	N/A	10.92	N/A	11.03	N/A
5	BA.013	10.36	N/A	10.83	N/A	10.93	N/A
6	BA.051	9.50	N/A	9.60	N/A	9.62	N/A
Area 2 and Area 6 – River Mude							
7	M021	10.08	10.07	10.30	10.30	10.51	10.51
8	M023	9.19	9.20	9.30	9.30	9.35	9.34
9	M025	8.00	8.00	8.19	8.20	8.72	8.71
10	m2127	7.34	7.35	7.72	7.72	8.06	8.05
11	m1867	7.08	7.08	7.47	7.46	7.73	7.73
12	m1582	6.48	6.48	6.74	6.74	7.27	7.27
13	m1265	5.57	5.57	5.99	5.99	7.16	7.16
14	m736	4.03	4.03	4.77	4.77	6.21	6.21
15	m567	2.68	2.72	2.89	2.88	3.00	3.00
16	m291	1.97	2.47	2.05	2.50	2.16	2.54
17	m97	1.87	2.45	1.87	2.45	1.87	2.45
Area 7 Clockhouse Stream							
18	C026	6.76	N/A	6.97	N/A	7.36	N/A
19	C_Lidar2	6.73	N/A	6.91	N/A	7.23	N/A
20	C029	4.79	N/A	4.99	N/A	5.41	N/A
21	C033a	4.18	N/A	4.27	N/A	4.33	N/A
22	C036	2.69	N/A	2.82	N/A	3.09	N/A
Area 7 Burton Brook							
23	B_Lidar1	4.39	N/A	4.48	N/A	4.62	N/A
24	B1.041	4.37	N/A	4.44	N/A	4.51	N/A
25	B1.044	3.57	N/A	3.66	N/A	3.86	N/A
26	B1.045	3.09	N/A	3.29	N/A	3.63	N/A
27	B1.047	2.10	N/A	2.29	N/A	2.44	N/A

* Note: Sea Level rise tidal levels only applicable to model FRA2/FRA6 – River Mude

10.3 Design flood events – Hampshire Avon, Christchurch model

Design flood events have been run for the 1:20, 1:100 and 1:1000 year events (5%, 1%, 0.1% annual probability). For climate change scenarios the flows have been increased by 20% and sea level rise applied to represent years 2086 and 2126. As a results summary, peak flood flows/levels at selected model nodes are detailed in Tables 10.3 and Table 10.4 (Climate Change), with these nodes located in Figure 10.2.

Table 10.3: Hampshire Avon, Christchurch, peak flows and water levels – current situation

Ref	Node	Co-ordinates		20-yr	100-yr	1000-yr	Description
		E	N	Level	Level	Level	
Hampshire Avon, Christchurch Model - Undefended							
28	01.042	415599	94276	3.42	3.50	3.61	u/s extents of model
29	01.038	415445	93998	2.94	3.06	3.29	Main weir adj to Water W
30	01.025u	415650	93448	2.36	2.55	2.81	Railway Bridge
31	01.020	415729	93274	2.23	2.43	2.71	junction with Mill leat
32	01.015u	416024	93137	2.09	2.26	2.43	Fountain Way Bridge
33	01.009u	416242	92832	1.96	2.15	2.29	Waterloo Bridge
34	02.006u	416073	92760	2.02	2.21	2.99	Town Bridge
35	06.018u	415779	93209	2.23	2.43	2.71	u/s extent of Mill Leat
36	01.001	416223	92308	1.22	1.22	1.22	d/s extents of model
Hampshire Avon, Christchurch Model - Defended							
28	01.042	415599	94276	3.42	3.50	3.61	u/s extents of model
29	01.038	415445	93998	2.95	3.07	3.33	Main weir adj to Water W
30	01.025u	415650	93448	2.45	2.66	2.89	Railway Bridge
31	01.020	415729	93274	2.37	2.59	2.81	junction with Mill leat
32	01.015u	416024	93137	2.26	2.48	2.52	Fountain Way Bridge
33	01.009u	416242	92832	2.12	2.32	2.43	Waterloo Bridge
34	02.006u	416073	92760	2.22	2.95	3.22	Town Bridge
35	06.018u	415779	93209	2.36	2.59	2.81	u/s extent of Mill Leat
36	01.001	416223	92308	1.22	1.22	1.22	d/s extents of model

Table 10.4: Hampshire Avon, Christchurch, peak flows and water levels – climate change

Ref	Node	20-yr +20% Tide 2086	20-yr +20% Tide 2126	100-yr +20% Tide 2086	100-yr +20% Tide 2126	1000-yr +20% Tide 2086	1000-yr+20% Tide 2126
		Level	Level	Level	Level	Level	Level
Hampshire Avon, Christchurch Model - Undefended							
28	01.042	3.48	3.48	3.55	3.55	3.68	3.69
29	01.038	3.03	3.08	3.17	3.20	3.44	3.46
30	01.025u	2.55	2.73	2.71	2.82	2.98	3.06
31	01.020	2.46	2.68	2.62	2.76	2.89	2.99
32	01.015u	2.31	2.59	2.43	2.61	2.55	2.71
33	01.009u	2.24	2.56	2.49	2.74	2.47	2.68
34	02.006u	2.28	3.14	2.38	2.92	3.22	3.40
35	06.018u	2.46	2.68	2.62	2.76	2.89	2.99
36	01.001	1.87	2.45	1.87	2.45	1.87	2.45
Hampshire Avon, Christchurch Model - Defended							
28	01.042	3.48	3.48	3.55	3.55	3.69	3.69
29	01.038	3.05	3.07	3.18	3.21	3.45	3.46
30	01.025u	2.63	2.70	2.76	2.83	3.04	3.08
31	01.020	2.57	2.65	2.68	2.78	2.96	3.01
32	01.015u	2.48	2.50	2.47	2.56	2.64	2.71
33	01.009u	2.36	2.50	2.38	2.57	2.61	2.76
34	02.006u	2.94	3.13	3.08	3.26	3.39	3.50
35	06.018u	2.57	2.65	2.68	2.78	2.96	3.01
36	01.001	1.87	2.45	1.87	2.45	1.87	2.45

10.4 Design flood events – Lower Stour

Design flood events have been run for the 1:25, 1:100 and 1:1000 year events (4%, 1%, 0.1% annual probability). It was agreed with the Environment Agency that the 1:25 year flood event could be taken to represent FZ3b, since this was modelled previously (2006). For climate change scenarios the flows have been increased by 20% and sea level rise applied to represent years 2086 and 2126. As a results summary, peak flood flows/levels at selected model nodes are detailed in Tables 10.5 and Table 10.6 (Climate Change), with these nodes located in Figure 10.2.

Table 10.5: Lower Stour, peak flows and water levels – current situation

Ref	Node	Co-ordinates		25-yr	100-yr	1000-yr	Description
		E	N	Level	Level	Level	
Lower Stour - Undefended							
37	ls06686	413404	95915	4.73	5.14	5.49	d/s A338
38	ls05656	413616	95041	4.16	4.66	5.15	River Stour
39	ls04813	413405	94408	3.69	4.39	4.96	River Stour
40	ls03967	413630	93618	3.41	4.27	4.86	u/s A35
41	ls03366	413930	93514	3.29	4.00	4.57	d/s A35
42	ls02890	414294	93286	2.75	3.43	4.11	River Stour
43	ls02261	414969	93030	2.40	3.03	3.58	u/s Railway
44	ls01060	414925	92272	1.58	1.90	2.23	u/s B3059
45	ls00000	415996	92296	1.22	1.22	1.22	d/s extents of model
Lower Stour - Defended							
37	ls06686	413404	95915	4.74	5.17	5.65	d/s A338
38	ls05656	413616	95041	4.18	4.71	5.38	River Stour
39	ls04813	413405	94408	3.72	4.44	5.24	River Stour
40	ls03967	413630	93618	3.46	4.32	5.17	u/s A35
41	ls03366	413930	93514	3.31	4.03	4.75	d/s A35
42	ls02890	414294	93286	2.74	3.43	4.13	River Stour
43	ls02566	414969	93030	2.40	3.03	3.59	u/s Railway
44	ls01485	414925	92272	1.59	1.90	2.23	u/s B3059
45	ls00000	415996	92296	1.22	1.22	1.22	d/s extents of model

Original Lower Stour Results highlighted in green

Table 10.6 Lower Stour, peak flows and water levels – climate change

Ref	Node	25-yr +20% Tide 2086	25-yr +20% Tide 2126	100-yr +20% Tide 2086	100-yr +20% Tide 2126	1000-yr +20% Tide 2086	1000-yr+20% Tide 2126
		Level	Level	Level	Level	Level	Level
Lower Stour - Undefended							
37	ls06686	4.92	4.93	5.34	5.35	5.67	5.67
38	ls05656	4.37	4.40	4.95	4.97	5.40	5.40
39	ls04813	4.00	4.08	4.74	4.77	5.22	5.23
40	ls03967	3.83	3.93	4.65	4.68	5.13	5.15
41	ls03366	3.66	3.77	4.35	4.39	4.86	4.89
42	ls02890	3.17	3.34	3.85	3.97	4.54	4.59
43	ls02566	2.85	3.08	3.42	3.54	3.92	4.00
44	ls01485	2.14	2.59	2.37	2.73	2.63	2.90
45	ls00000	1.89	2.47	1.89	2.47	1.89	2.47
Lower Stour - Defended							
37	ls06686	4.93	4.94	5.45	5.47	5.85	5.86
38	ls05656	4.40	4.43	5.12	5.16	5.62	5.63
39	ls04813	4.04	4.12	4.95	5.01	5.49	5.50
40	ls03967	3.86	3.97	4.87	4.93	5.43	5.44
41	ls03366	3.69	3.80	4.48	4.55	5.03	5.06
42	ls02890	3.17	3.35	3.86	3.99	4.64	4.70
43	ls02566	2.85	3.10	3.43	3.57	4.01	4.09
44	ls01485	2.14	2.60	2.38	2.73	2.67	2.94
45	ls00000	1.89	2.47	1.89	2.47	1.89	2.47

10.5 *Design flood events – Bure Brook*

Design flood events have been run for the 1:25, 1:100 and 1:1000 year events (4%, 1%, 0.1% annual probability). It was agreed with the Environment Agency that the 1:25 year flood event could be taken to represent FZ3b, since this was modelled previously (2006). For climate change scenarios the flows have been increased by 20% and sea level rise applied to represent year 2126. As a results summary, peak flood flows/levels at selected model nodes are detailed in Tables 10.7 and Table 10.8 (Climate Change), with these nodes located in Figure 10.2

Table 10.7: Bure Brook, peak flows and water levels – current situation

Ref	Node	Co-ordinates		25-yr	100-yr	1000-yr	Description
		E	N	Level	Level	Level	
Bure Brook - Undefended							
46	BB102709	420007	93744	14.10	14.18	14.51	u/s area of interest
47	BB102443	419785	93646	12.78	12.84	13.22	u/s Cornford Way
48	BB101823	419283	93392	9.34	9.47	9.98	u/s A337
49	BB101768	419222	93353	8.75	8.81	9.01	d/s A337
50	BB101444LI	418926	93013	5.96	6.14	6.52	adj Southcliffe Road
51	BB101146	418846	92894	5.45	5.53	5.94	d/s Bure Lane
52	BB100911	418741	92701	4.58	4.68	4.97	u/s Bure Homage
53	BB100748	418672	92544	3.75	3.84	4.35	u/s Bure Haven Drive
54	BB100293	418565	92129	1.92	2.09	2.33	u/s Mudeford Road
55	BB100044ds	418352	91977	1.22	1.22	1.22	d/s extents of model
Bure Brook - Defended							
46	BB102709	420007	93744	14.21	14.34	14.61	u/s area of interest
47	BB102443	419785	93646	12.79	12.93	13.26	u/s Cornford Way
48	BB101823	419283	93392	9.48	9.82	10.06	u/s A337
49	BB101768	419222	93353	8.81	8.90	9.11	d/s A337
50	BB101444LI	418926	93013	6.15	6.42	6.59	adj Southcliffe Road
51	BB101146	418846	92894	5.54	5.66	6.01	d/s Bure Lane
52	BB100911	418741	92701	4.69	4.84	5.09	u/s Bure Homage
53	BB100748	418672	92544	3.84	4.03	4.46	u/s Bure Haven Drive
54	BB100293	418565	92129	2.10	2.24	2.40	u/s Mudeford Road
55	BB100044ds	418352	91977	1.22	1.22	1.22	d/s extents of model

Table 10.8 Bure Brook, peak flows and water levels – climate change

Ref	Node	Co-ordinates		25-yr +20% Tide 2126	100-yr +20% Tide 2126	1000-yr+20% Tide 2126	Description
		E	N	Level	Level	Level	
Bure Brook - Undefended							
46	BB102709	420007	93744	14.15	14.24	14.65	u/s area of interest
47	BB102443	419785	93646	12.81	12.89	13.42	u/s Cornford Way
48	BB101823	419283	93392	9.42	9.56	10.06	u/s A337
49	BB101768	419222	93353	8.78	8.84	9.11	d/s A337
50	BB101444LI	418926	93013	6.12	6.29	6.59	adj Southcliffe Road
51	BB101146	418846	92894	5.50	5.58	6.01	d/s Bure Lane
52	BB100911	418741	92701	4.64	4.74	5.09	u/s Bure Homage
53	BB100748	418672	92544	3.81	3.89	4.46	u/s Bure Haven Drive
54	BB100293	418565	92129	2.47	2.48	2.54	u/s Mudeford Road
55	BB100044ds	418352	91977	2.45	2.45	2.45	d/s extents of model
Bure Brook - Defended							
46	BB102709	420007	93744	14.27	14.42	14.69	u/s area of interest
47	BB102443	419785	93646	12.86	13.02	13.37	u/s Cornford Way
48	BB101823	419283	93392	9.62	9.93	10.10	u/s A337
49	BB101768	419222	93353	8.85	8.96	9.16	d/s A337
50	BB101444LI	418926	93013	6.32	6.48	6.63	adj Southcliffe Road
51	BB101146	418846	92894	5.59	5.87	6.13	d/s Bure Lane
52	BB100911	418741	92701	4.75	4.91	5.30	u/s Bure Homage
53	BB100748	418672	92544	3.91	4.21	4.55	u/s Bure Haven Drive
54	BB100293	418565	92129	2.48	2.50	2.58	u/s Mudeford Road
55	BB100044ds	418352	91977	2.45	2.45	2.45	d/s extents of model

10.6 Sensitivity test on Area 1

A sensitivity test was undertaken for the 100 year flood event on Area 1 (Bournemouth International Airport) to assess the impacts of blockages of the culverts. The model assumes 50% blockage of all culverts and the changes in peak water level are detailed in Table 10.9 (for the nodes detailed in figure 10.1).

The model predicts increased water levels at all culverts and a reduction in water level downstream of the 220m airport culvert. The reduction in peak water level is due to the reduced in-bank flows, due to increased flows passing into the floodplain and not spilling back into the channel. Figure 10.3 shows the differences in flood extents

Table 10.9: Area 1 – Sensitivity test results

Ref	Node	Co-ordinates		100-yr	Blockage	Difference	Description
		E	Level	Level	Level	Level	
Area 1 – Bournemouth International Airport							
1	BA.001	409603	98374	11.50	11.50	0.00	u/s extent of model
2	BA.044	410190	98464	11.16	11.19	0.03	d/s Chapel Lane
3	BA.005	410413	98530	11.16	11.18	0.03	u/s culvert
4	BA.011	410576	98665	10.85	10.93	0.08	d/s culvert
5	BA.013	411051	98910	10.76	10.90	0.14	u/s Airfield Culvert
6	BA.051	411280	98935	9.59	9.26	-0.32	d/s Airfield Culvert

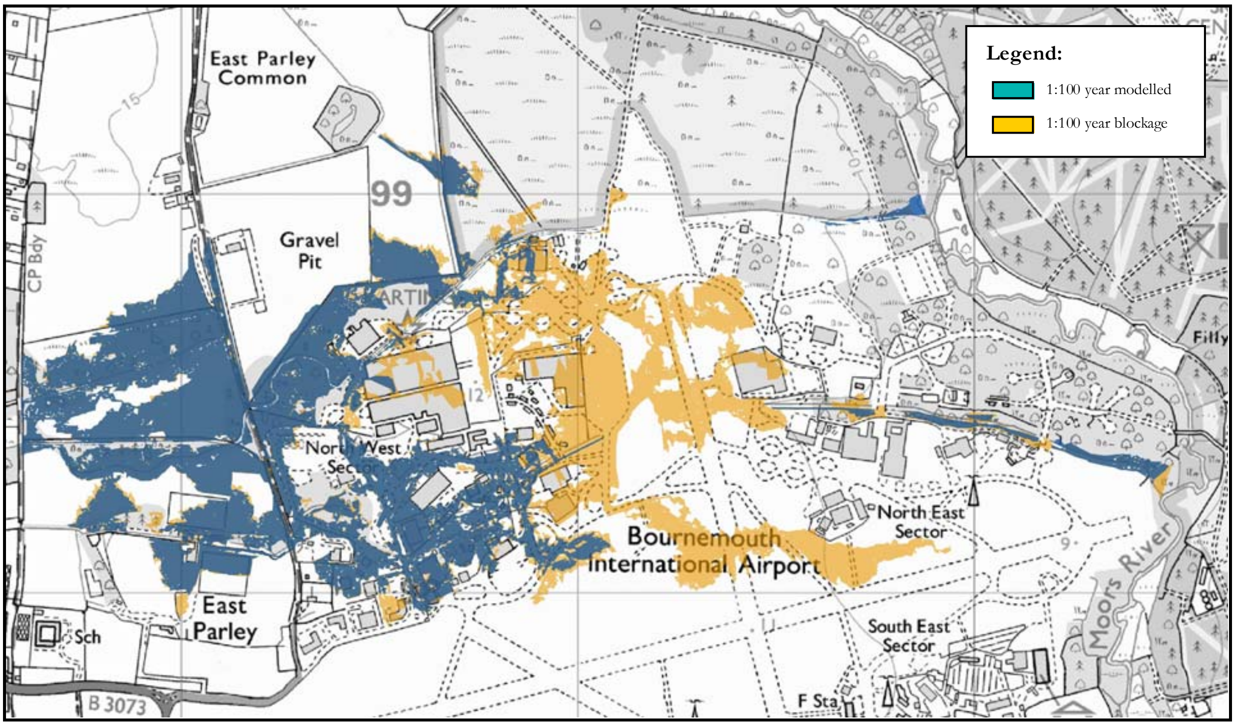


Figure 10.3: Area 1 – Sensitivity Test

10.7 Comparison of Christchurch tidal flood extents

As recommended by the Environment Agency, the TUFLOW model developed for the Mudeford & Stanpit Pre feasibility report (Haskoning, February 2008) was not used for this study, instead the Christchurch Tidal flood zone model (Haskoning, Nov 2007) was extended to cover this area. The flood extents compared in Figure 4 are similar, with small differences suspected to be due to the LiDAR. The DTM used for the original models was not supplied and the DTM was rebuilt from various LiDAR surveys, including LiDAR flown in 2007 which was not available at the time of the previous studies.

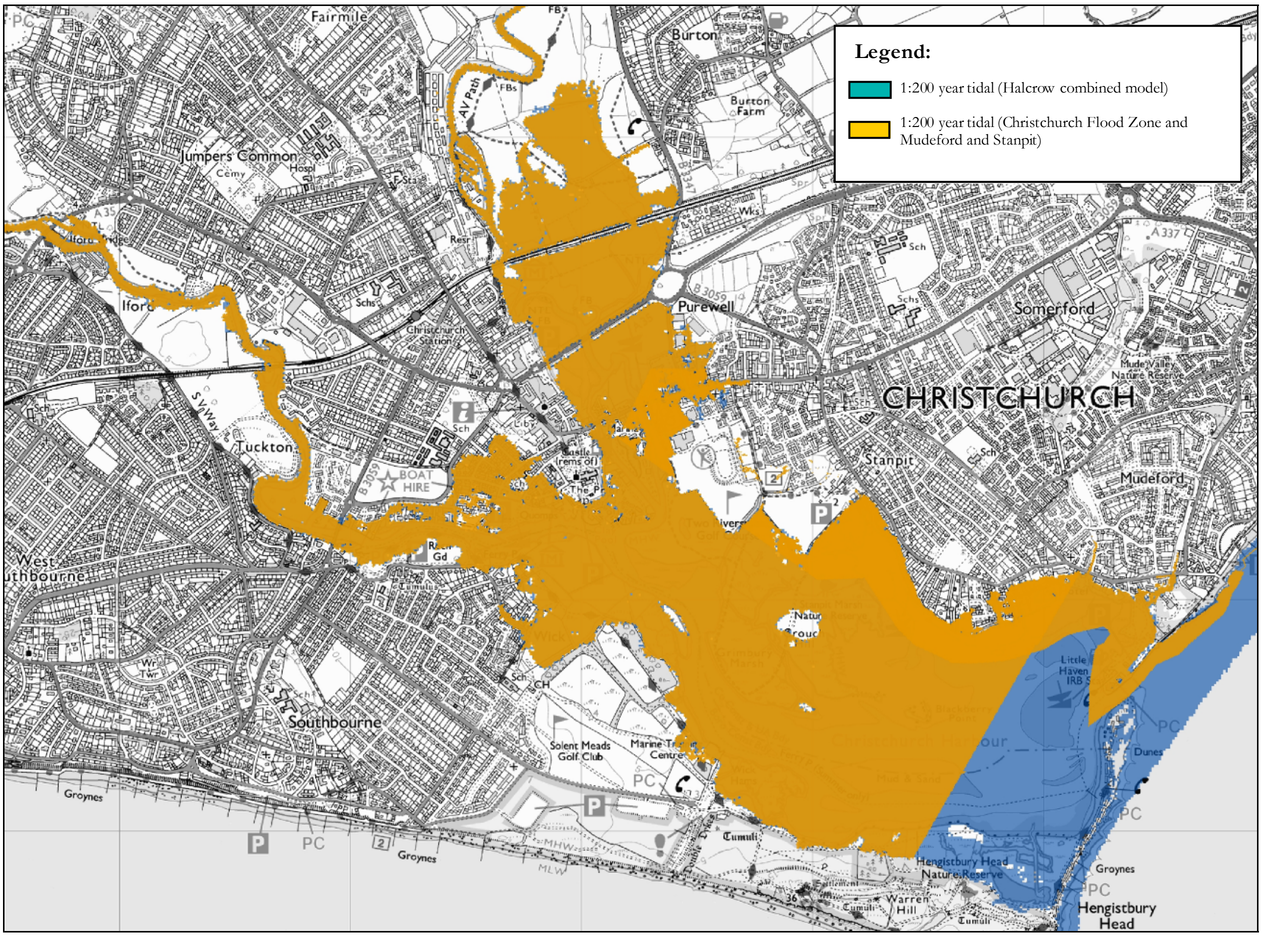


Figure 10.4: Comparison of Christchurch tidal flood extents

11 Flood Mapping

11.1 Overview

The output ASCII grids from the ISIS/TULFOW models are converted into shapefiles using ArcView to create the flood extents. For the 1D model (Area 6) a water surface is made from the peak water levels and cross sections and the DTM subtracted to create the flood extent polygon. The flood extents have been used to compare the areas benefiting from defences for fluvial and tidal events (Section 11.2 & 11.3) and compare against current Flood Zone maps (Section 11.4)

11.2 Areas benefiting from defences (fluvial events)

For the fluvial design events the defended and undefended model extents have been compared to identify which defences are effective and where areas are benefiting from the defences. The locations of the defences are detailed in Figure 11.1 and a summary of the effectiveness of the defences is presented in Table 11.1. For the current scenario a 1.2mAOD mean spring tide has been used, with an appropriate sea level rise for the years 2086 and 2126 (see Section 9.3). Figures 11.2 to 11.4 show the defended and undefended extents for the 1:25, 100 and 1000 year events including climate change for the years 2086 and 2126.

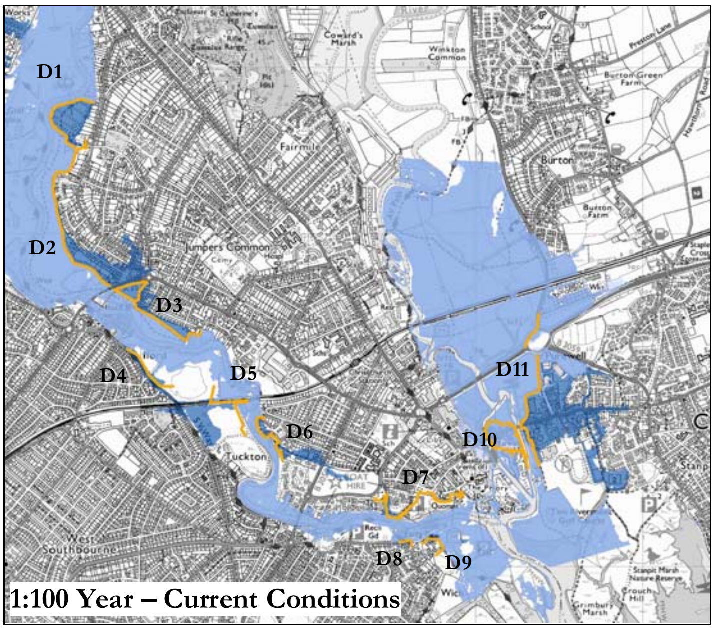


Figure 11.1: Defence locations

Table 11.1: Flood defence summary (fluvial events)

Return Period	Defence										
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
25 year Current Conditions											
25 year Climate Change 2086											
25 year Climate Change 2126											
100 year Current Conditions											
100 year Climate Change 2086											
100 year Climate Change 2126											
1000 year Current Conditions											
1000 year Climate Change 2086											
1000 year Climate Change 2126											

Defence Effective		Defence Breached	

Figure 11.2: 1:25-year ABD

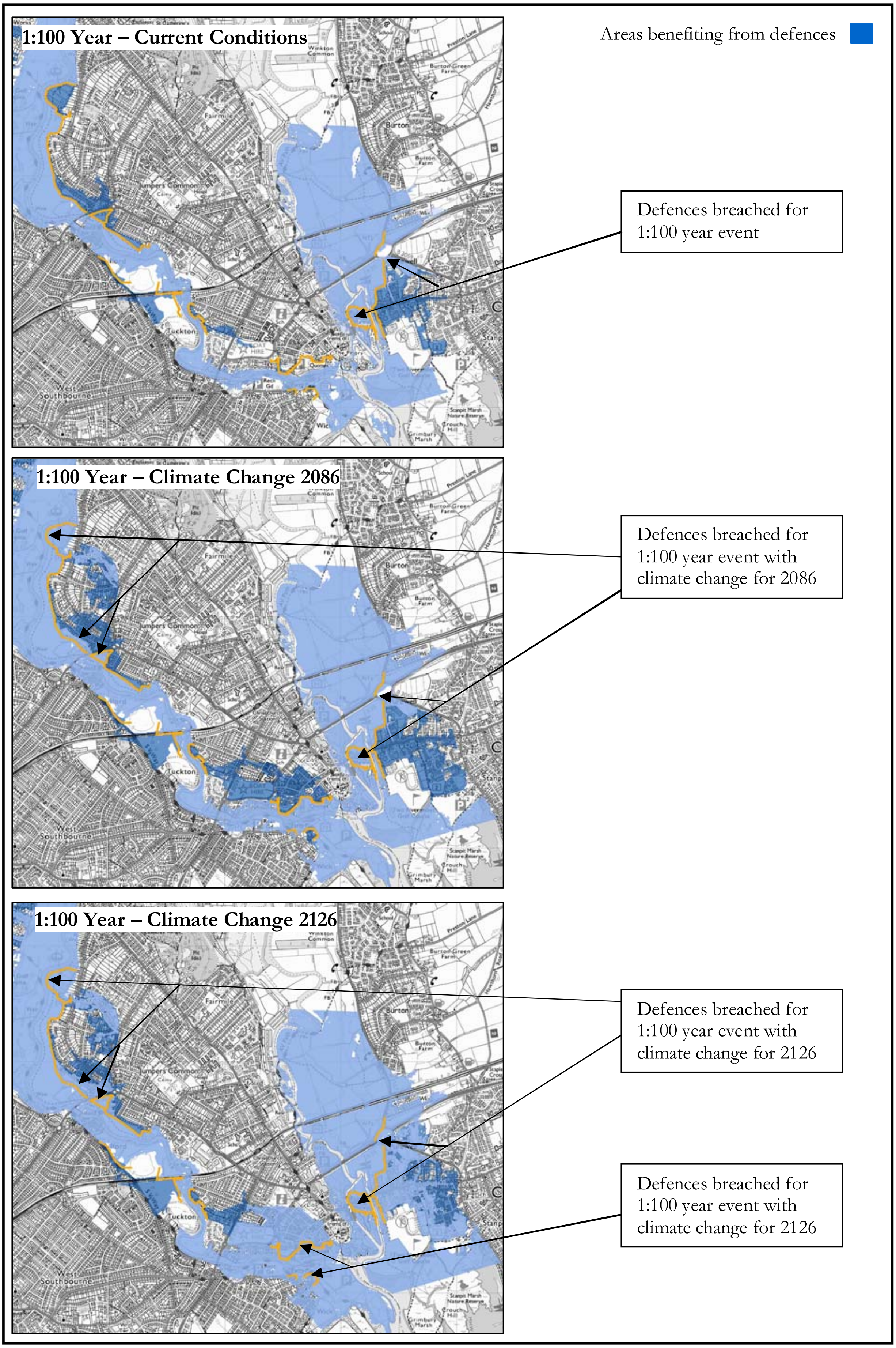


Figure 11.3: 1:100-year ABD

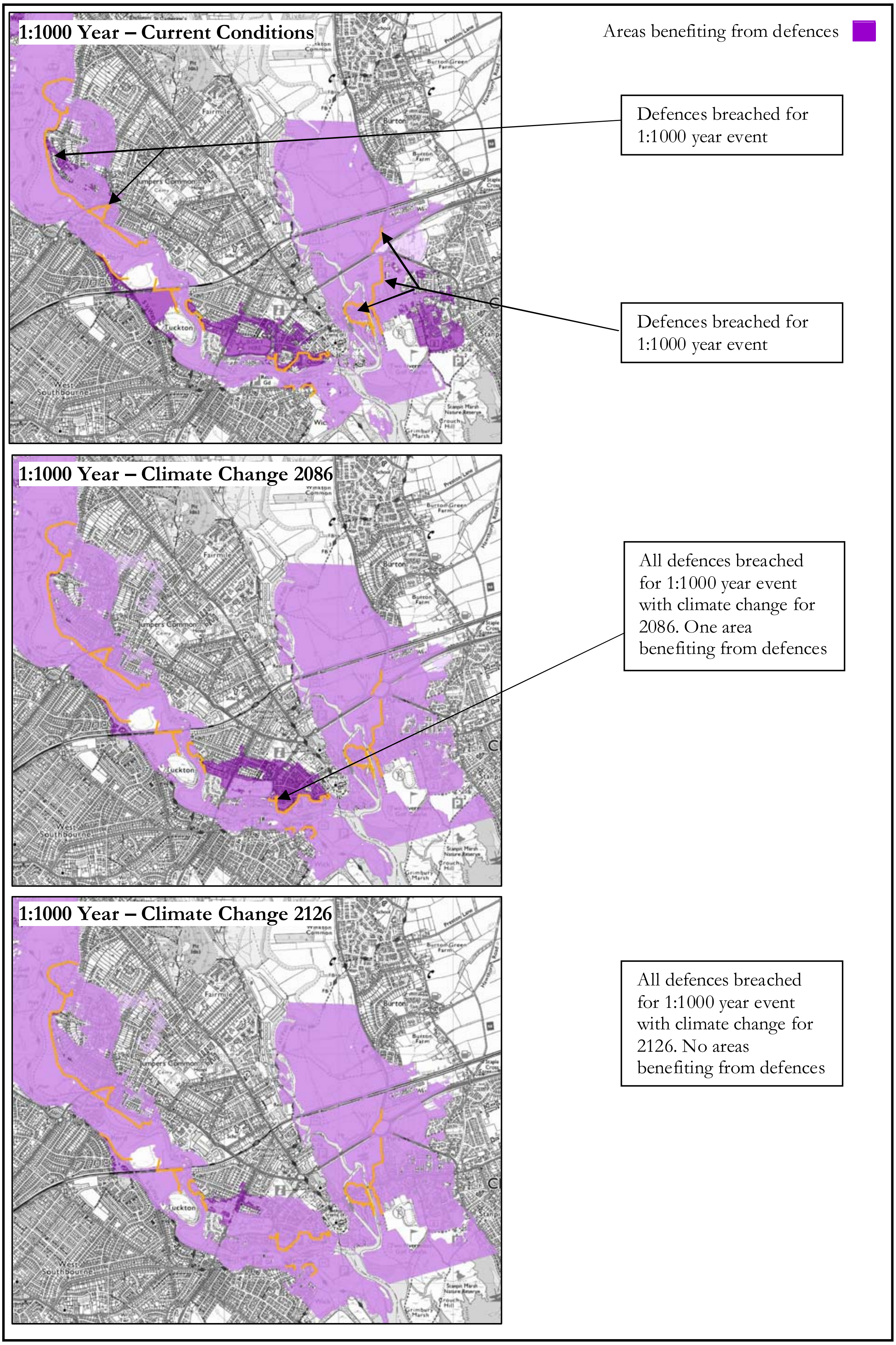


Figure 11.4: 1:1000-year ABD

11.3 *Areas benefiting from defences (tidal events)*

For the tidal design events the defended and undefended model extents have been compared to identify which defences are effective and where areas are benefiting from the defences. The locations of the defences are detailed in Figure 11.1 and a summary of the defences is presented in Table 11.2. Figures 11.5 and 11.6 show the defended and undefended extents for the 1:200 and 1:1000 year tidal events including climate change for the years 2086 and 2126.

Table 11.2: Flood defence summary (tidal events)

Return Period	**Def**										
	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**	**D11**
200 year Current Conditions	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective
200 year Climate Change 2086	Effective	Effective	Effective	Effective	Effective	Effective	Breached	Breached	Breached	Breached	Breached
200 year Climate Change 2126	Effective	Effective	Effective	Effective	Effective	Breached	Breached	Breached	Breached	Breached	Breached
1000 year Current Conditions	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Breached	Breached	Breached	Effective
1000 year Climate Change 2086	Effective	Effective	Effective	Effective	Effective	Effective	Breached	Breached	Breached	Breached	Breached
1000 year Climate Change 2126	Effective	Effective	Effective	Effective	Effective	Breached	Breached	Breached	Breached	Breached	Breached

Defence Effective	(green)	Defence Breached	(orange)

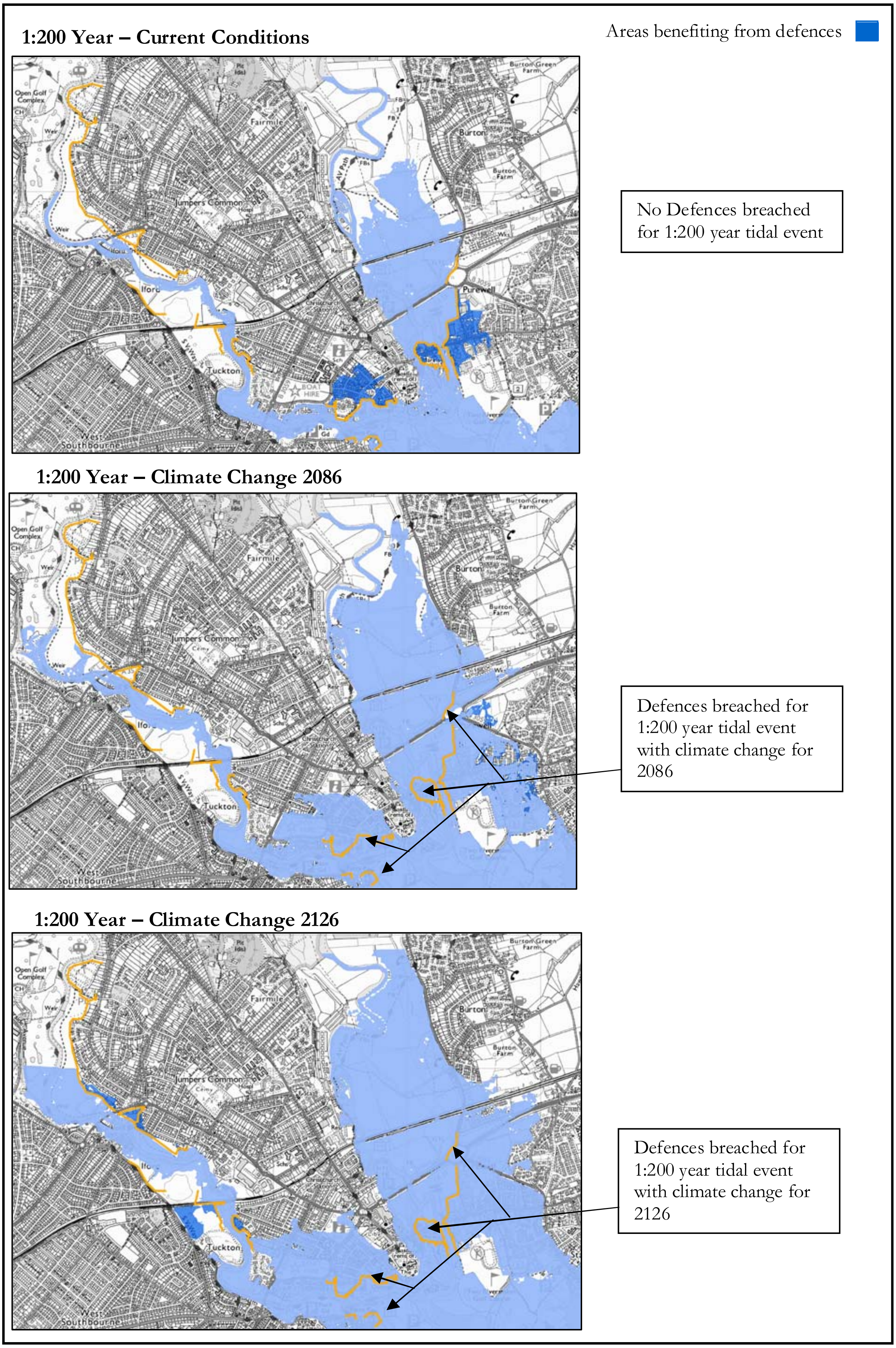
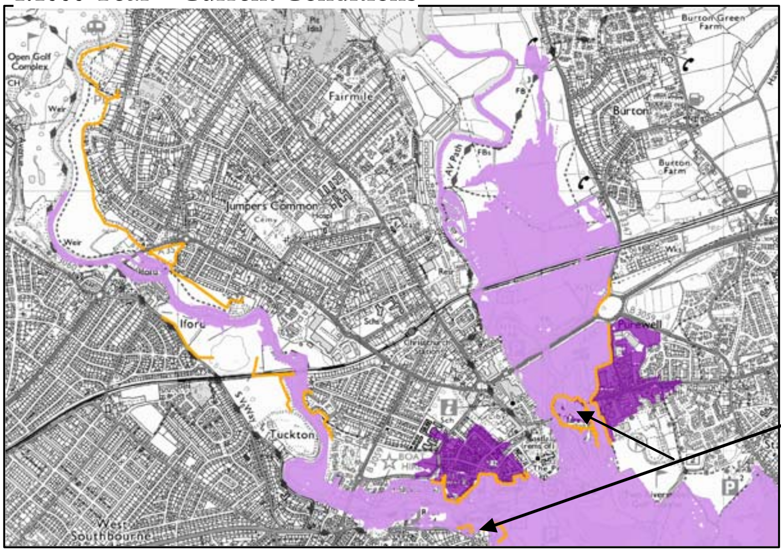


Figure 11.5: 1:200-year ABD (tidal)

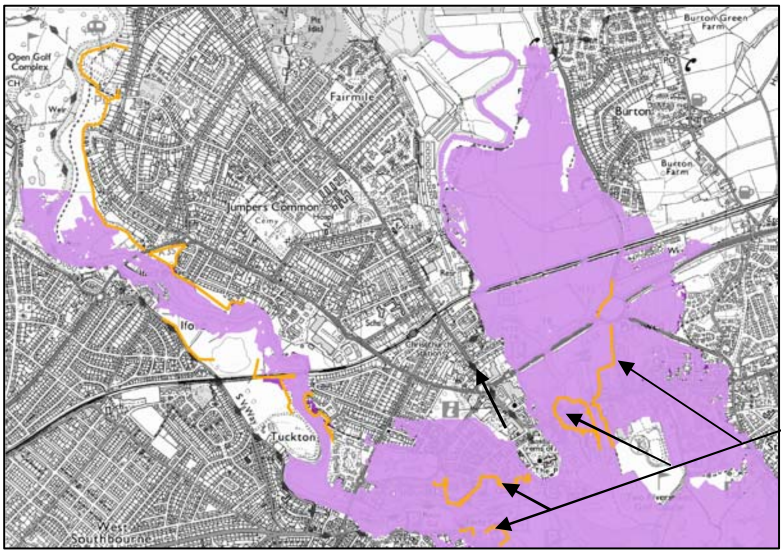
Areas benefiting from defences

1:1000 Year – Current Conditions



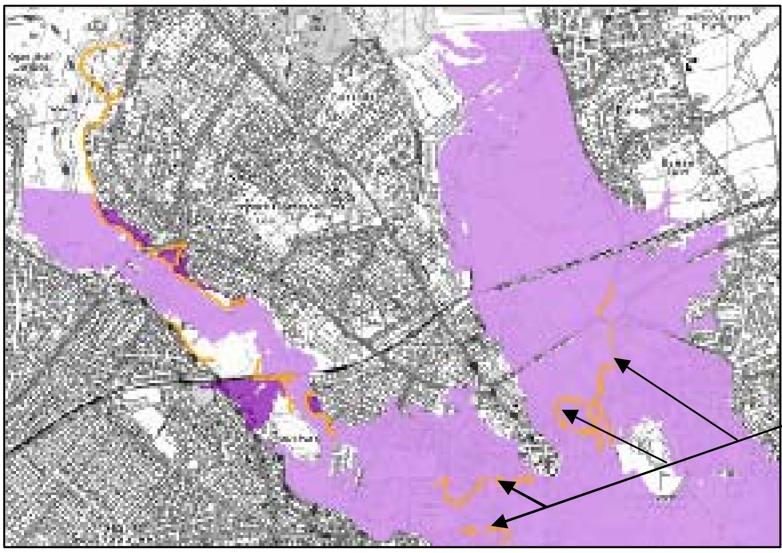
Defences breached for 1:1000 year tidal event

1:1000 Year – Climate Change 2086



Defences breached for 1:1000 year tidal event with climate change for 2086

1:1000 Year – Climate Change 2126



Defences breached for 1:1000 year tidal event with climate change for 2126

Figure 11.6: 1:1000-year ABD (tidal)

11.4 *Comparison the Flood Zone maps*

The latest flood risk maps under this study are compared to the Flood Zone maps as published by the Environment Agency. The sites are examined by the project flood risk areas as detailed in Figure 1.1, for the undefended 1:100 and 1000 year event. The comparisons are detailed in Figure 11.7 to 11.14, with significant differences identified in Table 11.3.

The flood zone limits supplied by the Environment Agency have been clipped to the Christchurch Borough Council Boundary (i.e. no flood zones mapping is shown outside of this boundary)

Table 11.3 Flood Zone map comparison

Area	Flood Zone 3, 1:100 year	Flood Zone 2, 1:1000 year
Area 1	Latest flood risk maps shows similar flooding on the western side of the airport and reduced flooding on the eastern half.	Flood extents similar on western side of the airport, with reduced flooding on eastern side
Area 2	Latest maps show a reduction in flooded areas, partly due to more accurate modelling techniques and the original mapping based on JFLOW which may of included the watercourses which fed the Mude which are not modelled for the SFRA	See 1:100 year comments
Area 3	Similar flooding shown on tidal areas and a reduction in flooded area to the north of Two Riversmeet golf course.	Limits are similar
Area 4	Limits are similar as based on previous Hampshire Avon Modelling and Lower Stour model outputs	See 1:100 year comments
Area 5	Limits are similar, as flood zone based on the previous Lower Stour Modelling outputs	See 1:100 year comments
Area 6 (Mude)	Latest maps show reduction in flooded areas, likely reason due to poor LiDAR coverage in wooded floodplain which could have been used in original JFLOW mapping	See 1:100 year comments but additional flooding down the B3059
Area 6 (Bure)	Limits are similar, as flood zone based on previous Bure Brook Modelling outputs	See 1:100 year comments
Area 7	Latest maps show reduction in flooded areas, due to more accurate modelling techniques	See 1:100 year comments

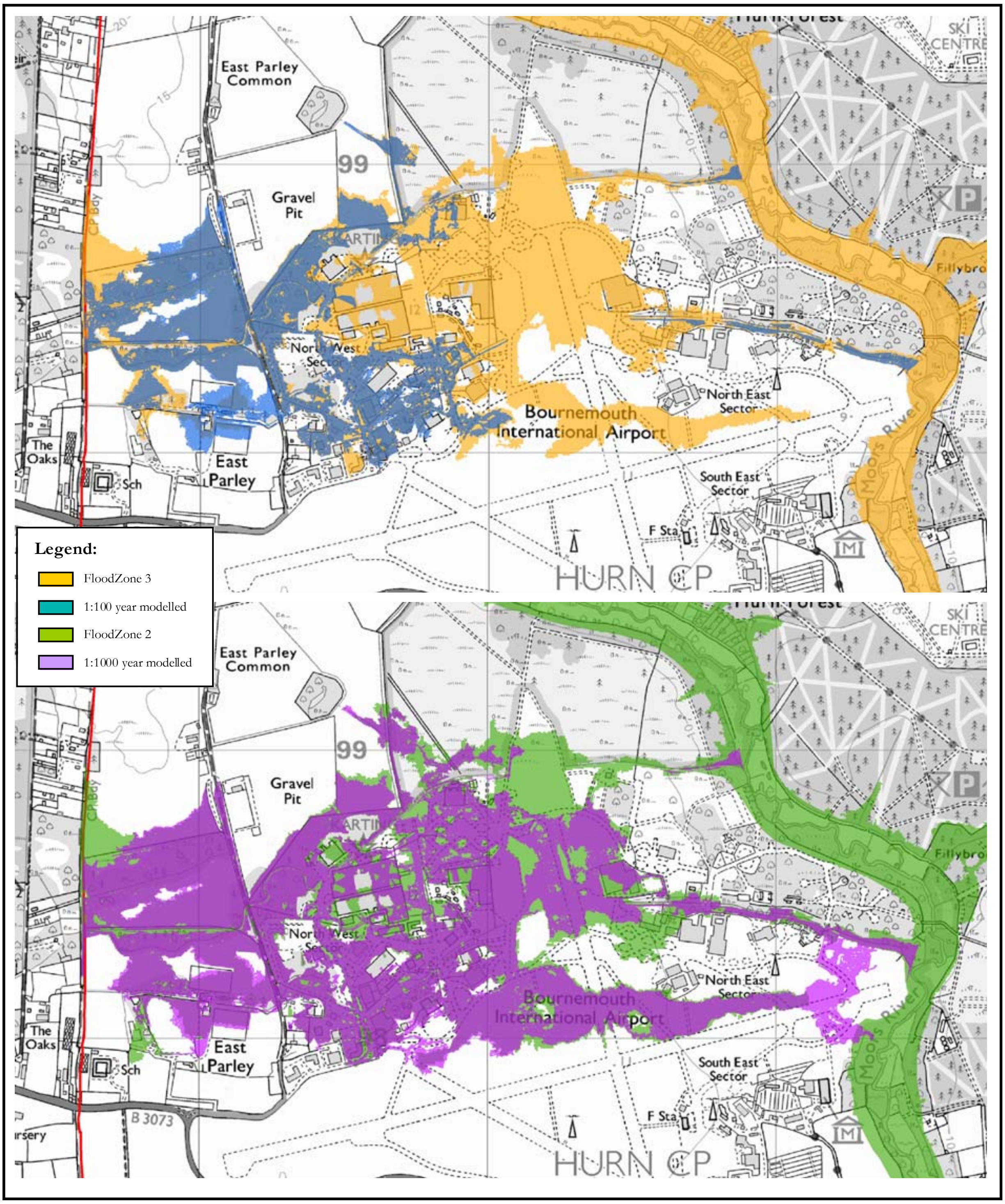


Figure 11.7: Area 1 – Flood Zone map comparison

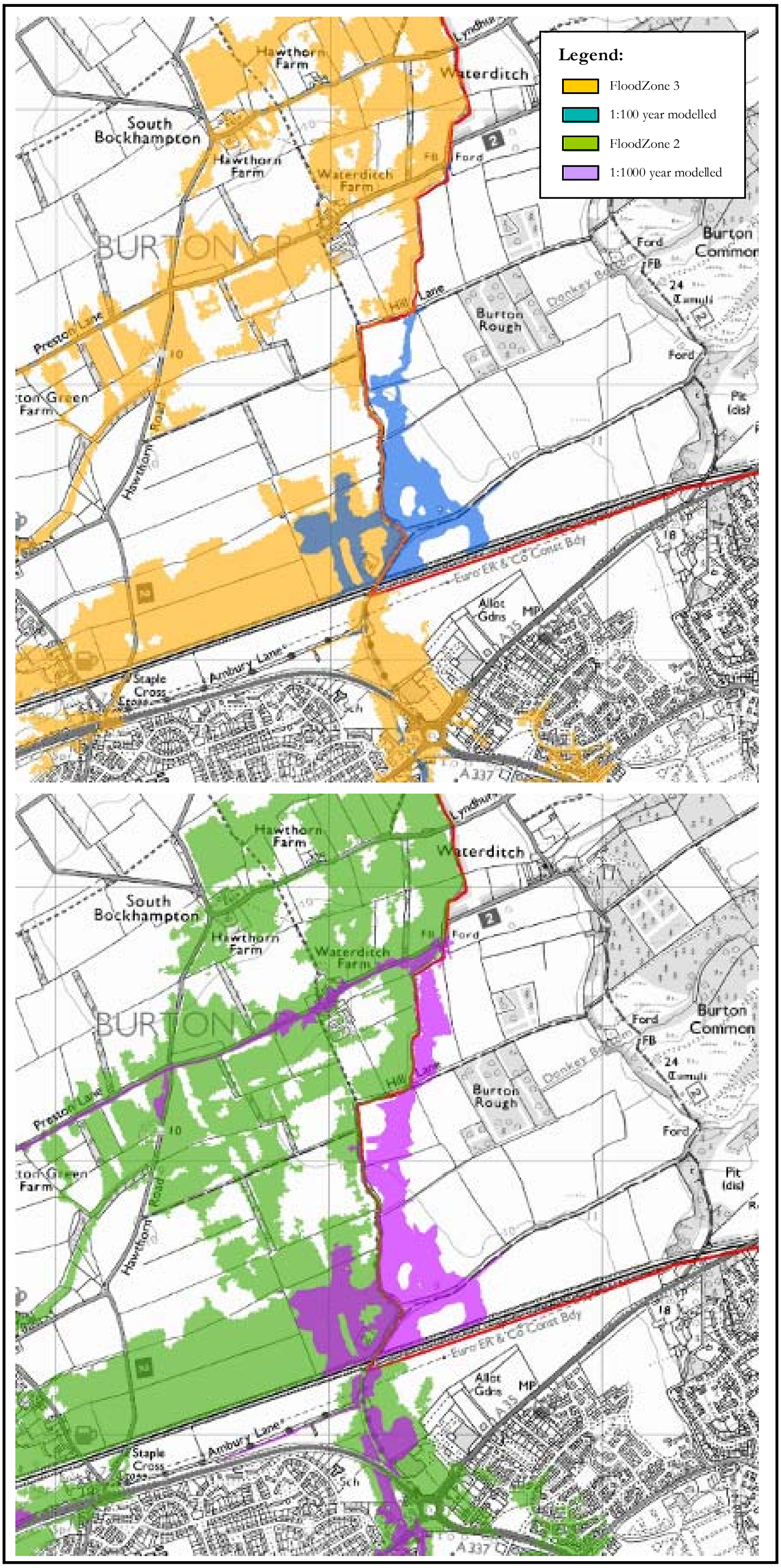


Figure 11.8: Area 2 – Flood Zone map comparison

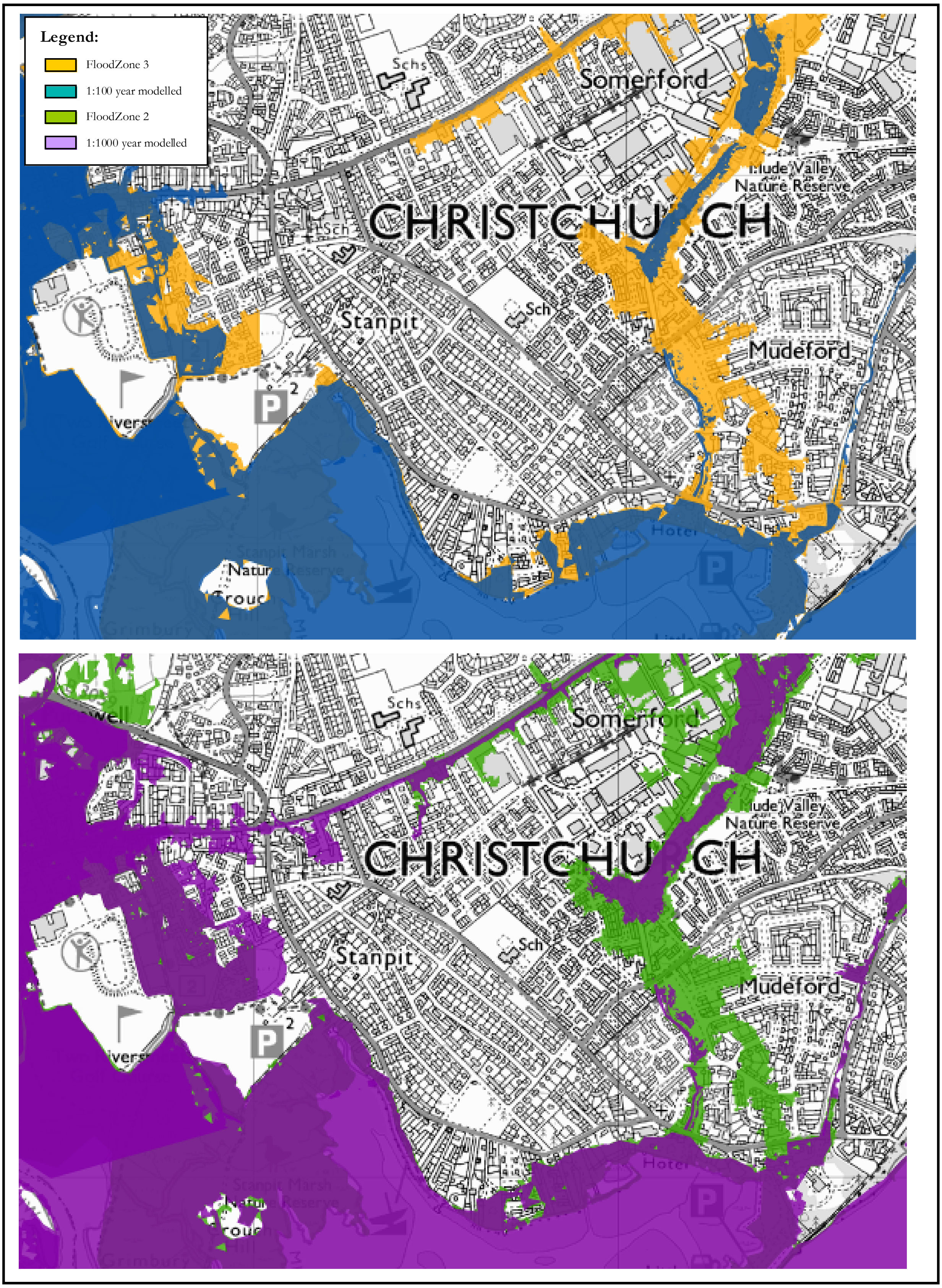


Figure 11.9: Area 3 – Flood Zone map comparison

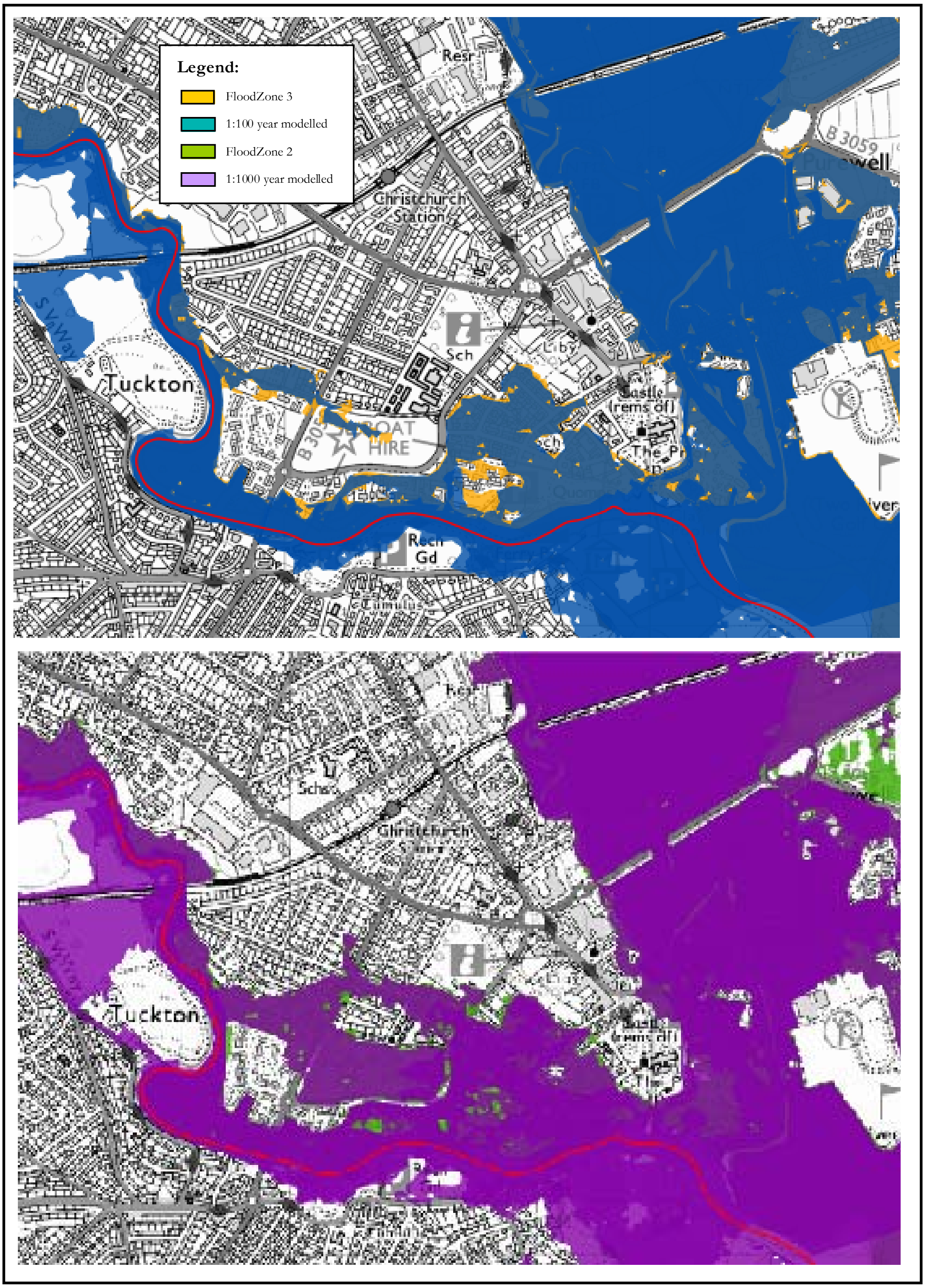


Figure 11.10: Area 4 – Flood Zone map comparison

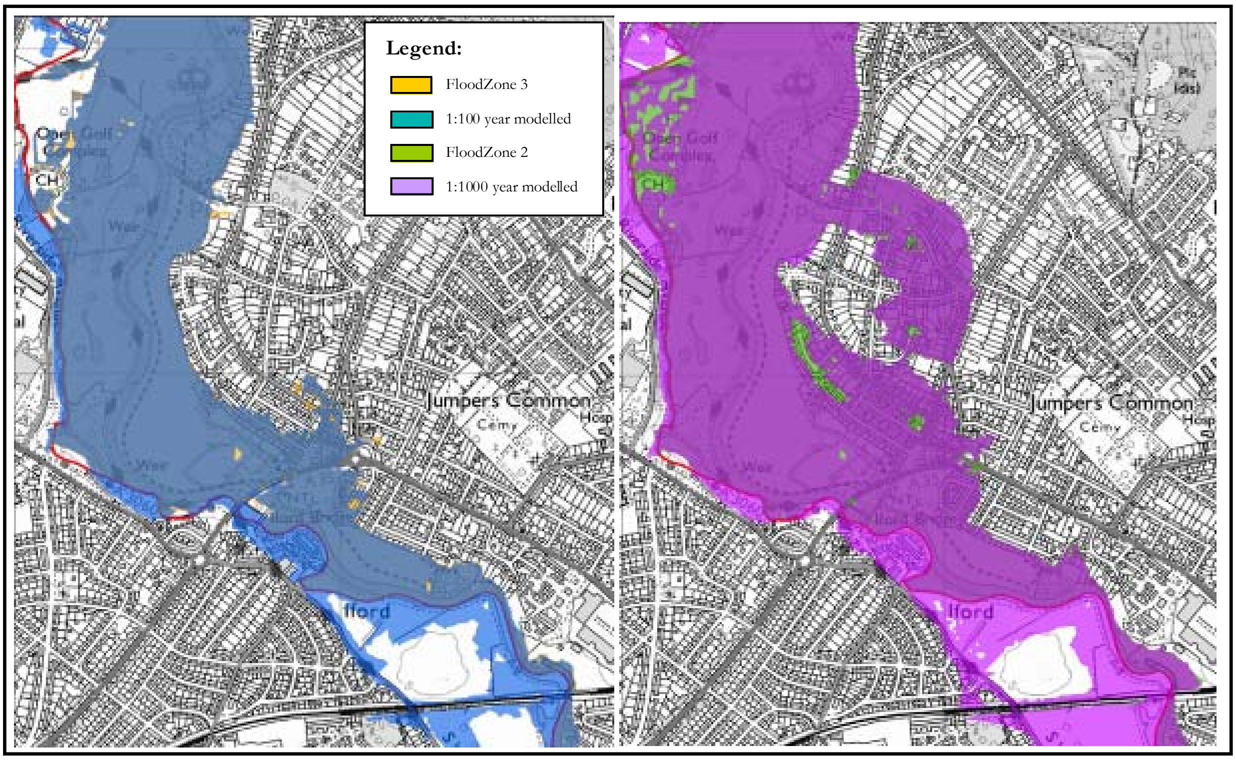


Figure 11.11: Area 5 – Flood Zone map comparison

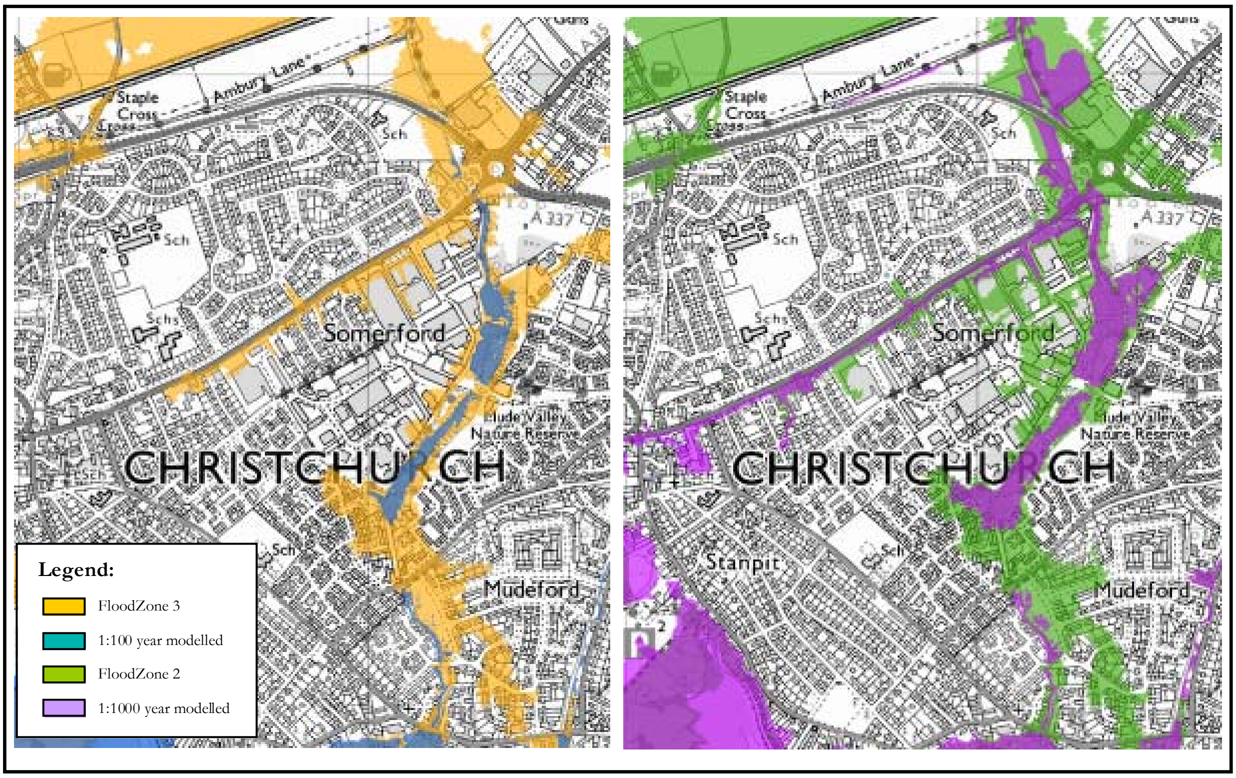


Figure 11.12: Area 6 (Mude) – Flood Zone map comparison

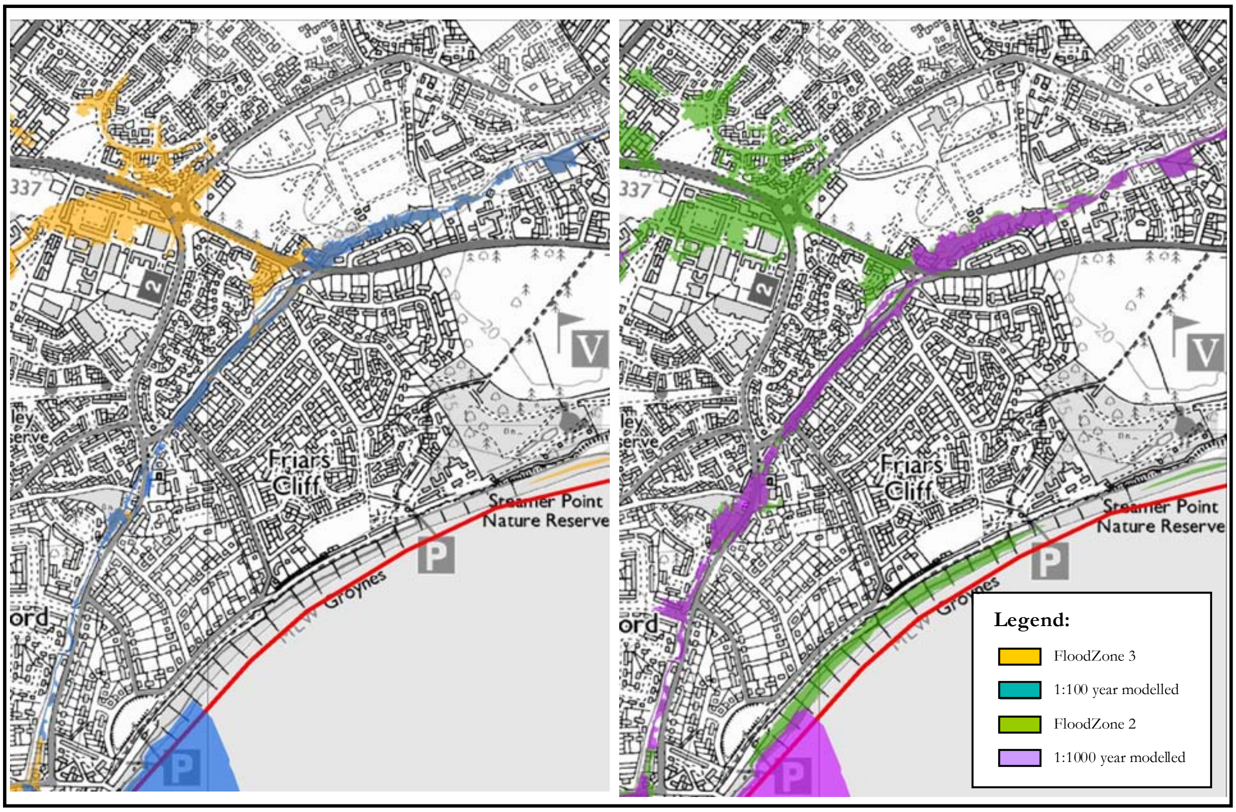


Figure 11.13: Area 6 (Bure) – Flood Zone map comparison

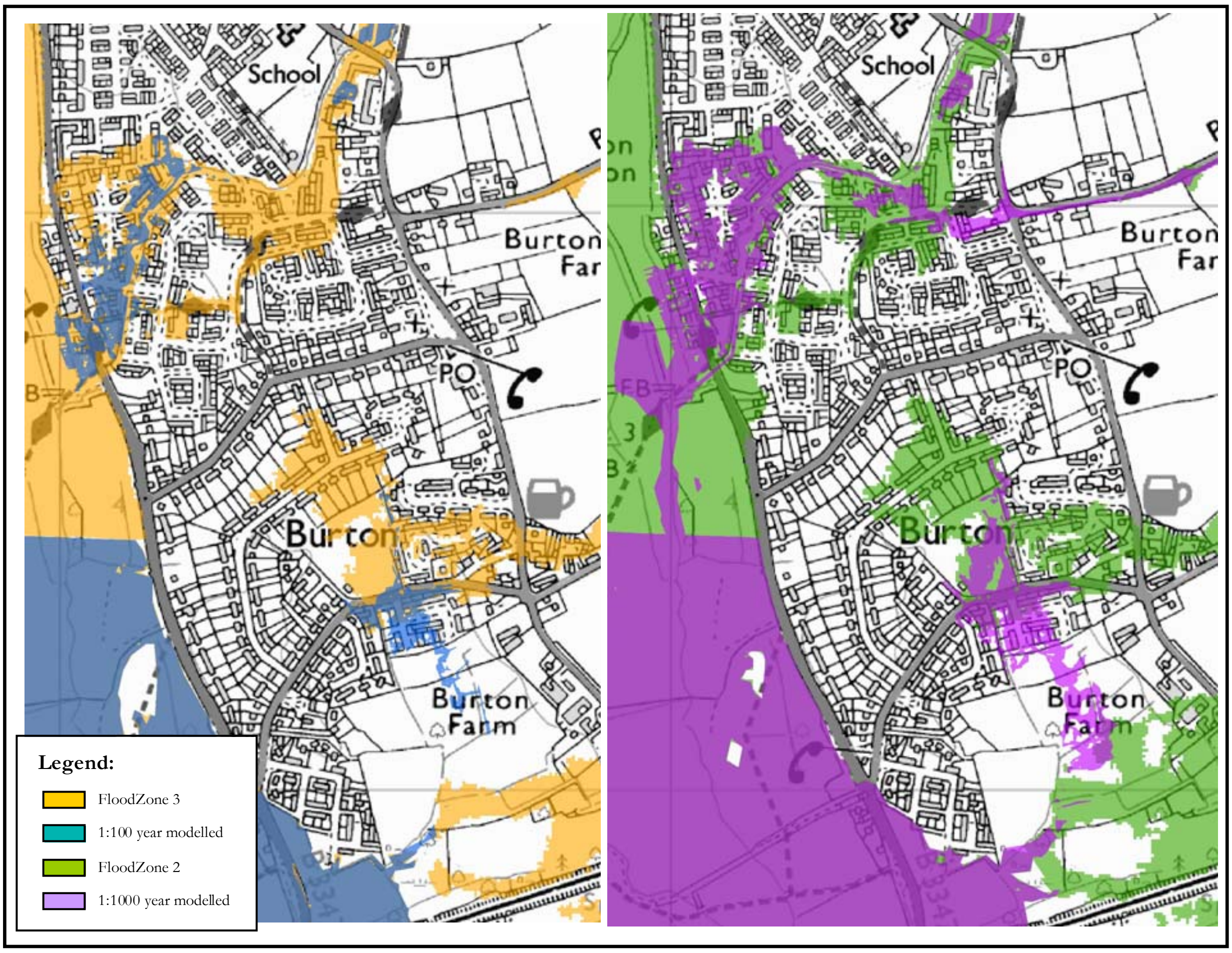


Figure 11.14: Area 7 – Flood Zone map comparison

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