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East Worthing Flood Alleviation Scheme
Teville Stream – Hydraulic Modelling Report

November 2011

ea/br/e/std/v1

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Document issue details:

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Version no.	Issue date	Issue status	Distribution
01	29/11/11	For comment	Malcolm Ward Ken Argent (WBC) Jamie Fielding

Jacobs Document Control Sheet

Client: Environment Agency | Project No: B1629800
Project: East Worthing FAS
Document Title: Model Build Report
Ref. No: B1750000-001

	Originated by	Checked by	Reviewed by	Approved by
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DATE **29/11/11**	INITIALS	INITIALS **MS**	INITIALS **AD**	INITIALS **MS**
	Document Status	For client review and comment		

REVISION	NAME	NAME	NAME	NAME
DATE	INITIALS	INITIALS	INITIALS	INITIALS
	Document Status			

REVISION	NAME	NAME	NAME	NAME
DATE	INITIALS	INITIALS	INITIALS	INITIALS
	Document Status			

REVISION	NAME	NAME	NAME	NAME
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Executive Summary

The River Adur Catchment Flood Management Plan (Capita Symonds, 2008) identified possible areas of flood risk within Worthing, but broad scale modelling of the catchment was not undertaken and instead the assessment of flood risk was based upon the Flood Zone maps. Jacobs was appointed in January 2011 to accurately determine the level of fluvial flood risk within the Teville Stream catchment by the construction of a hydraulic model of the catchment.

At the outset of the project the objectives were agreed as follows:

- Assess the flood mechanism and risk in the catchment;
- Deliver a hydraulic model which can be reused and adapted by the Environment Agency.
- Provide outputs suitable for updating the Environment Agency's published flood maps
- Identify any cross-connections between the surface water drainage network and the public foul/combined sewerage system
- Produce a sewer map based on the Southern Water and Worthing BC records

A hydraulic model was constructed of the Teville Stream catchment which incorporated inflows from the chalk upper catchment and the surface water sewers draining areas of Worthing and Lancing which outfall into the watercourse. The model was constructed using ISIS for the fluvial system, InfoWorks-CS for the surface water sewers and TUFLOW to simulate overland flow from both models. True verification of the model has not been possible due to the lack of flow data, however the surface water elements have been found to correlate well with historic flooding locations, confirmed by Worthing Borough Council (WBC). There are no records available of flood risk directly from the fluvial system to compare the model to.

The sources of flood risk are directly from the Teville stream itself and the surface water network (surface water and pluvial flooding). Other sources (e.g. groundwater) have not been considered in depth as they are considered to be of minimal risk compared to the primary sources.

The model was run with a number of storm events and scenarios. The model does predict flooding directly from the Teville itself however this affects the rural area between Worthing and Lancing and there is minimal risk to property with the exception of

- St Luke's Close and St Paul's Close, Lancing
- GSK Site.

There are significant areas of Worthing and Lancing that experience a shallow depth of surface water flooding (<100mm) which typically is conveyed along roads towards the watercourse. The model has identified three areas of significant surface water flood risk (which correlate with WBC's records and experience) as follows:

- The area in East Worthing between King Edward Avenue and the railway
- Tarring Road, East Worthing, on the south side of the railway line, corresponding to the now culverted route of the River Ditch.

We used the model to assess the impact of culvert blockage and the operation of Brooklands Lake. Blockage of the Deacon way culvert exacerbates flooding but primarily to the rural area on the left bank. With Brooklands lake 50% full of silt, there is minimal impact upon flood risk upstream, but with it 100% full of silt, flooding increases markedly, for example flooding is exacerbated in St Paul's Close.

1 Introduction

1.1 Background

The River Adur Catchment Flood Management Plan (CFMP) (Capita Symonds, 2008) identified possible areas of flood risk within Worthing, but broad scale modelling of the catchment was not undertaken and instead the assessment of flood risk was based upon the Environment Agency Flood Zone maps. The CFMP states that the current baseline is insufficient to appropriately determine fluvial flood risk within the system.

Based on the CFMP findings, Jacobs was appointed in January 2011 to accurately determine the level of fluvial flood risk within the Teville Stream catchment. The construction of a hydraulic model of the Teville Stream catchment was determined to be the most appropriate way to accurately assess flood risk.

The East Worthing Flood Alleviation Scheme (EW FAS) is a collaborative project between the Environment Agency (EA) and Worthing Borough Council (WBC). The overall aim is to achieve a better understanding of the operation of the Teville Stream and the contributing area with relation to flood risk, water quality and biodiversity.

1.2 Objectives

At the outset of the project, the objectives were agreed as follows:

- Undertake a modelling study to fully investigate and understand the flood mechanism and the flood risk in the Teville Stream catchment;
- Produce sound hydrological analyses based on the most up-to-date methods and Environment Agency guidance.
- Deliver a hydraulic model which can be reused and adapted by the Environment Agency.
- Provide outputs suitable for updating the Environment Agency's published flood maps
- Identify any cross-connections between the surface water drainage network and the public foul/combined sewerage system
- Confirm the extent of Main River within the catchment
- Confirm flood risk associated with asset failure (e.g. culvert blockage)
- Provide information to assist Worthing BC in determining if Brooklands Lake should be retained for flood mitigation reasons
- Produce a sewer map based on the Southern Water and Worthing BC records

1.3 Location

The town of Worthing is located on the southern coast of England in West Sussex.

The Teville Stream catchment drains both rural areas between Worthing and Lancing and receives inflows from the chalk South Downs and significant urban runoff from the two towns (see Figure B1629800/0001).

1.4 Catchment Description

The 16 km^2 Teville Stream catchment rises on the southern slopes of the South Downs. However, inflow from this area to the open channel section south of the A27 highway comes predominantly from groundwater, with the spring line running approximately along the road where the chalk submerges beneath the flatter coastal strip.

Eastern Worthing, Sompting and Lancing are drained by the Teville Stream channel network. The culverted Teville Stream itself rises around West Worthing rail station and as the urban drainage network, flows eastwards parallel to Tarring and Teville Roads and through Homefield Park until joining with the open Broadwater Brook near East Worthing station. The latter brook is spring fed from around the Broadwater area to the north-west. Drainage on the eastern urban area of the catchment, to a boundary around Grinstead Lane, also drains towards the open section of watercourse. The watercourse is not very well defined, having several tributary streams and agricultural drainage channels.

The Teville Stream catchment in the coastal strip is densely populated with considerable areas being culverted and integrated with the surface water drainage system of Worthing. The main channel is a mixture of closed and open sections, running under and alongside a pharmaceutical works, an industrial estate, historic landfill sites, a public amenity tip, allotments and a sewage works, finally emerging in an open channel which enters Brooklands Lake, which now acts as a fluvial balancing pond during tide-locked periods, as well as a public leisure facility/boating facility. This freshwater lake is maintained artificially by a terminal control structure at the seaward end, which drains into the sea after passing under the A259 seafront road. Flow from the north is augmented by runoff from the A27 highway and is discharged from a retention structure constructed on one of the tributaries.

1.5 Topography

The upper end of the fluvial catchment is approximately at the A27, at a level of 20-15mAOD. The catchment falls rapidly to 5m AOD and remains flat across the open field between Worthing and Lancing and then falls to sea level south of the railway line.

1.6 Geology

The Teville Stream catchment is predominantly underlain by London Clay and Lambeth Group that have limited permeability. The CFMP concluded that the catchment is predominantly fed by surface water runoff and is consequently ‘flashy’. However north of the A27, the catchment extends into the steep scarp slopes of the South Downs; these are predominantly chalk and consequently it is believed they may contribute some base flow to the Teville stream.

2 Qualitative Description of Flood Risk

2.1 Sources

The aim of this study was to gain a better understanding of the fluvial flood risk in the Teville Stream catchment. The primary sources of flooding within the Teville catchment are:

- Directly from the stream itself (fluvial flooding);
- The surface water drainage network (surface water and pluvial flooding) which serves the towns of Worthing and Lancing and outfalls into the Teville Stream;
- Other sources of flood risk e.g. groundwater flooding have not been considered as they were outside the scope of this study and are deemed to be of minimal risk when compared to fluvial, surface water and pluvial flooding.

The Teville catchment receives base flow runoff from the chalk South Downs to the north of the catchment. The catchment itself is primarily coastal alluvium. The majority of the flow in the Teville emanates from the urban surface water drainage networks serving Worthing and Lancing. This means the Teville experiences high runoff rates and responds quickly to rainfall events. There are a number of structures on the Teville Stream; the watercourse is culverted for a significant length and flows through a railway bridge before flowing into the Brooklands Lake prior to entering the sea outfall culvert.

2.2 Pathways

There are two primary pathways of flooding within the Teville Stream catchment: from the fluvial system and the urban drainage system.

Fluvial flooding results from exceedance of channel capacity and restriction from the hydraulic structures along the watercourse which induce backing-up and the flow goes out of bank.

Surface Water flooding occurs in the urban areas due to exceedance of the capacity of the drainage network. This may be exacerbated by the flooding preventing rainfall runoff entering the drainage network (pluvial flooding). It is important to remember that the surface water drainage network serving Worthing and Lancing would have been designed to retain a significantly less severe rainfall event than a new network or fluvial system would be designed for now. Urban surface water sewerage networks have historically been designed to contain the runoff from a 5-10 year return period storm event without flooding. Systems would now be built to contain a 30-year storm.

When the drainage network is exceeded, the flood water will flow overland and follow the natural topography to the lowest point (the Teville Stream) or to where it can re-enter the drainage network. The drainage paths can be influenced by land use or physical obstructions; at this point the flood water may be retained and will stand until it can return to the drainage network once water levels in the system recede.

2.3 Receptors

Flood water will follow the lowest topography and flow towards the lowest elevation. Consequently the buildings and properties along the edge of river floodplains are at risk, but so are buildings that are situated at the bottom of a valley in which the watercourses might have historically occupied, before it was culverted.

Residential and non-residential buildings have been considered in this study and demonstrate the broad spectrum of people at risk from fluvial flooding. The urbanisation of the area and limited space has put increased pressure on developers to build more properties and this has lead to building ever closer to floodplains and low lying areas. As more properties are constructed, the amount of impermeable surface is increased and coupled with the requirement to build more bridges/culverts, this further increases the risk of flooding.

3 Modelling Approach and Justification

3.1 Modelling Approach

The Teville Stream receives flow from two distinct sources: the chalk south downs to the north and runoff from the urbanised areas of Worthing and Lancing. It was decided to model these distinct systems separately with the most accurate method available for each and then combine them into a single catchment model using appropriate methodology to harmonise boundary conditions.

Following consideration of alternatives, the decision was taken as stated in our proposal to model the urban areas using InfoWorks-CS (collection systems), the industry standard software to simulate the response to rainfall of piped drainage systems. The fluvial system was modelled using ISIS and the overland flow from both systems was simulated using Tuflow. Linking ISIS and TuFlow is a tried and tested approach.

The most likely alternative was to use InfoWorks ICM (Integrated catchment Modelling) however as discussed at project inception this was then new software with the consultant encountering a steep learning curve along with possible bugs and glitches in the new software, increasing risk to the delivery of the project.

3.2 Modelling Limitations and Uncertainty

There are uncertainties with every type of numerical model that attempts to represent the physical world. The aim of constructing a hydraulic model is to accurately represent the complex interactions of the flood water, topography, frictional forces and physical obstacles. The ability of a computer model to represent those parameters is limited by the amount of data available and the scale of detail required, and these are dictated by the aims and budget of the project.

As with any hydraulic model the key uncertainty lies with the quality of the data entered. The characteristics of the fluvial elements have been based on LiDAR information augmented with a topographic survey of key locations along the watercourse. The urban elements are based upon a hydraulic model received from Southern Water. However this contained little information on the surface water drainage network, consequently gaps in this information were infilled using the WBC sewer record plans. There are a number of areas within the model where we are uncertain of the dimensions providing some uncertainty. The other key shortcoming of the urban model is connectivity; that is defining the areas that contribute flow to the model. We have used an Impermeable Area Survey provided by Southern Water to make our assessment but without significant expenditure to update and extend the IAS to cover newly developed areas, uncertainty will remain.

3.3 Model Accuracy and Appropriateness

The model has been developed to identify areas of flood risk within Worthing and Lancing. The model provides an overview of the whole catchment and as such focussing on the precise flood extent boundary should be treated with caution, particularly given the quality of the data used to develop the urban elements.

3.4 Model Verification

No flow data was available to verify the hydraulic model. Instead the areas of flooding predicted by the model have been compared to historic flooding records. The fluvial sections have not historically posed a significant risk of flooding to property; consequently there is no data to verify the model in these areas. The urban model does seem to verify reasonably well with locations of historic flooding

4 Input Data Plan

4.1 Data Used

The urban surface water drainage networks that outfall into the Teville Stream were modelled based on the digital sewer records provided by Southern Water. We consulted historic sewerage plans provided by, and consulted with Worthing Borough Council to augment the Southern Water data. We consulted with Southern Water to obtain information on the Dominion Road surface water pumping station.

A review of the available data used in the present study to build the fluvial hydraulic model of the Teville Stream is presented below:

- River cross-sections and bank top elevations were surveyed by Jacobs Geomatics in March - April 2011. The survey data was used to build the one dimensional model of the Teville Stream "bank-to-bank" channel using ISIS.
- To complement the river survey data, CCTV inspection reports provided by the Environment Agency were used to help in the schematisation of the culverted sections along the course of the Teville Stream.
- Tide gauge information was collected to derive downstream conditions at the Teville Stream sea outfall.
- Filtered LiDAR data covering the study area was provided by the Environment Agency. The LiDAR was principally used to inform the topographic grid (DTM) of the 2D model.
- OS background maps (10k, 25k and 50k) and Mastermap data covering the study area were supplied by the Environment Agency.
- Jacobs' staff undertook a site visit to gain a better knowledge of the study area.

4.2 Data Quality

There were significant gaps in the sewer records provided by Southern Water. This data was augmented with the paper sewerage records of Worthing Borough Council. We consulted with WBC to clarify further queries relating to the data but areas of uncertainty remain in the model although we do not believe that this would have a significant impact upon the estimate of flood risk within the urban area.

There were no particular issues relating to the quality of the data in the fluvial model.

4.3 Data Uncertainties

As mentioned previously the 2D model uses filtered LiDAR data with a horizontal resolution of 2m and a vertical accuracy of 150mm. The filtering process applied to the raw LiDAR data collected through a flight survey consists of removing areas of tree and building elevations. It is quite common that some elevation anomalies remain in the filtered LiDAR dataset following this process. It is particularly the case here within the GSK factory compound and Deacon Industrial estate. Although these anomalies have been manually corrected, some uncertainties remain on the ground elevations input to the model in these areas and consequently on the flood levels predicted by the model.

Following input of the Southern Water and WBC information into the urban model, uncertainty remained regarding the accuracy of the data in certain locations.

Significant numbers of sewers in Lancing (east of Brooklands Lake) were missing upstream and/or downstream node identifiers and could not be imported in to the model. These required manual digitisation between the imported nodes. Pipe invert levels were extracted from GIS data where available.

No survey information was available from Southern Water of the Dominion Road surface water pumping station.

Missing ground levels from the sewer records were either inferred from LiDAR or manually inferred from surrounding data.

4.4 Previous Studies

As mentioned in Section 1, The River Adur CFMP identified possible areas of flood risk within Worthing, but broad scale modelling of the catchment was not undertaken.

In September 2009, Royal Haskoning produced a scoping report[1] for restoring the Teville Stream Catchment. Although no modelling of the catchment was undertaken, the report provides some valuable information on the characteristics of the catchment that was used in this study.

[1] Restoring the Teville Stream Catchment for the Community, Scoping Report, Royal Haskoning, September 2009

5 Technical Method and Implementation

5.1 Hydrology

Catchmod software was used to simulate summer and winter baseflows to the Teville Stream from the chalk upper catchment..

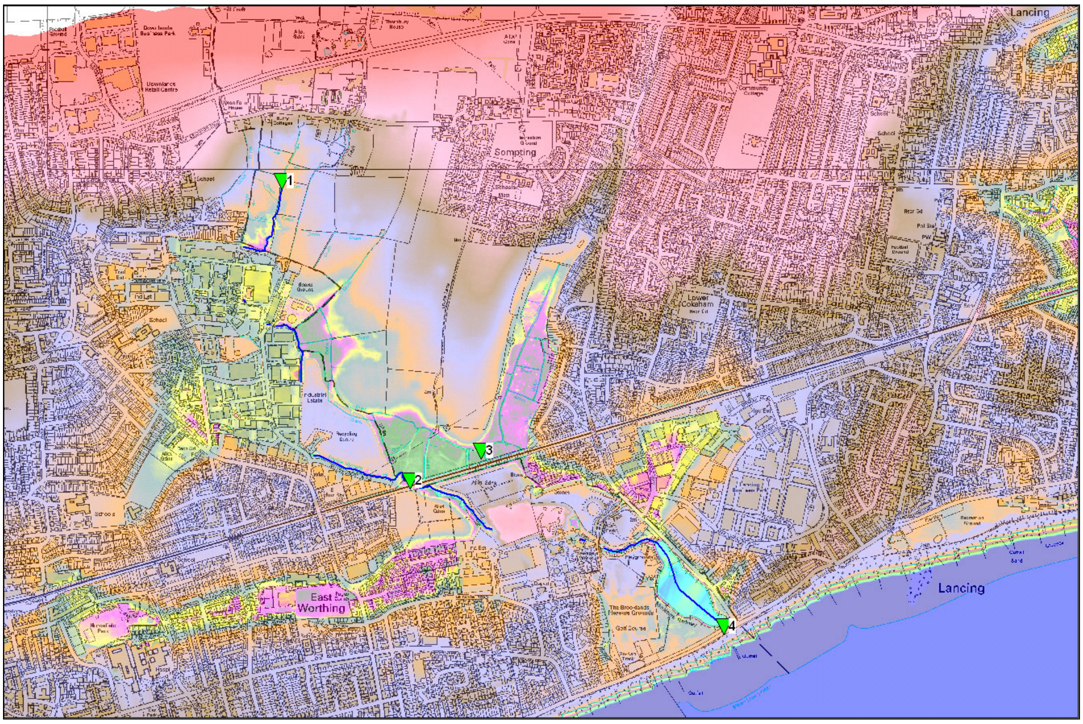

Figure 5.1 : Modelled Baseflow Inflow Locations

Baseflow has been calculated for four locations within the overall Teville catchment as indicated in Figure 5.1 The modelled baseflows are included in Table 5.1.

Table 5.1: Modelled Baseflows

Inflow Point	Location	Catchment Area (km^2)	Inflow catchment Area	Scaling factor	Typical Summer Flow (m^3/s)	Typical Winter Flow (m^3/s(
1	TQ 15900 04250	3.75	3.75	0.225	0.016	0.05
2	TQ 16900 03650	16.26	0.49	0.03	0.002	0.01
3	TQ 16900 03800	12.02	12.02	0.72	0.05	0.17
4	TQ 17450 03350	16.65	0.39	0.023	0.002	0.005
Total to 4	TQ 17450 03350	16.65	Whole catchment	1	0.07	0.23

The detailed Hydrology notes are included in Appendix E.

5.2 Hydraulic Modelling

In order to model the response of the catchment most accurately, a combination of modeling techniques was employed on this project. The urban surface water network was constructed and analysis using InfoWorks-CS, the industry standard software for the simulation of closed conduit networks. The fluvial system was simulated using ISIS. A 2D model was constructed using TuFlow which was used to route flooding over the ground surface taking inputs from both models. An iterative procedure was used to reconcile boundary water levels between the InfoWorks and ISIS models.

5.2.1 Surface Water Modelling

Modelling Software and Extent

InfoWorks-CS (version 10.5) was used to develop a hydraulic model of the urbanised areas of Worthing and Lancing whose surface water networks outfall into the Teville Stream.

Sewer Records / Base Data

Southern Water confirmed that they do not have a surface water model of the catchment. Our model was therefore based upon the digital surface water sewer records provided by Southern Water, augmented with the paper WBC sewer records to try and infill missing data. Furthermore, we liaised with WBC staff to understand the connectivity and details of the surface water network where uncertainties remained.

Detailed information on the amendments and additions made to the urban model are contained in Appendix D. The key amendments were as follows:

- Updates to the trunk sewers in Teville Road, Newland Road and Chesswood Road;
- Addition of a highway drain to the model in Brighton Road not in the SW sewer records;
- An isolated network serving the area around Seamill Crescent was found to drain directly to the sea rather than to Brooklands Lake;
- WBC confirmed that the Willowbrook Road estate (north of Lyons Way) drains to the Teville Stream.

Contributing Areas

In order to improve model accuracy, additional data was sought from Southern Water to better inform the connectivity to the model. SW provided an Impermeable Area Survey (IAS) of part of the catchment. It is believed the IAS dates from the early 1980's as later developments in the north of the catchment were shown as agricultural land and nurseries. The IAS covers most of Worthing town, but within that it excludes later developments such as retail parks and the Lancing area to the east. We have assumed that these industrial and retail parks drain to the surface water system, as infiltration systems (SuDS) were less prevalent at the time of construction.

Overall, the IAS identified a significant number of properties that drain to soakaways which resulted in a reduction in impermeable area and therefore runoff contributing to the surface water system.

Boundary Conditions

16 outfalls to the Teville Stream are included in the InfoWorks-CS model (see Figure B1629800/0001). The water level at these locations was developed via an iterative procedure in conjunction with the ISIS model to ensure both models utilise the same water level.

Pipe Roughness

A roughness of 0.6mm was used in the hydraulic model for surface water sewers, 1.5mm for combined (CSO) sewers and 15mm for brick culverts.

Outfalls

We have identified a number of outfalls from the surface water network into the Teville Stream (see Figure B1629800/0002) as listed in Table 5.2.

Table 5.2: Schedule of Outfalls to the Teville Stream

Location / Upstream Catchment	Outfall pipe
Highway drain on Brighton Rd	Highway dummy
Dominion Way Industrial estate	TQ15039951
Dominion Way Industrial estate	TQ15039952
Glaxo Smith Kline site	TQ15046550
Dominion Way Industrial Estate	TQ15047351
Clarendon Rd	TQ15047751
Dominion Way Industrial Estate	TQ15049051
Dale Rd	TQ16036650
Allotment gardens	TQ16036651
Allotment gardens	TQ16036652
St Paul's Avenue / Western Rd, Hove	TQ16039650
West Street, Hove	TQ16050152
Western Rd, Hove / Lancing Business Park	TQ17032652
Seafront / Brooklands Lake, Hove	TQ17035355
Willowbrook Rd estate	Willowbrook Rd Private 1
Willowbrook Rd estate	Willowbrook Rd Private 2
Willowbrook Rd estate	Willowbrook Rd Private 3

5.2.2 Fluvial Modelling

Modelling approach and software used

LiDAR and Topographic survey data collected along the watercourse were used to build a combined 1D/2D hydraulic model of the Teville Stream and its adjacent floodplain using ISISv3.4 and Tuflow 2009 modelling software.

A one dimensional (1D) ISIS model of the river channel including open sections and hydraulic structures has been "carved" through the 2D TUFLOW model of the floodplain as schematised in Figure 5.2.

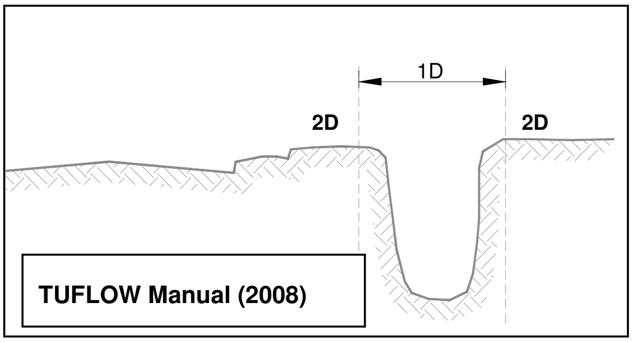

Figure 5.2: Modelling a river channel in 1D and the floodplain in 2D

On either side of the modelled watercourse, boundary lines were digitised along the bank crests to select 2D open flow boundary cells representing the dynamic links between the 1D ISIS model and the 2D TUFLOW domain.

Modelled area

The hydraulic model includes the Teville stream from downstream of the A27 attenuation facility (NGR 515890 105060) to its sea outfall corresponding to the culvert outlet of the Brooklands Lake (NGR 517561 103286).

The 2D domain coverage encompasses the floodplain areas along the course of the Teville stream including the urban areas to the west, east and south of the watercourse as well as the rural floodplain to the east. The latter includes numerous drains, some of which discharge into the Teville stream. These are explicitly represented in the 2D model.

ISIS model schematisation

As mentioned earlier, a bank-to-bank representation of the Teville Stream has been built within ISIS using river cross-section and structure survey data collected as part of this study.

Representation of some key culverts within the model has been developed using the CCTV survey reports.

There are a total of 13 hydraulic structures across the Teville Stream that have been included in the model. Details of these structures and how they are represented in the model are available in the Model User Report included in Appendix A.

Hydraulic roughness, represented by Manning's coefficient "n" in the hydraulic model, varies across the length of the watercourse. Values ranging from 0.020 (sand, silted bed) to 0.055 (tortuous bed with obstruction) were set on the channel bed. Different values were adopted for the bank sides depending of the varying type (reeds, short grass) and density of the vegetation.

TUFLOW model schematisation

The TUFLOW 2D grid comprises a single domain covering part of the urban and rural floodplain areas adjacent to the Teville Stream. The grid has been based upon a 5m cell size to allow for adequate representation of the urban features within the floodplain such as roads, buildings, gardens.

Several breaklines were used to define key topographical features that may have been inadequately represented by the 5m grid. Those include the small floodplain drains and the railway embankment running laterally across the study area. The bank tops along the Teville Stream have also been represented as breaklines.

The different land types (roads, buildings, open lands) across the 2D domain have been assigned various roughness values to account for hydraulic friction on the overland flow. The land type areas set in the 2D model were derived from Master Map data.

Boundary Conditions

Hydrological inflows from the upstream chalk catchment were input into the 1D ISIS model at the upstream extent of the Teville stream as well as in the 2D Tuflow model at the head of a floodplain drain to the South of Test Road, Sompting (NGR 516860 104650). Contributions from the lower catchment areas were input into the model as lateral inflows at appropriate locations.

In addition, flow contributions from the urban drainage system (modelled separately with InfoWorks-CS) were included into the ISIS model at appropriate locations corresponding to the discharge points of the surface water network into the Teville Stream.

In order to represent flooding from the surface water system, flood volumes predicted by the InfoWorks model, at manholes were also included into the 2D model as additional point source inflows.

The downstream conditions in the ISIS model consist of a Stage vs. Time (HT) boundary set to represent the Mean Spring Tide profile (MHWS peak level of 3.1m AOD) at the Teville Stream outfall. The tidal hydrograph has been adjusted so that the tide locking period coincides with the flood peak, which assumes a worst case scenario.

An Illustration of the model schematisation, as discussed above is shown on Figure A.2 in Appendix A.

5.3 Modelling Results Post-processing

For each event simulated, outputs from the ISIS-TUFLOW model were processed so as to create flood outlines showing the maximum extent of flooding across the study area.

Flood outlines have been produced for the following annual probability (annual chance) events: 20% (5-1), 10% (10-1), 5% (20-1), 2% (50-1), 1.33% (75-1), 1% (100-1) and 0.1% (1000-1) as well as the 1% AEP with 20% increase in hydrological flows to account for Climate Change.

These are presented in Appendix C of this report and are also available in digital format. In addition to the flood outlines, other model outputs such as maximum flood depth and flood hazard grids were produced and are available digitally.

6 Model Proving

6.1 Run Performance

6.1.1 Surface Water Model

A few issues were encountered with running particular return period events in the InfoWorks-CS model however liaison with Innovyze indicated this was a software issue rather than a particular problem with the model. They confirmed that these issues will be addressed with the next version of the software.

6.1.2 Fluvial hydraulic model

ISIS and TUFLOW hydraulic modelling software provide run performance guidance, along with levels of acceptable error ranges and convergence thresholds that should be achieved in each model run. The concept of an acceptable error range has been adopted by the developers of the software, as numerical errors occur due to the limitations of the software and underlying equation solving algorithms.

Run performance has been monitored throughout the model build process and during the simulation of the various scenarios, to ensure the optimum model convergence at any time step during the model runs.

In particular, the following run performance parameters have been considered: ISIS convergence, TUFLOW “dV” and Cumulative Mass Balance Error reports.

For all the simulation undertaken, the later parameters were found acceptable, staying within the tolerance ranges recommended by the software developers. In addition, model outputs (e.g. stage) have been reviewed to track any sign of instability at any ISIS model node and within the TUFLOW domain.

6.2 Model Calibration and Verification

6.2.1 Surface Water Model

There are no flow records of the surface water system that could be used to calibrate or verify the model. Consequently the proposed method to confirm the accuracy and therefore confidence in the urban hydraulic model was to compare predicted model flooding with historic flooding records within the catchment.

WBC confirmed that flooding has occurred at the following locations:

- Tarring Rd near the railway line, at the junction with South Street
- Teville Rd / Station Rd junction near the railway line
- Dominion Rd (refer to flooding complaint “20110218124210.pdf” from a local resident)
- Worthing Hospital (part of this associated network was removed as it drains to the sea outfall near Brooklands Lake).

The model predicted flooding at these locations and therefore provides some confidence in the accuracy of the model. However the volume of flooding does seem to be higher than might be expected.

Our experience of urban surface water sewers suggests that the model may be over predicting the severity of flooding (e.g. approx 19,500m^3 for the 10-year return period event), but with no means to verify the model this is merely supposition. WBC have confirmed that the two areas of greatest flooding in the model: Newland Road trunk sewers and Station Road, do correlate with historic flooding.

6.2.2 Fluvial hydraulic model

The ISIS-Tuflow model could not be calibrated due to lack of flow/level gauge information within the area of interest.

There is no historic data of sufficient detail or extent to use as a model verification tool.

6.3 Sensitivity Analysis

Sensitivity tests were carried out on the hydraulic model in order to assess the sensitivity of the system to alterations in a number of key hydraulic parameters.

The results of the sensitivity analysis give an indication of the level of confidence that can be placed in the peak flows and water level estimates predicted by the model.

The following sensitivity tests were carried out on the 1% AEP flood event:

Sensitivity to hydraulic roughness

Manning's "n" values were both increased and decreased by 20% in the ISIS model. This was carried out to both assess the sensitivity of the system to changing roughness in the ISIS model, for example vegetation growth, and also to consider the reliance of the modelled water levels on the estimates of channel roughness.

Changing the hydraulic roughness by +/-20% in the ISIS model resulted in very small variations to peak water levels (in the order of a few millimetres) in the Teville Stream. This is expected as conveyance throughout the Teville Stream is not significant and therefore bed friction has little effect on the peak water levels which are more affected by backing up process during the tide locking period.

Sensitivity to initial water level in Brooklands Lake

A test was carried out to assess how the peak water levels are sensitive to initial water levels in the Brooklands Lake. Whilst the design runs have been carried out assuming that Brooklands Lake is full (see Section 7), a low initial water level of 0m AOD corresponding to the winter penning level at the Lake outfall structure was assumed at the beginning of the simulation. Model results show that peak water levels in the Teville Stream are on average 100mm lower than the design case with a maximum difference of 144mm. Although less flood volume is spilled in the floodplain, the corresponding flood extent does not differ from the design case except on St Luke Close and St Paul's Avenues (516834 103890) where slightly less flooding is predicted.

7 Model Results

7.1 Model Runs

A range of scenarios entailing different situations and storm events within the Teville Stream catchment have been simulated. The following paragraphs detail the scenarios considered for this study.

<u>The baseline scenario</u> assumes the following:

- An undefended situation[2].
- Winter baseflow contribution from the chalk catchment.
- Surface Water inflows provided by the InfoWorks CS model assuming a 90-minute[3] winter storm event affecting the Teville Stream catchment.
- The Spring tide (MHWS) is the downstream water level, with the peak adjusted so that tide locking coincides with the fluvial flood event peak.
- Brooklands Lake full of water with an initial water level set at 0.98m AOD.
- 20 hour simulation duration to include two tidal peaks (i.e. two tide locking periods)

The hydraulic model has been run under the baseline conditions for a range of flood events with the following annual probabilities (annual chance): 20% (5-1), 10% (10-1), 5% (20-1), 2% (50-1), 1.33% (75-1), 1% (100-1), and 0.1 % (1000-1). The impact of climate change was also considered for the 1% AEP event.

It should be noted that the surface water inflows were derived following an iteration process conducted to harmonise the boundary conditions between the InfoWorks (Urban Drainage) model and the 1D/2D ISIS/TUFLOW model. Each iteration involves running the InfoWorks CS model to provide the inflows to the ISIS-TUFLOW model. In turn, after simulation, the latter provides the water levels at the outfall locations to the InfoWorks model for the next iteration and so on. Thus, the process involved running both models several times until reaching equilibrium in maximum stage in the Teville Stream. The model runs and results discussed in this report correspond to the final iteration.

<u>Blockage scenarios</u>

A series of three blockage scenarios has been run with the model for the 1% AEP flood event and the same baseline conditions. Blockages were set up respectively at the entrance of the GSK north culvert (515713 104717), at the inlet of the Deacon Way culvert (515926 104223) and at the sea outfall flapped outlet (517531 103209).

It should be noted that in the three blockage situations simulated, a blockage duration of 12 hours has been assumed as it is expected that beyond this period mitigation measures would be taken to avoid further flooding.

[2] Note there are no informal and formal defences within the Teville Stream catchment. As such the defended and undefended scenarios are the same.

[3] 90 minute winter storm correspond to the critical storm as determined using the InfoWorks model.

Silt level in Brooklands Lake

Two further scenarios assuming respectively the Brooklands Lake 50% full of silt and 100% full of silt[4] were also simulated under a 1% AEP flood event.

Table 7.1 below summarises the list of the runs carried out for this study for the different scenarios and flood events

Table 7.1: Model runs carried out in this study

Scenario	Storm Event (s) simulated	Simulation Duration	Silt Level	Blockage
Baseline	20%, 10%, 5%, 2%, 1.3%, 1%, 0.1% AEP and 1% AEP + Climate Change	20 hrs	None	None
Blockage	1% AEP	20 hrs	None	Total blockage of the GSK north culvert during 12hrs
Blockage	1% AEP	20 hrs	None	Total blockage of the Deacon Way culvert during 12hrs
Blockage	1% AEP	20 hrs	None	Total blockage of the sea outfall flapped valve during 12hrs
Silt in Brooklands Lake	1% AEP	20 hrs	Brooklands Lake 50% full of silt	None
Silt in Brooklands Lake	1% AEP	20 hrs	Brooklands Lake 100% full of silt	None

7.2 Model results and flood risk summary

The tabulated results from the 1D ISIS model are presented in Appendix B of this report and the complete set of flood outlines corresponding to the runs listed in Table 7.1 is provided in Appendix C.

This section of the report provides details on the flood risk areas identified within the Teville Stream catchment. Where possible, distinction is made between fluvial and surface water flood risk.

Surface Water Flooding (Baseline)

Surface water flooding happens when the capacity of the drainage system represented in the InfoWorks-CS model is exceeded.

Although the number of surcharged manholes predicted by the InfoWorks-CS model is large for all the events simulated, most of the flood volumes routed across the urban catchment by the Tuflow model consist of shallow overland flows (depth <100mm) draining along preferred pathways such as the road network.

Areas where flood depths are significant enough (>0.1m) to be considered at risk of surface water flooding are:

- GSK factory (see further comments below)
- In East Worthing, the low lying area located between King Edward Avenue and the railway line (515080 103500). Draining from the north, surface water ponds in this area as it is blocked by the railway embankment.

[4] 100% full silt level in the Brooklands Lake corresponds to an approximate bed level of 0.8m AOD in the Lakes

- Tarring Road, East Worthing, on the south side of the railway line, a large low lying area probably corresponding to the original route of the Teville Stream then the River Ditch, now culverted and part of the surface water sewer network running in a West to East direction from Station Road to the Teville Stream. This is shown on Figure 7.1.

Figure 7.1: Low lying area in East Worthing predicted at risk of surface flooding (orange area corresponds to the 1% AEP flood extent)

- In Sompting, Western Road North, Hurstfield by the railway embankment and a few locations within Lancing Business Park are also shown at risk of surface water flooding.
- A small amount of flooding near the Dominion Road pumping station correlating with a flooding complaint received by WBC.

Fluvial Flooding (Baseline)

Fluvial flooding (i.e. flooding due to the Teville Stream overtopping its bank) is not very extensive and generally limited to natural low lying floodplain areas in the rural part of the catchment. These are located respectively upstream of the GSK factory compound, on the left bank opposite Deacon Industrial Estate and north of the railway line on the left bank floodplain. As the bank tops are low, flooding in these areas is frequent, probably on a yearly basis.

St Luke's Close / St Paul's Close

South of the railway line, a few residential properties on St Luke's Close and St Pauls's Avenue (516785 103897), are predicted at risk of flooding from a 1.3% AEP (1 in 75 years) event onwards. Flooding occurs when water levels in the Teville Stream are high enough to fill up a drain running along the south side of the railway embankment. Flood waters travel eastward along the drain until they reach the residential area on St Paul's Avenue. Model results show 5 and 17 properties would be affected respectively for the 1% AEP and 0.1% AEP flood events. This is illustrated in Figure 7.2.

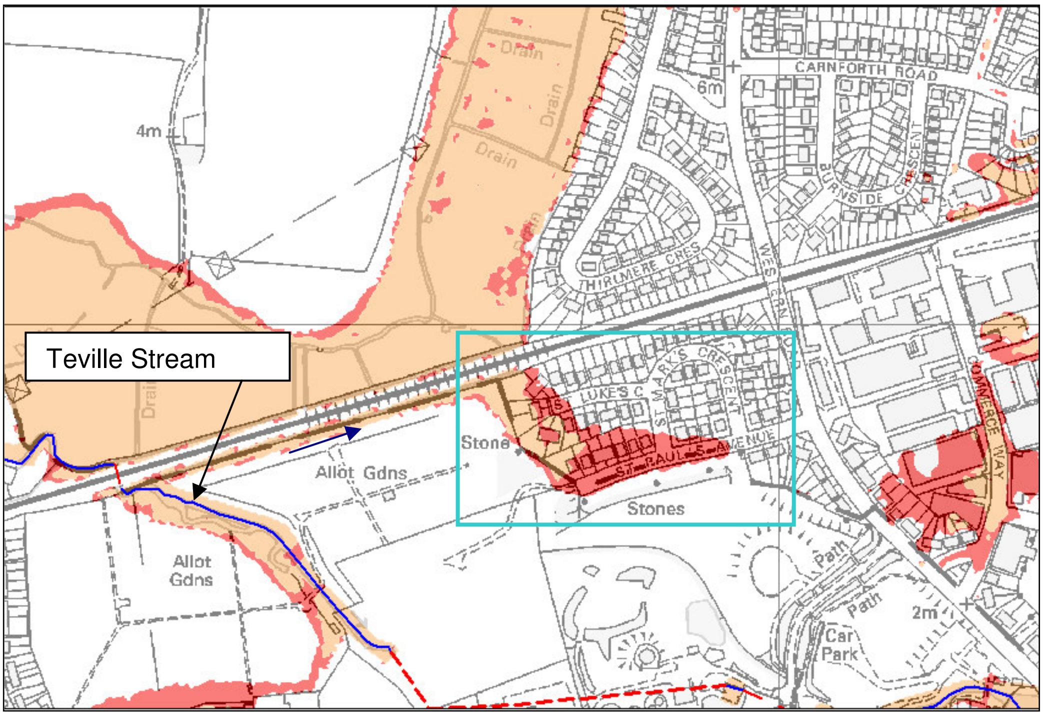

Figure 7.2: 1% AEP (in orange) and 0.1% AEP (in red) flood outlines showing fluvial flooding at St Luke's Close and on St Paul's Avenue.

GSK Factory

The GSK factory is another location shown at risk of flooding by the hydraulic model. For this area it is difficult to determine whether the source of flooding is surface water or fluvial as both are intrinsically linked. Manhole surcharging occurs first within the compound (onset prior to a 20% AEP event). As overland flow spreads across the site it reached the short open section of the Teville Stream fitted with a complex impounding structure meant to intercept any chemical leakage. This "intercepting" structure has a very limited capacity and therefore this open section of the Teville Stream rapidly fills up and overflows. Model results predict that two and up to four factory buildings would be affected respectively for the 1% AEP and 0.1% AEP flood events. This is shown on Figure 7.3.

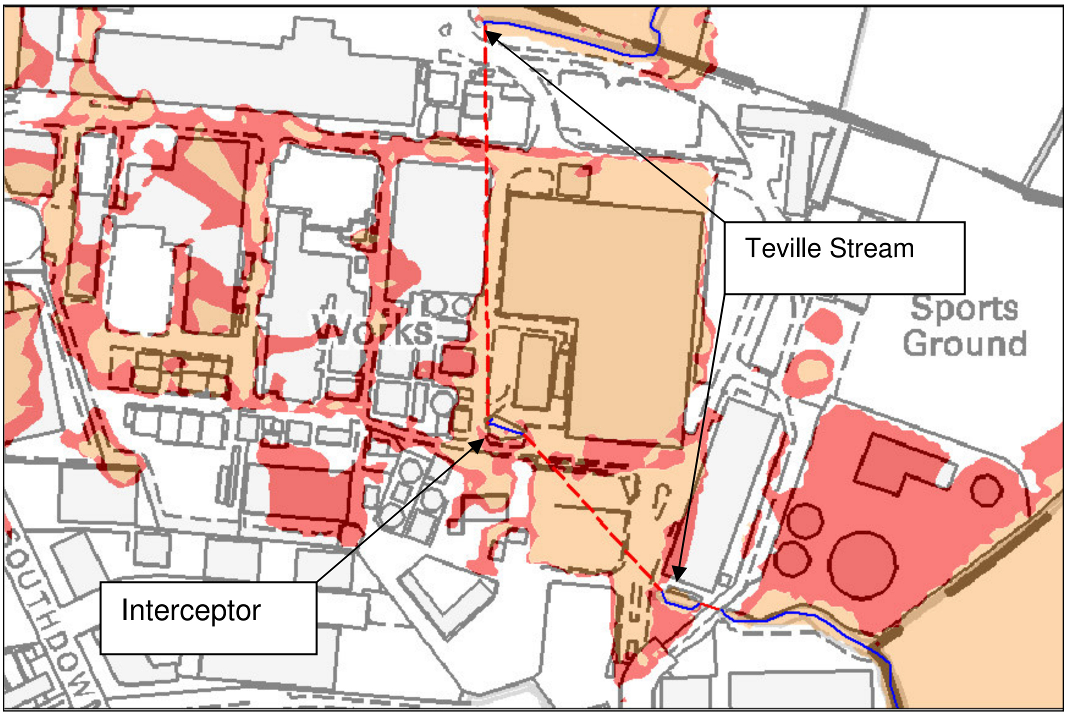

Figure 7.3: 1% AEP (in orange) and 0.1% AEP (in red) flood outlines showing fluvial flooding at St Luke's Close and on St Paul's Avenue.

Impact of culvert blockages on the flood risk

Drawings B1629800/D009, B1629800/D010, B1629800/D011 show the impact of culvert blockages on flood risk when comparing the resulting flood extents with the baseline situation for a 1% AEP event.

- Blockages to the GSK north culvert have a low impact on flood risk as the natural floodplain located upstream of the factory is large enough to accommodate the additional flood volume spilled onto the floodplain.
- Blockages to the Deacon Way culvert result in a larger flood extent on the left bank immediately upstream of the culvert entrance. Although most of the flooding remains within the natural floodplain, some storage tanks located within the GSK site are shown at risk.
- Blockages to the flap valve at the Teville Stream sea outfall has significant impact on the flood extent as the system is blocked from discharging into the sea. Backing up occurs into the Teville Stream up to the GSK factory leading to further areas being flooded such as Mansfield road (East Worthing) and existing flooding being exacerbated on St Paul's Avenue and at GSK factory.

Impact of silt level in the Brooklands Lake on the flood risk

Higher silt levels in the Brooklands Lake results in higher peak water levels upstream of the lake as less storage is available to the system and also high bed levels in the Lake act as an obstruction to the flow therefore reducing the conveyance and increasing the hydraulic head. However with Brooklands Lake 50% full of silt, the increase in peak levels is limited and not high enough to make a marked difference on the level of flood risk predicted under the baseline situation.

With Brooklands Lake 100% full of silt, flood risk increases markedly as larger flood volumes are spilled onto the floodplain. As such there is an increase in the residential properties are predicted at risk of flooding on St Paul's Avenue.

Impact of Increased Paving Area upon Flood Risk

Increasing impermeable area reduces the catchments capacity to directly infiltrate runoff to ground without it entering the surface water drainage network. In recent years the paving of front gardens to provide off-street parking has been identified as a potential source of additional flood risk in urban areas by removing this capacity and permitting the rainfall to enter the receiving watercourse more rapidly. WBC requested that an assessment was made of the potential of this activity to induce additional flood risk within Worthing.

The areas south of the railway line are densely developed consequently there is little opportunity to provide additional off-street parking in this manner. The residential areas north of the railway line are less densely developed and therefore these gardens could theoretically be paved. The impermeable area north of the railway was increased in the baseline model by 20% to simulate the paving of gardens which resulted in an increase in predicted flooding for the 30-year return period event of approximately 5,000m^3 (an increase of 11%).

Cross Connections to Foul Network

Our review of the data supplied by Southern Water identified no further cross connections between the foul and surface water sewerage networks in addition to those listed in Table 7.2 which were identified in the SW records. These locations have not been confirmed via survey.

Table 7.2: Cross Connections

Location	Receiving Watercourse Location
Inlet to WWTW (now pumped, exact outfall location TBC)	Teville Stream
Carnegie Rd junction with Cortis Avenue	TQ14043251
Outside Depot on Dale Rd	TQ14044050
Wigmore Rd junction with Kingsland Rd	TQ15040551
22 Sompting Rd junction with Southfield Rd	TQ1504146D
Sompting Rd junction with Kingsland Rd	TQ15041651

8 Limitations

8.1 Model Shortcomings

One of the main limitations of the modelling approach adopted in this study is the lack of dynamic connectivity between the InfoWorks CS model and the ISIS-TUFLOW where the drainage system discharges into the Teville Stream. To overcome this is an iterative process was required to harmonise the boundary conditions of the two models, which proved quite time consuming due to the run times of the two models.

Another limitation of the adopted approach is the representation of the surface water flooding in the model. The InfoWorks CS model only predicts flood volumes escaping surcharged manholes but not flow rates (m^3/s). As the TUFLOW 2D model requires flow rates to route the surface water overland, it has been necessary to convert the flood volumes into flow rates assuming a fixed duration of two hours and a triangular shape hydrograph.

The adopted modelling approach also does not allow overland flow to return to the drainage system where spare capacity exists. Thus areas where surface water flooding is predicted might be overestimated. Conversely it is possible there are some areas where the surface water flood risk is underestimated, as overland flow returning to system at some point upstream (where spare capacity exists) can lead to surcharging at another further location downstream.

8.2 Model Improvements

8.2.1 Surface Water Model

There are areas within the model where levels and dimensions are uncertain, particularly the trunk sewers along Teville Road, Newland Road and Chesswood Road. The possibility of a manhole survey was investigated. However, as many of the covers would require specialist equipment to lift and/or significant traffic management on a busy road this was not pursued further as part of the current study. The possibility of a survey could be investigated further.

To provide greater confidence on the model a short-term flow survey could be undertaken within the catchment to validate the model and identify inflows to the system to better confirm connectivity.

The connectivity in the Homefield Park areas is uncertain as a Southern Water sewer was diverted or blocked-off some time ago and the exact details are uncertain.

The runoff from the retail parks in Lyons Way have been assumed to drain directly to the surface water sewer; however this is based on our experience of similar systems rather than confirmed data.

To accurately model connections between the foul/combined and surface water systems surveys would be required of each location.

8.2.2 Fluvial Model

The combined 1D/2D approach adopted to model the fluvial system is robust enough to determine with a reasonable level of confidence the flood mechanisms and the extent of the fluvial flood risk within the study area. Nonetheless, there a few areas of improvement that could be beneficial. These are listed below:

- Although not critical infrastructure, it should be noted the railway arch bridge has not been fully surveyed due to access restrictions to Network Rail land. Survey of this structure would improve confidence in the flood level in this area.

- As mentioned in Section 4, the LiDAR data presents some ground level anomalies in the some areas of the 2D domain (i.e. GSK and Deacon Road Industrial Estate). Collection of topographic survey data to supplement the LiDAR data could reduce uncertainty on the flood levels predicted in these areas.

Very recent developments (October 2011) on both ISIS and TUFLOW software now permit the construction of an integrated 1D sewer, 1D river and 2D overland flow model. Although untested, this may increase model accuracy; however the additional expense may not prove cost-beneficial given the extent of flooding predicted by the current model.

8.3 Further Uses for the Model

As a common recommendation, we would advise that the fluvial model is reviewed before using it for other purposes. However, it is felt that the ISIS-TUFLOW model offers a reasonable level of detail which can be suitable for a wide range of studies including Flood Risk Assessment, Strategy and PAR studies.

9 Conclusions and Recommendations

This report has described the modelling methodology and results associated with the modelling of the Teville Stream catchment carried out to assess surface water and fluvial flood risk within the catchment.

The Teville Stream receives flow from two distinct sources: the chalk downs to the north and runoff from urbanised areas. It was decided to model these distinct systems separately with the most accurate method available for each and then combine them into a single catchment model using appropriate methodology to harmonise boundary conditions.

An InfoWorks-CS model was built to simulate the response to rainfall of the sewer systems across the urban areas of East Worthing, Sompting and Lancing. The fluvial system was modelled using ISIS and the overland flow from both systems was simulated using TUFLOW.

The hydraulic model was run for a series of design events under baseline conditions. Impact of culvert blockages and silt accumulation on the baseline flood risk were also investigated. Flood risk maps were produced for all scenarios and along with the model results, these allow for the determination of flood risk areas and key flood mechanisms.

Areas at risk of surface water flooding are numerous and include the GSK site, East Worthing (south of railway line) and Lancing Business Park.

Fluvial flood risk from the Teville Stream is mostly limited to the left bank rural floodplain north of the railway line. Areas at risk where commercial and residential properties exist are the GSK site and a few residential properties in St Luke's Close and St Pauls's Avenue. Model results have demonstrated that flood risk in these areas is sensitive to blockages to culverted section of the fluvial system as well as a large amount (more than 50% full) of silt into the Brooklands Lake.

It is important to note that the modelling results are heavily related to, and only valid under, the baseline assumptions common to all the simulations undertaken in this study; more specifically initial water level, tide regime and simulation duration are of particular importance. These have been adopted to provide a conservative estimation of the risk of flooding from the Teville Stream.

Drawing any general conclusions on the apparent low impact of changes to the Brooklands Lake (silt, initial water level) should be carefully considered as it is reminded that for a semi-closed and relatively flat[5] fluvial system such as the Teville Stream, water volume in the system at the beginning of a flood event and the tide regime governing the tide locking period can have a significant impact on flood risk. As such a combination of tidal surge and two or three medium range storm events occurring in a short period of time might be more onerous in terms of flooding than a single storm and MHWS conditions adopted in this study. This has not been investigated in this study. The apparent low level of fluvial flood risk to properties within the Teville Stream catchment benefits from the large rural floodplain areas available north of the railway line which greatly attenuate the fluvial flood wave. Thus it is recommended that any modifications to the course of the Teville Stream in these areas, as currently envisaged by the Environment Agency, are carefully reviewed to avoid increase of the flood risk elsewhere.

In terms of meeting the study objectives; we have confirmed the extent and route of Main River as we believe it to be (see Figure B1629800/0001) and the extent of the urban surface water sewerage network (see Figure B1629800/0002)

[5] Whilst many local variations in bed level can be found along the watercourse, the average bed level does not change much from the GSK factory to the Brooklands Lake outfall

Figures

Appendix A - Model User Report

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Appendix B - Tabulated Results (ISIS)

Appendix C – Flood Maps

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Appendix D – Surface Water Model Notes

Appendix E – Hydrology Summary

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Glossary

Term	Description