# Revision Schedule

**Paddock Wood Strategic Flood Modelling – Modelling Report**  
**Project Number: D115701/PMOD**  
**September 2009**

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1 Introduction

1.1 Commission

Scott Wilson was commissioned by Tunbridge Wells Borough Council (TWBC) in March 2007 to assist in the production of their Strategic Flood Risk Assessment (SFRA). Scott Wilson completed the Level 1 SFRA in November 2007 (Scott Wilson, November 2007). Prior to completion of the Level 1 SFRA TWBC had already identified the possibility of accommodating growth in and around the town of Paddock Wood.

The Environment Agency’s Flood Map and liaison with local Environment Agency officers (in the spring of 2007) identified parts of Paddock Wood and the surrounding area to be at flood risk and that information on flood risk held at that time would need to be refined for use in strategic planning.

1.2 Background

This modelling report describes the methodology and results for a hydraulic modelling exercise completed to investigate flooding in and around the Paddock Wood area. Results generated by this modelling report will be carried forward for use in a Level 2 SFRA to refine the current understanding of flood risk in and around Paddock Wood, suitable to inform strategic land use planning.

1.3 Previous Studies

With the exception of a site-specific Flood Risk Assessment at Church Farm in Paddock Wood (Coles Easdon, 2004); a Flood Risk Drainage Study of the land to the west of Maidstone (Babtie Group (2003); and Environment Agency’s national generalised mapping or strategic modelling projects for the River Medway (Mott MacDonald, 2003) and Beult, Bourne and Teise (Mott MacDonald, 2005), there have been no other studies undertaken to investigate the flood risk to Paddock Wood directly.

1.4 Aim and Objectives of Strategic Hydraulic Modelling

The aim of this modelling study is to refine the current level of information regarding flooding in and around Paddock Wood.

It is not the intention of this hydraulic modelling exercise to identify precisely where and to what magnitude flooding will occur. Specifically this modelling exercise is designed to provide sufficient information to enable TWBC to qualitatively identify favoured locations for development through the avoidance of flood risk. For specific development proposals, where flood risk may be an issue (identified through this strategic assessment), detailed flood modelling assessments will be required as part of a site specific flood risk assessment.

To achieve the aim of the study the following objectives were met:

- Estimation of flood flows for the 5%, 1% 1% plus the effects of climate change and 0.1% annual probability floods for the Tudeley Brook, Gravelly Way Stream, West Rhoden and East Rhoden watercourses draining through/near to the town of Paddock Wood;
- Development of 1-Dimensional hydraulic models of the four watercourses as they drain through Paddock Wood using available topographic data;
- Develop a 1-Dimensional model of the stormwater drainage system through Paddock Wood using available sewer network plans from Southern Water; and,
- Map the extent of the 5%, 1%, 1% plus the effects of climate change and 0.1% annual probability floods based on the combination of hydrology estimates and 1-Dimensional models.

1.5 Report Synopsis

Section 2 of this report introduces the study area and defines the extent of the hydraulic model. Section 3 introduces the data available for the 1-Dimensional model build, whilst section 4 presents the boundary conditions (flow estimates) used in the hydraulic model runs. Details of the hydraulic modelling in terms of models runs and calibration are presented in Section 5 with the results of model design runs presented in Section 6. The methodology used for the mapping of the hydraulic model results is presented in Section 7, with the conclusions and recommendations from the modelling exercise set out in Section 8.
2 Study Area

For the purpose of this strategic modelling exercise the study area is defined as the town of Paddock Wood and sufficient surrounding land to adequately characterise the primary watercourses and their associated floodplains. The extent of the hydraulic model and therefore study area is presented in Figure 1.

2.1 Paddock Wood

Paddock Wood lies to the north-east of Royal Tunbridge Wells in Kent at National Grid Reference (NGR) TQ 667 451 (Figure 1). The town/ward is home to approximately 8,300 people.

The town is largely comprised of two parts bisected by an embanked railway trending east to west. The southern part of the town is predominately residential with the light industrial, commercial and retail uses associated with a town centre. To the north of the railway Paddock Wood is characterised by larger industrial warehousing.

The town is founded on largely flat and level ground albeit with a slight incline towards the south, which increases markedly south of the town. To the north of the railway the ground is again largely flat associated with the floodplains of the River Medway, and Teise.

2.2 Local Watercourses

River Medway

The River Medway is the largest river catchment within the Environment Agency’s Southern Region. Its headwaters are found in the North Downs and the Weald. It flows along the western boundary of the study area for approximately 4km, and along the northern boundary for approximately 1.2km. The River Medway’s main tributaries that flow through or within the vicinity of the study area include the River Teise, River Beult, Alder Stream, Tudeley Brook and the Summerhill Stream. These all rise in the borough of Tunbridge Wells and have been sources of historic fluvial flooding.

The River Medway is a responsive catchment. The catchment is predominantly rural, with approximately 37% of the catchment being naturally impervious. The River Medway is a statutory navigation channel, with locks and weirs controlling flows along its course.

The Leigh Barrier is a strategic flood defence scheme on the River Medway approximately 8 miles upstream of Paddock Wood. The barrier is designed to provide flood relief to the town of Tonbridge and is considered to provide no benefit to Paddock Wood.

River Teise

The River Teise rises to the south east of Royal Tunbridge Wells and flows northeast to the River Medway. The catchment is predominantly rural, passing through the village of Lamberhurst in the upper reaches. The catchment is located on the Wealden Series, composed of sandstones, siltstones and clays (Hastings Beds). The catchment is naturally impervious across 28% of its area. The headwaters of the catchment develop on local aquifers and the catchment is very responsive to rainfall variations.
**Tudeley Brook**

Tudeley Brook originates to the south-west of Paddock Wood, near the small village of Henwood Green. It flows in a northerly direction to the west of Paddock Wood. It is culverted beneath the railway and continues to flow in a northerly direction eventually discharging to the River Medway.

Within the model extents, the channel is typically trapezoidal in shape with bed widths of between 2m and 4m and channel depths of between 1m and 2m.

**Gravelly Way Stream**

Gravelly Way Stream flows along the western boundary of Paddock Wood. It originates in the hills to the south of Paddock Wood and flows in a northerly direction. It is culverted beneath the railway and continues to flow in a northerly direction through the industrial part of Paddock Wood before discharging to the River Medway.

A culverted overflow connects Gravelly Way Stream with Tudeley Brook to the south of the railway. A number of storm sewer outfalls from Paddock Wood discharge to the stream.

In the upper extents of the model the Gravelly Way Stream has a triangular shaped cross-section profile which transform into a trapezoidal channel as the longitudinal gradient of the stream decreases. Typical channel depths are between 1m and 1.5m.

**East Rhoden**

The East Rhoden originates to the south-east of Paddock Wood. It flows in a northerly direction to the east of Paddock Wood. It originates in the hills to the south of Paddock Wood flowing through natural channels upstream of Church Road. Downstream of Church Road the channel is maintained by the Lower Medway Internal Drainage Board as a regular trapezoidal channel. The East Rhoden is culverted beneath the railway and flows north across the floodplain of the River Teise before converging with the Main Drain at NGR TQ 680463.

Immediately to the north of Church Road, a minor tributary joins the East Rhoden. This tributary has two branches to the south of Church Road that are essentially field ditches.

**West Rhoden**

The West Rhoden originates to the east of Paddock Wood and receives a large proportion of its inflow from the storm sewer networks of newer developments in the south of Paddock Wood, including discharge from attenuation ponds. As with the East Rhoden a short section of the West Rhoden upstream of the railway is also maintained by the Lower Medway IDB.

After issuing from the culvert beneath the railway the West Rhoden flows north, converging with the Main Drain north of Lucks Lane at NGR TQ678460. The combined watercourses then flow north to converge with the River Teise at NGR TQ 685475.

**Main Drain/Urban Drainage**

The head of the Main Drain is located in the hills to the south of Paddock Wood. It flows in a northerly direction through farmland before reaching the southern boundary of Paddock Wood. Through Paddock Wood, the Main Drain is predominantly culverted / piped with some minor open channel sections. An open channel section exists immediately south of the railway to the east of the Waitrose supermarket car park. The Main Drain is then culverted beneath the railway and becomes open channel for approximately 1.1km before converging with the West Rhoden.
A large proportion of Paddock Wood drains to the Main Drain via the stormwater sewer system. The public storm sewer system throughout Paddock Wood is maintained by Southern Water. The system comprises a conventional gravity system of standard pit / manhole / pipe network. There are a number of storm sewer outfalls discharging to the Gravelly Way Stream, Main Drain, and the West Rhoden. Drainage of recent housing developments is served by attenuation systems.

2.3 Flooding History

Paddock Wood is noted locally for its susceptibility to flood events. Flood events in the town have occurred due to surcharging of the storm water sewer system and out of bank flow from local watercourses. The presence of the embanked railway across the natural drainage paths also exacerbates flooding as catchment flows are routed through culverts beneath the railway.

Blockage of these culverts is likely to have exacerbated flooding to local properties from Gravelly Way Stream and Tudeley Brook and may have been the cause of at least one flood event. In addition surcharged drainage outfalls on Gravelly Way Stream cause some local manhole covers lifting, resulting in local flooding. Streets known to have experienced flooding include:

- Eldon Road
- Ribston Gardens
- Laxton Gardens, and
- Mercers Close (known to have flooded from over bank flow from Gravelly Way Stream)

Flooding from the storm water drainage system in January 2008 was reported to have occurred on Maidstone Road between Old Kent Road and Allington Gardens. Whilst flooding in 1996 also affected the Railtrack car park and the John Brant’s pub.

Additional data provided by the Environment Agency (Appendix A) for the Level 1 SFRA identified the following incidents of flooding in and around Paddock Wood:

- Flooding of roads and properties, Paddock Wood south of the railway line, Allington Road, Woodlands area (recorded 16/09/1998);
- Developing areas flood, Paddock Wood, west (recorded 16/09/1998); and,
- Flooding, Badsell Road, Capel (no date information provided with this record).

Photographic evidence of flooding in Paddock Wood has also been provided by the Environment Agency for flooding in October 2000 (Appendix A). The presented photographs indicate flooding during this event was primarily in the north of the town.
3 Topographic Survey

Various sources of topographic data were used to generate the 1-Dimensional models of the open channels and stormwater sewer systems. This section introduces the data used and highlights any issues associated with its use. Figure 2 illustrates the extent and source of available topographic survey. All survey used in the development of the hydraulic models is provided on a CD-ROM in Appendix B.

3.1 Floodplain Survey

LiDAR

The Environment Agency has provided Light Detection and Ranging (LiDAR) data for the study area. LiDAR is an airborne mapping technique which uses a laser to measure the distance between the aircraft and the ground. The data varies in accuracy depending on the nature of the terrain being surveyed such as in woodlands, complex urban areas and near lakes, the accuracy lowering due to the limitations in the technique. However, LiDAR collected since 2000 is generally recognised to be +/- 150mm in accuracy.

LiDAR data is not available for the whole of the study area, with coverage predominately available for the built areas of Paddock Wood and land to the east and west of the settlement.

The LiDAR was used to extend channel survey sections beyond their surveyed extents and to determine floodplain areas and storage volumes.

Photogrammetry Data

The Environment Agency also provided photogrammetry data. This data has more widespread coverage than the LiDAR data however is only available with an accuracy of +/- 1000mm with levels recorded on a 5m grid.

Whilst the data can be used for contouring the relatively flat floodplain of the River Medway the coarse resolution of the data makes integration with the better quality LiDAR data (covering the majority of the study area) impractical. This is particularly the case when attempting to resolve the extent and storage available in floodplains.

3.2 Channel Survey

In addition to topographic data for the floodplains of the hydraulic model build also required detailed topographic data for the river/watercourse channels. The hydraulic models have been built based on topographic survey provided primarily by field surveys, supplemented with ground imagery in the form of LiDAR. The sources of survey used in the development of the 1-Dimensional hydraulic models of the open channels are summarised below.

Capital Surveys Ltd (March – April 2005) - Tudeley Brook

As part of an Environment Agency programme to model the Tudeley Brook the Environment Agency’s Southern Region commissioned a topographic survey of the brook in March and April 2005. Due to inadequate funding the Environment Agency were unable to complete their modelling of the Tudeley Brook but were able to provide their topographic survey for use in this strategic modelling exercise.

The survey was undertaken by Capital Surveys between the 30/03/05 and the 26/04/05. A total of 64 channel cross sections were surveyed on Tudeley Brook from upstream of Paddock Wood at NGR
TQ653415 to its confluence with the River Medway at NGR TQ678485. All survey drawings and data are provided on a CD-ROM in Appendix B.

**Lower Medway IDB Records - East Rhoden and Main Drain**

The Lower Medway IDB holds survey records for watercourses both that it currently maintains and that it used to maintain. From a review of their records, survey from the 1930s of the Main Drain and the East Rhoden downstream (north) of the railway was identified.

The survey used the now redundant Liverpool Ordnance Datum and recorded distances in imperial units of inches, feet, and chains.

Through discussions with the Environment Agency it was agreed that as the IDB channels are maintained/dredged, their form is unlikely to have significantly changed from the survey drawings, consequently the data would be suitable for use in developing the hydraulic models.

Prior to use in hydraulic modelling this data was converted to metric units and elevations corrected to tie in with all other available survey data (recorded in metres above Ordnance Datum Newlyn). Figure 2 illustrates the extent of the topographic survey provided by the Lower Medway IDB.

**BW Surveying - East Rhoden, West Rhoden, Main Drain, and Gravelly Way Stream (2006 and 2008)**

Topographic data for the East and West Rhoden was also obtained from RPS Group Ltd. In 2006, RPS Group Ltd commissioned BW Surveying to undertake a cross-sectional survey of the East Rhoden and West Rhoden between Church Road and the railway on behalf of Network Rail. Network Rail permitted the release of this survey for the use of this project. The survey recorded cross-sections at regular intervals and included all structures. A total of 33 cross sections and 8 structures were provided. Figure 2 illustrates the coverage of the survey. Detail of the survey is included on the CD-ROM in Appendix B.

Following review of the survey data made available by the Environment Agency, the Lower Medway IDB and the RPS Group Survey, gaps were identified in the survey necessary for development of the hydraulic models.

Therefore for the purposes of this modelling study further cross-section and structure details were required on the East Rhoden and West Rhoden to supplement the existing survey. In January 2008, Scott Wilson commissioned BW Surveying to undertake a cross-sectional survey of:

- the East Rhoden upstream of Church Road (11 cross sections and 3 structures);
- the West Rhoden downstream of the railway (12 cross sections and 8 structures);
- the Main Drain upstream of the railway (5 cross sections and 7 structures); and
- all of Gravelly Way Stream within the study area (39 cross sections and 14 structures).

All topographic survey for open channels and associated structures collected through this modelling exercise are included in a digital format on a CD-ROM in Appendix B.

### 3.3 Stormwater Sewer Records

Survey data for the stormwater sewer system was obtained from Southern Water in a digital format. The survey consists of the public sewer record owned/maintained by Southern Water. Coverage of the survey is illustrated in Figure 2, digital records are provided on the CD-ROM in Appendix B.
4 Hydraulic Model Boundary Conditions

The 1-dimensional hydraulic models for each of the watercourses and storm water sewer system, require the specification of upstream and downstream boundary conditions.

Early discussions with the Environment Agency identified that there were no hydrology estimates for the catchments and no ‘local’ analogue sites for data transfer. In addition, the catchments are not gauged and neither are any other local tributaries of the Medway or Teise.

Therefore for the purpose of this model assessment the upstream boundary conditions for open watercourses were based on flow hydrographs estimated using the techniques described in the Flood Estimation Handbook (CEH, 1999) and the Revitalised Flood Hydrograph (ReFH) Method.

Downstream boundaries for the models were determined from a variety of sources including existing Environment Agency models of the River Medway and Teise or in the case of the storm water sewer model, iteratively through interrogation of the relevant 1-Dimensional models developed for this assessment.

4.1 Upstream Boundaries

Upstream boundaries for Tudeley Brook, Gravelly Way Stream, West Rhoden and the East Rhoden were derived using a combination of the statistical method described in the Flood Estimation Handbook and the ReFH method.

The upstream boundary condition for the open channel section of the Main Drain north of the railway was determined from a 1-Dimensional hydraulic model of the storm water sewer system through Paddock Wood.

Overview of the FEH Statistical Method

The Flood Estimation Handbook statistical method is an industry accepted method. The technique uses an index flood, QMED (the median annual flood), and applies growth factors (derived from a pool of hydrologically similar gauged catchments) to obtain the flow/return period relationship.

For ungauged catchments such as Tudeley Brook, Gravelly Way Stream, West Rhoden and the East Rhoden, the recommended method of determining the index flood is to calculate QMED from the catchment descriptors obtained from the FEH CD-ROM v1.0. During the project the FEH version 2.0 was released a comparison of the difference was undertaken and found to be negligible. The derived QMED is then adjusted by data transfer, using data from hydrologically similar (donor or analogue) gauged sites.

A pool of hydrologically similar gauged stations was generated (using the HiFlows database v1.1) to accumulate a combined length of record of five times the target flood. Therefore, to obtain the 100 year flood flow a combined record length of 500 years is required. The pooled stations are reviewed for their suitability (similarity to the subject site) and used to derive growth factors for a range of flood return periods. The adjusted QMED is then multiplied by the growth factor to obtain the peak flood flow for a given return period flood.

Overview of the ReFH Method

The ReFH Model was released in 2006. The ReFH method is considered an improvement on the Rainfall Runoff Model presented in FEH and therefore supersedes the FEH method. It enables a more direct and transparent description of flood-generating mechanisms and introduces the concept of seasonal variation in soil moisture content, design rainfall and baseflow.
Both soil moisture and rainfall are specified on a seasonal basis depending on the degree of urbanisation of the catchment under consideration (summer conditions for urbanised catchments and winter conditions for rural catchments).

Hydrographs are determined for each return period using the catchment descriptors (from the FEH CD-ROM) and importing them into the ReFH spreadsheet v1.3 produced by CEH Wallingford (CEH, 2005). Suitable time steps are considered (1 hour intervals) with durations set to the recommended default value. All models were run as a winter simulation as recommended and hydrographs were derived for each scenario.

Using the ReFH Method, peak flows can be determined from the generated design flood hydrographs.

**Methodology**

Peak flood flows were derived for each watercourse using the statistical method and compared to peak flood flows derived using the ReFH method.

For each of the watercourses, the ReFH method produced the larger flows and therefore flows from this method were adopted throughout the models. The calculation sheets for each of the watercourses are presented in Appendix C.

**Climate Change Estimates**

Estimates of peak flood flow accounting for the effects of climate change have been derived in accordance with guidance presented in Planning Policy Statement 25: Development and Flood Risk (CLG, December 2006). Annex B of PPS25 indicates that estimated peak flood flows should be increased by 20% to account for the effects of climate change up to 2115.

**Tudeley Brook**

Peak catchment flows on Tudeley Brook were calculated for a point immediately downstream of the railway line (NGR TQ 66500 46100). Appendix C presents the calculation sheets for Tudeley Brook. Table 4-1 presents a summary of the peak flows derived through the flow estimation process.

<table>
<thead>
<tr>
<th><strong>ANNUAL PROBABILITY FLOOD</strong></th>
<th><strong>FEH STATISTICAL</strong></th>
<th><strong>ReFH (M³/SEC)</strong></th>
</tr>
</thead>
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<tr>
<td>5% (Flood Zone 3b)</td>
<td>7.3</td>
<td>4.2</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>9.7</td>
<td>6.2</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>11.7</td>
<td>7.4</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>13.6</td>
<td>11.8</td>
</tr>
</tbody>
</table>

The summary of flows clearly illustrates the larger (more conservative) flows are derived from the FEH statistical method. Consequently the FEH statistical derived flows were carried forward for use in the hydraulic model of Tudeley Brook.

Guidance indicates the statistical method should not be used to estimate flows greater than five times the pooled gauge record (i.e. the method is unsuitable for estimation of the 0.1% annual probability event). However comparison of the 0.1% ReFH flood flow to the 1% plus climate change statistical flood flow shows negligible difference. Therefore despite the uncertainty associated with the statistical 0.1% annual probability flood flow it has been carried forward for use in hydraulic modelling as a conservative estimate.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.
Gravelly Way Stream

Peak catchment flows on Gravelly Way Stream were calculated for a point downstream of the railway line, south of the A228 road (NGR TQ 66850 46250). Appendix C presents the calculation sheets for Gravelly Way Stream. Table 4-2 presents a summary of the peak flows derived through the flow estimation process.

Table 4-2: Gravelly Way Stream Peak Flow Estimates

<table>
<thead>
<tr>
<th>ANNUAL PROBABILITY FLOOD</th>
<th>FEH STATISTICAL (M³/SEC)</th>
<th>ReFH (M³/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>0.955</td>
<td>0.7</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>1.276</td>
<td>1.1</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>1.531</td>
<td>1.4</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>-</td>
<td>2.7</td>
</tr>
</tbody>
</table>

The summary of flows clearly illustrates the larger (more conservative) flows are derived from the FEH statistical method for the 5%, 1% and 1% plus the effects of climate change. Consequently the FEH statistical derived flows for these return periods were carried forward for use in the hydraulic model of Gravelly Way Stream. In the case of the 0.1% annual probability flood only the ReFH method is considered to give a reasonable estimate for use in hydraulic modelling.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.

The Gravelly Way Stream also receives inflows from a number of storm sewer outfalls discharging along the length of Gravelly Way Stream between Badsell Road and the railway. To account for this contribution the outfall hydrographs generated by the 1-Dimensional model of the Paddock Wood stormwater sewer system have been inputted into the 1-Dimensional model of Gravelly Way Stream as lateral point inflows. The urban nature of Paddock Wood results in a quicker runoff response than the wider rural catchment of Gravelly Way Stream. As a consequence the timing of the flood peaks from the stormwater sewer and the wider Gravelly Way Stream catchment are not coincident. Therefore the peak discharges entering the Gravelly Way Stream from Paddock Wood occur before the peak in the fluvial Gravelly Way Stream hydrograph occurs.

West Rhoden

Peak catchment flows on the West Rhoden were calculated for a point downstream of the railway line (NGR TQ 68050 45750). Appendix C presents the calculation sheets for the West Rhoden. Table 4-3 presents a summary of the peak flows derived through the flow estimation process.

Table 4-3: West Rhoden Peak Flow Estimates

<table>
<thead>
<tr>
<th>ANNUAL PROBABILITY FLOOD</th>
<th>FEH STATISTICAL (M³/SEC)</th>
<th>ReFH (M³/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>0.51</td>
<td>0.4</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>0.672</td>
<td>0.6</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>0.806</td>
<td>0.7</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>-</td>
<td>1.3</td>
</tr>
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</table>
The summary of flows clearly illustrates the larger (more conservative) flows are derived from the FEH statistical method for the 5%, 1% and 1% plus the effects of climate change. Consequently the FEH statistical derived flows for these return periods were carried forward for use in the hydraulic model of the West Rhoden. In the case of the 0.1% annual probability flood only the ReFH method is considered to give a reasonable estimate for use in hydraulic modelling.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.

**East Rhoden**

Peak catchment flows on the East Rhoden were calculated for a point downstream of the railway line (NGR TQ 68150 45750). Appendix C presents the calculation sheets for the East Rhoden. Table 4-4 presents a summary of the peak flows derived through the flow estimation process.

<table>
<thead>
<tr>
<th>Annual Probability Flood</th>
<th>FEH Statistical (m³/sec)</th>
<th>ReFH (m³/sec)</th>
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<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>1.894</td>
<td>1.8</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>2.484</td>
<td>2.6</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>2.980</td>
<td>3.12</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>

The summary of flows clearly illustrates that the FEH statistical derived flows are comparable with the ReFH derived flows. The FEH statistical derived flows for the 5%, 1% and 1% plus the effects of climate change were carried forward for use in the hydraulic model of the East Rhoden. In the case of the 0.1% annual probability flood only the ReFH method is considered to give a reasonable estimate for use in hydraulic modelling.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.

Ordnance Survey mapping of the East Rhoden catchment indicates a confluence between a tributary of the East Rhoden and the main East Rhoden exists immediately north of Church Road. The tributary has a significantly smaller catchment than the main channel. Unfortunately, the FEH CD ROM does not recognise the tributary, instead considering its catchment to be part of the East Rhoden. Therefore flows for the East Rhoden have been apportioned between the tributary and the main channel based on their respective catchment areas (Table 4-5).

<table>
<thead>
<tr>
<th>Annual Probability Flood</th>
<th>East Rhoden (m³/sec)</th>
<th>Tributary of the East Rhoden (m³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>1.773</td>
<td>0.197</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>2.293</td>
<td>0.255</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>2.751</td>
<td>0.306</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>4.509</td>
<td>0.501</td>
</tr>
</tbody>
</table>
Storm Water Sewer System and Main Drain

The review of existing drainage network data for Paddock Wood Town shows that both surface water and foul systems were built for the town. The surface water network data were extracted from the drainage records in MapInfo format for the model build. It is found that surface water collected from Paddock Wood urban areas are discharged into Gravelley Way Stream, Main Drain and West Rhodden Stream respectively. To estimate the surface runoff to the storm water sewer system and accordingly to the downstream open watercourses, totally 433 sub-catchments have been delineated.

The surface runoff from each sub-catchment is considered as the upstream inflow boundary to the storm water sewer system. This was estimated by using Wallingford’s Fixed Runoff Volume module embedded in InfoWorks CS by assuming design rainfall profiles for return periods of 1 in 20 years, 1 in 100 years, and 1 in 1000 years, and plus the climate change as well.

4.2 Downstream Boundaries

Downstream boundaries for all the watercourses are still water levels (i.e downstream water level fixed throughout model run) based on outputs from Environment Agency strategic models of the River Medway and River Teise.

To account for the difference in catchment response times between the watercourses focused on in this study and those of the Rivers Medway and Teise, it was initially agreed with the Environment Agency that a return period relationship should be used. Table 4-6 illustrates the relationship suggested to determine the downstream boundary conditions for the modelled watercourses.

Initial discussions with the Environment Agency regarding the downstream boundary conditions to be used in the hydraulic modelling led to the agreement that a return period relationship between the modelled watercourses and the larger receiving watercourses of the River Medway and Teise would be appropriate as presented in Table 4-6.

Table 4-6: Proposed Flood Return Period Relationship

<table>
<thead>
<tr>
<th>RETURN PERIOD EVENT TO BE MODELLLED ON THE Paddock Wood WATERCOURSES</th>
<th>CORRESPONDING ANNUAL PROBABILITY FLOOD EVENT TO BE USED AS THE DOWNSTREAM BOUNDARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>10% RIVER MEDWAY 4% RIVER TEISE</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>2% RIVER MEDWAY 1.3% RIVER TEISE</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>2% RIVER MEDWAY 1.3% RIVER TEISE</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>Extrapolated from available flood levels RIVER MEDWAY Extrapolated from available flood levels</td>
</tr>
</tbody>
</table>

Unfortunately extensive model instabilities led to the need to abandon this approach and the selection of a constant downstream still water level for all modelled return periods. The downstream boundary conditions are based upon the 1% annual probability model results from Environment Agency strategic models of the Medway and Teise.

In the case of the River Medway the 1% flood level for node point CS111 level was used directly due to the proximity of the model result to the downstream boundary of the watercourses modelled as part of this assessment and the nature of the topography between the two points.
For the River Teise the 1% annual probability flood levels for two node points (T25 and T26; closest to the confluence of the East Rhoden with the River Teise) were extrapolated to the downstream boundary of the East Rhoden hydraulic model.

Table 4-7 presents the downstream boundary conditions used in the hydraulic model runs.

### Table 4-7: Downstream Boundary Conditions

<table>
<thead>
<tr>
<th>SUBJECT SITE</th>
<th>DOWNSTREAM WATERCOURSE</th>
<th>DOWNSTREAM BOUNDARY LEVEL (M AOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tudeley Brook</td>
<td>River Medway</td>
<td>14.688</td>
</tr>
<tr>
<td>Gravelly Way Stream</td>
<td>River Medway</td>
<td></td>
</tr>
<tr>
<td>Main Drain</td>
<td>West Rhoden</td>
<td>13.63</td>
</tr>
<tr>
<td>West Rhoden</td>
<td>East Rhoden</td>
<td>13.63</td>
</tr>
<tr>
<td>East Rhoden</td>
<td>River Teise</td>
<td>13.63</td>
</tr>
</tbody>
</table>

The one exception to this approach was the selection of the downstream boundary conditions for the InfoWorks CS hydraulic model of the storm water sewer system. Water levels extracted from InfoWorks RS models at the discharging points (outfalls) of InfoWorks CS surface water model were used as the downstream boundary condition.

Some of the lower reaches of the watercourses were truncated as the downstream boundary levels were significantly higher than the floodplains as the models do not run with the lower reaches swamped. This will not affect the flood levels predicted as the flows in the Paddock wood watercourses will be small compared with the storage on the Teise and Medway floodplains.
5 Hydraulic Modelling

5.1 Introduction

The Paddock Wood model extends from south of Badsell and Church Roads to Wagon Lane encompassing Paddock Wood and the five watercourses of Tudeley Brook, Gravelly Way Stream, Main Drain, the West Rhoden, and the East Rhoden and including their respective floodplains. This section includes details of the hydraulic models created.

This section also highlights model stability issues and the steps taken to resolve these instabilities in the interest of progressing the SFRA modelling. The study area included watercourses that were steep in their hinterlands and relatively flat through the floodplains. The steep, narrow nature of the watercourses combined with the unorthodox nature of some of the hydraulic sections led to severe model instabilities and unsuccessful model simulations.

InfoWorks RS (Version 8.5) and InfoWorks CS (Version 8.5) have been employed for the establishment of river hydraulic models for open water courses and drainage network models for urban storm water sewer systems respectively.

Model Program Limitations

InfoWorks RS is a 1-dimensional hydraulic modelling package for open channels that uses channel geometry and hydraulic characteristics, such as roughness, and estimated flood flows to produce flood water levels and flood outlines based on field surveys (channel cross-sections and structures) and LiDAR and photogrammetry (flood plains). The program has the ability to show where water is stored in floodplain however it is limited in that the program is unable to show the flow paths that link the channel spills to the storage areas, hence it being classified as a 1-dimensional model.

InfoWorks CS is an equivalent hydraulic modelling package for sewered networks. It can predict flood levels from surcharged manholes / links based on geometric information the user provides. However it cannot produce flood outlines from that data.

InfoWorks CS and InfoWorks RS cannot be linked together to produce flood outlines, but like all models the outputs from each model (such as flow hydrographs) can be interchanged.

Models

The fluvial modelling was split into three separate models due to software node limitations and stability issues created during model runs. The split between the three models has been arranged so that the watercourses offering the most clearly perceived interactions have been grouped together where possible.

The fourth model is the InfoWorks CS model of Paddock Woods storm sewer system. These are elaborated on further in this section.

5.2 Tudeley Brook and Gravelly Way Stream (Model 1)

Tudeley Brook and Gravelly Way Stream are the two adjacent watercourses to the west of Paddock Wood. Historically, and by a visual inspection of the Environment Agency’s flood mapping, it is clear that there are floodplain links between the two watercourses, especially to the immediate south of the railway. The railway culverts are a known contributor to flood problems in the area as they provide a constricted limitation to flows with the railway preventing spills over the culverts.
Model Structure

The finalised Model 1 consisted of the following elements:

- 2 x ReFH boundary flow hydrographs (1 each for Tudeley Brook and Gravelly Way Stream)
- 8 x InfoWorks CS output flow hydrographs, all on Gravelly Way Stream south of the railway
- 2 x downstream stage boundaries (1 each for Tudeley Brook and Gravelly Way Stream) being the 100 year return period level for the River Medway
- 37 cross-sections
- 143 interpolated cross-sections
- 56 spill units to floodplains
- 8 floodplains/storage areas
- 8 culverts
- 3 bridges

Exclusions to Model Structure

The downstream (northern) extent of Model 1 was cropped to the end of the available LiDAR survey. Severe out of bank flow occurred at the northern end of the study area, caused primarily by a downstream boundary condition with water levels higher than most of the northern topography (discussed further in Section 6). As a result modelling accuracy could only be achieved where the floodplains could not be correctly included in the model. Therefore, model extents were cropped to a suitable position within the LiDAR survey.

A number of unorthodox hydraulic structures are present in the Tudeley Brook and Gravelly Way Stream. Structures that were deemed likely to have limited effect on flood levels whilst adversely affecting model stability were excluded from the model. The major culverts of note omitted are:

**Tudeley Brook**

- Badsell Road culvert crossing.
- Culvert overflow link between Gravelly Way Stream and Tudeley Brook. This culvert would have had limited effect in the model as flood levels modelled in Tudeley Brook are noticeably higher than those of Gravelly Way Stream, therefore no overflow from Gravelly Way Stream to Tudeley Brook would occur. Preventing overflow from Tudeley Brook to Gravelly Way Stream is considered to give a conservative estimate of water levels in Tudeley brook.
- All culvert crossings downstream (north) of the Eastlands Cottages road.

**Gravelly Way Stream**

- Culverts upstream (south) of Badsell Road. These culverts are all minor with no spill overbank threat.
- Culvert north of railway culvert.

Whilst it is accepted that the removal in the model of the overflow link culvert between Gravelly Way Stream and Tudeley Brook does not mimic reality, it can be argued that the culvert is there to function as a flood relief from the Paddock Wood storm sewer system; a scenario that is not worse-case for Tudeley Brook and therefore not modelled in this study.
**River Sections**

Interpolations are required in hydraulic models where the profile varies significantly between adjacent river sections. In small watercourses, stability impacts caused by variations in river profile sections are exaggerated. These are further exaggerated when the longitudinal profile of the watercourse is steep.

The requirements for interpolated sections can be established in the model run reports where river section variability is identified. During the course of trying to generate stable model simulations, numerous river sections were identified as requiring interpolations with some interpolations required at intervals as low as 5m.

**Roughness Coefficients**

The roughness coefficient defines the frictional resistance of surfaces to flow. Generally, the effects of friction are most pronounced when the flow is fast. The Manning's number 'n' is a co-efficient used to quantify describing the roughness.

The following defaults have been adopted in Model 1.

**Table 5-1 Roughness Coefficients for Model 1**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MANNING'S 'n'</th>
</tr>
</thead>
<tbody>
<tr>
<td>In channel banks</td>
<td>0.045</td>
</tr>
<tr>
<td>Out of channel banks</td>
<td>0.05</td>
</tr>
<tr>
<td>Bottom of culvert</td>
<td>0.011</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>0.014</td>
</tr>
</tbody>
</table>

**Downstream Boundary**

The downstream boundary used was the 100 year return period level for the River Medway of 14.7m AOD as agreed with the Environment Agency. This was conservatively modelled as a constant level to ensure the peak flow through the InfoWorks RS model would coincide with the 100 year return period level for the River Medway.

5.3 **East Rhoden (Model 2)**

Historical records, previous modelling, and a visual inspection of the Environment Agency's flood mapping, identifies that there are floodplain links between the East Rhoden and West Rhoden to the immediate south of the railway. The railway culverts are a known contributor to flood problems in the area as they provide a constricted limitation to flows with the railway preventing spills over the culverts. Furthermore, the West Rhoden is a tributary of the Main Drain which is in turn a tributary of the East Rhoden. Unfortunately, a working stable model with the aforementioned watercourses was unachievable within the desired timeframes so a combined model was abandoned.

**Model Structure**

The finalised Model 2 consisted of the following elements:

- The East Rhoden with a tributary
- 2 x ReFH boundary flow hydrographs
- 1 downstream stage boundaries being the 100 year return period level for the River Teise
- 30 cross-sections
- 119 interpolated cross-sections
- 55 spill units to floodplains
- 3 floodplains/storage areas
- 4 culverts

Exclusions to Model Structure

The downstream extent of Model 2 was cropped to the end of the available LiDAR survey. Severe out of bank flow occurred at the northern end of the study area, caused primarily by a downstream boundary condition with water levels higher than most of the northern topography (discussed further in Section 6). As a result modelling accuracy could only be achieved where the floodplains could not be correctly included in the model. Therefore, model extents were cropped to a suitable position within the LiDAR survey.

Structures recorded within the IDB survey were omitted as these are unlikely to have been maintained. Structures that were deemed likely to have limited effect on flood levels whilst adversely affecting model stability were excluded from the model. The major structures of note to be removed are:

**East Rhoden**

- All IDB recorded structures.

**East Rhoden Tributary**

- Church Road culvert.

Roughness Coefficients

The following defaults have been adopted in Model 2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Manning’s ‘n’</th>
</tr>
</thead>
<tbody>
<tr>
<td>In channel banks</td>
<td>0.040</td>
</tr>
<tr>
<td>Out of channel banks</td>
<td>0.050</td>
</tr>
<tr>
<td>Bottom of culvert</td>
<td>0.011</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Floodplain Storage Areas

Floodplain storage areas that were used in Model 2 exist in Paddock Wood between the Main Drain and the West Rhoden, to the east of the Main Drain north of the railway, and to the east and west of the West Rhoden north of the railway. This storage area is shared with Model 3 (see later in this section). Flows spill from the East Rhoden upstream of the railway culvert in a westward direction to the localised low point in the north-east of Paddock Wood.

Other floodplain storage areas used to simulate the East Rhoden model are located to the south and north of Church Road.

Downstream Boundary

The downstream boundary used was the 100 year return period level for the River Teise of 13.63m AOD as agreed with the Environment Agency. This was conservatively modelled as a constant level to ensure
the peak flow through the InfoWorks RS model would coincide with the 70 year return period level for the River Teise.

5.4 West Rhoden and Main Drain (Model 3)

Historical records, previous modelling, and a visual inspection of the Environment Agency’s flood mapping, identifies that there are floodplain links between the West Rhoden and Main Drain, especially to the immediate south of the railway. The railway culverts are a known contributor to flood problems in the area as they provide a constriction to flows with the railway preventing spills (up to the level of the railway). Furthermore, the West Rhoden is a tributary of the Main Drain which is in turn a tributary of the East Rhoden. Unfortunately, a working stable model with the aforementioned watercourses was unachievable so a combined model was abandoned. A working model with the Main Drain and West Rhoden was achievable however.

Model Structure

The finalised Model 2 consisted of the following elements:
- The East Rhoden with a tributary
- 1 ReFH boundary flow hydrograph
- 1 x InfoWorks CS discharge hydrograph
- 1 downstream stage boundaries being the 100 year return period level for the River Teise
- 15 cross-sections
- 40 interpolated cross-sections
- 48 spill units to floodplains
- 4 floodplains/storage areas
- 2 culverts

Exclusions to Model Structure

The downstream extent of Model 3 was initially cropped to the end of the available LiDAR survey. Severe out of bank flow occurred at the northern end of the study area, caused primarily by a downstream boundary condition with water levels higher than most of the northern topography (discussed further in Section 6) forced the truncation of the reaches back to sections with topography higher than the boundary conditions. As a result modelling accuracy could only be achieved where the floodplains could not be correctly included in the model.

Structures recorded within the IDB survey were omitted as these are unlikely to have been retained over this period of time. Structures that were deemed likely to have limited effect on flood levels whilst improving model stability were excluded from the model. The major structures of note to be removed are:

West Rhoden
- All culverts upstream of the railway culvert.
- Culverts immediately downstream of the railway culvert

Roughness Coefficients

The following defaults have been adopted in Model 3.

Table 5-3 Roughness Coefficients for Model 3

<table>
<thead>
<tr>
<th>In channel banks</th>
<th>MANNING'S 'n'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.040</td>
</tr>
</tbody>
</table>
Out of channel banks 0.050  
Bottom of culvert 0.011  
Top of culvert 0.014  

### Floodplain Storage Areas

Floodplain storage areas that were used in Model 3 exist in Paddock Wood between the Main Drain and the West Rhoden, to the east of the Main Drain north of the railway, and to the east and west of the West Rhoden north of the railway.

Model 3 shares a floodplain storage area with Model 2 in Paddock Wood between the Main Drain and the West Rhoden. However, as discussed previously, the two models could not be linked together to provide a stable combined model. Flows spill from the East Rhoden south of the railway and spill westward across the West Rhoden into the localised low point. Model 3 has been set up to incorporate the peak flood depth in the Paddock Wood storage area from Model 2 as its initial condition and allows spills from the Main Drain and West Rhoden to superimpose on top of this initial flood depth. This approach is slightly conservative; however it provides a suitable solution to mapping the Paddock Wood storage area (discussed further in Section 7).

Initial flood levels used for the Paddock Wood Storage area are provided in Table 5-4 below.

<table>
<thead>
<tr>
<th>Return Period Event</th>
<th>Flood Level (m AOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 year</td>
<td>14.950</td>
</tr>
<tr>
<td>100 year</td>
<td>15.168</td>
</tr>
<tr>
<td>100 year + climate change</td>
<td>15.325</td>
</tr>
<tr>
<td>1,000 year</td>
<td>15.706</td>
</tr>
</tbody>
</table>

### Downstream Boundaries

The downstream boundary used was the 100 year return period level for the River Teise of 13.63m AOD as agreed with the Environment Agency. This was conservatively modelled as a constant level to ensure the peak flow through the InfoWorks RS model would coincide with the 100 year return period level for the River Teise.

### 5.5 Urban Paddock Wood (Model 4)

This is an urban drainage network model covering approximately 1.5 km² of Paddock Wood Town. The review of drainage records in MapInfo format indicates that both surface water and foul water systems have been built for the town. The records show approximately 1300 surface water drains and 1000 foul water sewers. In this study, the surface water network data were extracted for the mode build purpose.

There exist historical flooding records in the Paddock Town. It indicates that south and east of the town, where the ground levels are about 15-17 mAOD, are most likely subject to flooding.

To estimate surface runoff to the drainage network system, 433 sub-catchments have been delineated. The delineation of sub-catchment generally follows the following considerations and available data:
• layout of drainage networks
• digital topographical maps, that show the outlines of buildings, roads and open spaces etc
• LiDAR data
• satellite maps (ref Google Maps)

The open space areas or pervious areas, for example the grasslands, are excluded from the sub-catchment delineation and surface runoff modelling. The Wallingford’s Fixed Runoff Volume module has been employed for the surface runoff estimation. Storm events and design rainfall profiles were estimated separately by using FH methods and then imported into InfoWorks CS for application.

Some assumptions have been made in the model build, including
• all duplicate nodes were removed
• for nodes missing ground levels the LiDAR data were applied
• for links missing upstream and/or downstream invert levels, a gradient of 2 in 1000 was assumed
• initial loss value for impervious area is 0.00011m for the fixed runoff volume module of Wallingford
• The flood water on the catchment surface is retained in the storage volume defined by the flood levels and areas specified. The flood water returns to the drainage system as the levels drop.

Model Structure

The finalised Model 4 consisted of the following elements:
• 433 sub-catchments
• 636 manholes
• 634 links (drainage pipes)
• 17 outfalls

Roughness Coefficients

The Colebrook-White roughness coefficient Ks has been used for InfoWorks CS models. The following defaults have been adopted in Model 5.

Table 5-5

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>CW ‘Ks’ (MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom of culvert</td>
<td>3</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>3</td>
</tr>
</tbody>
</table>

Downstream Boundaries

The downstream water level boundaries at outfalls of drainage networks were extracted from predicted water levels in InfoWorks RS models. As a conservative approach the maximum water levels throughout modelling events of different return periods in InfoWorks RS models have been adopted as constant downstream water level boundaries for the InfoWorks CS Models.
5.6 Calibration

In order to assess the accuracy of the model, it is necessary to calibrate the model against historical flood events. Unfortunately the only calibration data available for this model has been anecdotal evidence, which indicates areas susceptible to flooding but is not related to either flood levels or probability, and sewer flooding records, which again do not record depth or relate to probability. The data all relates to the urban sewered part of the catchment.

No calibration has been possible for the open channel network. However, the coefficients used all lie within the range commonly found when calibration has been possible on similar watercourses.

Whilst the historic flooding data for the urban area is not ideal, it has been used to calibrate the extent of flooding from sewers. The methodology used to map areas of sewer flooding is described in section 7.3. For there to be either a record of sewer flooding or anecdotal evidence it is likely that flooding has occurred in the last 10 to 20, possibly more than once. Thus all the areas known to experience flooding have been assumed to flood in the 1 in 20 year event.

Historical sewer flooding incidents were overlaid on the 1 in 20 flooding extents to confirm the correlation between the modelling and the historical flooding and to ensure the extent of flooding from individual manholes was reasonable. Figure 3 shows the calibration based on the 1 in 20 year flood event.
6 Design Runs

This section summarises the flood extents from the hydraulic model runs for the 20 year, 100 year, 100 year plus allowances for climate change, and the 1,000 year events. Full tabulated model results for all locations are presented in Appendix D. Maps showing model node locations are included as figures 4 and 5.

All design runs were performed using as detailed in the methodology outlined in Section 5 with all the InfoWorks RS and InfoWorks CS default settings employed.

6.1 20 year

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage area between Tudeley Brook and Gravelly Way. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood.

Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain.

In the urban areas of Paddock Wood, the majority of storm water sewers were found seriously surcharged except for the area south-east of the town. Flooding (overflows from manholes) was also predicted along Maidstone Road, Ribston Gardens Street, Woodlands Street, The Cedars Street, Church Road and Warrington Road. These findings are in a good agreement with historical flooding records. The most severe flooding, however, was predicted along Commercial Road and Kiln Way.

6.2 100 year

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage between Tudeley Brook and Gravelly Way Stream. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available. Further flooding from the Tudeley Brook is observed to occur to the north of the railway and to the west of Tudeley Brook.

Flooding is also predicted to occur to the south of the railway in the west of Paddock Wood with the Gravelly Way Stream being the contributor of this flooding.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood including the Waitrose supermarket car park.

Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain.

Minor out of bank flooding is also predicted downstream and upstream of Church Road from the East Rhoden.
The flooding locations in the urban areas under 100-year flood event are similar to that of 20-year flood event but the situation is aggravated as a result of longer inundation time. The modelling results show that the averaged inundation time may be 1.5 times of that under 20-year flood event. In the south-east part of town, some of storm water sewers are found surcharged as well (these sewers are not surcharged under 20-year flood event).

6.3 100 year plus climate change

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage between Tudeley Brook and Gravelly Way Stream. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available. Further flooding from the Tudeley Brook is observed to occur to the north of the railway and to the west of Tudeley Brook.

Flooding is also predicted to occur to the south of the railway in the west of Paddock Wood with the Gravelly Way Stream being the contributor of this flooding.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood including the Waitrose supermarket carpark. The extent of flooding in this area is extensive.

Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain.

Out of bank flooding is also predicted downstream and upstream of Church Road from the East Rhoden.

The flooding locations in the urban areas under 100-year plus climate change event are similar to that of 100-year flood event but the situation is worse as a result of longer inundation time. The modelling results show that the averaged inundation time may be 2 times of that under 20-year flood event. In the south-east part of town, nearly all storm water sewers are found surcharged.

6.4 1,000 year

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage between Tudeley Brook and Gravelly Way Stream. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available. Further flooding from the Tudeley Brook is observed to occur to the north of the railway and to the west of Tudeley Brook.

Flooding is also predicted to occur to the south of the railway in the west of Paddock Wood with the Gravelly Way Stream being the contributor of this flooding.

Further out of bank flows are observed to the south of Badsell Road from Tudeley Brook.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood including the Waitrose supermarket car park. The extent of flooding in this area is extensive.
Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain. Out of bank flooding is also predicted downstream and upstream of Church Road from the East Rhoden. The flooding locations in the urban areas under 1000-year event are similar to that of 100-year flood event but the situation is worst as a result of longer inundation time. The modelling results show that the averaged inundation time may be 3 times of that under 20-year flood event. In the south-east part of town, nearly all storm water sewers are found surcharged and some are subject to flooding.
7 Flood Zone Mapping

7.1 Flood Zones

The Environment Agency defines flood zones for areas at risk of flooding. The flood zones are based on the return periods identified in Planning Policy Statement 25: Development and Flood Risk (CLG, 2006):

- **Flood Zone 2** – Area at risk of flooding during the 1000 year flood excluding the presence/effect of flood defences
- **Flood Zone 3a** - Area at risk of flooding during the 100 year flood excluding the presence/effect of flood defences
- **Flood Zone 3b** - Area at risk of flooding during the 25 year flood including the effect of flood defences

There are no flood defence defined by the Environment Agency within the study area.

7.2 Mapping Methodology – InfoWorks RS

Flood Inundation outlines have been mapped for each of the modelled scenarios. The following methodology has been applied within the MapInfo (version 9.0) software, using the Vertical Mapper extension.

**Digital Terrain Model**

A Digital Terrain Model (DTM) was built for the site, based on LiDAR that was provided by the Environment Agency in ASCII format (2m cell size), which can be directly imported into MapInfo. The LiDAR was used in the InfoWorks model for producing the inundation outlines.

**Import of Modelling Results**

InfoWorks exports the modelled inundation outline to a MIF file, a MapInfo Interchange Format. This can be directly imported and overlaid onto the LiDAR or OS Mapping.

**Manual Inspection and Adjustments**

Each of the flood inundation outlines was visually reviewed and manual adjustments made by either discounting the hydraulically disconnected areas or connecting flooded areas that do not appear to connect, based on the survey, LiDAR information and field observations on flood mechanisms and pathways.

7.3 Mapping Methodology – InfoWorks CS

The node locations and surcharged volumes were extracted from Infoworks CS to a CSV file, with the Node Identifier, Easting, Northing and Surcharged Volumes as columns. The CSV file was directly imported into MapInfo, and points created using the Easting and Northing columns as the X and Y, projected in the British National Grid coordinate system.
Using the DTM (LiDAR), a grid representing the slope of the terrain was created using Vertical Mapper. The Node Locations were split into 2 different files, one for nodes that do not flood, and the other for flooded nodes. A point inspection was carried out for the flooded nodes, using the Slope grid. The result is an additional column in the attribute table of the nodes that contains the percentage slope of the underlying slope grid at each node location.

The flooded nodes, with associated attributes of surcharged volume and percentage slope were exported to Excel to calculate buffer areas for the sewer flooding.

Initially a buffer area was calculated for each node, based on a volume range. The ranges used were:

- 2.5 – 250 m³
- 251 – 500 m³
- 501 – 750 m³
- 751 – 1000 m³
- > 1000

The buffer area was calculated using the upper limit of the range, and assuming a depth of 0.1 m at the manhole. E.g. Area of Buffer = 250 x 0.1. The radius of the buffer was then worked out (Buffer radius = \( \sqrt{\frac{\text{Area}}{\pi}} \)).

The buffer radius was decreased by a percentage based on the slope of the terrain at the manhole. This was calculated using the following percentage decreases:

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Once a final buffer radius was calculated, the table was then imported back into MapInfo, and a buffer drawn around each manhole based on that radius. The buffer areas were merged together to form the relative sewer flooding extent.
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Figure 3: Sewer Flooding Calibration
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Appendix B – Flood Flow Estimates
Appendix C – Predicted Flood Levels
Appendix D – Model Files
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Appendix D – Model File Index
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Revision Schedule

Paddock Wood Strategic Flood Modelling – Modelling Report
Project Number: D115701/PMOD
September 2009

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1 Introduction

1.1 Commission

Scott Wilson was commissioned by Tunbridge Wells Borough Council (TWBC) in March 2007 to assist in the production of their Strategic Flood Risk Assessment (SFRA). Scott Wilson completed the Level 1 SFRA in November 2007 (Scott Wilson, November 2007). Prior to completion of the Level 1 SFRA TWBC had already identified the possibility of accommodating growth in and around the town of Paddock Wood.

The Environment Agency’s Flood Map and liaison with local Environment Agency officers (in the spring of 2007) identified parts of Paddock Wood and the surrounding area to be at flood risk and that information on flood risk held at that time would need to be refined for use in strategic planning.

1.2 Background

This modelling report describes the methodology and results for a hydraulic modelling exercise completed to investigate flooding in and around the Paddock Wood area. Results generated by this modelling report will be carried forward for use in a Level 2 SFRA to refine the current understanding of flood risk in and around Paddock Wood, suitable to inform strategic land use planning.

1.3 Previous Studies

With the exception of a site-specific Flood Risk Assessment at Church Farm in Paddock Wood (Coles Easdon, 2004); a Flood Risk Drainage Study of the land to the west of Maidstone (Babtie Group (2003); and Environment Agency’s national generalised mapping or strategic modelling projects for the River Medway (Mott MacDonald, 2003) and Beult, Bourne and Teise (Mott MacDonald, 2005), there have been no other studies undertaken to investigate the flood risk to Paddock Wood directly.

1.4 Aim and Objectives of Strategic Hydraulic Modelling

The aim of this modelling study is to refine the current level of information regarding flooding in and around Paddock Wood.

It is not the intention of this hydraulic modelling exercise to identify precisely where and to what magnitude flooding will occur. Specifically this modelling exercise is designed to provide sufficient information to enable TWBC to qualitatively identify favoured locations for development through the avoidance of flood risk. For specific development proposals, where flood risk may be an issue (identified through this strategic assessment), detailed flood modelling assessments will be required as part of a site specific flood risk assessment.

To achieve the aim of the study the following objectives were met:

- Estimation of flood flows for the 5%, 1% 1% plus the effects of climate change and 0.1% annual probability floods for the Tudeley Brook, Gravelly Way Stream, West Rhoden and East Rhoden watercourses draining through/near to the town of Paddock Wood;
- Development of 1-Dimensional hydraulic models of the four watercourses as they drain through Paddock Wood using available topographic data;
• Develop a 1-Dimensional model of the stormwater drainage system through Paddock Wood using available sewer network plans from Southern Water; and,

• Map the extent of the 5%, 1%, 1% plus the effects of climate change and 0.1% annual probability floods based on the combination of hydrology estimates and 1-Dimensional models.

1.5 Report Synopsis

Section 2 of this report introduces the study area and defines the extent of the hydraulic model. Section 3 introduces the data available for the 1-Dimensional model build, whilst section 4 presents the boundary conditions (flow estimates) used in the hydraulic model runs. Details of the hydraulic modelling in terms of models runs and calibration are presented in Section 5 with the results of model design runs presented in Section 6. The methodology used for the mapping of the hydraulic model results is presented in Section 7, with the conclusions and recommendations from the modelling exercise set out in Section 8.
2 Study Area

For the purpose of this strategic modelling exercise the study area is defined as the town of Paddock Wood and sufficient surrounding land to adequately characterise the primary watercourses and their associated floodplains. The extent of the hydraulic model and therefore study area is presented in Figure 1.

2.1 Paddock Wood

Paddock Wood lies to the north-east of Royal Tunbridge Wells in Kent at National Grid Reference (NGR) TQ 667 451 (Figure 1). The town/ward is home to approximately 8,300 people.

The town is largely comprised of two parts bisected by an embanked railway trending east to west. The southern part of the town is predominately residential with the light industrial, commercial and retail uses associated with a town centre. To the north of the railway Paddock Wood is characterised by larger industrial warehousing.

The town is founded on largely flat and level ground albeit with a slight incline towards the south, which increases markedly south of the town. To the north of the railway the ground is again largely flat associated with the floodplains of the River Medway, and Teise.

2.2 Local Watercourses

River Medway

The River Medway is the largest river catchment within the Environment Agency’s Southern Region. Its headwaters are found in the North Downs and the Weald. It flows along the western boundary of the study area for approximately 4km, and along the northern boundary for approximately 1.2km. The River Medway’s main tributaries that flow through or within the vicinity of the study area include the River Teise, River Beult, Alder Stream, Tudeley Brook and the Summerhill Stream. These all rise in the borough of Tunbridge Wells and have been sources of historic fluvial flooding.

The River Medway is a responsive catchment. The catchment is predominantly rural, with approximately 37% of the catchment being naturally impervious. The River Medway is a statutory navigation channel, with locks and weirs controlling flows along its course.

The Leigh Barrier is a strategic flood defence scheme on the River Medway approximately 8 miles upstream of Paddock Wood. The barrier is designed to provide flood relief to the town of Tonbridge and is considered to provide no benefit to Paddock Wood.

River Teise

The River Teise rises to the south east of Royal Tunbridge Wells and flows northeast to the River Medway. The catchment is predominantly rural, passing through the village of Lamberhurst in the upper reaches. The catchment is located on the Wealden Series, composed of sandstones, siltstones and clays (Hastings Beds). The catchment is naturally impervious across 28% of its area. The headwaters of the catchment develop on local aquifers and the catchment is very responsive to rainfall variations.
Tudeley Brook

Tudeley Brook originates to the south-west of Paddock Wood, near the small village of Henwood Green. It flows in a northerly direction to the west of Paddock Wood. It is culverted beneath the railway and continues to flow in a northerly direction eventually discharging to the River Medway.

Within the model extents, the channel is typically trapezoidal in shape with bed widths of between 2m and 4m and channel depths of between 1m and 2m.

Gravelly Way Stream

Gravelly Way Stream flows along the western boundary of Paddock Wood. It originates in the hills to the south of Paddock Wood and flows in a northerly direction. It is culverted beneath the railway and continues to flow in a northerly direction through the industrial part of Paddock Wood before discharging to the River Medway.

A culverted overflow connects Gravelly Way Stream with Tudeley Brook to the south of the railway. A number of storm sewer outfalls from Paddock Wood discharge to the stream.

In the upper extents of the model the Gravelly Way Stream has a triangular shaped cross-section profile which transform into a trapezoidal channel as the longitudinal gradient of the stream decreases. Typical channel depths are between 1m and 1.5m.

East Rhoden

The East Rhoden originates to the south-east of Paddock Wood. It flows in a northerly direction to the east of Paddock Wood. It originates in the hills to the south of Paddock Wood flowing through natural channels upstream of Church Road. Downstream of Church Road the channel is maintained by the Lower Medway Internal Drainage Board as a regular trapezoidal channel. The East Rhoden is culverted beneath the railway and flows north across the floodplain of the River Teise before converging with the Main Drain at NGR TQ 680463.

Immediately to the north of Church Road, a minor tributary joins the East Rhoden. This tributary has two branches to the south of Church Road that are essentially field ditches.

West Rhoden

The West Rhoden originates to the east of Paddock Wood and receives a large proportion of its inflow from the storm sewer networks of newer developments in the south of Paddock Wood, including discharge from attenuation ponds. As with the East Rhoden a short section of the West Rhoden upstream of the railway is also maintained by the Lower Medway IDB.

After issuing from the culvert beneath the railway the West Rhoden flows north, converging with the Main Drain north of Lucks Lane at NGR TQ678460. The combined watercourses then flow north to converge with the River Teise at NGR TQ 685475.

Main Drain/Urban Drainage

The head of the Main Drain is located in the hills to the south of Paddock Wood. It flows in a northerly direction through farmland before reaching the southern boundary of Paddock Wood. Through Paddock Wood, the Main Drain is predominantly culverted / piped with some minor open channel sections. An open channel section exists immediately south of the railway to the east of the Waitrose supermarket car park. The Main Drain is then culverted beneath the railway and becomes open channel for approximately 1.1km before converging with the West Rhoden.
A large proportion of Paddock Wood drains to the Main Drain via the stormwater sewer system. The public storm sewer system throughout Paddock Wood is maintained by Southern Water. The system comprises a conventional gravity system of standard pit / manhole / pipe network. There are a number of storm sewer outfalls discharging to the Gravelly Way Stream, Main Drain, and the West Rhoden. Drainage of recent housing developments is served by attenuation systems.

### 2.3 Flooding History

Paddock Wood is noted locally for its susceptibility to flood events. Flood events in the town have occurred due to surcharging of the storm water sewer system and out of bank flow from local watercourses. The presence of the embanked railway across the natural drainage paths also exacerbates flooding as catchment flows are routed through culverts beneath the railway.

Blockage of these culverts is likely to have exacerbated flooding to local properties from Gravelly Way Stream and Tudeley Brook and may have been the cause of at least one flood event. In addition surcharged drainage outfalls on Gravelly Way Stream cause some local manhole covers lifting, resulting in local flooding. Streets known to have experienced flooding include:

- Eldon Road
- Ribston Gardens
- Laxton Gardens, and
- Mercers Close (known to have flooded from over bank flow from Gravelly Way Stream)

Flooding from the storm water drainage system in January 2008 was reported to have occurred on Maidstone Road between Old Kent Road and Allington Gardens. Whilst flooding in 1996 also affected the Railtrack car park and the John Brant’s pub.

Additional data provided by the Environment Agency (Appendix A) for the Level 1 SFRA identified the following incidents of flooding in and around Paddock Wood:

- Flooding of roads and properties, Paddock Wood south of the railway line, Allington Road, Woodlands area (recorded 16/09/1998);
- Developing areas flood, Paddock Wood, west (recorded 16/09/1998); and,
- Flooding, Badsell Road, Capel (no date information provided with this record).

Photographic evidence of flooding in Paddock Wood has also been provided by the Environment Agency for flooding in October 2000 (Appendix A). The presented photographs indicate flooding during this event was primarily in the north of the town.
3  Topographic Survey

Various sources of topographic data were used to generate the 1-Dimensional models of the open channels and stormwater sewer systems. This section introduces the data used and highlights any issues associated with its use. Figure 2 illustrates the extent and source of available topographic survey. All survey used in the development of the hydraulic models is provided on a CD-ROM in Appendix B.

3.1  Floodplain Survey

**LiDAR**

The Environment Agency has provided Light Detection and Ranging (LiDAR) data for the study area. LiDAR is an airborne mapping technique which uses a laser to measure the distance between the aircraft and the ground. The data varies in accuracy depending on the nature of the terrain being surveyed such as in woodlands, complex urban areas and near lakes, the accuracy lowering due to the limitations in the technique. However, LiDAR collected since 2000 is generally recognised to be +/- 150mm in accuracy.

LiDAR data is not available for the whole of the study area, with coverage predominately available for the built areas of Paddock Wood and land to the east and west of the settlement.

The LiDAR was used to extend channel survey sections beyond their surveyed extents and to determine floodplain areas and storage volumes.

**Photogrammetry Data**

The Environment Agency also provided photogrammetry data. This data has more widespread coverage than the LiDAR data however is only available with an accuracy of +/- 1000mm with levels recorded on a 5m grid.

Whilst the data can be used for contouring the relatively flat floodplain of the River Medway the coarse resolution of the data makes integration with the better quality LiDAR data (covering the majority of the study area) impractical. This is particularly the case when attempting to resolve the extent and storage available in floodplains.

3.2  Channel Survey

In addition to topographic data for the floodplains of the hydraulic model build also required detailed topographic data for the river/watercourse channels. The hydraulic models have been built based on topographic survey provided primarily by field surveys, supplemented with ground imagery in the form of LiDAR. The sources of survey used in the development of the 1-Dimensional hydraulic models of the open channels are summarised below.

**Capital Surveys Ltd (March – April 2005) - Tudeley Brook**

As part of an Environment Agency programme to model the Tudeley Brook the Environment Agency’s Southern Region commissioned a topographic survey of the brook in March and April 2005. Due to inadequate funding the Environment Agency were unable to complete their modelling of the Tudeley Brook but were able to provide their topographic survey for use in this strategic modelling exercise.

The survey was undertaken by Capital Surveys between the 30/03/05 and the 26/04/05. A total of 64 channel cross sections were surveyed on Tudeley Brook from upstream of Paddock Wood at NGR
Lower Medway IDB Records - East Rhoden and Main Drain

The Lower Medway IDB holds survey records for watercourses both that it currently maintains and that it used to maintain. From a review of their records, survey from the 1930s of the Main Drain and the East Rhoden downstream (north) of the railway was identified.

The survey used the now redundant Liverpool Ordnance Datum and recorded distances in imperial units of inches, feet, and chains.

Through discussions with the Environment Agency it was agreed that as the IDB channels are maintained/dredged, their form is unlikely to have significantly changed from the survey drawings, consequently the data would be suitable for use in developing the hydraulic models.

Prior to use in hydraulic modelling this data was converted to metric units and elevations corrected to tie in with all other available survey data (recorded in metres above Ordnance Datum Newlyn). Figure 2 illustrates the extent of the topographic survey provided by the Lower Medway IDB.

BW Surveying - East Rhoden, West Rhoden, Main Drain, and Gravelly Way Stream (2006 and 2008)

Topographic data for the East and West Rhoden was also obtained from RPS Group Ltd. In 2006, RPS Group Ltd commissioned BW Surveying to undertake a cross-sectional survey of the East Rhoden and West Rhoden between Church Road and the railway on behalf of Network Rail. Network Rail permitted the release of this survey for the use of this project. The survey recorded cross-sections at regular intervals and included all structures. A total of 33 cross sections and 8 structures were provided. Figure 2 illustrates the coverage of the survey. Detail of the survey is included on the CD-ROM in Appendix B.

Following review of the survey data made available by the Environment Agency, the Lower Medway IDB and the RPS Group Survey, gaps were identified in the survey necessary for development of the hydraulic models.

Therefore for the purposes of this modelling study further cross-section and structure details were required on the East Rhoden and West Rhoden to supplement the existing survey. In January 2008, Scott Wilson commissioned BW Surveying to undertake a cross-sectional survey of:

- the East Rhoden upstream of Church Road (11 cross sections and 3 structures);
- the West Rhoden downstream of the railway (12 cross sections and 8 structures);
- the Main Drain upstream of the railway (5 cross sections and 7 structures); and
- all of Gravelly Way Stream within the study area (39 cross sections and 14 structures).

All topographic survey for open channels and associated structures collected through this modelling exercise are included in a digital format on a CD-ROM in Appendix B.

3.3 Stormwater Sewer Records

Survey data for the stormwater sewer system was obtained from Southern Water in a digital format. The survey consists of the public sewer record owned/maintained by Southern Water. Coverage of the survey is illustrated in Figure 2, digital records are provided on the CD-ROM in Appendix B.
4 Hydraulic Model Boundary Conditions

The 1-dimensional hydraulic models for each of the watercourses and storm water sewer system, require the specification of upstream and downstream boundary conditions.

Early discussions with the Environment Agency identified that there were no hydrology estimates for the catchments and no ‘local’ analogue sites for data transfer. In addition, the catchments are not gauged and neither are any other local tributaries of the Medway or Teise.

Therefore for the purpose of this model assessment the upstream boundary conditions for open watercourses were based on flow hydrographs estimated using the techniques described in the Flood Estimation Handbook (CEH, 1999) and the Revitalised Flood Hydrograph (ReFH) Method.

Downstream boundaries for the models were determined from a variety of sources including existing Environment Agency models of the River Medway and Teise or in the case of the storm water sewer model, iteratively through interrogation of the relevant 1-Dimensional models developed for this assessment.

4.1 Upstream Boundaries

Upstream boundaries for Tudeley Brook, Gravelly Way Stream, West Rhoden and the East Rhoden were derived using a combination of the statistical method described in the Flood Estimation Handbook and the ReFH method.

The upstream boundary condition for the open channel section of the Main Drain north of the railway was determined from a 1-Dimensional hydraulic model of the storm water sewer system through Paddock Wood.

Overview of the FEH Statistical Method

The Flood Estimation Handbook statistical method is an industry accepted method. The technique uses an index flood, QMED (the median annual flood), and applies growth factors (derived from a pool of hydrologically similar gauged catchments) to obtain the flow/return period relationship.

For ungauged catchments such as Tudeley Brook, Gravelly Way Stream, West Rhoden and the East Rhoden, the recommended method of determining the index flood is to calculate QMED from the catchment descriptors obtained from the FEH CD-ROM v1.0. During the project the FEH version 2.0 was released a comparison of the difference was undertaken and found to be negligible. The derived QMED is then adjusted by data transfer, using data from hydrologically similar (donor or analogue) gauged sites.

A pool of hydrologically similar gauged stations was generated (using the HiFlows database v1.1) to accumulate a combined length of record of five times the target flood. Therefore, to obtain the 100 year flood flow a combined record length of 500 years is required. The pooled stations are reviewed for their suitability (similarity to the subject site) and used to derive growth factors for a range of flood return periods. The adjusted QMED is then multiplied by the growth factor to obtain the peak flood flow for a given return period flood.

Overview of the ReFH Method

The ReFH Model was released in 2006. The ReFH method is considered an improvement on the Rainfall Runoff Model presented in FEH and therefore supersedes the FEH method. It enables a more direct and transparent description of flood-generating mechanisms and introduces the concept of seasonal variation in soil moisture content, design rainfall and baseflow.
Both soil moisture and rainfall are specified on a seasonal basis depending on the degree of urbanisation of the catchment under consideration (summer conditions for urbanised catchments and winter conditions for rural catchments).

Hydrographs are determined for each return period using the catchment descriptors (from the FEH CD-ROM) and importing them into the ReFH spreadsheet v1.3 produced by CEH Wallingford (CEH, 2005). Suitable time steps are considered (1 hour intervals) with durations set to the recommended default value. All models were run as a winter simulation as recommended and hydrographs were derived for each scenario.

Using the ReFH Method, peak flows can be determined from the generated design flood hydrographs.

**Methodology**

Peak flood flows were derived for each watercourse using the statistical method and compared to peak flood flows derived using the ReFH method.

For each of the watercourses, the ReFH method produced the larger flows and therefore flows from this method were adopted throughout the models. The calculation sheets for each of the watercourses are presented in Appendix C.

**Climate Change Estimates**

Estimates of peak flood flow accounting for the effects of climate change have been derived in accordance with guidance presented in Planning Policy Statement 25: Development and Flood Risk (CLG, December 2006). Annex B of PPS25 indicates that estimated peak flood flows should be increased by 20% to account for the effects of climate change up to 2115.

**Tudeley Brook**

Peak catchment flows on Tudeley Brook were calculated for a point immediately downstream of the railway line (NGR TQ 66500 46100). Appendix C presents the calculation sheets for Tudeley Brook. Table 4-1 presents a summary of the peak flows derived through the flow estimation process.

<table>
<thead>
<tr>
<th>ANNUAL PROBABILITY FLOOD</th>
<th>FEH STATISTICAL (M³/SEC)</th>
<th>ReFH (M³/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>7.3</td>
<td>4.2</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>9.7</td>
<td>6.2</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>11.7</td>
<td>7.4</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>13.6</td>
<td>11.8</td>
</tr>
</tbody>
</table>

The summary of flows clearly illustrates the larger (more conservative) flows are derived from the FEH statistical method. Consequently the FEH statistical derived flows were carried forward for use in the hydraulic model of Tudeley Brook.

Guidance indicates the statistical method should not be used to estimate flows greater than five times the pooled gauge record (i.e. the method is unsuitable for estimation of the 0.1% annual probability event). However comparison of the 0.1% ReFH flood flow to the 1% plus climate change statistical flood flow shows negligible difference. Therefore despite the uncertainty associated with the statistical 0.1% annual probability flood flow it has been carried forward for use in hydraulic modelling as a conservative estimate.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.
Gravelly Way Stream

Peak catchment flows on Gravelly Way Stream were calculated for a point downstream of the railway line, south of the A228 road (NGR TQ 68850 46250). Appendix C presents the calculation sheets for Gravelly Way Stream. Table 4.2 presents a summary of the peak flows derived through the flow estimation process.

Table 4.2: Gravelly Way Stream Peak Flow Estimates

<table>
<thead>
<tr>
<th>Annual Probability Flood</th>
<th>FEH Statistical (m^3/sec)</th>
<th>ReFH (m^3/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>0.955</td>
<td>0.7</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>1.276</td>
<td>1.1</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>1.531</td>
<td>1.4</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>-</td>
<td>2.7</td>
</tr>
</tbody>
</table>

The summary of flows clearly illustrates the larger (more conservative) flows are derived from the FEH statistical method for the 5%, 1% and 1% plus the effects of climate change. Consequently the FEH statistical derived flows for these return periods were carried forward for use in the hydraulic model of Gravelly Way Stream. In the case of the 0.1% annual probability flood only the ReFH method is considered to give a reasonable estimate for use in hydraulic modelling.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.

The Gravelly Way Stream also receives inflows from a number of storm sewer outfalls discharging along the length of Gravelly Way Stream between Badsell Road and the railway. To account for this contribution the outfall hydrographs generated by the 1-Dimensional model of the Paddock Wood stormwater sewer system have been inputted into the 1-Dimensional model of Gravelly Way Stream as lateral point inflows. The urban nature of Paddock Wood results in a quicker runoff response than the wider rural catchment of Gravelly Way Stream. As a consequence the timing of the flood peaks from the stormwater sewer and the wider Gravelly Way Stream catchment are not coincident. Therefore the peak discharges entering the Gravelly Way Stream from Paddock Wood occur before the peak in the fluvial Gravelly Way Stream hydrograph occurs.

West Rhoden

Peak catchment flows on the West Rhoden were calculated for a point downstream of the railway line (NGR TQ 68050 45750). Appendix C presents the calculation sheets for the West Rhoden. Table 4.3 presents a summary of the peak flows derived through the flow estimation process.

Table 4.3: West Rhoden Peak Flow Estimates

<table>
<thead>
<tr>
<th>Annual Probability Flood</th>
<th>FEH Statistical (m^3/sec)</th>
<th>ReFH (m^3/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>0.51</td>
<td>0.4</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>0.672</td>
<td>0.6</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>0.806</td>
<td>0.7</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>-</td>
<td>1.3</td>
</tr>
</tbody>
</table>
The summary of flows clearly illustrates the larger (more conservative) flows are derived from the FEH statistical method for the 5%, 1% and 1% plus the effects of climate change. Consequently the FEH statistical derived flows for these return periods were carried forward for use in the hydraulic model of the West Rhoden. In the case of the 0.1% annual probability flood only the ReFH method is considered to give a reasonable estimate for use in hydraulic modelling.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.

**East Rhoden**

Peak catchment flows on the East Rhoden were calculated for a point downstream of the railway line (NGR TQ 68150 45750). Appendix C presents the calculation sheets for the East Rhoden. Table 4-4 presents a summary of the peak flows derived through the flow estimation process.

<table>
<thead>
<tr>
<th>ANNUAL PROBABILITY FLOOD</th>
<th>FEH STATISTICAL (M³/SEC)</th>
<th>REFH (M³/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>1.894</td>
<td>1.8</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>2.484</td>
<td>2.6</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>2.980</td>
<td>3.12</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>

The summary of flows clearly illustrates that the FEH statistical derived flows are comparable with the ReFH derived flows. The FEH statistical derived flows for the 5%, 1% and 1% plus the effects of climate change were carried forward for use in the hydraulic model of the East Rhoden. In the case of the 0.1% annual probability flood only the ReFH method is considered to give a reasonable estimate for use in hydraulic modelling.

In order to generate flood hydrographs for use in the hydraulic model the ReFH hydrographs were scaled for the peak flows derived from the FEH Statistical Method.

Ordnance Survey mapping of the East Rhoden catchment indicates a confluence between a tributary of the East Rhoden and the main East Rhoden exists immediately north of Church Road. The tributary has a significantly smaller catchment than the main channel. Unfortunately, the FEH CD ROM does not recognise the tributary, instead considering its catchment to be part of the East Rhoden. Therefore flows for the East Rhoden have been apportioned between the tributary and the main channel based on their respective catchment areas (Table 4-5).

<table>
<thead>
<tr>
<th>ANNUAL PROBABILITY FLOOD</th>
<th>EAST RHODEN (M³/SEC)</th>
<th>TRIBUTARY OF THE EAST RHODEN (M³/SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>1.773</td>
<td>0.197</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>2.293</td>
<td>0.255</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>2.751</td>
<td>0.306</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>4.509</td>
<td>0.501</td>
</tr>
</tbody>
</table>
Storm Water Sewer System and Main Drain

The review of existing drainage network data for Paddock Wood Town shows that both surface water and foul systems were built for the town. The surface water network data were extracted from the drainage records in MapInfo format for the model build. It is found that surface water collected from Paddock Wood urban areas are discharged into Gravelley Way Stream, Main Drain and West Rhodden Stream respectively. To estimate the surface runoff to the storm water sewer system and accordingly to the downstream open watercourses, totally 433 sub-catchments have been delineated.

The surface runoff from each sub-catchment is considered as the upstream inflow boundary to the storm water sewer system. This was estimated by using Wallingford’s Fixed Runoff Volume module embedded in InfoWorks CS by assuming design rainfall profiles for return periods of 1 in 20 years, 1 in 100 years, and 1 in 1000 years, and plus the climate change as well.

4.2 Downstream Boundaries

Downstream boundaries for all the watercourses are still water levels (i.e. downstream water level fixed throughout model run) based on outputs from Environment Agency strategic models of the River Medway and River Teise.

To account for the difference in catchment response times between the watercourses focused on in this study and those of the Rivers Medway and Teise, it was initially agreed with the Environment Agency that a return period relationship should be used. Table 4-6 illustrates the relationship suggested to determine the downstream boundary conditions for the modelled watercourses.

Initial discussions with the Environment Agency regarding the downstream boundary conditions to be used in the hydraulic modelling led to the agreement that a return period relationship between the modelled watercourses and the larger receiving watercourses of the River Medway and Teise would be appropriate as presented in Table 4-6.

<table>
<thead>
<tr>
<th>RETURN PERIOD EVENT TO BE MODELLLED ON THE PADDOCK WOOD WATERCOURSES</th>
<th>CORRESPONDING ANNUAL PROBABILITY FLOOD EVENT TO BE USED AS THE DOWNSTREAM BOUNDARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% (Flood Zone 3b)</td>
<td>10% (River Medway)</td>
</tr>
<tr>
<td>1% (Flood Zone 3a)</td>
<td>2% (River Medway)</td>
</tr>
<tr>
<td>1% + Climate change (Flood Zone 3a)</td>
<td>2% (River Medway)</td>
</tr>
<tr>
<td>0.1% (Flood Zone 2)</td>
<td>Extrapolated from available flood levels (River Medway)</td>
</tr>
<tr>
<td></td>
<td>Extrapolated from available flood levels (River Teise)</td>
</tr>
</tbody>
</table>

Unfortunately extensive model instabilities led to the need to abandon this approach and the selection of a constant downstream still water level for all modelled return periods. The downstream boundary conditions are based upon the 1% annual probability model results from Environment Agency strategic models of the Medway and Teise.

In the case of the River Medway the 1% flood level for node point CS111 level was used directly due to the proximity of the model result to the downstream boundary of the watercourses modelled as part of this assessment and the nature of the topography between the two points.
For the River Teise the 1% annual probability flood levels for two node points (T25 and T26; closest to the confluence of the East Rhoden with the River Teise) were extrapolated to the downstream boundary of the East Rhoden hydraulic model.

Table 4-7 presents the downstream boundary conditions used in the hydraulic model runs.

**Table 4-7: Downstream Boundary Conditions**

<table>
<thead>
<tr>
<th>SUBJECT SITE</th>
<th>DOWNSTREAM WATERCOURSE</th>
<th>DOWNSTREAM BOUNDARY LEVEL (M AOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tudeley Brook</td>
<td>River Medway</td>
<td>14.688</td>
</tr>
<tr>
<td>Gravelly Way Stream</td>
<td>River Medway</td>
<td></td>
</tr>
<tr>
<td>Main Drain</td>
<td>West Rhoden</td>
<td>13.63</td>
</tr>
<tr>
<td>West Rhoden</td>
<td>East Rhoden</td>
<td>13.63</td>
</tr>
<tr>
<td>East Rhoden</td>
<td>River Teise</td>
<td>13.63</td>
</tr>
</tbody>
</table>

The one exception to this approach was the selection of the downstream boundary conditions for the InfoWorks CS hydraulic model of the storm water sewer system. Water levels extracted from InfoWorks RS models at the discharging points (outfalls) of InfoWorks CS surface water model were used as the downstream boundary condition.

Some of the lower reaches of the watercourses were truncated as the downstream boundary levels were significantly higher than the floodplains as the models do not run with the lower reaches swamped. This will not affect the flood levels predicted as the flows in the Paddock wood watercourses will be small compared with the storage on the Teise and Medway floodplains.
5 Hydraulic Modelling

5.1 Introduction

The Paddock Wood model extends from south of Badsell and Church Roads to Wagon Lane encompassing Paddock Wood and the five watercourses of Tudeley Brook, Gravelly Way Stream, Main Drain, the West Rhoden, and the East Rhoden and including their respective floodplains. This section includes details of the hydraulic models created.

This section also highlights model stability issues and the steps taken to resolve these instabilities in the interest of progressing the SFRA modelling. The study area included watercourses that were steep in their hinterlands and relatively flat through the floodplains. The steep, narrow nature of the watercourses combined with the unorthodox nature of some of the hydraulic sections led to severe model instabilities and unsuccessful model simulations.

InfoWorks RS (Version 8.5) and InfoWorks CS (Version 8.5) have been employed for the establishment of river hydraulic models for open water courses and drainage network models for urban storm water sewer systems respectively.

Model Program Limitations

InfoWorks RS is a 1-dimensional hydraulic modelling package for open channels that uses channel geometry and hydraulic characteristics, such as roughness, and estimated flood flows to produce flood water levels and flood outlines based on field surveys (channel cross-sections and structures) and LiDAR and photogrammetry (flood plains). The program has the ability to show where water is stored in floodplain however it is limited in that the program is unable to show the flow paths that link the channel spills to the storage areas, hence it being classified as a 1-dimensional model.

InfoWorks CS is an equivalent hydraulic modelling package for sewered networks. It can predict flood levels from surcharged manholes / links based on geometric information the user provides. However it cannot produce flood outlines from that data.

InfoWorks CS and InfoWorks RS cannot be linked together to produce flood outlines, but like all models the outputs from each model (such as flow hydrographs) can be interchanged.

Models

The fluvial modelling was split into three separate models due to software node limitations and stability issues created during model runs. The split between the three models has been arranged so that the watercourses offering the most clearly perceived interactions have been grouped together where possible.

The fourth model is the InfoWorks CS model of Paddock Woods storm sewer system. These are elaborated on further in this section.

5.2 Tudeley Brook and Gravelly Way Stream (Model 1)

Tudeley Brook and Gravelly Way Stream are the two adjacent watercourses to the west of Paddock Wood. Historically, and by a visual inspection of the Environment Agency’s flood mapping, it is clear that there are floodplain links between the two watercourses, especially to the immediate south of the railway. The railway culverts are a known contributor to flood problems in the area as they provide a constricted limitation to flows with the railway preventing spills over the culverts.
Model Structure

The finalised Model 1 consisted of the following elements:

- 2 x ReFH boundary flow hydrographs (1 each for Tudeley Brook and Gravelly Way Stream)
- 8 x InfoWorks CS output flow hydrographs, all on Gravelly Way Stream south of the railway
- 2 x downstream stage boundaries (1 each for Tudeley Brook and Gravelly Way Stream) being the 100 year return period level for the River Medway
- 37 cross-sections
- 143 interpolated cross-sections
- 56 spill units to floodplains
- 8 floodplains/storage areas
- 8 culverts
- 3 bridges

Exclusions to Model Structure

The downstream (northern) extent of Model 1 was cropped to the end of the available LiDAR survey. Severe out of bank flow occurred at the northern end of the study area, caused primarily by a downstream boundary condition with water levels higher than most of the northern topography (discussed further in Section 6). As a result modelling accuracy could only be achieved where the floodplains could not be correctly included in the model. Therefore, model extents were cropped to a suitable position within the LiDAR survey.

A number of unorthodox hydraulic structures are present in the Tudeley Brook and Gravelly Way Stream. Structures that were deemed likely to have limited effect on flood levels whilst adversely affecting model stability were excluded from the model. The major culverts of note omitted are:

**Tudeley Brook**

- Badsell Road culvert crossing.
- Culvert overflow link between Gravelly Way Stream and Tudeley Brook. This culvert would have had limited effect in the model as flood levels modelled in Tudeley Brook are noticeably higher than those of Gravelly Way Stream, therefore no overflow from Gravelly Way Stream to Tudeley Brook would occur. Preventing overflow from Tudeley Brook to Gravelly Way Stream is considered to give a conservative estimate of water levels in Tudeley brook.
- All culvert crossings downstream (north) of the Eastlands Cottages road.

**Gravelly Way Stream**

- Culverts upstream (south) of Badsell Road. These culverts are all minor with no spill overbank threat.
- Culvert north of railway culvert.

Whilst it is accepted that the removal in the model of the overflow link culvert between Gravelly Way Stream and Tudeley Brook does not mimic reality, it can be argued that the culvert is there to function as a flood relief from the Paddock Wood storm sewer system; a scenario that is not worse-case for Tudeley Brook and therefore not modelled in this study.
River Sections

Interpolations are required in hydraulic models where the profile varies significantly between adjacent river sections. In small watercourses, stability impacts caused by variations in river profile sections are exaggerated. These are further exaggerated when the longitudinal profile of the watercourse is steep.

The requirements for interpolated sections can be established in the model run reports where river section variability is identified. During the course of trying to generate stable model simulations, numerous river sections were identified as requiring interpolations with some interpolations required at intervals as low as 5m.

Roughness Coefficients

The roughness coefficient defines the frictional resistance of surfaces to flow. Generally, the effects of friction are most pronounced when the flow is fast. The Manning's number ‘n’ is a coefficient used to quantify describing the roughness.

The following defaults have been adopted in Model 1.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MANNING’S ‘n’</th>
</tr>
</thead>
<tbody>
<tr>
<td>In channel banks</td>
<td>0.045</td>
</tr>
<tr>
<td>Out of channel banks</td>
<td>0.05</td>
</tr>
<tr>
<td>Bottom of culvert</td>
<td>0.011</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Downstream Boundary

The downstream boundary used was the 100 year return period level for the River Medway of 14.7m AOD as agreed with the Environment Agency. This was conservatively modelled as a constant level to ensure the peak flow through the InfoWorks RS model would coincide with the 100 year return period level for the River Medway.

5.3 East Rhoden (Model 2)

Historical records, previous modelling, and a visual inspection of the Environment Agency's flood mapping, identifies that there are floodplain links between the East Rhoden and West Rhoden to the immediate south of the railway. The railway culverts are a known contributor to flood problems in the area as they provide a constricted limitation to flows with the railway preventing spills over the culverts. Furthermore, the West Rhoden is a tributary of the Main Drain which is in turn a tributary of the East Rhoden. Unfortunately, a working stable model with the aforementioned watercourses was unachievable within the desired timeframes so a combined model was abandoned.

Model Structure

The finalised Model 2 consisted of the following elements:

- The East Rhoden with a tributary
- 2 x ReFH boundary flow hydrographs
- 1 downstream stage boundaries being the 100 year return period level for the River Teise
• 30 cross-sections
• 119 interpolated cross-sections
• 55 spill units to floodplains
• 3 floodplains/storage areas
• 4 culverts

**Exclusions to Model Structure**

The downstream extent of Model 2 was cropped to the end of the available LiDAR survey. Severe out of bank flow occurred at the northern end of the study area, caused primarily by a downstream boundary condition with water levels higher than most of the northern topography (discussed further in Section 6). As a result modelling accuracy could only be achieved where the floodplains could not be correctly included in the model. Therefore, model extents were cropped to a suitable position within the LiDAR survey.

Structures recorded within the IDB survey were omitted as these are unlikely to have been maintained. Structures that were deemed likely to have limited effect on flood levels whilst adversely affecting model stability were excluded from the model. The major structures of note to be removed are:

**East Rhoden**

- All IDB recorded structures.

**East Rhoden Tributary**

- Church Road culvert.

**Roughness Coefficients**

The following defaults have been adopted in Model 2.

**Table 5-2 Roughness Coefficients for Model 2**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MANNING’S ‘N’</th>
</tr>
</thead>
<tbody>
<tr>
<td>In channel banks</td>
<td>0.040</td>
</tr>
<tr>
<td>Out of channel banks</td>
<td>0.050</td>
</tr>
<tr>
<td>Bottom of culvert</td>
<td>0.011</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>0.014</td>
</tr>
</tbody>
</table>

**Floodplain Storage Areas**

Floodplain storage areas that were used in Model 2 exist in Paddock Wood between the Main Drain and the West Rhoden, to the east of the Main Drain north of the railway, and to the east and west of the West Rhoden north of the railway. This storage area is shared with Model 3 (see later in this section). Flows spill from the East Rhoden upstream of the railway culvert in a westward direction to the localised low point in the north-east of Paddock Wood.

Other floodplain storage areas used to simulate the East Rhoden model are located to the south and north of Church Road.

**Downstream Boundary**

The downstream boundary used was the 100 year return period level for the River Teise of 13.63m AOD as agreed with the Environment Agency. This was conservatively modelled as a constant level to ensure...
the peak flow through the InfoWorks RS model would coincide with the 70 year return period level for the River Teise.

5.4 West Rhoden and Main Drain (Model 3)

Historical records, previous modelling, and a visual inspection of the Environment Agency’s flood mapping, identifies that there are floodplain links between the West Rhoden and Main Drain, especially to the immediate south of the railway. The railway culverts are a known contributor to flood problems in the area as they provide a constriction to flows with the railway preventing spills (up to the level of the railway). Furthermore, the West Rhoden is a tributary of the Main Drain which is in turn a tributary of the East Rhoden. Unfortunately, a working stable model with the aforementioned watercourses was unachievable so a combined model was abandoned. A working model with the Main Drain and West Rhoden was achievable however.

Model Structure

The finalised Model 2 consisted of the following elements:

- The East Rhoden with a tributary
- 1 ReFH boundary flow hydrograph
- 1 x InfoWorks CS discharge hydrograph
- 1 downstream stage boundaries being the 100 year return period level for the River Teise
- 15 cross-sections
- 40 interpolated cross-sections
- 48 spill units to floodplains
- 4 floodplains/storage areas
- 2 culverts

Exclusions to Model Structure

The downstream extent of Model 3 was initially cropped to the end of the available LiDAR survey. Severe out of bank flow occurred at the northern end of the study area, caused primarily by a downstream boundary condition with water levels higher than most of the northern topography (discussed further in Section 6) forced the truncation of the reaches back to sections with topography higher than the boundary conditions. As a result modelling accuracy could only be achieved where the floodplains could not be correctly included in the model.

Structures recorded within the IDB survey were omitted as these are unlikely to have been retained over this period of time. Structures that were deemed likely to have limited effect on flood levels whilst improving model stability were excluded from the model. The major structures of note to be removed are:

West Rhoden

- All culverts upstream of the railway culvert.
- Culverts immediately downstream of the railway culvert

Roughness Coefficients

The following defaults have been adopted in Model 3.

Table 5-3 Roughness Coefficients for Model 3

<table>
<thead>
<tr>
<th>MANNING’S ‘N’</th>
<th>In channel banks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.040</td>
</tr>
</tbody>
</table>


MANNING’S ‘N’

<table>
<thead>
<tr>
<th></th>
<th>MANNING’S ‘N’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out of channel banks</td>
<td>0.050</td>
</tr>
<tr>
<td>Bottom of culvert</td>
<td>0.011</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>0.014</td>
</tr>
</tbody>
</table>

**Floodplain Storage Areas**

Floodplain storage areas that were used in Model 3 exist in Paddock Wood between the Main Drain and the West Rhoden, to the east of the Main Drain north of the railway, and to the east and west of the West Rhoden north of the railway.

Model 3 shares a floodplain storage area with Model 2 in Paddock Wood between the Main Drain and the West Rhoden. However, as discussed previously, the two models could not be linked together to provide a stable combined model. Flows spill from the East Rhoden south of the railway and spill westward across the West Rhoden into the localised low point. Model 3 has been set up to incorporate the peak flood depth in the Paddock Wood storage area from Model 2 as its initial condition and allows spills from the Main Drain and West Rhoden to superimpose on top of this initial flood depth. This approach is slightly conservative; however it provides a suitable solution to mapping the Paddock Wood storage area (discussed further in Section 7).

Initial flood levels used for the Paddock Wood Storage area are provided in Table 5-4 below.

**Table 5-4**

<table>
<thead>
<tr>
<th>RETURN PERIOD EVENT</th>
<th>FLOOD LEVEL (M AOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 year</td>
<td>14.950</td>
</tr>
<tr>
<td>100 year</td>
<td>15.168</td>
</tr>
<tr>
<td>100 year + climate change</td>
<td>15.325</td>
</tr>
<tr>
<td>1,000 year</td>
<td>15.706</td>
</tr>
</tbody>
</table>

**Downstream Boundaries**

The downstream boundary used was the 100 year return period level for the River Teise of 13.63m AOD as agreed with the Environment Agency. This was conservatively modelled as a constant level to ensure the peak flow through the InfoWorks RS model would coincide with the 100 year return period level for the River Teise.

5.5 Urban Paddock Wood (Model 4)

This is an urban drainage network model covering approximately 1.5 km² of Paddock Wood Town. The review of drainage records in MapInfo format indicates that both surface water and foul water systems have been built for the town. The records show approximately 1300 surface water drains and 1000 foul water sewers. In this study, the surface water network data were extracted for the mode build purpose.

There exist historical flooding records in the Paddock Town. It indicates that south and east of the town, where the ground levels are about 15-17 mAOD, are most likely subject to flooding.

To estimate surface runoff to the drainage network system, 433 sub-catchments have been delineated. The delineation of sub-catchment generally follows the following considerations and available data:
• layout of drainage networks
• digital topographical maps, that show the outlines of buildings, roads and open spaces etc
• LiDAR data
• satellite maps (ref Google Maps)

The open space areas or pervious areas, for example the grasslands, are excluded from the sub-catchment delineation and surface runoff modelling. The Wallingford’s Fixed Runoff Volume module has been employed for the surface runoff estimation. Storm events and design rainfall profiles were estimated separately by using FH methods and then imported into InfoWorks CS for application.

Some assumptions have been made in the model build, including
• all duplicate nodes were removed
• for nodes missing ground levels the LiDAR data were applied
• for links missing upstream and/or downstream invert levels, a gradient of 2 in 1000 was assumed
• initial loss value for impervious area is 0.00011m for the fixed runoff volume module of Wallingford
• The flood water on the catchment surface is retained in the storage volume defined by the flood levels and areas specified. The flood water returns to the drainage system as the levels drop.

Model Structure

The finalised Model 4 consisted of the following elements:
• 433 sub-catchments
• 636 manholes
• 634 links (drainage pipes)
• 17 outfalls

Roughness Coefficients

The Colebrook-White roughness coefficient Ks has been used for InfoWorks CS models. The following defaults have been adopted in Model 5.

Table 5-5

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>CW ‘Ks’ (MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom of culvert</td>
<td>3</td>
</tr>
<tr>
<td>Top of culvert</td>
<td>3</td>
</tr>
</tbody>
</table>

Downstream Boundaries

The downstream water level boundaries at outfalls of drainage networks were extracted from predicted water levels in InfoWorks RS models. As a conservative approach the maximum water levels throughout modelling events of different return periods in InfoWorks RS models have been adopted as constant downstream water level boundaries for the InfoWorks CS Models.
5.6 Calibration

In order to assess the accuracy of the model, it is necessary to calibrate the model against historical flood events. Unfortunately the only calibration data available for this model has been anecdotal evidence, which indicates areas susceptible to flooding but is not related to either flood levels or probability, and sewer flooding records, which again do not record depth or relate to probability. The data all relates to the urban sewered part of the catchment.

No calibration has been possible for the open channel network. However, the coefficients used all lie within the range commonly found when calibration has been possible on similar watercourses.

Whilst the historic flooding data for the urban area is not ideal, it has been used to calibrate the extent of flooding from sewers. The methodology used to map areas of sewer flooding is described in section 7.3. For there to be either a record of sewer flooding or anecdotal evidence it is likely that flooding has occurred in the last 10 to 20, possibly more than once. Thus all the areas known to experience flooding have been assumed to flood in the 1 in 20 year event.

Historical sewer flooding incidents were overlaid on the 1 in 20 flooding extents to confirm the correlation between the modelling and the historical flooding and to ensure the extent of flooding from individual manholes was reasonable. Figure 3 shows the calibration based on the 1 in 20 year flood event.
6  Design Runs

This section summarises the flood extents from the hydraulic model runs for the 20 year, 100 year, 100 year plus allowances for climate change, and the 1,000 year events. Full tabulated model results for all locations are presented in Appendix D. Maps showing model node locations are included as figures 4 and 5.

All design runs were performed using as detailed in the methodology outlined in Section 5 with all the InfoWorks RS and InfoWorks CS default settings employed.

6.1 20 year

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage area between Tudeley Brook and Gravelly Way. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood.

Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain.

In the urban areas of Paddock Wood, the majority of storm water sewers were found seriously surcharged except for the area south-east of the town. Flooding (overflows from manholes) was also predicted along Maidstone Road, Ribston Gardens Street, Woodlands Street, The Cedars Street, Church Road and Warrington Road. These findings are in a good agreement with historical flooding records. The most severe flooding, however, was predicted along Commercial Road and Kiln Way.

6.2 100 year

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage between Tudeley Brook and Gravelly Way Stream. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available. Further flooding from the Tudeley Brook is observed to occur to the north of the railway and to the west of Tudeley Brook.

Flooding is also predicted to occur to the south of the railway in the west of Paddock Wood with the Gravelly Way Stream being the contributor of this flooding.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood including the Waitrose supermarket car park.

Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain.

Minor out of bank flooding is also predicted downstream and upstream of Church Road from the East Rhoden.
The flooding locations in the urban areas under 100-year flood event are similar to that of 20-year flood event but the situation is aggravated as a result of longer inundation time. The modelling results show that the averaged inundation time may be 1.5 times of that under 20-year flood event. In the south-east part of town, some of storm water sewers are found surcharged as well (these sewers are not surcharged under 20-year flood event).

6.3 100 year plus climate change

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage between Tudeley Brook and Gravelly Way Stream. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available. Further flooding from the Tudeley Brook is observed to occur to the north of the railway and to the west of Tudeley Brook.

Flooding is also predicted to occur to the south of the railway in the west of Paddock Wood with the Gravelly Way Stream being the contributor of this flooding.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood including the Waitrose supermarket carpark. The extent of flooding in this area is extensive.

Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain.

Out of bank flooding is also predicted downstream and upstream of Church Road from the East Rhoden.

The flooding locations in the urban areas under 100-year plus climate change event are similar to that of 100-year flood event but the situation is worse as a result of longer inundation time. The modelling results show that the averaged inundation time may be 2 times of that under 20-year flood event. In the south-east part of town, nearly all storm water sewers are found surcharged.

6.4 1,000 year

Out of bank flows are predicted to spill into the area between Gravelly Way Stream and Tudeley Brook immediately to the south and north of the railway. These flood spills are primarily from the Tudeley Brook. Spills also occur to the west of Tudeley Brook north of the railway. Depths of up to 1m are predicted in the storage between Tudeley Brook and Gravelly Way Stream. Flood water is likely to spill beyond this storage area to lower areas however the model is limited by the extent of LiDAR available. Further flooding from the Tudeley Brook is observed to occur to the north of the railway and to the west of Tudeley Brook.

Flooding is also predicted to occur to the south of the railway in the west of Paddock Wood with the Gravelly Way Stream being the contributor of this flooding.

Further out of bank flows are observed to the south of Badsell Road from Tudeley Brook.

Out of bank flows are predicted to spill westward from the East Rhoden immediately south of the railway. These spills are shown to migrate to the storage area in the north-east of Paddock Wood where it is known for historical flooding to occur. Further spilling is predicted from the Main Drain to flood this area of Paddock Wood including the Waitrose supermarket car park. The extent of flooding in this area is extensive.
Spilling is also predicted to occur to the north of the railway from the eastern banks of the Main Drain. Out of bank flooding is also predicted downstream and upstream of Church Road from the East Rhoden. The flooding locations in the urban areas under 1000-year event are similar to that of 100-year flood event but the situation is worst as a result of longer inundation time. The modelling results show that the averaged inundation time may be 3 times of that under 20-year flood event. In the south-east part of town, nearly all storm water sewers are found surcharged and some are subject to flooding.
7  Flood Zone Mapping

7.1  Flood Zones

The Environment Agency defines flood zones for areas at risk of flooding. The flood zones are based on the return periods identified in Planning Policy Statement 25: Development and Flood Risk (CLG, 2006):

- **Flood Zone 2** – Area at risk of flooding during the 1000 year flood excluding the presence/effect of flood defences
- **Flood Zone 3a** - Area at risk of flooding during the 100 year flood excluding the presence/effect of flood defences
- **Flood Zone 3b** - Area at risk of flooding during the 25 year flood including the effect of flood defences

There are no flood defence defined by the Environment Agency within the study area.

7.2  Mapping Methodology – InfoWorks RS

Flood Inundation outlines have been mapped for each of the modelled scenarios. The following methodology has been applied within the MapInfo (version 9.0) software, using the Vertical Mapper extension.

**Digital Terrain Model**

A Digital Terrain Model (DTM) was built for the site, based on LiDAR that was provided by the Environment Agency in ASCII format (2m cell size), which can be directly imported into MapInfo. The LiDAR was used in the InfoWorks model for producing the inundation outlines.

**Import of Modelling Results**

InfoWorks exports the modelled inundation outline to a MIF file, a MapInfo Interchange Format. This can be directly imported and overlaid onto the LiDAR or OS Mapping.

**Manual Inspection and Adjustments**

Each of the flood inundation outlines was visually reviewed and manual adjustments made by either discounting the hydraulically disconnected areas or connecting flooded areas that do not appear to connect, based on the survey, LiDAR information and field observations on flood mechanisms and pathways.

7.3  Mapping Methodology – InfoWorks CS

The node locations and surcharged volumes were extracted from Infoworks CS to a CSV file, with the Node Identifier, Easting, Northing and Surcharged Volumes as columns. The CSV file was directly imported into MapInfo, and points created using the Easting and Northing columns as the X and Y, projected in the British National Grid coordinate system.
Using the DTM (LiDAR), a grid representing the slope of the terrain was created using Vertical Mapper. The Node Locations were split into 2 different files, one for nodes that do not flood, and the other for flooded nodes. A point inspection was carried out for the flooded nodes, using the Slope grid. The result is an additional column in the attribute table of the nodes that contains the percentage slope of the underlying slope grid at each node location.

The flooded nodes, with associated attributes of surcharged volume and percentage slope were exported to Excel to calculate buffer areas for the sewer flooding.

Initially a buffer area was calculated for each node, based on a volume range. The ranges used were:

- 2.5 – 250 m³
- 251 – 500 m³
- 501 – 750 m³
- 751 – 1000 m³
- > 1000

The buffer area was calculated using the upper limit of the range, and assuming a depth of 0.1 m at the manhole. E.g. Area of Buffer = 250 x 0.1. The radius of the buffer was then worked out (Buffer radius = $\sqrt{\text{Area}/\pi}$).

The buffer radius was decreased by a percentage based on the slope of the terrain at the manhole. This was calculated using the following percentage decreases:

<table>
<thead>
<tr>
<th>Slope (%)</th>
<th>Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
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</tr>
<tr>
<td>1 - 2</td>
<td>2.5</td>
</tr>
<tr>
<td>2 - 3</td>
<td>5</td>
</tr>
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<td>3 - 4</td>
<td>7.5</td>
</tr>
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<td>4 - 5</td>
<td>10</td>
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<td>5 - 6</td>
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<td>6 - 7</td>
<td>15</td>
</tr>
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<td>7 - 8</td>
<td>17.5</td>
</tr>
<tr>
<td>9 - 10</td>
<td>20</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Once a final buffer radius was calculated, the table was then imported back into MapInfo, and a buffer drawn around each manhole based on that radius. The buffer areas were merged together to form the relative sewer flooding extent.
8 References


9 Figures

Figure 1: Study Area
Figure 2: Topographic Survey Coverage
Figure 3: Sewer Flooding Calibration
Figure 4: Model Nodes
10 Appendices

Appendix A – Topographic Survey Data (CD-ROM)
Appendix B – Flood Flow Estimates
Appendix C – Predicted Flood Levels
Appendix D – Model Files
Appendix A – Topographic Survey Data (CD-ROM)
Appendix B – Flood Flow Estimates
Appendix C – Predicted Flood Levels
Appendix D – Model File Index
### Table 10-1: Model File Reference

<table>
<thead>
<tr>
<th>Folder</th>
<th>Name</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>WR MD Sept 08</td>
<td>20yr ss</td>
<td>Steady state 20 year return period flow for the West Rhoden and Main Drain</td>
</tr>
<tr>
<td>WR MD Sept 08</td>
<td>20yr uss</td>
<td>Unsteady state 20 year return period flow for the West Rhoden and Main Drain</td>
</tr>
<tr>
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<td>100yr ss</td>
<td>Steady state 100 year return period flow for the West Rhoden and Main Drain</td>
</tr>
<tr>
<td>WR MD Sept 08</td>
<td>100yr uss</td>
<td>Unsteady state 100 year return period flow for the West Rhoden and Main Drain</td>
</tr>
<tr>
<td>WR MD Sept 08</td>
<td>100yr cc ss</td>
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</tr>
<tr>
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<td>Unsteady state 100 year return period + climate change flow for the West Rhoden and Main Drain</td>
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<td>100yr uss</td>
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</tr>
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<td>100yr cc uss</td>
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<td>Steady state 20 year return period flow for the Tudeley Brook and Gravelly Way Stream</td>
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<td>20yr uss</td>
<td>Unsteady state 20 year return period flow for the Tudeley Brook and Gravelly Way Stream</td>
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<td>Steady state 100 year return period flow for the Tudeley Brook and Gravelly Way Stream</td>
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</tr>
<tr>
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<td>1000yr ss</td>
<td>Steady state 1,000 year return period flow for the Tudeley Brook and Gravelly Way Stream</td>
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<td>1000yr uss</td>
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<td>Modelling result file for 20-year return period</td>
</tr>
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<td>Main Drain Aug08</td>
<td>9June_100yr</td>
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</tr>
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<td>Modelling result file for 100-year storm event plus climate change</td>
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</tr>
</tbody>
</table>
LEGEND

- Surcharged Manholes
- Sewer Network
- Relative Sewer Flood Extent
  (1 in 20 year Event)

Historical Sewer Flooding

Southern Water
(DGIS Database)

EA Identified Problem Areas

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Figure 3

Plot Date: 03/09/2008

Filepath: L:\Water\Projects & Jobs\D115000 to D115999\D115701 Tunbridge Wells SFRA PEM\5 Design Information\5-7 Modelling\GIS

SEWER FLOODING
CALIBRATION
(1 in 20 year Event)

1:7,000

SEWER FLOODING
FLOOD MODELLING

FINAL

PADDOCK WOOD

Historical Sewer Flooding

LEGEND

Relative Sewer Flood Extent
(1 in 20 year Event)

Sewn Network

Surcharged Manholes

Southern Water (DGIS Database)

EA Identified Problem Areas