Monkton Heathfield
Flood Risk Assessment and
Drainage Strategy

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Report no: WX21483/D2
Date: June 2005

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Summary

The land identified for the proposed urban development at Monkton Heathfield lies northeast of Taunton, to the north of the Bridgewater and Taunton canal and west of the M5 motorway. The existing site area consists of two discrete parcels of land.

This FRA and Drainage Strategy were prepared to support an Environmental Statement being prepared for the proposed development.

The aim of the FRA and Drainage Strategy were to:

1. Identify the extent of the existing and potential flood risk arising from fluvial flows (watercourse) in the vicinity of the proposed development. To enable this, hydrological estimates of watercourse flows and hydraulic models of the watercourse channel and floodplain were prepared.

2. Identify and assess suitable mitigative measures for the development such that the impact on the surrounding watercourses is minimal. Of particular concern are the watercourses passing through the Bathpool urban area. To enable this, a drainage strategy incorporating an outline trunk drainage system, overland flow paths and attenuation storage was prepared.

Five watercourses are located adjacent to or within the Site: These include the Allen's Brook, Dyer's Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm. None of these watercourses are designated main river or critical ordinary watercourse by the Environment Agency.

Estimation of design flood flows (hydrology) was completed using the Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999) (Ref.2), which details the currently accepted best practice methodology in the UK.

The flood flow estimates were then utilised in baseline and post-development hydraulic models constructed using site survey and Environment Agency data and the HEC-RAS computer software package.

Modelling of the watercourses predicted flood extents for the “worst case” storm duration and river flood level combinations that affect the Site, Bathpool and other areas downstream of the Site.

The selected “worst-case” event consisted of the peak watercourse flow for the Monkton Elm Drainage Ditch and Langaller Drainage Ditch 1 & 2. In addition for the Allen's and Dyer's Brook and Old Tone Arm models this peak flow event also coincided with the peak 1-in-200 year River Tone flood level.

The Site is not effected directly by flooding from the River Tone in the 1-in-200 year flood event although water levels in some of the watercourses, Bathpool and areas downstream of the site are influenced by these levels.
to varying degrees. No significant existing flood storage is located on the Site and generally the baseline flows are predicted to stay in bank except for a few locations upstream of existing road culverts where minor localised flooding occurs.

Modelling of the watercourses for the post-development scenario has been undertaken and the findings have been incorporated into the Master Plan and Drainage Strategy. The results of the assessment indicated that the proposed drainage strategy, including the preliminary trunk drainage system, intercept ditches, attenuation basins and watercourse outfalls, would reduce the worst-case flood levels and volumes contained in the study watercourses. An option whereby surface water runoff from a proportion of the proposed site, in the Old Tone Arm catchment, is attenuating using underground storage is also under consideration. Marginal decreases in flood levels and volumes are predicted for the Allen's and Dyer's Brook while more significant reductions are predicted for the Monkton Elm Drainage Ditch and Old Tone Arm Ditch. The Langaller Drainage Ditch is unaffected by the proposed development.

The reductions in flood level and flood volume for all of the watercourses would provide a marginal reduction in the flood extents predicted for the baseline scenario.

It is therefore considered that the proposed development would have a minor beneficial impact upon flooding within the Site, Bathpool and areas downstream of the Site.

The Scheme would incorporate attenuation ponds and vegetative treatment systems that would improve the quality of run-off discharged to surface watercourses. It is therefore considered that the proposed development would have moderate beneficial impacts upon surface water quality.
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1 Introduction

Monkton Heathfield Consortium has commissioned Hyder Consulting to carry out a Flood Risk Assessment (FRA) and Drainage Strategy in connection with a proposed urban development at Monkton Heathfield. The FRA and Drainage Strategy are required to support an Environmental Statement being prepared in part by RPS Planning and Environment, with the remainder the responsibility of a variety of consultants, including Hyder Consulting.

The proposed development covers an area of 82.32ha and is located near Monkton Heathfield, south west of Taunton, Somerset (NGR 325,500 127,000).

This FRA has been prepared in accordance with the intent outlined in the Planning Policy Guidance Note 25, Development and Flood Risk (July 2001) (Ref. 1) (PPG Note 25). This provides guidance as to how flood risk should be considered at all stages of the planning and development process in order to reduce future damage to property and loss of life.

Its key requirements include, for example:

- Definition of the probability of flood occurrence and the likely depths and rates of flow,
- Consideration of the effects of climate change and,
- Assessment of the likelihood of impacts to other areas, properties and habitats.

The flood risk to the pre-development (baseline) and post-development site areas are evaluated. Several watercourses pass through or are located adjacent to the site, eventually discharging to the River Tone at various locations downstream. Flooding from the River Tone currently affects the residential areas located downstream of the site and water levels in the Tone can influence flooding within the study watercourses.

This FRA considers the potential impacts of flooding on the site and the potential for the development proposals to increase flood risk elsewhere. A drainage strategy is proposed which has been developed to tie-in with the FRA and meet site drainage requirements whilst also providing appropriate mitigation of flood risk issues.
2 Scope

2.1 General

The FRA and Drainage Strategy are required to support an Environmental Statement being prepared by Mason Richards Planning in connection with a proposed urban development at Monkton Heathfield.

The two objectives of the assessment are:

3. Identify the extent of the existing and potential flood risk arising from fluvial flows in the vicinity of the proposed development. Flood levels and extents for the study area reaches of the Allen's Brook, Dyer's Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm will be defined using the hydraulic model HEC-RASv3.1.2.

4. Identify and assess suitable mitigative measures for the development such that the impact on the surrounding watercourses is minimal. Of particular concern will be the watercourses passing through the Bathpool urban area.

2.2 Flood Risk Assessment

In order to achieve the above objectives, a scope of works was defined in consultation with the Environment Agency. The scope for the FRA, which was agreed by the EA, included the following tasks:

- Collection and review of data from a number of different sources including the Applicant, the Environment Agency, and Taunton Dean Borough Council.
- Detailed consultation with the Environment Agency and Taunton Dean Borough Council throughout the study.
- Detailed site reconnaissance to visually inspect topography, investigate sources of inflow to the watercourses, confirm flow paths and directions, identify watercourse structures, hydraulic characteristics, probable floodplain extents, identify wrack marks or other evidence of historical flood levels, define the extent of the hydraulic model, specify channel and floodplain cross sections and structures for inclusion in a topographic survey, assess the roughness characteristics of the channel and floodplain and to collect relevant anecdotal evidence of historic flooding from local residents.
- Topographic survey of river channel and floodplain, including structure dimensions and levels.
- Hydrological assessment of the 1-in-100 year design flood flows for the watercourses surrounding the site using best practice Flood...
Estimation Handbook (FEH) techniques, including an allowance for climate change, for input to the hydraulic models.

- Hydraulic modelling involving the construction of hydrodynamic models of Allen’s Brook, Dyer’s Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm using HEC-RASv3.1. The models will need to be hydrodynamic (i.e. time-variant) in order to take into account the effects of flood storage in the catchment and to allow changes in the volume of run-off in the catchment to be assessed.
- Adoption of the 1-in-200 year River Tone Flood Stage (level) hydrograph provided from the Environment Agencies Flood Risk Mapping – North Wessex Area.
- Calibration of the model using any available historic data and/or sensitivity analysis where calibration data was unavailable.
- Floodplain mapping of the agreed worst-case event combination. A flood inundation (indicative floodplain) drawing will be produced, illustrating the predicted flood levels including climate change and highlighting parts of the development site within the floodplain.
- The proposed drainage strategy for the outline master plan will be incorporated into the post development modelling to identify the potential flood risks. Discharge from the site attenuation basins will be added into the watercourse models at likely discharge points in order to quantify any predicted increase in water levels and flood volumes.
- A strategic FRA Report will be produced, detailing methodology and results, together with recommended mitigation.

2.3 Drainage Strategy

In order to achieve the objectives, the agreed scope of works for the Drainage Strategy include the following tasks:
- Determine pre-development “greenfield” runoff rates.
- Determine pre-development “volumetric” runoff rate.
- Liaise with Wessex Water, Environment Agency and Highway Authority to determine trunk drainage requirements, adoption, water quality and maintenance issues.
- Liaise with authorities to determine service, easement and access issues
- Develop a broad trunk-line drainage strategy for the master plan (1 year return period).
- Develop an outline overland flow path and cross-drainage strategy for the master plan (1-in-100-year return period).
- Develop an attenuation basin scheme, co-ordinated with the flood risk assessment.
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- Develop an attenuation basin scheme, co-ordinated with the flood risk assessment.

Estimation Handbook (FEH) techniques, including an allowance for climate change, for input to the hydraulic models.

- Hydraulic modelling involving the construction of hydrodynamic models of Allen's Brook, Dyer's Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm using HEC-RASv3.1. The models will need to be hydrodynamic (i.e. time-variant) in order to take into account the effects of flood storage in the catchment and to allow changes in the volume of run-off in the catchment to be assessed.

- Adoption of the 1-in-200 year River Tone Flood Stage (level) hydrograph provided from the Environment Agencies Flood Risk Mapping – North Wessex Area.

- Calibration of the model using any available historic data and/or sensitivity analysis where calibration data was unavailable.

- Floodplain mapping of the agreed worst-case event combination. A flood inundation (indicative floodplain) drawing will be produced, illustrating the predicted flood levels including climate change and highlighting parts of the development site within the floodplain.

- The proposed drainage strategy for the outline master plan will be incorporated into the post development modelling to identify the potential flood risks. Discharge from the site attenuation basins will be added into the watercourse models at likely discharge points in order to quantify any predicted increase in water levels and flood volumes.

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- Develop a broad trunk-line drainage strategy for the master plan (1 year return period).
- Develop an outline overland flow path and cross-drainage strategy for the master plan (1-in-100-year return period).
- Develop an attenuation basin scheme, co-ordinated with the flood risk assessment.
- Consider additional SUDS opportunities for the proposed developed areas. This could include soak-aways, filter strips, stormwater harvesting and pervious pavements.
- Discuss an over-pumping scheme for the proposed master plan (if required).
- Assess the trunk-line drainage strategy.
- Assess the overland flow path and cross-drainage strategy.
- Assess the attenuation/infiltration basin scheme with view to realising the required "greenfield" or "volumetric" runoff rates and minimising volumetric impacts.
- Assess the SUDS based scheme and determine potential component of runoff and volume reduction for the site.
3 Background

3.1 The Proposed Development

3.1.1 General
The land identified for the proposed urban development at Monkton Heathfield lies northeast of Taunton, to the north of the Bridgewater and Taunton canal and west of the M5 motorway. Figure 3-1 provides details on the proposed location. The existing site area consists of two discrete parcels of land.

3.1.2 Main Urban Expansion Site
The first and most significant proportion of development land is generally bounded by the A3259 to the north, Dyer’s Brook and the A38 to the west, the Bridgewater and Taunton canal to the south and the A3259 to the east. This parcel has an area of 79.5Ha and slopes in a southerly direction, with ground levels varying between 13mAOD and 32mAOD. The existing usage is rural with the Monkton Elm Drainage Ditch and the Langaller Drainage Ditch 1 crossing the site east of the A38. Langaller Drainage Ditch 2 has a confluence with Langaller Drainage Ditch 1 upstream of the A38. The Dyer’s Brook passes partially through and predominantly adjacent the site, west of the A38.

3.1.3 Other Urban Expansion Site
The second and significantly smaller parcel is located east of where the Allen’s Brook crosses the A3259. The site is currently rural with an area of 5.22Ha. Existing housing forms the northern boundary and the Milton Hill road forms the eastern boundary. The site slopes in a south-easterly direction, towards Allen’s Brook, with existing ground levels varying between 15mAOD and 26mAOD.
Figure 3-1 Proposed urban extension to Monkton Heathfield Location Plan
3.2 River Reach of Interest

The proposed developments has the potential to impact upon the following five watercourses:

1. Allen’s Brook
2. Dyer’s Brook
3. Monkton Elm Drainage Ditch
4. Langaller Drainage Ditch 1 & 2
5. Old Tone Arm

In addition the River Tone, the Bridgewater and Taunton Canal and the Bathpool urban area are located south of the proposed development sites.

The Environment Agency have stated that the five watercourses are not designated main river or critical ordinary watercourses. Therefore, they are all under the responsibility of Local Authority. The Environment Agency therefore only takes an interest in respect of PPG Note 25 and flood defence for Bathpool.

3.3 Catchment Descriptions

The development site watercourses and study catchment areas are illustrated in Drawing M1 in Appendix D.

1. Allen’s Brook

The watercourse upstream of the confluence with the Dyer’s Brook, drains a total area of 2.42 km² experiencing an annual average rainfall of 738mm. The catchment has a mean altitude of 48m AOD. The brook rises near Goosenford and flows generally in a southerly direction to its confluence. The catchment is predominantly rural with some residential development.

Allen’s Brook forms the western boundary to the second smaller parcel of land. Upstream of this parcel of land, Allen’s Brook passes under the A3259 road via two culverts. The watercourse also passes under a culvert under a lane downstream of the smaller parcel of land. Allen’s Brook passes under the Bridgwater and Taunton Canal via a piped arrangement before its confluence with Dyer’s Brook.

From this point the Allen’s Brook discharges to the River Tone, via a flap valve arrangement, such that at times of high river level in the Tone, the system is ‘locked’ and cannot discharge effectively. As a consequence, flooding in Bathpool (in particular, the Hyde Lane area) is common and a substantial part of Bathpool is shown to lie in Indicative Flood Plain.
The combined catchment area of Allen's Brook and the Dyers Brook tributary to its confluence with the River Tone is 5.29km².

Historical flooding issues in Bathpool have been highlighted in meetings with the Environment Agency and Taunton Deane Borough Council.

2. Dyer's Brook

The watercourse upstream of the confluence with the Allen's Brook, drains a total area of 2.83 km². The catchment experiences an annual average rainfall of 738mm and has a mean altitude of 44mAOD. The brook rises near Monkton Ho and flows generally in a southerly direction to its confluence with the Allen's Brook. The catchment is predominantly rural with significant existing residential development located adjacent to the brook downstream of the A38 road crossing.

Dyer's Brook passes under the A3259 road via a culvert at the northern boundary of the larger parcel of land. In the vicinity of the proposed development area Dyer's Brook is crossed by a series of bridge/culvert structures. Dyer's Brook then passes under the Bridgwater and Taunton Canal and the existing Bathpool urban area via a mixture of culverts and formal (concrete) and informal channels before its confluence with Allen's Brook.

3. Monkton Elm Drainage Ditch

This minor watercourse drains a total catchment area of 0.49 km² upstream of its confluence with the Langaller Drainage Ditch. The catchment experiences an annual average rainfall of 721mm and has a mean altitude of 19mAOD.

The watercourse crosses the larger land parcel in a southerly direction before turning south-easterly at which point it passes through a road culvert and then the M5 culvert.

From the confluence with the Langaller Drainage Ditch, which is located downstream of the M5 motorway crossing, the drainage ditch flows through Creech St Michael before passing under the Bridgwater and Taunton Canal to the River Tone.

4. Langaller Drainage Ditch 1 & 2

The watercourse drains a total area of 1.32 km² upstream of its confluence with the Monkton Elm Drainage Ditch and experiences an annual average rainfall of 730mm. The catchment has a mean altitude of 32mAOD.

Langaller Drainage Ditch 1 & 2 rise near West Monkton and flow in a mainly southerly direction, flowing through Langaller. Langaller Drainage Ditch 1 has its confluence with Langaller Drainage Ditch 2, upstream of the road that passes along the northern boundary of the site, before passing along the easterly edge of the larger land parcel. The ditch is then culverted.
under the M5, joining up with the Monkton Elm Drainage Ditch at a point further downstream.

5. Old Tone Arm

This watercourse to its confluence with the River Tone, drains a total area of 0.20 km$^2$ and experiences an annual average rainfall of 715mm. The catchment has a mean altitude of 23m AOD. The drainage ditch rises near Hyde Farm, flows in a mainly southerly direction before passing under the Bridgwater and Taunton Canal prior, to discharging into the old Tone.

3.4 Historical Flooding

The Environment Agency 1-in-100 year indicative floodplain for Allen's Brook and Dyer's Brook is shown in Figure 3-2.

Meetings with Local Council

Hyder Consulting met with Taunton Deane Borough Council on the 23rd November 2004 to discuss flood risk issues. In this meeting Taunton Deane Borough Council indicated that localised flooding was reported to occur in the Bathpool area under storm events of 1-in-2 year and 1-in-5 year return periods. Taunton Deane Borough Council also indicated that there were some existing flooding problems on the Langaller Drainage Ditch 1 at North End and West View, Creech ST Michael.

Meetings between Hyder Consulting and the Environment Agency

Detailed consultation with the Environment Agency has been undertaken. Initially this was carried out to define the scope of the study and highlight known historical issues, but at later dates discussions were held to review and adjust the modelling and assessment approaches, in light of the work carried out to that date.

From the outset the Environment Agency have highlighted there are historical flooding issues in the Bathpool area, which was subject to flooding every few years. The mechanism for this was thought to be a mixture of river-locking from the River Tone, old and undersized surface drainage infrastructure (pipes and culverts), poor maintenance or blockages and lack of flood storage in the area. They indicated that drainage studies in the Bathpool area had been undertaken by Taunton Deane Borough Council with view to alleviating the flooding problem. The Environment Agency indicated that a significant River Tone flood study had been recently completed and that flood information from this study would form an input to the development site FRA.

The Environment Agency also indicated that flooding of the Somerset Levels and Moors was frequent and the local communities were sensitive to
any potential changes to the existing flooding regime. An assessment and comment on this item were requested as part of the FRA.

Figure 3.2 Environment Agency Indicative floodplain extents in the development area.
4 Methodology

4.1 Data Collection

Data was collected from a number of different sources, including the Applicant, the Environment Agency and Taunton Deane Borough Council, The following information was provided by the Applicant:

- Topographic survey of the site;
- Site Investigation Report, including permeability results from trial pitting (Johnson, Poole & Bloomer Land Consultants, October 2004, and
- Supplementary watercourse cross-sectional and structure surveys.

The following information was provided by the Environment Agency:

- Extracts from the Flood Risk Mapping - North Wessex Area Report including the 1-in-200 year river stage/duration data;
- Superseded HEC-RAS models for the Allen's and Dyer's Brook system.

In addition, relevant flow gauging station data and historical flood level information was requested but no gauge data was available. Copies of any reports of relevance, for example into the flooding and flood defences at Bathpool, were also requested.

Taunton Deane Borough Council has recently undertaken a limited amount of modelling of the Allen's Brook at Bathpool. Copies of the report were requested from the relevant consultant, but were not made available in the time scale for the assessment. Whilst this report would have yielded details about the existing flooding problems at Bathpool, its unavailability was of no consequence to this Flood Risk Assessment. This is because it was agreed with the EA that potential third party impacts of the proposed development would be assessed at a location upstream of the Bridgwater and Taunton Canal.

To supplement the collected data outlined above, a site visit was undertaken to:

- Inspect the stream channel geometry,
- Investigate sources of inflow to the stream and confirm flow paths and directions,
- Identify in-stream structures,
- Define the extent of the hydraulic model,
- Specify channel and floodplain cross sections and structures for inclusion in a topographic survey,
• Assess the roughness characteristics of the channel and floodplain,
• Identify wrack marks or other evidence of historical flood levels, and
• Collect relevant anecdotal evidence of historic flooding from local residents.

A topographic survey was commissioned by Hyder and subsequently carried out by ALT Surveys. A total of 36 cross sections were taken across the five watercourses and their floodplain, with a small number of additional spot levels at key points. In addition, structures along the stream were also surveyed.

The cross-sections taken from the Allen’s and Dyer’s Brooks were utilised to supplement, update and confirm the detail in the Environment Agencies provided model.

Discussions with local residents and interpretation of the local topography of the area provided a means of determining overland flow paths in the vicinity of the Tone River.

4.2 Assessment of Flood Risk to the Site

Following the data collection, a risk assessment of the likelihood of flooding occurring on the site was carried out in accordance with the criteria presented in PPG Note 25. In general, this involves:

• Assessing the potential sources of flooding to the site i.e. the risk of flooding to the proposed development, as well as estimating the depth and rate of flooding.

• Reviewing existing topographical levels on the site and current access and comparing against predicted 1-in-100 year fluvial event (with and without climate change).

• Assessing the effect of the development on the surrounding areas.

• Determining mitigation measures, which would allow site development and ensure no additional risk to life and minimal disruption to people, property and the natural environment.

To carry out an assessment of the potential flood risks to the site, detailed hydrological and hydraulic modelling were undertaken.

An event combination incorporating the 1-in-200 year peak River Tone flood level and the 1-in-100 year localised flood event for the surrounding fluvial watercourses was agreed with the Environment Agency. Refer to the discussion regarding combined probabilities in Section 7.1.
4.3 Hydrological Modelling

Estimation of design flood flows was completed using the Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999) (Ref.2), which details the currently accepted best practice methodology in the UK. Briefly, the recommended statistical method involves three stages:

1. Calculation of the index flood ($Q_{\text{MED}}$). As gauged data was not available for any of the five watercourses, an estimate of $Q_{\text{MED}}$ was initially determined from catchment descriptors collected from the FEH CD-ROM.

2. This initial estimate of $Q_{\text{MED}}$ was further adjusted by means of ‘data transfer’ from similar gauged catchments (as outlined in FEH, Chapter 4, Volume 3).

3. Calculation of a ‘growth factor’ relating higher return periods to the index flood. This was completed using WINFAP-FEH software. A “pooled” group of data from hydrologically similar sites around the UK is created and this data is used to estimate the relationship (‘growth factor’) between the median annual flood and floods of other return periods.

Further details of the hydrological modelling methodology are provided in Section 6.

Another estimate of the 1-in-100 year design flow was calculated using the FEH Rainfall-Runoff method, based on catchment descriptors (as outlined in FEH, Volume 4).

A comparison of the design flow estimates resulting from the FEH Statistical and Rainfall-Runoff approaches was undertaken, and a suitable 1-in-100 year design flow established for input into the hydraulic model.

An additional 20% was added to the estimated 1-in-100 year design flow as an allowance for climate change, in accordance to PPG Note 25.

4.4 Hydraulic Modelling

The assessment of flood risk was made using a hydrodynamic hydraulic model, constructed using HEC-RAS software (US Army Corps of Engineers, version 3.1.2). The hydrodynamic approach was chosen, as downstream areas of the watercourses are sensitive to flooding and this approach would allow the assessment of volume changes as well as peak flows and levels.

Four models have been constructed:

1. The Allen's Brook and Dyer's Brook model was constructed using topographical survey information from two sources, the Environment Agencies Allen's and Dyer's Brook model and a new survey of the brooks.
2. The Monkton Elm Drainage Ditch model was constructed using new topographical and cross sectional survey of the site and watercourses.

3. The Langaller Drainage Ditch 1 model was constructed using new topographical and cross sectional survey of the site and watercourses. Flow from the Langaller Drainage Ditch 2 was included in this model.

4. The Old Tone Arm model was constructed using new topographical and cross sectional survey of the site and watercourses.

4.5 Drainage Strategy

The site drainage strategy was developed utilising the MICRODRAINAGE software package. This package contains several integrated modules that allow the development and assessment of trunk drainage systems including attenuation infiltration basins and other SUDS based solutions.

A conceptual trunk drainage layout incorporating standard highway design and overland flow routes was prepared for the site. Flows in excess of the trunk drainage capacity were channelled via the road network and intercept ditches into attenuation basin for storage and controlled release. This conceptual layout then allowed the attenuation basin configurations (levels, storage and outflows) to be finalised for input to the post-development hydraulic models. An option whereby surface water runoff from a proportion of the proposed site, in the Old Tone Arm catchment, is attenuated using underground storage is also under consideration.
5 Assessment of Potential Sources of Flooding

In order to assess all potential flood risks to the site, a wide range of potential sources have been considered:

- Tidal flooding
- Groundwater flooding
- Fluvial flooding
- Surface water flooding

There is no potential tidal flood risk to the development site.

The development site is located in a moderately steep clay catchment. Therefore, there is no potential groundwater flood risk to the development site.

The five watercourses Allen's Brook, Dyer's Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm pose a potential fluvial flood risk to the development site. It has been reported in Section 3.4 that localised fluvial flooding occurs in the Bathpool area for low return period storm events. There is no direct fluvial risk to the site from the River Tone.

The potential increase in the rates and volumes of surface water runoff from the site in the post development scenario (assuming no mitigation) has the potential to increase flooding within the site, the receiving watercourses and areas downstream of the site. Appropriate investigation would be required to prevent this scenario.

The FRA will assess the following identified flood risks:

1. Fluvial flooding Allen’s Brook
2. Fluvial flooding Dyer’s Brook
3. Fluvial flooding Monkton Elm Drainage Ditch
4. Fluvial flooding Langaller Drainage Ditch 1 & 2
5. Fluvial flooding Old Tone Arm
6. Surface water flooding

The FRA will also assess the possible increase of flood risk on neighbouring locations from the effects of increased surface water runoff and volumes from the proposed development site.
6 Hydrological Modelling

6.1 Statistical Method

6.1.1 Estimation of the Index Flood, QMED

As the sites are ungauged, estimates of the index flood, \( Q_{\text{MED}} \) were initially made using calculations based on characteristics of the subject catchments, such as area, soil type and average annual rainfall (as stated in FEH Volume 3, Chapter 3). An initial estimate of the \( Q_{\text{MED}} \) (urban adjusted) for the sites using catchment descriptors at the bottom of each model was calculated.

Table 6-1 provides a summary of the key catchment descriptors for the sites.

<table>
<thead>
<tr>
<th>Catchment Descriptor</th>
<th>Description</th>
<th>Allen's &amp; Dyer's Brook</th>
<th>Monkton Elm Drainage Ditch</th>
<th>Langaller Drainage Ditch 1 &amp; 2</th>
<th>Old Tone Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easting, Northing</td>
<td></td>
<td>325300, 125650</td>
<td>326900, 126300</td>
<td>326950, 126350</td>
<td>325790, 126070</td>
</tr>
<tr>
<td>AREA</td>
<td>Catchment area in km²</td>
<td>5.29, 0.49</td>
<td>1.32, 0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FARL</td>
<td>Index of lake influence</td>
<td>0.979, 1.00</td>
<td>1.00, 1.00</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>PROPWET</td>
<td>Proportion of time catchment is saturated</td>
<td>0.35, 0.35</td>
<td>0.35, 0.35</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>BFIHOST</td>
<td>Baseflow index based on soil types</td>
<td>0.59, 0.74</td>
<td>0.66, 0.75</td>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td>DPLBAR</td>
<td>Average drainage path length (km)</td>
<td>2.73, 0.42</td>
<td>1.65, 0.71</td>
<td></td>
<td>0.71</td>
</tr>
<tr>
<td>DPSBAR</td>
<td>Average drainage path slope (m/km)</td>
<td>47.60, 18.50</td>
<td>38.10, 22.60</td>
<td></td>
<td>22.60</td>
</tr>
<tr>
<td>LDP</td>
<td>Longest drainage path (km)</td>
<td>5.49, 0.82</td>
<td>3.74, 0.79</td>
<td></td>
<td>0.79</td>
</tr>
<tr>
<td>SAAR</td>
<td>Average annual rainfall (mm)</td>
<td>738, 721</td>
<td>734, 715</td>
<td></td>
<td>715</td>
</tr>
<tr>
<td>SPRHOST</td>
<td>Standard percentage runoff based on soil type</td>
<td>32.80, 26.30</td>
<td>30.20, 25.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>URBEXT 1990</td>
<td>Index of urbanisation</td>
<td>0.04, 0.00</td>
<td>0.01, 0.00</td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>

As indicated by the relatively low catchment urbanisation value (URBEXT = 0.00 to 0.04) in Table 6-1 above, the subject catchments are considered essentially rural.
Estimates of the index flood, Q\textsubscript{MED}, using catchment descriptors are based on a generalised model. An estimate of Q\textsubscript{MED} at an ungauged site, as stated in FEH Volume 3 - Chapter 4, involves adjusting the estimate by data transfer from one or more gauges on hydrologically similar catchments.

Based on this approach, 5 analogue catchments were used in each adjustment, which were weighted according to their degree of similarity to the subject catchment. All five of these catchments were selected from a pooling group established in WINFAP-FEH and two are also geographically close to the subject site. A description of each analogue catchment and its suitability are summarised in Table E1 Appendix E according to their allocated weightings.

The annual maxima flow data for all gauges, were updated using the most recent hydrometric registers to provide complete time series for the analysis.

Two estimates of Q\textsubscript{MED} at each of the analogue sites were evaluated, one using gauged data, and the other using catchment descriptors. A ratio of the two estimates for all 5 sites provided a weighted adjustment, which was applied to the generalised Q\textsubscript{MED} estimate for the sites (calculated from catchment descriptors). Table 6-2 provides an example of the Q\textsubscript{MED} estimates at the analogue site and the final adjusted Q\textsubscript{MED} for the site (cumecs). As indicated in Table E2 in Appendix E, greater weighting was provided to the gauges that were most hydrologically similar.

<table>
<thead>
<tr>
<th>Watercourse</th>
<th>Q\textsubscript{MED Rural (Catchment Descriptors)} (cumecs)</th>
<th>Adjusted Q\textsubscript{MED} (Weighted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen's Brook</td>
<td>0.409</td>
<td>0.64</td>
</tr>
<tr>
<td>Dyer's Brook</td>
<td>0.240</td>
<td>0.41</td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>0.019</td>
<td>0.03</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>0.019</td>
<td>0.02</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 2</td>
<td>0.103</td>
<td>0.15</td>
</tr>
<tr>
<td>Total Langaller Drainage Ditch</td>
<td>0.122</td>
<td>0.17</td>
</tr>
<tr>
<td>Old Tone Arm</td>
<td>0.019</td>
<td>0.01</td>
</tr>
<tr>
<td>Allen's &amp; Dyer's Brook upstream of Tone confluence</td>
<td>0.794</td>
<td>1.05</td>
</tr>
</tbody>
</table>
6.1.2 Estimation of Higher Return Period Flows

The Statistical Flood Frequency method for estimating the growth factor combines data from a number of gauging stations for statistical analysis. For this analysis, a pooling group of catchments similar in area, rainfall and soil types to the subject catchment was selected using WINFAP-FEH software and a growth curve was determined using data from this group. The general logistic curve fitting method was used to produce the growth curve.

No adjustment was made to the default-pooling group, except for the removal of sites with records of less than 8 years as recommended in FEH.

Table 6-3 and 6-4 details the growth curve factors and peak flow estimates at the end of each of the hydraulic models (either River Tone or downstream of the M5 motorway) for a range of return periods based on the FEH Statistical approach. Peak flow estimates were derived by applying Qmed adjusted to the growth curve factors.

Information on flows at the top of the model and at other locations such as confluence's are contained in Section 7.5.

Table 6-3: Summary of growth factors at the bottom of the models for higher return periods based on the FEH Statistical Method

<table>
<thead>
<tr>
<th>Growth Factor</th>
<th>Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-in-2 year</td>
</tr>
<tr>
<td>Allen's Brook upstream of Dyer's Brook confluence</td>
<td>1.00</td>
</tr>
<tr>
<td>Dyer's Brook upstream of Allen's Brook confluence</td>
<td>1.00</td>
</tr>
<tr>
<td>Allen's &amp; Dyer's Brook upstream of River Tone confluence</td>
<td>1.00</td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch 1</td>
<td>1.00</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>1.00</td>
</tr>
<tr>
<td>Old Tone Arm</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Rainfall-Runoff Method

The FEH Rainfall-Runoff method (as stated in FEH Vol.4) converts a rainfall input to a flow output using a deterministic model of catchment responses.

The Rainfall-Runoff method uses a unit hydrograph and loss model, which is based on three parameters: a unit hydrograph time to peak (temporal characteristics of runoff response to rainfall); percentage runoff (volumetric characteristics of runoff response to rainfall); and baseflow (river flow prior to flood event). For this study, the model parameters were estimated from catchment descriptors, as there was no available rainfall or runoff records.

Hydrographs were developed using the Rainfall-Runoff module in MIKE11 (a hydraulic modeling program), which is a direct implementation of the FEH Rainfall-Runoff method.

Table 6-5 outlines the derived critical storm durations and Table 6-6 outlines the 1-in-100 year peak flows based on the FEH Rainfall Runoff method.

### Table 6-4 Summary of existing peak flows at the bottom of the models for higher return periods based on the FEH Statistical Method

<table>
<thead>
<tr>
<th></th>
<th>Return Period</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-in-2 year</td>
<td>1-in-5 year</td>
<td>1-in-10 year</td>
<td>1-in-25 year</td>
<td>1-in-50 year</td>
<td>1-in-100 year</td>
</tr>
<tr>
<td>Allen's Brook Peak flow (cumecs) upstream of Dyer's Brook confluence</td>
<td>0.69</td>
<td>1.04</td>
<td>1.30</td>
<td>1.69</td>
<td>2.03</td>
<td>2.42</td>
</tr>
<tr>
<td>Dyer's Brook Peak flow (cumecs) upstream of Allen's Brook confluence</td>
<td>0.57</td>
<td>0.86</td>
<td>1.08</td>
<td>1.41</td>
<td>1.70</td>
<td>2.04</td>
</tr>
<tr>
<td>Allen's &amp; Dyer's Brook Peak flow (cumecs) upstream of River Tone confluence</td>
<td>1.06</td>
<td>1.69</td>
<td>1.98</td>
<td>2.55</td>
<td>3.04</td>
<td>3.61</td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch Peak flow (cumecs)</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1 Peak flow (cumecs)</td>
<td>0.18</td>
<td>0.26</td>
<td>0.33</td>
<td>0.43</td>
<td>0.52</td>
<td>0.62</td>
</tr>
<tr>
<td>Old Tone Arm Peak flow (cumecs)</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Table 6-5 Summary of critical storm duration and peak flows based on Rainfall Runoff method

<table>
<thead>
<tr>
<th>Watercourse</th>
<th>Critical Storm Duration (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen's Brook</td>
<td>5.5</td>
</tr>
<tr>
<td>Dyer's Brook</td>
<td>5.5</td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>3.8</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>5.5</td>
</tr>
<tr>
<td>Old Tone Arm</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Table 6-6 Summary of peak flows at the bottom of the model for higher return periods based on the FEH Rainfall Runoff Method.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen's Brook</td>
<td>0.89</td>
<td>1.29</td>
<td>1.59</td>
<td>2.08</td>
<td>2.49</td>
<td>2.91</td>
<td>2.42</td>
<td>20%</td>
</tr>
<tr>
<td>Dyer's Brook</td>
<td>1.02</td>
<td>1.48</td>
<td>1.84</td>
<td>2.40</td>
<td>2.39</td>
<td>3.36</td>
<td>2.04</td>
<td>66%</td>
</tr>
<tr>
<td>Allen's &amp; Dyer's Brook upstream of River Tone confluence</td>
<td>1.86</td>
<td>2.69</td>
<td>3.33</td>
<td>4.35</td>
<td>5.23</td>
<td>6.11</td>
<td>3.60</td>
<td>70%</td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>0.11</td>
<td>0.16</td>
<td>0.20</td>
<td>0.27</td>
<td>0.33</td>
<td>0.39</td>
<td>0.08</td>
<td>397%</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>0.42</td>
<td>*</td>
<td>0.75</td>
<td>0.99</td>
<td>1.19</td>
<td>1.40</td>
<td>0.62</td>
<td>125%</td>
</tr>
<tr>
<td>Old Tone Arm</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.04</td>
<td>125%</td>
</tr>
</tbody>
</table>

* Note the 1-in-100 year peak statistical estimate has been provided for comparison.

The peak flow estimated from the Rainfall-Runoff method is approximately 20% to 397% greater than the estimate produced via the Statistical Method. The difference is more notable on the smaller catchments.
6.3 Adopted Flows

In summary, two different FEH methods have been used to derive estimates of the 1-in-100 year flow for the Allen's Brook, Dyer's Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm catchments.

Whilst the statistical method is the preferred approach in FEH, it is known to underpresent very small catchments. The Rainfall Runoff method in general does tend to overestimate the 1-in-100 year flow, so represents an upper limit for what can be expected. It is suggested therefore that in the absence of recorded data, and due to the small size of the catchments, the flow estimates derived from the Rainfall Runoff method should be adopted as they provide a more conservative approach.

The Rainfall Runoff method adopted flows are summarised in Table 6-7. A 20% allowance has been added to take into account climate change as recommended in PPG25 for the modelling exercise.

<table>
<thead>
<tr>
<th>Return Period Flows (cumecs)</th>
<th>1-in-2 year</th>
<th>1-in-5 year</th>
<th>1-in-10 year</th>
<th>1-in-25 year</th>
<th>1-in-50 year</th>
<th>1-in-100 year</th>
<th>1-in-100 year +20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen's Brook</td>
<td>0.89</td>
<td>1.29</td>
<td>1.59</td>
<td>2.08</td>
<td>2.49</td>
<td>2.91</td>
<td>3.49</td>
</tr>
<tr>
<td>Dyer's Brook</td>
<td>1.02</td>
<td>1.48</td>
<td>1.84</td>
<td>2.40</td>
<td>2.39</td>
<td>3.36</td>
<td>4.03</td>
</tr>
<tr>
<td>Allen's &amp; Dyer's Brook</td>
<td>1.86</td>
<td>2.69</td>
<td>3.33</td>
<td>4.35</td>
<td>5.23</td>
<td>6.11</td>
<td>7.33</td>
</tr>
<tr>
<td>Brook upstream of River Tone confluence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>0.11</td>
<td>0.16</td>
<td>0.20</td>
<td>0.27</td>
<td>0.33</td>
<td>0.39</td>
<td>0.47</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>0.42</td>
<td>0.60</td>
<td>0.75</td>
<td>0.99</td>
<td>1.19</td>
<td>1.40</td>
<td>1.68</td>
</tr>
<tr>
<td>Old Tone Arm</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.11</td>
</tr>
</tbody>
</table>
7 Hydraulic Modelling

7.1 Combined Probabilities

The modelled combination of fluvial design events utilised in this Flood Risk Assessment is conservative.

The event combination selected in consultative agreement with the Environment Agency represents a reasonable comparative and indicative assessment combination. The use of the 1-in-100 year rainfall event on the site watercourse catchments in combination with the 1-in-200 year River Tone flood level will yield an event rarer than 1-in-100 years. Additionally the occurrence of the 1-in-100 year peak flow event on the site watercourse catchments have been timed to coincide with the rising limb of the River Tone flood level/duration curve (ie the worst case river-lock scenario for the site watercourses). This adds another significant level of conservatism, as the coincidence of peak flows (same time) from the smaller site watercourse catchments and the significantly larger River Tone catchment is very unlikely.

Planning Policy Guidance Note 25 (PPG25) (Ref. 11.1) requires an assessment of fluvial flood risk (incl flood storage loss and floor levels) of a minimum of 1-in-100 years for residential developments.

In addition, and after consultation with the Environment Agency, consideration of the consequences of much rarer fluvial event have been included, although protection of the site to this level is not required by PPG25.

The agreed design event is therefore considered satisfactory for these assessments.

7.2 Model Limitations Discussion

7.2.1 General

The models are an approximation of the channel and floodplain of the Allen's, Dyer's Brook, Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 & 2 and Old Tone Arm. The accuracy of the models is generally limited by the spacing of the surveyed cross-sections and the inclusion and representation of any significant restrictions to the channel and floodplain.

Whilst the level of detail is sufficient for the scale of this assessment, the models are not a prefect representation of reality and results should be assessed in this light.
This assessment has been conducted using hydrodynamic hydraulic models. This approach is essential due to the need to consider storage issues and has been agreed with the Environment Agency.

7.2.2 Bathpool Area

Initial modelling runs highlighted issues in this area. The base model provided by the Environment Agency and subsequent Hyder revisions of this generally defined the main Allen's Brook channel and immediate over bank flow areas through Bathpool to its confluence with the River Tone. However early model runs highlighted that even during more minor flows in the brook (ie early rising limb of 1-in-100 year flow hydrograph) and minor increases in the River Tone water level (ie early rising limb of 1-in-200 year stage duration curve) river-locking began to occur. The area upstream of the railway embankment was observed to flood with overtopping of the railway embankment in the model occurring prior to overtopping in the reverse direction from the rising River Tone. This observation however must be viewed with care as the storage defined in the model for the Bathpool area is limited and glass walling of the model cross sections did occur.

This observation would appear to support the Environment Agency and Taunton Deane Borough Council's concern regarding the relatively frequent flooding of the Bathpool area (advised as typically every 2-5 years by TDBC) and lack of flood storage in the catchment for river-lock events (TDBC have indicated that their strategy for the catchment includes increased flood storage within this area). The drainage strategy for the development site has the potential to assist in this regard and this is further discussed in Section 9.7.

Most critically however it highlights the limited nature of the FRA model in this area, which was originally developed as a steady state model where storage is not taken into account. To define baseline flood risk in this area much more detailed topographical survey data would be required.

PPG25 states that there is a requirement to demonstrate no impacts on existing flood risk to third parties, and this was achieved for the proposed development by comparing the pre- and post development outflows from the Site. Detailed topographical information in the Bathpool area was not therefore required, as agreed with the EA as detailed below. In addition complexity regarding overflows from adjacent catchments and the Bridgwater and Taunton Canal cannot be reasonably expected for inclusion in this FRA as the aim is not to define the flood risk in Bathpool but the impact of the site on Bathpool.

These issues were discussed with the Environment Agency and a modified approach to the modelling was agreed. A record of this discussion is contained within Appendix E.
The modified approach involved the identification of the critical "river-locked" period for the Bathpool area using the River Tone stage/duration curve provided by the Environment Agency. The pre and post hydrographs for the Allen's and Dyers Brooks would then be compared for this critical duration to ensure that the peak levels and volumes do not exceed the "greenfield" conditions. The downstream limit for this evaluation was set as the Bridgewater and Taunton Canal. A similar principal was applied to all other modelled watercourses.

### 7.2.3 Volume Considerations

Discussion with the Environment Agency and Taunton Deane Borough Council highlighted that while ensuring no detrimental impact on flood levels was the primary concern, in this instance, consideration of the impact of volume increases were necessary given the river-locking scenario (ie during river-locking the area behind the railway embankment acts as a lake before and after any overtopping from the River Tone or Alan's Brook).

Inline with the modified approach agreed with the Environment Agency and discussed in Section 7.2.2 the volumes within the watercourse networks surrounding the site upstream of the Bridgewater and Taunton Canal and M5 motorway (as applicable) were assessed using the baseline and post-development modelling.

In addition, the Environment Agency requested that a combination of more minor rainfall events (ie several 1-in-20 year rainfall events) be assessed to ensure that the site attenuation basins were adequately sized and controlled.

The worst case volumetric event for the watercourses surrounding the site would approximate to the runoff from a 1-in-100 year, 10-hour duration storm event. This event can fully occur within the rising limb of the River Tone river stage/duration curve which rises gradually to a peak flood level of 11.16m AOD over a period of 20 hours. This event combination approximates the greatest volume of runoff that can be river-locked by the rising River Tone water levels during the 1-in-200 year river flood event.

Modelling for this longer duration event was carried out for the post development scenario. Discharge from the attenuation basins for the peak volume scenario (1-in-100 year - 2hr storm on the site catchment) was added into the model to determine the impacts.

### 7.3 Model Overview

Four hydraulic models have been developed for this study. The main model the first incorporates the Allen' Brook and Dyer's Brook watercourses. Individual models have also been constructed for the remaining Monkton Elm Drainage Ditch, Langaller Drainage Ditch 1 and Old Tone Arm.
watercourses. Langaller Drainage Ditch 2 flows have been incorporated into the Langaller Drainage Ditch 1 model.

7.4 Model Geometry

7.4.1 Allen’s and Dyer’s Brook Model

The first model network consists of two branches representing a 2728m stretch of Allen’s and 1786m stretch of Dyer’s Brook. The extent of the modelled reach is summarised in Table 7-1 below:

<table>
<thead>
<tr>
<th>Watercourse</th>
<th>Upstream model boundary</th>
<th>Downstream model boundary</th>
<th>Length of modelled reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen’s and Dyer’s</td>
<td>Allen’s NGR: 324,800</td>
<td>NGR: 325,000</td>
<td>2728m</td>
</tr>
<tr>
<td>Brook</td>
<td>: 128,000</td>
<td>125,800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dyer’s NGR: 326,100</td>
<td>Confluence with River</td>
<td>1786m</td>
</tr>
<tr>
<td></td>
<td>: 127,200</td>
<td>Tone</td>
<td></td>
</tr>
</tbody>
</table>

Table 7-1 Summary of the extent of the stream reach included in the hydraulic model

Drawing M2 in Appendix D illustrates the hydraulic model details, including, the locations of the river cross-sections and the structures that were incorporated into the model.

Thirteen structures were incorporated into the model. Cross-sections were taken on both the upstream and downstream faces of each structure and ineffective flow areas were defined where appropriate. A brief summary of these structures starting from the bottom of the model is provided in Table 7-2 below:

The model provided by the Environment Agency contained 55 cross-sections while a further 13 cross-sections from the recent cross-sectional survey were used to supplement and verify the Environment Agency model. Surveyed cross-sections were typically 50-200m apart and interpolated cross-sections were added to the model where required.
Table 7-2 Details of modelled structures.

<table>
<thead>
<tr>
<th>Label</th>
<th>Chainage</th>
<th>Structure Type</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>184</td>
<td>2321.72</td>
<td>Culvert (Allen’s Brook)</td>
<td>324,930</td>
<td>127,830</td>
</tr>
<tr>
<td>108</td>
<td>1018.72</td>
<td>Bridge (Allen’s Brook)</td>
<td>325,030</td>
<td>126,610</td>
</tr>
<tr>
<td>75</td>
<td>527.73</td>
<td>Culvert (Allen’s Brook)</td>
<td>325,124</td>
<td>126,178</td>
</tr>
<tr>
<td>45</td>
<td>120.89</td>
<td>Bridge (Allen’s Brook)</td>
<td>325,127</td>
<td>126,168</td>
</tr>
<tr>
<td>25</td>
<td>55.99</td>
<td>Bridge (Allen’s Brook)</td>
<td>325,016</td>
<td>125,714</td>
</tr>
<tr>
<td>14</td>
<td>31.99</td>
<td>Culvert (Allen’s Brook)</td>
<td>325,003</td>
<td>125,680</td>
</tr>
<tr>
<td>355</td>
<td>1171.98</td>
<td>Culvert (Dyer’s Brook)</td>
<td>326,050</td>
<td>127,230</td>
</tr>
<tr>
<td>305</td>
<td>705.73</td>
<td>Bridge (Dyer’s Brook)</td>
<td>325,834</td>
<td>126,762</td>
</tr>
<tr>
<td>285</td>
<td>479.99</td>
<td>Bridge (Dyer’s Brook)</td>
<td>325,600</td>
<td>126,292</td>
</tr>
<tr>
<td>265</td>
<td>294.00</td>
<td>Bridge (Dyer’s Brook)</td>
<td>325,515</td>
<td>126,228</td>
</tr>
<tr>
<td>255</td>
<td>195.00</td>
<td>Culvert (Dyer’s Brook)</td>
<td>325,343</td>
<td>126,137</td>
</tr>
<tr>
<td>238</td>
<td>152.00</td>
<td>Bridge (Dyer’s Brook)</td>
<td>325,343</td>
<td>126,083</td>
</tr>
<tr>
<td>225</td>
<td>20.00</td>
<td>Culvert (Dyer’s Brook)</td>
<td>325,255</td>
<td>125,941</td>
</tr>
</tbody>
</table>

Note: River station labels taken from Environment Agency model to ensure consistency.

7.4.2 Monkton Elm Drainage Ditch

The second model consists of one branch representing a 1116m stretch of the Monkton Elm Drainage Ditch. The extent of the modelled reach is summarised in Table 7-3 below:

Table 7-3 Summary of the extent of the stream reach included in the hydraulic model

<table>
<thead>
<tr>
<th>Watercourse</th>
<th>Upstream model boundary</th>
<th>Downstream model boundary</th>
<th>Length of modelled reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>NGR: 326,450: 126,860</td>
<td>NGR: 326,880: 126,290</td>
<td>1116m</td>
</tr>
<tr>
<td></td>
<td>Just above Road crossing</td>
<td>200m downstream of the M5 culvert</td>
<td></td>
</tr>
</tbody>
</table>

Drawing M2 in Appendix D illustrates the hydraulic model details, including, the locations of the river cross-sections and the structures that were incorporated into the model.

A total of 13 surveyed cross-sections, were incorporated into the model. To improve the definition of water levels within the model, further sections were interpolated at 10m intervals between the surveyed sections.
Three structures were incorporated into this model. Cross-sections were taken on both the upstream and downstream faces of each structure and ineffective flow areas were defined where appropriate. A brief summary of these structures starting from the bottom of the model, is provided in Table 7-4.

<table>
<thead>
<tr>
<th>Label</th>
<th>Chainage</th>
<th>Structure Type</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
<td>599.00</td>
<td>Culvert</td>
<td>326,710</td>
<td>126,800</td>
</tr>
<tr>
<td>270</td>
<td>513.00</td>
<td>Culvert</td>
<td>326,700</td>
<td>126,740</td>
</tr>
<tr>
<td>-20</td>
<td>222.00</td>
<td>Culvert</td>
<td>326,880</td>
<td>126,530</td>
</tr>
</tbody>
</table>

**7.4.3 Langaller Drainage Ditch 1**

Langaller Drainage Ditch 2 is located off-site and its geometry was not included in the modelling. Flows from this ditch were included at the appropriate confluence point within the Langaller Drainage Ditch 1 model.

This model consists of one branch with two inputs, representing a 1021m stretch of the Langaller Drainage Ditch 1. The extent of the modelled reach is summarised in Table 7-5.

<table>
<thead>
<tr>
<th>Watercourse</th>
<th>Upstream model boundary</th>
<th>Downstream model boundary</th>
<th>Length of modelled reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>NGR: 326,360 : 126,970</td>
<td>NGR: 326,920 : 126,260</td>
<td>1021m</td>
</tr>
<tr>
<td></td>
<td>Just below Road crossing</td>
<td>200m down stream of the M5 culvert</td>
<td></td>
</tr>
</tbody>
</table>

Drawing M2 in Appendix D illustrates the hydraulic model details, including the locations of the river cross-sections and the structures that were incorporated into the model.

A total of 7 surveyed cross-sections were incorporated into the model. To improve the definition of water levels within the model, further sections were interpolated at 10m intervals between the surveyed sections.

Two structures were incorporated into this model. Cross-sections were taken on both the upstream and downstream faces of each structure and ineffective flow areas were defined where appropriate. A brief summary of these structures, starting from the bottom of the model, is provided in Table 7-6.
Table 7-6 Details of modelled structures.

<table>
<thead>
<tr>
<th>Label</th>
<th>Chainage</th>
<th>Structure Type</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>386.72</td>
<td>Culvert</td>
<td>326,520</td>
<td>126,250</td>
</tr>
<tr>
<td>-1</td>
<td>222.00</td>
<td>Culvert</td>
<td>326,670</td>
<td>126,270</td>
</tr>
</tbody>
</table>

7.4.4 Old Tone Arm

The fourth model consists of one branch representing a 1108m stretch of the Old Tone Arm. The extent of the modelled reach is summarised in Table 7-7.

Table 7-7 Summary of the extent of the stream reach included in the hydraulic model

<table>
<thead>
<tr>
<th>Watercourse</th>
<th>Upstream model boundary</th>
<th>Downstream model boundary</th>
<th>Length of modelled reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Tone Arm</td>
<td>NGR: 326,450 : 126,860</td>
<td>NGR: 326,880 : 126,290</td>
<td>1108m</td>
</tr>
<tr>
<td></td>
<td>Just above Hyde Farm</td>
<td>Confluence with Old River Tone</td>
<td></td>
</tr>
</tbody>
</table>

Drawing M2 in Appendix D illustrates the hydraulic model details, including, the locations of the river cross-sections and the structures that were incorporated into the model.

A total of 9 surveyed cross-sections, were incorporated into the model. To improve the definition of water levels within the model, further sections were interpolated at 10m intervals between the surveyed sections.

A single structure was incorporated into this model. Cross-sections were taken on both the upstream and downstream faces of this structure and ineffective flow areas were defined where appropriate. A brief summary of these structures starting from the bottom of the model, is provided in Table 7-8.

Table 7-8 Details of modelled structures.

<table>
<thead>
<tr>
<th>Label</th>
<th>Chainage</th>
<th>Structure Type</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>470</td>
<td>470.00</td>
<td>Culvert</td>
<td>325,680</td>
<td>125,790</td>
</tr>
</tbody>
</table>
### 7.5 Flow Inputs Baseline and Post Development

Hydrographs for the peak 1 in 100 year flow events were produced for Allen’s Bank, Dyer’s Brook, Monkton Elm Drainage Ditch and Llangallar Drainage Ditch 1 & 2. In addition a hydrograph for the 20 hour duration, 1 in 100 year flow event was produced.

Hydrographs were produced at several points within the watercourse catchments, typically at confluence locations.

Full hydrographs were input at the top of each of the models, however additional inflows from catchment areas adjacent to, the river reaches modelled, were introduced as lateral flows. Table 7-9, 7-10, 7-11 and 7-12 summarise the baseline and post-development flows.

#### Table 7-9 Details of baseline modelled flows and locations for the 1 in 100 year peak flow event including a 20% allowance for climate change. (Flow in cumecs)

<table>
<thead>
<tr>
<th>Modelled Watercourses</th>
<th>Location within the Watercourse Model</th>
<th>Peak Flow to this point</th>
<th>Flow Input</th>
<th>Flow Input type</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Year – Peak Event (Tp) - Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allen's and Dyer's Brook</td>
<td>Top of Allen's Brook</td>
<td>3.35</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Top of Dyer's Brook</td>
<td>2.54</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Allen's Brook U/S of Dyer's Brook Confluence</td>
<td>N/A</td>
<td>0.56</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Allen's Brooks U/S of confluence with the River Tone</td>
<td>N/A</td>
<td>0.57</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Dyer's Brook upstream of Allen's Brook confluence</td>
<td>N/A</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>Top of Monkton Elm Drainage Ditch</td>
<td>0.01</td>
<td>0.68</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>U/S of Langaller confluence</td>
<td>N/A</td>
<td>0.11</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 1</td>
<td>Top of Langaller Drainage Ditch</td>
<td>0.24</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td>Langaller Drainage Ditch 2</td>
<td>Top of Langaller Drainage Ditch</td>
<td>N/A</td>
<td>0.83</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td>Tone Arm Ditch</td>
<td>Top of Tone Arm Ditch</td>
<td>0.24</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
</tbody>
</table>
Table 7.10 Details of baseline modelled flows and locations – 1 in 100 year 20 hour duration flow event including a 20% allowance for climate change. (Flow in cumecs)

<table>
<thead>
<tr>
<th>Modelled Watercourses</th>
<th>Location within the Watercourse Model</th>
<th>Peak Flow to this point</th>
<th>Flow Input</th>
<th>Flow Input type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100 Year – 20 Hour Duration Event - Baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top of Allens Brook</td>
<td>3.12</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Top of Dyers Brook</td>
<td>2.28</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Allens Brook U/S of Dyers Brook Confluence</td>
<td>-</td>
<td>0.54</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Allens Brooks U/S of confluence with the River Tone</td>
<td>-</td>
<td>0.55</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Dyer’s Brook upstream of Allen’s Brook confluence</td>
<td>-</td>
<td>0.98</td>
<td>Lateral inflow</td>
</tr>
</tbody>
</table>
Table 7-11 Details of post-development modelled flows and locations – 1 in 100 year peak flow event including a 20% allowance for climate change. (Flow in cumecs)

<table>
<thead>
<tr>
<th>Modelled Watercourses</th>
<th>Location within the Watercourse Model</th>
<th>Peak Flow to this point</th>
<th>Flow Input</th>
<th>Flow Input type</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Year – Peak Event (Tp) – Post development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allens and Dyers Brook</td>
<td>Top of Allens Brook</td>
<td>3.35</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Top of Dyers Brook</td>
<td>2.48</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Allens Brook U/S of Dyers Brook Confluence</td>
<td>-</td>
<td>0.51</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Allens Brooks U/S of confluence with the River Tone</td>
<td>-</td>
<td>0.57</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Dyer’s Brook upstream of Allen’s Brook confluence</td>
<td>-</td>
<td>0.87</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td>Monkton Elm Drainage Ditch</td>
<td>Top of Monkton Elm Drainage Ditch</td>
<td>0.01</td>
<td>-</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>U/S of Langaller confluence</td>
<td>-</td>
<td>0.1</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td>Tone Arm Ditch</td>
<td>Top of Tone Arm Ditch</td>
<td>0.023</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
</tbody>
</table>
Table 7-12 Details of post-development modelled flows and locations – 1 in 100 year, 20 hour duration flow event including a 20% allowance for climate change. (Flow in cumecs)

<table>
<thead>
<tr>
<th>Modelled Watercourses</th>
<th>Location within the Watercourse Model</th>
<th>Peak Flow to this point</th>
<th>Flow Input</th>
<th>Flow Input type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100 Year – 20 Hour Duration Event - Post-Development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aliens and Dyers Brook</td>
<td>Top of Allens Brook</td>
<td>3.12</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Top of Dyers Brook</td>
<td>2.28</td>
<td>-</td>
<td>Full hydrograph</td>
</tr>
<tr>
<td></td>
<td>Allens Brook U/S of Dyers Brook Confluence</td>
<td>-</td>
<td>0.49</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Allens Brooks U/S of confluence with the River Tone</td>
<td>-</td>
<td>0.55</td>
<td>Lateral inflow</td>
</tr>
<tr>
<td></td>
<td>Dyer's Brook upstream of Allen's Brook confluence</td>
<td>-</td>
<td>0.83</td>
<td>Lateral inflow</td>
</tr>
</tbody>
</table>

7.6 Roughness Coefficients

The initial roughness coefficients (Manning's 'n') used in the models were determined from observations gathered during the site visit published values and prior experience.

Table 7-13 provides roughness coefficients that were adopted in all the models.

Table 7-13: Roughness coefficients (Manning's 'n') used in the model calibration

<table>
<thead>
<tr>
<th>Type of Surface</th>
<th>Manning's 'n'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Channel</td>
<td>0.045</td>
</tr>
<tr>
<td>Banks</td>
<td>0.050</td>
</tr>
</tbody>
</table>

No historical flood level or flow data was available for the calibration of these values.

7.7 Model Boundary Conditions

The downstream boundary conditions used in the model of the Dyer's, Allen's Brook and Old Tone Arm consisted of the river stage hydrograph curve for the 1-in-200 Yr River Tone peak flood event, with a maximum predicted water level of 11.16m. This boundary condition was agreed with the Environment Agency. A copy of the river stage hydrograph curve is contained in Appendix E.
The existing watercourse bed slopes were utilised to derive a normal depth boundary condition for the Monkton Elm Drainage Ditch and Langaller Drainage Ditch 1 models.

7.8 Model Sensitivity

Tests were carried out on the models by varying the flow, Manning's ‘n’ values and downstream boundary conditions to determine the model’s sensitivity to these variables.

In the models the sensitivity of the models to roughness was investigated by varying the Manning’s ‘n’ values by +/- 20%. An assessment of the resulting water levels at each cross section of the Monkton Elm Drainage Ditch and Langaller Drainage Ditch models, adjacent to the sites, indicated an approximate average change of +/-0.13m (+/-130mm) for the model’s. This shows that these models are not particularly sensitive to changes in Manning’s ‘n’, mainly due to the steep gradient of the streambeds. It is important to check the sensitivity of the model to changes in Manning’s ‘n’ as it is expected to vary throughout the year, especially as a result of heavy vegetation occurring along ditch's banks during the summer months.

The model's sensitivity to changes in flow was also analysed by applying a +/-20% variation to the 1-in-100-year flow, used as an input to the models. This produced an average change of +/-0.12 (+/-120mm) in the Monkton Elm Drainage Ditch and Langaller Drainage Ditch model’s water levels adjacent to the sites at each of the cross sections. This variation in water level did not greatly influence the predicted flood extents.

The downstream boundary condition used in the Allen’s Brook, Dyer’s Brook and Old Tone Arm models consist of a river stage hydrograph curve. To investigate the model’s sensitivity to changes in the downstream boundary condition, the downstream river stage (water levels) were varied +/-20%. Due to the steep nature of the watercourses the predicted water levels are only affected by the River Tone over a limited extent of the downstream reaches of Allen’s Brook, Dyer’s Brook and the Tone Arm. These alterations produced no change in model results adjacent to the development site.

To investigate the Monkton Elm Drainage Ditch and Langaller Drainage Ditch model’s sensitivity to changes in the downstream boundary condition, the downstream water levels were varied +/-0.25%. These alterations produced no change in model results adjacent to the development site.

The levels predicated by the four models near the site are therefore not sensitive to flow, manning’s ‘n’ or downstream boundary conditions due to the relative steepness of the watercourses.
8 Baseline Modelling Results

HEC-RAS model runs for the Allen's and Dyer's Brook networks were carried out for a number of various duration 100 year events (2,4,8,12,16,20 hrs) with start times set to ensure that the full storm event duration occurred on the rising limb of the River Tone flood level boundary condition.

During the baseline modelling process it became apparent that the level of catchment storage detail contained within the model was not suitable to provide meaningful results within the Bathpool area. However, as discussed in Section 7.2.2, this was not required in order to quantify any potential impacts of the proposed development on baseline flood risk to third parties. A decision was made to model only the single storm event that would produce peak flow (based on catchment time to peak) from the Allen's and Dyer's Brook catchment. A single event was also applied to the other study watercourses. A discussion on the reasons for this approach is contained in Section 7.0.

A check was also made for the worst case volumetric event for the Allen's and Dyer's Brook. Runoff from a 20-hour duration storm event can fully occur within the rising limb of the River Tone flood level boundary condition. This in effect produces the greatest volume of runoff that can be river-locked by the rising River Tone water levels during the 1 in 200 year river flood event.

A discussion on the reasons for this approach are contained in Section 7.0.

8.1 Allen's and Dyer's Brook (Baseline)

The first scenario modelled presents the baseline flood risk in the modelled combined event for the existing site. The time to peak flow for the Allen's and Dyer's Brook catchment was determined at 5.5 hours. For purposes of analysis, a 6-hour duration storm event has been utilised. Figure M3, Appendix B shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Allen's Brook

A maximum flood level of 16.01m AOD occurs at the upstream end of the site. Flows adjacent the sites are contained within bank and the site is relatively unaffected by flooding from Allen's Brook for the modelled event combination.

A constriction to flow occurs at the culvert crossing of the road upstream of the site. Modelling indicates significant heading up of the culvert, however, no overtopping of the road occurs.
In the area downstream of the site, flows are also predicted to be contained within bank until out of bank flow occurs in the area upstream of the culvert passing under the Bridgwater and Taunton Canal. A maximum flood level of 12.97 is predicted here for the modelled event.

The discharge from the culvert passing under the Bridgwater and Taunton Canal would be influenced by the River Tone flooding of the Bathpool area during the modelled event.

Within the vicinity of the site the predicted Allens Brook flood levels are not influenced (for the modelled event combination) by the culvert passing under the Bridgwater and Taunton Canal or the River Tone flood levels. This is due to the marked increase in the steepness of the brook upstream of the Bridgwater and Taunton Canal crossing.

**Dyers Brook**

A maximum flood level of 28.52m AOD occurs at the upstream end of the site with a maximum flood level of 24.63m AOD occurring at the point where the brook exits the site. The brook then continues adjacent to the site with a maximum flood level of 21.55m occurring at the downstream limit of the site.

Flows through the site are generally contained within bank, however, freeboard to the top of bank is low for the modelled event. Localised flooding occurs in the vicinity of the A3259 and the existing road culvert, with minor overtopping and flow across the road during the modelled event. In general, the site area is not significantly affected from any flooding from Dyer's Brook for the modelled event combination.

Flows adjacent to the site are generally contained within bank, however freeboard to the top of bank is low for the modelled event. Localised flooding occurs upstream (approx extent of 100m) of a footbridge culvert constriction with minor out of bank flows. Overtopping of the footbridge to a shallow depth occurs. The existing properties located on the western side of the brook in this location would be considered to be at some risk of flooding in the modelled event.

In the area downstream of the site, flows are predicted to be contained within bank, until out of bank flow occurs in the urban area upstream of the Bridgwater and Taunton Canal. In this area, Dyer's Brook is a mixture of informal and formalised channel profiles (earthen and concrete) with several culvert road crossings. A maximum flood level of 14.32m is predicted in this area with significant overflows across or into the Bridgwater and Taunton Canal. The existing properties in this location would be considered to be at some risk of flooding in the modelled event.

The discharge from the culvert passing under the Bridgwater and Taunton Canal would be influenced by the River Tone flooding of the Bathpool area during the modelled event.
Within the vicinity of the site the predicted Dyers Brook flood levels are not influenced (for the modelled event combination) by the culvert passing under the Bridgwater and Taunton Canal or the River Tone flood levels. This is due to the marked increase in the steepness of the brook upstream of the Bridgwater and Taunton Canal crossing.

8.2 Old Tone Arm (Baseline)

The time to peak flow for the Old Tone Arm catchment was determined at 2.8 hours. For purposes of analysis a 2-hour duration storm event has been utilised. Figure M3, Appendix B shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Flows are predicted to remain within the existing channel profile with freeboards greater than 300mm. The existing culvert crossing beneath the Bridgwater and Taunton Canal has an adequate capacity to convey the flows in the modelled scenarios.

Flows within the site are contained within bank and the site is relatively unaffected from any flooding from the Old Tone Arm for the modelled event combination.

Within the vicinity of the site the predicted Old Tone Arm flood levels are not influenced (for the modelled event combination) by the culvert passing under the Bridgwater and Taunton Canal or the River Tone flood levels. This is due to the marked increase in the steepness of the brook upstream of the Old River Tone.

8.3 Monkton Elm Drainage Ditch (Baseline)

The time to peak flow for the Monkton Elm Drainage Ditch catchment was determined at 3.8 hours. For purposes of analysis a 4-hour duration storm event has been utilised. Figure M3, Appendix B shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Flows adjacent to the site are generally contained within bank, however, localised flooding occurs upstream (approx 150m) of a road crossing constriction located at the southern site boundary. Minor out of bank flows occur with overtopping to shallow depths on the road. No existing properties or structures are affected.
Flows within the site are contained within bank and the site is relatively unaffected from any flooding from the Monkton Elm Drainage Ditch for the modelled event combination.

Within the vicinity of the site the predicted Monkton Elm Drainage Ditch flood levels are not influenced (for the modelled event combination) by the River Tone flood levels or M5 motorway culverts. This is due to the marked increase in the steepness of the brook upstream of the River Tone and adequately sized M5 motorway culverts.

8.4 Langaller Drainage Ditch (Baseline)

The time to peak flow for the Langaller Drainage Ditch catchment was determined at 4.5 hours. For purposes of analysis a 4-hour duration storm event has been utilised. Figure M3, Appendix B shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Flows are predicted to remain within the existing channel profile on the site, with freeboards typically greater than 300mm. A constriction to flow occurs at the culvert crossings upstream of the site. Modelling indicates heading up of the culverts, however, no overtopping of the road occurs.

Flows within the site are contained within bank and the site is relatively unaffected from any flooding from the Langaller Drainage Ditch for the modelled event combination.

Within the vicinity of the site the predicted Langaller Drainage Ditch 1 flood levels are not influenced (for the modelled event combination) by the River Tone flood levels or M5 motorway culverts. This is due to the marked increase in the steepness of the brook upstream of the River Tone and adequately sized M5 motorway culverts.
9 Drainage Strategy

9.1 General

The proposed development of Monkton Heathfield will increase the impermeable area of the site and consequently increase both the volume and magnitude of surface water run-off generated. If this additional run-off is discharged unattenuated into the surrounding surface water networks, it would increase the risk of these watercourses flooding both the Monkton Heathfield site, Bathpool and other areas downstream of the site.

Consequently, it is proposed that surface water discharges into the watercourse network, from the developed Monkton Heathfield site, will first be attenuated using a number of attenuation basins.

The consideration of Sustainable Urban Drainage Systems (SUDS), of which attenuation basins are an established type, is promoted in Planning Policy Guidance Note 25 - Development and Flood Risk. As well as providing attenuation, attenuation basins can provide some incidental treatment of flows (water quality) and also provide habitats for wildlife, flora and fauna and amenity.

The principles adopted in developing the surface water disposal options for the Monkton Heathfield site have been discussed with the Environment Agency, Taunton Dean Borough Council, Wessex Water and Somerset County Council. Where possible the surface water drainage system should be designed and constructed to have a minimal impact upon flood levels and flood volumes in the receiving watercourses and surrounding surface drainage networks. Ideally no flood level or flood volume increases or a reduction in flood levels or flood volumes should be attained. Where this cannot be reasonably achieved to a full extent, the scheme would be assessed on a case base by the Environment Agency and would take into account the associated risk and potential cost to property, infrastructure and the community.
Table 9-1 summarises the principal disposal options which were considered, together with associated comments.

<table>
<thead>
<tr>
<th>Mitigation Measure</th>
<th>Adopted for Investigation</th>
<th>Reason/Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Mitigation</td>
<td>No</td>
<td>Unacceptable flood level increases.</td>
</tr>
<tr>
<td>Offline Surface Storage</td>
<td>Yes</td>
<td>Significant open space would be available on the site. Gravity drainage is likely for the majority of the site areas. Opportunities for the offline storage ponds to operate in a multi-functional role as attenuation, amenity, water quality and wet/dryland ponds. Minimum maintenance required.</td>
</tr>
<tr>
<td>On-line Surface Storage</td>
<td>No</td>
<td>Significant open space would be available within the site watercourse corridors. Gravity drainage is likely for the majority of the site areas. Opportunities for the on-line storage ponds to operate in a multi-functional role as attenuation, amenity, water quality and wet/dryland ponds. Located in watercourse floodplain or existing watercourses with potential disturbance/impact on the local environment. Adoption and maintenance issues.</td>
</tr>
<tr>
<td>Tank Storage</td>
<td>No</td>
<td>Cost, maintenance, adoption and encumbrance issues.</td>
</tr>
<tr>
<td>Individual Property Storage</td>
<td>No</td>
<td>Cost, maintenance and encumbrance issues.</td>
</tr>
<tr>
<td>Infiltration</td>
<td>No</td>
<td>Site tests indicate that the infiltration potential for the site is poor.</td>
</tr>
<tr>
<td>Over Pumping Facilities</td>
<td>Yes</td>
<td>Cost, maintenance, adoption and encumbrance issues. Failure issue.</td>
</tr>
</tbody>
</table>
9.2 **Piped Drainage System**

Surface water from roofs, highways and other paved areas of the new development will generally be conveyed to the attenuation basins by piped gravity drainage systems. The layout of the piped systems will generally follow that of the new roads provided to access both the development plots and the properties within these plots.

It is proposed that the piped surface water systems will be designed and constructed to adoptable standard (Sewers for Adoption 5th Edition). This will result in the system being designed to a 1 in 1 year standard (Standard Highway) and checked for no flooding of any part of the site under a 1 in 30 year return period design storm with an additional 20% flow allowance for climate change. Overland flows resulting from storm events exceeding the design criteria will be channelled by the roads and, where possible, intercepted by ditches, which would convey the flows to the attenuation ponds.

The Monkton Heathfield site area has been divided into 8 sub-catchments based on the proposed attenuation basin and outfall locations. Figure M4 Appendix F show the 8 post-development sub-catchments. It should be borne in mind that these catchments are preliminary only. The final catchments will be subject to a co-ordinated detailed design that takes into account the arrangement of development plots, roads layouts and drainage design.

Table 9-2 summarises the sub-catchment surface drainage outfall location, details and characteristics and basin outfall location utilised in the post-development assessment.

<table>
<thead>
<tr>
<th>Monkton Heathfield Sub-Catchments</th>
<th>Sub-Catchment Area (Ha)</th>
<th>Surface Drainage Outfall Point</th>
<th>Surface Drainage Outfall Level to Watercourse (mAOD)</th>
<th>Outfall Comments</th>
<th>Basin Outfalls To</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.54</td>
<td>Upper Dyers Brook Basin</td>
<td>24.2</td>
<td>Dry Attenuation Basin</td>
<td>Dyers Brook</td>
</tr>
<tr>
<td>2</td>
<td>10.26</td>
<td>Lower Dyers Brook Basin</td>
<td>18.9</td>
<td>Dry Attenuation Basin</td>
<td>Dyers Brook</td>
</tr>
<tr>
<td>3</td>
<td>2.75</td>
<td>Allens Brook Basin 1</td>
<td>18.9</td>
<td>Dry Attenuation Basin</td>
<td>Allens Brook</td>
</tr>
<tr>
<td>4</td>
<td>1.38</td>
<td>Allens Brook Basin 1</td>
<td>17.8</td>
<td>Dry Attenuation Basin</td>
<td>Allens Brook</td>
</tr>
</tbody>
</table>
Attenuation Basin Assessment

9.3.1 General

Attenuation basin performance has been assessed using the WINDES software program, an industry standard drainage design tool developed by Micro-Drainage. Input hydrographs for the attenuation basins were calculated as part of the trunk drainage design. Full details of the preliminary trunk drainage system are contained in Appendix F. A summary of peak design inflows are given in Table 9-5.

Attenuation basin outlet arrangements were finalised after consideration of the existing brook/ditch invert levels at the point of discharge, attenuation storage top water level (TWL) and invert level of the incoming urban surface drainage system (piped). Discharges from the basin were limited, as appropriate, using appropriately sized orifice plates (other flow control mechanisms may be utilised during detailed design). An emergency spillway was also included in the attenuation basin arrangements.

The attenuation basin arrangements were assessed for various duration 100 year return period storm events. It was found that the 1 in 100 year, 2 hour duration storm event produced the greatest basin top water levels and volumes. Tail water levels in the receiving brook/ditch were obtained from the hydraulic modelling.

9.3.2 Setting Attenuation Basin Outflows

Controlled release from the Sites attenuation basins to the surrounding watercourses would have to ensure no impact on flood levels or brook morphology. In addition given the historical Bathpool flooding issues and sensitivity of the downstream Somerset Levels and Moors the volume of runoff released from the site will need to be controlled so as to ensure no impact on flood volumes during the rising limb of a river locking scenario.
The volume of runoff generated from the development site will always be greater than the current volume of runoff given the highly impervious nature of urban development and unsuitability of the local ground to infiltration. However the retention and release of this volume after the critical flood event and river locking would result in minimising any potential impacts.

**Greenfield Runoff Rates**

An estimation of "greenfield" runoff rates was prepared for the site using the Mike 11 Rainfall Runoff software. "Greenfield" runoff rates for different rainfall recurrence intervals (return periods) and duration were calculated from the general catchment descriptors for the Allen's and Dyer's Brook catchment as described in Section 5.0 Hydrological Modelling.

Table 9-3 summarises the proposed "greenfield" runoff rates for the development site.

<table>
<thead>
<tr>
<th>Duration (hrs)</th>
<th>Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>(100 Yr) 5.5 Tp</td>
<td>330</td>
</tr>
<tr>
<td>Greenfield Runoff Rate (flow l/s/ha)</td>
<td>3.6</td>
</tr>
</tbody>
</table>

The adopted greenfield runoff rate for the site is 3.6 L/s/ha. This equates to an approximate storage requirement of 500m³/ha.

**Volumetric Runoff Rate**

The worst case volumetric event would be a 20 hour duration storm event which can fully occur within the rising limb of the River Tone flood level boundary condition. This would produce the greatest volume of runoff that can be effect by the river-lock. This is further discussed in Section 7.0.

A preliminary estimate for the volumetric runoff rate is contained within Appendix F. The estimate is approximate only, but useful as a design guide in the strategic sizing of the attenuation storage's. The adopted volumetric runoff rate is 2.5L/s/ha. This equates to an approximate storage requirement of 600m³/ha.

**Adopted Runoff Rate**

Typically the 1 in 2 year "greenfield" runoff rates and volumes are adopted for development attenuation basin sizing. However for purposes of the preliminary strategic assessment the Volumetric Runoff Rate has been adopted. Their may be scope during detailed design to fine tune the basin arrangements.
9.3.3 Dry Ponds and Reed Zone

The dry ponds will be progressively inundated during storm events. The area most frequently inundated (ie typically during minor storms) will be planted out using suitable native grasses and reeds. This area will typically be located at 0.1 to 0.3m below the surrounding open space. The reed zone will be dry in most periods with inundation intermittent during a normal rainfall year (low return period storm events). This will be achieved by appropriate design of the pond outfall structure.

The reed zone volumes have not been included in the proposed attenuation basin volume assessments.

9.3.4 Attenuation Basin Design Parameters

Table 9.4 summarises the attenuation basin design parameters for basins out falling from the site to the surrounding surface drainage networks. Refer Appendix F for the preliminary attenuation basin general arrangements.

<table>
<thead>
<tr>
<th>Pond No</th>
<th>Dry Pond Invert (m AOD)</th>
<th>Attenuation Basin Design Surface Area at TWL (m²)</th>
<th>Attenuation Basin Design TWL (m AOD)</th>
<th>Attenuation Basin Design Storage Volume (m³)</th>
<th>Attenuation Basin Design Emergency Spillway (m AOD)</th>
<th>Attenuation Basin Design Top Of Bank (m AOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Dyers Brook Basin</td>
<td>24.5</td>
<td>470</td>
<td>26.0</td>
<td>450</td>
<td>26.15</td>
<td>26.3</td>
</tr>
<tr>
<td>Lower Dyers Brook Basin</td>
<td>19.5</td>
<td>5150</td>
<td>20.7</td>
<td>3100</td>
<td>20.85</td>
<td>21.0</td>
</tr>
<tr>
<td>Allens Brook Basin 1</td>
<td>18.8</td>
<td>1000</td>
<td>19.7</td>
<td>1000</td>
<td>19.85</td>
<td>20.0</td>
</tr>
<tr>
<td>Allens Brook Basin 2</td>
<td>18.3</td>
<td>500</td>
<td>19.5</td>
<td>500</td>
<td>19.65</td>
<td>19.8</td>
</tr>
<tr>
<td>Monkton Elm Basin 1</td>
<td>21.5</td>
<td>9000</td>
<td>23.3</td>
<td>11,000</td>
<td>23.45</td>
<td>23.6</td>
</tr>
<tr>
<td>Monkton Elm Basin 2</td>
<td>21.4</td>
<td>2300</td>
<td>23.2</td>
<td>2300</td>
<td>23.35</td>
<td>23.5</td>
</tr>
<tr>
<td>Tone Arm Ditch Basin 1</td>
<td>20.5 Stream</td>
<td>1000</td>
<td>21.8</td>
<td>500</td>
<td>21.8</td>
<td>21.8</td>
</tr>
<tr>
<td></td>
<td>21.5 Pitch</td>
<td>17000</td>
<td>21.8</td>
<td>4100</td>
<td>21.8</td>
<td>21.8</td>
</tr>
<tr>
<td>Tone Arm Ditch Basin 2</td>
<td>14.4</td>
<td>200</td>
<td>17.2</td>
<td>500</td>
<td>17.35</td>
<td>17.5</td>
</tr>
</tbody>
</table>
9.3.5 Attenuation Basin Assessment Results

The worst-case storage volume and basin TWL results are presented within this section. Output from the analysis including predicted storage volumes and basin TWL's are contained within Appendix F.

The worst case storm duration for the attenuation storage design was determined as the 2 hour duration event. Longer duration events were checked but, as these events have a lower rainfall intensity, did not produce the worst attenuation basin top water level and thence volume. Table 9-5 summarises the attenuation basin results.

<table>
<thead>
<tr>
<th>Pond No</th>
<th>Attenuation Inflow (l/s)</th>
<th>Attenuation Basin Outflow (l/s)</th>
<th>Attenuation Basin TWL (m AOD)</th>
<th>Attenuation Basin Storage Volume (m³)</th>
<th>Attenuation Basin Design Top of Bank (m AOD)</th>
<th>Attenuation Basin Freeboard (m AOD)</th>
<th>Attenuation Basin Storage Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Dyers Brook Basin</td>
<td>430</td>
<td>4</td>
<td>26.9</td>
<td>420</td>
<td>26.3</td>
<td>0.4</td>
<td>30</td>
</tr>
<tr>
<td>Lower Dyers Brook Basin</td>
<td>1045</td>
<td>23</td>
<td>20.65</td>
<td>2910</td>
<td>21.0</td>
<td>0.35</td>
<td>35</td>
</tr>
<tr>
<td>Allens Brook Basin 1</td>
<td>120</td>
<td>10</td>
<td>19.5</td>
<td>820</td>
<td>19.85</td>
<td>0.35</td>
<td>30</td>
</tr>
<tr>
<td>Allens Brook Basin 1</td>
<td>80</td>
<td>10</td>
<td>19.3</td>
<td>390</td>
<td>19.65</td>
<td>0.35</td>
<td>30</td>
</tr>
<tr>
<td>Monkton Elm Basin 1</td>
<td>3065</td>
<td>75</td>
<td>23.1</td>
<td>8900</td>
<td>23.6</td>
<td>0.5</td>
<td>33</td>
</tr>
<tr>
<td>Monkton Elm Basin 2</td>
<td>210</td>
<td>14</td>
<td>23.05</td>
<td>1100</td>
<td>23.35</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>Tone Arm Ditch Basin 1</td>
<td>1400</td>
<td>23</td>
<td>21.75</td>
<td>4400</td>
<td>21.8</td>
<td>0.05</td>
<td>33</td>
</tr>
<tr>
<td>Tone Arm Ditch Basin 2</td>
<td>450</td>
<td>8</td>
<td>17.0</td>
<td>420</td>
<td>17.35</td>
<td>0.35</td>
<td>30</td>
</tr>
</tbody>
</table>

The attenuation basin results highlight the significant attenuation storage that will be provided on-site. The time for these basins to empty during the worst case event combination are typically greater than a day and would coincide with the falling limb of the River Tone river stage/duration curve. The impact of the released flows therefore would be considered negligible.

9.3.6 Over-pumping Discussion

During initial discussion with the Environment Agency this was mentioned by the Environment Agency as a potential site mitigation measure. Subsequent assessment work has shown that significant site storage areas can be accommodated on-site.
Therefore an expensive and high maintenance mechanistic solution has not been developed further.

9.3.7 Storage For Lower Return Interval Storm Events

The analysis of less intense storm events (ie 1 in 2 year return period) on the study area was not within the scope of work for this assessment and would form part of detailed design work to finalise the basin storage and outlet arrangements.

It would be expected that a further reduction in peak flows and volumes would occur in the watercourses within, adjacent to and downstream of the site including the Bathpool area. There is significant attenuation storage provided on-site and flows from these basins, and therefore the new development areas have been heavily restricted.

This would need to be confirmed by further detailed investigation.
Post Mitigation Modelling Results

HEC-RAS model runs for the site watercourses were carried out for the peak flow and volumetric 1-in-100 year storm events with the River Tone 1-in-200 year river stage hydrograph curve. In addition further adjustments to the model were made to include the Drainage Strategy, including the proposed attenuation basins.

This enabled the worst-case storm duration, river flood level and attenuation basin operation combination to be identified. The worst-case combination only is discussed within this section.

Basin operation results for the worst case event are contained within Appendix F.

10.1 Allen’s and Dyer’s Brook (Post-Development)

The second scenario modelled presents the post-development flood risk in the modelled combined event for the site levels as shown on the RPS masterplan. The time to peak flow for the Allen’s and Dyer’s Brook catchment was determined at 5.5 hours. For purposes of analysis a 6-hour duration storm event has been utilised. Figure M3 Appendix D shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Generally the post-development flood levels are predicted to be marginally lower than the baseline flood levels at all locations. Minor flood level reductions are predicted over the pre-development scenario. In addition the volumes contained in the brooks are predicted to be marginally lower than the baseline conditions.

The decrease in flood levels and flood volume is a result of the proposed surface drainage strategy and attenuation storage.

Comparison of the baseline and post development hydrograph for flows in the brooks upstream of the Bridgewater and Taunton Canal, confirm no increase in peak flows into the brooks as a result of development and confirm the adopted drainage strategy as satisfactory.

As for the existing (baseline) scenario, Allen’s and Dyer’s Brook will be river-locked by the River Tone. Flood extents and depth would only differ marginally (beneficially) from those described for the baseline scenario. Therefore the baseline comments regarding the flood risk to the site, Bathpool and other downstream areas are essentially similar.

The majority of the Monkton Heathfield Development site would be considered at no risk of flooding from Allen’s or Dyer’s Brook. The principal...
accesses and development plots are all above the predicted worst case flood level combination. Adequate freeboard to development floor levels would be provided.

10.2 Old Tone Arm (Post-Development)

The second scenario modelled presents the post-development flood risk in the modelled combined event for the site levels as shown on the RPS masterplan. The time to peak flow for the Old Tone Arm catchment was determined at 2.8 hours. For purposes of analysis a 2-hour duration storm event has been utilised. Figure M3 Appendix D shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Generally the post-development flood levels are predicted to be lower than the baseline flood levels at all locations. Flood level reduction of up to 130mm are predicted over the pre-development scenario. In addition, the volumes contained in the brooks are predicted to be lower than the baseline conditions.

The decrease in flood levels and flood volume is a result of the proposed surface drainage strategy and attenuation storage. The majority of the Tone Arm catchment would be directed into the site attenuation basins where a significant constriction to flow is provided. There would appear to be scope to release additional flow from the catchment basins given the adopted volumetric rate of 2.5/s/Ha would appear overly conservative. This would need to be investigated and confirmed during detailed design.

Comparison of the baseline and post development hydrograph for flows in the ditch upstream of the Bridgewater and Taunton Canal confirm no increase in peak flows into the brooks as a result of development and confirm the adopted drainage strategy as satisfactory.

As for the existing (baseline) scenario, the Old Tone Arm Ditch is not influenced (for the modelled event combination) by the culvert passing under the Bridgewater and Taunton Canal or the River Tone flood levels.

Flood extents and depth would only differ marginally (beneficially) from those described for the baseline scenario. Therefore the baseline comments regarding the flood risk to the site, Bathpool and other downstream areas are essentially similar.

The majority of the Monkton Heathfield Development site would be considered at no risk of flooding from the Old Tone Arm Ditch. The principal accesses and development plots are all above the predicted worst case flood level combination. Adequate freeboard to development floor levels would be provided.
10.3 Monkton Elm Drainage Ditch (Post-Development)

The second scenario modelled presents the post-development flood risk in the modelled combined event for the site levels as shown on the RPS masterplan. The time to peak flow for the Monkton Elm Ditch catchment was determined at 3.8 hours. For purposes of analysis a 4-hour duration storm event has been utilised. Figure M3 Appendix D shows the indicative extent of flooding for this storm duration and the river flood level combination predicted in the modelling.

Comments regarding combined probabilities discussed in Section 7.0 should be noted when viewing the flood mapping.

Generally the post-development flood levels are predicted to be lower than the baseline flood levels at all locations. Flood level reduction of up to 470mm are predicted over the pre-development scenario. In addition, the volumes contained in the ditch are predicted to be lower than the baseline conditions.

The decrease in flood levels and flood volume is a result of the proposed surface drainage strategy and attenuation storage. There would appear to be scope to release additional flow from the catchments basins given the adopted volumetric rate of 2.5l/s/ha would appear overly conservative. This would need to be investigated and confirmed during detailed design.

Comparison of the baseline and post development hydrograph for flows in the ditch upstream of the M5 culvert crossing confirm no increase in peak flows into the brooks as a result of development and confirm the adopted drainage strategy as satisfactory.

As for the existing (baseline) scenario, the Monkton Elm Ditch is not influenced (for the modelled event combination) by the culvert passing under the M5 or the River Tone flood levels. Flood extents and depth would only differ marginally (beneficially) from those described for the baseline scenario. Therefore the baseline comments regarding the flood risk to the site, and other downstream areas are essentially similar.

The majority of the Monkton Heathfield Development site would be considered at no risk of flooding from the Monkton Elm Ditch. The principal accesses and development plots are all above the predicted worst case.

10.4 Langaller Drainage Ditch (Post-Development)

No post development modelling of Langaller Drainage Ditch was required. No areas of the proposed development will discharge to this ditch and therefore the baseline conditions remain unaltered.