Idle and Torne High Flow Study

Phase 2b

Environment Agency

November 2020
Quality information

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Revision History

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1. Introduction

1.1 Project Appreciation

The Idle and Torne catchments are closed to any new consumptive abstraction\(^1\) because there is a lack of an evidence base to prove whether high flow abstraction has an ecological effect or not, with regard to the following:

- Uncertainty over the role and importance of high flows in maintaining the geomorphological and ecological functioning of the river systems;
- A degree of uncertainty with respect to water levels and connectivity to floodplain washlands;
- Uncertainty over the importance of high flow in supporting downstream estuarine habitats associated with the river Humber; and
- Concerns regarding the over-abstracted nature of the underlying aquifer.

The first two points are considered further during Phase 2b.

Both systems, encompassing 1,200km\(^2\) in total, are hydrologically complex being comprised of a number sub-catchments including a number in the lower reaches which are pumped.

Abstractions of high flows greater than the Environmental Flow Indicator (EFI) in both catchments is being considered. The EFI for the Torne is equivalent to the Q\(_{15}\) while the EFI for the Idle is equivalent to the Q\(_{18}\).

The purpose of the overall project is to derive an evidence base to demonstrate whether abstraction at high flows on the Idle and Torne would have an adverse environmental impact or not. Specifically the project aim is to understand the importance of high flows for supporting the current and potential future ecological status of the river catchments with respect to compliance with relevant environmental protection obligations.

AECOM undertook the first study of this project, on the behalf of the Environment Agency, culminating in October 2015 in the production of a feasibility study report\(^2\). This identified the next steps from which the current project (Phase 2) has resulted.

1.2 Phase 2 Objectives

The key objective of Phase 2 is to understand the significance of high flows and floodplain connections for in-stream, riparian and terrestrial habitats that are hydraulically connected to the rivers and their floodplains.

Through developing this baseline understanding we would be able to determine the effects of potential abstraction of flows above the EFI.

Phase 2 is separated into two parts, as follows:

- Phase 2a: Review of hydraulic and groundwater models to examine their suitability of use in this study and updated and expanded review of the environmental baseline.
- Phase 2b: Undertake more detailed investigations (activities to be determined on completion of Phase 2a).

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\(^2\) AECOM (2015) - High Flow Abstraction for Multiple Environmental Benefits in the Idle and Torne Catchments – A Feasibility Study - Phase 1 Report
Phase 2a was completed in the spring of 2020 and outlined the recommended next steps for Phase 2b. Those steps were subsequently agreed with the Environment Agency. This report presents our findings from Phase 2b of the project. In addition to endeavouring to better understand the significance of high flows and floodplain connections for habitats, a key aspect of Phase 2b was to test alternate approaches that help answer these questions and ascertain how these approaches could be refined going forward.
2. Phase 2b Methodology

2.1 Background and Phase 2a findings

There are 37 Water Framework Directive (WFD) waterbodies in total in both catchments. During Phase 2a a more detailed review than undertaken in Phase 1, of the potential effects of abstractions at time of high flow (above the EFI in both catchments) on the physical environment of and receptors in the 37 waterbodies, was undertaken. Through this the following waterbodies were recommended to be explored further in Phase 2b:

- Idle from River Ryton to River Trent (including River Idle Washlands SSSI);
- Maun from Vicar Water to Rainworth Water;
- Meden from Sookholme Brook to River Maun;
- Poulter from Source to Millwood Brook;
- Poulter from Millwood Brook to River Maun (including Clumber Park SSSI); and
- Ryton from Anston Brook to Idle.

Future studies on the following waterbodies, considered to potentially be moderately sensitive to changes, were also recommended:

- Hatfield Waste Drain (trib of Torne/Three Rivs) and North Soak Drain (trib of Torne/ Three Rivs) (focussed on Crowle Borrow Pits SSSI);
- Meden from Source to Sookholme Brook;
- Ryton (to Anston Brook); and
- Sookholme Brook.

2.2 Phase 2b Tools

2.2.1 Overview

At the outset of Phase 2b the following tools were available to progress the investigations:

- CAESAR-LisFlood modelling;
- ISIS-TuFlow modelling; and
- Site visits and interpretation.

These are discussed further below.

2.2.2 Hydraulic Modelling

CAESAR-LisFlood

The potential effects of abstractions at high flows can be investigated through constructing CAESAR-LisFlood models of discrete reaches/areas. The tool can be used to determine flow conditions at which out of bank flows and inundation of riparian floodplain areas occurs and examine in channel effects (such as changes in velocities/shear stresses). Similarly potential differences, due to additional abstractions at times of high flow abstraction, can be investigated through scenario analysis using the CAESAR-LisFlood model.

Examples of some of the outputs from a previous study by AECOM in which the approach was tested, are provided below (Figure 2.1).

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CAESAR-LisFlood 2D (referred to as CAESAR) offers an efficient modelling approach solving the simplified depth-averaged St Venant equations to define flow routes and inundation levels dependent on an underlying digital elevation model (DEM). The model is benchmarked and approved by the Environment Agency.  

CAESAR-LisFlood is an open source modelling package where users interact with a graphic interface. It does not require administration rights for users to download and run. The model requires two primary inputs: a DEM that acts as the modelling surface over which flow is routed, and a flow input (multiple inputs are actually possible at multiple locations).

Where the CAESAR-LisFlood approach was used the DEM for each site was constructed from the available LiDAR, supplemented by measurements made on site (discussed further below under Site Visits).

Flow rates were determined from nearby flow gauging.

*The existing 1D/2D hydraulic FMP-TUFLOW flood model*

During Phase 2a the existing Environment Agency River Idle and Torne strategic scale linked 1D/2D hydraulic FMP-TUFLOW models were found to only cover a small proportion of the total study area (e.g. the River Idle model did not include any of the Rivers Meden, Maun, Ryton and Poulter catchments).

Further studies were desired in the level dependent section of the River Idle (Idle Washlands SSSI). However, through this section CAESAR-LisFlood was not considered ideal as amongst others, it is not able to include pumping stations. For this reason it was agreed to run a discrete number of high flow scenarios using the existing FMP-TUFLOW model and review results of these, for any affects and/ or recommend next steps.

*Scenario Modelling*

For both modelling systems a number of high flow scenarios were run. These were informed by hydrological studies undertaken during Phase 2a and included:

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Idle and Torne High Flow Study

Q_{18} (above which additional abstraction may become possible in the Idle catchment and potential new hands off flow);
Q_{15};
Q_{10};
Q_{5}; and
Q_{2}.

This range is considered to represent the range of high flows under which abstractions are most likely to occur and have the greatest effect. The amount and locations of abstraction are not stated and so potential affects have been considered in a general non-specific manner (e.g. may occur upstream of the sites being reviewed noting that if they were downstream affects would be potentially negligible).

No hydraulic modelling was undertaken in the Torne catchment (where the Q_{15} is the proposed hands off flow).

Model results, interpretation and limitations

Results from both models included velocities, depths and inundation extents. Shear stresses are also calculated within CAESAR-LisFlood while they can be calculated from other FMP-TUFLOW outputs.

The results were interpreted to ascertain potential effects of abstractions at time of high flow may be, and whether these would be significant, or indicate where further efforts are recommended.

For this phase of works approximation of a number of aspects, such as using coarse measurements of channel depths to stamp channels into the model rather than integrating formal channel surveys which can be expensive and had not been undertaken to date for much of either catchment. It is noted that aspects such as reach wide DEM adjustment based on a limited number of coarse measurements, rather than formal surveys, increases the levels of uncertainty and the confidence from in any subsequent results.

Ultimately, modelling undertaken during Phase 2b was done in order to explore the capability the alternate modelling approaches and if possible, acknowledging levels of confidence in the accuracy of specific model results, help improve the understanding of the potential effects of abstraction at times of high flow. Further refinements of the modelling, and general assessment, approach have been determined through the efforts outlined in this report.

2.2.3 Site Visits

During Phase 2b it was also possible to visit a number of locations in both catchments. These were used for the following purposes:

- To gather information used to calibrate, validate and sense check the hydraulic models described in Section 2.2.2 above; and
- Visit other locations/waterbodies identified as potentially sensitive during Phase 2a to further inform the appraisal of potential affects at these locations (one further site was indicated by the Environment Agency to be worth visiting).

Information gathered on site included observations of the site to:

- help understand how it functions (e.g. if distributaries were present, how in channel structures such as sluices function etc.);
- help understand site characteristics (e.g. with regard to hydromorphology);
- gather photos; and
- obtain site measurements.

On site measurements were made using a staff so that coarse measurements of channel dimensions could be undertaken such as channel widths, bank heights, wetted depths could be made. A limited
number of measurements at each site were made so full variability at a location/ section is not captured. Photographs of the site were taken from which an indication of variability across a channel can be gained, however. The limitations of such measurements are recognised as described above under “Model results, interpretation and limitations”.

Flow conditions at the time of site visits at particular locations were approximated with due regard to river level measurements on the days of the surveys, upstream and/or downstream of our sites. As levels varied throughout the day and time of travel of flow to or from the site were not know, estimates of flow conditions at the time of each survey were ultimately made. Similarly in level controlled sections flow conditions upstream would not be the only influence on the hydrology at the time of the site visit. Such approximations and potential uncertainties they bring into the appraisal are recognised within this study though have not been quantified.

Formal surveys, to Ordnance Datum, were not undertaken during this phase of the project. Site visits were undertaken on two days covering a number of locations, at a time when COVID-19 restrictions limited welfare conditions. Although site visits were undertaken rapidly they were undertaken by an experienced pair of Water Scientists who were able to gain useful information on each site visited that was subsequently used to inform the analysis approach, subsequent interpretation and inform the proposed next stages of the overall project.

2.3 Phase 2b Approach

Through discussions at the outset of Phase 2b the following approach was agreed (to help determine the potential effects of abstractions at times of high flow):

- Complete CAESAR-LisFlood modelling studies of the Meden at Budby and Poulter in the vicinity of Elkesley;
- Complete modelling of the potential effects on the Idle Washlands SSSI using the existing FMP-TUFLOW hydraulic flood model; and
- Visit a number of other waterbodies in the Torne and Idle catchments considered to be potentially sensitive to the effects of high flow abstraction (ultimately this included sites in the North Soak Drain, Ryton (Anston to Idle), Poulter (Source to Millwood) and Maun (Vicar Water to Rainworth) WFD waterbodies).

The approach was developed through discussions with the Environment Agency.

Results of Phase 2b efforts are presented in the following sections.
3. Meden (Sookholme Brook to Maun)

3.1 Environmental baseline

3.1.1 Site description

The River Meden lies in Nottinghamshire. It is one of the River Idle headwaters and a key tributary of the River Maun. The Meden flows north east through Warsop and Budby before merging with River Maun.

Based on the results of Phase 2a and subsequent discussions with the Environment Agency, the Meden (Sookholme Brook to Maun) WFD waterbody has been chosen to undertake more detailed investigations. The particular focus area of study around Meden, is located around the hamlet of Budby, Nottinghamshire (Figure 3.1). The Phase 2a review indicated higher value habitat in this waterbody compared to other waterbodies and rivers in the catchment. The higher value habitat sites could be more sensitive to deterioration with macroinvertebrate and macrophyte species present being sensitive to increased sedimentation and/or flow changes.

Review of imagery of the river indicated that it supports aquatic and submerged macrophyte populations. The Meden at Budby was also observed to have surface bed gravels which often serve as good habitat and which may be vulnerable to reduced fine sediment transport (less flushing/increased deposition) if high flows are abstracted. Results of the site visit are discussed further below.

Figure 3.1 Idle Catchment and location of the Meden (Sookholme to Maun) WFD waterbody

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3.1.2 Water Resources

Waterbodies and structures

An initial study area was determined and is indicated in Figure 3.2. The figure also shows a number of waterbodies through the study area, including ditches and reservoirs in addition to the river itself.

Figure 3.2 Meden (Sookholme Brook to Maun) at Budby structures

In addition, a further map of the area has been obtained and is provided in Figure 3.3. This shows the presence of a pumping station in the Budby area.

Figure 3.3 Meden (Sookholme Brook to Maun) at Budby structures

Hydrology

The Environment Agency maintains a network of two hydrological monitoring points throughout the River Meden catchment. Those gauging stations, located close to the study area, are Meden at Church Warsop (upstream) and Meden at Perlethorpe (downstream). Summary flow information for those sites is provided in Table 3.1.

Table 3.1 Summary flow information for gauges in the River Meden

<table>
<thead>
<tr>
<th>Name</th>
<th>Catchment area (km²)</th>
<th>Period of record</th>
<th>$Q_{95}$</th>
<th>$Q_{70}$</th>
<th>$Q_{50}$</th>
<th>$Q_{10}$</th>
<th>$Q_{5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meden at Church Warsop</td>
<td>63</td>
<td>1965-2018</td>
<td>0.25</td>
<td>0.37</td>
<td>0.48</td>
<td>1.06</td>
<td>1.39</td>
</tr>
<tr>
<td>Meden at Perlethorpe</td>
<td>97</td>
<td>2002-2013</td>
<td>0.35</td>
<td>0.51</td>
<td>0.62</td>
<td>1.11</td>
<td>1.36</td>
</tr>
</tbody>
</table>

3.2 Initial Site Walkover

3.2.1 Overview

The site was visited on the 12th June 2020 to improve our understanding of the functioning of the site and conditions present, as well as obtain a number of channel measurements. Each of these helped improve the modelling exercise as well as the subsequent interpretation of modelling results.

Site measurements Access through much of the site was restricted although at the upstream and downstream ends of the site the watercourse could be observed. Figure 3.4 shows the location of the sites surveyed along the Meden. In addition data from an RHS monitoring point just upstream of Survey locations 3 was obtained from the Environment Agency.

Figure 3.4 Sites surveyed at Meden (in red circles) flow direction is to the east/ right
Table 3.2 shows the levels measured on the study area when the survey was undertaken (12th June 2020) ordered from upstream to downstream. Images from the sites are provided in Plates 3.1 – 3.7. The channel was observed to be is uniform, characterised by gliding flow and with an absence of bedforms (pools, riffles, bars). Gravels appear to be present on the bed, covered in a layer of fine silt deposits. Mild undercutting of the banks was observed (e.g. Plate 3.3). Riparian vegetation appears to be continuous assemblages of scrub and shrubs with occasional trees. The planform, based on mapping, is artificially straightened. This potentially has resulted in downcutting and creation of an armoured bed. These are less favourable for invertebrates given that the gravels are not readily mobile though would mean that the channel is less sensitive to the effects of abstractions at times of high flow. No scour at the upstream end of the bridge was apparent while materials were observed to be deposited downstream of it, including urban debris (e.g. bricks) and cobble material (see Plates 3.6 and 3.7).

In addition during the limited site visit the observed flow was considered to be below the threshold for bank erosion, with riparian scrub providing stability while no significant silt problems were noted.

Table 3.2 Levels measured on Meden study area during the site walkover

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Description</th>
<th>Left hand bank height (m)</th>
<th>Channel Depth Left(m)</th>
<th>Channel Depth Middle(m)</th>
<th>Channel Depth Right(m)</th>
<th>Right hand bank height (m)</th>
<th>Channel Width(m)</th>
</tr>
</thead>
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<tr>
<td>S1</td>
<td>Pond u/s bridge</td>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>Pond d/s bridge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>Channel</td>
<td>0.3</td>
<td>0.4</td>
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<td>0.3</td>
<td>8</td>
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<td>S4</td>
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<td>0.4</td>
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<td>8</td>
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</tr>
<tr>
<td>S5</td>
<td>Channel</td>
<td>0.3</td>
<td>0.35</td>
<td>0.35</td>
<td>0.3</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>S6</td>
<td>Channel u/s bridge</td>
<td></td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>S7</td>
<td>Channel d/s bridge</td>
<td></td>
<td>0.48</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>
3.2.2 Review of flow/ level conditions on the day of the survey

Level records in the Meden were reviewed in order to establish approximate flow conditions at the time of the survey. The days leading up to the survey had been relatively wet.
There are two monitoring stations at River Meden close to Budby. These are

- Meden at Church Warsop: upstream; and
- Meden at Perlethorpe: downstream.

These are indicated in Figure 3.5 along with the study area.

Figure 3.5 Level (and flow) gauges in the Meden stations

Long term level data for both sites was available between late November 2012 and June 2020. Levels at both sites were also obtained on the day of the survey (at 5am and 7pm when they are measured and published) via RiverLevelsUK. Level statistics were determined for both sites and the levels on the day of survey were compared to these.

A summary of the level analysis is presented in Table 3.3 while levels which correspond to levels on the survey day are indicated in blue. Results indicate different level/flow conditions between the sites on the day of the survey.

Levels on the day of the survey at Church Warsop (the upstream monitoring site which is also upstream of our site) seem to indicate stage (levels with regard to Ordnance Datum) conditions were around the H_{25} \ Q_{25} early in the day before reducing to around the median flow (H_{50} \ Q_{50}). Correspondent levels at Perlethorpe, also downstream of our site, were higher indicating a level that is exceeded for around the H_{8} and one that is maintained throughout the day.

\(^7\) H refers to stage and stage refers to the water level in a river or stream with respect to a chosen reference height (Ordinance Datum for this study). H statistics relate to the percentage of time that a specific stage is exceed. For example, the H_{25} is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the H_{25} and Q_{25} for the same site should be equivalent to one another if derived from the same length of record).
Figure 3.6 indicates constant variability of levels at Church Warsop, along the record period, whereas levels at Perlethorpe seems to be an order higher since 2019, suggesting an issue with the more recent monitoring there, which would also impact on summary statistics. For this reason it is assumed that the level monitoring and associated exceedance statistics at the Church Warsop gauge were more reliable to inform this study. On the day of survey levels at the gauge at 5am were around the H25 before dropping to less than the H50 (indicating that the river is relatively responsive to rainfall and subsequent lack of it, with a speedy drop in flow apparent following a cessation of precipitation). Budby (our study area) is downstream of this level monitoring point and it is presumed that levels at the time of the survey (approximately 6pm) were between these and around the H35 (Q35).

Table 3.3 Level statistics for the Meden gauges stations (records from 26/11/12 to 21/06/20)

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Meden at Church Warsop</th>
<th>Meden at Perlethorpe</th>
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<tbody>
<tr>
<td>Level 12-06-2020 5am</td>
<td>0.287</td>
<td>0.516</td>
</tr>
<tr>
<td>Level 12-06-2020 7pm</td>
<td>0.216</td>
<td>0.524</td>
</tr>
<tr>
<td>H90</td>
<td>0.180</td>
<td>0.177</td>
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<td>H50</td>
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<td>H30</td>
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<td>H25</td>
<td>0.281</td>
<td>0.300</td>
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<tr>
<td>H20</td>
<td>0.300</td>
<td>0.328</td>
</tr>
<tr>
<td>H18</td>
<td>0.310</td>
<td>0.348</td>
</tr>
<tr>
<td>H15</td>
<td>0.323</td>
<td>0.379</td>
</tr>
<tr>
<td>H10</td>
<td>0.353</td>
<td>0.455</td>
</tr>
<tr>
<td>H5</td>
<td>0.406</td>
<td>0.617</td>
</tr>
<tr>
<td>H2</td>
<td>0.468</td>
<td>0.792</td>
</tr>
</tbody>
</table>
3.3 Second Site Visit

3.3.1 Overview

The site was re-visited on the 9th July 2020 in order improve our understanding of the functioning of the site and conditions present, as well obtain a number of measurements.

3.3.2 Site measurements

Sites S6 and S7 (Figure 3.4) located upstream and downstream of Budby road bridge were visited for a second time. Table 3.4 shows the levels measured on the study area when the survey was undertaken (9th July 2020) ordered from upstream to downstream. Images from the sites are provided in Plates 3.8 –3.11.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Description</th>
<th>Left hand bank height (m)</th>
<th>Channel Depth Left(m)</th>
<th>Channel Depth Middle(m)</th>
<th>Channel Depth Right(m)</th>
<th>Right hand bank height (m)</th>
<th>Channel Width(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6</td>
<td>Channel u/s bridge</td>
<td>0.56</td>
<td>0.70</td>
<td>0.58</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td>Channel d/s bridge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.6 Water levels in the River Meden at Church Warsop and Perlethorpe gauging stations (November 2012-June 2020)
3.3.3 Review of flow/level conditions on the day of the survey

To establish flow conditions at the time of the survey, flow and level conditions were reviewed in the same way as the first survey (Section 3.2.3). However, due to the issue at Perlethorpe gauging station described in Section 3.2.3, the data was only reviewed for the Meden at Church Warsop. The days leading up to the survey had been relatively wet. Levels recorded on the day of the survey seem to indicate level conditions were around H20 on the day of the survey (noting that the site is approximately 7.7 km downstream of the gauge and visited at 2 pm), slightly higher than the observed on the previous visit.

A summary of the level analysis is presented in Table 3.5 while levels which correspond to levels on the second survey day are indicated in blue. Plates 3.7 and 3.10 show imagery at S7 on the day of the first (~ Q35 event) and second site visit (~ Q20 event), respectively. At this location, the channel bed was apparent on the first day but not on the second. Channel depths were just 10cm higher on the second day which is not large increase so more turbid waters/ increased sediment load is believed to be the main cause of the bed becoming obscured.
Table 3.5 Level statistics for the Meden gauges stations (records from 26/11/12 to 09/07/20)

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Meden at Church Warsop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 09-07-2020 11am</td>
<td>0.302</td>
</tr>
<tr>
<td>Level 09-07-2020 7pm</td>
<td>0.252</td>
</tr>
<tr>
<td>H90</td>
<td>0.180</td>
</tr>
<tr>
<td>H50</td>
<td>0.225</td>
</tr>
<tr>
<td>H35</td>
<td>0.252</td>
</tr>
<tr>
<td>H30</td>
<td>0.267</td>
</tr>
<tr>
<td>H25</td>
<td>0.280</td>
</tr>
<tr>
<td>H20</td>
<td>0.300</td>
</tr>
<tr>
<td>H18</td>
<td>0.310</td>
</tr>
<tr>
<td>H15</td>
<td>0.322</td>
</tr>
<tr>
<td>H10</td>
<td>0.353</td>
</tr>
<tr>
<td>H5</td>
<td>0.406</td>
</tr>
<tr>
<td>H2</td>
<td>0.468</td>
</tr>
</tbody>
</table>

3.4 Model Build and Baseline Results

3.4.1 Modelling overview

A 2D flow model covering the area of interest at River Meden, as described above, was constructed using CAESAR-LisFlood. The model was constructed using available hydrological data, freely available LiDAR topographic data and information gathered during the site visit. It was used to run high flows at and greater than the EFI.

The results of the modelling were then interpreted to evaluate the importance of high flows for supporting the current and potential future ecological status of the river. For these purposes water depth, velocity and shear stress results were assessed. The first two parameters are generated when the model has been run, as raster files. Shear stress results were obtained during the modelling run by clicking on specific locations and viewing a pop up box. Therefore, several assessment points (prefix AP) in addition to the surveyed points (prefix S) were chosen. To define the location of this points, initial simulated shear stress were reviewed to see how they varied along the reach. Based on this assessment points were added along the reach at a distance of no more than 100m between them to enable results to be evaluated along it at a suitable spatial extent.

3.4.2 Model area

The initial model area, encompassing the surveyed area, is located between Hanger Hill Drive Road and Worksop Road. The selection of area to be modelled was informed through a review of available data and the site walkover undertaken on the 12th June 2020. It was determined that the study would focus on the downstream area (around S3 to S7) which could be accessed, amidst heavy vegetation growth, on the day of the survey. The final model reach area extends around 1.65 km in length between AP1 (SK 6104970389) to S6 (SK 61819 70146). The initial model floodplain was cut to the 1 in 100 year floodplain (based on Environment Agency flood mapping).

Surveyed and assessment points and final model study area are illustrated in Figure 3.7

---

8 Floodplain Zone 3 dataset. Described by the Environment Agency as “land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%)”
Figure 3.7 Meden at Budby surveyed and modelling area (latter between the red dotted lines)

3.4.3 Model build and calibration

Construction of the modelling surface

Following the steps outlined in Section 2.2.2, a DEM was constructed from freely available 1 m resolution LiDAR data.

The original LiDAR is represented on Figure 3.8 below. An initial review of this indicated an apparent lack of a distinct main channel. In contrast, the site walkover showed a well-defined main channel was observed that was flowing well. LiDAR is not able to penetrate water well and obtain accurate measurements plus the area is heavily forested which can also affect LiDAR measurements. Surrounding ditches appear to have been stamped into the channel and so an initial step was to improve the representation of the main channel in the DEM.
Hydrological assessment of inflows for the model

Flow rates are required as inputs to the hydraulic model. As mentioned above, the study area is located between 2 gauging stations with available flow data although the upstream gauge at Church Warsop was used to inform the flow at the top of the study area (given the recent issues at Perlethorpe described in Section 3.2.3).

Flows were modelled included a number of flows at or above the EFI (where abstraction may be permitted in the future) as well as flows approximating that observed on the days of the 2 site visits. Inflows for the model were calculated through catchment apportioning (acknowledging the relative catchment sizes at the gauge and the start of the model). Table 3.6 below shows the flow statistics at the Church Warsop gauge and those estimated at the top of the study area.

Table 3.6 Flow statistics for the Meden at Church Warsop and estimated model inflows

<table>
<thead>
<tr>
<th>Name</th>
<th>Catchment area (km²)</th>
<th>Q₃₅</th>
<th>Q₂₀</th>
<th>Q₁₅</th>
<th>Q₁₀</th>
<th>Q₅</th>
<th>Q₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meden at Church Warsop</td>
<td>63</td>
<td>0.55</td>
<td>0.74</td>
<td>0.78</td>
<td>0.84</td>
<td>0.98</td>
<td>1.27</td>
</tr>
<tr>
<td>Upstream model boundary (SK 6104970389)</td>
<td>80</td>
<td>0.70</td>
<td>0.94</td>
<td>0.98</td>
<td>1.07</td>
<td>1.24</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Interrogation of the initial modelling of the calibration event with the original DEM

As mentioned above, a review of the initial DEM (LiDAR) indicated that the main channel was not suitably stamped into it and representation of it should be improved. To do so, an initial Q₃₅ event (H₃₅) was run and modelled water depths at S3 to S6 were compared to those surveyed.
Figure 3.9 shows the water depths for the initial Q₃₅ run. Along the upstream area until S4, the channel is fragmented and flow seems to spill out of the river (neither of which corresponds to what was observed on site when the river was flowing well and in the channel). Downstream of S4, through to S6 the river appears better defined.

In addition, the LIDAR was originally clipped to the 100 year floodplain. However, in some instances this was quite close to the river, e.g. where river rises steeply up to roads via embankments next to Worksop Road. Consequently, it was decided to widen the modelling area by around 30m (i.e. a buffer of 30m was applied to the 1 in 100 year floodplain area).

Figure 3.9 Modelled and observed water depth values from an early Q₃₅ iteration of the Meden at Budby model

To further consider the amount of channel imprinting that is required the modelled cross sections were compared against those measured on site (at S3, S4 and S5 noting that the surveys were not benchmarked to Ordnance Datum and elevations are approximated from bank heights of the LIDAR). The results obtained are represented on Figures 3.10 - 3.12 below. This indicates that channel bed levels are potentially underestimated by approximately 0.5m on S3 and S5 and 0.6m around S4. Also, for those sections, the channel depth across the cross section was more uniform than that indicated from the LiDAR data (with refraction and / or tree coverage potentially affecting the latter).
Figure 3.10 Review of LiDAR data compared to surveyed elevations at S3 (approximated to tie in with LiDAR bank levels)

Figure 3.11 Review of LiDAR data compared to surveyed elevations at S4 (approximated to tie in with LiDAR bank levels)
Figure 3.12 Review of LiDAR data compared to surveyed elevations at S3 (approximated to tie in with LiDAR bank levels)

Surveyed depths at S6 were greater than upstream or downstream of the bridge, were surveyed. This indicates some ponding has occurred upstream with the bridge (Plate 3.6) likely to present an impediment to flow. The effect of this constriction was also accounted for within the modelling.

DEM manual adjustments

As a consequence of the DEM interrogation results, the following manual edits were made to the DEM:

1. Bed cells along the channel were reduce by 0.5m along the channel under existing bed level.
2. The constrictive effect of the bridge and upstream ponding was represented by creating a constrained channel (compared to upstream) out of CAESAR with levels reduced by 0.15m rather than 0.5m.

It should be noted that runs were iterated and results were reviewed until they were considered to reasonably represent depths observed during the survey (discussed further below). Limitations of manual adjustments are recognised and are discussed in Section 2.2.2 under “Model results, interpretation and limitations”. Figure 3.13 shows the Final DEM while Figure 3.14 shows the initial and final DEM long profiles along the river.
Figure 3.13 Meden at Budby. Final DEM used in the modelling

Figure 3.14 Initial (LiDAR data) and final (DEM edited) river bed levels/long profile
3.4.4 Calibration and validation scenarios results

Calibration Run ($Q_{35}$)

To calibrate the model several iterative runs were completed that simulated $Q_{35}$ flow conditions that were thought to best represent the conditions observed during the site visit (described above). Following each model run, inundation extent and depths were compared with the observations and measurements that were made during the site visit. Model results were critically evaluated and minor changes to the DEM were made accordingly. To carry out this evaluation, model water depths results were compared with the water depths cross sections measured on site within this area (S3 – S6).

Table 3.7 summarise the results of the final model run for the calibration process. Results show a reasonable fit at S4 and S6 in particular, in terms of relative depths. Modelled results at S3 and S5 seem lower than surveyed and potentially localised river forms have not been picked up on by the modelling. Nevertheless the overall fit was considered reasonable.

Approximate modelled levels were plotted on Figures 3.15 – 3.17 also for S3, S4 and S5 respectively. The process is approximated at two of the three sites the results suggest that modelled levels may be underestimated for the calibration event suggesting that if higher flows were simulated the threshold for when banks may be overtopped and the floodplain is inundated may be underestimated.
Table 3.7 Summary of water depth results obtained, for the $Q_{35}$ event, on S3, S4, S5 and S6 cross sections

<table>
<thead>
<tr>
<th>Site</th>
<th>S3</th>
<th></th>
<th>S4</th>
<th></th>
<th>S5</th>
<th></th>
<th>S6</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chainage</td>
<td>Water Depth (m)</td>
<td>Chainage</td>
<td>Water Depth (m)</td>
<td>Chainage</td>
<td>Water Depth (m)</td>
<td>Chainage</td>
<td>Water Depth (m)</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>None</td>
<td>0.00</td>
<td>None</td>
<td>0.00</td>
<td>None</td>
<td>0.00</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>1.55</td>
<td>None</td>
<td>1.21</td>
<td>None</td>
<td>1.46</td>
<td>None</td>
<td>1.02</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>3.10</td>
<td>0.192</td>
<td>2.43</td>
<td>None</td>
<td>2.92</td>
<td>0.262</td>
<td>2.05</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>4.65</td>
<td>0.215</td>
<td>3.64</td>
<td>None</td>
<td>4.39</td>
<td>0.272</td>
<td>3.07</td>
<td>0.535</td>
</tr>
<tr>
<td></td>
<td>6.20</td>
<td>0.221</td>
<td>4.86</td>
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<td>5.85</td>
<td>0.257</td>
<td>4.09</td>
<td>0.540</td>
</tr>
<tr>
<td></td>
<td>7.75</td>
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<td>6.07</td>
<td>0.266</td>
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<td>0.176</td>
<td>5.12</td>
<td>0.541</td>
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<tr>
<td></td>
<td>9.31</td>
<td>None</td>
<td>7.29</td>
<td>0.297</td>
<td>8.77</td>
<td>0.089</td>
<td>6.14</td>
<td>0.544</td>
</tr>
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<td></td>
<td>10.86</td>
<td>None</td>
<td>8.50</td>
<td>0.291</td>
<td>10.24</td>
<td>None</td>
<td>7.17</td>
<td>0.546</td>
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<tr>
<td></td>
<td>11.03</td>
<td>None</td>
<td>9.71</td>
<td>0.277</td>
<td>11.70</td>
<td>None</td>
<td>8.19</td>
<td>0.552</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.93</td>
<td>None</td>
<td>13.16</td>
<td>None</td>
<td>9.21</td>
<td>0.545</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.14</td>
<td>None</td>
<td></td>
<td></td>
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</tr>
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<td></td>
<td></td>
<td></td>
<td>13.36</td>
<td>None</td>
<td></td>
<td></td>
<td>11.26</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.28</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.31</td>
<td>None</td>
</tr>
<tr>
<td>Surveyed depth range (left, middle, right)</td>
<td>-</td>
<td>0.4 – 0.6</td>
<td>-</td>
<td>0.2-0.4</td>
<td>-</td>
<td>0.35</td>
<td>-</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Figure 3.15 Plot of LiDAR, measured elevations and water levels compared to adjusted DEM and modelled water levels at S3

Figure 3.16 Plot of LiDAR, measured elevations and water levels compared to adjusted DEM and modelled water levels at S4
Validating the model

A brief return site visit was made to the site (see Section 3.3) and more measurements at S6 were taken, which allowed the model to be validated. As described above, the flow at this time was considered to be around the Q_{20} (higher than the previous visit). An estimated inflow to the model was 0.938m^3/s (See Table 3.6 above). All other aspects of the calibration model were retained and the validation model was run.

Table 3.8 shows water depth results obtained on S6. Results indicate that water levels modelled are higher than the validation run and similar to those measured on site (between 0.56 and 0.7m). On this basis further confidence in the model was gained (i.e. model was considered validated) and scenario runs, of flows relevant to the wider study, were undertaken (see Section 3.5).
Table 3.8 Summary of water depth results obtained, for the $Q_{20}$ event, on S6 cross sections

<table>
<thead>
<tr>
<th>Chainage</th>
<th>Water depth ($Q_{20}$) (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>None</td>
</tr>
<tr>
<td>1.02</td>
<td>None</td>
</tr>
<tr>
<td>2.05</td>
<td>None</td>
</tr>
<tr>
<td>3.07</td>
<td>0.523</td>
</tr>
<tr>
<td>4.09</td>
<td>0.542</td>
</tr>
<tr>
<td>5.12</td>
<td>0.567</td>
</tr>
<tr>
<td>6.14</td>
<td>0.580</td>
</tr>
<tr>
<td>7.17</td>
<td>0.592</td>
</tr>
<tr>
<td>8.19</td>
<td>0.582</td>
</tr>
<tr>
<td>9.21</td>
<td>0.570</td>
</tr>
<tr>
<td>10.24</td>
<td>0.086</td>
</tr>
<tr>
<td>11.26</td>
<td>0.046</td>
</tr>
<tr>
<td>12.28</td>
<td>0.006</td>
</tr>
<tr>
<td>13.31</td>
<td>None</td>
</tr>
<tr>
<td>13.31</td>
<td>None</td>
</tr>
</tbody>
</table>

Model Calibration and Validation Run Results (Depths and Velocities)

Final modelled depths and velocities from the calibration and validation runs are shown in Figure 3.18. Differences between the runs are subtle when presented at this scale and best picked up through analysis of depths at assessment points, described above. Overtopping of the banks under both scenarios does not occur.
Figure 3.18 Calibration ($Q_{35}$) and Validation ($Q_{20}$) results (depths and velocities)

Prepared for: Environment Agency
3.5 Scenario testing and results

Following model calibration and validation, scenario model runs for \(Q_{18}, Q_{15}, Q_{10}, Q_5, Q_2\) were undertaken (model flow estimates as outlined in Table 3.6). Results are described below.

3.5.1 Depths and Long section

A long profile of the scenario results (as well as calibration and validation flows) is provided in Figure 3.19 while water depth results for the different scenarios are illustrated in Figure 3.20. The long profile generally indicates higher depths with increased flows while Figure 3.20 indicates that the model predicts some out overtopping of banks occurs between the \(Q_5\) and \(Q_2\) events, particularly in the upper part of the modelled reach. Some activating of drainage channels, acting as backwaters also occurs between these events. The review of levels during the model calibration suggested that they may be underestimated on occasion through the modelling though the results imply that floodplain inundation under high, though not flood flows, is limited through this reach and potentially not of significant importance.

![Figure 3.19 Water depth long profile of the scenario results (Q_{18}, Q_{15}, Q_{10}, Q_5 and Q_2), calibration (Q_{35}) and validation flows(Q_{20})](image)

3.5.2 Velocities

Water velocity results for the different scenarios are illustrated in Figure 3.21. These generally increase with higher flows though remain relatively modest, reflecting the moderate catchment size and gentle gradient of the system.
Figure 3.20 Water depth results from the high flow scenarios ($Q_{18}$, $Q_{15}$, $Q_{10}$, $Q_{5}$ and $Q_{2}$)
Figure 3.20 Velocity results from the high flow scenarios (Q18, Q15, Q10, Q5 and Q2)
3.5.3 Shear Stresses

Shear stresses can be obtained through CAESAR-LisFlood, by clicking on a point in the model at a particular time. Shear stresses at each assessment and survey points were obtained at the end of the model run. These are summarised in Table 3.9 below. At each site the shear stresses generally increase with increased flow, which is confirmed when looking at the average shear stress for the reach (average of the assessment and survey points results).

The critical shear stress required to initiate movement of unconsolidated sediment of sand size and above may be estimated from the following equation:

\[ \tau_{cr} = 0.045(\rho_s - \rho_w)gD_g \]

where \( \tau_{cr} \) = Critical shear stress (kg/m/s²), \( \rho_s \) = Density of sediment (2650 kg/m²), \( \rho_w \) = Density of water (1000 kg/m²), \( g \) = gravitational acceleration (9.81 m/s²) and \( D_g \) = Sediment size (intermediate axis) (m).

This is also illustrated graphically in Figure 3.21.

Figure 3.21 Dimensional Shields entrainment curve for unconsolidated sediment

Sediment displaying a low cohesive strength (sand grade and above) will behave as unconsolidated particles and Equation 3 and Figure 3.21 may be used, with caution, to determine the approximate shear stress required to initiate erosion.

Sediment observed in the Meden (and other observed locations in the Idle and Torne catchments) is silty sand with grain typically defined as having diameters between 0.01 mm and 0.1 mm - associated shear stresses to entrain and transport these materials would be 0.2 to 8 kg/m/s² (for lower and upper grain sizes respectively). For more consolidated deposits, such as vegetated berms and the armoured beds described previously, shear stresses would need to be potentially up to 75 kg/m/s² for these to be eroded.

A high level review of the results of the scenario modelling (Table 3.9) suggests that fine sediments would be transported through the Meden reach under the high flow range being considered. A reduction in flow as a result of high flow abstraction, e.g. from the Q₂ to the Q₁₈ would reduce

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9 1 kg/m/s² is the same as 1 Pascal (Pa) or 1 N/m²
sediment transport although the bed would generally remain free of silt and sand (avoiding detrimental effects such as smothering of habitats/assuming that no significant sediment sources become available, such as from a building site or from a field).

Numerically the results indicate a reduction of sediment transport potentially of the order of 20-30% although given the number of approximations made through the development of the model, the actual model results and direct use of them in interpretation is not recommended. Findings of a fluvial audit would also likely significantly reduce this number, e.g. accounting for sediment sinks and sediment exhaustion. Through the work to date it is considered that the ability of CAESAR LisFlood modelling to simulate such processes and produce useful results has been demonstrated. A number of improvements and refinements (described later) can be undertaken to increase confidence in the model results so that they numerical results can be appraised and further useful sediment analyses may be undertaken (e.g. exploring shear stresses for various grain sizes, flow ranges in which they would be transported and how this could vary with abstractions at times of high flow).

Shear stresses were found to vary along the reach, with local final DEM differences affecting the results. This would result in variation in modelled sediment transportation, deposition or erosion through the reach, e.g. can explain localised deposits that may be observed. Given that the channel was stamped into the CAESAR LisFlood DEM uniformly differences throughout the reach are unlikely to represent local changes in bed levels but differences in LIDAR penetration. Improved surveys of reaches and incorporation of these into the model would remove this issue, however, and localised differences could be teased out of the results.
Table 3.9 Modelled shear stress results at the assessment and surveyed points (for the calibration event (Q$_{35}$), validation event (Q$_{20}$) and high flow scenarios (Q$_{18}$, Q$_{15}$, Q$_{10}$, Q$_{5}$ and Q$_{2}$). Note results are presented to show model capability and show potential relative or orders of magnitude changes - given the number of approximations used within the modelling process actual results should be treated with caution.

<table>
<thead>
<tr>
<th>Scenario/ID</th>
<th>AP1</th>
<th>AP2</th>
<th>AP3</th>
<th>AP4</th>
<th>AP5</th>
<th>S3</th>
<th>AP6</th>
<th>AP7</th>
<th>S4</th>
<th>AP8</th>
<th>AP9</th>
<th>AP10</th>
<th>AP11</th>
<th>AP12</th>
<th>S5</th>
<th>AP13</th>
<th>S6</th>
<th>Reach average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q$_{35}$</td>
<td>5.32</td>
<td>10.76</td>
<td>11.69</td>
<td>5.51</td>
<td>9.60</td>
<td>9.99</td>
<td>7.356</td>
<td>8.83</td>
<td>14.55</td>
<td>6.61</td>
<td>7.57</td>
<td>8.85</td>
<td>11.05</td>
<td>5.67</td>
<td>6.47</td>
<td>5.89</td>
<td>0.98</td>
<td>8.04</td>
</tr>
<tr>
<td>Q$_{20}$</td>
<td>7.46</td>
<td>11.43</td>
<td>12.18</td>
<td>6.88</td>
<td>11.07</td>
<td>10.75</td>
<td>9.29</td>
<td>8.01</td>
<td>17.85</td>
<td>7.93</td>
<td>8.09</td>
<td>10.25</td>
<td>11.04</td>
<td>6.09</td>
<td>6.49</td>
<td>6.57</td>
<td>1.79</td>
<td>9.01</td>
</tr>
<tr>
<td>Q$_{10}$</td>
<td>8.84</td>
<td>12.0</td>
<td>12.35</td>
<td>7.62</td>
<td>11.32</td>
<td>12.51</td>
<td>10.30</td>
<td>10.24</td>
<td>16.84</td>
<td>9.66</td>
<td>9.96</td>
<td>10.97</td>
<td>12.34</td>
<td>7.06</td>
<td>7.57</td>
<td>7.65</td>
<td>2.91</td>
<td>10.01</td>
</tr>
</tbody>
</table>
3.6 Meden at Market Warsop

3.6.1 Site Visit

In addition to the Meden at Budby, the Meden at Market Warsop was visited on the 9th July 2020 (the same day that a number of other sites in the Rivers Idle and Torne were visited, as described in Section 6). The location of the site visit in the Meden waterbody and Idle catchment is shown in Figure 3.22. Market Warsop is also located in the Meden (Sookholme Brook to Maun) WFD waterbody although towards the top of the waterbody whereas Budby is located towards the lower end of the waterbody (see Figure 3.1). A more detailed map of the Meden through Market Warsop, and site visit location, is provided in Figure 3.23.

Figure 3.22 Meden (Sookholme Brook to Maun) WFD waterbody and location of Market Warsop
Figure 3.23 Meden (Source to Sookholme Brook) waterbody site visit location and environment

Images from the site visit are provided in Plates 3.12 to 3.16.

Plate 3.12 Mill Pond in Market Warsop
Plate 3.13 Mill Pond overflow and reconnecting point with the River Meden
The Meden at Market Warsop was visited around 5pm. The nearest gauging station from this site is Meden at Church Warsop, located approximately 1.5km upstream of the site and described previously in Sections 3.2.3 and 3.3.3. The site visit was the same day as the second visit to the Meden at Budby, and based on the timing of the Market Warsop visit and gauged levels measured on the day it is considered that levels during the visit were around the $H_{30}$/$Q_{30}$.

Under these moderately high flows the observed channel appeared relatively clear/un-turbid with some silt deposition observed in the channel (similar to that observed downstream at Budby). The Mill Pond serves as a sediment sink, meaning less sediment in reaches downstream of it, potentially making it more resilient to reduced high flows.

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10 $H$ refers to stage and stage $S$ refers to the water level in a river or stream with respect to a chosen reference height (Ordnance Datum for this study). $H$ statistics relate to the percentage of time that a specific stage is exceed. For example, the $H_{25}$ is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the $H_{25}$ and $Q_{25}$ for the same site should be equivalent to one another if derived from the same length of record).
3.7 Discussion and Recommendations

The Meden (Sookholme to Maun) waterbody was identified during Phase 2a as warranting further investigation. The area around Budby was considered by the Environment Agency as containing good habitat and thus potentially being more sensitive to additional abstractions at time of high flow. During a site visit the accessible channel was observed to be uniform, characterised by gliding flow and with an absence of bedforms (pools, riffles, bars).

A CAESAR-LisFlood model was constructed of the Meden at Budby. Two site visits were undertaken at moderate to high flows and these were used to essentially calibrate and validate the model. During calibration of the model a channel was imprinted into the LiDAR and the model was iterated until reasonable results, which resembled observations and measurements taken in the field, were obtained. The adjustment was undertaken based on a limited number of coarse measurements rather than a detailed survey. It is recognised that using the former brings introduces more uncertainties into the modelling and subsequent results. Reasonable validation of model did however provide confidence that the model was producing realistic results.

A number of high flow scenarios were run between the Q\textsubscript{18} and Q\textsubscript{2} flows. The former is the potential hands off flow above which additional abstractions may be permitted / the latter the upper limit being considered in this phase through scenario analysis as indicated in Section 2.2.2.

Model results indicate that although depths and velocities vary through the range of high flows considered (increasing with increased flows) and significant inundation of the floodplain did not occur. Transportation of fines through the system is still expected under the high flows considered though further development of the modelling and subsequent analysis is recommended after which more detailed morphological analyses may be undertaken.

Based on the above, it is considered that significant effects upon the aquatic species present through this reach would not be anticipated as a result of additional abstraction under times of high flow (with species present likely to have adapted to conditions that may occur following abstraction with no significant hydrological or geomorphic changes predicted). It is noted that the modelling efforts undertaken introduced a number of uncertainties however and that the levels of abstraction have not been defined). Further confidence in these results would be gained through the following:

- Re-visiting the sites during the winter when die back of vegetation had occurred and access to the site would likely be better.
- Re-visiting the site under times of high flow and confirming whether or not any distributaries are activated or floodplain inundation is occurring, under these conditions.
- A targeted fluvial audit of the waterbody being undertaken to confirm aspects such as if reaches are sediment sources/ exchanges/ transfers/ sinks or if sediment exhaustion has occurred as well as if results for around Budby could apply elsewhere. An audit is best undertaken during low or moderate flows when the channel can be observed. Further benefits of an audit are provided in the Phase 2b recommendations/ Section 7.2).
- Formal channel surveys cross sections and long sections could be undertaken that are referenced to Ordnance Survey datum and this information integrated into the CAESAR-LisFlood models. An improved spatial understanding of the river network would also improve stamping in of the channels into the LiDAR which seems to be a common requirement for CAESAR-LisFlood of these systems.

By undertaking the above, greater confidence in the results of CAESAR-LisFlood modelling would be obtained. Once this has occurred, more detailed interrogation and processing of the results can be undertaken than what has been indicated in this section. Such additional efforts could include further sediment analyses, which should be informed by the fluvial audit, and creation of velocity or depth scenario difference maps which would enable results between runs to be easily compared.
4. Poulter (from Millwood Brook to River Maun)

4.1 Environmental baseline

4.1.1 Site description

The River Poulter is in Nottinghamshire and is another of the River Idle headwaters. It flows north east through Welbeck Lake and Clumber park, both classified as SSSIs. Beyond the parklands the river flows eastwards past Elkesley, to join the River Idle.

According to the results of Phase 2a\(^{11}\) and following discussions with the Environmental Agency, the Poulter (from Millwood Brook to River Maun) WFD waterbody was chosen for more detailed investigations during Phase 2b, with it being considered potentially sensitive to effects of high flow abstraction\(^{11}\). Subsequent discussions with the Environment Agency indicated that further examination of the lowest stretch of the Poulter, around Elkesley, should be undertaken during Phase 2b. This is the focus of this chapter. Further details on the site and surrounding areas is provided in Figure 4.1.

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Figure 4.1 Idle Catchment and location of the Poulter (Millwood Brook to Maun) WFD waterbody
4.1.2 Water Resources

Waterbodies and structures

An initial study area was determined and is indicated in Figure 4.2. The figure shows the waterbodies through the study area, including an offline reservoir, ditches and a distributary, in addition to the river itself.

Figure 4.2 Poulter (Millwood Brook to Maun) at Elkesley structures

Hydrology

The Environment Agency maintains two hydrological monitoring points throughout the River Poulter. Those gauging stations are Poulter at Cuckney, located upstream of the study area and Poulter at Twyford Bridge, located downstream. Summary flow information for these sites is provided in Table 4.1.

Table 4.1 Summary flow information for flow gauges in the River Poulter

<table>
<thead>
<tr>
<th>Name</th>
<th>Catchment area (km²)</th>
<th>Period of record</th>
<th>Flow Statistics (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q⁹⁵</td>
</tr>
<tr>
<td>Poulter at Cuckney</td>
<td>32.2</td>
<td>1969-2015</td>
<td>0.16</td>
</tr>
<tr>
<td>Poulter at Twyford Bridge</td>
<td>128.2</td>
<td>1969-2016</td>
<td>0.23</td>
</tr>
</tbody>
</table>

4.2 Site Walkover

4.2.1 Overview

The study area was visited on the 12th June 2020 in order improve our understanding of the functioning of the site and conditions present, as well as obtain a number of measurements. Each of these are designed to inform the modelling as well as aid interpretation of modelling results.
4.2.2 Site measurements

Channel measurements were taken at a number of accessible points. These are indicated on Figure 4.3. The stretch between S1 to S4 was walked over though access was often difficult due to dense vegetation growth. In addition, data from an RHS monitoring point just upstream of S4 was obtained from the Environment Agency.

Figure 4.3 Sites surveyed on the Poulter (in red circles)/ flow direction is to the east/ right

Images from the sites are provided in Plates 4.1 – 4.6. Between S1 and S4 there was a general pool-riffle sequence observed along the river with bank levels varying throughout this stretch. Run-glade habitats were present while minimal fine sediment ingress into the gravels was observed through this reach where gravels beds were present. The water was generally clear. Channel bed through this reach appeared to be segregated/ armoured likely to be in response to historic channel straightening/ modification with some fine sedimentation observed. Around S5 (Plates 4.5 and 4.6) the channel was wider and more ponded, with siltation having occurred (area serving as a sink for sands).

Plate 4.1 Poulter S1 (looking u/s from left bank hand)

Plate 4.2 Poulter S2 right hand bank
Plate 4.3 Poulter S3 (looking d/s from left hand bank)

Plate 4.4 Poulter S4 (looking d/s from left hand bank)

Plate 4.5 Poulter S5 (looking d/s from foot bridge)

Plate 4.6 Deposited sediments in wider channel at Elkesley downstream of S5 (looking u/s from left hand bank)

Table 4.2 show the levels measured on the study area when the survey was undertaken (12th June 2020) ordered from upstream to downstream.

Table 4.2 Levels measured in the River Poulter study area during the site walkover

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Description</th>
<th>Left hand bank height (m)</th>
<th>Channel Depth Left (m)</th>
<th>Channel Depth Middle (m)</th>
<th>Channel Depth Right (m)</th>
<th>Right hand bank height (m)</th>
<th>Channel Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Channel (Riffle)</td>
<td>0.15</td>
<td>0.25</td>
<td>0.1</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>Channel (Pool)</td>
<td>0.4</td>
<td>0.35</td>
<td>0.35</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>Channel (Riffle/Pool)</td>
<td>0.25</td>
<td>0.35</td>
<td>0.15</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>Channel</td>
<td>1.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.9</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>Foot Bridge</td>
<td>0.1</td>
<td>0.57</td>
<td>0.28</td>
<td>0.2</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
4.2.3 Review of flow/ level conditions on the day of the survey

Level records in the Poulter were reviewed to establish approximate flow conditions at the time of the survey. The days leading up to the survey had been relatively wet.

There are two level / flow monitoring stations at River Poulter close. These are:

- Poulter at Cuckney: upstream; and
- Poulter at Twyford Bridge: downstream.

These are indicated in Figure 4.4 along with the study area.

![Figure 4.4 Level (and flow) gauges in the Poulter stations](image)

Figure 4.4 Level (and flow) gauges in the Poulter stations

Level data for the Poulter at Cuckney and at Twyford Bridge was available from late December 2015 and November 2012, respectively, until June 2020. A preliminary review of the level time series at both sites was undertaken and is presented in Figure 4.5. This suggests that the level gauge at Cuckney is more reliable and so levels on the day of the survey were used to inform the flow conditions on the day of the survey. These are presented in Table 4.3.

![Figure 4.5 Level times series for the Poulter at Cuckney and Poulter at Twyford Bridge gauges](image)
Levels at the Cuckney gauge varied from around the $H_{25}$ at 5am down to around the $H_{30}$ at 7pm. The site is somewhat downstream of the gauge (approximately 10km) and was visited around 2pm. Given this it is assumed that the levels at the site were closer to the $H_{25}$ / $Q_{25}$.

### Table 4.3 Level statistics for the Poulter at Cuckney gauging station

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Poulter at Cuckney</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 12-06-2020 5am</td>
<td>0.188</td>
</tr>
<tr>
<td>Level 12-06-2020 7pm</td>
<td>0.173</td>
</tr>
<tr>
<td>$H_{90}$</td>
<td>0.105</td>
</tr>
<tr>
<td>$H_{50}$</td>
<td>0.135</td>
</tr>
<tr>
<td>$H_{35}$</td>
<td>0.162</td>
</tr>
<tr>
<td>$H_{30}$</td>
<td>0.173</td>
</tr>
<tr>
<td>$H_{25}$</td>
<td>0.185</td>
</tr>
<tr>
<td>$H_{20}$</td>
<td>0.200</td>
</tr>
<tr>
<td>$H_{18}$</td>
<td>0.205</td>
</tr>
<tr>
<td>$H_{15}$</td>
<td>0.221</td>
</tr>
<tr>
<td>$H_{10}$</td>
<td>0.270</td>
</tr>
<tr>
<td>$H_{5}$</td>
<td>0.339</td>
</tr>
<tr>
<td>$H_{2}$</td>
<td>0.388</td>
</tr>
</tbody>
</table>

### 4.3 Model Build and Baseline Results

#### 4.3.1 Modelling overview

A 2D flow model covering the area of interest at River Meden, as described above, was constructed using CAESAR-LisFlood. Once more the model was constructed using available hydrological data, freely available LiDAR topographic data and information gathered during the site visit. It was used to run high flows at and greater than the EFI.

The results of the modelling were then interpreted to evaluate the importance of high flows for supporting the current and potential future ecological status of the river. For these purposes water depth, velocity and shear stress results were assessed. The first two parameters are generated when the model has been run, as raster files. Shear stress results were obtained during the modelling run by clicking on specific locations and viewing a pop up box. Therefore, several assessment points, along the river, were created in order to obtain shear stress values at fixed locations at the end of the modelling run.

#### 4.3.2 Model area

The initial study area was located south Elkesley, between Cross Lane and Dover Bolton. The selection of area to be modelled was informed through a review of available data. Ultimately it was

---

12 $H$ refers to stage and $H$ refers to the water level in a river or stream with respect to a chosen reference height (Ordnance Datum for this study). $H$ statistics relate to the percentage of time that a specific stage is exceed. For example, the $H_{25}$ is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the $H_{25}$ and $Q_{25}$ for the same site should be equivalent to one another if derived from the same length of record).
decided to focus on the upstream area through which the walkover was undertaken (as it was accessible). This is shown in Figure 4.6 and extended from SK 6720075200 to SK 6740674758 (approximately 560m). The model extent, to be inputted as LiDAR into CAESAR-LisFlood was cropped to the 1 in 100 year floodplain (based on Environment Agency flood mapping\textsuperscript{13}).

Surveyed and model assessment points and final model study area are illustrated in Figure 4.6 below. Following the approach outlined for the Meden above, it was decided to add assessment points through so that there was either a surveyed or and assessment points along the reach at a distance of up to 200m.

![Diagram](image)

**Figure 4.6 Final Poulter at Elkesley modelling area (including model assessment and surveyed points)**

### 4.3.3 Model build and calibration

**Construction of the modelling surface**

Following the steps outlined in Section 2, a DEM was constructed from freely available 1 m resolution LiDAR data. The original LiDAR is represented on Figure 4.7 below. As with the Meden, an initial review of this indicated an apparent lack of a distinct channel. At the upstream end in particular, the river is not clearly defined. In contrast, during the site walkover a well-defined channel was observed and flowing well. Also the LiDAR shows a number of distributaries (or paleo-channels), though there

\textsuperscript{13} Floodplain Zone 3 dataset. Described by the Environment Agency as “land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%).”
were no obvious flow offshoots when the site was visited at a time of moderately high flow. As such, an initial step was to improve the representation of the main channel in the DEM.

![Image of map showing Poulter at Elkesley original LiDAR data](image)

**Figure 4.7 Poulter at Elkesley original LiDAR data**

*Hydrological assessment of inflows for the model*

Flow rates are required as inputs to the hydraulic model. As mentioned above, the study area is located near to Poulter at Twyford Bridge gauging station with available flow data considered reliable to be used to estimate model inflows.

Ultimately flows were modelled that included a number of flows at or above the EFI (where abstraction may be permitted in the future) as well as flow approximating that observed on the day of the site visit. Inflows for the model were calculated through catchment apportioning (acknowledging the relative catchment sizes at the gauge and the start of the model). Table 4.4 below shows the flow statistics at the Twyford Bridge gauge and those estimated at the top of the study area.
Table 4.4 Flow statistics for the Poulter at Twyford Bridge gauging station

<table>
<thead>
<tr>
<th>Name</th>
<th>Catchment area (km²)</th>
<th>Q₂₅</th>
<th>Q₁₈</th>
<th>Q₁₅</th>
<th>Q₁₀</th>
<th>Q₅</th>
<th>Q₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poulter at Twyford Bridge</td>
<td>128</td>
<td>0.65</td>
<td>0.74</td>
<td>0.78</td>
<td>0.90</td>
<td>1.1</td>
<td>1.46</td>
</tr>
<tr>
<td>Upstream model boundary (SK 66650 75000)</td>
<td>117</td>
<td>0.60</td>
<td>0.68</td>
<td>0.72</td>
<td>0.82</td>
<td>1.01</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Interrogation of the initial modelling of the calibration event with the original DEM

As mentioned above, a review of the initial DEM (LiDAR) indicated that the main channel was not suitably stamped into it and representation of it should be improved. To do so, an initial $Q_{25}$ event (calibration event correspondent with the first survey) was run and modelled water depths at S1 to S4 were compared to those surveyed.

Figure 4.8 shows the water depths for the initial $Q_{25}$ run. Along the upstream area until, the channel is slightly fragmented and the water seems to flow through the side channels that were not observed to be flowing (these areas were observed to have high groundwater levels rather than be flowing at the time of the survey). At the downstream bend, flow is being conveyed into floodplain area by what appears to be blockages in the LiDAR – these were not apparent from the site visit and most flow remained in the channel (some flow splitting was apparent- though unlikely to be as extensive as that apparent in the initial modelling). After a review of old maps¹⁴ on this area, a footbridge that is no longer there was identified and so it was removed from the DEM.

Figure 4.8 Modelled and observed water depth values from an early $Q_{25}$ iteration of the Poulter at Elkesley model

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¹⁴Old-maps.co.ukTM. Nottinghamshire. Available at: [https://www.old-maps.co.uk/#/Map/467347/374760](https://www.old-maps.co.uk/#/Map/467347/374760) (Accessed July 06, 2020)
To further consider the amount of channel imprinting that was required, the modelled depths were compared against those measured on site (at S1, S2, S3 and S4/ noting that the surveys were not benchmarked to Ordnance Datum and elevations were approximated with regard to bank heights from the LiDAR). The results obtained are represented on Figures 4.9 – 4.12 below. This indicated that initial channel bed levels were potentially underestimated by approximately 0.5m along the river.

Figure 4.9 Review of LiDAR data compared to surveyed elevations at S1 (approximated to tie in with LiDAR bank levels)
Figure 4.10 Review of LiDAR data compared to surveyed elevations at S2 (approximated to tie in with LiDAR bank levels)

Figure 4.11 Review of LiDAR data compared to surveyed elevations at S3 (approximated to tie in with LiDAR bank levels)
Figure 4.12 Review of LiDAR data compared to surveyed elevations at S4 (approximated to tie in with LiDAR bank levels)

As a consequence of the DEM interrogation results, the following manual edits were made to the DEM:

1. Channel bed cells channel were reduced by 0.5m along the channel under existing bed level.
2. The obstacle located downstream of S4 was removed and levels adjusted to bed elevations of the cells immediately adjacent.

After this edits, the model was run several times and finer adjustments were made until results that reasonably resembled site observations were obtained. Figure 4.13 shows the final water depth values results for the Q25 / calibration event after several adjustments of the DEM. Limitations of manual adjustments are recognised and are discussed in Section 2.2.2 under “Model results, interpretation and limitations”. Figure 3.13 shows the Final DEM while Figure 3.14 shows the initial and final DEM long profiles along the river.
Figure 4.13 Water levels results, for the calibration (Q_{25}) event, after adjust DEM

The final DEM is shown in Figure 4.14 while Figure 4.15 shows the initial and final DEM long profiles along the river.

Figure 4.14 Poulter at Elkesley. Final DEM used in the modelling
4.3.4 Model calibration

To calibrate the model several iterative runs were completed that simulated Q_{25} flow conditions that were thought to best represent the conditions observed during the site visit. Following each model run, inundation extent and depths were compared with the observations and measurements that were made during the site visit. Model results were critically evaluated and minor changes to the DEM were made accordingly. To carry out this evaluation, model water depths results were compared with the water depths cross sections measured on site within this area (S1 – S4).

Table 4.5 summarises the results of the final model run for the calibration process. Results show a reasonable fit, particularly at riffle locations. Modelled depths through the pool section (S2) are lower than observed, perhaps indicating that such features are underestimated in the LiDAR as a result of refraction. Overall the fit was considered reasonable.

No model validation was undertaken in the current phase of works as the site was not visited on a second occasion (unlike the Meden site which was quicker to visit during the second visit when other sites were being visited, see Sections 5 and 6).
Figure 4.14 Plot of LiDAR, measured elevations and water levels compared to adjusted DEM and modelled water levels at S1

Figure 4.15 Plot of LiDAR, measured elevations and water levels compared to adjusted DEM and modelled water levels at S2
Figure 4.16 Plot of LiDAR, measured elevations and water levels compared to adjusted DEM and modelled water levels at S3

X and Y axes are not to scale with one another (y axis exaggerated)

Figure 4.17 Plot of LiDAR, measured elevations and water levels compared to adjusted DEM and modelled water levels at S4

X and Y axes are not to scale with one another (y axis exaggerated)
Table 4.5 Summary of water depth results obtained, for the $Q_{25}$ (calibration) event, at S1, S2, S3 and S4 cross sections

<table>
<thead>
<tr>
<th>Site</th>
<th>S1 Chainage</th>
<th>Water Depth (m)</th>
<th>S2 Chainage</th>
<th>Water Depth (m)</th>
<th>S3 Chainage</th>
<th>Water Depth (m)</th>
<th>S4 Chainage</th>
<th>Water Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
<td>None</td>
<td>0.00</td>
<td>None</td>
<td>0.00</td>
<td>None</td>
<td>0.00</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>1.25</td>
<td>None</td>
<td>1.01</td>
<td>None</td>
<td>1.01</td>
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<td></td>
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<tr>
<td></td>
<td>3.74</td>
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<td>3.04</td>
<td>None</td>
<td>3.03</td>
<td>None</td>
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<td>None</td>
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<tr>
<td></td>
<td>4.98</td>
<td>None</td>
<td>4.05</td>
<td>None</td>
<td>4.04</td>
<td>None</td>
<td>4.03</td>
<td>None</td>
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<tr>
<td></td>
<td>6.23</td>
<td>None</td>
<td>5.07</td>
<td>None</td>
<td>5.05</td>
<td>0.226</td>
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<td>6.06</td>
<td>0.242</td>
<td>6.05</td>
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</tr>
<tr>
<td></td>
<td>8.72</td>
<td>0.250</td>
<td>7.09</td>
<td>0.222</td>
<td>7.07</td>
<td>0.255</td>
<td>7.05</td>
<td>0.191</td>
</tr>
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<td></td>
<td>9.96</td>
<td>0.233</td>
<td>8.11</td>
<td>0.224</td>
<td>8.08</td>
<td>0.262</td>
<td>8.06</td>
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</tr>
<tr>
<td></td>
<td>11.21</td>
<td>0.212</td>
<td>9.12</td>
<td>0.206</td>
<td>9.09</td>
<td>0.252</td>
<td>9.07</td>
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<td></td>
<td>12.45</td>
<td>0.183</td>
<td>10.13</td>
<td>0.173</td>
<td>10.09</td>
<td>0.238</td>
<td>10.08</td>
<td>0.000</td>
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<td>13.70</td>
<td>0.144</td>
<td>11.15</td>
<td>0.143</td>
<td>11.10</td>
<td>0.210</td>
<td>11.08</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>14.94</td>
<td>0.109</td>
<td>12.16</td>
<td>None</td>
<td>12.11</td>
<td>None</td>
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<td>13.17</td>
<td>None</td>
<td>13.12</td>
<td>None</td>
<td>13.10</td>
<td>None</td>
</tr>
<tr>
<td>Surveyed depth range (left, middle, right)</td>
<td>-.</td>
<td>0.10-0.25</td>
<td>-</td>
<td>0.34-0.4</td>
<td>-</td>
<td>0.15-0.35</td>
<td>-</td>
<td>0.2-0.25</td>
</tr>
</tbody>
</table>
4.4 **Scenario testing and results**

Following model calibration, scenario model runs for Q\textsubscript{18}, Q\textsubscript{15}, Q\textsubscript{10}, Q\textsubscript{5}, Q\textsubscript{2} were undertaken (model flow estimates as outlined in Table 4.4). Results are described below.

### 4.4.1 Depths and Long section

A long profile of the scenario results (as well as calibration and validation flows) is provided in Figure 4.18 while water depth results for the different scenarios are illustrated in Figure 4.19.

The long profile generally indicates higher depths with increased flows while Figure 4.19 indicates that the model predicts minimal overtopping of banks in the lower end of the model under the Q\textsubscript{2} event. Flow splitting was observed in this lower stretch during the walkover although access to interrogate this wasn’t possible. As such this is not picked up well in the modelling, with imprinting of the channel restricted to the main channel indicated on Ordnance Survey mapping. Distributary flow is different to bank overtopping and floodplain inundation however, and so the model prediction that floodplain inundation occurring at flows greater than the Q\textsubscript{2} (tending towards flood flows) is considered possible.

![Figure 4.18](image-url)

**Figure 4.18** Water depth long profile of the scenario results (Q\textsubscript{18}, Q\textsubscript{15}, Q\textsubscript{10}, Q\textsubscript{5} and Q\textsubscript{2}) and calibration flow (Q\textsubscript{25}). Note intermittent zero depths are associated with the Q\textsubscript{25}.

### 4.4.2 Velocities

Water velocity results for the different scenarios are illustrated in Figure 4.20. These generally increase with higher flows though remain relatively modest, reflecting the moderate catchment size and gentle gradient of the system. They vary along the system suggesting the model is picking up on variation in the system (associated with the pool-riffle sequence observed through the model area).
Figure 4.19 Water depth results from the high flow scenarios (Q_{18}, Q_{15}, Q_{10}, Q_5 and Q_2)
Figure 4.20 Velocity modelling results. Scenarios Q18, Q15, Q10, Q5 and Q2
4.4.3 Shear Stresses

Shear stresses for each run were taken from CAESAR-LisFlood and are presented in Table 4.6. Results are of a similar order as simulated for the Meden at Budby, see Section 3.5.3. They vary between points, reflecting local conditions (with more varied channel form being observed through this reach than in the Meden at Budby), but generally increase with increased flow.

Table 4.6 Summary of the shear stress at the assessment and surveyed points. Results for the calibration event (Q$_{25}$) and scenario flows (Q$_{18}$, Q$_{15}$, Q$_{10}$, Q$_{5}$ and Q$_{2}$). Note results are presented to show model capability and show potential relative or orders of magnitude changes given the number of approximations used within the modelling process actual results should be treated with caution.

<table>
<thead>
<tr>
<th>Scenario/ID</th>
<th>AP1</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>AP2</th>
<th>S4</th>
<th>AP3</th>
<th>Reach average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q$_{25}$</td>
<td>15.90</td>
<td>7.12</td>
<td>6.54</td>
<td>3.94</td>
<td>8.73</td>
<td>7.88</td>
<td>5.57</td>
<td>7.95</td>
</tr>
<tr>
<td>Q$_{18}$</td>
<td>16.52</td>
<td>9.67</td>
<td>9.23</td>
<td>4.64</td>
<td>9.25</td>
<td>10.30</td>
<td>6.89</td>
<td>9.50</td>
</tr>
<tr>
<td>Q$_{15}$</td>
<td>17.68</td>
<td>10.55</td>
<td>11.77</td>
<td>6.35</td>
<td>11.23</td>
<td>10.58</td>
<td>7.46</td>
<td>10.80</td>
</tr>
<tr>
<td>Q$_{10}$</td>
<td>18.05</td>
<td>13.81</td>
<td>12.98</td>
<td>9.14</td>
<td>11.53</td>
<td>12.19</td>
<td>9.61</td>
<td>12.47</td>
</tr>
<tr>
<td>Q$_{2}$</td>
<td>21.14</td>
<td>17.63</td>
<td>15.37</td>
<td>14.21</td>
<td>11.89</td>
<td>14.85</td>
<td>12.97</td>
<td>15.44</td>
</tr>
</tbody>
</table>

Reviewing the results of the scenario modelling suggests that fine sediments would be transported through the Poulter reach under the high flow range being considered. A reduction in flow as a result of high flow abstraction, e.g. from the Q$_{2}$ to the Q$_{18}$ would reduce sediment transport although the bed would generally remain free of silt and sand (avoiding detrimental effects such as smothering of habitats).

Numerically the results indicate a reduction of sediment transport potentially of the order of 40% although given the number of approximations made through the development of the model, the actual model results and direct use of them in interpretation is not recommended. Findings of a fluvial audit would also likely significantly reduce this number, e.g. accounting for sediment sinks and sediment exhaustion. Through the work to date it is considered that the ability of CAESAR LisFlood modelling to simulate such processes and produce useful results has been demonstrated. A number of improvements and refinements (described later) can be undertaken to increase confidence in the model results so that they numerical results can be appraised and further useful sediment analyses may be undertaken (e.g. exploring shear stresses for various grain sizes, flow ranges in which they would be transported and how this could vary with abstractions at times of high flow).

As with the Meden reach, shear stresses were found to vary along the reach, with local final DEM differences affecting the results. This would result in variation in modelled sediment transportation, deposition or erosion through the reach, e.g. can explain localised deposits that may be observed. Given that the channel was stamped into the CAESAR LisFlood DEM uniformly differences throughout the reach are unlikely to represent local changes in bed levels but differences in LIDAR penetration. Improved surveys of reaches and incorporation of these into the model would remove this issue, however, and localised differences could be teased out of the results.

Although not in the model area, further downstream, at Elkesley/ see Plate 4.6, the channel widens and large in channel sediment deposition / sink is observed (with shear stresses likely to be lower in this area).
4.5 Discussion and Recommendations

CAESAR-LisFlood modelling was undertaken of the Poulter upstream of Elkesley, of a reach ~600m in length that was accessible.

Results from the Poulter modelling are generally similar to those described for the Meden (see Section 3.6). A sequence of riffles and pools were observed throughout the reach that was modelled. Simulated depths do reduce under reduced high flows, that may result, but remain high enough for migratory fish to maintain passage and find deeper areas to stay safe from predation (confirmed by site visit depth measurements of riffles and pools under flow conditions lower than the minimum high flow, Q_{18}, above which abstractions may be possible down to no less than the Q_{18}).

Results of the modelling indicated no significant hydrological (including no floodplain inundation under any scenario) or sediment changes are anticipated through the high flow range considered. It is noted that the modelling efforts undertaken introduced a number of uncertainties however and that the levels of abstraction have not been defined. Once more refined modelling has been undertaken and results are analysed a more detailed morphological appraisal can be undertaken though it is recommended that this is undertaken following a fluvial audit (which could, for example, indicate sediment exhaustion through the reach). Similarly the appraisal can be extended to consider the wider area. For example downstream of the modelled reach a wider channel is observed at one footbridge crossing over the river. This potential sedimentation zone would likely have potential hydromorphic connectivity effects on the wider system. Through this area changes may be more significant though this has not been simulated at this time, with access limited in this section.

Clumber Park SSSI lies in this waterbody though was not visited during Phase 2b. It was identified as being potentially sensitive under previous studies. Features of interest in the SSSI include standing open waters and heath woodland. The Environment Agency previously indicated that no formal Water Level Management Plan (WLMP) of the site exists and that habitats along the lake fringes and notable colonies of water starwort in the lake would more likely be susceptible to a reduction in low flows rather than a reduction in high flows.

The SSSI includes Clumber Park Lake which is online. An aerial imagery review of the outflow of this seems to indicate there is an overflow over which flows above a certain level would spill downstream. This level moderation likely indicates that there would be no impact to the lake as a result of additional abstractions at times of high flow. Effects on other terrestrial parts of the SSSI are considered to be low though could be confirmed by further studies, such as site visits to check hydrological connectivity of the large SSSI site with the River Poulter and interrogation of the LiDAR.

Only one visit of the site was undertaken and so a further visit, ideally under high flows is recommended to validate the model. Clumber Park SSSI could also be visited on the same day as this second site visit. In addition, the other recommendations outlined in Section 3.7 also apply to this waterbody/ site.
5. **Idle Washlands**

5.1 **Background and Environmental Baseline**

5.1.1 **Overview**

Phase 2a identified the River Idle (from Ryton to Trent) WFD waterbody as a priority waterbody to explore further for potential effects of abstraction at times of high flow. This was primarily due to potential effects of abstractions at times of high flow on the River Idle Washland SSSI. This has been investigated further and results are presented in this section.

5.1.2 **Site description**

The Idle Washlands are indicated in Figure 5.1 (note the units are those used in this study rather than those used by Natural England, in which 'a' would be Unit 1, 'b' would be Unit 2, 'c' would be Unit 3 and 'd' would be Unit 4). The features of interest at the site are wet grassland plant communities, large numbers of wintering and passage waterfowl. The Phase 2a appraisal stated the following (after which the site was screened in):

*The SSSI contained the remaining washland grasslands along the River Idle floodplain. Characteristically the grassland swards are dominated by marsh foxtail in a community which contains such wet meadow herbs as la smock and great burnet. In wetter areas the vegetation is dominated by stands of reed sweet-grass which has also colonised the internal drains although, locally, a more varied wetland plant community occurs which includes such plant species as meadow rue.*

*The SSSI has a WLMP which implies it is sensitive to water level variation in the Idle. Similarly a reduction in floodplain inundation, as a result of additional high flow abstraction, could impact upon this site.*

![Figure 5.1 River Idle Washland SSSI (units a, b, c and d)](image-url)
The River Idle through this area is low lying and level dependent, with water downstream being pumped into the Tidal Trent at West Stockwith pumping station. A review of imagery of the river through this waterbody found that the channel appeared engineered (realigned and deepened) and embanked, which will have impacts on lateral connectivity and sediment loads.

5.2 Site Walkover

5.2.1 Overview

The Washlands were visited on the 9th July 2020 to improve our understanding of the functioning of the site and conditions present. The upstream and downstream sites (‘a’ and ‘d’) were successfully surveyed. However, sites ‘b’ and ‘c’ have not been visited.

5.2.2 Idle Washlands: Unit ‘a’

A map of Idle Washland unit a is provided in Figure 5.2. This is the most upstream of the 4 SSSI units. It covers 50.9ha in area and elevations range from 2 to 6m AOD. Flood embanking tends to hug the site.

![Figure 5.2 River Idle Washlands SSSI Unit ‘a’](image_url)

Imagery from the site walkover is presented in Plates 5.1 to 5.6 below. The walkover indicated that the SSSI unit is in connectivity with the river and so levels in the river would affect levels in this unit of the SSSI (noting that levels in the Idle are controlled through this reach).
Plate 5.1 Idle Washlands ‘a’ observed from raised flood embankments at north eastern corner of the unit

Plate 5.2 Idle Washlands ‘a’ looking in a south westerly direction

Plate 5.3 Idle Washlands ‘a’ from northern flood embankments (looking to the west)

Plate 5.4 Idle Washlands ‘a’. Connection to the main channel is indicated (small boat behind some ground is on the river).

Plate 5.5 Idle Washlands ‘a’ – flapped outflow from a ditch through the flood embankments
5.2.3 Idle Washlands: Unit ‘b’

A map of Idle Washland unit b is provided in Figure 5.3. It extends 10.4ha in area ground levels range between 2 and 5m AOD. This site was not walked over and so it is not possible to confirm on its connectivity with the River Idle (drains on Figure 5.3 suggest there is connectivity though direction of flow in these is not known).

Figure 5.3 River Idle Washlands SSSI Unit ‘b’

5.2.4 Idle Washlands: Unit ‘c’

A map of Idle Washland unit c is provided in Figure 5.4. It extends 4.6ha in area ground levels range between 2 and 5m AOD. This site was not walked over and so it is not possible to confirm on its connectivity with the River Idle. Figure 5.4 and a review of aerial imagery suggests the central area of the unit can form a large pond. Although the site was not accessed imagery from the River Idle close downstream of it was taken and is shown in Plates 5.7 and 5.8. This show a low gradient slow flowing river that appears over deepened, straightening and trapezoidal that is behaving as a sediment sink.
5.2.5 Idle Washlands: Unit ‘d’

A map of Idle Washland unit d is provided in Figure 5.5. This is the most downstream of the 4 SSSI units. It covers 22.6ha in area and elevations range from 1 to 6m AOD. The site was observed from the left hand bank, with vegetation along that bank restricting views for much of it. Imagery from the site walkover is presented in Plates 5.9 to 5.16 below. Based on the walkover and a review of maps and aerial imagery, hydrological connectivity between the river and unit ‘d’ seems limited, although a review of the site LiDAR suggests there are flow route between the river and SSSI at the upstream and downstream ends of the SSSI.
Figure 5.5 River Idle Washlands SSSI Unit ‘d’

Plate 5.9 River Idle from left hand bank looking u/s (unit d to the south/ across the channel)

Plate 5.10 River Idle from left hand bank looking u/s (unit d across the channel)

Plate 5.11 River Idle Washlands from left hand bank looking d/s (edge of ‘d’ on the right)

Plate 5.12 River Idle looking downstream – Washlands Unit ‘d’ apparent across the river
Routine level monitoring in the Idle and Mattersey (just upstream of the level dependent section) was tracked on the day of the site visit. Level data for this site was available from November 2012 until June 2020. Level statistics for this data are presented in Table 5.1.

Levels at the Cuckney gauge varied from around the H\textsubscript{25} at 5am down to around the H\textsubscript{30} at 7pm. The site is somewhat downstream of the gauge (approximately 10km) and was visited around 2pm. Given this it is assumed that the levels at the site were closer to the H\textsubscript{25}/Q\textsubscript{25}.

\textsuperscript{15} H refers to stage and stage refers to the water level in a river or stream with respect to a chosen reference height (Ordinance Datum for this study). H statistics relate to the percentage of time that a specific stage is exceed. For example, the H\textsubscript{25} is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the H\textsubscript{25} and Q\textsubscript{25} for the same site should be equivalent to one another if derived from the same length of record).
Table 5.1 Level statistics for the Idle at Mattersey gauge stations

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Poulter at Mattersey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 09-07-2020 5am</td>
<td>1.397</td>
</tr>
<tr>
<td>Level 09-07-2020 7pm</td>
<td>1.485</td>
</tr>
<tr>
<td>H90</td>
<td>0.735</td>
</tr>
<tr>
<td>H50</td>
<td>1.070</td>
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<tr>
<td>H35</td>
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<td>H30</td>
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<td>H25</td>
<td>1.323</td>
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<td>H20</td>
<td>1.410</td>
</tr>
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<tr>
<td>H15</td>
<td>1.500</td>
</tr>
<tr>
<td>H10</td>
<td>1.630</td>
</tr>
<tr>
<td>H5</td>
<td>1.856</td>
</tr>
<tr>
<td>H2</td>
<td>2.107</td>
</tr>
</tbody>
</table>

This suggests that inflows to the level controlled section on the day of the survey may have been around the Q18 (equivalent to the EFI above which new abstractions may become possible). How this manifested through the level dependent section is less clear however, and likely linked to antecedent conditions (including recent River Idle surface water levels that would have influenced pumping rates out of the system as well as groundwater levels).

5.3 Modelling
5.3.1 Overview

A review of the latest Environment Agency River Idle strategic scale linked 1D/2D hydraulic FMP-TUFLOW flood model was undertaken during Phase 2a. This found that the Idle model was limited to the main stem of the Idle itself (downstream of the River Maun/ from Retford). This limited extent reduces the value of the Idle model as a tool so that it could not be used for other areas in the catchment, including the Meden (see Section 3) and Poulter (see Section 4).

In addition the review flagged a number of other aspects that warranted further examination and some other issues that should be ideally be resolved if the model was to be used extensively in Phase 2b. These are documented in the Phase 2a report. A number of these are linked to using the model to explore flooding events (i.e. when significant overtopping of the banks occurs) rather than high flows, which are the focus of this project. The existing model has been found to simulate flows through the whole of the Idle, however, including the lower level-dependent section, and includes abstractions and logical rules to represent pumps rather than pump units. Both are seen as advantages over developing one or more new CAESAR-LisFlood models through this reach.

On this basis it was decided to run high flows using the 1D/2D hydraulic FMP-TUFLOW flood model without model refinements being undertaken to provide an indication of the value of the model for assessing potential effects on the Idle Washland SSSI. Without undertaking much of the recommended, and other improvements to the model outlined in Phase 2a, then results from this

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exercise are considered unlikely to be reliable. The purpose of the modelling was to further explore the capability of the existing model.

Scenarios were run for the entire River Idle extent (including the free flowing and level dependent sections) for the $Q_{18}$ (similar to inflows observed on the day of the walkover), $Q_{15}$, $Q_{10}$, $Q_5$, $Q_2$ events. Hydrology unit files to simulate the high flow events were created with the flow inputs as outlined in Section 5.3.2 below. No other modifications were made to the existing flood model.

### 5.3.2 Model inflows

The model extent is indicative in Figure 5.6 along with the inflow locations.

![Hydraulic Model Inflows in River Idle flood model](image)

Inflows were estimated to input into the model. These build on the hydrological analyses undertaken in Phase 2a of the project. Flow was inputted to the model at four locations: Poulter, Maun/Med, (idle at) Mattersey and Ryton, these locations are shown in Figure 5.6. The flow inputted at each location is given in Table 5.2.

**Table 5.2 Model inflows at each location**

<table>
<thead>
<tr>
<th>Inflow</th>
<th>Inflow location and flow ($m^3/s$) (numbers are with reference to Figure 5.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top of the Idle/ Poulter inflow Bridge (1)</td>
</tr>
<tr>
<td>$Q_2$</td>
<td>1.53</td>
</tr>
<tr>
<td>$Q_5$</td>
<td>1.18</td>
</tr>
<tr>
<td>$Q_{10}$</td>
<td>0.94</td>
</tr>
<tr>
<td>$Q_{15}$</td>
<td>0.77</td>
</tr>
<tr>
<td>$Q_{18}$</td>
<td>0.82</td>
</tr>
</tbody>
</table>

* Based on results from the gauge at this location minus inflows at the Poulter and Meden/ Maun gauges upstream
5.3.3 Scenario Results

As indicated above, the following was undertaken in order to explore the capability of the model to improve the understanding of the potential effects of abstraction at times of high flow, noting that Phase 2a of this study determined that several improvements should be undertaken if the model is to be used further in this project. These have not yet been undertaken and so results of the modelling and discussion of them are likely to be inaccurate. Further improvements have been determined through this exercise as outlined through the remainder of this chapter.

Idle Washlands Unit ‘a’

A plot of water depths for the different scenarios is provided in Figure 5.7 below. Interrogation of the model results indicate an increase of depths in the unit of around 0.65m between the Q_{18} and Q_{2} scenario (with depths in the former typically around 0.15-0.2m and in the latter of around 0.8-0.85m).

The spatial extent of inundation for the Q_{18} model is similar to that observed in the field, when flow in the Idle was also around the Q_{18}. The extent of inundation appears similar under the Q_{15} and Q_{10} events though increases substantially under the Q_{5} and Q_{2} events. A reduction in high flows, as a result of abstraction, could reduce the extent of inundation and depths of inundation of the floodplain through unit ‘a’. Such changes could impact upon the vegetation throughout the unit. As the system is level dependent it may be possible to overcome such effects by controlling levels throughout the system and reducing pumping out of the Idle. The SSSI reportedly has a Water Level Management Plan (WLMP) and the Environment Agency are undertaken further investigations in the hydrology through the level dependent section of the hydrology. It is suggested that potential effects and mitigation are considered further through interrogation of these.

Figure 5.7 Water depth results for Idle Washlands SSSI Unit ‘a’ (scenarios Q_{18}, Q_{15}, Q_{10}, Q_{5} and Q_{2}). Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.

A plot of water velocity results is provided in Figure 5.8. This generally shows low velocities, even at times of high flow, throughout the system demonstrating the low gradient and oversized channel.
Such low flows would be conducive to high rates of siltation though the system may have stabilised (although would quickly infill if dredging were to occur).

Shear stresses through the main channel were also calculated using the modelling results and the following formula\textsuperscript{17}:

\[
\text{Shear stress} = \text{Density of water} \times \text{acceleration due to gravity} \times \text{flow depth} \times \text{slope of channel}
\]

Calculation locations are indicated in Figure 5.9 and results are shown in Figure 5.10. As observed in the velocity results, shear stresses are also low for each of the high flow scenarios indicating an environment where deposition is dominating the system. This is likely the same in the vicinity of the downstream units and so is not considered further in this report.

\textsuperscript{17} Given very low gradient throughout the whole system some negative bed gradients were apparent (where the bed locally rises) which would result in negative shear stresses being calculated. To avoid negative values the slope of the water surface level was used.
Figure 5.9 Locations where shear stresses have been calculated in the River Idle alongside Washland unit ‘a’ from the modelling results. Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.

Figure 5.10 Calculated shear stresses in the River Idle, along Washlands SSSI Unit ‘a’. Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.

Idle Washlands Unit ‘b’

Modelled water depths and velocities in the Idle Washlands unit ‘b’ are indicated in Figures 5.11 and 5.12 below. The modelling suggests that there is some hydrological connectivity between the Washland and the Idle at high flows toward the lower end of unit ‘b’. Under the Q5 and Q2 scenarios there appears to be an inflow at the upper end of the unit too. Interrogation of the model results...
indicate an increase of depths in the unit of around 0.6m between the $Q_{18}$ and $Q_2$ scenario (with depths in the former typically around 0.15m and in the latter of around 0.75m).

Velocity results show a relatively languid environment as described for unit ‘a’ and neighbouring Idle above.

Figure 5.11 Water depth results for Idle Washlands SSSI Unit ‘b’ (scenarios $Q_{18}$, $Q_{15}$, $Q_{10}$, $Q_5$ and $Q_2$). Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.

Figure 5.12 Water velocity results for Idle Washlands Unit ‘b’ (scenarios $Q_{18}$, $Q_{15}$, $Q_{10}$, $Q_5$ and $Q_2$). Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.
Idle Washlands Unit ‘c’

Modelled water depths and velocities in the Idle Washlands unit ‘c’ are indicated in Figures 5.13 and 5.14 below.

An initial review of the model results suggested that there is good hydrological connectivity between the Washland unit under each of the high flows examined. Depths are quite high for most of the unit suggesting limited wetland vegetation through most of the unit at times of high flow with this likely to be focussed in the marginal areas of the ponded area where depths would be lower.

Interrogation of the model results indicate an increase of depths in the unit of around 0.2m between the Q18 and Q2 scenario (lower than indicated for the units ‘a’ and ‘b’ upstream).

Again velocity results show a relatively languid environment as described for units ‘a’ and ‘b’ upstream. With the good connectivity between the river and SSSI unit the modelling indicates that the system is effectively a large pond through this reach with even lower velocities, than upstream.

On review of aerial imagery and further review of the depth results, however, it is considered that the modelling does not represent this area well. Depth results do not show a clear trapezoidal channel that is known to be present and levels of inundation appear unrealistic. Depths grade up across the unit in uniform manner suggesting that they have been iterated.

Interrogation of the flood model in this area has indicated that the washlands are included within the 1D model cross section. The model operates model works is that the 1d water level is consistent across the whole cross section and actual elevations through the SSSI are not represented. Thus modelled flow depths are unrealistic. If the model is to be used further through this area then the representation of the river and SSSI unit would need to be improved. How similar areas in the lower Idle, where connection between the floodplain would be anticipated at times of high flow, are represented in the model should also be examined and iterated if the model is to be used further in this study (as affects in one area may have knock on effects elsewhere).

Figure 5.13 Water depth results for Idle Washlands Unit ‘c’ (scenarios Q18, Q15, Q10, Q5 and Q2).

Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.
Figure 5.14 Water velocity results for Idle Washlands Unit ‘c’ (scenarios Q_{18}, Q_{15}, Q_{10}, Q_5 and Q_2). Note figure demonstrates capability/potential of the modelling – with confidence in the actual results being low.

Idle Washlands Unit ‘d’

Modelled water depths in the Idle Washlands unit ‘d’ are indicated in Figures 5.15 below.

Figure 5.15 Water depth results for Idle Washlands Unit ‘d’ (scenarios Q_{18}, Q_{15}, Q_{10}, Q_5 and Q_2 - note review of results and further review of the model show this area is not represented well in the current model). Note figure demonstrates capability/potential of the modelling – with confidence in the actual results being low.
As with unit ‘c’ an initial review of the model results suggested that there is good hydrological connectivity between the Washland unit under each of the high flows examined. Depths are quite high through the SSSI along the river although this doesn’t match up with observation of the site (which were of the riparian area not being inundated when flows into the level dependent system where potentially around the $Q_{25}$ (moderate to high).

Modelled water velocities in the Idle Washlands unit ‘d’ are indicated in 5.16 below.

![Figure 5.16 Water velocity results for Idle Washlands Unit ‘d’ (scenarios $Q_{18}$, $Q_{15}$, $Q_{10}$, $Q_{5}$ and $Q_{2}$ - note review of results and further review of the model show this area is not represented well in the current model). Note figure demonstrates capability / potential of the modelling – with confidence in the actual results being low.](image)

A review of the LiDAR through this area (Figure 5.17) does indicate lowerings in the embanking that could enable flow into the unit from the river although a review of the aerial imagery suggests that these are exaggerated and/or that the channel is not deep enough. On further review of the results the same issues as observed in the unit ‘c’ results were found (i.e. unit was included in the 1d domain). As such model results are not representative of what would occur and further work would be required to improve this, if the model was to be used further in this study.
5.4 Discussion and Recommendations

Modelling using the existing Environment Agency 1D/2D hydraulic FMP-TUFLOW flood model was undertaken in order to assess potential effects of additional abstractions at times of high flow (greater than the Q_{18}) may be on the Idle Washlands SSSI. The features of interest at the site are wet grassland plant communities, large numbers of wintering and passage waterfowl.

The units is comprised of 4 units, referred to units ‘a’, ‘b’, ‘c’ and ‘d’. Units ‘a’ and ‘d’ were visited during Phase 2b though the other two were not.

The modelling was undertaken in order to explore the capability of the model to improve the understanding of the potential effects of abstraction at times of high flow, noting that a review of the model in Phase 2a raised a number of concerns and improvements to that if it were to be used in earnest. These were not undertaken for this phase, with efforts being focussed on testing the approach using CAESAR-LisFlood modelling. Nonetheless it was decided by the project team do run a few scenarios using the existing model to further explore its value as a tool to help establish the potential effects of abstractions at time of high flow in the lower Idle, along the Idle Washland SSSI and also if further improvements would be needed if it was to ultimately be used. As such, there is low confidence in results of the modelling that has been undertaken to date.

To examine different flows, inflows to the model were adjusted to reflect 5 high flow scenarios, the $Q_{18}$, $Q_{15}$, $Q_{10}$, $Q_{5}$ and $Q_{2}$. No other adjustments were made to the models prior to them being run.

Results of the modelling of units ‘a’ and ‘b’ indicated changes in extents and levels of inundation between the range of high flows considered that appeared reasonable. Depth were around 0.6m greater in the $Q_{2}$ run than the $Q_{18}$ run and it is likely that this is greater than the managed level variation through the lower River Idle system and so we suggest the managed operating levels are obtained and accounted for in future studies. It is possible that the West Stockwith operating rules in
the model that was used do not represent pumping from the Idle into the Tidal Trent well, under the high flow range considered.

It is considered that at present units ‘c’ and ‘d’ and the Idle nearby are not represented well in the current model, with results not matching observations during the site visit and/ or aerial imagery reviews. On further review of the model it was found that these units were included in the 1d domain of the model and so results of the modelling of these are considered to be inaccurate and should not be used further.

In general, velocity and shear stress results confirmed an essentially flat and languid waterway in this reach, with sedimentation dominating. Site observations and general understanding of the system confirmed this aspect with the system being low lying and of very low gradient in this area. In this environment the river would be of low sensitivity to flows being reduced at times of high flow as a result of the abstraction with regard to sediment processes.

The following are recommended, in order to confirm any effects on the SSSI as a result of additional abstractions from the River Idle:

- The Environment Agency are currently undertaking a detailed review of the hydrology of the Isle of Axholme, including the level dependent section of the River Idle that includes the river along the Idle Washlands SSSI. Results of this should be reviewed with regard to this ongoing project. Outputs of the hydrology study are anticipated to include the following:
  - Improved understanding of how levels vary in the lower Idle. This would include a review of the operating levels at West Stockwith.
  - An estimate of all inflows to and outflows from (latter including to the Tidal Trent) the level dependent section of the River Idle resulting in water balance conceptualisation of the system being produced.
  - Derivation of flow duration curve and flow duration statistics for volumes released from West Stockwith pumping station to the Trent (at the end of the Idle). This will be the combination of gravity release and pumped release volumes.

- It is understood that a WLMP of the Idle Washlands is available and this should be reviewed further. A piezometer was observed in unit ‘d’ and indicates that ongoing monitoring in the SSSI is undertaken, by Natural England or partner. This should be sought and interrogated to explore potential effects. Similarly Natural England should also be consulted with regard their management of the system, any more detailed habitat mapping they may hold (not available online) and with regard to any expectations they may have of further studies during future stages of this project.

- Subject to the results of the above it may be possible to complete the review based on information received and analysis of historical datasets. If not, it may still be possible to use the existing flood model though if this is undertaken further refining of it is recommended. This would include improving how the river is represented through this reach (notably ensuring that units ‘c’ and ‘d’ are included in the 2d domains) and reviewing how realistically the pumping stations are operating in the model.
6. **Other Sites**

6.1 **Overview**

In addition to the areas that have been investigated further during Phase 2b, a number of other sites were visited to improve our understanding of them and the potential effects that may occur as a result of abstractions at times of high flows. Sites were visited on one day (9th July 2020). The sites were as follows:

- Ryton (Anston to Idle) – identified as a Tier 1 waterbody in Phase 2a;
- Poulter (Source to Millwood) – identified as a Tier 1 waterbody in Phase 2a;
- Maun (Vicar Water to Rainworth) – identified as a Tier 1 waterbody in Phase 2a;
- Hatfield Waste Drain/ North Soak Drain (focussed on Crowle Borrow Pits SSSI) – identified as Tier 2 area in Phase 2b; and
- Torne at Papermill Dyke – not identified as a Tier 1 or 2 waterbody during Phase 2a although the Environment Agency considered it worth visiting if possible as characteristic of the Torne.

The site visits and our interpretation of them are presented in the following sub-sections. Sites in the Torne catchment are presented first followed by those in the Idle catchment.

6.2 **Hatfield Waste Drain/ North Soak Drain (focussed on Crowle Borrow Pits SSSI)**

6.2.1 **Waterbody overview**

According to the results of Phase 2a and following discussions with the Environmental Agency, the Hatfield Waste Drain and North Soak Drains WFD waterbodies were chosen for more detailed investigations (in the second tier of priority). This was primarily due to potential effects on the Crowle Borrow Pits SSSI which lies in both waterbodies. This is the focus of this section. The study area location, that was visited during the site visit, as well as both waterbodies is shown in Figure 6.1.
6.2.2 Site visited

A more map detailed of the Crowle Borrow Pits SSSI and location from which the SSSI was observed is indicated in Figure 6.2.

The SSSI is bounded by South Soak Drain at its northern end and Hatfield Waste Drain at its southern end. Stainforth and Keadby Canal lies at an elevated level compared to the South Soak Drain and land immediately to the south, including the SSSI.

Access into the SSSI was not possible through Curlews Farm to the centre of the SSSI. The site is bounded by the A18 to the south, which also prevented access there. Thus it was only possible to view the site from the path north of South Soak Drain.

Figure 6.2 Map of Crowle Borrow Pits SSSI, site visit viewing area and surrounding features

Images of the site and environ are provided in Plates 6.1 to 6.6. Smooth flow in and marginal vegetation around South Soak Drain indicates it to be a sediment sink.
Plate 6.1 Stainforth and Keadby Canal looking eastwards

Plate 6.2 Stainforth and Keadby Canal looking westwards

Plate 6.3 Former train line at western end of the Crowle Borrow Pits SSSI

Plate 6.4 South Soak Drain and end of the former rail line embankment

Plate 6.5 South Soak Drain and northern end of Crowle Borrow Pits SSSI (no obvious hydrological connection between these apparent, noting visibility was restricted)

Plate 6.6 South Soak Drain and northern end of Crowle Borrow Pits SSSI (no obvious hydrological connection between these apparent, noting visibility was restricted)
Routine level monitoring in the Torne at Auckley (upstream of the level dependent section) was tracked on the day of the visit. Level data for this site was available from December 2015 until June 2020. Level statistics for this data are presented in Table 6.1.

The site visited is located upstream of the canal (approximately 4km) and was visited around 11am on the 9th July 2020. Given this it is assumed that the flows into the level controlled section of the Torne system levels at the site were closer to the H30. This may equate to conditions in South Soak Drain though as levels are controlled through this section by a number of other elements, including the management of levels in the system and pumping rates to the tidal Trent via Keadby pumping station, this assertion is heavily caveated.

Table 6.1 Level statistics for the Auckley LVL Monitoring Station

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Torne at Auckley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 09-07-2020 10am</td>
<td>0.409</td>
</tr>
<tr>
<td>Level 09-07-2020 7pm</td>
<td>0.463</td>
</tr>
<tr>
<td>H90</td>
<td>0.245</td>
</tr>
<tr>
<td>H50</td>
<td>0.328</td>
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<tr>
<td>H35</td>
<td>0.384</td>
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<td>H30</td>
<td>0.417</td>
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<td>H25</td>
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<td>H20</td>
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<td>H5</td>
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<tr>
<td>H2</td>
<td>0.808</td>
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<tr>
<td>H2</td>
<td>0.920</td>
</tr>
</tbody>
</table>

Based on a restricted view of the northern edge of the site it appeared that hydrological connectivity between the SSSI and South Soak Drain was not occurring under the conditions at the time of the site visit (moderately high flow into the level dependent section of the Torne). This was confirmed through a review of the LiDAR, outlined in Figure 6.3. This shows raised levels between the SSSI and that elevations in the SSSI are lower than the surrounding area.
Levels in both the South Soak Drain and Hatfield Waste Drain are managed to vary to a relatively limited amount. Operating levels at Belton Grange pumping station (located on Hatfield Waste Drain upstream of the SSSI) are controlled to be between -0.25m AOD and -0.6m AOD during winter and 0m AOD and -0.2m AOD in summer. This suggests that other than during large flooding events, when downstream pumps are unable to pump out of the system as quickly as floodwaters enter it, minimal variation in levels at the drains would be expected. Given the embankments levels identified in the LIDAR data, connectivity between the SSSI and drains is likely to be infrequent.

6.2.3 Discussion

Crowle Borrow Pits SSSI lies either side of the embankment of a disused railway line and include a variety of habitats including alder carr, scrub, fen and open water in which several locally uncommon plant species occur. Several small ponds exist within the fen and scrub and contain aquatic and marginal species. The review above indicates that connectivity between the South Soak Drain and Hatfield Waste Drain and the SSSI is limited indicating that the source of water in the SSSI is groundwater or direct rainfall runoff. Given this it is considered that abstraction at times of high flow would not have a significant effect on this SSSI.

6.3 Torne at Papermill Dyke

6.3.1 Waterbody overview

Following discussions with the Environmental Agency, the Torne at Papermill Dyke was selected as a site to be visited. It lies within the Torne from Ruddle to St Catherine’s Well Stream WFD waterbody. This was not identified to be particularly sensitive to the effects to high flow abstraction, during Phase 2a, although considered to be worth visiting by the Environment Agency as it is typical of the free flowing part of the Torne (i.e. upstream of the level controlled low lying area). Further details on the site are provided in Figure 6.4.

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Figure 6.4 Torne from Source to Ruddle (Paper Mill Dyke) WFD waterbody and location of the site visit (near Papermill Dyke)

6.3.2 Site visited

A more map detailed of the area around the Torne at Papermill Dyke is provided in Figure 6.5. Images from the site visit are provided in Plates 6.7 to 6.9.

Figure 6.5 Torne at Papermill Dyke site visit viewing location (black box) and environ
The Torne at Papermill Dyke was visited around 1:30pm on the 9th July 2020. The nearest gauging station from this site is Torne at Auckley, located approximately 12km downstream from Torne at Papermill Dyke. Torne at Auckley was described previously on section 6.2.2. Referring to Table 6.1 above, given the site is upstream of the gauge it is assumed that levels observed were closer to the $H_{25}$, $Q_{25}$.

The site visit suggest that the system is similar to the Torne waterbody downstream (Torne from Ruddle to St Catherine’s Stream), acting as a sediment sink and that:

“... (waterbody is) considered to be homogenous in nature. It has been channelised and re-sectioned into long straight sections. Flow is predominantly slack with little habitat heterogeneity and heavy rates of sedimentation.”

$H$ refers to stage and stage refers to the water level in a river or stream with respect to a chosen reference height (Ordinance Datum for this study). $H$ statistics relate to the percentage of time that a specific stage is exceed. For example, the $H_{25}$ is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the $H_{25}$ and $Q_{25}$ for the same site should be equivalent to one another if derived from the same length of record).
Such a river environment is considered to be of low sensitivity to the effects of additional abstractions at times of high flow.

6.3.3 Discussion

The site visit confirmed our interpretation of the system, during Phase 2a, that the site is not particularly sensitive to the effects of abstractions at times of high flow. As representative of other free flowing areas of the Torne catchment then, this interpretation also applies elsewhere in the system.

6.4 Ryton (Anston to Idle)

6.4.1 Waterbody overview

According to the results of Phase 2a\textsuperscript{11}, the Ryton (Anston to Idle) waterbody was chosen as a Tier 1 waterbody worthy of more detailed investigations during Phase 2b. This was primarily due to macrophytes that are present potentially being sensitive to flow and the watercourse being considered pristine at one RHS monitoring location in the waterbody.

The study area location, that was visited during the site visit, as well as location of the waterbody in the Idle catchment is shown in Figure 6.6.

![Figure 6.6 Ryton (Anston to Idle) WFD waterbody and location of the site visit (in Worksop)](image)

6.4.2 Site visited

A more map detailed of the area around the Ryton through Worksop that was visited is provided in Figure 6.7. Images from the site visit are provided in Plates 6.10 to 6.15. Plates 6.10 to 6.12 indicate the Ryton through this area to be a highly straightened urbanised channel.
Figure 6.7 Ryton (Anston to Idle) waterbody site visit viewing locations and environ

Plate 6.10 River Ryton in Priorswell Recreational Ground (looking across the channel from right hand bank)

Plate 6.11 River Ryton in Priorswell Recreational Ground (looking upstream from right hand bank)
The Ryton (Anston to Idle) site was visited around 2pm on the 9th July 2020. The area visited is located approximately 17 km upstream of Ryton at Blyth gauging station.

Level data for this station was available from November 2012 until June 2020. Also, levels at the station were tracked on the day of the visit. Level statistics for this data are presented in Table 6.2. River level at Blyth was above \( H_2 \) between 10:30am-08:30pm. Given this it is assumed that the levels at the site were closer to the \( H_2^{20} / Q_2 \). The level record was reviewed and appears reliable (even after the late 2019 and early 2020 floods) suggesting that high flows were observed during the site visit.

\( H \) refers to stage and stage refers to the water level in a river or stream with respect to a chosen reference height (Ordnance Datum for this study). \( H \) statistics relate to the percentage of time that a specific stage is exceed. For example, the \( H_{25} \) is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the \( H_{25} \) and \( Q_{25} \) for the same site should be equivalent to one another if derived from the same length of record)
Table 6.2 Level statistics for the Ryton at Blyth gauge stations

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Ryton at Blyth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 09-07-2020 10:30am</td>
<td>1.259</td>
</tr>
<tr>
<td>Level 09-07-2020 08:30pm</td>
<td>1.173</td>
</tr>
<tr>
<td>H90</td>
<td>0.490</td>
</tr>
<tr>
<td>H50</td>
<td>0.590</td>
</tr>
<tr>
<td>H35</td>
<td>0.641</td>
</tr>
<tr>
<td>H30</td>
<td>0.668</td>
</tr>
<tr>
<td>H25</td>
<td>0.697</td>
</tr>
<tr>
<td>H20</td>
<td>0.735</td>
</tr>
<tr>
<td>H18</td>
<td>0.750</td>
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<td>H15</td>
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<td>1.144</td>
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<tr>
<td>H1</td>
<td>1.310</td>
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</table>

The site visit occurred after a period of heavy rainfall and high flows observed are in accordance with the antecedent conditions. Flows observed are also those potentially which may be reduced as a result of high flow abstraction.

The Ryton observed in this reach is disconnected from the floodplain and in a trapezoidal channel. Water levels were approximately 0.5m below bank level suggesting that a reasonable amount more flow would be required before floodplain inundation would be expected. The observed water in the river was relatively turbid suggesting it is a carrying a reasonable amount of sediment.

6.4.3 Discussion

The Phase 2a report documented an RHS site considered to be in pristine condition, when surveyed, in this waterbody. This, or similar sites, was not observed on the day of the site visit. The site that was observed is a highly straightened and trapezoidal urbanised channel which would be likely be of low sensitivity to abstractions at times of high flow (with it being disconnected from its floodplain). High flows were observed to be carrying a reasonable load of sediment.

Further studies in this waterbody are recommended to help examine potential effects of abstractions at times of high flow in this waterbody.

6.5 Poulter (Source to Millwood)

6.5.1 Waterbody overview

According to the results of Phase 2a\textsuperscript{11}, the Poulter (Source to Millwood) waterbody was chosen as a Tier 1 waterbody worthy of more detailed investigations during Phase 2b. This was primarily due to certain macroinvertebrate and macrophytes species that are present being considered as potentially sensitive to flow changes. Good habitat in the river has also been recorded in this waterbody.

The study area location, that was visited during the site visit, as well as location of the waterbody in the Idle catchment is shown in Figure 6.8.
6.5.2 Site visited

A more map detailed of the area around the Poulter through Cuckney, that was visited, is provided in Figure 6.9. Images from the site visit, including from Cuckney Dam which serves as a sediment sink, are provided in Plates 6.16 to 6.25.
Figure 6.9 Poulter (Source to Millwood) waterbody site visit viewing locations and environ

Plate 6.16 Poulter from path to the north of the downstream end of Cuckney Dam

Plate 6.17 Sluice at lower end of Cuckney Dam (near path/bridge referred to in Plate 6.16)
Plate 6.18 Cuckney Dam (observed from above the sluice referred to in Plate 6.17)

Plate 6.19 Cuckney Dam (looking upstream from downstream end)

Plate 6.20 Overflow from Cuckney Dam into the River Poulter

Plate 6.21 Cuckney Dam (looking upstream from downstream end)
The Poulter at Cuckney (Source to Millwood) site was visited around 3pm. The nearest gauging station from this site is Poulter at Cuckney, located approximately 1km downstream from the site visited. The Poulter at Cuckney level record was described previously in Section 4.2.3.

Table 6.3 show the levels tracked at Poulter at Cuckney during the day of the visit. With reference to the level statistics calculated for this station (Table 4.3) and Table 6.2, it seems levels at Cuckney varied from around the \( H_{20} \) at 11am down to around \( H_{30} \) at 7pm. As the site is close to the gauge and time of the visit was approximately midway between the two level recordings it is assumed that levels may have been around the \( H_{25}^{21} \).  

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\( H \) refers to stage and stage refers to the water level in a river or stream with respect to a chosen reference height (Ordinance Datum for this study). \( H \) statistics relate to the percentage of time that a specific stage is exceed. For example, the \( H_{25} \) is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the \( H_{25} \) and \( Q_{25} \) for the same site should be equivalent to one another if derived from the same length of record).
Table 6.3 Levels recorded on the day of the site visit at the Poulter at Cuckney gauge station

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Poulter at Cuckney</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 09-07-2020 11am</td>
<td>0.192</td>
</tr>
<tr>
<td>Level 09-07-2020 7pm</td>
<td>0.168</td>
</tr>
</tbody>
</table>

Plate 6.25 indicates that the water in the river was relatively clear in the river suggesting relatively low suspended sediment concentrations. Silt on the bed and macrophytes in the river were observed too. Cuckney Dam (which can be considered as a man-made lake) is potentially online and may trap some sediment from the system. The Phase 2a review found that suspended sediment loads in the Poulter were low compared to other rivers in the Idle (such as the Meden, Maun and Ryton) and the site visit appears to corroborate this.

6.5.3 Discussion

At moderately high flows, some siltation in the Poulter was observed while no floodplain inundation was observed. Some similarities with the waterbody upstream were apparent (low suspended sediment concentrations) which indicates that some of the findings of the CAESAR-LisFlood modelling exercise (Section 4) from there could apply. Ultimately, however, through the brief site visit it is not possible to state whether abstraction at times of high flow would have significant effects through this reach and wider waterbody. Further studies, which could include CAESAR-LisFlood modelling and site surveys are recommended to investigate potential effects of high flow abstraction.

6.6 Maun (Vicar Water to Rainworth)

6.6.1 Waterbody overview

According to the results of Phase 2a\(^1\), the Maun (Vicar Water to Rainworth) waterbody was chosen as a Tier 1 waterbody worthy of more detailed investigations during Phase 2b. This was primarily due to certain macroinvertebrate and macrophytes species that are present being considered to either be sensitive to flow or sedimentation changes, which could occur as a result of additional abstractions at time of high flow.

The study area location, that was visited during the site visit (Edwinstowe), as well as location of the waterbody in the Idle catchment, is shown in Figure 6.10.
6.6.2 Site visited

A more map detailed of the area around the Maun through Edwinstowe, that was visited, is provided in Figure 6.11. Images from the site visit are provided in Plates 6.26 to 6.31.
Figure 6.11 Maun (Vicar Water to Rainworth) waterbody site visit viewing location and environ

Plate 6.26 River Maun looking upstream from the B6034 bridge

Plate 6.27 River Maun looking upstream towards B6034 bridge
The River Maun in Edwinstowe was visited around 4pm on the 9th July 2020. The site is located 8 km downstream of Maun at Mansfield the Dykes flow gauging station (which is the nearest gauge on the Maun).

Level data for this station was available from November 2012 until July 2020. Level statistics for this data are presented on Table 6.4. Also, routine level monitoring in the Maun at Mansfield the dykes was tracked on the day of the site visit. Levels tracked varied from around the H_{10} at 12pm down to around the H_{18} at 7pm. Given this, and noting the gauge is 8 km of the site visits, it is assumed that the levels at the site may have been approximately around the H_{15}/Q_{15}.

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\(^{22}\) H refers to stage and stage refers to the water level in a river or stream with respect to a chosen reference height (Ordnance Datum for this study). H statistics relate to the percentage of time that a specific stage is exceed. For example, the H_{25} is the stage value which is exceeded for 25% of the time, based on the record used to derive the stage statistics. When stage and flow is measured at the same location (e.g. typically at a flow gauge), the equivalent stage statistic should correspond to the flow statistic if the period used to inform both is the same (e.g. the H_{25} and Q_{25} for the same site should be equivalent to one another if derived from the same length of record).
Table 6.4 Level statistics for the Maun at Mansfield the Dykes.

<table>
<thead>
<tr>
<th>Gauge station</th>
<th>Maun at Mansfield the Dykes</th>
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<td>Level 09-07-2020 12 pm</td>
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<tr>
<td>Level 09-07-2020 7pm</td>
<td>0.337</td>
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<tr>
<td>H90</td>
<td>0.249</td>
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<tr>
<td>H50</td>
<td>0.286</td>
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<tr>
<td>H35</td>
<td>0.300</td>
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<td>H15</td>
<td>0.342</td>
</tr>
<tr>
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</tr>
<tr>
<td>H5</td>
<td>0.410</td>
</tr>
<tr>
<td>H2</td>
<td>0.487</td>
</tr>
</tbody>
</table>

Flows observed on the during site are potentially at the lower end of high flows during which additional abstraction may occur within the Idle catchment. Observed waters were generally not turbid suggesting sediment concentrations were low (Plates 6.26, 6.27 and 6.31). Some siltation of the bed (comprised of stones) was apparent (Plate 6.26) and bankside sedimentation was observed (Plate 6.31). The latter was not vegetated suggesting it may be transient, e.g. eroded under higher flows and replenished under lower flows.

6.6.3 Discussion

As with the Poulter (Source to Millwood) site visit findings, through the brief site visit it is not possible to state whether abstraction at times of high flow would have significant effects through this reach and wider waterbody. Further studies, which could include CAESAR-LisFlood modelling and site surveys are recommended to investigate potential effects of high flow abstraction.
7. Summary and Recommendations

7.1 Summary

7.1.1 Phase 2b Overview

Phase 2a identified 6 waterbodies ('Tier 1' waterbodies) in the River Idle catchment most worthy of further investigations to help ascertain if abstractions at times of high flow (above the Q18) would have significant effects or not. These waterbodies were:

- Idle from River Ryton to River Trent (including River Idle Washlands SSSI);
- Maun from Vicar Water to Rainworth Water;
- Meden from Sookholme Brook to River Maun;
- Poulter from Source to Millwood Brook;
- Poulter from Millwood Brook to River Maun (including Clumber Park SSSI); and
- Ryton from Anston Brook to Idle.

5 further waterbodies were also considered potentially sensitive and next worthy of further studies ('Tier 2' waterbodies). These were:

- Hatfield Waste Drain (trib of Torne/Three Rivs) and North Soak Drain (trib of Torne/Three Rivs) (focussed on Crowle Borrow Pits SSSI);
- Meden from Source to Sookholme Brook;
- Ryton (to Anston Brook); and
- Sookholme Brook.

A number of tools were utilised during this phase to test their suitability for this study. Ideally they would be used to ideally confirm or rule out potential effects but at least help determine what additional studies may be required. The tools were constructing and running CAESAR-LisFlood models of two discrete river reaches (one in the Meden from Sookholme to River Maun WFD waterbody and another in the Poulter from Millwood Brook to River Maun), utilising the existing 1D/2D hydraulic FMP-TUFLOW model of the main stem of the Idle to assess potential effects on the Idle Washlands SSSI as well as rapid site visits of a number of areas throughout the catchments.

It is recognised that the modelling efforts utilised existing or best available information (e.g. LIDAR with no formal additional surveys being undertaken during this phase which could be incorporated into the models). As such there is a low confidence in the accuracy of current model results although the ability of the tools has been appraised and example outputs have been generated through the Phase 2b efforts.

Scenario modelling, of various high flows, were run for each model. Values of flows simulated were informed by hydrological studies undertaken during Phase 2a and corresponded to the:

- $Q_{18}$ (above which additional abstraction may become possible in the Idle catchment and potential new hands off flow);
- $Q_{15}$;
- $Q_{10}$;
- $Q_{5}$; and
- $Q_{2}$.

This range was considered to represent the range of high flows under which abstractions are most likely to occur and have the greatest effect. The amount and locations of abstraction are not stated and so potential affects were considered in a general non-specific manner (e.g. may occur upstream of the sites being reviewed noting that if they were downstream affects would be potentially
negligible). No hydraulic modelling was undertaken in the Torne catchment (where the Q_{15} is the proposed hands off flow).

Site visits were also undertaken to inform the modelling as well as aid local interpretation of potential affects.

Results of the modelling and site visits were reviewed to appraise the potential effects of additional abstraction in the Torne or Idle catchments at the time of high flow on the geomorphological and ecological functioning of the river systems in channel as well as with the floodplain.

7.1.2 Phase 2b findings for waterbodies where CAESAR-LisFlood modelling was undertaken

CAESAR-LisFlood models were built of the Meden at Budby (Meden (Sookholme to Maun) WFD waterbody) and Poulter (Poulter (from Millwood Brook to River Maun) WFD waterbody) in the vicinity of Elkesley. Models were calibrated, using measurements from site visits, and the Meden model was also validated (possible through a second visit). A number of high flow scenarios were then run and results analysed.

During the works the channels were found to not be well represented in the LiDAR. It was possible to adjust the DEM based on a limited number of coarse measurements rather than a detailed survey (which was not available or undertaken during this project). It is recognised that using the former brings introduces more uncertainties into the modelling and results in low confidence in the accuracy of the modelling results.

Model results, for the Meden at Budby, indicated that although depths and velocities vary through the range of high flows considered (increasing with increased flows), significant inundation of the floodplain did not occur, sufficient depths for migration were observed. The latter corresponded with site observations (undertaken at a moderately high flow). Similarly a hydromorphological review of imagery of the identified the presence of an armoured bed through the reach. These are less favourable for invertebrates given that the gravels are not readily mobile though would mean that the channel is less sensitive to the effects of abstractions at times of high flow. Shear stress results were generated at the site though given low confidence in the accuracy of the modelling results undertaken to date we recommend that these are appraised once the modelling has been refined. Overall results for the stretch of the Poulter that was modelled were similar.

It was acknowledged that in both further efforts could provide greater confidence in these findings. Similarly efforts elsewhere in both waterbodies (such as site surveys and targeted fluvial audits), could indicate if the findings would be applicable elsewhere in the system or what alternate findings may be. Potential further efforts are outlined in Section 7.2 (Recommendations). Clumber Park SSSI (and lake) lies in the Poulter (from Millwood Brook to River Maun) WFD waterbody and visits to this may confirm if additional abstractions at time of high flow may have an impact upon this site (noting that no indication of detrimental effects have been identified to date).

7.1.3 Phase 2b findings for waterbodies where modelling using the existing 1D/2D hydraulic FMP-TUFLOW flood model was used

Modelling using the existing Environment Agency 1D/2D hydraulic FMP-TUFLOW flood model was undertaken in order to assess potential effects of additional abstractions at times of high flow (greater than the Q_{18}) may be on the Idle Washlands SSSI. The features of interest at the site are wet grassland plant communities, large numbers of wintering and passage waterfowl.

The units is comprised of 4 units, referred to units ‘a’, ‘b’, ‘c’ and ‘d’. Units ‘a’ and ‘d’ were visited during Phase 2b though the other two were not. High flow scenario modelling was undertaken as outlined above though models themselves were not adjusted (noting issues identified during Phase 2a with purpose of the modelling to fully gauge its continued use in the study).
Results of the modelling of units ‘a’ and ‘b’ indicated changes in extents and levels of inundation between the range of high flows considered that appeared reasonable although potentially exaggerated (depth were around 0.6m greater in the $Q_{2}$ run than the $Q_{18}$ run although levels are generally managed through this system to a smaller range than this).

Review of the results from units ‘c’ and ‘d’ ultimately found that neither is suitably represented in the existing model for this study (with both lying in the 1d domain rather than the 2d domain). This could be improved if the modelling was to be used further in this project.

In general, velocity and shear stress results confirmed an essentially flat and languid waterway in this reach, with sedimentation dominating. Site observations and general understanding of the system confirmed this aspect with the system being low lying and of very low gradient in this area. In this environment the river would be of low sensitivity to flows being reduced at times of high flow as a result of the abstraction with regard to sediment processes.

### 7.1.4 Phase 2b findings from the site visits

Through site visits and analysis of LIDAR information potential effects on Crowle Borrow Pits SSSI in have been screened out. Another visit to the Torne, at Papermill Dyke, indicated that the river there was serving as a sediment sink, has been substantially modified (channelised, straightened etc). Flow in it was observed to be predominantly slack with little habitat heterogeneity.

Brief visits to the three locations in the Idle catchment, in the Ryton (Anston to Idle), Poulter (source to Millwood) and Maun (Vicar Water to Rainworth) waterbodies were also undertaken. Although useful data was obtained, further more intensive surveys and/ or modelling, is required to assess potential effects of additional abstraction at times of high flows in these waterbodies.

### 7.1.5 Overall Phase 2b findings

The combination of tools outlined in Phase 2b has been found to be effective in examining the potential effects of additional abstractions at time of high flow in the Idle and Torne catchments.

Phase 2a of the project only identified the Hatfield Waste Dr (trib of Torne/Three Rivs) and North Soak Drain waterbodies in the Torne system as being potentially sensitive to the effects of abstractions at times of high flow. The specific area considered potentially sensitive was Crowle Borrow Pits SSSI which straddles a small area of each waterbody (neighbouring South Soak Drain and Hatfield Waste Drain).

The site was visited during Phase 2b and a topographic review of the site and wider area was also undertaken. The review found that connectivity between the South Soak Drain and Hatfield Waste Drain and the SSSI is limited indicating that the source of water in the SSSI is groundwater or direct rainfall runoff. Given this it is considered that abstraction at times of high flow would not have a significant effect on this SSSI.

Additional evidence, such as site visits at times of high flow or review of results of ongoing studies, could increase certainty in this.

Through the combination of targeted site visits and modelling, potential effects on sensitive areas of the Idle catchment have been delimited or additional requirements to ascertain the potential effects of abstractions at times of high flow have been determined. Additional requirements are summarised in Section 7.2 below (Recommendations)

### 7.2 Recommendations

For the 2 waterbodies were CAESAR-LisFlood modelling was undertaken, further confidence in the modelling and associated results would be gained through the following:
• Re-visiting the sites during the winter when die back of vegetation had occurred and access to the site would likely be better.
• Re-visiting the site under times of high flow and confirming whether or not any distributaries are activated or floodplain inundation is occurring, under these conditions.
• A targeted fluvial audit of the waterbody being undertaken (a fluvial audit is discussed further below).
• Channel surveys cross sections and long sections could be undertaken that are referenced to Ordnance Survey datum and this information integrated into the CAESAR-LisFlood models. An improved spatial understanding of the river network would also improve stamping in of the channels into the LiDAR which seems to be a common requirement for CAESAR-LisFlood of these systems.

Once this has occurred, more detailed interrogation and processing of the results can be undertaken than what has been indicated in this report. Such additional efforts could include further sediment analyses, which should be informed by the fluvial audit, and creation of velocity or depth scenario difference maps which would enable results between runs to be easily compared.

In addition it is recommended that a visit to Clumber Park SSSI, including its lake, is undertaken. Natural England should also be consulted with regard to this site and they may be able to provide relevant information that can be used in future phase of the project.

The following are recommended, in order to confirm any effects on the Idle Washlands SSSI as a result of additional abstractions from the River Idle:

• The Environment Agency are currently undertaking a detailed review of the hydrology of the Isle of Axholme, including the level dependent section of the River Idle that includes the river along the Idle Washlands SSSI. Results of this should be reviewed with regard to this ongoing project. Outputs of the hydrology study are anticipated to include the following:
  o Improved understanding of how levels vary in the lower Idle. This would include a review of the operating levels at West Stockwith.
  o An estimate of all inflows to and outflows from (latter including to the Tidal Trent) the level dependent section of the River Idle resulting in water balance conceptualisation of the system being produced.
  o Derivation of flow duration curve and flow duration statistics for volumes released from West Stockwith pumping station to the Trent (at the end of the Idle). This will be the combination of gravity release and pumped release volumes.

• It is understood that a WLMP of the Idle Washlands is available and this should be reviewed further. A piezometer was observed in unit ‘d’ and indicates that ongoing monitoring in the SSSI is undertaken, by Natural England or partner. This should be sought and interrogated to explore potential effects. Similarly Natural England should also be consulted with regard their management of the system, any more detailed habitat mapping they may hold (not available online) and with regard to any expectations they may have of further studies during future stages of this project.

• Subject to the results of the above it may be possible to complete the review based on information received and analysis of historical datasets. If not, it may still be possible to use the existing flood model though if this is undertaken further refining of it is recommended. This would include improving how the river is represented through this reach (notably ensuring that units ‘c’ and ‘d’ are included in the 2d domains) and reviewing how realistically the pumping stations are operating in the model.
Fluvial audits of River Idle waterbodies identified as potentially sensitive during Phase 2a are also recommended. These could be targeted through an initial desktop review to reduce the number of sites that should be visited. The field audit should be undertaken according to the method of Sear, Newson and Brookes (1995)\textsuperscript{23}. And ideally be undertaken under low to moderate flows when the bed and channel features may be best observed. The audit should result in the following, amongst others, being determined:

- What type of material is being transported and whether it is a permanent feature or not.
- Characterising the channel into sources, sinks and transfer/exchange reaches.
- Identifying other potential sediment sources, e.g. from diffuse pollution or building sites.

Ultimately the audit should confirm how sensitive sections of the river may be and whether upstream influences, such as sediments sinks may reduce potentially adverse effects. For example segregated and armoured beds were observed in the Meden and Poulter areas that were visited. These are less favourable to invertebrates, compared to static gravels and not readily mobile, and would be likely resilient to the effects of abstraction at times of high flow. Results of the audit could be used to confirm if modelling results from discrete areas could apply elsewhere in the same waterbody or in other similar waterbodies in the catchment.

The CAESAR-LisFlood (including complimentary surveys)/fluvial audit combined approach could be completed (where initial modelling work has already been undertaken during Phase 2b) or undertaken in full in the following waterbodies:

- Maun from Vicar Water to Rainworth Water (identified as a Tier 1 waterbody in Phase 2a);
- Meden from Sookholme Brook to River Maun (identified as a Tier 1 waterbody in Phase 2a/initial modelling already completed during Phase 2b);
- Poulter from Source to Millwood Brook (identified as a Tier 1 waterbody in Phase 2a);
- Poulter from Millwood Brook to River Maun (identified as a Tier 1 waterbody in Phase 2a/initial modelling already completed during Phase 2b);
- Ryton from Anston Brook to Idle (identified as a Tier 1 waterbody in Phase 2a);
- Meden from Source to Sookholme Brook (identified as a Tier 2 waterbody in Phase 2a);
- Ryton (to Anston Brook) (identified as a Tier 2 waterbody in Phase 2a); and
- Sookholme Brook (identified as a Tier 2 waterbody in Phase 2a).

Reviews of macroinvertebrate and macrophyte populations in the Torne catchment did identify some population sensitivity to changes in the physical environment though these were generally with regard to water quality rather than flow or sedimentation changes. Improved understanding on the potential effects of abstractions at times of high flow, e.g. informed by SIMCAT/ SAGIS modelling, may improve the understanding of potential effects on water quality which may in turn allow further appraisal on potential effects on aquatic life.

Similarly continuous water quality monitoring in a discrete number of locations is recommended and this may inform how it varies temporally and spatially with potential effects on aquatic life often dependent on how long drops occur and last when compared to annual spot measurement lows (noting that further lows may also be captured through continuous monitoring). Continuous records could be compared with flow records to further tease out the effects of flow on water quality.

Potential water quality sensitivity was also identified in the Idle system and efforts through this catchment would also be beneficial (with potential flow and sedimentation issues picked up through fluvial audits and modelling, as described above).