POTENTIAL RESIDENTIAL DEVELOPMENT, OAK MILLS, CLIFF HOLLINS LANE, OAKENSHAW, BRADFORD

FLOOD RISK ASSESSMENT

Prepared for

FMB Investments Limited

July 2016
Ref:116/01/fmb/fra/0716

S M Foster Associates Limited
Hydrological and Hydrogeological Consultants

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Document Revisions

Ref:	Details	Date
3		**31/07/2016**

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1. Introduction

1.1 This report has been prepared in response to instructions from Mr J Fawthrop of FMB Investments Limited dated 11th April 2014 and 29th June 2016. The report presents the findings of a Flood Risk Assessment (FRA) related to proposed residential development on land at Oak Mills, Cliff Hollins Lane, Oakenshaw, Bradford. Although there is no history of flooding at the site it is partially designated a high risk flood zone on the current Environment Agency flood map for the area. The assessment has been undertaken as a requirement of the planning process and to support an application for outline planning permission for the development. The site is located in the administrative area of Kirklees Council.

1.2 The assessment has incorporated desk-based analysis of flood mechanisms, a hydrological site survey and evaluation of flood risk constraints on potential development at the site. Following preliminary consultation with the Environment Agency (EA) the assessment has also included the development of a hydraulic model of the Hunsworth Beck at the site. The assessment has been prepared in accordance with the requirements of the National Planning Policy Framework (NPPF), Environment Agency flood risk Standing Advice and local authority policy regarding development and flood risk. The Environment Agency has also provided site-specific flood data which has been used to evaluate flood risk and support definition of flood protection measures at the site. Reference has been made to the Calder Valley Strategic Flood Risk Assessment (SFRA).

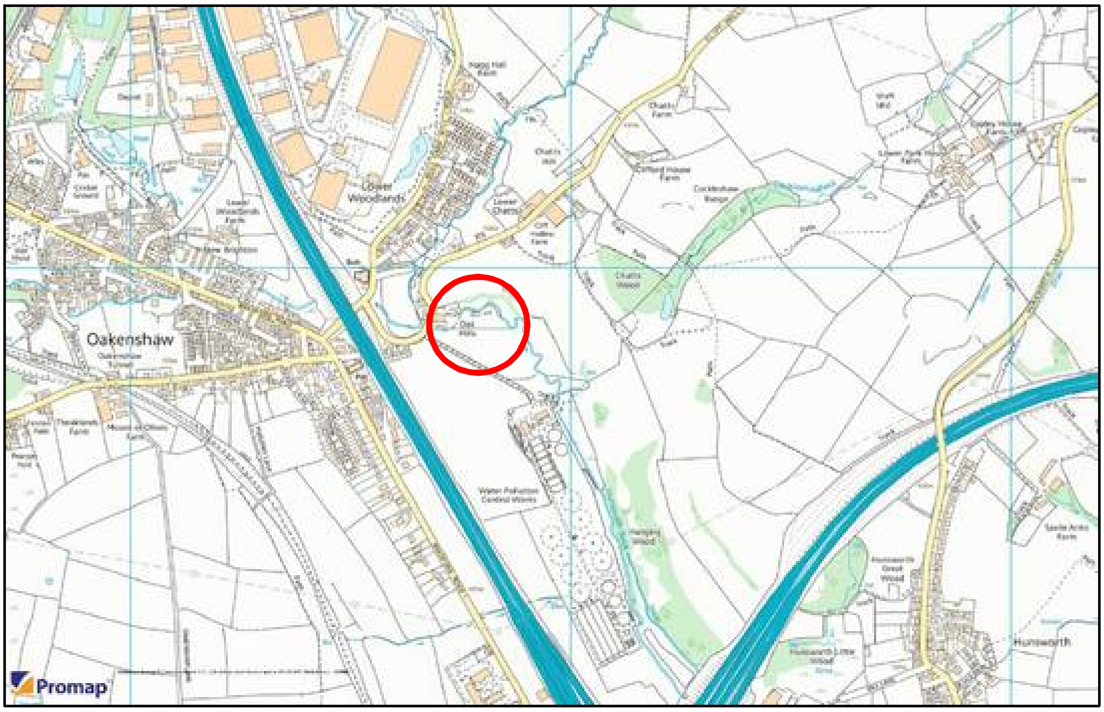
1.3 Detailed topographic survey data was submitted to the EA during preliminary consultations in June 2014 with a request to re-consider flood zone designation for the area. The EA had previously advised that it does not have any flood model data for the area and that the current flood zone designation is based on high level modelling only. The EA responded by correspondence of 29th July 2014 advising that a challenge to the flood map could not be considered without supporting hydraulic modelling studies based on site-specific hydrological data. Hydraulic modelling work has now been completed and the results are included in this report.

1.4 Hydraulic modelling studies have demonstrated that part of the site currently designated Flood Zone 3 should be re-designated Flood Zone 1 and that flood water depth in the residual area of the site within Flood Zone 3 would be relatively shallow. Hydraulic modelling studies have also indicated that where there is a risk of flooding it is solely related to flow restriction at a culvert that crosses the site. The proposed development includes provision to open the culvert and remove the existing flow restriction. Further hydraulic modelling work has therefore been undertaken to demonstrate that removal of the culvert would eliminate fluvial flood risk at the site and bring the entire site out of Flood Zone 3. Removal of the culvert and reinstatement of the section of Hunsworth Beck to its natural state would result in a significant environmental benefit to the site and surrounding area, reducing existing flood risk on land to the south of the site. Culvert removal is supported by the EA at national policy level.

2. Site location, development and flood risk

2.1 The site, which consists of former mill buildings and yard areas, is located on Cliff Hollins Lane in Oakenshaw, Bradford as shown on Figure 1. The postcode for the site is BD12 7ER and the centre of the site is located at NGR 417750 427875.

Figure 1: Site location



2.2 The site, which extends to approximately 0.8ha, is accessed directly from Cliff Hollins Lane and is currently used for light industrial works. Immediately surrounding land is primarily open grassland subject to agricultural or equestrian use although residential development occurs within a distance of 50-100m to the west and north west.

2.3 The site is crossed by a small watercourse known as Hunsworth Beck which is a tributary of the River Calder. It is understood that there is no recorded evidence of flooding at the site and the EA has confirmed that it has no historic flood records for the area. Hunsworth Beck flows along the southern site boundary before crossing the site to form the northern site boundary. The route of the beck is shown on Drawing 116/01/01 which accompanies this report. As shown in Figure 2, Hunsworth Beck flows in a natural channel on entry to the site before flowing beneath a steel and concrete deck to emerge in a natural channel around the northern site boundary. There are no other surface water features within the site.

Figure 2: Entry to Hunsworth Beck box culvert through the centre of the site

2.4 The Hunsworth Beck receives inflow from High Royds Beck. High Royds Beck joins Hunsworth Beck just upstream of the site at Cliff Hollins Road Bridge. The bridge consists of a double low stone arch with road deck and boundary wall as shown in Figures 3 and 4. Further upstream Hunsworth Beck flows through a similar culvert that passes beneath the M606 motorway.

Figure 3: Cliff Hollins Lane road bridge at Oak Mills - upstream

2.5 Existing ground levels at the site fall from a maximum elevation of approximately 100.4mAOD at the northern boundary to approximately 97.25mAOD at the south eastern (downstream) boundary. In general ground levels slope from north west to south with lowest elevations along the southern boundary and route of Hunsworth Beck.

Figure 4: Cliff Hollins Lane road bridge at Oak Mills - downstream

2.6 National planning policy related to flood risk is set out in the National Planning Policy Framework (NPPF) and supporting technical guidance. The primary objectives of the NPPF are to direct new development to areas at lowest flood risk where possible, and to ensure that new development can be safely established without adverse impact on flood risk in surrounding areas. NPPF guidance, based on the preceding PPS25 Development and Flood Risk, is typically incorporated into the local authority Strategic Flood Risk Assessment (SFRA) which sets out local policy with regard to development and flood risk.

Flood risk status

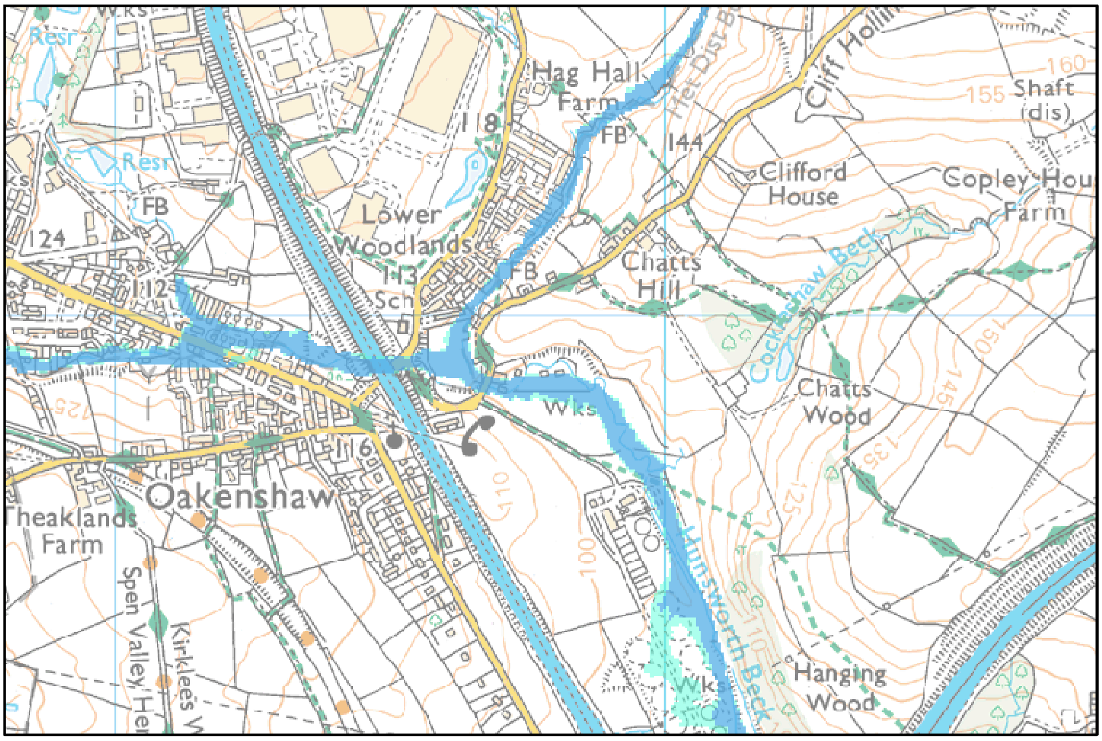
2.7 The flood risk status of the site and surrounding area is indicated on the current Environment Agency flood map which indicates that the southern part of the site is designated Flood Zone 3 and therefore at high risk of fluvial flooding. The northern part of the site is designated as Flood Zone 1 at low risk of fluvial flooding. A copy of the flood map is included as Figure 5 with a more detailed version at Appendix A with Environment Agency correspondence.

2.8 The Environment Agency has confirmed that, as Hunsworth Beck is not Main River at this location, there has been no detailed flood modelling of the beck in the vicinity of the site. It is therefore assumed that current flood zone designation is based on the Agency's high level modelling work which typically consists of JFLOW modelling based on Lidar sourced ground level data. On this basis it is accepted that the published flood map is an approximation of the potential extent of flooding in response to a 1 in 100 year flood event (Flood Zone 3).

2.9 The Calder Valley SFRA includes information to sub-divide Flood Zone 3 into 3a and 3b (functional floodplain). As shown on the SFRA flood map for the area (see Appendix B), there are no areas designated Flood Zone 3b within the Oak Mills site.

2.10 The published flood map suggests that any flooding of the site during extreme flood conditions would not occur as a consequence of out of bank flow from the Hunsworth Beck which flows through and around the site. The flood map indicates that flooding of the site would occur due to a combination of downstream backing-up in the beck and inundation from upstream flood water to the west of Cliff Hollins Lane.

Figure 5: Environment Agency flood map extract



2.11 A detailed topographic survey of the entire site was undertaken during 2014. The survey provides ground level elevations relative to ordnance datum and hence allows evaluation of the published flood map in relation to local ground levels. A copy of the survey is included at Appendix C of this report.

2.12 The detailed site survey confirms that some parts of the site designated Flood Zone 3 are above the predicted flood elevation as defined by the ground elevation at the limit of the flood zone on the published flood map. The site is relatively flat and the predicted flood water depth in inundated areas is typically less than 0.2m which may be at the limit of resolution of Lidar ground level data used to compile the published flood map.

2.13 Consideration has been given to flood inundation mechanisms. Published flood mapping suggests that the site would be at risk of flooding by inflow of water from the west, to the west of Cliff Hollins Lane. The site survey has confirmed that existing ground level at the western site boundary is generally higher than predicted flood water depth on Cliff Hollins Lane and therefore flood water would not enter the site by this route. Water flowing across Cliff Hollins Lane would tend to flow onto lower lying grassland to the immediate south of the southern site boundary.

2.14 As detailed topographic survey data indicates potential inaccuracies in the current EA flood map of the Oak Mills area, it has been necessary to define flood zone limits by development of a site specific hydraulic model. The model has been used to establish the 100 year and 1,000 year flood extent at the site and surrounding area.

Figure 6: Hunsworth Beck looking east from Cliff Hollins Lane with lower ground to the south.

2.15 The modelled extent of Flood Zone 3 covers a significantly smaller area of the Oak Mills site than suggested by the current EA flood map. The majority of the site is outside Flood Zones 2 and 3 and therefore should be re-classified as Flood Zone 1. Full details of model configuration and results are included at Section 5 of this report.

2.16 Although hydraulic modelling studies have demonstrated that part of the central/eastern area of the site would remain in Flood Zone 3, due to restriction at the in-site culvert, the proposed development would incorporate flood alleviation works, including opening of the culvert and installation of stormwater attenuation facilities, that would eliminate flooding of the site during a 1:100 year and 1,000-year storm event. As a consequence, the development would be established entirely outside the 100 year and 1,000-year flood limit.

Flood risk policy

2.17 The Calder Valley SFRA, which was prepared in 2008, reconfirms the approach to flood risk management previously established in PPS25 and now incorporated in the NPPF. Key requirements are as follows:

(i) Implementation of the Sequential Test in relation to development location and flood vulnerability;
(ii) Implementation, where necessary, of the Exception Test as set out in the NPPF;
(iii) New development to be sited away from flood defences;
(iv) Development floor levels to be established on a site by site basis;
(v) Provision of a safe refuge and emergency escape route;
(vi) Adoption of SUDs principles for surface water drainage.

2.18 General policy with regard to flood risk management in Kirklees is set out in the SFRA as follows:

Kirklees UDP Policy EP3
"Development will not be permitted within designated washlands … except where:

a) *It would not significantly affect the function of the washland or it incorporates adequate alternative flood water storage capacity*

b) *There would be no serious risk to the development from flood debris or pollution*

The SFRA also provides guidance with regard to 'Assessment and Mitigation of Flood Risk' and confirms that mitigation measures should be referenced to the 1% flood event (1 in 100yrs) and that any loss of floodplain storage should be compensated for by provision of new compensatory storage.

2.19 Residential development is classified as 'more vulnerable' development as defined at Table 2 of the NPPF Planning Practice Guidance (PPG). More vulnerable development is considered to be 'appropriate development' in Flood Zone 1 which will cover the entire development site following flood alleviation works based on culvert removal.

The Sequential Test

2.20 The objective of the Sequential Test is to direct new development to lowest risk flood zones and to demonstrate that there are no suitable alternative locations for the development that are at lower risk of flooding. The development will consist of residential dwellings and associated infrastructure.

2.21 As the proposed development incorporates measures that will bring the entire development area out of the high risk flood zone (Flood Zone 3) and into the low risk flood zone (Flood Zone 1) all proposed residential development will be outside the 100-year flood limit. As a consequence, there can be no suitable alternative sites at lower flood risk and therefore the site passes the Sequential Test with no requirement to undertake the Exception Test.

3. Proposed development

3.1 The development would consist of up to 19 residential dwellings with garages, access roads and gardens. At preliminary design stage it is indicated that total above ground development would extend to an area of approximately 1,860m^2 (20,000 sq ft) which is approximately 20% of the total site area. An indicative site layout plan is included at Appendix D.

3.2 Following removal of the existing concrete culvert through the site and opening of the natural Hunsworth Beck channel, the entire site would be removed from the limit of the 1:100-year flood event resulting in a low risk of fluvial flooding. The development layout has been designed with the eastern end of the site allocated for greenfield areas required to accommodate surface water attenuation and management systems.

3.3 In accordance with the requirements of Kirklees Council, as defined in the SFRA, and general EA policy, the site would incorporate a sustainable surface water drainage system (SUDS).

As discussed at Section 6, consideration will be given to a range of SUDS systems to manage runoff from roads and driveways including use of permeable surfacing, use of swales and detention areas in green space and incorporation of attenuation systems prior to offsite discharge. Off-site discharge of surface water will be restricted to the current 'greenfield' rate.

4. Definition of flood hazard

4.1 In accordance with the requirements of the NPPF, consideration needs to be given to identification of all potential flood risks to the proposed development including, fluvial flood risk from the Hunsworth Beck and the potential risk of flooding from groundwater and surface water sources. These issues are considered in the following sections of this report.

Flooding from rivers and sea

4.2 The Oak Mills site is situated adjacent to Hunsworth Beck which crosses the site and forms the northern site boundary. There has been no independent monitoring of flood levels in the beck and the Environment Agency has advised that it does not have any flood level or flood modelling data for the beck in the vicinity of the site.

4.3 As discussed above, there is no recorded history of flooding at the site and current flood mapping suggests that any flood inundation would occur in response to culvert surcharging and overland flow from adjacent land rather than from direct overbank flow from the Hunsworth Beck. However, backing-up of water in the beck downstream of the site could act to reduce the capacity for drainage of any floodwater from the site.

4.4 The primary route for flood water to enter the site during extreme event conditions appears to be overflow from adjacent land to the immediate east of the entry to the Hunsworth Beck culvert beneath the site. At this location ground levels along the southern boundary are potentially lower than the predicted 1:100-year flood level as indicated on the site survey at Appendix B.

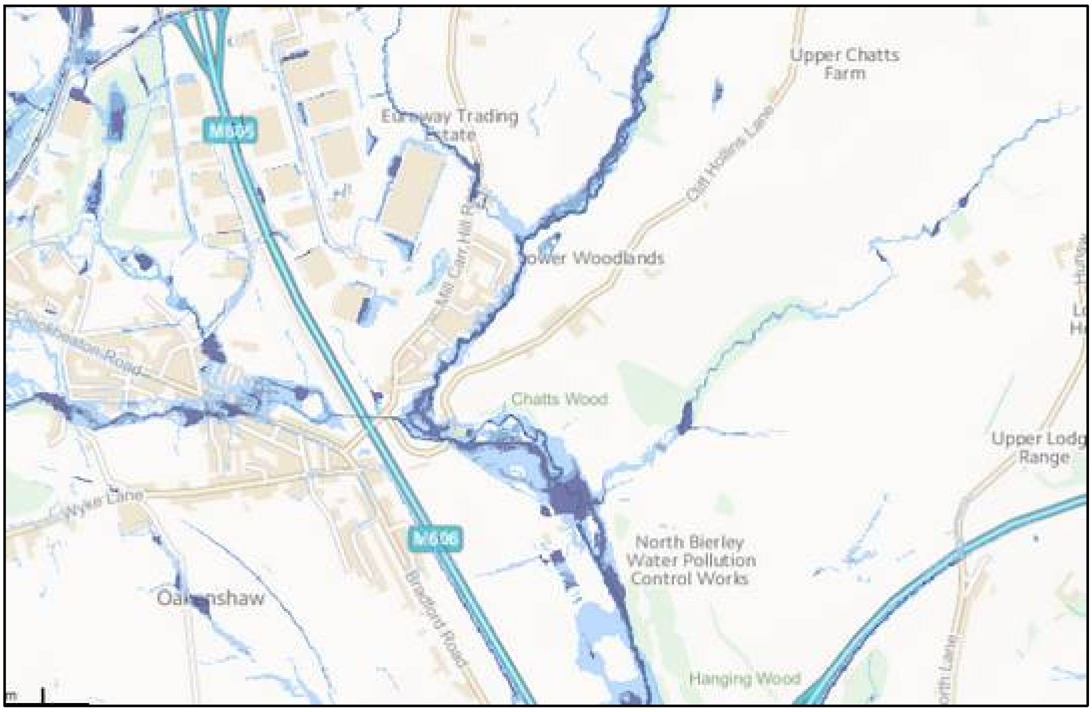
4.5 Predicted climate change effects are likely to influence the vulnerability of the site to fluvial flooding and may affect the ability of existing surface water drainage systems, natural and man-made, to accommodate surface water runoff during high-intensity, short-duration rainfall events. The impact of climate change on flood risk is considered during discussion of flood hazards in the following sections of this report.

4.6 As detailed at Section 5 of this report, in the absence of EA flood data, a hydraulic model has been used to determine fluvial flood levels and extents at the site in its current condition. Predicted flood levels in relation to existing ground levels are indicated on Drawing 116/01/03. Flood depths are derived from maximum flood levels and surveyed ground level. On the basis of available information it can be concluded that in response to a 1:100 year fluvial flood event the development site could be inundated with a flood water depth of up to 0.2m.

Surface water flooding

4.7 Information related to risk of surface water flooding at the site is available on current Environment Agency surface water flood maps. These maps indicate that some areas of the site have a low to medium risk of surface water flooding. An extract from the current surface water flood map is included as Figure 7.

Figure 7: Environment Agency surface water flood map for Oakenshaw



4.8 Surface water flooding at the site could occur in response to:

(i) On-site accumulation of surface runoff generated from rainfall across the site itself;
(ii) Inflow of surface water from land to the south of the site
(iii) Inflow of surface water across Cliff Hollins Lane in the vicinity of the site entrance.

4.9 As the site is largely bounded to the north by Hunsworth Beck there is no significant risk associated with runoff from land to the north.

4.10 Risk and magnitude of surface water flooding is likely to be greatest when the Hunsworth Beck is in flood and there is temporary restriction in the capacity for surface water to drain off-site. However, as the site is established at an elevation that is generally above grassland to the immediate south and south east there is limited potential for on-site storage of surface water and hence surface water flooding depths are unlikely to be significant.

Groundwater flooding

4.11 The site is underlain by Alluvium consisting of clay, silt and sand & gravel. The Alluvium is underlain by mudstones and siltstones of the Lower Coal Measures. The Clifton Rock sandstone is present beneath higher ground to the immediate north of the northern site boundary. Coal Measures strata typically form secondary aquifers with groundwater restricted to the more permeable sandstone horizons. Such systems do not generally exhibit rapid response to rainfall recharge and are rarely a source of groundwater flooding unless affected by historic mining activity.

4.12 The Alluvial deposits beneath the site are likely to have variable permeability with potential for relatively high permeability in some areas. Any groundwater present in the Alluvium is likely to be in hydraulic continuity with Hunsworth Beck with groundwater levels at around beck bed level. The site survey shows beck bed level to be approximately 1.5m below adjacent ground level within the site. The presence of variable permeability and overlying Made Ground will act to limit the potential for increase in alluvial groundwater levels during extreme rainfall or flood conditions. As a consequence, the site is considered to be at low risk of groundwater flooding.

5. Flood risk assessment

5.1 Flood hazard assessment has indicated that parts of the site are at risk of fluvial flooding from Hunsworth Beck. Detailed hydraulic modelling studies have been undertaken to investigate fluvial flood risk at the site and the extent of flood inundation in response to a 1:100 year and 1:1,000 year flood event. Full details of the hydraulic model configuration and results are included at Appendix E of this report.

Methodology and approach

5.2 In the absence of any flood flow or flood level data for the Oak Mills site or surrounding area it has been necessary to investigate flood characteristics through the development of a hydraulic model. A one-dimensional hydraulic model of the Hunsworth Beck and upstream tributaries has been developed with the main focus on the site itself. The HEC-RAS v4.1 code has been used to develop the model.

5.3 Following an assessment of local hydrology it became apparent that there are a number of structures on the Hunsworth Beck that have a critical impact of flood flow characteristics in the area. With the regard to the Oak Mills site the two most important features are (i) Cliff Hollins Lane Bridge, and (ii) the culvert through the centre of the site. Other culverts are present beneath the M606 and Bradford Road further upstream.

5.4 The hydraulic model covers a total reach length of approximately 2km extending from the M62 at the downstream boundary to central Oakenshaw at the upstream boundary. Model extents and boundaries have been established at upstream and downstream distances that are far enough away from the Oak Mills site to have negligible influence of model predictions within the site. In practice, as the model is a one-dimensional model operated in steady-state mode, upstream boundary conditions are effectively provided by Cliff Hollins Lane Bridge which restricts flood flow downstream. Flood characteristics upstream of the bridge have negligible impact on flood flow conditions through the Oak Mills site but are relevant to assessment of the reliability of the model in relation to flood flow prediction in the catchment in general. It is important to note, however, that as upstream flood characteristics have little impact on flood flow within the site there has been no requirement to define upstream catchment characteristics at the same level of detail or resolution as downstream of Cliff Hollins Lane Bridge.

5.5 Flood flow estimates have been prepared by application of standard Flood Estimation Handbook (FEH) techniques. Both the statistical and rainfall-runoff methods have been used to estimate flood flows and donor sites have been used to improve estimation reliability. Further details are provided in subsequent sections of this report.

5.6 The approach to hydraulic modelling is complicated by the presence of the culvert through the centre of the site. Careful consideration of potential flood inundation mechanisms has been required to produce an appropriate representation of flood hazards at the site. As detailed at Section 8, baseline flood modelling indicates that in response to a 1:100yr flood event, flood flows would remain in-bank in the Hunsworth Beck around the perimeter of the site but that due to the restricted capacity of the central site culvert there is potential for discharge onto the site at the culvert outlet. One-dimensional steady-state modelling approaches do not allow simulation of overland flow across the site when downstream model section capacity is high enough to retain all flood flow in-bank i.e. the model assumes all overland flow is returned to the beck at the next downstream section.

5.7 Analysis of internal site topography confirms a shallow west to east gradient through the site. As a consequence, any flood water discharging at the central culvert outlet would tend to flow west to east across the site and return to the beck at the eastern site boundary rather than returning to the beck immediately downstream of the culvert. Overland flow has therefore been simulated by development of a separate, second, HEC-RAS model of the eastern area of the site to provide an accurate predication of the areas of the site that would be inundated due to overland flow. Further details are provided at in subsequent sections of this report.

5.8 The analysis has been subject to sensitivity analysis related to boundary conditions, hydraulic characteristics and simulation with and without levees. Model results are interpreted in relation to predicted flood extents and flood water depths. Analysis of flood water depth is an important aspect of flood hazard assessments related to Flood Risk Assessment for potential development at the site.

Historic data used

5.9 There is no recorded evidence that the site has been subject to historic fluvial flooding and no evidence of flooding is recorded on the EA historic flood map included at Appendix A. A search of internet-based information sources has not identified any other information to suggest any history of flooding at the site. The local authority SFRA does not indicate any recorded history of flooding at the site. On this basis no historic flood data has been available for this study.

Topographic survey used

5.10 The site-specific topographic survey has been used to extract existing ground levels within the site boundary. The survey also provides ground elevation data from Cliff Hollins Lane in the vicinity of the site entrance and water levels/bed levels in Hunsworth Beck. Detailed ground level data for areas of the model outside the site-specific survey, including all floodplain areas, has been derived from Astrium 2m resolution LiDar data obtained via Getmapping.com.

5.11 Topographic information used in the hydraulic model consists of the following:

(i) a full topographic site survey undertaken to ordnance datum and including channel section details for Hunsworth Beck;

(ii) Astrium 2m resolution LiDar data.

5.12 A copy of the site topographic survey is included at Appendix C. A CAD version of the survey accompanies this report. As indicated on the survey drawing, the survey datum is an OSGB benchmark at ST04 which has a reference elevation of 99.014. The location of all channel sections used in the hydraulic model is shown on Drawing 116/01/2. The surveyors have confirmed that the GPS reading for ST04 was derived from 30 GPS readings used to define both the location and the elevation of the station. They have provided the raw survey data which has been issued to the EA as part of the flood zone challenge as requested.

5.13 The channel geometry within the site was determined from the site survey, which includes channel bed level and channel width dimensions, and on site measurement during the hydrological survey plus reference to 1:1,250 OS mapping. Outside the site boundary channel configuration and bed elevation was determined from published OS mapping, LiDar data and on-site measurements.

5.14 The hydraulic model incorporates sections of the Hunsworth Beck, Cockleshaw Beck, High Royds Beck and Toad Holes Beck. Cross-sections of the channel and adjacent floodplains of each watercourse are included through 32 cross-sections. Topographic data has been supported, as required, by visual observation and on-site measurement of channel dimensions. The model also incorporates four culverts, including the box culvert through the site.

Rainfall estimates

5.15 Flood Estimation Handbook (FEH) software provides rainfall data for design storm events of predetermined duration and frequency. FEH statistical techniques provide a basis for calculation of the design storm duration likely to produce the peak flood flow for a given return period. Design storm duration is based on the time of concentration for the catchment (the time for rainfall at the farthest point in the catchment to reach the site).

5.16 Time of concentration is calculated from catchment characteristics as follows:

$Tc = 1.56\ DPSBAR^{-0.28}\ PROPWET^{-1.09}\ DPLBAR^{0.6}\ (1 + URBEXT)^{-3.34}$
Tc = 0.85 hours

The design storm duration is therefore calculated as follows:
D = Tc (1+ SAAR/1000)
D = 1.58 hours

A design storm duration of 2 hours is therefore appropriate for flood flow analysis in the Hunsworth Beck at Oak Mills. The 2 hour duration event results in a rainfall intensity as indicated in Table 1.

Table 1. Rainfall intensities – Hunsworth Beck catchment at Oak Mills.

Storm frequency (years)	Rainfall intensity (mm)
10	24.9
20	30.5
50	39.9
100	48.7
200	94.1

The information presented in Table 1 is used in rainfall runoff analysis referenced at Section 6 of this report.

Flood flows and flood frequency

5.17 The Hunsworth Beck is un-gauged and therefore flood flows have to be estimated by hydrological calculation and simulation techniques. Of the two standard approaches to flood flow estimation i.e. statistical and rainfall-runoff, flood flow estimation has been based on statistical methods. The Hunsworth Beck catchment area is relatively small at 14.38km^2 and with a reasonably significant degree of urbanisation the catchment is not ideally suited to application of the ReFH rainfall runoff methods[1]. Initial trials of the ReFH method for this catchment indicated unrealistically high runoff rates.

5.18 WIN-FAP software, with the most recent parameter updates, has been used to construct a pooled growth curve using the latest catchment characteristics data from FEH catchment analysis as summarised below. The approach adopted has been to develop a QMED estimate from catchment descriptors and to use WIN-FAP software to develop growth curve fittings. Detailed analysis of potential donor catchments has been undertaken and a donor site has been used to refine the ungauged QMED estimate for Hunsworth Beck.

5.19 A pooling group was established from the latest HiFlows dataset. The pooling group consisted of 11 sites with a total gauging record of 387 years after adjustment to remove unsuitable sites. Pooled growth curve fittings have been derived for all distributions but, due to significant variation in results, reference is made in this assessment to the Generalised Logistic and Generalised Extreme Value distributions which are considered to be most applicable for UK catchments. A list of stations included in the pooling group is included at Appendix E1. The pooling group was used to derive growth curve fittings for application to QMED estimates.

5.20 The catchment QMED was calculated using the latest version (2008) of the catchment descriptor estimation equation as follows.

$$QMED = 8.3062AREA^{0.8510}\ 0.1536^{(1000/SAAR)}\ FARL^{3.4451}\ 0.0460^{BFIHOST2}$$

The result is a calculated QMED value of 4.43m^3/sec.

5.21 Due to the relatively high degree of uncertainty associated with predictions based only on catchment characteristics an attempt has been made to find a gauged donor site. Ideally a donor site should be relatively local to the subject site and have similar size, rainfall and soil characteristics. Of the 19 pooling group sites only one site meets the hydrological criteria but is not local.

5.22 The Ecclesbourne at Duffield catchment (Station 28055) is located in north Derbyshire, the adjacent hydrometric area, with similar catchment geomorphology but a lower degree of urbanisation. With a catchment area of 50.58km^2 the catchment is approximately three times the size of the Hunsworth Beck catchment at Oak Mills. QMED based on AMAX for the Ecclesbourne catchment is 12.681m^3/sec. This compares to a QMED calculated from

[1] Revitalised FSR/FEH rainfall-runoff method. CEH. 2007

catchment descriptors of 13.697m^3/sec resulting in an observed to catchment descriptor ration of 0.925.

5.23 A search of the Hi-flows website for catchments in the same hydrometric area as Hunsworth Beck resulted in identification of a comparable catchment in relatively close proximity to Oakenshaw. Eastburn Beck catchment at Crosshills (Station 27084) has a catchment area of 41.01 km^2. The catchment is focussed on the Keighley area of West Yorkshire with the inter-catchment distance being approximately 25kms north west of Oak Mills. Eastburn Beck is a tributary of the River Aire which flows west to east to the north of Bradford. Catchment descriptors for Eastburn Beck catchment at Crosshills are summarised below together with catchment descriptors for Ecclesbourne and Hunsworth Beck.

Table 2: Catchment descriptors

Descriptor	Hunsworth Beck	Eastburn Beck	Ecclesbourne
AREA	14.29	41.01	50.58
BFIHOST	0.471	0.315	0.456
DPLBAR	2.77	7.46	7.55
DPSBAR	60.60	114.2	109.20
FARL	1.000	0.998	0.997
PROPWET	0.57	0.62	0.35
SAAR	857	1123	853
SPRHOST	28.2	46.64	30.3
URBEXT	0.249	0.0101	0.0129

5.24 On the basis of location and catchment size the Eastburn Beck has been selected as the most appropriate donor site for Hunsworth Beck. QMED for Eastburn Beck based on AMAX as defined on Hi-Flows is 29.912m^3/sec. QMED based on catchment descriptors as described above is 27.235m^3/sec resulting in an observed to catchment descriptor estimate ratio of 1.098.

5.25 Although the Ecclesbourne catchment descriptors are more comparable to the Hunsworth Beck catchment descriptors the more remote location is considered to be less representative. It is noted that application of the Ecclesbourne as a donor site would result in a reduction in the QMED estimated from catchment descriptors for Hunsworth Beck and therefore adoption of the Eastburn Beck as a donor site is considered to be a more conservative option.

5.26 In accordance with FEH procedures, this factor has been applied to the estimated QMED for Hunsworth Beck to produce an adjusted QMED based on donor gauged data as follows:

$QMED_{adj}$ = QMED x 1.027
$QMED_{adj}$ = 4.55 m^3/s

5.27 Due to the urbanised nature of the catchment an urban adjustment has been applied to both the QMED estimate and the pooled growth curve. QMED had been adjusted manually by application of the twin equations in FEH as follows:

$UAF = (1+URBEXT2000)^{0.37}\ PRUAF^{2.16}$

PRUAF has been calculated using the SPRHOST based approach resulting in a UAF of 1.51. Application of the UAF to the QMED of 4.55m^3/sec results in an adjusted QMED value of 6.87m^3/sec.

5.28 The adjusted QMED of 6.87 m^3/s has been used as the basis for flood flow prediction and subsequent modelling. This estimate, although higher than the estimate based solely on Hunsworth Beck catchment descriptors, is considered to be the best estimate available of QMED for the Hunsworth Beck catchment.

5.29 Flood flow rates for less frequent flood events have been derived by application of growth curve fittings as summarised in Table 3. Growth curve fittings have been adjusted for urbanisation within WIN-FAP in accordance with current guidance. Average growth curve fittings derived from GL and GEV distribution estimates have been used to define flood flows as shown in Table 3.

Table 3: Predicted flood flows

Return period (years)	Growth curve fittings - GL	Growth curve fittings - GEV	Growth curve fittings - mean	Flow (m^3/sec)
2	1.000	1.000	1.000	6.87
5	1.257	1.292	1.275	8.76
10	1.401	1.439	1.420	9.76
25	1.571	1.579	1.575	10.82
50	1.693	1.657	1.675	11.51
100	1.815	1.715	1.765	12.13
200	1.936	1.756	1.846	12.68
500	2.097	1.789	1.943	13.35
1000	2.238	2.114	2.176	14.95

5.30 The Cockleshaw Beck was added to the model following flow calculations for the other three watercourses. Separate estimate of Cockleshaw Beck flows has been undertaken by application of the ReFH method leading to predicted 25yr, 100yr and 1,000yr peak flow rates of 0.74m^3/sec, 1.01m^3/sec and 1.76m^3/sec respectively. The full ReFH report for Cockleshaw Beck is included at Appendix E2. Only the lower 100m of the beck is included in the model as the primary interest is flow at the confluence with Hunsworth Beck. The downstream culvert in Cockleshaw Beck has been ignored and therefore model flow rates may represent an over-estimate which takes no account of culvert flow restriction.

5.31 Predicted flood flows as defined above have been used to provide input data to the hydraulic model of the Hunsworth Beck catchment as described in the following sections of this report.

Approach to hydraulic modelling

5.32 Translation of flood flow rates to flood water depths and flooding extent requires analysis of the way in which flood water flows through the Hunsworth Beck channel adjacent to the site. This is achieved by hydraulic modelling. For this assessment flood flow depth, extent and velocity assessment has been undertaken using a hydraulic model constructed with HEC-RAS modelling software (version 4.1.0) which is approved by the Environment Agency for use in flood risk modelling in England and Wales.

5.33 The HEC-RAS model has been constructed using site specific topographic data to define channel and floodplain configuration for the Hunsworth Beck, High Royds Beck, Toad Hole Beck and Cockleshaw Beck. As Hunsworth Beck is culverted through the centre of the site a series of manual measurements were taken to accurately define channel and culvert dimensions.

5.34 The model extends upstream and downstream of the site for a distance at which any boundary conditions would not affect on-site water levels or flow. Downstream of the site, Hunsworth Beck flows in a natural channel with no flow control structures until the M62 culvert is reached approximately 1km downstream. The downstream model boundary was established at this location.

5.35 The upstream boundary of the site is formed by the culvert beneath Cliff Hollins Lane Bridge which restricts downstream flow. High Royd Beck joins Hunsworth Beck immediately upstream of the bridge and therefore is a key contributor to flood flow through the site. Due to the presence of further upstream flow restriction at the M606 and beneath Teasel Close in Oakenshaw the decision was taken to extend the model upstream for approximately 900m from the site boundary and to incorporate flow from Toad Holes Beck.

5.36 Sections of the model upstream of Cliff Hollins Lane Bridge provide a basis for review of model performance and reliability. As all model simulations are steady state, flood flow characteristics upstream of Cliff Hollins Lane Bridge have no significant impact on flow in Hunsworth Beck downstream of the bridge i.e. through the Oak Mills site, as the model assumes that all water is returned instantaneously to the beck downstream of the bridge.

5.37 The model has been run with flood flows associated with the 1:25yr, 1:100yr and 1:1,000yr events with inflow data derived from WINFAP analysis as summarised in Table 3. Although WINFAP flood flows are calculated for a catchment area for the Hunsworth Beck at the eastern site boundary it has been assumed that all catchment contributions flow into the site at the upstream boundary. As a consequence there is likely to be a degree of over-estimation in the predicted flood flows.

5.38 Flow distribution between the three model inflow points (i) Hunsworth Beck, (ii) Toad Holes Beck and (iii) High Royds Beck have been assigned on a catchment area basis on the assumptions that catchment characteristics in each small sub-catchment are similar. Cockleshaw Beck inflows are separately calculated as detailed above. Inflow distribution used in the model is summarised in Table 4 below.

Table 4: Model inflow distribution

	1:25 year (m3/sec)	1:100 year (m^3/sec)	1:1,000 year (m^3/sec)
Toad Holes Beck	0.97	1.09	1.35
Hunsworth Beck	6.17	6.91	8.52
High Royds Beck	3.68	4.12	5.08
Cockleshaw Beck	0.74	1.01	1.74
Totals	10.82	12.13	14.95

5.39 In the absence of any historic flood information for the area, or other comparative modelling work, there is no external basis to support model calibration. Model reliability has therefore been tested by sensitivity testing as detailed at Section 8 of this report.

Model design and configuration

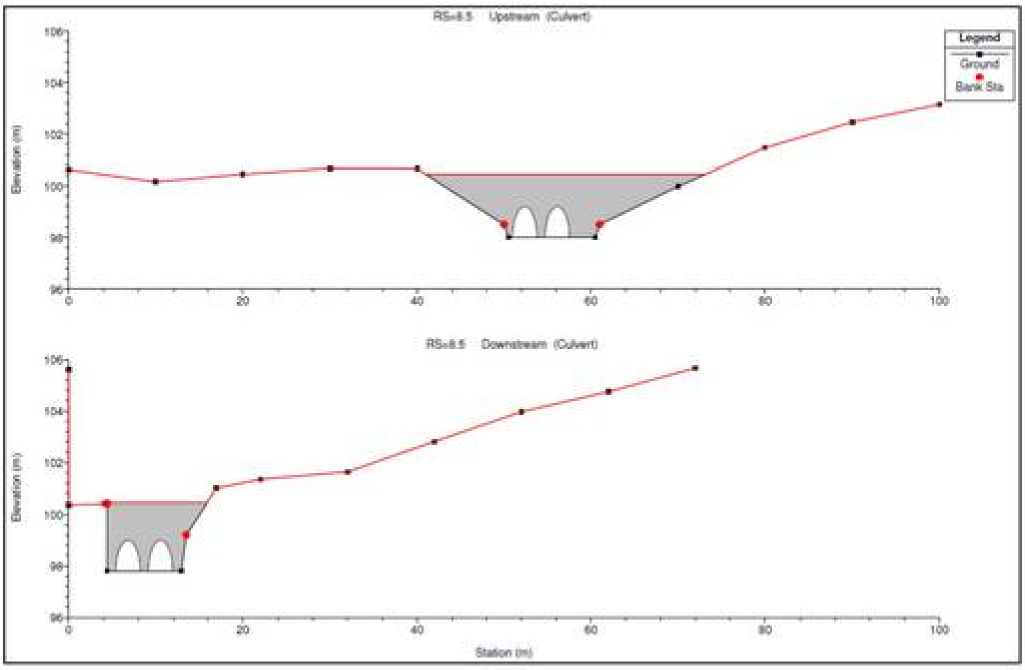
5.40 The hydraulic model simulates flow along the Hunsworth Beck over a distance of approximately 2km between Oakenshaw and the M62. Due to the presence of tributaries, Hunsworth Beck is modelled as four reaches separated by junctions at the Toad Holes Beck, Cockleshaw Beck and High Royds Beck confluence. High Royd Beck and Toad Holes Beck contribute flow to the Hunsworth Beck upstream of the site and are therefore included in the model. Cockleshaw Beck downstream of the Oak Mills site is included to investigate potential backwater effects on site water levels.

5.41 Model geometry is established by the inclusion of 32 separate cross-sections and four separate bridge/culvert structures. Of the 32 model sections, 13 sections are located within the site boundary. Model configuration and section locations are shown on Drawings 116/01/2 and 116/01/03. All model reaches and cross-sections have been fully geo-referenced.

5.42 Cross-sections within the site have been orientated to provide full site coverage whilst remaining perpendicular to the direction of the Hunsworth Beck. Where appropriate, section lines have been extended across the adjacent floodplain to a ground elevation above expected flood level for all model simulations. All existing flood walls around the site have been removed from the model to simulate 'undefended' conditions.

5.43 Cliff Hollins Lane Bridge culvert has been defined from reference to the site topographic survey and on-site measurement. The culvert is represented as a double span stone arch with a basal width of 2.750m and height of 1.2m. Road deck elevation is referenced to surveyed ground level. The boundary wall has been omitted as it is not continuous and does not form a continuous flood barrier. The culvert as represented in the model is included as Figure 7.

Figure 7: Cliff Hollins Road Bridge culvert as modelled



5.44 Visual inspection confirmed that the M606 culvert, upstream of Cliff Hollins Lane, has the same construction and dimensions as the Cliff Hollins Lane Bridge culvert and is represented as the same in the model. The downstream end of the Teasel Close culvert appears to be of similar dimensions but the upstream end was not accessible. The same construction and dimensions has been assumed in the model. The Toad Hole Beck culvert beneath Dyehouse Terrace is a 600mm diameter round pipe and has been included in the model as same.

5.45 The friction loss characteristics of the main channel and the culverts have been designated on the basis of the site hydrological survey with subsequent refinement during model calibration.

5.46 Downstream boundary conditions have been set at critical depth as distance from the site ensures that boundary conditions are unlikely to influence flood flow characteristics within the site. Upstream boundary conditions in all three watercourses have been set with a known water surface at approximately two-thirds channel fill elevation.

5.47 The full model configuration report including schematic sections is included at Appendix E3 of this report. The model has been calibrated in relation to existing flood level and extent information available from published sources and anecdotal site specific reference.

5.48 Baseline modelling indicates the potential for overland flow across the eastern area of the site in response to out-of-bank flow at model Section 7.07, the outflow from the central site culvert. As it is unrealistic to assume that this water would return to the beck at the next model section, as assumed by the model, separate simulation of overland flows across the site has been undertaken by construction of a second HEC-RAS model based on seven cross sections from east to west across the site. Section locations are shown on Drawing 116/01/03. Section geometry is derived from the detailed site topographic survey/LiDar and model upstream and downstream boundary conditions are defined as the flood water overflow elevation at Section 7.07 in the main model and flood water level at Section 7.00 in the main model respectively.

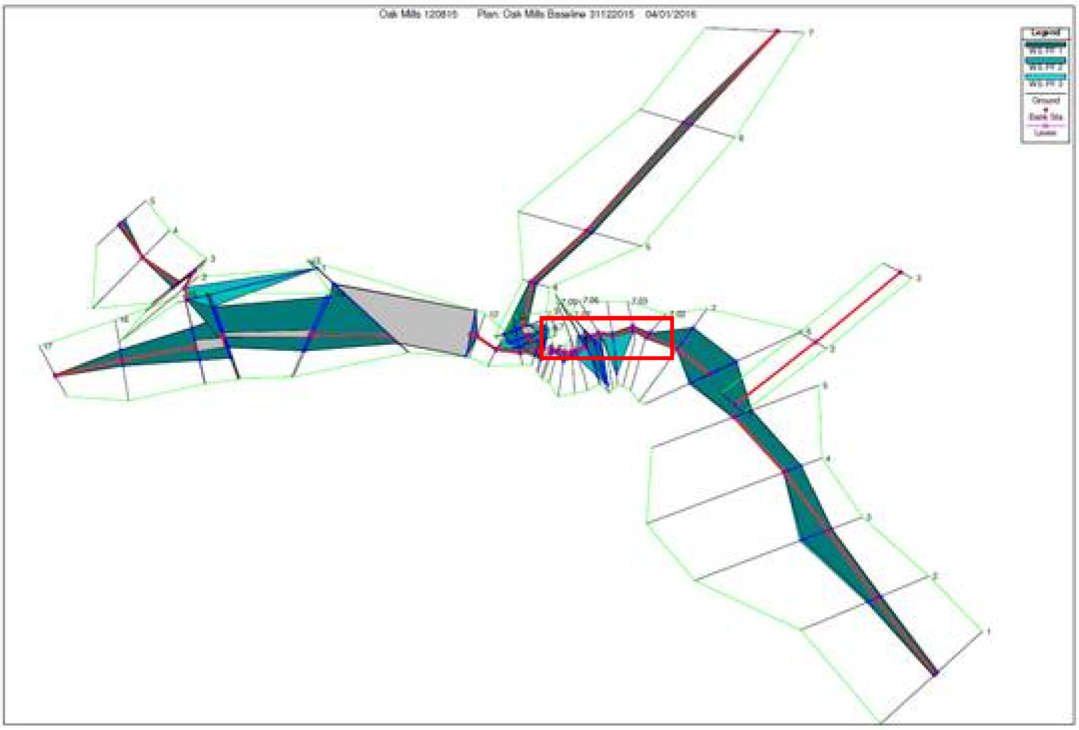
5.49 Inflow to the overland flow model is derived from predicted right bank flow from the main hydraulic model. For the 1:100yr simulation the main model predicts right bank flow of 6.88m^3/sec. This increases to 9.48m^3/sec in response to a 1:1,000 yr flood event.

5.50 Flood extents have been derived from a combination of results from the main Hunsworth Beck model and the overland flow model. It is apparent that as the main model assumes all overland flow water is returned to the beck at the next downstream section the modelled flow rate in the beck downstream of model Section 7.07 is higher than would occur in practice. The loss of 6.88m^3/sec of water to overland flow during a 1:1,00yr flood event and 9.48m^3/sec during the 1:1,000yr flood event means that predicted flood levels in Hunsworth Beck during both events may be significantly over estimated around the northern site boundary. However, as all flood flows remain in-bank around this boundary there are no significant implications for prediction of flood extents or flood water levels within the site.

Model results

5.51 For the purpose of assessment of current flood risk and flood map challenge, model simulations have been carried out for flood events of 100 and 1,000 years frequency without any allowance for the effects of climate change.

Figure 8: HEC-RAS model output showing flood extent in response to 100-year flood event.



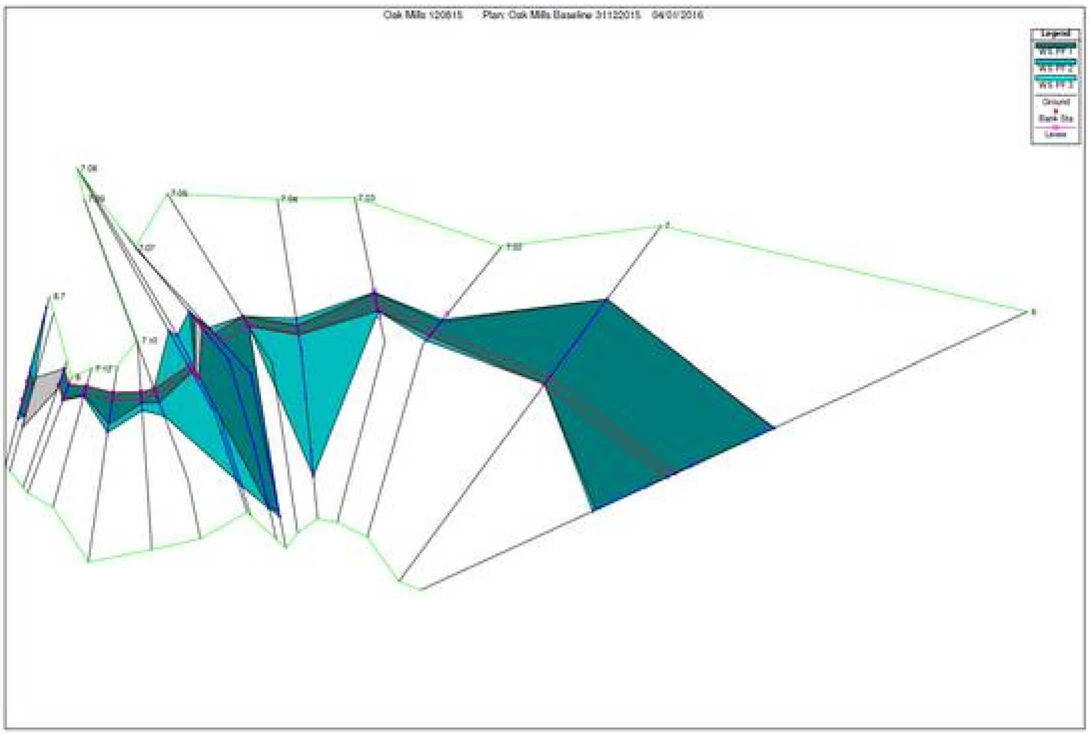
5.52 The model has realistically simulated flood flow in the Hunsworth Beck and tributaries. In general, the scale of potential flooding predicted by the model is consistent with EA flood mapping upstream and downstream of the site. A schematic illustration of the extent of flooding across the full model domain for a 1:100-year flood event is presented as Figure 8.

5.53 Key characteristics of flooding in the area represented by the model domain are as follows:

- The M606 culvert, Teasel Close Culvert and Toad Hole Beck culvert all restrict downstream flow during a 1:100 year flood event leading to upstream floodplain inundation on both banks of the respective watercourses;
- Cliff Hollins Lane Bridge culvert acts to restrict downstream flood flow but water levels remain below road level:
- The 1:25 year flood flow remains in-bank throughout the Oak Mills site;
- Downstream of Cliff Hollins Lane Bridge land to the south of the site is inundated by over-bank flow.
- Flood flow for all events including the 1:1,000yr event, remain in-bank along Hunsworth Beck through and around the site with the exception of surcharging at the central site culvert and localised overflow upstream of the culvert;
- Out-of-bank flow occurs onto the eastern side of the site at the central culvert outlet. Overland flow modelling indicates inundation of the central and south eastern part of the eastern site area;

5.54 A schematic diagram showing model results for a 1:100 year flood event for just Reach 3 of the Hunsworth Beck model i.e. the Oak Mills site area to the downstream model boundary, is included as Figure 9. The diagram shows the general area of potential inundation within the site boundary. It should be noted that the schematic diagram shows the predicted extent of flood inundation within the site as direct overbank flow from the beck and does not show the areas of dry land between the beck and the centre of the site (see individual cross-section results at Appendix E4).

Figure 9: HEC-RAS model output showing flood extent in response to 100 year and 1000-year flood events at Reach 3 only.



5.55 The modelled extent of the 100-year flood has been overlain on OS mapping of the site and surrounding area as presented at Drawings 116/02/03 & 116/01/04. The drawing also shows the extent of the 1:1,000-year flood limit. Supporting evidence is provided in the cross-section results which are included in full at Appendix E of this report. As the source of flooding on the site is restricted to overflow from the central culvert the flood extent associated with the 100yr and 1,000yr flood flow are similar.

5.56 As HEC-RAS is a one-dimensional hydraulic model it has been necessary to give careful consideration to the interpretation of model results in areas of the model where floodplain inundation is predicted whilst beck water level remains below bank top. This has been achieved by reference to the separate overbank flow model results. Full details are provided in the HEC-RAS model files that accompany this report.

5.57 As shown on Drawings 116/02/3 & 116/01/04, the overland flow model indicates potential overland flow from the central site culvert in an easterly direction across the central area of the site towards the south eastern boundary and return to the Hunsworth Beck downstream of the site. The flow route is formed by the lowest sections of the site as defined by the detailed topographic survey and the lower sections of the right bank floodplain to the south. The model indicates that the majority of the overspill from the site culvert would drain in a south easterly direction away from the site and onto grassland to the south. The 1:1,000-year simulation indicates that a slightly larger area of the eastern site would be inundated, as would the floodplain to the south of the site. As discussed in subsequent sections of this report, potential flood water depths are relatively shallow in all overland flow simulations.

5.58 To check the interpretation of model results within the site boundary the model was reconfigured with levees on all right banks upstream of the site box culvert to force over-bank flow within the site and allow evaluation of the areas of inundation. The results of this approach were comparable to the model without levees. It was therefore concluded that model representation of flood water inundation of the central site area is realistic and reliable but dependant on overland flow from land to the south.

5.59 The results of hydraulic modelling for the 1:100 year and 1:1,000-year flood flow at Oak Mills are shown graphically on Drawings 116/02/3 & 116/01/04. Modelled water levels for the 1:100-year event at all model sections is included at Appendix E4. Detailed water level/velocity/flow tables for all model sections are also included at Appendix E4.

5.60 The potential depth of flood water on the site during a 1:100 year and 1:1,000 year flood event can be determined by comparison of predicted flood water depth in the overland flow model and minimum ground level. Flood water elevation at each cross section of the model are included on data tables at Appendix E4. When compared with minimum ground levels from the topographic survey at Appendix C, on-site flood water depths are established as indicated in Table 5.

5.61 In general, the depth of flood water on the site in response to a 1:100-year flood event is shallow with an average depth of approximately 0.25m in the central part of the site.

Table 5: Flood water depth within the site – 1:100-year flood event

Model section	Water level (mAOD)	Ground level (mAOD)	Flood depth (m)
1	96.92	97.19	-
1.5	97.16	97.12	0.04
2	97.66	97.72	-
3	98.26	98.01	0.25
3.5	98.39	98.07	0.32
4	98.67	98.35	0.32
5	98.94	98.70	0.24

Sensitivity analysis

5.62 Sensitivity analysis has been undertaken to investigate model results sensitivity to variation in estimated parameters. Model configuration and geometric design has been based on a detailed site topographic survey and site-specific measurements. There is no basis to vary geometric parameters that are fixed by site-specific measurement. The flood flow values used in the model are likely to be an over estimate of actual flood flows due to the use of all catchment outflows as catchment inflows. As a consequence, any sensitivity analysis related to variation in flow rate would be undertaken with lower flow rates. It is considered appropriate to continue to reference model results derived from the existing flow rates.

5.63 Additional model runs have been undertaken to investigate model sensitivity to variation in channel roughness and to partial blockage of the Cliff Hollins Lane Bridge culvert. Channel roughness in the original model was assigned following visual assessment of the channel and floodplain. Although Manning's 'n' values were assigned conservatively the model was re-run with channel and floodplain values increased globally by 10%. Model results showed no significant change in flood water level or flow distribution and only minor change in channel flow velocity at sections remote from channel control structures.

5.64 The culvert at Cliff Hollins Lane Bridge appears to have dominant influence on the flow of flood water in Hunsworth Beck through the site. Although the culvert is located in an area with floodplains consisting of short grassland with low potential for deposition of materials with the potential to cause blockage it was considered appropriate to investigate the impact of partial blockage on downstream flood flow. The model was re-run with blockage of the lower 0.1m of the culvert to simulate partial blockage by vegetation of progressive channel siltation.

5.65 With 10% channel blockage the model indicated slightly elevated water levels upstream of Cliff Hollins Lane Bridge but water levels remained well below road level.

5.66 As discussed above, further sensitivity runs were undertaken with the inclusions of levees to force overbank flow within the Oak Mills site as a means of evaluating the reliability of indicated flood inundation areas within the site. This approach tended to confirm the reliability of the assessments made on the basis that flood water may enter the site as a consequence of overland flow from land to the south.

5.67 Additional model runs were undertaken with the downstream boundary condition established at 500mm above the baseline modelled elevation. Whilst this change had minor impact on predicted flood levels downstream of the Oak Mills site there was no change in predicted flood levels within the site.

5.68 Sensitivity analysis has demonstrated that model results within the Oak Mills site area are relatively insensitive to variation in friction coefficient, downstream boundary conditions and the condition of upstream flow control structures.

5.69 Detailed consideration of Manning coefficients and culvert contraction/expansion coefficients was undertaken as part of the model sensitivity analysis. With regard to contraction/expansion coefficients the values used in the model are derived from HEC-RAS guidance which is based on Chow 1959. The run-up to the bridge at River Station 7.08 consists of a masonry wall producing a channel width that is approximately the same width as the culvert. There are no bridge abutments and no significant change in channel width at either the entry of the exit to the culvert. On this basis the entry/exit to and from the culvert is considered to be 'gradual' and hence contraction/expansion coefficients of 0.1 and 0.3 respectively are applicable (Table 5.2 of HEC-RAS Reference Guide).

5.70 Manning N values have been derived from the HEC-RAS reference manual which is based on the 1959 Chow data. Away from the Oak Mills site Hunsworth Beck is essentially a clean straight channel, engineered in places, with a gravel/stoney bed and grass banks. We have assigned an N value of 0.035 for the channel at these locations to represent ‘clean, straight with stones and weeds’. Manning N values for the channel around the site have been increased to 0.04 to represent ‘clean, winding, some pools and shoals’. All values are further increased by 10% during sensitivity analysis. At sections 7.08 & 7.09 N value is set at 0.015 & 0.017 respectively to represent the open concrete culvert runup with clean concrete sides as Chow ‘finished concrete channel with gravel bottom’.

6. Flood risk management

6.1 Flood hazard analysis has indicated that parts of the proposed development site are at risk of flooding from fluvial and surface water sources. As a consequence, measures will be required to provide an adequate standard of protection for any new residential development on the site. The primary approach to flood risk management at the site will be to eliminate the source of fluvial flooding by removing restriction at the existing on-site culvert. Hydraulic modelling studies have demonstrated that culvert surcharging is the main source of fluvial flood risk at the site.

Culvert removal

6.2 Further hydraulic modelling studies have been undertaken to investigate the effect of culvert removal on flood flows and flood levels through the site. Removal of the existing concrete deck, as proposed, will open up Hunsworth Beck at entry to the site and across the central area connecting the western and eastern areas of the site. Deck removal will be accompanied by minor re-profiling of the right bank (site side) of the Hunsworth Beck bank to increase stability and allow re-profiling following removal of culvert sides. Right bank re-profiling will be undertaken around the northern boundary of the site.

6.3 Hydraulic modelling studies have been undertaken with model geometry amended to reflect the proposed channel changes as follows:

(i) The existing culvert deck between model sections 7.08 and 7.07 removed; and

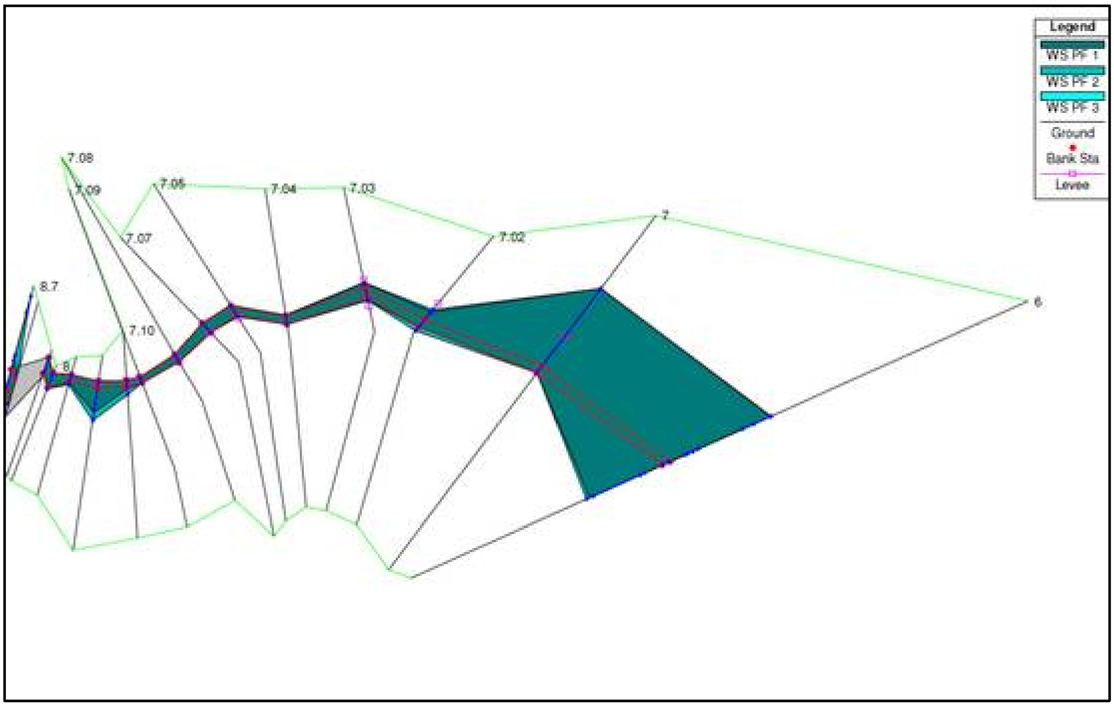
(ii) Right bank re-aligned by 1m at model sections 7.08 to 7.02

All other aspects of the model remain unchanged. Flood flow rates remained as used in the baseline flood model.

6.4 Model results confirm that with the culvert removed and minor channel realignment, flood water for both the 1:100 year and 1:1,000 year flood events remain in-bank along the route of Hunsworth Beck throughout the site. Localised inundation of the right bank floodplain would still occur upstream of the former culvert entry outside the site boundary. Model results for model reach 3 (Hunsworth Beck through and around the site) are shown in Figure 10.

6.5 Analysis of model results indicates that the proposed culvert removal and realignment works would lead to a reduction in flood water levels through and around the site but would have no significant impact on upstream or downstream water levels. Similarly, analysis of flood flow velocities indicates that, in direct response to culvert removal there would be an increase in flow velocity along the route of the culvert and immediately downstream but no change in flood flow velocity upstream or downstream of the site. Full model results are included in Tables at Appendix E4.

Figure 10: Hydraulic model results showing floodplain extents with culvert removed



6.6 Predicted flood water level in Hunsworth Beck through and around the site, in comparison to predicted water levels with the culvert in place are summarised in Table 6. Reference to Table 6 suggests that following removal of the culvert and associated right bank re-profiling works, the 1:100-year flood level through the site would be reduced by up to 10-15cms.

Table 6: Predicted flood water levels with and without the culvert

Model section	Location	100yr WL Pre-development	100yr WL Post development
9.0	HRB confluence	99.87	99.89
8.7	Upstream CHL bridge	99.86	99.88
8.0	Downstream-CHL Bridge	99.40	99.42
7.12	Upstream boundary	99.14	99.10
7.11	Western site	99.23	99.22
7.10	Western site	98.99	98.79
7.9	Upstream channel	98.85	98.73
7.8	Culvert entry	98.82	98.78
7.7	Culvert exit	98.78	98.61
7.5	Central site	98.55	98.41
7.4	Central site	98.04	97.90
7.3	Eastern site	97.87	97.76
7.2	Downstream boundary	97.52	97.48
7	Downstream	97.08	97.08

6.7 The proposed flood alleviation works based on culvert removal and minor bank re-profiling should take the entire site out of Flood Zones 2 and 3 and mitigate fluvial flood risk from

Hunsworth Beck during flood events with a frequency of up to 1:1,000 years. Due to the increase in channel capacity that would be achieved by the proposed works there would be no significant effect on flood levels or flow rates upstream or downstream of the site and therefore no change in external flood risk.

Finished floor levels

6.8 Although re-configuration of the beck channel by culvert removal is expected to remove the primary fluvial flood hazard from the site, there will still be a requirement to ensure that dwelling floor levels are established at an adequate elevation above predicted flood levels.

6.9 Current guidance indicates that for residential development finished floor levels should be established at least 600mm above the 1:100 year flood level plus an allowance for climate change uncertainty. The predicted increase in flow in the Hunsworth Beck from a 1:100 year event to a 1:10,000 year event is approximately 23% which is comparable to the usual 20% flow increase used to account for climate change. Hydraulic model results for the 1:1,000 flood flow have therefore been used as the equivalent of the 1:100-year flood plus climate change allowance.

6.10 The hydraulic model results indicate that, following implementation of flood alleviation works, the highest channel flood level during a 1:1,000 year flood event would be 98.53mAOD in the vicinity of the downstream end of the former culvert at the upstream end of the site, falling to 97.42mAOD at the downstream end of the site. Reference to these levels indicates a minimum finished floor level of 99.13mAOD to 98.02mAOD from west to east across the site. If it is assumed that property floor levels will be 200-300mm above ground level there would be a requirement to ensure minimum ground levels of approximately 98.9mAOD to 97.8mAOD from west to east across the site. Reference to the site topographic survey, included at Appendix C, indicates that localised ground raising of up to 0.5m in the central area of the site would be required.

6.11 In summary, it is therefore proposed that flood protection for the site will be achieved by culvert removal and channel re-profiling works plus localised raising of ground levels to produce the basis to establish minimum finished floor levels at 600mm above the 1:100-year flood level plus allowance for climate change.

Sustainable drainage

6.12 Current National Standards[2] for Sustainable Drainage Systems (National Standards - Defra 2011) require that, where reasonably practicable, all new developments are to be equipped with sustainable drainage systems (SUDS) that are approved by the local SUDS Approving Body (SAB) under the terms of the Flood and Water Management Act 2010. The SAB for the proposed development site is Bradford MDC. Further detail is provided in the current Defra non-statutory technical standards (2015).

[2] Defra 2011. *National Standards for sustainable drainage systems*. December 2011. Defra

6.13 Sustainable drainage systems are generally based on a stormwater management train that assigns priority to local control of surface water. SUDS systems should be designed to optimise control at the earliest stage in this sequence.

1. Prevention: Good site management, best practice approaches to minimise the risk of flooding or migration of pollutants to surface water;

2. Source control: control of runoff at or close to the source using permeable surfaces, filter trenches or swales etc.;

3. Site control: local facilities that receive surface runoff to attenuate off-site discharge i.e. balancing ponds etc.;

4. Regional Control: larger ponds and wetlands used to control flow and quality prior to final discharge to receiving water.

6.14 The National Standards define five principles that apply to design of SUDS systems as follows:

a. Surface runoff managed at source where reasonably practicable
b. Surface runoff is managed on the surface where reasonably practicable
c. Public space is used and integrated with the drainage system
d. The design is cost-effective to operate and maintain over the lifetime of the development
e. Design accounts for (i) climate change and (ii) changes in impermeable areas, over the design life of the development.

Although the site will be fully in private ownership sustainable drainage systems can be designed to make effective use of greenfield areas of the development.

6.15 National Standards define the appropriate SUDS approach to final discharge destination as the following in order of preference:

1. Discharge into the ground
2. Discharge to a surface water body
3. Discharge to a surface water sewer
4. Discharge to a combined sewer

Geological evidence indicates that the site is underlain by Alluvium above low permeability mudstone. Such formations are unlikely to be suitable for discharge of surface water to ground. All surface water from the proposed development will therefore discharge to the Hunsworth Beck as at present.

6.16 A SUDS based site drainage system will be required to accommodate surface water generated from within the site and to intercept any surface water runoff from land to the south or west. Ground raising within the site is likely to eliminate risk of surface water inflow from the field to the south of the site. A detailed SUDs based drainage system would be prepared for the site and agreed with the Local Planning Authority prior to development of the site.

6.17 In accordance with the current Defra Non-statutory technical standards for sustainable drainage systems, SUDs schemes should be referenced to the 1 in 1 year and 1 in 100-year storm events. The standards specify that the flow rate discharged should comply with the following:

S3 *For developments which were previously developed, the peak runoff rate from the development to any drain, sewer or surface water body for the 1 in 1 year rainfall event and the 1 in 100 year rainfall event must be as close as reasonably practicable to the greenfield runoff rate from the development for the same rainfall event, but should never exceed the rate of discharge from the development prior to redevelopment for that event.*

S4 *Where reasonably practicable, for developments which were previously developed, the runoff volume from the development to any drain, sewer or surface water body for the 1 in 100 year, 6-hour rainfall event must be constrained to a value as close as is reasonably practicable to the greenfield runoff volume for the same event, but should never exceed the runoff volume from the development site prior to redevelopment for the event.*

6.18 At present the Oak Mills site includes several existing buildings with a combined surface footprint of 1,096m^2 and existing areas of hardstanding with a combined surface area of 4,376m^2 making a total impermeable area of 5,471m^2. The proposed development could incorporate up to 19 residential properties with associated driveways and new site access road. An estimate of potential impermeable areas associated with the proposed development indicates the following.

Combined building footprint	-	2,000m^2 approx.
Combined parking/drives	-	750m^2 approx.
Combined access road/turning	-	1,500m^2 approx.
Total impermeable area	-	4,250m^2 approx.

6.19 The proposed development would therefore result in a net reduction in the impermeable area of the site by approximately 1,220m^2 or approximately 22%. As a consequence, there should be a net reduction in surface water runoff from the site. However, as surface water runoff from the site currently drains to Hunsworth Beck in a dissipated manner across the site, and the proposed development will have a surface water drainage system with a single outfall, surface water attenuation and management systems are proposed.

6.20 The eastern end of the site will not be developed for residential use and will remain open green space. This area will accommodate a shallow surface water attenuation area upstream of a new outfall to Hunsworth Beck, subject to Local Authority approval. The stormwater attenuation pond will be designed to restrict off-site discharge to greenfield rates and hence deliver a significant net reduction in off-site surface water discharge rates. All surface water from the proposed development would be directed to the attenuation pond prior to discharge to Hunsworth Beck.

6.21 The existing average annual greenfield runoff rate for the site can be estimated, in accordance with current Environment Agency guidance, from the widely used IH124 method as follows.

$Q\ (m^3/sec) = 0.00108\ AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17}$,

where the parameters AREA and SAAR are derived from FEH catchment characteristics for the catchment as $0.50km^2$ (scaled for a site area of 0.80ha) and 857mm respectively. SOIL is estimated by reference to the FEH SPR value of 28%.

6.22 The calculation produces an estimated peak greenfield runoff rate for the site of 1.6l/sec which equates to approximately 2.0l/sec/ha which is within the range of expected values for this area. Greenfield runoff rates for the 30 year and 100 year storm events can be derived by application of regional growth rates of 1.7 and 2.1 respectively. The results are summarised in Table 7.

Table 7: Greenfield runoff rates

Storm frequency (years)	Peak runoff rate (l/sec)
1	1.60
30	2.72
100	3.36

6.23 Post-development runoff rates have been calculated through application of the Rational Method which tends to over predict for particularly small catchment areas and therefore incorporates a degree of conservancy. Using design rainfall data as indicated in Table 1, and the Rational Method in the following format, post development runoff rates, including allowance for climate change at 40% have been calculated as shown in Table 8.

$Q = 0.278CiA$, where

Q=peak discharge (m^3/sec)
C=runoff coefficient
i=design rainfall intensity (mm/hr)
A=catchment area (km^2)

Table 8: Post-development runoff rates and volumes

Storm frequency (years)	Peak runoff rate with climate change (l/sec)	Total runoff volume 2-hour duration (m^3)
1	13.9	100
30	28.2	203
100	50.0	360

6.24 It is apparent from comparison of Tables 6 and 7 that the post-development runoff rates from the site would be significantly higher than the natural greenfield runoff rates.

6.25 Off-site discharge rates are to be restricted to estimated greenfield rates. There are two approaches to definition of on-site storage requirements. The first is to consider restricting off-site discharge to the relevant greenfield rate for all discharge rates. This implies the installation of storage and a flow control system i.e. hydrobrake. The alternative is to restrict all discharges to the annual rate with implications for increased on-site storage requirements.

6.26 To restrict off-site discharge rates to the greenfield rates for 1 in 1 year and 1 in 100-year storm events would require on-site storage capacity of $90m^3$ and $335m^3$ respectively.

However, in accordance with UK drainage design practice, the site drainage system will be designed to accommodate the 1 in 30-year flow. Off-site discharge will therefore be restricted to the 1 in 30-year greenfield rate. To restrict off-site discharge to the annual greenfield rate for all storm events up to the 1 in 100-year event the required on-site storage would be approximately 350m^3. On-site storage capacity of approximately 350m^3 is therefore required to restrict off-site discharge to greenfield rates.

6.27 The proposed development incorporates provision for a stormwater attenuation pond with capacity of in excess of 350m^3 at the eastern end of the site. Subject to confirmation of drainage invert levels it is anticipated that the pond would have an average depth of 1-2m and provide capacity to accommodate temporary storage of surface water up to the 1:100 year storm event plus climate change allowance of 40% (30% + 10% allowance for urban creep).

Safe access/egress to and from the site

6.28 Following completion of flood risk mitigation measures, including ground raising in the centre of the site, the entire development area will be above the 100-year flood level plus climate change allowance. As a consequence, the site will be outside the 100-year flood limit. Under such conditions all internal access roads and pathways would be free from fluvial flood water inundation and remain passable by pedestrians and vehicles. The main site access onto Cliff Hollins Lane is outside the limit of both the 100 and 1,000-year flood and therefore would remain accessible under extreme flood conditions.

6.29 On the basis of available evidence it is concluded that, subject to implementation of flood risk mitigation measures as defined above, the development would remain accessible during extreme flood conditions and that no additional access arrangements are required or proposed.

7. Off-site impacts

7.1 Flood risk assessments undertaken in accordance with the requirements of the NPPF must include consideration of potential off-site impacts of any proposed development on a site. Specific reference is made to (i) surface water management, (ii) flood flow conveyance and (iii) flood storage.

Surface water management

7.2 In accordance with Kirklees Council requirements, the development will include provision for a SUDS based drainage system that will be designed to restrict off-site discharge of surface water to current ‘greenfield’ rates. As the site currently consists of approximately 70% impermeable area the intension to restrict off-site discharge of surface water to greenfield rates by installation of a SUDS based drainage system will lead to a significant reduction in the off-site discharge rate. As a consequence, there would be no increase in downstream flood risk.

7.3 Hydrological analysis has indicated that is technically feasible to control surface water through adoption of SUDS techniques within the site boundary. It is proposed that a detailed surface water management scheme for the site be prepared and agreed with the LPA/EA following granting of planning permission for the proposed development.

Flood flow conveyance and flood storage

7.4 Hydraulic modelling studies have confirmed that, at present, the southern site boundary, and the southern central part of the site, may have a role in facilitating transfer of flood water from the Cliff Hollins Lane area in the west to Hunsworth Beck downstream of the site. However, the proposed flood alleviation works would introduce additional capacity within the main Hunsworth Beck channel and effectively remove overland flow along the southern boundary or through the site itself.

7.5 All proposed development would occur outside Flood Zone 2 and 3, following flood alleviation works, and hence there would be no restriction on flood flow conveyance through the site or the surrounding area. The introduction of additional channel capacity would reduce the risk of fluvial flooding on land along the southern site boundary and agricultural land to the south.

7.6 As all proposed development would be located outside Flood Zones 2 and 3, following flood alleviation works, the development would not lead to any loss of floodplain storage. As a consequence, the development would have no adverse effect on flood risk upstream or downstream of the site.

8. Summary and conclusions

8.1 Flood risk assessment has been undertaken to support a planning application for new residential development at Oak Mills, Cliff Hollins Lane, Oakenshaw, Bradford. The assessment has included review of local development and flood risk policy and detailed analysis of potential flood hazards. The study has been informed by a site hydrological survey and analysis of site-specific flood data obtained from the Environment Agency. A detailed hydraulic model has been developed to provide site-specific flood level and flood extent information.

8.2 Hydrological analysis combined with a detailed site survey has demonstrated that the published flood zone map is inaccurate in the vicinity of the site and a more detailed map showing potential flood inundation areas and flood levels has been prepared by detailed hydraulic modelling.

8.3 The assessment has concluded that there are unlikely to be any flood risk policy related constraints on the development and that the development passes the Sequential Test as defined in the National Planning Policy Framework. There is no requirement to pass the Exception Test.

8.4 Flood hazard assessment has indicated that parts of the proposed development site are at risk of fluvial and surface water flooding. Flood management measures are therefore required to mitigate flood risk to an acceptable level. Flood protection will be achieved by removal of an existing culvert through the site and re-profiling the right bank of the Hunsworth Beck to increase channel capacity and improve bank stability. Additional protection would be achieved by establishing finished floor levels above the 1:100-year flood level including climate change plus the installation of a SUDS based drainage system designed to manage surface water on site.

8.5 The development would have no adverse impact on flood flow conveyance or floodplain storage.

8.6 On the basis of available evidence it is concluded that, subject to implementation of flood risk mitigation measures as defined above, the development would remain accessible during extreme flood conditions and that no additional access arrangements are required or proposed.

8.7 It is concluded that the proposed development can be designed and constructed with an adequate standard of flood protection and without adverse impact on flood risk in the surrounding area. In this context the development has been designed to comply with NPPF guidance and the flood risk management objectives of the local authority planning policy.

For S M Foster Associates Limited

Stephen M Foster
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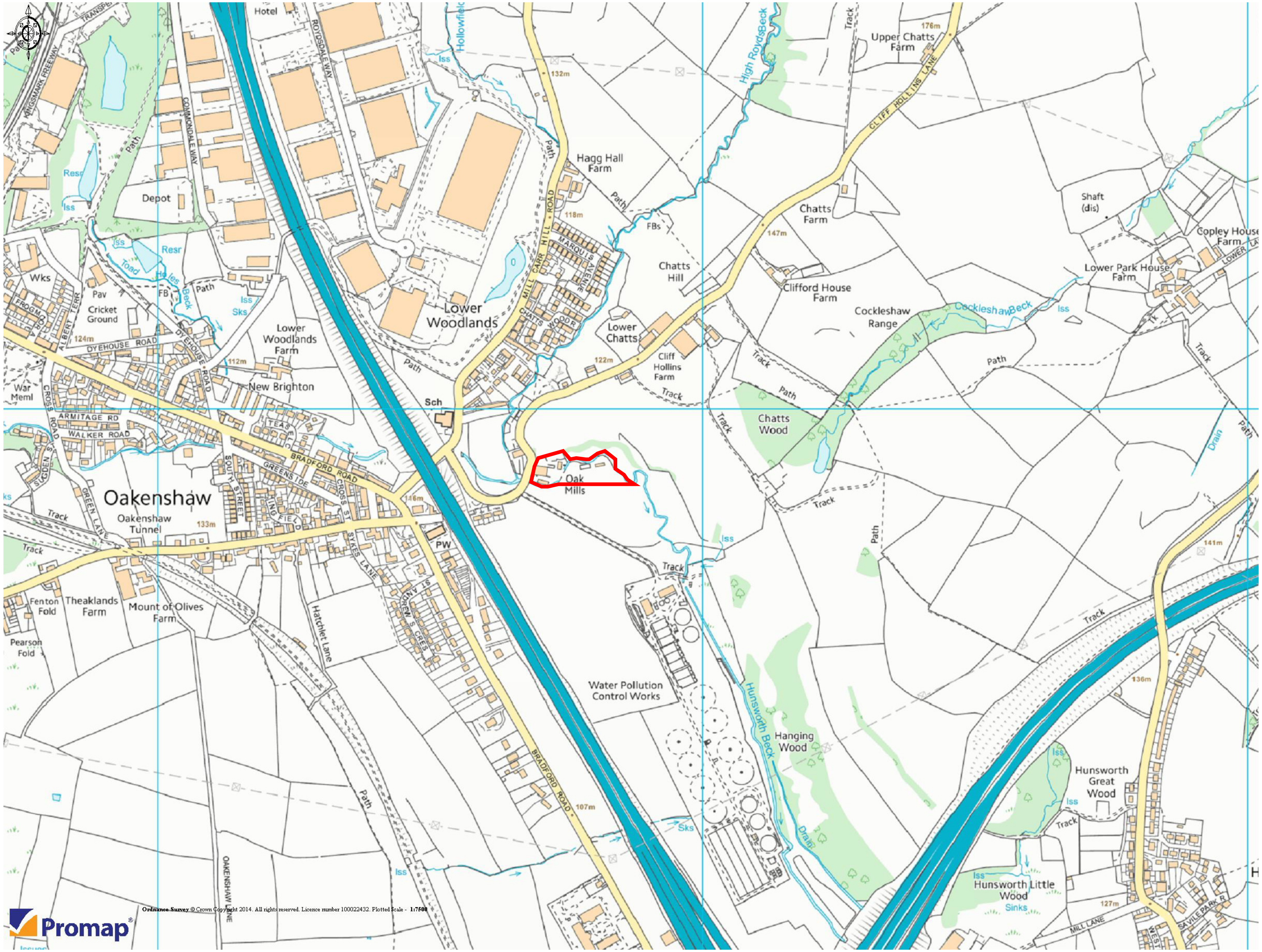
Principal Consultant

Drawings



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Approximate site boundary

CLIENT:

FMB Investments Limited

PROJECT:

LAND OFF CLIFF HOLLINS LANE
OAKENSHAW

FLOOD RISK ASSESSMENT
HYDRAULIC MODELLING

Ref: 116/01/01/0115	Date: January 2015
Approved: smf	Scale: 1:7,500 @A3

DRAWING 116/01/01
SITE LOCATION AND LOCAL HYDROLOGY

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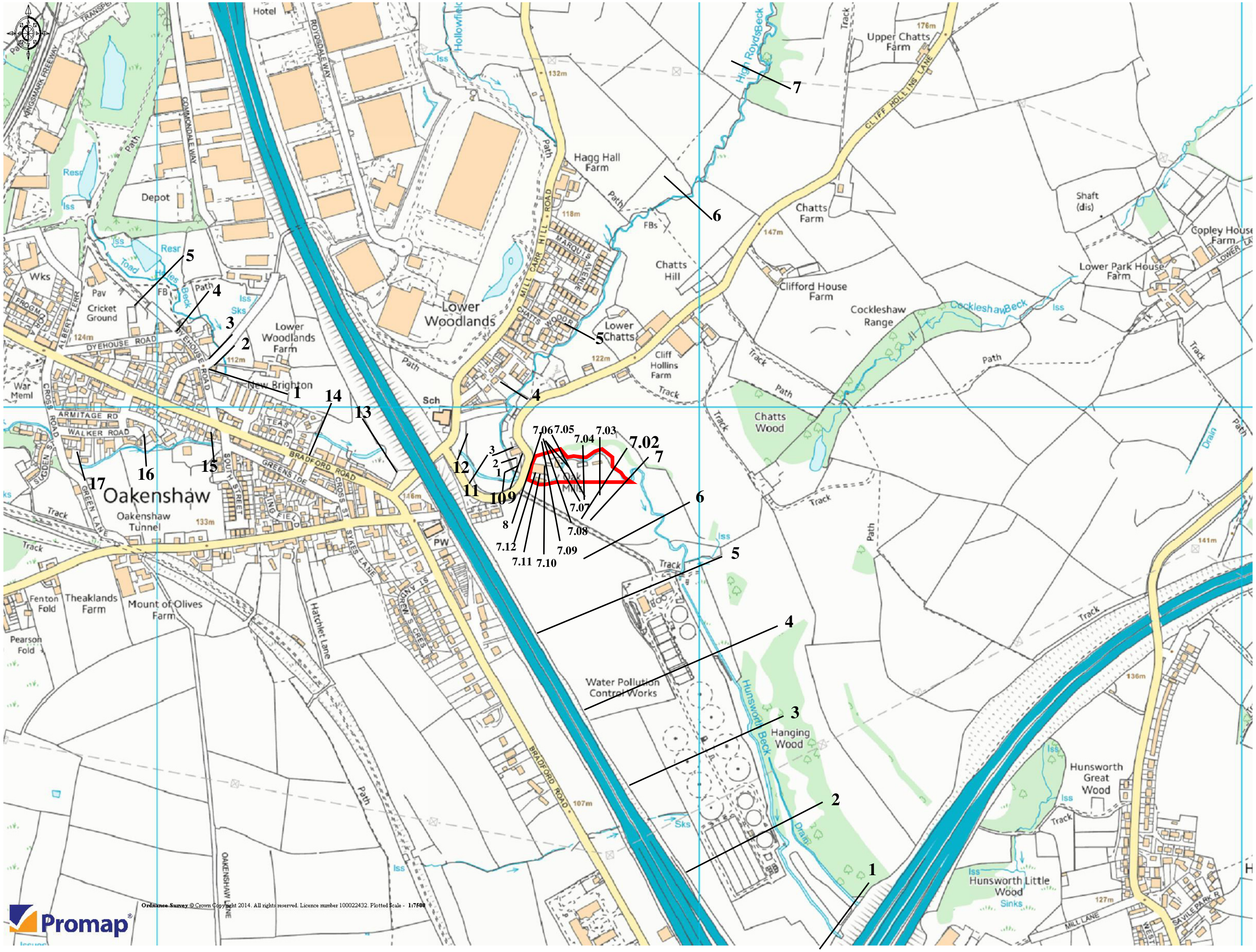


9 Approximate location of model sections. For more detailed plan of site sections see Drawing 116/01/03.

Approximate site boundary

CLIENT:

FMB Investments Limited

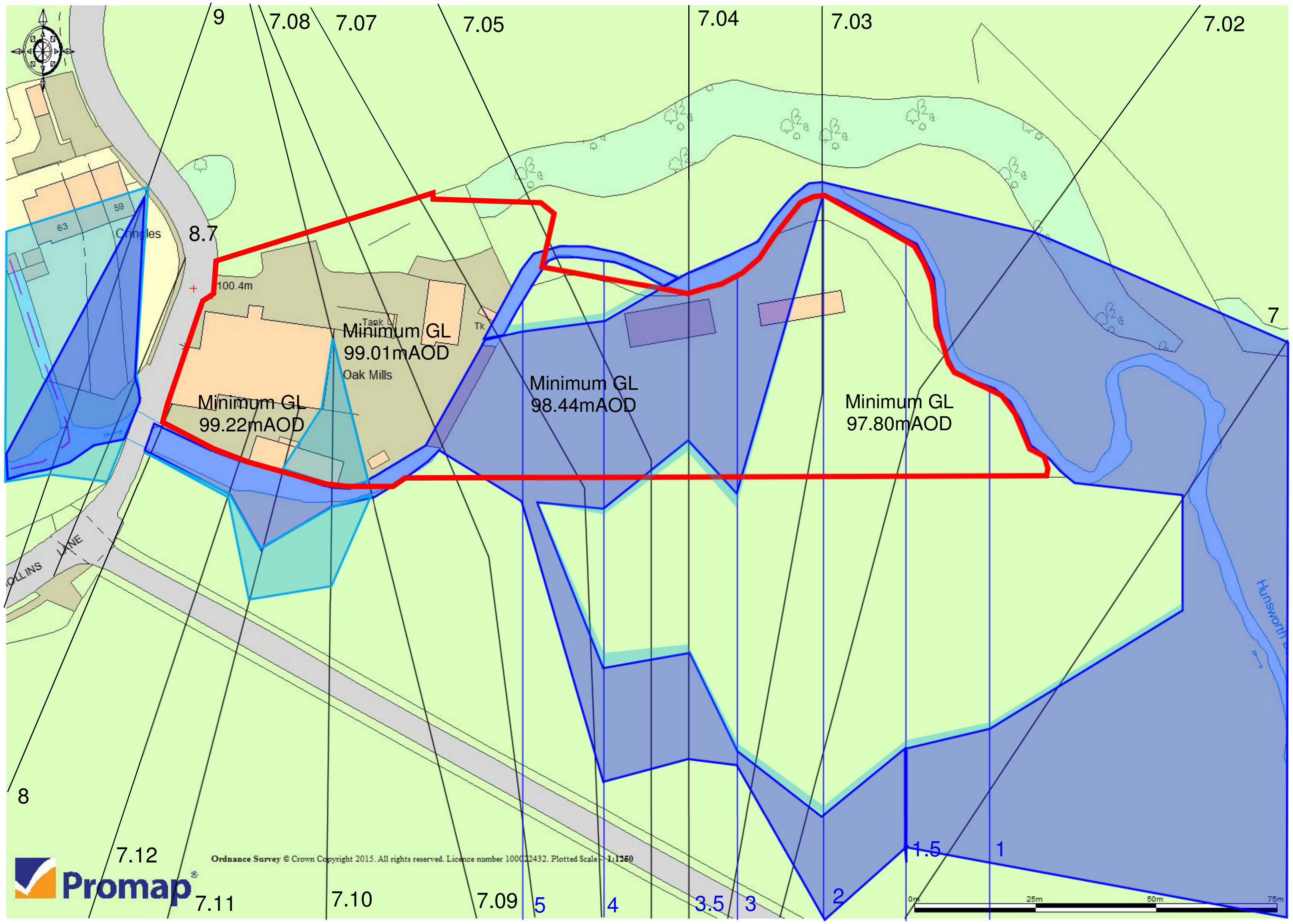
PROJECT:

LAND OFF CLIFF HOLLINS LANE
OAKENSHAW

FLOOD RISK ASSESSMENT
HYDRAULIC MODELLING

Ref: 116/01/01/0115	Date: January 2015
Approved: smf	Scale: 1:7,500 @A3

DRAWING 116/01/02
MODEL SECTION LOCATIONS



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Section line

Section line - overland flow model

1:100yr flood limit

1:1000yr flood limit

Approximate site boundary

CLIENT:
FMB Investments Limited

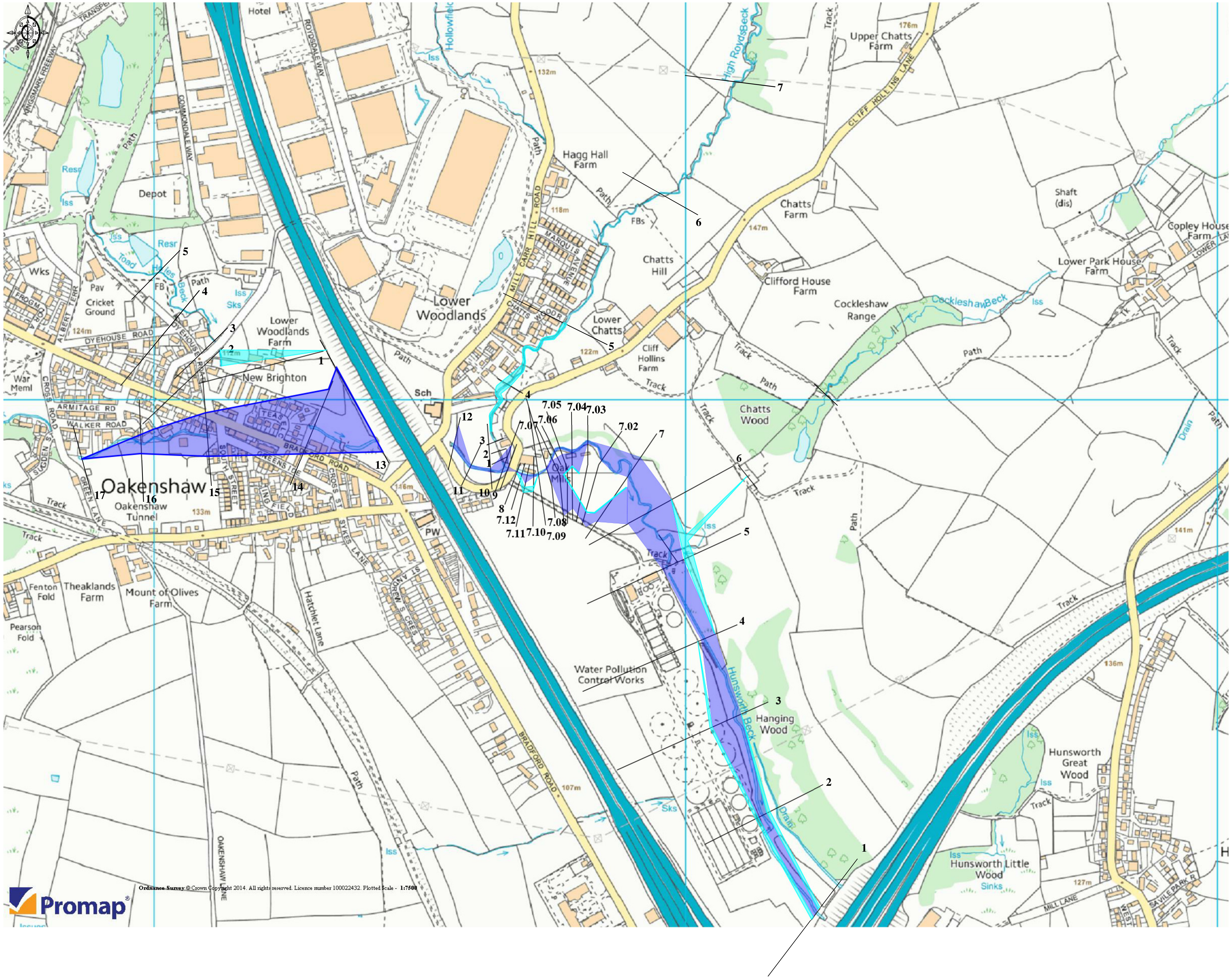
PROJECT:
LAND OFF CLIFF HOLLINS LANE
OAKENSHAW

FLOOD RISK ASSESSMENT
HYDRAULIC MODELLING

Ref: 116/02/11/1015	Date: October 2015
Approved: smf	Scale: as indicated

DRAWING 116/02/03

MODELLED FLOOD EXTENTS



S M F

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9 Georeferenced model cross sections and section number

Modelled extent 1:100yr flood

Modelled extent 1:1000yr flood

CLIENT:

FMB Investments Limited

PROJECT:

LAND OFF CLIFF HOLLINS LANE
OAKENSHAW

FLOOD RISK ASSESSMENT
HYDRAULIC MODELLING

Ref: 116/01/01/0115	Date: August 2015
Approved: smf	Scale: 1:7,500 @A3

DRAWING 116/02/04
MODEL FLOOD EXTENTS