Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

Witness Statement of Professor JD Rhodes CBE, FRS, FREng for Menston Action Group

---

I Professor David Rhodes of Dabarda, West Winds, Moor Lane, Menston will say as follows:

1. I have received the OBE and CBE and also several Queen's Awards for Technology and Export. I have received the BSc. Ph.D., D.Sc. and Honorary D.Eng Degrees from Leeds University and further Honorary Degrees from Bradford and Napier Universities. I am a fellow of the IEEE, IET, RAE, The Royal Society and a Foreign Associate of the Academy of Engineering (USA).

2. I have been been awarded numerous prizes for engineering including the Microwave Prize, the Browder J. Thompson Award, The Guillimin – Cauer Award and the Microwave Career Award all from the IEEE (USA) together with the CASS Golden Jubilee Medal and the Third Millenium Medal; The JJ Thompson Medal and the Faraday Medal from the IET; The Mountbatten Medal from the National Electronics Council; The Mullard Award from the Royal Society and the premier distinction from the Royal Academy of Engineering of the Prince Philip Gold Medal (an award given occasionally for significant contributions to engineering on a worldwide basis). I have also received the European Microwave Career Award and many business awards and have sat on government appointed committees dealing with different aspects of engineering including nuclear energy, alternative energy sources and education.

3. I am also an Emeritus Professor at Leeds University.

4. The sites at Bingley Road and Derry Hill are of a similar size, the same elevation, have similar slopes, are within 500m of each other (centre to centre) and have the same exposure to water run-off from

the adjacent moorland. As referred to in the Sirius Geoenvironmental Report prepared for the Bingley Road site the 'numerous small streams and surface drains…appearing to drain the area of land 500 – 1,000 m to the south of the site' are similar to those photographed above the Derry Hill site on 24 September 2012.

5. Eastwood & Partners were responsible for the Flood Risk and Drainage Assessment Reports (**FRDA**) for both sites. Those reports generally comply with normal good practice but not best practice since no account has been taken of local knowledge with regard to the significant volume of water run-off from the sites.

6. In considering the requirements for the volume of water required to be stored on the sites a storm scenario of 21mm of rain falling in a period of 3 hours 50 minutes was used and it was stated by Eastwood & Partners as being the critical storm period. This is not the critical storm period for this area of Menston.

7. In a recently produced map from the Environmental Agency (see Exhibit 1) these sites are located in an area where 25 → 50% of the area has a high probability of groundwater emergence.

8. The correct interpretation of this map was clarified in a recent letter (see Exhibit 2) from David Macdonald, Senior Hydrogeologist, British Geological Survey where he stated:

> "Our dataset was used by the Environment Agency to help lead local Flood Authorities to make the Preliminary Flood Risk Assessments required by the Flood Regulations 2009. They identified the proportion of land within each 1km square that has very high susceptibility to groundwater flooding. From your letter it would appear that 25 → 50% of the square in your area of interest is classified as very high."

9. In the Sirius Geoenvironmental Appraisal Report commissioned by the appellant, following a sharp rise in the measured groundwater level it was concluded that:

> "The site is, however, located within an area in which groundwater flooding may be a significant issue. Inspection of the site has identified a number of locations in which

springs, possibly seasonal exist within and near to the site, discharging across the site."

10. The guidance given by the British Geological Survey is:

> "Where high groundwater flooding susceptibility is indicated, this means that given the geological conditions in the area groundwater flooding hazard should be considered in all land-use planning decisions."

11. The only current method to determine the quantity and frequency of groundwater emergence is from local knowledge of the conditions when it occurs and from photographic records of the events themselves to determine the quantity of water.

12. It is known that significant increases in water flow from these sites only occurs during prolonged storm events considerably longer in time than the storm period considered in the FRDA and typically for storm periods lasting 10 hours or more.

13. Two such recent events have been recorded and are presented in detail.

Storm event: 24, and 25 September 2012

14. In the JBA Report dated February 2012 (See Rainfall Data Analysis – September 2012) (Exhibit 3) there is a comprehensive record of the rainfall data during this storm when 80mm of rain fell in 54 hours at an average rate of 1.5mm / hour.

15. For the Bingley Road site water flowed evenly across the site and between the houses on Hawksworth Drive with some entering the watercourse on the eastern boundary presenting difficulties in establishing the total rate of flow but significant ponding did occur in the field to the east of the site under which the watercourse is culverted (see photograph from 25 September 2012) (Exhibit 4). At the Derry Hill site there is a V shaped gorge above the site approximately 20m wide and 10m deep which channels some of the water into the top of the watercourse on the site and from the video recordings (which can be viewed at http://bit.ly/MAGMPCMCAVideos) taken at around 6:00pm on 24 September 2012 and the two photographs (Exhibits 5 and 6) this enables the rate of flow of water to be calculated.

16. As referred to in the JBA Report (Exhibit 3) the calculations made by Eastwood & Partners were confirmed by JBA to give a mean rate of flow of water in the top of the watercourse at the time of the recording of about 1.25m^3/s or 4500m^3/hour. Although the measurement was established 6 hours after the peak rainfall if it is (very conservatively) assumed that it was measured at the peak of 5mm/hour the minimum surface water capture area (A) assuming 100% run-off rate is:

$$A = \frac{4{,}500 \text{ x } 10^{-4}}{5 \text{ x } 10^{-3}} = 90ha$$

17. The surface area which captures the rainfall and would channel the water from ground contour information into the watercourse is about 24ha giving a ***discrepancy factor*** of near 4:1. This is the same as the factor given in the JBA report (ref 1.a – Excessive level of high local run off rates i.e. the ratio of observed flows to estimated flows) (Exhibit 3). It follows that this increase in water must have originated from other sources; several of which have been photographed (Exhibits 7, 8 and 9).

18. It is important to note that this storm event is estimated (by JBA) (Exhibit 3) to be a 1 in 11-year event.

Storm event: 21 January 2008

19. Rainfall data compiled by JBA (Rainfall Data Analysis – January 2008) (Exhibit 10) evaluates this rainfall event when 45mm of rain fell in 18 hours with an average of 2.5mm/hour and a mean peak of 7.6mm/hour. A photograph (on the front of the JBA Report) (Exhibit 3) shows significant amounts of water flowing from the watercourse on the Derry Hill site and through the 9m wide gap containing an 11,000 Volt electricity substation with the equipment raised above a flat concrete base with the land falling away at the rear.

20. At the bottom of the watercourse following the line of the trees the water enters a watercourse in the garden of 28 Moorfield Avenue and has an estimated (by Eastwood & Partners) capacity of 330l/s. The water flow was such as to flood the gardens and the street and hence must have been flowing at close to 0.5m^3/s.

21. For the water flowing on the concrete slab, it is known from energy considerations that there is a direct relationship between the depth of water on the slab and the minimum rate at which the water is flowing since the slab falls away rapidly at the rear. To determine the depth of water a new photograph of the same image was taken in dry conditions. The part of the original image showing

the water flowing through the substation was accurately superimposed on the dry conditions image as shown in the enclosed figure (Exhibit 11) with the area of interest highlighed. From the exact heights of the horizontal bar and the main posts above the slab ratioing gives a depth of water of 24cm plus or minus 5%.

22. From the effective width of the aperture the calculated amount of water flowing through the substation was at least 1.5m^3/s. Thus, the total flow rate at the top of the watercourse was about 2.0m^3/s and if it were at the peak of 7.6mm/hour then the effective capture area is within plus or minus 5% of the area established from the 24 and 25 September 2012 event.

23. It follows that the conclusion to be drawn is that the discrepancy factor of 4:1 referred to above is correct since the same value has been obtained from two unrelated events both assuming a 100% run-off rate.

24. My conclusions as to the volume of water which is required to be stored on the Bingley Road site and the Derry Hill site are referred to in Appendix 1 and Appendix 2 respectively.

Appendix 1 Water Storage Requirements for the Bingley Road Site (calculated from the storm even on 24 and 25 September 2012).

1. Yorkshire Water have placed a constraint upon the Bingley Road site that surface water run-off must not exceed 15l/s. Hence, any amount of water entering the site above this run-off rate must be stored on site.

2. According to the submitted Eastwood & Partners Report, the surface water capture area is 38ha for the wider catchment area and for the 54 hour duration storm with 80mm of rain falling; the quantity of water, Q_1, is given by:

$$Q_1 = 80 \, x \, 10^{-3} \, x \, 38 \, x \, 10^4 = 30{,}400 m^3$$

3. Using the same discrepancy factor as established for the Derry Hill site of 4:1 based upon 100% run-off rate, Q_1 increases to:

$$Q_2 = 121{,}600 m^3$$

4. To factor the event for a 100-year return period using the average of standard factors shown in the enclosed JBA table (Exhibit 12) requires a factor ratio of 5:3. If a further 20% is added to account for climate change this ratio then becomes 2:1. Hence, for the 100-year return period plus climate change:

$$Q_3 = 243{,}200 m^3$$

5. For a run-off rate of 15l/s the quantity of run-off, Q_R, is given by:

$$Q_R = 15 \, x \, 10^{-3} \, x \, 54 \, x \, 3{,}600 = 2{,}916 m^3$$

6. Subtracting this quantity from the total gives the required amount of water to be stored Q_S as:

$$Q_S = 240{,}000 m^3$$

7. It should be noted that this large quantity of water is dominated by the contributions from the springs and seasonal springs both on and above the site, discharging across the site; where the land is totally saturated during these types of storm conditions.

8. The equivalent storage number estimated by Eastwood & Partners was about 1,500m^3.

Conclusions

9. As can be seen from the calculations, the constraint imposed by Yorkshire Water means that most of the water discharging across the site has to be stored on the site.

10. As the ground is likely to be totally saturated considerable thought needs to be addressed to the issue of the type of structure which will be necessary to store this quantity of water. It should also be noted that this quantity of water only occurs during storms of a long duration and not during storms which last only 4 hours or less. It is known that the seasonal springs appear to become active after about 5 hours storm duration and are in full flood after about 10 hours.

Appendix 2 Water Storage Requirements for the Derry Hill Site (calculated from the storm event on 24 and 25 September 2012)

1. Yorkshire Water have placed the constraint upon the site that **no** surface water run-off from the site can enter the combined sewer system. Hence, the amount of water that can run-off is limited to the capacity of the downstream culverted water course (as identified in the JBA Report 1.b) (Exhibit 3). The constraint from this is an allowable rate of about 1,500m^3/hour.

2. Eastwood & Partners calculate that the wider catchment area for the site is 45ha resulting in Q_1 to be:

$$Q_1 = 36{,}000m^3$$

3. Using the discrepancy factor of 4:1 based upon the measured flow from the Derry Hill site gives:

$$Q_2 = 144{,}000m^3$$

4. And for a 100-year return period plus climate change:

$$Q_3 = 288{,}000m^3$$

5. The amount which can be run-off in the culverted watercourse is $54\ x\ 1{,}500 = 81{,}000m^3$ leaving a net amount to be stored of approximately $200{,}000m^3$ as compared to about 1,500 m^3 estimated by Eastwood & Partners.

Conclusions

The constraint placed by Yorkshire Water still requires a considerable amount of water to be stored either on or above the site.

Statement of Truth

I believe that the facts stated in this witness statement are true.

Signed..................
Professor JD Rhodes
Dated 15 March 2013

Exhibit: JDR1

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR1"

This is Exhibit "JDR1" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed......................................

Professor JD Rhodes
Dated: 15 March 2013

City of Bradford MDC
www.bradford.gov.uk

City of Bradford Metropolitan District Council
Preliminary Flood Risk Assessment

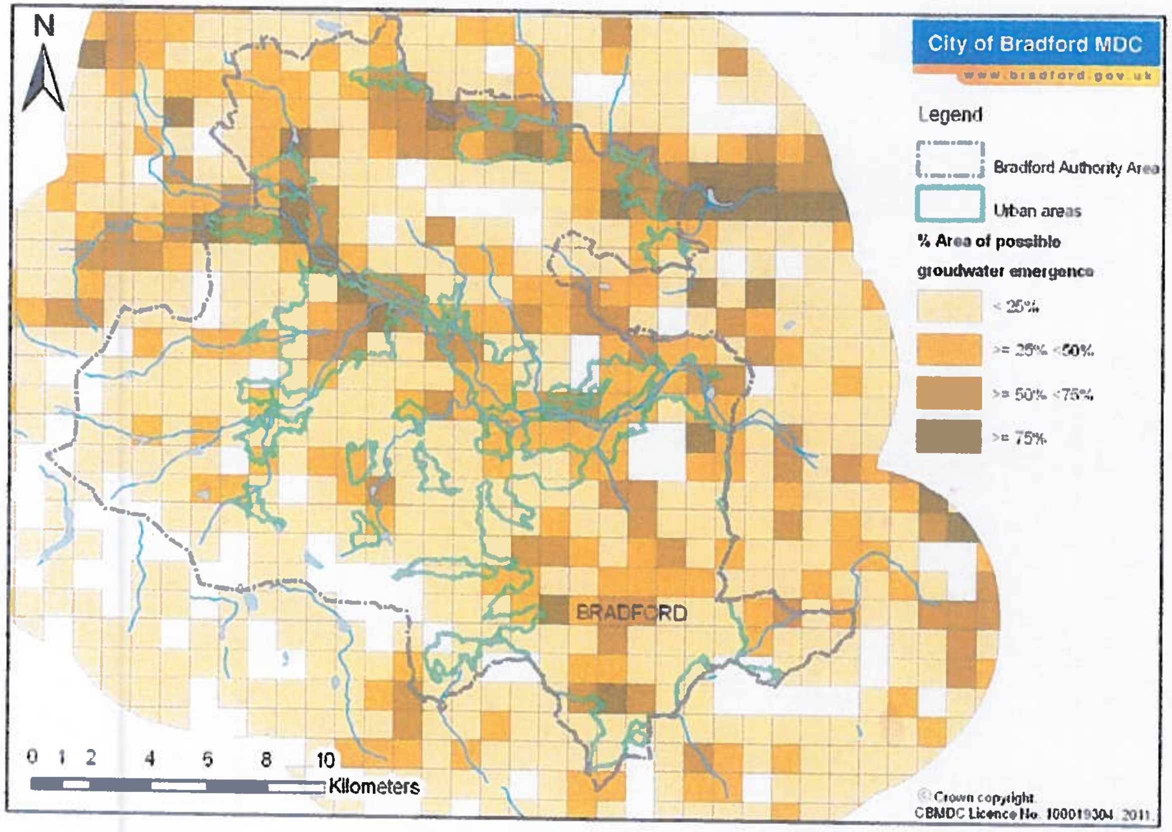


Exhibit: JDR2

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR2"

This is Exhibit "JDR2" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed..
Professor JD Rhodes
Dated: 15 March 2013

A2

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Wallingford
Maclean Building
Crowmarsh Gifford
Wallingford
Oxfordshire
United Kingdom
OX10 8BB

Telephone +44(0)1491 838800
Direct Line +44(0)1491 692306
Main Fax +44(0)1491 692345
E-mail dmjm@bgs.ac.uk

Mr C Schofield
Schofield Sweeney
Springfield House
76 Wellington Street
Leeds
LS1 2AY

18 February 2013

Dear Mr Schofield and Prof Rhodes

Thank you for your letter dated 25 Jan 2013 and the accompanying CD.

The British Geological Survey does not comment on individual flood enquiries, however, we can provide some background information on the groundwater flood susceptibility classification in your area of interest.

The British Geological Survey produces susceptibility to groundwater flooding maps. but this is not the same as groundwater flooding risk. Susceptibility maps seek to identify areas where the geological conditions and water tables indicate that groundwater may be present at shallow depths and could rise to enter basements/cellars or under certain circumstances come above the ground surface. A high susceptibility to groundwater flooding classification does not necessarily mean that groundwater flooding has ever occurred in the past, or will do so in the future as the susceptibility maps do not contain information on how often flooding may occur or to what depth. The consultants Sirius Geotechnical and Environmental Limited will not have obtained any data from BGS which identifies 'high probability' of groundwater flooding.

You can find an explanation of how groundwater flood susceptibility is calculated on our web site http://www.bgs.ac.uk/products/hydrogeology/groundwaterFlooding.html. We have looked at the areas immediately around the grid references that you supplied to check the groundwater flood susceptibility. The land at both grid references provided is underlain by superficial deposits overlying Millstone Grit bedrock. The superficial deposits are till which comprises diamicton-mixed grainsize material (eg stony clays) that is generally of low permeability but may contain some more permeable sand and gravel horizons. The bedrock comprises sandstones (permeable) interbedded with undifferentiated mudstones, siltstones and sandstones (less permeable). Geological maps for the area can be viewed at http://mapapps.bgs.ac.uk/geologyofbritain/home.html. The more permeable horizons may contain groundwater, and this may discharge at the surface as springs where underlain by less permeable material or at times of high water levels.

The groundwater flood susceptibility dataset is relatively coarse with a resolution of 50 x 50 m. The pixels immediately around the grid references you provided where till is underlain by Millstone Grit sandstone have 'low' to 'very low' susceptibility to groundwater flooding from bedrock and the areas where till is underlain by Millstone Grit undifferentiated mudstones, siltstones and sandstones have 'very high' susceptibility to groundwater flooding from the superficial deposits. However, as there is some variability in the lithology and hence permeability of both the superficial deposits and bedrock around this site, this classification is generalised. The confidence in the data is 'low', where it relates to susceptibility to groundwater flooding from bedrock and 'moderate' where it relates to susceptibility to groundwater flooding from superficial deposits.

Our dataset was used by the Environment Agency to help Lead Local Flood Authorities to make the Preliminary Flood Risk Assessments required by the Flood Regulations 2009. They identified the proportion of land within each 1 km square that has very high susceptibility to groundwater flooding. From your letter it would appear that 25-50% of the square in your area of interest is classified as very high.

I hope the information provided gives you a better understanding of the BGS groundwater susceptibility dataset and its classification in your area of interest. If you have any further queries there is some more information, and some frequently asked questions, on groundwater flooding on our website
http://www.bgs.ac.uk/research/groundwater/flooding/groundwaterHomesFAQ.html.

Yours Sincerely

David Macdonald
Senior Hydrogeologist

Exhibit: JDR3

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR3"

This is Exhibit "JDR3" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed..
Professor JD Rhodes
Dated: 15 March 2013

[redacted]

JBA
consulting

Derry Hill and Bingley Road Menston

Evaluation of September 2012 Runoff Event and the Consequences for Future Development

Final Report

February 2013

Client: Professor David Rhodes

JBA Project Manager

David Stark
South Barn
Broughton Hall
Skipton
North Yorkshire
BD23 3AE

Revision History

Revision Ref / Date Issued	Amendments	Issued to
Final Report 26 February 2013		David Rhodes and Chris Schofield in pdf format with all appendices

Contract

This report describes work commissioned by Professor David Rhodes, by an email dated 7 August 2012. David Stark and Jeremy Benn of JBA Consulting carried out this work.

Prepared by ....David Stark BSc CEng MICE

Principal Engineer

Reviewed by ....Jeremy Benn FREng MA MSc CEng FICE FCIWEM C.WEM MASCE MIEI

Chief Executive

Purpose

This document has been prepared as a technical report for Professor David Rhodes. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to Professor David Rhodes.

Copyright

Background

Planning applications have been submitted for 173 dwellings at Derry Hill and 135 dwellings at Bingley Road, Menston (see Figures 1 and 2). Since the original applications, there has been an incident of prolonged heavy sustained runoff from the Derry Hill catchment (24/25 September 2012), for which photographic and other measurements are available. Incidents of sewer surcharging have also been reported in Menston, and further information on the catchment area draining through the Bingley Road site provided.

This new information has been analysed and possible consequences of the proposed developments on flood risk have been considered.

1. Flood Risks Posed by the Proposed Derry Hill Development

The Flood Risk Assessment (FRA) submitted with the Derry Hill planning application (see Reference 1) has been reviewed in the light of the new information. It is considered that this Flood Risk Assessment generally complies with normal good practice. However, it falls short of best practice in that it fails to take account of the following four key local flood risks:

- Evidence of unusually high local runoff rates.
- Diversion by the proposed development of existing watercourse overland flow paths.
- The catchment area captured by the proposed swales.
- That part of the development site is floodplain.

1a. Evidence of High Local Runoff Rates

It is best practice and clearly stated in the Environment Agency's Flood Estimation Guidelines and Volume 1 of the Flood Estimation Handbook that evidence of high local runoff rates and past flooding should be taken into account when estimating flood flows (References 3 and 4).

Rain gauge data was analysed and flows in the Derry Hill watercourse were estimated from observations from a high runoff event in September 2012. The analysis suggests that runoff was greater during the September 2012 event than predicted by standard flood estimation methods, and hence estimates previously made for the 100-year return period flow are too low. In particular:

- When information from observed flows in the catchments is used, the 100-year flow estimate is in the range **2.79m^3/s - 5.59m^3/s.**
- By comparison, estimated 100-year flows using the standard methods are lower. The most recent method for flow estimation in this type of catchment is the ReFH method and this gives flows in the range **0.78m^3/s - 1.42m^3/s.**
- The 100-year flow estimate of **1.09m^3/s** in the Eastwood & Partners FRA is therefore considered to be too low. That estimate was based on the FSR Rainfall Runoff Method (referred to in their FRA as the FSR/FSSR16 and IoH Report No. 124 method).

Local residents have reported that high runoff continued for a long period during the September 2012 event, resulting in overtopping floodwaters from the existing watercourse on Derry Hill flowing overland for an extended period. High runoff of such duration is not replicated in standard models of flood flow estimation (including ReFH). Hence, in addition to underestimating peak flows, these models are underestimating the duration and hence the volume of flood flows when compared to observations within the catchment. As a result of the above findings, the design of the drainage and storage facilities for the proposed development should be reviewed, and as a minimum should be based on the higher results from the ReFH method, with an additional allowance to take account of the evidence that these could be underestimates.

As a result of the above, the current dimensions of the proposed on-site and off-site drainage systems will not be able to ensure that the flood flows leaving the site are at least the same as, or ideally less than, those that occur currently. To ensure that flow rates do not increase the design flood flows and volumes for the following features will need to be substantially changed:

- The re-sectioning of the watercourse channel through the Derry Hill site.
- The proposed uphill interceptor swales (which are outside the development site) at Derry Hill.
- The proposed land drainage system of ditches and swales at the Bingley Road site.
- The combined storage volume provided by the detention basin and oversized adoptable surface water sewers at the Bingley Road site.

1b. Downstream 400mm Culvert in Dick's Garth Road

The estimated capacity of the downstream 400mm culvert in Dick's Garth Road is quoted as **336l/s** (full bore) and **430l/s** (surcharged) in the FRA by Eastwood & Partners. This culvert has insufficient capacity to convey the estimated flows and thus flooding occurs in Dick's Garth Road and to gardens and houses on Moorfield Avenue.

1c. Diversion of Watercourse Overland Flowpaths at Derry Hill

The existing route of the Derry Hill watercourse is to be maintained through the development and watercourse flows are to be contained within this "flow corridor". The evidence from the recent high runoff events shows that such works will largely prevent the spillage of floodwaters over the right (eastern) bank of the watercourse that currently occurs. The result will be the redirection of these flows along the line of the watercourse (see Figure 3). This will result in an increased flood risk (in terms of an increase in the frequency of flooding and also the extent and depth of flooding) to adjacent properties immediately downstream of the proposed development, particularly on Moorfield Avenue.

1d. Catchment Area Captured by the Proposed Swales at Derry Hill

A proposed land drainage system of ditches and swales is to be installed along the southern uphill boundary of the Derry Hill development to intercept runoff from the hillside and direct it into the watercourse. The proposed land drainage system will effectively enlarge the catchment of the watercourse by **27%** (see Figure 4). The proposed land drainage system will therefore result in an increased flood risk to adjacent properties immediately downstream of the site (particularly at the head of Moorfield Avenue). The design of the swales will need to incorporate a restricted discharge to the watercourse and sufficient storage volume to mitigate this adverse impact.

1e. Functional Floodplain at Derry Hill

The photographic evidence from the high runoff event in September 2012 clearly show that flows spill from the Derry Hill watercourse and cross part of the lower portion of the proposed development area. Given the frequency of these events, this part of the development site should be considered to be floodplain and therefore not suitable for development (see Figure 5).

1f. Overloading of the Public Sewerage System

There is photographic and video evidence that the existing public combined sewerage system in Menston is overloaded. In particular, during 2012 floodwaters have escaped on several occasions through manholes on the combined sewer system particularly near the Menston Arms public house in the centre of Menston and on Hawksworth Drive (4 and 7 July, 15 and 21 August, and 12 and 16 September 2012). It is acknowledged that foul flows from the proposed developments are probably small in comparison with the capacity of the combined sewer system and that discharge of foul flows to the public combined sewer system is therefore unlikely to significantly exacerbate the existing flooding problems. However, additional foul flows will result in a higher concentration of sewage in any overflowing floodwaters, therefore posing increased health risks.

2. Bingley Road Site

The installation of the proposed drainage systems on the Bingley Road development will tend to intercept some overland floodwaters from the adjacent hillside (which currently tend to flow northwards into the existing development along Hawksworth Drive) and divert them eastwards towards Cleasby Road. Thus flooding to the existing properties along Hawksworth Drive will be alleviated but the frequency, extent and depth of flooding to properties near Cleasby Road could be increased.

The original FRA prepared by Eastwood & Partners (see Reference 2) quoted a total catchment area of 0.380km^2 **(38ha)** for the watercourse system considered at the Bingley Road site. By contrast, the Bradford Council Drainage Officer's Report for the Planning Committee in February 2012 mentioned a revised much smaller catchment area of **8.6ha**. The revised catchment area of 8.6ha appears to have been based on information supplied by Eastwood & Partners to the Council (not seen by JBA Consulting). It is considered that the revised submission by Eastwood & Partners should be carefully reviewed to ensure that the substantial reduction in catchment area (and corresponding flows to be accommodated) is justifiable.

The rates of runoff for the Bingley Road catchment can be reasonably expected to be similar on a unit area basis to those from Derry Hill given the similar rainfall, soil type and slope. Hence, a similar conclusion regarding the flow estimates based on the FSR Rainfall Runoff Method being underestimates can be drawn for this catchment.

Taking the catchment boundary/area uncertainty and the likely underestimation of runoff rates, it is unlikely that the proposed detention basin will be adequate to mitigate the impact of intercepting and diverting overland flows from the adjacent hillside. This will lead to an increase in flood risk to downstream properties.

Contents

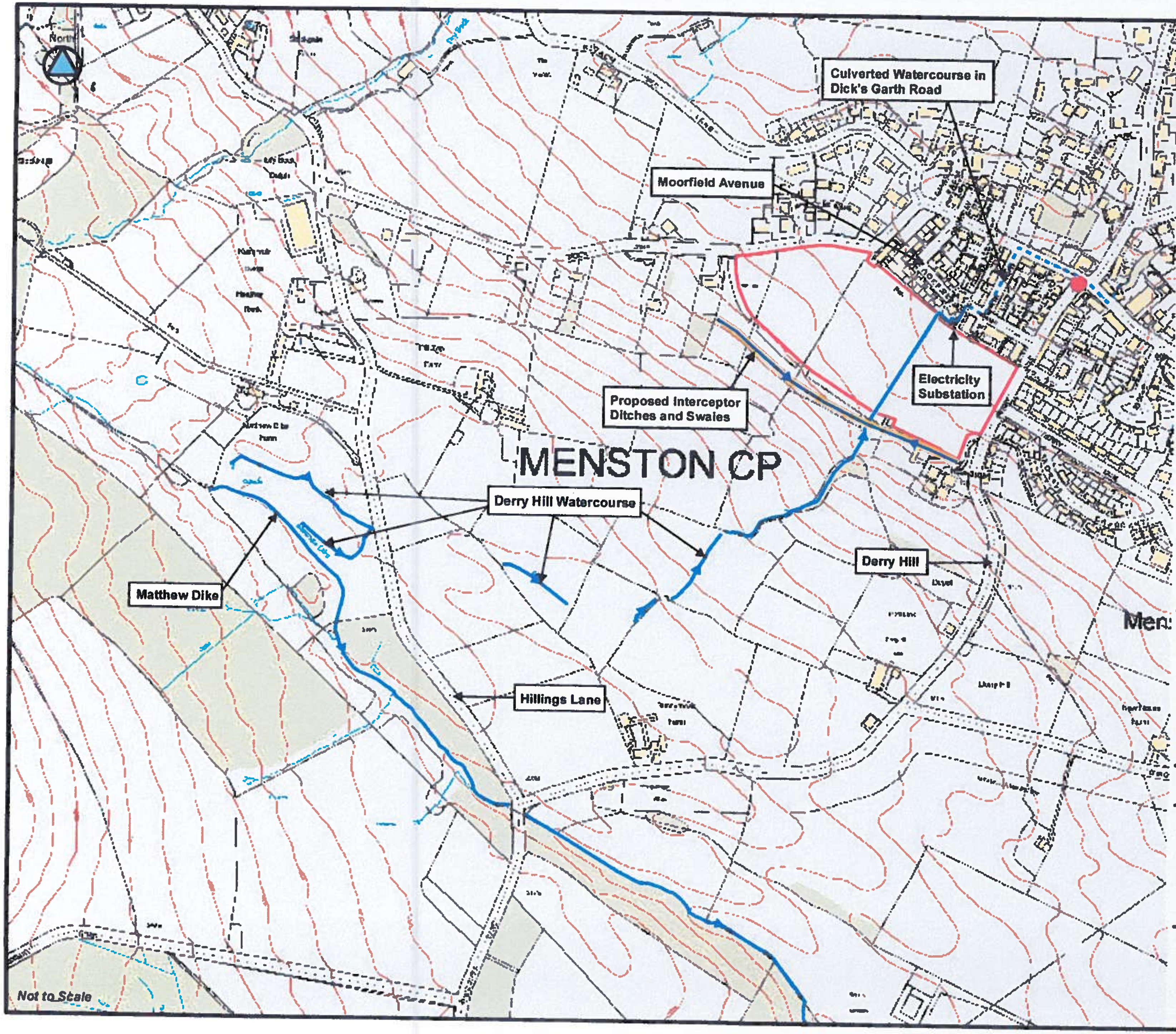
List of Figures

Abbreviations

AEP	Annual Exceedance Probability
FEH	Flood Estimation Handbook
FES	Flood Estimation System (JBA in-house software)
FRA	Flood Risk Assessment
ha	hectare
IH124	Institute of Hydrology Report No. 124 (flood estimation in small catchments)
l/s	Litres per second
l/s/ha	Litres per second per hectare
m^3/s	Metres cubed per second (cumecs)
MAG	Menston Action Group
mAOD	Metres Above Ordnance Datum
OS	Ordnance Survey
ReFH	Revitalised Flood Hydrograph
SPRHOST	Standard Percentage Runoff (Hydrology of Soil Types)
SUDS	Sustainable Drainage Systems

Definitions

Annual Exceedance Probability / Return Period	The severity of a flood event is now described in terms of its annual probability of exceedance. A 1% annual exceedance probability (AEP) flood has a 1 in 100 chance of being exceeded in a given year. Descriptions using 'return period' are now regarded as being misleading, but the two may be related by taking the inverse of the AEP. For example, a 1% AEP event may be equated to a '100-year' return period flood.
Left bank, Right bank	The relevant bank of a watercourse looking in a downstream direction.



Development Site

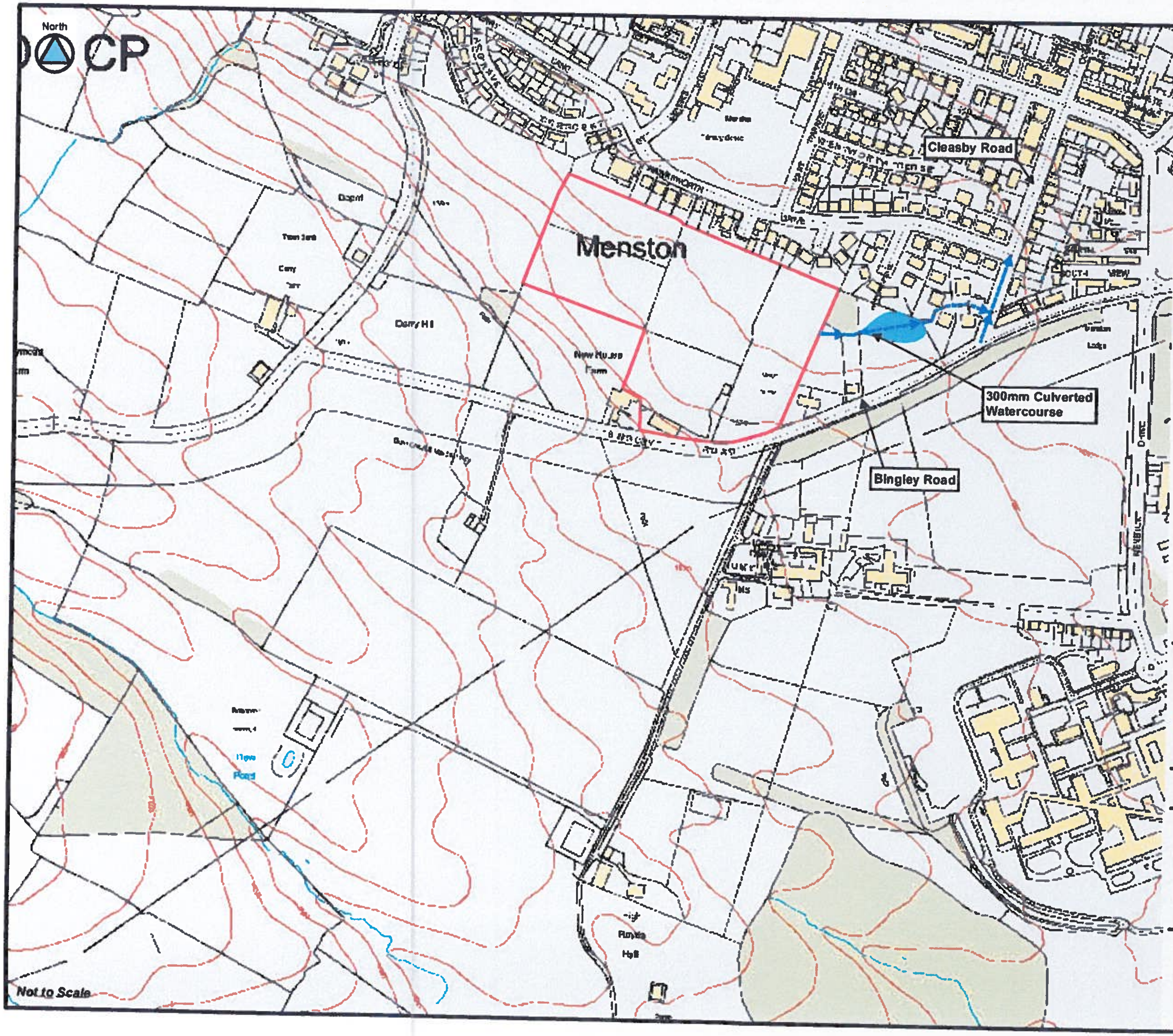
LEGEND

- Development Site
- Existing Watercourse
- Existing Culverted Watercourse
- Proposed Interceptor Ditches and Swales
- Location where Sewage and Floodwaters escape from Public Sewers

JBA consulting

FIGURE 1

SITE LOCATION AND DRAINAGE FEATURES - DERRY HILL



KEYPLAN

Not to Scale

Development Site

Contains Ordnance Survey data © Crown copyright and database right (2011)

LEGEND

- Development Site
- Existing Watercourse
- Existing Culverted Watercourse
- Approx Area Prone to Flooding

JBA consulting

FIGURE 2

SITE LOCATION AND DRAINAGE FEATURES - BINGLEY ROAD

KEYPLAN *Not to Scale*

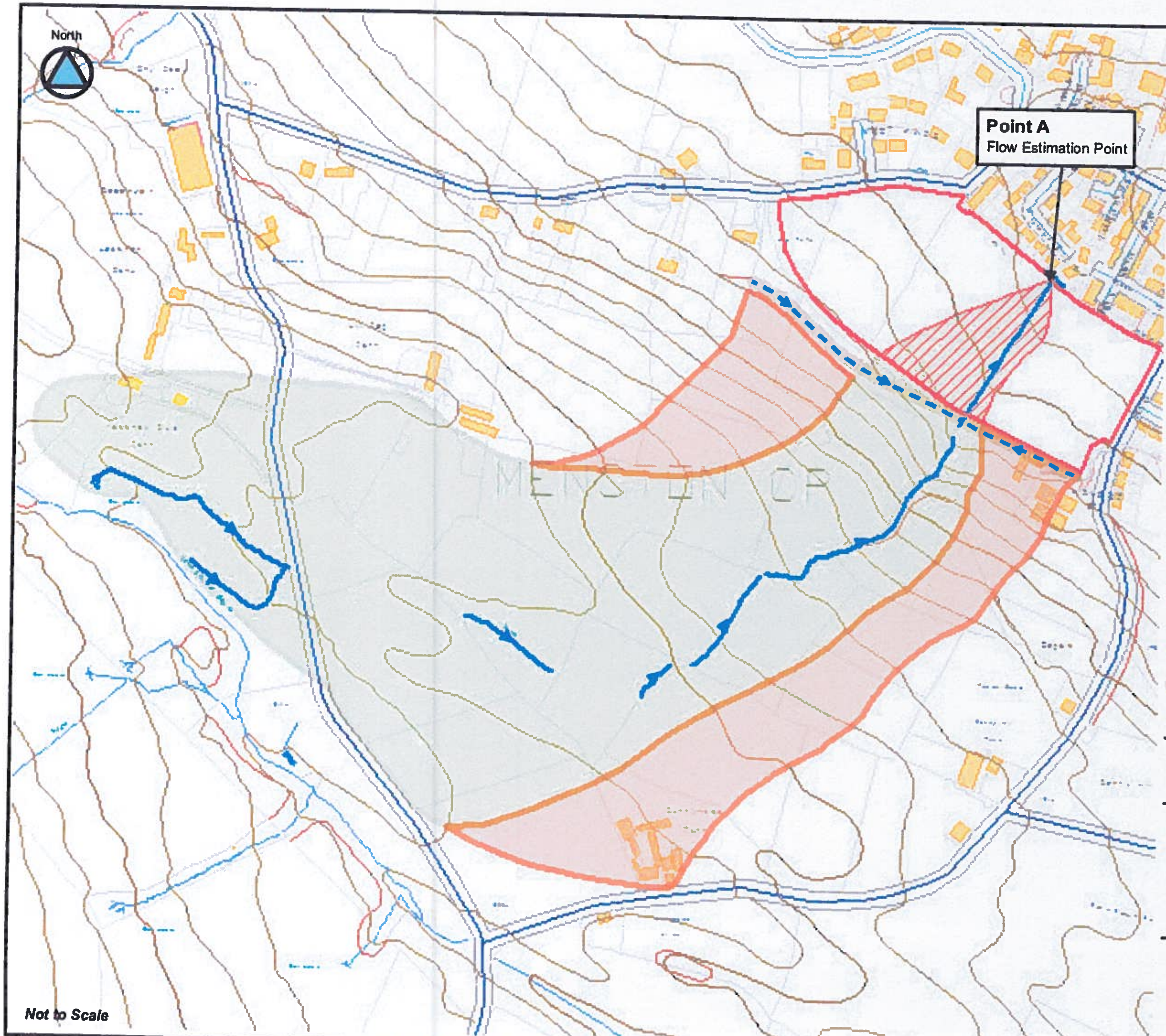
LEGEND

- Existing Open Watercourse
- Existing Culverted Watercourse
- Existing Spills
  (Will remain after development)
- Existing Spills
  (Will be prevented by development, contained within watercourse channel and will augment existing 'orange' spills)

JBA consulting

FIGURE 3

FLOWPATHS OF OVERLAND FLOODWATERS AT DERRY HILL



KEYPLAN

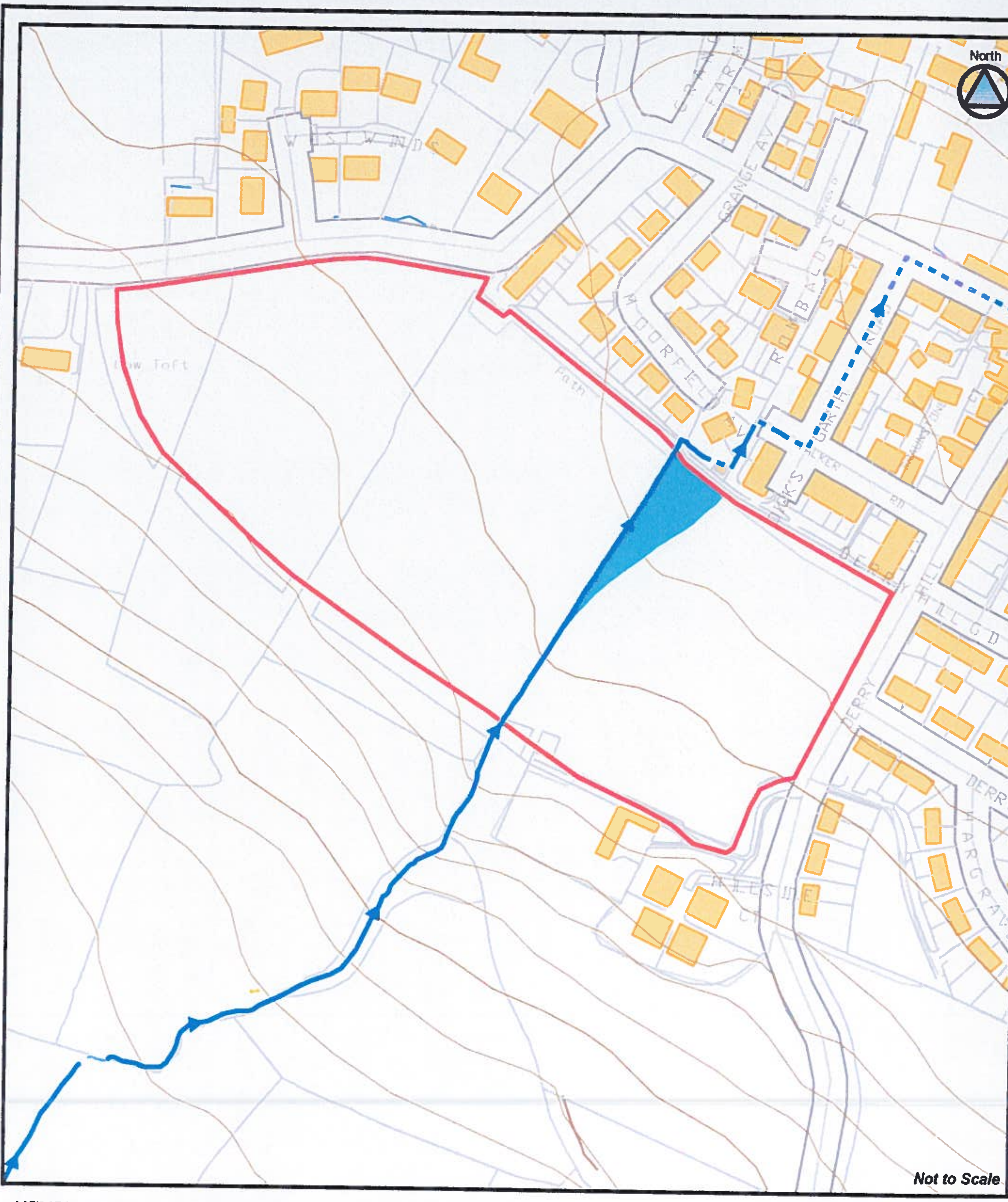
Not to Scale

LEGEND

- Development Site
- Existing Watercourse Catchment Area (23.50ha)
- Catchment Area Effectively Removed by Development Scheme (1.24ha)
- Additional Catchment Areas Captured by Proposed Swales (7.50ha)
- Swale
- Existing Open Watercourse

FIGURE 4

CATCHMENT AREAS CAPTURED BY SWALES AT DERRY HILL



KEYPLAN *Not to Scale*

LEGEND

- Development Site
- Open Watercourse
- Culverted Watercourse
- Approx Area of Floodplain within the Derry Hill Site

JBA consulting

FIGURE 5

APPROXIMATE AREA OF FLOODPLAIN WITHIN THE DERRY HILL SITE

NOTE TO FILE N004 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	17 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – September 2012

1 Purpose of note

This note summarises the results of an analysis of rainfall data from the Menston area for September 2012. Several rainfall events were recorded which exhibited different characteristics; high intensity short duration storms and a longer duration low intensity storm.

2 Rainfall datasets

No rainfall data is directly available for Menston. Therefore, sub-daily data (15-minute resolution) from the following tipping bucket raingauges were obtained under licence from the Environment Agency:

- The record from the Tipping Bucket Raingauge (TBR) at Otley Sewage Works
- The record from the Tipping Bucket Raingauge (TBR) at Silsden Reservoir

Figure 1 shows the locations of the surrounding raingauges in relation to the proposed development site and their respective elevations. Silsden Reservoir and Otley Sewage Treatment Works only have been used in this analysis.

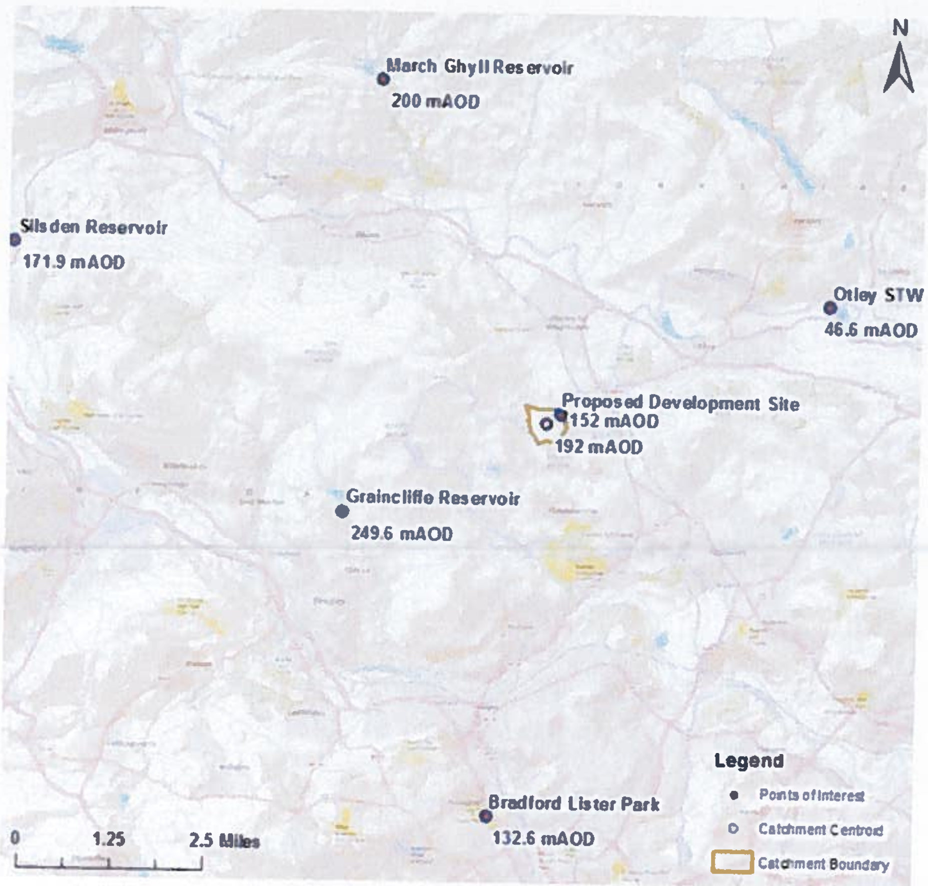


Figure 1: Raingauge and proposed development location with respective elevations. Catchment boundary with average elevation is also shown

NOTE TO FILE N004 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	17 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – September 2012

3 Rainfall rarity for September 2012

3.1 Temporal variations in rainfall

Figure 2 illustrates the temporal variations in rainfall for the longer duration event, which occurred within a 72 hour period centred on 25th September 2012. Rainfall between midday on September 23rd and midday on 26th September was prolonged but of low intensity, with 82.8mm recorded at Otley and 80.4mm at Silsden raingauge respectively. Similar rainfall durations, onset and volume add confidence to the recorded values from these sites.

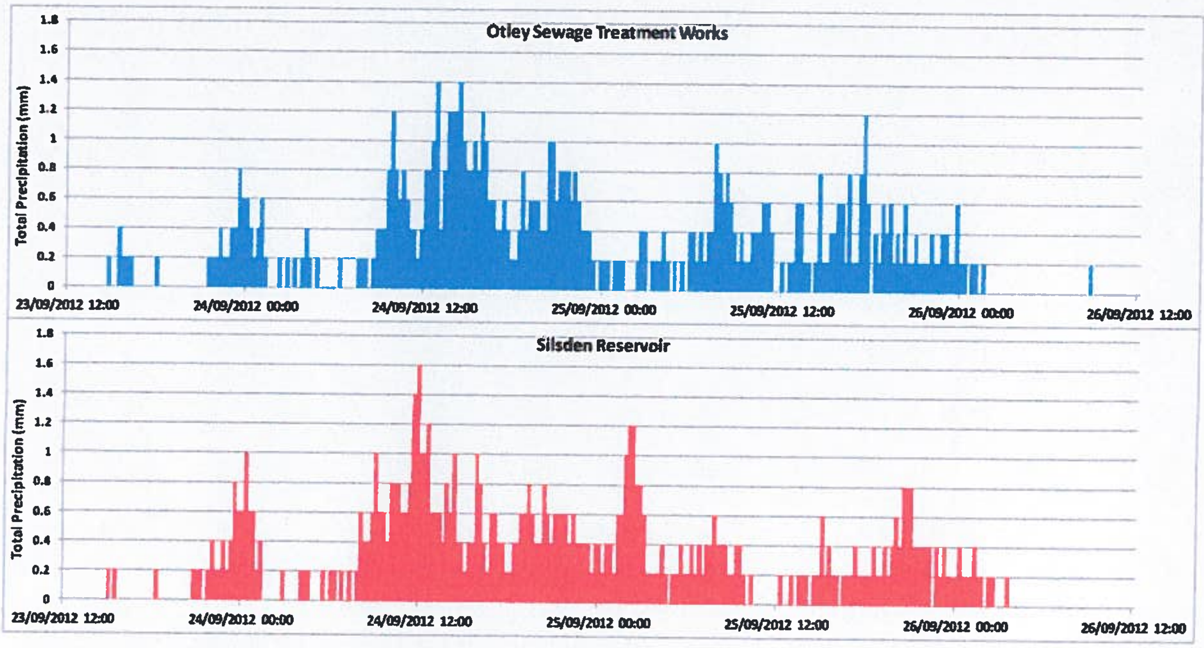


Figure 2: 15-minute interval rainfall totals for gauges at Otley Sewage Treatment Works (top) and Silsden Reservoir (bottom)

Two short duration high intensity rainfall events were recorded on September 12th and 16th respectively. These events were captured in the records at both Otley and Silsden, however the September 16th event was the most severe of the two for Otley (Figure 3) whilst the event on the 12th was the most severe at Silsden.

On September 16th, the Otley TBR captured rainfall between 15:30 and 17:15 with a mean intensity of 7mm/hour and a total precipitation of 12.2mm. On September 12th, the TBR at Silsden captured rainfall from 11:15 onwards with an average intensity of 6mm/hour and total accumulation of 15.6mm.

NOTE TO FILE N004 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	17 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – September 2012

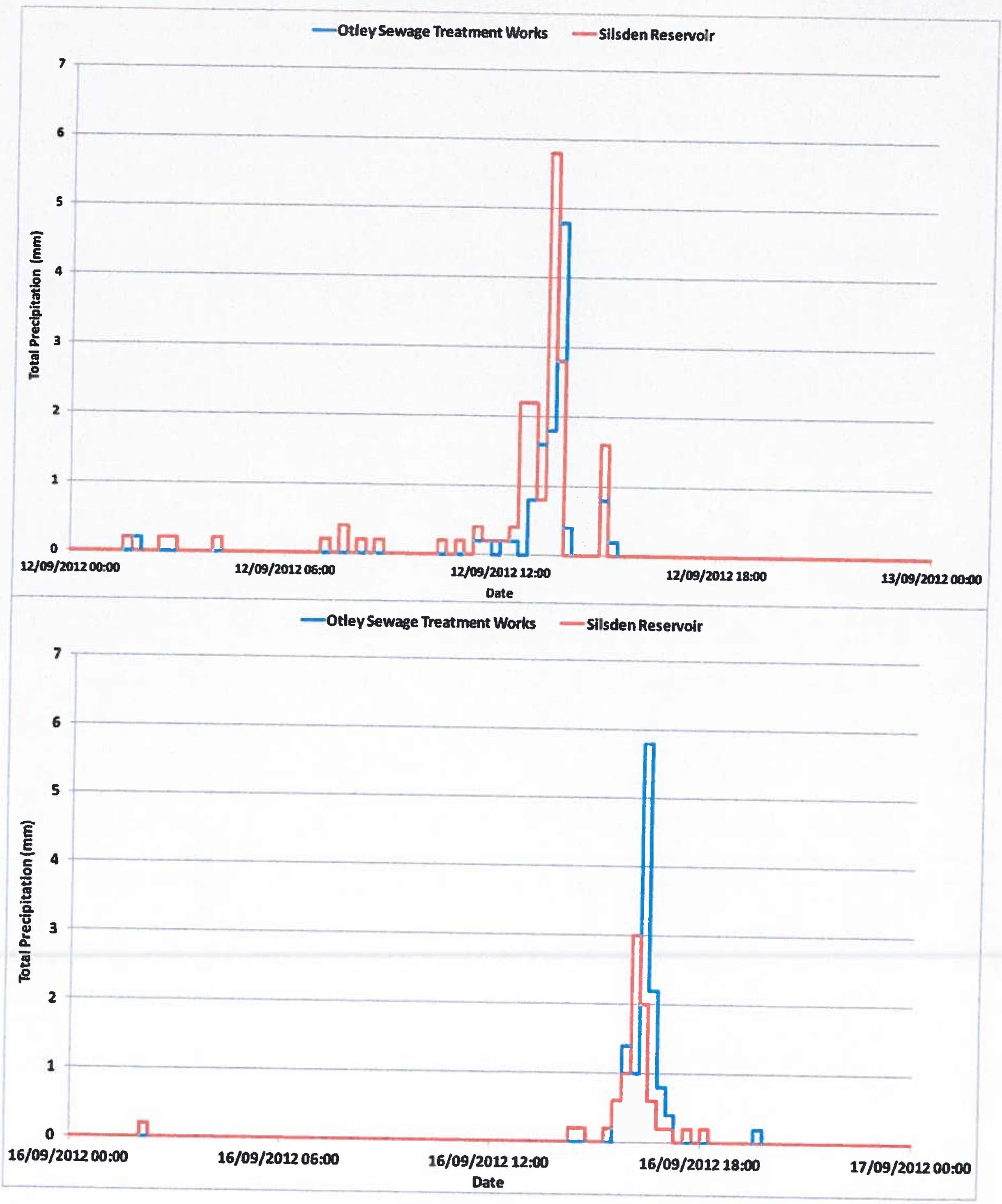


Figure 3: 15-minute interval rainfall totals for both Otley Sewage Treatment Works and Silsden Reservoir for September 12th 2012 (top) and September 16th 2012 (bottom)

NOTE TO FILE N004 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	17 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – September 2012

3.2 Depth-duration analysis

After checking the integrity of the rainfall data obtained from each TBR, a depth-duration analysis was carried out. This involved calculating the maximum depth of rainfall measured for durations ranging from 1 hour to 72 hours for the available data. A 'sliding window' approach was used; for example in the 1 hour duration case, the total rainfall between 09:00 and 10:00am, between 09:15 and 10:15am, between 09:30 and 10:30am and so forth is determined. The maximum depth for that duration is the largest of these rainfall totals.

The results of the analysis are summarised in **Table 1**.

3.3 Return period analysis

The second volume of the Flood Estimation Handbook presents equations representing the depth-duration-frequency behaviour of storm rainfall on a 1km grid resolution. When coupled with site-specific parameters of depth-duration-frequency, known as DDF (Depth, Duration, Frequency) parameters, these equations allow the frequency of occurrence to be calculated for any depth and duration of rainfall.

The specific DDF parameters for the Silsden and Otley sites were extracted from the FEH CD-Rom v3 and used with the equations to predict the return period (in years) for each of the depth-duration combinations. The results are shown in **Table 1**; durations of three hours or less at Silsden refer to the event on Sept 12th and those durations of two hours or less at Otley relate to rainfall on Sept 16th.

Table 1: Rainfall Depth-duration-frequency analysis for storm event.

Otley Sewage Works								
Event start date	16th	16th	24th	24th	24th	24th	23rd	23rd
Duration (hours)	1	2	3	6	12	24	48	72
Maximum depth (mm)	10.4	12.2	12.4	20.2	34.8	50.2	77.4	84.4
Return period (years)	1.5	1.1	1.1	1.5	3.3	4.8	10.3	10.2
Rainfall Intensity (mm/hour)	10.4	6.1	4.1	3.4	2.9	2.1	1.6	1.2
Silsden Reservoir								
Event start date	12th	12th	12th	24th	24th	24th	23rd	23rd
Duration (hours)	1	2	3	6	12	24	48	72
Maximum depth (mm)	11.6	14.6	16.0	18.8	30.6	51.6	74.4	80.4
Return period (years)	1.9	1.3	1.6	1.3	2.3	6.4	11.5	9.4
Rainfall Intensity (mm/hour)	11.6	7.3	5.3	3.1	2.6	2.2	1.6	1.1

www.jbagroup.co.uk
www.jbaconsulting.com
www.jbarisk.com
www.jbaenergy.com
www.jbatrust.org

The results indicate that the short duration events on their respective dates were not unusual. The longer duration storm is, however, more significant, giving rise to return periods of approximately 1 in 11 years at both Otley and Silsden for 48-72hr durations.

4 Spatial patterns in rainfall

Whilst the Otley gauge is the nearest sub-daily raingauge to the proposed development site in Menston, the rainfall it captures may not necessarily be representative of that at Menston. A comparison of the Standard Annual Average Rainfall (SAAR), a site characteristic extracted from the FEH CD-Rom v3, (**Table 3**) indicates that rainfall patterns at Silsden may be more representative of conditions at Menston.

Table 3: Comparison of long term rainfall measured/expected at Otley, Silsden and Menston

Standard Annual Average Rainfall (mm)		
Otley	Silsden	Menston
1298	962	922

5 Conclusions

The conclusion that may be drawn from this analysis is that, for the most severe of the short duration events experienced at Otley and Silsden on the 12th and 16th September 2012, the total accumulated rainfall was not uncommon with return periods more common than 1 in 2 years.

Similar rainfall characteristics recorded at both gauged sites between September 23rd and 26th 2012 provide a large degree of confidence in the timing and volumes of precipitation received. It is therefore likely that conditions at Menston were comparable, the volume of rainfall accumulated over the course of the event corresponding to a return period of approximately 1 in 11 years.

CALCULATION RECORD

Project Code:	201155297	**Page**	1	**of**
Project Title:	Derry Hill, Menston			
Subject:	Existing Watercourse Capacity of Channel in Site			

	Initials	Date
Designer:	DCS	15/01/13
Checker:	[signature]	25/02/13
Approver:		
Office:	Skipton	

jba

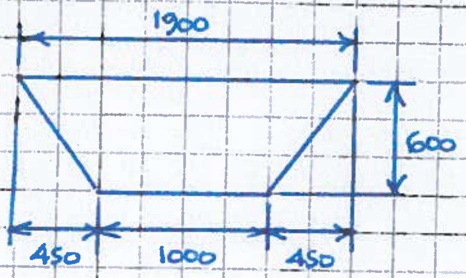
Information in Eastwood's FRA

Eastwood's FRA includes an assesment of the capacity of the existing watercourse channel within the Derry Hill site.

See extracts from Eastwood's FRA: p2 – p5.

JBA Estimate of Channel Capacity

Flow estimates were obtained using the Flowmaster Software using the same parameters as Eastwoods: p6 & p7.



Typical Cross Section

Flowmaster Sideslope $= \frac{H}{V} = \frac{450}{600} = 0.75$

Flowmaster Channel Slope $= 1:25 = 0.04$ m/m

Channel Capacity $= 1.72\ m^3/s$ (Manning's $n = 0.050$)

Channel Capacity $= 0.86\ m^3/s$ (Manning's $n = 0.10$)

Volumetric Discharge

Sheets 1.02 and 1.03 of the calculations relate to the total volume of water discharged from the site over the calculated critical storm duration, and show that for all return periods considered in excess of 1 in 1 years, the volume is reduced.

Sheets 2.00 and 2.01 of the calculations relates to the predicted volume for the developed site and estimated storage volumes required

Potential Sources of Flooding

Existing Watercourse

The existing open watercourse running through site is a potential source of flooding.

In accordance with PPS25, it is recommended that a precautionary approach is adopted in relation to proposed building floor levels, having due regard to:

- The type of development proposed (houses).
- Maintaining freeboard.
- Building levels generally and provision of adequate access/egress routes in the case of an extreme storm event.

An assessment of the maximum flow in the watercourse has been made using the Flood Studies Report FSSR16 and IOH124 for a 1 in 100 year return period, the figure obtained is 1.2m^3/sec, which becomes 1.4m^3/sec after adding 20% for the potential effects of climate change, equivalent to taking a 1 in 200 year return period.

The maximum depth of flow in the watercourse has been estimated, using the Manning formula, as being in the range 475-860mm relative to bed level, this being up to 300mm above the bank level. The likely consequence of this is some overland flow along the watercourse corridor in an extreme storm event. It is considered that the risk can be mitigated by ensuring either or both the following conditions are met:

- Floor levels set at least 1000mm above the stream bed level, at a position measured at right angles from the watercourse, --- and/or
- The ground between the stream and the properties (e.g. road, path, private drive) set at least 1000 mm above the stream bed level.

The intention is to provide a flow corridor for any overland flow due to flood routing. Freeboard will be in the range 160-500mm, which is considered acceptable given the gradient of the watercourse

201155297 Existing Watercourse - Capacity of Channel in Site 15/01/13 ③

25/02/13

EASTWOOD & PARTNERS (Consulting Engineers) Ltd.

Project: **Barratt Homes (Leeds)** **Derry Hill, Menston**		Sheet	1.00
		Job No.	30864
		Date	18/07/08
Subject: **Capacity Of Existing Watercourse** **Open Watercourse Within Site**		Designed	NJB
		Checked	
		Revision	A

Open Watercourse Within Site

Channel Flow - using Manning's Formula

		100 year	100 year +20%	
Return period for run-off from land		**100 year**	**100 year +20%**	
Estimated flow		**1200.0**	**1400.0**	litres/sec
Earth channel with poor alignment				
Manning's "n"		**0.05**		
Normal depth of flow required	*	**475**	**530**	mm
Channel width	Bottom	1000		
	Top	1900		
Assumed average for depth of flow		1450		mm
Check critical depth:				
Critical depth of flow, dc		412	456	mm
		Subcrit	*Subcrit*	
Flow area, A		0.69	0.77	m2
Velocity, V		1.74	1.82	metres/sec
		OK	*OK*	
Wetted perimeter, P		2.40	2.51	m
Hydraulic mean depth, m		0.29	0.31	m
Required gradient, i		0.0401	0.0402	
	= 1 in	25	25	
Earth channel with poor alignment and moderate weed growth				
Manning's "n"		**0.10**		
Normal depth of flow required	*	**770**	**860**	mm
Channel width	Bottom	1000		
	Top	2000		
Assumed average for depth of flow		1500		mm
Check critical depth:				
Critical depth of flow, dc		403	446	mm
		Subcrit	*Subcrit*	
Flow area, A		1.16	1.29	m2
Velocity, V		1.04	1.09	metres/sec
		OK	*OK*	
Wetted perimeter, P		3.04	3.22	m
Hydraulic mean depth, m		0.38	0.40	m
Required gradient, i		0.0392	0.0399	
	= 1 in	25	25	

* Depth of flow adjusted by trial and error to give a required gradient approximately equal to the actual gradient.

Conclusion

Worst case depth of flow for 100 year return period +20% for climate change =

	860	mm
Add freeboard of	**500**	mm
Therefore minimum FFL relative to watercouse bed level =	**1360**	mm

2011S5297 Existing Watercourse - Capacity of Channel in Site 15/01/13 (4)

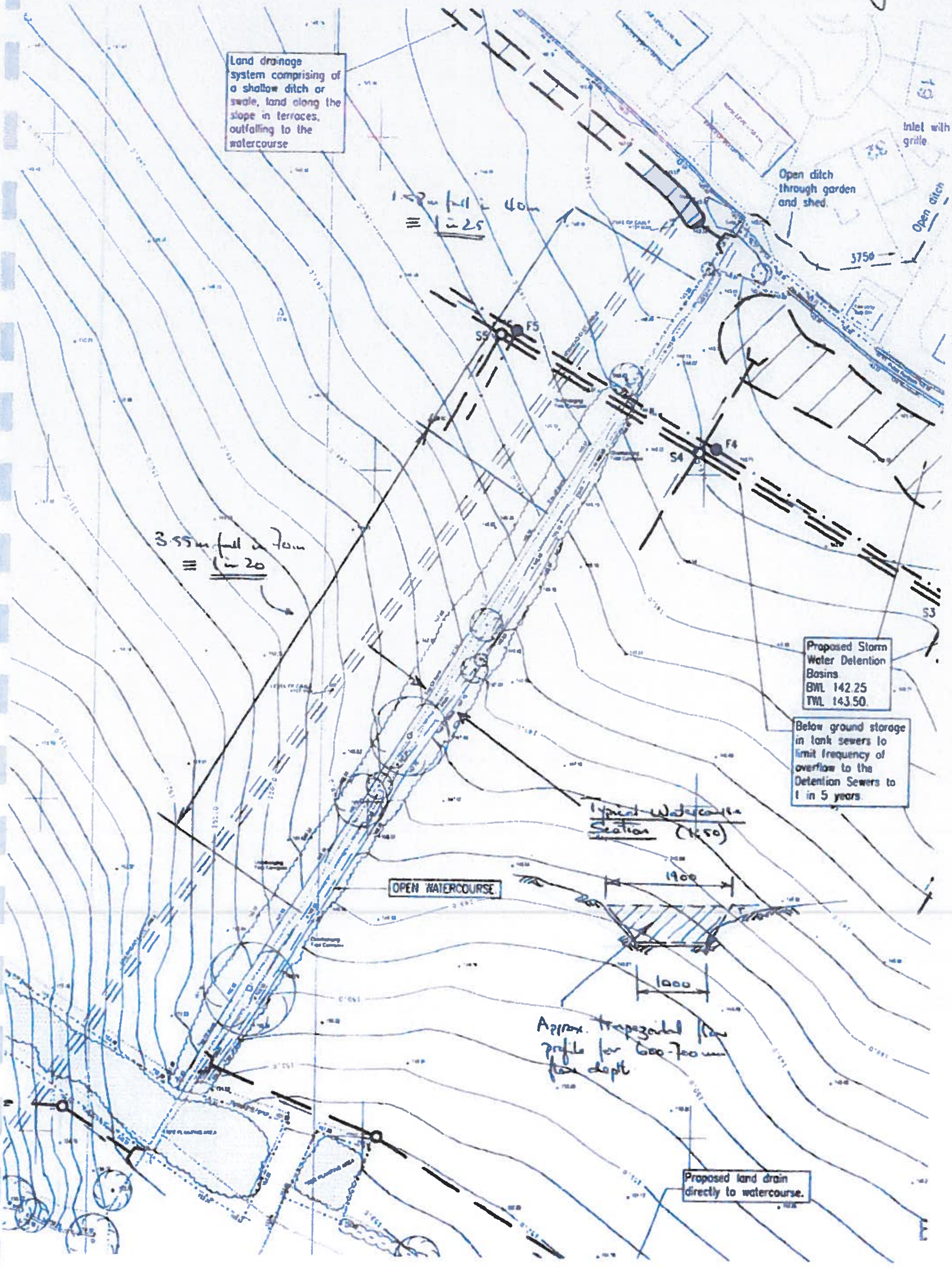
A 2 25/02/13

Suggested Manning coefficients:

Earth	Straight alignment Free from weed Stones up to 75mm	0.020	to	0.025
	Poor alignment Free from weed Stones up to 75mm	0.030	to	0.050
	Poor alignment With weeds Stones up to 75mm	0.050	to	0.150

20115S297 Existing Watercourse - Capacity of Channel in Site 15/01/2013 (5)

25/02/13



201155297 Existing Watercourse - Capacity of Channel in Site 15/01/2013 (6)

25/02/13

Existing Channel Capacity n = 0.05
Worksheet for Trapezoidal Channel

Project Description	
Project File	c:\haestad\fmw\project1.fm2
Worksheet	Existing Channel Capacity n = 0.05
Flow Element	Trapezoidal Channel
Method	Manning's Formula
Solve For	Discharge

Input Data		
Mannings Coefficient	0.050	
Channel Slope	0.040000	m/m
Depth	0.60	m
Left Side Slope	0.750000	H : V
Right Side Slope	0.750000	H : V
Bottom Width	1.00	m

Results		
Discharge	1.72	m^3/s
Flow Area	0.87	m^2
Wetted Perimeter	2.50	m
Top Width	1.90	m
Critical Depth	0.58	m
Critical Slope	0.046063	m/m
Velocity	1.98	m/s
Velocity Head	0.20	m
Specific Energy	0.80	m
Froude Number	0.93	
Flow is subcritical.		

20115297 Existing Watercourse - Capacity of Channel in Site 15/01/2013 ⑦

25/02/13

Existing Channel Capacity n = 0.10
Worksheet for Trapezoidal Channel

Project Description	
Project File	c:\haestad\fmw\project1.fm2
Worksheet	Existing Channel Capacity n = 0.10
Flow Element	Trapezoidal Channel
Method	Manning's Formula
Solve For	Discharge

Input Data		
Mannings Coefficient	0.100	
Channel Slope	0.040000	m/m
Depth	0.60	m
Left Side Slope	0.750000	H : V
Right Side Slope	0.750000	H : V
Bottom Width	1.00	m

Results		
Discharge	0.86	m³/s
Flow Area	0.87	m²
Wetted Perimeter	2.50	m
Top Width	1.90	m
Critical Depth	0.38	m
Critical Slope	0.193113	m/m
Velocity	0.99	m/s
Velocity Head	0.05	m
Specific Energy	0.65	m
Froude Number	0.47	
Flow is subcritical.		

References

(Copies available on the City of Bradford Metropolitan District Council Planning Department website)

1. Eastwood & Partners, Flood Risk and Drainage Assessment - Land off Derry Hill, Menston, Bradford, Report NJB/30864 Rev D, 23 August 2010.
2. Eastwood & Partners, Flood Risk and Drainage Assessment - Land off Bingley Road, Menston, Bradford, Report NJB/32482 Rev D, 24 November 2010.
3. Flood Estimation Handbook, Volume 1.
4. Environment Agency Flood Estimation Guidelines.

Exhibit: JDR4

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR4"

This is Exhibit "JDR4" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed...
Professor JD Rhodes
Dated: 15 March 2013

Exhibit: JDR5

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR5"

This is Exhibit "JDR5" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed...
Professor JD Rhodes
Dated: 15 March 2013

Exhibit: JDR6

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR6"

This is Exhibit "JDR6" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed...
Professor JD Rhodes
Dated: 15 March 2013

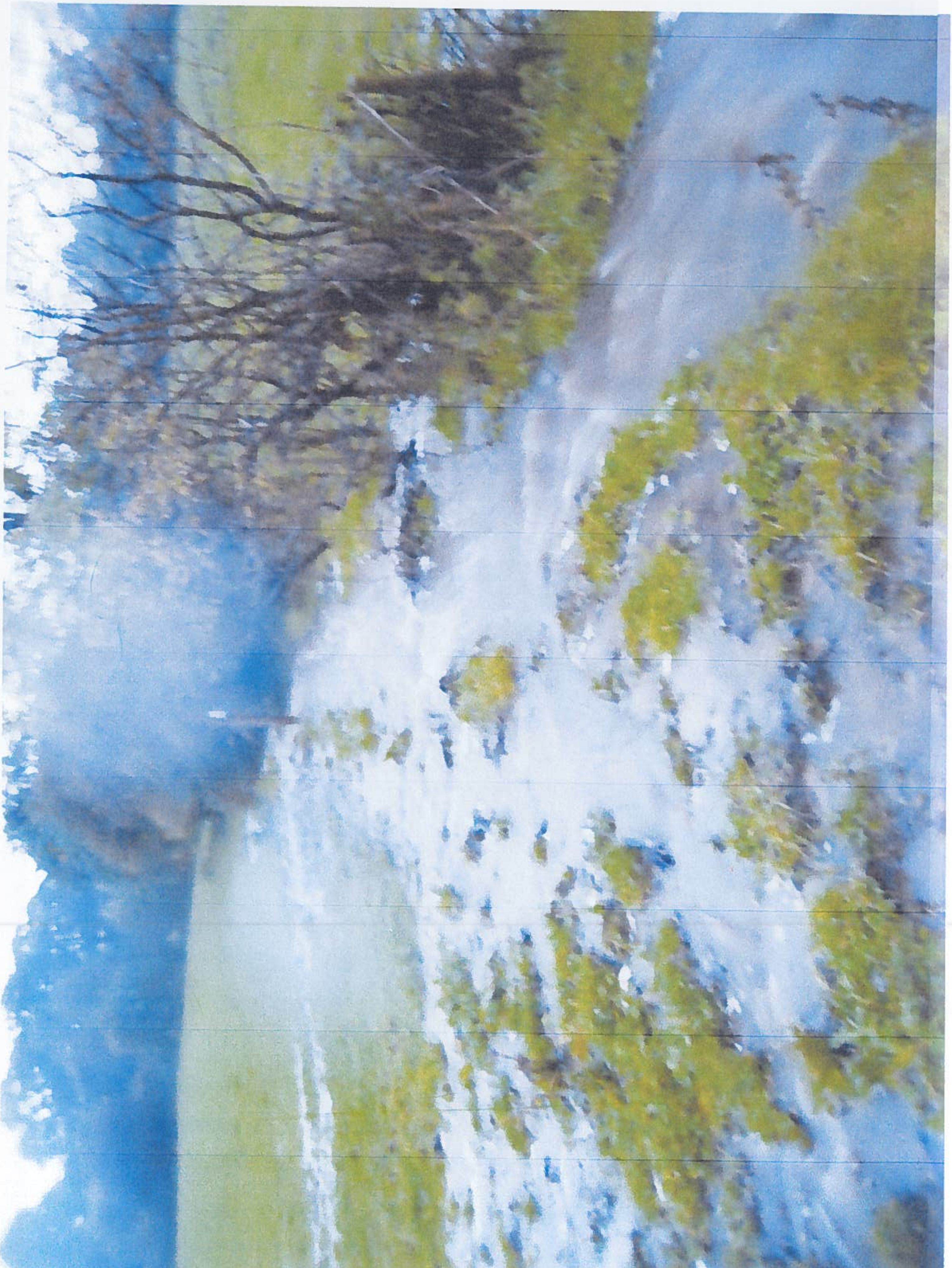


Exhibit: JDR7

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR7"

This is Exhibit "JDR7" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed..
Professor JD Rhodes
Dated: 15 March 2013

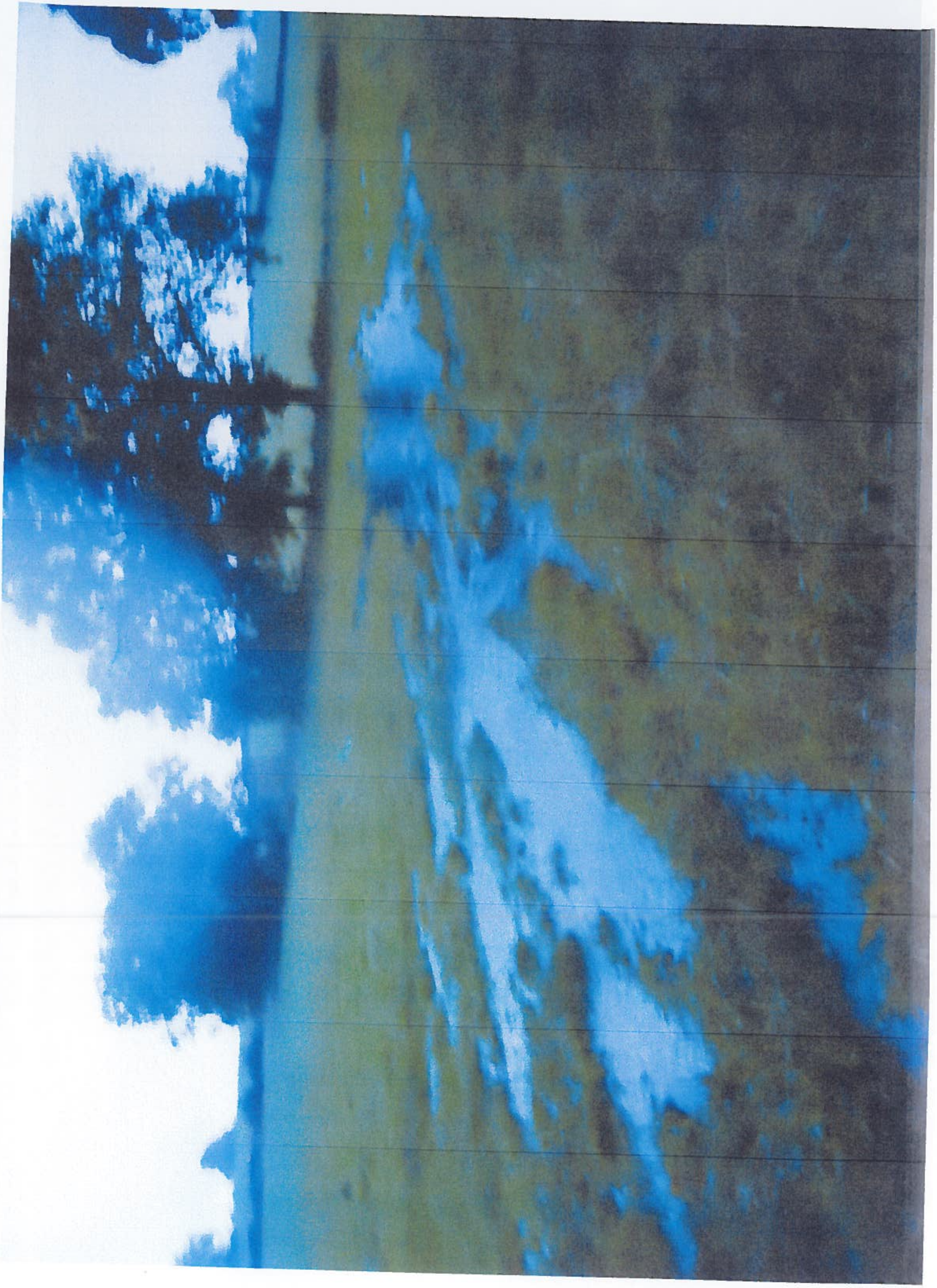


Exhibit: JDR8

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR8"

This is Exhibit "JDR8" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed...
Professor JD Rhodes
Dated: 15 March 2013

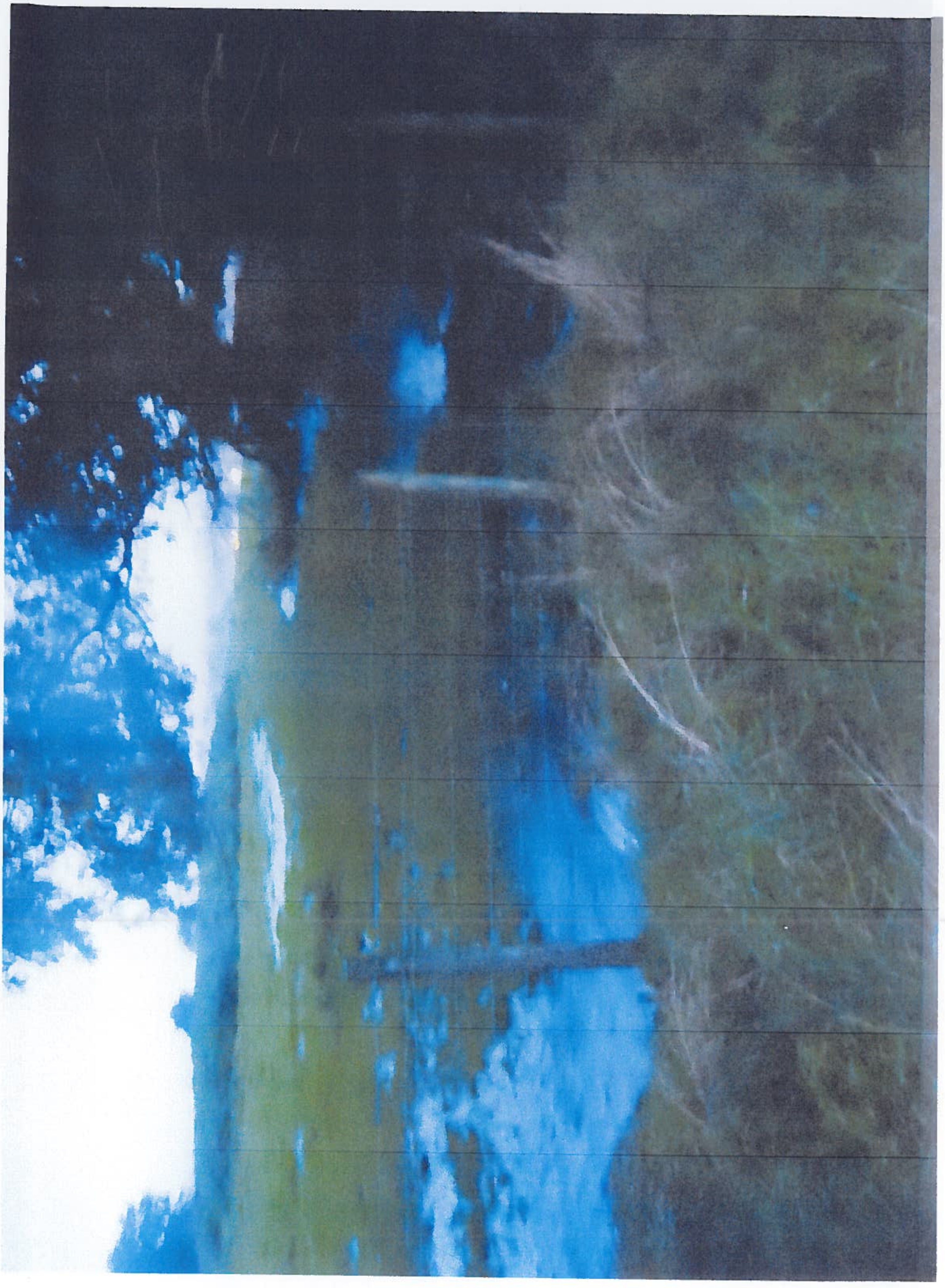


Exhibit: JDR9

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR9"

This is Exhibit "JDR9" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed...
Professor JD Rhodes
Dated: 15 March 2013

Exhibit: JDR10

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR10"

This is Exhibit "JDR10" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed..
Professor JD Rhodes
Dated: 15 March 2013

NOTE TO FILE N003 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	22 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – January 2008

JBA group

1 Purpose of note

This note summarises the results of an analysis of rainfall data from the Menston area for the period from 1 December 2007 to 31 Jan 2008. The aim of the work was to determine the rainfall return period for the event of 21 January 2008, which caused flooding to some parts of Menston.

2 Rainfall datasets

No rainfall data is directly available for Menston. Therefore, sub-daily data from nearby tipping bucket raingauges at Otley Sewage Treatment Works and Silsden Reservoir were sought. Additional daily rainfall data from around the district was also sought, this being used to investigate spatial variability in rainfall over the period of interest and to determine how representative the rainfall records for Otley and Silsden might be of conditions at Menston. **Figure 1** shows the locations of the respective raingauges in relation to the proposed development site and their respective elevations.

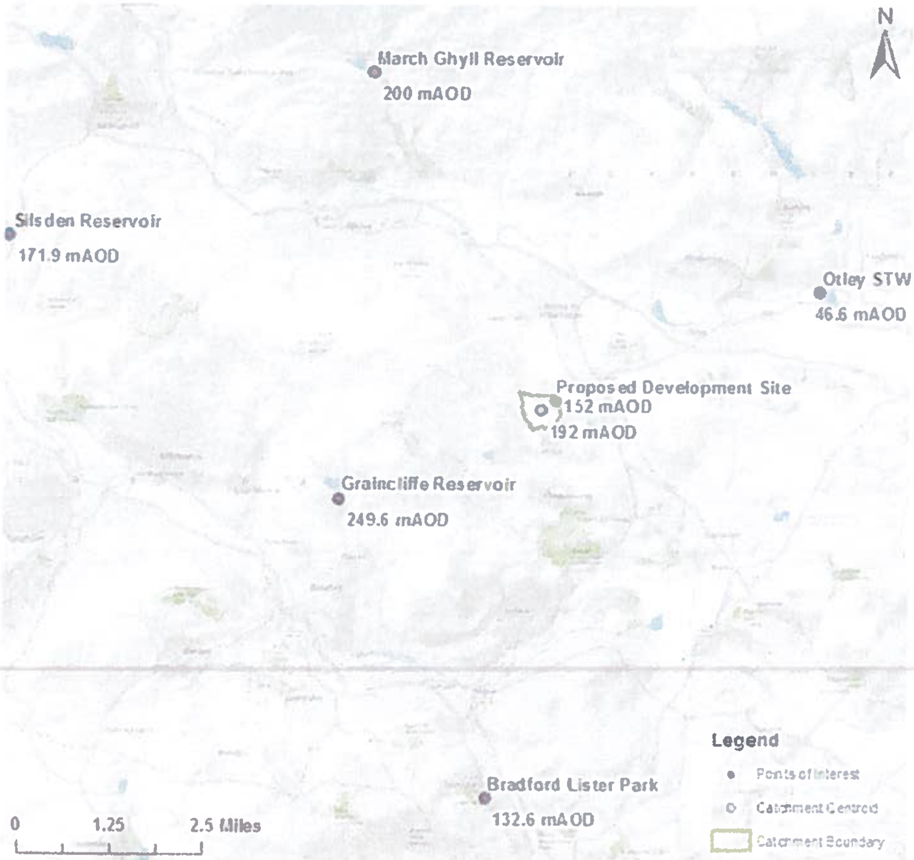


Figure 1: Raingauge and proposed development location with respective elevations. Catchment boundary with average elevation is also shown

NOTE TO FILE N003 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	22 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – January 2008

The following rainfall datasets were therefore obtained under license from the Environment Agency.

<u>15-minute resolution data</u>

- The record from the Tipping Bucket Raingauge (TBR) at Otley Sewage Works
- The record from the Tipping Bucket Raingauge (TBR) at Silsden Reservoir

The associated daily/monthly rainfall records for these sites were also obtained.

<u>Daily resolution data</u>

- The record from March Ghyll daily raingauge, Ilkley
- The record from Graincliffe daily raingauge, Bingley
- The record from Bradford Lister Park raingauge

Note that a daily gauge records the rainfall that has fallen over a 24 hour period starting at 09:00 GMT each day.

3 Rainfall rarity for 21 January 2008

3.1 Temporal variations in rainfall

Figure 2 illustrates the temporal variations over a 48 hour period centred on 21st January 2008. As can be seen, rainfall commences in the early hours of January 21st at approximately 02:00 and continued until 21:00 that evening. The rain gauge at Otley recorded some rainfall for approximately 14.5 hours with dry spells accounting for 4.5 hours, or ~24% of the total time. A similar proportion of time can be attributed as raining at the Silsden gauge, ~67%.

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	22 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – January 2008

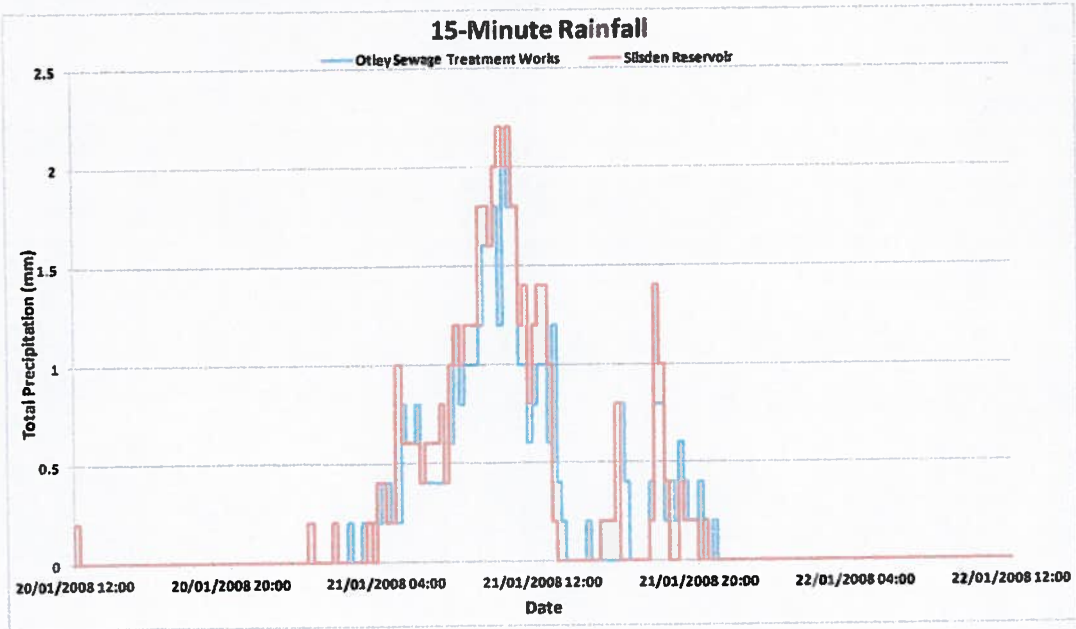


Figure 2: 15-minute interval rainfall totals for gauges at Otley Sewage Treatment Works and Silsden Reservoir

3.2 Depth-duration analysis

After checking the integrity of the rainfall data obtained from each TBR, a depth-duration analysis was carried out. This involved calculating the maximum depth of rainfall measured for durations ranging from 1 hour to 24 hours. A 'sliding window' approach was used; for example in the 1 hour duration case, the total rainfall between 09:00 and 10:00am, between 09:15 and 10:15am, between 09:30 and 10:30am and so forth is determined. The maximum depth for that duration is the largest of these rainfall totals.

The results of the analysis are summarised in **Table 1**. The rainfall totals calculated indicate that the event on the 21st January was a relatively modest storm.

3.3 Return period analysis

The second volume of the Flood Estimation Handbook presents equations representing the depth-duration-frequency behaviour of storm rainfall on a 1km grid resolution. When coupled with site-specific parameters of depth-duration-frequency, known as DDF (Depth, Duration, Frequency) parameters, these equations allow the frequency of occurrence to be calculated for any depth and duration of rainfall.

The specific DDF parameters for the Silsden and Otley sites were extracted from the FEH CD-Rom v3 and used with the equations to predict the return period (in years) for each of the depth-duration combinations. The results are shown in **Table 1**.

NOTE TO FILE N003 (VERSION 3)

JBA Project Code	2011s5297
Contract	Drainage Advice on Planning Applications at Bingley Road & Derry Hill, Menston
Client	David Rhodes
Day, Date and Time	22 October 2012
Author	Maxine Zaidman & Andrew Peacock
Subject	Rainfall data analysis – January 2008

Table 1: Rainfall Depth-duration-frequency analysis for storm event

Otley Sewage Works								
Duration (hours)	1	2	3	6	12	18	24	36
Maximum depth (mm)	6.8	13.0	17.0	26.6	33.6	39.6	40.0	40.0
Return period (years)	1.0	1.1	1.8	3.0	2.9	3.0	2.1	1.3
Rainfall Intensity (mm/hour)	6.8	6.5	5.7	4.4	2.8	2.2	1.7	1.1
Silsden Reservoir								
Duration (hours)	1	2	3	6	12	18	24	36
Maximum depth (mm)	8.4	15.4	20.4	32.4	39.4	44.6	45	45.2
Return period (years)	1.1	1.5	3.00	6.3	5.7	5.3	3.70	2.2
Rainfall Intensity (mm/hour)	8.4	7.7	6.8	5.4	3.3	2.5	1.9	1.3

The results indicate that the rainfall on the day in question (21st January 2008) was significant only for durations of around 12 hours, giving rise to return periods of around 3 years at Otley, and 6 years in Silsden.

4 Rainfall rarity over antecedent period

As both the Otley and Silsden TBRs recorded monthly rainfall totals that were much higher than average in January 2008, a depth-duration analysis was carried out based on longer durations and using data from 1 Dec 2007 to 31 Jan 2008 inclusively. The results are shown in **Table 2**.

Table 2: Rainfall Depth-duration-frequency analysis for antecedent conditions

Otley Sewage Works				
Duration (days)	1	3	7	14
Maximum depth (mm)	40.0	50.6	95.4	133.0
Return period (years)	2.0	1.3	7.2	21.0

Silsden Reservoir				
Duration (hours)	1	3	7	14
Maximum depth (mm)	45.0	61.6	104.4	148.2
Return period (years)	3.70	2.79	9.7	23.4

The analysis indicates that the antecedent conditions prior to January 21st 2008 were saturation as a result of prolonged rainfall. This is highlighted by the 'wettest' 14 day period within the Dec-Jan records at both Otley and Silsden occurring between the 7th and 21st January 2008. These depths of rainfall equate to return periods in Otley and Silsden of 21 and 23 years respectively. Similarly, the wettest single week was between the 14th and 21st January 2008 and the wettest three days were between January 18th and January 21st 2008.

5 Spatial patterns in rainfall

Whilst the Otley gauge is the nearest sub-daily raingauge to the proposed development site in Menston, the rainfall it captures may not necessarily be representative of that at Menston. Due to its lower elevation (46.6 mAOD) it is likely to capture less rainfall than seen at the development site (~152 mAOD) and within the catchment itself, which has an average elevation of 192mAOD. Furthermore, rainfall generally comes in from a westerly direction which also suggests that Otley may receive less rainfall being more to the east of the region.

Analysis of monthly rainfall totals (**Table 3**) confirms that Otley received slightly lower rainfall than other nearby gauges, e.g. it received approximately 30mm less rainfall in January 2008 than neighbouring sites. We would expect the rainfall received at Menston to be closer to that at Silsden than that recorded at Otley.

Table 3: Rainfall Depth-duration-frequency analysis for antecedent conditions

Monthly rainfall accumulations (mm)				
	Otley	Graincliffe	Silsden	Bradford
December 2007	82.4	101.2	114.2	102.3
January 2008	179.8	209.47	209.4	214.4

6 Conclusions

The conclusion that may be drawn from this analysis is that the rainfall event on January 21st 2008 was not a rare event in itself (a rainfall return period between 1 in 3 years and 1 in 6 years), but followed a longer wet spell of return period of 1 in 20 years.

Exhibit: JDR11

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR11"

This is Exhibit "JDR11" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed..
Professor JD Rhodes
Dated: 15 March 2013

Exhibit: JDR12

Date: 15 March 2013

Reference App/W4705/A/11/2167397

Town and Country Planning Act 1990

Appeal by Taylor Wimpey North Yorkshire

Site at Land at the North of Bingley Road, Menston

EXHIBIT "JDR12"

This is Exhibit "JDR12" referred to in the witness statement of Professor JD Rhodes dated 15 March 2013.

Signed...[signature]...
Professor JD Rhodes
Dated: 15 March 2013

Watercourse Flow Calculations
29 November 2012

6.3 GROWTH FACTORS

Return Period	Growth Factors			
	FEH Stat	ReFH	IH 124	Average Growth Factors
2	1.00	1.00	0.94	
5	1.38	1.42	1.24	1.35
10	1.67	1.76	1.45	1.63
25	2.08	2.25	1.70	
50	2.46	2.70	1.89	
100	2.88	3.25	2.08	2.74
150	3.17	3.64	2.19	