Independent review of Menston flooding problems

Dr Duncan W Reed

11 December 2014

(This page is intentionally blank.)

Executive summary

The extent of flooding problems has been a source of dispute at Menston in connection with planned development of Greenfield sites labelled Bingley Road and Derry Hill. At a late hour, an independent external opinion has been sought. This report presents that opinion.

The developers have relied on generalised methods of flood estimation that are widely but wrongly applied to such sites. There is always specific local information about drainage and flooding. An important factor neglected in this case is the prevalence of springs and responsive groundwater from the Millstone Grit aquifer underlying the hillside on which Menston sits. The areal extent of the topographic catchment draining to Derry Hill has also been underestimated.

The hillside on which Menston sits can be summarised as hummocky. It is drained by a number of small streams. Some of these are seasonal, with flows only occurring in wet weather and/or when groundwater levels are unusually high.

The progressive migration of Menston village up the hillside has led to problems previously. Because there is no dominant stream, each has in turn been culverted, diverted into sewer systems or obstructed by development. Some defiles lacking a permanent watercourse have been filled in: overlooking that these may be routes taken by floodwater in exceptional conditions.

These problems are heightened by the unique setting of Menston. The most unusual feature is the transverse drainage of Matthew Dike. This watercourse cuts off stream flow from Reva Hill, and guides it eastwards towards Mire Beck. Were Matthew Dike absent, there would be larger streams in Menston of the kind evident in Burley in Wharfedale: streams that are less easy to culvert or neglect.

It transpires that upper sections of Matthew Dike overflow into the Derry Hill catchment in major flood events such as that of 24 September 2012. Thus the effective catchment to Derry Hill (and to the culvert behind Dick's Garth Road) – which was already underestimated – is increased further in major floods.

A second unusual feature arises from the siting of the huge asylum at High Royds in 1888. My report refers to this chiefly as High Royds Hospital (HRH). HRH was designed to be as self-sufficient as possible, and the availability of a strong source of groundwater was a key asset. The groundwater abstraction at the HRH Pump House continued throughout the lifetime of HRH. The abstraction ceased on closure of the hospital in 2003.

Extension of Menston village southwards has mainly taken place in an era where spring flows were being suppressed by this major abstraction. The spring flows are no longer suppressed and groundwater levels are now typically higher. Agricultural (and other) lands on the hillslope are now typically wetter than previously. The Bingley Road development lies within the area where typical groundwater levels can be expected to be appreciably higher than during the lifetime of HRH.

The report explores these and other features. The penultimate chapter tentatively considers some actions that might make the Bingley Road and Derry Hill sites less flood-prone.

(This page is intentionally blank.)

Contents

Maps

Figures

Boxes

Abbreviations and descriptor names

ADAS	Agricultural Development and Advisory Service (previously part of MAFF)
AEP	Annual exceedance probability
AM	Annual maximum
AOD	Above ordnance datum (i.e. above sea level)
AREA	Catchment area (km^2)
BFI	Baseflow index
BFIHOST	Baseflow index derived from HOST soils data (a UK descriptor)
BHS	British Hydrological Society
CBMDC	City of Bradford MDC
CEH	Centre for Ecology & Hydrology
CIRIA	Construction Industry Research and Information Association
CS	Chris Schofield
CV	Curriculum vitae
CWI	Catchment wetness index
DANI	Department of Agriculture for Northern Ireland
Defra	Department for Environment, Food & Rural Affairs
EA	Environment Agency
EEC	European Economic Community
FEH	Flood Estimation Handbook
FMCD	First [year] of machined climate data
FRM	Flood risk management
FSR	Flood Studies Report
FSSR	Flood Studies Supplementary Report
FY	First year
GD	Gladedale
g.p.hr	Gallons per hour [1 gallon = 4.546 litres]
HEI	Higher education institution
HOST	Hydrology Of Soil Type
HR	Hydraulics Research
HRH	High Royds Hospital (= former Menston Asylum)
IH	Institute of Hydrology
IOH	Institute of Hydrology
ISO	Inflow-Storage-Outflow
JDR	J David Rhodes
l	litre
LH	Left hand
LCC	Leeds City Council
LSA	Linear systems analysis
LY	Last year
MAFF	Ministry of Agriculture Fisheries and Food (predecessor to Defra)
MDC	Metropolitan District Council
m.g.d.	Million gallons per day [1 gallon = 4.546 litres]
Ml	Megalitre, i.e. a million litres
MLURI	Macauley Land Use Research Institute
NERC	Natural Environment Research Council
NGR	National grid reference
OS	Ordnance Survey
QBAR	Denotes mean AM flood
QMED	Denotes median AM flood
R&D	Research & development
Resr	Reservoir
RH	Right hand
RSSB	Rail Safety and Standards Board

SAAR	Standard-period average annual rainfall (mm)
SHLAA	Strategic Housing Land Availability Assessment
SPD	Supplementary Planning Document
SPR	Standard percentage runoff
SSLRC	Soil Survey and Land Research Centre
UH	Unit hydrograph
UK	United Kingdom
URBEXT	Proportional extent of catchment area mapped as urbanised
WMO	World Meteorological Organization
WRAP	Winter Rain Acceptance Potential (a classification of soils and slopes)
WTW	Water Treatment Works
WYAS	West Yorkshire Archive Service
YW	Yorkshire Water

Glossary

Term	Meaning
Annual exceedance probability AEP	Probability of one or more exceedances in a year of a given extreme value
Annual maximum flow series	Time series comprising the largest flow in each year or water-year of record (see Appendix E2)
Easting and Northing	Coordinates of a location expressed as distance eastwards and distance northwards from a fixed reference point
Essentially rural (catchment)	Catchment for which the proportional extent mapped as urbanised (in FEH descriptor URBEXT) is less than 0.025
Hydrogeology	The science, technology and management of underground water and its emergence
Hydrometry	The science, technology and practice of water measurement (see Appendix E1)
Index flood	A reference flood that can be relatively reliably estimated from gauged data; the index flood adopted in the FEH is the median annual flood QMED; this is the median of the annual maximum (AM) flow series.
Interpolation	Any method of computing new data points from a set of existing data points
Median annual flood QMED	QMED is the median of the annual maximum (AM) series. Half of AM floods are larger than QMED and half are smaller; thus, the annual exceedance probability associated with QMED is precisely 0.5; QMED is said to have a return period of two years on the AM scale of frequency
Return period T	Average number of years between years with floods exceeding a certain value. T is the inverse of the annual exceedance probability; thus, a 50-year return period corresponds to an AEP of 0.02. See Appendix E3.
Standard-period average annual rainfall SAAR	Standard-period average annual rainfall, i.e. annual average rainfall evaluated across a WMO standard period; in FEH usage, SAAR relates to 1961-90.
Subject catchment	Catchment for which the flood estimate is required
Water-year	Hydrological year beginning 1 October and ending 30 September

(This page is intentionally blank.)

1 Introduction

1.1 Disclaimer

I undertake all work personally. Please note that I do not have Professional Indemnity Insurance. I judge that premium rates for a self-employed sole-trader working in flood risk are unaffordably high for a meaningful degree of cover. I protect myself by applying due care and attention, and sometimes by explicit disclaimer. You should endeavour to protect yourself from the consequences of accepting, neglecting or misconstruing my advice.

1.2 Why we estimate flood frequency

Flood frequency analysis is concerned with the assessment of flood magnitudes of stated frequency (or degree of rarity) for use as input into the process of flood risk assessment and management. Flood risk assessment is needed in the design of flood alleviation works and in the assessment of the safety of existing and planned infrastructure. This includes domestic properties, commercial and industrial buildings, bridges, roads and railways, and critical infrastructure such as hospitals, electrical stations, gas stations and water works.

No development can be guaranteed immune from flooding during its projected life. Flood-proofing every structure would be prohibitively costly. As a result, developments for which the consequences and costs are modest may be required to tolerate occasional flooding. Assessment of the residual risk requires estimation of the probability of occurrence of the flood magnitude that would inundate or damage the structure or infrastructure. It is these probabilities that are estimated with the help of flood frequency analysis.

2 Context

2.1 Experience

Appendix A provides a miniature CV. I led the research team that developed the UK Flood Estimation Handbook. Published in 1999, the FEH revolutionised methods of flood estimation in the UK, and was the first study in any nation to present practitioners with generalised methods of flood estimation based on digital catchment data.

I resigned a senior management post at CEH Wallingford in 2001 and went into practice as a self-employed sole-trader (DWRconsult) specialising in flood research and consultancy. While I have not directly contributed to further development of the FEH, I have for many years acted as technical advisor to the Office of Public Works in planning, developing, editing and implementing the Irish Flood Studies Update. I completed my work in July 2014.

Expertise directly relevant to this independent review is reflected in my 1987 conference paper *Engaged on the ungauged* (Reed, 1987) and my 2002 Royal Society paper on *Reinforcing flood-risk estimation* (Reed, 2002). These papers proselytise how local information (historical and physical) can and should be used to improve or reinforce flood estimates otherwise based on generalised methods.

2.2 Personal interest in Menston

The following notes summarise the extent of my interests in Menston and West Yorkshire:

- I was born in Bramley and brought up in Pudsey: attending Leeds Grammar School from 1962-68 as a West Riding County Council scholar. The Chief Education Officer at the time was A. B. Clegg. I knew of Menston only by hearsay.

- My mother hails from Sowerby Bridge. I have relatives in Birstwith and Harrogate, but none now in West Yorkshire.

- I have no contacts in West Yorkshire beyond a few elderly friends of my mother and a few professional contacts in the Leeds office of major consultants. My principal studies for Leeds-based consultants have been of river flood risk in Edinburgh (2002), York (2003) and Louth (2008), and of rainfall frequency estimation in Jeddah (2012). So far as I am aware, none of these contacts has any connection with Menston.

- I have one personal interest in Menston:

    - Since 1993, I have lived in Cholsey near Wallingford, South Oxfordshire;
    - My work has been based there since becoming self-employed in 2001;
    - Prior to 1974, Cholsey was in Berkshire;
    - The Berkshire Lunatic Asylum was opened in Cholsey in 1870, in part influenced by the arrival of the Great Western Railway some decades earlier.
    - The village rapidly grew in consequence.
    - Rebadged as Fairmile Hospital, the Asylum was run down in the early 2000s and the site sold off for redevelopment;
    - The Cholsey asylum site was (and is) roughly a third the size of the equivalent site in Menston; the current Cholsey population is about a third of the Menston population;
    - Parallels and differences between Cholsey and Menston intrigue me.

2.3 Past work with a West Yorkshire connection

- While employed by CEH Wallingford, I took a close interest in a colleague's investigation of the extreme Calderdale storm of 19 May 1989.

- Working in 2003 through JBA Consulting of Skipton, I reviewed hydrological conditions associated with 30 historic railway-bridge failures for the Rail Safety and Standards Board (RSSB). The incidents investigated included the 16 November 1866 railway-bridge failure on the Aire at Apperley Bridge failure, and railway-bridge failures on the Calder at Horbury in 1918 and 1920. I judged the Apperley Bridge failure to have been induced by a relatively rare flood. My report to RSSB identified a further ten incidents not in the supplied list. One of these arose from the exceptional Ilkley storm of 12 July 1900. This is listed here in the Menston flood chronology presented as Appendix G.

- Also in 2003, I undertook a special matched appraisal of Ouse at York flood events for the Environment Agency, working through the then Bradford Office of Bullen

Consultants (now part of AECOM). I examined the meteorological signature in time and space of the 19 largest floods at York in the period 1881 to 2000. [Although Wharfedale falls just outside the Ouse at York catchment, rainfall records were consulted and indicated that conditions in the 10 March 1881 and 22 January 1899 floods were exceptionally severe in Upper Wharfedale.] With only one exception, the relative sizes of the floods at York were found to be consistent with the meteorological conditions experienced, once due account was taken of the many factors. Only the November 1951 Ouse flood was larger than expected from the meteorological conditions. Further reference to *British Rainfall 1951* revealed that the flood attracted particular comment at the time for much the same reason, i.e. that flood runoff was surprisingly intense. The event struck many rivers, with both the Ouse and the Severn seriously affected. One hypothesis is that – in the exceptional post-war drive to increase agricultural productivity – field drainage works may have aggravated flood responses for a period. Alternatively, the antecedent conditions or the temporal sequence of rainfall in November 1951 may have been uniquely exceptional. Importantly, the special matched appraisal of Ouse at York flood events found no evidence that recent floods were any higher than might be expected from the meteorological conditions experienced.

2.4 How I came to be involved in Menston

I do not advertise for work, and rarely join any bidding process. I wait for work to reach me by personal recommendation. In 13 years as an independent, I have joined only three substantial disputes:

- For a developer appealing the refusal of planning permission. [The Inspector found that the Environment Agency's Lower Thames model had been unacceptably neglectful of long-term water-level records.]
- To assist in the adjudication of a wet-weather compensation claim. [The Contract had set the bar to claims unacceptably high by specifying a reference site for rainfall measurement that was much wetter than the actual site.]
- Acting as a "second expert" in one phase of a legal dispute related to a highly damaging flood in Ireland.

I make it a rule never to join a dispute unless there is already a substantial professional report that one party is unhappy with. I will then review the report and make recommendations for further work.

Circumstances in this instance were somewhat different. The dispute at Menston is at an advanced stage, with quite a number of reports. However, few of these use local data to investigate and strengthen the flood estimates and designs made using highly generalised (and intrinsically weak) methods. The flooding witnessed and photographed on 24 September provided valuable evidence. However, the event had been analysed by Prof J David Rhodes (JDR) in a non-standard though imaginative way. Other parties had tried to assist but I was approached as someone who might be able to provide rigorous criticism of the JDR methods of rainfall-runoff assessment.

For the avoidance of doubt, I attach my feedback letter to JDR (see Appendix B). I was irritated by his method and notation, and judged it preposterous that one should attempt to apply a new twist on linear systems analysis without having paired rainfall and flow data for the subject catchment at Derry Hill. Before dismissing his method as misguided, I had to learn something of the context of the flooding problems at Menston. While I only charged for the feedback on his methods, I attached an additional set of "Notes and remarks on the Menston flooding problem" specifically watermarked "Do not cite; personal use only". This first phase of my involvement ran from 22 August to 12 September 2014 and was a desk study only. I did not meet JDR and had no contact with or knowledge of Chris Schofield (CS).

My impression was that it was far too late for me to influence planning outcomes. Thus, it was a surprise when I was approached by CS on Tuesday 21 October to provide an independent expert review to be submitted to City of Bradford MDC.

2.5 Why I agreed to take the review on

From material I had then seen, I suspected a fundamental problem with further upslope expansion of Menston village to the south. The requirement for new development not to worsen existing flooding problems (except in exceptionally rare events) can itself be a considerable challenge to meet. But there is also the requirement to ensure that new development is not itself unduly vulnerable to flooding.

Maps of flood risk published by the Environment Agency can provide an adequate representation of flood risk along the main river system, without necessarily doing so for small watercourses within the district. It is unwise to rely on generalised methods alone when planning major developments on small catchments, and foolish to ignore specific evidence of flooding problems and/or of unusual catchment features.

2.6 Proposed work

For the record, and to neutralise conjecture, I attach my proposal of 24 October 2014 in full as Appendix C. The text is unaltered but the numbering of sections and subsections has changed to fit the style of appendices in this review report. The proposal was accepted by CS without amendment on 27 October.

2.7 Approach taken to maintain independence

I started the six-week study on 28 October and visited Menston by train the next day for a preliminary reconnaissance and to be handed additional documentation. JDR guided me round the study area. At my request, we called in at Matthew Dike Farm. The contact made allowed me to traverse their land during my main site visit on 25-28 November.

I have not met CS, nor met JDR a second time. CS sent me some additional papers received from CBMDC. These reached me on 22 November. There comes a point when there is no longer time to read, digest and evaluate all information found or made available. Thus, I have made only limited use of this additional material.

Having agreed to take on the independent review, I have initiated contact with JDR and CS only by email. Email is my preferred medium of contact in all studies. In this instance, it also helps to ensure that the extent of my contacts can be tracked.

I emailed CS to report a persistent health problem and a glaring factual error in the statutory planning notices displayed at the Derry Hill site. The Northing of the grid reference cited is out by 19 km.

I sought some supplementary information from JDR related to the additional papers received from CBMDC halfway through my study. Specifically, I sought the document that a number of respondents (inc. Mrs J E Naylor and Mrs S Wells) refer to in their comments on Planning Application 13/04897/MAF. A typical such comment is "Read the report commissioned by Bradford Council, I believe in 2000/01 that again says this land is not suitable due to the seasonal springs and poor drainage". However, JDR was unable to enlighten me as to where I could find a copy of the report in question.

2.8 Flooding problems downstream of the development sites

I have researched flooding problems in Menston in considerable detail but find them too many and complex to summarise authoritatively. Some of the opinions expressed are based on fact and some on impressions gained from the information seen and studied: on paper, online and in my site visits to Menston.

The dates of flooding incidents in Menston appear in the flood chronology assembled in Appendix G. Not all flooding incidents have been proved. The list is provided as a reminder, and as an aid to further investigations (see Section 9.2).

Development of land suffering poor drainage or vulnerability to flooding is nothing new. Section 7.4 points to some recent examples of developments in Menston that have taken place in areas that may be vulnerable to flooding.

2.9 Vulnerabilities

2.9.1 Hot-spots

Four roads and many flooding problems meet at Lane Ends. The location is low-lying and the watercourse in this vicinity is not self-evident. The topographical outlet for water from Lane Ends is to the north-east. That this is not a well-developed watercourse indicates that drainage at Lane Ends is almost exclusively dependent on sewered systems. I have not investigated the details. Any sewered system has its limitations, and will overflow or reject inflow when blockage occurs or the incoming flow exceeds its carrying capacity. Lane Ends is therefore intrinsically vulnerable to flooding.

Other hot-spots include areas centred on Dick's Garth Road, Derry Hill, Hawksworth Drive and Red House Gardens. This list is not intended to be comprehensive.

2.9.2 Sewer flooding records

While it would be helpful to see Yorkshire Water records of reported and confirmed sewer-flooding incidents, such records are not publicly available. Those summaries that are available may not tell the full story. In the most serious events – where external and/or internal flooding of property occurs – the water company may seek to demonstrate that flooding occurred only because the rainfall was of exceptional rarity. The property does not then need to be added to the formal DG5 Register of properties liable to sewer flooding. If the cause of flooding (e.g. from surface water, from sewers and/or the role of blockages) is itself disputed, the flooding incident may not be recorded in full. Where external and/or internal flooding of property has occurred or has been only narrowly averted, the property owner/occupier may be reluctant to declare the incident: for fear of weakening the insurability or market value of the property.

In these circumstances, it is difficult for an outsider to form a clear judgement of flood frequency. Some flooding incidents on highways may, of course, reflect blocked gullies rather than surcharging of the drainage system.

2.9.3 YouTube

The wide availability of mobile phones – and other devices that act as a camera or video camera – provides additional information, and bypasses the formal behaviour and notifications of water company, local authority and "floodee". Floodee is a term for flood victims favoured by the former Chief Executive of the National Flood Forum, Mary Dhonau.

When uploaded several weeks after the event, there may be doubt about whether the date shown on a YouTube video is correct. Also, the location may not always be pinpointed. Nevertheless, such videos provide valuable additional information and, in some cases, demonstrate categorically that foul sewage is involved. The video of fast-flowing water on the Derry Hill site (see https://www.youtube.com/watch?v=ek65kA907VY) on 24 September 2014 demonstrates flood potential that is utterly undeniable. I have seen mention that the video was shot at about 18:00 hours but I cannot recall the source document.

2.9.4 Further downhill

The report (Telegraph & Argus, 14 January 2013) of a major sewer collapse near Westbourne Drive in late 2012 reminds that there can be knock-on effects for property a considerable distance from Derry Hill and Bingley Road. I found this response from Consultee 66 to the Menston draft SPD (see 0) particularly perceptive:

> "I live adjacent to the railway line immediately below (or down in altitude terms) from Derry Hill. In the last 10 years, building 'above/higher' than us at 'Whiddon Croft' has led to severe drainage issues for us and adjoining homes with run-off causing water ingress (into our homes) in heavy rain (and foul water in the cellars of our neighbours)"

Whiddon Croft was one development (and Reevadale another) where toponymy (see Appendix D) suggests to me that they might lie on a neglected route for excess water. Without definitive data, this is of course speculation.

But all water flows downhill … except, as JDR correctly states … in special cases where its kinetic energy carries water forward before it has had the opportunity to find the theoretical line of steepest descent! https://www.youtube.com/watch?v=TkfKPhcjlKc demonstrates this for floodwater leaving the Derry Hill site on 24 September 2012.

2.9.5 Sensitivity to extreme rainfalls of different durations

This brings me to a matter that influenced my willingness to take on this independent review. JDR is wrong to insist that flooding at Derry Hill is only sensitive to long duration storms. Yes, groundwater is a neglected and important element of the flood response: at Bingley Road, at Derry Hill, to Lane Ends and beyond. But the catchments are also sensitive to heavy rainfalls of short duration. The groundwater effect merely extends the spectrum of heavy rainfall events to which Menston is sensitive.

Appreciation of the sensitivity to extreme rainfalls of a range of durations is important if the under-design of drainage systems and the under-appreciation of flood risk are to be avoided. It is also important to underscore that a sensitivity to intense short-duration storms remains. High-velocity flows down/across roads are a threat to life: not least on steep Menston streets such as Derry Hill and Cleasby Road.

3 Investigations at Matthew Dike

Laurence (1991) reports: "If we are so disposed, a stiff walk over the top of Derry Hill brings us to the narrow and steep-sided ravine called Matthew Dike, which forms the boundary division between Hawksworth and Menston. In 1273 this same dike or ravine was known as Black Syke." Matthew Dike is a highly unusual drainage feature that lies above Menston.

3.1 Relevance to determining the catchment boundary to Derry Hill

Recognising from mapped streams that the upper section of Matthew Dike might overflow into the Derry Hill catchment, I arranged to visit Matthew Dike Farm and roam their land. My visit on 27 November 2014 proved effective save only for the very poor visibility. The Armstrongs have farmed the land since 1974, moving into the new farmhouse in 1999.

3.2 Origin of Matthew Dike

I have been unable to trace the origin of the name *Matthew Dike* or find a definitive account of the origin of the feature.

In its middle and lower course, Matthew Dike lies in a pronounced *defile*. [Laurence's use of the word *ravine* is too strong for my taste.] My best guess is that it is a remnant from, or consequence of, glacial action. This is known to have been pronounced and distinctive in the area. An arm of the Wharfedale glacier flowed to Airedale through the so-called Guiseley Gap. One account (see http://www.ilkleymoor.org/discovering-ilkley-moor/geology/) reports that "During the last ice age, the ground and underlying rocks would have been deeply frozen. The shales, in particular, were left in a softer weakened state when this permafrost melted. The escarpments would then have been susceptible to landslipping as the grits slipped over the underlying waterlogged shales. Rocky hummocky ground occurs in many places below the edges of the moor."

I conclude that – in spite of its manly name – the incised section of Matthew Dike most likely reflects post-glacial landslides.

3.3 Middle section

Photo 3.1 (copied from https://geolocation.ws/v/E/2288806/matthew-dike-menston/en) provides an excellent view of the incised middle section of Matthew Dike, with "hummocky" a good description of the moorland topography in this area.

Photo 3.1: Middle section of Matthew Dike (looking upstream)

After crossing under Hillings Lane – at the Bingley Road turn to Menston – Matthew Dike continues into its lower section (also incised). It further traverses the footslopes of Reva Hill before joining Mire Beck just south of the HRH pump house (see also Photo 4.1).

3.4 Upper section

The upper section of Matthew Dike is different in character. Opposite Matthew Dike Farmhouse (ringed in Photo 3.1), the watercourse is less impressive and is no longer in a pronounced defile. It looks more like a minor drainage improvement (to make farmland more workable) than a glacial remnant.

I regret that descriptions here are necessarily detailed and that my photos were taken in foggy conditions. My appointment with the Armstrongs was on 27 November 2014, and the days either side were also persistently foggy in this location. I trust that the two plans will help a little. The mapped stream network and field boundaries are best seen in Map 3.1.

I have added some labels to Photo 3.2, and sketched in blue part of the upper section of the course of Matthew Dike. The aerial photo allows an appeciation of vegetation patterns.

Map 3.1: Plan of upper and middle sections of Matthew Dike

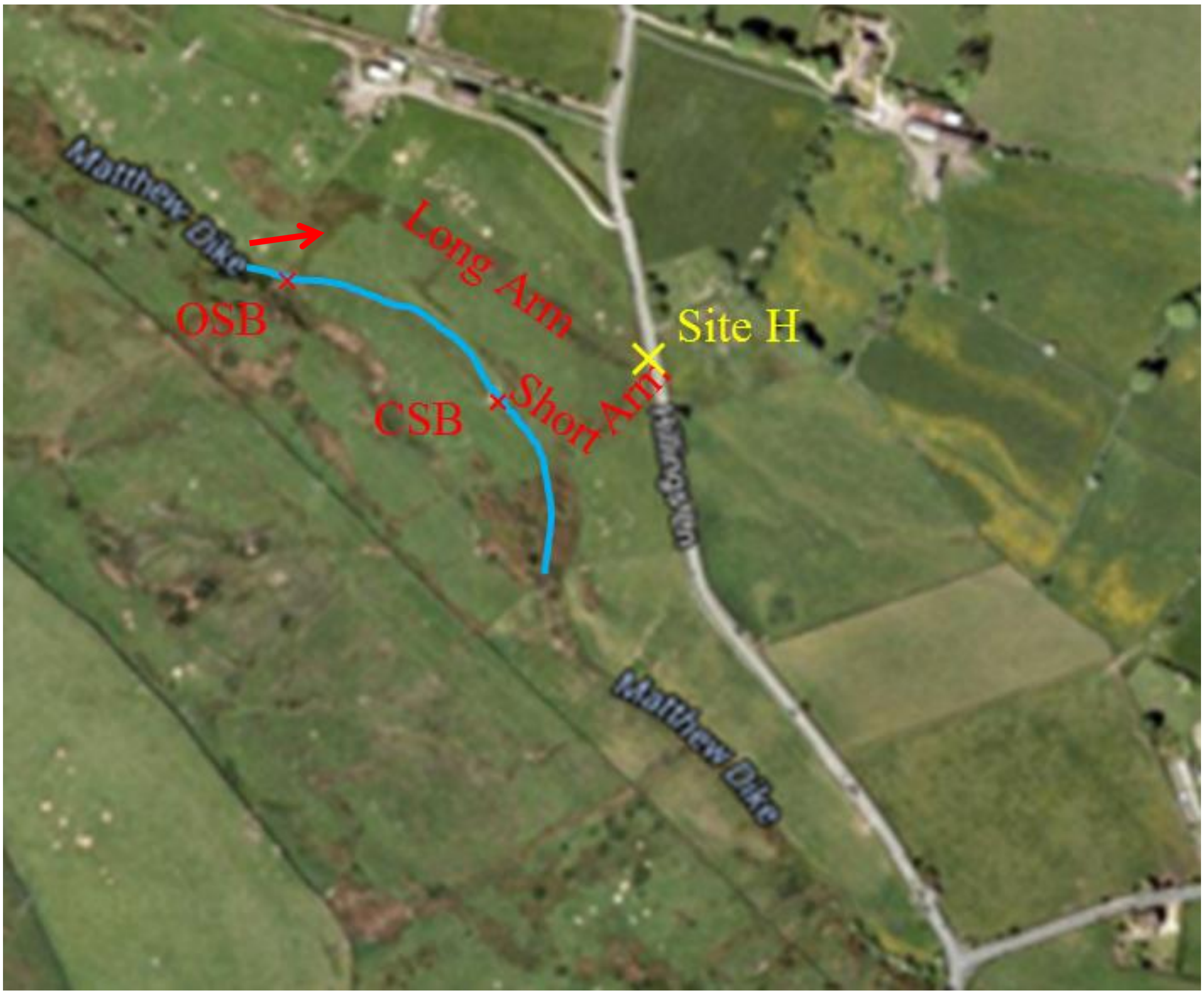


Photo 3.2: Aerial view of upper and middle sections of Matthew Dike

3.5 Site H

Reports indicated that Hillings Lane was flooded to a moderate depth in September 2012. I confirmed details with Mr and Mrs Armstrong. They found Hillings Lane flooded when returning from the somewhat curtailed Nidderdale Show in the early evening of Monday 24 September 2012. It had rained all day. According to the Armstrongs, there was maybe nine inches (0.23 m) of water across Hillings Lane. But cars were getting through OK.

The flooded location is marked as Site H in Photo 3.2. The area upstream is characterised by short and long rush-covered drains descending to Hillings Lane. Views of these from Site H are shown in Photos 3.3, which almost do justice to the near 90° angle between the two arms. I took these fog-free photos during my preliminary site visit on 30 October 2014.

Photos 3.3: Short and Long drainage arms viewed from their confluence at Site H

3.6 Overflowing of Matthew Dike into the Derry Hill catchment

The close approach of mapped stream channels seen in Map 3.1 and the merging of modelled water levels in one of the JBA reports (see Appendix A to JDR (2014)) was one reason I was willing to take the independent review on. I expected to find that – in large flood events – floodwater in Matthew Dike over-spilled into the catchment that drains to Site H, and thence to the Derry Hill development site. It transpired that my hunch was correct although the detail was not quite as I had expected.

Matthew Dike is of limited cross-section in the reach marked in blue in Photo 3.2. The watercourse does not lie in the bottom of a marked defile as it does in other reaches.

In normal flow conditions, there is no surface-water spillage from Mathew Dike into the catchment to Site H. I spent considerable time inspecting what I had anticipated to be the likely site for threshold spillage into Catchment H, i.e. when Matthew Dike is in flood. This site is just upstream of an old (low-level) stone bridge over Matthew Dike marked OSB in Photo 3.2. There was some limited evidence from vegetation that overspill can occur here into the Longer Arm draining to Site H. This is because – just upstream of this point – Matthew Dike clips the edge of Field F in Map 3.1. Depending on the state of vegetation, some floodwater may find it easier to follow the red arrow in Photo 3.2 than return through the fence to continue in Matthew Dike.

I explored further down Matthew Dike and found the channel to be of modest cross-section. I noticed two small waterfalls (one is shown in Photo 3.4) and then realised that the channel has been dredged relatively recently. CSB marks a concrete slab bridge.

Photo 3.4: Minor waterfall in dredged section between OSB and CSB

The dredging was evident from excavated "slugs", with the majority deposited on the SW side of the watercourse. I refer to them as slugs in view of their typical (roughly cylindrical) shape. I do not know a more appropriate term. Photos 3.5 do not show them very clearly.

Photos 3.5: Excavated "slugs" from Matthew Dike, seen between sites OSB and CSB

To my untutored eye, the slugs appeared to be of mixed age. Some were almost bare of vegetation while others showed abundant regrowth. I later learned from the Armstrongs that all the dredging had been carried out soon after the September 2012 event, when they realised that Matthew Dike had overflowed. I guess that vegetation is established more on some "slugs" than others because of soil and exposure differences.

The slugs are somewhat more numerous towards the concrete slab bridge at CSB, seen in Photo 3.6. I judge that Matthew Dike overflowed at (and just upstream of) Site CSB, most likely because of limited capacity or partial blockage of the culvert under the concrete slab.

On this basis, I judge that the excess floodwater reached Site H by the Shorter Arm rather than the Longer Arm.

Photo 3.6: Concrete slab bridge (CSB) viewed from upstream, with A4 sheet for scale

It would be illogical to blame the Armstrongs for not routinely digging out Matthew Dike. When a large flood occurs, it will overflow here again. Were Matthew Dike dug deeper it would soon refill with sediment. The longitudinal gradient in this reach is relatively mild, with an average gradient of less than 1:50.

3.7 Topographic divide between Matthew Dike and the catchment to Site H

Leaving aside any over-spill from Matthew Dike, the topographic catchment to Site H is a little larger than shown in JBA (2013). The land incorrectly omitted is principally the greater part of Field G, sketched as an addition to Map 3.1.

3.8 Implications for the catchment to Derry Hill

The upshot is that the effective surface-water catchment area to the Derry Hill site is threshold-dependent. It is considerably increased in large floods by runoff from the hillside that drops northwards (and then NNE) from the summit of Reva Hill.

One further matter came to light in my site visit to Matthew Dike Farm. Occupation Lane, runs NW from Hillings Lane up to Stocks Hill. The lane takes its name from old mineral workings in the area between Fields F and G in Map 3.1.

The matter concerns the headwaters of Dry Beck which cross Occupation Lane just beyond the newly redeveloped Pump House, seen in Photo 3.7. Field G (referred to above) lies immediately to the left in the photo. Just beyond the gate straight ahead, the headwaters of Dry Beck pass through a culvert under Occupation Lane.

Photo 3.7: Redeveloped Pump House, Occupation Lane

3.9 Overflowing of headwaters of Dry Beck into Derry Hill catchment

A second critical area for overflow into the catchment to Derry Hill lies just NW of the redeveloped Pump House on Occupation Lane. Mr Armstrong has farmed Matthew Dike Farm for 40 years and reports that he has seen water flowing down Occupation Lane past the Pump House on a number of occasions: not just in September 2012. He attributes the flow to inadequate capacity of the culvert under Occupation Lane, which takes water to Dry Beck and Burley in Wharfedale.

This is a critical site because it forms the coming together of a number of small channels draining perhaps 20 hectares of Craven Hall Hill. Once in Occupation Lane, water will most likely continue down the track to Hillings Lane. Once in Hillings Lane, it will turn right to reach Site H.

There appears to have been some drainage works done here recently. The level of Occupation Lane is possibly somewhat higher following redevelopment of the Pump House. This should lessen the scope for overflow from the Dry Beck catchment into the Derry Hill catchment in all but the most extreme events … provided that the culvert is adequately maintained. When overspill does occur, it will be a matter of the local levels on Occupation Lane as to whether the water stays in the Dry Beck catchment or is exported into the Derry Hill catchment.

3.10 Groundwater catchment to Derry Hill

I suspect that the groundwater catchment area to the Derry Hill site is somewhat larger than the topographic catchment. This is not my field of expertise. However, one only has to look at the rushes colonising the long and short arms upstream of Site H to know that these areas are systematically wet. If … as I believe to be the case … Matthew Dike overflows into the

Derry Hill catchment only in large floods, the soil wetness that is characteristic of the vegetation must be sustained by groundwater.

3.11 Conclusion

The catchment area to Derry Hill is somewhat bigger than portrayed by JBA. More pertinently and seriously, in times of major flooding, the upper course of Matthew Dike over-spills into the Derry Hill catchment. There is also some scope for over-spill from the headwaters of Dry Beck into the Derry Hill catchment arising from culvert blockage under Occupation Lane. However the potential area involved is not as significant as the over-spill from Matthew Dike, and there is scope to do minor works to eliminate the risk. The owners of the redeveloped Pump House will presumably be keen to ensure that the relevant culvert is adequately maintained.

4 Groundwater abstraction at High Royds Hospital

4.1 Population growth

I inspected a folder presented to Menston Primary School on 12 February 2000 by the Millennium Link Project. This is entitled the “1888-1962 [history of] the West Riding Pauper Lunatic Asylum and the “1963-2000 [history of] High Royds Hospital”. p24 provides the census information summarised and annotated in Figure 4.1.

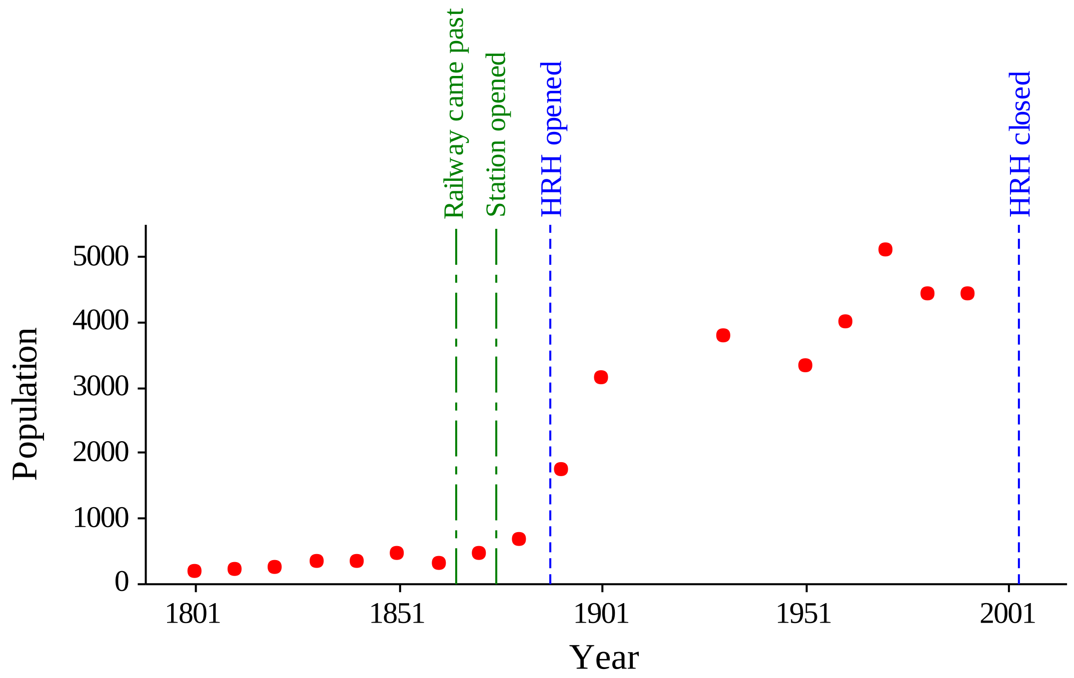


Figure 4.1: Census returns for the Parish of Menston (includes HRH residents)

4.2 Design and performance of HRH water resource

p26 comprises a newspaper cutting of an article by Ernest Longfield of Weston Ridge, Otley, ahead of the HRH centenary in 1988. The article refers to the work of Mr Edwards (Surveyor for the County Magistrates) in selecting the site for the new asylum:

> "First of all he made sure there would be an adequate supply of good drinking water. He had noticed even in the dry summer of that year the boreholes had shown supplies of the finest quality and High Royd Spring was still in full flow. However, the Committee set aside the sum of £5,000 for the purpose of building a pumping station and storage… reservoir on ground above Menston to supply water for washing and other domestic purposes, knowing extensions were visualised in the future. For the time being Mr Edwards promised an artesian supply and his word was accepted."

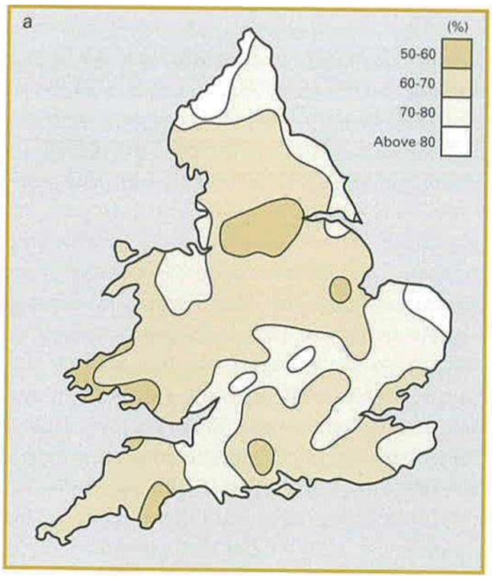
Laurence (1991) reports the original design to be "a reservoir capable of holding a three months' supply, calculated on an estimated rate of consumption." The relevant data will doubtless be in HRH archive records held by the West Yorkshire Archive Service (WYAS). Rough figures are that the storage reservoir holds 8 million gallons [≈36 Ml] based on ≈90 days at ≈90,000 gallons per day [≈0.41 Ml/day].

The somewhat dated reference to *artesian* will mean that Mr Edwards promised that the supply *from the storage reservoir* would have enough "head" to drive water to all parts of the hospital.

The mid-1880s was a period of repeated droughts. 1887 was amongst the worst, and was especially severe in the Pennines. An article in Symons's British Rainfall 1887 includes:

> "July 12th.—The drought is very severe in Yorkshire, water frequently has to be fetched long distances, as most of the ponds and wells in elevated localities are exhausted."

Map 4.1 taken from Marsh *et al.* (1994) indicates that February-October rainfall totals in 1887 were exceptionally low in West Yorkshire: being below 60% of the long-term average. So this was indeed a notable drought.

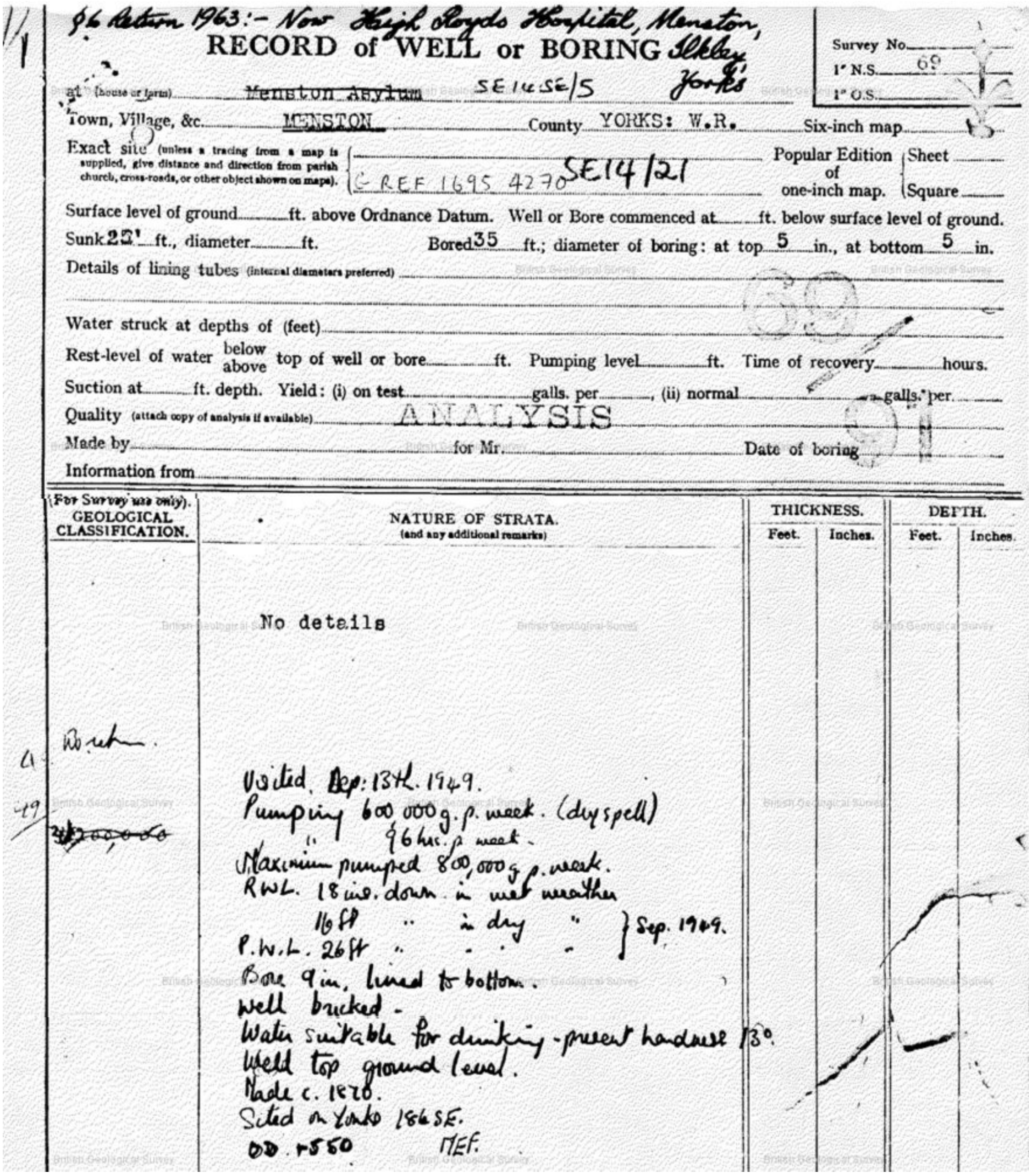


Map 4.1: Rainfall (as % of long-term average) for drought episode Feb - Oct 1887

4.3 Borehole records

The British Geological Survey (BGS) maintains extensive archives, including borehole records. Figure 4.2 is copied from:

http://scans.bgs.ac.uk/sobi_scans/boreholes/55054/images/14437984.html



96 Autumn 1963:- Now High Royds Hospital, Menston,

RECORD of WELL or BORING Ilkley, Yorks

Survey No. 1" N.S. 69 1" O.S.

at (house or farm) Menston Asylum SE14SE/5

Town, Village, &c. MENSTON County YORKS: W.R. Six-inch map

Exact site (unless a tracing from a map is supplied, give distance and direction from parish church, cross-roads, or other object shown on maps). GREF 1695 4270 SE14/21 Popular Edition of one-inch map. Sheet Square

Surface level of ground ft. above Ordnance Datum. Well or Bore commenced at ft. below surface level of ground.

Sunk 23' ft., diameter ft. Bored 35 ft.; diameter of boring: at top 5 in., at bottom 5 in.

Details of lining tubes (internal diameters preferred)

Water struck at depths of (feet)

Rest-level of water below/above top of well or bore ft. Pumping level ft. Time of recovery hours.

Suction at ft. depth. Yield: (i) on test galls. per , (ii) normal galls. per

Quality (attach copy of analysis if available) ANALYSIS

Made by for Mr. Date of boring

Information from

(For Survey use only). GEOLOGICAL CLASSIFICATION.	NATURE OF STRATA. (and any additional remarks)	THICKNESS. Feet.	THICKNESS. Inches.	DEPTH. Feet.	DEPTH. Inches.
	No details				
	Visited Sep: 13th. 1949.				
	Pumping 600 000 g. p. week. (dry spell)				
	" 96 hrs. p. week.				
	Maximum pumped 800,000 g. p. week.				
	RWL. 18 ins. down in wet weather				
	16 ft " in dry " } Sep. 1949.				
	P.W.L. 26 ft " "				
	Bore 9 in, lined to bottom.				
	Well bricked.				
	Water suitable for drinking - present hardness 130.				
	Well top ground level.				
	Made c. 1870.				
	Sited on Yorks 186 SE.				
	OD. +550 MEF.				

Figure 4.2: Borehole record for HRH groundwater abstraction

The record notes details from an inspection made on 13 Sep 1949. RWL denotes the *rest water level* when no recent pumping has been undertaken. PWL denotes the *pumping water level* when a sustained period of pumping is about to stop. Thus, the rest water level is said to be 18 inches (0.46 m) down in wet weather but as much as 16 feet (4.9 m) down in dry weather.

The 13 Sep 1949 inspection took place during a noted drought. After pumping for about 14 hours, the water level was (in that dry month) as much as 26 feet (7.9 metres) down.

It is clear that the groundwater resource available at the HRH borehole is considerable. I have discovered nothing to indicate that this has changed in the 126 years since 1888 or the 65 years since 1949.

The current licence related to this groundwater abstraction was issued by the Environment Agency (EA) under Licence Serial No. 2/27/19/172. The schedule attached to the licence indicates a borehole of depth 23.07 metres (75 feet 8 inches) and 230 mm (9 inches) diameter within a well of depth 5.8 metres (19 feet) and diameter 1.8 metres (6 feet). [It appears that the Figure 4.2 record states the borehole depth from the bottom of the bricked well, whereas the current licence states the borehole depth below ground level.]

The time series of annual quantities returned is presented in Figure 4.3. These figures were sought from the EA, and handled and supplied as a Freedom Of Information request. The reference value of 100,000 gallons per day shown is the maximum daily abstraction permitted under the licence. [I might instead have marked a reference value of 82,200 gallons per day, which is the maximum annual average abstraction permitted under the licence: terms which the current licence implies have stood since the licence was issued to Leeds Community & Mental Health Authority on 26 June 1993.]

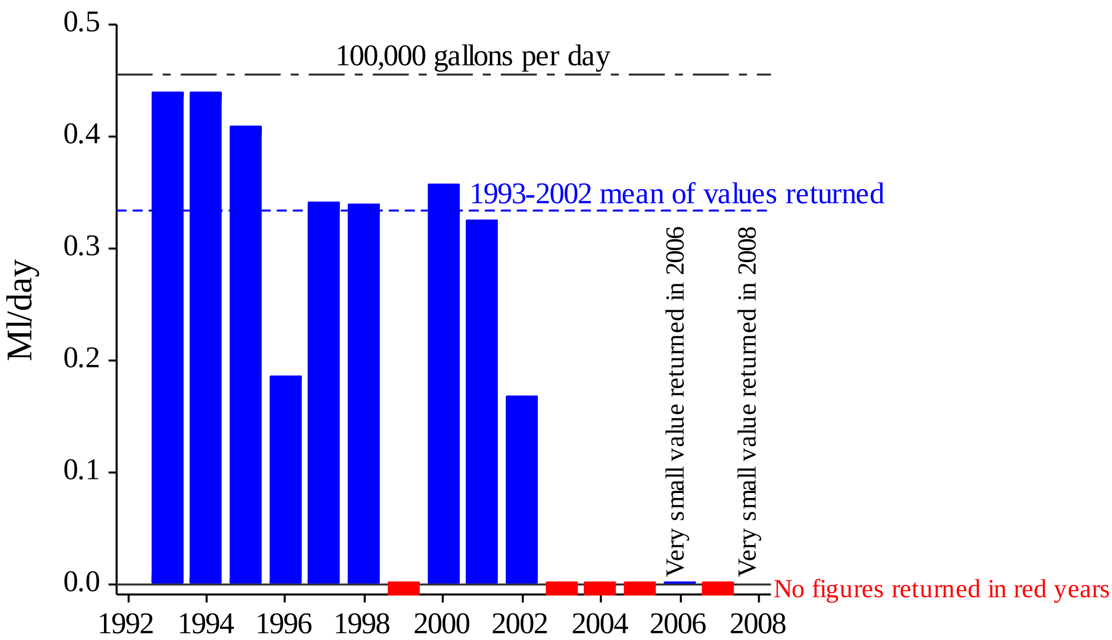


Figure 4.3: Annual average rates of groundwater abstraction at the HRH borehole

The average rate of abstraction recorded over 1993-2002 – for which records are almost complete – was 0.333 Ml/day. This corresponds to the typical usage expected of say 1650 people at 200 l/head/day: confirming that the abstraction rates are realistic.

4.4 Impact of groundwater abstraction on springs and watercourses

As might be expected, there is evidence – albeit indirect – that the cone of depression created by abstraction from the HRH borehole extended over a considerable distance. Three roughly parallel watercourses running West-East south of Bingley Road and north of High Royds Hall appear on Map 4.2. These watercourses do not appear on the 1:10,560 map of 1906-1907, seen in the Groundsure Report which forms Appendix B to the Sirius C3545 Geoenvironmental Appraisal of the Bingley Road site prepared for Taylor Wimpey UK in December 2009.

Map 4.2: OS First Series 1:63360 map, 92 SE – Skipton (1858)

Wells just south of Bingley Road are marked Lady Well and Well on the 1851 1:10,560 map (see Map 7.1) but do not appear on the 1906-1907 1:10,560 map cited above. In addition, the well south of High Royds Hall – close to where the HRH groundwater abstraction borehole was sunk – is now marked “Pump House”.

4.5 Cessation of pumping on closure of HRH

According to the statutory returns to the EA shown in Figure 4.3, groundwater abstraction under Licence Serial No. 2/27/19/172 continued until HRH closed in early 2003. Returns for 1999, 2003, 2004 and 2005 are missing. The return for 2002 shows a considerable reduction on the typical quantities returned previously. This appears consistent with running down of HRH prior to its closure in February 2003.

4.6 Impact of cessation of the HRH groundwater abstraction

4.6.1 General

Cessation will have triggered rebound of groundwater levels towards the natural pre-1888 condition. Given the characteristic water levels reported in the inspection of September 1949, it appears likely that groundwater levels will have largely recovered during the first really wet winter following cessation of pumping.

The average rate of abstraction recorded over 1993-2002 – for which records are almost complete – was 0.333 Ml/day. This corresponds to a mean flow of about 4 l s^{-1}. Spring flows since the mid/late 2000s can nevertheless be expected to have been typically stronger: both local to the HRH borehole and in the peripheral area – nominally represented by a circle centred on the Pump House – over which the pumped abstraction routinely depressed groundwater levels (see Photo 4.1). The significance lies in both the greater spring flows and the wetter soil conditions to be routinely experienced since cessation of the groundwater abstraction.

It would be worth exploring whether any of the three watercourses appearing in Map 4.2 has started to flow. A recent LCC Planning Application 14/05510/FU relating to further redevelopment of the HRH site notes that: "A number of minor ridges and valleys characterise the western portion of the site."

Given the agricultural and other drainage works undertaken in the 1889-2002 period, typical groundwater levels cannot be expected to return to their full 19th Century heights. The cessation of the HRH groundwater abstraction is nevertheless a highly significant factor.

4.6.2 Specific

High Royds (*aka* Chevin Park)

Minutes of meetings of the High Royds Residents Association indicate that residents have experienced flooding in basements/cellars at Litton Court (minutes of 4 June 2009 meeting) and Askrigg Court (minutes of 4 February 2010 meeting). It is possible that such flooding relates to a local drainage defect. However, a minute of the 4 March 2010 meeting reports that Gladedale (abbreviated in the minutes as GD) appear to suggest otherwise: "Re the issue of cellars in a refurbished Gladedale block flooding with water, GD noted that as the cellars were never sold as dry habitable space, just as empty storage space then they have no obligation to remedy the matter. Nothing was known of any underground drainage runs being blocked up or cut off which may be causing the flooding."

The blocks reporting basement/cellar flooding – although towards the east of the HRH site – lie within 800 metres ENE of the HRH groundwater abstraction site. They are roughly marked in Photo 4.1.

Bingley Road development site and Red House Gardens

One might argue that saturated ground within the Bingley Road site – not least close to Red House Gardens – is further evidence that spring water is more of a problem than formerly. Red House Gardens lies about 800 metres from the HRH borehole. The Bingley Road site as a whole lies 550 to 875 metres from the borehole. The sites are roughly marked in Photo 4.1.

Photo 4.1: Aerial view copied from LCC Planning Application 14/05510/FU

4.6.3 Further exploration

The Sirius C3545 Geoenvironmental Appraisal of the Bingley Road site prepared for Taylor Wimpey UK in December 2009 appears to have been based on a commendably detailed and thorough investigation of maps and other information sources. I have certainly found their report valuable. It is therefore especially disappointing that their programme of instrumented fieldwork on the Bingley Road site was either prematurely curtailed or the results never published.

Appendix F of the Sirius C3545 Geoenvironmental Appraisal presents water level data (measured in metres below ground level) at four of six "window sample probe holes" on the Bingley Road site. These holes were sunk on 29/30 October 2009 and water level readings measured on 20 and 27 Nov 2009 are reported. The ledgers clearly show that these were the first two of six observations intended over three months. Later readings were either never taken or not published. Without hearing an explanation for this, it is difficult to suppress the thought that the observations may have been considered unfavourable to the client's plans. In one week, the water levels recorded at monitoring points WS1, WS2, WS5 and WS6 had risen by 0, 140, 160 and 180 mm respectively.

It is worth noting that November 2009 was outstandingly wet throughout the British Isles. Exceptionally heavy and prolonged rainfall in the period 18-20 November 2009 led to highly damaging floods: not least in Cockermouth & Workington in Cumbria and Cork City in Ireland. The event led to the annual maximum river flow on the River Wharfe at Addingham on 30 November 2009. Though large, the Wharfe flood was not exceptional: being only the 20th highest annual maximum flood in 52 years of composite (Addingham/Ilkley) records (see also Appendix F).

5 Trends in flood estimation methods

5.1 Flood estimation in large catchments

In rivers such as the Wharfe, long series of peak flow data form the bedrock of flood frequency estimation (see Appendix E for an introduction). Where the interest is in estimating the size of rare floods – e.g. one expected to be exceeded in any year with a probability of 1% – the analysis of gauged flood series is augmented by studying date, photograph and water-level information about exceptionally large floods that occurred before the formal gauging of river flows began.

This practice is well developed in the UK because of the long documentary records typically available in the settlements through which our main rivers run. However, the priority given to long records of gauged and historical flood data is challenged by questions arising about the significance of climate and land-use changes, and whether gauged information is quite as good as seasoned flood hydrologists think it is. Such questioning would be more welcome were the flotillas of modellers using hydrological models relevant at the catchment scale and hydraulic models focused on representing flow behaviour in the immediate vicinity of flow gauging stations.

The character of flood risk estimation in the UK has changed radically in the 15 years since publication of the Flood Estimation Handbook. The main differences lie in the way in which flood estimates are subsumed into basin-wide models. Results attain their authority not by the length of gauged records or the seasoned experience of hydrologists in understanding particular rivers but in acceptance by the Environment Agency and in the presentation of results in visually stunning flood-risk maps.

Public understanding and expectations are not really to blame. Professionals and agencies have been lured into believing that flood-risk estimation has been successfully generalised along the main rivers. Indeed, it seems that some believe that it is only a matter of time before digitally based methods extend to cover all watercourses within the river basin: regardless of their size and whether gauged flow records exist for them at all.

5.2 Flood estimation in small catchments

The presumption seems to be that – if our models are sufficiently detailed in space – what is known tolerably well for large rivers can somehow be transferred to small watercourses. This is a valid ambition in applications such as flood warning. As short-term rainfall forecasting and catchment models improve, we can have a shot at forecasting how conditions are likely to change a few hours ahead. This has many potential benefits. If a flood warning is issued or withheld, the quality of the decision is soon tested. We wait a few hours and then learn whether our flood forecast was reasonable and whether dissemination of the flood warning was effective in reducing flood impacts.

Flood estimation of the kind needed in development planning – how big is the 50-year flood in the pre-development state and how do we ensure that the development does not increase this? – is entirely a different kind of problem. We may believe that detailed modelling will help. But if the modelled results do not agree with what is known to happen on the ground, the flood estimates are worthless and should not be used.

Flood professionals are practitioners who seek a living by applying methods to flooding problems. They may be expert in using IT systems to apply generalised methods of flood estimation. But they may not be expert in knowing the limitations of the methods. http://www.uksuds.com/references.htm demonstrates that a plethora of guidance now abounds for the design of sustainable drainage systems (SUDS).

It seems that some of those drawing up and reviewing guidance do not know really understand the research that has been done and what applications can be reasonably supported. The level of statistical competence in SR744 can be judged from the high-profile advisory that *three annual probabilities are used to define discharge compliance limits though the critical criteria are for the lowest and highest frequency events; 100% (1 year), 3.33% (30 year) and 1% (100 year)*. Reference to a flood with an annual probability of 100% is nonsense.

It is therefore necessary to say something about the limitations of the methods being applied. I focus here on the use made – at Bingley Road and Derry Hill and many other sites – of a peak flood estimation method given in IH Report 124.

None of what follows is saying that flood estimation on small ungauged catchments should not be attempted or that a particular method should be avoided. Rather, it is saying that observed circumstances on the ground should always carry more weight than any generalised model or estimate. Instrumentation of key sites is to be recommended.

6 IH Report 124

6.1 The research project

I devised and supervised the research project that led to IH Report 124 *Flood estimation on small catchments* by Marshall and Bayliss. Funded by MAFF (predecessor to Defra), the experimental research addressed the estimation of *flood response times* on lowland catchments smaller than about 25 km^2. The remarkable achievement of IH Report 124 was to demonstrate how much can be learned about the response behaviour of a small catchment by gauging it for two or three years with simple but robust equipment. The research monitored water levels (and rainfall) on 15 such catchments. It did not gauge any flows.

Given the success of the water-level monitoring, IH was asked to combine FSR, DANI and ADAS Soil & Water Research peak flow datasets for small catchments and develop a method for estimating typical flood size from catchment characteristics. The catchments contributing to the IH124 equation for estimating QBAR ranged in size from 0.87 to 24.9 km^2. Sixteen of the 87 catchments were partly urbanised. The other 71 were essentially rural.

In contrast to the 15 catchments that Marshall and Bayliss set up to monitor flood response times, the QBAR dataset did not focus exclusively on lowland sites. Indeed, thirty of the 71 catchments (i.e. 42%) used as the basis of Equation **6.1** – have a standard-period average annual rainfall (SAAR) in excess of 1500 mm! UK housing developments are very rarely attempted in such persistently wet upland areas. [For the Derry Hill and Bingley Road catchments at Menston, SAAR is somewhat less than 1000 mm.]

6.2 What gets used from IH Report 124 – and why

The IH124 equation that chiefly gets used is:

$$QBAR_{rural} = 0.00108\,AREA^{0.89} SAAR^{1.17} SOIL^{2.17} \qquad 6.1$$

This represents the three factors commonly held to be most influential on the flood magnitude on rural catchments: the catchment size (AREA measured in km^2), the climatic wetness (indexed by SAAR measured in mm) and the soil properties (indexed by the dimensionless term SOIL). QBAR is the mean annual maximum flood measured in m^{3}s^{-1}.

In contrast to most other formulae for flood size, Equation **6.1** does not include any terms that are explicitly scale-dependent. No property of the watercourse – such as channel width, stream slope or stream length – appears. This makes it possible to apply the method to catchments of almost any size, irrespective of whether a stream is mapped or even exists. This factor alone has led to widespread adoption of Equation **6.1**. The adoption in some cases amounts to abuse.

6.3 Abuse of IH Report 124

There are three main ways in which application of IH Report 124 is abused.

6.3.1 Soil maps

Little attempt is made to refine the estimate of the SOIL descriptor. Indeed, a number of providers of guidance and software appear to encourage use of the 1:1,000,000 WRAP map published in Volume 3 of the 1981 Wallingford Procedure for the design and analysis of urban storm drainage. Avoidance of licence fees appears to be a part-justification of this practice.

It is utterly crass to recommend use of a 1:1,000,000 soil map on small and very small catchments. It is not possible to map areas much less than 10 km^2 distinctively at this scale. The recommendation to use such a map in 1981 was reasonable in the circumstances then prevailing. Thirty or more years later, the recommendation is absurd. General soil maps of England & Wales were published at 1:250,000 scale in 1983 and form the basis of the HOST classification used in (amongst other studies) the UK Flood Estimation Handbook. This is the coarsest scale at which soil maps should be used in hydrological assessments: even on large catchments.

It is not possible at the 1:250,000 scale to map areas much less than 2 km^2 distinctively. Perfunctory use of the FEH representation of soils through SPR_{HOST} and BFI_{HOST} is therefore inadvisable on catchments less than about 5 km^2. Acceptable practice is summarised somewhat clumsily in Box 6.1. Best practice on very small catchments is to consult a soil surveyor who can sample soils and allocate them to appropriate HOST classes.

Box 6.1: FEH guidance on representation of soils on small catchments

Quotes from p30 of FEH Volume 5 and pp 246-249 of FEH Volume 4:

- "For some small catchments, the use of SPRHOST values based on a summary of the HOST classes present in each 1 km square may be inappropriate. In these cases, a value may be derived manually, based on more detailed soil information, using the methodology described in … ."
- "Soil maps at '1 inch', 1:50,000 and 1:25,000 scale are available for some areas."
- "The Hydrology Of Soil Type or HOST classification is the product of a collaboration between the Institute of Hydrology (IH), the Soil Survey and Land Research Centre (SSLRC), the Macauley Land Use Research Institute (MLURI), and the Department of Agriculture for Northern Ireland (DANI). … The classification is available as digital data sets in raster form at 1 km and 100 m resolution. Because the classification is series-based, many HOST classes may be present within each 1 km or 100 m cell. Therefore, although the classification can be represented as a map showing only the dominant HOST class … this disguises the refinement of the parent dataset."
- "In particular applications, especially on small catchments, users may wish to purchase the 100 m resolution data set (held by SSLRC, MLURI and DANI), or manually derive the HOST classes on the study catchment."
- "It may also be worth investigating whether the soils in that region of the country have been mapped at a larger scale e.g. the 1:25K soil maps available for some regions of the UK."

6.3.2 Extrapolation to represent catchments with no permanent watercourse

It is understandable that – for the want of something better – some users apply Equation **6.1** to estimate QBAR on catchments where there is no permanent watercourse. However, this extrapolation is risky and ought not to be considered best practice for anything beyond a preliminary assessment.

All catchments used in the IH Report 124 research had a permanent watercourse. If there is no permanent watercourse, there is no prospect of validating that the QBAR estimate is reasonable.

The FEH recommendation – and indeed the FSR recommendation before that – is to seek a downstream site at which a particular method can be applied and to make the flood estimation there. The required flood estimate at the subject site is then typically obtained by pro rata, based on the ratio of the two catchment areas. In steep catchments, something more sophisticated form of data transfer may be appropriate to reflect that (especially in steep areas) upstream catchments generally produce bigger specific runoff rates (i.e. m^3s^{-1} per km^2) than do catchments to downstream sites.

6.3.3 Application to non-catchments

It is reprehensible that the IH Report 124 method is sometimes applied to areas that are not actually catchments. This practice encourages designers to focus only on their development site. Implementations recommended in spreadsheet's and in detailed documents such as

Kellagher (2012) instruct the user to consider only the development site itself, irrespective of whether this represents a complete topographic catchment. Moreover, users are instructed to discount those areas of the development site that are being left nominally green, and not being drained [see calculation tool in Section 4.1 of Kellagher (2012)]. This level of abuse of applied hydrological research is extraordinary. The author may argue that the guidance is for preliminary appraisals only. But, once introduced, shoddy thinking is liable to persist.

It is a recognised principle of flood risk management that the catchment is the correct unit to use when assessing flooding problems and when demonstrating the soundness of proposed designs. Legal precedents [perhaps most famously, Rylands *v* Fletcher and Bybrook Barn Garden Centre *v* Kent County Council] require the developer and the planning authority to be alert to the possible adverse impact of development on flood risk to property owners and residents downstream. But this must surely also imply that full account be taken of floodwater entering the development site from upstream!

I am confident that the principle (if not the delivery) is well understood by all parties. But how can it be correct to apply flood estimation methods to non-catchments whilst purporting to respect the catchment approach?

6.3.4 Steep catchments

Although of very minor significance compared to the defects noted above, it is a possible weakness to be applying – on *catchments* (as opposed to *sites*) as steep as Bingley Road and Derry Hill – a flood estimation formula (Equation 6.1) that does not recognise catchment slope explicitly.

7 Evolution of Menston in relation to drainage

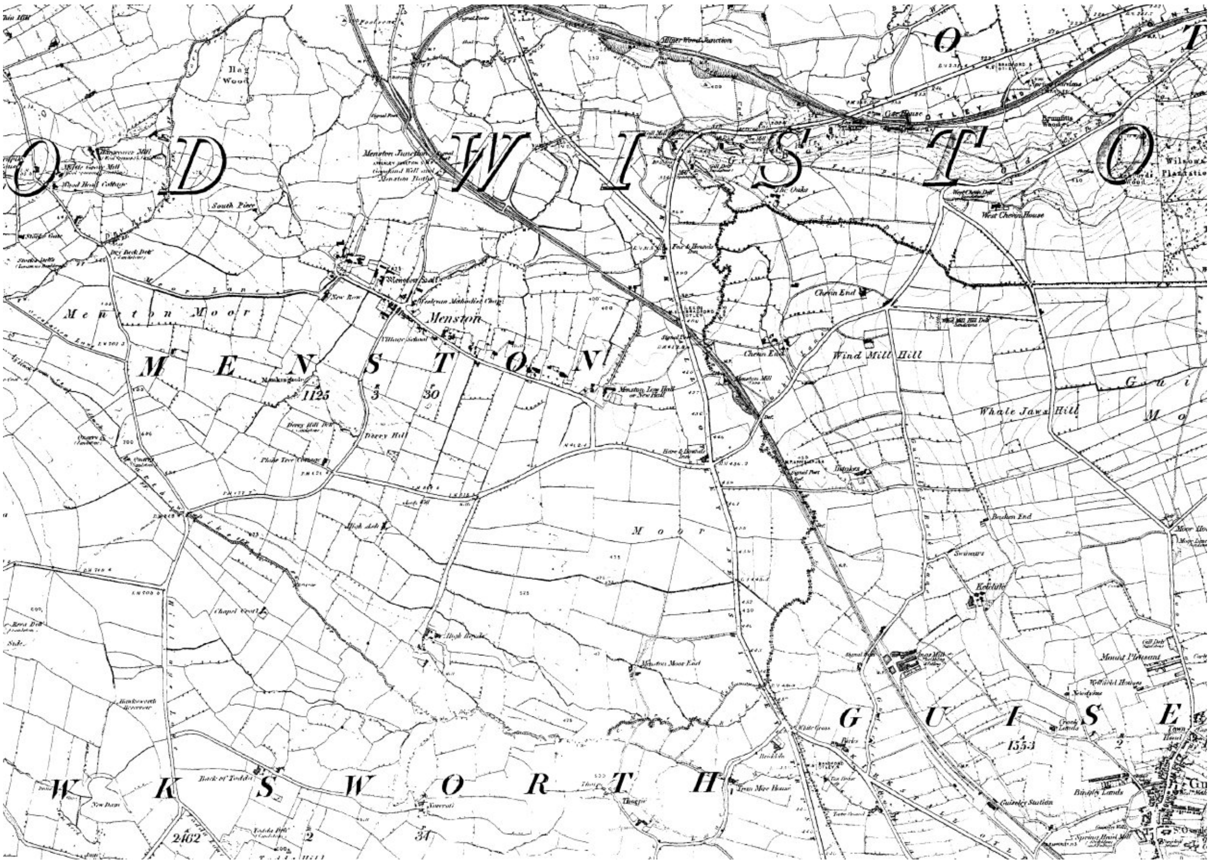
7.1 Catchment features in 1851

Ordnance Survey maps dating from the middle of the 19th Century in 1851 (see Map 4.2 above and Map 7.1 below) are a valuable guide to the stream configuration prior to the expansion of Menston village that took place once the railway had become established and (especially) after the opening of HRH in October 1888 (see also Figure 4.1).

7.2 Peculiar configuration at Menston

At Burley in Wharfedale, most development has stayed N of the railway and at a relatively low elevation. The natural stream network draining NE from Burley Moor is considerably clearer (and less culverted) than the equivalent in Menston. The 1934 Burley map (see Map 7.2) copied from http://www.burley-in-wharfedale.org/gallery/maps/photo10.jpg marks four main becks coming off the moors: Rushy Beck, Coldstone Beck, Wood Head Beck and Carr Beck. These are substantially still evident in modern-day 1:25,000 maps.

The distinctive situation at Menston – in contrast to Burley in Wharfedale, Ben Rhydding and Ilkley – largely reflects the unique configuration of Matthew Dike (see Chapter 3) in intercepting much of the moorland water … at least most of the time.



Map 7.1: OS 1851 1:10,560 map

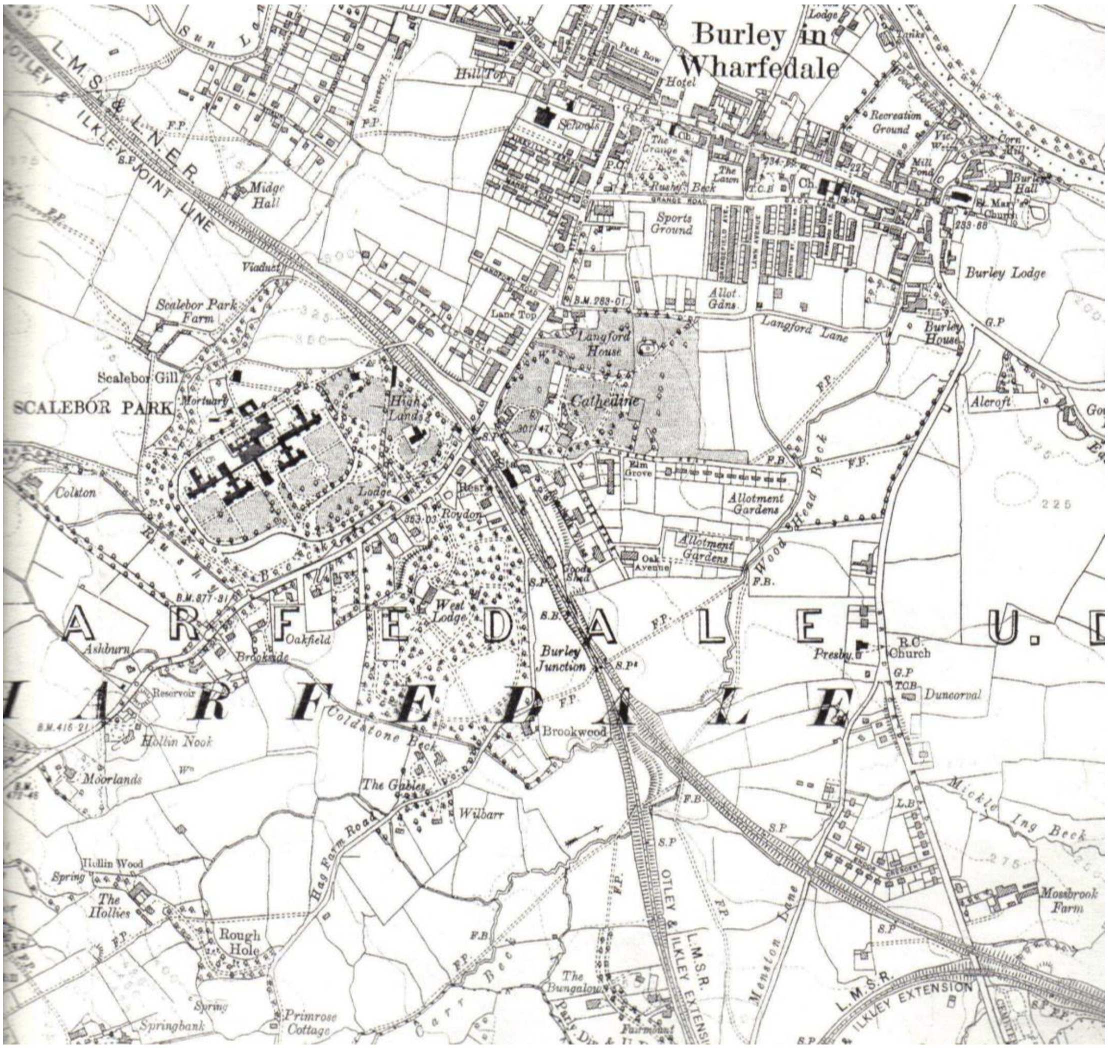
7.3 Development and drainage in Menston – the briefest overview

The history of development in Menston is that minor watercourses – some of them seasonal – have been culverted, sewered, filled in or obstructed as development has progressed. Local history books make many references to small streams (and some springs and wells) that are now obscured or no longer exist. Some of these appear on old maps. It has been helpful to study the old maps presented in the Groundsure Report which forms Appendix B to the Sirius C3545 Geoenvironmental Appraisal of the Bingley Road site prepared for Taylor Wimpey UK in December 2009.

Listing and naming the many examples went well beyond what could be attempted in a 6-week review. An arbitrary (almost trivial) example must suffice. p54 of Preston (1994) reports:

> [In about 1966/67] " 'There was great excitement amongst the children as the new [infant school] building was erected and it provided ready-made opportunities for learning experiences. Alongside the playing fields of the old school was a long ditch lined with alder trees, beyond which lay the ground for the new building. This area had often been explored by groups of children and teachers searching for wildlife. It was boggy in parts and a lot of drainage was needed to prepare the ground. The alder trees were felled and the excavators and large machines moved in. …' "

One hopes that the learning experiences of Menston children have not been in vain.



Map 7.2: 1934 map of Burley in Wharfedale

7.4 Development of land set aside for drainage or flood alleviation

I have found several examples where plots of land close to the line of watercourses or ponds shown on older maps have been left vacant (or green or set-aside for recreation) in the initial development only for the parcels of land to be developed at a later date.

I was already aware that a bungalow on Hawksworth Drive had been constructed on a site where a pond had formerly been mapped. [Compare 1969 and 1979 1:2500 maps seen in the Groundsure Report which forms Appendix B to the Sirius C3545 Geoenvironmental Appraisal of the Bingley Road site prepared for Taylor Wimpey UK in December 2009].

Three representations to the Menston draft SPD (see Consultees 19, 32 and 33 in 0) specifically refer to ponding of water behind or within the gardens of property on the south side of Hawksworth Drive.

p70 of Preston (1991): "When Hawksworth Drive was constructed (1968-1972), the top of the [school] field was relinquished to make way for the new road. The land to the south of the road, which was also part of the original school field, was used to build a small housing development in the 1980s." My perception is that there was nothing especially significant in the phased development of Hawksworth Drive. However, the section initially left unfilled includes the area on which one section of a watercourse is marked on the 1893 1:2500 map (seen in the Groundsure Report which forms Appendix B to the Sirius C3545 Geoenvironmental Appraisal of the Bingley Road site prepared for Taylor Wimpey UK in December 2009).

An example I came across by chance is of land on Derry Lane now used for recreation. This has clearly been raised above natural ground levels (see Photo 7.1). The local authority will presumably know whether this was done because the land was too often unacceptably wet or to meet some other amenity, landfill or special purpose.

Photo 7.1: Playground on north side of Derry Lane

A plot along the same general line (as the Derry Hill playground) had been left vacant on the south side of Hargrave Crescent. This is currently being filled by the construction of two houses under Planning Application 13/04012/FUL.

These examples illustrate the relentless and incremental nature of development … and the potential for forgetfulness in the planning system. These development pressures are not unique to Menston. But, given its unusual hydrogeological setting, the impacts are likely to be felt more strongly than elsewhere.

One final example has been well aired by others. It is contended that part of the Bingley Road site close to Red House Gardens had been allocated for flood attenuation. This sounds plausible and I regret that the Environment Agency does not appear to have been clearer on the matter.

The Red House provides in microcosm an example of the sequential nature of development. The 1937 (and earlier) 1:2500 maps (seen in the Groundsure Report which forms Appendix B to the Sirius C3545 Geoenvironmental Appraisal of the Bingley Road site prepared for Taylor Wimpey UK in December 2009) mark a pond in the SE corner of the grounds of The Red House. However, the 1969 (and later) 1:2500 maps mark a water sink here. While it is possible that the original pond was artificial, and that the lining eventually breached, it seems more likely that the change reflects the sensitivity of the feature to groundwater levels in the local aquifer. The groundwater abstraction at HRH likely caused the pond to perish.

A fear of local residents Mr & Mrs Booth is that ponding will again become a regular feature. I am unclear about the precise drainage arrangements in this vicinity, or their full history, so I will not say more. But it is undoubtedly a hot-spot for flooding.

8 What actions might be taken?

This chapter considers actions that might be taken to make the Bingley Road and Derry Hill sites less flood-prone. Please note that these fixes are speculative and potentially costly.

8.1 Bingley Road site

8.1.1 Present failure to meet sustainability criteria

Reed (2011) defines a sustainable system as one that balances cost, environment and aspiration. Three-way balances are intrinsically difficult. It should therefore be no surprise that interpretations of what makes a system sustainable are a frequent source of misunderstanding and dispute.

The definition followed in development of the Derry Hill and Bingley Road sites refers only to ensuring that the development deals with runoff from rainfall. This is not sustainable when it is known that spring flows are an important feature on the Derry Hill and Bingley Road catchments.

The latest plans for the Bingley Road development – received too late for detailed scrutiny – appear to indicate that spring water will be piped through the development site. This amounts to culverting the watercourse in a manner that minimises the storage of water on site.

This breaches the principle that development should not aggravate flood risk downstream. To pipe the spring water is to pass the problem on without attenuation. In the present position, emergent spring water is naturally attenuated by ponding of water on the development site. This will be lost if the spring water is piped.

Chapter 4 has identified the important past influence of groundwater abstraction at HRH. A possible remedy is blindingly obvious.

8.1.2 Groundwater control by pumping

One possibility relevant to the Bingley Road site is to seek to control groundwater levels by groundwater pumping. This would act to lower water levels in the aquifer, thus freeing up storage to help attenuate runoff into and from the development site. Subject to approvals from the Environment Agency and the agreement of the current licence-holder, pumping might resume at the HRH borehole.

It appears that the pump house (though not the storage reservoir nor the pipeline and easement connecting the two) was conveyed to Gladedale as part of their acquisition of the

HRH site. Environment Agency records indicate that the most recent holder of the right to abstract groundwater is Gladedale (Yorkshire) Ltd, under Licence Serial No. 2/27/19/172 (effective 5 March 2007).

Undertaken in conjunction with water-level monitoring in boreholes on the Bingley Road site, trials might confirm the effectiveness of such pumping in controlling groundwater levels and spring flows in and above the site. If, as seems likely, this proves to be quite effective, the question arises as to where the water is pumped in the long term, and to what additional benefit or consequential detriment.

Pumping to Mire Beck might loosely emulate the conditions experienced historically when water was abstracted for use at High Royds Hospital and – after wastewater treatment – discharged to Mire Beck. It might be advisable to locate the discharge to the Mire Beck some distance away from the abstraction borehole and at a level not much higher than the target groundwater level in the abstraction borehole, to minimise energy costs, to lessen the scope for recirculation and to maximise drainage benefits to the Chevin Park site as a whole.

As a prior measure, it would be advisable to review direct evidence of the extent of groundwater level recovery following cessation of HRH pumping in 2003. Questions that might be asked include:

- Are the minor valleys immediately west of the HRH site still dry?
- How prevalent is groundwater flooding of basements/cellars at HRH?
- Do former maintenance staff recall, or archive records indicate, that these basements sometimes flooded during the lifetime of the hospital?

It would be advisable to consult a geotechnical engineer with expertise in groundwater level control – or, at minimum, a highly experienced hydrogeologist – before this course of action is relied on.

It might be possible to offset some of the cost of pumping against environmental gains to wetland habitats near the discharge point, in addition to benefits to some residents of reduced frequency of flooding of basements. Because of the additional discharge to Mire Beck, the views of the Environment Agency will be important.

8.2 Derry Hill site

I am doubtful that the upper course of Matthew Dike can be secured against spillage into the Derry Hill catchment. To guarantee that Matthew Dike overflows to Site H *only in the most exceptional floods*, it might be necessary to line the channel and to install sediment traps where significant tributaries join from the slopes of Reva Hill. In this respect, the critical reach of Matthew Dike seems to run from about 415500 443750 to 415850 443500 over a channel length of at least 500 m.

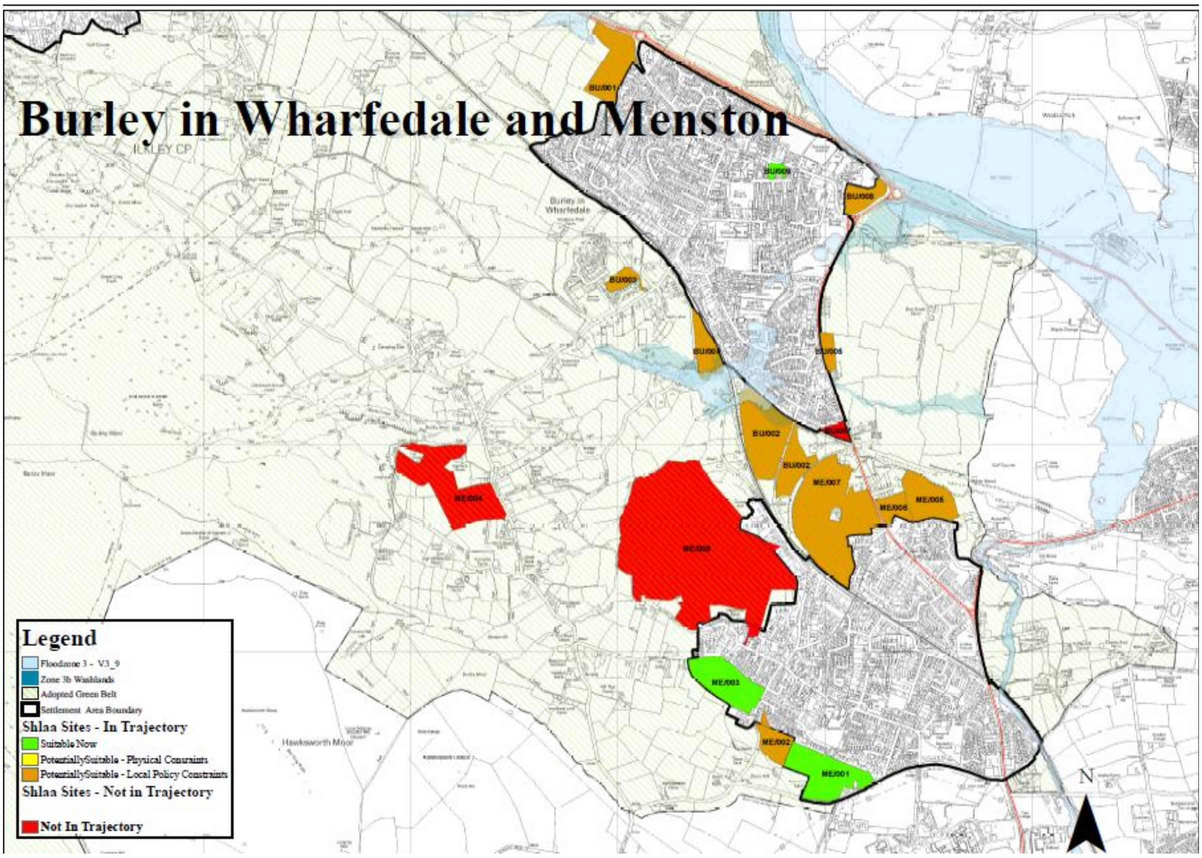
Given the boggy ground between Matthew Dike and Matthew Dike Farmhouse, access for heavy equipment could be problematic. Any drainage improvement works would of course require landowner agreement. Canalisation of the upper course of Matthew Dike might be to the detriment of agricultural use of the land. The sediment traps would require maintenance.

A more secure approach could be to formalise flood storage on the upstream side of Site H on Hillings Lane. This might incorporate raising of the highway. Given the presence of seepage, reference to a suitably experienced geotechnical engineer or dam engineer would be required. The works would also require agreement with the landowner. The views of the Environment Agency will be important.

The further work recommended in Section 9.1 has some bearing on the Derry Hill site.

8.3 How did we get to this position?

There is a requirement for more housing. In an attempt to understand how these problematic lands came to be firmly allocated for development, I briefly examined the Strategic Housing Land Availability Assessment (SHLAA) Settlement Analysis Map and Tables for Burley in Wharfedale and Menston. The [March 2013?] SHLAA reveals a fairly relaxed regard for fluvial flood risk, with three of the 15 sites including some land in Flood Zone 3. In this respect, BU/002 is perhaps the most alarming allocation of potentially suitable land.



Map 8.1: Sites considered in the Strategic Housing Land Availability Assessment (SHLAA)

The description (see Box 8.1) of ME/002 as a level area of land is incomprehensible. Immediately east of Derry Hill, the land is steeply sloping (see Figure 8.1a).

The current designation of ME/008 (land north of Bleach Mill Lane) as unsuitable is understandable, not least given the difficult access via Bleach Mill Lane. However, undesignated land south of Bleach Mill Lane is less steeply graded (see Figure 8.1b) and might be accessible via Moor Lane.

(a) ME/002, immediately east of Derry Hill

(b) Land south of Bleach Mill Lane

Figure 8.1: Greenfield land contiguous with currently developed areas in Menston

Box 8.1: SHLAA Settlement Analysis for Burley in Wharfedale and Menston (subset only)

BU/002 Menston Old Lane, Burley in Wharfedale: "Sloping and level fields either side of Menston Old Lane, east of the railway line and south of the disused Menston to Otley railway line. This is large site and is likely to require off and on site highway infrastructure."

BU/004 Hag Farm Road, Burley in Wharfedale: "Land to west of the Wharfedale railway lin [sic] accessed via private road serving a small number of homes. The site is level to slightly sloping with trees on the boundary. A small part of the southern edge falls within the flood zone."

ME/001 Bingley Road, Menston: "Sloping fields behind existing homes and farm. Application was pending for up to 135 new homes on part of the site and open space at the base date. This has now been approved in principal the site has further capacity in addition to this number of units. Forecasted yield currently appears in the trajectory this will be updated at the next review."

ME/002 Bingley Road, Menston: "Level area of land within the green belt with potential for development. Landowners current intentions are unknown."

ME/007 Burley Road, Menston: "Undulating pasture with open views to the moor beyond. Pockets of the site closest to the urban area could come forward sooner but in the main the off site infrastructure required will in the main delay the developability of the site."

ME/008 Bleach Mill Lane, Menston: "Rolling countryside to the west of Menston. 2 scheduled ancient monuments are present on the site. Access is extremely poor and the site is out of scale with the size of the settlement and is thus considered to be unsuitable."

9 Further work

9.1 Water resources information

Menston Waterworks Company initiated a largely spring-fed supply from gathering grounds where the headwaters of the Dry Beck and Matthew Dike abut. I have yet to satisfy myself of the precise facts. It would be helpful to establish what changes (if any) have been made in Yorkshire Water's abstraction of groundwater in the Menston area. Some supply changes have clearly been made in connection with selling off the Pump House (near Stocks Hill) on Occupation Lane and of Menston Service Reservoir. The name of the service reservoir is sometimes prefixed "Moor Lane". In view of the perceived consequences of cessation of the HRH groundwater abstraction in 2003, it will be prudent to confirm that YW groundwater abstractions around Stocks Hill have not changed materially in recent decades.

While annual returns of quantities abstracted could be sought from the Environment Agency in a Freedom of Information request, the informed cooperation of Yorkshire Water would be a considerable asset. The aim would be to confirm whether cessation of the HRH groundwater abstraction is the only notable change affecting groundwater levels close to Menston.

9.2 Flood chronologies

It would be helpful to search local newspaper records for evidence of flood impacts (and the absence of flood impacts) in Menston. A starting point will be to examine the dates in the flood chronologies presented in Appendix F (for the Wharfe) and Appendix G (for Menston).

Searching on both sets of flood dates should help to dispel the myth that Menston is principally sensitive to long duration rainfall events. It should be noted that the list of flood events that I have compiled for Menston is tentative. Local residents and historians may be able to add to it.

9.3 Other matters

9.3.1 Logistics

I had hoped to inspect archive records of the Menston Waterworks Company Ltd held by the West Yorkshire Archive Service (WYAS). For a combination of reasons – including a persistent chest infection and WYAS constraints – this fell down my list of priorities. The items related to Menston Waterworks include BMT/IL 3/3 and BMT/IL 3/6 administered by WYAS Bradford and item QE20/1/1898/22 administered by WYAS Wakefield.

Speaking of logistical difficulties, it is relevant to note the complication that – in the vicinity of HRH – Mire Beck forms the boundary between CBMDC and Leeds City Council (LCC). In a Section 106 agreement signed on 28 January 2005, LCC required contributions from the developers of the land at High Royds Hospital towards drainage improvements on some sections of the Mire Beck.

9.3.2 Designing for exceedance

It is trumpeted that drainage practice should adopt the principle of designing for exceedance (see Digman *et al*., 2006). Expressed in plain language, the principle recognises that a drainage system design with care and prudent expenditure will be overwhelmed by the exceptional flood that occasionally arises. The best example locally is the Ilkley storm of 12 July 1900.

Major developments – such as (the larger) Bingley Road site and the Derry Hill – inevitably extend or alter the drainage system. It is important for either the developer or the planning authority to consider what happens when an extreme storm eventually strikes their catchment. What route would excess floodwater take and with what likely outcome? To the known hot-spots listed in Section 2.9.1, it might be prudent to add the railway line at the foot of Cleasby Road.

Acknowledgements

Given the nature of the brief, I have worked independently. Being a self-employed sole-trader, this is nothing new. I am very grateful to Mr and Mrs Armstrong for their cooperation in allowing me to roam Matthew Dike Farm, to all staff at Menston Library and to those authors (some still living) who have written local histories.

The Environment Agency met my request for HRH groundwater abstraction information with courtesy and efficiency. However, it is disappointing that the annual returns of quantities abstracted are incomplete and that accessible EA holdings of these statutory returns seldom go back earlier than 1993.

References

Aitkenhead, N. and Riley, N.J. 1996. Kinderscoutian and Marsdenian successions in the Bradup and Hag Farm boreholes, near Ilkley, west Yorkshire. *Proc. Yorkshire Geol. Soc.*, **51**: 115–125. [See also discussion of paper on pp 373–374 of the same volume.]

Bayliss, A.C. and Reed, D.W. 2001. The use of historical data in flood frequency estimation. Report to MAFF, 87pp. http://nora.nerc.ac.uk/8060/1/BaylissRepN008060CR.pdf

Brumfitt, E. 1988. Otley and Menston: A glimpse of the past. M.T.D. Rigg (Publications), 139pp.

City of Bradford MDC 2003. Menston Conservation Area assessment. City of Bradford MDC, 67pp.

City of Bradford MDC 2007. Menston Conservation Area appraisal. City of Bradford MDC, 14pp.

Digman, C., Balmforth, D., Kellagher, R. and Butler, D. 2006. Designing for exceedance in urban drainage - good practice. CIRIA report C635, 255pp.

Fletcher, E.M. 1953. The story of Menston. Menston Coronation Committee, 51pp.

Fletcher, E.M. 1971. The story of the Manor of Menston and its site from AD971 to AD1971. Ernest Cummins Printers, 68pp + plates.

JDR 2014. A report on the observed rainfall run-off on the Derry Hill and Bingley Road sites during prolonged rainfall events. [JDR = Prof J David Rhodes]

Kell, J.H. 2014. Menston remembered. Croft Publications, Boroughbridge, 208pp.

Kellagher, R. 2012. Preliminary rainfall runoff management for developments. EA R&D Technical Report W5-074/A/TR/1, Revision E, HR Wallingford Report SR 744, 109pp.

Laurence, A. 1991. A history of Menston and Hawksworth. Smith Settle, 103pp.

Marsh, T.J., Monkhouse, R.A., Arnell, N.W., Lees, M.L., Reynard, N.S. 1994. The 1988-92 Drought. Hydrological data UK series, Institute of Hydrology/British Geological Survey, Wallingford, 78pp.

NERC 1975. *Flood Studies Report* (5 volumes). Natural Environment Research Council, Wallingford, UK.

Preston, D. 1994. Menston Village Schools: 1622-1995. Smith Settle, Otley, 72pp.

Reed, D.W. 1987. Engaged on the ungauged: Applications of the FSR rainfall-runoff method of flood estimation. Proc. BHS National Hydrol. Symp., Hull, September 1987, 2.1–2.19.

Reed, D.W. 2002. Reinforcing flood-risk estimation. *Phil. Trans. Roy. Soc. Lond., Series A*, **360**: 1373-1387.

Reed, D.W. 2004. A review of British railway bridge flood failures. Proc. BHS International Conf., London, 12-16 July 2004, 210-216.

Reed, D.W. 2011. Letters in applied hydrology. DWRconsult, 86pp.

Waters, C.N. 1999. Geology of the Bradford district: A brief explanation of the geological Sheet 69 Bradford. British Geological Survey, Keyworth, 31pp.

Appendices

Appendix A Miniature Curriculum Vitae

Name	Dr Duncan W Reed	Profession	Hydrologist
		Address	Duncan Reed, DWRconsult 32 Ilges Lane, Cholsey Wallingford, Oxfordshire OX10 9PA, UK
		Tel	+44 (0)1491 651441
Date of birth	19 July 1951	Mobile	+44 (0)7929 214544
Birthplace	Bramley, West Yorkshire	Nationality	British
E-mail	duncanreed@dwrconsult.demon.co.uk		

A1 Career summary (very brief)

2001 - date	Independent consulting hydrologist (self-employed, trading as DWRconsult).
1999 - 2001	Head of Risks & Hydrological Extremes Division, CEH Wallingford (formerly Institute of Hydrology). Senior manager responsible for 25 scientists researching frequency estimation, flood risk mapping, hydrological & climate-impact modelling, rainfall & flood forecasting, trend detection and urban studies.
1991 - 2001	International expert on spatial dependence in rainfall extremes, regional frequency analysis and reservoir flood safety assessment. Expert studies of UK flood risk problems, inc. Sellafield (2000), Northampton (1999), Boroughbridge (1998) and Bideford (1993).
1994 - 1999	Leader of £1.9m *Flood Estimation Handbook* research programme to develop & implement generalised methods for UK rainfall & flood frequency estimation.
1979 - 1994	Various research positions at Institute of Hydrology: reservoir floods research, rainfall frequency studies, generic studies of dependence in extremes …
1976 - 1979	Hydrologist with North West Water. Water resource & hydrological analyses.

A2 Education

1972	BSc (1st Class Hons) in Applied Maths & Computing Science, Univ. of

	Sheffield.
1976	PhD in Appl. Science, Dept of Engineering Maths, Univ. of Newcastle upon Tyne. Thesis: *Deterministic modelling of catchment systems*.

A3 Membership of professional institutions

1979 - date	MCIWEM: Full member of CIWEM (Chartered Institution of Water & Environmental Management).
1983 - date	Member of British Hydrological Society.
2001 - date	Fellow of Royal Statistical Society.
2013 - date	Fellow of Royal Meteorological Society.

A4 Recent international experience (selected)

2012-2014	Editor of Technical Research Reports comprising Irish Flood Studies Update (published July 2014).
2012-2103	Rainfall growth curve estimation in an arid zone. Aramco via AECOM.
2010-2012	"Second expert" for Aviva Insurance Europe SE in legal action regarding role of hydro-power dam operator in Nov 2009 Cork flood.
2004-2011	Technical advisor to Office of Public Works on Irish Flood Studies Update. [Major R&D programme inc. research on flood frequency and rainfall frequency estimation, digital catchment data and web-based implementation of methods.]

A5 Recent UK experience (selected)

2014	2013/14 flood rarity in SE England. Reviewer of preliminary JBA assessments.
2009-2011	Flood risk in (fenland) pumped catchments. Hydrol. advisor to HR Wallingford.
2010	Rainfall frequency scrutiny of wet-weather claim at Norton Fitzwarren. Report to Barratt Homes and Hyder, July 2010, 17pp; solicitor forwarded to Adjudicator.
2001-date	Numerous reviews of flood estimation assessments for consultants and others.
2006-2008	Advanced workshops on flood risk estimation based on client case-examples. Special events for Capita Symonds, Atkins Water and Bureau Veritas.
2007-2008	Expert witness on frequency & non-stationarity of Lower Thames floods. Report and proofs of evidence for McCarthy & Stone (via Peter Brett Associates). Decisive contribution. Planning appeal against Local Authority and EA upheld.

Please visit **www.dwrconsult.demon.co.uk/business/jobsdone.html** for a full list.

A6 Recent publications (selected)

Reed, D.W. 2011. *Letters in applied hydrology*. DWRconsult, 88pp. Available at www.lulu.com.

Reed, D.W. 2009. *Basinwide flood-risk mapping: beware hydropendicitis*. Proc. 33rd IAHR Congress, Water Engineering for a Sustainable Environment, Vancouver, 9-14 August 2009, 8pp.

Reed, D.W. 2008b. *Inter-site dependence in extremes: unlocking extra information*. Proc. FLOODrisk2008 International Conf., Oxford, 30 September – 2 October 2008.

Reed, D.W. 2008a. *Eight things you don't want to know about flood risk*. Proc. Flood and Coastal Management 2008 Conf., Manchester, 1-3 July 2008, 8pp.

See www.dwrconsult.demon.co.uk/business/publications.html for full list & to view abstracts.

Appendix B Feedback letter on JDR methods of rainfall-runoff assessment

Prof J David Rhodes
Isotek Oil and Gas Ltd
9 Clayton Wood Bank
West Park Ring Road
Leeds
LS16 6QZ

32 Ilges Lane
Cholsey
Wallingford
Oxfordshire
OX10 9PA

Date 12 September 2014

Your ref: Letter of 20 Aug 2014 and email exchange of 22 Aug 2014

My ref : job060/letter

Dear David

Feedback on JDR methods of rainfall-runoff assessment

Thanks for the opportunity to comment on the draft paper "General constraints on water runoff from a rainfall event" and related matters. I found myself immensely interested in the related matters but barely lukewarm about the paper. So that you can tell that this is nothing personal, it may help to know where I am coming from.

My conversion from mathematician to hydrologist began in October 1969, when I accepted an SRC Engineering Mathematics Award to do research at the University of Newcastle upon Tyne. Naughtily, my doctoral studies looked at the application of linear systems analysis to the deterministic modelling of catchments: something that belonged in NERC's domain at the time. The greater change in outlook came during the 3.5-year period I worked for North West Water Authority alongside design engineers and operational staff. Arriving in January 1976, I was just in time for the famous drought. I became absolutely committed to problem-solving, and this marked my later research career. For better or worse, I have never given tuppence for peer review or genuflection ever since.

My father was a fine scientist and a true polymath. As a Lancastrian working in Yorkshire, he was given to bluntness … the only trait I have really inherited! Almost 25 years after his death – his career at Leeds University was always plagued by ill health – Ronald Reed's amazing knowledge is still remembered by some studying ancient parchments and skins. [He made extensive use of electron microscopy: first with Astbury and then in the Leather Department and its successors. Subsumption into Food Science was far from ideal. He was perhaps most at home in the Leeds Lit and Phil. Mum gave his Dead Sea Scrolls collection to the John Rylands Library in Manchester, the university where they met as undergraduates. Conservation in a dark damp loft in Pudsey had done a better job on the scroll off-cuts than professionals had managed elsewhere, and the materials have again been used in active research.]

I won't itemise my career beyond saying that I led the research team that produced the UK Flood Estimation Handbook in 1999. You may find a copy of my book "Letters in applied hydrology" in your post. Despite its many word-plays, the book is entirely serious. So please pass the copy on if it is not to your taste or need. The research topic that interests me most is inter-site dependence in rainfall, flood and drought extremes.

Comments on the draft paper

Lots of things irritated me about the paper. Given that I started out in research by applying linear systems analysis to rainfall-runoff modelling, I have at least enjoyed a brief wander down Memory Lane.

Notation

I was irritated by the notation. D is commonly used for duration of rainfall, PR is used to denote percentage runoff (i.e. % of rainfall becoming flood runoff), and N is commonly used to denote an integer such as the number of gauged sites or the number of flood events. Rainfall is generally measured in mm, and rainfall rates in mm/h. "Rainfall per unit area" is a bizarre phrasing.

Linear systems analysis

I am easily irritated by linear systems analysis (LSA). In "harder" sciences, there may well be mileage in particular transform techniques. But in the flimsy science of hydrology, I find the range of methods a distraction. In hydrology, the linear system is typically written as the convolution relation:

$$y(t) = \int_0^t h(\tau)\, x(t-\tau)\, d\tau$$

where y is the quick-response runoff and x is the causal (or net or effective or excess) rainfall. Although the standard convention is otherwise, it is neat to represent x and y as rates in mm/hour over the catchment. h is the system response function. In rainfall-runoff analysis it is called the *instantaneous unit hydrograph*.

http://co2.coe.utah.edu/CVEEN4410b/class/class_17/Class17_unithydrographconvolution.pdf presents an introduction to unit hydrograph methods though runs a mile to avoid presenting anything as scary as an integral equation. Still, it gives a discrete version of the convolution relation OK and I give top marks to anyone who knows to write "convolve" rather than "convolute"!

A plethora of LSA methods for rainfall-runoff modelling appeared in the 1960s and early 1970s. In the first few months of my PhD research, I had to find a diplomatic way of telling one of my supervisors that his Laplace transform method of deriving the system response function was OK as far as it went (not very far) but that he had misconstrued use of the Mellin transform. He had miswritten the upper limit in the convolution relation as the time interval T rather than varying time t and his results were wrong. The faulty conference paper melted away in the literature but other faulty findings do not. The Dis a peer page from my book presents a classic example. Such experience underlies my disrespect for peer review.

When applying LSA methods, I favoured a straightforward discretisation of the convolution relation, and solution (i.e. "deconvolution" to identify h from x and y) by a linear least-squares method using Householder (orthogonal) transformations. My chief PhD novelty was to take special measures to avoid the worst effects of ill-conditioning, by forcing the derived unit hydrograph (UH) to be unimodal. I liked this "restricted least squares" method because the user could see what they were getting.

But, post-Thatcher, HEI scientists criticised all UH methods so heavily that it became impractical to secure further funding. UK research on rainfall-runoff modelling went off in many different directions: statistical, physical and conceptual. Research groups did their own thing with little more than genuflection towards the importance of developing tools to solve practical problems.

Rainfall-runoff models in which the water stored plays a central role

In the early 1970s, Lambert developed an empirical approach that gives a central role to tracking the volume of water (expressed as mm over the catchment) stored in the catchment. This is the ISO-function (Inflow-Storage-Outflow function) method. Because it was useful and developed by an engineer, the method never quite gained the attention it deserved! But ISO-functions did gain currency through a WMO technology transfer scheme that was especially active in the 1980s:
https://www.wmo.int/pages/prog/hwrp/homs/Components/English/j04105.htm.

The ISO-function method was developed for real-time flow forecasting. The assumption is made of a unique (monotonic rising) relationship between water stored and the catchment outflow*. When you receive a new telemetered observation of flow at the catchment outlet – usually this is a flow inferred from a sensed water level – you can immediately update the modelled value of stored water. This is exceptionally useful because the most important thing in flood warning is to be up-to-the-minute (see flood forecasting page of book). [*This assumption is not strictly valid. Hysteretic effects mean that the relationship between flow and water stored will be different in the recession phase of a flood event. But the approach can be fine in real-time flood forecasting, where the focus is mainly on the rising limb of the hydrograph.]

ISO-function models can provide for a change in behaviour during wetter conditions, e.g. by formulating the ISO-function as piecewise linear segments. Some ISO-function models are explicitly nonlinear.

I mention ISO-functions here because I think you are right to consider important the water stored on/in the catchment above Menston.

Applying LSA methods without rainfall data

Researchers in Ireland (Parmentier, Dooge and Bruen, 2003) present a method for deriving the UH from runoff data alone. It uses a root-finding technique and cites a 1979 paper by de Laine. Estimation of the system response function from a long record of the output variable is possible because (in effect) you pick out those features of the hydrograph response that are always there i.e. regardless of whether the flood was triggered by a short-duration, long-duration or highly complex storm. I suspect that such methods are highly developed in some other sciences! But estimation of the response function from input data alone (i.e. just rainfall data) is not possible in any useful way.

Explanations for LSA methods being so primitive in rainfall-runoff modelling are that the overall catchment system is insufficiently linear and that rainfall data are way too patchy. But features such as the disciplinary background of research hydrologists no doubt play a factor.

LSA methods do not provide a rainfall-runoff model

An important point to note is that the LSA approach deals only with net rainfall. The analyst has to decide how to distinguish the part of rainfall that is effective (in terms of producing flood runoff) from that which is "lost" to: neutralising soil moisture deficits, filling local depressions, evaporation, infiltration to an aquifer, etc. [These are all things that don't contribute to the flood runoff … except, of course, that groundwater can be influential to flooding in exceptional cases such as above Menston!]

Processes giving rise to "losses" are anything but linear. Threshold effects are characteristic at all spatial scales within a catchment. "This much and nothing much happens; this much and things start to motor." Until you model the losses, you do not have a rainfall-runoff model. It is unacceptable to assume 100% runoff. You will appreciate that it is unacceptable to impose a linear system when threshold effects are such a strong feature.

Although I can just about see where you are coming from, it seems ridiculous to present a new twist on LSA methods by reference to a case study where you do not have paired rainfall and flow data. If you are serious about publishing the method, you will need to concentrate on a gauged catchment such as the Leven at Tarm. [My recollection is that the Leven is a lively river. So it might make for an interesting case study. My copy (of the figure in Appendix E of your later report) is not very clear but it looks as though a fixed proportion of rainfall has been taken to be effective. This may not be realistic. In practice, "losses" tend to be proportionately greater in the early part of a flood event than later on.] Please note that I have no personal interest in doing such studies or in seeing them done. My research interests lie elsewhere.

Sadly, it is not uncommon for even experienced rainfall-runoff analysts to overlook that calibrating the overall rainfall-runoff model involves more than just deriving the average unit hydrograph (i.e. system response function). One has to model the reduction of rainfall to net rainfall and also represent the contribution of slow runoff (or "baseflow") to the final hydrograph. My apology for the repetition but this point is important. Please look at Slide 5 in: http://co2.coe.utah.edu/CVEEN4410b/class/class_17/Class17_unithydrographconvolution.pdf if my terminology has confused you.

Is it worth the candle?

The aspect that your method focuses on is, I agree, rather interesting. I think you are saying that – irrespective of the detailed temporal profile of rainfall (which the rainfall data in Figure 3 of your paper confirms to have been decidedly complex for the 24-26 September 2012 event) – a linear system cannot deliver as an output a greater proportion of the total flow in a time window of particular width than the greatest proportion that the input achieves in this time window as a proportion of the total rainfall.

I can accept this statement with the sole proviso that it assumes that the temporal profile of the rainfall will need to be sufficiently indicative of the temporal profile of the effective rainfall. However, your method seems to be a blunt tool. I doubt that the inequality thus determined is worth the candle.

It seems to be saying that, as the point of interest moves to downstream sites, the system response function inevitably becomes more attenuated. Any method that produced flood estimates that did not comply with this feature would be very quickly thrown out!

Put another way, the three physical constraints you note and enforce in Appendix E of the later report are too obvious to add value. They are necessary but not sufficient.

I note the very thoughtful caveats you make in lines 71-74 of the draft paper. The above natural state of play can be over-turned in the event of an abrupt failure of a dam, embankment, trash-dam or hill-slope (by landsliding). [The scope for such eventualities needs to be considered by the engineer when judging the efficacy of a planned development and its flood alleviation works. If the flood retention storage is of sufficient size, it may come within the ambit of the Reservoir Act 1975 and associated guidance.]

Conservatism

In general, we need “best” estimates. It is of little use in design flood estimation to make best-case or worst-case assumptions. [This is absolutely not the case when rainfall-runoff models are used for real-time flow forecasting or when critical infrastructure is concerned, where a degree of conservatism can be appropriate.] Unspecified conservatism obstructs clear understanding of whether the required design condition – e.g. that flooding downstream is not made worse in anything less than (say) a 200-year event – has been met.

I suspect that no amount of conservatism can convert an inferior method into a better one. Maybe I will think of a counter-example after clicking “send”!

Flood alleviation is costly. If an overly large scheme is built in one place, the capital is lost and there is reduced opportunity to find capital for necessary (and perhaps urgent) flood alleviation works elsewhere.

Conservatism in design at an upstream site can sometimes worsen flooding problems downstream.

Sensitivity

Nevertheless, when a “best” flood estimate has been reached, it can be prudent and informative to test the sensitivity of the overall scheme to uncertainty in the design hydrograph.

When asking such “what if?” questions, it typically suffices to make factorial changes: e.g. how large would the proposed flood retention storage need to be if the design flood hydrograph were half/twice as big as our best estimate? And what if the same runoff volume occurred within 75%/133% of the event duration implicit in the best estimate?

Language

I got irritated by some of the language in the reports. Theorems are precise and formal things. So I rather expected those who use them to be precise with language elsewhere!

Figure 3 of the paper is a travesty. The graph shows raw rainfall data that are fully relevant. But the flows are simulated from the rainfall data under large assumptions. The caption "Rainfall and flow capture for September 2012 event" gives a wholly misleading impression.

Use of the phrase "capture line" annoyed me initially. Why not say "catchment" and note that a series of catchments is relevant as one's focus shifts downstream? Perhaps the unusual usage (of capture line) is warranted in the rare situation that some flood-producing runoff is crossing into (or out of) an area of interest by unspecified underground routes rather than in a formal channel. So that complaint might be unfair.

Other stuff

Generic methods have been used to derive the flood-risk map of Figure 2 and the simulated flood map for the September 2012 event. Such generic maps can be usefully "indicative" of flood risk – and are something to be borne in mind when there is little time or few data. However, such generic methods make a lot of assumptions. The unusual features of the catchment above Menston suggest to me that the generic methods are not to be trusted even in this minor way.

I found it hard to put theoretical paper to one side and Menston application to the other, since your draft paper and reports intertwine the two. Photographs and witness statements of the extent, timing and longevity of flooding are highly relevant information. But I struggled to keep track of how this information has been used. In line 272 of the paper, you state that the high flow was maintained for 5-6 hours. In line 293 of the paper, you state that the flow was observed to peak 5-6 hours after the peak in the rainfall. Perhaps both of these statements are correct. But I am unclear which photographs and witness statements support which statement. [The simulated flows in Figure 3 are neither here nor there. They are not observations.]

Although I think it was mentioned in the reports rather than in the paper, I was incensed at the notion that this catchment can only flood in long-duration rainfall events. This is completely wrong. My apology if you did not say that.

Summary

There's little point in me commenting further on the draft paper. One of the delights of self-employment is that I get to follow my interest, so you will be hard-pressed to get me to come up to Yorkshire to discuss your method. Sorry, but your method isn't going anywhere important.

I plan to invoice you for the agreed sum of £720 + VAT (12 hours at £60/hour + VAT) for the above feedback.

Notes and remarks on the Menston flooding problem

I have great respect for Jeremy Benn in all regards. In directing your enquiry towards me, he may have guessed that I would not be able to resist scratching this really interesting flooding problem!

You accepted my terms on 22 August 2014 including [with regard to the dispute about development and flooding problems in Menston] that: you must not quote my opinion in the case, whether in support or against.

I was already aware that the Menston flooding problem is a hot potato. Having delved further, I doubt that I will be able to police whether or not you respect this condition. Professional colleagues, family and family-friends in the area may report any abuse. However, life is too complicated and interests too changeable for that to be guaranteed. Anyway, the damage will have been done. It would be a great shame to weaken our strong mutual regard for Jeremy.

In deciding whether to respect the restriction that you must not quote my opinion in the case, I ask you to consider the following. There is a further outcome beyond whether the planned developments proceed, are changed or are abandoned. At some stage, nature will play a part. In the relatively steep setting of Menston, there could be loss of life as well as considerable damage to property.

For the avoidance of doubt, I attach my notes and remarks on the Menston flooding problem in a separate document. I am not charging for these notes and remarks on Menston. They are offered in goodwill from a fellow Yorkshireman.

Many thanks again for this interesting distraction.

Yours sincerely

Dr Duncan W Reed

Appendix C Proposal for independent review of Menston flooding problems

C1 Context

From material so far seen, I suspect that there is a fundamental problem with further upslope expansion of Menston village to the south. The requirement for new development not to worsen existing flooding problems (except in exceptionally rare events) can itself be a considerable challenge to meet. But there is also the requirement to ensure that new development is not itself unduly vulnerable to flooding.

Maps of flood risk published by the Environment Agency can provide an adequate representation of flood risk along the main river system, without necessarily doing so for small watercourses within the district. It is unwise to rely on generalised methods alone when planning major developments on small catchments, and foolish to ignore specific evidence of flooding problems and/or of unusual catchment features.

C2 Experience

I led the research team that developed the UK Flood Estimation Handbook. Published in 1999, the FEH revolutionised methods of flood estimation in the UK, and was the first study in any nation to present practitioners with generalised methods of flood estimation based on digital catchment data.

I resigned a senior management post at CEH Wallingford in 2001 and went into practice as a self-employed sole-trader (DWRconsult) specialising in flood research and consultancy. While I have not directly contributed to further development of the FEH, I have for many years acted as technical advisor to the Office of Public Works in planning, developing and implementing the Irish Flood Studies Update, published in June 2014.

Other expertise directly relevant to this independent review is reflected in my 1987 paper *Engaged on the ungauged: Applications of the FSR rainfall-runoff method of flood estimation* (Proc. BHS National Hydrol. Symp., Hull, September 1987, 2.1–2.19) and in my 2002 paper *Reinforcing flood-risk estimation* (Phil. Trans. R. Soc. Lond. A, 360, 1373-1387). These papers illustrate and proselytise how local information (historical and physical) can be used to improve or reinforce flood estimates based on generalised methods.

C3 Critical factors at Menston requiring examination

The three most influential factors affecting flood formation are the size of catchment, its climate, and the character of its soils and geology. The general wetness of the district is not in doubt, and is well represented in maps of average annual rainfall. However, there is considerable doubt about the effective drainage area to development sites above Menston. There is also reason to doubt that generalised representations adequately represent the unusual soils and geology on this flank of Rombald's Moor.

Historical maps indicate springs, sinks and intermittent streams consistent with a swift connection between surface water and groundwater. This appears consistent with photographs seen of the general terrain and of floodwater at sites above Menston during the flood event of September 2012. There is a history of groundwater abstraction (relatively close to the development sites) to supply the former High Royds Hospital. Although I have yet to inspect the evidence, I have seen reference to a geotechnical survey that found flowing groundwater at a shallow depth within one of the sites planned for development. In such unusual conditions, it is improper to rely wholly on generalised methods of flood estimation.

The major doubts about the effective catchment area and about the unusual soils and geology are themselves linked. Unusual topographic features run laterally across the lower slopes of Reva Hill. One hypothesis is that glacial or post-glacial effects led to weakening of soils and fracturing of sandstones, and that this made the hillside vulnerable to landslip.

The most prominent of these features is Matthew Dike. The name perhaps suggests a manmade structure rather than a geological remnant. From stream mapping, it has the appearance of a catchwater system that intercepts runoff from Reva Hill and redirects it laterally to join the headwaters of Mire Beck. However, I have yet to inspect or find a definitive account of the origin of these features.

C4 Specific questions

It is essential to examine the present condition of the above features in an attempt to establish:

i Whether Matthew Dike receives flood runoff from the northern flanks of Reva Hill and takes it transversely (towards High Royds and the Mire Beck) or whether some such runoff enters the area above Menston (where development is planned);

ii Whether the surface topography is so eroded or the subsurface geology so fractured that flood runoff now passes through or under Matthew Dike, and therefore enters the area above Menston (where development is planned);

iii The extent to which groundwater abstraction at High Royds Hospital used to influence (and partly control) groundwater levels in the district, and to judge the extent to which this abstraction may have masked flooding problems – during the upslope expansion of Menston village in the 20th Century – by artificially reducing flows in the native streams and by providing soil-water storage capacity to act as a buffer during heavy rainfall.

C5 Proposed work

C5.1 Studying documentation

Finding and reading documentation about recent and historical flooding incidents in, and above, Menston.

Digesting material concerned with the planning disputes, including the Sirius geotechnical report. It would be helpful to be pointed to the documents most relevant to understanding the positions taken by the developers and by Bradford MBC [sic]. It can be difficult to correct misapprehensions without knowing something of their origin.

Scrutinising the technical documentation supporting the developer's current assessment of flood risk and their plans for dealing with this.

Please note that I consider the various development sites above Menston to be sufficiently closely related in their physical setting as not exclude any one of them from perusal. The effective catchment to each development site may be somewhat indeterminate. If (as I suspect) shallow groundwater flows are a strong feature and specific precautions are not taken, the design and/or construction of one development may alter conditions for the neighbouring development. I will, however, reflect on your guidance should you judge this collective approach a hindrance or requiring special care at the reporting stage.

Inspecting the documentation – relating to an earlier development (about 20 years ago?) – in which the Environment Agency or its predecessor or some other body identified, designated or set aside a particular area for flood storage. In that era, these would likely have been called "balancing ponds". I consider this to be potentially very important.

I have heard reference to a road on the slopes of Reva Hill being impassable during one recent flood event. It would be helpful to know the date, time and location of the flooding, and the basis of the assertion. This may help to demonstrate that the effective catchment to one of the sites is larger than portrayed by the developer.

C5.2 Site visit

I propose a detailed site visit, focusing in particular on clarifying the effective catchments to the development sites, and looking for evidence of flow paths or seepage from or under Matthew Dike. Sight of the former pumping abstraction at High Royds may also be valuable.

In addition, I propose selective inspection of watercourses and topography within Menston to get a feel for the evolution of drainage and to judge the extent to which past development has culverted perennial channels and filled in ephemeral channels. Reevadale and Whiddon Croft are two locations I propose to include.

C5.3 Local books and maps

To give more scope for the site visit to be effective, I propose as a high priority to obtain copies of local history books and old maps. Otherwise, it may prove necessary to make a further site visit.

My preference is to purchase copies of such books and maps outright for my own use. If you wish to avoid this expenditure or to accelerate my work it would of course be fine to supply copies that you have to hand. I will draft a list, pending your confirmation of the study.

C5.4 Other matters

There are other factors requiring investigation. Just a few topics are touched on here but all will be considered in the review.

Some photographs I have seen of the Derry Hill site have the appearance to me of "made ground". It will be helpful to know more about landform changes that have occurred on the developed sites (and on the slopes above) once High Royds Hospital was built and Menston village began to expand southwards. For example, a quarry on Derry Hill is marked on the OS First Series, 92 SE – Skipton 1:63360 (1") map of 1858. How extensively was the topography altered when (according to one statement by Mr and Mrs Booth) the watercourse was culverted?

Reports of flooding come in many forms. Local newspapers are typically less authoritative than in earlier eras. This is offset (possibly not quite the right word) by social media and the wider use of cameras. The difficulty typically lies in finding and distinguishing the most relevant information. The reasoned opinion of an expert may be undermined if unseen photographic or eye-witness evidence emerges at a late stage in a dispute.

It is always helpful to investigate features of a notable flood that has occurred, most especially a recent one. When assessing significance, it is important to recognise that some catchments of mixed permeability, mixed land-use or unusual terrain are capable of generating floods of different character. The longevity of flooding in the September 2012 event demonstrates that, when the antecedent period is sufficiently wet, the site can be sensitive to moderate rainfalls of long duration. It is essential to appreciate that this observed behaviour does not preclude the site from also flooding in an extreme storm of short duration.

Judging flood frequency from rainfall frequency is always perilous. The typical upshot is that the rarity of a flood that has occurred is exaggerated. The future flood risk is consequently underappreciated. Judging flood frequency from rainfall frequency *on catchments sensitive to a wide range of storm durations* is especially perilous. In such cases, flood risk may be grossly underappreciated.

Some research of conditions in Menston following the extreme short-duration storms of 12 July 1900 and 25 April 1930 is recommended. These storms had greater impacts on Ilkley and Ben Rhydding respectively, but local newspapers may also report impacts in Menston.

I may undertake some limited selective search for additional sources of information about historical flood impacts in Menston. Where appropriate, I may research rainfall and wetness condition appertaining to specific flood events. However, I will undertake a specific search of local newspapers only if I fail to find adequate reports within local history books or in online sources.

C5.5 Reporting

I envisage one report, submitted within six weeks of confirmation of the study.

C6 Groundwater control

It is possible that explicit measures taken to control groundwater levels by pumping might help development upslope from Menston to meet the twin requirements of not making flooding elsewhere worse, and of not itself being excessively vulnerable to flooding. This is a specialist matter beyond my expertise. My report may therefore include a recommendation to consult a suitably qualified geotechnical engineer or hydrogeologist. If it does, I may make informal suggestions (outside the report) as to persons who might be able to assist.

I have identified someone I believe to have the required skills. However, he is a very active and senior academic based in the South of England and may not have the time to take on such an assignment. He knows nothing of the specific case but I have explained broad features to an intermediary.

I mention this now because I am aware that the 29 January 2015 review date by Bradford MBC will soon come round.

C7 Costs

I can achieve an effective review with ten to 12 days' work spread over six weeks. Flood estimation is inherently uncertain. The key factor is to find and exploit all relevant material. Sound interpretations and best estimates gain from (elapsed) time for reflection.

My rate for the work will be £600/day (equivalent to £80/hour). The higher estimate of 12 days will apply if a second site visit is required or if extensive datasets are found that are directly relevant to understanding flood risk above Menston.

The cost if the higher estimate of 12 days applies will be £7200 + expenses + VAT. The expenses I envisage are: travel and subsistence and the purchase of local history books and old maps.

I will seek specific approval should appreciable additional expense (>£100) be required in acquisition of specific groundwater level and/or groundwater abstraction data held by (e.g.) the British Geological Survey or in acquisition of specific rainfall data. I will acquire such data only if I judge them likely to be relevant in extending or reinforcing understanding, and will endeavour not to duplicate data already available within the existing documentation.

C8 Terms and conditions

I propose to submit one invoice on completion of my report. Invoices are payable in full within 30 days of issue. Payments must reflect the timing of my outputs rather than the timing of your receipts.

Please note that I am required to charge VAT on all my work and for the full service that I provide. Thus I charge VAT at 20% on my entire fee (including expenses). This applies regardless of the VAT status of my client.

I maintain Public Liability Insurance up to a limit of £5m (Certificate No. GMQT474033XB, expiring 28 Feb 2015). Please note that I do not have Professional Indemnity Insurance. I judge that premium rates for a self-employed sole-trader working in flood risk are unaffordably high for a meaningful degree of cover. I protect myself by applying due care and attention, and sometimes by explicit disclaimer. You should endeavour to protect yourself from the consequences of accepting, neglecting or misconstruing my advice.

I would be very grateful for your guidance in anticipating how my role might develop following submission of the independent review, so that there are as few surprises (unpleasant or otherwise) as possible.

Dr Duncan W Reed
24 October 2014
duncanreed@dwrconsult.demon.co.uk

Appendix D Toponymy

Toponymy is the study of place names. It is consistently useful in the study of land-use change in areas with a long and varied history of settlement such as West Yorkshire.

Toponyms abound in the Menston area. There are far too many to list.

The translation of the ~1250 Menston Charter cited by Fletcher (1953) refers to "our land called Mereriding lying between the land of Richard Puer' and the ditch to the West". While the word *mere* can refer to "a strip of uncultivated land which serves as a boundary", the attachment to an area of land makes this interpretation unlikely. The toponym for marshy ground is more likely in the Menston setting. [On p1 of his local history, Laurence (1991) favours the origin "boundary" for the naming of Mire Beck but immediately relents by accepting *Tranmire* as a toponym for "crane marsh".]

Toponymy confirms the naturally boggy adjacent to Mire Beck. An unusual feature – possibly a remnant or consequence of glacial action – is that Mire Back bifurcates on the southern fringe of the HRH site. The main course continues east before turning north to reach the River Wharfe via Ellar Ghyll and Gill Beck. The minor course – more evident on older maps than nowadays – takes a different route to the North Sea: via Guiseley Beck and the River Aire. This is Tran Mire Beck. Tran Mire gives rise to the modern place name of Tranmere. I have not inspected the current state of the bifurcation.

Appendix E Flood frequency analysis – some brief notes

E1 Flood data

Flood data suitable for flood frequency analysis are river flows measured at formal gauging stations. The standard unit of measurement is a cubic metre per second (i.e. m^3s^{-1}). The unit is often spoken as a "cumec". One cumec is 1000 $l\ s^{-1}$.

River flow measurement is a central element of *hydrometry*: the science, technology and practice of water measurement. The measurement of flood flows is relatively specialised and typically revolves around establishing a long-term relationship between river flow and water level known as the *flood rating curve*. The rating curve is also known as the stage-discharge relationship.

E2 Annual maximum series

Flood frequency analyses are often based on annual maximum data. The annual maximum flow is the largest instantaneous flow recorded in the hydrological year beginning 1 October. This is also known as the *water-year*.

The annual maximum flow is sometimes referred to as the annual maximum flood. This alternate name is a little loose. In some years, the annual maximum flow is too small to be considered a flood event.

E3 Flood rarity

Strictly, any measure of event rarity should refer to a precise feature such as the peak flood level or the peak flow in m^3s^{-1}.

The recommended measure of flood rarity for communication to the public is the *annual exceedance probability* (AEP) of the flood rather than the return period in years. For example, a large and damaging flood may have an AEP of 0.01, meaning that there is a one in a hundred chance of its magnitude being exceeded in any one year.

Despite this clear statement of preferred terminology, the principal measure of rarity adopted here is the *return period* (T) in years. The return period is simply more convenient in technical reports. The two measures of rarity are fully interchangeable, with:

$$AEP = 1/T$$

The return period is defined as the *average* number of years elapsing between successive exceedances of that flood magnitude. The word average needs to be stressed as a reminder that any flood magnitude can be exceeded at any time, regardless of the recent flood history.

E4 Index flood

An index flood is a reference flood that can be relatively reliably estimated from gauged data. The index flood adopted in the FEH is the median annual flood, QMED. This is the median of the annual maximum (AM) flow series. This contrasts with the FSR where the index flood used is the mean of AM flow series

QMED is a neater index. Half of AM floods are larger than QMED and half are smaller. Thus, the annual exceedance probability associated with QMED is precisely 0.5. QMED is said to have a return period of two years on the AM scale of frequency.

Appendix F Wharfe flood chronology

With effect from April 2014, the National River Flow Archive managed by CEH has subsumed the role of supplying peak flow datasets, previously played by HiFlows-UK. From this and other sources – including Volume IV of the Flood Studies Report (NERC, 1975), the Chronology of British Hydrological Events and other books and websites – the following flood chronology is offered for the River Wharfe at Ilkley and Otley.

Flood date	Rank or size relative to reference flood of 9 Dec 1965
11 Sep 1673	Notably destructive at many sites
19 Oct 1775	Notably destructive at Otley; impact may have been on 20 Oct 1775
23 Nov 1866	≈ 7 % greater than reference flood
16 Jan 1910	Damaging at Ilkley, Otley and Tadcaster
14 Nov 1923	≈ 10 % greater than reference flood
[Nov/Dec?]	p20 of Brumfitt (1988) has a photo of a Wharfe flood at Otley in 1929. This

Flood date	Rank or size relative to reference flood of 9 Dec 1965
1929	likely occurred during the exceptionally wet November and December of that year. 11 Nov 1929 is a candidate date.
14 Dec 1936	8.7 % greater than reference flood
21 Sep 1946	4.5 % greater than reference flood
9 Dec 1965	Reference flood: Rank 1 flood in 1960/61-2011/12 period (52 water-years)
3 Jan 1982	Rank 2 flood in 1960-2012 annual maximum series
23 Feb 1991	Rank 4 flood in 1960-2012 annual maximum series
31 Jan 1995	Rank 3 flood in 1960-2012 annual maximum series
31 Oct 2000	Rank 6 flood in 1960-2012 annual maximum series
11 Feb 2002	Rank 5 flood in 1960-2012 annual maximum series
30 Nov 2009	Rank 20 flood in 1960-2012 annual maximum series (see also Section 4.6.3)
25 Sep 2012	Rank 17 flood in 1960-2012 annual maximum series (see Chapters 2 and 3)

Appendix G Menston flood chronology

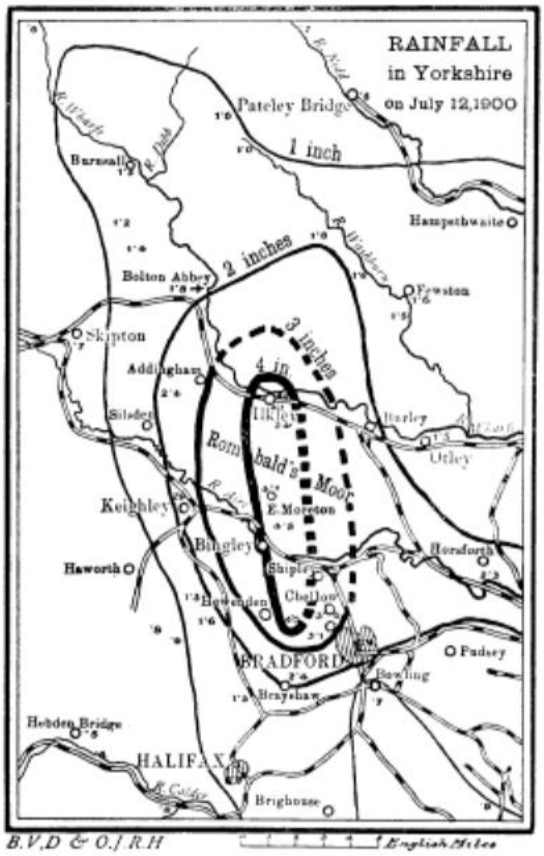
This flood chronology is tentative and incomplete. http://www.bradfordtimeline.co.uk/ points to some notable floods in the Bradford area but none specifically in Menston.

p13 of Preston (1994): Severe thunderstorm in Menston during afternoon on a school day in **Sep 1882**. Symons's British Rainfall 1882 reports that an observer at Esholt noted a thunderstorm on [Wednesday] **27 Sep 1882**, so this is the most likely date.

12 Jul 1900: Devastating storm centred on Rombalds Moor and leading to loss of life and exceptional damage to structures and property in Ilkley. A paper by H.R. Mill forms pp16-22 of *British Rainfall 1900* and describes the event in considerable detail. There is an isohyetal map (see Map G.1) and two photos, with a further photo in the Frontispiece to the yearbook. The isohyets are shown as a broken line on the E side of Ilkley because "the boundary could not be defined on account of the absence of rain gauges in the immediate vicinity". There will have been at least some flooding in Menston.

p28 of Preston (1994): "July 1907: 'Owing to heavy rain and blocked drainage, the three roads leading to the school are entirely impassable – water being knee-deep. The children arriving at school are soaking, having had to wade through the water. Have closed school this morning.' " This event was likely on [Monday] **22 July 1907**. *British Rainfall 1907* highlights exceptional thunderstorms in Western and Central Britain on 21 and 22 July 1907.

25 April 1930: Severe thunderstorm storm in Ilkley reported in *British Rainfall 1930* "...when about 1.84 inches of rain and hail fell in 30 minutes." The raingauge was sited in Ben Rhydding. The Frontispiece to the yearbook shows flooding of the Ilkley-Otley Road "at Escroft, near Ben Rhydding" (see Photo G.1). The correct location is Esscroft, just west of Burley in Wharfedale.



Map G.1: Isohyetal map of 12 July 1900 storm

THUNDERSTORM NEAR ILKLEY, YORKS.
25th April, 1930.

British Rainfall, 1930.] [Frontispiece.

Photo by A. Anning, Ben Rhydding.]
Flood Scene on the Ilkley-Otley road at Escroft, near Ben Rhydding.

Photo G.1: Flooding at Esscroft, just west of Burley in Wharfedale

p50 of *British Rainfall 1930* provides furtherdiscussion:

> "The following measurements were originally supplied by Mr. Terence More, of Ben Rhydding, and further details are given in *The Meteorological Magazine* 1930, pages 110-112.
> 'At Ilkley (Spence's Garden), about 2 miles further west, 1.08 in. was recorded as falling in 25 minutes, while it is estimated that 1.84 in. of rain fell at Ben Rhydding in 30 minutes. At Ben Rhydding, thunder was first heard at 15h. 25m. and rain began at 15h. 30m., changing to hail at about 15h. 40m., which lasted for 5 minutes or a little longer.'

> The photograph is taken looking towards Rumbald's [sic] Moor. There is hail on the wooded hillside in the background, but none on the footpath. The River Wharfe, visible through the railings on the right, is no higher than the ordinary winter level."

This storm may not have been experienced at Menston.

p28 of Preston (1994): Severe storm and impacts in Menston in **Jul 1907**. Judging from *British Rainfall 1907*, this may well have been on 21 July 1907.

15 Jun 2007: Bingley had 2.8 inches [71 mm] of rain in 24 hours on Friday 15 June 2007. Otley Carnival cancelled. One report refers to Menston's Moor Lane and Goose Lane being closed by flooding. There may be confusion with Moor Lane in Burley in Wharfedale.

21 Jan 2008: This flood event has been studied by JDR.Bingley Road in Menston was closed, also Burley Oaks Primary School. The Hare & Hounds car park was flooded. [Serious flooding in Silsden on same day; footage on: http://www.youtube.com/watch?v=peHOv3_tRbY.]

No specific dates given

- YW sewer works on Station Road and Leathley Road began ~17 January 2008 to address flooding of properties at Station Road.
- http://www.nce.co.uk/yorkshire-and-humber-awards-finalists/1995414.article says: *The Crescent, Menston DG5 Flooding Scheme* was shortlisted for the Yorkshire and Humber Awards 2009. Designer was Mott MacDonald Bentley.
- May 2008 article about flooding of cricket pitch at the Fox and Hounds being more frequent following rebuilding of a wall by Bradford MDC "several years ago".

15 Aug 2008: Photo (LH below) of flooded cricket pitch at the Fox and Hounds.


7 Oct 2008: Photo (RH above) of flooded woodland at Thorpe Lane. Note that tide marks indicate a recent higher depth.

15 and 21 Aug 2012: Videos uploaded to YouTube by CS imply that sewer surcharging occurred near Lane Ends and on Hawksworth Drive in one or both of these events.

24 Sep 2012: Major flooding of Hillings Lane, Derry Hill site and other parts of Menston. See notes in Chapter 3 about flooding at Hillings Lane and its origin. Pateley Bridge raingauge is said to have registered 71.2 mm between Sunday and Tuesday [presumably in 48 hours ending 09:00 Tuesday]. Although this rainfall event led to some flooding on main rivers, gauged flow data at Addingham indicate that this was not an especially rare flood on the River Wharfe (see Wharfe flood chronology in Appendix F).

6 Jan 2014: Newspaper reports (e.g. Ilkley Gazette, 10 January 2014) and photo: “A combination of blocked street drains and heavy overnight rain led to the problem on a low-lying stretch of the A65 Burley Road, near Endor Crescent, yesterday. … A Bradford Council spokesman said: ‘The water collected due to a blocked gully. The gully had become blocked with leaves which were cleared and the water was subsequently cleared by 10am on Monday morning.’ ”

Appendix H Geological snippets

Although there is no public access, rock exposures in the Derry Hill quarry may be informative to a suitably experienced hydrogeologist. Eye witness accounts or photographs of flow and seepage conditions in the quarry during the 24 September flood would be helpful.

Aitkenhead and Riley (1996) provide an account of the lithology at Hag Farm, Burley Woodhead (41583 44461).

Waters (1999) provides an account of the geology of the Bradford district.

A further potentially valuable reference is the Yorkshire Ouse and Hull River Authority *Survey of water resources* published in 1969. A locally catalogued copy of the main volume is held in Menston Library.

Appendix I Representations to draft Menston SPD (selected)

SPD denotes the Supplementary Planning Document. I recognise that local residents and organisations can sometimes have ulterior motives for opposing development. But residents with long connections to a locality sometimes know of features that an outsider may overlook, regardless of experience. I have selected comments related to runoff, drainage and flooding which I consider may have particular relevance. I have not attempted to link these to specific proposals or wordings in the draft SPD. Items in red confirm or support statements made elsewhere in the report based on my own judgement.

Consultee	Representation(s) to Draft Menston SPD
6. Mr R Ryde	No mention of springs or that rain runoff will be increased by development. Draining should take into account natural springs. Keep the small stream in Derry Hill site as part of the development.
19. Mr E Sotherby	More landscaping is required to stop water from pooling along the boundary of the bungalows on Hawksworth Drive and the houses on Hawksworth Close. There is a problem from Autumn to Summer every year. …
23. Mr A. Monaghan	As regards Sustainable Urban Drainage Systems, there is no consideration of springs, only rain run-off. Therefore the SPD should be amended and give full consideration to both in terms of their impact upon property within the area.
26. Matthew Naylor (Yorkshire Water)	Yorkshire Water supports the use of SUDS. Although an adoption and maintenance plan should be in place prior to development. There is enough current spare capacity at Burley in Menston waste water treatment works to serve the two sites. However any development within the catchment prior to these sites being developed could take away some of this capacity. Yorkshire Water will need to be informed of any proposed development so that we can create accurate population forecasts. This is to guide our planning process for creating additional capacity where and when it is necessary.
32. Mr C Dewhirst	What about the streams and springs, have these been located on the sites and on the ground, not just on maps. At this time all the water runs into one pipe behind 34/36 Dicks Garth Road. A full drainage plan for Derry Hill, Dicks Garth Road and Walker Road should be formulated before construction commences. The drainage system should be of primary concern. The stream mentioned on … runs behind my house, and is already prone to flooding. If the ‘ponding’ is rectified the flow of the stream will increase, together with the possibility of flooding. The full capacity and layout of the drainage system in this area is still unknown. In order to alleviate this problem I believe that the stream should be diverted into the drainage system to go down Derry Hill. However as this already overflows in heavy rain and hence the whole drainage system around Dicks Garth, Walker Road and Derry Hill should be upgraded before development commences. There is already ponding behind numbers 21 and 23 Hawksworth Drive, with the gardens of these properties already being waterlogged for most of the year. Terming this as ‘rain runoff’ fails to convey the severity of the problem and disregards the current state of the land, this being very wet with surface water draining from either Bingley Road or the hill behind the farm. In summary there should be a more comprehensive SUD system of increased capacity incorporated into the Bingley Road site in order to alleviate drainage problems around Hawksworth Drive.

Consultee	Representation(s) to Draft Menston SPD
33. Mrs Christelow	… Therefore 1 storey houses or an open space should be provided immediately behind the boundary of the bungalows on Hawksworth Drive. This is very wet land with springs and at least one pond on the northern boundary. SUDs are shown (Diagram Page 31) draining to that boundary, but where do they go from there? There is no land drainage until Hawksworth Drive is reached. A system of SUDS is required that has taken into account the slope gradient and can remove water from the site whilst not exacerbating the current drainage problems around Hawksworth Drive.
36. Mrs E G Dewhirst	The problem of drainage needs to be addressed before any work commences as there are springs and a stream running down the two sites, as a result houses in this area have been flooded within the last five years. As any resident of Menston knows, the junction of Derry Hill, Main Street and Burley Lane can flood after exceptional downpours, as can the cellars of the properties around this junction also. A proper survey of the water course from the main watershed needs to be carried out.
45. Menston Community Association	The issue of ponding is recognised, but we cannot find mention of the need to solve this problem. Even more serious is that there is no mention of the springs. Full surveys and solutions would be required prior to a grant of planning permission. Desk top studies etc would not be sufficient. We do not understand what is meant by paragraph 3.17. Run-off is an issue, but the springs have not been considered. There does not appear to be any consideration given to off-site problems (to the North of the sites), of run-off, springs or drainage or the need for such solutions. There is also no mention of the probable need to expand the existing sewerage and drainage infrastructure to cope with the additional housing.
66. Julia Bateson	Water and Drainage Issues - my understanding from the documentation is that this issue is one that will have to be addressed by any eventual developer. However, as with many matters of this type it is people who are not directly involved who are likely to be most affected. I live adjacent to the railway line immediately below (or down in altitude terms) from Derry Hill. In the last 10 years, building 'above/higher' than us at 'Whiddon Croft' has led to severe drainage issues for us and adjoining homes with run-off causing water ingress (into our homes) in heavy rain (and foul water in the cellars of our neighbours). The issue of increased pressure on surface drains should, in my opinion, be addressed before the planning stage as further hard-surface cover of what is currently absorbent land will potentially exacerbate what is barely controlled at the moment.