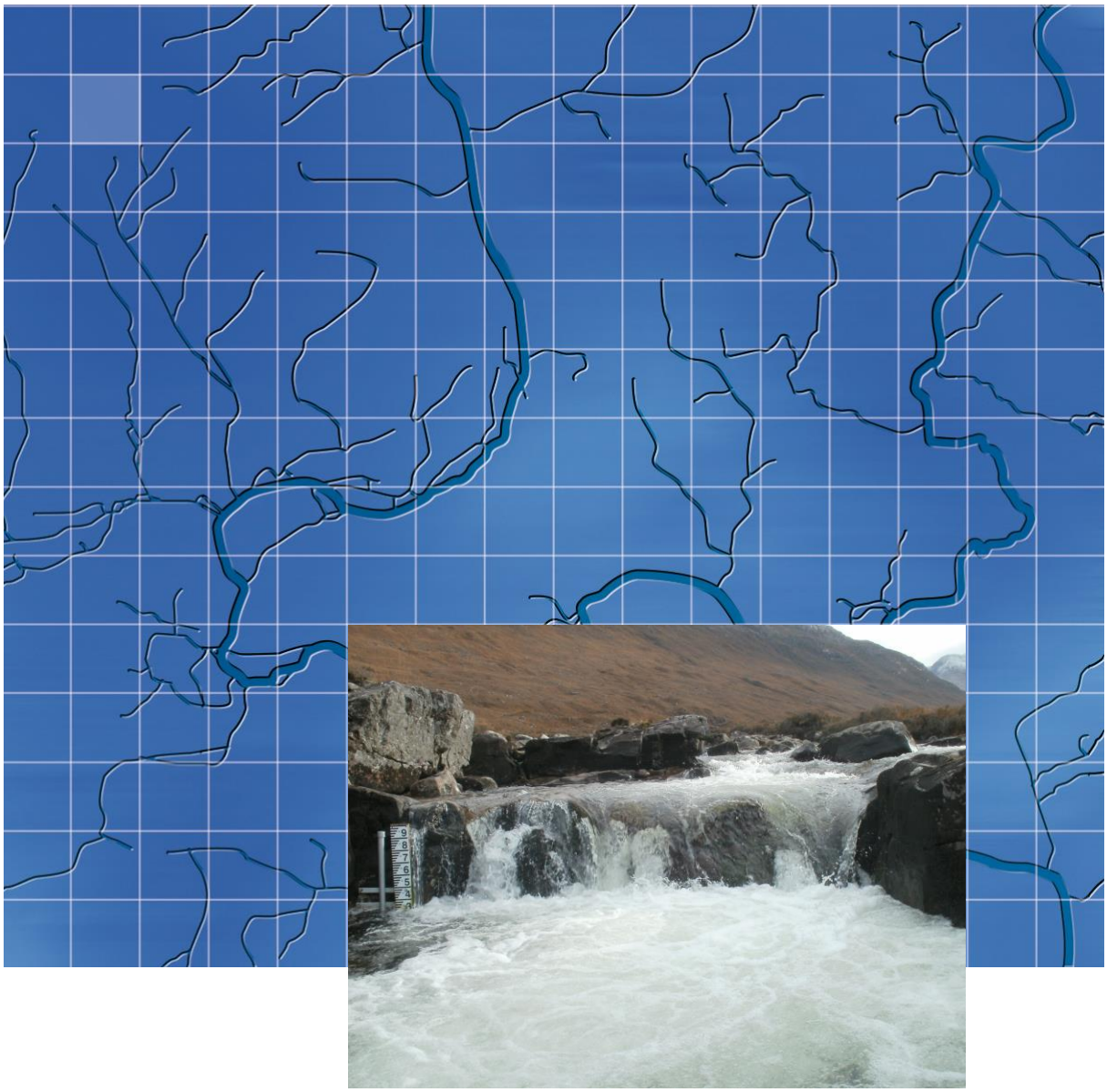
LowFlows Report 530_18

July 2017

Flow estimate for Hafod y Rhedrwydd



Wallingford HydroSolutions Limited

For and on behalf of Wallingford HydroSolutions Ltd

Client	Roger Moss
Prepared by	Daniel Hamilton
Approved by Position	Jude Jeans *Principal Consultant*
Invoice value	195 (excl. VAT)

The WHS Quality Management system is certified as meeting the requirements of ISO 9001:2008 and ISO 14001:2004 providing Environmental Consultancy (including monitoring and surveying), the development of Hydrological Software and associated Training.

Registered Office Maclean Building, Benson Lane, Wallingford OX10 8BB
www.hydrosolutions.co.uk

Contents

1 Introduction

This report presents the annual and seasonal flow statistics for the site(s) requested using the WHS LowFlows Enterprise model. The site location(s) have been confirmed using a digital map and copies of the correspondence are contained within Annex 1.

The LowFlows software system is the standard software system used by the Environment Agency, Natural Resources Wales, the Scottish Environment Protection Agency and the Northern Ireland Environment Agency for providing estimates of river flows within ungauged catchments. The software and underpinning science have been widely published in the scientific literature. The LowFlows software system is available for purchase as two versions; LowFlows 2 and LowFlows Enterprise.

Section 2 of the report provides an overview of our consultancy services; specifically our hydrometry services for supplementing the flow statistics presented within this report with at site measurements and flood event estimation services. We also provide a range of software products including the Flood Estimation Handbook (FEH).

Section 3 presents the methods for the derivation of catchment characteristics and the annual and monthly flow estimates. Following the results for each site, Sections 5 and 6 present the assumptions and uncertainties within the flow estimates, followed by the consideration for use in section 7 and the warranty and liability in section 8.

2 WHS Consultancy Services

WHS is an independent company founded by the Centre for Ecology and Hydrology to deliver high quality consultancy services and environmental software systems to the water, energy and development sectors. WHS has a team of experienced technical staff including leading UK scientists located in three offices across the UK. We have a proven track record in provision of flood risk, water resources, environmental (including EIA) and field measurement consultancy services across the whole of the UK.

Our field measurement services, range from hydrometric (flow), topographic, ecological and geomorphological surveys through to aquatic habitat mapping.

We install and operate flow measurement installations (gauging stations) support of a wide range of activities including hydropower development, water supply, flood risk and research.

WHS is committed to continuously improving company performance and customer satisfaction. We are proud of our ISO 9001 certification for the provision of environmental consultancy services, development of hydrological software and associated training. For further information on all of our services and software, please visit our website www.hydrosolutions.co.uk.

3 Derivation of the LowFlows Results

Section 3.1 presents the methods used to define the catchment characteristics, and section 3.2 provides an overview of the long term annual and monthly flow statistics provided for the site(s). The flow statistic estimates contained in this report have been produced by LowFlows Enterprise[1] using models and relationships that relate these flow statistics to the climatic and hydrological characteristics of the catchment of interest. All flow statistics provided in this report are for natural flows, thus do not contain any artificial influences such as abstractions, discharges or impounding reservoirs.

3.1 Catchment Characteristics

The following catchment characteristics are provided in the results section of this report:

- **Catchment Area:** The catchment boundary may be derived using either a digital terrain model or an analogue river network based method. The digital method is the default option used in preference to the analogue method but may be misleading or not possible in some areas. The estimation method used to estimate the catchment boundary is identified within the results section for the site(s).
  - The digital method uses a Digital Terrain Model (DTM) to determine the topographic boundaries of the catchment.
  - The analogue method associates grid squares (200 m resolution) to the nearest stretch of river and defines the boundary by selecting grid squares which are assigned to river reaches upstream of the ungauged point.
- **Base-Flow Index (BFI):** The proportion of a hydrograph occurring as base flow, hence varying between zero and unity. BFI is indicative of catchment permeability with values approaching unity associated with highly permeable systems. BFI is estimated from a revised form of the HOSTBFI multivariate linear regression equation [2].

[1] Young A. R., Grew R. and Holmes M.G.R. 2003. Low Flows 2000: A national water resources assessment and decision support. Water Science and Technology, 48 (10).
[2] Boorman, D.B., Hollis, J.M. and Lilly, A. 1994. Hydrology of Soil Types: a Hydrologically-based Classification of the Soils of the United Kingdom. IH Report 126.

3.2 Long Term Natural Flow Statistics

The following long term flow statistics are provided in the results section of this report.

- **Annual Mean Flow (MF):** The estimation of Mean Flow is based on a grid of long term average annual runoff developed by the Centre for Ecology and Hydrology (CEH). This was derived using the outputs from a deterministic water balance model using observed data from over 500 gauged catchments[3].
- **Mean Monthly Flows (MMF):** The MMF for each month are derived from the natural MF estimate by distributing the total average flow volume for the year between the months of this year. This distribution is based upon observed data from hydrologically similar gauged catchments.
- **Annual Flow Duration Curve (FDC) statistics:** The flow duration curve statistics are estimated using a procedure based on measured flow data from hydrologically similar gauged catchments[4]. This methodology was further updated by WHS in 2009. Flows are provided for the following exceedence percentiles: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99.
- **Mean Monthly Flow Duration Curves (MFDC):** The MFDC for each month is estimated using gauged MFDCs from hydrologically and climatologically similar catchments and the estimate of MMF for that month. The MFDC statistics are presented, by month for the following exceedence percentiles: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99.

If these long term natural flow statistics were calculated directly from a gauged flow record the annual statistics would be equivalent to those calculated using all of the daily flow data from all years of record and the monthly statistics for a month equivalent to those calculated from the gauged data for that month from all years.

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[3] Holmes, M.G.R., Young, A.R., Gustard, A.G. and Grew, R. 2002. A new approach to estimating Mean Flow in the United Kingdom. Hydrology and Earth System Sciences. 6(4) 709-720.
[4] Holmes, M.G.R., Young, A.R., Gustard, A.G. and Grew, R. 2002. A Region of Influence approach to predicting Flow Duration Curves within ungauged catchments. Hydrology and Earth System Sciences. 6(4) 721-731.

4 Low Flows Results for Hafod y Rhedrwydd

4.1 Catchment Characteristics

The catchment characteristics and map for this catchment are presented in the table and figure below. The catchment boundary was provided by the client. The catchment is dominated by deep peat. As the catchment is smaller than 5km^2, it is considered a small catchment. Guidance associated with this is found in section 7.

Table 4.1 Catchment Characteristics

Basin Details	
Outlet grid reference	276169, 345663
Hydrometric area	66 (Conway and Clwyd)
Catchment definition method	Manual
Basin area (km^2)	0.87
Base-Flow Index	0.23

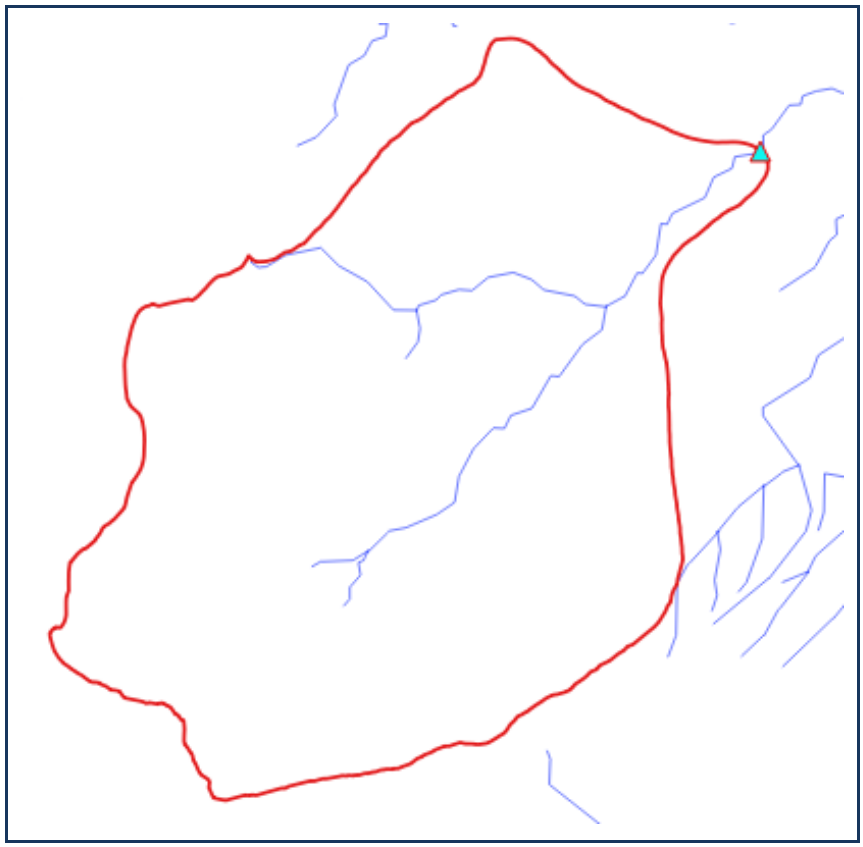


Figure 4.1 Catchment Boundary

4.2 Long Term Natural Flow Statistics

This section presents the long term natural flow statistics. The table below presents both the monthly mean flows and the annual flow duration statistics. The annual flow duration curve is also presented in the figure below, followed by a table displaying the monthly flow duration statistics.

Table 4.2 Mean Flows and Annual Flow Duration Curve Statistics

Mean Flows	Flow (m³/s)
Annual	**0.058**
January	0.091
February	0.078
March	0.072
April	0.051
May	0.033
June	0.026
July	0.025
August	0.036
September	0.048
October	0.069
November	0.085
December	0.088

Percentile	Flow (m³/s)
5	0.236
10	0.155
20	0.084
30	0.051
40	0.033
50	0.022
60	0.016
70	0.011
80	0.008
90	0.005
95	0.004
98	0.003
99	0.003

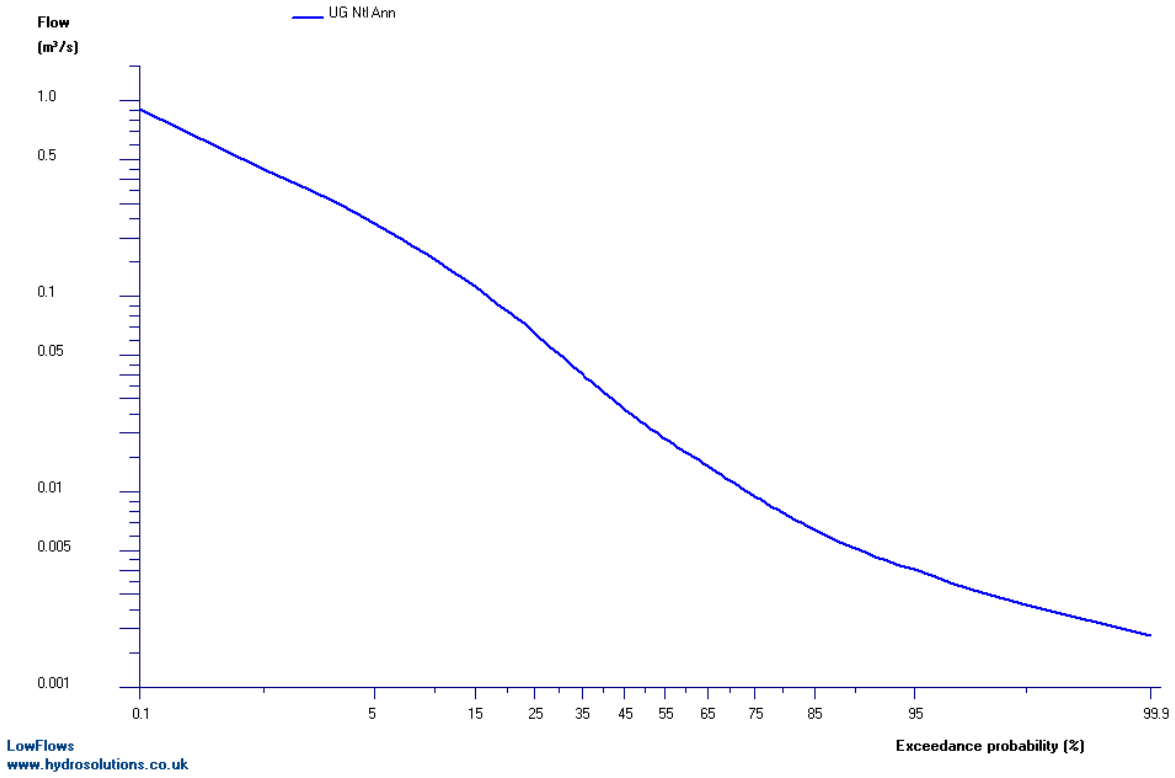


Figure 4.2 Annual Flow Duration Curve

Table 4.3 Monthly Flow Duration Curve Statistics

January		February		March		April	
Percentile	Q (m³/s)	Percentile	Q (m³/s)	Percentile	Q (m³/s)	Percentile	Q (m³/s)
5	0.286	5	0.289	5	0.242	5	0.179
10	0.22	10	0.198	10	0.165	10	0.124
20	0.141	20	0.106	20	0.103	20	0.076
30	0.096	30	0.063	30	0.067	30	0.047
40	0.062	40	0.041	40	0.045	40	0.033
50	0.042	50	0.03	50	0.032	50	0.023
60	0.031	60	0.022	60	0.024	60	0.017
70	0.023	70	0.018	70	0.018	70	0.013
80	0.017	80	0.014	80	0.014	80	0.009
90	0.012	90	0.011	90	0.01	90	0.007
95	0.01	95	0.009	95	0.009	95	0.005
99	0.007	99	0.006	99	0.006	99	0.004

May		June		July		August	
Percentile	Q (m³/s)	Percentile	Q (m³/s)	Percentile	Q (m³/s)	Percentile	Q (m³/s)
5	0.13	5	0.108	5	0.11	5	0.147
10	0.086	10	0.068	10	0.061	10	0.092
20	0.045	20	0.033	20	0.027	20	0.046
30	0.028	30	0.019	30	0.016	30	0.026
40	0.017	40	0.013	40	0.011	40	0.016
50	0.012	50	0.009	50	0.008	50	0.011
60	0.009	60	0.007	60	0.007	60	0.008
70	0.007	70	0.006	70	0.006	70	0.006
80	0.006	80	0.005	80	0.005	80	0.005
90	0.005	90	0.004	90	0.004	90	0.004
95	0.004	95	0.003	95	0.003	95	0.003
99	0.003	99	0.003	99	0.003	99	0.002

September		October		November		December	
Percentile	Q (m³/s)	Percentile	Q (m³/s)	Percentile	Q (m³/s)	Percentile	Q (m³/s)
5	0.19	5	0.248	5	0.28	5	0.307
10	0.126	10	0.175	10	0.202	10	0.223
20	0.069	20	0.104	20	0.128	20	0.135
30	0.038	30	0.067	30	0.086	30	0.082
40	0.023	40	0.045	40	0.061	40	0.053
50	0.016	50	0.03	50	0.045	50	0.036
60	0.011	60	0.021	60	0.034	60	0.026
70	0.008	70	0.016	70	0.024	70	0.02
80	0.006	80	0.011	80	0.018	80	0.016
90	0.004	90	0.008	90	0.013	90	0.012
95	0.003	95	0.005	95	0.009	95	0.009
99	0.003	99	0.003	99	0.006	99	0.007

5 Assumptions

Assumptions implicit in the estimated flow estimates are:

- Only natural flow statistics have been estimated and the impact of any artificial influences (for example abstractions, discharges or impounding reservoirs) is not included.
- The topographic catchment area identified is assumed to accurately reflect the true catchment area contributing to flows at the catchment outlet.
- The flow estimates are based on long term average records.

6 Model Uncertainty

The figures for factorial standard error of estimate for long term mean flow and Q95 are shown in Table 6.1. So, as an example the uncertainty in the estimate of mean flow in Scotland will generally be less than 11%. These standard errors are presented as a general guide only and should be considered in the context of the information presented within section 7. These errors are broadly comparable to the sampling errors that might be expected if mean flow was calculated from two to three years of error free gauged data and Q95 for in the order of five years error free gauged data.

If these estimates are to be used for high value decision making we would recommend that the estimates are corroborated through appropriate local flow measurement. For advice on flow measurement please contact us at info@hydrosolutions.co.uk.

Table 6.1 Model Factorial Standard Error (FSE)

Regions of the UK	FSE Mean Flow	FSE Q95
England and Wales	16	42
Scotland	11	35
Northern Ireland	11	30

7 Consideration for Use

The predictive performance of the Mean Flow and FDC Estimation Models may vary according to local conditions. The following is a list of significant, but not comprehensive, issues that need to be considered when estimating flows within ungauged catchments:

- Care needs to be taken when interpreting the results in smaller groundwater catchments in which river flows may be strongly influenced by point geological controls (such as spring lines and swallow holes).
- A catchment water balance is assumed within the LowFlows software; this assumption may be incorrect in smaller groundwater fed catchments where part of the regional groundwater flow bypasses the surface water catchment.
- The estimation of Mean Flow is based on a grid of long term average annual runoff developed by CEH. This was derived using the outputs from a deterministic water balance model using observed

data from over 500 gauged catchments. The predictive performance of the model may therefore be reduced in areas of low rainfall gauge density.

- Care needs to be taken when interpreting the result in very small catchments as the size of the catchment approached the spatial resolution of the underlying catchment characteristic datasets within LowFlows (1 km²). For very small catchments it is recommended that the topographic contributing catchment is confirmed by a site walkover to identify any unmapped features that might modify the catchment area.
- Where available local measured flow data should be used to corroborate the LowFlows software estimates. This is good practice when using any generalised hydrological model.

8 Warranty and Liability

1. The assumptions and uncertainties associated with the flow estimation methods must be considered when making use of flow estimates produced by the system.
2. You are responsible for the interpretation of the Results presented within this report and training in the use of the estimation methods is strongly recommended.
3. Subject to 1 and 2 above, WHS do not seek to limit or exclude liability for personal injury or death arising from our negligence.
4. Except for 3 above our entire liability for any breach of our duties, whether or not attributable to our negligence, is limited to the fee that you have paid for this report.
5. Except for 3 and 4 above, in no event will WHS be liable to you for any damages, including lost profits, lost savings or other incidental or consequential damages arising on your use of the results even if we have been advised of the possibility of such damages.
6. Should any of these provisions be ruled invalid under any law or Act of Parliament, they shall be deemed modified or omitted only to the extent necessary to render them valid and the remainder of these provisions shall be upheld.

Annex 1: Copies of key correspondence with the client

Hello Daniel,

Thanks very much, I'll be in touch once have paid.

Kind regards
Roger

From: lowflows [mailto:lowflows@hydrosolutions.co.uk]
Sent: 11 July 2017 15:59
To: Moss, Roger <R.Moss@warwick.ac.uk>
Cc: Philip Hastings <philip.hastings@hydrosolutions.co.uk>; 'WHS Accounts' <accounts@hydrosolutions.co.uk>
Subject: RE: Hafod y Rhedrqydd

Hello Roger,

Thank you for sending this through, I have managed to load the catchment boundary into low flows and will progress the estimate once our accounts team have confirmed payment.

Kind Regards,

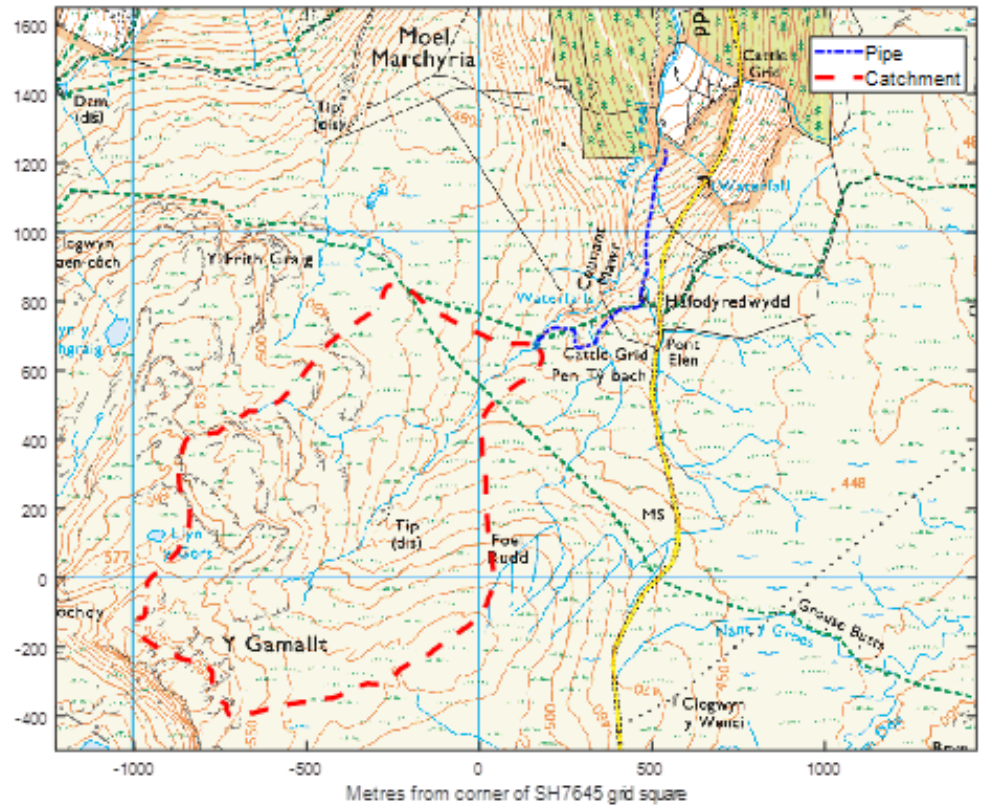
Daniel Hamilton
Flood Risk Consultant

Wallingford HydroSolutions Ltd
Castle Court, 6 Cathedral Road, Cardiff, CF11 9LJ
Direct Tel : +44 2920647739
Email : daniel.hamilton@hydrosolutions.co.uk
www.hydrosolutions.co.uk

From: Moss, Roger [mailto:R.Moss@warwick.ac.uk]
Sent: Monday, July 10, 2017 1:08 PM
To: LowFlows <lowflows@hydrosolutions.co.uk>
Subject: RE: Hafod y Rhedrqydd

Dear Philip,

I'm attaching the coordinates in an Excel sheet together with the outline in Google Earth (.kml file). The catchment looks like this on an OS map:



The area is 0.865 km^2.

I'll pay tonight (or now if you take cards).

Kind regards
Roger

From: LowFlows [mailto:lowflows@hydrosolutions.co.uk]
Sent: 10 July 2017 10:18
To: Moss, Roger <R.Moss@warwick.ac.uk>
Subject: Hafod y Rhedrqydd

Good Morning Roger,

I have spoken to my colleague Jude, and she has confirmed that if you are able to provide the catchment, the additional £75 does not apply. However, you will assume the risk that the catchment is correct and our estimate will be based on this.

This estimate will cost £195 (excluding VAT). As you are a new customer we will require payment in advance before commencing the works. If you wish to proceed with this work, please make payment via one of the following options:

By Cheque : Payable to Wallingford Hydrosolutions Ltd

By BACS : Account : Wallingford Hydrosolutions Ltd

Sort Code : 40-34-27 Account : 52177145

Alternatively I can arrange for our accounts team to provide you with a proforma invoice. Once payment is received I will begin progressing the report straightaway.

Kind Regards,

Philip