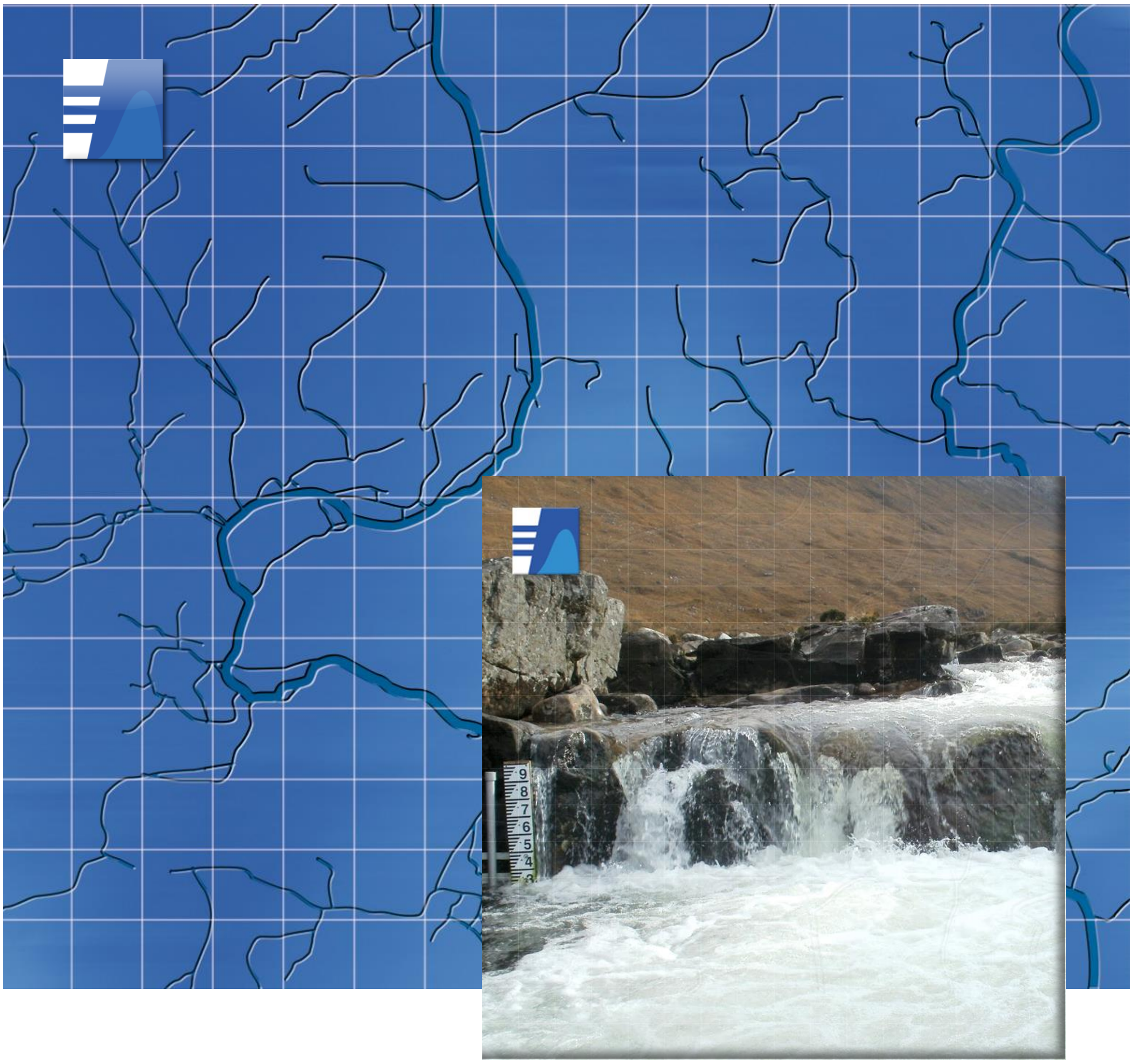
ReFH2 Technical Note: Applying ReFH2 FEH13 in small clay catchments



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1 The issue

It has been identified that ReFH2 when used with the FEH13 rainfall model may overestimate peak runoff rates and volumes in small clay catchments in the South East of England. This also affects plot scale applications. This is not an issue when the FEH99 rainfall model is used primarily as the root cause of the issue is masked by the alpha parameter that is invoked when FEH99 is used.

This issue is a cause for concern where the BFIHOST[1] value is less than 0.25 in clay catchments. As is discussed within this note, this is attributable to the BFIHOST coefficients for $HOST_{23}$ and $HOST_{25}$ (representing the soft massive clays) being lower than would be expected when compared with the BFI values from observed records in catchments dominated by these classes. This leads to an overestimate of the design initial soil moisture content (Cini) in these catchments, as Cini is estimated as the ratio of Cini to Cmax and is a function of BFIHOST in ReFH2-FEH13. A full description of the development of ReFH2 Cini model is described within the ReFH2 Technical Guidance[2].

This issue was not identified during the development of ReFH2 as there are no as rural clay dominated catchments in the NRFA Peak Flow dataset that are suitable for QMED estimation. The BFIHOST model is currently being revisited and re-parameterised by the Centre for Ecology and Hydrology and a revised BFIHOST dataset will be released through the FEH Web Service.

It is important to note that this only affects areas of clay in the south east of England. In other parts of the UK, such as the peats of the uplands, values of BFIHOST lower than 0.25 are entirely appropriate and catchments dominated by these peat soils are well represented within the NRFA Peak Flow dataset and the flood response of these catchment is characterised well by ReFH2.

In the medium term this issue will be readdressed through review and revision of the BFIHOST model to reflect the experience of nearly 20 years use of HOST for both low and flood flow estimation. In the interim, simple options for adjusting the value of BFIHOST have been developed, as summarised in Section 2. Appendix 1 provides the supporting evidence for the BFIHOST coefficients for the clay $HOST_{23}$ and $HOST_{25}$ being too low. Appendix 2 then presents the derivation and details of the procedures for correcting the BFIHOST value.

[1] Boorman, D.B.; Hollis, J.M.; Lilly, A.. 1995 Hydrology of soil types: a hydrologically-based classification of the soils of United Kingdom. Wallingford, Institute of Hydrology, 146pp. (IH Report no.126) Available for download from the Centre for Ecology and Hydrology's website.
[2] http://files.hydrosolutions.co.uk/refh2/ReFH2_Technical_Report.pdf

2 Identifying problem clay catchments and correcting BFIHOST

Problem catchments can be confirmed by reviewing the soils maps and using the appendix within IH Report 126[1].

The majority of clay catchments or plots where the estimate of BFIHOST needs to be corrected for ReFH2-FEH13 can be identified through consideration of the value of BFIHOST and PROPWET. Catchments or plots in the south east of England where the BFIHOST value from the FEH Web Service is ≤0.28 and PROPWET is less than ≤0.38 are likely to be predominantly $HOST_{23}$ or $HOST_{25}$.

Once identified there are two approaches that can be adopted to correct the value of BFIHOST. An appropriate approximate correction can be calculated using:

$$BFIHOST_{adj} = 0.18 + 0.71BFIHOST,$$

This correction is appropriate in the context of the application of ReFH2-FEH13. A full correction can be calculated using:

$$BFIHOST_{adj} = \sum_{i=1}^{29} a_i HOST_i + 0.3(HOST_{23} + HOST_{25})$$

This will require the identification of the fractional extents ($HOST_i$) for $HOST_{23}$ and $HOST_{25}$ from the soil association maps that underpin the HOST classification.

The derivation of these procedures is detailed in Appendix 2.

Appendix 1 What is an appropriate value of BFI for clay dominated catchments in the south east of England?

1.1 The background to BFI estimation and BFIHOST

BFI from gauged records in the UK is generally estimated using the baseflow separation algorithm published in IH Report 108[3]. This separation algorithm separates the daily mean flow hydrograph into a low frequency (base flow) component and a high frequency (rainfall driven) component. The BFI is the ratio of the base flow volume to the total flow volume and is used as measure of permeability within a catchment. This is illustrated in Figure 1 for a chalk and a clay catchment. Much of the flow within chalk catchment is ground water derived baseflow whereas in the impermeable clay catchment much of the flow is derived from short residence time runoff.

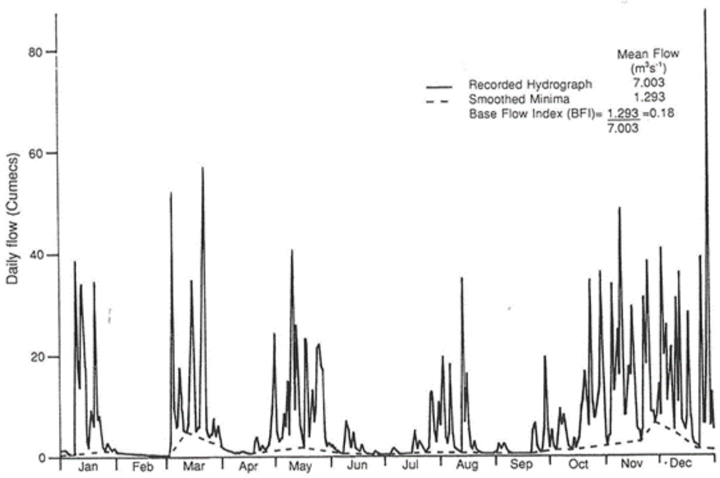
BFI is therefore a useful comparative statistic. HOST is a 29 class system classifying mapped soil associations across the UK into hydrological response classes (Hydrology Of Soil Types). BFIHOST is a bounded regression model relating BFI values calculated from gauged flows records to the soils and geology of a catchment as represented by the fractional extent of catchment HOST classes.

The development of the BFIHOST model is documented in IH Report 126[1]. The modelling exercise was used as a tool to guide and refine the classification of soil associations into HOST classes. It was inevitably the case that coefficients for certain HOST classes which either occur infrequently within the gauged catchment dataset, or frequently but with low fractional extents would be unidentifiable. Similarly, the co-location of HOST classes, the number of HOST classes variables and the fact that fractional extents sum to unity within a catchment meant that there are significant issues regarding the independence of HOST classes when considered within a regression framework.

The outcome was that the BFIHOST model was developed in an iterative process with revisions to both the classification and bounds placed on allowable parameter coefficients. The revisions were made on combination of professional judgement and the significance of parameter estimates of the regression modelling after each revision. Nevertheless, despite these limitations, BFIHOST has been proved to be a useful catchment classification tool and probably because of the added value of experienced soil scientists and hydrologists exercising professional judgement in the development process.

[3] Gustard A, Bullock A. & Dixon, J.M. 1992 Low Flows Estimation in the United Kingdom, Institute of Hydrology, 89pp (IH Report no.108).

a) Lambourn at Shaw



b) Falloch at Glen Falloch

Figure 1. BFI for two catchments with contrasting geology and soils a) predominantly permeable and b) predominantly impermeable

1.2 Estimating an appropriate BFIHOST coefficient for clay catchments

The clay HOST classes in question, $HOST_{25}$ and $HOST_{23}$, have BFIHOST coefficients of 0.170 and 0.218 respectively. $HOST_{12}$ (undrained peat) also has a low BFIHOST coefficient of 0.170, whereas the remaining HOST classes all have higher BFIHOST coefficients.

The locations of the $HOST_{25}$ and $HOST_{23}$ classes are presented on Figure 2. Small catchments dominated by these HOST classes are poorly represented within the NRFA Peak Flow catchments and the small number of catchments that are present are dominated by $HOST_{25}$ and are very urbanised. As a consequence of the urbanisation, these catchments were not used in the development of the as rural Cini model within ReFH2-FEH13. This is in contrast to flashy peat catchments of the uplands which are well represented within the NRFA Peak Flow dataset. $HOST_{23}$ occurs infrequently in all catchments and in the UK in general.

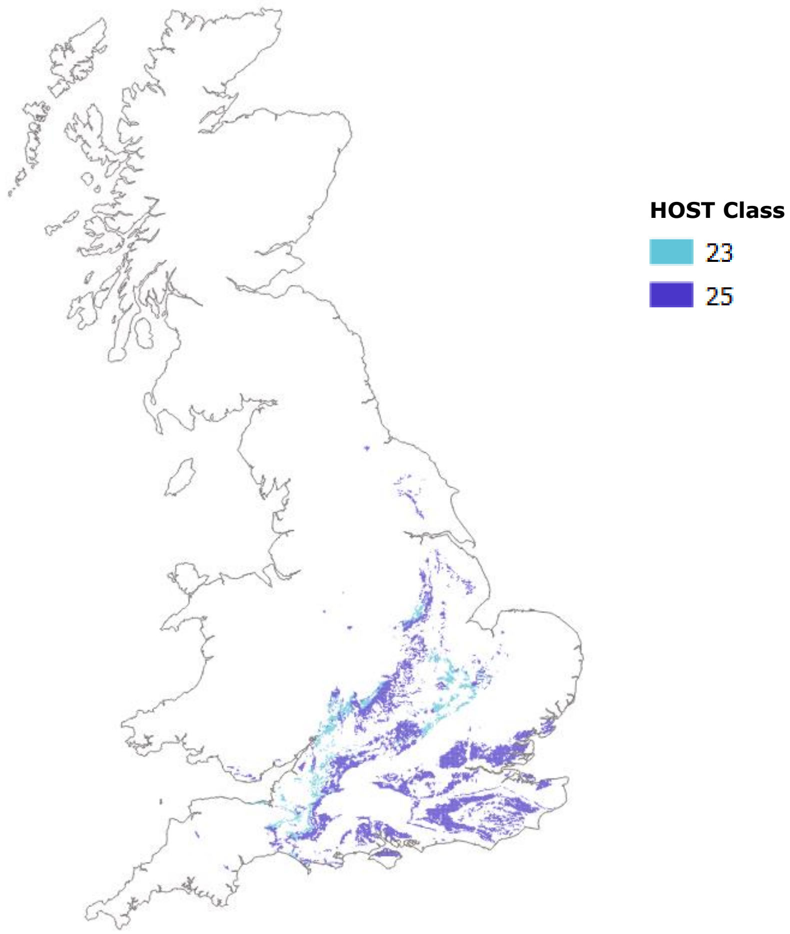


Figure 2. UK Map of $HOST_{23}$ and $HOST_{25}$

To investigate this further the Cini optimisation procedure underpinning the development of the ReFH2 FEH13 Cini model was applied to the $HOST_{25}$ dominated, albeit urbanised catchments in the NRFA Peak Flow dataset. This analysis suggested that the optimal Cini should be lower than would be suggested by the BFIHOST coefficient of 0.17.

The relationship between BFIHOST and BFI from gauged records was explored across a larger dataset of 1219 catchments held by the NRFA (including 947 catchments from the NRFA Peak Flow dataset), presented on Figure 3. Within the figure the catchments are classified according to urban extent with the catchments dominated by $HOST_{25}$ highlighted using open circles, demonstrating these catchments are predominantly very heavily urbanised.

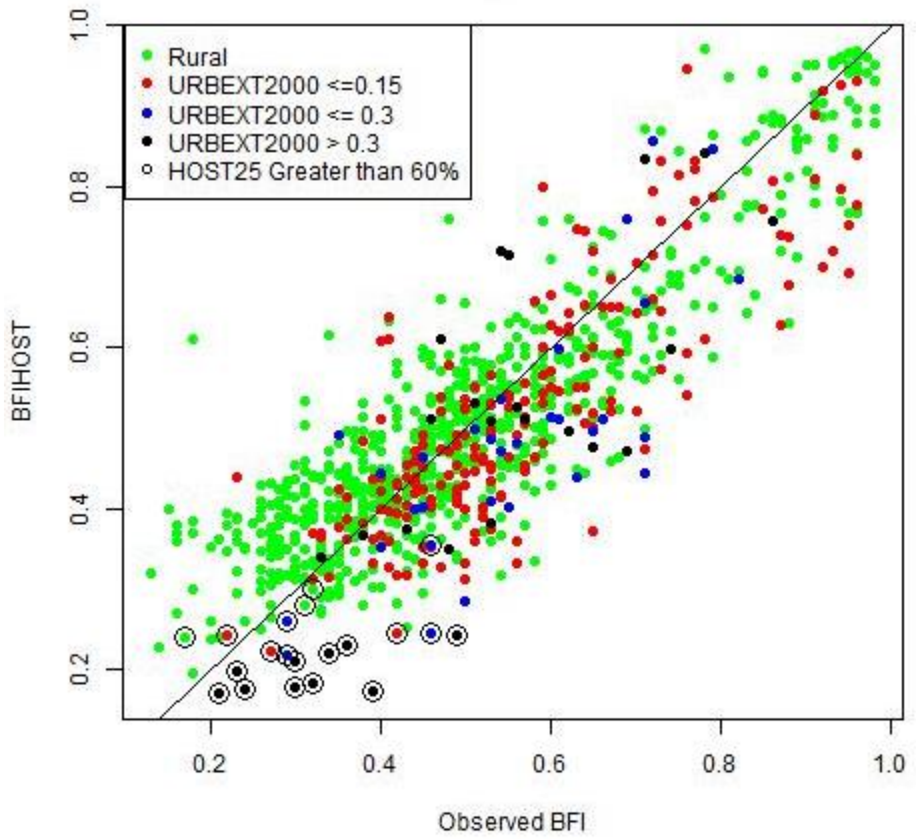


Figure 3. Observed BFI and BFIHOST. Degree of urbanisation is highlighted as are those catchments where HOST25 is greater than 60%.

Figure 3 shows that the BFIHOST model is generally biased towards over estimation of BFI in low BFI catchments which is expected in a regression model of this type. The exception to this is catchments with high $HOST_{25}$ fractional extents where the BFIHOST model significantly underestimates BFI.

To discount the influence of urbanisation, the bias in BFIHOST estimates was evaluated across catchments for different levels of urbanisation. Within a urbanisation class, catchments were classified on the basis of whether they contained a significant (>60%) fraction of $HOST_{25}$. These results are summarised on Table 1. This confirms that within a given urbanisation class, BFIHOST is significantly lower on average for catchments dominated by $HOST_{25}$ than other catchments types.

Table 1. Geometric bias (%) for the estimation of BFI within the dataset where HOST25 is dominant.

URBEXT2000	HOST25 < 60%	No. of Catchments	HOST25 >60% Only	No. of Catchments
<=0.03	-2.5	707	6.1	3
0.03-0.15	6.8	192	-19.2	3
0.15-0.3	-11.9	27	-27.5	4
>0.3	-5.15	20	-36.5	10

The relationship between gauged BFI and the fractional extent of $HOST_{25}$ across the catchment dataset is illustrated in Figure 4. In this figure there are two rural catchments which have BFI values less than 0.2 with significant extents of $HOST_{25}$. These are 39017 - The Ray at Grendon Underwood and 41018 - Kird at Tanyards. However the flow regimes for these catchments are ephemeral with zero flows in many summer months. Thus, the gauged BFI is unduly biased towards a low value.

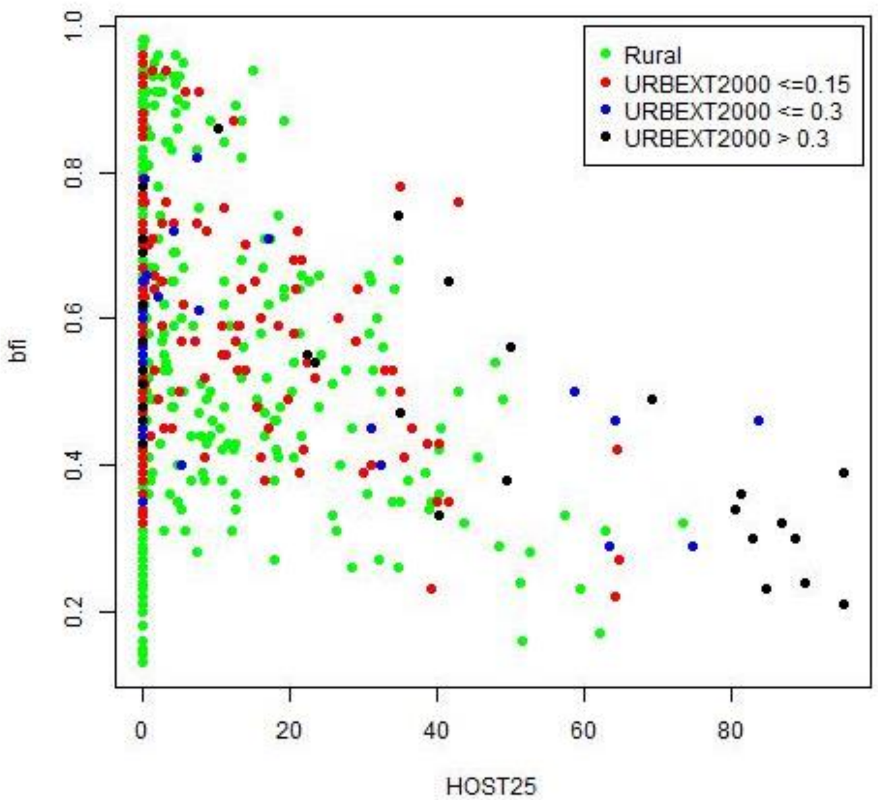


Figure 4. The percentage of $HOST_{25}$ in the catchment dataset alongside the observed BFI.

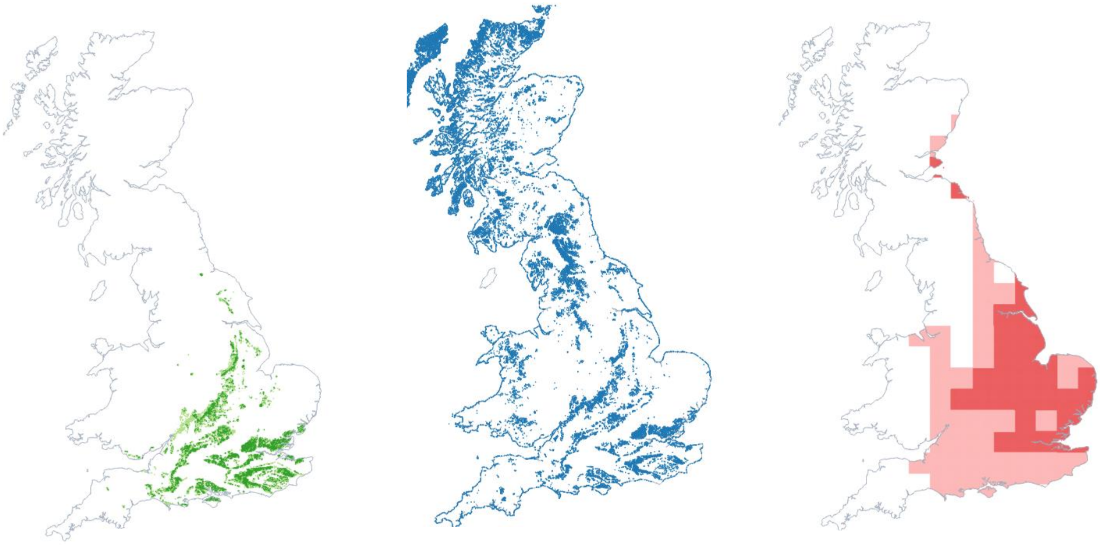
The balance of evidence is such that it is likely that the BFIHOST coefficients for $HOST_{25}$ and, possibly $HOST_{23}$, are too low giving rise to estimation problems when ReFH2 is applied to small catchments dominated by these HOST classes.

To propose an interim alternative BFIHOST coefficient for $HOST_{25}$ (and by analogy $HOST_{23}$) the fit of the BFIHOST model was re-optimised over the dataset of 1219 catchments by calibrating the coefficients for $HOST_{25}$ and $HOST_{23}$ (treating as one class) to minimise estimation bias. This analysis suggested that the most appropriate BFIHOST coefficient for these HOST classes would be 0.30.

Appendix 2 Adjustment of BFIHOST for catchment and plots containing $HOST_{23}$ and $HOST_{25}$

The parameterisation of the BFIHOST model is currently being re-evaluated by CEH and will then be updated in the FEH Web Service. The following presents interim guidance for adjusting BFIHOST to reflect the revised parameter estimate of 0.30 for $HOST_{23}$ and $HOST_{25}$.

$HOST_{23}$ and $HOST_{25}$ tend to be in drier areas of the UK. Spatial analysis of these classes and PROPWET has identified that the selection of 92% of the 1km cells that are dominated (>60%) by these classes can be achieved by selecting cells that have PROPWET<0.38 and BFIHOST<0.28, as illustrated in Figure 5.



a) b) c)

Figure 5. England, Wales and Scotland. a) Distribution of where $HOST_{25}$ percentage is greater than 60%. b) where BFIHOST is less than or equal to 0.28, c) where PROPWET is less than or equal to 0.38 respectively.

The BFIHOST model is a linear model of the form:

$$BFIHOST = \sum_{i=1}^{29} a_i HOST_i \qquad \textbf{Equation 1}$$

where a_i is the BFIHOST coefficient for the fractional extent that a HOST class represented within a catchment. With a knowledge of the fractional extent of $HOST_{23}$ and $HOST_{25}$ a corrected value of BFIHOST can be calculated using:

$$BFIHOST_{adj} = \sum_{i=1}^{29} a_i HOST_i + 0.3(HOST_{23} + HOST_{25}) \qquad \textbf{Equation 2}$$

In small catchments it is not onerous to manually inspect the 1:250,000 soils maps and calculate the fractional extents of the soil associations corresponding to $HOST_{23}$ and $HOST_{25}$. The tabular information in the Flood Estimation Handbook (Volume 4, Appendix C) provide details of the mapping of soil associations to HOST classes. Given the resolution of the soils maps, it is also good practice to inspect the underlying soil maps when working at small scales anyway.

As an alternative approach an approximate adjusted value of BFIHOST can be estimated using:

$$\boldsymbol{BFIHOST_{adj} = 0.18 + 0.71BFIHOST} \qquad \textbf{Equation 3}$$

This equation was considered by considering all cells selected using the BFIHOST and PROPWET selection criteria and optimising the average BFIHOST coefficient for the remaining HOST classes within a cell discounted the fractional extents of $HOST_{23}$ and $HOST_{25}$. The optimisation was based on minimising the bias and f.s.e. of the relationship between the approximate and corrected and true corrected BFIHOST across all cells. This gave and average over all cells of 0.62. Using this value the BFIHOST for either a cell or catchment can then be adjusted using:

$$\boldsymbol{BFIHOST_{adj} = 0.62(1 - A) + 0.3A} \qquad \textbf{Equation 4}$$

However, A, the fractional area of $HOST_{23}$ and $HOST_{25}$ is unknown but an approximate value can be estimated using the same formulation:

$$\boldsymbol{BFIHOST = 0.62(1 - A) + 0.17A} \qquad \textbf{Equation 5}$$

Rearranging equation 5 to express A in terms of BFIHOST and substituting in equation 4 yields equation 3.

This is obviously a pragmatic approximation for correcting the value of BFIHOST in the absence of knowledge of the fractional extents of HOST classes within a cell or catchment.

The ratio of the approximated correction to Cini and the true correction to Cini are plotted as a function of the collocated BFIHOST values in Figure 6. The ratio of the uncorrected and true corrected Cini values are included for comparison. The difference between the approximate and true corrections to Cini are significantly smaller. Across all cells the average uncorrected value of Cini is 0.84Cmax and for both the true corrected and approximated cases this is reduced to 0.55 and 0.56Cmax respectively.

Table 2. Cini/Cmax estimates: summary statistics

	Cini/Cmax BFIHOST	Cini/Cmax Corrected BFIHOST	Cini/Cmax Approximated BFIHOST
Standard Deviation	0.08	0.04	0.04
Mean	0.84	0.55	0.56

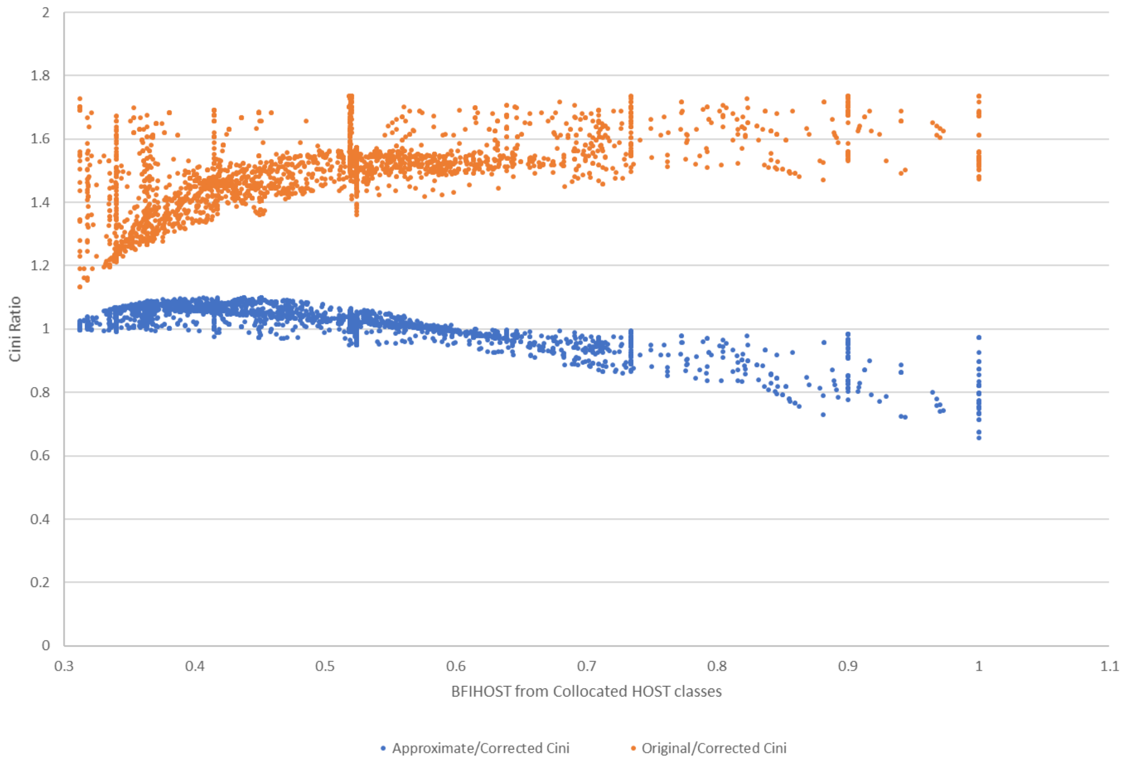


Figure 6. Cini ratios plotted as a function of collocated BFIHOST classes