Wallingford HydroSolutions Ltd

Low Flows 2000™ in Scotland:

The Estimation of Natural Flow Statistics

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Contents

1 Introduction

This technical report describes the hydrological models deployed within the version of the Low Flows 2000^{TM} software system in operational use with the Scottish Environment Protection Agency.

The purpose of the report is to provide background information on the derivation of natural flow estimates within Low Flows 2000. The software also incorporates methods for addressing the impact of artificial influences on natural flows. These methods are fully documented within the literature and the reader is directed to (Young et al. 2003) for further information. The document provides an overview of estimation methods and hence does not represent formal guidance. The estimation of flow regimes within ungauged catchments is not straightforward and it is strongly recommended that the interpretation of results from Low Flows 2000 should be undertaken by a competent hydrologist who has received appropriate training. Please contact Wallingford HydroSolutions for more information on appropriate training courses.

2 Background to Low Flows 2000

Consents to discharge, planning approvals, environmental impact statements, abstraction licences applications, reservoir planning and the assessment of hydropower potential are all examples of projects that require information on river flows. However, there is little or no measurement of river flow for the majority of river reaches within the UK.

In lieu of site specific observed data hydrologists are faced with the problem of estimating flows. The Low Flows 2000 software system was developed within the Centre for Ecology and Hydrology (CEH) to meet this challenge by integrating within a GIS framework the latest regionalised models for predicting for the estimation of natural and artificially influenced river-flows, as represented by flow duration statistics, within ungauged catchments.

The Low Flows 2000 software system is the standard software system used by both the Environment Agency and the Scottish Environment Protection Agency for providing estimates of river flows within ungauged catchments.

Wallingford HydroSolutions (WHS) is the sole appointed developer and distributor of the Low Flows 2000 system. The software is currently available for purchase parties as two versions; LowFlows ™ and LowFlows Enterprise ™. LowFlows provides for the estimation of natural flows following the import of a catchment boundary whilst the Enterprise edition allows for automatic boundary definition and facilitates the incorporation of the impact of artificial influences within the estimation methods. In addition to these software options, WHS also provide a retrievals service for the low volume user, or the user without experience in the estimation of river flows within ungauged catchments. The reader is also reminded that Low Flow estimation science continues to improve and thus this report represents a snapshot of the operational estimation methods as at the date of publication.

WHS is an environmental and information technology consultancy established by the Natural Environment Research Council. WHS was founded in 2004 as a specialist technology transfer company located at the Wallingford Site of the Centre for Ecology and Hydrology (CEH). In addition to modelling software, WHS also provides a wide range of hydrological, water quality and aquatic habitat consultancy services with a focus on the assessment of resource availability, the potential impacts of development and the derivation of cost effective, mitigation measures. For further information on WHS, or LowFlows products please visit our website www.hydrosolutions.co.uk.

3 Background to Low Flow Estimation within Scotland

The first regionalised models for predicting flow duration statistics within Scotland were those published in 1987 in the Institute of Hydrology Report 101 "Low Flow Estimation within Scotland" (Gustard et al, 1987). These methods were, essentially, a supplementary report to the original Institute of Hydrology Low Flows Studies report, published in 1980. Based on a regional model for predicting the base flow index coupled to linking equations (incorporating climatic effects and a lake factor) these methods estimated the natural long term "annual" flow duration curve. The form of the linking equation was:

$$\sqrt{Q95(10)} = \left(8.81 \times \sqrt{BFI}\right) + \left(0.0248 \times \sqrt{SAAR}\right) - \left(2.4 \times \sqrt{FALAKE}\right) - 2.66 \quad ,$$

where:
Q95(10) is the 10 day Q95 (%MF) estimate;
BFI is the Base Flow Index;
SAAR is the Standard Annual Average Rainfall; and
FALAKE is the proportion of the catchment which is covered by 'lake'.

A further equation was required to transpose the Q95 (10) to Q95 (1). In practice the value of BFI is obtained from a 1:250,000 scale BFI map on which river stretches are assigned BFI values. These BFI values were based on the results of the regression analysis, with subsequent adjustments made through consultation with staff from the former River Purification Boards within each area and based on observed values at gauging stations.

Low Flows 2000 (Scotland) was developed for use within Scotland, as a replacement to the Report 101 methods following the implementation of Low Flows 2000 within England and Wales. In addition to the estimation of long term "annual" flow duration statistics, the software can also be used to estimate long term monthly flow duration curves and the impacts of common water use practices upon all flow statistics.

This software incorporates the same functionality as Low Flows 2000 within England and Wales, which has been fully published within the scientific literature (Holmes et al, 2002a,b&c; Young et al, 2003). However, the methodology used to estimate the standardised flow duration curve has been modified to take account of the importance of surface water bodies within Scotland and the strong East - West rainfall gradient across the country.

4 Estimation of the annual flow statistics

4.1 Overview

A flow diagram outlining the methods used within Low Flows 2000 (SEPA) for estimating an annual flow duration curve and annual mean flow from the characteristics of a catchment is presented within Figure 1. The methods are based around using the software to generate a catchment boundary for the ungauged catchment of interest. Using this boundary, the relevant physical and catchment characteristics are extracted from digital grids of these characteristics. These then form the input into the models, or procedures, for estimating the flow statistics.

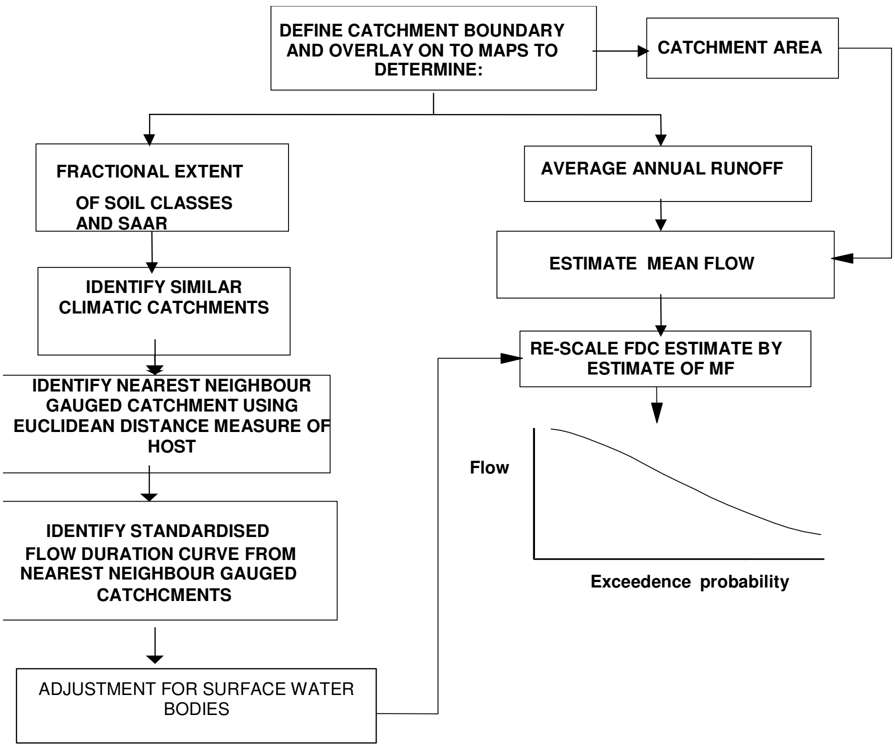

Figure 1 The estimation of the annual flow duration curve

4.2 The methods

An assumption central to the estimation procedures is that when low flows are expressed as a percentage of the long-term mean flow (standardised), the dependencies on the climatic variability across the country and the effect of catchment area are minimised. As a result, the estimation of standardised flow duration curves is largely dependent on the hydro-geological and soils characteristics of the catchment. Within Low Flows 2000 the Hydrology of Soil Types (HOST) classification of soils (Boorman *et al*, 1995) is used to represent these characteristics. However, in Scotland the strong east - west rainfall gradient also influences the duration of stream flow recessions for a given catchment type and hence within Scotland the base methods for estimating the standardised flow duration curve are based on both the hydrogeological and climatological characteristics of the catchment.

There are over 13000 surface water bodies within Scotland. Whilst almost 800 of these are associated with dams (and hence should be treated explicitly within Low Flows 2000 as a water use feature) natural surface water bodies (lochs, wetlands, etc) also have an influence on the variance of the flow regime of a catchment and hence the shape of the flow duration curves. A model to account for the influence of surface water bodies within a catchment is also included within the methods in Scotland.

The model used to estimate the flow duration curve within Low Flows 2000 (Scotland) is a multi step procedure, incorporating a similarity of climate measure within a Region Of Influence (ROI) regionalisation approach and the optional inclusion of the model for adjusting the estimates for the presence of natural surface water bodies within a catchment.

The ROI approach to regionalisation is an approach that is used both within the Flood Estimation handbook (FEH) statistical methods (in which pools of self similar catchments are derived based upon catchment area, SAAR and BFIHOST) and in Low Flows 2000 within England and Wales (based on hydrogeological similarity). The ROI approach develops an estimate of a flow statistic or hydrologic parameter at an ungauged 'target' catchment from observed values of that flow statistic or hydrologic parameter made at number of gauged catchments which are considered to be 'similar' to the ungauged catchment. Similarity is measured by catchment characteristics that can be obtained for any ungauged catchment in the UK.

The ROI based model seeks to reduce the variability of the dependent variable within the data set by reducing it to a much smaller 'region' of catchments that are 'similar' to the target catchment. Within Low Flows 2000 (Scotland) the ROI approach of Low Flows 2000 (England and Wales) has been extended by introducing a nested ROI approach including climatic similarity in addition to hydrogeological similarity. In application to a catchment, the methods can be summarised as the following steps:

1. Catchments which are climatically similar to the target catchment are selected from a station pool of all natural gauged catchments within Scotland to form a climatically similar "region" of catchments.

2. Catchment similarity is subsequently assessed by calculating a weighted Euclidean distance, in HOST space, between the target catchment and the catchments within the climatically similar pool.

3. A "region" is formed around the target catchment by ranking all of the catchments in the data pool by their weighted Euclidean distance in HOST space and selecting the five catchments that are closest to the target catchment.

4. A standardised annual flow duration curve is estimated for the ungauged site by taking a weighted combination of the standardised flow duration curves for the gauged catchments within the region.

5. The derived flow statistics can then optionally be adjusted to account for the presence of lakes within the catchment.

The Euclidean distance measure in step 3 is calculated as:

$$de_{it} = \sum_{m=1}^{M} W_m \left(X_{mi} - X_{mt}\right)^2 ,$$

where; di_e is the weighted Euclidean distance from the target catchment, *t,* to catchment, *i,* from the climatically similar data pool; W_m is the weight applied to catchment characteristic, *m,* and X_{mi} is the standardised value of catchment characteristic, *m,* for catchment, *i*.

The catchment characteristics, X_m, used are the fractional extents of the HOST classes within a catchment, which will vary between zero and unity. The use of differing weights for individual HOST classes reflect the fact that relatively small proportions of certain HOST classes, especially HOST classes of permeable soil overlying permeable geologies, strongly influence the variability of the flows within a catchment. The weights were derived using the output from a bounded regression model

The process for estimating the standardised annual flow duration curve for the target site from those within the region (Step 4) involves weighting each of the donor catchment flow duration curves by the inverse absolute distance, in weighted HOST space, of the catchment from the target catchment. Thus, greater weight was given to catchments that are more similar in HOST characteristics to the target catchment. This is expressed mathematically as:

$$\mathrm{QP(x)EST_t} = \sum_{i=1}^{n} \left[\frac{\left(\dfrac{1}{\mathrm{de_i}^{0.5}}\right)}{\sum_{j=1}^{n} \left(\dfrac{1}{\mathrm{de_j}^{0.5}}\right)} \right] \times \mathrm{QP(x)OBS_i} ,$$

where: $QP(x)EST_t$ is the estimate of the flow for the target catchment, *t,* at exceedence percentile P(x); $QP(x)OBS_i$ is the observed value of QP(x) for the *ith* source catchment in the region of 5 catchments closest to the target catchment and de_i is the weighted Euclidean distance of the *ith* catchment from the target catchment, *t,* in HOST space.

As with all models, there is a tendency for prediction bias at the extremes of the range of catchment types for which the model estimates. This is largely removed by applying the following adjustment factor to all estimated flows below Q80 (as at higher flows the systematic error is negligible).

$$Qx\_adj = -[[(m_x \times (Qx - 17.796)) + 0.0471] * Qx] + Qx\ .$$

The parameter m_x is a function of the target flow percentile.

The optional method for incorporating the influence of natural surface water bodies (lochs and lakes) involves three stages once the number and extent of surface water bodies within a target catchment is identified:

1. The calculation of the influence adjustment at Q95 flow
2. Calculation of the influence adjustment at the Q5 flow
3. Calculation of the influence adjustment at other flow percentiles.

For all stages the influence adjustment is weighted by the position of the surface water body within the ungauged catchment of interest.

In stage 1 the influence at Q95 (%MF) is estimated using the variance attenuation potential of each surface water body as represented by the ratio of the lake catchment area (LCarea) to the surface water body surface area (LSarea).

If LCarea/LSarea is less than 2 then the influence at Q95 (IMPACTQ95) is equal to 50, that is, the Q95 would increased by a factor of 1.5. If LCarea/LSarea is greater than 100 then the influence at Q95 is taken to be zero as if the catchment area is much larger than the surface water body surface area the attenuation potential of the surface water body will be low (the surface area is used as a surrogate for loch volume which is not readily available). For any other case the influence at the Q95 flow is estimated as:

IMPACTQ95 = (56.03 * Exp(-0.0863 * LCarea/LSarea).

In practice the lakes lie upstream of unguaged point of estimation and thus the influence of incremental catchment are between a lake outlet and the point of estimation needs to be accounted for. This is accounted for using the following reduction factor:

IMPACTQ95= IMPACTLQ95 * CTArea / UGArea,

where UGArea is the catchment area above the point of estimation.

This process is repeated for all (n) lakes and the total adjustment is derived by taking the sum of the n individual adjustment factors.

Stage 2 involves the estimation of the relationship between the influence of the surface water bodies at Q5 and at Q95 using:

$$\frac{IMPACTQ5}{Q5} = f\,\frac{IMPACTQ95}{Q5}.$$

In practice:

$$\left(\frac{IMPACTQ5}{NQ5}\right)+1=\left(-0.1201\times\left(\left(\frac{IMPACTQ95}{NQ95}\right)+1\right)\right)+1.056.$$

Based on this the influence on Q5 can be calculated using the influence at Q95 and the base estimates of Q5 and Q95 for the catchment.

Stage 3 of the procedure involves the linear interpolation of the influence to other percentile points based around a point of inflexion at Q30.

The standard error of estimate for the estimation of Q95%MF estimation is 48%. This estimate is derived via jack knife sampling by sequentially removing gauging stations from the pool and predicting the flow statistics at the gauged site based upon the remaining gauging stations within the pool. This process yields an estimate of the prediction error for each gauging station within the pool. However, the uncertainty derived using this approach includes both model uncertainty (including structure and parameterisation error and catchment characteristic error) and gauging station measurement uncertainty. The criteria used to accept gauging stations (Institute of Hydrology, 1992) into the pool of Low Flows 2000 gauging stations considered hydrometric accuracy and imprecision and the degree of artificial influence on the flow record. The likely measurement error at the Q95 flow for the gauging stations within the pool ranges from approximately 15% for the highest quality stations to between 30-40% for the lowest quality stations. It is important to note that the lowest quality stations are still regarded by measuring authorities as representing an acceptable measurement of low flows. Taking this into account indicates that the true predictive uncertainty of Low Flows 2000 is likely to be significantly less than 48%.

4.3 The estimation of annual mean flow

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 development of this grid is described in detail by (Holmes *et al.*, 2002a).

The long-term mean flow is used to scale the flow duration curve so that the range of flows can be expressed in cubic metres per second (m^3s^{-l}). The mean flow can be estimated from the average annual runoff depth (RO) in mm over the whole catchment (AREA in km^2) using the equation:

$$MF = RO \text{ x } AREA \text{ x } CONST \text{ .}$$

The performance of this model was assessed at 167 gauging stations across Scotland by calculating the factorial standard error (f.s.e) of a logarithmic regression of estimated runoff against gauged runoff (calculated by dividing the observed mean flow by the gauged catchment area). This indicated that the 68% predictive uncertainty for the estimation of runoff and hence Mean Flow using this runoff grid within Scotland is approximately +/- 11%.

4.4 The predictive performance of the methods

A key question to be answered within the development of the Low Flows 2000 methods in Scotland was how does the method compare with the R101 methods? The estimation of Mean Flows within The Low Flows 2000 estimates of Q95 were compared with those from Report 101 across 167 gauged catchments. To ensure a fair test and to realistically emulate the predictive performance at ungauged sites jack-knifed Low Flows 2000 estimates were estimated for each site. Similarly, the R101 estimates were derived based on predicted BFI estimates at the gauged locations rather than the estimates derived directly from the gauged records.

The two sets of estimates were compared using RMSE and BIAS statistics. The RMSE was computed as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Q95^{i} - \hat{Q95}^{\,i}\right)^{2}},$$

where $Q95^I$ is the observed Q95 value for catchment *i*, $\hat{Q95}^{\,i}$ is the estimated Q95 value for catchment *i* and *n* is the total number of catchments in the data set considered. The RMSE was calculated for both the standardised estimates of Q95 and those once rescaled by the catchment estimate of mean flow. For the latter the Q95 values (m3s-1) were expressed in units of $l^{-1}s^{-1}km^{-1}$ by dividing through by the catchment area. This formulation removes the influence of catchment size on the analysis. The RMSE statistics provide an assessment of the random error within the model. The BIAS statistic was calculated as:

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Q95^{i} - \hat{Q95}^{\,i}}{Q95^{i}}\right).$$

BIAS will be negative for a systematic tendency to over-predict and positive for a systematic tendency to under-predict.

The results from these comparisons are summarised within Table 1. This shows that the LF2000 represent a significant advance over the Report 101 methods both in terms of reduced BIAS and RMSE.

Table 1 Comparison of the predictive performance of Low Flows 2000 (Scotland) and Report 101 methods.

	RMSE (%MF)	BIAS	RMSE ($ls^{-1}km^{-2}$)
Report 101	6.74	-33.1	2.6
LF2000 Scot	4.84	-6.19	1.41

5 Estimation of Monthly Statistics

The driver for developing methods for estimating monthly statistics within Low Flows 2000 was the estimation of artificial influences which are incorporated as a monthly influence profile (Young et al. 2003). This allows both the seasonal variations in flows and influences to be taken into account. Low Flows 2000 contains models for predicting both monthly mean flows and flow duration curves (Holmes et al. 2002c).

Figure 2 provides an overview of the overall estimation procedure. Each of the monthly statistics and methods for estimating them are discussed in the following sections.

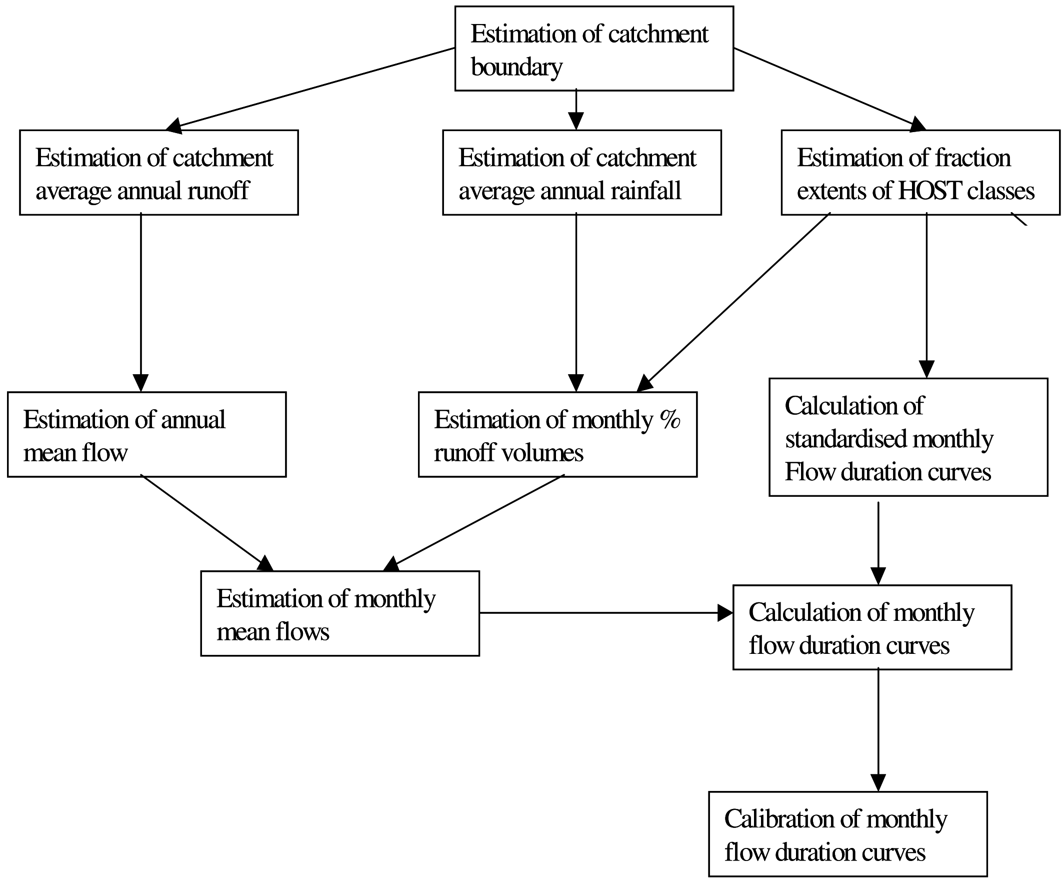

Figure 2 Overall estimation procedure

5.1 Estimation of Monthly Mean Flow

The monthly flow duration curve and mean monthly minima are estimated, as a percentage of the monthly mean flow. As discussed previously, the magnitude of the variation in UK flow regimes is dominated by catchment hydrogeology. Expressing these flow statistics in dimensionless form removes the overlying effects of the scale of catchment hydrological processes and enables statistical relationships between these low flow statistics and catchment characteristics to be developed. Estimates of the monthly mean flows are required so these estimated low flow statistics can be expressed in m^3s^{-1}.

Considering the distribution of the total volume of annual runoff between the months of the year, the distribution is clearly a function of the magnitude and seasonal distribution of rainfall, the strong seasonality of evaporation demand and the presence of soil moisture deficits that suppress the generation of runoff. Furthermore the distribution is strongly influenced by catchment hydrogeology.

For example, the lowest flows in groundwater fed catchments will typically occur in the autumn when groundwater levels are at their lowest, whilst the lowest flows in low storage impermeable catchments will typically occur in the summer months when evaporation demand is highest. The distribution of annual runoff within dry impermeable catchments will tend to be more skewed towards the winter months than in wet impermeable catchments. This is a function of the enhanced role that soil moisture deficits will play in suppressing summer runoff within dryer catchments.

Three stages are required for the derivation of the monthly mean flows as illustrated in Figure 3. The first is the estimation of the long-term annual mean flow (as previously described). The second is the estimation of the percentage of the annual runoff volume that occurs within each month, termed the Monthly Runoff Volume (MRV). The third is the conversion of the monthly runoff volume to monthly mean flow.

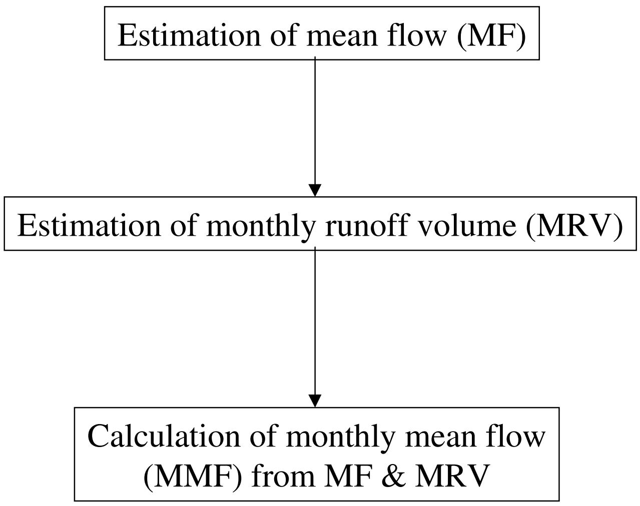

Figure 3 Stages in the estimation of monthly mean flow

The monthly runoff volumes are estimated using a region of influence approach. In this approach a region of “nearest neighbour” gauged catchments to the ungauged catchment is formed. The monthly runoff volumes for the ungauged catchment are then estimated as a weighted average of those for the gauged catchments forming the region. The method for estimating MRV at an ungauged “target” catchment in the UK involves four steps;

1. Catchment similarity is assessed by calculating the weighted Euclidean distance, in HOST space, between the target catchment

and every other catchment in the "data pool" of potential candidate catchments using

$$de_{it} = \sum_{m=1}^{M} W_m \left(X_{mi} - X_{mt} \right)^2 ,$$

where, de_{it} is the weighted Euclidean distance from the target catchment t to catchment i from the data pool; W_m is the weight applied to catchment characteristic m; X_{mi} is the standardised value of catchment characteristic m for catchment i. The catchment characteristics X_m used were the fractional extents of the 30 HOST classes within a catchment. The weights, W_m, to assess catchment similarity are those used in the estimation of the flow duration curve.

2. A "region" of 10 catchments is formed around a target catchment by ranking all of the catchments in the data pool by their weighted Euclidean distance in HOST space and selecting the 10 catchments closest to that target catchment. The modulus of the difference (ds) in average annual rainfall between the target catchment and each catchment in the pool is calculated.

3. An estimate of the MRV for the target catchment is calculated from a weighted average of the observed MRVs for the 10 catchments in the region using

$$MRV\%_{tj} = \sum_{i=1}^{n} \left[\frac{\left(\frac{1}{d_S} \right)}{\sum_{k=1}^{n} \left(\frac{1}{d_S} \right)} \right] \times MRV\%OBS_{ij} ,$$

where:

MRV_{tj} = the estimate of MRV for month j for target catchment t;

$MRVOBS_{ij}$ = the observed MRV for month j for the ith catchment in the region of n catchments closest to the target catchment;

d_{St} = the absolute difference in average annual rainfall of the target catchment *t* and the *i*th catchment.

The predictive uncertainty of the ROI MRV model was assessed using a log-log regression of the predicted values of MRV on the observed values of MRV for each month in the year.
The factorial standard errors (f.s.e.) for each month are presented in Table 2. The results indicate that the estimation of MRV in the dry summer months is more uncertain than the estimates for MRV during wet winter months. The results of the regression show that the uncertainty in the estimate of a MRV varies between approximately ±13% for the wetter winter months to ±33% for the drier summer months. When expressed as the MMF the uncertainty in estimates of MMF varies between ±20% and ±36%.

The final step in the estimation of monthly mean flows is to re-scale the estimated MRV by the estimate of annual mean flow. Remembering that the MRV for a month is the percentage of the total annual runoff volume occurring within that month the Monthly Mean Flow (MMF) for the month is estimated using:

$$\text{MMF} = \frac{\text{MRVxMF}}{(100/12)}.$$

Assuming a 68%ile prediction interval of ±14% in the estimate of annual MF a predictive uncertainty in the estimation of MMF for each month can be estimated by pooling the predictive uncertainties for the estimation of MRV for the month and MF.

The results indicate that the estimation of MRV in the dry summer months is more uncertain than the estimates for MRV during wet winter months. The results of the regression show that the uncertainty in the estimate of a MRV varies between approximately ±13% for the wetter winter months to ±33% for the drier summer months. When expressed as the MMF the uncertainty in estimates of MMF varies between ±20% and ±36%.

Table 2 Predictive uncertainties for estimating MMV and MMF by month

Month	f.s.e. for ROI predictions of MMV	68% confidence level predictive uncertainty in the estimation of MMF (m^3s^{-1})
January	1.13	21%
February	1.15	22%
March	1.12	20%
April	1.14	21%
May	1.20	26%
June	1.24	29%
July	1.33	36%
August	1.32	36%
September	1.29	33%
October	1.17	24%
November	1.14	22%
December	1.13	21%

The fact that the ROI model predicts winter mean flows more accurately than it predicts summer mean flows is a consequence of the complex relationships between rainfall, soil moisture deficits, evaporation demand and runoff during the summer months. The impact will also be exacerbated by the fact that summer flows are lower than winter flows, and thus a given volumetric error will represent a larger percentage error for summer flows.

5.2 Monthly and Reconstructed Annual Flow Duration Curves

The method for the estimation of the standardised monthly flow duration curves is also based on a region of influence approach using "nearest neighbour" gauged catchments. The annual flow duration curve can be reconstructed from the 12 standardised monthly flow duration curves and the monthly mean flow estimates. It is important that the reconstructed annual flow duration curve is identical to the natural, annual flow duration curve, for purposes of consistency. The estimation procedure is summarised in Figure 4.

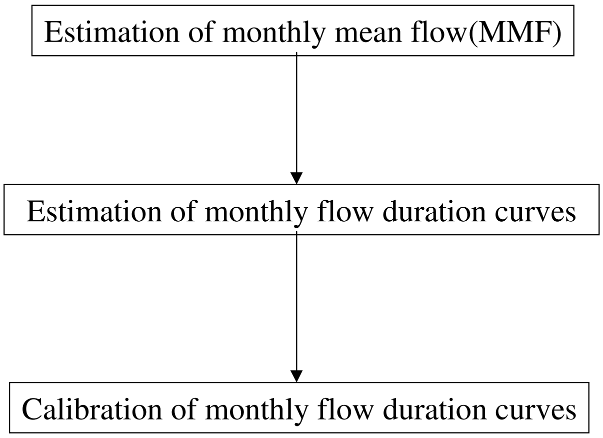

Figure 4 Stages in the estimation of monthly flow duration curves

5.2.1 The estimation of standardised monthly flow duration curves

In the UK, periods of high flows are typically experienced in the winter months and periods of low flows in the summer months, when the evaporation demand is highest. The hydrogeology of a catchment, as with the annual FDC, also has a strong influence of the variability of flows within a month.

The region of catchments identified using the ROI approach for estimating the annual flow duration curve within an ungauged catchment are also used to estimate the monthly flow duration curves for the ungauged catchment. The monthly flow duration curves for the ungauged site are estimated by taking a weighted average of the observed monthly flow duration curves (standardised by the relevant monthly mean flows). In the weighting procedure the observed monthly FDC points for the individual catchments in regions are weighted by absolute distance in weighted HOST space.

Analysis of the predictive performance of the estimation of standardised monthly flow duration has demonstrated that, overall the predictive performance of this model is also higher for winter months than summer months.

For illustration, factorial standard errors are presented within Table 3 for the prediction of three percentile points for January and August monthly flow duration curves (over 653 catchments covering the whole of GB). The three percentile points presented cover high, median, and low flows within the month.

Table 3 Results of a regression of Qx_{OBS} vs Qx_{PRED} for 653 catchments for the Monthly FDC

Month	Q10 f.s.e.	Q50 f.s.e.	Q95 f.s.e.
January	1.098	1.138	1.452
August	1.168	1.266	1.806

The f.s.e. shown on Table 3 can be used to approximate the 68% confidence interval for the estimate of *Qx* (as a proportion of MF), since n is large. These results show that the January Q10 can be predicted with 68% confidence to within ± 9.8% while the August Q10 can only be predicted to within ± 16.8%, to the same degree of confidence. It can also be seen that the confidence interval is larger for lower flows with a month. This is a consequence of the dependence of these lower flows on the release of water from storage within the catchment.

5.2.2 Reconstruction of Annual Flow Duration Curves

The area under a flow duration curve is the equal to the total volume of water over the period in question. The sum of the areas under the 12 estimated monthly flow duration curves (once they have been re-scaled by the appropriate estimate of monthly mean flow) should equal the area under the estimated annual flow duration curve. To ensure that this is the case a fitting routine is used. The monthly flow duration curves (with units of m^3s^{-1}) are disaggregated into 100 "daily flows" at equally distributed percentiles. The resultant 1200 flow values are placed within a pool whilst retaining a flag to identify the month from which the flows are derived. A composite flow duration curve is then derived from the pooled values and compared with the long term annual flow duration curve estimated directly from catchment characteristics. The values within the composite curve are adjusted to ensure that the two curves coincide and the monthly curves are then reconstructed from the adjusted composite curve values.

6 Estimation of Base Flow Index

BFI is a useful, general hydrological measure. There is a strong relationship between the base flow index (BFI) and the hydrogeology (and with the Q95 (%MF)). BFI was the primary hydrological classification variable used within the development of the HOST classification. The resultant model for predicting BFI from HOST (BFIHOST) is widely used, particularly within the Flood Estimation Handbook statistical methods. An evaluation of the predictive performance of BFI HOST within Scotland highlighted a significant bias at low values of BFI and hence the model was re-parameterised for use within Low Flows 2000 Scotland. The RMSE and BIAS statistics evaluated across 217 catchments within Scotland are presented within Table 4, which demonstrate a considerable reduction in BIAS.

Table 4 Performance statistics for the BFIHOST_SCOT and BFIHOST_UK method for estimating BFI

	RMSE	BIAS
BFIHOST_SCOT	0.11	-3.2
BFIHOST_UK	0.1	-14.8

7 Considerations for use

The assumptions and uncertainties associated with the flow estimation methods must be considered when making use of flow estimates produced by the system and appropriate training is strongly recommended.

The 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:

1. 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).
2. A catchment water balance is assumed within the methods; this assumption may be incorrect in smaller groundwater fed catchments

where part of the regional groundwater flow bypasses the surface water catchment.

3. 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.
4. Care needs to be taken when interpreting the results in very small catchments as the size of the catchment approaches the spatial resolution of the underlying catchment characteristic datasets within Low Flows 2000 ($1km^2$)
5. Where available, local measured flow data should be used to corroborate the Low Flows software estimates. This is good practice when using any generalised hydrological model. However, careful judgement should be exercised as many of the methods for incorporating local data are subject to many of the same issues that might limit the predictive performance of the models within Low Flows 2000.

8 References

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