# LowFlows 2™

*UK best practice low-flow estimation*
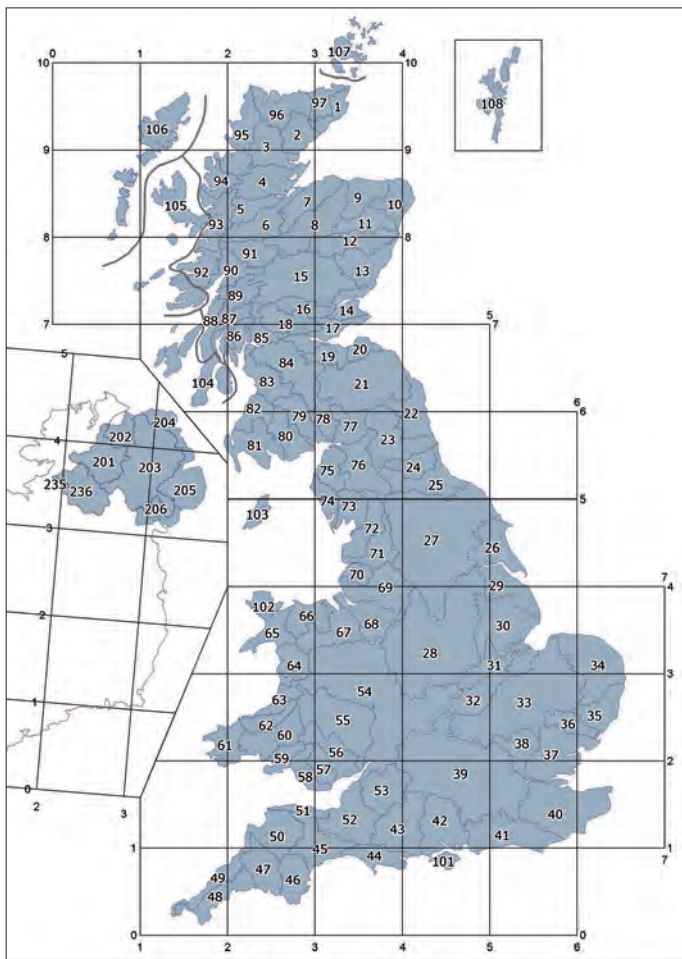
*Estimation of natural and influenced flow regimes in ungauged catchments*

# User Guide

**WHS** Wallingford HydroSolutions Ltd

UK Hydrometric Areas and National Grid coordinates

# LowFlows 2™

## User Guide
December 2010

**WHS**

# WHS

## Development team

Wallingford HydroSolutions Limited (WHS) software development team are responsible for the development of the LowFlows™ software.

## Document history

**V1.0**
January 2007
WHS software development team
January 2007 release

**V2.0**
December 2010
WHS software development team
December 2010 release

## Technical specification

*Minimum recommended specification*

**Base computer**
Intel or equivalent PC with CD drive

**Chip**
Pentium III 1 GHz or equivalent

**RAM**
512Mb

**Free drive space**
200Mb

**Monitor**
XGA:1024 X 768 at 8-bit 256 colours

**Operating system**
Windows XP, Windows Vista, Windows 7

## Contents

**Licence terms and conditions**

The use of the LowFlows 2™ software is governed by the terms and conditions of the licence agreement between Wallingford HydroSolutions Limited and the User. The User is required to accept the licence terms and conditions of use prior to installation and at runtime. These terms and conditions can be viewed within the software and on the licence certificate.

Your attention is particularly drawn to clauses relating to your responsibilities and licence termination, and that your licence agreement specifies the number of computers on which you may install and use the software.

## 1  Overview

The need to rapidly estimate the available water resources within a catchment is an issue facing environmental managers across the world. The LowFlows software system has been developed to enable river flows to be estimated for ungauged catchments in the United Kingdom. The hydrological estimation methods used in the software are derived from the Low Flows 2000 software system that was developed jointly by the Centre for Ecology and Hydrology (CEH) and the Environment Agency of England and Wales (EA). Subsequent research and development in conjunction with the Scottish Environmental Protection Agency (SEPA) and the Northern Ireland Environment Agency (NIEA) has lead to the expansion of the software coverage to include these regions. All of these regulatory authorities have adopted the LowFlows Enterprise system (an enhanced version of Low Flows 2000) as a standard method for predicting flows within ungauged catchments.

The LowFlows software employs the same underlying hydrological models as the LowFlows Enterprise system, at a cost suitable for use by a wide range of users from engineering consultants to environmental scientists. The functionalities of the system include:

- **National coverage**, hence the ability to estimate flows for any catchment in England, Wales, Scotland and Northern Ireland, with spatial orientation by hydrometric area.
- The ability to **estimate** the following for user-defined catchments, imported using either Esri shapefiles (polygons) or CSV files.
  - Annual mean flow (m³/s);
  - Annual runoff (mm/yr);
  - Base flow index (BFI);
  - Annual and monthly flow duration statistics (including Q95) for the natural flow regime;
  - Annual and monthly flow duration statistics for an influenced flow regime (based on user-supplied quantification of influences);
- The ability to improve natural flow estimates by incorporating preloaded **local data gauges** (LDGs).

- The ability to generate **flow statistics** for catchments in Scotland with and without the impact of natural surface waters.
- The ability to browse a wide range of **contextual information**, for example digital Ordnance Survey maps, viewed via the geographical interface.

The specific enhancements included in the 2010 release of LowFlows 2™ are:

- Updates to the hydrological models underpinning natural flow estimation (see **Section 8**).
- Automatic incorporation of LDGs within the model framework (see **Section 9**).
- Extension of coverage to include Northern Ireland following work commissioned by the Northern Ireland Environment Agency and completed by Wallingford HydroSolutions in 2009.

## 2 Appropriate use of LowFlows 2™

**LowFlows is a decision-support tool** designed to assist water-resource management through the estimation of flow regimes in ungauged catchments by experienced hydrologists with expertise in the field.

It is strongly recommended that the software is used by competent hydrologists who have received appropriate training. Care and experience is needed when interpreting results because:

■ The estimates generated using the hydrological models in the software contain uncertainty arising from a variety of sources, including:
- the underlying model form
- input data used to develop the models
- the assumption of a closed water balance
- the impacts of unquantified artificial influences.

■ The performance of the models may vary with local conditions.
- In smaller groundwater catchments 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 methods; 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 catchment Mean Flow is based on gridded long-term average annual runoff. Derivations from runoff grids are sensitive to **raingauge density** and the predictive performance of the model may therefore be reduced in areas of low rainfall-gauge density.
- In very small catchments the size of the catchment may approach the **spatial resolution** of the underlying catchment characteristic datasets within LowFlows (1km$^2$).
- 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, but 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 LowFlows.

- LowFlows estimates long-term flow statistics. Flow statistics calculated from **short-record local data** will not be representative of these long-term flow statistics so caution should be used when comparing LowFlows estimates with short-record data.

- Significant **artificial influences** must be included in the LowFlows model if observed flow statistics are to be derived.

- If **reservoirs** with a significant hydrological impact on downstream flows exist in a catchment, then estimating influenced flow regimes directly using LowFlows may not be appropriate. Please contact Wallingford HydroSolutions for advice.

**Note** The estimation methods in LowFlows are summarised in **Section 8**, but this does not represent formal guidance in their use.

Please contact Wallingford HydroSolutions for information on appropriate training courses.

## 3  An outline of the estimation process and this guide

The LowFlows software produces flow estimates for catchments defined by you, the user. First, you import your catchment boundary into the software (as a shapefile or simple CSV file). The software then automatically overlays this 'target' boundary on spatial data sets to derive required catchment characteristics. These characteristics form the inputs to the underlying hydrological models which produce estimates of the natural flow regime for the catchment. You can improve these natural flow estimates by including local data gauges (LDGs), if they are relevant to the specific target catchment. You can also estimate the impacts of artificial influences on the flow duration statistics.

The sections of this guide will lead you through the use of the software and the process of obtaining low-flow estimates as follows.

- **4 Getting started** How to install and run the software and the functionality of the Main window.
- **5 Bringing in catchment boundaries** How to develop, import and archive catchment boundaries.
- **6 Generating low-flow estimates** A step-by-step description of how to make natural and influenced flow estimates.
- **7 Using contextual data** How to import vector and raster contextual data sources and modify how they are displayed.
- **8 The hydrological models in LowFlows** A summary of the models underpinning the software.
- **9 Incorporating local data** How to incorporate LDGs to improve natural flows estimates.
- **10 References** Directions to further technical details.
- **11 Glossary** Commonly used terms and concepts explained.

The table below shows the conventions used in the text.

| Convention | Explanation |
|---|---|
| [Square brackets] | Pull-down menu choices, for example [Estimate low flows]. *Functions can be accessed via pull-down menus or icons/tabs.* |
| **Bold grey** | Text appearing in the window currently displayed. |

## 4  Getting started

### 4.1  Installing the software

To install the LowFlows software from your CD, place the CD in the drive of the target machine and run the **setup.exe** file.

LowFlows Setup will prepare to install the software, displaying the **Preparing to install...** screen (Figure 4.1).
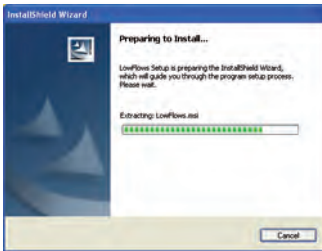


**Figure 4.1** Preparing to Install screen

The installation **Welcome** screen will then be displayed (Figure 4.2).
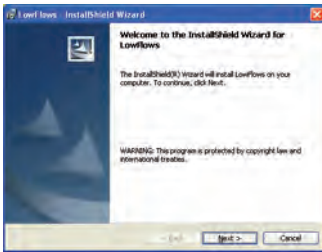


**Figure 4.2** Installation Welcome screen

Click **Next** to continue to the **Licence Agreement** screen (Figure 4.3).

**Figure 4.3** Licence Agreement screen

You must agree to the terms and conditions in the licence agreement before you can install the software.

Select the **I accept…** button and click **Next** to continue to the **Destination Folder** screen (Figure 4.4).
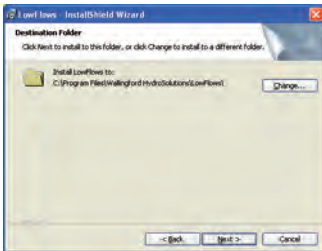


**Figure 4.4** Destination Folder screen

The recommended location for the LowFlows folder is set by default. To change this location click **Change…** and select a new folder.

Click **Next** to continue to the installation **Setup Type** screen (Figure 4.5).
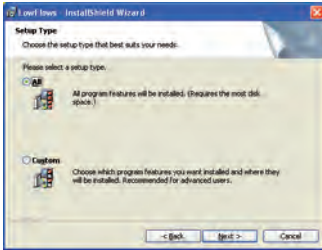


**Figure 4.5** Installation Setup Type screen

This screen allows you to choose between installing **All** program features and **Custom** installation, for instance installing just the LowFlows data, the LowFlows application files, or both.

It is recommended that you select **All** when installing LowFlows, to ensure the software functions correctly.

For the first installation of LowFlows on any PC, the **Custom** setup type should not be selected.

Click **Next** to continue to the Ready to Install… screen (Figure 4.6).
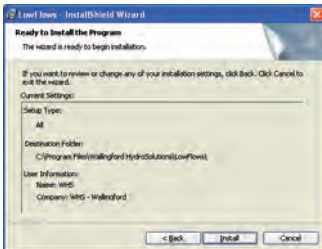


**Figure 4.6** Ready to Install... screen

**Note** For future installations it may be useful to select the **Custom** setup type in order to update the data only, without overwriting the licence files. In this case select **Custom** and click **Next** to continue to the **Custom Setup** screen (Figure 4.7).

To install the data only, click on the **Application** icon and select [This feature will not be available], then click **Next** to continue to the Ready to Install… screen (Figure 4.6).
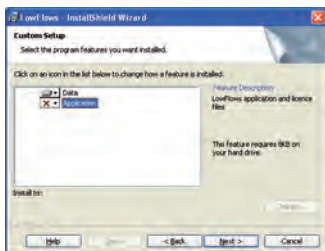


**Figure 4.7** Custom Setup screen

Click **Install** to begin the installation. The **Installing LowFlows** screen will now be displayed (Figure 4.8).
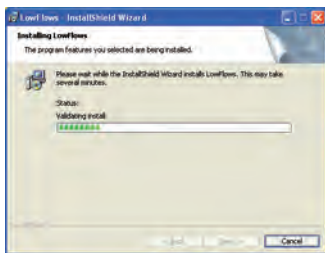


**Figure 4.8** Installing LowFlows screen

When the installation is complete the **InstallShield Wizard Completed** screen will be displayed (Figure 4.9).
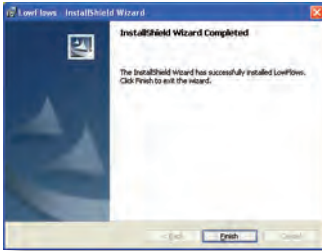


**Figure 4.9** InstallShield Wizard Completed screen

Click **Finish**. If the message below is displayed (Figure 4.10) you should restart your PC before using LowFlows.
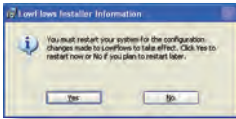


**Figure 4.10** Restart message

## 4.2  Activating the software licence

LowFlows 2™ is protected by a licence held on the USB dongle which is supplied with the software. You must insert the dongle into the computer whenever you run the software.

The first time you use the software, you need to click **Browse licence...** in the login screen (Figure 4.11) and browse to the LowFlows.lic file on the USB dongle. During subsequent uses the software will automatically look for the licence in the same place, however if the drive letter of the dongle changes (for example when you are using it on another computer) you may need to browse to the file again.

If the licence file is valid you will see a message on the login screen confirming that you have a valid licence for the software.

Figure 4.11 Login screen

## 4.3 Logging in

You must agree to the **Licence Terms and Conditions** before running the software. Click **Accept** to confirm that you have read and accepted the Licence Terms and Conditions presented in the login screen.

The **Region Selection** screen will now be displayed (Figure 4.12) showing the list of Hydrometric Areas included in the installation.
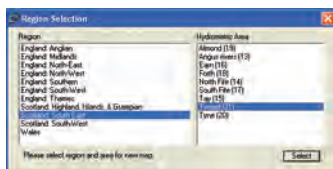


Figure 4.12 Selecting Hydrometric Area 45 in the England: South-West region

Choose a hydrometric area from the list and click **Select** to continue to the main window (Figure 4.13).

**Note** Hydrometric Areas 21 and 77 are cross-border catchments but are listed as Scottish. In this guide, Hydrometric Area 45 (the river Exe) is used for illustrative purposes.

## 4.4 Using the main window
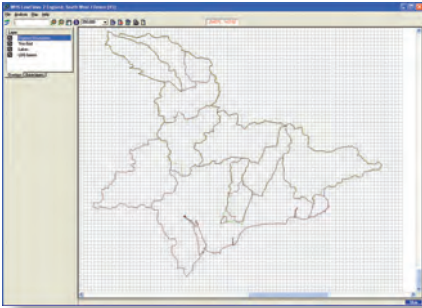


Main window

The table opposite shows the menus and icons available.

You can control the display of spatial layers in the main window by selecting and deselecting specific **Overlays** and **Base-layers** tabs.

The **Overlays** tab shows vector data and the **Base-layers** tab contains raster data. You can only view one raster data set at a time.

The following basic spatial data sets are included with the software:

- **Digitised Boundaries** Showing the hydrometric area boundaries from the National River Flow Archive (NRFA).
- **1 km Grid** A grid with cells of 1000 x 1000 m which can be used to provide a quick reference scale and to illustrate spatial data sets.
- **Lakes** A layer of points showing those natural lakes/lochs which are used to adjust natural flows due to the impact of lakes.
  **Note** The natural lochs/lakes currently included are restricted to Scotland. *Lake* and *loch* are used interchangeably within this guide.
- **LDG basins** A polygon layer showing the catchments associated with the base set of LDGs included in the software.

The mouse location is updated as a National Grid Reference (NGR) and Ordnance Survey grid X Y coordinates (shown in red).

| Menu | Menu item | Icon | Description |
|------|-----------|------|-------------|
| File | Exit | | Exit the software |
| | Switch Area | | Switch display to a different hydrometric area |
| Analysis | Estimate low flows | | Begin the low flows estimation procedure |
| Map | Zoom in | | Zoom in by bounding box |
| | Zoom out | | Zoom out by incremental steps |
| | Show map-key | | Display a key to visible layers |
| | Import layer | | Display new contextual data as layers |
| | Layer-maintenance | | Edit display options for layers |
| | Map-snapshot | | Take a screenshot of the current Map window to paste into external applications |
| | Render 1000m grid | | Display the spatial data gridded at 1000×1000 m resolution |
| | Import Boundary Polygon | | Begin the process of importing a catchment boundary |
| Help | LowFlows Help | | Go to the User Guide |
| | Installation Help | | Go to the Installation Help file |
| | About | | View details of the LowFlows version and licence |
| Tool bar | | | Pan over the Map window |
| Tool bar | | | View information about a feature selected on the map |
| Tool bar | | 250,000 | Set the map scale by selecting a predefined scale or entering a scale defined by you using the keyboard |

## 5  Bringing in catchment boundaries

To generate flow estimates for a catchment, you must first import an externally defined catchment boundary.

- ■ **Section 5.1** summarises how to define your catchment boundary externally, for import into LowFlows. A more in-depth description of boundary definition is given in most good hydrological textbooks.
- ■ **Section 5.2** explains the formats you can import into LowFlows.
- ■ **Section 5.3** takes you through importing your catchment boundary.
- ■ **Section 5.4** explains how to delete a saved boundary.

### 5.1  Defining catchment boundaries

A catchment boundary delineates the upstream area draining to the point of interest called the catchment outlet.

Catchment boundaries should reflect the topographic and artificial boundaries (such as catch-waters and leats) of the catchment, and may include some allowance for groundwater divides.

You can identify catchment boundaries manually using topographic maps of appropriate scale (typically 1:25,000 or 1:50,000). It is now common to use **digital maps** in conjunction with GIS tools, but you can use **paper maps**, in which case you need to read the string of coordinate pairs that accurately defines the boundary from the map (see **Section 5.2** for more details).

Whichever type of map you use, the following steps are usually involved.

- ■ Identify the grid reference of the catchment outlet, giving particular attention to the verification of the site in relation to upstream and downstream confluences.
- ■ Identify the topographic catchment boundary using mapped information regarding:
  - ● river network location
  - ● contours
  - ● spot heights.

When you have chosen a topographic map of a scale suitable for the catchment of interest, first select the **catchment outlet**. Then start

defining the boundary by moving in an uphill direction, perpendicularly crossing contours until a peak is reached.

If there is only one peak in the boundary, close the catchment boundary by continuing downhill until the catchment outlet is reached, ensuring that contours are crossed perpendicularly.

If the boundary passes through a number of peaks and troughs (which is most common) the principle is the same, you continue the boundary ensuring that contours are crossed perpendicularly. Ensure the boundary does not cross any rivers/streams except at the catchment outlet.

See Figure 5.1 for an example of a catchment boundary. Contours display the shape of the hills surrounding the rivers flowing down to an outlet.
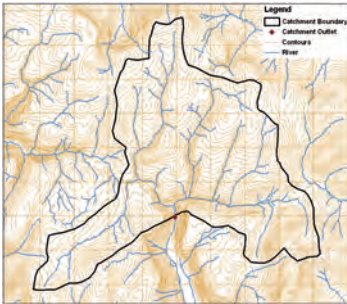


**Figure 5.1** Example of catchment boundary definition (Contains Ordnance Survey OpenData™ data © Crown copyright and database right 2010)

**Note** It is essential that you define catchment areas accurately. An inaccurately defined catchment will severely constrain the accuracy of any of the subsequent analysis. The flow estimates produced by the software scale linearly with the catchment area and hence an error in catchment area of 10%, would result in an error of 10% in all flow estimates produced. Site inspection may be necessary to fix the boundary of small or flat catchments.

## 5.2  Catchment boundary formats

You can import catchment boundaries into LowFlows in either of the following formats.

- ■ **Esri polygon shapefile** This is a GIS file containing polygons to represent the catchments. GIS programmes, for example Esri ArcGIS and MapInfo, have the ability to digitise boundaries from electronic maps. Using a GIS interface, import an appropriately scaled topographic map and draw the catchment boundary using the 'create polygon' feature in most GIS programmes. Save the boundary polygon as a shapefile.

- ■ **Comma-separated values (CSV) file** Obtain coordinate pairs of the catchment boundary manually by either drawing the boundary on a paper map and physically reading off the coordinates or by reading the coordinates from an appropriate web-based map. Record six-figure grid references for each new point of the catchment boundary (usually indicating a change of direction), enter them into a spreadsheet and save it as a CSV file. See Figure 5.2 for an example spreadsheet with X (Easting) coordinates in column A, and Y (Northing) coordinates in column B. You should list the X,Y coordinates in order (clockwise or anticlockwise) to show the sense of the polygon. The last point in the file should be a repeat of the first point, to ensure polygon closure.



**Figure 5.2**  Catchment boundary coordinates in a spreadsheet

## 5.3  Importing a catchment boundary

You can import catchment boundaries:

- ■ 'on the fly' during the flow estimation process
  via [Analysis][Estimate low flows][Use polygon from external source]

or

- ■ to save them for later use, as follows.
  - ● Go to [Map][Import boundary polygon] to add a boundary polygon from a shapefile or CSV file to the layer.
  - ● Once you have imported the polygon or CSV file, the boundary will be saved to the **Saved Boundaries** layer (a hydrometric-area-specific archive).
  - ● The saved boundary can then be recalled during flow estimation via [Analysis][Estimate low flows][Use previously imported polygon].

If you are using a shapefile, you will need to select the **Import from Shapefile** option and browse to the Esri shapefile that contains your boundary polygons representing catchments. Select one of the polygons to use/import it.

If you are using a CSV file, you will need to select the **Import from Comma-Separated Variables File** option and browse to the file containing X,Y coordinates defining the extent of the required boundary polygon. Select the file to use/import it.

**Note** You must inspect the boundaries saved to the Saved Boundaries layer to ensure that you have defined the correct boundary. Incorrect boundary definition will impact on the flow estimates you produce for the catchment.

## 5.4  Deleting a saved boundary

You can delete a boundary from the Saved Boundaries layer.

Right-click the boundary in the Main window and select **Delete Saved Basin**.

## 6  Generating low-flow estimates

Go to [Analysis][Estimate low flows].

If you have already imported catchment boundaries and a Saved
Boundaries layer exists, the following options will be displayed enabling
you to select the target catchment boundary you want to use.

**1** **Use Polygon from External Source** Enables you to select a
boundary directly from a shapefile or CSV file.

**2** **Use Previously-Imported Polygon** Enables you to select a boundary
from the Saved Boundaries layer (see **Section 5** on importing
boundaries into LowFlows).

If no Saved Boundaries layer exists, you are restricted to the first option.

When you have selected your target boundary you need to set the
resolution of the virtual **grid** which defines how the catchment boundary
will be overlaid on spatial data sets. The larger the number selected the
coarser the overlay procedure. Typically, a 50m resolution is appropriate
for catchments smaller than 50km$^2$ , a 200m resolution is appropriate
for catchments larger than 50km$^2$ and you should consider adopting a
resolution larger than 200m for catchments larger than 1000km$^2$.

The process of overlaying the catchment boundary on to the spatial data
sets may take a few seconds for a small catchment at low resolution, or a
few minutes for a very large catchment at high resolution.

If **local data gauges** (LDGs) are found in the vicinity of the catchment,
you need to confirm if data from these should be incorporated in the
flow estimation procedure. The incorporation of LDG data enables flow
estimates to be improved by making use of observed flows at points
upstream and/or downstream of an ungauged catchment (see **Section 9**).

You will also be asked if **artificial influences** should be included in
the flow estimates. If you require estimates of the natural flow regime,
select **No** (see **Section 6.1**). If you require estimates of the flow regime
including net impacts of influences such as abstractions and discharges,
select **Yes** (see **Section 6.2**).

The **Ungauged Low-Flow Estimates** window will then be displayed
with the estimated flow statistics for the catchment. This window
displays the estimates of the flow regime on two tabs: **Results Summary**
and **Flow Duration**. You can view contextual information about the
catchment on the **Map** tab.
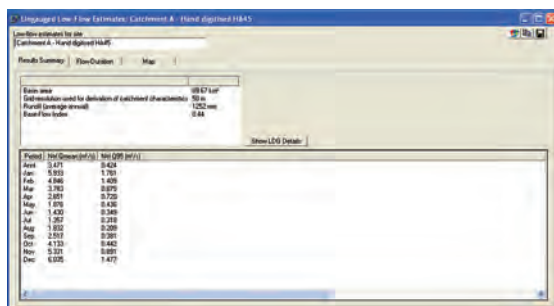


**Figure 6.1** The Ungauged Low-Flow Estimates window – the Results Summary tab shows natural
flows where LDGs have been included

**Note** If the catchment is located in Scotland then a set of estimates
including adjustment for the impact of lakes may be included, if relevant.

Cross-border Hydrometric Areas 21 and 77 are only listed in the Scottish
regions, but you can estimate flows using the English & Welsh methods
or the Scottish methods (see **Section 8**).
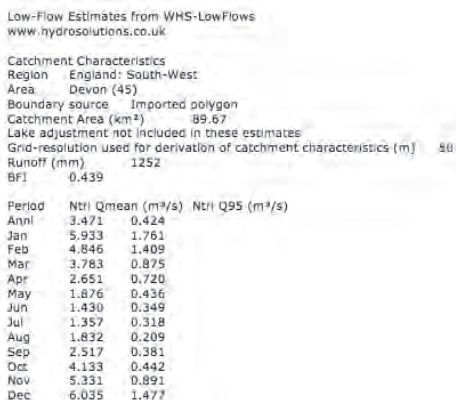
## 6.1 Natural flow duration statistics

The principle flow estimates shown in the Ungauged Low-Flow Estimates
window are flow duration curve (FDC) statistics at both an annual and
monthly resolution. These are derived using the catchment characteristics
of the target catchment and the hydrological models summarised in
Section 8. They are described as 'natural' FDCs as they don't include the
impact of artificial influences (eg. abstractions and discharges) on flows.

### *6.1.1 Results summary*

The **Results Summary** tab (Figure 6.1) provides the catchment statistics of size, average annual runoff and base flow index (BFI). The monthly and annual mean flows are shown in the **Ntrl Qmean (m³/s)** column and the monthly and annual Q95 flows (a commonly used flow duration statistic) are shown in the **Ntrl Q95 (m³/s)** column.

Click on the **Copy to Clipboard** icon to copy this data for pasting into other applications (Figure 6.2) or the **Save** icon to save as a CSV file.



Low-Flow Estimates from WHS-LowFlows
www.hydrosolutions.co.uk

Catchment Characteristics
Region    England: South-West
Area      Devon (45)
Boundary source    Imported polygon
Catchment Area (km²)        89.67
Lake adjustment not included in these estimates
Grid-resolution used for derivation of catchment characteristics (m)    50
Runoff (mm)       1252
BFI       0.439

| Period | Ntrl Qmean (m³/s) | Ntrl Q95 (m³/s) |
|---|---|---|
| Annl | 3.471 | 0.424 |
| Jan | 5.933 | 1.761 |
| Feb | 4.846 | 1.409 |
| Mar | 3.783 | 0.875 |
| Apr | 2.651 | 0.720 |
| May | 1.876 | 0.436 |
| Jun | 1.430 | 0.349 |
| Jul | 1.357 | 0.318 |
| Aug | 1.832 | 0.209 |
| Sep | 2.517 | 0.381 |
| Oct | 4.133 | 0.442 |
| Nov | 5.331 | 0.891 |
| Dec | 6.035 | 1.477 |

**Figure 6.2**  Example of data pasted from clipboard

You can use the **Influenced Flows** icon to generate influenced low-flow estimates (see **Section 6.2**).

If you have included LDGs in the estimation process, the **Show LDG Details** button will be visible, enabling you to view which LDG have been used in the estimation process.

### *6.1.2 Flow duration*

The **Flow Duration** tab (Figure 6.3) enables you to plot monthly and annual FDCs by selecting tick boxes. You can select alternate axes and switch the units between m³/s and flows expressed as a percentage of the mean flow (annual or monthly) (%MF) using the radio buttons.
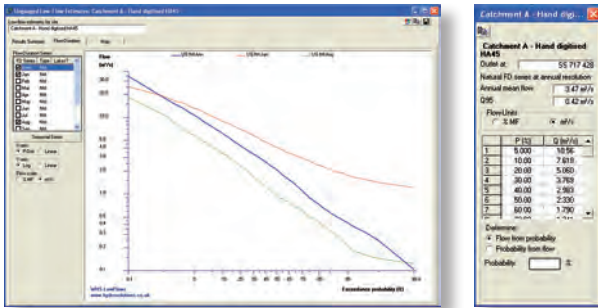


**Figure 6.3** The Ungauged Low-Flow Estimates window – the Flow duration tab shows the monthly and annual FDCs and tabulated data for the annual FDC

Click on the **Copy to Clipboard** icon or right-click in the plot area to copy a screen shot for pasting into other applications (Figure 6.4).
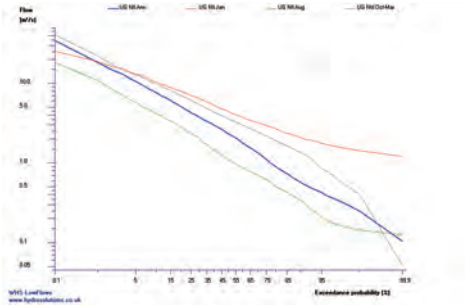


**Figure 6.4** Exported plot of FDCs from Flow duration tab showing May, August, Annual and Seasonal (Oct to Mar) natural FDCs

Double right-click on any of the listed FDCs (ie double right-click on text

'**Annl**') to view tabulated data. Click on the **Copy to Clipboard** icon to copy this data for pasting into other applications (spreadsheets and word processing packages).

Clicking on the **Seasonal Series** button brings up the **Season Definition** window and allows you to determine what is included in the Results Summary and Flow duration tabs by selecting the start and end months for FDCs covering the chosen period.

### 6.1.3  Map

Go to the **Map** tab to view the selected catchment together with other contextual information already loaded into the **Overlays** or **Base Layers** tabs (Figure 6.5).

You can change the scale of the map using the drop-down list.

Turn layers on and off using the tick boxes.
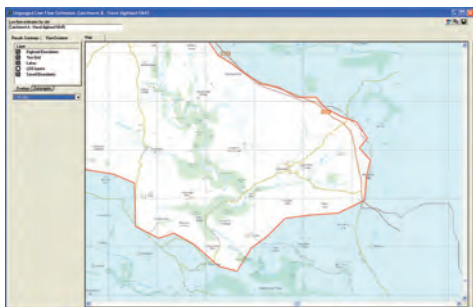


**Figure 6.5**   The Ungauged Low-Flow Estimates window – Map tab with OS VectorMapTM District raster loaded as contextual information (contains Ordnance Survey OpenData™ data © Crown copyright and database right 2010)

## 6.2 Influenced-flow estimates

The hydrological models underpinning LowFlows enable the natural FDC to be estimated for ungauged catchments. For catchments with significant water-use features or artificial influences the flow regime observed will reflect the natural FDC plus the impact of abstractions (removing flows) and discharges (providing additional flow).

**Note** Impoundments/reservoirs also have an impact on the flow regime downstream of their location, but the impact of reservoirs cannot be modelled in the current version of LowFlows. Please contact WHS for information on how flow estimates can be produced for catchments with significant reservoirs.

To produce a net monthly influence profile which characterises the net seasonal variation of water use (by type of influence) within the catchment, you need to determine and sum the individual artificial influences, represented by monthly profiles. In the case of a groundwater abstraction, you need to determine the net effect of the abstraction on surface waters, rather than the actual abstraction regime at the borehole. This is a simplification of how groundwater abstractions are treated in LowFlows Enterprise, where the Theis solution is applied to individual abstraction points to determine the stream deletion factors appropriate for the nearest river reach.

Algorithms within the software superimpose these net monthly influence profiles onto the natural flow regime (as defined by monthly FDCs) to produce influenced flow estimates. For instance, if significant net abstractions occur during the summer months then the influenced flows during these months are less than the natural flows.

If you select to include artificial influences during the low-flow estimation process then the **Set Influence Profile** window is displayed prior to viewing the results in the Ungauged Low-Flow Estimates window. Enter the net monthly influence profile for different types of influences into the Set Influence Profile window (Figure 6.6).
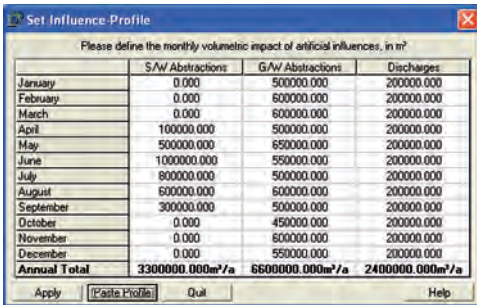
**Figure 6.6** Set Influence Profile window

■ You can enter values directly into the table, using the Enter or arrow keys to move between cells of the table.

■ You can copy a block of 3×12 cells from a spreadsheet and paste it directly into the screen using the **Paste Profile** button.

**Note** When using **Paste Profile**, you must paste in an entire block of 3×12 cells (ie a single column of 1×12 cells is not acceptable). All values entered must be positive. Enter zeros in the cells that signify no impacts.

Figure 6.7 shows an example where the grey cells are being copied to the clipboard to be pasted in using the **Paste Profile** button. This example shows net surface water abstractions typical of spray irrigation abstractions with higher summer abstraction rates, a relatively constant net groundwater abstraction regime and a constant net discharge regime. All cells contain values, even if zero.



**Figure 6.7** Example of data from a spreadsheet to be added using the Paste Profile button

## *6.2.1 Results summary including influenced flows*

If you have set an influence profile, the **Results Summary** tab of the Ungauged Low-Flow Estimates window will now include both natural and influenced flow estimates (Figure 6.8).
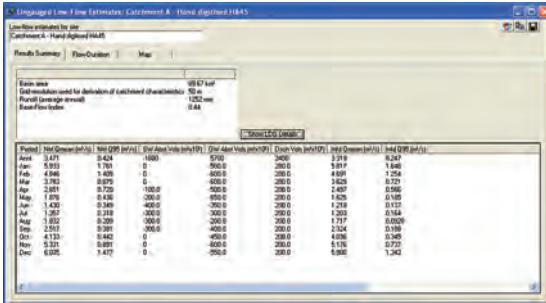


**Figure 6.8**  The Ungauged Low-Flow Estimates window – Results-Summary tab showing natural and influenced flows

Descriptions of the values displayed are shown here.

| Column Header | Description |
|---|---|
| Ntrl Qmean (m³/s) | Natural mean flows |
| Ntrl Q95 (m³/s) | Natural Q95 flows |
| SW Abst Vols (m³×10³) | Net surface water abstraction volumes |
| GW Abst Vols (m³×10³) | Net ground water abstraction volumes |
| Dsch Vols (m³×10³) | Net discharge volumes |
| Infd Qmean (m³/s) | Influenced mean flows |
| Infd Q95 (m³/s) | Influenced Q95 flows |

As mentioned in Section 6.1.1, you can click on the **Copy to Clipboard** icon to copy this information for pasting into other applications (Figure 6.9) or the **Save** icon to save as a CSV file.

Low-Flow Estimates from WHS-LowFlows
www.hydrosolutions.co.uk

Catchment Characteristics
Region    England: South-West
Area      Devon (45)
Boundary source Imported polygon
Catchment Area (km²)      89.67
Lake adjustment not included in these estimates
Grid-resolution used for derivation of catchment characteristics (m)      50
Runoff (mm)      1252
BFI      0.439

| Period | Ntrl Qmean (m²/s) | Ntrl Q95 (m³/s) | SW Abst Vols (m³x10³) | GW Abst Vols (m³x10³) | Dsch Vols (m³x10³) | Infd Qmean (m³/s) | Infd Q95 (m³/s) |
|--------|------|------|------|------|------|------|------|
| Anni | 3.471 | 0.424 | -1600 | -5700 | 2400 | 3.319 | 0.247 |
| Jan | 5.933 | 1.761 | 0 | -500 | 200 | 5.817 | 1.646 |
| Feb | 4.846 | 1.409 | 0 | -600 | 200 | 4.691 | 1.254 |
| Mar | 3.783 | 0.875 | 0 | -600 | 200 | 3.629 | 0.721 |
| Apr | 2.651 | 0.72 | -100 | -500 | 200 | 2.497 | 0.566 |
| May | 1.876 | 0.436 | -200 | -650 | 200 | 1.625 | 0.185 |
| Jun | 1.43 | 0.349 | -400 | -350 | 200 | 1.218 | 0.137 |
| Jul | 1.357 | 0.318 | -300 | -300 | 200 | 1.203 | 0.164 |
| Aug | 1.832 | 0.209 | -300 | -200 | 200 | 1.717 | 0.0928 |
| Sep | 2.517 | 0.381 | -300 | -400 | 200 | 2.324 | 0.188 |
| Oct | 4.133 | 0.442 | 0 | -450 | 200 | 4.036 | 0.345 |
| Nov | 5.331 | 0.891 | 0 | -600 | 200 | 5.176 | 0.737 |
| Dec | 6.035 | 1.477 | 0 | -550 | 200 | 5.9 | 1.342 |

**Figure 6.9**   Example of data pasted from clipboard

### 6.2.2 Flow duration including influenced flows

As above, if you have set an influence profile, the **Flow Duration** tab will now include FDCs for the natural regime and the influenced regime. You can display any combination of annual or monthly FDCs for the natural or influenced regimes by using the tick boxes. Figure 6.10 shows annual FDCs for natural and influenced regimes.

As described in Section 6.1.2, to paste from the Ungauged Low-Flow Estimates window into other applications:

■ you can double right-click on any of the listed FDCs to display tabulated data and copy it to the clipboard

■ you can right-click within the plot area or click on the **Copy to Clipboard** icon and copy a screen shot to the clipboard.
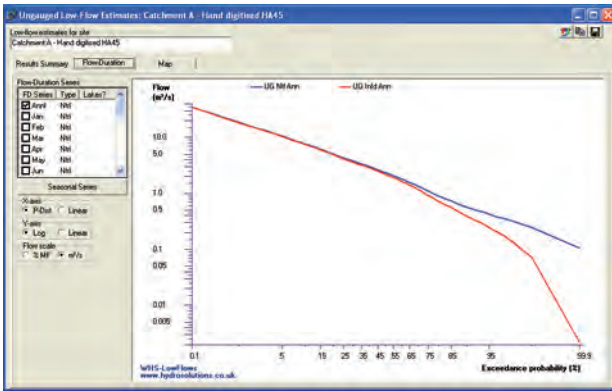
**Figure 6.10**   The Ungauged Low-Flow Estimates window – Flow Duration tab showing Annual Influenced and the Natural FDCs

## 7  Using contextual data

You can import Spatial data sets to provide contextual information. For example, Ordinance Survey tiles can be added as a base layer to the map windows.

Go to [Map][Import layer] to define the type of data you are going to import and how it should be imported. You will be able to select the imported layers in the Main window on either the **Overlays** or **Base Layers** tabs.

Go to [Map][Layer-maintenance] to edit your imported layers. You can set attributes such as line colour, thickness, point symbols and polygon transparency.

### 7.1  Importing contextual data

You can import contextual data in the form of vector data (SHP) or raster data (BMP and TIF) and view it through the geographical interface of LowFlows.

Go to [Map][Import layer] and select your **Import Type** in the **Import Layer** screen (Figure 7.1).
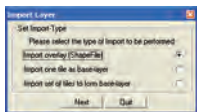


**Figure 7.1**  Import Layer window

The Import Type options are:

■ **Import Overlay (ShapeFile)** to load an image from a shapefile containing vector features. Imported shapefiles are added to the **Overlays** tab.
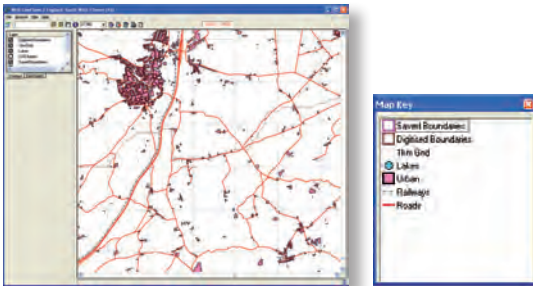
**Figure 7.2**  Example of imported ShapeFile data (Contains Ordnance Survey OpenData™ data ©
Crown copyright and database right 2010)

■ **Import one tile as base-layer** to add one set of raster data as a
 'tile'. For example a scanned image of a map, saved as in a bitmap
 (BMP) or tagged image file (TIF) format.
 **Note** These files must contain a 'world' file (BPW or TFW) to
 enable the image to be orientated correctly in relation to real world
 coordinates. Imported raster data is added to the **Base Layers** tab.
■ **Import Set of Tiles to Form Base Layer** to load raster images that
 have been created in more than one file and reference as a single base
 layer. An example is Ordinance Survey maps, which are produced as
 tiles. These would also be BMP or TIF files and require world files (BPW
 or TFW) to enable correct orientation.

When you have browsed to the file(s) you are importing, you need to
choose how the contextual data is to be displayed in the software.

The options for vector data (SHP) are:
■ **Set Name** to create a name for the layer.
■ **Set Symbol**  to define the symbol to be used for the layer.
■ **Set Regionality** to choose whether to display this layer for all
 hydrometric areas or only the current area.
■ **List on Start-up** to add the contextual data to the list of layers
 included whenever you run the software, or to display it for this
 session only.

The options for raster data (BMP and TIF) are:

- **Set Name** as for vector data.
- **List on Start-up** as for vector data.
- **Set Regionality** as for vector data.
- **Set Visibility Range** to set a range of map scales within which the raster data will be visible. In Figure 7.3 the range has been set so that the raster layer will only be visible between the scales of 1:20,000 and 1:500,000. This layer would not be visible if the map scale was set to 1:501,000 or 1:19,000.
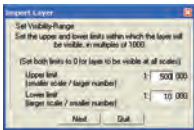


**Figure 7.3**  Illustration of setting visibility range for raster data

## 7.2  Managing contextual data

Go to [Map][Layer-maintenance] to manage the contextual layers you add to the software. In the **Layer Maintenance** window, select the layer you want to edit (Figure 7.4).



**Figure 7.4**  Initial Layer-Maintenance window

## 7.2.1  Deleting a contextual layer from the auto-load list

Select the layer in the Layer Maintenance window, press Delete and confirm the decision to remove the layer from the auto-load list.

**Note** The source vector/raster data is not deleted during this process, it is just removed from the list of layers that are automatically loaded into LowFlows.

**Note** The Saved Boundaries layer is a special data layer that represents the archive of imported catchment boundaries (see **Section 5**). If this layer is deleted from the auto-load list, you will not be able to use catchment polygons from this layer to perform low-flow estimates via the **Use Previously-Imported Polygon** option (see **Section 6**).

### 7.2.2  Editing the properties of a contextual layer

Select the layer and then right-click on it in the Layer Maintenance window to access the editing options. The different options are available for vector and raster data sets.

The edit options for vector data (from Overlays) are:

*General edits* (Figure 7.5)

- ■ **Name** as in Set Name when importing the data.
  **Note** Do not change the name of the Saved Boundaries layer, as it is referenced by the software. Other editing options are available for this layer.
- ■ **Regionality** as in Set Regionality when importing the data.
- ■ **Initial Visibility** to define whether the layer will appear automatically when you run the software or whether you must select it manually from the Overlays tab.
- ■ **Set Symbol** as in Set Symbol when importing the data.
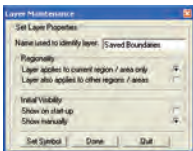


**Figure 7.5**   Editing vector data (Stage I) – general edits

*Setting symbols* (Figure 7.6)

The options available at the **Set Symbol** window depend on the type of data in the ShapeFile, eg point, line or polygon. The example shown here is for the **Saved Boundaries** layer of polygons. Editing options are self-explanatory and the preview box shows the impact of choices made.
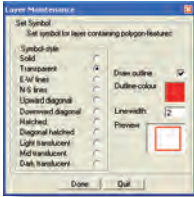


**Figure 7.6**  Editing vector data (Stage II) – setting symbols.

The edit options for raster data (from base layers) are: (Figure 7.7).

- **Name** as in Set Name when importing the data.
- **Regionality** as in Set Regionality when importing the data.
- **Visibility Range** as in Set Visibility Range when importing the data.
- **Initial Visibility** defines whether the layer automatically appears when the software to define whether the layer will appear automatically when you run the software or whether you must select it manually from the Base Layers tab.



**Figure 7.7**  Editing raster data.

When you made your chosen edits click **Done**.

## 8  The hydrological models in LowFlows

The hydrological estimation models used in the software are derived from the LowFlows 2000 software system that was developed jointly by the Centre for Ecology and Hydrology (CEH) and the Environment Agency of England and Wales (EA), the Scottish Environmental Protection Agency (SEPA) and the Northern Ireland Environment Agency (NIEA). The model structures are described in detail by Young et al. (2003) and Holmes et al. (2002a, 2002b).

In summary, these models enable annual and monthly flow duration curve (FDC) statistics to be estimated at the ungauged site.

- An annual mean flow model – used as an annual runoff grid (1km resolution) developed by a variety of methods.
- Region of influence (ROI) models for annual and monthly flow duration statistics standardised by mean flow. The standardised statistics are then rescaled by the respective estimates of mean flow.
- An ROI model for estimating monthly mean flows, when expressed as fractions of annual runoff.

The software also provides an estimate of the base flow index (BFI) (Gustard et al. 1992), based upon the *Hydrology of soil types* (HOST) classification (Boorman et al. 1995).

The hydrological models are summarised below.

**Note** Section 9 describes how local data gauges (LDGs) are used to improve the initial natural flow estimates produced by the hydrological models.

### 8.1  Estimation of annual mean flow

The estimation of annual mean flow is based on a 1km$^2$ grid of long-term average annual runoff underpinning the software.

- In England, Wales and Scotland the runoff grid was developed using 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).

■ In Northern Ireland the runoff grid was developed using an annual water balance model to predict runoff from rainfall and potential evaporation with a reduction factor of 0.86 applied to potential evaporation.

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 × AREA × CONST

The long-term mean flow is used to scale the annual FDC so that the range of flows can be expressed in cubic metres per second (m$^3$/s).

## 8.2 Estimation of the annual flow duration curve

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 FDCs is largely dependent on the hydro-geological and soils characteristics of the catchment. The software uses the HOST classification of soils (Boorman et al, 1995) to represent these characteristics. Research has shown that climate also exerts an influence on stream flow recessions, the strong east–west rainfall gradient across Scotland, for example. Hence, catchment mean annual runoff (RUNOFF) is used to explain observed variation in flow variability.

The models used to estimate the FDC statistics are based on a ROI regionalisation approach. The ROI method 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 a 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. Implicit in the methodology is a data set of good quality natural observed flow records for a wide range of catchment types.

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. In application to a catchment, the methods can be summarised as the following steps:

1  The similarity of the target catchment to donor catchments in the ROI data set is calculated as a weighted Euclidean distance:

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

where $de_{it}$ is the weighted Euclidean distance from the target catchment, t, to donor catchment, i, in the ROI data set, $W_m$ 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 used, Xm, are the fractional extents of the HOST classes within a catchment and the logarithm (10) of mean annual runoff (LOGRUNOFF) value for a catchment. The use of weights for individual HOST classes reflects 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 weight assigned to the LOGRUNOFF value reflects the relative importance of climatological factors.

2  A region is formed around the target catchment by ranking all of the catchments in the data pool by their weighted Euclidean distance and selecting the n catchments that are closest to the target catchment.

3  A standardised annual FDC is estimated for the target catchment by taking an inverse weighted combination of the standardised FDCs for the gauged catchments in the region. Thus, greater weight was given to catchments that are more similar in HOST characteristics to the target catchment.

This is expressed mathematically as:

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

where QP(×)ESTt is the estimate of the flow for the target catchment, t, at exceedence percentile P(×), QP(×)OBS$_i$ is the observed value of QP(×) for the ith source catchment in the region of n catchments closest to the target catchment and de$_i$ is the weighted Euclidean distance of the ith catchment from the target catchment, t.

This procedure is used for estimation in England, Wales, Scotland and Northern Ireland.

### 8.2.1 Adjustment of FDCs in Scotland for the influence of natural lochs

The original LowFlows research in Scotland developed a procedure for estimating the influence of the many natural lochs in Scotland on the estimation of flow duration statistics. The storage associated with natural lochs within a catchment tends to maintain (increase) base flow and hence low flows, and attenuate high flows (all other factors being equal). It is important to note the distinction between a natural loch and a reservoir or managed loch. The influence of the latter on the downstream flow regime may be complex and will be directly related to how outflows from the reservoir are managed by the operator.

The original Loch Adjustment Procedure was revised in collaboration with SEPA. The new procedure is based on available data from a relatively small number of larger Scottish lochs, supplemented by data from Cumbrian lakes and is currently only deployed within LowFlows in Scotland for significant lochs identified in consultation with SEPA. Recommendations have been presented to SEPA to collect additional data to both validate the algorithm and provide data sets for smaller lochs. The model is not

used in the current LowFlows software for England, Wales and Northern Ireland, although this position will be reviewed in the future.

When used in the LowFlows software, a Loch Adjustment Factor (LAF) is calculated for each loch in the target (ungauged) catchment based on the ratio of the surface area of the loch/lake (LA) and the catchment area of the loch/lake (LCA) as follows.

LAF = 0                  if LA <0.1km$^2$

LAF = 0                  if LCA <1.5km$^2$

LAF = 0                  for case LA/LCA < 2%

$LAF = 0.068 * e^{0.344 \frac{LA}{LCA}}$    for case 2% ≤ LA/LCA < 10%

                         for case LA/LCA ≥ 10%

Where                LA = Loch/Lake surface area (km$^2$)

                       LCA = Catchment area above lake (km$^2$)

                       LAF = Loch/Lake Adjustment Factor (%MF)

An adjustment to the raw estimate of Q95 as %MF obtained from the ROI algorithm (Q95$_{Raw}$) for the target catchment is then calculated as:

$$ADJ_{Q95} = \sum_{i=1}^{n} LAF_i \, x Q95_i \times \frac{LCA_i}{CA} \quad \text{in \%MF}$$

where ADJ$_{Q95}$ is the adjustment to Q95 in %MF for the target catchment, LAFi is the LAF value for the i$^{th}$ loch, Q95$_i$ is the natural Q95 estimate at the outlet of the i$^{th}$ loch (if the loch was not present in the catchment), LCA is the catchment area of the i$^{th}$ loch and CA is the catchment area of the target catchment.

Hence the adjusted value of the Q95(%MF) for the target catchment is

Q95$_{LakeAdjusted}$ = Q95$_{Raw}$ + ADJ$_{Q95}$ in %MF

The adjustment statistic for high flows is defined at Q5 to be:

$$Q5_{LakeAdjusted} = \frac{Q5_{Raw}}{\left[ -0.82 \times \left( \frac{Q95_{Raw}}{Q95_{LakeAdjusted}} \right) + 1.82 \right]}$$

The adjustment of other flow percentiles is then made as a non-linear interpolation between the $Q5_{LakeAdjusted}$ and $Q95_{LakeAdjusted}$ noting that at Q30 there is no adjustment applied (ie point of inflexion suggests that lakes have no impact on mean flow).

If the lake adjustment algorithm is used then it is not possible to determine the uncertainty associated with the flows estimated.

## 8.3 Uncertainty in annual flow estimates

The figures for standard error of estimate for annual Q95 (as %MF) for each national region of the UK are shown on Table 8.1. These are 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 provides an estimate of the prediction error for each gauging station in 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 (hydrometric uncertainty).

**Table 8.1** Model Factorial Standard Error (FSE)

| Regions of the UK | FSE MF | FSE Q95 |
|---|---|---|
| England and Wales | 16 | 39 |
| Scotland | 11 | 33 |
| Northern Ireland | 11 | 28 |

This table also shows the standard error of estimate for annual mean flow (ignoring errors in estimating catchment area) which also includes model uncertainty and hydrometric uncertainty.

The magnitude of the hydrometric uncertainty can be estimated by considering the criteria used to accept gauging stations into the ROI data set. Both hydrometric accuracy, imprecision and the degree of artificial influence on the flow record were considered. Considering all of these factors, the uncertainty (standard error of estimate) at the Q95 flow for the gauging stations within the ROI data set ranges from less than 10%

for the highest quality stations to 30% for the lowest quality stations.

**Note** The lowest quality stations are still regarded by measuring authorities as representing an acceptable measurement of low flows.

The net model uncertainty in estimated Q95 values in (m³/s) can be calculated by pooling variances using the formula below:

$$\varepsilon_{MODEL} = \sqrt{{\varepsilon_{Q95\%MF}}^2 + {\varepsilon_{MF}}^2 - {\varepsilon_{HYDROMETRIC}}^2}$$

where $\varepsilon_{Q95\%MF}$ is the standard error of the Q95 model (in %MF), $\varepsilon_{MF}$ is the standard error of the annual mean flow model and $\varepsilon_{GAUGE}$ is the assumed standard error associated with the hydrometry of gauged data. This formula can be used in conjunction with the values in Table 8.1. A value of 10% would be a conservative estimate of the gauging station uncertainty.

These results are presented as a guide for users and you should read them in conjunction with Section 2. The standard error for hydrometric uncertainty presented is a general rule-of-thumb. In a well-founded gauging structure this may be less and in many cases it may be more. An analysis of the scatter in check gaugings (taken routinely to evaluate rating curves) for 1,366 primary gauging stations demonstrated that the factorial standard error of this scatter was less than 10% in 527 stations, between 10 and 20% in 278 and greater than 20% for 442 gauging stations (Gustard et al. 1992).

Analysis of the FSE in the mean flow model for each UK region shows uncertainty is reduced in areas that receive higher rainfall (> 850mm/yr). In these areas significant (evaporation-limiting) soil moisture deficits will generally only develop in the driest years, and thus in most years evaporation will take place at the prevailing potential rate throughout the year.

## 8.4 Estimation of monthly flow duration statistics

The development of methods for estimating monthly statistics within the LowFlows software systems was driven by the desire to estimate influenced flow regimes in which artificial influences 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.

The method used to estimate standardised monthly FDCs is identical to the ROI approach for the annual FDC outlined in Section 8.1.

## 8.5 Estimation of monthly mean flow

An estimate of monthly mean flow is required to rescale the standardised monthly FDCs derived as described previously.

In UK catchments, the distribution of the total volume of annual runoff between the months of the year 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. The distribution is also 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 play in suppressing summer runoff in dryer catchments.

An ROI model was developed to estimate the percentage of the annual runoff volume that occurs within each month, termed the monthly runoff volume (MRV), using catchment characteristics of hydrogeology (HOST) and RUNOFF (the balancing of rainfall and evaporative demand).

The MRV ROI model differs to the one used to determine flow duration statistics and the steps are detailed opposite.

1  The similarity of the target catchment to donor catchments in the ROI data set is calculated as a weighted Euclidean distance, identical to that used in the flow duration statistic algorithm (Section 8.1):

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

where $de_{it}$ is the weighted Euclidean distance from the target catchment, t, to donor catchment, i, in the ROI data set, $W_m$ is the weight applied to catchment characteristic, m, and $X_{mi}$ is the standardised value of catchment characteristic, m, for catchment, i.

2  A region is formed around the target catchment by ranking all of the catchments in the data pool by their weighted Euclidean distance and selecting the n catchments that are closest to the target catchment.

3  The modulus of the difference between the target and donor catchment LOGRUNOFF values ($DIFF_{RO}$) is calculated for all n donors in the region.

4  An estimate of the MRV for the target catchment is then calculated as the weighted average of the observed MRV from the n donor catchments:

$$MRV_{tj} = \sum_{i=1}^{n} \left[ \frac{\left( \dfrac{1}{DIFF_{RO}^{i}} \right)}{\sum_{k=1}^{n} \left( \dfrac{1}{DIFF_{RO}^{k}} \right)} \right] \times MRVOBS_{ij}$$

where $MRV_{tj}$ is the estimate of MRV for month j for target catchment t; $MRVOBS_{ij}$ is the observed MRV for month j for the $i^{th}$ catchment in the region of n catchments closest to the target catchment, and $DIFF^{i}_{RO}$ is the absolute difference in LOGRUNOFF between the target catchment t and the $i^{th}$ donor catchment.

This procedure is used for estimation in England, Wales, Scotland and Northern Ireland. The parameters used in the ROI algorithm are identical to those used in the FDC ROI model (Section 8.1).

## 8.6 Estimation of base flow index

The base flow index (BFI) can be conceptualised as the proportion of the long-term river flow considered to be derived from groundwater stores, hence varies between 0 and 1. When considering an observed flow record, the BFI is calculated as the ratio of the area under the base flow hydrograph to the area under the flow hydrograph. In the UK, permeable catchments (eg chalk) have higher values of BFI than impermeable catchments (eg clay).

During the development of the HOST classification Boorman et al. (1995) derived bounded linear regression equations relating the fractional extents of HOST classes to catchment BFI. A similar model structure has been used in the LowFlows software using coefficients refined by recent data sets. Three sets of coefficients are used, one for England & Wales, one for Scotland and one for Northern Ireland.

# 9  Incorporating local data

The regional hydrologic models in LowFlows do not explicitly take into account local hydrometric data in the context of the estimation of long-term mean flow and only partially within the estimation of the flow duration curve (FDC). The estimation of FDCs in catchments with locally gauged data can be improved by explicitly incorporating this data.

The LowFlows software includes algorithms to incorporate gauged data in the estimation of natural flow regimes in ungauged catchments. Local data gauges (LDGs) are points representing gauged catchment outlets for which the observed flow statistics are considered natural and the hydrometry of the station is good. The observed data stored at LDGs is then used to improve the estimation of flows at points lying upstream or downstream of the LDG. So, for a given ungauged site, there may be a number of upstream LDGs and/or a single downstream LDG (Figure 9.1).



**Figure 9.1** LDG 2 is an upstream LDG for target catchment B, LDG 3 is a downstream LDG for target catchment B and LDG 1 is a downstream LDG for target catchment A

### 9.1  Upstream LDGs

In the case of one or more upstream LDGs, the flow at the ungauged catchment may be considered to be the total of all the flows recorded at the upstream LDGs, with additional runoff from the incremental area, which is the area in the ungauged catchment which is not included in any of the LDG sub-catchments.

The mean flow for the incremental area is determined by subtracting the total LowFlows runoff-derived mean flow for all of the LDG catchments, from the LowFlows runoff-derived mean flow for the ungauged catchment.

The estimated mean flow for the ungauged catchment is obtained from the sum of the runoff-derived mean flow for the incremental area and the sum of the recorded mean flows at all of the upstream LDGs.

Where the total area of the LDG catchments is small in comparison to the area of the ungauged catchment, estimates of mean flow using this method are unlikely to be strongly influenced by the upstream LDG data and will be similar to the mean flow estimated by the runoff method within LowFlows.

The Q95 value for the incremental area is estimated using the LowFlows ROI algorithm. The Q95 statistic for the ungauged catchment is estimated as the sum of the measured Q95 values for all LDG catchments, and the ROI-estimated Q95 value for the incremental area. Other flow percentiles are estimated using a similar methodology.

### 9.2  Downstream LDGs

Where a downstream LDG exists then the flow at the ungauged catchment may be considered to be the difference between the flow recorded at the downstream LDG and the flows from the incremental area catchment between the ungauged site and the LDG.

The mean flow for the incremental area in this case is determined by subtracting the total runoff-derived mean flow for the ungauged catchment from the runoff-derived mean flow for the LDG catchment.

For downstream local data, a first estimate of the mean flow for the ungauged catchment is obtained by subtracting the runoff-derived mean flow in respect of the incremental area from the mean flow at the LDG.

Since flows from the ungauged catchment may represent only a small proportion of flows recorded at a downstream gauge, a weighting factor (derived from the ratio of the estimated mean flows for the ungauged and LDG sites) is applied to the first estimate of mean flow for the ungauged catchment, to derive a weighted estimate of a runoff correction term. The runoff for the ungauged catchment is then estimated as the sum of the un-adjusted runoff estimate and the runoff correction term.

An analogous procedure is also used for estimating an adjusted-at-site estimate of the Q95 flow (retaining the MF derived weighting factor). Other flow percentiles are adjusted following the same methodology.

**Note** If the ungauged catchment represents less than 10% of the downstream LDG catchment area then the downstream LDG is not used to adjust the estimates at the ungauged site.

If including a downstream LDG results in negative flows being predicted for the ungauged site, it is excluded from the adjustment process.

### 9.3  Using both upstream and downstream LDGs
Where both upstream LDGs and a downstream LDG exist then both types of gauged data are used to improve the estimation of flows at the ungauged site. Upstream LDGs are used to derive a first correction for catchment MF and Q95, which is then improved further by adjustment considering the downstream LDG.

### 9.4  LDGs preloaded in the software
The LowFlows software is preloaded with a base set of LDGs that were derived for the Environment Agency of England and Wales, the Scottish Environment Protection Agency and the Northern Ireland Environment Agency. These are the ROI gauges used in the estimation methodology.

## 10 References

**Boorman D B, Hollis J M and Lilly A** (1995)
Hydrology of soil types: a hydrologically-based classification of the soils of the United Kingdom. Report 126, Institute of Hydrology, Wallingford.

**Gustard A, Bullock A, and Dixon JM** (1992)
Low-flow estimation in the United Kingdom. Report 108, Institute of Hydrology, Wallingford.

**Holmes MGR, Young AR, Gustard AG and Grew R** (2002a)
A Region of Influence approach to predicting flow duration curves within ungauged catchments. Hydrology and Earth System Sciences 6(4) 721–731.

**Holmes MGR, Young AR, Gustard, AG and Grew R** (2002b)
A new approach to estimating mean flow in the United Kingdom. Hydrology and Earth System Sciences. 6(4) 709–720.

**Holmes MGR and Young AR** (2002)
Estimating seasonal low-flow statistics in ungauged catchments. In Proc. British Hydrological Society 8th National Symposium, Birmingham, 2002, 97 102.

**Institute of Hydrology** (1992)
Low-flows estimation within the United Kingdom. Report 108. Institute of Hydrology, Wallingford.

**Young AR, Grew R and Holmes MGR** (2003)
Low Flows 2000: A national water resources assessment and decision support. Water Science and Technology, 48 (10).

## 11 Glossary

**Artificial influences** Abstractions, discharges and impounds (reservoirs). These features can impact on rivers by reducing flows (abstractions and storage of water in impounds during winter) or increasing flows (discharges and releases from impounds in summer) to produce an 'artificially influenced' flow regime. This influenced regime differs to the 'natural' flow regime which represents flows that would naturally occur in the catchment (assuming no anthropogenic influences).

**Note** The impact of reservoirs cannot be modelled in the current version of LowFlows. Please contact WHS for information on how flow estimates can be produced for catchments with significant reservoirs.

**Base flow index** (BFI) The proportion of the long-term river flow considered to be derived from groundwater stores, hence varies between 0 and 1. When considering an observed flow record, the BFI is calculated as the ratio of the area under the base flow hydrograph to the area under the flow hydrograph. In the UK, permeable catchments (eg chalk) have higher values of BFI than impermeable catchments (eg clay) (Figure 11.1).
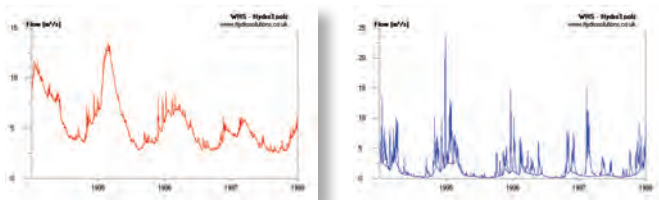


Figure 11.1 Base flow hydrographs from chalk (left) and clay (right) catchments showing that the BFI for chalk is higher than the BFI for clay

The model used to estimate BFI in the software is that described in Boorman et al. (1995) and is based on the relationship between hydrogeology/soils and catchment response to rainfall.

**Catchment boundary** The upstream area draining to the point of interest called the **catchment outlet**. This area can be conceptualised by considering the downhill direction in which a drop of water would

move. If the direction is towards the point of interest, it lies within the catchment boundary and if it moves away it does not. So, based upon topography, the catchment boundary separates the area which drains to the point of interest and the areas that drain away.

**Flow duration curve** (FDC) A graphic representation of the percentage of time a particular river flow is equalled or exceeded. A popular design statistic is the Q95 flow; this is the flow that is equalled or exceeded for 95% of the time. The FDC is therefore an inverse cumulative frequency diagram of flow values.

An FDC is commonly plotted with probability on the x-axis and the logarithm of flow on the y-axis. It is also common practice, when comparing the FDCs for two or more catchments, to express the individual catchment daily flows on the FDC as a percentage of the long-term mean flow for the catchment (%MF). This removes the majority of the influence of hydrological scale (how large and how wet the catchment is). Example annual FDCs for two catchments are shown on Figure 11.2. This example shows the relationship between hydrogeology and the shape of FDCs observed in the UK, with the more permeable, base-flow-dominated chalk catchment (42010) showing less variability in flows than the flashy, less permeable sandstone catchment (56013).
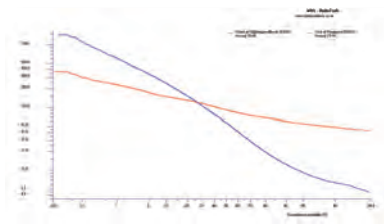


**Figure 11.2** FDCs from two catchments with logarithms of flow expressed as a percentage of the observed catchment mean flow (%MF) and probability on the x-axis

Flow duration statistics are commonly used in the field of water resources to describe the dependability of flows. FDCs can be derived

from observed data for gauged catchments, but estimates of resource availability are often required in catchments without gauging stations.

The models used in the LowFlows software estimate a standardised annual FDC (as %MF) for the ungauged catchment based on catchment characteristics are described by Holmes et al. (2002a). An estimate of mean flow for the catchment is derived by models described by Holmes et al. (2002b) and used to re-scale the FDC to flow units. The estimation of seasonal FDCs is described by Holmes and Young (2002).

**Hydrometric areas** Divisions of the United Kingdom which represent the main river basins (Figure 11.3). See information produced by the NRFA.
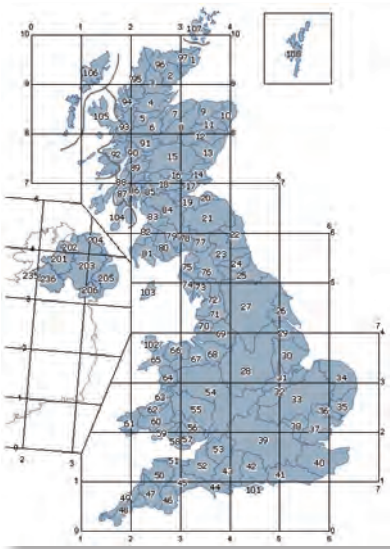


Figure 11.3 UK Hydrometric Areas and National Grid coordinates

**Influenced flow estimates** Estimates of flow produced by LowFlows which include the impact of any artificial influences you have entered via the net monthly influence profile. These estimates represent the long-term flow conditions that would be observed in a river where a number of artificial influences were operating in a catchment.

**Natural lakes/lochs in Scotland** When significant, these are considered in LowFlows and their impact on the estimated natural flow regime can be simulated using the software.

If you select this option, the FDC is adjusted on the basis of the ratio of the lake catchment area to the lake surface area, summed for all lakes in the catchment. Section 8 contains a full description of the adjustment process. In essence, for catchments with a large number of lakes with a high ratio of lake catchment area to the lake surface area the net result is to maintain base flows and attenuate high flows (Figure 11.4).
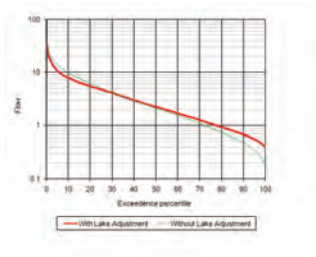


**Figure 11.4** Example of the impact of lakes on the natural FDC

**Net monthly influence profiles** The long-term impact of all influences of a particular type within the catchment of interest, at a monthly resolution.

The software assumes that the impact of water use/return for an individual artificial influence can be represented by 12 values, reflecting the long-term average monthly rates for that influence. Taking the example of surface water abstraction, in a catchment there may be multiple surface water abstractions, for a variety of purposes.

You need to sum these impacts to derive a net monthly influence profile for all surface water abstractions applicable for that catchment. Figure 11.5 illustrates a simple example where a catchment has one spray irrigation abstraction and one abstraction for industrial processes and a net profile is constructed by summing the two.
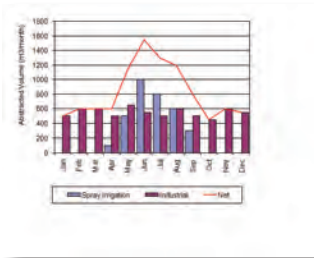


**Figure 11.5** Example of summation of monthly abstraction profiles

The three types of profiles that can be entered are:

■ **Surface water abstractions (SW_ABS)** Abstractions directly from streams and rivers. The monthly profile represents the average monthly volumes abstracted from the river, as the impact is a direct impact, summed for all surface water abstractions within the catchment.

■ **Groundwater abstractions (GW_ABS)** Abstractions made from boreholes and wells which have an indirect impact on the rivers as a result of the complex response of stream flow to the pumping of water from an unconfined, or semi-confined aquifer. For an individual borehole, the impact of the abstraction on the river flow is dependent upon factors including:

  ● the bulk aquifer hydrogeology and geometry
  ● the distance of the borehole to the connected stream
  ● the seasonality of pumping
  ● the pumping rate
  ● the degree of hydraulic connection between stream and aquifer
  ● features such as swallow holes and spring lines.

You need to assess the impact of each groundwater abstraction, and determine the long-term average monthly profile representing the impact on the nearest/connected surface water, considering the above factors. You then sum these profiles to give a net monthly influence profile for groundwater abstractions in the catchment, which you can enter into the software.

**Note** This is a simplification of how groundwater abstractions are treated in LowFlows Enterprise, where the Theis solution is applied to individual abstraction points to determine the stream deletion factors appropriate for the nearest river reach.

■ **Discharges (DIS)** Discharges made directly to rivers. Discharges to boreholes/groundwater sinks are not currently modelled. The monthly profile represents the average monthly impact of all discharges to surface waters in the catchment.

**NRFA** The National River Flow Archive. Part of the Centre for Hydrology and Ecology, Wallingford, OXON OX10 8BB. The Archive is responsible for the acquisition, archiving and validation of hydrological data for the entire United Kingdom and publishes the Hydrometric Register and Statistics. http://www.ceh.ac.uk/data/nrfa/

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