

Reducing uncertainty for the estimation of hydropower potential – the use of local data.

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Introduction

The correct estimation of long term resource availability, as represented by the flow duration curve, is a key component of hydropower design for both generation capacity estimation and environment protection. In the case where long record gauged flows are available for the site catchments the flow duration curve will be estimated from the gauged flow record. However as the majority of river reaches are ungauged there is a requirement for models for estimating resource availability at the ungauged site. The LowFlows software system (<http://www.hydrosolutions.co.uk/lowflows.html>) has been developed to meet this requirement and is widely used by SEPA, the EA and consultants.

This paper will discuss the application of LowFlows to estimate resource availability for hydropower design and will explore how local hydrometric data might be used to supplement these estimates. We will discuss the uncertainties associated with these approaches using a case study site within the North West of England and will conclude by summarising our work to formalise methods for incorporating local data within the context of the North West Hydro Resource Model project.

A Summary of the LowFlow software system

Information on the magnitude and variability of flow regimes, at the river reach scale is a central component of most aspects of water resource and water quality management. At the catchment scale, the flows will also be strongly influenced by the physical characteristics of a catchment. Young et al. (2000) present a review of the history of regionalisation of flow duration statistics in the UK in the context of models implemented within predecessors to LowFlows; Micro LOW FLOWS and the HydrA software. Previous studies have clearly demonstrated that when flow duration curves are expressed as a percentage of the long-term mean flow (standardised), to reduce the influence of scale dependencies, the shape of the resultant standardised flow-duration curve gives a good indication of the characteristic relationship between

precipitation and stream flow for a catchment. This relationship is strongly influenced by the hydro-geology of the catchment.

The natural flow statistics that may be estimated for an ungauged site in LowFlows include the long term mean flow and flow duration curve, monthly mean flows and monthly flow duration curves. For this paper, the discussion is restricted to long term Mean Flow (MF) and the long term flow that is equalled or exceeded for 95% of the time, Q95. In common with previous models, the models for estimating flow duration statistics within LowFlows are based on explaining the relationships between the curve shape and catchment hydrogeology with the estimate of a standardised flow duration curve being subsequently re-scaled by an estimate of mean flow. The models within LowFlows use a dynamic algorithm for selecting the gauged catchments used to estimate the flow duration statistics for the ungauged site. This represents a significant departure from previously reported regional models which all use a-priori statistical (normally multivariate regression) relationships between the flow statistics and catchment characteristics for a fixed sample of gauged catchments. Furthermore, LowFlows uses the output of a dynamic soil moisture accounting model to estimate long term mean flow rather than the simple average annual water balance formulation previously used. These hydrological models are described in detail by Holmes et al. (2002a & b) and are summarised in this paper in the context of the implementation within Low Flows 2000. Within the type of catchments in which hydropower developments are located the LowFlows standard errors of estimate for MF and Q95 are 11% and 45% respectively.

Analogue Gauged catchments

Local hydrometric data is commonly sourced from one or more long term gauged catchments that are considered to have the same hydrological characteristics as the ungauged site, commonly termed Analogue Catchments. An analogue catchment is one that is believed to have a similar hydrological response to precipitation and evaporation demand and that experiences similar climatic patterns to the ungauged site such that it can be assumed that the river flows within the ungauged and analogue catchments are synchronous; i.e. the flows increase and decrease together. An analogue catchment is, hence, usually a catchment that is:

- geographically close to the ungauged site, and hence has the same climatic regime;
- hydrogeological similar;
- similar in size;
- either a natural catchment or a catchment for which there is a naturalised flow record.

Ideally, the analogue catchment should lie upstream or downstream of the ungauged site, i.e. nested with the target ungauged site. In the case of a nested analogue, there is a strong serial correlation between the flow measured at the analogue gauge and the flows at the ungauged site as the water that flows past

both points has a common component. It is quite common that there is no nested analogue available, and thus a catchment from an adjacent system or tributary for the same system is selected as the analogue for the ungauged site.

Analysis of relationships between the flow regimes of many sets of paired gauged catchments (Young, 2002; Holmes et al., 2002c) has demonstrated that reasonable rules of thumb for defining a good analogue are: less than 50km separation between the design catchment and the analogue catchment, hydrogeological similarity defined as less than a 0.1 difference between estimates of BFIHOST (BFIHOST is a catchment characteristic based estimate of the Base Flow Index, Boorman et al., 1994) for the two catchments and less than a factor of two difference in catchment area. These are relatively stringent requirements and in many cases it will be necessary to relax these criteria with the consequence that the choice of analogue catchment might not be as good.

Transposition of flow statistics from an Analogue Catchment

The estimation of stream flow for ungauged sites by transposing gauged stream flow data from an analogue catchment is a widely used technique requiring the re-scaling of the flow regime to the ungauged target catchment. In the UK it is common practice to rescale by area and average annual rainfall using:

$$QX_T = \left(\frac{A_T AAR_T}{A_A AAR_A} \right) QX_A,$$

where:

- QX_T = the flow in the target ungauged site, T;
- QX_A = the corresponding flow in the analogue catchment, A;
- A_T = the catchment area for the ungauged site;
- A_A = the catchment area for the analogue catchment;
- AAR_T = the Average Annual Rainfall for the ungauged site;
- AAR_A = the Average Annual Rainfall for the analogue catchment
- QX_T = the flow in the target ungauged site T

Young & Holmes (2001) have demonstrated that the standard errors for estimating MF and Q95 through transposition from analogues meeting the selection criteria above are 28% and 98% for adjacent analogues and 16% and 38 for nested analogues over the type of catchments used for hydropower development. For adjacent catchment these results compare unfavourably with the corresponding values for LowFlows whilst for nested catchments meeting the stringent selection criteria the results are very comparable. This is primarily because the factor of 2 catchment area criterion ensures that 50% of the stream flow at both locations is common to both.

Calculating flow statistics directly from short periods of recorded flows at the design site

For larger schemes developers may be required to measure flows at the site of interest for a relatively short period, typically between 6 months and a year in duration. Flow duration statistics may be calculated directly from the short record. Previous work (Young et al, 2002) has demonstrated, as a rule of thumb, that between 6 and 10 years of gauged flow data are required to minimise sampling errors in flow duration statistics. as a representative sample from which to calculate flow duration curves that are not overly influenced by sampling error. Therefore, whilst these data have undoubted value being direct measurements of flows at the design site, the flow duration statistics compiled from these data are very sensitive to sampling errors when used to represent the long term resource availability. Typically the standard error of estimates for MF and Q95 statistics drawn from 1 year of data are 20% and 50% respectively within the type of catchment used for hydropower development. The standard errors of estimates for the LowFlows estimates of MF and Q95 equate to those associated with flow statistics calculated from approximately 3 and 2 years of data respectively within the type of catchment used for hydropower development.

Record Extension using long term records from an Analogue Catchment

If a suitable analogue catchment exists, which has a long flow record overlapping the short flow record at the ungauged site, then it is possible to address the limitations associated with the short record by synthesising a flow record at the ungauged site from the long record. This is accomplished by developing a statistical relationship between the short and long record. Regression is a commonly used tool with the relationship being developed by regressing the short flow record against the flows at the long term station using the overlap period and predicting a relationship between the two flow series for this period. The so-developed regression equation can then be used to predict flows at the design site for periods outside the overlapping period, which then can be used to derive a flow duration curve. A core assumption in this approach is that the flows within the catchments are synchronous.

Relationships developed this way often have significant uncertainties associated with them these can be constrained by developing relationships within more than one suitable analogue. Furthermore, if the emphasis is on simulating low flows the dependence of the regression relationship on the high flow can be reduced by applying a logarithmic transformation to the data prior to developing the regression model and then taking the anti-logs of the resultant model.

Spot Gauging Records

Flow duration statistics can be derived by assigning exceedence percentiles to spot flow measurements. Measurement approaches include the use of an impeller type or ultrasonic current meter or dilution gauging. Exceedence percentiles are derived from the flow percentile corresponding to the flow measured at a suitable gauged natural analogue catchment on the day of measurement. Again the flows at the two sites are assumed to be synchronous. To enable an approximation of the flow duration curve to be made the flow measurements should be made at a wide range of flows. However, if the specific design problem is in the low flow range then more metering should be carried out at low flows.

There are three sources of error that must be considered within this method:

1. the hydrometric error associated with the current meter measurements within the ungauged site;
2. the assumption that the measurement is representative of the average flow within the day; and
3. the errors associated with assuming that the flows within the ungauged and analogue catchments are synchronous.

If good hydrometric practice is followed the largest errors are associated with (3) at all flows. The errors have a random component and a systematic component. The random (sampling error) component can be reduced by repeat measurement. However, the systematic error cannot be reduced and is most dominant at low flows. The origins of the systematic component can be best understood by considering the probability of occurrence of a specific flow percentile. If the target catchment is at the Q95 flow for the catchment there is a 95% chance that the flow within the analogue catchment will be equal to or greater than the Q95 flow and only a 5% chance that it will be lower.

Estimating flows within an ungauged site: an example from the North West of England

The paper has considered the general uncertainties associated with different methods for estimating MF and Q95 within an ungauged site.

A small example gauged catchment (station number 74006) from the Northwest together with a good quality, un-nested analogue catchment (station number 74007) has been used to illustrate the application of these methods. Summary information about the two catchments is presented within Table 1 together with the gauged flow statistics for the two catchments. The locations of the gauged catchments are presented within Figure 1. The outlet of the analogue gauged catchment (74007) is approximately 11km from 74006.

Table 1 Summary information catchments 74006 and 74007

	74006	74007
Area	43.87km ²	70.03 km ²
BFIHOST	0.42	0.42
Long term measured Mean Flow	1.84m ³ /s	4.43m ³ /s
Long term measured Q95	0.32m ³ /s	0.37m ³ /s

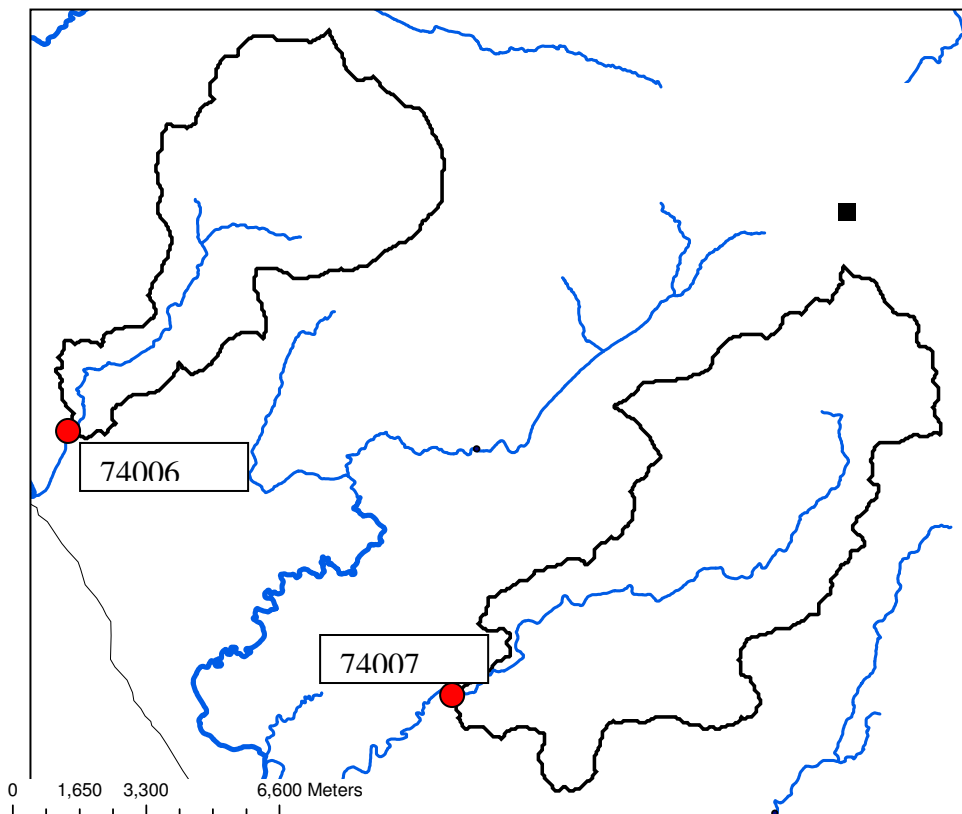


Figure 1 Location of the two catchments, 74006 and 74007 used for the Case Study.

Estimates of the flow statistics were generated for 74006 using a range of methods, treating 74006 as ungauged. One year of flow data (2004) was extracted from the gauged record for 74006 to represent a short period of gauged flows. Spot current meter measurements were represented by extracting flows from the record for 74006.

Estimates were generated using the following methods:

1. From LowFlows excluding the target catchment from the pool of stations used to construct the estimates.
2. Record extension of the short record at the target station using a regression relationship between the short record for the target station and the corresponding period of record for 74007 and subsequent calculation of the MF and Q95 flow from the extended record.
3. Transposition of the Q95 and MF values from the analogue gauging station to the target site using catchment area and AAR from the period 1961-1990
4. Extraction of “spot current meter” flows from the record for 74006 when the analogue catchment was flowing at the Q95 flow.

The estimates generated using these methods are compared to the “true” values of MF and Q95 derived from the long term record for 74006 within Table 2.

Table 2 Comparison of estimation methods for the Mean Flow and Q95 for gauging station 74006.

		MF (m ³ /s)	Difference (m ³ /s)	Q95 (m ³ /s)	Difference (m ³ /s)
	Long record gauged values at site	1.84		0.32	
1	Low Flows 2000	2.11	-0.27	0.25	0.07
2	1 Year of Data and record extension	1.73	0.11	0.12	0.20
3	Transposing by SAAR and Area	2.18	-0.34	0.18	0.14
4a	Estimation with 1 Spot Gauge values at Q95			0.43	-0.11
4b	Estimation with an average of 5 Spot Gauge values at Q95			0.38	-0.06

It is stressed that this case study example is one example for the methods described within this paper however the results demonstrate the complexities of hydrological design when working within ungauged sites.

In this case study the closest representations of the true Q95 is given by the LowFlows estimate and the average of 5 spot current meter measurements taken when the analogue catchment is running at the Q95 value. The worst estimate is given by the Q95 calculated from the extended record (2). This is a result of the difficulties in defining robust relationships between flows regimes at different sites that hold across the full range of flows. The fact that the analogue is adjacent to, but not nested with the ungauged target catchment will exacerbate these problems. The estimates from both one spot gauging and the transposed flow record are also poor supporting the generalised analysis presented within the paper.

The best mean flow estimate is given by the record extension method, this indicate that the errors in the regression relationship (in this case) are fairly random across the flow range. Again the transposition method performs poorly. The Low Flows estimate lies between the two.

Conclusions and further work

This paper has summarised approaches to incorporating local data within hydrological design, identified some of the uncertainties associated with these approaches and has illustrated them with regard to a case study drawn from the North West of England.

Whilst it is undoubtedly good practice to supplement model estimates from LowFlows with local hydrometric data (both historical and at-site data) there is no formalised framework for undertaking this. Without due regard to the inherent uncertainties associated with local data methods it is entirely likely that the final estimate may indeed be more uncertain than the original model estimate!

Our research within the Joule Centre funded North West Hydro Model project will seek to establish a formal framework for both the acquisition and appropriate incorporation of local data within the LowFlows estimation framework. Particular emphasis will be given to improving the flow duration curve information that can be extracted from short record at-site measurements and the formal incorporation of information from records for nested gauging stations within a catchment.

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