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NOTE

Estimation of low flow statistics at unmonitored sites by correlation of concurrent base flow gaugings

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Abstract

The concurrent base flow gauging technique is the most accurate tested method available in New Zealand for estimating low flows at unmonitored sites. It involves the establishment of a well-defined linear regression between concurrent flows at a primary site having a continuous long-term flow record and a secondary site having just very limited gauging data. The regression is used to predict flow statistics at a secondary site given prescribed values at a primary site.

The method is described and guidelines are given concerning natural flow, primary site selection, concurrent gauging runs, concurrent gauging range, regression, errors, and normalisation, together with comments about climate change effects. Further regular and careful use of the technique is encouraged because of its practicality and the ability to estimate standard errors of predictions.

Keywords

concurrent gauging techniques; concurrent gauging errors; low flow statistics; low flow estimation; base flow measurement; water resource assessment.

Introduction

Estimation of low flow statistics is of the first importance in understanding the hydrology of low flows, here defined as flows less than the median, and has direct application in, for instance, drought analysis, regional water resource assessments, and various aspects of water allocation; in particular, the evaluation of consent applications for surface water takes.

A number of methods are available for calculating low flow statistics at unmonitored sites. Perhaps the simplest is the drainage area ratio method (Stedinger *et al.*, 1993), where the value of a chosen statistic, say 7-day mean annual low flow (7dMALF), at an unmonitored or secondary site is its value at a monitored or primary site scaled by the ratio of the two basin areas. National studies in New Zealand using flow records and catchment physical characteristics provide another approach. Hutchinson (1990) employed regression equations based on different regions and Pearson (1995) used both a regression equation and contours of specific yield. However, tests show that these studies yield results that vary by up to an order of magnitude from estimates made from analysis of actual low flow data (Caruso, 2000; Henderson *et al.*, 2003)

At present the most accurate method available is the concurrent base flow gauging technique, which aims to establish a well-defined linear or logarithmic regression between concurrent base flows at a primary site having a continuous long term flow record, and an unmonitored or secondary site or sites having just very limited gauging data (Riggs, 1965, 1985; Hardison and Moss, 1972). Once defined, the regression can be used to generate a synthetic flow record or predict flow statistics at the secondary site. Scarf (1972) presents perhaps the first systematic application of the concurrent gauging technique in New Zealand in order to produce a map of isohyds of mean flows in the Nelson area. This work has been followed by numerous similar studies, for example Whitehouse *et al.* (1983), Griffiths (1986) and Gabites and Horrell (2005). Most applications derive maps of 7dMALF, usually for a large catchment or catchments; for instance, the Waitaki catchment (Gabites and Horrell, (2005).

The purposes of this note are to: (1) describe the concurrent base flow gauging technique, as no reference manual seems to be available; (2) provide guidelines based on experience in New Zealand about naturalisation of flows, selection of a primary site or sites to be paired with secondary sites, concurrent gauging runs, concurrent gauging range, linear regression, errors and normalisation of flow statistics; and (3) give an example of use of the technique. The aim is to encourage use of the concurrent base flow gauging technique for estimating low flow statistics for New Zealand rivers and streams.

Technique description and guidelines

Technique

In applying the concurrent base flow gauging technique the first step is to identify the secondary site or sites where prediction of the low flow statistics is required. Next a primary site or sites is selected and a series of concurrent flow gaugings of base flows is carried out to provide data for establishing a correlation or correlations between the primary and secondary sites using regression analysis. The primary and secondary sites need not be within the same catchment and the flow value for a concurrent measurement at the primary site may be taken as, say, the daily mean value at that site. The resulting correlation formula or formulae may then be employed to derive flow statistics at the secondary site or indeed, the formula may be employed to derive a synthetic continuous flow record for the secondary site.

Guidelines

The following guidelines are based on collective experience since the early 1970's in New Zealand obtained in applying the concurrent gauging technique and on conclusions given in Henderson *et al.* (2003).

Natural flows

At primary and secondary sites, a naturalised flow value should be used, that is, any abstractions from surface water takes or hydraulically connected groundwater should be added back into the recorded flow value. Any effects from, for example, changes to natural drainage systems and storages, construction of artificial storages and recharge from irrigation also need to be accounted for. With takes in particular, it is important to measure actual water use rather simply adopt consented use values. Similarly, with groundwater takes, the stream depletion component of the actual take should be used in flow naturalisation calculations.

Primary site selection

The primary and secondary sites should be located in catchments having similar hydrologic and physiographic characteristics. Henderson *et al.* (2003) used normalised parameters from the dataset of Pearson (1995) including basin average rainfall, depth-weighted soil porosity, elevation, slope and indices of erosion, hydrogeology and vegetation to select appropriate primary sites for given secondary sites with a reasonable degree of success. More recently, Griffiths and McKerchar (2015) found that weighted normalised values of parameters, including; total storm rainfall depth of two-year return period and duration equal to the time of concentration, porosity of subsurface storage, median size of surface streambed material measured at the halfway point on the main channel above a site, slope of the main channel, drainage density and mean annual flood runoff, gave good results where the degree of similarity or affinity between a primary and a secondary site was measured by Euclidean distance.

Concurrent gauging runs

To reduce uncertainties, at least 10 runs of concurrent gaugings should be undertaken (Henderson *et al*., 2003). Gaugings should be carried out on the falling limb of a hydrograph some four days after rainfall has ceased to ensure that all quickflows from the surface and subsurface storages have ceased. Runs should be separated in time by at least a fortnight and spread out over at least a year with two or more gaugings in each season. Monitoring of established correlations requires a run every season.

Concurrent gauging range

Gaugings should be made at less than the median flow at primary sites so that only base flows are sampled, in order to reduce the scatter in plots of secondary versus primary flows and obtain acceptable values of the correlation coefficient and standard error of a regression. If prediction of, say, a 7dMALF is required at the secondary site, it is important to obtain several concurrent gaugings at flows less than 7dMALF at the primary site to obviate the need to extrapolate the regression relationship.

Regression

The optimal regression model to use is an open question, but if the regression line is fitted to natural or logarithmic sample values for the purposes of predictions then ordinary least squares regression techniques are generally applied (Sokal and Rohlf, 1981).

Errors

The standard error, SE, in the predicted value of, say, 7dMALF at a secondary site is SE(7dMALF) and is obtained by ordinary least squares regression, given by:

$$SE(7dMALF) = SE(R)\ \{1 + 1/N + [7dMALF - Q_{mean}]^2/[(N-1)SE(Q)^2]\}^{0.5} \quad (1)$$

where SE(R) is the standard error of regression, N is the number of sample values or paired gaugings, 7dMALF is the sample value at the primary site, Q_{mean} is the mean of sample values at the primary site, and SE(Q) is the standard deviation of the sample values at the primary site (Sokal and Rohlf, 1981). With logarithmic regression, Equation 1 applies in the logarithmic domain: its antilogs are the factorial standard errors. Use of ordinary least squares regression allows statements of the significance of SE(7dMALF) values to be made because a sampling statistic (Students t) is available.

Normalisation

Because of long term climate variability, it is often useful to define predicted values relative to a reference or normal period of record, such as 1981-2010, as is done routinely in rainfall analysis. Normalisation is usually carried out using correlations with records from other long-term flow or rainfall sites or by using the ratio rule. Here the ratio of the mean value, say, for the period of common record between two sites is assumed equal to the ratio of the mean values for a defined normal period.

Climate change

The results of concurrent base flow gauging analyses are often employed to evaluate whether a long term (30 year) water permit should be granted or not. In these cases consideration should be given to the potential effects of climate change induced by humans. To provide guidance for assessing impacts of these effects we recommend use of the manual produced by the Ministry for the Environment (2008) for local government in New Zealand. Moreover, consideration should also be given to the effects of potential changes in land use, such as afforestation or urbanisation.

Example

An example is given below to illustrate application of the concurrent base flow gauging technique to predict a value of 7dMALF for a single primary and secondary site.

The selected secondary site is Taylors Stream at SH72 (Site No. 68819; Walter, 2000) near Methven in Canterbury, New Zealand. Choices for a primary site include Selwyn at Whitecliffs (68001), South Ashburton at Mt Somers (68806), North Ashburton at Old Weir (68810) and Orari at Gorge (69505). Subjective comparison of rainfall intensity, porosity, sediment size, channel slope flood runoff and drainage density, defined previously, for these catchments with those of Taylors Stream suggests that North Ashburton at Old Weir is the most suitable choice. This was confirmed by a Euclidian distance calculation using Equation 6 of Griffiths and McKerchar (2015). Alternatively, one could simply carry out correlations between each of the primary sites and Taylors Stream and determine the best performing primary site, in the manner of Gabites (2006).

Figure 1 shows the correlation between North Ashburton at Old Weir and Taylors Stream at SH72 for naturalised flows less than the median of 6720 L/s at Old Weir. Scatter increases markedly for flows above about 3600 L/s at Old Weir, very probably due to quickflow contributions. Accordingly, a further correlation was undertaken to capture only base flows; that is, for flows less than about half the median flow. The equation of the ordinary least squares regression line is:

$$Q(\text{Taylors}) = 0.341\ Q(\text{Nth Ashburton}) - 217 \qquad (2)$$

where Q is the flow rate. The correlation coefficient, r, is 0.607 and SE(R) is 153 L/s. This value of r is significantly greater than zero at the 95% significance level according to a Students t test. There is still much scatter of data in Figure 2, which is quite typical of the correlations between primary and secondary sites in the Ashburton River catchment – see for example Gabites (2006, Appendix A). The normalised 7dMALF value at North Ashburton at Old Weir is 3000 L/s and the predicted value from Equation 2 at Taylors Stream at SH72 is 806 L/s. The standard error, SE(7dMALF), from Equation 1 (where

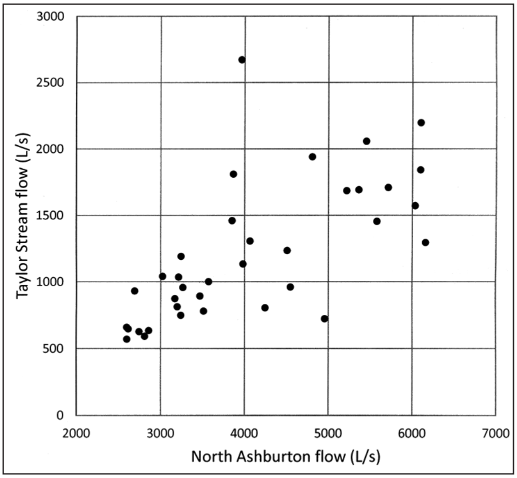

Figure 1 – Correlation between concurrent flow gaugings at Taylors Stream at SH72 and North Ashburton at Old Weir, for flows less than the median (6720 L/s) at North Ashburton.

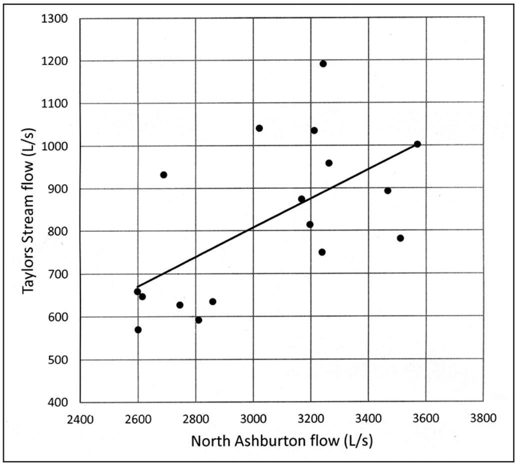

Figure 2 – Correlation between concurrent flow gaugings at Taylors Stream at SH72 and North Ashburton at Old Weir, for flows less than 3600 L/s in the North Ashburton River.

n = 17, Q_{mean} = 3047, SE(Q) = 331) is ±158 L/s or ±19.5%, which is consistent with the Monte Carlo results of Henderson *et al.* (2003, Table 3) who obtained an average error of ±26% for 10 concurrent gaugings per sample for 21 samples.

The predicted 7dMALF value of 806 L/s for Taylors Stream is a normal value because the 7dMALF value of 3000 L/s at North Ashburton is the normal value for the period 1981-2010; it was calculated from the flow record for the North Ashburton for that period. As to the potential effects of human-induced climate change, if the summer season and mid-range values are considered, then MfE (2008) predicts a 0.9°C rise in temperature and about a 4% increase in mean annual rainfall for North Ashburton catchment for the period 1990-2040. The projected increase in temperature would probably result in only a marginal change in actual evapotranspiration. The effect of the 4% increase in rainfall on 7dMALF values is difficult to assess but any increase is likely to be within the standard error values of ±19.5%.

Conclusion and recommendations

The concurrent base flow gauging technique is the most accurate tested method available in New Zealand for estimating low flow statistics at unmonitored sites.

It is important to estimate the standard error associated with low flow predictions, because the standard error is usually relatively large.

When predictions are to be used for the long-term, potential effects of human-induced climate change and land use change on low flows should be carefully considered.

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