# Analysis of low flows in selected New Zealand catchments

**Dr. Nimal P.D. Gamage**
GHD Limited, Level 1, Merial Building, Putney Way, Manukau City, New Zealand

**Abstract**

The understanding of low-flow statistics of streams is essential for the development and management of surface water resources. Low flow statistics are also useful as a basis for forecasting seasonal low flows, as indicators of the amount of groundwater inflow to streams, and as legal indices for maintaining water quality standards. Low flows can be affected by mining, urbanization, land-use practices such as logging and farming; and construction of small detention reservoirs for flood control, recreation, or low-flow augmentation. The flow statistics of selected catchments in New Zealand were studied to quantify the magnitude of statistical variability of low flows. Biologically based low-flow frequencies were determined using a daily series of average n-day daily mean flows. Unlike hydrologically based statistics, biologically based statistics are computed by identification of "excursions" in the record. The excursion concept relates to the biological concept of aquatic-life recovery after a period of stress. The n-day series is evaluated for the desired frequency of occurrence of the excursions on the basis of number of years of record. The results of this study are used to identify the capacity of watersheds to meet current and future water supply demands and to provide for ecological health.

*Key words*: Low-flow, stream flow, flow frequency, stream ecology

**Introduction**

Assessment of stream flows is an important part of selecting an ecological flow regime for rivers. Stream flow establishes the biological communities, amenity and other values that could be affected. Rivers in New Zealand vary greatly, influenced by geographic and climate features, including the maritime location and tectonically young/active landscape (MfE, 2008). Information on the low-flow statistics of streams is also essential for development and management of water resources. Such information is useful for assessing the availability of water for municipal or industrial supplies, irrigation, recreation, aquatic life and wildlife conservation, and disposal of liquid wastes. Low-flow statistics also are useful as a basis for forecasting seasonal low flows, as indicators of the amount of groundwater inflow to streams, and as legal indices for maintaining water-quality standards. Low flows are normally derived from groundwater discharge or surface discharge from lakes, marshes, or melting glaciers. Lowest annual flow usually occurs in the same season each year. The magnitude of annual low flows, variability of flows and the rate of streamflow depletion in the absence of rain, duration of continuous low-flow events, relative contribution of low flows to the total streamfow hydrograph are a few of the widely used characteristics which are dealt with in low-flow hydrology in a variety of ways. Those effectively constitute the 'temporal' component of low-flow hydrology and require continuous streamflow time series for the analysis.

Effluent flows into river channels from agricultural, industrial, and municipal sources can significantly affect the composition of low flows leading to deterioration of water quality and therefore limiting its availability for downstream users. Pirt (1989) and Pirt and Simpson (1983) illustrated how multiple abstractions and effluent discharges may affect the dry season flow and suggested Residual Flow Diagrams (RDF) as a graphical illustration of these effects on a catchment scale. Reliability of low-flow frequency curves is related to the record period, and confidence is increased if the record period includes a substantial drought; a record period representing long-term flow characteristics is desired (Riggs, 1972). Arbitrarily using entire record periods at stream-flow gauging stations will result in statistics that, for some stations, represent wet or dry periods because all or most of the entire record period is significantly different from average conditions over a longer term. Low-flow statistics representative of average conditions expected over a defined time period that includes a substantial drought are better than arbitrary use of entire record periods from stations that may not represent long-term average conditions.

The purpose of this paper is to look at the low-flow hydrology of two New Zealand catchments to quantify the magnitude of statistical variability of low flows. Biologically based low-flow frequencies were determined using a daily series of average n-day daily mean flows.

**Stream flow data**

The stream flow gauging data at Ahuriri River at South Diadem and Mary Burn River at Mount MacDonald in South Canterbury, New Zealand were used for this study (Table 1).

Table 1 River flow sites used for the study

| Site Number | Site Name | Length of records used (Yrs) | Catchment Area ($km^2$) | Annual mean flow ($m^3/s$) | Median Flow ($m^3/s$) |
|---|---|---|---|---|---|
| 71116 | Ahuriri River at South Diadem | 43 | 557 | 23.5 | 18.0 |
| 71122 | Mary Burn at Mount MacDonald | 37 | 52.2 | 0.6 | 0.4 |

**Statistical variability of low flows**

*Flow duration curve*

Flow duration curve (FDC) is a relationship between any given discharge value and the percentage of time that this discharge is equalled or exceeded. A review of numerous possible applications of FDCs in engineering practice, water resources management and water quality management is given by Vogel and Fennessey (1995). Of most interest for low-flow studies is the ‘lowflow section’ of a FDC, which may be arbitrarily determined as part of the curve with flows below mean flow, MF (which corresponds to the discharge equalled or exceeded 50% of the time-Q50). This entire section of the curve may be interpreted as an index of groundwater (and/or subsurface flow) contribution to streamflow from subsurface catchment storage. If the slope of the low-flow part of the FDC is small, groundwater/subsurface flow contribution is normally significant and low-flows are sustainable. A steep curve indicates small and/or variable baseflow contribution. In this sense, the shape of FDC is an indication of hydrogeological conditions in the catchment.

Flow duration curves of the selected rivers are shown in Figure 1 and Figure 2. The Ahuriri River flow characterizes the ability of the basin to sustain low flows during dry seasons with a mean flow of 18.1 $m^3/s$. The Mary Burn River has a very steep curve (high flows for short periods) as expected due to rain-caused floods on a small watershed and a very flat curve indicates that moderate flows are sustained throughout the year.

*Low-flow frequency analysis*

Low-flow Frequency Curve (LFFC) shows the proportion of years when a flow is exceeded (or equivalently the average interval in years (‘return period’ or ‘recurrence interval’) that the river falls below a given discharge). The low flow quantile DQT can be used to characterize the T year average lowflow of a stream over D-days (e.g. 7Q10, D=7 days, T=10 years). If the stream is gauged quantiles can be estimated using single station low flow frequency analysis (SSLFFA)

(Maidment, 1993), though regulation can lead to problems with the analysis. Vogeland Kroll (1989) reviewed the studies which compared the fit of alternative probability distributions and parameter estimation procedures to the time series of annual 1 and 7-day minima. Pearson (1995) and Vogel and Wilson (1996) have recently performed an assessment of the probability distributions of low flows at the national scale in New Zealand and the USA. The universally accepted distribution function for low-flows, however, is unlikely to exist or ever be identified. Bardsley (1994) suggested to stop testing different distribution functions in lowflow frequency analysis and advocated a subjective extrapolation using an interactive computer graphics. Tasker (1987) and Loaiciga and Marino (1988) examined non-parametric methods for low-flow frequency analysis, which do not require the specification of a parent distribution. In general, non-parametric procedures for frequency analysis are becoming more accepted in hydrological practice. A detailed review of non-parametric functions and their applications in hydrology is given by Lall (1995).

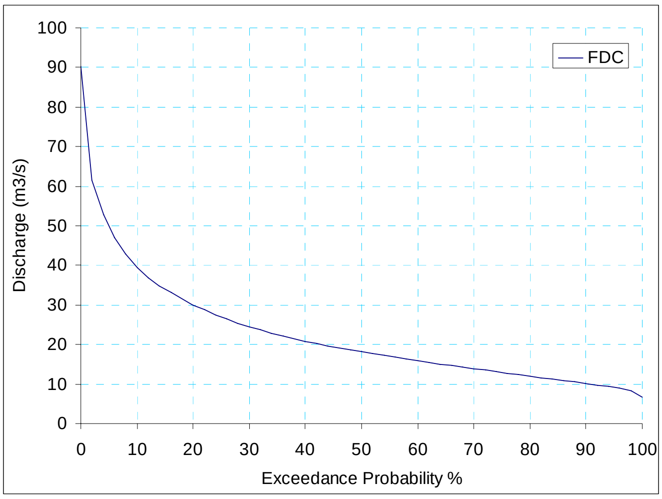

Figure 1 Flow duration curve for Ahuriri River

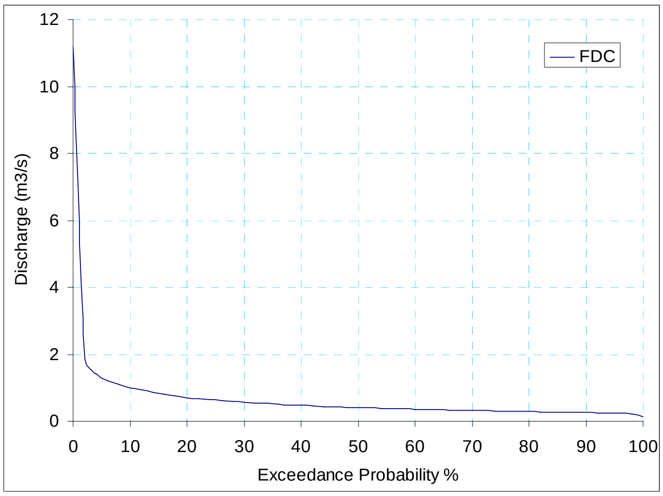

Figure 2 Flow duration curve for Mary Burn River

The average of the annual series of minimum 7-day average flows is known as *DryWeather Flow* (Hindley, 1973) or as Mean Annual 7-day Minimum flow (MAM7) (Pirt and Simpson, 1983; Gustard et al., 1992) and is used in the UK for abstraction licensing. The 7-day period covered by MAM7 eliminates the day-to-day variations in the artificial component of the river flow. Also, an analysis based on a time series of 7-day average flows is less sensitive to measurement errors. Figure 3 and Figure 4 shows the LFFC of Ahuriri River and Mary Burn River respectively. The Log Pearson Type III probability density function was used for this analysis as it can accommodate a large variety of distributional shapes. Ahuriri River low flow data appear to be well matched with the fitted probability density function while Mary Burn River low flow data shows deviations from the fitted distribution. Comparison of 30-day, 7-day, 1-day, 1-hour frequency curves for different averaging times are shown in Figure 5 and Figure 6.

## Biologically based low-flow frequency

Instream needs include hydraulic needs (geomorphology, sediment and stream movement, and floodplain maintenance) and the specific species needs such as habitat maintenance, connectivity, depth and velocity. The water demand for habitat uses, typically referred to as the "Instream Flow Requirement" (IFR), is determined based on the perceived or measured needs of the habitat in the water course (Karim et al., 1995). In the past, this has been a single flow that was to be maintained as a lower threshold at all times, though later a flow curve that reflects the variability of habitat flow needs over a typical year has been used (Karim et al., 1995). Previous methods of environmental flow assessment had a focus on the most sensitive or economically/ ecologically important user. Hooper and Ottey (1982) examined the impacts of low and high discharge fluctuations on benthos communities. Singh (1983) suggested the method based on fish preferences and incremental costs to provide extra storage to meet the environmental low-flow releases.

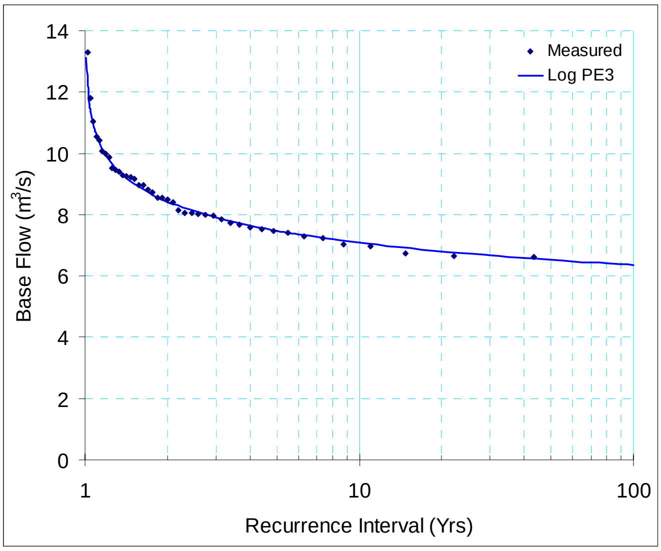


Figure 3 Ahuriri River 1-day average low flow frequency curve

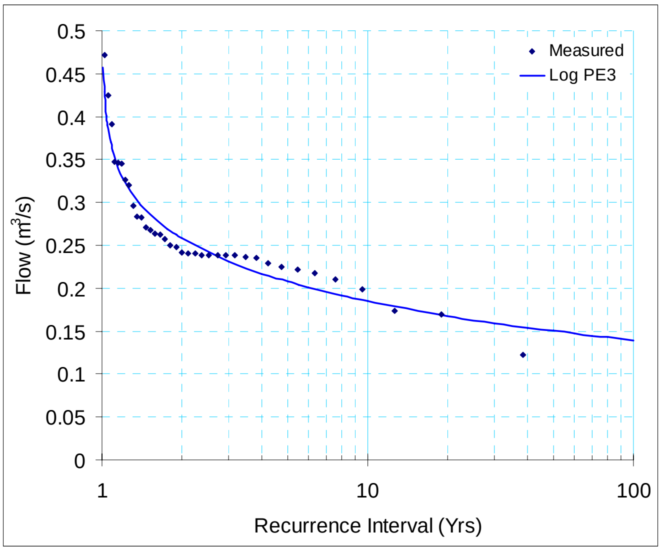


Figure 4 Mary Burn River 1-day average low flow frequency curve

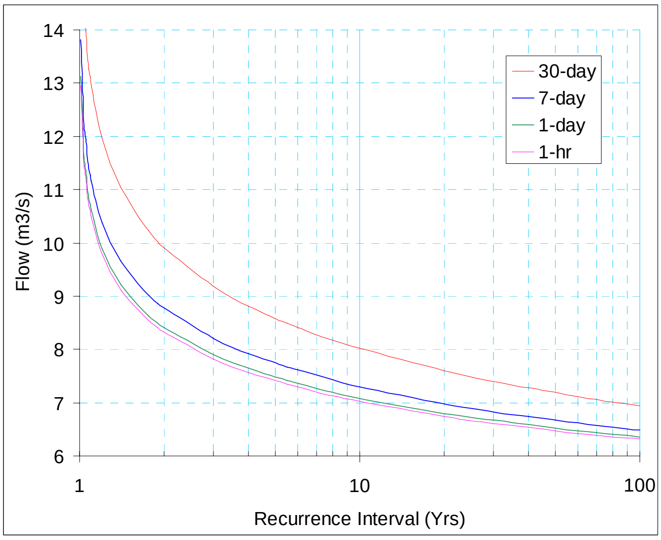


Figure 5 Ahuriri River frequency curves for different averaging time

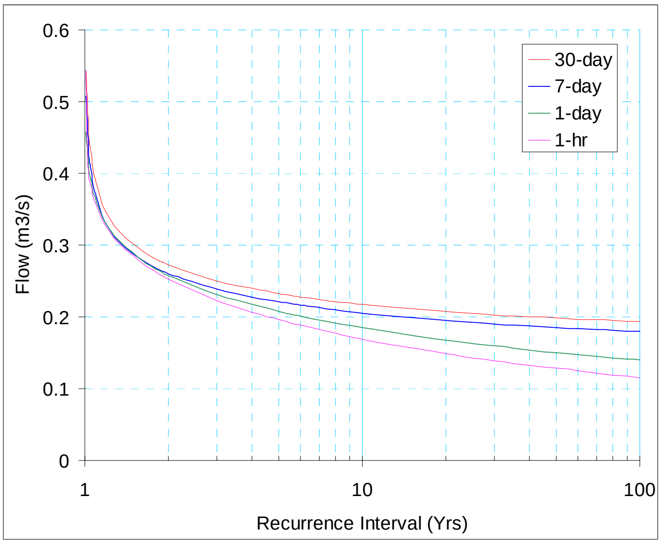


Figure 6 Mary Burn River frequency curves for different averaging time

In this study biologically based low-flow frequencies were determined by use of methods described by the U.S. Environmental Protection Agency (1986). For these statistics, a daily series of average n-day daily mean flows is computed for a streamflow record. Unlike the hydrologically based statistics, the biologically based statistics are computed by identification of “excursions” in the record. An excursion is a low-flow period that is determined to be hydrologically separate from other low-flow periods, typically by a measure of a minimum of 120 days between excursions. The number of excursions in an excursion period is calculated as the number of days in the excursion period divided by the duration (in days) of the averaging period. A low-flow period is defined as one or more excursion periods occurring within a 120-day interval. As discussed above, if the calculated number of excursions that occur in a 120-day low-flow period is greater than 5, the number is set at 5 for the purposes of calculating the design flow.

**Results**

Ahuriri river 30-day average low flow shows higher deviation from 7-day average flow, which indicates high variability of flows in the river, where as Mary Burn River shows a low deviation from 7-day average curve compared with 30-day average curve indicating low variability of flows during a 30-day low flow period (Table 2). However percentage variation is very significant between 1-hr, 1-day, and 7-day average flows in Mary Burn River.

Table 2 Comparison of low flow quantiles

| Low flow quantile DQT | Ahuriri River | | Mary Burn River | |
|---|---|---|---|---|
| | Flow ($m^3/s$) | $\left(\frac{Flow-7Q10}{7Q10}\right)\%$ | Flow ($m^3/s$) | $\left(\frac{Flow-7Q10}{7Q10}\right)\%$ |
| 1hr. Q10 | 7.02 | -3.8 | 0.169 | -18.0 |
| 1Q10 | 7.08 | -3.0 | 0.185 | -10.2 |
| 7Q10 | 7.30 | 0.0 | 0.206 | 0.0 |
| 30Q10 | 8.01 | 9.7 | 0.218 | 5.8 |

Figure 7 and Figure 8 shows the comparison of median flow of the lowest month with the design flow 7Q10 for Ahuriri River and Mary Burn River. Ahuriri River has a low flow margin of 5.1 $m^3/s$ while Mary Burn River has a low flow margin of 0.08 $m^3/s$.

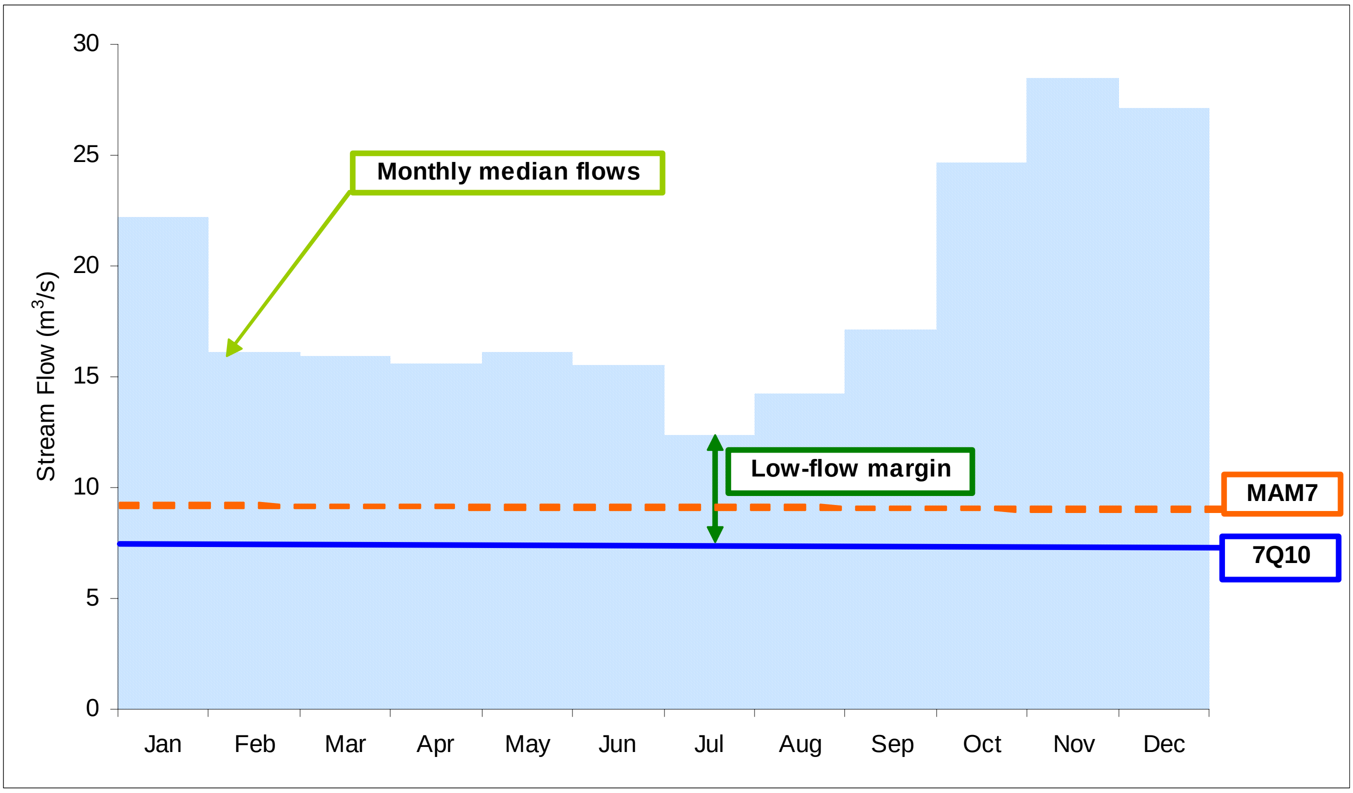


Figure 7 Comparison of median flows and design flows for Ahuriri River

Biologically-based stream design flow – Design flow based on the averaging periods and frequencies specified in water quality criteria (WQC) for individual pollutants and whole effluents. According to the U.S. Environmental Protection Agency (1986) WQC for ammonia, an averaging period as long as 30 days was used in situations involving treatment designed to remove ammonia where low variability of effluent concentrations and the resulting concentrations in the receiving waters. Table 3 shows a comparison between the biologically-based 30-day 3-year low flows and the hydrologically-based 30Q10 low flows for Ahuriri River and Mary Burn River for ammonia.

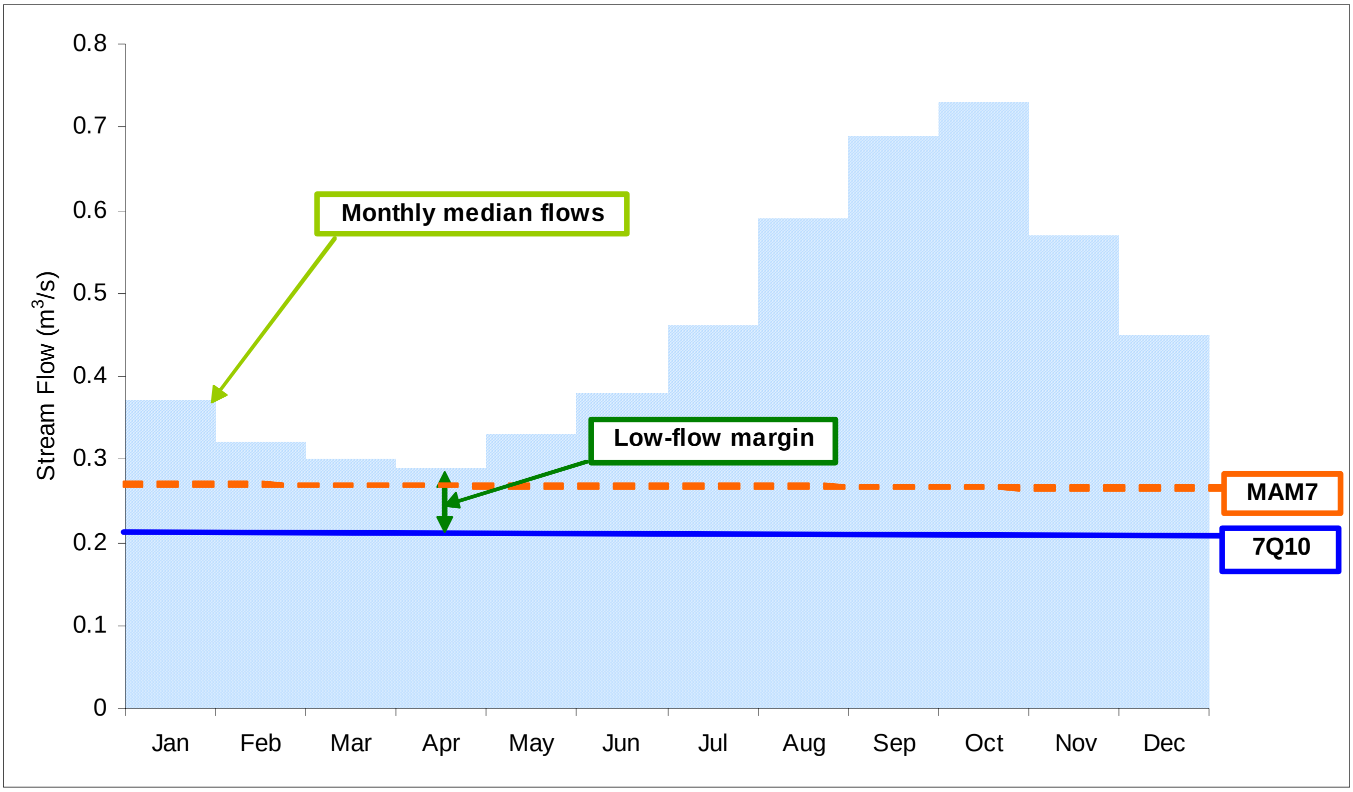


Figure 8 Comparison of median flows and design flows for Mary Burn River

Table 3 Comparison of low flow margin of safety

| Flow description | | Ahuriri River ($m^3/s$) | Mary Burn River ($m^3/s$) |
|---|---|---|---|
| Lowest median flow | | 12.4 | 0.29 |
| 7Q10 | | 7.3 | 0.21 |
| MAM7 | | 9.02 | 0.274 |
| Low flow margin | 100% | 5.10 | 0.08 |
| | 50% | 2.55 | 0.04 |
| | 10% | 0.51 | 0.008 |
| Consumptive withdrawal | | Xah | Xmr |
| Low-flow margin of safety for 50% Low flow margin | | 2.55 - Xah | 0.04 - Xmr |
| 30Q10 | | 8.02 | 0.218 |
| 30-day 3 year | | 9.7 | 0.23 |

## Conclusion

Understanding of low-flow processes and reliable low-flow information will attract more focus from the side of integrated and environmentally sustainable catchment management. In the context of such management, low flows should rather be viewed as a dynamic concept and not described by just one single low-flow characteristic. Hydrologically based and biologically based low-flow frequencies were compared for two New Zealand catchments in this study.

- The hydrologically based design flow (7Q10) for Ahuriri River is 7.3 $m^3/s$ and Mary Burn River is 0.21 $m^3/s$.
- Mean Annual 7-day Minimum flow (MAM7) for Ahuriri River is 9.02 $m^3/s$ and Mary Burn River is 0.274 $m^3/s$.
- Flow variability for 7Q10 compared with 1 hour averaged 10 year return period flow for Ahuriri River is 3.8 % and Mary Burn River is 18 %.
- The estimated low flow margin for Ahuriri River is 5.10 $m^3/s$ and for Mary Burn River is 0.08 $m^3/s$.
- Biologically based 30-day 3 year flow for Ahuriri River is 9.7 $m^3/s$ and Mary Burn River is 0.23 $m^3/s$.

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