2. FLOW REGIMES

There are many different ways of defining flow regime characteristics of rivers using qualitative descriptions, or a wide range of quantitative values. The latter could be based on analyses of time series of flow data at the specific site of interest (either observed, through some method of flow measuring, or simulated by some model or extrapolation procedure), or taken from a regional analysis. The important characteristic that should be defined, regardless of whether qualitative or quantitative descriptors are used, is the degree of variability over different time scales.

2.1 Qualitative Descriptors

Rivers in South Africa are usually referred to as ephemeral or permanent, with a further sub-division of the ephemeral group into the truly ephemeral (flowing only in response to specific rainfall events) and those that are seasonally flowing.

2.1.1 Ephemeral

Within the drier areas of South Africa the majority of rivers are ephemeral, with some experiencing flow very rarely and others experiencing flow more frequently, but still intermittently. The majority of flow events occur in direct response to major rainfall events and are frequently of short duration. The majority of the streamflow will be derived from runoff generated on the catchment surface with only a small contribution derived from drainage out of saturated soils and rocks. The latter may form a larger component of the total flow in a single event after prolonged rainfall events, when subsurface storage is more effectively recharged.

In some areas of the country, ephemeral rivers may experience extended periods of still water pondage within their channels. This would mainly be caused by very slow groundwater seepage that is sufficient to maintain a pool, but not sufficient to overcome evaporation losses and generate channel flow. The water quality implications of the length of time that the pool has been in existence since the last flow event should be clear. Evaporation will cause progressive concentration of salts, which may be exacerbated by the fact that the groundwater seepage may already have high salt concentrations (depending on the rock type).

In general terms, ephemeral rivers are characterised by highly variable flow regimes at all time scales caused by the intermittent occurrence of short duration events with steeply rising and falling hydrographs.

2.1.2 Seasonal

Seasonal rivers are those which have more reliable flow regimes, but where the contributions from groundwater storage are not sufficiently sustained to generate streamflow during the dry season. Streamflow during the wet season will be generated by a variety of processes, ultimately dependent upon the specific catchment conditions, including rapidly responding surface runoff, more delayed flow from near surface soil water storage and even slower responding baseflow from springs or deeper groundwater. The surface and soil water runoff components are responsible for the hydrographs that occur in response to individual rainfall events, while the slower responding springflow and groundwater will provide a seasonally rising and falling baseflow contribution.

In general terms, seasonal rivers will have characteristics during the wet season that are similar to permanent rivers, but will experience zero flow conditions during most dry seasons.

2.1.3 Permanent

The comments made above about seasonal rivers are also applicable to permanently flowing rivers, with the difference that the slower responding baseflow contributions are sufficiently sustained to generate flow during most dry seasons. The relative contributions of the different flow components influence the degree of short term variability in the flow regime. For example, systems such as the Sabie River have a relatively high contribution from groundwater storage and this results in an annual hydrograph shape characterised by a smoothly rising and falling baseflow response with relatively low individual event peaks superimposed on top. In contrast, many of the Lesotho rivers (for example) have a lower (but still mostly continuous) groundwater contribution but more ‘flashy’ surface runoff response. The result is a lower (relatively) and flatter seasonal baseflow hydrograph with larger events superimposed on top.

2.2 Time scales of variability

It is important to recognise that there are different time scales when considering the variability of flow regimes.

2.2.1 Greater than annual

For the purposes of this document, this scale represents variations over several years caused by climatic fluctuations that lead to periods of dry, average and wet conditions, as well as longer term fluctuations that lead to overall downward or upward trends in streamflow over hundreds of years. The important aspect of the latter is the scale of the trend and the period over which it is occurring. An example might be changes caused by global warming - how long will it take for streamflow to reduce by 10% or 20% ? As far as the former fluctuations are concerned, the important aspects to be able to recognise are the likely number of years at, below, or above, average flow and the expected durations of severe wet and dry periods.

2.2.2 Annual

This scale refers to the nature of the fluctuations within a year and essentially has been covered by the discussion on different flow regime types. Ephemeral flow regimes have highly variable annual regimes, while permanent rivers generally have less variable and more consistent regimes.

2.2.3 Monthly and less

This scale refers to the shorter time scales that are mostly influenced by catchment responses to individual, or sequences of, rainfall events. Thus, some systems may be considered variable at this scale because they experience flow events with steeply rising and falling hydrographs, while others may be more baseflow driven and have flatter hydrograph responses.

2.3 Quantitative Descriptors

There are a wide range of quantitative descriptors of hydrological variability and in general terms the choice of the best to use is very dependent upon what the data are required for. In terms of low flows, most of the relevant measures, and their methods of derivation, are discussed in Smakhtin and Watkins (1997). Those referred to below represent those most widely used within a South African context.

2.3.1 Single measures of variability

Probably the most widely used single measure of variability is the coefficient of variation (CV = the standard deviation of a data set divided by the mean). This type of statistic can be used at all time scales, such that if annual total flow volumes are analysed then a measure of long term variability will result. However, if daily flows for all the data available in the month of February (say) are analysed, then a measure of the short term flow variability in that month will result.

2.3.2 Integrated measures of variability

One of the most widely used integrated measures of variability is the Flow Duration Curve (FDC) which is a graph of flow values (daily, 10 day totals, monthly totals, etc.) plotted against the percent of time that such a value is equalled or exceeded in the flow time series being analysed. Highly variable regimes have steep FDCs with a large range of values (from minimum to maximum flows), while less variable regimes have flatter curves and lower relative ranges. To enable comparisons to be made between the shapes of FDCs derived from different rivers, it is frequently useful to base them on standardised, non-dimensional, flow data (i.e. flow rates divided by the long term mean flow, or by the catchment area). FDCs are valuable hydrological analysis tools and provide an excellent summary of the flow regime characteristics of a river. It is also possible to extract a wide range of indices from FDCs to determine single values. Q70 (the flow equalled or exceeded 70% of the time) has often been used as a measure of the baseflow component of a flow regime, while Q90-Q10 (or similar) can be used as an expression of variability which excludes the extremes at both ends (dry and wet). The percentage of time at zero flow is also a useful statistic that can be used to distinguish between ephemeral, seasonal and permanent rivers, or to describe the impact of man-made changes to the flow regime of a river.

FDCs are defined by the time step of the data being analysed, as well as the data that are included in the analysis. Thus, and FDC based on all available mean daily flow data, is usually referred to as a 1-day, annual FDC, while an FDC based on all daily data for the month of February only will be a 1-day, February FDC. Splitting a full time series up into two or more periods and subjecting each period to separate FDC analyses can be useful for detecting trends caused by natural or man-made effects.

It is important that all river scientists working with the effects of flow regimes on instream biota develop a good understanding of flow duration curves and are able to interpret them correctly.

2.3.3 Extreme event analysis

Other methods of looking at variability concentrate on extreme events and commonly carry out probability analyses of annual extremes, referred to as flood and low-flow frequency analysis. In terms of floods, the procedure involves identifying the highest flood in all the years of record and subjecting those data to probability analysis. This allows statements to be made about what is a flood that has a 1 in 10 chance of occurring (i.e. a 1 in 10 year flood). These analyses can be useful from a geomorphological point of view in that the larger and rarer floods are considered to be those that are responsible for maintaining the main channel cross-sectional shape. The same type of analysis can be carried out for low flows to determine probabilities of likely droughts of defined durations and magnitudes.

It is important not to confuse the type of probability statement made from an extreme event analysis with an expression of frequency of being equalled or exceeded that can be obtained from an FDC analysis. The former refers to the likelihood of experiencing such an event or worse during a year, while the latter expresses the frequency with which a flow of a certain magnitude will be equalled or exceeded. For example, if the maximum flood peak in 10 years out of 100 is greater than 50 $m^3 s^{-1}$, then this would be the 1:10 year flood (or the flood with an annual probability of exceedance of 0.1%). However, there may be 20 events within the 100 years where the flow is greater than 50 $m^3 s^{-1}$ for an average of 3 days per event. The percentage time that 50 $m^3 s^{-1}$ is equalled or exceeded (considering all possible days) is then 0.16%.

2.3.4 Time dependent measures (persistence analysis)

The indices referred to above are independent of time sequences. Q70, for example, suggests that the flow will be equalled or exceeded 70% of the time on average over a long period, but does not say anything about the length of time a river can be expected to experience such a flow or less continuously. To introduce a measure of persistence it is necessary to carry out a ‘Spell’ or ‘Run’ analysis which can summarise the likely lengths of time that flows of a particular magnitude and less (or greater) will be experienced. Such an analysis will typically result in histograms of the frequency with which a flow is not exceeded for defined periods of time (0-10, 11-20, 21-30, 31-40 days, etc.). From these results it should be possible to decide how rare an extended dry, or wet, period might be.

2.4 Anthropogenic influences

Very few of South Africa's rivers have flow regimes that are natural and the type of impacts vary from small to large scale direct abstractions, construction of small and large reservoirs to a wide variety of landuse impacts. All of these can affect flow regimes and all of these influences have been changing over the main period for which the country has reliable flow records. It is therefore difficult in many situations to isolate natural fluctuations from those that are caused by artificial, man-made, influences. Anthropogenic impacts also make it extremely difficult to select suitable key Department of Water Affairs and Forestry streamflow gauging sites to use as indicators of natural flow conditions elsewhere in the same region.