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Use of Spell Analysis as a Practical Tool to Link Ecological Needs with Hydrological Characteristics

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SUMMARY: A computer program was developed to characterise the key components of the flow regime using spell analysis that are considered to be ecologically important. This will be of benefit in determining environmental flow needs for rivers and floodplains, negotiating with stakeholders to obtain environmental water allocations and developing appropriate plans for the delivery and use of environmental water.

THE MAIN POINTS OF THIS PAPER

- Pattern of flow, in terms of the timing and sequence of flow events, is emerging as an important consideration but means of characterising it are not established
- Communication with stakeholders needs to be clear and easily understood
- Require tools to facilitate investigating the links between changes in hydrologic regime and ecological consequences
- Tool needs to be user friendly to use to facilitate use by ecologists and water managers

1. INTRODUCTION

Competing demands for water in Victoria have lead to altered flow regimes for many rivers. This has seriously affected aquatic biota and habitats, and ecological function. Impacts have been expressed through problems such as increased salinity, channel erosion and siltation, and declines in native biota (Maheshwari et al. 1995). In order to redress such problems, Victoria's Water for the Environment Program is designed to assess and implement environmental flow provisions in rivers and streams across the state.

The extent of our understanding of riverine biological systems and flow requirements to maintain ecological health is currently limited. Therefore managers are using other available data, particularly hydrological information, for environmental flow determination. The natural hydrological regime of a stream may be the most appropriate indicator of what the stream ecosystem requires (Poff et al. 1997). Hydrological information useful in assessing environmental flow requirements includes the duration and frequency of floods, low flow periods and cease-to-flow conditions as well as seasonality and variability.

Although an array of statistical methods can be used to describe changes to these features, some of the statistics may not be biologically relevant. This is in part due to the importance of the timing and sequence of the features that together form a suitable flow regime. For example, flow exceedance curves show the percentage of time that a flow is exceeded but do not reveal the interval between such flows. Similarly, flood and low flow frequency analyses do not indicate the sequence of floods or low flow events. It is important to know the sequence of floods and low flow events objectives for providing environmental flows may be to break excessive drought periods or extend the duration of a flood in the appropriate time of a year.

It is important that the hydrological analysis produces results that are easily understood by stakeholders. Communication of information is a critical part of obtaining agreement to environmental flow provision. Thus, the other aim of this analysis tool was to express the output in an accessible format that clearly establishes links between the hydrology and the ecology of a stream.

Particular needs identified by environmental water managers in Victoria were to develop a tool which (1) extracted ecologically relevant components of the flow regime, and (2) produced an output that is easily interpreted by stakeholders.

2. EXISTING METHODS AND LIMITATIONS

A number of methods of analysing hydrological data are currently used to assist environmental flow assessment. However the extent to which these methods are able to usefully characterise the streamflow regime is debatable.

The methods currently in use range from simple to complex. Simple methods are easily computed, but provide a poor description of the flow dynamics that may be important to sustain ecological function. Complex methods may provide a better description of the flow regime, though they usually require specialist skills and are often not easy to understand.

Probably the most common measures used to characterise environmental requirements are statistics of central tendency, flow exceedance indices, and quantiles

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derived from the frequency analysis of flow minima and maxima. Statistics of central tendency include mean, standard deviation and coefficient of variation. These are simple to compute but provide little information regarding overall nature of streamflow regime; ephemeral streams may have the same mean as streams sustained by baseflow and streams with markedly different flow seasonality may have the same coefficient of variation.

Flow exceedance indices (i.e. selected ordinates of a flow duration curve) merely provide an indication of the percentage of time that flows of a given magnitude are exceeded. They are reasonably straightforward to derive, but provide no information on the sequence or seasonality of events. For example, flow exceedance values alone do not discriminate between those streams in which flows tend to remain at low flow conditions for a long period of time, and those in which flows tend to fluctuate over a given low flow range. The gradient of the flow duration curve is a useful index of flow variability, but it does not incorporate differences in streamflow sequencing.

Information on low and high flow spells is useful in incorporating characteristics related to flow sequences. A spell is a period of consecutive days where the flow remains either entirely below or above a given flow threshold (Nathan and Weinmann 1993). In ecological terms a “spell” can be the duration of a particular sized flood, low flow or even cease-to-flow event. Alternatively, a spell can be the length of time between events, e.g. time between floods. Therefore, characteristics of spell analyses can provide useful information related to environmental flow requirements, but they are difficult to derive. In addition, there are different ways in which the spell regime can be characterised. Consequently, the analysis is useful but is not commonly used in practice.

In general, processed information incorporating the above characteristics is not useful as it is not tied to specific environmental requirements. The Low Flow Atlas (Nathan and Weinmann 1993) is an example of processed information that is not widely used by ecologists because it was not derived with specific environmental flow requirements in mind. Thus although spell analysis is a readily available technique able to describe aspects of the flow regime related to sequences and seasonality, ecologists are not using it because it is difficult to compute and existing processed indices are not useful.

3. GENERAL REQUIREMENTS FROM VICTORIAN PERSPECTIVE

Although ecological information is limited, the available information needs to be better linked to and incorporated into hydrological analyses. This was evident when determining environmental flows for the River Murray floodplain wetlands. While key ecological thresholds (commence to flow) for floodplain inundation could be identified, extracting more detailed information proved difficult. For example, flows of a particular size with durations of at least 3 months were identified as important for waterbird breeding. However, describing changes to durations under different water management conditions and the associated ecological implications was problematic. Therefore, to facilitate the linkage of hydrological characteristics to ecological information, the analysis tool needed to incorporate the facility to:

- Input a range of relevant threshold flows.
- Allow the option of describing, for various water management scenarios, the differences in:
  - durations of threshold flows; and
  - intervals between threshold flows.
- Display different thresholds in a single graph. This is useful for demonstrating to stakeholders that a range of flow thresholds, and not just a single threshold, are important.
- Display information either simply or with more details depending on the audience or purpose.
- Demonstrate the impact on variation. A table of means, medians, coefficients of variation or skewness does little to convince stakeholders of the importance of developing flexible management strategies to ensure the instream environment is exposed to a range of flow conditions through time.
- Demonstrate the changes to seasonality or start month of threshold flows.
- Be easy to use.

4. DESCRIPTION OF THE TOOL “GETSPELLS”

A computer program called GetSpells was developed specifically to incorporate the above requirements. The primary objective of the program is to derive characteristics of streamflow spells.

For the purposes of the program:

- a spell is the total period of time when flows are continuously either entirely above or entirely below a given threshold flow. For example, in Figure 1 the numbers 1-5 indicate the spells that occur above the threshold flow A;
- a spell duration is the number of days (or months) when the streamflow is above (or below) a given threshold. Thus, in Figure 1 the duration of spell 1 is the number of days the flow remains above the threshold flow A. Spell 1 ends immediately when the flows goes below threshold A and a new spell and spell duration begin when the flow rises above the threshold flow A; and
- a spell interval is the number of days (or months) between spells. In Figure 1 the amount of time the flow remains below threshold flow A between spell 1 and spell 2 is only short and is defined as the spell interval.

Therefore, if examining floods (e.g. Figure 1), a spell is a flood (flow above a threshold flow), a spell duration is the length of a flood (period of time the flow remains above the threshold flow for a single flood) and spell interval is the time between two floods (period of time flow is below the threshold flow). Alternatively, if examining droughts, a spell is a drought (flow below a threshold flow), spell duration is the length of the drought (period of time the flow remains below the threshold flow for a single drought) and spell interval is the time between two droughts (period of time flow is above the threshold flow).

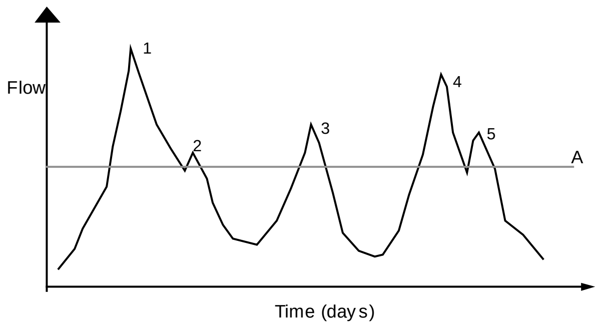

Figure 1: Dependence of spell occurrence on flow threshold. (Numbers indicate spell events over threshold flow A).

It is worth noting that the number of spells does not necessarily decrease if the flow threshold is increased because in some cases a higher flow threshold divides a single spell into two spells. For example, a spell may consist of two peaks in streamflows. This spell may be divided into two spells if the flow threshold is then increased to a flow that is higher than the minimum streamflow between the two peaks.

4.1 Central tendency of spell characteristics

Some of the simplest characteristics to extract are the statistics of central tendency. These statistics indicate overall difference between spells. The tool provides a full range of central tendency statistics, though the most useful are the mean and the coefficient of variation. All of these statistics are provided in a tabular format by the GetSpells program.

4.2 Frequency of spell occurrences

A simple analysis undertaken by GetSpells is an examination of the percentiles relating to the frequency distribution of spell occurrences. This could answer, for example, how often particular sized floods occur. The spell characteristic of interest to the user can be defined as either the spell duration or the interval between spell occurrences. The time spent above or below selected thresholds can be extracted if the user chooses to do so.
The difference between the frequency of spell occurrences for different scenarios (e.g. natural and regulated management) is plotted using floating bars (i.e. a box diagram). The top and bottom of the bars denote a selected percentile (Figure 2). This plot clearly highlights differences between natural and regulated conditions for a range of different thresholds the user has selected as being of interest.

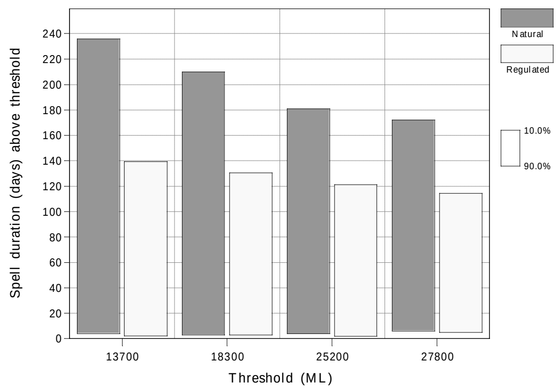

Figure 2: Simple percentile plot for spell durations above selected thresholds, for both natural and regulated conditions in the River Murray.

To gain more information from a plot, multiple percentiles can be shown (Figure 3). This plot highlights the difference over a greater range of exceedance frequencies, and in the example shown it is seen that the differences between the more common events (the median, and the 25% and 75% percentiles) are appreciable.

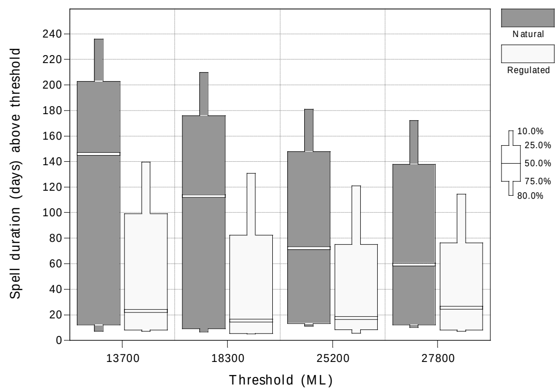

Figure 3: Complex percentile plot for spell durations above selected thresholds, for both natural and regulated conditions in the River Murray.

4.3 Frequency of spell occurrences per 100 years

The occurrence of spells is often standardised to the equivalent number of spells per 100 years to facilitate interpretation. The tool can calculate and present this information (Figure 4).

4.4 Frequency of 'start month' of spell

The month that spells usually start is also an important ecological indicator (Figure 5). Regulation may not significantly alter the frequency of spell occurrences, but it may alter the seasonal distribution of the wetting or drying regimes. The width of the bar corresponds to the number of spells that began in the given month.

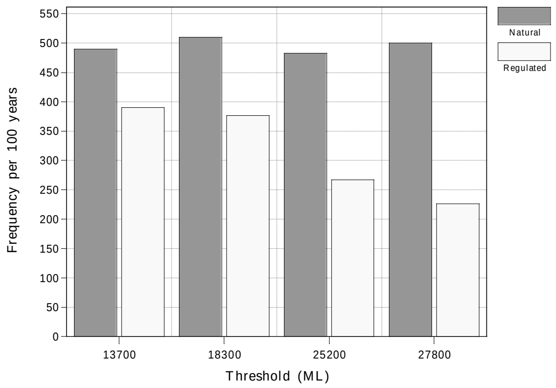

Figure 4: Bar chart of the number of spell events per 100 years for different thresholds, under natural and regulated conditions in the River Murray.

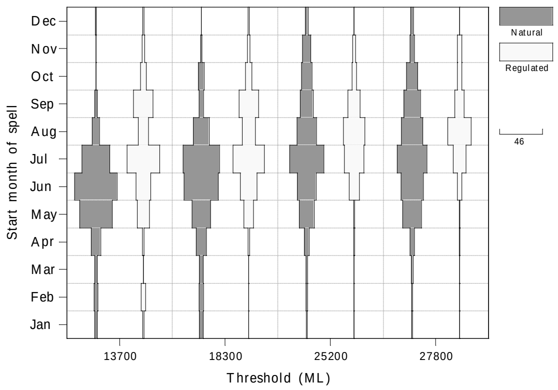

Figure 5: Frequency of 'start month' for various thresholds, under natural and regulated conditions in the River Murray.

4.5 Tailoring the analysis

The preceding examples are based on the analysis of spells above or below a given threshold, regardless of the time of year or season. However for many biota it is important to consider the impact of flow regulation at a particular time of year. For example, the consideration of the flow regime outside a particular fish spawning season may be of little importance. The tool allows the user to restrict analysis of data to certain months or seasons.

Another important consideration is spells within a given range of durations. For example, flooding events of less than 7 days duration may not be relevant to the environmental requirements of a wetland. The GetSpells program allows the user to specific the spell duration of interest and then calculate relevant information about the number or start month of spells for that duration.

5. EXAMPLE APPLICATION - RIVER MURRAY

Data for the River Murray are used for the purpose of demonstrating functions of the program. The general spell characteristics extracted relate to the amount of time the River Murray spends above flood thresholds of 13700 ML/day, 18300 ML/day, 25200 ML/day and 27800 ML/day. These thresholds were based on available information on the flows in the River Murray that cause different degrees of flooding in the Barmah-Millewa Forest. It was also established that floods greater than three months duration are an important length as this duration is likely to promote successful waterbird breeding (Murray Water Entitlement Committee 1997).

Figure 2 shows the difference in flood (spell) durations between natural and regulated conditions for different threshold flows. There is little difference for the short duration floods (exceeded 90% of the time) but the number of long duration floods (exceeded only 10% of the time) are significantly reduced under regulation.

Figure 3 highlights the difference over a greater range of frequencies. The differences between the common duration spells (the median, and the 25% and 75% percentiles) are greater. For the threshold flow of 18500 ML/d it can be seen that the median spell duration under natural conditions was 110 days but this has been severely reduced under regulated conditions to less than 20 days. This fails to give waterbirds a long enough flood time for successful breeding.

GetSpells also allows a detailed examination of spells of known duration. For example, the 'start month' of floods longer than 3 months can be quite different under natural conditions as compared to regulated conditions (Figure 6). Such a change may delay plant regeneration, with the result that new seedlings are not well enough established to survive a hot, dry summer.

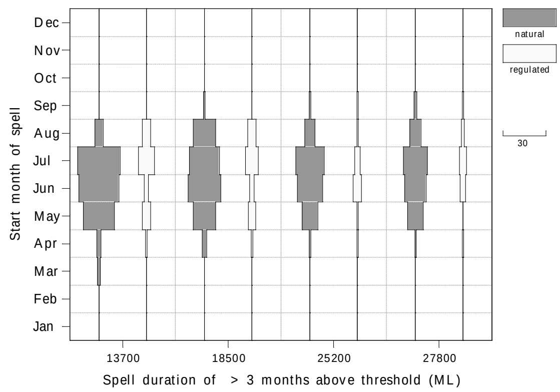

Figure 6: Frequency of start month of spells with durations > 3 months for various thresholds, under natural and regulated conditions in the River Murray.

It is often important to examine the spell interval. Breaking an excessive period between floods, for example, can be a very important aspect of establishing effective environmental flows. Examining the interval between spells with GetSpells is particularly useful in demonstrating the difference between current and proposed flow management strategies. For example, the length of time that the Barmah-Millewa forest goes without experiencing the different flooding levels is much greater under regulated conditions that would have occurred naturally (Figure 7), particularly for larger floods. Periods of greater than 5 years (1825 days) start to raise concern for the health of river red gums. Also such a long time between floods may exceed the lifespan of fish species and therefore not provide them with an opportunity to breed and maintain viable populations with good age-class structure.

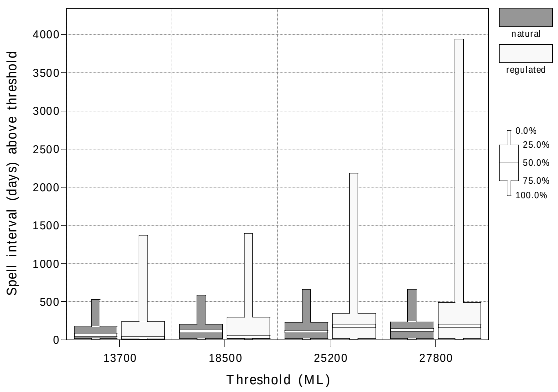

Figure 7: Complex percentile plot of intervals between spells that occur above selected thresholds, for both natural and regulated conditions in the River Murray.

Another important link between hydrology and ecology is the ‘start month’ of a spell. While a river may experience an adequate number of minor floods, if they do not occur at the appropriate time of the year they may have little ecological benefit, and in some cases do more harm than good. For example, flow regulation of the River Murray has changed the ‘start month’ of floods. Under natural conditions the majority of floods begin in the May to August period whereas under regulated conditions floods are delayed and begin two to three months later (Figure 5). Later floods can extend into the summer months resulting in unseasonal flooding of wetlands which can cause water-logging and change plant communities.

GetSpells can also be used for examining spells below threshold flows, i.e. low flows. For example, Figure 8 shows that the occurrence of cease-to-flows (when the river stops flowing) under regulated conditions in the Campaspe River below Eppalock Reservoir occur more frequently (the width of the bar corresponds to the number of spells) and during months that they never occurred under natural conditions. Further analysis using the tool could be performed to show that the duration of cease-to-flow events has also increased markedly under regulated conditions as compared to natural.

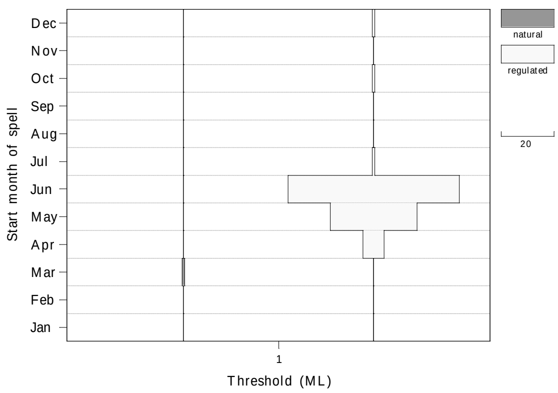

Figure 8: Frequency of start month for the cease-to-flow threshold, under natural and regulated conditions in the Campaspe River.

6. COMPARISON WITH OTHER ANALYSES

Conventional analyses calculate statistics of central tendency and presents them in a tabular format (Table 1 for the River Murray data) whereas GetSpells presents these statistics in box diagram format (Figure 3). This is more readily understood and interpreted by a range of people, including stakeholders – one of the primary objectives in developing this program – and facilitates the linkage of ecological needs and hydrological data.

Statistic	Natural	Regulated
Minimum	0	0
Maximum	91715.9	66278.6
Average	19894.33	9676.03
St. Deviation	17656.68	11584.94
Cv	0.86	1.20
Skewness	0.96	2.45

Table 1: Statistics of central tendency for natural and regulated conditions in the River Murray.

A flow exceedance curve for the River Murray shows a 23% reduction in the time a flow threshold of 25,000 ML/day is exceeded under regulated flow conditions as compared to natural conditions (Figure 9). However, the curve does not indicate how the pattern of flow has been altered. GetSpells displays the equivalent information (Figure 4), but can also illustrate when threshold flows commence (Figure 6) and the interval between these flows (Figure 7). By displaying the changes to spell intervals and ‘start month’ of spells the sequence of floods above 25,000 ML/day is better characterised than with a flow exceedance curve.

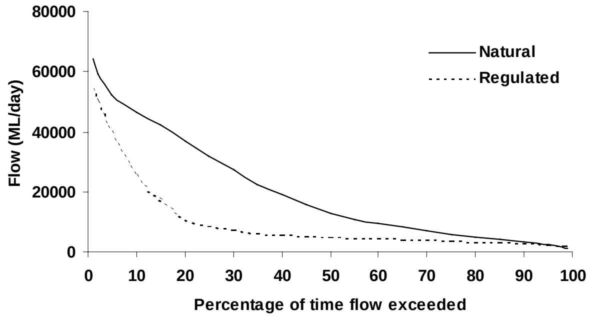

Figure 9: Flow exceedance curve for both natural and regulated flow conditions in the River Murray.

7. DISCUSSION

Spells analysis is a useful technique for characterising a flow regime whilst considering the importance of the sequence and timing of events. Essentially, the GetSpells program makes spells analysis accessible to ecologists. The program achieves this not only by being easy to operate but also by producing an output that is easily interpreted and by facilitating the investigation of the links between changes in hydrologic regime and associated ecological consequences.

Although GetSpells was developed in the context of Victoria's approach to environmental flows, the analyses used are easily transferable to other states provided the policy framework of those states is amenable.

8. CONCLUSION

Analysing, interpreting and displaying hydrological data is a difficult but integral part of determining environmental flows, and developing an appropriate pattern of use for environmental water. It is hoped that GetSpells will be one of many tools that facilitate this process and which helps the understanding, support and implementation of adequate environmental flow regimes in Australian rivers. GetSpells was developed for specific use in Victoria but may prove useful to water managers in other States. GetSpells is available at no charge from the Department of Natural Resources and Environment, Victoria.

9. REFERENCES

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