Magnitude of response: selecting sites for monitoring vegetation response to environmental flows

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Abstract

Monitoring environmental flows is a necessary and valuable investment. The design of a program to monitor environmental flows must accommodate flow-related objectives for biota known to have differing dependencies on flow, yet for practical reasons only a limited number of monitoring sites can be used. The resulting 'one size fits all' approach to site selection assumes all biota and all ecological processes are equally well-served at each site, an assumption that risks inefficient returns on outlay. In recognition of this, the Wimmera CMA commissioned the development of a site-selection tool. The tool is based on a simple model (for a given physical template, ecological response is driven by hydrology) and on a practical proposition (ecological response must be detectable and measurable); it relies on site inspections and three inputs (knowledge of the proposed environmental flow regime, capacity to translate this into on-site hydraulics, capacity to interpret this as magnitude of likely ecological response). The tool is described first in generic terms, to demonstrate its potential, then specifically for riparian and in-channel vegetation, using sites from the Wimmera River as examples. The tool was found to be effective at reviewing proposed monitoring sites and useful for identifying response variables for monitoring.

Keywords

Conceptual modelling, design, expert opinion, hydraulics

Introduction

For reasons of accountability, investment, and unique learning opportunity, it is necessary to monitor ecological responses to the delivery of environmental flows. To this end, substantial monitoring programs are being developed or are already underway in south-eastern Australia such as the Victorian Environment Flows Monitoring and Assessment Program (VEFMAP) for eight priority rivers in Victoria (e.g. Chee *et al.*, 2006) for Victoria, the Snowy River Flow Response Monitoring Project based in NSW (Rose and Bevitt, 2005) and the various icon sites for the Living Murray (e.g. Scholz *et al.*, 2006). These programs place considerable importance on design and analyses (e.g. Rose and Bevitt, 2005, Cottingham *et al.*, 2005) but pay relatively little attention to site selection. In general, site location is guided by some or all of the following: design criteria, reach representativeness, availability of historical data, co-location with another program, proximity to a gauging station, and site access (e.g. Chee *et al.*, 2006). These reasons are intrinsically valid, but fail to consider site suitability across the many variables being monitored. This is particularly relevant to multi-disciplinary monitoring programs, such as those associated with environmental flows where a number of ecological components are monitored. Although it is well-accepted that various biota and processes may have quite differing flow-ecology relationships, the validity of using one site for these differing flow-ecology relationships in a monitoring program has been largely ignored. To put it bluntly, there is no guarantee that a 'one-size-fits-all' approach to site selection will suit all ecological components. This risk of non-suitability is higher for an ecological component that is poorly known, or responds to a slightly different array of site characteristics, or responds to a different time or spatial scale compared with the majority of the components of the monitoring program.

This risk can be minimised by using the procedure, referred to as a tool, described in this paper. The tool is a field-based assessment that considers, on a site by site basis, the likely responses (of a particular ecological component) to delivering each of the recommended flows. It requires site-specific understanding of how environmental flow releases are translated into inundation patterns (differing depths and relative velocities) and expertise in ecology-flow responses. The tool was developed specifically to address management concerns that riparian and in-channel vegetation were not being adequately covered in an environmental flows monitoring program, but has wider application.

The site selection tool and how it works

Describing the approach
The tool is based on the following simple model, which is widely used to describe the functioning of river channels and floodplains, viz:

Geomorphology + Hydrology >>>>> Ecology

Geomorphology in this context means the range of shapes and sizes of features, occurring at different elevations and comprising different substrates, that are found within the river channel and adjacent floodplain; these features form a landscape usually referred to as the geomorphic template. Hydrology in this context means river flow, and specifically its changing pattern through time, within the channel and across the floodplain. This changing pattern determines whether the geomorphic template is wet or dry, if wet then how deep, how fast the water is flowing and for how long (the hydraulics); all of these influence ecological processes at the site, so hydrology is referred to as a driver. The model can then be written as:

Geomorphic Template + Hydrologic Driver >>>>> Ecological Response

The tool is an application of the above model. What makes it novel and distinctive is that it focuses on the site-specific *magnitude* of the ecological response. This is particularly relevant to monitoring environmental flows. If an ecological response is small, it is likely to be hard to detect, and be difficult and impracticable to monitor, making the site where this occurs poorly suited for inclusion in a monitoring program. In contrast, if the response to the environmental flows is large, it will be detectable, measurable and probably significant for the river; thus the site where this occurs can be considered well-suited for inclusion in the monitoring program.

Determining the magnitude of ecological responses
Some preparation is necessary before determining if an ecological response is large or small.
First, defining the target. The 'target' is the ecological component of interest. This may be particular biota, such as fish, or an ecological process, such as carbon flux. The target in the examples below is riparian and in-channel vegetation, defined to mean woody and non-woody plants, ranging in size from small to large; it specifically excludes biofilms, algae and phytoplankton. Note that target may be sub-divided if it is intrinsically diverse, as is the case for riparian and in-channel vegetation. Hence this target is considered to comprise several plant groupings, meaning plants with similar growth forms, and similar responses especially to water regime. A grouping may be flexibly defined: it can comprise one or several species, and can occur on one or more geomorphic features. Groupings are thus distinct from plant communities defined by floristics. In the examples below, the target is given as 5 plant groupings: riparian trees; riparian shrubs; understorey, forbs and herbs; in-channel macrophytes; bank and edge macrophytes.

Second, characterising the model. Each of the three parts in *Geomorphic Template + Hydrologic Driver >>>> Ecological Response* needs to be characterised in relation to the target. Thus in the case of geomorphic template, the features occurring in the channel are considered as potential habitats or habitat patches for the target, and the number present is a site and hence river characteristic. The number of features recognised as relevant to the target is determined by the user, but should aim to be comprehensive at the expense of being simplistic, however a large number of habitats is not really practicable. In the examples below, the geomorphic template comprises 8 habitats: islands, banks, bars, benches, anabranches & flood runners, pools, runs and riffles.

For the hydrological driver, this means expressing the environmental flow regime and its set of specific flow recommendations, in terms of volume, duration, return or timing. The descriptions used in flow recommendations may not perfectly correspond with what the target requires, hence it is also necessary to identify what is critical for the target. Water regime for plants means frequency, depth, duration and timing of inundation, and may also include rates of rise, rates of fall or even velocity. However, as with geomorphic template and number of features, it is more practicable to be simple and concentrate on what is known or relevant to the site and river in question. In the examples below, hydrologic driver is restricted to 3 components of water regime following Casanova and Brock (2000): depth, duration, timing.

For the ecological response, this means the response of the target to hydrological driver. This can be expressed in a number of ways, depending on each plant grouping: thus for communities, it can be a change in composition; for populations, it can be regeneration, recruitment; for individuals, it can be a growth pulse, reproduction, or the alleviation or imposition of stress. Which and how many to use will be empirically determined by the user, in response to site-specific situations. In the Wimmera study, fourteen ecological responses were identified.

Having defined the target and characterised the model, the magnitude of the ecological response can now be determined. This is done by projecting how a recommended flow will 'engage' with the geomorphic template and then considering the spatial, temporal and depth characteristics of that engagement, particularly the extent and duration of inundation. Thus the relevant geomorphic characteristics are slope (gentle or steep) and channel complexity (simple or complex in cross-section, or simple in cross-section but with longitudinal variations); the relevant hydrologic characteristics are vertical range in water level (ie depth) and its temporal pattern (duration and timing). Water quality may also be considered, but only as a flow-related characteristic: for example, in salinised systems, flow may have a freshening effect, in which case water quality should be considered. As described here, this is a form of conceptual modelling but applies equally well to a whole-of-system hydraulic model, where available.

The spatial extent of inundation (or exposure) is considered as it determines scientific information, such as how much of a plant grouping will be affected, as well as practical issues, such as what area can be sampled for monitoring: in both these, the size (ie dimensions such as height and cover) of the plant grouping is an important consideration. A flow that inundates only 200 m^2 will affect few trees but many perennial grasses; so could be classified as *small* for a tree grouping but *large* for a grass grouping. Similarly, the temporal characteristics of inundation (or exposure) are considered as these determine how much of the soil becomes waterlogged, how long existing plants are submerged and deprived of oxygen, and whether there is time for seeds to imbibe and germinate. A flow that inundates a clay area for 4 days will only moisten the soil surface so may result in growth in shallow-rooted species, prevent seedling desiccation and stimulate germination in rapidly-responding species. The ecological response would thus be *small* for a tree grouping, and verging on *large* for seedlings or opportunistic plant groups. Inundation would need to last much longer to have a *large* response in a tree grouping.

The magnitude of response cannot be simply predicted from hydrologic and geomorphic characteristics, because it is relative to the target; when the target is diverse, as is riparian and in-channel vegetation, then response magnitude needs to be considered relative to each plant grouping. In contrast, the spatial and temporal characteristics of engagement have real dimensions such as hectares and weeks, so are not relative. Hence *small* in the tool means either a small to negligible change in the target, which for riparian and in-channel vegetation means little to no change in biomass, growth, phenological status, physiological condition or composition, or else only a small area of the target is expected to change. If there are no *large* ecological responses for any plant grouping, then the site is rejected as being not suitable for monitoring.

Worked examples for riparian and in-channel vegetation in the Wimmera
Two worked examples of this tool with contrasting outcomes are illustrated in Figures 1 & 2, taken from a study on vegetation monitoring for the Wimmera River system (Dyer & Roberts, 2006). An environmental flow monitoring program had been broadly outlined for the Wimmera (Sharpe & Quinn, 2004) identifying a series of potential monitoring sites and highlighting monitoring components. The monitoring program outlined did not provide guidance and specification for the monitoring of individual ecosystem components (it was outside the scope of the report) and the Wimmera CMA were supplementing the Sharpe and Quinn (2004) report with expert consultancies. The implementation of the tool involved 3 steps:

Step 1. As described above, the target was defined as five plant groupings.

Step 2. The characteristics of the channel and the recommended environmental flow regimes were defined (Figures 1 & 2).

River: Wimmera
Reach: between Glenorchy Weir and Huddleston's Weir
Site: Dave's Lane
Channel: steep sides, simple cross section. Few in-channel topographic features (such as bars, benches or backwaters) are present and these are relatively small in relation to the overall channel dimensions.

Recommended Environmental Flows:

Component	Discharge	Duration
Cease-to-flow	0 ML/day	15-34 days
Summer baseflow	6 ML/day	
Summer Fresh	>16 ML/day	>5days
Winter minimum	25 ML/day	
Annual High	5,500 ML/day	>5 days

Resulting Hydraulic Characteristics:
All recommended environmental flow components are likely to be contained within channel. The Summer baseflow, Summer Fresh and Winter minimum will result in small changes in water depth. The Annual High Flow will run close to the top of the bank.

Water Quality Changes:
Water quality is unlikely to change markedly with the provision of environmental water.

Magnitude of vegetation response:
Only three plant groupings are present here: riparian trees, woodland understorey, in-channel macrophytes. All three may be affected by the release of environmental water however the steep sides, permanent pools and small discharges for the majority of the flow components means the extent will be small. The duration of the annual high flow event is probably too short to have a large effect on the plant groupings.

Figure 1. Example: Dave's Lane on the Wimmera River.

River: Wimmera
Reach: between MacKenzie River confluence and Lake Hindmarsh
Site: Tarranyurk gauging station
Channel: complex cross section containing bars, benches, flood runners & minor anabranches.

Recommended Environmental Flows:

Component	Discharge	Duration
Cease-to-flow	0 ML/day	5-24 days
Summer baseflow	5 ML/day	
Summer Fresh	>20 ML/day	7-15 days
Spring Fresh	>334 ML/day	>14 days
Winter minimum	34 ML/day	
Winter High	>3,000 ML/day	>2 days
Annual High	6,000 ML/day	3-5 days

Resulting Hydraulic Characteristics:
Most environmental flow components will engage a variety of channel features.

Water Quality Changes:
Saline groundwater intrusions may mean that the provision of flows will result in a major change to water quality, particularly during summer.

Magnitude of vegetation response:
All five plant groupings are present, and all five are expected to be affected by the release of environmental water. The complexity of the channel, the engagement of a variety of channel features and freshening effects means that the response magnitude will be large

Figure 2. Example: Tarranyurk Gauging Station on the Wimmera River.

These definitions were then used to estimate the hydraulic and water quality characteristics created by the release of the environmental water:

- Will the vertical range of provided flows be large or small relative to the channel?
- Will the vertical range of provided flows be large or small relative to the vegetation?
- Will the change in water level last long enough to affect plant growth?
- Will the flow cause a large and sustained change in water quality?

The vertical range combined with the channel characteristics defined the size of the zone in which a vegetation response may be expected and this is termed the response zone. The size of the response zone will be dependent on the slope of the banks as well as the vertical range, eg. For a small vertical range, the response zone will be small if the slope of the banks is steep but large if the slope of the banks is gentle.

Step 3. At each site, answers to these are combined to determine the magnitude of each expected response, following the scope of large and small outlined above. Specifically, plant responses are established linking the hydrologic parameter for a specific flow recommendation to affected geomorphic features and noting which plant groupings are affected (Table 1).

Table 1. Expected responses by vegetation at Tarranyurk Gauging Station.

Hydro Parameter	Geomorphic features	Relevant Plant Grouping	Expected Responses
Freshening	In-channel, benthos and littoral zones.	In-channel macrophytes (submerged aquatic plants).	Change in relative abundance of submerged macrophytes; shift or turnover in species composition, and functional types.
Depth Duration Timing	Bars, benches, channel margins, sills.	Riparian Shrubs.	Improvement in canopy of adjacent riparian shrubs. Growth pulse & possibly increased flowering intensity in riparian shrubs.
(Spring Fresh)	Channel margins.	Riparian Trees.	Improvement in canopy of adjacent riparian trees; slowing of mortality rate.

The response magnitude is *small* if:

- The response zone is small and there is no change in water quality.
- The response zone is large but duration is too short to allow plant growth, germination, mortality, etc.

The response magnitude is *large* if:

- The response zone is large, regardless of whether water quality changes or not. The response zone may be large even if the vertical range is not, if the slope is very gentle.
- The response zone is small but the environmental water releases result in a major change in water quality notably from saline to fresh, or turbid to clear or vice versa.

An example of applying this tool is given for two sites in the Wimmera system (Figures 1 and 2), with differing outcomes: Dave's Lane was considered suitable for monitoring the response of vegetation to environmental flows, but Tarranyurk was not.

Benefits of the tool

The tool was used to evaluate 29 sites in the Wimmera system (Dyer & Roberts, 2006); this included sites recommended for vegetation monitoring ('key' sites *sensu* Sharpe & Quinn, 2004), additional sites and sites already used for routine water quality monitoring (VWQMN sites). Only 9 of the 13 key sites assessed were found to be useful for monitoring vegetation response to environmental flows, a failure rate of 30%. Sites that were rejected (4 through this field protocol and 2 by preliminary criteria not discussed here) were concentrated in the middle parts of the Wimmera system, indicating that monitoring riverine vegetation is worthwhile only in the Reach upstream of Glenorchy and the Reach from theMcKenzie River junction to Lake Hindmarsh. The findings are significant, both in their number and distribution.

An unexpected benefit arising from using the tool was the potential to contribute to aspects of the monitoring program. The tool (see example above) requires that vegetation-flow responses be described on-site. Articulating these is equivalent to describing a series of relevant flow-response models, ready to incorporate into a hypothesis-based monitoring program. Although only five plant groupings were used to evaluate 29 sites (Dyer & Roberts 2006), a total of fourteen potential flow-responses were articulated (Table 2), covering different aspects of vegetation from communities to specific growth-forms and individual problematic species. Transforming these into fourteen monitoring options with variables, sampling frequency was then relatively straight-forward (see Dyer & Roberts, 2006, section 5.3). These fourteen flow response models were consistent with reach-specific hypotheses described by Sharpe and Quinn (2004, section 7.3) but are distinct from those recommended for priority monitoring under VEFMAP (Chee *et al.*, 2006).

Table 2. Flow Responses in five plant groups

Adjacent Trees	Riparian Shrubs	Woodland understorey; forbs and herbs	In-channel macrophytes	Bank and channel edge macrophytes
Improvement in canopy of adjacent trees; slowing of mortality rate	Growth pulse and reproduction (flowering, fruit set)	Understorey change in species composition, and/or functional groups or growth forms (eg away from grasses-dominated to sedges & amphibious plants)	Change in abundance, species composition (turnover) and functional types of submerged macrophytes after freshening	Increased diversity, most likely with sedges
Regeneration opportunity for riparian trees near to channel	Regeneration opportunity	Growth surge and re-growth of forbs and herbs along flood-runner	Colonisation and expansion by *Phragmites australis*	
Growth surge for seedlings or saplings of riparian trees		Development of recession flora in depressions and flood-runners	Vigorous growth in existing *Phragmites australis*	
			Establish and set fruit in flow path	
			Increase in diversity, altered distribution patterns	

Conclusion

This tool provides a strong scientific basis for monitoring, and can be used to make monitoring more efficient.

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