Turning flow events into dollars and cents

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Key Points

- As climate dries, waterway managers are searching for additional sources of water.
- Environmental water shortfalls may be provided through alternative water sources such as harvested stormwater.
- To evaluate the potential benefits and disbenefits of providing alternative water, a method was developed to better quantify waterway health benefits and value these benefits in economic terms.

Abstract

Environmental flows are difficult to value in economic terms. How do you put a price on flows in a river, fish spawning or a healthy platypus population? Previous methodologies have looked at the community's willingness to pay for additional environmental entitlements in storages or improvements in overall river health, but these methodologies can't be applied easily to Integrated water management (IWM) projects returning water to the environment.

The Economic Benefits of Flow (or EB Flow) methodology has been created to translate changes in flow into an economic value. This is done by first identifying the relationships between waterway values and key hydrological indices. Modelled flows from proposed projects are then analysed to generate changes to the same key hydrological indices. From this, changes to waterway values are generated. These changes to waterway values are then used as a relative representation of the changes to waterway health, which can then be used to generate the community's willingness to pay for the environmental flow benefit.

This project has increased the value of environmental flow contributions, compared with previously available methodologies. This methodology also draws clear links between the flows provided to the waterway and the values that are benefiting from these flows. This improves the clarity and justification of the economic benefits attributed to flow improvements.

As the climate dries, waterway managers are looking for additional sources of water for the environment via substitution or direct supply of alternative water. Increasing the economic value of environmental flows will assist waterway managers to progress business cases for these projects and achieve improvements for local waterways.

Keywords

Environmental flows, climate change, cost benefits, IWM, stormwater

Introduction

Waterway managers have a responsibility to deliver positive outcomes for waterway health, including the delivery of water for the environment (environmental flows). For many flow stressed systems, waterway managers must look to integrated water management (IWM) and alternative sources of water to substitute extractive uses, allowing for more water to remain in the river, or to supply directly as environmental flows. These projects are often complex in nature, involving a variety of stakeholders and infrastructure options. When developing these projects, costs and benefits must be identified for the project options. Valuing the benefits of environmental flows has been a challenge for the industry, with previous methods providing relatively low benefit values compared to project costs.

Melbourne Water undertook a previous study with the University of South Australia to assess the community's willingness to pay (WTP) for increasing environmental entitlements (Cooper, B. et. al 2017). While this study identified that there is community WTP for improved outcomes due to environmental flow, the underlying valuation approach means that the quantity of environmental flow entitlements held in storage must increase for environmental flow benefits to be estimated. As a consequence, this valuation approach cannot be applied to IWM projects that result in a change in the timing of environmental flows, rather than an increase in the quantity of environmental flow entitlements held. As a result, the benefits from optimizing the timing of environmental flow releases to maximise ecological benefits will not be recorded in monetary terms when using this valuation approach.

In planning for future challenges, a method to provide economic value of altered flows from a variety of sources was needed to fill this gap in the environmental flow valuation toolbox. This method, developed originally for a project in the Werribee River, can be applied to a broad range of projects that have an impact on environmental flows and is particularly suited where a change in the condition of a waterway is primarily dependent on targeted environmental flows. This methodology aims to increase the benefit value of these projects, while staying in line with the community's willingness to pay for waterway health and aligning with economic evaluation guidelines published by state governments across Australia.

Developing the method

The conceptual links between ecology and hydrology are the foundation underpinning the method developed to quantify waterway health benefits. The hydrologic regime was linked to specific flow metrics such as the timing, duration and magnitude of particular flow events. These metrics are the elements of the hydrologic and hydraulic regime which have direct impacts on aquatic habitats. Through this understanding of impacts on habitat conditions, likely effects on ecological values which rely on these habitats can be articulated. The key steps in the method are as follows: identification of flow dependent values, articulating the conceptual associations between flow and flow dependent values, identification of appropriate flow metrics, hydrologic and hydraulic analysis of change in flow metrics and calculation of waterway health benefits.

While the method was initially developed to test alternative water source supplementation to the Werribee River in the west of Melbourne, the method provides enough flexibility to allow it to be applied to other systems and scenarios. It also strongly aligns with the principles of habitat suitability modelling. Habitat suitability modelling aims to assess the quality and quantity of habitats for a species within a study area or river reach by identifying the relationship between flow, hydraulic characteristics, and biota (Melcher et al., 2018). The method developed for this project in essence looks to create a habitat suitability type index with two key differences. Firstly, the analysis for this project sits at a higher level than a habitat suitability model because there is a lack of specific species surveys, therefore a list of likely species was used. Secondly, the intent of this method – which seeks to identify the level of improvement possible with more flow (but short of the environmental flow recommendations) – differs from that of habitat suitability modelling which is aimed at defining the types of flows required for species.

Understanding the ecological response to altered flow regimes is critical to this process undertaken as a part of this project. The ecological responses to changes in key aspects of the flow regime are well established in the literature and outlined in Table 1.

Table 1 Ecological responses of (a) aquatic and (r) riparian organisms to changes in key components of the flow regime. Source: Zeiringer et al., 2018

Flow component	Alteration	Ecological response	
Magnitude	Flow stabilization (loss of extreme high and/or low flows)	(a)	Reduced diversity, loss of sensitive species, altered assemblages and dominant taxa, reduced abundance, increase in non-natives
		(r)	Seedling desiccation, ineffective seed dispersal, terrestrialization of flora, lower species richness, encroachment of vegetation into channels, increased riparian cover, altered assemblages
	Greater magnitude of extreme high and/or low flows	(a)	Life cycle disruption, reduced species richness, altered assemblages and relative abundance of taxa, loss of sensitive species
Frequency	Decreased frequency of peak flows	(a)	Aseasonal reproduction, reduced reproduction, decreased abundance or extirpation of native fishes, decreased richness of endemic and sensitive species, reduced habitat for young fishes
		(r)	Shift in community composition, reductions in species richness, increase in wood production
Duration	Decreased duration of floodplain inundation	(a)	Decreased abundance of young fish, changes in juvenile fish assemblage, loss of floodplain specialists in mollusk assemblage
		(r)	Reduced growth rate or mortality, altered assemblages, terrestrialization or desertification of species composition, reduced area of riparian plant cover
	Prolonged low flows	(a)	Concentration of organisms, downstream loss of floating eggs
		(r)	Reduction or elimination of plant cover, diminished plant species diversity
	Prolonged inundation	(a)	Loss of riffle habitat
		(r)	Change in vegetation functional type, tree mortality
Timing	Shifts in seasonality of peak flows	(a)	Disruption of spawning cues, decreased reproduction and recruitment, change in assemblage structure
	Increased predictability	(a)	Change in diversity and assemblages structure, disruption of spawning cues, decreased reproduction and recruitment
	Loss of seasonal flow peaks	(a)	Disruption of migration cues, loss of accessibility to wetlands and backwaters, modification of food web structure
		(r)	Reduced riparian plant recruitment, invasion of exotic riparian plant species, reduced plant growth and increased mortality, reduction in species richness and plant cover
Rate of change	Rapid changed in river stage	(a)	Drift (washout) and stranding
	Accelerated flood recession	(r)	Failure of seedling establishment

Habitat suitability modelling brings together several methods that have been used to determine environmental flow requirements to assess requirements more accurately. In developing the method for this project, we have incorporated the same methods to assess flow benefits which include hydrologic analysis, hydraulic analysis, and habitat simulation.

Hydrologic analyses used to understand environmental flow requirements are based on relatively simple minimum flow thresholds derived from hydrographs however, on its own lacks a direct link to the habitat requirements of biota (Zeiringer et al., 2018). In the method developed for this project, a hydrologic analysis is undertaken for each of the flow scenarios to improve understanding of the potential benefits of additional flow. The next component undertaken in this project was a hydraulic analysis. The hydraulic analysis, as in environmental flow determination methods, seeks to quantify the relationship between discharge and instream habitats (Zeiringer et al., 2018). In the Werribee River system the changes in flow between the different scenarios were too small to have a meaningful impact of hydraulic characteristics and were therefore excluded from the calculation of relative benefit. It is noted however, that the lack of sensitivity in hydraulic metrics to changes in flow may not be the case for other waterways in Melbourne. If applied to other systems, hydraulic metrics should be incorporated which would align the method more closely to the habitat suitability modelling approach outlined in Melcher et al. (2018).

Habitat simulation methods are more sophisticated methods of determining environmental flow requirements as they attempt to combine flow with habitat availability by weighting available habitat for certain species under different flow scenarios (Zeiringer et al., 2018). The method developed for this project incorporates this aspect of understanding flow/ecology relationships by combining flow associations with values through a percentage change in each of the flow metrics.

Quantifying waterway health benefits

Identifying water dependent values

The first task to apply the quantification of benefits method is to identify all the flow dependent values within the system being investigated. These are values whose condition is in some part dependent on the flow regime of the system or the presence of water within the system. In its application to the Werribee system, the identification of values was undertaken through a review of existing documents (e.g., flows study), however value identification could also be undertaken using detailed ecological surveys or spatial databases such as the Atlas of Living Australia or NatureKit. In the test application, blue-green algae and Azolla were added to the list of values so that associations with flow components could be established. This was important because the Werribee system is occasionally subject to outbreaks and adding these "values" will allow managers and others to understand the impact that additional flow may have on negating potential risks to water quality and waterway health. It is important to note that with blue-green algae and Azolla, negative associations with flow (discussed in the next section) are considered positives for the quantification of overall waterway health benefits (e.g., Azolla would have a negative association with fresh events because velocities flush it through the system and prevent it from colonizing large areas of the channel, but from a waterway health perspective, this negative association is a benefit).

Flow value relationships

To understand the relationship between biota and flow, the flow regime is often broken up into its core components. Environmental flow recommendations for waterways are developed by identifying the magnitude, duration, and frequency of some or all these flow components. Recommendations are linked to ecological objectives through an understanding of the conceptual links between water dependent values and flow components.

The strength of the associations between individual flow components and water dependent values underpins the method to quantify waterway health benefits. The method provides associations between values and standard flow components (e.g., baseflow) and the characteristics of these flow components (e.g., magnitude, frequency, duration).

The association between values and flow components is quantified using a Likert scale ranging from –3 to +3 where scores represented:

- +3 Strong, positive association
- +2 Moderate, positive association
- +1 Weak, positive association
- 0 No association
- -1 Weak, negative association
- -2 Moderate, negative association
- -3 Strong, negative association

For example, diadromous fish require a year-round baseflow which inundates enough habitat for survival of populations, therefore, the relationship between diadromous fish and zero flow periods is a strong negative association. With extended zero flow periods, the survival of populations is at risk. Freshes are also identified as critical for migration and dispersal of diadromous fish so the association between them is a strong positive one. However, overbank flows have not been identified as providing essential conditions for diadromous fish, therefore the association is a weak association (Table 2). While associations between values and overbanks flows were established, they were excluded from the final assessment because they cannot be delivered.

Table 2 Example of flow/value relationship for zero flows, baseflows and freshes

Values	Zero flows		Baseflows	Freshes	
	Mean duration of zero flow periods	*% of time flow is zero*	*low flow magnitude*	*Events/year >3 times baseline median flow*	*% of time >3 times median flow*
Fish - diadromous	-3	-3	2	3	3
Fish - non-diadromous	-3	-3	2	2	3
Fish - Common galaxias	-2	-2	2	3	3
Fish - Climbing galaxias	-2	-2	2	3	3
Fish - Australian smelt	-3	-3	2	2	3
Fish - Tupong	-3	-3	2	3	3
Fish - River blackfish	-3	-3	2	2	3
Fish - Southern pygmy perch	-3	-3	2	2	3
Fish - Mountain galaxias	-2	-2	2	2	3
Fish - Aus. Grayling	-3	-3	3	3	3
Fish - Black bream	-2	-2	3	3	3
Platypus	-3	-3	3	2	2
Birds - waterway	-3	-3	2	2	1
Birds - riparian	-2	-1	1	1	0
Flora - aquatic/ instream	-3	-3	2	1	2
Flora - emergent/fringing	-3	-3	3	3	3
Flora - riparian	-2	-2	2	2	2
Flora - Estuary	-3	-3	3	2	2
Flora - Floodplain	-1	-1	2	2	2
Frogs -stream dependent	-3	-3	2	2	1
Frogs - Growling grass frog	-3	-3	3	2	1
Macroinvertebrates	-3	-3	2	2	2
Azolla	3	2	-2	-3	-3
Blue-green algae	3	2	-2	-3	-3

The quantification of these links can be undertaken through expert elicitation workshops, literature review or a combination of both. Expert elicitation workshops may be required to expand the linkages across a broader range of values as there is some literature which discusses flow associations although much of the focus is on fish and often at the level of 'altered flow hydrology' impacts rather than links to specific flow increments (e.g., Merg et al, 2020; Dawson and Koster, 2018). Tonkin et al (2020) summarises the outcomes from the VEFMAP program which does link flow components to different life stages, although the strength of the link for each flow component is not as well defined.

Identifying flow metrics

The method to quantify waterway health benefits has been tested using two different sets of flow metrics. Option 1 is to adopt the flow metrics based on the Urban Streamflow Impact Assessment (USIA) which are considered most relevant to the urban and peri-urban settings. Option 2 is to utilise the flow metrics associated with the environmental flow recommendations (FLOWS metrics).

The previous application used Option 1, which were initially assessed in this project for the Werribee River. A review of the outputs identified unexpected differences between the scenarios and there was uncertainty as to whether these differences were a result of how the alternative water scenarios were being modelled or the choice of metrics.

The alternative water scenarios being assessed for the Werribee River in this project were significantly more complex than those tested during the initial application of the method. The scenarios included system reconfiguration and water sharing rule changes and needed to examine the benefits and disbenefits across several reaches.

Given the complexity of changes being assessed it was felt that Option 2 to utilise the environmental flow recommendations and their compliance would be more straightforward and provided a further check of the applicability of different flow metrics. We note that both the USIA and FLOWS metrics are similar, and the links between both sets of metrics and environmental values can be derived in the same way.

With the FLOWS metrics, the links between values and metrics were assigned using the flow objectives with recommendations and compliance against all flow components (including bankfull and overbanks) considered for each reach (where applicable).

Interestingly, when interpreting the FLOWS metrics results, it was discovered that the setup of the alternative water scenarios in the SOURCE hydrologic model was impacting on compliance results. The model used for this project was adopted as is from DEECA without any modifications to the settings. As a result, it became apparent that there were several instances of ineffective environmental water releases, leading to a worse flow metric compliance outcome than expected. Approximately 50% of releases from Pykes Creek Reservoir and approximately 25% of releases from Melton Reservoir were either ineffective or in excess of the flow target. This highlights the importance of understanding the model configuration when using any flow metrics in quantifying environmental benefits. Ideally the model would be configured to output the most accurate results for its use. However, where this is not possible, it is essential to understand its limitations and potential impact on the results.

The overall outcome from this work was that both flow metrics options are suitable for applying this method and the choice of which type of metrics to use will be based on how applicable and relevant they are to the system as well as the how the hydrologic scenarios being tested have been setup in the models.

Application of flow metrics

Choosing which metrics to adopt for the flow benefits assessment comes down to the available flow data or modelled data, the complexity of the alternative water scenarios, and the flows being targeted by the additional water. Essentially the method for assessing flow benefits looks at how a Business as Usual (BAU) or Existing Conditions (EC) scenario compares to an Alternative Water scenario, with the relative difference between metrics for each scenario providing a measure of benefit (where positive) or disbenefit (where negative).

FLOWS metrics cover the same types of flow components as the USIA metrics, the difference being in how a “fresh” event is defined in each, and the lack of metrics for zero flow events in the FLOWS metrics as these are not typically specified in environmental flow recommendations. If the additional water will mitigate existing or future zero flow events, then the USIA metrics will capture these outcomes. If there is concern that the alternative water scenario may increase flows too much and cause increased bed or bank erosion, then the USIA “fresh” and hydraulic metrics provide a way of checking for these outcomes.

A benefit of the FLOWS metrics approach is that there may be an existing compliance assessment for a reach (or reaches), and these compliance assessment results can be readily utilised in the method without further analysis. Conversely, where there is no compliance assessment the calculation of difference between a BAU/EC and alternative water scenario(s) is the same no matter what metrics are adopted.

It is also recommended that as well as modelled scenarios, if there is a flow gauge within the reach of interest that the metrics be calculated for the gauged flows. It was found in the initial testing that comparison of the BAU/EC modelled scenarios to gauged records can identify inconsistencies in how flows are specified and/or delivered in hydrologic models which can assist in interpreting the analysis results.

The hydrologic analysis should calculate the magnitude of change between the flow metrics for all the flow scenarios being tested and a base case scenario (BAU/EC). It is important to identify which types of change are a benefit or a disbenefit to the waterway.

From both the applications to date, a key outcome is the importance of understanding what type of changes are going to be a benefit or disbenefit to the waterway. This comes down to understanding the current flow regime and ecological values within it. For instance, in the USIA application, a reduction in zero flow days is a benefit. Whereas in the flow compliance application a reduction in baseflow compliance is a disbenefit. This needs to be kept in mind when calculating the benefits.

Calculating benefits

Relative improvement score (RIS)

The benefit of each flow scenario for individual values is calculated by bringing together the flow/value associations and the percentage change in the hydrologic metrics analysed or the percentage change in compliance. For each value, the association between flow and value is then multiplied by the percentage change in the hydrologic metric/compliance. This is calculated for each of the metrics being assessed. The percentage change in hydrologic metric/compliance were reviewed to ensure that the results for individual metrics did not inadvertently skew the results.

These values were then summed to give a relative improvement score. It is important to note that the improvement scores are relative to the base case scenario and demonstrate improved performance relative to this case, not absolute improvement in condition.

Deriving a benefit

There is very good contemporary evidence available on the economic value of improving and maintaining the condition of urban waterways in Sydney and Melbourne. Recent evidence shows that Victorian households place a high value on ecologically healthy waterways and are willing to pay extra to maintain waterway health, and/or rehabilitate degraded waterways (see (Bennett, et al., 2016), (Bennett, et al., 2017) and (Morrison, et al., 2016)).

Marsden Jacob Associates (MJA) developed the Waterway Value Estimation Tool (WVET) to assist stakeholders with a role in urban waterway management to quantify the economic value of changes in condition of individual urban waterways across Australia.

Drawing on published evidence (Rolfe, et al., 2013), the WVET includes a formula that links changes in waterway condition to the average household's Willingness to Pay (WTP) for improvements or to prevent deterioration. Represented by an S-shaped curve, the data shows that households are most willing to pay for initiatives that elevate waterway conditions from Moderately Poor to Good. This range corresponds to an Index of Stream Condition (ISC) score of 20 to 40. At both extremes, there is comparatively lower WTP for improving waterways that are already in very good condition or those in very poor condition.

In this project, the RIS calculated using the EB flows approach was integrated into WVET as an indicator of waterway condition. Developed by Streamology, the EB Flows approach is well-suited for analysing flow-stressed waterways and aims to fully capture the value of environmental flow contributions. Conversely, the ISC methodology accommodates five potential determinants of waterway condition, ensuring no single determinant disproportionately influences the ISC score. This design inherently restricts significant ISC score improvements in scenarios where well-targeted environmental flows are crucial for condition improvement. Consequently, the ISC score does not fully reflect the ecological benefits of environmental flows where the condition of a waterway is disproportionately dependent upon environmental flows. This in turn leads to an underestimation of these benefits in monetary terms within the WVET. By incorporating the RIS measure, this project ensured that the monetary value of improved waterway conditions from optimised environmental flows was fully recognised.

The WVET recognises that changes in waterway condition typically occur over many years, rather than within a single year. The tool assigns a marginal WTP to the year an increase in RIS is detected, and only for the fraction of the total RIS improvement attributable to that year. This approach generates annualised cash flows within the Cost Benefit Analysis (CBA) model. It enables the calculation of the Present Value (PV) of benefits from waterway condition improvements—essentially, PV translates future economic benefits into today's monetary value, in accordance with CBA guidelines. The PV costs of implementing the initiatives that deliver these beneficial environmental flows can then be deducted from the PV benefits to calculate the Net Present Value (NPV) of the initiative, along with the Benefit-Cost Ratio (BCR).

Moreover, the WVET can assess deterioration in waterway conditions, making it just as suitable for analysing policies, initiatives, or projects that may negatively impact environmental flows.

Conclusions

This methodology draws a clear link between the waterway health improvements generated by increased environmental flow and the community's willingness to pay for these improvements. By creating associations between water dependent values and flow, impacts of a project (both positive and negative) can be assessed to generate a relative improve score that is most likely to capture the full environmental change in flow-stressed waterways from providing targeted, beneficial environmental flows.

The full economic value of the initiative is also most likely to be captured under this methodology, because the WVET is adapted to reflect a comprehensive evaluation of ecological benefits generated through the EB flows approach, resulting in relatively higher economic benefits than would be the case if utilising approaches less suited to flow-stressed waterways. This is a useful improvement for waterway managers who can have greater confidence that the true ecological value of improvements in environmental flow as part of major works and strategic planning are reflected in economic evaluations.

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