Farms Rivers Markets – Environmental Targets

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SCOPE: This discussion paper is restricted to ecological considerations in target setting including key challenges in current practice and how Farms Rivers Markets is responding to these.

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1 Introduction

Environmental water requirements are often treated as a fixed constraint on water resource planning and operation. Indeed the environmental water "requirement" routinely exceeds that which is available for the environment. This means either the constraint is revised and applied in some diminished form or ignored entirely.

One objective of the Farms Rivers Markets Project is to lead a shift from treating environmental water use as a constraint on delivery for consumptive users to water resource planning for achievement of ecological and consumptive targets. In other words, we wish to treat environmental demands in an equivalent way to competing human water demands where priorities, trade-offs and synergies are explicitly identified. This applies whether outcomes are achieved through water management or market-based mechanisms. Inside this challenge is the goal of identifying water systems, which deliver more, both in terms of consumptive and environmental outcomes.

Establishing environmental water targets is important for achieving this research goal. Consumptive users can quite clearly state their desired watering regime and evaluate consequences of alternate water allocations. In contrast the environmental demands are often poorly expressed in current practice, even to the extent of not being able to define the water required to avoid catastrophic collapse. This paper discusses some of the challenges we face in articulating these environmental demands as targets and informing trade-off decisions. The structure is described as follows.

1. It begins with a discussion of “ecological targets”. These are the ecological equivalents to targets of maximizing regional production from irrigation or profit for individual producers. Ecological targets relate to the desired outcomes in terms of ecosystem change.
2. The second section deals with environmental water targets, which are the desired watering regimes to achieve the ecological targets. There has been an emphasis on natural flow variability in environmental water regimes. There is a particular opportunity for benefiting environmental and consumptive water uses in terms of delivery of a sequence of environmental water regimes with different volumes required in different years to achieve long-term outcomes. Questions of dynamics and risk related to this concept are discussed in the second section.
3. A core challenge of improving the efficiency of environmental water management is a substantial lack of knowledge around environmental responses to watering decisions. This is true both in terms of predicting consequences of proposed actions or evaluating past watering actions. If we are to improve the efficiency of environmental water delivery than we must radically improve our knowledge-base and the way we use it to inform environmental watering decisions. The third section discusses this challenge
4. A final challenge is how to express ecological outcomes in terms which can be evaluated in a water resource planning context. The challenge here is the ecosystem outcomes are (i) in terms of multiple ecosystems responses; (ii) at multiple spatial and temporal scale; and (iii) with a high degree of uncertainty. The fourth section provides a very brief discussion on this issue.
5. The final section describes how the Ecology Component of Farms Rivers Markets is tackling some of these issues.

2 Ecological Targets

Targets are an important component of any strategy to achieve an environmental goal. Targets are important because they help make manager’s choices explicit and transparent and they assist in justifying trade-offs and allocations of resources to sceptical stakeholders (Sanderson, 2006). Targets are also an important component of the adaptive management process as they enable quantification of the success of management programs or interventions and the adequacy of our understanding of the system.

Targets, like the ecosystems they describe, exist within a complex, nested system. Targets represent a component of a larger system and are often comprised of finer scale targets (Figure 1). Our management of a system usually has an over-arching goal (purpose) that is imbedded within a larger system of management goals and policies. The goal may give rise to a number of desirable characteristics, termed objectives. A target represents a quantifiable or measurable entity whose achievement would, according to our knowledge of the system, mean we have achieved our objective and contributed to our goal. For example, the goal may be a healthy floodplain ecosystem. The objective may be to sustain redgum forest communities and the target would be conservation of 70% of the current area of redgum forest.

Within the nested system, achieving targets should all relate directly to the management goal, objective or a higher level target. In turn, any target should either give rise to finer scale targets or objectives or inform an assessment program that would enable determination of progress toward the target.

It is important that the nested nature of ecosystems be considered when setting targets. Ecosystems are organised as complex, nested systems, being a component of a larger system and comprised of interacting component systems. The nested nature of ecosystems is apparent in both the temporal and spatial dimensions. In the temporal dimension, short-term events merge to appear as regimes or long-term cycles when examined over longer temporal scales. Similarly, in the spatial dimension, a floodplain complex is comprised of a number of wetland and floodplain components and each of these may be comprised of component habitats. Scale mis-matches between management regimes and the ecosystems they are managing often leads to management failure with adverse outcomes for the ecosystem. For example, setting a bird abundance target for an individual wetland may be futile if the major drivers of bird numbers occur over larger spatial scales.

Setting targets occurs within the context of goals, objectives and higher level targets and given the variety of environmental goals, specific advice is beyond the scope of this paper. One source of variation in goals and objectives is the level of biological organisation at which they are aimed, ranging from ecosystems down through communities, species, populations and genes. At the ecosystem level most objectives refer to an aspect of biodiversity (usually habitats or species), however, aquatic ecosystems often also have water quality objectives.

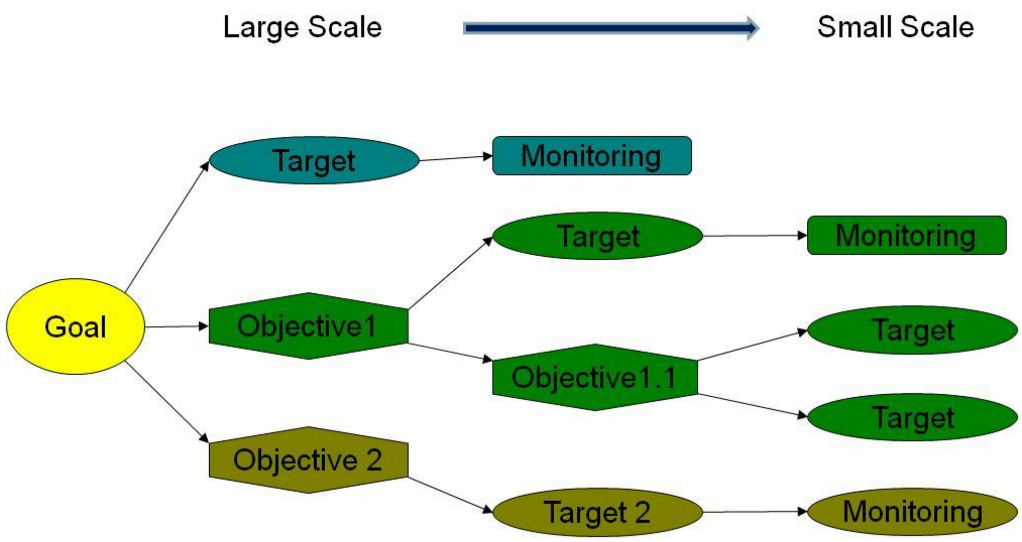

Figure 1. Illustration of the nested relationship between a program's overall Goal, Objectives and Targets and the monitoring program associated with each larger scale targets.

Measuring species diversity is complex and prohibitively expensive, so, invariably indicators of biodiversity that can be measured cost-effectively are used. Indicators are often either a suite of organisms believed to indicate overall species diversity or a single species whose abundance gives an indication of ecosystem condition (health). In the case of a target based on a suite of species the extent to which achievement of the target will correspond with the achievement of the goal will depend on the relationship between the target group's diversity and overall species biodiversity. This relationship is seldom examined and this often means that the extent to which goals are achieved is never evaluated. To minimise the risks associated with this approach it is important to apply knowledge of the ecology of the system to the selection of organisms to be included in the target or subsequent assessment program. In general the more diverse the suite of species included, the more likely the target group trend will correlate with the system's biodiversity.

The alternate approach is to set habitat diversity targets on the basis that protection of the system's components will ensure protection of the system's biodiversity. Habitat is, however, a meaningless term unless it is used in reference to a specific organism. Typically, habitat targets are often based on vegetation classifications. The adequacy of this approach depends on the relationship between the vegetation classification and the goal, a relationship that is seldom evaluated. The risks of this approach can be reduced if multiple classifications are considered and potential risks associated with each classification identified.

This approach is further complicated in riverine ecosystems where the vegetation mosaic can be quite dynamic in space and time and where main channel habitats are defined by hydraulic conditions that are also highly dynamic. This approach has been widely applied, however, on the basis that as the flow regime is one of the major determinants of habitat distribution, a return to a natural flow regime will protect the habitat mosaic. This model assumes that the geomorphology (the other major driver of the habitat mosaic) has remained natural. We know that in many instances this is not the case (e.g the Murray R.; Thoms and Walker 1993) but the effects of the interactions between changes in flow and geomorphology have not been widely investigated. Our knowledge of how changes in river channel hydraulic landscapes affect ecosystem character remains inadequate to enable anything other than the use of natural as a benchmark at this time.

At a species level, objectives are usually framed around conserving species or maintaining viable populations. Targets are typically based on characteristics of populations, most commonly abundance, but demography, ecological function, social requirements and the maximum possible abundance may all be considered (Sanderson, 2003) , depending on our knowledge of the factors that influence the risk of extinction.

Ultimately, a target needs to be defined as a quantity. In the case of biodiversity targets, this requires an understanding of the number of species that are required to achieve the goal or objective. This knowledge is rarely available to managers and the task is complicated as it is unlikely that all species contribute equally to the desired characteristics of the system. The common response to this dilemma is to use either "natural" or "status quo" as targets, or as reference points with the target being defined either as some increase toward or as no decline away from the reference point. However, natural is problematic to define as natural character would have varied through time and accurate information about the abundance, demography or ecological function under natural conditions is often unknown.

Similarly, setting habitat targets requires some knowledge of the amount and spatial arrangement of habitats within the landscape matrix. Once again, at the ecosystem level, managers usually don't have access to the knowledge required to set habitat targets that would ensure goals and objectives are achieved. As a result, knowledge of the habitat requirements of individual species is used or the default (natural or status quo) is applied.

At the species level, managers require knowledge of the factors that influence the viability of populations, including causes and rates of mortality and the factors that influence breeding recruitment and dispersal. There are relatively few species for which this information is known. Research undertaken on conservation of endangered species provides some insight into the likely risk of extinction as populations decline to critical levels, however, the risk of extinction is known to vary widely in response to the life history traits and evolutionary history of the species. As a result, applying knowledge from other species increases the risk of failure. This leaves managers with the default position of natural or status quo.

One further approach is to set targets for habitat for a species on the basis that protection of a certain amount of habitat will ensure that the objective for that species will be met. This is an attractive option when there is very little knowledge of the target species, but there is knowledge of historical habitat distribution. Unfortunately, the assumptions imbedded in this approach (e.g. we understand the species habitat requirements and the relationship between habitat availability and species abundance) make this approach among the riskiest.

Once again, this approach is problematic for river channels as our understanding of habitat requirements remains inadequate. The challenge is further complicated by the dynamic nature of the habitat mosaic within river channels. For instance, Murray Cod are known to prefer snags located in relatively fast flowing water, but have been observed to persist for extended periods of time in isolated pools.

In general, the more that targets can be based on an understanding of the ecology of a species, the more likely that managers will be able to set realistic targets and that their endeavours to achieve those targets will feed back into the ecological knowledge base in a manner consistent with the principles of adaptive management.

Given the complex environment in which targets are developed and the diverse knowledge on which targets ought to be based, there are a number of other issues that need to be considered as targets are developed. These are often summarised in the saying; targets need to be SMART; specific, measurable, achievable, relevant and timely. The issues of specificity and measurement have been touched on in the discussion above and relate to the importance of being able to track performance against the target. That targets be achievable is important from a management context where resources will not be invested in initiatives that have no chance of success.

Targets need to be relevant and clearly linked to the stated objectives and goals. One of the most effective ways of ensuring this is through the development of a conceptual model for each objective that represents the consensus view of the relationships among the key factors that influence the objective or goal.

Targets also need to be timely, not for any environmental reason, but because they are part of socio-political system and if targets are to be achieved the temporal scale of the target must be aligned with the temporal scales of management. This means that if there are scale mis-matches between environmental and management scales, then targets need to be configured in a nested hierarchy with, for instance, long term (decadal) targets being comprised of a series of shorter term targets.

Target development is also confounded by other issues that arise due to the complex environment in which they are generated. This paper has tried to use the terms goal, objective and target in a consistent and clear manner, however, the terminology used varies widely and this can lead to considerable confusion. It is therefore important that teams agree on a lexicon and apply this as consistently and transparently as possible.

The complex hierarchy of goals, objectives and targets means that it is relatively easy for targets to end up being contradictory or incompatible. Harmonizing targets is important to the credibility of the program, but identification of conflicts can reveal valuable insights into knowledge gaps or potential trade-offs that need to be managed.

In the Farms Rivers & Markets project the Rivers program is undertaking two broad activities that will improve manager's capacity to develop targets. The first is that through the research on slackwaters and wetlands the project will improve our knowledge of the habitat mosaic within riverine ecosystems that can be used to inform targets around the amount and distribution of slackwater and wetland habitats within the system. The second is the population modelling component of the project which will enable the evaluation of population viability under a variety of climate and land use scenarios. Scenario testing will enable targets to be set for key species and the risks associated with those targets made explicit.

3 Environmental Water Targets

Flow management is one of the key actions available to river managers to enable achievement of environmental targets. In this context environmental water targets are one of a range of targets that would contribute to the achievement of an environmental objective. Environmental flows are used to achieve a variety of objectives including the creation or maintenance of habitat or to facilitate recruitment or dispersal opportunities. It is also possible to use flow management to achieve mortality, particularly in situations where the loss of disturbance has had a detrimental effect on the system. An example of this would be anti-drought in regulated systems (McMahon and Finlayson, 2003)

Environmental water targets characterize components of the flow regime to achieve ecological objectives or targets. They are expressed in hydrological terms (i.e. flow magnitude, duration, frequency timing and rate of change). Early Methods for establishing environmental water targets were based on flow statistics (e.g. a fixed flow percentile) and maintaining minimum habitat requirements for individual species (e.g. PHABSIM). More recently, the natural flow paradigm has led to a broader consideration of water-dependencies and characteristics of the flow regime, specifically including flow variability.

There exist a number of comprehensive reviews of environmental flow methods (see for example reviews by Arthington *et al.* 1998; Tharme 2003). They highlight the large number of specific approaches that have been developed for establishing environmental water targets (or requirements) to achieve particular environmental and ecological objectives. Tharme (2003) identified 255 distinct methods that have been applied globally. Despite this diversity four broad forms of environmental flow assessment can be discerned – *hydrologic*, *hydraulic*, *habitat-based* and *holistic* approaches.

Environmental water targets may be assessed using different types of studies depending on factors such as resources available or the importance of the asset. Arthington et al. (Arthington, Brizga et al. 1998b) recommend a three-tiered hierarchical approach with relatively rapid 'reconnaisance' studies at a catchment scale, holistic studies at the catchment or sub-catchment level and detailed investigations for special issues at all scales. For the more detailed studies (catchment or finer) there are two approaches: bottom-up or top-down. Bottom up approaches, of which the 'holistic' approach and building block methodology are the most commonly cited, is commonly multidisciplinary, field based and reliant on existing knowledge of participants. Bottom-up approaches are often criticized for their reliance on quantitative understanding of flow-ecology relationships for identifying important components of the flow regime. These relationships can be poorly developed or particularly site or species-specific. This results in the method being prone to large error, however, advancements are being made in regard to improving these relationships and their availability. Top-down approaches are determined by identifying the maximum departure of the flow regime from natural before a level of environmental value is unachievable. Top-down approaches are not often used in isolation from some form of bottom-up determination. It is largely infeasible to determine the ecosystem impact of flow alterations unless the link between the ecosystem values and hydrologic components is explicit. Purely hydrologic deviation from the 'natural' regime is unlikely to be justifiable.

Australia's state and Federal governments have largely settled on use of bottom-up, holistic methods, which consider the broad range of requirements for maintaining freshwater ecosystems including ecosystem functions. Various modeling tools are applied to develop these targets and integrated by a panel of experts. In Victoria, the FLOWS method has been used for almost ten years for setting environmental water targets. This was the first formal holistic method adopted by an Australian state government. In a recent review, Turner et al. (2009) identified a number of shortcomings in the scientific robustness of the FLOWS method. Some of these apply more generally to environmental flow planning across Australia and are described below.

- Lack of consistency was highlighted as a concern in terms of:
    - hydraulic model calibration, sensitivity analysis and reporting;
    - adaptive management approaches;
    - principles to strengthen the link between environmental flow objectives and regional river heath strategies.
- It was noted that "*reporting on the confidence in environmental flow recommendations is also required to strengthen the understanding of the underlying uncertainty in recommendations and their uptake in an operational sense" (p.3).* To investigate the level of effort for which uncertainties are revealed the effort of investigation and reporting for consumptive use could be identified and a level commensurate could be determined.
- Risk protocols have been suggested as a way to identify whether levels of uncertainty are acceptable for each project (an example includes

identifying the influence of groundwater on base environmental flow estimates)

- Enhancements were required for:
  - Site selection
  - Representative reaches
  - Habitat preference data (lower reliance on generic hydraulic data)
  - Independence between events, rates of rise/fall and inter-annual variability
  - Adaptive management (Turner et al. 2009)

Site selection and representative reaches are currently defined in a relatively *ad hoc* manner. Improving our understanding of spatial variability from the scale of morphological units within a site (Newson 2002) up to reach and system scale. Quantifying this uncertainty is an important advancement. Identifying a protocol for representative site and reach selection would assist environmental flow studies generally. The approach to the selection of cross section locations within a site is also open to considerable interpretation and can lead to some highly unsuitable hydraulic model datasets and inappropriate representation of important habitat morphology.

Habitat preference data used in environmental flow studies is often generic or unfounded. For example a minimum depth for passage for large bodied fish, equal to 0.4 m, was identified in the Loddon River study (LREFSP 2002) and is still being used recently without further interrogation. Other studies have identified fish passage depths based on calculations for which no empirical evidence is seemingly available e.g. such as D50 + 100mm (Ecological Associates 2005). Scientific uncertainty will always exist in the flow alteration–ecological response relationships (Poff and al. 2010). However, improved knowledge of flow-ecology relationships and guidance on protocols for incorporating species specific hydraulic criteria would lead to more specific and targeted recommendations. In particular slackwaters, low velocity habitats of importance to invertebrates and fish throughout many life stages, are relatively unknown in terms of their relationship to changes in discharge (Humpries, Cook et al. 2006; Ning, Nielsen et al. 2009). Models for the Broken River will assist in quantifying the link between flow and slackwater habitat and enable predictions of temporal changes to dependent populations.

Characteristics of the flow regime such as independence of freshes and rates of rise and fall are often derived using a number of methods, which are not scientifically justified. Improving the ecological relevance of the approaches would improve the relevance of resulting recommendations.
There are 3 additional issues associated with the application of bottom-up flow techniques that relate to the way that temporal variation is dealt with. As noted in Section 2, aquatic ecosystems are nested with larger-scale and longer-term phenomena setting the context for small-scale and short-term events. The ways in which bottom-up flow methods deal with longer term patterns and rare events may undermine their reliability as a tool for setting targets.

Many approaches for determining environmental flows rely on statistics derived from the analysis of flow time series data and historical hydrology. How reliable a metric are they in environmental flows? Summary statistics are invariably used in the four categories of environmental flow assessment detailed in section 3.2. For example, hydrologic methods typically rely on monthly or daily simulated or gauged flow data. Historically these tend to be associated with minimum flow estimates, for example the in-stream incremental methodology (Cavendish and Duncan, 1986). Similarly, the Tennant Method (Tennant, 1976) comprises a table linking different percentages of average or mean annual flow to different categories of river condition.

Typically, the environmental flow assessment results in the production of a modified flow regime where the overall volume of water allocated for environmental purposes is a combination of different monthly and flow event-based allocations (Tharme, 2003). In most regional or global comparisons of river regimes, flow variability has been described by statistics that invariably include coefficients of variation (CV) of daily and maximum and minimum mean annual flows, and differences between mean and median flows (Jowett and Duncan 1990). Hydrological statistics are often calculated for periods of several years and apply to average changes in flow across a stream (Stewardson and Gippel, 2003).

The use of long term historical statistics often ignores long term cycles that occur within the historical record. The recent drought in the area of the Broken River system, which has resulted in severe water stress, provides an example of the importance of this issue. Over the past four years, there has been progressively less water in storage in Lake Nillahcootie at the start of each irrigation season. Rights to water have been qualified by the Minister for Water under a declared water shortage for the 2009/2010 season. This temporarily restricts the Minister for Environment’s right to extract water as set out in the Bulk Water Entitlement (2004) from the Broken River system, until the declared water shortage is revoked. This is a common story across the southern MDB.

This Qualification of Rights (QoR) ensures that essential needs of towns, stock and domestic customers and rural industries are met under the continuing dry conditions. There are provisions within the qualification to re-instate environmental flows when an irrigation allocation is declared. Although, the QoR restricts any minimum environmental flows, catchment inflows are providing around 40ML/day of flow in the Broken River (end of August 2009).

The QoR decisions are largely driving variations in environmental water delivery from year to year in many Victorian rivers. In reality it is possible to plan for these episodes, anticipating stochastic dry and wet cycles as part of the planning process. In this way, the trade-off of among environmental and consumptive water outcomes needs to be undertaken within the context of year-to-year or longer time scale variations that will influence water allocation decisions.

A further weakness of analyzing historical data is that it tends to smooth over extreme events. These events can play a critical role in structuring aquatic ecosystems through, for example, their effect on fish populations that may require years to recover from a single extreme habitat event (Hickey and Diaz, 1999, Douglas et al, 2003). The incorporation of extreme events into the first step of the environmental flows planning process could be used to explicitly identify risks from extreme events such as floods or droughts. This would identify periods when shortfalls in the availability of water to meet consumptive demands would impinge on the delivery of environmental allocations. The inclusion of extreme events analysis would therefore underpin further risk-based planning and decision-making.

Climate change also represents a major challenge to existing bottom-up techniques. Using bottom-up methods, streamflow has traditionally been viewed as fluctuating around a stable mean within an envelope of variability that occurs over a range of timescales from minutes to inter-annual and beyond. This is termed stationarity (Milly et al, 2008) and has been a ubiquitous implicit or explicit assumption in most environmental flow studies. We can no longer assume stationarity in river systems because projected climate change results in a change in mean flow and the variability. Water management systems throughout the developed world have been designed and operated under the assumption of stationarity (Milly et al, 2008). Climate change therefore undermines a basic assumption that has, historically, facilitated management of water supplies, demands, and risks (Milly et al, 2008).

The global pattern of observed annual streamflow trends is consistent with modeled response to anthropogenic changes in climate forcing (Milly et al, 2005). This has important consequences for water infrastructure projects as projected changes in runoff are large enough to push hydroclimate beyond the range of historical behaviors (Seager et al, 2007).

3.2 Strategies and Tools to support robust environmental flows assessment and delivery

Addressing the short-comings of existing flow methods will require new approaches and tools. Various tools and methodologies already exist in water engineering and planning that can be used to complement existing environmental flows methods in order to address the issues cited above, such as extreme events and stationarity. For example, the 'peaks over threshold' (POT) originated in hydrology and has been around for many years. The basic rationale for POT is that if additional information about the extreme upper tail were used in addition to the annual maxima then more accurate estimates of the parameters and quantiles of extreme value distributions would be obtained (Katz et al, 2002). The incorporation of these types of analyses in environmental flow analyses would enable quantification of the risks posed to the system by increases in the frequency of extreme events and long-term changes in flow regime. This improved capacity could then facilitate evaluation of whether environmental targets are achievable.

3.2.1 Generalized Extreme Value (GEV) Analysis

The statistics of extremes have played an important role in engineering practice for water resources design and management (Katz et al, 2002). In light of climate change, and the resulting weakness in the assumption of stationarity in hydrologic time series, advanced methods in extreme value analysis have been developed and applied in hydrology (Khaliq et al., 2006). Extreme value analyses can be based both on block maxima(e.g. annual maxima) and peaks over threshold.

Little, if any, literature exists on the application of extreme value analysis in environmental flows.

3.2.2 Non Stationary Extreme Value Analysis

Non-stationarity potentially invalidates the use of the historical flow series as a proxy for future conditions or at the very least suggests caution in its application. If non-stationary behaviour within the time series exists, the use of a non-stationary extreme value analysis approach can be applied (Mudersbach and Jensen, 2010), where the constant parameters of the distribution function are replaced with time-dependent parameters.

Non stationary extreme value analysis is based on the GEV distribution. Mudersbach and Jensen (2010) use non stationary extreme value analysis to determine coastal design water levels for future time horizons. To derive future design water levels, a parametric approach is applied in the extrapolation of the time-dependent parameters. The authors conclude that the nonstationary GEV method offers the prospect not only of considering the observed trend but also of incorporating climate scenarios for changing water-level heights or frequencies.

3.2.3 Improved Flow-Ecology relationships

Given the predicted impacts of climate change, the use of historical information to set targets for either the abundance of either organisms or their habitat increases the risk that targets will not be achievable. Most ecological response functions used in environmental flows planning are based on habitat suitability models (HSMs), in which habitat quality for particular species/life-stage etc is often modeled on a daily basis, and alternative flow-scenarios are compared by assessing the frequency with which appropriate habitat requirements are provided. These static assessments of habitat suitability have often proved useful in predicting relative abundances in small reaches of stream (e.g based on pool volumes) but have always had limited reliability at larger scales and will become increasingly inappropriate.

If we are to set achievable targets with explicit levels of risk under climate change scenarios it will be increasingly important to apply knowledge of the processes that help maintain those populations, such as rates of recruitment and mortality. These models will need to represent multiple life-stages, and capture temporal lags and interdependencies implicit in population dynamics.

3.3 Conclusions

To improve the robustness of environmental flow decision-making in regulated rivers, planning and implementation of environmental flows need to be linked more closely. A disconnect comes from the use of historical flows and application of habitat suitability models in the environmental flows planning process. Habitat and flow variability are widely accepted as primary determining factors in the biodiversity of a system (Resh et al., 1988). Thus, current methods in environmental flows are fundamentally lacking in their ability to address issues of ecological sustainability and biodiversity.

The problem lies in the planning phase of environmental flows, specifically in the use of short-term historical time-series and summary statistics as a basis for predicting future states of a river system, whether that be under assumed similar future or climatically altered flow regimes. Such an approach to environmental flows assessment leads to the exclusion of rare, but potentially predictable, flow related events such as flood and droughts. Existing techniques such as extreme value analysis could conceivably be embedded in existing environmental flows methodologies and be used to address these deficiencies.

The Farms Rivers Markets project will explore potential solutions to the problems identified above by using a range of climate change scenarios to model future flow scenarios and then examine the likely effects of the flow scenarios of population models that include key life history information. If successful, this approach will enable managers to move away from the current reliance on natural or current biological or hydrological targets that will become increasingly unreliable under climate change. The population models may also help identify critical thresholds for populations would enable GEV analysis to complement other methods.

4 Knowledge Base and Adaptive Management

The Australian Governments' environmental flow programs represent the biggest environmental intervention in Australian rivers to date. Given the poor state of knowledge around environmental watering outcomes, there is a need to recognize the experimental nature of this billion-dollar intervention. With the growing public investment in environmental purchasing and watering there is an imperative for (i) a stronger evidence basis to policy, planning and operational decisions; and (ii) reporting on the benefits delivered by environmental watering programs. Practical approaches to evidence-based adaptive management are urgently needed to support these initiatives. This includes efficient methods (i) to apply best available knowledge to support planning and operational decisions and (ii) coordinated approaches to updating the knowledge base through environmental flow monitoring and evaluation.

The need for evidence-based practice is evident in the development of the new Murray-Darling Basin Plan. The Water Act calls for transparent use of best-available science in the development of this plan. It can be expected that this aspect of the plan will be challenged, particularly where there is an apparent threat to the livelihoods of water-dependent rural communities. Such challenges have become common in the politics surrounding environmental water planning. A robust decision making framework should be *risk-based*, *transparent*, able to *communicate uncertainties* associated with decisions, and *recommend strategies* for reducing uncertainties in an *adaptive management* context. Demonstration of utility in this area will build long-term confidence, trust and usability. The emerging science of complex linked socio-ecological systems can serve as a useful conceptual model in effective environmental flow decisions making.

Acreman (2005) identifies several key criteria for effective decision making regarding environmental flows

- Transparency
- Consistency
- Openness
- Inclusiveness

Berkes (2007) alludes to the '*irreducible nature of uncertainties in complex systems'* and argues for the need for a two-pronged approach to managing social and ecological systems. This approach should seek to reduce the degree of uncertainty about the dynamics of complex systems and at the same time develop new approaches to '*cope with change that cannot be predicted*'.

A key component of risk reduction is an increased understanding of flow-ecology linkages and the complex suite of interactions that dictate the sometimes seemingly unpredictable relationships between particular flow management decisions and the ecological outcomes they trigger. This seeming uncertainty has led to a strong push for a more evidence based approach to environmental water management, although most recent reviews conclude the evidence base is still small in evaluating the likely response of most species to particular flow management decisions.

So what is evidence-based practice in environmental water planning and management? Furthermore, how does one demonstrate use of best available knowledge? Providing tools to support the application and documentation of evidence-based practice is central to the increasing focus on environmental water management as a primary water management role for governments.

We identify the following key elements as essential to underpinning evidence-based practice in environmental water planning, operation and assessment (including setting ecological and environmental water targets).

1. a widely-available and updated catalogue of knowledge in a useful form to support evidence-based environmental water planning (This includes tools to support the use of this knowledge base in the broad range of environmental watering planning and delivery activities);

2. a commitment from environmental water management and planning agencies to use this knowledge base in making decisions, and also for sharing knowledge gained from monitoring and evaluation programs; and

3. a commitment to coordinated environmental water monitoring and evaluation planning, which adopts
    a. common hypotheses (conceptual models) for testing in multiple systems; and
    b. comparable monitoring and documentation standards allowing for sharing of data for meta-analysis across rivers.

There is an opportunity to underpin environmental water management in Australia with an evidence-based approach, which is comparable with that used in medical sciences. The challenge for programs such as Farms Rivers Markets is to invent and implement such a system.

5 Addressing Environmental Targets in the Farms Rivers Markets Ecology Project

The Discussion Paper has highlighted the difficulties associated with developing and some of the limitations inherent in current approaches to setting environmental targets and the hydrological targets required to achieve the environmental targets. The paper has also identified that these difficulties and limitations are likely to increase under the influence of climate change.

The Farms, Rivers Markets project will both trial new approaches that may remedy some of the problems of existing techniques and also improve our ecological knowledge that will improve our capacity to set targets regardless of the technique employed.

The major issues identified by the Discussion Paper include;

- Current bottom-up flow determination techniques are reliant on an analysis of historical flow data that do not accord extreme events or long term cycles the significance they merit. The Farms, Rivers & Markets project will trial the use of modeled flow scenarios to enable evaluation of the ecological outcomes from future flow scenarios.
- Most of the information used to inform environmental flow targets is presented in the form of static habitat suitability models. These models

have a number of limitations that will affect target reliability. The Farms, Rivers & Markets project will trial the use of population models to evaluate the ecological outcomes of flow scenarios. A suite of species will be modeled to provide an indication of ecosystem response. This approach, if successful would improve the application of ecological knowledge to target setting and help move managers away from their reliance on current or historical condition as either targets or reference points.

- Conserving individual species relies on our knowledge of that species' habitat requirements. The Farms Rivers and Markets project will synthesize existing knowledge on the role of slackwater habitats in river channels to identify those species reliant on slackwater habitats for part or all of their life.
- One of the ways of protecting ecosystems is to ensure that component habitats nested within the system are protected. Knowledge of the ways flow regimes influence the distribution and abundance of habitats within river channels remains poor which reduces our capacity to set targets. The Farms Rivers and Markets project will develop a two-dimensional hydraulic model (River2D) for a number of Broken River sites. The model will be used to characterize the important physical characteristics of slackwaters and quantify the way that flow affects the abundance and distribution of slackwaters in the river channel. This analysis can be used to set flow targets that will protect these critical habitats.
- Similarly, understanding habitat requirements of individual species and conserving habitat is important for floodplain wetland components of river-floodplain ecosystems. The wetland inundation component of the Farms Rivers and Markets project will both explore the way that some elements of a wetland's flow regime influence habitat suitability for a range of organisms. The wetland component will also identify the possibility that alternate watering strategies (using wetlands as temporary storages) might protect habitat values which may then influence the way that water can be allocated in the system as a whole. This knowledge will improve our capacity to set environmental targets, but more importantly, may influence the setting of environmental flow targets required to meet the environmental target.

Overall, the Farms Rivers and Markets project will improve our capacity to set targets through the generation and synthesis of new ecological knowledge. In addition, there is a strong chance that if the hydrological and ecological modeling approaches are successful that Farms, Rivers & Markets will significantly enhance manager's capacity to set targets with improved confidence that those targets will ensure that goals are achieved.

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