A RISK-BASED ECOHYDROLOGICAL APPROACH TO ASSESSING ENVIRONMENTAL FLOW REGIMES

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Water use alters river flow regimes and for several decades there has been recognition that water resource development can impact ecosystem values. Determining appropriate strategies to protect or restore flow regimes to achieve ecological outcomes is now a focus of water policy and legislation in many parts of the world, including Queensland. However, consideration of existing environmental flow assessment approaches for application in Queensland identified several deficiencies precluding their adoption. Firstly, many ignored the fact that river ecosystems are subjected to many threatening processes other than flow regime alteration, therefore ecosystem condition outcomes cannot be achieved by environmental flows alone. Secondly, many focus on providing flows for particular responses without considering how often they are necessary to sustain ecological values in the long term. Finally, few consider flow requirements at spatial-scales relevant to the desired outcomes, with frequent focus on individual places rather than the regions supporting sustainability. Consequently, the Queensland government developed a risk-based ecohydrological approach which identifies ecosystem values linked to desired ecological outcomes, sensitive to flow alteration and indicators of broader ecosystem requirements. Monitoring and research is undertaken to quantify flow dependencies and ecological modelling are used to quantify flow-related opportunities for relevant ecological responses to occur over an historical flow period. The relative risk from different flow management scenarios can then be evaluated using risk to the values and outcomes at the spatial-scales over which they function. This overcomes the deficiencies identified above and provides a robust and useful foundation upon which to build the information needed to support water planning decisions.

1 INTRODUCTION

Determining appropriate strategies to protect or restore river flow regimes to achieve sustainable ecological outcomes is a focus of water policy and legislation in many parts of the world. In Queensland this is achieved by Water Resource Plans (WRPs) at the catchment scale, as prescribed in the Water Act 2000. A WRP is a framework for the sustainable management of water that defines water availability, priorities of water use, management strategies, performance indicators and monitoring and reporting requirements that apply over its life. A key objective of a WRP is to achieve an acceptable balance between existing water users, the environment and potential future water users by providing for ecologically sustainable development. The plan's strategies for managing and allocating water are designed to maintain and/or restore ecosystem condition and to help provide the necessary water requirements to sustain aquatic environments, including both surface water and groundwater dependent ecosystems.

Consideration of existing environmental flow assessment approaches for application to Queensland WRPs, both to inform their development and assess their effectiveness, identified several common deficiencies precluding their adoption. Many existing approaches ignore the fact that river ecosystems are subjected to multiple threatening processes as well as flow regime alteration; therefore ecosystem condition outcomes cannot be achieved by environmental flows alone. Approaches without exclusive emphasis on flow have low inferential power and difficulty discriminating the effects of confounding stressors in the catchment impacting on ecosystem condition because they use general indicators of ecosystem condition which may not be sensitive to changes to the flow regime. Furthermore it is common for assumptions to be made that hydrological metrics can be directly associated with ecological responses without due consideration of the way flow interacts with geomorphology and antecedent conditions. Many approaches focus on providing flows for particular ecological responses without considering how often they are necessary to sustain the associated values in the long term.

Few have considered environmental flow requirements at spatial-scales relevant to the desired ecological outcomes, with frequent focus on individual places such as wetlands or river reaches downstream of dams and weirs, rather than at the regional scale which supports sustainability as measured by long term persistence or population viability. An over reliance on the natural flow paradigm [1] in establishing environmental watering requirements is also problematic as it fails to recognise existing or future competing water demands and that most systems are unlikely to be returned to a pre-European state. Nor does it identify which aspects of the flow regime are important to support the ecological values of the system.

Consequently, the Queensland government developed a novel approach for environmental assessments to support the development and review of WRPs. This approach builds on the strengths and overcomes many of the deficiencies of existing approaches outlined above. Environmental assessments are undertaken to evaluate the risk of water management scenarios to the ecological values of the catchment. Assessments identify ecosystem values associated with desired ecological outcomes and indicators of these that are sensitive to flow alteration. These indicators, termed *ecological assets*, are the focus of the assessments; collectively they represent the broader ecosystem values and requirements of the WRP catchment.

2 RISK-BASED ECOHYDROLOGICAL APPROACH

Environmental assessments use an ecohydrological modelling approach based upon the principles of ecological risk assessment (ERA) to assess the risk to ecological assets. It draws on existing information and knowledge of the ecological values of the catchments as well as relevant flow-ecology information in the broader scientific domain following the steps outlined below (Figure 1). ERA is defined herein as a quantitative process that evaluates the likelihood that adverse effects may occur as a result of a modified flow regime.

2.1 Identifying ecological assets

Ecological assets are a sub-set of the water dependent ecosystem components and functions that are (i) representative of the ecological values of the plan area, (ii) critically-linked to one or more aspects of the flow regime (i.e. magnitude, duration, timing, rate of change, etc.) in order to maintain its long term viability, and (iii) potentially sensitive to the types of water management relevant to a WRP catchment. Ecological assets may be a species, a group of species, an ecological function, an ecosystem, or a place of value. They are identified by comprehensive reviews of the scientific literature, information in technical reports, guidelines, action plans, regional ecosystem mapping, government databases, and through extensive consultation with relevant local experts and stakeholders. Ecological assets are chosen to represent all flow components relevant to water management within a WRP catchment and as such are the focus of the risk modelling.

2.2 Defining ecohydrological rules

Data on the ecological asset's life history or process requirements is distilled into a combination of discrete aspects of the flow regime with respect to location, timing, magnitude, duration frequency, habitat provision and associated water quality attributes where relevant. These 'ecohydrological rules' allow the risk to the asset's long term viability or value to be modelled. At this stage in the process knowledge limitations often reduce the set of assets to those with sufficient information of their flow requirements to enable quantitative ecohydrological modelling.

2.3 Defining assessment endpoints

Assessment endpoints are the focus of the risk assessment. For most ecological assets, the assessment endpoints relate to the maintenance of their long-term viability in the WRP area. Typically assessment endpoints cannot be directly measured. Therefore measurement endpoints are used to represent them. For most species-based assets, measurement endpoints relate to the provision of connectivity, spawning and recruitment opportunities, or access to dry season refuge provided by aspects of the flow regime. Measurement endpoints for ecological processes vary, however they generally relate to the provision of critical habitat, or conditions that support ecosystem structure and/or function.

2.4 Defining consequence–thresholds of concern

In the absence of robust ecological response functions to altered flow regimes for many ecological assets, Thresholds of Concern (ToC) [2] are defined as measures of consequence to represent the frequency with which

flow-based opportunities are required to sustain ecological asset viability. ToCs represent failure thresholds for the ecological asset and as such can be considered minimum environmental watering requirements. The probability of achieving a desired ecological outcome is directly related to meeting a ToC over time. Where possible, ToCs are based on the biology or process knowledge of the asset. In most applications, ToCs have been used to represent: (i) the known time species-based ecological assets will survive without experiencing a flow-based opportunity, (ii) the reproductive life time of the ecological asset, or (iii) the minimum number of annual recruitment opportunities that are required to sustain the population over time.

2.5 Defining likelihood–ecological modelling

Information on the flow requirements of ecological assets as represented by their ecohydrological rules, are used to develop time series of flow-related opportunities from modelled daily river flow simulations representing a range of water resource development scenarios. Flow time series typically are typically long term, exceeding 100 years. In an ERA context, time series of opportunities represent likelihood or exposure data which is an estimate of the probability of an ecological asset experiencing the critical conditions required at a given location over the assessment period.

2.6 Assessment of risk

The risk to ecological assets is assessed at locations reflecting their known distribution and where hydrological simulations are available. Risk is a product of the time series of flow-related opportunities (i.e. likelihood) and the frequency of exceedance of a ToC (i.e. consequence) as it relates to the measurement endpoint.

The risk to ecological assets at the catchment scale recognises that populations are at a greater risk when multiple locations suffer simultaneous failure over time. This approach utilises the spatio-temporal sequence of risk generated by a water resource development scenario across multiple locations. It incorporates aspects of the population structure and dispersal characteristics of the ecological assets to define spatio-temportal patterns of risk across a catchment [3], [4]. The relative risk from different flow management scenarios can then be evaluated using risk to the values and outcomes at the spatial and temporal scales over which they function.

As the process outlined above requires both a sound conceptual understanding of the flow dependent ecological assets and detailed biological and/or process knowledge relating to their critical flow dependencies in terms of the facets of the flow regime, targeted monitoring and autecological research is undertaken throughout the life of the plan to improve to understanding which informs future WRP evaluations.

3 CONCLUSIONS

The risk-based assessment approach described here has been applied to over 25 different ecological assets, including key ecological components and functions, in the development and review of WRPs throughout Queensland. It is flexible in that the ecohydrological requirements of assets can be represented by models of different types including population viability models, simple rules-based models, Bayesian models, and other algorithms. The approach has been successful in overcoming the range of deficiencies of other environmental flow assessment approaches identified above. It is underpinned by mechanistic understandings of cause-effect relationships allowing selection of indicators that are sensitive to the relevant flow regime alterations. It partitions the effects of flow modification from other threats by considering only flow-related opportunities for ecological assets. The use of ToCs and hydrological sequences modelled over 100 years or more, together with the integration of risk at spatial scales appropriate to ecological asset populations generates assessments relevant to desired WRP outcomes of sustainability. The approach allows the systematic identification of components of the flow regime that are critical to sustaining ecological values in a catchment or region and supports decisions about how water can be allocated to support human uses while also achieving ecological outcomes.

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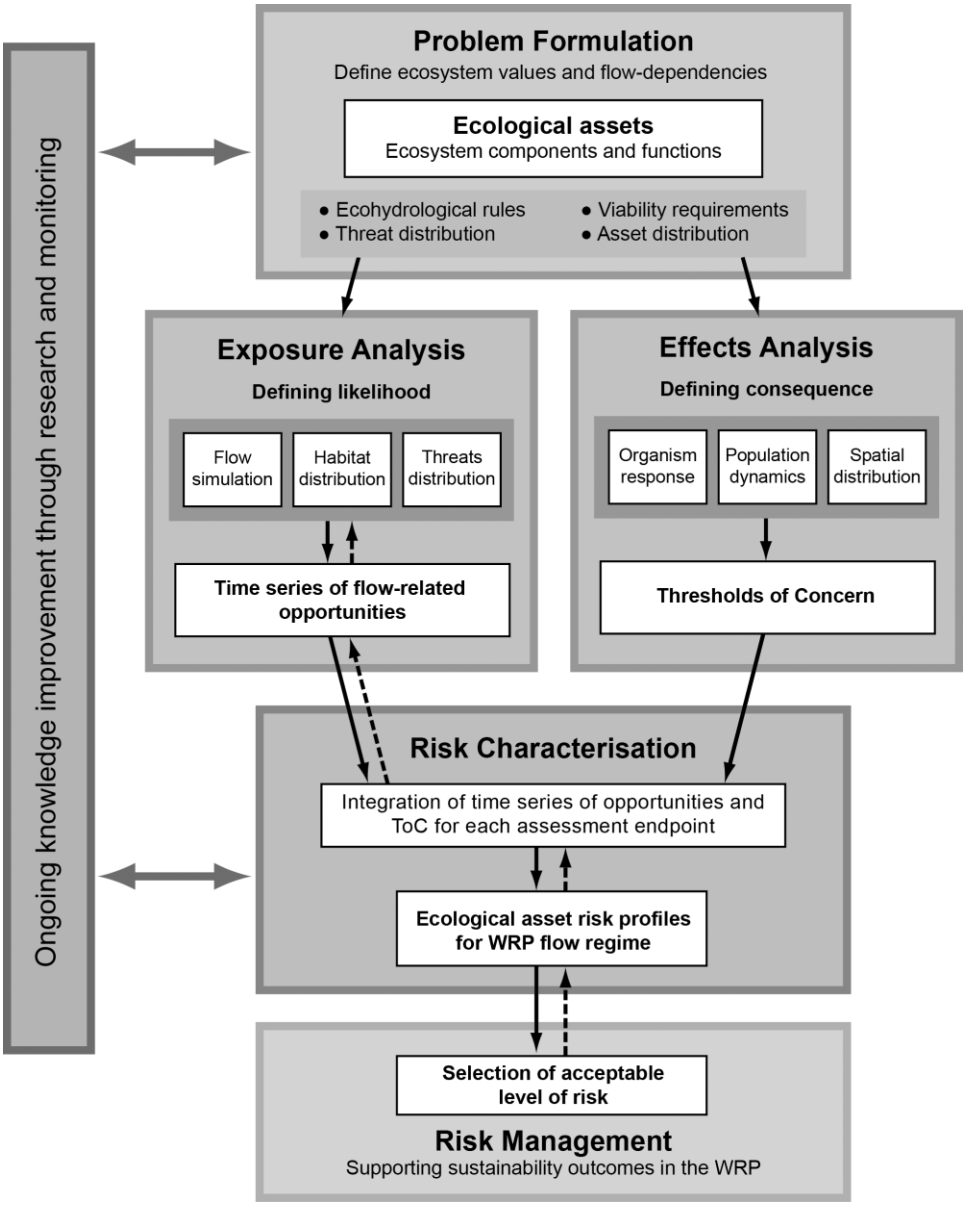

Figure 1. Risk-based ecohydrological assessment process

REFERENCES

[1] Poff L., LeRoy J., Allan D, Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks R.E and Stromberg J.C., "The natural flow regime", *BioScience*, Vol. 47, No. 11, (1997), pp 769–784.

[2] Rogers K. and Biggs H., "Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park", *Freshwater Biology*, Vol. 41, No. 2, (1999), pp 439–451.

[3] Burgman M.A., Ferson S. and Akçakaya H.R., "*Risk assessment in conservation biology. Vol. 12*", Springer Science & Business Media, (1993).

[4] Hughes J.M., Huey J.A. and Schmidt, D.J., "Is realised connectivity among populations of aquatic fauna predictable from potential connectivity?", *Freshwater Biology*, Vol. 58, No. 5, (2013), pp. 951–966.