THE TASMANIAN ENVIRONMENTAL FLOWS FRAMEWORK.

TECHNICAL REPORT.

Technical report on the outcomes of the Holistic Environmental Flows Project, funded under the National Action Plan for Salinity and Water Quality.

Water Assessment Branch
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The Department of Primary Industries and Water

The Department of Primary Industries and Water provides leadership in the sustainable management and development of Tasmania's resources. The Mission of the Department is to advance Tasmania's prosperity through the sustainable development of our natural resources and the conservation of our natural and cultural heritage for the future.

The Water Resources Division provides a focus for water management and water development in Tasmania through a diverse range of functions including the design of policy and regulatory frameworks to ensure sustainable use of the surface water and groundwater resources; monitoring, assessment and reporting on the condition of the State's freshwater resources; facilitation of infrastructure development projects to ensure the efficient and sustainable supply of water; and implementation of the *Water Management Act 1999*, related legislation and the State Water Development Plan.

Executive Summary

In Tasmania, many rivers in rural areas are unregulated and water is generally allocated through direct abstraction or collected in small storages on natural drainage lines. While large floods events are essentially natural, water abstraction and collection acts to 'dampen' the magnitude, frequency and duration of smaller flow events and low flows. Therefore, recommending environmental flows for these rivers requires the limits and conditions under which water can (and cannot) be abstracted.

Environmental flow recommendations are required for Water Management Plans, where they are combined with other water demands and implemented as Environmental Water Provisions. Historically, environmental flow recommendations have been based on modelling the amount of wetted useable area available for instream aquatic organisms, namely fish, macroinvertebrates and macrophytes. Designating risk bands to the amount of habitat available identifies the minimum flow required to maintain these instream populations at a specified risk level.

Setting minimum flow levels is obviously imperative, but in the absence of other flow recommendations, tends to encourage the belief among water users that water above these levels not required by the environment and is therefore available for extraction. As demand for water increases, water users are looking to other parts of the flow regime to complement their water needs. This demand, combined with the growing understanding that all parts of the flow regime are important for the healthy functioning of rivers, has seen a shift to addressing all aspects of the flow regime and the water requirements of the entire ecosystem.

This report describes the framework, developed over 2004-2005, to guide the assessment and recommendation of holistic environmental flow regimes for Tasmanian catchments. The project was undertaken by the Water Assessment Branch of the Department of Primary Industries and Water (DPIW), and was funded under the National Action Plan for Salinity and Water Quality (NAPSWQ). The Tasmanian Environmental Flows Framework (TEFF) builds on the hydraulic modelling previously used for minimum flows, and incorporates the principles of the natural flow paradigm. Particularly, that the ecology of a riverine system has evolved to the pattern of the natural flow regime, so to preserve the freshwater-dependent values of that system, the pattern of the natural flow regime should be retained as far as possible.

The project was initiated with a knowledge-seeking workshop in December 2003 to identify the factors leading to the successful implementation of environmental flow recommendations. Literature reviews were conducted to examine the role of hydrological variability in the functioning of riverine ecosystems and to identify associated knowledge gaps, and to identify the range of environmental flows methods already available and their suitability for use in Tasmanian catchments. Riparian vegetation (NorthBarker Ecosystem Services) and geomorphological (Technical Advice on Water) consultants were contracted to identify the flows likely to maintain riparian vegetation and geomorphological values and describe the most appropriate methods for determining their environmental flow requirements. The habitat, spawning and migratory requirements of native freshwater fish species in Tasmania were compiled in a literature review conducted by a consultant aquatic ecologist (Freshwater

Systems), and the freshwater requirements for estuaries were also addressed in a literature review conducted by the Marine Farming Branch, DPIW.

The TEFF resembles holistic approaches employed in other states and reflects the common goals water managers around Australia are attempting to achieve. It broadly aims to link the physical heterogeneity and biota present within a river to specific flow events, and then to link these flow events to specific environmental flow objectives. The framework has four major components:

1. characterise the freshwater-dependent values and hydrology of the system to derive targeted objectives of the environmental flows,
2. conduct relevant field assessments and hydraulic modelling to identify important flows to meet the objectives,
3. conduct hydrological analyses to define the pattern of occurrence of important flows, and
4. recommend the flow regime required to meet the environmental flows objectives, including rules for abstraction.

The TEFF has been designed to provide guidance on how to assess, determine and recommend environmental flow regimes for Tasmanian catchments, and to ensure the transparency and objectivity of how such recommendations are developed.

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Table of Contents

Introduction

In December 2003, the Water Assessment (WA) Branch of the Department of Primary Industries and Water (DPIW, then the Department of Primary Industries, Water and Environment, DPIWE) commenced a project to develop a method for recommending holistic environmental flows for Tasmanian rivers. This project was funded for 12 months under the National Action Plan for Salinity and Water Quality (NAP), and was focussed on river catchments in Tasmania's NAP region, particularly the Little Swanport River catchment on the east coast.

This report documents the rationale behind the project, the science behind the proposed framework, and the framework itself. The proposed framework is intended as a guide rather than a prescriptive approach; it is hoped this will ensure its adoption for a range of environmental flow assessments, regardless of the catchment under investigation.

The Appendices which accompany this report are in a separate document and provide more detail on the background of the framework and reports from the project's consultants. Appendix A reviews the influence of flow variability on the physical structure of riverine ecosystems – namely the interactions between hydrology, geomorphology and riparian vegetation. Appendix B documents the discussions and outcomes from a knowledge-seeking workshop conducted at the onset of the project in December 2003. Appendices C-F comprise the consultants' reports describing the information required for assessing the environmental flow requirements for geomorphology, riparian vegetation, Tasmanian freshwater fish, and estuaries, respectively. Appendix G provides the final financial report to NAP and details the activities and milestones achieved under this project.

Legislation, policy and water management in Tasmania

Environmental flows refer to the part of a riverine ecosystem's water necessary to maintain specified environmental objectives for that system. In Tasmania, the water required to sustain the ecological values of an ecosystem is referred to as the Environmental Water Requirement (EWR). The water actually provided to an ecosystem is referred to as the Environmental Water Provision (EWP); it is that part of the EWR which can be met given competing demands (ARMCANZ – ANZECC 1996). EWPs can include unregulated flows and in regulated systems, specific volumetric releases from water storages. To determine how much water in a system is available for allocation to various users, information is needed on the magnitude, timing, duration, frequency, and rate of change of water required to maintain (or in the case of degraded ecosystems, to restore) ecological processes and values.

Tasmania accounts for approximately 12% of Australia's water resources, and 29% of its storage capacity, but only 1% of the water used nationally (Australian Bureau of Statistics (ABS) 2004). Over 97% of the water used in Tasmania is surface water (ABS 2004). The biggest water use in Tasmania is hydroelectricity generation and accounts for 44% of the total water used per year. Agriculture accounts for 36%, about half of which is for livestock and pasture irrigation, followed by manufacturing at 13%, household use at 6%, and other uses (including mining and water supply, sewerage and drainage services) at 1%. Historically, increases in storage-building in Tasmania correspond to periods of drought, and the last couple of decades have seen increased emphasis on how water is used and the systems from which it is taken. While water use accounting and efficiency is slowly increasing, particularly in the agricultural sector, so is the demand for water and therefore the importance of managing water use sustainably.

In 1994, the Council of Australian Governments (COAG) agreed to implement a strategic, national framework to achieve efficient and sustainable water use. This COAG agreement has provided much of the impetus for water reform and the development and implementation of environmental flows policy across Australia. Under the COAG National Water Reform Agreement of 1994, the States and Territories must report on their methodologies for assessing and recommending environmental flows, and how those environmental flows are negotiated and applied under water allocation processes. The COAG process has since been superceded by the National Water Initiative to which Tasmania became a signatory in 2005.

In Tasmania, the mechanism for managing water resources on the catchment scale is the Water Management Planning process (see the *Water Management Act 1999*). This process involves identifying the stakeholders in a catchment, and through community consultation (and in parallel with scientific and technical consultation), identifying the important water values. Once these values are identified, the goals of water management for that catchment can be defined; they include environmental goals as well as water use and water development goals. Environmental water requirements are assessed and determined, and are examined with other water management issues relating to water licensing, allocation surety, potential water availability and development options, and monitoring requirements. These issues are collectively negotiated amongst stakeholders and community representatives. The outcomes of negotiations are reflected in a Draft Water Management Plan, which is made available for public comment. Stakeholder representations and the Department's response to these are considered by the Resource Planning and Development Commission (RPDC), which provides recommendations to the Minister. Any modifications to the EWPs (or other provisions) arising from this process are incorporated into the Plan, and the finalised Water Management Plan is adopted by the Minister as operational. The water rules provided for the environment in the final Plan are the Environmental Water Provisions; they may be identical to the Environmental Water Requirements originally recommended, or they may reflect those environmental water needs that can be met after the consideration and negotiation of other water demands in the catchment. The Plan is then implemented, monitored and reviewed according to its conditions.

The part of this process to which the current report relates is the assessment and determination of EWRs. According to the *National Principles for the Provision of Water for Ecosystems* (ARMCANZ – ANZECC 1996), "the provision of water for ecosystems should be on the basis of the best scientific information available on the water regimes necessary to sustain the ecological values of water-dependent ecosystems". Most States and Territories are therefore investing in the development and refinement of their methodologies for assessing and recommending environmental flows.

Environmental flows assessments in Tasmania

A variety of approaches to recommending environmental flows have been used in Tasmania (and Australia) and there is currently no standard methodology available. Minimum environmental flows have been recommended in over 40 Tasmanian catchments, many of which are unregulated or semi-regulated, using a number of methods that can be classed as hydrological or habitat-based assessments (Tharme 2003).

Hydrological approaches have been used in 'unstressed' catchments, those without a great demand for water and a flow regime essentially close to natural. Ecological indicators (e.g. river health and river condition monitoring) and hydrological indicators (e.g. the amount and number of abstractions) are used to determine the status of these rivers, and water allocation is usually via direct abstraction or small storages on natural drainage lines. These hydrological approaches are the simplest methods for determining environmental flows and have included the Tennant method (Tennant 1976), which was used for a number of precursory environmental flow investigations in the early 1990's. Another hydrological method more widely used for assessing small storages is the 'SKM Tool' (SKM 2002a), which basically recommends the 30^{th} percentile of summer flows and the 20^{th} percentile of winter flows are passed by the storage. Other methods, which have not been used in Tasmania and have been designed to assess departure from natural flow regimes, rely on hydrological indices derived from a range of hydrological parameters (e.g. Gehrke et al. 1995, Richter et al. 1996) to inform environmental flow recommendations. These hydrological methods are rapid but their drawbacks are that they do not account for hydrological variability or disturbance at a range of temporal scales, and when used for recommending environmental flows, they do not account for non-linear relationships between habitat and flow (Stewardson and Gippel 1997). Such low-resolution approaches are considered to be most appropriate at the broad planning level of water resource development but not for the recommendation of environmental flow regimes (Tharme 2003).

Minimum environmental flows have been recommended for most Tasmanian rivers on the basis of habitat-based assessments. Habitat-based assessment combines hydraulic, hydrological and biological data to assess the amount of physical habitat available under different discharges for target species. This type of assessment was originally developed by the US Fish and Wildlife Service for salmonid populations (Bovee 1982), but has since been adapted to southern hemisphere systems (Jowett 1996). In Tasmania it is used in a risk assessment framework developed by Davies and Humphries (1996). Habitat-based assessments involve the derivation of habitat-use curves for target instream taxa (most often fish, macroinvertebrates and platypus, but macrophytes have also been used), constructing hydraulic models of representative reaches based on depth, velocity and substrate composition, and then modelling habitat-discharge relationships for the target species using the River Hydraulic Habitat Simulation (RHYHABSIM) package (Jowett 1999).

These type of assessments rely on the assumption that maintaining habitat availability for target species will maintain the populations of those species. There is a relatively good understanding of the relationship between flow and physical habitat (see Appendix A for review), and between physical habitat and the biota it supports (Palmer et al. 2000, Lamouroux et al. 2002, Lamouroux and Jowett 2005), but there is still much to learn of the relationship between flow and ecological populations and communities. These flow-ecology links require more research, so physical habitat is often used as a 'surrogate' for biota. The major advantage of habitat-based methods over hydrological methods is that biological information from the system in question is collected, providing considerable data on the habitat use of instream species.

Davies and Humphries (1996) developed a risk assessment framework for habitat-based assessments in Tasmania. This framework designates a level of risk to instream biota based on the degree to which wetted habitat is reduced as discharges decreases, and the consequential risk of species loss. It provides a means to recommend minimum flows at a specified level of risk to the instream biota, and thereby allows decisions to be made regarding minimum environmental water flows and level of risk water managers are prepared to accept (see Appendix B for further discussion of risk assessment).

The drawback of habitat-based assessments is that they only provide an assessment of minimum EWRs and do not include other components of the flow regime for other components of the ecosystem. More recent studies in Tasmania and around Australia reflect a more sophisticated understanding of how riverine ecosystems operate and have become more holistic in their approach (e.g. Davies and Warfe 2002, SKM 2003, TMEFTF 2004). In Tasmania, these studies have improved upon habitat-based assessments by including flood components to recommend a flow regime which more closely resembles a natural flow regime and is more likely to meet the requirements of the entire ecosystem, or they have incorporated requirements for specific ecological components (e.g. geomorphic features). An holistic approach has been used to assess and in some cases recommend flow regimes for the Tomahawk and Boobyalla Rivers (Davies and Warfe 2002), the Coal River (Davies et al. 2002), the Lower Derwent River (Davies et al. 2002), the Elizabeth River (Davies and Cook 2003), the Jordan River (Davies et al. 2005), and the Gordon River (Hydro Tasmania 2005). A different holistic method, the FLOWS method, was developed by Sinclair Knight Merz in Victoria and has been used to recommend holistic EWRs for the Welcome River (SKM 2003) in northwestern Tasmania.

These more recent assessments reflect the growing understanding in the scientific literature that riverine ecosystems are more than just channels and their instream biota. They are comprised of a range of components, such as riparian vegetation, floodplain wetlands, geomorphological features, and estuaries, which depend on the range of flow components (not just minimum flows) present in a natural flow regime. However, collectively, these studies illustrate the variety of holistic approaches which have been used in Tasmania and the lack of an overall contextual framework.

The natural flow regime

The natural flow regime can be described as the pattern of a river's flow in terms of its quantity, timing and variability, and is described by the magnitude, frequency, duration, timing and rate of change of hydrological conditions (Poff et al. 1997). Each of these parameters varies in itself, and it is their combination that defines the range of flow events. The flow events present in a natural flow regime include, but are not necessarily limited to: cease-to-flow events, minimum flows, high flows, freshes, flush flows, bankfull and overbank floods. The flow events that are present in a flow regime depend on the regional climate, catchment topography, geology, geomorphology and vegetation (see Appendix A for further detail), and together they regulate the range of ecological patterns and processes in riverine ecosystems (Poff et al. 1997). In other words, the ecology of a riverine system has evolved to the pattern of the natural flow regime, so to preserve the freshwater-dependent values of that system, the pattern of the natural flow regime should be retained as far as possible.

The processes occurring in a riverine landscape which are regulated by the flow regime are best considered in a four-dimensional context (Ward 1989):

- Lateral processes include the formation of instream physical heterogeneity for habitat, riparian vegetation dynamics (dispersal, recruitment, germination, establishment and reproduction), and floodplain dynamics (nutrient and organic matter exchange, wetland inundation, aquatic-terrestrial linkages), and connect the mainstream to the riparian and floodplain zones.

- Longitudinal processes, such as sediment and nutrient transport and the movement, migration and dispersal of biota, connection of headwaters and tributaries with the mainstream, and the mainstream with bottom wetlands and estuaries.
- Vertical processes, such as microbial dynamics and the metabolism of energy and nutrients, connection of surface waters with the hyporheic and groundwater zones.
- Time represents the fourth dimension linking these processes.

Ideally, environmental flow recommendations should address the range of these processes, and therefore the range of flow events that influence them. Holistic methods of assessing environmental flows are designed to meet this goal, and have predominantly been developed in Australia and South Africa (Tharme 2003). These methods arose from a common conceptual base (Arthington et al. 1992) and now include the Holistic Method (Arthington et al. 1998), the Building Block Methodology (King and Louw 1998), the DRIFT method (King et al. 2003) and the Benchmarking method (Brizga et al. 2002). These methods are considerably prescriptive and they rely on numerous workshops with relevant experts, requiring significant time and financial resources and limiting their application in smaller systems or systems without large water allocations. These methods are more suited to major proposals of water resource development.

Other methods include the FLOWS method (SKM 2002b), the Flow Events Method (Stewardson and Gippel 2003), and the Scientific Panel Assessment method (Thoms et al. 1996). These methods are not as prescriptive, but consequently rely more heavily on the input of scientific experts to identify the flow-ecology linkages and define the appropriate flow requirements. Scientific panels can be rapid and relatively cheap, but because they rely on the knowledge, experience and advice of experts with a good understanding of how freshwater ecosystem function, this knowledge can sometimes be difficult to capture and can lead to a lack of transparency as to how final recommendations are reached. The Flow Events method, and particularly the associated River Analysis Package (RAP) software (Marsh et al. 2003), is the best method available to make the process of recommending environmental flows more transparent. Consequently, the Tasmanian Environmental Flows Framework incorporates the use of RAP, but still resembles all these holistic methods to some degree, as they are all designed to provide a framework to recommend environmental flows for riverine ecosystems in their entirety.

The Tasmanian Environmental Flows Framework

This project was initiated by the recognition that the minimum EWRs that have been recommended for the majority of Tasmanian catchments are insufficient for meeting the needs of the entire riverine ecosystem. Setting minimum EWRs also tends to encourage the belief among water users that the minimum flow is the total environmental flow requirement, and that flows above this level are available for allocation. As demand for water increases, water users are looking to other parts of the flow regime to complement their water needs. The major aim of this project was to develop a framework for the assessment, determination and recommendation of holistic environmental flow regimes for riverine ecosystems, and to ensure the transparency, objectivity, and consistency of how such recommendations are reached.

The Tasmanian Environmental Flow Framework (TEFF) is not intended to replace the detailed scientific assessments necessary for significant water development proposals, but to complement those studies. In many catchments where this method will be applied, the demand for water is generally incremental and water is captured by direct abstraction or small storages on natural drainage lines. In these catchments, large flood events (e.g. events with an annual recurrence interval of 1 in 5 years) will not be significantly impeded by water use infrastructure and will occur naturally. It is the smaller-scale events (e.g. low flows and within-year floods and freshes at a local spatial scale) which are likely to be impacted by water use and which are the focus of the TEFF.

The overall objective of environmental flow recommendations is to provide water for the riverine ecosystem that allows it to function as a healthy system. However, current understanding of flow-ecology links, and how flow drives the ecological patterns and processes observed, is limited; non-linear causal relationships are common and patterns are often occurring at multiple spatial scales (Walker et al. 1995, Bunn and Davies 2000, Tockner et al. 2000). In riverine systems, physical heterogeneity is predominantly regulated by flow variability (Tockner et al. 2000, Thoms and Parsons 2002), and the physical heterogeneity of the system regulates its ability to support the ecological processes leading to biodiversity (Ward et al. 2001). Therefore, where the flow requirements for specific ecological components and processes are not known, environmental flows should be directed towards maintaining the natural flow variability of the system. Natural flow variability will maintain the natural physical heterogeneity of the system, and should provide the conditions necessary for the natural ecological functioning of the system (Ward et al. 2001, see Appendix A for a detailed review).

Consequently, the TEFF broadly aims to link the biological components and physical heterogeneity present within a river to specific flow events, and to link these flow events to specific environmental flow objectives. The proposed framework has four major components:

1. characterise the freshwater-dependent values and hydrology of the system to derive targeted objectives of the environmental flows,
2. conduct relevant field assessments and hydraulic modelling to identify important flows to meet the objectives,
3. conduct hydrological analyses to define the pattern of occurrence of important flows,
4. recommend the flow regime required to meet the environmental flows objectives, including rules for abstraction.

The following sections discuss each of the framework's components in detail.

1. Define the objectives of the environmental flows

This step is the most crucial step of any environmental flows assessment: it is where the objectives that the environmental flows are intended to achieve are stated. In order to develop objectives for environmental flows, the freshwater-dependent values, and potential impacts on those values, must be identified. This is achieved by conducting a catchment characterisation, which includes, but is not necessarily limited to, a characterisation of the catchment's hydrology, its physical condition and its freshwater-dependent values, and the values of the catchment community.

Hydrology

The natural flow regime of the catchment, as well as the historical and current flow conditions, must be characterised to determine the current impact on natural flows. Previously, 'natural' flows have been derived from historical stream gauge data, but the presence of significant gaps in stream records, or the absence of gauges from many rivers, has been problematic for many catchments in Tasmania. The recent and continuing construction of water balance and rainfall-runoff models for catchments across the state is improving the estimation of natural flows, and has the added advantage of being able to test different water use scenarios on catchment hydrology.

Characterisation of the natural and current flow regimes show which parts of the flow regime are most impacted by water use, and allows the natural flow regime to be used as a reference condition. In systems with large water allocations which cannot be returned to the system, the current flow regime may be preferable to use as a reference (e.g. Davies et al. 2002).

Freshwater-dependent values

The freshwater-dependent values in a catchment can be obtained by interrogating the Conservation of Freshwater Ecosystem Values (CFEV) database. An audit of all freshwater-dependent systems in Tasmania (including rivers, wetlands, lakes, wetlands, karst, saltmarshes and estuaries) has provided the hydrological, geomorphological and biological information to develop a GIS classification of their representativeness, naturalness (condition) and distinctiveness, as well as their level of land tenure security (DPIW 2006). This classification has formed the basis of conservation management priorities, where areas of high priority represent the best examples of those types of ecosystems in a state-wide context. Therefore, CFEV objectively identifies areas of conservation significance and high freshwater-dependent 'value' within a catchment. CFEV should be used in combination with an 'on-the-ground' assessment of the catchment to identify differing geomorphology, riparian vegetation condition and land use at the sub-catchment and reach scale, and to provide direction on where to locate field assessment sites.

Defining environmental flows objectives

The catchment characterisation should be seen as the development of a conceptual model of how the catchment works and to explicitly and unambiguously define the environmental flow objectives. Such conceptual models are useful tools for communicating the potential effects of various water use scenarios to stakeholders, and allows the community to make a more informed decision about what it wants from the catchment. They also identify exactly what should be monitored to ascertain the effectiveness of any implemented environmental flows, ensuring the monitoring has relevance to the objectives (Cottingham et al 2005).

In defining the environmental flow objectives it is important to be cognisant of how the community views and values water. A good Tasmanian example is that of brown trout which is present in most catchments and has a high recreational value, despite being an introduced predator. A 'knowledge-seeking' workshop was conducted early in this project to draw on the expertise and experience of scientists and water managers around the country (see Appendix B for details). A major outcome was that for any environmental flow recommendation to be successfully implemented, the community and relevant stakeholders must be engaged in a dialogue to determine their values in the catchment, and these must be taken into consideration when defining the environmental flow objectives. The characterisation of the catchment's hydrology and freshwater-dependent values essentially identifies the scientifically-derived objectives of an environmental flow regime, but unless they are placed in a realistic water use context, they will be unachievable. Appropriate community consultation ensures that stakeholders are 1) fully informed on the freshwater-dependent values of the system, 2) can express their dependence on water and know their needs are being addressed, 3) ensures that potential future demands and impacts are identified, and 4) can potentially pinpoint where multiple objectives may be achieved.

2. Conduct relevant field assessments

Once the environmental flows objectives have been identified and the catchment has been characterised, sites are chosen for relevant field assessments to determine the flow events required to meet the objectives. The flow events required to meet the objectives are determined from hydraulic models of specific sites, so to have relevance to the catchment-scale objectives, it is imperative the sites are truly representative samples of river reaches in the catchment. Sites must incorporate the range of hydraulic conditions found within a length of river, and the site survey must have sufficient detail to appropriately capture this range (Stewardson 2004).

The site assessment involves surveying the physical structure and heterogeneity of the reach (including the vegetation), and constructing a hydraulic model to determine the specific flow magnitudes associated with the range of physical features. These flow magnitudes can be viewed on a longitudinal map of the reach to predict the physical features they are likely to disturb. For example, a small flow event may inundate edge zones and top up macrophyte pools, whereas larger events will inundate lateral bars and herbfields. It cannot be assumed that any one flow event has a uniform effect as it travels down a river reach, so by mapping the 'patchiness' of physical features, the differential disturbance created by a flow event can be identified. Linking different physical features or patches to specific flow events provides the capacity to predict which components of physical heterogeneity are most likely to be affected by the removal of certain flow magnitudes due to water use.

Hydraulic modelling should be used to complement, not replace, using specific ecological flow requirements if they are known because it is only linked to the physical characteristics of the reach. Known relationships between flow and particular species, communities or ecosystem processes, should also be incorporated when determining the flow events required to meet the objectives.

3. Conduct hydrological analyses

Site assessments provide a means for identifying the magnitude of flow events which influence the physical heterogeneity of the river. However, flow magnitudes are also obtained by analysing natural flow time-series data, usually modelled, for events that occur over larger spatial and temporal scales. This is important for flow requirements that have a known ecological influence but do not necessarily correspond to a physical feature and which may therefore be missed by concentrating on the physical structure alone. For example, seasonal triggers for fish spawning, length of floodplain inundation events, and events that transport nutrients to estuaries. Combining the flow magnitudes determined from hydraulic modelling with those identified from the natural flow regime engenders confidence that if the recommended flow regime incorporates the range of natural flow events, then it is likely to meet the unknown as well as the known roles of flow variability.

Once the magnitudes of particular flow events have been determined, the flow time-series are analysed for the frequency, duration, timing and rate of change of these events. The River Analysis Package (RAP), developed by the Cooperative Research Centre for Catchment Hydrology (Marsh et al. 2003), has been specifically designed to conduct these event analyses, and is highly recommended for use under this framework. The major advantage of RAP is its ability to combine a hydraulic model with time series analysis to support the determination of environmental flow regimes. It allows the development of hydraulic 'rules', which can be analysed against a time-series, deriving a time-series of habitat availability. This enables the distribution of different physical features or habitats over time to be assessed as an 'event', thereby allowing their spatial and temporal distribution to be combined in the development of a flow regime.

It is important to recognise that the successful characterisation of the environmental flow regime depends on knowing hydraulic and hydrological requirements of the system's components and processes. Where these are not known, it relies on maintaining the pattern of the natural flow regime as much as possible to provide the best opportunity of maintaining the freshwater-dependent values of the system.

4. Recommend the environmental flow regime

The final step in the TEFF is to combine the flow events identified and defined in the previous steps into a flow regime to meet the objectives of the assessment. As such, it is anticipated that an environmental flow regime will comprise

- large-scale flow events, which in many systems will be essentially natural,
- small- and intermediate-scale flow events which will be explicitly linked to the habitat and life history requirements of the system's biota (where they are known), to the physical heterogeneity of the system, and to the natural flow regime as far as possible,
- minimum flows (depending on season) to maintain hydrological connectivity during periods of high water demand.

These events should be defined by their hydrological parameters – their magnitude, frequency, duration, timing and rate of change – and combined to describe the recommended environmental flow regime.

In Tasmania, where instream dams, and thus environmental releases, are rare, the recommended environmental flow regime will reflect the impact of current water use in the natural flow regime and the available tools to manage that use. It should incorporate guidelines on where and when water should be allocated in the future to minimise further departure from the natural flow regime, and will therefore resemble a statement of water allocation limits.

Conclusions, unresolved issues and future directions

The aim of this project was to develop a framework to guide the assessment and recommendation of holistic flow regimes in Tasmanian catchments. The Tasmanian Environmental Flows Framework has been developed to address the holistic flow requirements of freshwater-dependent ecosystems, building on the hydraulic modelling used for minimum flows recommendations and incorporating the principles of the natural flow paradigm (Poff et al. 1997).

The successful determination of environmental flows under the TEFF relies on the known hydraulic and hydrological requirements of ecosystem components and processes. Where these are not known, it relies on maintaining the pattern of the natural flow regime as much as possible. This assumes that

1. Natural flow variability regulates the physical heterogeneity of the ecosystem through fluvial disturbance, and
2. The physical structure of the system combined with natural flow variability supports the biological diversity of the system and its ability to maintain ecosystem processes.

These assumptions are currently being addressed in another project, the Tasmanian Environmental Flows (TEFlows) Project, also being conducted by the Water Assessment Branch and funded by NAPSWQ. The aim of the TEFlows Project is to determine how small-scale flow variability might drive the physical structure and biological function of river systems. Catchment studies on a range of physical and biological variables, in rivers, wetlands and estuaries, are being conducted on two types of river systems: those with flow regimes which are highly variable, and those with flow regimes that have low flow variability and are more predictable. The knowledge gained from these studies will be used to develop a decision-support system to assist water managers in developing environmental flow regimes and exploring water use scenarios in rivers of similar flow regimes. It will also provide a range of potential flow-related indicators to monitor implemented environmental flows in the future.

During the development of the TEFF, and particularly since its application, a significant issue relating to the application and communication of environmental flow recommendations has arisen that remains unresolved. It is the concept of risk and how it may be applied to the entire flow regime. Davies and Humphries (1996) developed the risk assessment framework for minimum flows which has been used in Tasmania to designate levels, or bands, of risk to instream biota as the amount of their wetted habitat is reduced with decreasing discharge. As it stands, this risk approach does not address other freshwater-dependent components of the system, and it cannot be expanded to incorporate other flow events and the risk of not providing them. The Water Resources Division is currently considering how to quantify risk in environmental flow regimes and how to best communicate risk, in this context, to water users. It is likely that the successful communication of risk will depend to a degree on the ability of water managers to communicate the uncertainty of ecological knowledge given the array of potentially interacting factors and non-linear responses.

Another issue that has not yet been addressed in the TEFF is that of climate change. The TEFF is designed to provide a context to guide the assessment and recommendation of environmental flow regimes. It deliberately does not provide a prescriptive approach, with the intention to promote addressing environmental flows on a catchment-by-catchment basis. While there are general climate changes predictions for regions of Australia, it appears that hydrological effects will manifest themselves on a more localised scale. Consequently, the WA Branch has decided that climate change impacts should be considered on a catchment basis during the catchment characterisation and the development of environmental flows objectives. It is here that climate change effects can be incorporated as another hydrological scenario and thereby addressed in the final recommendations.

It is intended that the TEFF will provide an objective and transparent means of assessing and recommending environmental flows in the future. By placing environmental flows within the context of the natural flow regime, it should also serve to encourage water users to view all flows, not just minimum flows, as potential environmental flows with a multitude of ecological roles. This understanding will lead to more strategic and sustainable water use in the future.

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