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Department of Water
Western Australia**

Peer Review of Ecologically Sustainable Yield Method in South-West Australian Streams

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Review of WA Department of Water Ecologically Sustainable Yield Method

1. Background

This report contains a review of the Western Australian Department of Water method for determining the environmental flow requirements, and then the ecologically sustainable yield (ESY) for rivers and streams in the south-west of Western Australia.

The review was undertaken by a team (Review Team) put together by the University of Melbourne, which consisted of:

- Dr Michael Stewardson (The University of Melbourne),
- Professor Barry Hart (Water Science Pty Ltd), and
- Dr Terry Hillman (La Trobe University).

The objectives of the review were to:

1. Review the methodology developed by the WA Department of Water (DoW) for estimating the environmental flow requirements of streams in SW Western Australia. The review should assess[1]:
    - the conceptual structure for the whole method,
    - desired environmental values,
    - hydrological data inputs and supporting hydrological modeling,
    - field surveys and hydraulic modeling,
    - flow-ecology relationships and thresholds developed,
    - analytical methods to determine ESYs (RESYM - River Ecological Sustainable Yield Model),
    - uncertainties and risk assessment.
2. Review the application and extension of this methodology to the determination of ESYs for the Warren-Donnelly catchments.
3. Recommend future work that should be undertaken to strengthen the methodology.

The material available to the Review Panel included:

- Presentation to Panel by Rob Donohue and Felicity Bunny (both WA Department of Water) on Tuesday 25 January 2011.
- DoW (2011a). Briefing Paper 1: Environmental Flow Studies in South-West Western Australia, WA Department of Water, Perth, 1 January 2011.

[1] Note – The Department of Water would like the Review Team to benchmark their methodology against best practice environmental flow method used in eastern Australia and overseas.

- DoW (2011b). Briefing Paper 2: Estimation of Sustainable Flows in the Warren-Donnelly Management area, WA Department of Water, Perth,14 January 2011.
- Donohue, R.B., Lang, S. and Pearcey, M. (2009). The River Ecological Sustainable Yield Model (RESYM), 18th World IMACS/MODSIM Congress, Cairns, Australia.
- A number of Department of Water environmental water reports on specific streams in South-west WA (see Reference section).
- A number of unpublished reports on various aspects of the method (e.g. hydrology, ecology) – see Reference section.

2. Context for Environmental Flow Planning in Western Australia

The key distinctive features of environmental flow planning in the south west of WA are as follows.

- The objective in defining environmental flows in Western Australia is generally to protect existing ecological value rather than to restore degraded streams, since most catchments in south-west WA are not currently over-allocated. However, this is in the context of historic catchment development for agriculture and potentially ongoing decline in freshwater ecosystems in response to these anthropogenic disturbances.
- None of the catchments in question have reservoirs in them of the size used for example in the Murray-Darling. – water for agriculture is taken by (a) direct pumping from a stream, (b) direct pumping from a stream into a dam, (c) collected into a catchment dam via surface runoff or stream flow, or (d) groundwater pumping.

3. Review details

3.1 Environmental flows and environmentally sustainable yields

Conceptual framework

The method developed by the WA Department of Water is well described in Briefing Paper #1 (DoW, 2011a).

In brief, the ecological water requirements (EWRs) of a particular river are determined using an approach called the Proportional Abstraction of Daily Flows (PADFLOW). PADFLOW was developed to better define the EWR flow regime needed to maintain the ecological values of rivers (at a low level of risk). The PADFLOW approach ‘constructs’ an environmental flow regime by removing a proportion of daily flow from an existing flow record. The volume of daily flow removed is arrived at with reference to known ecologically important flows.

The Review Team note that the PADFLOW method is based on the assumption that the rivers in the south-west of WA are under-allocated, and that more water can be abstracted for consumptive purposes without adverse effect on the ecological values of the river. We were not presented with any evidence to test this assumption.

The PADFLOW method is also highly dependent on the River Ecological Sustainable Yield Model (RESYM), which the Department of Water developed to estimate the EWRs of rivers. An expert panel uses RESYM in a workshop setting to assess changes in the frequency and duration of flows above ecologically important thresholds with increasing proportional reduction in flows relative to a reference flow regime (e.g. Donohue et al., 2009a, 2009b). The expert panels generally included experts in water resource management, channel morphology, vegetation and aquatic ecology. The panel establishes the maximum flow reductions iteratively (i.e. the environmental flow regime), to maintain the target frequency and duration of required ecological flow events. The sustainable yield for each year of record is calculated as the difference between the annual flow in the reference flow regime and this environmental flow generated by RESYM.

The WA Department of Water have completed PADFLOW studies at a number of sites across south-west Western Australia but there are numerous other sites where sustainable yield needs to be estimated but for which surveys are yet to be undertaken. They have generalised results for the detailed PADFLOW investigations to allow an estimate of sustainable yields across the region. The method for this generalisation of PADFLOW results is described in Briefing Paper #2 (DoW, 2011b)

We provide our review comments on the PADFLOW procedure and subsequent regionalisation of Sustainable Yield under the following headings:

Step 1: Ecological objectives

Step 2: Identifying study reaches

Step 3: Flow-ecology relationships and flow thresholds

Step 4: Obtaining the long-term daily flow record

Step 5: Hydraulic modeling

Step 6: Flow thresholds

Step 7: Parameterise RESYM and determine environmental flow requirements

Step 8: Converting annual series of ESY to single ESY and regionalisation of this

A subsequent section discusses the application of this method in the Warren-Donnelly catchments

Step 1: Ecological objectives

It appears from the environmental flow studies undertaken that the ecological objective is to *maintain the existing ecological values* in the study systems (DoW, 2009a,b, 2010, 2011). We could find no mention of either *protecting* or *restoring* ecological values of the river ecosystems and no indication of contingency protocols if particular streams are judged to be currently in an ‘unacceptable’ condition either by DoW, the expert panel, or the regional community.

Given this objective, it is first necessary to define the existing ecological values. This was done in each of the environmental flow studies by describing the existing ecological condition of the river ecosystem through surveying the various biological components making up the ecosystem, including: riparian vegetation communities, aquatic macro-invertebrate communities, native fish and other taxa (e.g. water-birds, reptiles, amphibians and mammals. Additionally, two ecosystem processes - carbon sources and ecosystem productivity – are listed in each of the environmental flow studies reviewed, but we could not determine whether these were specifically considered in determining the environmental flow requirements.

This information on the existing ecological condition of the study system was obtained either from literature information, or where this was not available from site-specific studies (DoW, 2011a; WRM, 2007,2008). Systematic catchment-specific surveys of macro invertebrates appear to have been common but in most other cases, current values are based largely on expert knowledge and qualitative information. Elsewhere in Australia vegetation, channel form and fish surveys have been used but these studies but require significant investment if they are to be carried out regionally and interpretation of survey results is not straightforward.

<u>Assessment</u>

- *The scope of ecological values assessed in these studies is comprehensive*
- *The qualitative nature of ecological condition assessment is of concern given the objective of the EWR is to maintain current condition. Unless this is established to begin with, it will be difficult to demonstrate whether or not the objective has been achieved. While most catchments are in good condition (at least with* regard *to water abstraction), it seems some at least may be 'over-allocated' because of the number and size of existing farm dams. There are also other serious catchment disturbances including land clearance. In some cases current conditions may represent a serious departure from pre-European condition.* It is also conceivable that, in some cases, current condition might be determined by factors not directly linked to hydrology or hydraulics. *An understanding of the current condition is important for understanding the benefits of its protection and hence justification for the EWR and/or complimentary works to rehabilitate streams.*

Step 2: Identifying study reaches

The Department of Water EWR studies are based on detailed information obtained for particular (representative) sites within the river system because of their 'good' condition. This is reasonable for determining environmental flow characteristics on the assumption that other reaches will be rehabilitated to a good condition in the future. DoW indicates that the most important consideration when selecting a study site is the 'naturalness' of the channel morphology. This is because their environmental flows methodology is underpinned by a detailed knowledge of channel form since it is this that largely determines the magnitude of flows needed to inundate important aquatic habitats. Highly modified channels, such as those that have been cleared of vegetation, are often deeply incised and simplified in terms of habitat types.

As an example, the Margaret River EWR study used two study reaches - Reach 1 (800 m long) chosen to represent the current condition of the catchment's lower section, and Reach 2 (470 m long) as representative of the middle section of the river (DoW, 2011c). These surveys specifically target reaches in good condition and cannot be considered representative of the current condition of the river.

In those reports reviewed, the study reach(es) selected appeared to contain both riffle and pool habitats, with an appropriate number of cross-sections per reach surveyed (this compares well with methods used in the eastern states [e.g. the Victorian FLOWS method, (DNRE, 2002)]

<u>Assessment</u>

- *The river surveys follow standard practice for environmental flow studies.*
- *The basis for selecting the location of the study reach(es), its length and the number and location of cross-sections should be better documented.*
- *A particular issue is representing whole river lengths by single short survey reaches. Note for the Margaret River study DoW surveyed 1.27km of the river with this assumed to be representative of the total river (ca. 60km), i.e. approx 2% of the river surveyed. This is a limitation imposed on similar studies elsewhere in Australia and a balance is needed between the costs of surveys and their capacity to represent hydraulic variations through the river network. A detailed investigation with more intensive surveys would be worthwhile in investigating this tradeoff.*

Step 3: Flow-ecology relationships and flow thresholds

All environmental flow methods attempt to divide the annual flow regime into various flow components that are thought to have particular ecological functions. For example, high river flows have considerable impact on the river geomorphology, by scouring pools and influencing the distribution of sand bars, woody debris, and the complexity and distribution of habitat. As a result, high river flows have a direct influence on the structure of aquatic communities and food webs in the rivers of south-west Western Australia (Pen, 1999).

Another example of flow-ecology relationships are the flows that occur at the end of the dry season, which relieve summer stress (particularly high temperatures and low dissolved oxygen), provide cues for breeding migrations of native fish, and provide habitat for micro-crustaceans, aquatic insects, waterbirds and the larval stages of some terrestrial insects.

In the reports reviewed, DoW outlined the key ecological components of the flow regime relevant to the rivers of south-west Western Australia. In doing this they first divided the annual flow (climate) pattern into two seasons:

- dry season (December to May) when flows are either zero or low,
- wet season (June to November) when most of the flow occurs, with freshes, bankfull and flood flows experienced.

The ecological significance of the various flow components that occur during the dry and wet seasons are clearly documented in DoW, 2011a. For example, the important flow components identified are:

- Dry season – spring recession, trickle flow, no-flow,
- Wet season – increasing trickle flow, freshes, low baseflow, high baseflow, high flow events, floods.

Subsequently, flow thresholds are defined for each of these flow components in terms of water depths and related flow rates, to maintain the ecology and channel morphology (see Step 6 below for more details). For example, the key ecological objectives considered in the determination of EWRs for both reaches of the Margaret River, and the corresponding depth criteria, are listed in Table 3 of DoW (2011c).

These flow criteria are then used to develop a set of flow-ecology ‘rules’ (or thresholds) that define the components of the flow regime required to maintain the ecological values of the study river. These rules were used as defining criteria for hydraulic modelling that identified the flow rate needed to achieve the ecological depth criteria identified. This process is described in greater detail below.

<u>Assessment</u>

- *The Review Panel believes this to be a very sensible approach given the quite predictable climatic pattern (hot dry summers, cool wet winters) generally experienced in south-west WA (Kennard et al., 2010).*
- *The Review Panel believes the subdivision into the above flow components is sensible and the ecological significance of each of the components is well supported by scientific evidence.*

Step 4: Obtaining the long-term daily flow record

The preparation of hydrological data and description of catchments is well documented in the hydrology summary reports. There is a large proportion of streamflow gauges with substantial periods of missing data. Infilling of data gaps in streamflow records used rainfall runoff modeling (e.g. Margret River) and regression with nearby gauges (e.g. Cowaramup Brook). It is a strength of the WA environmental flow assessments that hydrographers are included in study teams as they will be familiar with limitations of existing gauging station data.

There seems to be limited discussion and justification for use of the historical flow record as the reference regime for environmental flow studies. Issues that might be considered in assessing the robustness of this approach include: (a) are there any important catchment disturbance that may have altered its hydrological behavior during the period of record, (b) should records from prior to this disturbance be included?, and (c) is the period of record representative of the longer-term or expected future climate?

The precision of low flow gauging should be considered given the importance of low flows in setting minimum environmental flows.

<u>Assessment</u>

- *The review panel considered that the hydrological investigations are of a good standard and well-documented.*
- *Streamflow data records appear to be quite patchy. It would be sensible to identify critical gauging stations required to monitor performance of environmental flow regimes in the future and ensure these are well maintained.*
- *The precision of low flow gauge observations should be considered in the EWR investigations.*

- *There is a need to better document the justification for using the historic streamflow record as the reference flow regime, with particular regard to any catchment disturbances that have altered hydrology prior to or during the period of record.*

Step 5: Hydraulic Modelling

A standard one-dimensional hydraulic modeling approach (with HecRas) was used to model changes in water level with discharge along the study reaches. This is a common approach and suitable for the rivers under investigation. There is no documentation of how flow-resistance for the hydraulic is calibrated and how it is estimated at flows other than that for which water levels are surveyed. Also the method of modeling stage-discharge relation for the downstream cross-section is not documented.

Assessment

- *The hydraulic model used for these studies (HecRas) is the industry standard tool and widely used for environmental flow assessments.*
- *An investigation of model performance is warranted in some intensively surveyed reaches including surveys at high and low flows to examine uniformity of calibrated flow resistance across a range of flows.*

Step 6: Flow thresholds

In this step, the flows required to inundate the various river habitat types are determined. The River Analysis Package (RAP – Marsh, 2003) was used for this purpose. The calibrated HEC-RAS model was imported into RAP and used to examine water level changes at each cross section for different discharges using either the scroll bar function (e.g. the top of bank on relevant cross-sections) or the rule library (e.g. % coverage of riffles to 5cm depth). Some thresholds were specifically developed based on expert opinion (e.g. no-flow = 0, or trickle flow = 1.0 ML/day).

Table 4 lists the ecological flow thresholds that were used to model the environmental flows for Margaret River. These include flows that flood out rock bars for fish migration, inundate benches (carbon sources) and key habitats (pools and riffles), and over bank flows (flood riparian vegetation).

The method used to determine flow thresholds for use in the PADFLOW method is robust and very similar to that used in most environmental flow method elsewhere in Australia.

Assessment

- *The Review Panel finds the method used to determine flow thresholds for use in the WA PADFLOW method to be robust, and similar to that used in most environmental flow method elsewhere in Australia.*

Step 7: Parameterise RESYM and evaluate ecological flows

The RESYM software is used to model the effect of removing a proportion of flow on the frequency and duration of flows above the ecologically significant flow thresholds. Different proportions of abstractions can be applied for different ranges of flow. Typically the acceptable proportion of flow abstracted would decline with reduction in reference flow. The expert panel examined the effect of setting different flow reduction percentages during a workshop and agreed on an acceptable level of flow abstraction to maintain at the agreed environmental objectives.

Assessment

- *The Review Panel finds the method used to be quite logical. However the documentations could provide more detail on how the panel decided on the final abstraction proportions. Ideally these decisions should be reproducible. Some testing of this process using multiple teams would build confidence in the reproducibility of the results. The review panel accepts that judgment is required in this step of the analysis (given current limitations of knowledge) and the RESYM approach allows these judgments to be documented.*

Step 8: Converting annual series of ESY to single ESY

The Ecological Sustainable Yield for each year is estimated as the difference between the reference flow regime and the environmental flow regime modeled using RESYM. Farm dams provide little opportunity for carrying over storage between years. If the same yield is to be delivered by dams in every year of record, then the overall sustainable yield for that site is set as the minimum annual value for the record. This assumes that farmers cannot accept or deliver restricted yields in particularly dry years. On this assumption the approach appears reasonable. In many years there will be considerable flow maintained in rivers, well in excess of minimum requirements. This may seem wasteful to farmers but any increase in water diversion for farms would result in failure to meet the minimum environmental water required in all years.

A limitation of this approach is that the minimum flow year will be sensitive to length of streamflow record with longer records generally including a broader range of flow conditions and hence lower minimum flow. A statistical approach to defining the ‘minimum flow’ year may be preferable. This would mean describing the distribution of annual sustainable yields statistically and then defining the 1 in 20 or 1 in 50 (for example) year minimum sustainable yield as the overall environmentally sustainable yield.

Assessment

- *The Review Panel finds the method used to be quite logical. However there is an opportunity to improve the method using a statistical approach to defining the overall minimum environmental yield rather than simply the minimum annual yield for the period of record.*

3.2 Regionalisation of the ESY: Application and extension of PADFLOW methodology to the Warren-Donnelly catchments

The WA Department of Water released a draft surface water allocation plan for the Warren-Donnelly River basins in June 2010 for public (DoW, 2010).

In providing new allocation limits for 25 management sub-catchments, the plan aimed to:

- provide (where possible) for a level of growth of storage in farm dams and water use,
- maintain the current high level of reliability of supply to the irrigation industry,
- provide for water-dependant ecosystems.

Because of the size of this region (Warren – 4370 km^2, Donnelly – 1730 km^2), it was not feasible to undertake individual ecological and hydraulic studies for each of the 25 sub-catchments. The ecologically sustainable yield (ESY) for each sub-catchment was determined on the basis of a *regional yield model* developed from the results of environmental flow (ecological flows) studies carried out in south-west WA rivers between 2005 and 2009.

Briefing Paper #2 (DoW, 2011b) describes the procedure used to develop, validate and apply the regional yield model, and also the uncertainty and risk in the yield estimates obtained from the regional model.

This section contains the Review Panel’s review of the regional yield model.

Current water resource development in the Warren-Donnelly catchment

The Warren-Donnelly catchment is located in the south-west corner of WA, with the major towns in the catchment being Pemberton and Manjimup. The climate is temperate with dry, hot summers and wet cool winters, and an annual rainfall that reduces with distance from the coast varying from 1200 mm in the south-east to 500 mm in the north-east.

The Warren River catchment covers an area of 4370 km^2, with land use dominated by national park or conservation areas and irrigated agriculture. Flow in the Warren River averages 300 GL/yr and varies between about 80 and 650 GL/yr. The Donnelly River catchment covers an area of 1728 km^2, most of which is native eucalypt forest. Flow in the Donnelly River averages 280 GL/yr and varies between about 105 and 520 GL/yr.

There are around 484 licensed farm dams in the Warren-Donnelly catchment, most being located in the Warren catchment. These dams intercept and store a combined total of 35 GL of river flow or around 15% of mean annual flow and 40% of annual flow in years of low rainfall. Around 85 percent of the commercial farm dams have a volume of between 50 and 300 ML when full. Currently, the reliability of supply to the irrigators is high and most dams fill by the end of the wet season in years of low annual flow. Irrigators are dependent on variable but reliable wet season flows to fill dams before the start of the irrigation period (December through May).

In the Upper Lefroy sub-catchment, the most developed in this system, DoW estimate that farm dams reduced the annual flow by ~20 percent on average between 1975 and 2003 (DoW, 2011b). The reduction in flow is considerably greater (ca. 80-90%) during the dry season (Nov-May) than during the wet season (0-50%). The dams are located either on-stream or within the catchment, and capture any runoff during the dry season and during the first part of the wet season, begin over-flowing by July in most years.

There is considerable pressure by irrigators for DoW to allow an increase in the volume of water storage in on-stream farm dams in the Warren-Donnelly catchment.

Identifying an ESY relevant to interceptions by on-stream farm dams

In seeking to identify an ESY relevant in the Warren-Donnelly catchment, DoW were faced with several issues, including:

(a) There is only one ecological flows study undertaken in this catchment – DoW decided to develop a regional ESY model based on EF studies that have been done in 7 rivers (14 sites) in the south-west region of WA (see below),

(b) The reference flow data series used for any ecological flows studies include changes to the hydrology, including catchment clearing and interceptions of flow by existing farm dams (already discussed in Section 3.1 above),

(c) The volume of water intercepted by on-stream farm dams is fixed, being dependent on the total storage volume of the existing dams, and will vary little between years despite variations in the annual flow. Thus, once an additional allocation is allowed new dams will be built to take up the extra and this volume will be lost to the environment.

These issues are discussed below.

Issue (b) – The estimates of ESYs for these reference flow data sets are additional to the yields already occurring in current farm dam storage. It is relevant that DoW have argued that their modelling (unpublished data) suggests that the decreases in flow caused by interception by on-stream farm dam are slightly less or match increases in runoff associated with catchment clearing in the early 1990s. The implication being that the current streamflows are close to those that would have occurred before any development in these catchments. Some evidence of this would be reassuring.

Issue (c) – The review panel agrees with DoW that the focus needs to be on dry years (and the dry season) to ensure that any increase in allocation does not result in over-allocation.

Regional model of the minimum annual ESY

To address issues (a) and (c), DoW decided to develop a regional ESY model based on ecological flows studies that have been done in 7 rivers (14 sites) in the south-west region of WA, and to focus only on the ESY for the minimum flow year in each of the data sets.

These data (ESY versus minimum annual flow) are plotted in Fig 6 (DoW, 2011b). This regional ESY versus minimum annual flow relationship suggests that an additional ca. 33% of the minimum annual flow in each catchment can be allocated for consumptive purposes.

Review Panel comments:

- *This seems to the Review Panel to be a broadly sensible approach. We note that once any additional allocation is allowed it will not be possible to reduce the level of farm dam development so a precautionary approach is wise.*
- *DoW have fitted a polynomial to these data, but the Review Panel can see no basis for this and recommend that a straight line be used.*
- *The streamflow series use data for the period 1975-2003 in most cases. This is a good length of record for representing inter-annual variability in streamflow assuming a stationary time-series. However, there has been a step-change in streamflow in south-west WA over this period. An explanation of how this non-stationarity is addressed would be useful.*
- *It does not appear that future climate change has been taken into consideration in these estimates. One way to do this would be to reduce the historical daily flow record by an agreed amount (10%, 20%….) and then redo the ESY versus minimum annual flow estimates.*

Risk associated with applying the predicted ESY

There are a number of uncertainties associated with the predicted ESYs that need to be considered in using these values to allocate further water in the Warren-Donnelly catchment.

The risk is that if the predicted ESY is an over-estimate of the 'true' ESY then licensing to this limit could result in over-allocation, particularly in dry years. Additionally, because applying the predicted ESYs would result in the allocation of an *additional* volume to the current dam network and interception volumes, DoW argued that the risk of over-allocation would be greatest in those catchment which had the highest current level of storage.

In an attempt to account for uncertainties in the predicted ESYs from the regional ESY model, DoW used error estimates obtained for a panel of 10 experts selected because of their knowledge of, and experience with, flow measurement, flow modeling and methods used in the ecological flow studies (DoW, 2011b). The estimates of errors in the predicted ESYs ranged from $\pm$20% to $\pm$60% (mean $\pm$40%).

Assessment

- *This is a sensible approach to ensure undue confidence is not placed in the predicted ESYs,*
- *However, this review cannot assess the competence of the expert panel that developed these uncertainties without knowing who was on it*.
- *A more quantitative assessment of the risks should be considered in the future*, *as this current assessment is highly qualitative.*
- *As this approach appears in part to be an accommodation of future climate change, it may be simpler to run climate change scenarios through the models.*

In applying the regional ESY model to determine possible additional allocations in the Warren-Donnelly catchment, DoW sought to balance the two main risk factors:

- the uncertainty in the predicted ESY,
- the current storage capacity in the sub-catchment being considered.

Current storage density in the Warren-Donnelly sub-catchments varies between sub-catchments from <1 ML/km^2 to 76 ML/km^2. DoW argue that they were less concerned with the risk of over-allocation in a sub-catchment with low storage density (e.g. the lower Warren) compared to a sub-catchment with a high storage base (e.g. the Upper Lefroy) (DoW, 2011b).

Thus, to account for these two risk factors, DoW used a different error value for different current storage densities. The relationships are shown in the Table below.

Current storage density	**Value (ML/km^2)**	**Uncertainty in ESY**
Very low	<15	±0%
Low	15-25	±20%
Medium	25-75	±40%
High	>75	±60%

Assessment

- *The Review Panel finds this to be a sensible approach to reduce the risk of over-allocation*
- *The Review Panel recommends* DoW *investigate the development of a Bayesian network to assist with risk-based decision making.*

3.3 Possible future work

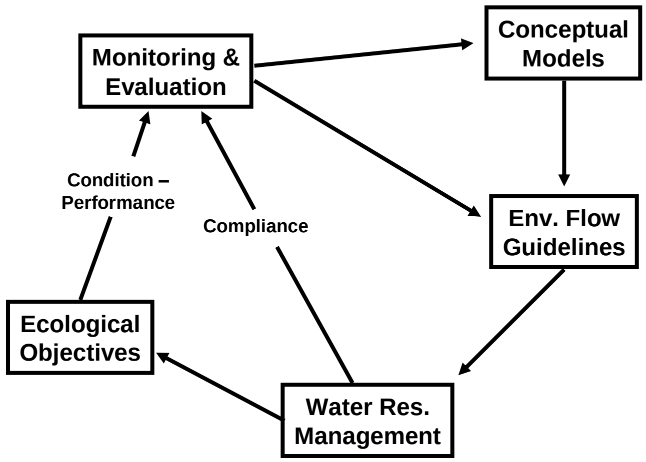
The review panel makes the following major recommendations for future work to strengthen the current WA environmental flow methodology:

- The individual catchment-based investigations and research underpinning application of the PADFLOW method should be peer reviewed in the future.
- Where possible, the science underpinning the flow-ecology links that are fundamental to these studies, should be continually strengthened and peer-reviewed.
- There is a need for a method to establish a robust procedure for surveying current environmental river condition and for establishing environmental objectives for environmental water management.
- An environmental monitoring and evaluation program is needed to test that the environmental objectives are met.

- Better documentation is required to explain and support use of the recorded streamflow series as the reference flow regime for environmental flow studies and also an explanation of where this approach is not applicable.
- There is merit in an investigation of the trade-offs between the number and size of river reach surveys versus cost for future environmental flow studies.
- A statistical-based method should be investigated for defining the environmentally sustainable yield based on annual series of sustainable yield, similar to the concept of a design 20-year flood.
- A quantitative Bayesian risk framework should be considered for future environmental water studies potentially including modeling of future climate change scenarios

4. Conclusions

- PADFLOW method is broadly consistent with current best practice.
- The developers of the WA environmental flows methodology have a clear understanding of distinctive aspects of environmental flow requirements in south western WA streams and have tailored best practice from elsewhere in Australia to meet their particular needs.
- Additional documentation and peer review of underpinning evidence particularly relating to flow-ecology linkages would strengthen the methodology.
- Building on the current database and methods, there is an opportunity to review data needs for representing spatial variation in environmental flow requirements, particularly in terms of streamflow gauging and hydraulic surveys.
- Environmental flow planning should be explicitly placed within a broader river health strategy, which considers non-flow drivers in these systems. Where non-flow drivers are predominant and there is no realistic expectations these can be managed, there may be a case to accept a lower standard of environmental flow delivery,
- It is unclear how risks associated with projected climate change are accommodated in the PADFLOW method.
- Ideally there should be a monitoring and evaluation program tailored to the unique needs of environmental flow planning in southwest WA. It should include compliance monitoring (based on assessment of future farm dam development) and performance monitoring (that predicted environmental objectives are sustained). This supports an adaptive management approach as shown in the diagram below.


Monitoring & Evaluation
Conceptual Models
Condition – Performance
Compliance
Env. Flow Guidelines
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