Technical Review of Elements of the WAMP Process of the Queensland DNR

**Outcomes of a workshop
held at the River Glen Conference Centre
on the 9th and 10th November 1999**

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Cooperative Research Centre for Freshwater Ecology
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RESEARCH

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The Cooperative Research Centre for Freshwater Ecology aims to improve the health of Australia's rivers, lakes and wetlands through research, education and knowledge exchange. By linking industry, government and universities in collaborative research projects, the Centre produces cutting edge information about the ecology of Australia's water resources.

The Cooperative Research Centre for Freshwater Ecology is a collaborative venture between:

- ACTEW Corporation
- CSIRO Land and Water
- Department of Land and Water Conservation, NSW
- Department of Natural Resources, Queensland
- Department of Natural Resources and Environment, Victoria
- Environment ACT
- Environment Protection Authority, NSW
- Environment Protection Authority, Victoria
- Goulburn-Murray Rural Water Authority
- Griffith University
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- Murray-Darling Basin Commission
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- Sunraysia Rural Water Authority
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EXECUTIVE SUMMARY

The Cooperative Research Centre for Freshwater Ecology (CRCFE) was appointed to review the framework that the Queensland Department of Natural Resources (QDNR) has developed for identifying relationships between various indicators of river health and various hydrological measures.

These are the main conclusions and recommendations of the review.

(i) Technical Advisory Panels

- The existing models of Technical Advisory Panel (TAP) membership and roles should be maintained, with due reference to the specific skills needed.

- It may be perceived that there is a conflict of interest when TAP members are engaged as consultants to the TAP. Often, TAP members are clearly the most appropriate consultants for the work because of their expertise (which is why they have been chosen for the TAP). However, because the TAP's role is to provide advice to the Water Allocation Management Plan (WAMP), rather than to formulate the WAMP, it is unlikely that there can be a conflict of interest.

- A conflict of interest may occur if QDNR staff, who may be involved with development of the WAMP, are also members of the TAP (though none have been to date). In this situation there may not be an independent review of that TAP member's work by the Department.

(ii) Choice of key hydrological indicators

- The existing flow regime must be accurately quantified using an Integrated Quantity–Quality Model (IQQM), to provide a sound basis for investigating relationships between the flow regime and ecological conditions and impacts. The case of 'full utilisation of existing entitlements' is generally not an appropriate surrogate for the current flow regime.

- A basic comprehensive statewide set of *flow statistics* should be developed and the most relevant and applicable of them should be chosen as hydrological indicators for each river across the state. This set of flow statistics should encompass the core water requirements of the full range of components of the ecosystem, including riparian, wetland and end-of-system requirements. As well as this core set of flow statistics, others may be required on a basin by basin basis as indicated by hydraulic information for that basin (or parts thereof) or to cover special cases such as a particular in-channel feature or wetland.

- The ecological relevance of each of the chosen flow statistics should be clearly stated.

- Flow statistics should be interpreted in the context of the flow regime, and temporal sequencing should be taken into account.

(iii) Choice of ecological condition indicators

- The criteria for selecting reference sites should ensure the setting of ecologically relevant targets.

- The current assessment criteria provide a useful guide to selecting reference sites. Further development of the selection criteria could be undertaken, giving consideration to defining 'reference condition' in terms of best management practice. Best management practice should include all aspects of land and water use, because it represents the target to be achieved.

(iv) Benchmarking method

- The Review supports the use of the benchmarking method.

- The best available benchmarks should be used. The Review recognises that it is necessary to use benchmarks from outside the basin of interest when there are no suitable sites within the basin. Limitations associated with the chosen benchmarks should be acknowledged.

- River health–flow relationships should be investigated with various univariate and multi-variate analyses, as a research priority. The analyses can involve the use of non-standard statistical techniques and input from a specialist statistician. These relationships will provide an empirical model for assessing the ecological implications of altering the flow regime.

- If statewide river health–flow models are to be developed, it is recommended that the relationships correlate observable biological and physical indices directly with modelled indicator data sets for a range of flow statistics and sites across Queensland and northern New South Wales.

- The overall structure of the 'adaptive assessment approach' (which takes an adaptive management approach by setting hypotheses, testing them as part of the management cycle and then using these outcomes to improve management), provides a sound basis for water resource management. However, the use of ecological assessment curves is not recommended, for the reasons outlined below (see vii).

- The Review endorses the QDNR's modified approach to environmental flow assessment (Appendix A). The method provides an efficient framework for determining ecosystem requirements for water, and the likely ecological consequences of water development.

- To refine the benchmarking method the Review recommends that a set of criteria for benchmarking be developed, based on comparison of sites firstly within a basin and then in other basins, where the sites have the following characteristics:
  - similar geomorphology;
  - similar flow regime type;
  - same or close biogeographic region;
  - same relative position in catchment;
  - as similar as possible land use and presence of alien or introduced biota;

  taking account of the time since any upstream dam or weir was built.

(v) Process–response models

- Process–response models are useful tools for generating research questions and for community education. In the absence of suitable empirical data they provide a basis for setting interim flow options.

- Process–Response models may also be used to integrate empirical information, when it is available. If environmental flow process–response models are sufficiently understood and empirical data have been incorporated, they may be used as predictive tools.

(vi) Traffic light diagrams

- The Review supports the use of traffic light diagrams. They provide an easily interpreted display of the outputs of benchmarking analysis, but the data on which they are based should be made available.

(vii) Ecological assessment curves

- If ecological assessment curves are used, the TAP should indicate what literature, site data and theoretical knowledge were used to generate the estimates of ecological merit, and what the curves actually represent. It should be made clear that the curves do not represent empirical relationships in cases when empirical relationships do not exist

- The Review does not support the use of ecological assessment curves for the presentation of benchmarking analysis because:
    - they are confusing and complicated to interpret;
    - assumptions in their development are not obvious;
    - they are susceptible to misuse or misinterpretation;
    - they appear to present qualitative data and professional opinion in a overly precise and quantitative way;
    - an ecological merit score does not add value to the raw flow statistic;
    - the shading around the ecological assessment curve has no formal basis, and this should be stated clearly. It is highly probable that the uncertainty associated with such a curve would be considerably greater than ±5%.

INTRODUCTION

This report summarises discussions and recommendations resulting from a two day workshop held at the River Glen Conference Centre, Indooroopilly, Queensland, on the 9th and 10th November 1999.

The objective of the workshop was to review the framework developed by the Queensland Department of Natural Resources (QDNR), and used by the Technical Advisory Panels (TAPs), for identifying relationships between indicators of river health and various hydrological measures.

Members of the workshop heard presentations of the following key issues:

- how WAMP Technical Advisory Panels assess the current condition of river systems;
- how WAMP Technical Advisory Panels develop a relationship between flows and ecological health and how this relationship is represented;
- the use of ecological assessment curves for correlating flow and river health; and
- the development of an 'adaptive assessment approach'.

This document reports the outcomes of the workshop.

The workshop was attended by the following people:

Peter Cullen	Cooperative Research Centre for Freshwater Ecology (CRCFE)
Angela Arthington	CRCFE
Stuart Bunn	CRCFE
John Harris	CRCFE
Terry Hillman	CRCFE
Richard Norris	CRCFE
Gerry Quinn	CRCFE
John Whittington	CRCFE
Sandra Brizga	Consultant
Satish Choy	QDNR
David Moffatt	QDNR
Tom Vanderbyl	QDNR
Gary Burgess	QDNR
Dale Bell	QDNR
Rina Lloyd	QDNR
John Ruffini	QDNR
Jon Marshall	QDNR
Dane Moulton	EPA

WATER ALLOCATION MANAGEMENT PLANS

A Technical Advisory Panel (TAP) is appointed by the QDNR to provide advice and reference material from which a Water Allocation Management Plan (WAMP) can be formulated.

Water Allocation Management Plans are intended to provide frameworks for the fair, efficient and ecologically sustainable use of water at the scale of a river basin. The WAMPs are formulated to fulfil Queensland's commitment to the Council of Australian Government's water reforms, National Competition Policy agreements and the National Principles on the Provision of Water for Ecosystems. The staff who formulate the WAMPs also consider economic, social and cultural issues, to determine an appropriate balance between water for the environment and water for consumptive purposes.

The QDNR is currently developing eight WAMPs, four of which were presented to the Review:
- Fitzroy Basin;
- Barron Basin;
- Logan; and
- Condamine–Balonne.

Each WAMP is supported by a TAP appointed by the QDNR to provide advice to the Department on the environmental requirements of aquatic and riparian habitats and species in that particular basin. The specific terms of reference vary between the TAPs.

The Fitzroy TAP was appointed to provide advice upon:
- the likely environmental flow requirements of the river system;
- possible environmental flow management scenarios that might address some of these requirements; and
- the potential ecological implications associated with various combinations of future development scenarios and/or environmental flow scenarios.

The Condamine–Balonne TAP was asked to:
- provide an assessment of the existing ecological condition of the Condamine–Balonne River system;
- establish hydrologic criteria for assessing environmental flows;
- provide a basis for assessing the ecological merit of changes in each of the hydrologic criteria;
- provide an environmental flow assessment of the long-term flow regime associated with the level of development that existed at the end of 1997, under current flow management rules;
- propose appropriate flow management strategies;
- provide the community with the information and methods used to determine such proposed strategies and enhance awareness of the importance of environmental flows within the basin; and
- outline monitoring and research requirements over the longer term (up to 7–10 years).

For the Barron and Logan TAPs the process has been split into two stages, and to date the TAPs have been asked to do the following:
- provide an overview of the environmental values and significance of riverine and wetland ecosystems in the study area;

- identify hydrological indicators relevant to geomorphological and ecological processes;
- assess present river and stream conditions in relation to the impacts of existing water resource management;
- provide recommendations regarding performance measures of environmental flows and other flow-related environmental management criteria;
- provide recommendations regarding research and monitoring requirements; and
- assess current environmental conditions related to flow.

The Review understands that in Stage 2 the Logan and Barron TAPs will be asked to provide advice similar to that asked of the Fitzroy TAP. We are uncertain of the timeframe for Stage 2. During Stage 2, advice will be required on possible flow management scenarios and the ecological implications of future water development, whereas to date the Barron and Logan TAPs have been asked to provide advice only on the current condition.

TECHNICAL ADVISORY PANELS (TAPs)

The aim of a TAP is to provide advice on the environmental requirements of aquatic and riparian habitats in particular river basins. To do this, the TAP assesses the current state of the riverine environment and makes predictions about the likely environmental consequences of further water abstraction. Through this process, the TAP may develop environmental flow management strategies (Fitzroy and Condamine–Balonne and Stage 2 of Logan and Barron), that may then be considered during the formulation of the WAMP. It is emphasised that the role of the TAP is to provide advice, rather than to recommend specific courses of action.

The TAP consists of a small group of experienced scientists representing a range of disciplines. To be a TAP member, a person must be an experienced scientist, preferably with experience in that river basin or a similar one, and able to work effectively in a team environment. The TAP is likely to have expertise in fish ecology, river geomorphology, macroinvertebrate ecology, and wetland/riparian ecology.

The assessment of river health and the development of environmental flow management strategies are two of the most important applications of our current understanding of freshwater ecology. These are complex tasks made even more difficult by the lack of adequate baseline information. To provide advice on these tasks it is critical that experts of the highest calibre and with considerable experience are selected as TAP members. In the absence of substantive empirical data, the credibility (and perhaps the defensibility) of the TAP's advice will rely, in part, on the reputation and capacity of the TAP members.

For a TAP to achieve its goals, five steps have to be completed:
1. development of an Integrated Quantity Quality Model (IQQM) (undertaken by QDNR);
2. collation and review of existing literature and data, and, if necessary, recommendation for further data collection;
3. data collection;
4. analysis of available information (literature reviews, collected data) to assess current ecological condition and to develop river health–flow relationships; and
5. review of relationships and provision of advice on flow management strategies.

The QDNR undertakes step 1. Steps 2–5 are undertaken by the TAP and can involve reports prepared by QDNR and consultants.

The level of involvement by members of the TAPs at each stage varies between WAMPs. In the Fitzroy, the TAP was formed in November 1995 with the aim of reviewing existing information. The TAP recommended to QDNR that significantly more information was needed before advice on flow options could be given. The TAP reconvened during 1997, once the IQQM had been developed, and various reports on biological indicators were provided by QDNR. The TAP reviewed aspects of the Draft WAMP recommendations. To date, TAP members in the Logan and Barron WAMPs have been engaged as consultants by QDNR to collect and analyse data and collate information from existing data and reports. Individual members have also provided reports to the TAP which have been used in preparing advice to the WAMP.

The level of engagement of the TAP represents two different models for the function of the TAP:

- expert opinion or best guess, based on other experience and assessment or evaluation of existing data, which may include a brief site inspection;
- field investigation and collection of new data specific to the WAMP.

Each model probably has an inherent level of reliability; therefore it is important to be clear about which model is being used, so that the WAMP can be 'transparent'.

Recommendations/conclusions

The existing models of TAP membership and roles should be maintained, with due reference to the specific skills needed.

It may be perceived that there is a conflict of interest when TAP members also act as consultants to the TAP. Often the TAP members are clearly the most appropriate persons to do the work because of their expertise (which is also why they have been chosen for the TAP). However, because the role of the TAP is to provide advice to the WAMP, rather than to formulate the WAMP, it is unlikely that there can be a conflict of interest.

A conflict of interest may occur if QDNR staff, who may be involved with development of the WAMP, are also members of the TAP (though none have been to date). In this situation there may not be an independent review of that TAP member's work by the Department.

CHOICE OF KEY HYDROLOGICAL INDICATORS

The development of an IQQM that simulates flows is an integral component of the WAMP. It is the basis from which the TAP provides its ecological advice.

The IQQMs developed for the four WAMPs provide daily stream flow simulations based on catchment inflows, making allowances for the effects of dams and weirs, water abstraction and transmission losses. Simulated flows have been developed for the river basins for some or all of the following scenarios:

- 'no-development', representing the pre-development (original) state (note this is not the same as 'reference condition' used for ecological condition assessment);
- the current usage of entitlements;
- full use of entitlements; and
- in some cases, the effect of potential developments on flow regime.

In many river systems current usage can be considerably less than existing entitlements (because not all entitlements are activated), so it is important that the IQQM be used to simulate current usage as well as natural condition and existing entitlements. Without this information it is impossible to accurately relate the current ecological condition of the river to flow statistics derived from the IQQM.

Recommendation/conclusion

The existing flow regime must be accurately quantified using IQQM in order to provide a sound basis for investigating relationships between the flow regime and ecological conditions and impacts. The case of 'full utilisation of existing entitlements' is generally not an appropriate surrogate for the current flow regime.

The ability to recommend flow options, and then to evaluate whether or not those flow options have an environmental benefit, depends critically on the quality of the IQQM. Also, public confidence in the recommendations of the TAP will be strongly influenced by the community's confidence in the IQQM. An analysis of the development, validation and use of IQQM was beyond the terms of reference for the workshop and will not be discussed in this report but should be included in a wider review of the WAMP process.

The IQQM allows for quantification of the hundreds of flow statistics that can be used to describe the flow regime of a river. The flow characteristics are likely to vary in their importance to the ecology of the river. The value of a selected flow statistic may change along a river. No single flow statistic is likely to describe the range of flows required to maintain a riverine ecosystem. It is critical that the key flow statistics chosen are those required to support the riverine ecosystem.

The flow statistics are generally presented to show how the current (or future) flows are different from the natural flow. The Review considers it important that the chosen key statistics highlight the most ecologically important features of flow within the system, so that they provide a sound basis for determining the system's environmental flow requirements.

The key flow statistics chosen by the relevant TAPs for each WAMP are listed in Table 1. At the broad level, there is similarity of the flow statistics chosen for each basin. All (except the Logan Basin) have a general measure of water abstraction on an annual basis. All have measures of flow variability and of in-channel and low flow requirements. All consider the high flow requirements and all consider flooding at a variety of flood return intervals, which can be related to floodplain and wetland requirements. The Condamine–Balonne and the Fitzroy WAMPs consider the area of river inundated by impoundments. The Logan and Fitzroy TAPs consider effects of flow regime on estuarine productivity.

An important point to note is that flow indicators need to be looked at in the context of the flow regime as a whole to be properly interpreted. For example, a flow statistic showing that a stream has zero flows 20% of the time could mean that flows are zero 20% of the time in each year, or that flows totally cease in 20% of years but are continuous in all other years.

If statewide river health–flow models are to be developed, a comprehensive basic set of flow statistics across all basins will need to be chosen. The TAP would need the capacity to choose the most relevant and applicable of them for each individual rivers. At present the key flow statistics chosen for the four WAMPs address degree of abstraction, variability, low flows, and high flows. However, the statistics chosen to describe these flow attributes differ between basins. These differences may occur because ecosystems may have differing flow requirements, both within and between basins. The challenge is to determine a core set of flow statistics relevant across the state.

> ***Recommendations/conclusions***
>
> A basic comprehensive set of flow statistics should be developed and the most relevant and applicable of them should be chosen for each river across the state. This set of flow statistics should encompass the core water requirements of the full range of components of the ecosystem including riparian, wetland and end-of-system requirements. As well as this core set of flow statistics, others may be required on a basin by basin basis, as indicated by hydraulic information for that basin (or parts thereof) or to cover special cases such as a particular in-channel feature or wetland.
>
> The ecological relevance of each of chosen flow statistics should be clearly stated.
>
> Flow statistics should be interpreted in the context of the flow regime, and temporal sequencing should be taken into account.

CHOICE OF KEY ECOLOGICAL CONDITION INDICATORS

The TAPs of the four WAMPs presented to the Review indicated that the ecological data initially available to them were insufficient for full assessment of the conditions of the whole basins. Consequently, additional information was collected both by and for the TAPs.

The TAPs analysed existing literature and conducted field trips on which rapid assessments were performed at a number of key sites. Rapid assessments evaluated geomorphology and riparian vegetation in the Condamine–Balonne, Barron and Logan. The Barron TAP used the Snowy Water inquiry criteria for 'habitat structure', 'channel morphology', 'riparian vegetation' and 'aquatic vegetation' as checklists. For a limited number of sites in all catchments macro-invertebrate data collected for the National River Health Program (NRHP) and the First National Assessment of River Health (FNARH) were available. Some information on fish distributions, geomorphology, riparian and aquatic vegetation, and water quality was available for each basin.

The Logan, Barron and Condamine–Balonne TAPs had more 'hands on' roles than the Fitzroy TAP, with TAP members undertaking a number of studies. Some of the studies were commissioned as part of the WAMP process (e.g. Brizga — fluvial geomorphology in the Barron Basin); others were undertaken as part of projects external to the WAMP process (e.g. Moffat — fish distribution in Condamine–Balonne).

To aid with selecting indicators of ecosystem condition in future the workshop identified a list of indicators (habitat variables) likely to be influenced by alterations in the flow regime (Table 2). A subset of these indicators would be a minimum requirement for a WAMP, but data are not currently available for many of them. Not all the ecological indicators will be useful in every river Basin, and no one indicator gives a full description of ecosystem health. Rather, a suite of core indicators should be generated. The Review emphasises that these indicators are intended as a starting point for the development of suitable key indicators for a particular catchment.

TABLE 1.   Key flow statistics chosen for WAMPs

Flow statistic	Condamine –Balonne[a]	Fitzroy[b]	Logan[c]	Barron[d]
General				
Median annual flow (% of natural)	✓	✓		
Mean annual flow (% of natural)		✓		✓
Annual proportion of flow deviation	✓	✓		
Variability				
Proportion of natural monthly flow variability	✓			
Flow regime class (Flow seasonality)			✓	✓
Inter-annual variability			✓	
Ratio of 10% exceedance flow to 90% exceedance flow for each month of the year			✓	
In-channel and low flow				
Frequency of half bank-full flows (% of natural)		✓		
Frequency of bank-full flows (% of natural)		✓		
80% daily exceedance flow for each month (% of natural)			✓	✓
50% daily exceedance flow for each month (% of natural)			✓	
5% daily exceedance flow for each month (% of natural)			✓	
Proportion of natural 'low flow' event frequency	✓		✓	✓
Proportion of 'no flow' event frequency	✓			
Flow duration percentile for zero flow			✓	✓
High flows and floodplain				
Proportion of natural 'high flow' event frequency	✓			
1.5 year average return interval (ARI) (% of natural)		✓	✓	✓
5 year ARI (% of natural)			✓	✓
10 year ARI (% of natural)				✓
20 year ARI (% of natural)			✓	✓
Volume of the first post-winter flow event (% of natural)		✓		
Frequency of floodplain inundation (% of natural)		✓		
Proportion of natural storage level duration for the Narran Lake system	✓			
Estuarine productivity		✓	✓	
Direct infrastructure effects				
Proportion of river inundated by dams and weirs	✓	✓		
Frequency of weir drown-outs		✓		

[a] Condamine–Balonne WAMP Environmental Flows Technical Report. These flow statistics were expressed as the proportion change from natural flow conditions.

[b] Fitzroy Basin technical reports.

[c] Draft Logan Basin TAP report.

[d] Barron Basin Draft Technical Report 4 Environmental Investigations (1999).

TABLE 2.   List of key indicators of ecosystem condition

Habitat variable	Description	Availability of data
AUSRIVAS habitat measures	As part of the NRHP and the FNARH various habitat measures were collected including assessments of: • riparian condition • bank stability • stock access to banks • depth of water over riffles Little use of these measures has been made in the past, but they do provide the basis for an index of habitat condition.	Habitat assessment was carried out for NRHP and FNARH and data are available in all catchments
River cross-sections	River cross section is sensitive to gross changes in the flow regime. Channel contraction has been identified as a significant effect of water abstraction.	At all river-gauging stations cross-sections are frequently measured. It is acknowledged that gauging stations are not always ideal sites for measuring cross-section as they have often been chosen because of their geomorphic stability. It is likely that there will be limited data on changes in channel morphology available from gauging stations and that targeted surveys to quantify channel contraction would be needed.
Channelisation	Channelisation is an issue in areas of floodplain harvesting, particularly in distributary systems. Channelisation is likely to be a useful interpretive tool, rather than a general index.	
Macrophytes	The presence or absence and the percentage cover of macrophytes can be strong indicators of flow regime; however more research is required to interpret macrophyte data. Macrophytes do not occur in the western rivers because of high turbidity, and consequently are not a suitable indicator in these regions.	There are some data on presence / absence cover and biomass available for most Queensland rivers covered by the FNARH and MRHI programs (these include Albert, Brisbane, Mary, Burnett, Burdekin, Pioneer, Proserpine and wet tropics rivers).
Index of Biotic Integrity (IBI), using fish communities	Metrics used in the fish-based Index of Biotic Integrity (IBI) include: • number of native or alien species • numbers of individual fish • species richness • trophic and habitat guilds • condition of fish For fish data there is poor understanding of reference conditions and the spatial and temporal variability of fish community structure. Fish stocking activity and the effect of barriers on fish passage may need to be considered. The most cost effective and efficient sampling method is electro-fishing. Problems of turbidity in western rivers can be overcome. A combination of methods (both passive and electro-fishing) may provide best results.	Good data are available for coastal rivers (Arthington), though further effort is needed to develop relationship between fish community structure and function and flow regime and to determine the effects of different aspects of flow regulation. Some data are available for western rivers (Moffatt). Aspects of NSW Rivers Survey and IBI work can be used in southern Qld rivers (Harris). Arthington presented a modified IBI used in the Burnett and Logan WAMPs. This is being extended to include more metrics of fish community composition.

Table 2 continued

Habitat variable (cont'd)	Description (continued)	Availability of data (continued)
Incidence of fish kills	Fish kills may be flow-related and autopsy data plus flow records should indicate if this is the case. It may be difficult in some cases to know if fish kills are a response to environmental change or a density-dependent response to successful recruitment.	Good data are available from EPA. Difficult to relate fish kills with changes in flow regime.
Fish condition (lesions, etc.)	May be flow-related, caused by crowding below barriers during migration, or sudden contraction of habitat through water diversion.	Lack of good data. Will require research to relate fish condition to changes in flow regime. Seasonal effects in some species, such as bony herring.
Water quality • turbidity • diel dissolved oxygen • temperature	 • Turbidity is catchment specific and temporally variable with very high turbidities occurring naturally in most western rivers. Difficult to determine what are 'good' and 'bad' turbidity values. A reference-related predictive capability is required. A preliminary assessment has been carried out as part of the Water Quality Risk Assessment Project in QDNR. • Open water oxygen percent saturation may be a valuable indicator; however it is highly variable over short time scales (e.g. day/night). • Temperature data will indicate thermal pollution (such as below a major impoundment or through loss of riparian vegetation) and the development of stratification, which is important for blue–green algal growth under low flow conditions.	Generally good information: • Turbidity data are available and easy to collect. • Open water dissolved oxygen measurements are available for coastal streams, particularly in the sugar cane growing regions where acid sulphate soils are an issue. • Temperature data are available but temperature is usually only a useful indicator when there is an identified reason for measuring it, such as the presence of a major dam, or the threat of blue-green algal growth.
Riparian vegetation	The extent and condition of riparian vegetation can be flow-dependent. Examples include the contraction of riparian vegetation below the Ord Dam because flood frequency was reduced, and the declining recruitment and survival of red gums along many Murray-Darling Basin rivers as flow regime is altered. Structural changes in riparian vegetation and changes in vegetation condition do respond to the flow regime.	There is limited riparian vegetation information currently available, however, more information may be available by accessing remote sensing information. To obtain useful riparian vegetation information from remote sensing data will require a cooperative approach between biologists and remote sensing computational experts and some ground truthing work. Remote sensing is still constrained by the pixel resolution available, though this will improve in future. Information can also be gathered from aerial photography.

Table 2 continued

Habitat variable (cont'd)	Description (continued)	Availability of data (continued)
Macroinvertebrates AUSRIVAS	The AUSRIVAS approach to sampling and analysis of macro-invertebrate communities provides a valuable index of river health. AUSRIVAS data are generally the most comprehensive, currently available, on general river health. (This does not mean that it should be the only indicator of ecological condition used.) The value of AUSRIVAS predictions relies on the quality and applicability of the reference sites and regional models. The method currently has had little validation in lowland rivers.	AUSRIVAS is arguably Queensland's most comprehensive data set for interpreting riverine environmental condition. There is a need for incorporation of further reference sites and the development of regional models.
Marine and estuarine indicators	Freshwater inputs affect marine and estuarine environments. Commercial fish and prawn catch data can be related to the flow regime. Catches of fin fish and prawns are confounded by the effect of flow on catchability. Problems associated with catchability can be overcome by analysing recruitment patterns. The impacts of water resource development and reduced flows to estuaries are complex and more effort is required to develop suitable indicators to reflect these impacts.	Fisheries catch data are available. Commercial catch data are a good indicator for coastal catchments, but Queensland western rivers do not have commercial fisheries.
Land use	Indices such as area of a particular land use upstream, human populations, road development, remnant native vegetation or percentage tree cover may explain some of the variation in river health, especially through the River Disturbance Index. Land use has also to account for quality of land management.	Data on land use, tree cover, urbanisation, levee banks and point source pollution should be available through the Wild Rivers Program, in April 2000.

Ideally, ecological condition indicators will be established with respect to a reference condition (for example AUSRIVAS O/E taxa). It is difficult to determine what is the reference condition and then to select suitable reference sites, especially in heavily developed regions such as large lowland river systems, because all systems have been disturbed, the larger ones extensively so.

At the workshop, Choy presented nine criteria that a site should pass before it is considered suitable as a reference site for the development of AUSRIVAS models. These criteria are based on the discriminators described in the *NRHP/MRHI Bio-assessment Manual*. The development of these criteria assumes that reference sites should be as close as possible to a 'natural' or least impacted state. Professional judgement is applied to final selection, e.g. in lowland and urban streams.

The selection criteria are:

- no intensive agriculture within 20 km upstream;
- no major extractive industry (past or present) within 20 km upstream;
- no major urban areas (population >5000) within 20 km upstream;
- no significant point source pollution within 20 km upstream;
- no dam or major weir within 20 km upstream;
- seasonal flow regime not greatly altered;
- riparian zone of natural appearance;
- riparian zone and banks not excessively eroded beyond natural levels or significantly damaged by stock;
- stream channel not affected by major geomorphological change.

The AUSRIVAS method of river assessment compares indicators from test sites with those at groups of sites representing 'reference conditions'. The approach most commonly used (including Choy – QDNR) has been to select reference sites that are 'minimally disturbed'.

The reference condition simply sets a benchmark against which other sites are compared. In the AUSRIVAS set-up, some reference sites might be close to pristine or they might have some level of disturbance. In some systems, for example, where it is impractical to return to a 'natural' condition, it may be more appropriate to define the reference as a site where best management practice (for flows, land use, etc.) is currently implemented. Deviation from reference condition then indicates the 'room for improvement'. The choice of reference sites acknowledges that the majority of human land uses are not going to be removed from the landscape, and management targets initially should be set so they are meaningful and achievable.

Four possible ways of defining reference conditions to provide useful targets for management are suggested:

1) as having biological integrity and being sustainable;

2) as the conditions that exist when best management practices are applied;

3) as the worst case or negative reference; and

4) as modelled relationships where scenarios representing management actions can be tested.

Recommendation/conclusion

The criteria for selecting reference sites should ensure the setting of ecologically relevant targets.

The current assessment criteria provide a useful guide to selecting reference sites. Further development of the selection criteria could be undertaken, giving consideration to defining 'reference condition' in terms of best management practice. Best management practice should include all aspects of land and water use, because it represents the target to be achieved.

RELATIONSHIPS BETWEEN FLOW REGIME AND RIVER HEALTH

When developing environmental flow recommendations it is crucial to understand how ecological processes and biota are affected by altering components of the flow regime.

A relationship must be established between indicators of river health and flow regime before the effectiveness of environmental flows can be quantified. The development of this relationship is complicated by the lack of data on river health and, at times, a universally accepted definition of river health. The method for developing this relationship has been left to each TAP. Four models have emerged, all of which rely on a process called the 'benchmarking method'.

The relationships presented by the four TAPs have relied at some stage of their development on expert opinion. The experts have had access to some empirical data in developing their opinion, but as yet, the TAPs have not presented empirical relationships. The development of empirical relationships between flows, geomorphology, water quality, biota and ecological processes is seen as a priority, not just for the development of WAMPs but broadly across Australia, and will be discussed later in this report.

A major difficulty, acknowledged by each TAP, is how to separate non-flow effects on river health from flow-related effects. For example, the river health downstream of a major irrigation district will depend not only on the water abstraction for irrigation and the effects of irrigation land use, but also on the management on the river. Some of these issues are addressed by process–response models (see below).

Benchmarking

The benchmarking method is a 'top-down' method that aims to define the environmental flows required to maintain river health. In benchmarking, the degree of departure from the natural flow regime is assessed and related to ecological conditions. These relationships are derived by comparing a range of sites that are subject to varying levels of flow modification. Departure from the natural flow regime is quantified in terms of key hydrological indicators. The benchmarking method was originally developed in the Fitzroy WAMP and further developed in the Barron WAMP[1]. It also forms the basis of the Condamine–Balonne and Logan WAMPs.

In each basin the TAP has developed a suite of flow statistics (from the IQQM) that quantifies the extent of change in the flow regime. The specific ecological and/or physical implications of these statistics for riverine, estuarine and riparian environments have been determined from literature studies and site inspections. The apparent relationship between various flow statistics and the levels at which significant or severe impacts on river health are observed differs somewhat among flow statistics. Benchmark sites can be from within the basin or from rivers in other basins with similar characteristics.

A number of criticisms have been levelled against benchmarking, including:
- the difficulty of separating flow-related changes from non-flow-related changes, such as land use or pollution;
- the differences between rivers in their hydrology and biota, which reduce the validity of benchmarks from other basins;

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[1] Barron Basin Water Allocation Management Plan Technical Report 4, 1999.

- the various types of flow regulation, which are likely to have different types of impact in different river valleys;
- longitudinal problems: upstream reaches may behave differently from downstream reaches;
- the impacts of alien or introduced species on river health;
- that a benchmark does not show how close the system is, in terms of a flow statistic, or a suite of statistics, to possible threshold levels for ecological change — assuming there is a threshold rather than a gradient; and,
- that flow-related impacts may take decades to show up, and so the benchmark system may not be at dynamic equilibrium.

However, if benchmarks are carefully chosen to represent the system that they are to be compared against, they provide a useful guide to the estimated level of risk to which a system might be placed as a result of a particular future development scenario or flow management strategy[2]. Compared to bottom-up methods such as the building-block method, benchmarking is relatively rapid and more conservative.

Benchmarking models used in the WAMPs have been developed to a stage where they provide a framework within which to analyse options, rather than a comprehensive stand-alone assessment method.

In the Fitzroy Basin, the Upper McKenzie was chosen as a site that is at present in a reasonable but somewhat degraded condition. Other benchmarks for this basin were chosen from other river basins that have river systems with significant or severe ecological impacts. In contrast, the benchmarking models used in the Barron WAMP were developed using data from rivers and streams in the Barron catchment only. The TAP recognised that the benchmarking models developed in their study were not transferable to all sites within the Barron WAMP study area. When suitable benchmarks were not available, relationships between flow changes and river condition were not presented.

The Condamine–Balonne TAP used benchmarking sites from within the Basin (16 sites — 55%) and from other basins in similar river valleys in northern NSW (13 sites — 45%).

The Logan WAMP used the benchmarking method for reaches where suitable benchmarks were available. If appropriate benchmarks were not available, process–response models (discussed below) were used to describe the impacts of flow regulation.

Recommendations/conclusions

The Review supports the use of the benchmarking method.

The best available benchmarks should be used. The Review recognises that it is necessary to use benchmarks from outside the basin of interest when there are no suitable sites within the basin. Limitations associated with the chosen benchmarks should be acknowledged.

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[2] Fitzroy Basin WAMP Technical Reports, 1998.

Correlating observed indicators of river health directly with flow statistics

Modelled indicator data sets[3] (X_i), such as a flow statistic, can be directly related with observed ecological, physical or other indicator data (U_i). Significant correlations between modelled hydrological data and river health can provide a tool for making water management decisions based on a 'what if' scenario.

Choy presented the results of such an exercise using AUSRIVAS and other macroinvertebrate-based data for the Condamine–Balonne. The Review strongly endorses the principle of attempting these correlations. Choy presented the results of approximately 140 correlations between modelled flow values and AUSRIVAS indices, of which a proportion was significant. For example, Stream Invertebrate Grade Number Average Level (SIGNAL) was correlated with high flow duration ($r = 0.9$, $p = 0.006$). A similar approach could be used for any observed data sets, such as fish indices.

To relate modelled flow statistics and various measures of ecological condition is a statistically challenging exercise. Simple correlations tell part of the story although there are difficulties in interpreting so many *p*-values, and more complex multivariate analyses may be more appropriate. There might be two aims of these analyses. First, to see which flow variables are the best descriptors of ecological condition, i.e. which of the many relevant flow variables contribute the most to our various measures of ecological condition. Second, to predict ecological condition from flow for new sites, i.e. to develop a predictive model from benchmarking sites and use this to predict condition at new sites. Different techniques may be required for these two aims, and both univariate (a single measure of ecological condition) and multivariate techniques will be relevant. It is unlikely that routine application of traditional statistical modelling techniques (e.g. multiple linear regression) will be straightforward. More robust and sophisticated procedures are likely to be needed, e.g. generalised linear and additive modelling, hierarchical partitioning, neural networks. An appropriately designed survey to increase the amount of relevant observed data would increase confidence in these statistical procedures.

The approach taken by Choy provides a useful initial survey of the available data and supports the value of further rigorous analysis to develop river health–flow relationships. This further analysis provides considerable statistical challenges. It is likely that the approach will involve the use of various complex univariate and multivariate analyses requiring considerable statistical experience. The workshop supports the extension of this analysis from the Condamine–Balonne to other river basins, as suggested by Choy.

Choy also presented correlations of current condition ecological indices (V_i) with modelled river condition indices (Y_i), 'ecological merit score', generated from ecological assessment curves (Figure 1). The current condition indices included data from fish and macroinvertebrate surveys. There is limited value in this analysis because it is attempting to correlate one subjective index (current condition — which has been rated from good to bad via a subjective function) against another subjectively modelled index. It would be more instructive to correlate modelled river condition index (Y_i) directly with the actual raw biological index (U_i). However, even this is not necessary, because we believe it is more appropriate to use the raw flow statistic (X_i) than the modelled river condition index (Y_i).

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[3] This report has used the definitions and notation presented by Vanderbyl and Choy at the workshop. However, we consider the notation confusing and are only using it for consistency with information presented at the workshop. We do not advocate its use outside QDNR.

U_i = observed ecological, physical or other data set (e.g. AUSRIVAS O/E taxa, IBI score, etc.).

X_i = modelled indicator data set (e.g. a flow statistic). Each value is generally expressed as a statistic for a particular modelled scenario divided by the same statistic modelled for the undeveloped (natural) case.

V_i = interpreted/rated value of observed data set (it is generally expressed as a score between 1 and 10).

Y_i = interpreted or rated value of the model data set (ecological merit score derived from ecological response curve).

Figure 1

Fish example from Condamine-Balonne
Richness score (V_i) vs. no flow duration score (Y_i)

$V_i = (f(U_i))$
Current condition index

Linear regression giving r
and p values

$Y_i = (f(X_i))$
Modelled river condition
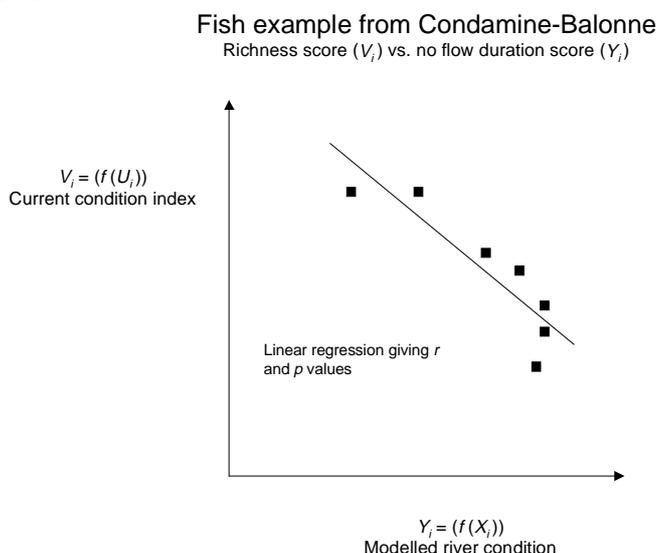
Recommendation

River health–flow relationships should be investigated with various univariate and multivariate analyses, as a research priority. The analyses can involve the use of non-standard statistical techniques and input from a specialist statistician. These relationships will provide an empirical model for assessing the ecological implications of altering the flow regime.


Adaptive assessment approach

The 'adaptive assessment approach', as presented by QDNR, is a process by which decisions are made about the environment's water requirements. The framework is shown in Figure 2. The framework is adaptive and is designed to allow hypotheses to continually evolve, as further data become available. In the framework the current condition of the river (V_i) is assessed using observable biological and physical indices (U_i). Predicted condition is decided upon by interpreting 'ecological merit' (Y_i) from a modelled indicator set (X_i), such as a modelled flow statistic.

The observed condition ratings can then be compared with the predicted condition of a range of sites for which they have been calculated. The procedure for this seems to be:

(i)   use benchmarking to predict ecological condition from flow statistics;

(ii)   test at a new site to see if the predicted condition matches observed condition;

(iii)   if not, then there are two possibilities — either the original benchmarking is not appropriate for this new site or some other process, besides those represented by flow statistics, may be driving change.

The statistical significance of the relation between the observed and predicted condition indicates whether or not the initial hypotheses were valid. If correlations are poor or negative, the original hypothesis should be revised or rejected.

Figure 2
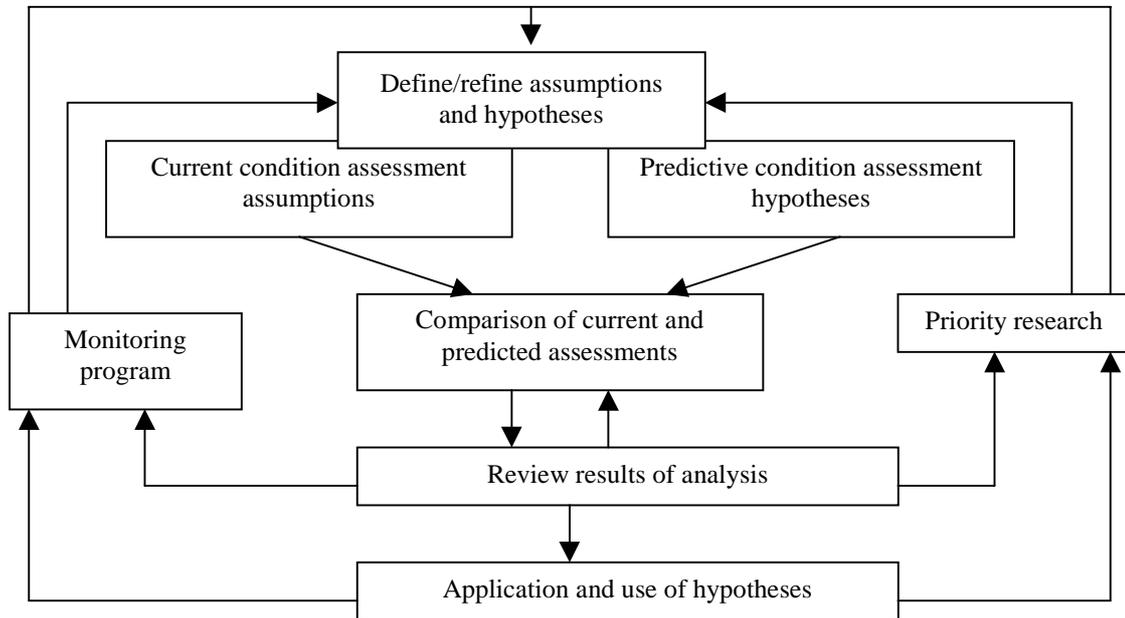
The results of the correlations will be used to

- propose improvements to the current set of indicators, assumptions and hypotheses;
- apply and use the best available set of indicators, assumptions and hypotheses within the context of resource management decisions;
- propose priority areas of research;
- propose priority programs.

There is a strong desire that a common set of predictive assessment hypotheses should be derived for the whole of Queensland. If valid, this would dramatically reduce the time required to produce flow options for the WAMP.

As discussed earlier, the workshop determined that there was little value in attempting to correlate current condition ecological indices (V_i) with modelled river condition indices (Y_i).

Recommendation/conclusion

If statewide river health–flow models are developed, it is recommended that the relationships correlate observable biological and physical indices directly with modelled indicator data sets for a range of flow statistics and sites across Queensland and northern New South Wales.

The overall structure of the Adaptive Assessment Approach presented in Figure 2 (which takes an adaptive management approach of setting hypotheses, testing them as part of the management cycle and then using these outcomes to improve management), provides a sound basis for water resource management. However, the use of ecological assessment curves is not recommended for the reasons outlined below.

DNR's proposed approach to environmental flow assessment

Based on feedback from this workshop, the QDNR has provided a modified approach to environmental flow assessment. This approach is presented in Appendix A.

The approach presented in Appendix A is consistent with the recommendations of the workshop and includes the following steps:

1. identify ecological condition indicators;
2. identify modelled flow (or other) performance indicators; and
3. develop relationships between performance indicators and ecological condition indicators.

These steps are consistent with the recommendations in this report.

Specific comments

Appendix A.1. *Fish*. The Review recommends the following addition: Fish community structure/function, following the IBI model.

Appendix A.2. The Review recommends that performance indicators be more clearly defined (e.g. in terms of a flow statistic, etc.).

Appendix A.2. The Review recommends the following alteration. Select a set of ecologically meaningful performance indicators and couch them in terms of level of change from natural or reference or towards a target.

Not all flow indicators are sensibly expressed in terms of change from natural, but where possible they should be expressed in those terms. The way in which departure from natural should be expressed varies depending on whether the data are numerical or ordinal flow indicators, as follows:

- numerical (e.g. a specific flow rate, such as mean annual flow) — it is appropriate to express change as a proportion of natural (e.g. the proportion of mean annual flow);

- ordinal (indicators expressed as percentages or percentiles, such as flow duration percentile for zero flow) — it is misleading to express these as a proportion of natural, because similar proportions of change have quite different implications depending on the initial starting point (the exception is where an identical starting point is used in all instances). For example, a 50% reduction in the flow duration percentile for zero flow, from an initial starting point of 98, means that a stream that is near perennial (flowing 98% of the time) becomes considerably more intermittent (flowing 49% of the time). The same reduction from an initial starting point of 4 means that a stream that is highly intermittent (flowing 4% of the time) becomes slightly more intermittent (flowing 2% of the time). With these indicators it is recommend that the actual percentiles (not proportions thereof) be looked at.

Appendix A.3. The Review recommends that correlation analysis be replaced by more sophisticated statistical analysis. Correlation analysis may not be appropriate for this task.

The proposed model could be made more generic in the first instance by not explicitly identifying sites on the *x*-axis. Also, if a flow statistic is sampled over time then positions for that site on the *x*-axis may be variable over time. Sites or Basin could be identified with different symbols.

Recommendations

The Review endorses the QDNR's modified approach to environmental flow assessment (Appendix A). The method provides an efficient framework for determining ecosystem requirements for water and the likely ecological consequences of water development.

To refine the benchmarking method the Review recommends that a set of criteria for benchmarking be developed, based on comparison of sites firstly within a basin and then in other basins, where the sites have the following characteristics:

- similar geomorphology;
- similar flow regime type;
- same or close biogeographic region;
- same relative position in catchment;
- as similar as possible land use and presence of alien or introduced biota;

taking account of the time since any upstream dam or weir was built.

Process–response models

The TAP for the Logan Basin WAMP concluded that there were insufficient comparative sites to adequately benchmark the flow regime of the whole basin. For sites where benchmarking was not possible, process–response models were developed.

Process–response models are conceptual models that aim to predict the effect of a change in a flow statistic on an attribute of river health (for example, on community structure or on biodiversity). A model is composed of a description of the mechanisms by which ecological processes are likely to function and how that function will be altered by a change in a flow regime. The model is a 'best guess' of the processes. However, some features of the models are based on field data and known life histories and responses to flow regime.

Process–response models can be represented in a number of ways, such as a box and arrow diagram or as a cartoon. A process–response model can be a useful tool for explaining to community reference panels why certain impacts can be expected in response to particular features of flow regimes. These models are also useful for identifying gaps in knowledge about the basin and for developing research projects to address these gaps, which are important functions of the TAPs.

The validation and application of process–response models, as with the benchmarking method, is compromised by a lack of empirical data and a lack of information from comparable rivers. In the absence of empirical data, process–response models, even though not perfect, provide some basis upon which to make flow management decisions.

The detailed conceptual models that have been developed for the SE Queensland Regional Water Quality Management Strategy (SEQRWQMS) are useful in the development of process–response models.

Recommendations/conclusions

Process–response models are useful tools for generating research questions and for community education. In the absence of suitable empirical data they provide a basis for setting interim flow options.

Process–response models may also be used to integrate empirical information, when it is available. If environmental flow process–response models are sufficiently understood and empirical data have been incorporated, they may be used as predictive tools.

PRESENTATION OF RIVER HEALTH–FLOW RELATIONSHIPS

Relationships between river health and key flow statistics were developed using the benchmarking method for the Fitzroy, Barron and Condamine–Balonne WAMPs. The TAPs chose to present these relationships in different ways. Each TAP assumed that the relationship between a change in the flow regime (key flow statistic) and river health is likely to be non-linear. However, the choice of how to determine and then represent this non-linearity, in the absence of empirical data, varied between the TAPs. The Fitzroy and Barron and Logan TAPs chose to use 'traffic light' diagrams while the Condamine–Balonne TAP chose to derive 'ecological flow assessment curves'.

The most appropriate way of presenting a river health–flow relationship depends, in part, on the audience for which it is being prepared. If the relationship is primarily an educational tool with which to show a basin community how flow and river health are related, then clear, simple visual representations that summarise accepted general concepts and large (or limited) data sets may be appropriate. On the other hand, if the relationship is to be used as a decision-making tool for management, it is appropriate to maintain as much information as possible in the relationship. This could mean presenting a wide range of relationships covering a number of flow statistics and observable river health indices. There was considerable confusion at the workshop about the intended audiences and uses of some of the relationships presented.

Traffic light diagrams

Traffic light diagrams are useful for visualising the ecological outcome of altering a flow statistic.

Flow statistics for benchmark sites can be used to determine the level of change in flow that has significantly and severely affected the health of a river system, using the conclusions developed from the benchmarking method. The trend from 'no impact' through to 'severely impacted' is expressed visually as a change from green (good) to red (bad) on the *y*-axis. Flow statistics for existing and future water developments are plotted. Traffic light diagrams can show temporal data, if monthly flow statistics are graphed on the *x*-axis, for example. This visual approach was used to display the relationships between key flow statistics and environmental outcomes for the Fitzroy, Logan and Barron WAMPs.

Traffic light diagrams are easy to interpret but provide only a broad indication of river health under different development and flow-management scenarios.

Recommendation/conclusion

The Review supports the use of traffic light diagrams. They provide an easily interpreted visual display of the outputs of benchmarking analysis, but the data on which they are based should also be made available.

Ecological assessment curves

Ecological assessment curves were generated for the Condamine–Balonne[4]. An ecological assessment curve describes a general ecological condition (on the *y*-axis) that would be expected in relation to a particular flow statistic (on the *x*-axis). The flow statistic is expressed as a change from 'natural' undeveloped conditions. The general ecological response, termed 'ecological merit' is scored from 0 (bad) to 10 (good). It is subjectively derived from:

- theoretical knowledge of how rivers function;
- published research literature (if available);
- personal scientific knowledge of the sites; and
- site data available for the Condamine–Balonne, some NSW basins, and other river systems.


Recommendation/conclusion

If ecological assessment curves are used, the TAP should indicate what literature, site data and theoretical knowledge were used to generate the estimates of ecological merit — and what the curves actually represent. It should be made clear that the curves do not represent empirical relationships in cases when empirical relationships do not exist.

The 'ecological merit' score was divided into four equal bands: very poor (0–2.5), poor (2.5–5), fair (5–7.5) and good (7.5–10). These bands were chosen because the TAP decided that the community and decision-makers would understand this rating better than an abstract ecological merit value. A major consideration when deriving the curves was that a curve should remain smooth throughout its length and not exhibit any major discontinuities. A ±5% shading line was drawn around the curves. However, there is no formal basis for the extent of the shading, nor for the implication that the (undefined) ecological merit values can be predicted with ±5% accuracy from a flow statistic.

All benchmarking sites were placed on the ecological assessment curves on the basis of the flow statistic for that site. However, the resultant 'ecological merit' score was not plotted against any of the biological or physical river health variables that had been measured. Our understanding is that the 'ecological merit' score is essentially a hydrological descriptor of only imputed ecological significance, and as such adds little, if any, value to the raw flow statistic.

The shape of the ecological response curve was strongly questioned during the workshop. The ecological response curves presented for the Condamine–Balonne were generally smooth, shallow sigmoidal curves (e.g. proportion of median annual flow, APFD; proportion of river impounded) or bell-shaped curves (e.g. proportion of natural 'no flow' duration percentile). It was argued that ecological response might equally well behave as a step function, and that once some critical threshold was reached, a severe response would result (e.g. Figure 3). Further, once a threshold had been exceeded, ecosystem rehabilitation might require an improvement in the flow statistic to well beyond the threshold level — hysteresis. Such a response has been argued for nitrogen eutrophication in Port Phillip Bay, Victoria. The presentation of a smooth ecological response curve implies that there would not be any hysteresis in the system.

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[4] Condamine–Balonne WAMP Technical Advisory Panel Report, 1999.

Figure 3
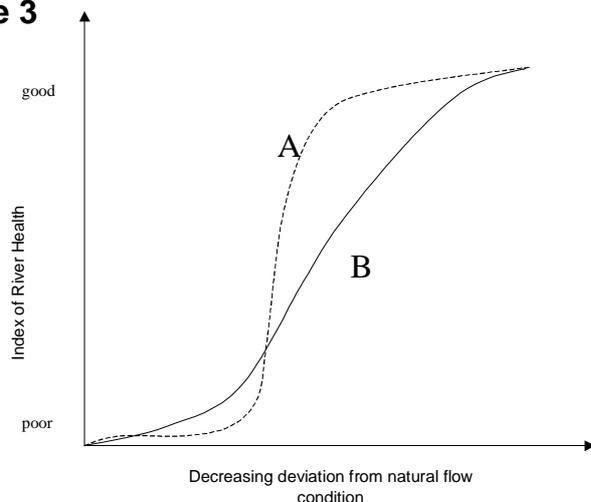
Hypothetical relationship between flow and river health. In example A, there is a threshold in the flow statistic, at which a significant decline in river health occurs. In example B, there is a gradual decline in river health with increasing deviation from natural flow condition. The Ecological Assessment Curves presented for the Condamine-Balonne assume a relationship similar to B.

The workshop discussed the value of combining all individual indices of river health (for example, IBI, AUSRIVAS O/E, Native Fish O/E, Water Quality, Habitat Assessment, etc.) into one score that could replace the hydrologically-derived 'ecological merit'. The Review considers that considerable information is lost when combining individual indices of river health. Rather than combining all ecological condition data into one index, each indicator of river health should be plotted individually against the flow statistic to determine environmental flow recommendations.

Recommendation

The Review does not support the use of ecological assessment curves for the presentation of benchmarking analysis because:

- they are confusing and complicated to interpret;
- assumptions in their development are not obvious;
- they are susceptible to misuse or misinterpretation;
- they appear to present qualitative data and professional opinion in an overly precise and quantitative way;
- an ecological merit score does not add value to the raw flow statistic;
- the shading around the ecological assessment curve has no formal basis, and this should be stated clearly. It is highly probable that the uncertainty associated with such a curve would be considerably greater than ±5%.

APPENDIX A   (received 17/11/99)

QDNR Approach to Environmental Flow Assessment

To date, environmental flow assessments in the WAMP have been based primarily on a process of benchmarking. Benchmarking involves determining relationships between levels of departure from the natural flow regime and environmental conditions. These relationships are determined from assessment of a range of sites subject to varying degrees of flow modification. Levels of departure from the natural flow regime are quantified in terms of key hydrological indicators.

The environmental flows benchmarking technique provides a framework for analysis of environmental condition and environmental flow requirements. As such it differs from most other methods for assessing flow requirements that focus on making flow recommendations for specific sites.

Based on feedback from the River Glen workshop, QDNR is proposing to test a suite of hypotheses to identify the relationships between ecological condition and change to the flow regime; these underpin the benchmarking approach.

Testing process

A.1. *Identify ecological condition indicators*

Depending on availability of data, select appropriate indicators of ecologic condition giving consideration to the following (other indicators may have been recorded by John Whittington):

Fish

Fish community structure/function following IBI method (which needs to be validated for Queensland rivers);

Fish kills;

Exotic:Native ratio (a barrier effect will complicate this assessment — e.g. sites with pristine flow regime may be depauperate if fish do not have access because of a barrier).

Macrophytes

Macrophyte community structure/function including recruitment.

Geomorphologic

Terrestrial vegetation encroachment;

Catchment area/stream width ratio;

Degree of floodplain contraction.

Water Quality

Temperature;

Diel dissolved oxygen;

Riparian width;

Land use type and area.

Ideally ecological condition for each indicator data set would be established with respect to a reference condition, (for example AUSRIVAS O/E taxa).

A.2. *Identify modelled flow (or other) performance indicators*

Select a set of ecologically meaningful performance indicators and couch in terms of level of change from natural. Initially QDNR would focus on modelled flow parameters, using daily flow data from the hydrology model, IQQM.

A.3. *Develop relationships between performance indicators and ecological condition indicators*

Initially, correlation analysis would be used to examine the relationship between performance indicators and ecological condition indicators, as shown in the following diagram.
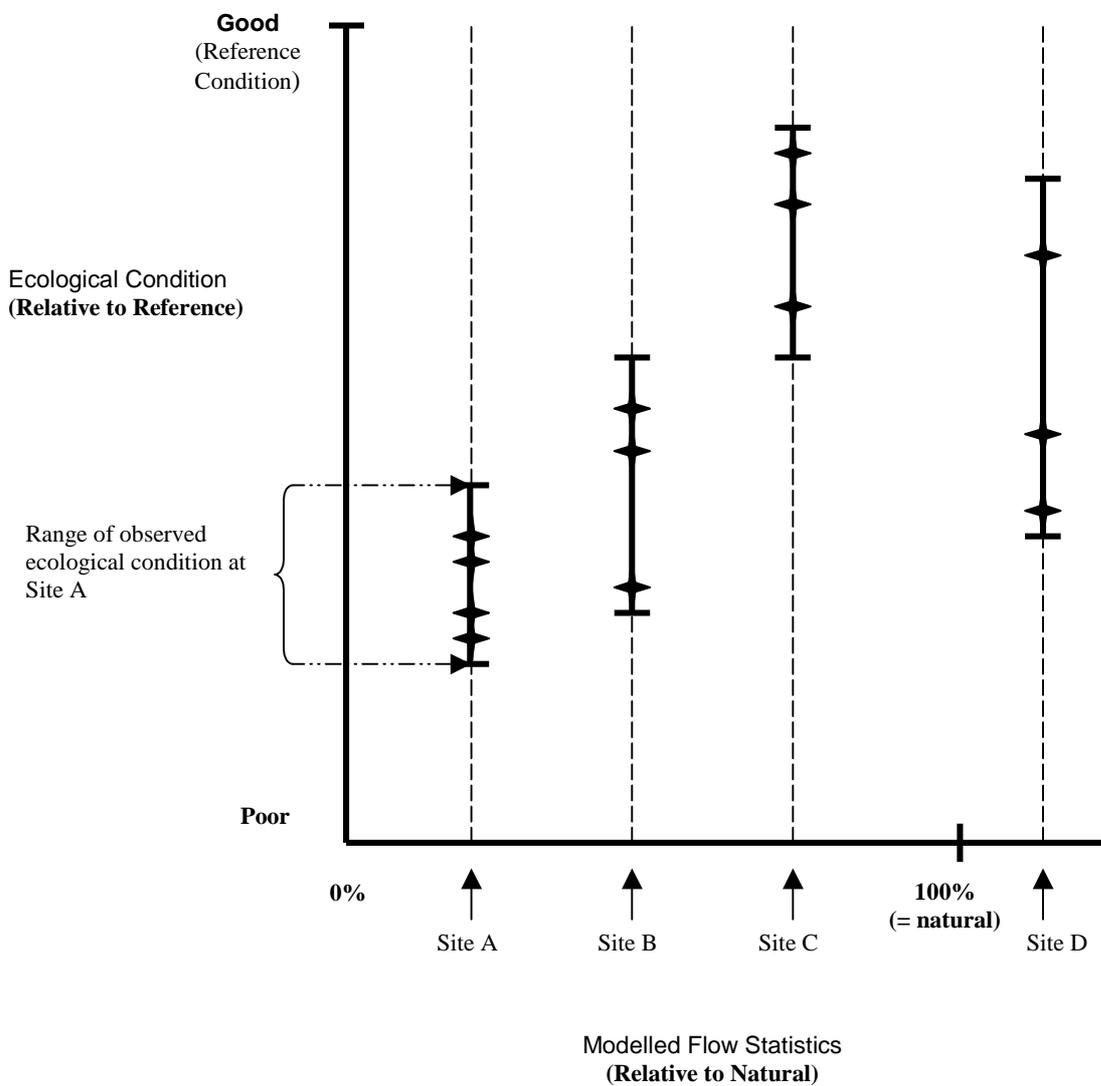
Notes

For any site, ecological condition may be presented by one or more points depending on replicate sampling (for example, condition at each sampling time, or mean and standard deviation for entire sampling period).

Sites within Queensland and the NSW Murray-Darling Basin will be used, provided that data for ecological condition and from a hydrologic model are available.

Data would be processed on a statewide basis followed by regional assessment, as data permit.

To assess the influence of other factors (for example, land-use or water quality), step-wise linear correlation or multivariate analysis, or some other modelling approach such as neural networking would be applied to the same data sets. The amount and type of data will have a bearing on which type of assessment is most appropriate.

Application and use

The proposed testing process is designed to improve the scientific basis for the benchmarking approach. The calibration of modelled parameters such as flow statistics against observed ecological condition will enable managers, scientists and the community to assess future scenarios involving possible changes to the flow regime that may arise from different potential levels of water resource allocation and different types of flow management strategies.

QDNR will be applying the benchmarking technique statewide, and will be using the results of the testing process to improve its understanding of the likely consequence of changing the flow regime, as measured against benchmark conditions.