

# **Development of Relationships between Flow Regime and River Health**

**Outcomes of a Joint Cooperative Research  
Centre for Freshwater Ecology and Queensland  
Department of Natural Resources Workshop**

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Technical Report no. 6/2000



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Printed in October 2000

ISBN 1 876810 36 X

## Development of Relationships Between Flow Regime and River Health

John Whittington Cooperative Research Centre for Freshwater Ecology

This report summarises the proceedings of a joint Cooperative Research Centre for Freshwater Ecology - Queensland Department of Natural Resources workshop to discuss the development of relationships between flow regime and river health held at Clear Mountain Lodge, Queensland on the 31<sup>st</sup> July and 1<sup>st</sup> August 2000.

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## Executive Summary

The Cooperative Research Centre for Freshwater Ecology (CRCFE) and Queensland's Department of Natural Resources (DNR) hosted a 2 day workshop at Clear Mountain Lodge, Queensland, on the 31<sup>st</sup> July and 1<sup>st</sup> August 2000. This report summarises the presentations, discussions, observations and recommendations of the workshop.

The objectives of the workshop were:

- to review progress made by Queensland DNR in response to conclusions and recommendations made by the CRCFE as part of its earlier review of technical elements of the WAMP process in February 2000; and
- to explore issues relating to the definition, measurement and reporting of Ecological Sustainable Management within the context of Queensland's current Water Allocation and Management Planning (WAMP) processes.

The workshop heard presentations on the following key issues:

- Ecologically Sustainable Development (ESD) including issues of its definition, reporting and determination of appropriate spatial scales;
- the determination of flow preference groups of aquatic macro-invertebrates;
- approaches and results of various univariate and multivariate correlations and simulations between flow statistics and macro-invertebrate indices;
- multi-metric scoring for separating flow impacts from non-flow impacts on macro-invertebrates
- results of new approaches for analysing and reporting water quality data sets from across the State, including the use of reference conditions;
- recent enhancements of risk assessment (or traffic-light) diagrams that are used to present risk of ecological degradation in the WAMP's; and
- the potential use of the concepts of Limits of Acceptable Change (LAC) and of Ecological Risk Assessment (ERA) within natural resource management planning processes.

The main observations and recommendations from the workshop follow:.

### **Ecologically Sustainable Development**

- The definition and measurement of 'ecological integrity' is critical for determining whether current and proposed activities are ecologically sustainable.
- It is likely that ecological sustainability should be assessed at the level of ecoregions.
- Protection of high priority rivers from water resource development is likely to deflect development pressure to other regions.
- State-wide assessment and classification of rivers would facilitate the development and prioritisation of planning outcomes based on eco-regions.

### **Development of river health-flow relationships**

- The Resource Science and Knowledge Group (RSK) of DNR has made significant progress towards quantifying relationships between flow and ecological condition of rivers, particularly in the Burnett Basin. The methods developed demonstrate the value of multivariate analyses in developing ecologic condition–flow relationships and simulation models for testing management scenarios.
- The RSK team is commended in its progress and urged to prepare and submit this work for publication in appropriate peer reviewed journals.
- The approaches successfully developed in the Burnett Catchment should now be trialed and developed in other river valleys, where suitable data are available.
- Further development of ecologically relevant flow indices, including the use of hydraulic modelling, should be a management priority for DNR.
- It is likely the most thorough indication of river health will come from a combination of biotic indicators including fish *and* macro-invertebrate indices. Drivers of river health (water quality, physical habitat and flow) are required to interpret indicators of biological condition. However, some components may be more cost-effective than others and dropping some components may not result in a significant loss of information. This is an active area of research within the CRCFE.
- In developing future monitoring programs, consideration should be given to increasing the number of sites at which macro-invertebrate data is collected, the inclusion of other biotic indicators, and the use of indices based on physical habitat and ecological processes. DNR should closely monitor research and development of these indices being undertaken in various research programs with a view to their adoption once they are sufficiently developed and tested.
- The CRCFE recommends that the internal validity and error propagation associated with the multi-variate analyses that are being developed by DNR for developing relationships between flow and river health be investigated through statistical approaches such as bootstrapping.
- The proportion of certain types of habitat change with flow regime. Changes in flow change both physical and hydraulic habitat availability and this will influence or mediate correlations between flow and biota. For example, the area of riffle is very sensitive to flow and consideration of how flow related changes in the relative area of riffle habitat influence the correlation between flow and macro-invertebrates sampled from riffle habitat is required.

### **Development of methods for analysing water quality data**

- Commendable progress has also been made by DNR in the development of methods for critically assessing water quality. RSK are urged to publish this work in peer reviewed journals at the earliest opportunity.
- The CRCFE recommends that the outputs from the water quality models be compared and linked to the outputs from the biological models. This will give clues as to the importance of water quality in river-health assessment in these river valleys.

### **Risk Assessment Diagrams – Traffic Light Diagrams**

- DNR should examine extending the current risk assessment diagrams into basin-wide risk assessment maps that indicate the current ecological condition of the

ivers. These maps could also be used to indicate the spatial dimensions of the risk of ecological degradation under various management scenarios.

- The term 'Environmental Flow Limit' (EFL) is misleading and should be removed. The term limit implies a level of certainty that, given our current knowledge, does not exist. The risk assessment diagram indicates the level of risk of environmental degradation associated with a change in flow statistic by means of a colour coding (green through red). By its definition EFL represents a point at which the Queensland Government proposes that this risk becomes unacceptable. This is essentially a social choice made after being informed by science along-side other social and economic inputs.
- There is a need to explicitly state ecological outcomes in each WAMP. The size and nature of environmental impacts predicted by the risk assessment diagram are not well defined. Currently the diagrams are simply annotated "minimal impact" and "severe impact". It may be useful to attempt fuller descriptions of the colour coding that indicate the likely outcomes associated with different levels of change, eg. "moderate impact resulting in severe loss of ecological processes".

#### **Limits of acceptable change**

- The concept of Limits of Acceptable Change may be a useful tool suited for water resource planning where there are a number of competing goals, and particularly where ESD is the ultimate goal.

#### **Ecological Risk Assessment**

- Ecological Risk Assessment (ERA) frameworks may be a useful tool to guide management of the effects of flow alteration on river health. Research projects to develop ERA frameworks are being undertaken by the CRCFE and others. DNR should monitor this research with a view to trialing this approach should it prove successful.

## Introduction

Choosing an appropriate level of water resource development is a social choice made by the community in light of various social, economic and environmental trade-offs. The role of science in this process is clearly one of informing the decision making process of the consequences system of the various options for the health of the river. Science should also suggest alternative flow regimes to optimise ecological outcomes.

The health of Queensland's rivers is a result of current and past management. In some cases, management has resulted in the condition of rivers falling below what the community believes to be acceptable. Where the community seeks to rehabilitate rivers, science provides the best avenue for defining and choosing between rehabilitation options.

It is a community aspiration that water resource development be ecologically sustainable. While there is not a universally agreed definition of Ecologically Sustainable Development (ESD), the principles of ESD are clearly stated in various Commonwealth and State Acts. A major issue discussed at the workshop concerned the appropriate spatial scales for assessing ESD.

The challenge for science is to identify the consequences of water resource development and the consequences of alternative development options and to indicate actions to rehabilitate degraded rivers. Science has to ensure that this information is communicated in ways that inform the community's decision-making process. These are difficult tasks, and are an area of active research for the CRCFE and other organisations in Australia.

An aim of the workshop was to review progress that the Resource Science and Knowledge group of DNR has made towards understanding and communicating the relationships between river health and flow regime.

Technical Advisory Panels (TAPs) are appointed to the WAMPs to provide the science needed for an informed decision making process. The TAPs, in providing advice to government, have chosen to present scientific information in a number of ways, including the use of risk assessment diagrams. Risk assessment diagrams, commonly referred to as traffic light diagrams, are used to display the likely risk of ecological degradation from water resource development. The workshop commented on the use and interpretation of risk assessment diagrams in the WAMP documentation.

As well as DNR's development of risk assessment diagrams, there are other significant developments taking place in the range of tools for assisting water resource management. These include the development of sophisticated ecological risk assessment frameworks, the concept of Limits of Acceptable Change and the importance of spatial scales in ecological assessment. The workshop heard presentations on developments in these emerging areas.



## Defining Ecologically Sustainable Development

### Overview and Discussion

There is no commonly agreed definition of the term sustainability. Development can be defined as a process of *improvement* with respect to some set of criteria and does not necessarily refer to a change in quantity. Garcia & Staples (2000), as have many others, argued that sustainability is not a stable property of a system that can be defined (and exploited) but rather it is a journey – is what we are doing now driving us in a direction that is sustainable?

The following are a selection of definitions of sustainable development and ecologically sustainable development:

- 'Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.' *World Commission on Environment and Development, 1987.*
- 'Sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable.' *United Nations Food and Agriculture Organisation Council, 1988*
- 'Economic growth which does not jeopardise the future productive base' *Our Country, our Future - A Statement on the Environment, Commonwealth of Australia, 1989.*
- 'Using, conserving, and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased' *National Strategy for ESD, Commonwealth of Australia, 1992.*
- 'Sustainability should be defined as *the indefinite preservation* of:
  - a functional and diverse ecosystem which, as well as meeting aesthetic and ethical requirements, provides a natural resource suitable for (all) human uses and production;
  - a socio-economic system capable of using the natural resource productively to the maximum good of the current and future communities'.*Ecological Sustainability of the Rivers, Review of the Operation of the Cap, CRC for Freshwater Ecology, 2000.*

Fundamental to the concept of sustainability is the need to preserve intergenerational equity. Intergenerational equity requires 'present generations to ensure that a healthy, diverse and productive environment is bequeathed to future generations, ensuring that choices available to individuals and communities are maintained over time' (Chesson and Clayton, 1998). Importantly, Ecologically Sustainable Development requires that both the conditions of the ecosystem, and the people living within it, are either good

or improving. The three core objectives of the National Strategy for Ecologically Sustainable Development (Productivity Commission 1999) are:

- Enhance individual and community wellbeing and welfare by following a path of economic development that safeguards the welfare of future generations;
- Provide for equity within, and between generations; and
- Protect biological diversity and maintain essential processes and life-support systems.

ESD is now established in the legislative frameworks of the Commonwealth and the States. For example, ESD is included in the *Environment Protection and Biodiversity Conservation Act* (CoA, 1999) and in Queensland's *Water Act 2000* (Queensland, 2000). Legislation incorporating ESD defines the principles of ESD. For example, in the *Environment Protection and Biodiversity Conservation Act* (CoA, 1999) the principles of Ecologically Sustainable Development are listed below – and these are very similar to those in the *Water Act 2000*:

- (a) decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equitable considerations;
- (b) if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;
- (c) the principle of inter-generational equity—that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;
- (d) the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making;
- (e) improved valuation, pricing and incentive mechanisms should be promoted.

Principle (d) relates to ecological sustainability, and it directly states that conservation of both biodiversity and ecological integrity are fundamental considerations.

Biodiversity is conceptually easy to define, measure and report against, though in practise it is very difficult to quantify. Ecological integrity is not nearly as explicitly defined and with techniques currently available is not quantifiable. The concept of ecological (biological) integrity as defined by Norris and Hawkins (2000) is provided:

"As conceived of by Karr (1981), biological integrity would be best defined as an aggregate measure of individual, population, community, and ecosystem attributes. This idea is based on the concept of biological integrity first articulated by Frey (1977) and later restated by Karr & Dudley (1981). Frey defined biological integrity as '*the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region*' (1977 p. 128). He expanded further on this idea by stating: '*Such a community can accommodate the repetitive stresses of the changing seasons. It can accept normal variations in input of nutrients and other materials without disruptive consequences. It displays a resistance to change and at the same time a capacity to recover from even quite major disruptions*' (1977 p. 128). Biological integrity as Frey defined it, and Karr

applies it, would also be measured by comparing observed conditions with those expected to occur in the absence of human alteration to a system."

Following discussion at the workshop, the following points emerged:

- The definition and measurement of 'ecological integrity' is critical for determining whether current and proposed activities are ecologically sustainable.
  - Ecological integrity, as Karr applies it, compares current condition to pristine condition. Any movement away from pristine condition is considered a reduction in ecological integrity. However, this definition provides limited guidance as to how to assess whether the current management is setting conditions that move us towards sustainability. Ecological condition includes information on the ecological processes and on community and habitat structure. It was argued that we currently do not have tools to adequately measure ecological processes and therefore ecological integrity.
  - The use of pristine as reference is problematic for many streams and rivers. There may be few, if any, reference sites that are pristine or minimally disturbed with which to compare. In many regions, minimally disturbed is an inappropriate management objective. Other reference systems to use as comparisons include best available management practice and negative reference (i.e. "benchmarking" sites as used in WAMP).
- The appropriate spatial scale(s) for conserving biodiversity and ecological integrity to fulfil the requirements of ESD requires further investigation. For example, do biodiversity and ecological integrity have to be maintained (or improved if degraded) for river reach, for each Basin, or at the State level or at the National level? This question is discussed further in the following section, Spatial Scale of Sustainability.

## **Spatial Scale of Sustainability**

### ***Overview and Discussion***

The workshop considered the appropriate spatial and temporal scales for assessing ecologically sustainable development. Currently, assessments of river health are carried out at the scale of a river basin through the WAMP and WMP processes. Within this framework, there is limited guidance as to what scale ESD should be assessed. For example, does each node within the river valley have to be assessed as ecologically sustainable before development within the river valley can be considered ecologically sustainable? Similarly, does water resource development in each river basin (ie. the scale of a WAMP or WMP) require the same maximum level of risk of ecological degradation across the State? Or are there river basins with a higher conservation priority and those with a lower conservation priority, in which a greater risk of ecological degradation would be tolerated provided that those of higher priority are conserved and protected?

Arguments were presented for a State-wide assessment and classification of Queensland's rivers that would indicate the current ecological condition, threats to current ecological condition and conservation status (presence of rare species, habitats or processes etc) of rivers. This has been recommended several times previously (e.g. Arthington 1997; and written submissions to EPA by CCISR). Such a classification would provide a State-wide context for natural resource planning processes by targeting areas of highest conservation value and areas of lower conservation value – perhaps suitable for further water resource development – the rationale being that water resource planning may be prepared to take greater risks of ecological degradation in the lower priority conservation areas. Queensland EPA (with funding from LWRRDC) has recently released a review of such methods and is developing a set of protocols that will be examined for their potential use nationally.

During discussion at the workshop, the following points emerged:

- Catchments may not necessarily be the appropriate spatial units for assessment of ecological sustainability – though in some catchments they may be a suitable unit for assessing ecological sustainability. Alternatively, the appropriate unit is likely to be defined by the biological, physical and chemical characteristics of the region.
  - Recent studies with fish have identified eco-regions within catchments that are clearly identified by genetic differences within species. The identification of these eco-regions is helpful for assessing the influence of water resource development on biodiversity. However, eco-regions may not be consistent for different species and therefore choosing between eco-regions identified by a range of aquatic species would be required.
- All scales of water resource development need appropriate management.
  - There is a temptation to consider certain areas that are unavoidably degraded by water resource development as 'sacrificial areas'. For example, a river immediately below a major dam that releases water for irrigation causing a seasonal inversion of flows. A danger with the concept of these being 'sacrificial areas' is that they will receive little or no management (because they are being sacrificed) – when in reality they are the areas that may need the most intensive management. The alternative “don't raise the Titanic” concept was also discussed, which suggests that conservation funding may be better spent on less degraded systems. A catchment-wide overview of each and all potential water resource developments would be needed to evaluate the importance to system integrity of particular stream reaches and tributaries. The need for this overview has been recommended in the Burnett TAP.
- Protecting high priority rivers from water resource development can deflect development pressure to other regions.
  - For example, the commendable protection proposed for the Paroo River through the draft Water Management Plan (WMP) may deflect development pressure to other dryland river systems. Also, tightening of water resource development in other States (eg. the Cap in the Murray-Darling Basin), is likely to increase development pressure in other Queensland valleys. This reinforces the need for a pro-active State-wide planning process, particularly for the undeveloped water resources. It also supports the argument that ESD

planning should be undertaken at large (State-wide) scales. Some conservation goals will also extend beyond the State level, e.g. endangered species distributions may extend into several states.

- The *Heritage Rivers Act* (1992) of Victoria is an example of legislative protection for a river.
  - The purpose of the Act is to make provision for Victorian heritage rivers by providing for the protection of public land in particular parts of rivers and river catchment areas in Victoria which have significant nature conservation, recreation, scenic or cultural heritage attributes and to make related amendments to other Acts. The Act provides a range of protection that primarily affects planning and development on the river and in the catchment. The *Heritage Rivers Act* (1992) has influenced the development of catchment management plans.

## Linking Ecological Condition to Flow

### **Overview and Recommendations**

The Resource Science and Knowledge (RSK) group of DNR have investigated river health–flow relationships, predominantly in the Burnett Basin, using a series of analyses, including univariate and multivariate correlations and simulations. The aim of developing these analyses is to better interpret the complex relationships between altering flow regime and the biological data collected by DNR.

In November 1999, the CRCFE was presented with preliminary univariate analysis of river health–flow relationships developed for the Condamine-Balonne Basin. The recommendation of that review (see Whittington 2000) was that multivariate correlations be attempted. The CRCFE argued that in reality, river health is influenced by, or correlated with, many variables and therefore we would expect multivariate analysis to better represent the relationship between flow and biotic variables. Also, multiple univariate analysis inflates Type I errors—each individual univariate analysis adding to the chance that one of the null hypotheses of no correlation will be rejected due to error.

In Queensland, as with most of Australia, macro-invertebrate data, collected as part of the NRHP and other programs, provide the most comprehensive spatial and temporal coverage of the possible biotic indicators. However, there are large parts of Queensland, particularly in the west of the State, with very limited coverage. Also, site selection for much of the macro-invertebrate data was not done to optimise assessment of flow–river health relationships. Despite these shortcomings, macro-invertebrate data sets provide the most appropriate data with which to start developing river health–flow relationships in Queensland.

The analyses linking ecological condition to flow presented by DNR were based on the available macro-invertebrate data, particularly from the Burnett Basin, and included:

- the determination of flow preference groups of aquatic macro-invertebrates at the family level, which showed three flow preference groups: high, low and no preference;
- uni-variate correlations and graphical analyses, which indicated a small number of weak relationships between various flow statistics and macro-invertebrate indices;
- multi-variate correlations, which indicated several significant relationships between flow statistics and macro-invertebrates from riffle habitats;
- multi-variate simulations, which were used to simulate the effects of three management scenarios on macro-invertebrate indices and were in agreement with predictions using process-response models; and
- multi-metric scoring, which showed promise as a method for separating flow impacts from non-flow impacts on macro-invertebrates.

Following discussion at the workshop, the following comments and recommendations with respect to linking current ecological condition to flow were made:

- Significant progress has been made towards quantifying relationships between flow and ecological condition of rivers, particularly in the Burnett Basin.
- Progress presented at the workshop and documented in the report *Ecological Relationships Between Flow Regime and Ecological Condition in Queensland Rivers* (DNR 2000) demonstrates the value of both multivariate analyses to develop relationships between ecological condition and flow and simulation models to test management scenarios.
- It is critical that water resource management provides clear ongoing direction to RSK to maintain the relevance of their output to water resource management.
- The RSK team is commended in its progress and urged to prepare and submit their work for publication in appropriate peer reviewed journals.
- The approaches successfully developed in the Burnett Catchment should be trialled and developed in other river valleys, where suitable data are available.
- River health–flow relationships should be developed within a regional scale conceptual framework and be hypothesis-driven. Conceptual frameworks linking river flow and condition are presented in a number of TAP reports (in particular, Barron, Logan and Pioneer) and a DNR funded project by Griffith University is developing process-response models as the basis for analysing relationships between flow regime, fish community structure and life history processes.
  - Regional and catchment scale characteristics such as geology, topography, climate and land-use influence local scale habitat characteristics, which in turn influence the biota. Consequently, assessments of river health based on biological indices may integrate the effect of impacts on river health at the regional scale.
  - Flow regime is an important driver of river health but so too are land use, land management, water quality and habitat availability. The complex task of differentiating between the flow and non-flow drivers of river health is

strengthened by the use of conceptual diagrams and process response models. Such models are being developed for the Pioneer (research funded by DNR carried out at Griffith University).

- The development of ecologically relevant hydrological indicators should be a management priority for DNR.
  - Many different flow statistics can be used to describe the hydrology of a river, however some will have more ecological merit than others. A management priority for DNR, and a research priority for the CRCFE, is to identify hydrological indicators with the greatest ecological merit. There are opportunities for collaboration between the CRCFE and DNR in this task, and these opportunities should be pursued. For example, the CRCFE project *Characterisation of Flows in Regulated and Unregulated Streams in Eastern Australia* (Growns and Marsh 2000) addresses the question of how to classify river hydrology using a small number of variables that have ecological merit. User-friendly computer software is currently being developed by the CRCFE for calculating these flow statistics from gauged data (contact M Thoms).
- Broader scale hydrological variables predicted by IQQM can be used in the development of river health–flow relationships.
  - Not all of the biological data available in the Burnett Catchment have been used in the development of river health-flow relationships because of a lack of corresponding gauged hydrological data. There is potential to use modelled data when accurate gauged data are unavailable. The predictive capabilities and sensitivity of IQQM are major considerations in this. However, some of the larger scale hydrological variables, such as flood return frequency are adequately modelled with the current IQQM and these can be included in ecological model development.
- Hydraulic modelling should be investigated as a method for better defining ecologically important flow statistics.
  - It is likely that stronger relationships between river health (as measured by macroinvertebrate indices) and flow can be obtained with flow statistics that better describe the changes in hydraulic characteristics of the river (e.g. flow depths, velocities, the frequency that discharge required to mobilise bedload is exceeded etc). This type of information will come from hydraulic modelling at sites where biological data have been collected. One approach for linking hydraulic conditions to river health is to model the effect of hydraulics on physical habitat and then correlate changes in physical habitat with the biota. Several TAP's (Pioneer, Burnett and Logan TAP's) have used hydraulic information as an integral component of their studies. The Burnett WAMP included assessments of water resource development on hydraulic habitat (e.g. daily exceedance duration of 10 and 30cm depth etc).
- The best indication of river health will come from a combination of biotic indicators, including fish *and* macroinvertebrate indices. Data on fish, aquatic macrophytes and hydraulic habitat has been collected at numerous sites in Queensland's coastal rivers by Griffith University and could be analysed as suggested.

- Different taxa are likely to show different responses to changes in the flow regime. Consequently, if one taxon does not respond to a flow statistic, it does not necessarily mean that the particular flow statistic is irrelevant to other taxa or other measures of river health. Arguably, indicators based on fish may be more responsive to long-term alterations in flow than macroinvertebrates (for example, fish passage may be highly vulnerable to reductions in stage height), although the best index of river health will incorporate a number of biotic indicators, including fish and macroinvertebrates. Aquatic and riparian vegetation respond to changes in river flows (e.g. changed zonation of riparian vegetation, growth of dense beds of macrophytes, weed invasion) and could become a key biotic indicator. Biotic indices should be reported individually, even if they are aggregated to provide an overall condition score. This is the approach being adopted in the Sustainable Rivers Audit (SRA, see Cullen et al 2000), the National Land and Water Audit and also research to develop a suite of river health indicators using fish is being undertaken for Queensland rivers (Kennard, PhD candidate, CRCFE).
- DNR should closely monitor research and development of indices for physical habitat and ecological processes being undertaken in various research programs with a view to their adoption once they are sufficiently developed.
  - Relationships between flow and physical habitat (availability and condition), and between flows and ecological processes (eg production/respiration ratios) are being developed in a number of research programs for Australian conditions. How habitat is influenced by alterations in flow is critical to understanding the biological outcomes of river management. What constitutes habitat is defined by the organisms using it – therefore it is important that the link between physical indicators of habitat and biota, such as fish and invertebrates, are known or included in such analyses.
- In developing future monitoring programs consideration should be given to improving the spatial coverage of macroinvertebrate data, the inclusion of other biotic indicators and the use of indices based on physical habitat and ecological processes.
  - DNR faces a critical resource allocation decision; improving the spatial coverage of the macroinvertebrate data and/or increasing the number of biotic indicators collected, for example, including a fish index. The CRCFE argues that both of these approaches need to be investigated. Process-response models and statistical models will help with this decision. The Sustainable Rivers Audit currently being developed will provide guidance in site selection and sampling protocols. The SRA will provide an indication of the number of samples required to achieve a desired confidence level for an indicator at the river valley scale. Similar work is being undertaken in other CRCFE research, for example, "Development and Implementation of Baseline Monitoring" project.
- The CRCFE recommends that the internal validity and error propagation associated with the multivariate analyses be investigated through statistical approaches such as bootstrapping.
  - There is a need to consider error propagation when using multivariate methods. Multivariate analyses provide information about relationships



between variables, however they provide no information on the replicability of these relationships. Several techniques can be used to get an estimate of the replicability of results from multivariate analyses, such as cross-validation, jackknife and bootstrap techniques. There is also an issue with a series of linked correlations. If A is correlated with B, B with C and then C is used to predict D, how much error in the prediction is due to errors in A, B and C? Additionally, some of the relationships presented at the workshop had no indication or prediction error. Re-sampling techniques can help with that.

- Consideration needs to be given to how flow-related changes in the relative area of riffle habitat influence the correlation between flow and macroinvertebrates sampled from riffle habitat.
  - Multivariate correlations and simulations were undertaken with the macroinvertebrate data. In the Burnett catchment strong correlations were found between riffle samples and flow, but only weak correlations with edge and pool samples. The relative amount of riffle habitat is strongly influenced by flow and that this needs to be considered when interpreting these analyses. Process-response models would assist in refining such flow-invertebrate relationships.
- Macroinvertebrates collected from edge habitats may show stronger correlation with flow in lowland river systems than sites tested in the Burnett Basin and this should be investigated as the analysis is extended to lowland river systems.
  - The lack of riffle habitat in lowland rivers raised the question of the usefulness of macroinvertebrate models in lowland rivers. However, it was argued that in lowland rivers, macroinvertebrates collected from edge habitats may show stronger correlations with flow than in coastal and upland rivers. This is because the edge and snag habitats in lowland rivers are areas that are significantly disturbed by changes in flow with the wetting and drying regime of the littoral area affecting the biofilm and macroinvertebrates present. Also, under some flow conditions, significant accumulations of organic material occur in edge habitats that will affect macroinvertebrate populations.
- The definition of appropriate reference states remains one of the major challenges for effective water resource condition assessment.
  - In many systems minimally disturbed (or pristine) condition does not provide an appropriate reference condition, either because there are no minimally disturbed sites or minimally disturbed is an inappropriate management goal. Apart from minimally disturbed there are several other ways of defining reference condition that may overcome these difficulties. These include the use of negative reference conditions (representing what we don't want to happen, e.g. the concept of benchmarking against degraded sites as employed by TAP groups in WAMP) and good management practise. Defining good management practise may be difficult when there are multiple land and water uses in the catchment. The concept of using good management practise recognises that we are not attempting to remove humans from the landscape – therefore how good ecologically can a river be in a particular situation (surrounded by some land use) and what things do we need to do to get it into that state. If we can do this we can then define sites with those attributes that will be reference condition. The CRCFE is undertaking several projects

investigating the use of different reference models (contact R Norris). The SRA will be considering alternate reference models in the next six months.

## **Development of Methods for Analysing Water Quality Data**

### ***Overview and Recommendations***

RSK has developed a reference approach for the assessment of water quality in Queensland as part of a program to determine where efforts to improve water quality are likely to lead to improvements in river health. The approach developed is based on the philosophy behind the models developed in AUSRIVAS, where water quality at a test site is compared to predicted water quality using information collected from reference sites.

To date there has been limited consideration of water quality data sets in the development of the WAMPs and WMPs, however the Burnett and Pioneer TAPs have considered some water quality information. DNR has a long history of water quality monitoring at a large number of sites across the state. The Department's water quality database contains approximately 34,000 water quality data sets from 1,462 sites. However, an assessment of the usefulness of these data, based on representativeness of the data, indicated that 694 sites had sufficient data for preliminary assessment and of these, 166 sites had moderate or better data. This simple assessment indicates the value of critically reviewing water quality data collection in Queensland and elsewhere.

These data were used to assess water quality in SE Queensland. This assessment found that water quality was relatively poor in SE Queensland when assessed against various published guidelines.

The following recommendations are made with respect to the methods for critically interpreting water quality data developed by DNR:

- Commendable progress has been made by DNR in the development of methods for critically assessing water quality.
- RSK are urged to publish this work in peer reviewed journals at the earliest opportunity.
- The CRCFE recommends that the outputs from the water quality models be compared and linked to the outputs from the biological models. This will give clues as to the importance of water quality in river-health assessment in these river valleys. For example, are poor macroinvertebrate scores correlated with poor water quality scores?

## Risk Assessment Diagrams [traffic light diagrams]

### ***Overview and Recommendations***

Risk Assessment Diagrams or '*traffic light diagrams*' have been developed by QDNR as a graphical method for displaying ecological risk associated with changing flow regime. Traffic light diagrams aim to inform the decision making process of the likely consequences of various water resource development options. The CRCFE have previously recommended the development and use of traffic light diagrams for this purpose (Whittington 2000). Traffic light diagrams show the risk of unacceptable environmental degradation associated for each flow statistic and have been generated for several flow statistics in each river basin.

The Burnett TAP for example, estimated environmental impacts of existing levels of water resource development on a five-point scale. Hydrological and ecological impacts were combined to identify levels of environmental impact expected from alterations in flow statistics. These become the benchmark sites.

The Burnett TAP identified two levels of development using benchmarking data. Level 1 represents a value of the flow statistic above which benchmarking sites showed little or no impact. Level 2 represents a value of a flow statistic below which benchmarking sites identified major impacts due to flow regulation. The TAP advised that they would expect little or no environmental impact of water resource development while the flow statistic remains above Level 1 and probable major impacts of water resource development if it caused the flow statistic to fall below Level 2.

The Environmental Flow Limits (EFLs) which are set by the Queensland Government within a WAMP represent "the levels of change beyond which there is considered to be an increased risk of environmental degradation" (p. 18 draft Burnett WAMP). The draft Burnett WAMP proposed that "EFL's be set at 2% above the level 2 values" that had been identified by the TAP, and indicated these levels on the traffic light diagrams.

The Planned Development Limits (PDL) were also plotted onto the traffic light diagrams for various management scenarios proposed by the Queensland Government within the draft Burnett WAMP. The PDL's were defined in the draft Burnett WAMP as representing "the levels of deviation from the environmental flow limits that would accommodate existing and future water development and water usage in the Burnett Basin" (p18. draft Burnett WAMP).

DNR has generally generated and displayed traffic light diagrams for various nodes (sites) in the river basin. The method of presentation does not give a full appreciation of the localised spatial variations in the indicators. For example, if a node is located immediately below a dam and upstream of a major tributary, the hydrological and ecological assessment while accurate for the node, would be quite different upstream and downstream of the site. Also, data exist for more nodes than are shown by traffic light diagrams in the Water Allocation Management Plans.

The data used to develop the traffic light diagrams presented in the WAMP's are distilled from a number of more comprehensive reports. For example the traffic light diagrams in the Burnett Basin Draft WAMP (2000) were developed from the:

- Burnett Basin Condition and Trend Report DNR 2000;
- Burnett Basin WAMP: Current Environmental Conditions and Impacts of Existing Water Resource Development, Volume I and II. TAP 2000; and
- Burnett Basin WAMP: Proposed Environmental Flow Performance Measures. S Brizga and Associates, 2000.

The Department has made each of these reports available to the public.

Following discussion at the workshop, the CRCFE makes the following recommendations:

- DNR should examine extending the current risk assessment diagrams into basin wide risk assessment maps that indicate current ecological condition of the rivers.
  - Colouring reaches on a map of the Basin's rivers to indicate ecological condition can achieve this [care should be taken with the colours so as not to confuse current condition assessment with risk associated with future development]. It is understood that there are limited data to construct these maps and so care will be needed to indicate the nodes from which measured data exist. The condition of the remaining reaches may be modelled. The National Land and Water Audit is developing techniques for modelling river condition from a limited number of sites that will help in this process.
- These risk assessment maps could also be used to show the spatial dimensions of the risk of ecological degradation for various management scenarios.
  - These maps would be complimentary to the ecological condition map. Such maps would provide a spatial context for the existing traffic light diagrams giving estimates of the likely spatial extent of the risks associated with various developments.
  - The spatial extent of impacts can only be mapped if the details of that scenario are adequately described (e.g. impacts of all key flow indicators and details of the nature and location of any associated infrastructure).
- The use of the term 'Environmental Flow Limit' (EFL) is misleading and should be removed.
  - The vertical axis on the traffic light diagrams represents an increasing risk (moving from green which represents limited or no risk through yellow to red which indicates a high risk) of environmental degradation associated with a change in that flow statistic. The EFL represents a point at which the Queensland Government proposes that this risk becomes unacceptable. This is essentially a social choice made after being informed by science along-side other social and economic inputs. However, there is no clear indication of what is meant by an "unacceptable" level of risk and it is unclear as to how risk averse the Queensland Government is effectively being in setting the EFL's.
  - The severity of environmental degradation at the level of risk represented by the EFL is not defined. What are the biological consequences of this level of environmental degradation? It appears that the EFL line represents an unacceptable risk of *relatively minor impact* when compared to levels of

- impact in many rivers in southeastern Australia. This highlights one of the key issues associated with risk assessment. The relationship between risk and impact will depend on the size of the impact. The problem with the EFL used in the draft WAMPs to date is that it states risk as being 'unacceptable' without commenting on the size or nature of the impact.
- The EFL turns subjective judgements made by the Queensland Government, using TAP Levels 1 and 2, into hard lines. Such a limit indicates a degree of certainty that, given our current level of knowledge, does not exist. The reason for introducing a colour gradation (in the form of a traffic light diagram) was to indicate both the uncertainty associated with our knowledge and that different interests tolerate different levels of risk. That the proposed development limit is often below the EFL indicates that the Queensland Government is prepared to accept a greater level of risk of environmental degradation than the Line 1 and 2 benchmarks identified by the TAP.
  - Currently the diagrams are simply annotated “minimal impact” and “severe impact”. It may be useful to attempt fuller descriptions of the colour coding that indicate the likely outcomes associated with different levels of change, eg “moderate impact resulting in significant loss of structural elements of ecosystem” or “major impact resulting in severe loss of ecological processes”.
- There is a need to explicitly state ecological outcomes in each WAMP.
    - Environmental flow objectives identified on the traffic light diagrams are essentially hydrological, although there is ecological input into the setting of these objectives. Nationally, the focus is moving from the reporting of drivers of river health (flow, water quality etc) toward reporting and evaluating biological outcomes (eg AUSRIVAS, IBI etc). The drivers of river health still require reporting, however, as they remain important management strategies for the achievement of biological outcomes. While there is a requirement in the Draft WAMP (Burnett Basin) 2000 to monitor aquatic ecosystems with respect to various matters (Sect 16.1) this monitoring is not specifically linked to the achievement of ecological outcomes. Therefore, it is not possible to assess performance towards the overall purpose of the plan "...provide a framework for the sustainable allocation and management of water in the plan area". Examples of possible ecologic outcomes that might be included in a WAMP are: maintain breeding of native fish (species X,Y,Z) in this reach, or maintain in-stream, riparian and wetland vegetation etc.
    - It has been noted subsequently to the workshop that the environmental implications of the proposed plan development limits associated with draft WAMP scenarios are being evaluated in the third stage of the TAP process (which is currently underway in the Burnett and Barron WAMPs), and it is expected that explicit statements of likely outcomes of each of the WAMP scenarios will be made based on these assessments.

## Limits of Acceptable Change

### *Overview and discussion*

Society has a number of goals it seeks to achieve with water resource management. For example, two goals that are potentially in conflict are to maximise agricultural production through consumptive use of water and to maintaining ecological integrity of the water resource. The WAMPs and WMPs aim to strike a balance between the various competing demands on a water resource. That balance is described by achieving the principles of Ecologically Sustainable Development. In the United States a concept of *Limits of Acceptable Change* has been developed to assist management of natural resources to optimise community goals and values. The concept of *Limits of Acceptable Change* was presented at the workshop as an example of an alternative approach for assisting decision making for situations where there are competing demands on a water resource.

The concept of *Limit of Acceptable Change* was developed as a tool for managing natural resources when there are multiple and conflicting goals for use. An implicit assumption of *Limit of Acceptable Change* is that natural resource use has an impact, and that impact has to be managed so that it doesn't exceed a pre-determined acceptable level.

The *Limit of Acceptable Change* requires that:

- the resource is divided into zones for which an ultimate management goal and any subsidiary goals are identified;
- an acceptable level of impact on the resource is agreed *a priori* (Limit of Acceptable Change). Not allowing impact to exceed this ensures the ultimate goal is met;
- subsidiary goals are optimised without compromising the ultimate goal;
- measurable standards which will secure the ultimate management goal are identified;
- regular monitoring and reporting of indicators is undertaken to determine whether standards are being met – is the level of impact acceptable?; and,
- if standards are threatened then management has to be altered to remedy the problem – failing this, the standards have to be revised.

The example presented to the workshop was the use of *Limit of Acceptable Change* to manage camping access in forested wilderness regions in the United States. The issue was how to manage recreational campers at identified forested sites whilst retaining wilderness values of the forest. Physical indicators for measuring the impact of camping were developed (for example, the amount of exposed tree roots) and a standard for forest camping sites set. This indicator was measured frequently. Once the indicator approached the standard set (the limit of acceptable change that would result in the threat to the wilderness values of the forest) then the campsite was closed, camping moved to another area and rehabilitation of the campsite undertaken.

The concept of *Limits of Acceptable Change* is useful when:

- attempting to resolve conflicts between several goals,
- a hierarchy of goals can be established when one is ultimate and constrains others,

- all goals can be compromised to some extent, and
- standards can be identified and are able to be monitored.

The use of *Limit of Acceptable Change* may prove to be a useful tool for water resource management in the future. We have some understanding of the elements that influence river health, for example flow, riparian condition, pollutants, habitat quality and quantity and measures of river health are being developed for example, AUSRIVAS and the indicators being developed for the Sustainable Rivers Audit and other projects.

To use *Limit of Acceptable Change* requires goals for the desired condition of the river system to be determined. This is a social choice made by community and governments. The choice has to be informed by the best available science. In setting goals, standards that define the goal will be determined. These standards will not be targets of desired condition; rather they represent the limit of acceptable change. If river condition falls to the standard, then river management is failing. If a standard is breached for more than some specified period, then the goal has to be redefined and management has failed to deliver its goal.

*Limit of Acceptable Change* has been developed and used in natural resource management in the US. The tool may be useful for use in water resource planning where there are a number of competing goals, and particularly where ESD is the ultimate goal.

## Ecological Risk Assessment

### ***Overview and discussion***

Ecological Risk Assessment has been developed as a process for determining the level of risk posed by multiple stressors (for example, biocides, heavy metals, nutrients, salinity, altered flow regime) to survival and health of an ecosystem. Risk assessment seeks to account for both the complexity and variability of natural ecosystems. There are three components to risk; the likelihood of an adverse effect occurring, the consequences of that event and the timeframe over which the risk is considered. A matrix can be constructed which expresses the likelihood of an event occurring against the consequences of the event occurring. Obviously, those events or actions leading to a high likelihood and severe consequences are those that must be avoided.

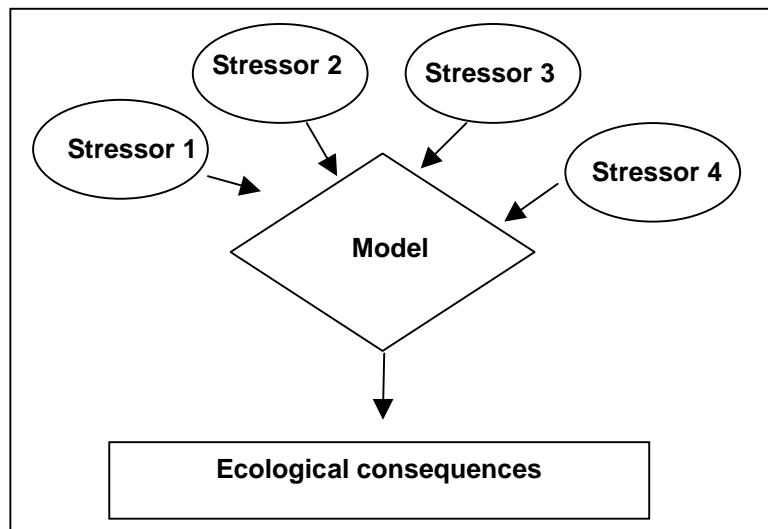
Undertaking an Ecological Risk Assessment requires a model to be developed that predicts the ecological consequences of a range of stressors acting either singly or together (Fig 1).

The current challenges with this approach include:

- the large number of target species and the complexity of ecosystems;
- incorporation of variability into the risk assessment;
- therefore what are the critical end points or ecological consequences to be targeted;

- determining what is an acceptable level of risk (this is linked with acceptable level of change); and
- the assessment often relies on subjective judgements, but these judgements are made as explicit and as transparent as possible.

Figure 1 Conceptual Model of ERA for each major ecological sequence.



Currently, ecological risk assessment has been used in the development of the ANZECC/ARMCANZ Water Quality Guidelines. A number of projects are being undertaken to advance the use of ecological risk assessment, including Ok Tedi Mining – health and environmental risk assessment and Norske Skog Paper Mills (Aust) Ltd – Boyer Mill effluent discharge into the Derwent Estuary. Research programs have also been designed to advance the development of ecological risk assessment frameworks including projects in the CRCFE and in the LWRRDC/MDBC river contaminants program.

- Discussion following this presentation indicated that ecological risk assessment frameworks might usefully be applied in managing the effects of flow alteration on river health. Research projects attempting this in the CRCFE and elsewhere should be monitored by DNR with a view to trialing this approach should it prove successful.
- There may be scope to link ERA approaches with other decision support approaches already being used within DNR.
- Negative benchmarking and process models used in the WAMPs are similar to an ecological risk assessment model.
- The difficulty with developing ERA's for flow-condition relationships is that there are multiple stressors and multiple ecological consequences with numerous interactions.



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