

4 The method

4.1 AquaBAMM framework

As Dunn (2000) and Chessman (2002) advocated, ecological data need to be summarised and presented in such a way as to be transparent to the user and organised in a logical assessment framework for supporting decision making. After the review of scientific literature and the authors' experiences, five guiding principles were developed for Aquatic Conservation Assessments (ACA) using AquaBAMM:

- The method should work with all available datasets and with any number of spatial units for a given study area.
- The method must be applicable even where data are lacking. That is, it must be able to incorporate 'missing data' or 'no data' without distorting the overall value of a spatial unit or any other outcomes of the assessment.
- The scale of an assessment should be useful for sub-catchment and regional planning processes.
- Non-social, non-economic conservation value necessarily includes both objective and subjective elements (e.g. expert opinion where data are lacking). These elements in the method should be clearly distinguished from each other.
- The assessment outcomes should be transparent by enabling the end user to interrogate the data and results at every level of analysis or data combination within the method.

Given these guiding principles, the AquaBAMM method was built as a hierarchical approach with four levels of data analysis (Figure 3). For each spatial unit within a study area, the raw data and expert panel derived data are incorporated into the Measure score (Level 1). Each Measure score is arithmetically combined into an Indicator score (Level 2). Each Indicator score is arithmetically combined into a Criterion rating (Level 3). Each Criterion rating for a spatial unit is combined using a 'decision filter table' to form the overall AquaBAMM Conservation Value or AquaScore (Very Low, Low, Medium, High and Very High) (Level 4). Hierarchical approaches to combining data for conservation assessment are not new (refer Bennett *et al.* 2002 and Dunn 2000); however, AquaBAMM enlists novel approaches to hierarchy architecture and to calculation and combination methods.

The final and critically important principle of the AquaBAMM framework is its data and result transparency at every level through each assessment. The assessment calculation tool and the assessment GIS output each provide for simple interrogation of data and calculated scores at all levels through the assessment hierarchy (AquaScore, Criteria, Indicators and Measures) rather than just producing a final AquaScore for each spatial unit. Other important benefits of this flexibility include assessment of missing data (and future work needs/priorities) and the ability to produce a wide range of derived products aimed at answering specific ecological or natural resource management questions.

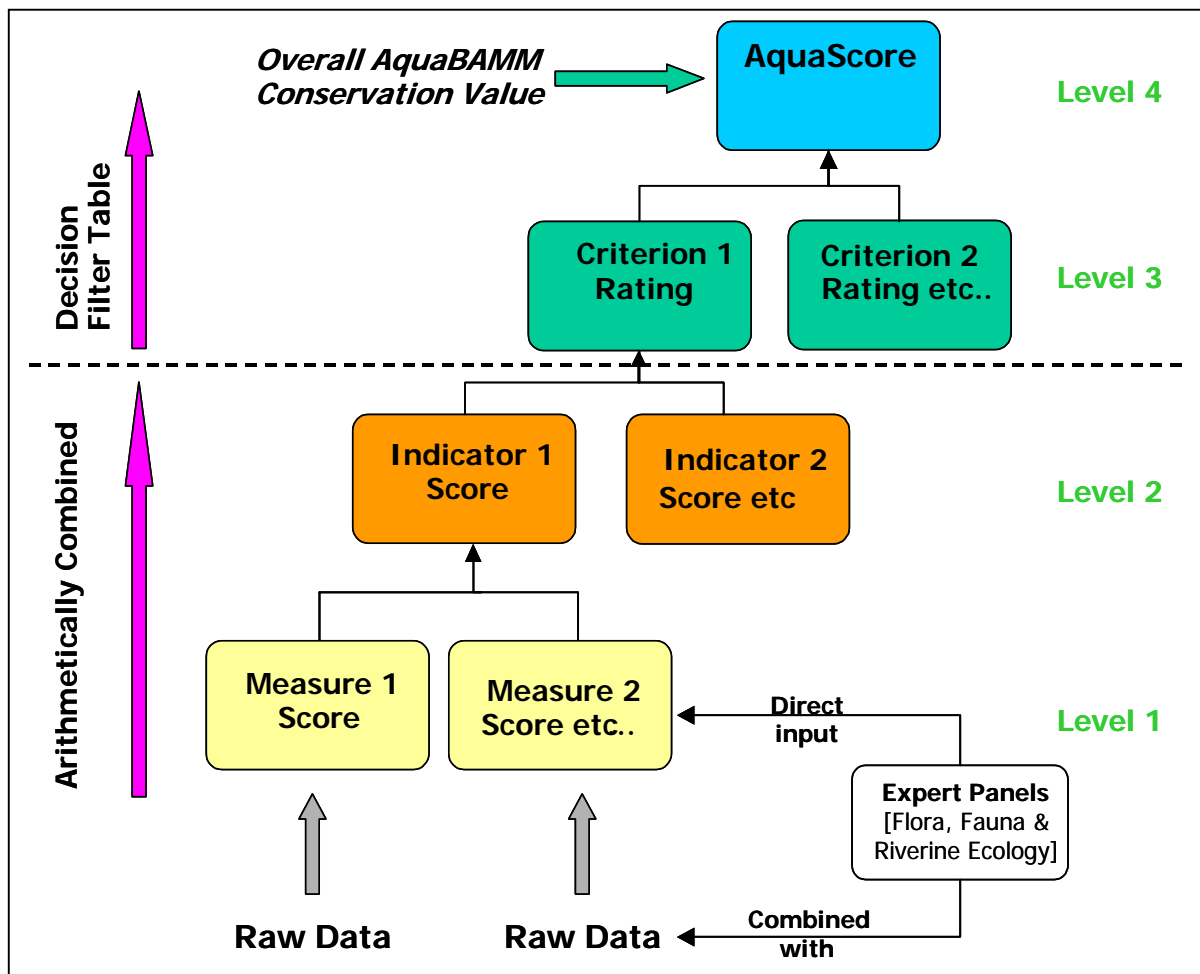


Figure 3 The AquaBAMM hierarchical approach structured around Measures, Indicators, Criteria and an AquaScore. The Measures (Level 1) and Indicators (Level 2) are arithmetically combined. A decision filter table is used to combine Criteria ratings (Level 3) into the Overall AquaBAMM Conservation Value or AquaScore (Level 4) for each spatial unit

4.2 AquaBAMM criteria

Defining criteria and indicators is central to a systematic assessment and evaluation process (Dunn 2000) and is a commonly used approach for conservation assessments (e.g. Chessman 2002; Bennett *et al.* 2002; Chadderton *et al.* 2004; Kingsford *et al.* 2005). With previous research effort in mind, eight criteria were defined for adoption in the AquaBAMM:

1. Naturalness - Aquatic
2. Naturalness - Catchment
3. Diversity and Richness
4. Threatened Species and Ecosystems
5. Priority Species and Ecosystems
6. Special Features
7. Connectivity
8. Representativeness.

The criteria may be primarily diagnostic (quantitative) or primarily expert opinion (qualitative) in nature but, in each case, are designed to accommodate a range of data types. The criteria can be compared to categories from similar methods (Table 5) and, in this way, can be seen as useful and well established summary categories for many internationally considered concepts in conservation ecology. The eighth criterion, called 'Representativeness', is considered critical for a complete assessment of conservation value and is supported within AquaBAMM; however, Criterion 8 was not implemented for the trial application in the Burnett River catchment for reasons of data availability. Indicators and Measures, with supporting data, suitable for nesting within this criterion are under development for implementation in future aquatic conservation assessments and this extension is strongly aided by the recent advances in wetland mapping and classification in Queensland.

It is important, when drawing from published discussions about criteria and indicators in conservation assessment, to distinguish measures of condition (or 'health') from those measures of value. Equally important is to distinguish measures requiring detailed, site-specific sampling/data collection effort (or longer term ecological analysis based on community structure and dynamics) from measures based around less intensive datasets or that have critical links to conservation in freshwaters. A number of authors have discussed these issues (e.g. Chessman 2002, EPA 2002; Phillips *et al.* 2001). AquaBAMM has been developed for a purpose, and not to be reliant on detailed field investigation or to provide ecosystem condition assessment.

Table 5 The selected AquaBAMM Criteria including their type (i.e. diagnostic or expert opinion) and other aligned criteria from the literature

AquaBAMM criteria	Other criteria that align with the AquaBAMM criteria	Criterion type
1. Naturalness Aquatic	Naturalness ^{1,2,7} Condition ^{5,7} Limited existing disturbance from artificial structures ⁸ Good water quality ⁸ Disturbance to fish passage and flows from upstream water impoundment structures is limited or reducing ⁸ Largely unaffected by the direct influence of water resource development ¹² Portion of catchment upstream and downstream of dam ³ Number of major point discharges ³ Exotic fish ³	Diagnostic
2. Naturalness Catchment	Naturalness ^{1,2,7} Condition ^{5,7} Adjacent riparian buffer zone is generally in good condition ⁸ Largely unaffected by the direct influence of land development ¹² Percent natural cover ³ Percent urban land use ³ Land use ³	Diagnostic
3. Diversity and Richness ^{1,2}	Physical diversity ⁴ Biological diversity ⁴	Diagnostic

AquaBAMM criteria	Other criteria that align with the AquaBAMM criteria	Criterion type
	Ecosystem diversity ⁵ Contains high fish species richness ⁸ Habitat diversity ^{8,9} Wetland supports 1% or more of the national populations of any native plant or animal ¹⁰ Demonstrates unusual diversity and/or abundance of features, habitats, communities or species ¹² Catchment richness (river types) ³	
4. Threatened Species and Ecosystems	Rarity ^{1,2,4,11} Role in supporting rare and threatened taxa ⁷ Ecosystem value ⁵ Essential habitat for endangered, vulnerable or rare species ⁵ Is the habitat for rare or threatened species or communities ¹² Weighted threatened fish, birds, frogs and plants ³	Diagnostic
5. Priority Species and Ecosystems	Core Habitat for Priority Taxa ⁵	Expert opinion
6. Special Features ^{1,2}	International/national significance ^{3,5} Ecosystem value ⁵ Uniqueness ⁷ Special biodiversity values ⁵ Contains regionally unique fish habitat features ⁸ An important wetland for maintaining the natural functioning of a major wetland complex ¹⁰ Important wetland for fauna at a vulnerable stage in their lifecycle or is a drought refuge ¹⁰ Is the location of rare or threatened geomorphic or geological features ¹² Performs important functions within the landscape ¹² Provides evidence of the course or pattern of the evolution of Australia's landscape or biota ¹²	Expert opinion
7. Connectivity ³	Context and Connection ⁵	Expert opinion
8. Representativeness ^{1,2}	Rarity of estuarine type in relation to geographic area ⁹ Uniqueness (river types) within a biogeographic area ³	Diagnostic

1 – Dunn 2000; 2 – Bennett *et al.* 2002; 3 – Chadderton *et al.* 2004; 4 – Chessman 2002; 5 – EPA 2002; 6 – Page & Hoolihan 2002; 7 – Phillips *et al.* 2001; 8 – McKinnon *et al.* 2003; 9 – Turpie *et al.* 2002; 10 – National Directory of Important Wetlands; 11 – Linke & Norris 2003; 12 – Kingsford *et al.* 2005

Dunn (2000) and Bennett *et al.* (2002) group several attributes under a single criterion of naturalness. However, it was decided to split naturalness into Naturalness Aquatic (aquatic components) and Naturalness Catchment (the broader catchment and riparian zone). This

distinction is important to allow reporting on the ecological/conservation values of the broader catchment and riparian zone (i.e. primarily terrestrial) to be separate from reporting of instream values. This flexibility increases the capacity of end users for making decisions regarding natural resource management of riparian and catchment areas or of instream habitats (e.g. planning and implementation of on-ground works).

The Diversity and Richness criterion is common to many ecological assessment methods and can include both physical and biological features. Unlike most methods, the AquaBAMM Criterion 4 'Threatened Species and Ecosystems' is restricted to legislatively protected species and ecosystems and does not incorporate physical features that are considered to be rare or unique. The benefit of structuring the criterion this way is that, by development of a derived product from this criterion alone, the information can be used directly for conservation planning purposes (i.e. protection and restoration) for threatened species and ecosystems – a priority for Governments and non-government organisations. In the parallel terrestrial BMM (EPA 2002), for example, a similar legislatively based criterion (i.e. 'Habitat for Endangered, Vulnerable and Rare Taxa') has been used to develop essential habitat maps for threatened species, and these maps were incorporated into Queensland Government policy on tree-clearing laws.

Conversely, the AquaBAMM Criterion 5 'Priority Species and Ecosystems' has been restricted to species and ecosystems not currently recognised through the statutes and that are largely identified through expert opinion (not including physical features). This criterion can also be used independently according to the specific aims of the end user of the AquaBAMM product.

Data to satisfy Measures within Criterion 6 'Special Features' and Criterion 7 'Connectivity' are derived through expert panels (refer to section 4.4 Expert panel process). The Special Features criterion assimilates information that is not accessible or not in a format that is easily incorporated into the AquaBAMM. As noted in the literature review, connectivity is an inherent attribute of flowing freshwater streams. However, the practicalities of measuring connectivity in a riverine environment are complex, making general principles difficult to develop and implement. Connectivity in its broadest meaning incorporates hydrological processes (quantity and quality, temporal and spatial variability), organism dispersal (barriers) and disturbances from natural. Connectivity can be bi-directional movements within a stream (e.g. fish passage), uni-directional contribution to a downstream spatial unit or special area, or lateral connectivity to floodplain wetlands or groundwater ecosystems. These aspects of connectivity are compounded, and when combined together provide a matrix of competing and differing values from an ecological conservation viewpoint.

Although representativeness (Criterion 8) is identified in the literature as an important criterion of ecological value, there was also recognition by some (e.g. Dunn 2000; Chessman 2002) of the inherent difficulties in its application. Representativeness, as defined by CAR principles (comprehensive, adequate and representative), is best applied in a framework where the landscape units are classified, such as a wetland classification, so that 'types' of units (e.g. palustrine wetlands) can be compared with each other. Without such a framework, the concept and application of representativeness of aquatic ecological values is more elusive. Such a framework was required for an assessment based on CAR principles for the application of the Tasmanian Conservation of Freshwater Ecosystem Values (CFEV) project (Davies 2005). With the benefit of recent wetland mapping and classification advances, development of this criterion within the AquaBAMM becomes possible.

4.3 AquaBAMM indicators and measures

Dunn (2000) and Bennett *et al.* (2002) provide lists of potential indicators (or attributes) that relate to Dunn's proposed criteria for an aquatic conservation value assessment method. Potential indicators, though, differ significantly depending upon data limitations, the scale of the method application and an output purpose. Indicators suitable for use by AquaBAMM were considered from a range of sources and chosen through a combination of literature review, expert elicitation and original development. Measures within each Indicator were similarly established.

Although a long list of Indicators and Measures can be created for any assessment, final application is always data dependent which, in turn, is usually study area dependent. For AquaBAMM development and trial application in the Burnett River catchment, 28 Indicators and 64 Measures were identified (Table 6). Of these, 52 Measures only were implemented for the trial ACA due to data limitations (refer Part B).

Table 6 The AquaBAMM Criteria, Indicators and Measures – only those defined for use in the Burnett River catchment ACA.

Criteria & Indicators	Measures
1 Naturalness Aquatic	
1.1 Exotic flora/fauna	1.1.1 Presence of 'alien' fish species within the spatial unit
	1.1.2 Presence of exotic plants instream within the spatial unit
1.2 Aquatic communities/ assemblages	1.2.1 SOR ¹ aquatic vegetation condition
	1.2.2 SIGNAL2 ² score (Max)
	1.2.3 AUSRIVAS ³ score - Edge (Min band)
	1.2.4 AUSRIVAS ³ score - Pool (Min band)
	1.2.5 EPT ⁴ score (Max)
1.3 Channel features modification	1.3.1 SOR ¹ bank stability
	1.3.2 SOR ¹ bed & bar stability
	1.3.3 SOR ¹ aquatic habitat condition
	1.3.4 Presence of dams/weirs within the spatial unit
	1.3.5 Inundation by dams/weirs (% of waterway length within the spatial unit)
	1.3.6 Snag removal within the spatial unit
1.4 Hydrological modification	1.4.1 APFD ⁵ score - modelled deviation from natural under full development
	1.4.2 % natural flows - modelled flows remaining relative to predevelopment
	1.4.3 % no flows - modelled low flows relative to predevelopment
1.5 Water quality	1.5.1 Median Total Phosphorous (ug/L)
	1.5.2 Median Total Nitrogen (ug/L)
	1.5.3 Median Turbidity (ug/L)
	1.5.4 Median Conductivity (ug/L)
	1.5.5 Median pH
2 Naturalness Catchment	
2.1 Exotic flora/fauna	2.1.1 Presence of exotic plants in the riparian zone within the spatial unit

Criteria & Indicators	Measures
2.2 Riparian disturbance	2.2.1 % area remnant vegetation across the spatial unit relative to preclear extent within buffered watercourses (i.e. in the riparian zone)
	2.2.2 % area of wetland REs in the spatial unit relative to preclear extent
	2.2.3 Total number of REs within riparian areas relative to preclear number of REs within buffered watercourses
	2.2.4 SOR ¹ reach environs
	2.2.5 SOR ¹ riparian vegetation condition
2.3 Catchment disturbance	2.3.1 % 'agricultural' land-use area by spatial unit (i.e. cropping and horticulture)
	2.3.2 % 'grazing' land-use area by spatial unit
	2.3.3 % 'vegetation' land-use area by spatial unit (i.e. native veg + regrowth)
	2.3.4 % 'settlement' land-use area by spatial unit (i.e. towns, cities, etc)
2.4 Flow modification	2.4.1 Farm storage (overland flow harvesting and gully dams) calculated by surface area within the spatial unit
3 Diversity and Richness	
3.1 Species	3.1.1 Richness of amphibians
	3.1.2 Richness of native fish
	3.1.3 Richness of native reptiles
	3.1.4 Richness of native waterbirds
	3.1.5 Richness of aquatic plants (macrophytes)
3.2 Communities/assemblages	3.2.1 Number of macroinvertebrate taxa (Family level taxonomy)
	3.2.2 Riparian vegetation richness represented by richness of REs along watercourses within a specified buffer distance from the stream
3.3 Habitat	3.3.1 SOR ¹ channel diversity
3.4 Geomorphology	3.4.1 Richness of geomorphic features (i.e. features determined according to GAR ⁶ method) within the spatial unit
4 Threatened Species and Ecosystems	
4.1 Species	4.1.1 Presence of rare or threatened aquatic ecosystem dependent fauna species – NCAct ⁷ , EPBCAct ⁸
	4.1.2 Presence of rare or threatened aquatic ecosystem dependent flora species – NCAct ⁶ , EPBCAct ⁷
4.2 Communities/assemblages	4.2.1 % area of 'of concern' or 'endangered' wetland REs in the spatial unit relative to preclear extent
5 Priority Species and Ecosystems	
5.1 Species	5.1.1 Presence of aquatic ecosystem dependent 'priority' <u>fauna</u> species (Expert Panel list/discussion or other lists such as ASFB ⁹ , WWF ¹⁰ , etc)
	5.1.2 Presence of aquatic ecosystem dependent 'priority' <u>flora</u> species (Expert Panel list/discussion)
	5.1.3 Habitat for, or presence of, migratory species (Expert Panel list/discussion and/or JAMBA ¹¹ / CAMBA ¹² agreement lists)

Criteria & Indicators	Measures
	5.1.4 Habitat for significant numbers of waterbirds (Expert Panel data/discussion)
5.2 Ecosystems	5.2.1 Presence of 'priority' aquatic ecosystem as per Expert Panel lists and/or discussions
6 Special Features	
6.1 Geomorphic features	6.1.1 Presence of distinct, unique or special geomorphic features (Expert Panel list/discussion)
6.2 Ecological processes	6.2.1 Presence of (or requirement for) distinct, unique or special ecological processes (Expert Panel list/discussion)
6.3 Habitat	6.3.1 Presence of distinct, unique or special habitat (including habitat that functions as refugia or other critical purpose) (Expert Panel list/discussion)
6.4 Hydrological	6.4.1 Presence of distinct, unique or special hydrological regimes (e.g. spring fed stream, ephemeral stream, wetland, boggomoss) (Expert Panel list/discussion)
7 Connectivity	
7.1 Significant species or populations	7.1.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of significant species or populations, including those features identified through Criterion 5 and/or 6
	7.1.2 Possibility for migratory or routine 'passage' of fish and other fully aquatic species (upstream and/or downstream movement) within the spatial unit
7.2 Groundwater dependent ecosystems	7.2.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of groundwater ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6 (e.g. karsts, cave streams, artesian springs)
7.3 Floodplain and wetland ecosystems	7.3.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of floodplain and wetland ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6
7.4 Terrestrial ecosystems	7.4.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of terrestrial ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6
7.5 Estuarine and marine ecosystems	7.5.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of estuarine and marine ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6
8 Representativeness	
<i>Indicators & Measures not developed or implemented for Burnett River catchment ACA</i>	

1 – State of the Rivers for the Burnett River catchment, Van Manen (1999); 2 – SIGNAL2, Chessman (2003); 3 – Australian River Assessment System; 4 – An index of three macroinvertebrate families *Ephemeroptera*, *Plecoptera* and *Trichoptera*; 5 – Annual Proportional Flow Deviation as modelled by the Department of Natural Resources and Mines 2005; 6 – Geomorphic Assessment of Rivers, Gardiner and Brennan (2004); 7 – Queensland *Nature Conservation Act 1992*; 8 – Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*; 9 – Australian Society of Fish Biologists; 10 – World Wide Fund for Nature; 11 – Japan and Australia Migratory Birds Agreement; 12 – China and Australia Migratory Birds Agreement.

4.4 Expert panel process

Chessman (2002) states that the assessment of conservation value is by definition a human value judgement since as yet no one has devised a totally objective means of river health or ecological assessment. He argues that some methods may give the appearance of complete objectivity, but in reality embed value judgements within their protocols (e.g. AUSRIVAS). The Guidelines for Protecting Australian Waterways (Bennett *et al.* 2002) acknowledges that ecological value necessarily includes both objective and subjective elements (expert opinion where data are lacking) also. AquaBAMM, likewise, was developed with this issue in mind and incorporates expert elicitation as a critical element of data gathering, weighting and interpretation.

Data for three of the eight AquaBAMM criteria are primarily derived by expert elicitation: Criterion 5 'Priority Species and Ecosystems', Criterion 6 'Special Features' and Criterion 7 'Connectivity'. To consider the Measures within these criteria, three separate expert panels (fauna, flora and riverine ecology) were convened for the trial application of AquaBAMM in the Burnett River catchment ACA and their reports are presented in Part C of this document. Panel members were selected to contribute based on their expertise in a scientific discipline relevant to freshwater ecosystems, processes or species. Panel members were required to have direct knowledge and experience of the Burnett River catchment. Experience in the identification and assessment of riverine values including natural processes, species and places of significance were viewed as an important factor in the selection process. Panel members were from a range of professional and community organisations, including academic institutions, government agencies, regional bodies and naturalist/enthusiast groups.

Expert Panels were structured in an attempt to ensure that, at least, each ecological discipline addressed by the assessment Measures was represented (Table 7).

Table 7 The scientific disciplines covered by the three expert panels for the trial application of the AquaBAMM in the Burnett River catchment

Aquatic Fauna Panel	Aquatic Flora Panel	Riverine Ecology Panel
<ul style="list-style-type: none"> • Fish species values, • Amphibian values, • Turtle values, and • Waterbird values. 	<ul style="list-style-type: none"> • Aquatic flora species values, • Riparian flora species values, and • Regional ecosystem values. 	<ul style="list-style-type: none"> • Natural geological and geomorphological values, • Water quality values, • Connectivity between riverine systems, and • Hydrological processes.

The primary tasks set for each expert panel were to:

Aquatic Fauna Expert Panel

- Review relevant existing spatial data (species point records) and available information (reports etc.).
- Provide advice on aquatic dependent *rare or threatened* fauna species habitat and localities.
- Provide advice on aquatic dependent *priority* fauna species habitat and localities.
- Identify significant ecosystems or areas for waterbirds and migratory species.

- Identify priority ecosystems or areas important for significant fauna communities or species.
- Provide advice on aquatic dependent exotic fauna species localities and abundance.

Aquatic Flora and Riparian Expert Panel

- Review relevant existing spatial data (species point records) and available information (reports etc.).
- Provide advice on aquatic dependent *rare or threatened* flora species habitat and localities.
- Provide advice on aquatic dependent *priority* flora species habitat and localities.
- Identify priority ecosystems or areas important for significant floral communities or species.
- Provide advice on aquatic dependent exotic flora species localities and abundance.

Riverine Ecology Expert Panel

- Establish principles for applying the Connectivity Criterion in the Burnett River catchment's freshwater ecosystems (bi-directional, unidirectional and lateral directions) to spatial units.
- Weight 'measures' relative to their importance for an 'indicator'.
- Identify areas of significant geomorphological, ecological or hydrological processes or priority areas; and
- Provide advice on biodiversity 'hot-spots' or areas of particular significance for species or communities.

Each expert panel workshop used an interactive approach, incorporating ArcView GIS software, to display and interrogate the Burnett River catchment and, where necessary, a background of topographic 250k maps, roads, rivers and other relevant datasets were used to identify areas of interest. A draft report was circulated to panel members prior to the production of a final report. In some cases, follow-up meetings or discussions were needed to collect additional data and information from members who were unable to attend the workshop.

4.5 Spatial unit

Whether for conservation 'valuing' purposes, condition assessment or other research/analytical reason, environmental investigations are necessarily bound geographically. The spatial unit chosen for the assessment is both scale dependent and, in most cases, dependent on data availability, but it has direct relevance to data analysis, reporting and application of the results. The spatial unit chosen, therefore, is an important decision and one that is usually heavily debated. For conservation assessment, spatial unit determination might be centred around natural resource management (e.g. Queensland's water resource planning), a bioregional framework (Tait *et al.* 2002; EPA 2002; Chadderton *et al.* 2004), an ecological regionalisation, a geomorphological analysis (Brierly *et al.* 2002; Thomson *et al.* 2004; Gardiner 2004), a mathematical analysis of topology and drainage area (Phillips *et al.* 2001), political boundaries or a combination of many methods (Anderson 1993).

AquaBAMM is conceptually applicable at any spatial scale and has, therefore, no fixed spatial unit inherent to the method. The choice of spatial unit may vary depending upon the assessment but, broadly, has three guiding principles:

1. Spatial unit must be data independent. That is, data intended for input to the analysis can not be used to determine spatial unit boundaries without obvious confounding effects.
2. Spatial unit must be chosen with an expectation that data are available for most or all units. That is, choice of spatial unit can not be at the expense of populating data fields for the majority of units without compromising analytical rigour.
3. Spatial unit must be appropriate for the intended application. That is, the scale chosen for defining spatial units must be reconcilable with respect to reporting scale or resultant management action.

Flexibility in spatial unit definition, with adherence to the principles above, means also that AquaBAMM can be applied or reapplied for different purposes by simple redistribution of data according to a different set of spatial units. There is not necessarily any prerequisite for complete restructuring of the assessment through altering Criteria, Indicators and Measures.

For the purposes of tool development and for trial, AquaBAMM has been applied to the riverine wetlands of the Burnett River catchment using a spatial unit defined by the DNR&M State of the Rivers program (DNR&M 1992). In the State of the Rivers program, these spatial units were called 'sub-sections' and were identified as 'homogeneous' stream sections in terms of their natural attributes (i.e. physical, chemical, biological and utilitarian values) and natural resources (Anderson 1993). For the Burnett River catchment, 376 spatial units are defined with an average size of 88km² (a total catchment area of 33,000km²).

Use of the State of the Rivers program sub-sections enabled investigation that was appropriate for a regional scale assessment and facilitated direct reconciliation with a body of existing data suitable for the analyses. While AquaBAMM is not solely dependent on the use of this spatial unit, its application suitability and availability across most of Queensland may be of benefit for future assessments. Again, however, it is important to emphasise that AquaBAMM is functional at any relevant spatial scale, including case-by-case user defined spatial units if appropriate and if the guiding principles are satisfied.

4.6 Stratification

For relevant Measures, a referential approach is used within AquaBAMM for categorisation of raw data prior to analysis. This occurs by comparison of raw data values to Measure-specific threshold values for each scoring category, based on real or calculated reference values. The manipulation of raw data to achieve this is explained in detail in Section 5 'The AquaBAMM Assessment Tool'; however, it is critical to note here that establishment of a relevant reference may require sub-division of the study area (or stratification). Importantly, stratification is NOT mandatory for a successful assessment nor is the method of stratification, when it is considered appropriate, specified or fixed by AquaBAMM. The use (necessity) and method of stratification in any assessment is a user decision and is dependent upon the Measures selected and the ecological character of the assessment area.

AquaBAMM makes provision for data to be stratified, and therefore data comparisons or reference value calculations can also be stratified, in any user-defined way that is determined to be ecologically appropriate. A decision regarding stratification must,

however, be made *a priori* since it influences data categorisation at the earliest stage of analysis.

For example, in the Burnett River catchment analysis, AquaBAMM uses the 150masl contour line to stratify the catchment into two geographic zones, and each spatial unit that lies more than 50% within a strata was attributed as belonging to that strata. This altitudinal cut-off parallels the accepted protocol of the National Water Quality Management Strategy (ANZECC and ARMCANZ 2000). Data comparisons and reference value calculations were then made within each of the strata rather than across the whole catchment. The ecological distinctions, which are many, that are clear between the upland and lowland Burnett River catchment zones make stratification the only sensible approach.

Stratification mitigates the effects of data averaging across large study areas, and is particularly important where ecological habitat diversity and complexity is high. Methods of stratification are not limited but, ideally, should attempt to remain independent of data that are expected to contribute to the assessment. Altitudinal stratification has been, and continues to be, a common approach across a variety of ecological investigations (e.g. Sustainable Rivers Audit – A Program of the Murray-Darling Basin Commission and Partner Governments 2004; National Water Quality Management Strategy, ANZECC & ARMCANZ 2000).