Department of
Primary Industries
Office of Water

River Condition Index in New South Wales

Method development and application

Publisher

NSW Department of Primary Industries, a division of NSW Department of Trade and Investment, Regional Infrastructure and Services.

River Condition Index in New South Wales: method development and application

First published August 2012

ISBN 978 1 74256 317 6

Report to be cited as:

Healey, M., Raine, A., Parsons, L., and Cook, N. (2012) River Condition Index in New South Wales: Method development and application. NSW Office of Water, Sydney.

Publication number 12_223

Contents

Acknowledgements 1

1. Introduction....2

1.1 Background 2

1.2 The need for a spatially expressed state-wide investment and reporting tool in NSW....2

1.2.1 Water sharing plans 2

1.2.2 NSW statewide natural resource management targets and the NSW monitoring evaluation and reporting strategy....4

1.2.3 Updating catchment action plans....5

1.2.4 The need to better align natural resource management plans....5

1.2.5 Meeting national commitments 6
1.2.5.1 The National Water Initiative 6
1.2.5.2 Murray Darling Basin Plan 6
1.2.5.3 National compliance and enforcement framework....7

1.3 Review of other river condition reporting tools....8

1.5 Aim of this report 10

2. Method development....10

2.1 Derivation of management units 11

2.2 The River Condition Index 12

2.2.1 Data sets and methods 13
2.2.1.1 River Styles® Geomorphic Condition assessment – surrogate input under FARWH “Physical Form” category (RSGC). 13
2.2.1.2 Riparian vegetation cover assessment (native woody vegetation) – surrogate input under FARWH “Fringing Zone” category (RVC)....14
2.2.1.3 Macro water planning: hydrologic stress or risk rating – surrogate input under FARWH “Hydrological Change” category. 17

Distributed hydrologic stress assessment 19

Macro water sharing plan hydrologic stress layer....20

Sustainable Rivers Audit (SRA) Hydrology Condition Index 21
2.2.1.4 River biodiversity condition data – surrogate input under FARWH “Aquatic Biota” category (RBCI)....22

Aquatic Biodiversity Forecaster Tool analysis 23
Sustainable Rivers Audit Fish and Macroinvertebrate Condition Indices 24
2.2.1.5 Catchment Disturbance Index – surrogate input under FARWH “Catchment Disturbance” category (CDI)....24
Infrastructure Index (I)....24
Land Use Index (LU) 25
Land Cover Change Index (LCC)....26
Catchment Disturbance Index (CDI) 27

2.2.3 River Condition Index (RCI) score 27
2.2.3.1 Bands of Condition....28

2.2.3.2 Spatial representation 28

2.2.4 Assumptions 29
Aggregation of Aquatic Biodiversity Forecaster Tool outputs into larger catchment units 30
Linking geomorphic condition to aquatic biodiversity 30
Relationship of riparian vegetation extent to condition 30
Extrapolation of site assessments 30

2.3 River value assessment 30

2.3.1 Method associated with using the conservation priority outputs of the Aquatic Biodiversity Forecaster Tool 33

2.3.2 Method to associate threatened species with River Styles® 33

2.3.3 Macro water sharing plan Instream Value Assessment 35

2.3.4 River Styles® Assessment 36

2.3.5 Key basin assets 36
2.3.5.1 MDBA key environmental assets 37
2.3.5.2 DPI key fish assets 38

2.3.6 Additional CMA data 38
2.3.6.1 Refugia data 38
Western and Lower Murray Darling CMA 38
2.3.6.2 High Conservation Value (HCV) vegetation 39
Border Rivers-Gwydir CMA 39
2.3.6.3 Community data 40
2.3.3 Method for calculating final instream value scores 40

2.4 River risk assessment 41

2.4.1 Risk of physical disturbance to instream values 43
2.4.1.1 Likelihood 43
2.4.1.2 Consequence 50
2.4.1.3 Raw risk of physical disturbance to instream value score 51

2.4.2 Risk of extraction to instream values 51
2.4.2.1 Likelihood: 51
2.4.2.2 Consequence 51

2.4.3 Combined risk to instream values 52

2.4.4 Distributing and displaying raw risk scores 52

2.5 Priority area assessment 54

2.5.1 Preparation of priority maps 54

3. Discussion 57

3.1 Using the River Condition Index to achieve alignment of natural resource management plans 57

3.2 Linking the River Condition Index to resilience thinking 58

3.3 Adaptive management 61

3.4 Application of the approach in NSW 62

3.5 Limitations of the approach 63

3.6 Projects underway to improve the River Condition Index 66

3.6.1 Improving the hydrologic stress index..66

3.6.2 Development of NSW regional water quality targets 67

3.6.3 River Styles® Reference Reach Project 68

3.6.5 Completion of Aquatic Bioforecaster Tool mapping across NSW.........................68

3.7 Recommendations for further work 69

4. References 73

Appendix 1...82

Appendix 2...85

Appendix 3...86

Figures

Figure 1: Summary of the steps involved in developing a macro water sharing plan (from NSW Office of Water 2010).. 3

Figure 2: Map showing subcatchments derived from the Geofabric as compared against the Water Sharing Plan water source boundaries. 12

Figure 3: Indices used in the assessment of the RCI to date (in green), with future indices (in grey), with reference to the FARWH indices... 13

Figure 4: Decision tree for the use of hydrologic data.. 18

Figure 5: Map showing where each of the hydrologic stress indices were used (NB. In cases where more than 50 per cent of the rivers in the subcatchment were covered by a regulated river (based on the Regulated Water Source spatial layer from the NSW Office of Water), the sub-catchment would receive a score of 0.5, indicating “very high stress”). 18

Figure 6: Map showing the availability of the Aquatic Biodiversity Forecaster outputs and SRA data 23

Figure 7: River Condition Index results for the Hunter Central Rivers CMA area.............................. 29

Figure 8: Decision tree options for each CMA based on data availability for river value.................... 32

Figure 9: An example output showing instream values for the Hunter Central Rivers CMA region. .. 41

Figure 10: The three stage process to determine the risk from key riverine activities and overall risk to river instream values. 42

Figure 11: Example output map showing the overall risk to instream values from both physical disturbance and extraction from the Hunter Central Rivers CMA................................. 54

Figure 12: Process to develop risk priority for each RCI component... 55

Figure 13: Action priority map for geomorphology in the Hunter Central Rivers CMA region. 57

Figure 14: Conceptual basis for the use of the RCI spatial products to inform water sharing plans and Catchment Action Plans (adapted from Brierley et al 2011). 59

Figure 15: Conceptual state and transition model for a river classified as high fragility in the Central West CMA (Source: CWCMA 2011). 60

Tables

Table 1: Alignment of Sydney Metropolitan CMA rankings to those used in the River Condition Index. 16

Table 2: Weightings used in the derivation of the infrastructure index layer 24

Table 3: Weightings used for the derivation of the land use index layer 25

Table 4: Scoring Features for threatened species legal status and river reaches in good condition 35

Table 5: Scoring system for river reaches that intersected MDBA key environmental assets 37

Table 6: Refugia categories as defined in the Western CMA River Styles® report 38

Table 7: Definitions of geomorphic recovery potential listed in decreasing order or priority (Source: Cook and Schneider 2006) 46

Table 8: Decision assistance table to enable the determination of the likelihood of a river reach to physical disturbance (red and orange colours indicate those reaches most vulnerable to threats, lighter colours indicate lesser levels of likelihood) 50

Table 9: Application of likelihood score ranges (derived from Table 7) to specific likelihood categories and associated risk input scores. 50

Table 10: Four risk categories developed from the standard deviations from the mean. 53

Table 11: Condition Index categories to assist in differentiating management actions required. 55

Table 12: Action Priority categories for RCI criteria that are assigned to a river reach. 56

Table 13: Current and recommended frequency of data collection for existing programs (note that the use of some of these data sets may cease or change following the implementation of the other recommendations in section 7, or identification of other appropriate regional data by CMAs). 71

Appendix Figures

Figure A 1: Map showing where the fragility classification apply. 84

Figure A 2: Model showing the process to calculate River Styles® Geomorphic Condition input index (RSGC) – example from the Hunter Central Rivers CMA region 86

Figure A 3: Model Showing the process to calculate the percentage of Native Woody Riparian vegetation for River Styles® river reaches 87

Figure A 4: Model showing the process to calculate the Riparian Vegetation Condition input index (RVC) – example from Central West CMA shown 88

Figure A 5: Model showing the process to calculate the River Biodiversity Condition input index (RBCI) based on the River Biodiversity Forecaster data– example from Northern Rivers CMA shown 89

Figure A 6: Model showing the process to calculate the River Biodiversity Condition input index (RBCI) based on the SRA Fish and Macroinvertebrate data – example from Murray CMA shown. 90

Figure A 7: Model Showing the process to calculate the Hydrologic Stress input index (HS) based on the Distributed Hydrologic Stress data - example from Hunter-Central Rivers CMA shown. 91

Figure A 8: Model showing the process to calculate the Raw Risk of Physical Disturbance to instream Value score - example from Hunter-Central Rivers CMA shown. 92

Figure A 9: Model showing the process to calculate the Raw Risk to Extraction to Instream Value score - example from Hunter-Central Rivers CMA shown. 93

Figure A 10: Model showing the process to calculate the Final Risk to Instream Value score and final Risk categories - example from Hunter-Central Rivers CMA shown. 94

Appendix Tables

Table A 1: Fragility rankings used in the analysis of likelihood of physical disturbance 82

Acknowledgements

This project was funded by the Australian Government through the National Water Commission's Raising National Water Standards Program. The project team would like to thank the National Water Commission (Raising National Water Standards program) and Catchment Action NSW for providing the funding that enabled further development of the tools and collection of data to develop the River Condition Index (RCI) and alignment program with the Catchment Management Authorities (CMAs).

Appreciation is also given to the agency Steering Group for overseeing the project management of the National Water Commission-funded project components. Thankyou to the staff in the CMAs with whom we have undertaken trials and pilot Catchment Action Plan (CAP) reviews for providing assistance in the development of the methods and data sets used in the RCI, in particular, Hunter-Central Rivers, Central West, Namoi, Border Rivers and Northern Rivers CMAs. Thank you to all CMAs who have continued to offer support in the development of key spatial data that form the back-bone of the RCI. Without this support development of State-wide datasets would not be possible.

The Monitoring Evaluation and Reporting (MER) Riverine Ecosystems theme team are thanked for their support and input into the development of the RCI to improve State-wide MER reporting needs, in particular Eren Turak from the Office of Environment and Heritage (OEH) for the provision of Biodiversity Forecaster Tool information, data and development of project outcomes during the Hunter-Central Rivers CMA trial.

The NSW Natural Resource Commission (NRC) provided advice, encouragement and support during the development of the Water Sharing Plan (WSP) – CAP alignment process.

Thank you for the support and encouragement of our Office of Water's Environmental Evaluation and Performance Branch management team and staff during the development of the RCI and alignment activities with the CMAs and Maxine Rowley for compiling method information on geomorphic condition and risk.

1. Introduction

1.1 Background

The development of a River Condition Index (RCI) for New South Wales arose from a project funded by the National Water Commission to develop a framework for aligning Water Sharing Plans (WSP) and Catchment Action Plans (CAP). Such alignment is a requirement under the National Water Initiative (NWI). The pilot project was undertaken by the NSW Office of Water in the Hunter Valley in collaboration with the Hunter-Central Rivers Catchment Management Authority, the NSW Office of Environment and Heritage (OEH), and the NSW Natural Resources Commission (NRC). In summary, the framework for aligning the two types of plans utilised a range of spatial products from which both plans then developed their respective objectives, strategies and targets. Detailed information on the pilot project can be found in Hamstead (2010). Subsequent to this project, aspects of the pilot have applied to two pilot CAP reviews in the Central West and Namoi Catchment Management Authority (CMA) areas, and are now being progressively rolled-out in other CMA areas.

This report represents the initial process of rolling out the approach across New South Wales. However, it is intended that the approach be regularly refined and updated as new data and approaches become available.

1.2 The need for a spatially expressed state-wide investment and reporting tool in NSW

The NSW Office of Water has identified a number of programs that need a range of spatial assessment and reporting tools. These are discussed in turn below. At the time of writing this report, funding for new monitoring programs was not available, so the development of the RCI and associated spatial products was undertaken using existing datasets, and within existing resourcing constraints and policy and legislative contexts.

1.2.1 Water sharing plans

Water Sharing Plans (WSPs) for the state’s unregulated water sources are developed using the macro water sharing plan approach. The approach used is detailed in *Macro Water Sharing Plans, the approach for unregulated rivers, report to assist community consultation* (NSW Office of Water 2010) and is summarised in Figure 1.

The process defines the instream value using a range of indicators. The instream value score is then plotted against hydrologic stress to assign each water source to a particular category in a nine cell matrix. The resulting position of a water source within the matrix then determines the indicative trading rules for the particular water source. That is, a water source with high instream values and high hydrologic stress is likely to have indicative trading rules to reduce entitlement.

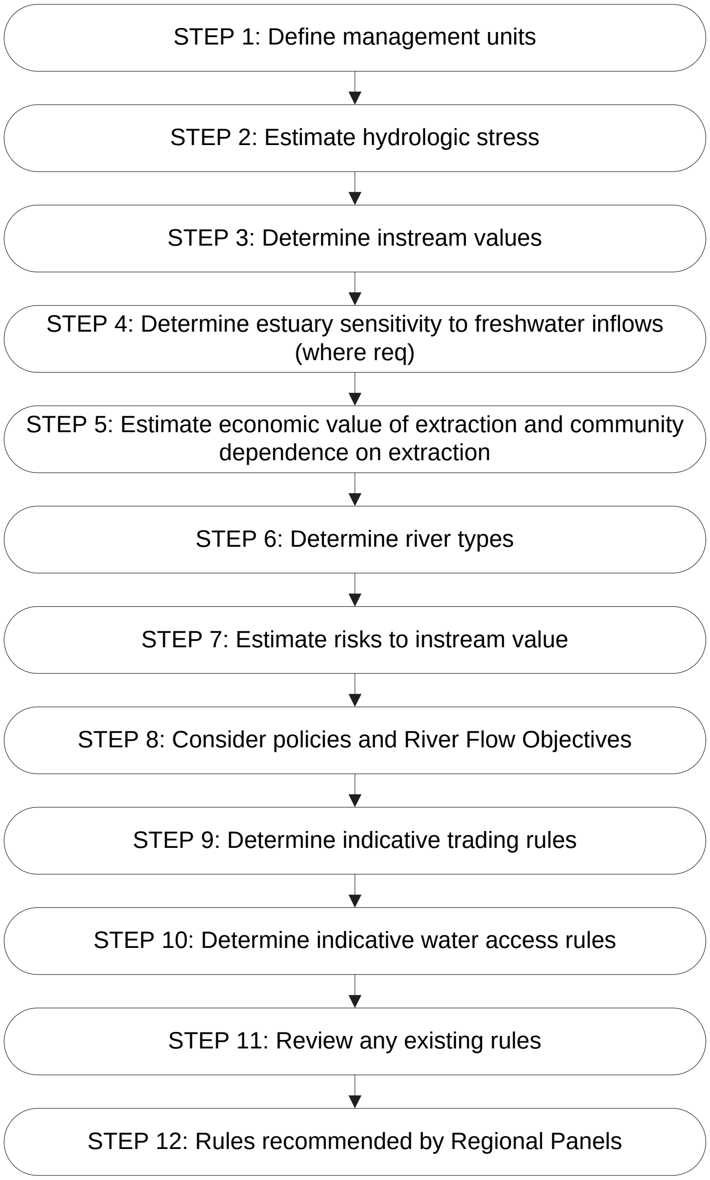

Figure 1: Summary of the steps involved in developing a macro water sharing plan (from NSW Office of Water 2010)

Risk to instream values is then used to define water access rules. In brief, the analysis defines risk to instream value as Risk = Consequence x Likelihood as per the equation below.

Risk to instream value from water extraction = instream value (consequence) x hydrologic stress (likelihood)

Risk to instream value is then plotted with Community Dependence on Extraction (the volume and economic value of water extracted and the social benefit of water extraction). Regional Interagency Panels then review the above data and make any changes based on local knowledge or additional data.

The above process, while allowing the setting of indicative trading and access rules for a given water source, does not allow for more detailed analysis at the reach scale, because risk and value are determined at the scale of the water source. As such, within a large water source, it is possible that the instream value may change significantly along a stream's length. The capture of value and risk at the reach scale allows water source boundaries and trading and access rules to be adjusted to better reflect the variable condition and stresses on a given stream within a water source. If a water source has high instream values in its middle and upper reaches and low values in the lower reaches, then trading rules could be designed to move entitlement from the upper and middle reaches to the lower reaches.

This project aims to address this issue by updating the data used in the macro water sharing approach, and by spatially representing value and risk at the reach scale.

1.2.2 NSW statewide natural resource management targets and the NSW monitoring evaluation and reporting strategy

In 2005, the NSW Natural Resource Commission recommended 13 state natural resource management targets to the NSW Government. These targets were subsequently adopted by Government. The introduction of the targets was part of a new institutional model for delivering natural resource management in NSW, including the devolution of significant planning and investment responsibilities to the 13 newly established regional Catchment Management Authorities (CMAs). It flowed from agreements between the Australian and NSW Governments, which jointly committed funds for investment by CMAs over the period 2004 to 2007.

The role of the targets was to help ensure that this initial investment (and expected future investment) results in the achievement of natural resource outcomes that are in the environmental, economic and social/cultural interests of the state (Natural Resources Commission 2005). The targets were also designed to help make CMAs and other natural resource managers accountable for achieving these outcomes, while allowing for the regional flexibility and innovation that is critical to the success of the model.

There is a requirement to report on progress in meeting the 13 statewide targets for Natural Resource Management (NRM) (see Appendix 1 in DECCW 2010). The NSW Government has developed the NSW Monitoring, Evaluation and Reporting (MER) Strategy, 2010-2015 (DECCW 2010) as the primary tool to achieve this. Progress against the targets is reported by producing State of the Catchment Report Cards (SoC) every three years. The development of the RCI was designed to meet the need for SoC reporting at a scale that is useful for both regional planning and investment, and for reporting statewide progress against the riverine target. The riverine target (Target 5) is specifically:

***By 2015 there is an improvement in the condition of riverine ecosystems*.**

The SoC produced for 2010 (NSW Government) largely utilised data and analysis from the Murray Darling Basin Authority (MDBA) Sustainable Rivers Audit (SRA) (Davies et al 2008). For hydrology, macroinvertebrate, and fish data, the 2010 SoC presented condition data using the same altitudinal zones as SRA across each NSW CMA area. While this was useful for long-term statewide reporting against NRM Target 5, it did not provide any value for reporting at a regional scale, and was not useful to guide investment at a scale suitable for water sharing plans or CAPs.

The RCI was designed to address this issue, by reporting at a subcatchment scale that could be utilised by both state and regional natural resource management agencies.

1.2.3 Updating catchment action plans

NSW CMAs are currently undergoing a process to review and update their CAPs. The NSW NRC has developed a framework that each CMA must follow in updating their CAP (NRC 2011). State agencies responsible for natural resource management are also required to provide science support to ensure agency priorities are available and considered in CAP planning and reviews (NRC 2011). The approach requires that CMAs spatially represent their natural resource assets, and assess their resilience as well as the risk to the assets from human-induced disturbance. The approach used for macro water sharing planning, which uses a value and risk approach, was also deemed appropriate for CAP development as it focuses on an asset and risk-based approach.

Unlike RCI spatial products used for macro water sharing plan, which utilise hydrologic stress to represent likelihood, the RCI for CMA riverine investment, uses the concept of stream fragility and recovery potential to represent likelihood (see section 2.4 for detail). Stream fragility and recovery potential are both products of the River Styles® framework (Brierley and Fryirs 2005). *Stream fragility* refers to the susceptibility or sensitivity of certain geomorphic categories to physical adjustments and changes when subjected to degradation or certain threatening activities (Cook and Schneider 2006). Significant adjustment is sometimes seen in geomorphic categories that have higher levels of fragility (ie. streams that are not robust or have lower resilience). This significant adjustment can also result in certain geomorphic categories changing to another one when a certain threshold (level of disturbance) of a damaging impact is exceeded (Cook and Schneider 2006).

Risk to instream value from physical disturbance is therefore defined as:

Risk of physical disturbance to instream value =
instream value (consequence) x (stream fragility x recovery potential) (likelihood))

1.2.4 The need to better align natural resource management plans

Integrated water resource management is considered an effective catchment planning mechanism that considers water quality, quantity and land use planning due to the way aquatic ecosystems interact with a range of other landscape components (Shrubsole 2004; World Bank 2006). In Australia, alignment of NRM programs was initially seen as a valuable component to provide a broad focus to key programs being addressed under the Commonwealth's Framework for Future NRM Programs (NRMMC 2006). The Commonwealth of Australia continues to aim for alignment between federal NRM targets and state and Territory targets and regional NRM programs to reduce duplication of effort (Commonwealth of Australia, 2011). Regional alignment of NRM has been a focus across states and Territories in Australia (Landcare 2005; SA 2009; WCB 2009; Qld Government 2011), although none of these strategies or programs have successfully developed a framework that aligns water planning with catchment planning activities.

In NSW, the Natural Resources Commission (NRC) is the independent agency responsible for auditing the Catchment Action Plans (CAPs) developed by each CMA. CAPs are assessed against the State Standard for Quality Natural Resource Management (NRC 2005a, 2005b), as well as their contribution to the achievement of the state natural resource management targets. The NRC requires that new CAPs align with other state NRM plans and policies. The NSW NRC has reviewed the outcomes of two recent pilot CAP reviews in NSW and this evaluation provided learnings and improvement, including the development of a Framework for preparing all other CAP reviews in NSW that will guide the alignment of NRM plans with CAPs. The criteria and attributes in the Framework, along with the State Standard for Quality Natural Resource Management, will be used to assess the quality of the CAP reviews and how whole-of-government planning has been incorporated into CAPs (NRC 2011).

1.2.5 Meeting national commitments

1.2.5.1 The National Water Initiative

The National Water Initiative (NWI) provides a national framework for the management of water resources, agreed to by the Council of Australian Government (COAG, 2004). The NWI provides specific direction and actions to be undertaken by governments across eight inter-related elements of water management including issues such as the development of water sharing plans, water markets, licensing, and urban water management. The National Water Commission (NWC) is responsible for the delivery of the NWI and undertakes regular audits of each jurisdictions progress against implementation (see NWC 2009 for example). Of particular interest to the development of a RCI in NSW are:

1. the requirement to better align water sharing and catchment action planning (Schedule E of the NWI);
2. undertaking planning, management and monitoring commensurate with the risk to the water resource;
3. transparency and repeatability in the science used for decision-making in water allocation; and
4. reporting on progress in meeting environmental outcomes (COAG 2004).

The NWC assesses the progress of each jurisdiction in meeting the requirements of the NWI through Biennial Assessments of progress. To that effect NSW has a NWI Implementation Plan that guides implementation (NSW Government 2006). The RCI project is aimed at addressing the requirements of the NWI listed above.

1.2.5.2 Murray Darling Basin Plan

The Murray Darling Basin Plan will provide an agreed Basin-wide framework to manage the water resources of the Murray–Darling Basin (MDB). Working within the Basin Plan (BP) framework states, communities and industry will need to work towards a common goal, but in ways that suit their particular situations best, and where flexibility, innovation and local solutions can operate.

The BP will identify, and seek to protect and restore key environmental assets that are regarded as important to the life of the rivers, their surrounding landscapes and the cultural values of the communities which depend on those water resources.

The *Water Act 2007 (Cth)* specifies some content that must be in the BP, including:

- limits on the amount of water (both surface water and groundwater) that can be taken from Basin water resources on a sustainable basis
- identification of risks to Basin water resources, such as climate change, and strategies to manage those risks
- the requirements that state water resource plans must comply with them to be accredited or adopted under the Commonwealth Act
- an environmental watering plan to optimise environmental outcomes for the Basin
- a water quality and salinity management plan
- rules about trading of water rights in relation to Basin water resources
- a monitoring and evaluation component.

Basin States will be required to meet certain accreditation requirements for their plans to be approved by the MDBA. The RCI project aims to fulfil some of these requirements which include aligning water and catchment planning, and identifying assets at a valley scale, and the risk to these from water extraction.

1.2.5.3 National compliance and enforcement framework

The NSW Office of Water has been funded by the Commonwealth government to implement a National Framework for Compliance and Enforcement Systems in Water Resource Management (National Framework). Milestone two of the National Framework Implementation Plan is to categorise water resources according to risk categories set out under the National Framework.

The National Framework has four risk categories to categorise water resources. The categories are designed to classify and prioritise water resources to ensure that targeting of monitoring and compliance is directed to the water resources with the highest competition between consumptive uses and the environment.

Milestone two of the Office of Water National Framework Implementation Plan requires the completion of four activities:

1. Compile basin risk assessments for NSW
2. Current risk ratings to be aligned with the National Framework
3. Categorise remaining water sources according to risk
4. Develop and implement strategies for ongoing review and update of water source risks

The RCI will be used as one of the methods to enable the water resources in NSW to be assigned to a risk category as set out under the National Framework.

1.3 Review of other river condition reporting tools

Freshwater systems are regarded as one of the most essential resources in the world and are increasingly under threat from anthropogenic activities and climate change (Vorosmarty et al. 2010; Aldous et al. 2011). In Australia, freshwater systems can become degraded as a result of increasing anthropogenic requirements compounded by widespread areas having experienced prolonged drought (Likens et al. 2009; Kingsford 2011). River health or condition is considered to be analogous to human health (Norris and Thoms 1999). In order to understand the condition of river systems and what, if any factors, promote or degrade condition, specific tools are required. Having tools that can spatially locate good and poor condition areas can assist with the prioritisation of sections of rivers for improvement in condition and aid in the development of specific management strategies. However, this applies at a range of time and space scales.

River health or condition assessment has been considered internationally in Europe (Pont et al. 2006; Noble et al. 2007), the United States (Reeves et al. 2004; Krogman 2011) and New Zealand (Young et al. 2004). Some methods have relied on biotic indicators and associated variables as surrogates for river condition (Wright 1994; Bowman and Summers 2005).

River condition assessment in Australia has been undertaken for over a decade with comprehensive reports at the national scale (NLWRA 2002). The National River Health Program (NRHP) was developed in 1994 to enable the standardised reporting on river condition at the national scale, but also aimed to enable reporting across jurisdictions (Norris et al. 2001; Environment Australia 2002). Additional assessment tools developed to measure aquatic condition across rivers and wetlands have enabled refined reporting on aggregated impacts on water resources (Norris et al. 2007a). Systematic river health assessments have also been developed to measure river condition at the valley scale within the Murray-Darling Basin and this approach continues to use methods for assessing macroinvertebrates that were developed in the National River Health Program (Davies et al. 2008).

Specific river condition assessment methods have also been developed for state reporting needs in Victoria (Ladson and White 1999) and Queensland (Anderson 1993, ERM 2011). In Northern Australia, a trial of the High Conservation Value Aquatic Ecosystems (HCVAE) criteria used a range of attributes that could be considered as useful attributes to measure and identify the location of specific riverine condition values (Kennard 2010). Some assessments have focused on key elements related to overall river condition, and included the measurement of riparian condition at the catchment scale (Jansen and Robertson 2001). In NSW, a multi-attribute river health assessment known as Pressure, Biota Habitat (PBH) was developed (Chessman 2002) but not adopted for ongoing river condition reporting. Many of these condition assessment approaches focus on multi-metric techniques for assessment with similarities between some of the assessment indicators. Some of these river condition methods rely on existing data (Ladson and White 1999) while others can be resource intensive as new data is required to be collected to help define condition (Jansen and Robertson 2001; Chessman 2002; Kennard 2010). However, comprehensive river condition assessment tools that provide detail at usable regional scales, are still lacking across many Australian jurisdictions.

Although there is no recommended ‘standard’ to assess river condition in Australia, it is considered a critical step in the planning and management of river systems (Whittington 2002). Indicators used to measure river condition vary according to the availability of consistent data sets in the areas or regions being assessed. However, the selection of indicators to report river condition should be scrutinised to ensure they comply with recommended criteria (Fairweather and Napier 1998; Whittington 2002).

Debate continues as to the effectiveness of science in developing policy for water management and the robustness of management decisions that are not developed with the principles that underlie scientific research (Tomlinson and Davis 2010). Often the best understanding of all the information required to inform water management needs is missing. This requires scientists, policy-makers and managers to focus on the best available science in their decision making processes (Ryder et al. 2010). Lack of funding and other resources preclude new data from being collected so the only options available, apart from changing funding priorities, are to use the best available information to identify river condition and inform policy and management of riverine systems. NRM scientists have an important role in participating in policy and management development to ensure that existing data used in objective decision making is considered in an appropriate way.

Reporting on river condition in Australia usually relies on existing data that has often been collected from different projects that are brought together to describe riverine systems (NLWRA 2002; Muschal et al. 2010). The indicators used to describe and report river condition can be considered as assets or values that warrant protection. Approaches have been developed in Australia providing a basis for riverine asset selection that can assist in identifying aquatic ecological values at different scales (Bennett et al. 2002). These guidelines were developed based on the need to understand the significance of the values requiring protection, and how susceptible these are to threats, thereby guiding planning and management outcomes (Bennett et al. 2002). It is these values, recommended via consultation with NRM scientists and managers (Dunn 2000) that are a key component in the development of a new RCI for NSW.

The RCI was developed due to the need to have a method that could combine multiple indices into a single condition score for reporting needs at required scales. Monitoring, evaluating and reporting on river condition required an overall index to be developed as a specific tool similar to that used in the SRA (Davies et al. 2008). This was not available for all state-wide condition data. The Framework for Assessing River and Wetland Health (FARWH) (Norris et al. 2007a) was chosen for the NSW RCI, tested and found to be useful for integrating sub-indices based on existing data into a single condition metric that can be applied to different spatial scales (Hamstead 2010). The FARWH was developed as part of the national Australian Water Resources 2005 reporting program, with the aim to provide details on key National Water Initiative requirements including establishing environmental and other public benefit outcomes and the integrated management of environmental water as well as a national standard for reporting river and wetland health details (Norris et al. 2007a). The FARWH uses a standardised Euclidean distance approach that enables sub-indices based on different measures to be combined into a single score (Norris et al. 2007a). The existing river ecological datasets available (eg geomorphology and riparian extent) or being collected in NSW also complement the sub-indices recommended in the FARWH approach. The separate components of each sub-index of the RCI and the rationale for including attributes associated with each one are described in section 2.2.

1.5 Aim of this report

The aim of this technical report is to present the technical details that describe all of the methods used in the development of the RCI and associated spatial products, as well as documenting a forward plan for refining and improving the methods. This latter point is particularly important as it is the intention that the spatial products developed as part of this project represent a starting point, and will be regularly updated over time, as new data and approaches become available.

2. Method development

The methods applied in each of the pilot CMA CAP reviews, where possible, adopted those used in the initial pilot tested in the Hunter-Central Rivers CMA (Hamstead 2010). The methods described below focus on providing extended detail to that provided in Hamstead (2010) and include additional primary methods developed during the pilot CAP review process in 2009-2010. At times, data used in one CMA was not available in another. In these cases, better and/or different data could be used.

The following methods are presented in the format of how data is compiled (spatially and non-spatially) to systematically determine primary water planning outcomes for each river reach in each CMA. Specifically these are:

1. Derivation of management units – provides an appropriate spatial scale to allow regional analysis and investment prioritisation;
2. River condition index (RCI) – provides the long-term reporting tool for changes in riverine condition and associated input attributes, for use in state of the catchment and state of the environment reporting. The spatial models can be used for deriving an overall valley condition score, if required.
3. River value assessment – provides a reach-based tool for assigning riverine values to highlight the value of each reach relative to others. This information has been used for the setting of water dealing (trading) rules, and highlighting important natural assets to assist in the review of CMA CAPs;
4. River risk assessment – provides a reach-based tool for assigning risk from water extraction and / or physical disturbance, and is the preferred layer for investment prioritisation in CMA CAPs and rule development in water sharing plans. A combined risk layer (ie. Extraction and physical disturbance) has been developed to enable better alignment of natural resource management plans.
5. Priority area assessments – provides a reach-based tool for prioritisation by overlaying the above risk layer, with the RCI layer, by theme (eg. geomorphology, riparian vegetation, etc.). The relationship in this process is that risk determines priority (as above) and condition determines whether the investment is in protection or rehabilitation.

Further detail on each of the above spatial products are provided in the later sections of this report. A diagram showing the relationship between the spatial products and NRM prioritisation, planning, and reporting is provided at Figure 14.

2.1 Derivation of management units

In the development of the RCI and associated spatial products consideration had to be given to the scale at which condition, value, and risk would be reported so that it was useable and useful for different agencies reporting and management needs (e.g. NSW Office of Water and CMAs) thereby allowing alignment and coordination. The initial SoC reports were developed to report against the statewide NRM targets and are reported at the CMA scale. The first SoC reports utilised the SRA 1 valley or catchment scale outcomes for inland CMAs, that were re-modelled to associate outcomes to the CMA region scale. Feedback received by the CMAs on the usefulness on the initial scale of SoC reporting indicated the scale was inadequate to effectively inform where investment in priority works should occur. Hence the RCI index focused on developing outputs at the reach scale for the values, risk and priority action assessments, and a subcatchment scale for the condition assessment.

CMA regional boundaries and unregulated river water sharing plan water source boundaries were visualised using ARC GIS 9.3 and the existing spatial layers available from the NSW Office of Water’s Enterprise Database (EDB). The spatial units called water sources were generally derived from the Stressed Rivers process developed for unregulated rivers in 1998 (DLWC 1998). In later years as the macro water planning process evolved in NSW, a small number of water source boundaries were adjusted based on the re-assessment of hydrologic features. For the CAP review process, hydrologic units smaller than the unregulated river water sources were required. These needed to be developed to a scale that would enable adequate assessment of attributes associated with river condition, but also at a scale that both CMA investment in natural resource management and development of specific water sharing rules could be applied.

The Bureau of Meteorology (BOM) has recently developed the Australian Hydrologic Geospatial Fabric (Geofabric) as part of the Australian Water Resource Information System (BOM 2010a). The Geofabric is a spatial framework that enables specific development of hydrologic mapping, modelling and reporting and enables relationships to be formed using a range of hydrologic features (BOM 2011). The Geofabric data was downloaded from BOM (2011) to enable the construction of smaller hydrologic management units.

Smaller hydrologic units were identified using the Geofabric Contracted Catchment feature dataset that enables aggregations of hydrologic features upstream of contracted nodes (BOM 2010b). This effectively lumps-up smaller hydrologic units into a size suitable for the end user depending on management or investigation needs.

The Geofabric contracted catchments were compared against the macro water sharing plan water source boundaries. The Geofabric contracted catchments are smaller than the water sharing plan water source boundaries, and therefore provided an indication of where the macro water sharing plan water sources could be broken down further into smaller subcatchments. Where the contracted catchments did not align with water sources boundaries, the new subcatchment boundaries were adjusted to fit the Geofabric boundaries (see Figure 2) based on the Geofabric’s catchment feature class. The Geofabric catchment boundaries are considered a more accurate and consistent representation of hydrologic boundaries than those applied to water sources. Ensuring that new smaller subcatchments would fit as well as possible within the macro water source boundary was important as the new subcatchments will likely be used in the next iteration of water sharing plan development in NSW.

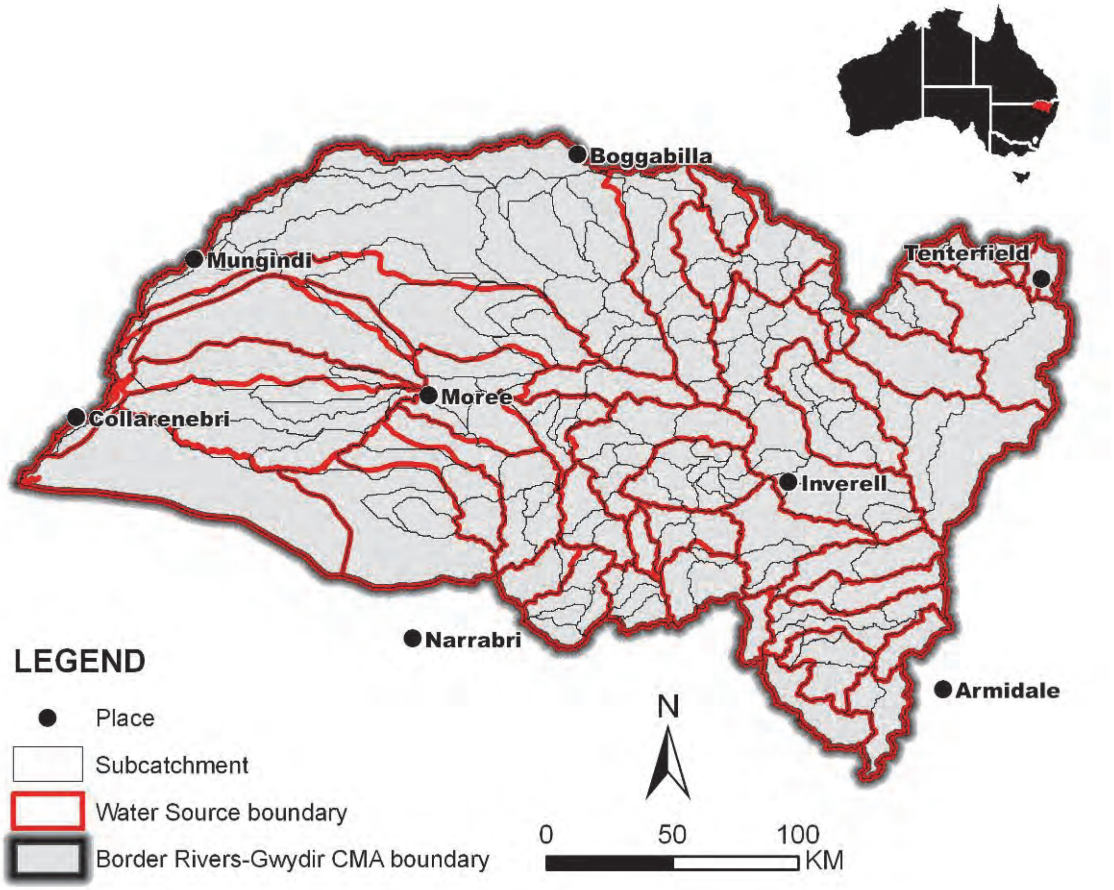

Figure 2: Map showing subcatchments derived from the Geofabric as compared against the Water Sharing Plan water source boundaries.

2.2 The River Condition Index

During the first round of reporting for the state-wide MER program in NSW, there was no appropriate method available to combine indicators of river condition into a single condition score (Muschal et al. 2010). The method used to develop the RCI was based on the NWC's FARWH approach (Norris et al. 2007a). This framework developed as the national standard under the NWC (Norris et al. 2007a). Subsequently the RCI for NSW has been developed using the FARWH approach that enables and assessment within and between CMA boundaries of riverine condition as it enables the use of different metrics within the sub-indices. This overcomes data gap issues particularly when most of the subindex metrics are standard across all CMAs for example River Styles® information as use of physical form. As such, subindices are capable of being used as an objectively assessable measure of progress in achieving improvement in water ecosystem condition, useful to CMAs for CAPs, NSW Office of Water for water sharing plans, OEH for Floodplain Management Plans and Environmental Water Management Plans and for water theme targets in the NSW MER Strategy for 2010-2015.

The FARWH framework recommends that six key components (indices) are appropriate for the assessment of river and wetland health (Figure 3), all of which are considered to be representative of ecological integrity. If the data for all six components are not available, the framework suggests a minimum of three indices are used. The NSW Office of Water has considered that it is important to also include a biotic sub-index as one of three minimum indices, particularly where there is sufficient spatial coverage of the data. For the development of the RCI, five components were measured to assess the RCI (Figure 3). This complies with the requirements of the FARWH for which a minimum of three sub-indices must be calculated where uniform data is available across all river reaches (Norris et al. 2007a). It is anticipated that as the RCI develops, additional data for water quality and catchment disturbance will be available for integration into the RCI. It is intended that the method be flexible enough to enable regional comparisons using different sub-indices, to deal with a lack of statewide data in some datasets.

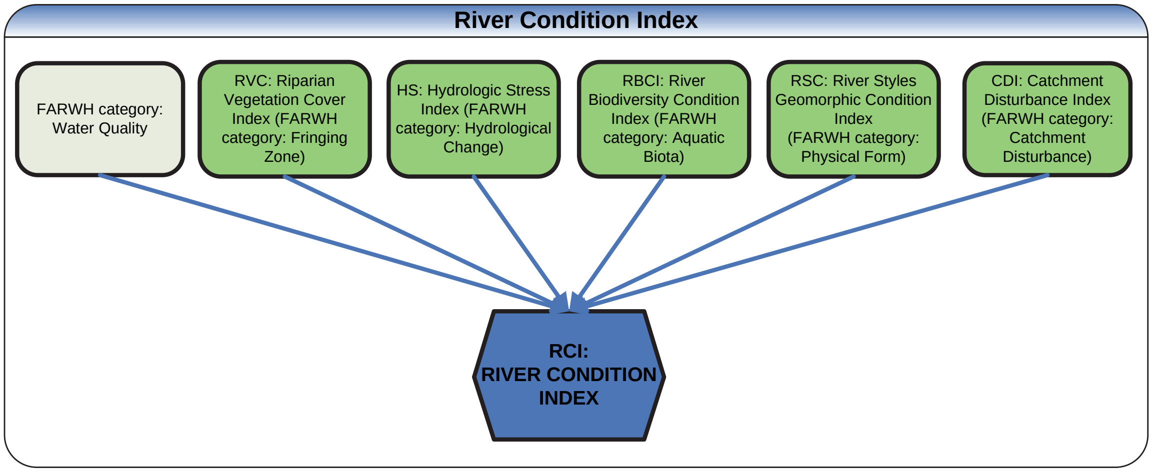

Figure 3: Indices used in the assessment of the RCI to date (in green), with future indices (in grey), with reference to the FARWH indices.

2.2.1 Data sets and methods

2.2.1.1 River Styles® Geomorphic Condition assessment – surrogate input under FARWH “Physical Form” category (RSGC).

River Styles® geomorphic condition is a measure of departure from a natural or expected state and can be defined as the ability of a river or reach to perform functions expected for a specific river type (Brierley and Fryirs 2005). The geomorphic or physical components within streams are regarded as key habitat features for aquatic biota (Maddock 1999; Newson and Newson 2000; Thomson et al. 2001) and have been measured in a number of riverine condition assessment programs (Anderson 1993; Reeves et al. 2004; Ladson and White 1999). River reaches in good condition have been found to be important for instream biodiversity (Chessman et al. 2006). A variety of mesohabitat types can be identified at the reach scale from which biologically relevant physical features can be identified and related to stream condition (Maddock 1999). The River Styles® assessment process enables the identification of geomorphic condition at the reach scale, relative to a reference condition for the given style, and provides an indication of the cumulative effects on a stream section from a range of disturbance events (Brierley and Fryirs 2005; Fryirs and Brierley 2005). Streams in poor geomorphic condition are unlikely to favour aquatic biodiversity due to a reduction in available physical habitats (Chessman et al. 2006).

Riverine channel and bank physical form is suggested to be useful to assess local aquatic habitat and its potential to support aquatic biota hence its inclusion as a key index in FARWH (Norris et al. 2007a). The RCI has adopted the River Styles® framework as the key data set underpinning the physical form sub-index.

The River Styles® Geomorphic Condition (RSGC) input index score (range 0–1) for each sub-catchment was determined from the percentage stream length of the Good, Moderate, and Poor River Styles® Geomorphic Condition categories in each subcatchment. This was done by intersecting the River Styles® spatial layer with the subcatchments spatial layer for each CMA region using ArcGIS. The percentage stream length of each category in each subcatchment was then calculated. The RSGC score was then calculated for each subcatchment as follows:

$$RSGC = \frac{(\%Good * 1) + (\%Moderate * 0.5) + (\%Poor * 0)}{100}$$

‘Good’ reaches were weighted double that of ‘Moderate’ reaches. ‘Poor’ reaches had zero weighting and therefore did not record a value. Refer to Appendix 3 for a detailed model of this process.

This equation was chosen as the dataset recorded values for the whole catchment and a simple weighting comparison between values was desired. The formula is the same as Equation 45 in the NWI report *Assessment of River and Wetland Health: Potential Comparative Indices* (Norris et al. 2007b), and results in an overall condition score ranging between 0 and 1, with higher scores representing better condition.

2.2.1.2 Riparian vegetation cover assessment (native woody vegetation) – surrogate input under FARWH “Fringing Zone” category (RVC).

The riparian zone is considered an important stream or wetland fringing feature that may contain attributes associated with the physical form and aquatic biota indices of FARWH (Norris et al. 2007a). Riparian zones provide the structure and stabilising function for stream banks preventing erosion, buffer against stream flows, filter nutrients, moderate instream primary production, and provide habitat for wetland and stream dependent biota (Spencer et al.1998; Werren and Arthington 2002; Lovett and Price 2007). Anthropogenic activity resulting from settlement and stock grazing are seen as significant factors influencing riparian zone condition (Jansen and Roberston 2001), and altered flow regime can reduce zonation, width, vigour and floristics of riparian zone plant communities (Werren and Arthington 2002). The removal of riparian and floodplain vegetation is associated with the modification of river geomorphic structure and *vice versa* (Brierley et al. 1999).

Attributes of riparian zones are commonly measured in river, riparian and wetland condition assessments in Australia (Ladson and White 1999; Jansen and Roberston 2001; Chessman 2002; Clayton et al. 2006). Riparian width and measures of native versus exotic plants species are common attributes in these assessments.

Native woody vegetation is an important measure of riparian zone condition as it reflects the level of stability or disturbance if exotic species are present. Native woody vegetation is considered better than exotic vegetation in terms of stream ecology and for re-introduction as large woody debris into streams, as some exotic species can re-sprout and others can leach toxicants into waterways (Cottingham et al. 2003; Brooks 2006). Native wood falling from riparian zones into streams is considered more valuable as aquatic habitat for native fish and macroinvertebrates and are important sites for biofilms and ecological processes (Cottingham et al. 2003; Galvin and Storer (2009).

Where more detailed assessments were unavailable, native woody vegetation extent within the riparian zone has been adopted for use in the RCI as riparian vegetation cover, estimated within a 30m buffer from the stream or rivers edge. This data is derived from Garlapati et al. (2010) who produced spatial mapping products of riparian vegetation extent for 24 catchments in NSW for the NSW Office of Water. Garlapati et al. (2010) used the NSW Interim Native Vegetation Extent (INVE) dataset (DECC 2008) to derive riparian extent data. The INVE used Landsat TM data at a 30 metre pixel resolution. Although 30m is a recommended width for riparian vegetation management in agricultural areas (Price et al. 2004), it also fits the pixel resolution of the INVE data and is within the range of widths recommended for other riparian management objectives (Price et al. 2004).

This data was available for all CMA areas except the Lower Murray Darling and Western CMA areas.

The analysis of this data resulted in a spatial layer that identifies the percentage cover of native woody riparian vegetation on each river reach. This was generated using ArcGIS, by converting the riparian vegetation raster layer into a polygon, and intersecting it with the River Styles® river reaches spatial layer, and then calculating the percentage cover of ‘Native Woody’ Riparian Vegetation for each river reach. Each reach was then assigned one of five categories, being 0-20%, 20-40%, 40-60%, 60-80%, 80-100%. Refer to Appendix 3 for a detailed model of this process.

The percentage stream length of each category in each subcatchment was then calculated. This was done by intersecting the resulting Native Woody Riparian Vegetation River Reach layer with the subcatchments layer. The percentage stream length of each category within each subcatchment was then able to be calculated.

Riparian Vegetation Cover (RVC) input index scores (range 0–1) for each sub-catchment were determined from the percentage stream length in each percentage category and was calculated as follows:

$$RVC = \frac{(\%\ 80\text{-}100\% * 1) + (\%\ 60\text{-}80\% * 0.75) + (\%\ 40\text{-}60\% * 0.5) + (\%\ 20\text{-}40\% * 0.25) + (\%\ 0\text{-}20\% * 0)}{100}$$

This index was scored using five categories; with higher percentage cover reaches weighted more than reaches with lower percentage riparian vegetation cover. This equation was chosen as the dataset recorded values for the whole catchment and a simple weighting comparison between values was desired. The formula is based on Equation 45 in the NWI report *Assessment of River and Wetland Health: Potential Comparative Indices* (Norris et al. 2007b), and results in an overall condition score ranging between 0 and 1, with higher scores representing better condition. This is also consistent with the type of equation used to calculate RSGC as described in section 2.2.1.1 Refer to Appendix 3 for a detailed model of this process.

The above equation assumes that the highest vegetation extent of cover equates to the best condition. This assumption obviously does not apply for areas where the riparian vegetation extent cover is naturally sparser (eg. riverine open woodland). . Until regional benchmarks for riparian vegetation cover are available, this approach will present a major limitation to the riparian vegetation sub-index (see section 3.5).

Where detailed local assessments of Riparian Vegetation are available for the whole CMA region, this is the preferred data to use. In the case of the Namoi CMA, a detailed assessment of the condition of Riparian Vegetation had been completed for their region. The condition of Riverine Vegetation in the Namoi Catchment was assessed by EcoLogical (2009). The study used metrics such as percentage woody cover, continuity of vegetation along rivers, connectivity, benchmark or reference conditions for species richness, canopy cover, and coarse woody debris. These metrics were used to develop an overall condition score for River Assessment Units (RAUs) within the catchment ranging between 0 and 100, where a higher score indicated better condition. The condition scores for RAUs, were used in the RCI as the Riparian Vegetation input. RAU spatial layer was intersected with the River Styles® spatial layer so that RAU scores were attributed to River Styles® river reaches. Five broad condition categories were then defined (0-20, 21-40, 41-60, 61-80 and 81-100) and assigned to each river reach for the RCI input.

The percentages length of each category within each subcatchment was calculated and then used to generate an overall RVC score (range 0–1) for each subcatchment. Reaches with higher scores for riparian vegetation condition were weighted more than reaches with lower scores for riparian vegetation condition. The same process was used as described above and detailed in Appendix 3.

In the case of the Sydney Metropolitan CMA, a detailed report had been completed on the mapping of river health, and included an analysis of riparian vegetation condition (see Earthtech, 2007) expressed spatially across streams in the CMA area. In this case, the categories used by Earthtech (2007) were grouped into five classes, being Very Good, Good, Moderate, Poor and Very Poor (see Table 1 below). The percentage stream length of each category in each subcatchment was then calculated and then used to generate an overall RVC score (range 0–1) for each subcatchment. Reaches in better condition were weighted more than reaches in poorer condition. The same process was used as described above and detailed in Appendix 3. i.e. using the formula

$$RVC = \frac{(\%\ \text{Very Good}*1) + (\%\ \text{Good}*0.75) + (\%\ \text{Moderate}*0.5) + (\%\ \text{Poor}*0.25) + (\%\ \text{VeryPoor}*0)}{100}$$

Table 1: Alignment of Sydney Metropolitan CMA rankings to those used in the River Condition Index.

Sydney Metro CMA Condition and Vegetation Rankings	RCI Vegetation Categories
No vegetation/flood control	Very Poor
Degraded condition - little/no vegetation	Poor
Moderate condition - little/no vegetation	Poor
Degraded condition - good/moderate vegetation	Moderate
Good condition - moderate recovery	Moderate
Moderate condition - good/moderate vegetation	Moderate
Good condition - high recovery	Good
Near intact - inside reserve	Very Good
Near intact - outside reserve	Very Good

2.2.1.3 Macro water planning: hydrologic stress or risk rating – surrogate input under FARWH "Hydrological Change" category.

Alteration to flow is considered a major threat to freshwater biodiversity (Dudgeon et al. 2005). Flow regimes are regarded by many ecologists as the key factor that influences riverine ecosystems (Bunn and Arthington 2002; Poff et al. 2009). Modification to flows in Australian rivers systems is a result of a variety of human impacts related to catchment disturbance or land clearing, water extraction, damming of rivers and installation of weirs and road crossings to name a few. The regulation of rivers in Australia is regarded as a key factor influencing the deterioration of river condition (Boulton and Brock 1999; Arthington and Pusey 2003).

Hydrologic stress or modification is considered as a measure to report alteration to flows within catchments or subcatchments. It is a reporting measure on river and catchment assessment adopted in the United States (WRC 2001) and in some jurisdictions in Australia (DLWC 1998; Ladson and White 1999; NLWRA 2002). Indicators of flow and flow metrics have also been used to describe the condition of hydrology more recently in the Murray-Darling Basin (Davies et al. 2008).

Hydrologic stress was first recognised in NSW water planning reforms and was adopted as a key measure to assist in priority setting for water management planning in unregulated rivers (DLWC 1998). The metric used in this process was already calculated for each water source and was based on estimates of current daily water use by proportioning estimates of peak daily water extraction to an estimate of low streamflow, often the 80th percentile or 50th percentile flow in the peak demand month (NSW Office of Water 2010). This method represents a much simpler approach to those cited above, and is applied to unregulated rivers in NSW where most extraction pressures are on low flows.

The data used for the assessment of hydrology varied depending on availability. Three core datasets were used:

1. Distributed hydrologic stress assessment (most of NSW);
2. Macro water sharing plan hydrologic stress data;
3. Sustainable Rivers Audit (SRA) Hydrology Condition Index

Figure 4 shows the decision tree for the use of each dataset, and Figure 5 shows the distribution of data usage for each set.

Additionally, in cases where a subcatchment did not contain any active licences (based on the Surface Water License spatial layer from the NSW Office of Water), the subcatchment was assigned a "very low stress" score of 1. In cases where more than 50 per cent of the rivers in the subcatchment were covered by the Regulated Water Sources (based on the Regulated Water Source spatial layer from the NSW Office of Water), the sub-catchment would receive a score of 0.5, indicating "very high stress". The above rules override any other estimates of hydrologic stress.

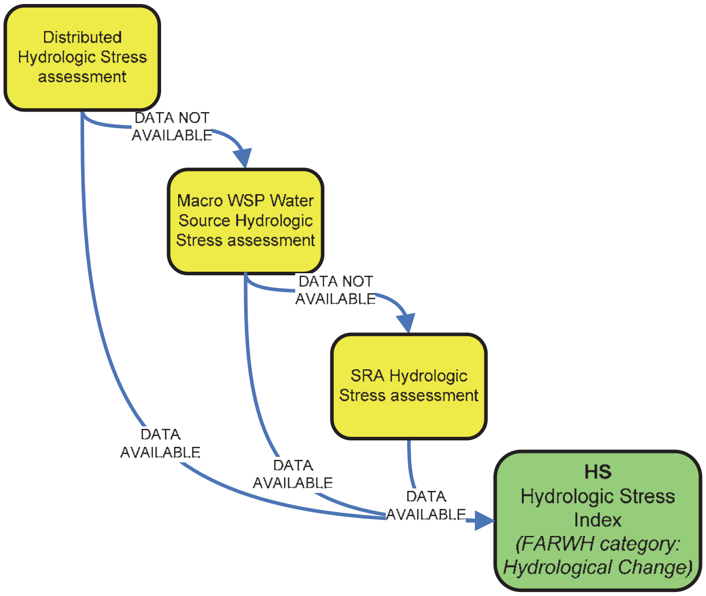

Figure 4: Decision tree for the use of hydrologic data

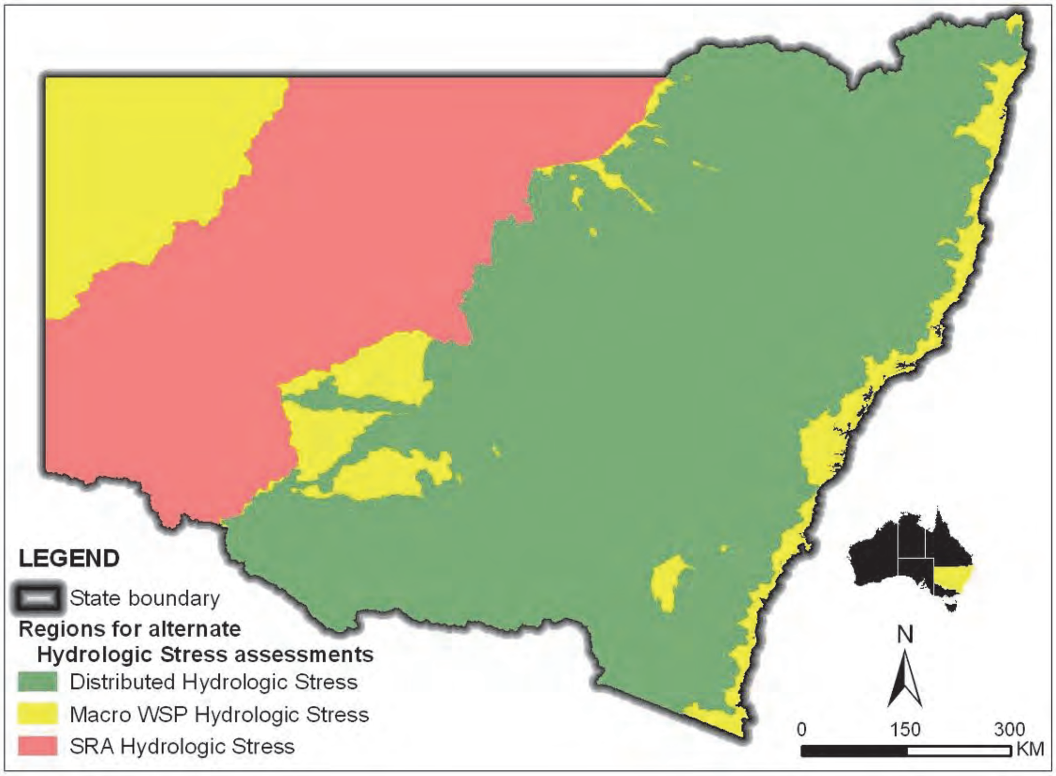

Figure 5: Map showing where each of the hydrologic stress indices were used (NB. In cases where more than 50 per cent of the rivers in the subcatchment were covered by a regulated river (based on the Regulated Water Source spatial layer from the NSW Office of Water), the sub-catchment would receive a score of 0.5, indicating "very high stress").

Distributed hydrologic stress assessment

The distributed hydrologic stress layer is the preferred hydrologic stress index, as it generates hydrologic stress at a reach scale. However, there are limitations with this approach, and these are discussed in section 3.5. To produce this pressure indicator for individual reaches the 80th percentile flow and peak daily water demand needed to be estimated for each reach. This is only possible due to the capability of Geographic Information System (GIS) software to analyse the river systems, more specifically to accumulate spatial input data along the river system. The GIS is used to generate two spatial layers: an indicative 80^{th} percentile flow layer, and an estimated peak daily demand (PDD) layer, which can then be compared, to estimate the proportion the peak daily water demand is of the 80^{th} percentile flow (i.e. hydrologic stress).

The PDD is estimated by allocating each individual licence a PDD based on its water use profile and the amount of entitlement on the licence. These PDDs can then be accumulated downstream to the end of the river system using GIS, producing a distributed representation of the water extractive pressure along the river system with the accumulated PDD increasing with each individual licence along the river.

The indicative 80^{th} percentile flows are also estimated using the accumulation function within the GIS. A flow accumulation grid was created and used to interpolate between points in the river system where the streamflows are measured. Where the 80^{th} percentile flow is estimated to be increasing along the river the flow is increased in proportion to the amount of area contributing to that reach of river, and where the 80^{th} percentile flow is estimated to be decreasing along the river the flow is diminished proportionally with length of stream (not area). A more detailed description of the method and the data compiled to estimate the 80^{th} percentile flows is presented in the (Sayers, in prep).

The hydrologic pressure, or stress, is then estimated by dividing the indicative 80^{th} percentile flow layer by the PDD layer. Where the PDD is greater than the flow the stress index is 1 (or 100 per cent of the 80^{th} percentile flow is in demand) and where the PDD is zero the stress is zero (or none of the flow is in demand). Similarly where the PDD is 75 the size of the 80th percentile flow the stress index is 0.75.

The estimation of hydrologic stress along the systems uses the Spatial Analyst Tools\Hydrology\Flow Accumulation tool within the ArcToolbox, which utilises flow direction rasters or grids that represent the land surface as cells. The grids represent the stream locations reasonably, but not as accurately as the mapped river lines, which the River Styles® information is attributed to. Hence a mechanism is required to transfer the hydrologic stress attributed to grid based lines (referred to as network line) to the River Styles® cartographic lines.

The approach has been to convert the River Styles® cartographic lines to network lines, which coincide with the Hydrologic Stress network lines. Then to use the Spatial Joining function to attribute the River Styles® network lines with the Hydrologic Stress index. Finally, reverting back to the original cartographic River Styles® lines to maintain the more acuate mapped representation of the rivers, by using Attribute Joining to transfer the stress value, from network to cartographic line.

See Appendix 3 for a more detailed description of the process.

Each reach was then assigned one of five condition categories, being Very Good (0-0.2), Good (0.2-0.4), Moderate (0.4-0.6), Poor (0.6-0.8) and Very Poor (0.8-1.0). Very Good reaches had a lower Hydrologic Stress score (indicating Low Stress), while Very Poor reaches had a higher Hydrologic Stress score (indicating High Stress).

The percentage stream length of each category in each subcatchment was then calculated. This was done by intersecting the resulting Hydrologic Stress River Reach layer with the subcatchments layer. The percentage stream length of each category within each subcatchment was then able to be calculated.

Hydrologic Stress (HS) input index scores (range 0–1) for each sub-catchment were determined from the percentage stream length in each percentage category and was calculated as follows:

$$HS = \frac{(\%\ \text{Very Good}*1) + (\%\ \text{Good}*0.75) + (\%\ \text{Moderate}*0.5) + (\%\ \text{Poor}*\ 0.25) + (\%\ \text{Very Poor}*0)}{100}$$

This index was scored using five categories; with better condition (low stress) reaches weighted more than reaches poorer condition (higher stress). This equation was chosen as the dataset recorded values for the whole catchment and a simple weighting comparison between values was desired. The formula is based on Equation 45 in the NWI report *Assessment of River and Wetland Health: Potential Comparative Indices* (Norris et al. 2007b), and results in an overall condition score ranging between 0 and 1, with higher scores representing better condition. This is also consistent with the type of equation used to calculate RSGC as described in section 2.2.1.1, and RVC as described in Section 2.2.1.2. Refer to Appendix 3 for a detailed model of this process.

Macro water sharing plan hydrologic stress layer

This measure of hydrologic stress was used in the macro water sharing process for unregulated rivers to assist in the development of water sharing rules (Office of Water 2010). The hydrologic stress data set is available for most of the state and was considered a useful surrogate for input into the FARWH index of Hydrologic Change where the distributed hydrologic stress assessment was not available.

Extraction levels for each water source were based on all current water licence entitlements accessing either surface water or groundwater (in the highly connected alluvial aquifers). The extraction calculation assumes full development of all access licences, (which is generally greater than the actual volume of water being currently extracted) but reflects potential extraction. Extraction demand was based on surveyed crop types and an estimate of water use.

The macro water sharing plans assigned a Hydrologic Stress or Risk rating (range 0 – 1) to each of the macro water sharing plan water source planning units. These are described in the manual for macro water plans (NSW Office of Water 2010). The original scores used in the macro water sharing plan process were joined to the macro water sharing plan surface water source spatial layer, which was then used to apply the scores to the RCI subcatchments. These hydrologic stress or risk scores were applied evenly to all subcatchments within each water source planning unit.

As High Stress for the macro water sharing plan (a score of 1) was equivalent to a low condition for the RCI (a value of 0), the raw water sharing plan Hydrological Stress scores needed to be reversed for input into the RCI.

Since the Hydrological Stress or Risk ratings were determined at a larger scale no differentiation between the subcatchments within each water source planning unit could be made, as the stress rating was assigned to the whole water source. Accordingly the overall weighting of this index was modified to half that of the RSGC, RVC, RBCI and CDI scores. This was done by recalculating the input scores from a range of 0 to 1 to a range of 0.5 to 1. The *Field Calculator* tool was used to recalculate the Hydrologic Stress scores for the subcatchments within ArcGIS.

Additionally, in cases where a subcatchment did not contain any active licences (based on the Surface Water License spatial layer from the Office of Water), the subcatchment was assigned a “very low stress” score of 1. In cases where more than 50 per cent of the rivers in the subcatchment were covered by the Regulated Water Sources (based on the Regulated Water Source spatial layer from the Office of Water), the sub-catchment would receive a score of 0.5, indicating “very high stress”.

While there are a number of licences in the far north-west corner of NSW (comprising the Bullo River and Lake Eyre Basins), most of them are for stock and domestic purposes covered by basic landholder rights, and as such there is limited volumetric entitlement. At this stage the total entitlement within this water source is 30 megalitres, for irrigation purposes. Given the lack of detailed knowledge of this area, low entitlement and unreliability of flows, these water sources were given a low hydrologic stress rating.

Sustainable Rivers Audit (SRA) Hydrology Condition Index

Where neither the distributed hydrologic stress assessment or the macro water sharing plan hydrologic stress assessment were available, the SRA Hydrology Condition Index was used. A summary of the index is provided below from Davies et al (2008), and the reader is referred here for further details. The index combines the five indicators below and reflects the relative ecological importance of high and low flow events, changes in flow variability and seasonality, and the annual flow volume:

1. High-Flow Events Indicator - A measure of change in the size of high flow events relative to Reference Condition.
2. Low- and zero-flow events indicator - An integrated measure of change in the size of low flows and the duration of zero flow periods relative to Reference Condition.
3. Flow variability indicator - A measure of change in the variability of flows relative to Reference Condition.
4. Flow seasonality indicator - A measure of change in the seasonal pattern of flows relative to Reference Condition.
5. Gross annual flow volume indicator - An integrated measure of changes in mean and median annual flow volumes relative to Reference Condition.

For SRA Report 1 (Davies et al 2008), hydrological indices and indicators could only be calculated for individual sites, not for zones or valleys. The Hydrological Condition of each valley was made by semi-quantitative evaluation based on Expert Rules applied to site scores.

Reference Condition for Hydrology was estimated using models that simulate conditions with no direct human influence within the Basin (storages, diversions and inter-valley transfers set to zero). The models were run for each site, covering the same period of record as for an observed ‘current’ scenario.

Current and Reference Condition data for Hydrology accounts for both wet and dry periods. Assessments therefore reflect the overall effects of water resource development on the historical flow regime rather than the recent prevailing drought.

The original scores used in the SRA process were available as a spatial layer, which was then used to apply the scores to the RCI subcatchments. These hydrologic stress or risk scores were applied evenly to all sub-catchments within each SRA Valley zone.

As High Stress for the SRA (a score of 1) was equivalent to a low condition for the RCI (a value of 0), the raw SRA Hydrological Stress scores needed to be reversed for input into the RCI. (ie. A high SRA score = low stress or good condition, whereby SRA scores condition 1 to 0 = Good to bad whilst RCI scores Stress 1 to 0 = High to Low).

Since the Hydrological Stress or Risk ratings were determined at a larger scale no differentiation between the subcatchments within each valley zone could be made, as the stress rating was assigned to whole valley. Accordingly the overall weighting of this index was modified to half that of the RSGC, RVC, RBCI and CDI scores. This was done by recalculating the input scores from a range of 0 to 1 to a range of 0.5 to 1. The *Field Calculator* tool was used to recalculate the Hydrologic Stress scores for the subcatchments within ArcGIS.

2.2.1.4 River biodiversity condition data – surrogate input under FARWH “Aquatic Biota” category (RBCI).

The FARWH recognises the importance of including an aquatic biota index to report on river condition as the condition of catchments and habitats are not the only factors that can reliably inform on the attributes of aquatic biota (Norris et al. 2007a). Aquatic biota have widely been used as sub-index components to report on river condition and conservation assessments overseas (Boon 2000; US EPA 2002) and in Australia (Ladson and White 1999; Chessman 2002; NLWRA 2002; Davies et al. 2008). Many biotic indicators are available to incorporate into river condition assessments, with reduced river condition associated with loss of taxa (Norris and Thoms 1999). Macroinvertebrates have been used widely as a surrogate measure of instream biota and many taxa have been shown to be responsive to broad scale landscape attributes (Richards et al. 1996) alteration to natural flow regimes (Growns and Growns 2001; Bunn and Arthington (2002) and water quality (Chessman 2003).

Two approaches have been used to develop an input on biodiversity condition, depending on the data available. These are:

1. Aquatic Biodiversity Forecaster Tool analysis (Turak et al. 2011)
2. SRA macroinvertebrate and fish condition data

Figure 6 shows the distribution of these.

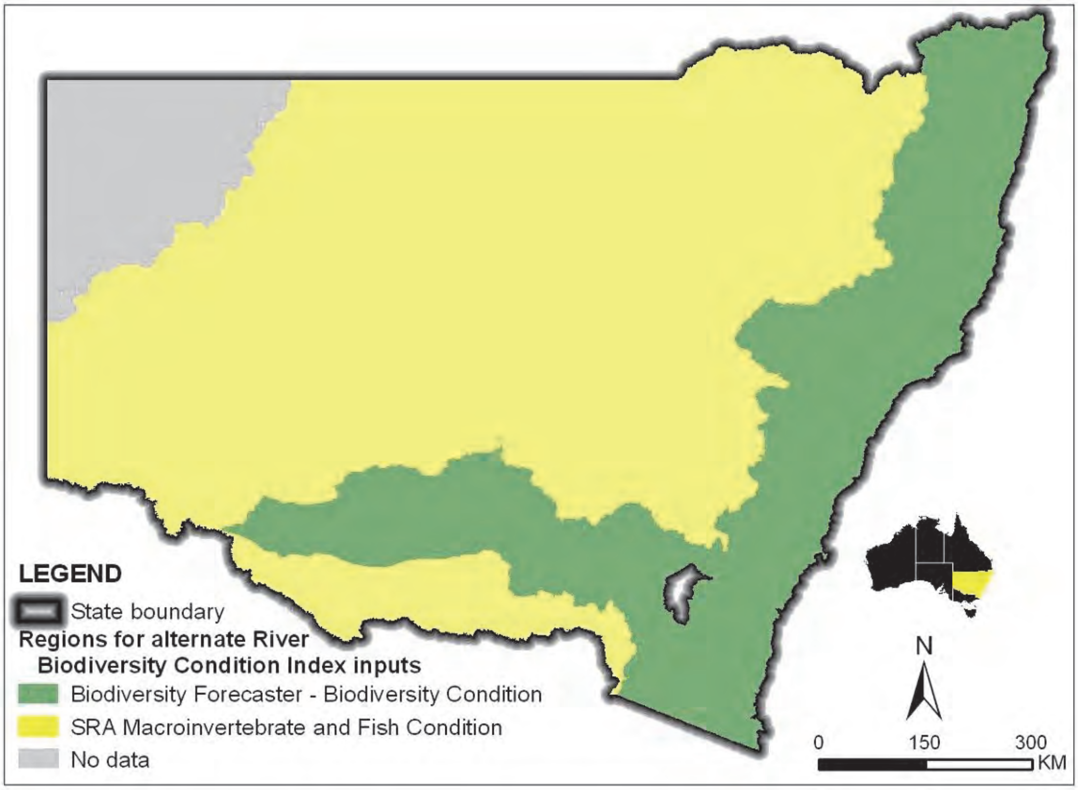

Figure 6: Map showing the availability of the Aquatic Biodiversity Forecaster outputs and SRA data

Aquatic Biodiversity Forecaster Tool analysis

The Aquatic Biodiversity Forecaster Tool (ABFT) was developed by Turak et al. (2011) in the Hunter-Central Rivers CMA in NSW, primarily as a tool to predict and map where catchment protection, restoration or conservation priorities should occur. The ABFT utilises macroinvertebrates and the influence of human-induced disturbances to predict the biological condition at river sites (see section 3.5 and 3.7 re the limitations of only using one biotic assemblage). Models using the ABFT have been developed for Murrumbidgee CMA as well as the coastal CMAs.

Where the ABFT analysis has been completed it is the preferred data set to be used and has been utilised for those areas shown in Figure 6.

The original Biodiversity Condition outputs from the ABFT were based on the National Catchment Boundaries (NCB) from the GeoFabric database (BOM 2011). Since the original data output is at a scale smaller than the subcatchments used in the RCI, the output scores are aggregated for each subcatchment, using an area weighted average. That is bioforecaster subcatchments are spatially assigned to the larger RCI subcatchments. The score of the smaller subcatchment is multiplied by the percentage area of the larger RCI subcatchment occupied by the smaller subcatchment. The products are then added for each RCI subcatchment in order to get an overall RBCI score for each RCI subcatchment ranging between 0 and 1. Appendix 3 shows in detail the process used to generate the RBCI using the ABFT.

Sustainable Rivers Audit Fish and Macroinvertebrate Condition Indices

With the exception of the Murrumbidgee catchment, the ABFT is not available for inland NSW. For these areas SRA data (Davies et al. 2008) on macroinvertebrate and fish condition is used.

SRA data is reported using altitudinal zones within a given valley. The altitudinal zones are intersected with the RCI subcatchments. The SRA score is multiplied by the percentage area of the RCI subcatchment occupied. The products are then added for each RCI subcatchment in order to get an overall score for each RCI subcatchment ranging between 0 and 1 for both fish and macroinvertebrates. (This method is consistent with the method used for calculating RBCI using the ABFT.) The two SRA scores for each subcatchment are then averaged to get an overall RBCI score for each RCI subcatchment ranging between 0 and 1. Appendix 3 shows in detail the process used to generate the RBCI using the SRA data.

2.2.1.5 Catchment Disturbance Index – surrogate input under FARWH "Catchment Disturbance" category (CDI).

This index provides a measure of anthropogenic changes that have the potential to impact on river condition and biota. Land Use data, Loss of Woody Vegetation (Land Cover Change), and Infrastructure data were combined in order to characterise changes in the land surface within the catchment.

Infrastructure Index (I)

Spatial infrastructure data from the NSW Office of Water's spatial database was used to determine the coverage of infrastructure within each subcatchment. Specific infrastructure features were weighted according to Table 17 of the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands.* The derivation of weights is described in detail in the section on Integration and aggregation in the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands* and is provided in Table 2 below (see Stein et al [2002] for derivation of weightings).

Table 2: Weightings used in the derivation of the infrastructure index layer

CATEGORY	INFRASTRUTURE WEIGHT
Main Sealed Road	0.70
Other Sealed Road	0.70
Railway	0.22
Unsealed Road	0.55
Vehicular Track	0.55
Utilities (power, pipes)	0.07
Walking Track	0

(Table adapted from Table 17 in the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands)*

Vector data layers of the appropriate infrastructure features (based on Table 1) were converted to Raster data layers, where each grid cell had a value of 0 or 1 depending on the presence or absence of features. The individual rasters were combined into a single raster. Where features overlapped, only the feature with the highest weighting was recorded. The Infrastructure Index was assessed by the extent of each infrastructure category within the catchment adjusted by the associated weights, in accordance with Equation 4.7 on page 35 of the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands:*

$$I = 1- ((FI_1 * w_1) + (FI_2 * W_2) + (FI_3 * W_3) + (FI_4 * W_4))$$

(where I = Infrastructure Index, FI_1 = fraction of the catchment of infrastructure category 1, w_1 = the weight for infrastructure category 1, etc)

Land Use Index (LU)

Land use data for this component came from the Australian land use mapping project. The land use data was aggregated into categories that reflected the land use effects on aquatic biota, in accordance with Table 18 in the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands.* Each category received a weighting to account for the different impacts of the various land use categories. The derivation of weights is described in detail in the section on Integration and aggregation in the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands* and is provided in Table 3 below.

Table 3: Weightings used for the derivation of the land use index layer

Audit Land Use categories	ALUM major category	Weighting
Horticulture, orchards, legumes, cotton, rice, non-cereal forage crops	Intensive animal husbandry	0.7
	Intensive horticulture	
	Irrigated perennial horticulture	
	Irrigated seasonal horticulture	
	Perennial horticulture	
	Seasonal horticulture	
	Irrigated cropping	
	Grazing irrigated modified pastures	
Transport, utilities, urban uses, institutional uses	Manufacturing and industrial	0.68
	Mining	
	Residential and farm infrastructure	
	Services	
	Transport and communication	
	Utilities	
	Waste treatment and disposal	
	Channel/aqueduct	
	Reservoir/dam	

Audit Land Use categories	ALUM major category	Weighting
Cropping not included in intensive and irrigated agriculture	Cropping	0.48
Production forests, farm forestry, plantations	Irrigated plantation forestry	0.2
	Plantation forestry	
	Production forestry	
Grazing	Grazing modified pastures	0.33
	Grazing native vegetation	
	Land in transition	
Wilderness area, protected landscape, National park, habitat/species management area, strict nature reserve, national monument, managed resource protected areas, unmanaged land, water	Estuary/coastal waters	0
	Lake	
	Managed resource protection	
	Marsh/wetland	
	Nature conservation	
	Other minimal use	
	River	

A raster layer was created from the land use polygon layer based on the categories in the above table.

The Land Use Index was assessed by the extent of each land use category within the catchment adjusted by the associated weights, in accordance with Equation 8 on page 36 of the NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands:*

$$LU = 1- ((LUI_1 * w_1) + (LUI_2 * W_2) + (LUI_3 * W_3) + (LUI_4 * W_4))....$$

(where LU = Land Use index, LUI₁ = fraction of the catchment of land use category 1, w₁ = the weight for land use category 1, etc)

Land Cover Change Index (LCC)

This index provides an assessment of the loss of woody vegetation based on the statewide Land Cover And Trees Study (SLATS) method applied by the NSW Office of Environment and Heritage (OEH). The SLATS method, developed in Queensland, is based on the analysis of multi-date Landsat imagery and applies an automated change analysis process followed by visual interpretation of the results by experienced image interpretation staff (http://www.derm.qld.gov.au/slats/index.html). The change rasters are coded to classes that indicate the type of vegetation change. The 2007-2008, 2008-2009, and 2009-2010 eras have been processed for this assessment. (http://sdi.nsw.gov.au/GPT9/catalog/search/viewMetadataDetails.page?uuid=%7B3882A688-95A1-4B92-A438-EC6822A62E3A%7D). These three assessments were combined and analysed for RCI purposes. Note however that land clearing (and therefore the chosen time-slices) will vary across NSW, with some areas likely to have been quite substantially cleared by the early 1900s, whereas other areas are likely to have been more recently cleared.

The total area of ‘Land Cover Change’ for each subcatchment was calculated. A weighting of 0.68 was then applied to ensure consistency with other measures comprising the catchment disturbance index. The derivation of the weight is described in detail in the section on Land Cover Change data NWC’s *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands.*

The final Land Cover Change index score for each subcatchment was calculated in accordance with Equation 9 on page 38 in the NWC’s *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands*

$$LCC = 1 - ((Area_d * W) / \ Area_t)$$

(where LCC = Land Cover Change Index, $Area_d$ = area of catchment in which woody vegetation decreased, W = weight (0.68), $Area_t$ = total area of catchment for which there is data)

Catchment Disturbance Index (CDI)

The three subindices (infrastructure, land use, and land cover change) were integrated into a single catchment disturbance index for each subcatchment. No weighting was applied when the three measures were integrated. This is because although there is evidence of a linkage between each factor and aquatic biota, there is little evidence on the *relative* impact. The final Catchment Disturbance Index score was calculated in accordance with Equation 10 on page 45 of the NWC’s *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands.*

$$CDI = I + LU + LCC - 2$$

(where CDI = Catchment Disturbance Index, I = Infrastructure index, LU = Land Use index, LCC = Land Cover Change index)

Note: This equation has the potential to give a score of less than 0. In these cases, the scores were set back to 0 indicating a major impact, and very poor condition.

2.2.3 River Condition Index (RCI) score

Multimetric indices used to report biological condition are useful tools that enable biologists and natural resource managers to explain what they know about biological systems (Karr 1999). Methods to explain how a specific ecosystem’s condition can be represented in a dimensionless geometric space using integrated metrics have been accomplished by natural resource planners using Euclidian distance measures (Norris et al. 2007b; Nestler et al. 2010). The River Condition Index (RCI) follows this method to integrate river condition metrics into a unified score developed by Norris et al. (2007a). This process was initially developed to report on other river condition reporting needs for the Murray-Darling Basin (Norris et al. 2001) and was later expanded to the development of whole-of–nation method represented by the FARWH (Norris et al. 2007a). River condition sub-indices are standardised using the Norris et al. (2007a) approaches for sub-indices prior to being integrated into the RCI and this approach has been used in other Australian studies (Young et al. 2004) with the outcome enabling sub-indices to be represented on a dimensionless 0-1 scale where 1 represents the best or reference condition (Norris et al. 2007a). Using the standardised Euclidean distance measure to integrate river condition sub-indices used in the RCI provides a level of consistency in the way river condition outcomes have been reported across

Australia. The standardised Euclidean distance formula was chosen in accordance with Table 3 in NWC's *Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands*. Accordingly, the RCI uses base indices that "are different but [use] complementary ways of estimating status". The NWC also recommends using a Euclidean distance formula for integrating sub-indices for flow regulation, physical form and integrating a range of index types generally.

The formula used is:

$$RCI = 1 - \frac{\sqrt{(1 - RSC)^2 + (1 - CDI)^2 + (1 - HS)^2 + (1 - RBCI)^2 + (1- RVC)^2}}{\sqrt{5}}$$

Application of the method resulted in a score (range 0 – 1) for all subcatchments with a higher score applying to subcatchments in better condition.

Where CMAs did not have all five indices, the RCI formula was altered accordingly. For example

$$RCI = 1 - \frac{\sqrt{(1 - \text{Index } A)^2 + (1 - \text{Index } B)^2 + (1 - \text{Index } C)^2 + (1 - \text{Index } D^2}}{\sqrt{4}}$$

2.2.3.1 Bands of Condition

The range of scores was split into five classes in the following ranges:

0.81 – 1 = Very Good (equivalent to FARWH "Largely Unmodified")
0.61 – 0.8 = Good (equivalent to FARWH "Slightly Modified")
0.41 – 0.6 = Moderate (equivalent to FARWH "Moderately Modified")
0.21 – 0.4 = Poor (equivalent to FARWH "Substantially Modified")
0 – 0.2 = Very Poor (equivalent to FARWH "Severely modified")

2.2.3.2 Spatial representation

All of the sub-indices as well as the RCI were calculated using ArcGIS, Microsoft Excel$^{\text{TM}}$, and Microsoft Access$^{\text{TM}}$. All layers are able to be displayed as map layers (see Figure 7). River Condition Index spatial outputs were checked by relevant CMA staff to validate, or otherwise, the results in most CMA areas. CMA staff were satisfied that the spatial outputs represented, to the best of their knowledge, the actual condition of the rivers within their CMA area.

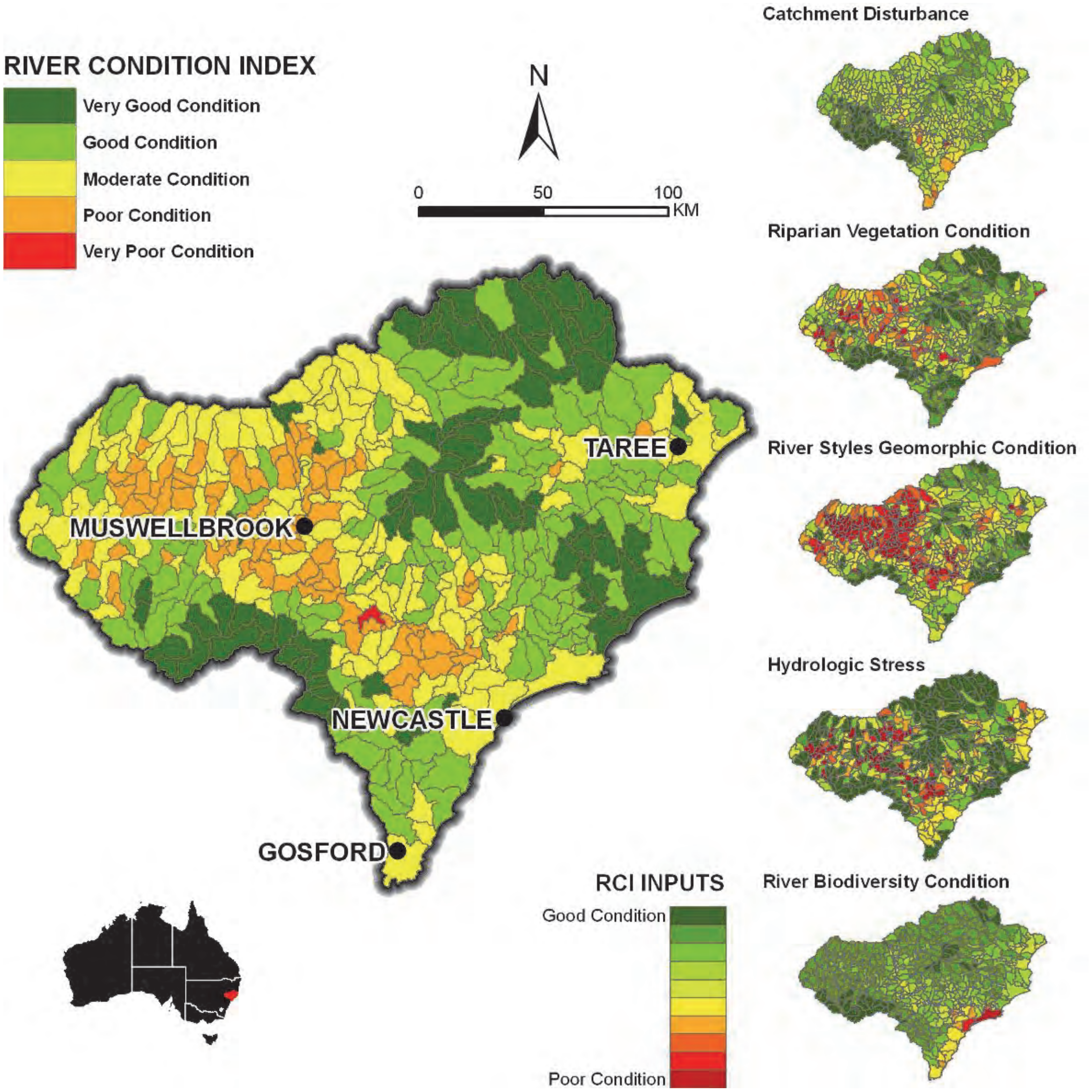

Figure 7: River Condition Index results for the Hunter Central Rivers CMA area.

2.2.4 Assumptions

There are a number of assumptions that have been made in the development of the RCI. These are discussed below. Many of the details listed in Sections 2.2.1 to 2.2.3 assist in justifying these assumptions.

The key assumptions underlying the RCI method and its application are:

Aggregation of Aquatic Biodiversity Forecaster Tool outputs into larger catchment units

The integrity of river macro-invertebrate assemblages provides a useful measure of the biological condition of river reaches; spatial patterns in biological condition of river reaches in the region are determined by spatial patterns in the extent of human-induced disturbance, together with location of the river reach within the catchment and the landscape; and, by aggregating the assessments made for small subcatchments into larger subcatchments, critical information on spatial patterns in the river health in the region is not lost.

Linking geomorphic condition to aquatic biodiversity

The work of Chessman et al. (2006) concluded that river geomorphic condition significantly influenced macrophyte and macroinvertebrate diversity, with species loss when a stream moves from high to moderate or poor geomorphic condition. Based on this work, and that of Jones and Byrne (2010) the assumption used in the RCI is that native aquatic taxa favour stream locations in good geomorphic condition as poor geomorphic condition reaches lack the complexity of geomorphic units relative to their reference condition required to support higher ecosystem services and functions.

Relationship of riparian vegetation extent to condition

In the cases where the Riparian Vegetation Cover Index calculates Riparian Vegetation Condition based on percentage cover, the RVCI is based on the assumption that a greater cover of native woody riparian vegetation provides greater benefits to base food-web requirements, increases shade and shelter for instream organisms, increases geomorphic complexity, reduces significant bank and bed erosion and increases channel roughness (Cottingham et al. 2002; Brooks 2006). It also assumes a uniform referential cover across the entire catchment of 80-100 per cent. It was considered that this is the most appropriate measure of impact on the “fringing zone”. However, the preference is to always use regionally-based riparian cover benchmarks, and these were used in the development of the RCI for the Namoi CMA area.

Extrapolation of site assessments

The outputs from the aquatic biodiversity forecaster tool (and the SRA) are based on the extrapolation of site assessments of the biological health of short river reaches to the entire drainage network in the region (see Turak et al. (2010) for justification of this).

2.3 River value assessment

This section describes the method used to capture instream values. It should be noted that values are a separate dataset to instream condition (see section 2.2). While there may be some overlap in the indices used, for others, a high value does not necessarily imply good condition. For example, river reaches of high value because of high fish diversity may not necessarily coincide with reaches that are in good condition.

The consideration of value assessment for water management in Australia is enshrined in both Commonwealth and state water management legislation. The Intergovernmental Agreement on a National Water Initiative (NWI) (COAG 2004) requires jurisdictions when undertaking water planning activities to: *identify and acknowledge surface and groundwater systems of high* *conservation value, and manage these systems to protect and enhance those values*. The NSW *Water Management Act (2000)* requires that when water management plans are being developed that water sources are classified: *as to the extent of their conservation value (that is, the extent to which their intrinsic value merits protection from risk and stress).*

A number of studies in Australia have been undertaken that recommend the types of conservation or ecological values that should be considered when undertaking water planning and management activities. These recommend a range of attributes and criteria and associated evaluation techniques to determine value types and how to consider them for these management activities (Dunn 2000; Bennett et al. 2002).

The recommendations from the work of Dunn (2000) and Bennett et al. (2002 have largely been adopted by a number of jurisdictions in Australia to improve water planning and management activities. The Commonwealth Government has undertaken a range of trials under a High Conservation Value Aquatic Ecosystems (HCVAE – now called HEVAE) project to recommend to jurisdictions an appropriate process to meet the requirements of the National Water Initiative (Peters 2010). The Queensland Government has also developed a process called AquaBAMM (Clayton et al. 2006) to assist meeting their obligations under the NWI and State water management legislation. The AquaBAMM method has since been adopted in trials of the HCVAE method in NSW (DPI 2008) due to the similarity in criteria used by each approach.

The AquaBAMM method adopted eight key criteria; Naturalness – aquatic, Naturalness – catchment, Diversity and richness, Threatened species and ecosystems, Priority species and ecosystems, Special features, Connectivity and Representativeness (Clayton et al. 2006). The HCVAE method initially adopted seven criteria to trial and included; International recognition, Representativeness, Diversity, Distinctiveness, Critical habitat, Evolutionary history, Naturalness (Peters 2010). However, as a result of the trials, both Naturalness and International recognition have been recommended to be removed as criteria, and other recommendations to modify attributes associated with each criteria (Peters 2010).

In NSW, water planning and management activities have also adopted similar criteria used in the HCVAE and AquaBAMM methods to enable value assessment to support water planning activities. The macro water sharing plan instream value assesses attributes associated with six criteria; Naturalness, Diversity, Rarity, Special features, Non extractive values and place values (NSW Office of Water 2010). The macro water sharing plan instream value method does not assess Evolutionary history and Representativeness largely due to the lack of availability of suitable existing State-wide spatial layers for this data.

The river value assessment complements the instream value assessment undertaken for macro water sharing plans (NSW Office of Water 2010). This process assists NSW in meeting its obligations under the NWI with the Commonwealth where water planning frameworks are required to identify and protect water systems identified as having high conservation value (Commonwealth of Australia, 2004). In the macro water sharing plan process and river value assessment, a water source or river reach classified as having high instream value is synonymous with high conservation value.

The instream value assessment was completed on a river reach scale using a range of datasets based on availability. Rather than adopting the approach of only using data that was available state-wide, the river value assessment aimed to use the best available data for each CMA area.

While this may not allow direct comparisons between CMAs, it ensures that each CMA has the most up to date data. The various options for presentation of river value data for each CMA are presented in Figure 8, and methods discussed thereafter.

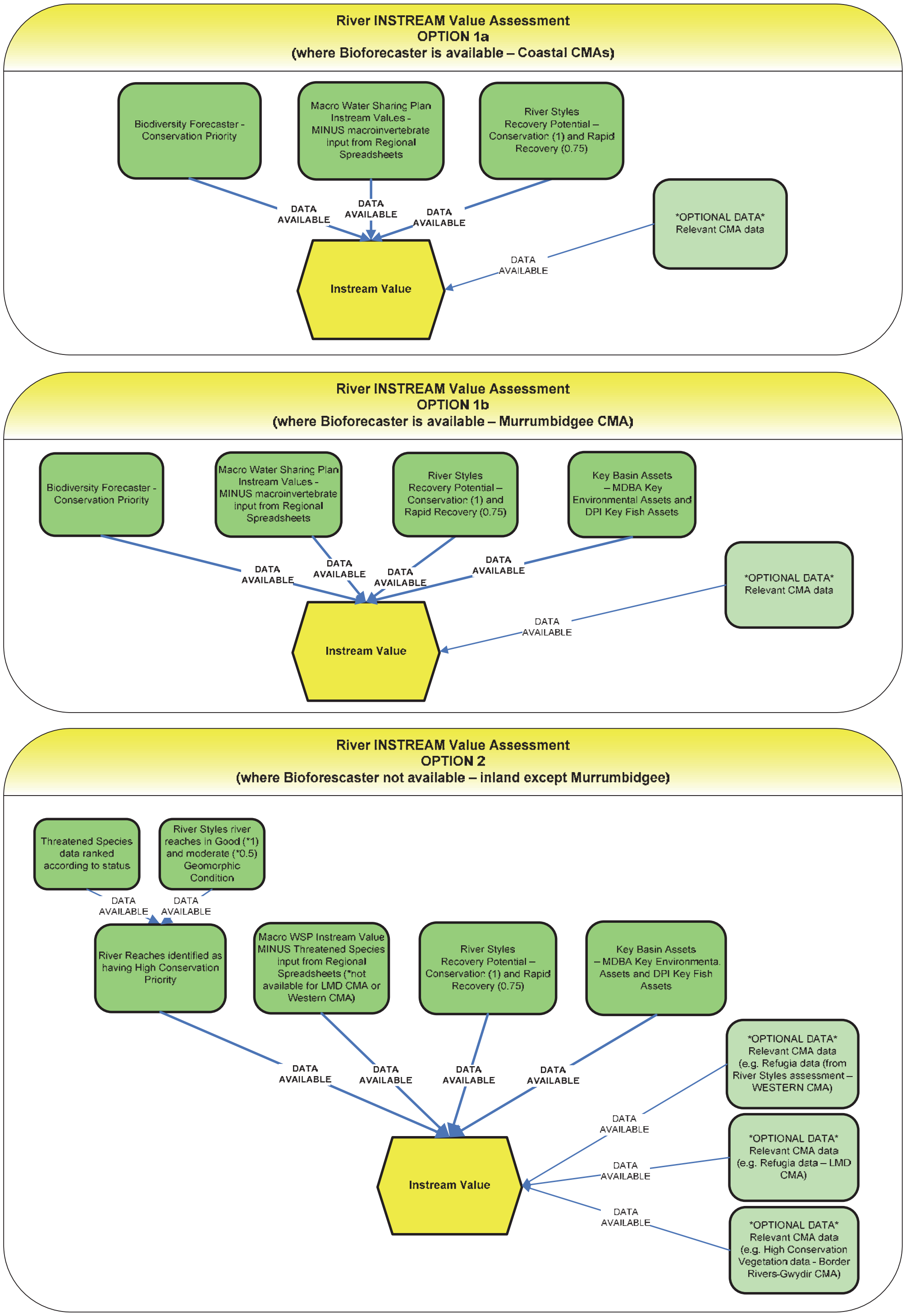

Figure 8: Decision tree options for each CMA based on data availability for river value

The River Styles® data layer is used as the underlying reference scale for the analysis of values, as it provides the initial reach stratification. For instream value, each river reach identified in River Styles® mapping is assigned input scores from the input datasets described later in this section. The input scores are then averaged in order to get an overall Instream Value score.

2.3.1 Method associated with using the conservation priority outputs of the Aquatic Biodiversity Forecaster Tool

In CMAs where the Aquatic Biodiversity Forecaster Tool (ABFT) was available, River Section Conservation Priority scores from the ABFT were used to calculate Conservation Priority scores for river reaches as an input into the Instream Value score. The original Conservation Priority outputs from the Biodiversity Forecaster Tool were based on the National Catchment Boundaries from the Geofabric database, and represent the biodiversity components of instream value. This prioritization ranks subcatchments in terms of the importance of the biodiversity contained in river sections that fall within that subcatchment (see Turak et al. 2011). It allows comparisons among river reaches in terms of the regional significance of the biodiversity they contain. Subcatchments are ranked in terms of their quantitative contribution to catchment biodiversity where the integrity of macroinvertebrate assemblages is used as a surrogate for biodiversity condition (see Turak et al, 2010). The contribution of each river reach to river biodiversity is computed as a function of both the current condition of the reach and the river type it belongs to. Using this method, a river reach that is in relatively poor biological condition but belongs to an uncommon river type may be given a higher conservation priority than a river type that is in very good condition but belongs to a common river type because the loss of its remaining biodiversity would have greater regional significance then the loss of value that river reaches that are more common.

River Styles® river reaches were assigned the Conservation Priority score from the AFBT subcatchment they intersected. It is important to note that in these cases, macroinvertebrate data was removed from the Macro water sharing plan instream value assessment calculation, in order to avoid duplication of data. This process was used in Murrumbidgee and coastal CMAs.

2.3.2 Method to associate threatened species with River Styles®

In regions where outputs were not available from the Aquatic Biodiversity Forecaster Tool, an assessment of the presence of threatened water-dependent aquatic taxa was made, and associated with the geomorphic condition of river reaches, in order to identify areas for Conservation Priority. It is important to note that in these cases, threatened species data was removed from the Macro water sharing plan instream value assessment calculation, in order to avoid duplication of data.

River reaches in good geomorphic condition have been found to be important areas for instream biota and aquatic threatened species. Chessman et al. (2006) found that instream biota, particularly macroinvertebrates and macrophytes can be sensitive to geomorphic change from good to moderate condition. In this study the most significant reduction in macrophyte and macroinvertebrate diversity occurred when river s moved from good to moderate or poor geomorphic condition. Other evidence suggests that river geomorphology and riparian vegetation condition can also influence the abundance, population structure and suite of freshwater mussel species (Brainwood et al. 2006; Jones and Byrne 2010).

For threatened species management, the loss of the ‘chain-of-ponds’ river types through channel incision that has occurred since European settlement has been implicated in the decline of up to five threatened frog species in the Southern Highlands of NSW (Hazell et al. 2003). Maintaining the integrity of the physical geomorphic habitat is seen as an important factor to assist in the management of the threatened Stuttering frog *Mixophyes balbus* (Hunter and Graham 2010).The endangered fish, the Macquarie Perch, is generally not found in NSW rivers or streams where in-stream geomorphic conditions cause bank undercutting. (Gilligan et al. 2010). The introduced Mosquito fish is listed as a key threatening process in NSW due to the impact this species has via predation on native fish, tadpoles and macroinvertebrates and displacing of native species from habitat (NPWS 2003). Mosquito fish are generally not found in unaltered lotic environments with natural flow regimes and they tend to favour modified rivers and streams in poor physical condition (NPWS 2003, Brookhouse and Coughran 2010). This information provided the basis to develop an approach whereby threatened species scores were apportioned to river reaches in good physical condition.

Threatened species data were provided by DECC (now OEH) and DPI during the macro water sharing plan classification of unregulated rivers in 2006. To ensure that current listings of threatened species, populations and communities were accounted for, threatened species information was assessed for each CMA using the current information available on DECCW (now OEH) and DPI threatened species web sites (OEH 2011; DPI 2011). Threatened species scores were applied to each macro water sharing plan water source to indicate presence (known or predicted) or absence. The aim of this method is to associate each threatened species, population or community and their known habitat with specific River Styles® in good and moderate condition in each CMA region. This will enable the linking of threatened species habitat with the condition of each River Style® and allow for the identification of habitat located in specific river reaches of ‘good’ and ‘moderate’ condition. This approach has the limitation of assuming that most threatened species are more likely to occur in rivers that are in good (as opposed to moderate or poor) geomorphic condition. While this assumption may hold for some species (see those referred to above) it may not apply to others. Further testing of this assumption is required.

The following approach was used:

1. Water dependent threatened species identified in the macro classification spreadsheets are associated with each water source. As a pragmatic approach, all species are associated with a water source whether they are scored as *known* or *predicted* to occur in the macro classification spreadsheets. The assumption is based on the precautionary principle in that:
    - any species predicted to occur could occur within a water source, and
    - the instream and/or riparian habitat of each threatened species could occur in each water source and is likely to be linked to the physical (geomorphic/physical assemblages) habitat associated with a River Style at the reach scale.
2. The macro classification process captured threatened species scores for data as listed in 2006. To ensure all current listed threatened species, populations or communities are accounted for, NSW OEH and DPI threatened species web sites were checked and new listings after 2006 relevant to each CMA area were also included in the assessment.
3. The legal status of threatened species were used to assign rankings as this method provides a means to describe the value of a water source to different categories of threatened

species. Legal Status for threatened species are those listed under the *Threatened Species Conservation Act 1995* or the *Fisheries Management Act 1994*.

The legal status of each threatened species in a water source was assigned scores from highest to lowest, where any listing of critically endangered species was weighted highest, any endangered listing, next highest score and any vulnerable species the lowest score. A critically endangered listing in a water source automatically received the highest 'final' score. This approach allows the ranking of water source threatened species values (using a Final threatened species (TS) score) no matter how many threatened species occur in a water source.

5. Threatened species scores (TS scores) based on legal status were then associated with river reaches in good and moderate condition (based on River Styles® condition rankings) to determine spatially where threatened species habitat is likely to occur. River Reaches with moderate geomorphic condition received half the TS score, while poor condition reaches received a score of 0. These calculations for river reaches based on geomorphic condition formed the Final Threatened Species Score (Final TS score). See section 3.5 and 3.7 for limitations and recommendations on this approach.
6. Threatened species habitat were ranked from very high to very low based on the Final TS score, listed in Table 4. Ranges of Final TS scores were normalised to a range from 0 to 1 to be consistent with other value rating scores used in the value assessment process.

Table 4: Scoring Features for threatened species legal status and river reaches in good condition

Final Threatened Species Score Range	**Normalised Score Range**	**Threatened species water dependent habitat value (conservation priority)**
8.01 – 10.00	0.801 – 1.000	Very High Value
6.01 – 8.00	0.601 – 0.800	High Value
4.01 – 6.00	0.401 – 0.600	Moderate Value
2.01 – 4.00	0.201 – 0.400	Low Value
0.00 – 2.00	0.000 – 0.200	Very Low Value

This assessment was used in all inland CMA regions except Murrumbidgee, where the aquatic biodiversity forecaster tool was used instead.

2.3.3 Macro water sharing plan Instream Value Assessment

The initial instream value data was compiled in 2005-2006 by former NSW agencies of DECC, DPI and Natural Resources (DNR). Microsoft Excel^{TM} was used to capture data for each valley in a "regional spreadsheet". NSW Office of Water (2010) provides more information on the macro planning approach, and the spreadsheets referred to. The key criteria and consideration of attributes for inclusion for assessing instream values were derived from Dunn (2000) and Bennett et al. (2002). Only values associated with water extraction are considered in the macro water sharing plan process as they guide the development of trading (dealings) rules.

In cases where the Aquatic Biodiversity Forecaster Tool was used, macroinvertebrate data was removed from the Macro water sharing plan instream value assessment calculation to reduce duplication of using similar datasets. In cases where outputs were not available from the ABFT, and the assessment of the presence of threatened water-dependent aquatic taxa was made, threatened species data was removed from the macro water sharing plan instream value assessment calculation. In both cases, the macro water sharing plan instream Value scores were recalculated within the spreadsheets.

The recalculated raw scores from the regional spreadsheet analysis were spatially assigned to macro water sharing plan water sources. The river reaches that fell inside these water source subcatchments were given the corresponding score ranging from 0 to 1 with 1 representing High Instream Value. This assessment was available for every CMA except Lower Murray-Darling.

2.3.4 River Styles® Assessment

A change in geomorphic condition has been shown to result in a loss of aquatic biodiversity for some assemblages. For example Chessman et al (2006) found that instream biota is sensitive to geomorphic change from good to moderate condition, with macrophyte and macroinvertebrate assemblages changing significantly once geomorphology changes to a more degraded state (see also Jones and Byrne (2010) work on freshwater mussels). River Styles® reaches with conservation recovery potential are, by definition, in good geomorphic condition. River Styles® reaches with a “rapid” recovery potential classification are those reaches in moderate condition that will respond rapidly to minimalist management intervention over a short timeframe, and are usually proximal to reaches in good condition.

River reaches with recovery potential of conservation were assigned a score of 1, and river reaches with recovery potential of rapid were assigned a score of 0.75. All other reaches were assigned a score of 0. This assessment was available for every CMA.

2.3.5 Key basin assets

The Murray Darling Basin Authority (MDBA) is currently developing a Basin Plan for water management that defines a sustainable level of water take for the Murray Darling Basin. Part of the process to determine a sustainable level of take is to identify key environmental assets (MDBA, 2010) and then determine their water requirements. Given that the Basin Plan will guide water planning in NSW and other basin states, it is important that the key environmental assets are included in any assessment of value.

To determine the ‘key’ environmental assets, five criteria were established by the MDBA.

The five criteria are:

- Criterion 1 — The water-dependent ecosystem is formally recognised in, and/or is capable of supporting species listed in, international agreements.
- Criterion 2 — The water-dependent ecosystem is natural or near-natural, rare or unique.

- Criterion 3 — The water-dependent ecosystem provides vital habitat.
- Criterion 4 — The water-dependent ecosystem supports Commonwealth-, state or territory-listed threatened species and/or ecological communities.
- Criterion 5 — The water-dependent ecosystem supports or is capable of supporting significant biodiversity.

Additionally, Fisheries NSW have identified a range of river reaches within the Murray Darling Basin that support a high diversity of native fish species. Such reaches were not necessarily captured by the process used by the MDBA, and were identified by Fisheries NSW using data from SRA and the literature.

The above two datasets were combined to create a value input index called Key Basin Assets. This analysis was used for every CMA that is in the Murray Darling Basin.

2.3.5.1 MDBA key environmental assets

Only those MDBA key environmental assets associated with Criteria 1,2,3 and 5 were used, as Criteria 4 relates to threatened species and/or ecological communities, which is picked up in either the threatened species assessment, or the water sharing plan instream value data (depending on which data was used – see sections 2.3.2 and 2.3.3). The number of MDBA key environmental asset criteria the river reach met, determined the associated value score that was assigned to the River Styles® river reach (see Table 5 below). The lowest score for reaches that intersected MDBA key environmental assets was 0.7, and it was applied to river reaches that matched only one criteria. Those reaches were assigned a 0.7, because the value was still regarded as reasonably high compared to reaches where no assets were identified by the MDBA.

Table 5: Scoring system for river reaches that intersected MDBA key environmental assets

Number of MDBA Key Environmental Asset Criteria assigned to reach	Value score assigned to reach
0	0
1	0.7
2	0.8
3	0.9
4	1.0

2.3.5.2 DPI key fish assets

The NSW Fisheries (DPI) key fish assets represent those reaches most important for the largest number of native species. The analysis uses electrofishing catch data collected between 1 January 2000 to 8 July 2010. The CPUE (individuals per 60 seconds of electrofishing) for each site sampled is then calculated. Sites are then partitioned into each of the 4 SRA altitude zones.

Within each altitude zone, each site is ranked for CPUE for each native species in ascending order (highest CPUE for native species is largest rank value). The ranks for all species for each site are then summed and the site that has the highest 'sum of ranks' identified. All sites are then scaled within the zone as a percentage of the 'sum of ranks' of the best site in the zone.

Sites with higher percentage scores represent sites that generally have the highest abundances of the largest number of native species (between years 2000 and 2010). Confidence in the approach is supported by observed autocorrelation among proximal sites (ie. sites with similar values are clustered rather than randomly distributed) (Dean Gilligan pers comm.). Reaches with high biodiversity value for fish are those that have clusters sites with percentage points ranging from 61-100 per cent.

If River Styles® river reaches intersected DPI key fish assets they received a score of 1, regardless of the score assigned from the MDBA key environmental assets. This approach was chosen, as fish in the Murray Darling Basin are recognised as undergoing serious decline (Lintermans 2007), and high value reaches should be afforded a high level of protection.

2.3.6 Additional CMA data

If CMAs had additional relevant data they deemed to be important to an Instream Value assessment for their region, and the data was available catchment wide, these data sets were incorporated into the value assessment. Examples of these datasets include Refugia data (Western CMA), DPI Key Fish Habitats (Lower Murray Darling CMA), and High Conservation Vegetation data (Border Rivers-Gwydir CMA).

2.3.6.1 Refugia data

Western and Lower Murray Darling CMA

As part of the River Styles® assessment, an attempt to map instream drought refugia was undertaken in conjunction with the River Styles® mapping project (GHD, 2011). Six categories were defined as described in Table 6.

Table 6: Refugia categories as defined in the Western CMA River Styles® report

Refugia Category	Description
Disconnected Pools	Mapped reach contains a series of relatively large, disconnected pools that are likely to hold water for a significant period of time following rainfall or flow events.
Isolated Pools	Mapped reach contains one or two relatively large, isolated pools that are likely to hold water for a significant period of time following rainfall or flow events.

Refugia Category	Description
Potential	Ability to determine presence of pools was limited by either vegetation or resolution of imagery. If pools are present they are likely to be relatively small and only hold water for relatively short periods following rainfall or flow events.
Lake	Mapped reach is a lake with some water present at the time imagery was captured.
Dam or Weir Pool	Mapped reach is a dam or weir pool and would hold water almost continuously.
None to Limited	No pools observed within reach. Any pools following rainfall or flow events are likely to be short-lived. Includes lake beds dry at the time of image capture.

River reaches with refugia identified as *none* to *limited* received a score of 0. River reaches with refugia identified as *potential* received a score of 0.5. River reaches with refugia identified as *dam or weir pool*, *disconnected pool, isolated pool*, or *lake* were assigned a score of 1. This is because pools have a key ecological function as a critical refuge and habitat for flora and fauna, particularly in the far west, where many of the streams are highly intermittent.

Pools also have a key ecological function as a critical refuge and habitat for flora and fauna. A fundamental principle for the effective management of pools is the NSW Government's River Flow Objective 1 which is to 'protect natural water levels in pools of creeks and rivers and wetlands during periods of no flow'."

2.3.6.2 High Conservation Value (HCV) vegetation

Border Rivers-Gwydir CMA

High Conservation Value (HCV) vegetation is defined in the Border Rivers / Gwydir Catchment Action Plan as, "areas that make a significant contribution to the conservation of biodiversity or cultural heritage" (BRGCMA 2007). A project was completed in 2009 in order to identify these areas within the BRGCMA area. BRGCMA proposed that this data was relevant and important for an Instream Value assessment in their CMA, as it identified areas for conservation priority for riparian vegetation; hence the data was included in the analysis.

The polygon spatial layer of HCV was intersected with the River Styles® river reach spatial layer. The percentage length of river sections in High, Moderate and Low HCV was calculated for each river reach. The final HVC value score was calculated for each river each as:

$$\text{HVC value score} = \frac{(\%\text{High} * 1) + (\%\text{Moderate} * 0.5) + (\%\text{Low} * 0)}{100}$$

This equation was chosen as a simple weighting comparison between values was desired. The formula is based on Equation 45 in the NWI report *Assessment of River and Wetland Health: Potential Comparative Indices* (Norris et al. 2007b), and results in an overall condition score ranging between 0 and 1, with higher scores representing higher value.

2.3.6.3 Community data

Where CMAs have additional information on instream values associated with waterways that are identified by the community in a given CMA area, they can also be included (see Figure 8 and Hamstead 2010). Inclusion of community data assists alignment between the water sharing plans and CAPs via the inclusion of a wider range of values associated with waterways. However, since this data is often not based on legislation or known scientific methods or needs, but personal opinion, it is weighted half that of the other data inputs.

2.3.3 Method for calculating final instream value scores

Each input data set (Figure 8) had a score ranging between 0 and 1 assigned to each river reach within the CMA region (Figure 9). The final Instream Value score was calculated by averaging the available Instream Value input scores assigned to each river reach.

The Final Instream Value scores are then displayed in increments of 0.2, with higher scores representing higher Instream Value for a CMA region (see Fig 9).

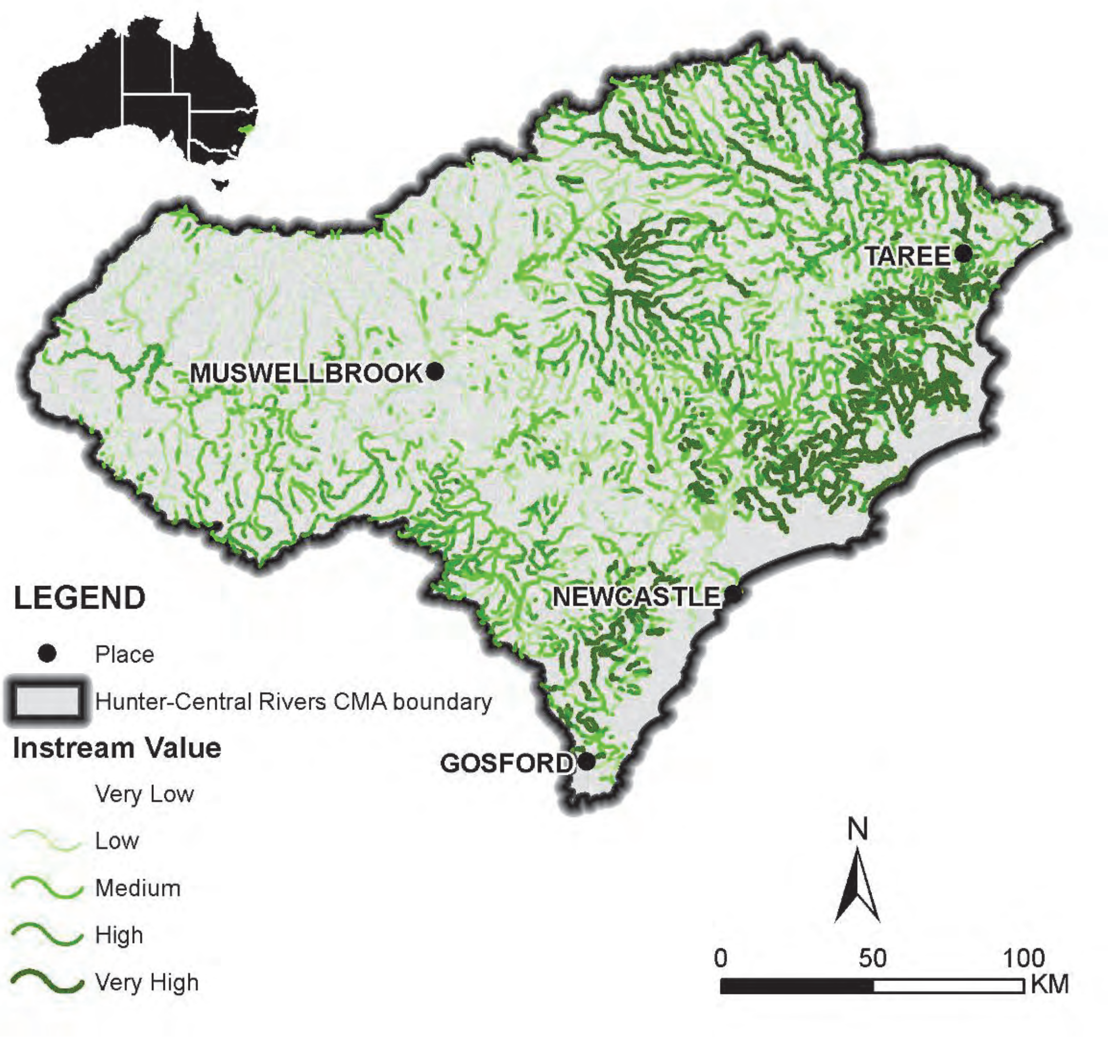

Figure 9: An example output showing instream values for the Hunter Central Rivers CMA region.

2.4 River risk assessment

Ecological risk assessments are undertaken to inform managers about the potential adverse effects of different management decisions. The management of risks associated with human activities is considered a significant challenge in the face of uncertainties and potentially high costs (US EPA 1998). Water management in Australia is examining the risks associated with water extraction on environmental assets with the Murray Darling Basin Plan, examining key areas of future risk to water resource condition and availability at the Basin scale (MDBA 2010). Risk assessment, in an environmental management context, is a process that can express the probability that a hazard will occur and the magnitude of the environmental outcome (Muschal 2003). Risk assessment is a useful tool for prioritisation of both management action and for the stratification of monitoring effort where work-force or budget resources are limited.

Using the macro water sharing plan approach to the management of unregulated rivers in NSW, the Office of Water has also implemented a risk assessment approach to manage the level of extraction demand against the risk to instream values to assist in developing rules that manage water extraction at low flows (NSW Office of Water 2010).

The river risk assessment approach draws on the experience from both the macro water sharing plan approach for unregulated rivers (NSW Office of Water 2010) and the trial of an alignment project in the Hunter catchment of NSW (Hamstead 2010). River risk assessment has developed into a three stage process that enables a final risk assessment to key instream values (Figure 10).

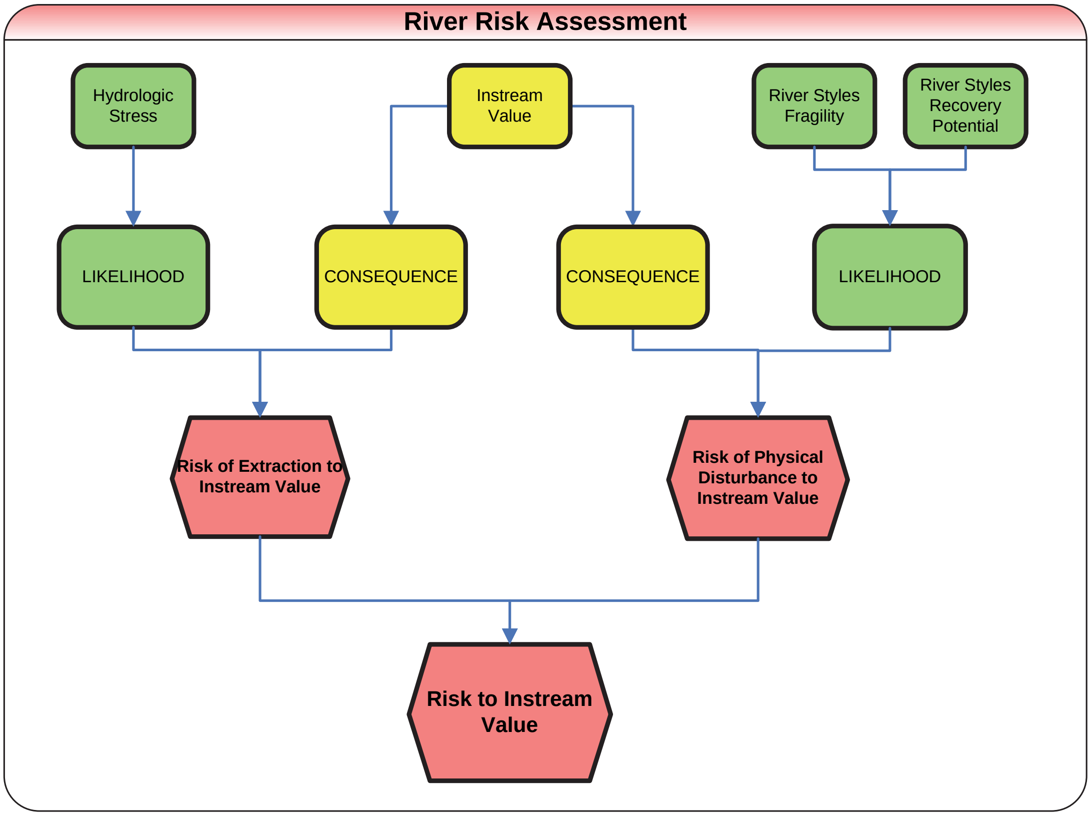

Figure 10: The three stage process to determine the risk from key riverine activities and overall risk to river instream values.

The three stage process involves firstly, an assessment of risk to instream values from extraction, secondly an assessment of risk to instream value from physical disturbance and thirdly, an overall risk assessment that combines the initial two risk assessment outcomes. The aim of this process is to provide a risk assessment outcome at the river reach scale. The assessment helps identify river reaches where priority strategies, primarily for investment in water management and CMA rehabilitation, can be considered. When these two strategies are aligned they can provide for multiple environmental outcomes from two natural resource management programs.

The risk assessment processes described below utilises the traditional risk assessment approach whereby:

Risk = Likelihood x Consequence

Likelihood provides and indication of how probable a hazard will occur while *consequence* is a measure of the magnitude of the effect if a hazard eventuates (Muschal 2003). The following sections provide the details of how available data are applied to the *likelihood* and *consequence* components of the risk assessment approach.

2.4.1 Risk of physical disturbance to instream values

The risk of physical disturbance to instream values involves an assessment of likelihood using fragility and recovery potential. The assessment of consequence uses the determined instream values. The following information is based on the details provided in Hamstead (2010) and Brierley *et al* (2011).

The *Risk of Physical Disturbance to Instream Value* is assessed by combining the following sub indices:

1. River Styles® of the CMA region – recovery potential and fragility assessments (i.e. likelihood); and
2. Instream value assessment as described in the previous section (i.e. consequence).

2.4.1.1 Likelihood

The method employed calculates the likelihood of risk as:

Likelihood = Fragility x Recovery Potential

The likelihood of physical disturbance of river reaches was calculated using information available from River Styles® assessment projects (see Cook and Schneider 2006 for example). Through this approach a description of geomorphic condition at a river reach scale is determined and the potential of the river reaches to return to good condition is identified, through the additional consideration of existing physical disturbance threats ('Recovery Potential'[1]). A measure of the vulnerability or susceptibility of river reaches to these threats was also developed ('Stream Fragility'). Both Recovery Potential and Stream Fragility assessments are used to calculate the likelihood of physical disturbance, representing a susceptibility to potential change.

The River Styles® Framework provides a methodical description of the geomorphic interactions that are operating within a catchment (Brierley and Fryirs 2005). Each River Style identified integrates the variations, thresholds, lags, interactions and combined effects of a number of independent controlling factors that operate in both temporal and spatial contexts (Table 7). The controlling factors also affect the variations between reaches of the same River Style within a catchment and control the differences in the geomorphic condition of each Style.

The way in which the River Styles® Framework incorporates the variables listed in Table 7 is to assess the geomorphic character and behaviour interactions that are operating within a reach. Definition of stream types based upon the adjustment potential and expected responses allows for the differentiation of a behavioural regime for a given river type. It also allows for an appraisal

---

[1] Note the term "recovery potential" refers to geomorphic recovery only. It does not include ecosystem recovery (see Table 7 for definitions).

of river condition and recovery potential based upon the likely pattern of adjustment (Brierley and Fryirs 2005). Responses in the character and behaviour of each River Style to the physical controls listed in Table 7 differs between the different Styles, with some more responsive than others.

Stream fragility refers to the susceptibility or sensitivity of certain geomorphic categories to physical adjustments and changes when subjected to degradation or certain threatening activities (Cook and Schneider 2006). Significant adjustment is sometimes seen in geomorphic categories that have higher levels of fragility (ie. streams that are not robust or have lower resilience). This significant adjustment can also result in certain geomorphic categories changing to another one when a certain threshold (level of disturbance) of a damaging impact is exceeded (Cook and Schneider 2006).

An understanding of the fragility of geomorphic categories and the streams in which they occur is important for river managers. Such understanding provides river managers with an opportunity to determine those streams that are most vulnerable to significant change and therefore require a higher level of management intervention or protection to minimise potential threatening impacts (Cook and Schneider 2006).

The fragility classification described below was developed as part of the Hunter River Styles® report (Cook and Schneider 2006). It is based on the adjustment potential of three main characteristics of each River Styles®, these being channel attributes (geometry, size and connection to floodplain), stream planform (lateral stability, number of channels and sinuosity) and bed character (bedform and bed materials). Each style is then categorized as either high, moderate, or low fragility.

During the mapping of River Styles® across NSW, it was found that several styles regarded as being of high or moderate fragility on the coast and slopes, tended to be more resilient on the inland plains. This particularly applied to the laterally unconfined, fine-grained styles, on the plains, where very low stream slopes (hence low stream power), relatively low flood frequency, and the cohesive nature of the fine-grained sediment has resulted in much more stable and resilient systems. Fragility ratings have therefore recently been updated by the NSW Office of Water, from those used in Schneider and Cook’s (2006) work in the Hunter catchment, and are presented in Appendix 1.

This significant adjustment can also result in certain geomorphic categories changing to another one when a certain threshold (level of disturbance) of a damaging impact is exceeded.

Cook and Schneider (2006) used three categories based on this definition:

> – **Low fragility**: Resilient (‘unbreakable’). Minimal or no adjustment potential. Only minor changes occur such as bedform alteration and the category or sub-category never changes to another one regardless of the level of damaging impact.
>
> – **Medium fragility**: Local adjustment potential. It may adjust over short sections in response to a threatening process. Major character changes can occur or the category or sub-category can change to another - but only when a high threshold of damaging impact is exceeded. For example, it may require a catastrophic flood, sediment slug or clearing of a significant proportion of the vegetation from bed, banks and floodplain.
>
> – **High fragility**: Significant adjustment potential. Sensitive. It may alter / degrade dramatically and over long reaches. Major character changes can occur or the category or sub-category can change to another one when a low threshold of damaging impact is exceeded (eg. clearing of bank toe vegetation alone).

Table 7: Definitions of geomorphic recovery potential listed in decreasing order or priority (Source: Cook and Schneider 2006)

Recovery Potential	Geomorphic Condition	Recovery Potential Criteria	Actions Required
Conservation	Good	Must contain all of the following: • Good geomorphic condition. • No recovery occurring or required. • Has not been recently disturbed or has fully recovered from past disturbances.	Protect from human disturbance, provide fencing if required, establish a native vegetation maintenance program and prevent debris removal. Encourage conservation agreements where these reaches occur on private land.
Strategic	Specific locations of rapid change from good to moderate or poor, with the potential to impact both upstream and downstream	Must contain one or more of the following: • Specific locations of rapid change from good geomorphic condition to moderate or poor condition with the effects usually detrimentally affecting upstream and/or downstream reaches. • A head cut or bend cut off present or imminent or; • A site of recent bed material extraction, vegetation clearing or large woody debris removal or; • A site of accelerated bank erosion or a gully that is supplying excess sediment to downstream reaches or; • Poorly represented riparian vegetation community or; • Upstream or downstream of a poorly represented / unique / fragile stream category and has the potential to impact upon the poorly represented / unique / fragile stream category or; • Small reach in moderate/poor condition separating larger upstream or downstream conservation reaches or; • Poorly represented, unique or fragile stream category.	Control the disturbance agent eg head cut extraction or further clearing and plan control works eg bed controls and revegetation programs.

Recovery Potential	Geomorphic Condition	Recovery Potential Criteria	Actions Required
Rapid Recovery	Moderate	Must contain all of the following: • Moderate geomorphic condition as it has not fully recovered from past disturbances • Recovery presently occurring quickly due to a connection with upstream reaches in good condition (e.g. supplying seed, large woody debris and sediment if required to allow channel contraction recovery) or; • No excess sediment supply sediment balance neutral. • Generally degradation has stopped or has been reduced so that natural recovery is occurring at a relatively quick pace.	Stop further human induced disturbances, erect fencing, encourage revegetation with the focus of maintenance of planting and weed removal/ management.
High Recovery Potential	Moderate	Must contain all of the following: • Moderate geomorphic condition. • Potential to recover quickly if existing pressures are removed (e.g. livestock access) or; • Recovery presently occurring at a moderate rate due to a lack of connection with good condition reaches upstream (eg supplying seed, large woody debris and sediment if required to allow channel contraction recovery). • Excess sediment supply arriving in small slugs eg inappropriate sediment distribution on bars or shallow pools. • Will recover faster if connected to good condition upstream reaches or if recovery requirements are artificially provided in this reach. • Generally these are reaches where a more intense level of land use is occurring or has recently ceased. They are in a relatively moderate condition with some degradation pressures still occurring and are usually downstream of a conservation or rapid recovery reach.	Ensure rehabilitation is occurring in upstream reaches, fence and revegetate and install large woody debris or bed controls in this reach and target weed management.
Moderate Recovery Potential	Moderate to Poor	Must contain all on the following: • Moderate to poor geomorphic condition. • Potential to recover at a slow to moderate rate if existing pressures are removed (e.g. livestock access) or; • Recovery presently occurring at a slow rate. • Little sediment, seed or large woody debris input (if required to allow channel contraction recovery) or; • Excess sediment supply in moderate slugs. • Can only recover faster if upstream reaches are rehabilitated and this reach receives rehabilitation works.	Ensure rehabilitation is occurring along upstream reaches. Plan revegetation, weed management and bed raising structures eg large woody debris and bed controls.

Recovery Potential	Geomorphic Condition	Recovery Potential Criteria	Actions Required
Low Recovery Potential	Poor	Must contain one or more of the following: • Poor geomorphic condition. • No or very little recovery occurring. Often degradation still occurring. • Has recently changed or is on the verge of changing to a different style category. • No sediment/seed/ large woody debris input (if required to allow channel contraction recovery) or; • Excess sediment supply large and continuous.	Ensure extensive rehabilitation has or is occurring upstream and in this reach, including bed raising structures, bank erosion control structures to reduce rates of change before vegetation can be established or large woody debris installed.
None	Moderate to Poor	Must contain one or more of the following: • Moderate to Poor geomorphic condition. • No longer has fluvial geomorphological processes operating due to inundation • Locked in position by concrete or rock lining.	No action required as reach is no longer influenced by fluvial geomorphological processes.

The measure of *recovery potential* (see Table 7) is used in the risk assessment as it inherently considers geomorphic condition (as it is an input for determining recovery potential). Condition is an assessment of deviation from 'natural' or 'expected' for any given reach at any given time. Recovery potential is a measure of the capacity of a reach to return to good condition or to a realistic rehabilitated condition, given the limiting controls of the reach. These controls are based on the physics of hydraulics and the capacity of vegetation and sediment to facilitate geomorphic evolution (Cook and Schneider 2006). Recovery potential places that reach in a catchment context and examines whether it has potential to improve its condition given it position in the catchment and the impacts associated with pressures and limiting factors operating in the catchment (see Brierley and Fryirs, 2005 and Fryirs and Brierley, 2001). These principles are well documented within the current literature. For example, Petts and Gurnell (2005) state that fluvial geomorphology is responsible for maintaining the structural features essential for a healthy riverine ecosystem.

Similar to geomorphic condition assessment, the determination of a streams recovery potential is based upon a series of visual observations. It uses observable features such as the condition and function of riparian vegetation, sediment transport, channel stability, geomorphic features, and the rate/degree of physical pressures acting on these reaches over time and space (Cook and Schneider 2006). Ecological processes (eg. weed succession), water extraction (eg. irrigation), landuse (eg. livestock grazing and trampling impacts) and infrastructure (eg. dams) are all examples of threats/pressures that can significantly influence a streams recovery potential (Cook and Schneider 2006). Other factors act as controls influencing a streams recovery potential and include vegetation sources (eg. areas of seed and large woody debris (LWD) supply), channel confinement (eg. bedrock steps) and infrastructure (eg. causeways and streambed control structures) (Cook and Schneider 2006).

Reaches of similar geomorphic category can be subdivided into a range of recovery potential combinations over a given stream length. These categories are applied to the natural range of variability that could be expected for each geomorphic category.

The observable physical features considered when assessing recovery potential include (see Cook and Schneider 2006);

- sediment calibre, distribution and quantity;
- water flow regimes;
- infrastructure;
- geological control and soil type;
- indigenous riparian vegetation structure, function and density;
- degree of weed invasion and geomorphic interaction;
- impact of past, current and likely future landuse practices, and
- ecological interactions.

Merging the categories of fragility and recovery potential described above into a decision assistance table, *likelihood* outcomes can be determined (Table 8). This approach enables a rapid determination of the most vulnerable river reaches to threats when fragility and recovery potential outcomes are combined using spatial tools (Hamstead 2010). That is, Likelihood is represented by assigning a score to both Recovery Potential and Fragility classifications, then multiplying these scores together in order to calculate a final Likelihood score (i.e. likelihood = vulnerability (Fragility) to a threat (Recovery Potential)). This is completed within ArcGIS to the River Styles® spatial layer.

Table 8: Decision assistance table to enable the determination of the likelihood of a river reach to physical disturbance (red and orange colours indicate those reaches most vulnerable to threats, lighter colours indicate lesser levels of likelihood)

			THREAT River Styles® ***Recovery Potential – based on Condition***					
			Conservation	**Strategic**	**Rapid**	**High**	**Moderate**	**Low**
			6	**5**	**4**	**3**	**2**	**1**
VULNERABILITY River Styles® ***Fragility***	**High**	**3**	18	15	12	9	6	3
	Medium	**2**	12	10	8	6	4	2
	Low	**1**	6	5	4	3	2	1

Five Likelihood categories are determined from the combinations of fragility and recovery potential (Table 9). Note that the weighting used in Table 7 for Low Vulnerability rivers is currently being reviewed to determine whether it should be reduced from “1” to “0.5”. This would reduce the likelihood of perverse outcomes (for example, a conservation gorge setting being ranked as a moderate likelihood of change due to physical disturbance, when such areas have a very low likelihood). From these five categories, each river reach was assigned a value (Risk Input Score) ranging from 0 to 1 (Table 8).

Table 9: Application of likelihood score ranges (derived from Table 7) to specific likelihood categories and associated risk input scores.

Likelihood Score	Likelihood Category	Risk Input Score
18-15	Very High Likelihood	1
12-10	High Likelihood	0.8
9-6	Moderate Likelihood	0.6
5-4	Low Likelihood	0.4
3-1	Very Low Likelihood	0.2

2.4.1.2 Consequence

Using the macro water sharing plan approach, the *consequence* is considered to be equivalent to the instream values (identified in step 2.3 above) under threat. This implies that the consequence of losing an asset of high instream value is greater than losing a low instream value (NSW Office of Water 2010).

2.4.1.3 Raw risk of physical disturbance to instream value score

The River Styles® data layer is used as the underlying reference scale for the analysis of risk, as it provides the initial reach stratification. An assessment of the risk to instream values from physical disturbance for each river reach was undertaken. The score outcomes from step 2.3 (Instream Value) ranged from 0 to 1 and are applied to each river reach. Each River Reach identified in the River Styles® mapping is assigned a Risk input score for Likelihood based on the approach described in 2.4.1.1 (Likelihood).

Since each river reach has been assigned a Consequence Score (i.e. Instream Value score), as well as a Likelihood score (i.e. Recovery Potential x Fragility scores), the two scores may be multiplied together in ArcGIS in order to calculate the raw *risk of physical disturbance to instream value score* (see Hamstead 2010) for each river reach. i.e.:

Risk of physical disturbance to instream value =

Likelihood (fragility x recovery potential) x Consequence (instream value)

Appendix 3 shows the process used in detail.

These raw scores are then distributed based on standard deviations from the mean, and then displayed as four risk categories as described in section 2.4.4. This approach was based on the pilot described in Hamstead (2010) and may not be statistically valid. Revision of this approach has been included as a recommendation in section 3.7.

2.4.2 Risk of extraction to instream values

2.4.2.1 Likelihood:

The method employed calculates the likelihood of risk to instream values as:

Likelihood = the level of hydrologic stress

Likelihood is considered to be Hydrological Stress as described in section 2.2.1.3 (input data for Hydrologic Stress RCI input index). River reaches were able to receive a likelihood score ranging between 0 and 1, being the raw hydrologic stress score (either distributed hydrologic stress, macro water sharing plan hydrologic stress, or SRA hydrologic condition). Macro water sharing plan and SRA hydrologic condition were scaled to range between 0 and 0.5 (in line with the scaling done for the RCI input index). A high hydrologic stress indicates a high likelihood.

Furthermore, regulated rivers as identified in the NSW Office of Water Regulated Rivers spatial data layer were given to a value of 1 indicating high stress, and therefore high likelihood.

2.4.2.2 Consequence

The same step for ***Consequence*** as described in 2.4.1 above was used for water extraction. This refers to the consequence of losing low value instream values versus high instream values.

Thus, the method calculates the raw *Risk to Instream Value from Water Extraction for each River reach* (NSW Office of Water 2010) as:

Risk to Instream Value from of Water Extraction

= Likelihood (Hydrologic Stress) x Consequence (Instream Value)

Since each river reach has been assigned a Consequence Score (i.e. Instream Value score), as well as a Likelihood score (i.e. Hydrologic Stress), the 2 scores can be multiplied together using ArcGIS. Appendix 3 shows the process used in detail.

These raw scores are then distributed based on standard deviations from the mean, and then displayed as four risk categories as described in section 2.4.4.

2.4.3 Combined risk to instream values

The *Overall Risk to Instream Value* assessment is prepared by combining the following sub indices:

- *Risk of physical disturbance to instream values* (step 2.4.1)
- *Risk of extraction to instream values* (step 2.4.2)

The raw combined risk to instream values score was calculated by averaging the scores of risk of physical disturbance to instream values and risk of extraction to instream values for each river reach. This is done using calculate field in ArcGIS, where:

Overall Risk = (Risk of Extraction + Risk of Physical Disturbance) / 2

These raw scores are then distributed based on standard deviations from the mean, and then displayed as four risk categories as described in section 2.4.4.

2.4.4 Distributing and displaying raw risk scores

When calculated from the raw information as described above, the actual distribution of risk values were heavily lumped into a small range. A greater differentiation of risk values was needed for the purpose of prioritisation within a CMA region. This was achieved by converting the raw risk values to the number of standard deviations from the mean within each CMA region. This enabled a ranking of the level of risk *within* the CMA catchment (Table 10). Firstly, the mean was calculated individually for each of the three risk scores:

$$\mu=\sum X/N$$

Secondly, the standard deviation was calculated individually for each of the three risk scores:

$$O' = \sqrt{}(\sum(X-\mu)^2)/(N-1)$$

Thirdly, the number of standard deviations from the mean was calculated for each river reach, for each risk score.

$$Z=(X-\mu)/o'$$

Four risk categories were then defined based on the number of standard deviations from the mean, as displayed in Table 10. These final risk categorisations for each of the three risk assessments where calculated for river reaches in ArcGIS as so could be displayed spatially.

The process in detail is displayed in Appendix 3. An example of this spatial representation is displayed in Figure 11.

Table 10: Four risk categories developed from the standard deviations from the mean.

Variance from the Mean	Risk Category
<-0.5 standard deviations	Low Risk
-0.5 – 0.5 standard deviations	Moderate Risk
0.5 – 1.5 standard deviations	High Risk
>1.5 standard deviations	Very High Risk

This approach allows for *within* region prioritisation, but does not allow for absolute comparisons between different CMA regions (Hamstead 2010). This approach was taken because investment, evaluation and reporting decisions are usually made at the catchment or valley scale, and it also allows a flexible approach, whereby catchment-specific data can also be incorporated. It is also important that values within a given valley are relative to each other, so that natural resource management agencies operating at a regional level can assess the relative trade-offs in investment within their area of management. If a statewide approach was adopted, it is likely that the result would be a clustering of high value areas on the NSW coast, and fewer high value areas inland. If statewide reporting was required, then further development would be undertaken to stratify assessment units using tools such as the IBRA Regions (NPWS 2003) or the ecohydrological classification of Australia (Pusey et al. 2009).

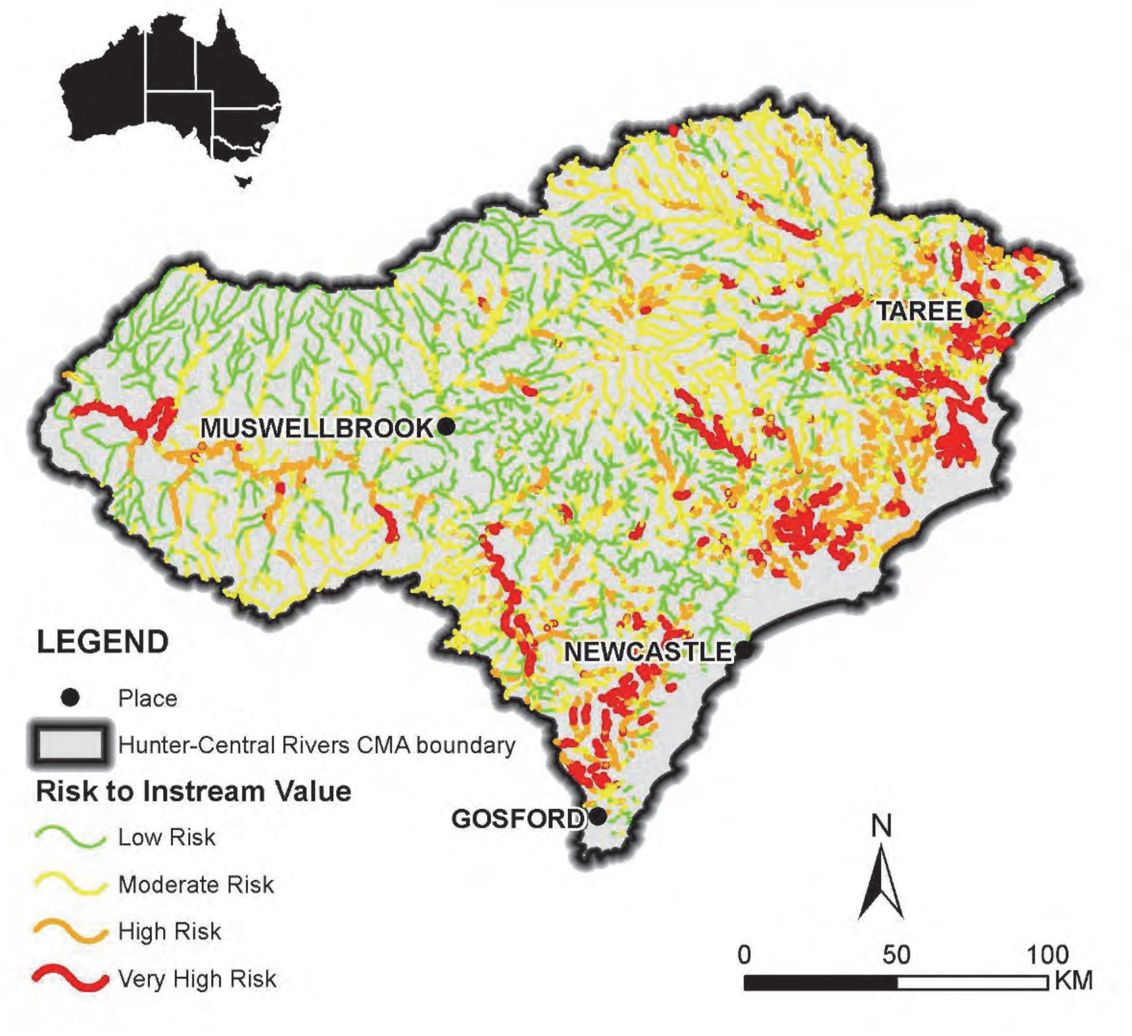

Figure 11: Example output map showing the overall risk to instream values from both physical disturbance and extraction from the Hunter Central Rivers CMA.

2.5 Priority area assessment

Detailed spatial mapping of areas where protection or rehabilitation should be focused can assist greatly when catchment priorities and objectives for natural resource managers are considered in any decision making and planning. By developing priority maps it is assumed that these represent the areas of greatest need or urgency for management intervention or conservation. This also assumes that there will be a level of coordinated action across the other types of related actions towards the same priorities, so that the work done will not be negated by inaction of another type. A limitation of the approach is that is does not consider any social, cultural or economic drivers. These issues would need to be considered in conjunction.

2.5.1 Preparation of priority maps

Priority maps were produced based on the combined (overall) risk assessment and input datasets for the RCI (see Section 2.2 above). Because the risk assessment integrates all type of risks related to water extraction and physical disturbance to riverine geomorphology, there will be some areas where risk is high but a particular matter (for example riparian vegetation), may be good. The high risk may be a consequence of other factors. To differentiate these cases, the condition of particular aspects of the RCI is combined with the overall risk, resulting in maps of priority for action for each type of management action (Fig. 12).

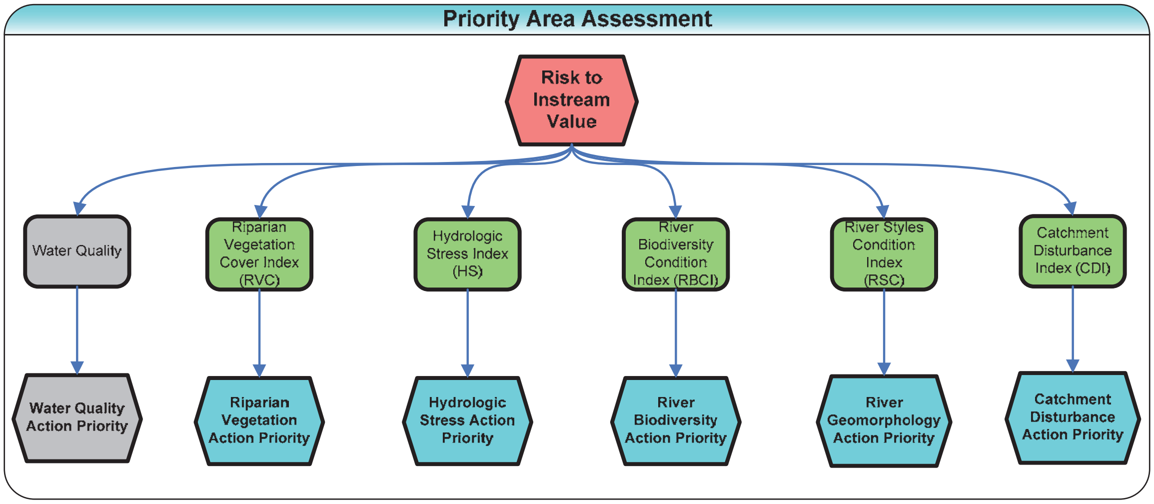

Figure 12: Process to develop risk priority for each RCI component

Additionally, it was considered important to differentiate between whether the type of action required is to protect currently good condition, or restore/rehabilitate from currently moderate or poor condition towards good. Each RCI input was divided into Good, Moderate and Poor condition categories, based on their final input index score or category (Table 11).

Table 11: Condition Index categories to assist in differentiating management actions required.

	Poor	Moderate	Good
River Styles® Geomorphic Condition	Poor	Moderate	Good
Riparian Vegetation Condition Score	0-0.33	0.33-0.66	0.66-1
Macro water sharing plan / SRA Hydrologic Stress Condition	0.5-0.66	0.66-0.83	0.83-1.0
Distributed Hydrologic Stress Condition	0-0.33	0.33-0.66	0.66-1.00
Biodiversity Condition	0-0.33	0.33-0.66	0.66-1.00
Catchment Disturbance Condition	0-0.33	0.33-0.66	0.66-1.00

River reaches were assigned an action priority categorisation based on the categories derived in Table 11. This differentiates management actions in two ways. Firstly it distinguishes the priority based on risk. Secondly it differentiates whether the type of action is to protect (if the condition is currently good) or to restore or rehabilitate (if the condition is less than good). Each River Reach in the study area are attributed the relevant priority category spatially by selecting records where the Risk *AND* RCI inputs match the categories listed in Table 12.

Table 12: Action Priority categories for RCI criteria that are assigned to a river reach.

Risk rating	**Very High**	Very High Priority - Restoration / Rehabilitation	Very High Priority - Restoration / Rehabilitation	Very High Priority - Protection
	High	High Priority - Restoration / Rehabilitation	High Priority - Restoration / Rehabilitation	High Priority - Protection
	Moderate	Medium Priority - Restoration / Rehabilitation	Medium Priority - Restoration / Rehabilitation	Medium Priority - Protection
	Low	none (low risk)	none (low risk)	none (low risk)
		Poor	**Moderate**	**Good**
		RCI sub index rating		

It might intuitively look as if there should be a differentiation required between poor and moderate condition but this is not the case as the condition only differentiates the type of action (protect or restore) and not the priority.

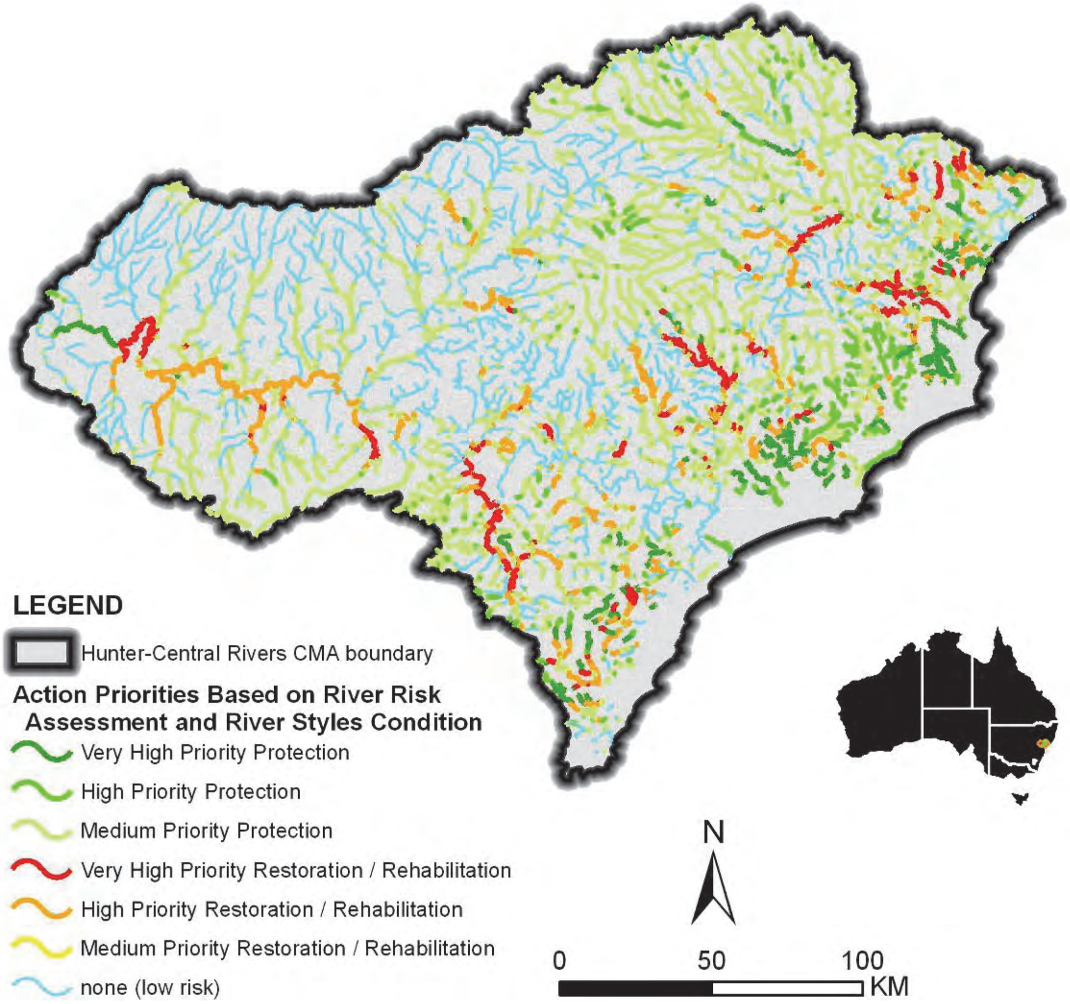

Figure 13: Action priority map for geomorphology in the Hunter Central Rivers CMA region.

3. Discussion

3.1 Using the River Condition Index to achieve alignment of natural resource management plans

The RCI was based around a number of spatial products designed to inform both natural resource management planning for riverine systems and to track long-term changes in condition at a suitable scale for regional planning. Alignment is achieved by each type of plan utilising the RCI spatial products to guide its investment (see Figure 14). In summary, both types of plans acknowledge the same riverine assets and common risks from either water extraction or physical disturbance. The spatial product that utilises the combined risk from extraction and physical disturbance can then used to guide investment in both types of plans to ensure areas at risk from both extraction and physical disturbance are a focus for investment. The action priority maps can then be used to outline those river reaches requiring either conservation and / or rehabilitation.

For example, many of the moderate to highly fragile river types support important pool refugia when they are in good condition. These areas are also likely to support high values in terms of biota (see Chessman et al. 2006). Such areas would be a high priority for conservation protection in a CMAs Catchment Action Plan, but would also be a high priority for restricting water access during low flows in water sharing plans prepared by the NSW Office of Water. The RCI spatial product is then used to track long term changes in the condition of rivers as a result of investment across both types of plans.

3.2 Linking the River Condition Index to resilience thinking

Resilience is the capacity to tolerate disturbance without passing a threshold and collapsing into a significantly different (possibly unstable) state that is controlled by a different set of processes (Walker and Salt 2006; Parsons et al. 2009). Resilience within an ecological context identifies those assets that can be easily degraded or may change states relatively quickly under the influence of an external disturbance. Once degraded, they may take a long time or be expensive to recover, or may never recover. Resilience analysis allows us to identify what underpins the high risk assets or “systems” and what gives them the ability to resist a change in state i.e. what controls that change (“controlling variables”). The RCI uses a process to spatially identify those aquatic values most at-risk from change at a regional scale. It is largely underpinned by the use of the River Styles® framework for assessing physical character and behaviour. River Styles® is used to determine a stream’s resilience to change (based on its fragility, or ability to absorb disturbances). River Styles® inherently considers resilience. It does this by considering the fragility of different styles based on their position in the landscape, the controls and degrees of freedom in bed and bank movement, as well as their current condition and trajectory. For example River Styles®, such as those rivers confined by bedrock (low fragility rivers), are more resistant to physical disturbance, than those that rely on undisturbed riparian vegetation or inputs of large woody debris to maintain stability, for example.

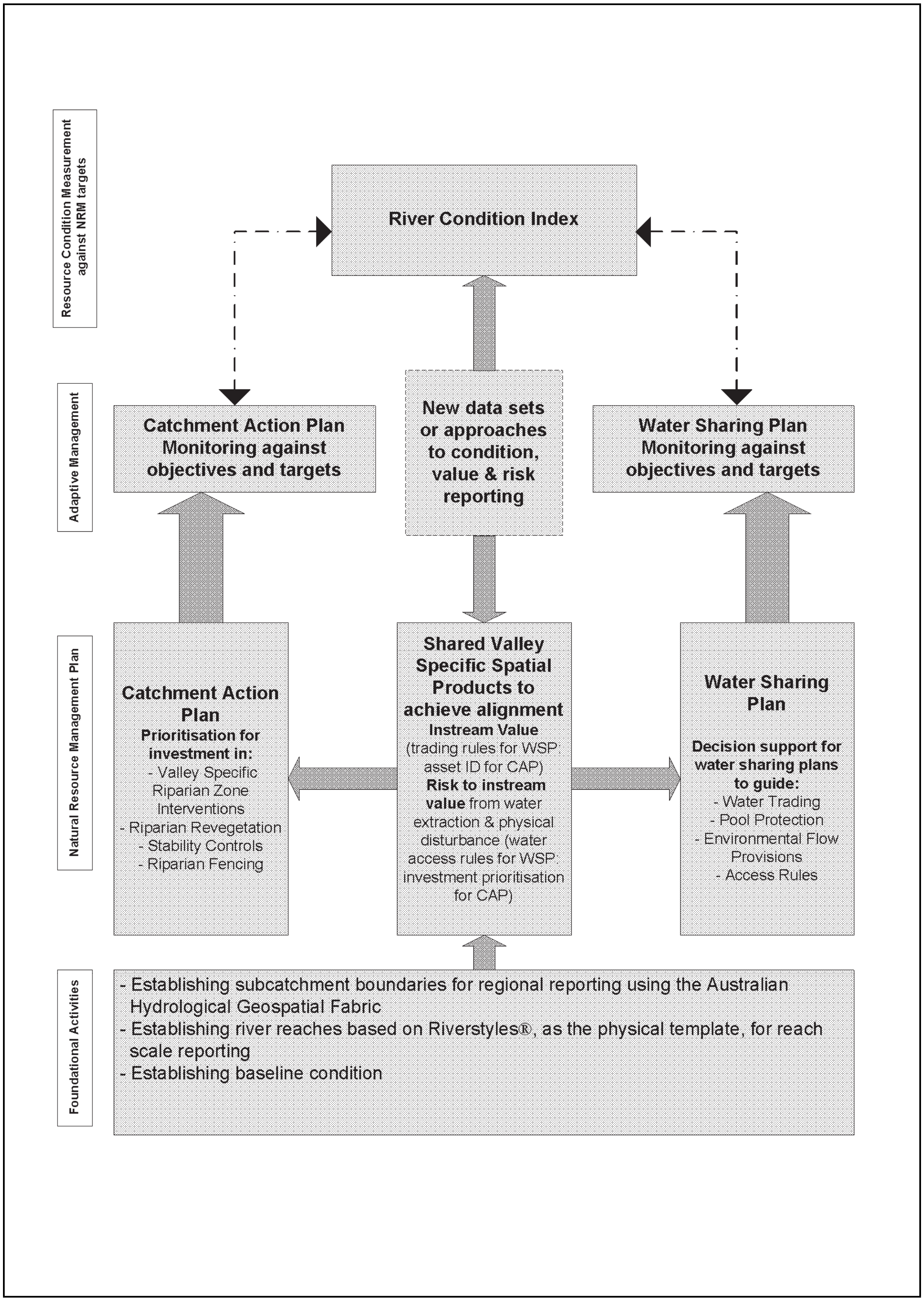

Figure 14: Conceptual basis for the use of the RCI spatial products to inform water sharing plans and Catchment Action Plans (adapted from Brierley et al 2011).

Habitat diversity is known to be a key driver of biodiversity in rivers (Maddock 1999). The more diverse the bed of a river is (e.g. pools and riffles, different depths and speed of water) generally the more species it is likely to support. The ability of a river to maintain a diversity of habitats is influenced by its resilience.

By using stream fragility with a reach's recovery potential and a range of other aquatic value attributes, such as threatened species, a risk-based spatial product can be produced. This highlights those systems which are fragile but are still in good condition, where investment should be aimed at conservation, as well as those priority areas for rehabilitation in order to increase resilience and reverse any progression to an altered state. This approach has been used to develop state and transition models in the Central West CMA CAP (see Figure 15), based on the detailed concepts presented in Brierley and Fryirs (2005).

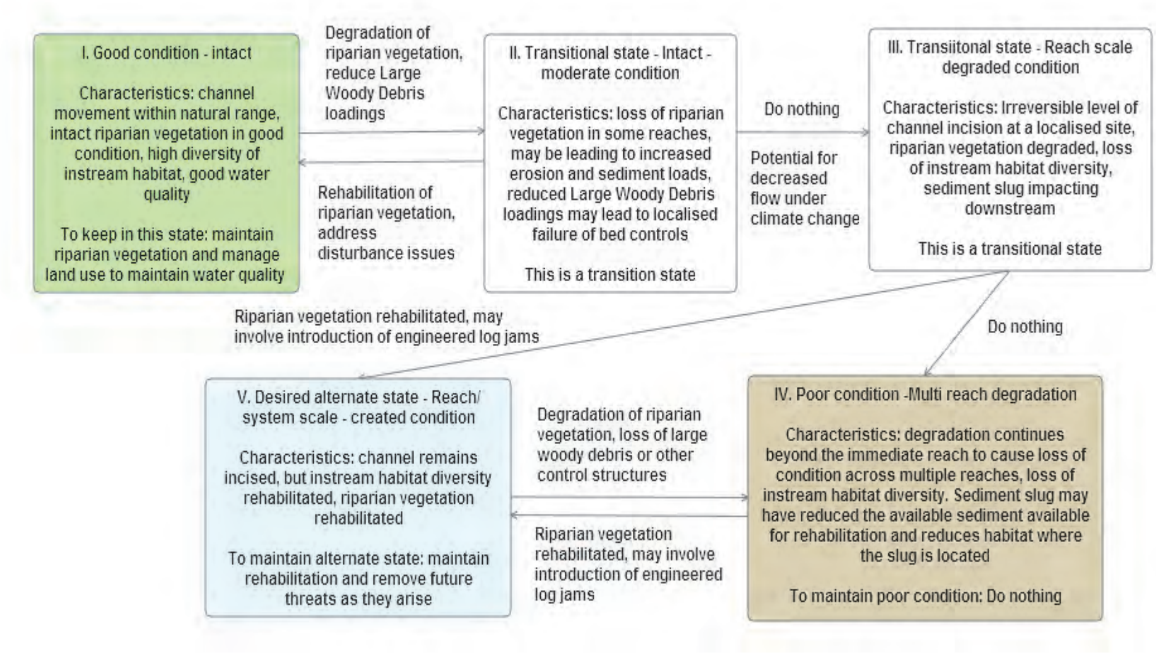

Figure 15: Conceptual state and transition model for a river classified as high fragility in the Central West CMA (Source: CWCMA 2011).

Enhancing or stabilising the resilience of river systems should also lead to an improvement in river condition. Multiple factors influence the resilience within riverine ecosystems. Along with modifications to river geomorphology, changes in natural flow regime, siltation, changes to water quality, loss of riparian vegetation, changes in water quality, impacts from grazing stock, barriers to downstream flow, and large dams are considered key threats to the habitat and biodiversity in Australian riverine and wetland systems (Boulton and Brock 1999). Underpinning the management of these threats to riverine systems and associated resilience is an understanding of thresholds and function of alternate states associated with processes and functions of freshwater systems at different spatial scales (Parsons et al. 2009). There are some threshold and alternate state details on wetland systems but there are few details on riverine systems other than those based on physical form. There is a growing understanding of the influence of altered flow regimes on physical thresholds of river geomorphology, and the biological thresholds associated with riparian vegetation reproduction and recruitment and the influence of grazing pressure, along with altered flow regimes influencing regime shifts in floodplain communities (Parsons et al. 2009).

Further work is required to inform managers of freshwater systems how single threats related to exotic species, barriers to flow, sedimentation and changes to habitat, and all threats working in combination, influence thresholds and divergence into alternate states. However, landscape managers such as CMAs have good knowledge of specific riverine threats and continue to invest in specific rehabilitation to improve riverine components, in particular rehabilitation of river geomorphic zones and riparian vegetation communities. Water managers continue to aim to provide specific environmental flows in regulated rivers and water sharing measures to protect and enhance instream ecological assets in regulated rivers using best available science where available (NSW Office of Water 2010; Saintilan and Overton 2010).

The development of the RCI and alignment with CAPs provides the basis for improving the resilience of riverine systems in NSW and provide a focus for shared investment in priority river areas for multiple ecosystem benefits, including enhanced levels of resilience in aquatic communities. Although this alignment process focuses on best available data (see Section 2), there is scope to improve this alignment process as new, spatially relevant information on river ecosystem processes and functions come to hand, in particular the influence of threats. This will greatly improve the ability to focus on specific areas for investment in improving and stabilising the resilience and condition of freshwater river systems.

3.3 Adaptive management

Adaptive management in Australia underpins most natural resource management strategies that involve learning from management actions and using learning to improve ongoing steps in the management process (Allan and Curtis 2003). Adaptive management is considered a fundamental process to protect waterway values and achieve ecologically sustainable activities in catchments (Bennett et al. 2002). Adaptive management and good prioritisation are known to lead to actions and prioritisation of investments that maximise ecosystems benefits (NRC 2010). Through recommendations for the upgrade of CAPs, the NSW Natural Resource Commission (NRC) recognises that the regional model for natural resource management is well grounded in adaptive management and that CAPs should improve over time as new information, in particular science, is incorporated into current and future reviews of the CAPs (NRC 2011). The NSW Monitoring, Evaluation and Reporting Strategy 2010 – 2015 also indicates that adaptive management is required for effective natural resource management (DECCW 2010).

Water planning and management in NSW is required to comply with the principles of adaptive management *(Water Management Act 2000* (NSW) s5), while the CMAs under their legislation (*Catchment Management Authorities Act 2003* (NSW) s3) are required to adhere to the NSW Standards for Natural Resource Management (NRC 2007) that promotes the use of adaptive management.

The development of the RCI and alignment activities that have been progressively developed during several pilot CAP reviews in NSW is part of this adaptive management process. Aligning water sharing plans, information on river geomorphology, instream values and risks, and the science underpinning each of these with CMA local knowledge, has developed a new natural resource management process to prioritise investment. This is the whole-of Government adaptive management outcomes the NRC requires in its regional framework for CAP upgrades (NRC 2011). The alignment process itself is evolving as new spatial data sets are developed to encompass all of NSW rivers for which new science on riverine ecosystems can be associated, leading to improved natural resource outcomes across a wide range of management plans.

However, the above approach is not a surrogate for adaptive management associated with targeted intervention monitoring. Such monitoring is undertaken to assess a specific management action at the point of investment (eg reintroduction of large woody debris along a river reach).

3.4 Application of the approach in NSW

To date the Central West and Namoi CMA have both completed their draft CAP upgrades, and most of the remaining 11 CMA have commenced work on their CAP.

The products developed for the RCI have been utilised by both Central West and Namoi CMAs to develop management targets and priority actions for their aquatic themes. The Central West CMA used the concepts of river fragility and recovery potential to determine resilience, and thence used instream value to determine relative risk. The spatial products were then used as the basis for determining the priorities in the following Catchment Goal in the draft CAP:

> **By 2021, 1-5 per cent of priority river reaches are within a good condition stable state**

The following draft management target was then developed:

> **By 2021, 1-5 per cent of priority river reaches are actively managed to maintain a good condition stable state**

The Namoi CMA used the same approach to determine priorities for investment within their CAP (NCMA 2010). Their draft water target 1 is:

> **By 2020 there is an improvement in the condition of those riverine ecosystems that have not crossed defined geomorphic thresholds as at the 2010 baseline.**

The following actions are then defined to meet the target:

> **Increase the area of river reach that is managed to maintain or recover geomorphic condition where recovery potential is high or geomorphic condition is good against benchmark condition.**
>
> **Identify areas of reach that are in good geomorphic condition that are acting as key refugia and prioritise for protection.**
>
> **Increase the area of river reach that is managed to maintain and improve riparian vegetation condition and extent.**

The above actions use the RCI spatial products to identify areas in good geomorphic condition, as well as to define areas likely to support refugia and riparian vegetation extent.

Spatial products are currently being finalised for the remaining CMA areas across NSW.

The development of the RCI has also lead to an improvement in capacity to report on overall river condition across multiple scales in NSW. The spatial tools developed in the RCI can report at river reach scale for CMA priority needs, multiple river reaches in a water source for water planning requirements and whole or multiple catchment scale for broad scale State of Catchment (SoC) or State of Environment (SoE) reporting needs. This will enhance reporting on the Riverine

Ecosystems theme under the NSW Monitoring Evaluation and Reporting Strategy 2010 – 2015 (DECCW 2010). The ability to report on overall river condition was missing from the first round of reporting on State of the Catchments – Riverine Ecosystems in 2010 (Muschal et al 2010). Additionally feedback from the CMAs on the first round of SoCs identified that products and outputs were not useable at the CMA or regional scale. The RCI method can remediate this. Through a number of successful trials, the RCI method not only allowed for the integration of a number of indicators of river condition collected by state agencies, it also allows for the inclusion of locally collected data on riverine condition and/or values collected by CMAs. Additional work is required to further investigate valid indicators of the condition of other state-wide MER themes to enable the further development of the RCI, in particular indicators of water quality. Work is currently being undertaken to improve on reporting of regionally relevant water quality targets, and outcomes from this process may be incorporated into the RCI and enhance overall reporting on the MER Riverine Ecosystems theme.

Of particular importance in the RCI and CAP alignment process was the development of new spatial data that enabled reporting on river condition across multiple scales. The first round of reporting on State of the Catchments – Riverine Ecosystems in 2010 (Muschal et al 2010) reported on single river condition attributes at the same spatial scale used in the Sustainable Rivers Audit (SRA) for which indictor condition data was apportioned to specific altitude zones (Davies et al 2008). The alignment process between water sharing plans and CAPs provided the basis for existing spatial data related to river condition to be merged and applied to river reach scale and/or subcatchment scale. This is a more relevant spatial scale for CMAs to focus investment for improvement in river condition and it also provides a new spatial scale to consider applying water sharing rules or management zones in the development of water sharing plans in NSW rivers.

3.5 Limitations of the approach

One of the major limitations of the RCI and its associated spatial products is the lack of statewide and fit-for-purpose data, collected at the appropriate scale, to enable a high level of confidence in the outputs. This is because the development of the RCI was required to be undertaken utilising existing, available, datasets. A summary of limitations with the approach include:

1) *Hydrologic stress*: The macro water sharing plan data used in the analysis, namely hydrologic stress and instream value, is captured at the water source scale (the minimum scale required by the *Water Management Act 2000* for rules to be apportioned). This data is then attributed equally to every reach in the water source. This approach does not recognise the wide variation in water use and the distribution of entitlement within a water source, and may lead to perverse outcomes when determining instream value and risk to instream value from water extraction, and the hydrologic stress input for the River Condition Index. This limitation applies to those areas where the distributed hydrologic stress metric was not available (see Figure 5). Additionally, on the coastal strip the areas not covered by the distributed hydrologic stress index are based on the water source stress score from the macro water sharing plan stress ranking. This may result in over or under representation of hydrologic stress in these areas.

   The 80th percentile flow data used to determine hydrologic stress is derived from gauging station data which represents current conditions over the period of record. This means that extraction impacts are included in the data. This results in a worst case scenario for those unregulated rivers where extraction pressures are high, where by peak daily demand is compared to flow that is already impacted.

The distributed hydrologic stress index is based on low flow stress only and does not account for high flow stress which can dominate the impacts on unregulated rivers on the western plains, or streams on the slopes and coast which have high flow extraction infrastructure (eg. town water supplies).

2) *Peak Daily Demand* utilised in the Hydrologic Stress score was collected from water user surveys, and is now dated. While it is recognised that there is unlikely to have been significant shifts in irrigated agricultural activity, it introduces a source of error. When water use in unregulated systems is metered, the metered data will be used to update the hydrologic stress index;

3) *Frequency of collection of geomorphic information* - It is unlikely that River Styles® data will be collected at a frequency of less than 10 years. A long interval is also likely for collection of riparian vegetation extent data, and there is generally a large lag time for riparian vegetation change. Therefore changes detected over time periods of less than 10 years are not appropriate for geomorphology data and will be based on biota, and potentially hydrologic stress and catchment disturbance only (note that this may change if water quality indicators are also developed).

4) *River Styles® Geomorphic Condition* - The River Styles® approach uses a qualitative approach to scoring geomorphic condition, which could make results subject to biases by operatives;

5) *Riparian vegetation* - For areas where there are no regional benchmarks for riparian vegetation extent, it is assumed that a higher cover of native woody species is better then a lower cover. This assumption does not hold for grassland and open woodland areas. For this reason, the development of riparian vegetation benchmarks for different landscapes would be beneficial. Additionally, riparian vegetation data is not yet available for the whole state, with mapping not available for Lower Murray Darling and Western CMAs.

6) *Water Quality* - The approach does not include a water quality sub-index as listed in the FARWH. This data is anticipated to be included when appropriate indicators are available.

7) *Aquatic Biodiversity Forecaster Tool* - Limitations of the Aquatic Biodiversity Forecaster Tool are:

   - The Aquatic Bioforecaster is not available statewide yet.
   - The Biodiversity Forecaster tool outputs were based on the previous version of the National Catchment Boundaries (GeoFabric) database. The new version of the NCB differs in the coding system, the delineation of the subcatchments and some of the attribute data. It would be desirable to repeat the modelling with the latest version of the NCB database.
   - The biological assessments used come from all assessments prior to 2008 so it does not include the last two assessment periods (2008 and 2010). It would be

desirable to explore the development of models using data from single assessment periods to see if the outputs can be used to represent trends. If the outputs cannot be used to quantify trends over time, then their general value for condition reporting will need to be reassessed.

- The river classification that underlies the bioforecaster is based on macroinvertebrates only. Also the number of classes is relatively small so it may not adequately represent the variation that exists among river ecosystems in certain regions even just in regards to macroinvertebrates. It would be desirable to generate outputs for more than one group of biota and explore the alternative ecosystem classification methods for generating biodiversity surrogates. For example work has just been completed in the Murrumbidgee catchment where separate aquatic priority layers generated for frogs, invertebrates and wetland vegetation, which were based on a classification that used generalized dissimilarity modelling (GDM) (Turak pers. comm.). These classifications are a lot more promising than the ones that were generated as part of the state wide classification (Turak pers comm.). For example the new GDM derived macroinvertebrate classification has 13 classes just in the Murrumbidgee catchment compared with the four classes in the state-wide classification. It would be desirable to generate similar new classifications in other regions, especially in the MDB.

8) *Stream Fragility* - The weighting used in Table 8 and Table A1 (Appendix 1) for Low Vulnerability rivers is currently being reviewed to determine whether it should be reduced from “1’ to “0.5”. This would reduce the likelihood of perverse outcomes (for example, a conservation gorge setting being ranked as a moderate likelihood of change due to physical disturbance, when such areas have a very low likelihood). Additionally the assignment of fragility rankings to individual styles is based on expert opinion and basic statistics.

9) *SRA data and water sharing plan data* – Data from SRA and Macro water sharing plan assessments are not reported at a reach scale. This means that, where this data was used, all river reaches that occur in the SRA valley altitudinal zones or Macro water sharing plan water sources receive the same score. This provides a very coarse assessment, and does not provide for any differentiation within the zones or water sources. Additionally, much of the data used in the macro water sharing plan spreadsheets is now dated, and it is unlikely they will be updated in the immediate future. This situation may be addressed (at least for the hydrology theme) when the second SRA report is released and data are available at the gauge / node scale for the Basin.

10) *Sensitivity Analysis* - There is a need to do sensitivity analysis to determine the influence of each index in the RCI and instream value layers, particularly how weightings influence condition outcomes.

11) *Field Assessment and Validation* - No field assessments of any of the RCI model outcomes have been undertaken to validate mapping outcomes. However, during CAP review programs, CMA staff review mapping products and local knowledge provides one level of assessment that provides a check of the outcomes. Changes are made to the data if local knowledge indicates this is required.

12) *Limitations for use in planning at a local scale* – The RCI and associated spatial products are developed for use as a regional planning tool. The maps used in this report (and the GIS spatial layers) should be used as a general guide for regional and local scale natural resource planning and management only, not for the assessment of specific sites which can only be assessed by investigations specific to those sites.
13) *Representation of biota for condition* – biota indicators for fish and macroinvertebrates, used in the River Biodiversity Condition input index layer, are currently merged into one layer representing biota where the Biodiversity Forecaster is not available. This may result in an "averaging" of results where the two indicators differ. Further analysis on the merits of inputting these indicators separately needs to be undertaken. Alternatively, further investigation to include additional biotic data in the River Biodiversity Condition input index (such as aquatic birds, water plants and frogs) as suggested by the FARWH needs to be undertaken.
14) *Representation of biota for Values* – biota indicators for the key basin assets used in the instream values layer are currently merged into one input layer. Further analysis on the merits of inputting these indicators separately needs to be undertaken. Furthermore, the addition of DPI Key Fish Assets in coastal CMA regions should be incorporated into the Value assessment once this data becomes available. Additionally, a further review of how threatened species data is incorporated into the Value assessment should be undertaken, particularly linking geomorphic condition to spatial data on the distribution of threatened species.

3.6 Projects underway to improve the River Condition Index

Work has commenced on a range of projects aimed at addressing some of the above limitations. This section of the report describes these.

3.6.1 Improving the hydrologic stress index

In the tablelands and slopes, where topography and cost issues prevent the construction of off-river storages "run of river" extraction practices are often used. "Run of river" refers to the practice of extracting straight from the river on to a crop. In these cases competition for access to unregulated flows most often peaks during very low flow periods. At such times, there is potential for very low flows to be significantly impacted upon, resulting in loss of lotic habitats and changes to water quality in pool refugia. This can occur, despite the entitlement being only a small proportion of average annual flows for a given river. It is for this reason that a distributed low flow hydrologic stress index has been applied to the coast and slopes.

In the plains, unregulated water access is less reliable at low flow, so irrigators access high flow water to fill large off-river storages, which they then utilise throughout the growing season. The infrastructure for the filling of off-river storages is often significant in size in comparison to much large more infrequent flows. Flows that stay in bank, so are not flood flows, but are direct quick flow events are often termed "freshes" in a rivers. These are also important for maintaining the habitat in a river, resetting water quality in the pools and providing opportunities for longitudinal connectivity.

As discussed in section 3.5, the distributed hydrologic low flow stress index currently only applies to the coast (except the very small <100km^2 coastal catchments) and slopes of NSW. Outside of this area, the SRA hydrologic index or macro water sharing plan hydrologic stress scores are applied.

For the coast, it is intended that the small coastal catchments be mapped progressively to ensure complete coverage. For the inland plains of NSW, a distributed low flow stress index is not appropriate, as most extraction from unregulated rivers in these areas occurs as high flow extraction to fill off-river storages. A high-flow stress metric is therefore intended to be developed for these areas. Additionally, those coastal rivers where high flows are extracted by utilities (eg town water supply) will also be assessed.

3.6.2 Development of NSW regional water quality targets

The most important guiding framework for improving water quality management practices in Australia is the National Water Quality Management Strategy (NWQMS). The NWQMS sets out the key principles that should be considered by all natural resource management (NRM) bodies when managing water quality, with the long-term objective of guiding them towards a nationally consistent water quality management approach. The NWQMS's key strategy document is the Australian Water Quality Guidelines for Fresh and Marine Waters, commonly referred to as the 'ANZECC Guidelines' (ANZECC and ARMCANZ 2000). The NWQMS generally advocates the development of water quality management plans and is made up of a number of guideline documents and principles that are designed to encourage that process. Some of the ANZECC documents offer default water quality guidelines and trigger values that, if exceeded, can direct water managers towards a range of investigations or management actions. These default and trigger values are, however, developed for extremely broad scales: the guidelines therefore encourage local NRM bodies to research and develop regionally specific water quality guidelines that may be more appropriately matched to regional conditions.

The NSW Office of Water has a project underway to develop regional water quality targets for NSW (Ryan et al, 2011). Previous SoC reporting for water quality simply analysed water quality station results for Phosphorus and Turbidity against the ANZECC default trigger values which in some of the western streams indicated a high exceedence when underlying catchment characteristics may naturally lead to higher values. This project aims to improve water quality condition and trend reporting by developing catchment specific targets.

The project is being undertaken in two phases. Phase one was a proof of concept phase, and was used to establish the following key points:

1. water quality monitoring stations form natural and discrete groupings based on their different water quality characteristics alone;
2. specific sets of geospatial factors (measurements associated with geographic features) associated with each water quality station's drainage area (such as station altitude, average rainfall, geology, total drainage area, percentage of drainage area used for agriculture etc.) can be used to explain the water quality characteristics of that station; and

3. the geospatial factors with any given water quality station be used to predict which discrete group of stations it should belong to – and therefore what its water quality characteristics should be.

The Stage One research focused on five common water quality indicators: electrical conductivity; turbidity; water temperature; total nitrogen; and total phosphorus. Stage Two of the project is currently underway, and has expanded on the number of water quality stations across NSW used in the analysis, as well as refining the methods. It has a consultation phase with the CMAs and other agencies in order to validate the results and to derive the regional targets. Once the project is completed, further work will be undertaken to determine how the water quality information can be integrated into RCI. This may provide the RCI with more sensitivity to detect change.

3.6.3 River Styles® Reference Reach Project

River Styles® forms one of the major spatial layers on which the RCI is based. Although Geomorphic Condition has been determined for all river reaches used in the RCI, these are based on an assessment against an assumed "reference" for each particular style and are subjective. To improve the approach in establishing "condition", geomorphologists must make an objective determination of what the river should be like when in a good condition. The NSW Office of Water has developed the Reference Reach Project to provide quantitative detail on the condition of contemporary undisturbed reaches of river for each river style (Outhet and Young 2004a,b). Geomorphic reference reaches are reaches of rivers that are in 'good' condition and therefore provide a reference to compare other rivers of unknown condition. A reach is a length of channel that has a characteristic assemblage (suite) of geomorphic units (Brierley and Fryirs 2000).

As set out in the latest version of the River Styles® framework (Brierley and Fryirs, 2003) the definition of good condition is: '*reaches in which river character and behaviour are appropriate for the type (Style) of river, given its valley setting and within-catchment position. Geomorphic structures are in the right place and operating as expected for a natural or near-natural version of that Style of river*'. In this context, the word 'appropriate' means the test reach indicators are within the reference reach range for a given River Style®.

Adopting the reference reach approach enables river scientists to quantitatively determine the natural range of a river's geomorphology when in good condition (for a given River Style®), the relative condition of a river reach that is being assessed (the 'test reach') and the cause of moderate or poor condition in the test reach.

Reference reaches are currently being established for each River Style® across NSW. The aim is to have five reference reaches per style. The information will allow a much improved understanding and interpretation of condition and recovery trajectory for each style, and will allow the development of more informed decision-making when interpreting the outputs of the RCI.

3.6.5 Completion of Aquatic Bioforecaster Tool mapping across NSW

The NSW Office of Environment and Heritage (OEH) is attempting to complete the assessment and mapping outcomes for the Aquatic Biodiversity Forecaster Tool, with recent trails being undertaken in the Murrumbidgee CMA region. With the exception of this CMA region, further work needs to be undertaken in other inland CMA regions for which outcomes for this product are lacking.

3.7 Recommendations for further work

The RCI and associated spatial products represent the first attempt at spatially capturing river condition, value, risk and priority outputs across NSW. As reported in section 3.5, there are some limitations to the work. The following recommendations for further investigation are made (not in priority order), with the aim of improving the outputs of the River Condition Index as part of an adaptive management cycle:

1) *Riparian Vegetation Extent Mapping and Establishment of Cover Benchmarks*: Complete riparian vegetation extent mapping across NSW and establish regional riparian vegetation condition and extent benchmarks, to improve the interpretation of remotely captured riparian vegetation extent data;

2) *Predictive Modelling for Biota*: Expanding the use of predictive modelling for biota by enhancing the capability of the Aquatic Biodiversity Forecaster Tool and examining other predictive approaches; (eg. Maxent modelling outcomes for aquatic plants, fish and frog habitat and diversity).

3) *Incorporation of threats and disturbances*: Incorporation of threats or disturbances to river risk measures such as barriers to fish passage (eg weirs, road crossing culverts). CMAs in partnership with the Department of Primary Industries undertake remediation or removal of ‘priority’ barriers. Removal of these can lead to an improvement in river condition for many kilometres upstream. Given the pressures on fish populations in the Murray Darling Basin, in particular, further work on the development on a risk to fish layer which incorporates barriers, alien species, and thermal pollution, should be undertaken.

4) *Incorporation of a Water Quality Index* into the RCI (see Chapter 3.6.2 for details)

5) *Threatened species assessment for calculating instream value* as there is limited evidence in the literature to link threatened species with reaches in good geomorphic condition, further assessment is required. This will involve overlaying threatened species records (eg. NSW Wildlife Atlas and Fisheries NSW datasets) with geomorphic condition classification to examine relationships, thence reassessment of the method if required.

6) *Field assessment and validation:* Undertake field assessments of selected river reaches to validate spatial outcomes for reference reaches and reaches with different condition outcomes.

7) *Assessment of hydrologic indices:* In NSW there are likely to be rivers where all three types of hydrologic assessment referred to in section 2.2.1.3 have been undertaken. A desk-top study is required to check if they align and therefore if their information content is roughly equivalent. Such a study might support a subjective (expert?) assessment of their relative value and help design future improvements of the hydrologic stress index. Additionally, the method for incorporation of water usage data will need to be developed and implemented as metering is rolled out across NSW.

8) *Sensitivity Analysis*: Complete a sensitivity analysis on the input data sets for the RCI and Value assessments. In particular:

a. the weightings, or lack thereof, for each of the inputs (eg. refugia) needs to be justified. This should also include an assessment of whether an approach that weights abiotic vs biotic indicators differently is warranted, as opposed to an additive approach.

b. The comparability of lumping the reach-based outcomes for RCI (and each of its individual indices) up to the valley scale, and comparing them to those generated by SRA and comparison with any other updated data layers and analysis methods (eg. the release of the second SRA report);

c. Sensitivity of the reach-based (or subcatchment) RCI outcomes to raw data from one or more datasets from other programs (eg. SRA; NRM regional experts);

d. Testing the assumption that fish and macroinvertebrates are suitable surrogates for other riverine biota; and

e. Assessment of whether the outputs, and data used between CMAs, are comparable and consistent over the complete range of river types.

9) *Better representation of biota*: Currently biota values for the River Condition Index and Instream Values key basin assets layer are combined (using fish and macroinvertebrates) into a single input layer. Further analysis is required to determine whether this approach is appropriate, or whether these layers should be used as separate inputs. Additionally, Key Fish Asset data should be refined to include recent advances in fish data compilation, including native fish condition, updated threatened fish species layer, barriers impacting on fish passage, pest fish hotspots, and acid sulfate soil hotspots.

10) *Representation of instream value* – Further work is required on representing instream value, so that the approach is consistent with nationally recognised approaches, such as the HEVAE framework.

11) *Use of standard deviation for risk* - The raw scores used in the calculation of risk are distributed based on standard deviations from the mean, and then displayed as four risk categories as described in section 2.4.4. This approach was based on the pilot described in Hamstead (2010) and may not be statistically valid. Revision of this approach is required to ensure a more valid method is used.

12) *Aquatic biodiversity forecaster tool* - The biological assessments used come from all assessments prior to 2008 so it does not include the last two assessment periods (2008 and 2010). It would be desirable to explore the development of models using data from single assessment periods to see if the outputs can be used to represent trends. If the outputs cannot be used to quantify trends over time, then the use of the forecaster tool will need to be reassessed.

13) *Incorporation of estuarine areas* – the approach has not been tested or evaluated in estuarine river reaches, hence the results reported for these areas should be treated with caution. Further analysis is required to ascertain the quality of the outputs and the extent to which additional estuary-specific data needs to be included.

14) *Development of a QA/QC protocol for data and outputs –* Any rigorous piece of research, science, or decision-making framework should have a QA/QC protocol developed. This may include a reliability score or measure on the input datasets and the subsequent outputs. It is proposed that a section on QA/QC be developed and applied in later editions of this report. A QA/QC process provides a much better basis for:

    a. Justifying further monitoring and assessment and data gathering on river health;

    b. Highlighting the reliability of the data and the output against which prioritisation and decisions are made (based on outcomes from the sensitivity analysis at 8 above); and

    c. Highlighting data gaps in the assessment that could be filled.

15) *Frequency of data collection* – the development of this report has largely relied upon availability of existing datasets. As a result datasets collected over different time periods have been integrated into the RCI and associated spatial products, and this may result in the potential for spurious outputs and results. Ideally, the datasets should be collected, and reported upon, using an agreed timeframe, so that there can be some confidence in the integration of results (ie. They represent the same slice in space and time).

    As this first report is based on existing datasets, recommendations are provided in Table 13 below to justify the need for recurrent monitoring and repeat surveys that can be used to more confidently track change over time. This will provide part of the evidence-base to measure the achievement of investment in CAP priorities and water sharing plan evaluation.

Table 13: Current and recommended frequency of data collection for existing programs (note that the use of some of these data sets may cease or change following the implementation of the other recommendations in section 7, or identification of other appropriate regional data by CMAs).

Spatial Product	Input Dataset	Current Frequency of Collection	Recommended Frequency of Collection
River Condition Index	Riparian Vegetation Condition	No regular program	Ten yearly maximum, five yearly minimum, due to lag response between management action and vegetation growth and establishment
	Hydrologic Stress	SRA reported on a three-yearly cycle for inland NSW; low flow distributed hydrologic stress completed once.	SRA as per current cycle; distributed hydrologic stress on a three-yearly cycle statewide.

Spatial Product	Input Dataset	Current Frequency of Collection	Recommended Frequency of Collection
	River Biota Condition Index	SRA and coastal MER program collected and reported on a three-yearly cycle for macroinvertebrates and fish	As per current cycle
	Catchment Disturbance Index	No regular program other than SLATS (which measures Tree and Land Cover annually).	Three-yearly, as land clearing is instantaneous.
	Geomorphic Condition (based on Riverstyles®)	No regular program	Ten yearly (for all reaches), five yearly (for high fragility or strategic reaches only), due to lag response between management action and recovery
Value	Biodiversity Conservation Priority	Model that relies on SRA and coastal MER program that collects data on a three-yearly cycle for macroinvertebrates. Model has only been run for pre 2008 data	Model run on a three-yearly cycle to allow trend assessment (see section 3.7, point 12)
	Macro water sharing plan Instream Values	Excel matrix with no regular program for updating	Three-yearly, noting that this dataset will likely become redundant and replaced by spatially reflected value input layers
	River Styles® Recovery Potential	No regular program	Ten yearly (for all reaches), five yearly (for high fragility or strategic reaches only), due to lag response between management action and recovery
	Key Basin Assets (from MDBA)	No regular program	Three-yearly to account for any changes in designation of threatened aquatic species, communities, or populations
	DPI Key Fish Assets	Relies on data from SRA and coastal MER program collected on a three-yearly cycle for fish	Three-yearly, as per current program
	High Conservation Priority based on threatened species	No current program for reporting (although threatened species databases are updated regularly)	Three-yearly to account for any changes in designation of threatened aquatic species, communities, or populations

4. References

Aldous, A., Fitzsimons, J., Richter, B., and Bach, L. (2011). Droughts, floods and freshwater ecosystems: evaluating climate change impacts and developing adaptation strategies. *Marine and Freshwater Research* **62**, 223–231.

Anderson, J. R. (1993). *State of the Rivers Project: Report 1. Development and validation of the methodology.* A report to Department of Primary Industries, Queensland.

Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), (2000). *Australian Water Quality Guidelines for Fresh and Marine Waters, National Water Quality Management Strategy.* Australian and New Zealand Environment and Conservation Council, Canberra.

Arthington, A.H. and B.J. Pusey (2003). Flow restoration and protection in Australian Rivers. *River Research and Applications* **19** (5-6): 377-395.

Bennett J, Sanders N, Moulton D, Phillips N, Lukacs G, Walker K, Redfen F. (2002). *Guidelines for Protecting Australian Waterways.* Land and Water Australia, Canberra.

Bureau of Meteorology *see* BOM

BOM (2010a). *Australian Hydrological Geospatial Fabric (Geofabric) Product Guide*. Bureau of Meteorology, Canberra.

BOM (2010b*) Australian Hydrological Geospatial Fabric (Geofabric) Tutorial - Visualising Contracted Catchments*. Bureau of Meteorology, Canberra.

BOM (2011) Bureau of Meteorology. http://www.bom.gov.au/water/geofabric/index.shtm

Boon, P. J. (2000). The development of integrated methods for assessing river conservation value. *Hydrobiologia* **422/423**: 413 – 428.

Boulton, A. J. and Brock, M. A. (1999). *Australian Freshwater Ecology: Processes and Management.* Gleneagles Publishing, Australia.

Bowman, M. F. and Summers, K. M. (2005). Considerations when using the reference condition approach for bioassessment of freshwaters. *Water Quality Research Journal of Canada*. **40 (3)** 347 – 360.

Brainwood, M., Burgin, S. and Byrne, M. (2006). Is the decline of freshwater mussel populations in a regulated coastal river in south-eastern Australia linked with human modification of habitat? *Aquatic Conservation: Marine and Freshwater Ecosystems* **16**, 501 – 516.

BRGCMA (2007). Border Rivers Gwydir – Catchment Action Plan. Border Rivers Gwydir Catchment Management Authority, Moree.

Brierley, G. J., Cohen, T., Fryirs, K. and Brooks, A. (1999). Post-European changes to the fluvial geomorphology of Bega catchment, Australia: implications for river ecology. *Freshwater Biology* **41**, 839 - 848

Brierley, G.J. and Fryirs, K. (2001).Creating a catchment-framed biophysical vision for river rehabilitation programs. In Rutherfurd, I., Sheldon, F. Brierley, G. and Kenyon, C. (Eds.) *Third*

Australian Stream Management Conference proceedings: The value of Healthy Rivers, 27-29 August, 2001, Brisbane. Cooperative Research Centre for Catchment Hydrology, Melbourne. Vol 1, pp59-65.

Brierley G. J. and Fryirs K. A. (2005). *Geomorphology and River Management: Applications of the River Styles Framework.* Blackwell Publishing, Oxford, UK.

Brierley, G., Fryirs, K., Cook, N., Outhet, D., Raine, A., Parsons, L., and Healey, M. (2011). Geomorphology in action: Linking policy with on-the-ground actions through applications of the River Styles framework. *Applied Geography*, **31**, pp 1132 – 1143

Brooks, A. (2006), *Design guideline for the reintroduction of wood into Australian streams, Land and Water Australia,* Canberra.

Brookhouse, N. and Coughran, J. (2010) Exploring the potential for an ecological-specific physical control method for the exotic pest Mosquitofish *Gambusia hoolbrooki. Ecological Management and Restoration* **11 (3),** 226 – 228.

Bunn, S.E. and A. H. Arthington (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* **30**, 492-507.

CWCMA (2011). Central West CMA Catchment Action Plan: 2011 – 2021. Central West Catchment Management Authority, Dubbo.

Chessman, B. (2002). *Assessing the conservation value and health of New South Wales rivers: The PBH (Pressure-Biota-Habitat) project*. NSW Department of Land and Water Conservation.

Chessman, B. C. (2003). New sensitivity grades for Australian river macroinvertebrates, *Marine and Freshwater Research* **54**, 95–103.

Chessman, B.C. Fryirs, K.A. and Brierley, G.J. 2006 Linking geomorphic character, behaviour and condition to fluvial biodiversity: implications for river management. *Aquatic Conservation: Marine and Freshwater Ecosystems* **Vol 16**: 267-288 Wiley Inter Science

Chessman, B., Royal, M., and Muschal, M. (2011). The challenge of monitoring impacts of water abstraction on macroinvertebrate assemblages in unregulated streams. *River Res. Applic*. **27**: 76–86 (2011)

Clayton, P.C., Fielder, D.F., Howell, S. and Hill, C.J. (2006) *Aquatic biodiversity assessment and mapping method (AquaBAMM): a conservation values assessment tool with trial application in the Burnett River catchment.* Queensland Environmental Protection Agency, Brisbane.

COAG (2004). *Intergovernmental Agreement on a National Water Initiative Between the Commonwealth of Australia and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and the Northern Territory.* Commonwealth of Australia, Canberra.

Commonwealth of Australia (2011). *Caring for our Country: Business Plan 2011 – 12.* Commonwealth of Australia, Canberra.

Cook, N. and G. Schneider (2006). *River Styles® in the Hunter Catchment*. Science and Information Division, New South Wales Department of Natural Resources, ISBN 0-7347-5770-0

Cottingham, P., Bunn, S., Price, P. and Lovett, S. (eds), 2003*, 'Managing wood in streams'*, River Management Technical Update No. 3, Land and Water Australia, Canberra

CWCMA (2010). *Catchment Action Plan: Support Document*. Central West Catchment Management Authority, Dubbo.

Davies, P.E., Harris, J.H., Hillman, T.J., Walker, K.F. (2008). *SRA Report 1: A Report on the Ecological Health of Rivers in the Murray–Darling Basin, 2004–2007.* Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council. MDBC Publication No. 16/08.

DECC (2002). *Descriptions for NSW (Mitchell) Landscapes Version 2 (2002)* - Based on descriptions compiled by Dr. Peter Mitchell. NSW Department of Environment, Climate Change, and Water, Sydney

DECC (2008). *NSW Interim native vegetation extent, report and data prepared for the National Land and Water Resources Audit*, Project no. DONR 000397, ANZLIC metadata no. ANZNS0208000244. NSW Department of Environment, Climate Change, and Water, Sydney

DECCW (2010). *New South Wales Natural Resources Monitoring, Evaluation, and Reporting Strategy*, 2010-2015. Department of Environment, Climate Change, and Water, Sydney.

DLWC (1998) *Stressed Rivers Assessment Report: NSW State Summary 1998*. NSW Department of Land and Water Conservation, Sydney.

Department of Primary Industries *see* DPI

DPI (2008) NSW Department of Primary Industries (2008). Identification of High Conservation Value Aquatic Ecosystems in the Northern Murray-Darling Basin – Pilot Project – Macquarie-Castlereagh Results. Report to the Murray-Darling Basin Commission. Department of Primary Industries (Aquatic Habitat Rehabilitation), Port Stephens.

DPI (2011). Threatened species conservation. Date viewed 12 January 2012. http://www.dpi.nsw.gov.au/fisheries/species-protection/conservation

Dudgeon, D., Arthington, A.H., Gessner, M.O, Kawabata, Z., Knowler, D., Leveque, C., Naiman, R.J., Prieur-Richard, A.-H., Soto, D. and Stiassny, M.L.J. (2005). Freshwater biodiversity: importance, threats, status, and conservation challenges. *Biological Reviews* **18**: 163 – 182.

Dunn H. (2000). *Identifying and protecting rivers of high ecological value*. Occasional Paper No. 01/00. Land and Water Resources Research and Development Corporation, Canberra.

Earthtech (2007). Sydney Metropolitan Catchment Management Authority Waterways Health Strategy. Earthtech, Sydney.

Ecological (2009). *Riverine Vegetation in the Namoi Catchment - An Assessment of Type and Condition: (Project No. 222-001)* Final Report prepared for: Cotton Catchment Communities CRC Namoi Catchment Management Authority. Ecological Australia.

Emerton, L. (ed), 2005, *Values and Rewards: Counting and Capturing Ecosystem Water Services for Sustainable Development.* IUCN Water, Nature and Economics Technical Paper No. 1, IUCN — The World Conservation Union, Ecosystems and Livelihoods Group Asia.

Environment Australia (2002). *National River Health Program AusRivAS Protocol Development and Testing Project- Final Report*. Environment Australia, Canberra.

ERM (2011) *State of the rivers condition report series from 1999*. Queensland Department of Environment and Resource Management.
http://www.derm.qld.gov.au/science/state_of_rivers/reports.html

Fairweather P. and Napier, G. (1998) *Environmental indicators for national state of the environment reporting – Inland waters, Australia: State of the Environment* (Environmental Indicator Reports), Department of the Environment, Canberra.

Fryirs , K. and Brierley, G. (2005).*Practical Application of the the River Styles® framework as a tool for catchment-wide river management: A case study from the Bega catchment NSW.* Macquarie University. http://www.riverstyles.com/ebook.php

Galvin, L, van Looij, E and Storer, T 2009, *River Health Assessment Scheme for the sub-catchments of the Swan Canning, Project summary*, Water Science Technical Series Report No. 7, Department of Water, Western Australia.

Garlapati, N., Shaikh, M. and Dwyer, M. (2010). *Riparian vegetation extent for environmental monitoring, evaluation and reporting: Project report.* NSW Office of Water, Sydney.

GHD (2011). *NSW Office of Water: Report on Western CMA River Styles Assessment*. GHD, Newcastle.

Gibbons, P., Briggs, S.V., Ayers, D., Seddon, J., Doyle, S., Cosierc P., McElhinnya, C., Pellyd, V. and Roberts, K. (2009). An operational method to assess impacts of land clearing on terrestrial biodiversity. *Ecological Indicators*. **9(1),** 26-40.

Gilligan, D, McGarry, T. and Carter, S. (2010). *A scientific approach to developing habitat rehabilitation strategies in aquatic environments: A case study on the endangered Macquarie perch (Macquaria australasica) in the Lachlan catchment*. Industry & Investment NSW –Fisheries Final Report Series No. 128

Growns, I. O. and Growns, J. E. (2001). Ecological effects of flow regulation on macroinvertebrate and periphytic diatom assemblages in the Hawkesbury-Nepean River, Australia. *Regulated Rivers: Research and Management* **17**, 275 -293.

Hamstead, M. (2010). *Alignment of water planning and catchment planning*. Waterlines Report 36. National Water Commission, Canberra.

Hazell, D, Osborne, W. and Lindenmayer, D. (2003). Impact of post-European stream change on frog habitat: southeastern Australia. *Biodiversity and Conservation* **12**. 301 – 320.

Hunter , D. and Gillespie, G. (2010). *National Recovery Plan for the Stuttering Frog Mixophyes balbus. Draft for comment – March 2010*. Department of the Environment, Water, Heritage and the Arts, Canberra.

Jansen, A. and Roberston, A. I. (2001). Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. *Journal of Applied Ecology* **38**, 63 – 75.

Jones, H. A. and Byrne, M. (2010). The impact of catastrophic channel change on freshwater mussels in the Hunter River system, Australia: a conservation assessment. *Aquatic Conservation: Marine and Freshwater Ecosystems* **20**, 18 – 30.

Karr, J.R. (1999). Defining and measuring river health. *Freshwater Biology* **41**, 221-234

Kennard, M. J. (ed) (2010). *Identifying high conservation value aquatic ecosystems in northern Australia.* Interim Report for the Department of Environment, Water, Heritage and the Arts and the National Water Commission. Charles Darwin University, Darwin.

Kingsford R. T. (2011). Conservation management of rivers and wetlands under climate change - a synthesis. *Marine and Freshwater Research*, 2011, **62**, 217–222

Krogman, R M (2011). *A review of the Index of Biotic Integrity in the US*. United States Army Corps of Engineers. Landcare (2005). Northern Territory Regional Investment Strategy. Final Report 21 June 2005.

Ladson, A. R. and White, L. J. (1999). *An Index of Stream Condition: Reference Manual.* Department of Natural Resources and Environment, Melbourne, September 1999.

Likens, G. E., Walker, K. F., Davies, P. E., Brookes, J., Olley, O., et al.(2009). Ecosystem science: toward a new paradigm for managing Australia's inland aquatic ecosystems. *Marine and Freshwater Research* **60**, 271–279.

Lintermans, M. (2007). Fishes of the Murray-Darling Basin: An Introductory Guide. Murray Darling Basin Commission.

Lovett, S. and Price, P. (eds). (2007). *Principles of riparian lands management*. Land and Water Australia, Canberra.

Maddock, I. (1999). The importance of physical habitat assessment for evaluating river health. *Freshwater Biology* **41**, 373 – 391.

Muschal, M. (2003). *Ecological Risk Assessment of alterations to low flows in unregulated rivers and streams, NSW, Australia*. A scoping paper with specific reference to the NSW Water Planning process. NSW Department of Infrastructure, Planning and Natural Resources.

Muschal M,, Eren T., Miller J., Gilligan D., Sayers, J., and Healey M. (2010). *Technical Support Document – Riverine Ecosystems: NSW State of the Catchments 2008*. NSW Office of Water.

MDBA (2010). *Guide to the proposed Basin Plan: Technical background*, Murray–Darling Basin Authority, Canberra.

Nestler, J. M., Theiling, C. H., Lubinski, K. S., Smith, D. L. (2010).Reference condition approach to restoration planning. *River Research and Applications* **26**, 1199 - 1219.

Newson, M. D. and Newson, C. L. (2000). Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. *Progress in Physical Geography* **24 (2)** 195 – 217.

NLWRA (2002). *Australian catchment, river and estuary assessment 2002 - Volumes 1 and 2:* National Land and resources Audit. National Heritage Trust.

NPWS (2003). *The Bioregions of New South Wales – their biodiversity, conservation and history*. NSW National Parks and Wildlife Service, Hurstville.

NPWS (2003). *Predation by Gambusia holbrooki - The Plague Minnow*. Approved NSW Threat Abatement Plan. NSW National Parks and Wildlife Service, Sydney.

Norris, R. H. and Thoms, M. C. (1999). What is river health? *Freshwater Biology*. **41**, 197 – 209.

Norris R.H., Liston P., Davies N., Coysh J., Dyer F., Linke S., Prosser I. and Young B. (2001). *Snapshot of the Murray-Darling Basin River Condition*. Murray-Darling Basin Commission, Canberra. 60 pp. ISBN 1 876830, 22 0.

Norris, R. H., Prosser, I., Young, B., Liston, P., Bauer, N., Davies, N., Dyer F., Linke, S. and Thoms, M. (2001). *The assessment of river condition (ARC): An audit of the ecological condition of Australian Rivers.* Final report submitted to the National Land and Water resources Audit Office. CSIRO Land and Water

Norris R, Dyer F, Hairsine P, Kennard M, Linke S, Merrin L, Read A, Robinson W, Ryan C, Wilkinson S, and Williams D, (2007a), Australian Water Resources 2005: A baseline assessment of water resources for the National Water Initiative, level 2 assessment, river and wetland health theme: *Assessment of river and wetland health: a framework for comparative assessment of the ecological condition of Australian rivers and wetlands*, May 2007, National Water Commission, Canberra

Norris R, Dyer F, Hairsine P, Kennard M, Linke S, Merrin L, Read A, Robinson W, Ryan C, Wilkinson S, and Williams D, (2007b). Australian water resources 2005: A baseline assessment of water resources for the National Water Initiative, level 2 assessment, river and wetland health theme: *Assessment of river and wetland health: potential comparative indices*, May 2007, National Water Commission Canberra.

NSW Government (2006). *NSW Implementation Plan for the National Water Initiative.* NSW Government, Sydney.

NSW Government (2010) State of the Catchments 2010. http://www.environment.nsw.gov.au/soc/stateofthecatchmentsreport.htm

NSW Office of Water (2010). Macro water sharing plans: *The approach for unregulated rivers. Report to assist community consultation*. NSW Office of Water. http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/planning-process/default.aspx

NRC (2005a). *Recommendations: state-wide standards and targets*. NSW Natural Resource Commission, Sydney.

NRC (2005b). *Standard for Quality Natural Resource Management*. NSW Natural Resource Commission, Sydney.

NRC (2007). An introduction to the standard for quality natural resource management: for everyone involved in NRM. Natural Resources Commission, Sydney.

NRC (2010). *Progress towards healthy resilient landscapes: Implementing the Standards and Targets and Catchment Action Plans – 2010 Progress report.* NSW Natural resource Commission, Sydney.

NRC (2011). *Framework for assessing and recommending upgraded catchment action plans.* NSW Natural Resource Commission.

NRMMC (2006). *Framework for future NRM Programmes*. Natural Resource Ministerial Council, November 2006.

NWC (2009). *Australian Water Reform 2009: Second biennial assessment of progress in implementation of the National Water Initiative*, NWC, Canberra

Office of Environment and Heritage *see* OEH

OEH (2011, updated 12 September 2011). Threatened species. Date viewed 12 January 2012. http://www.environment.nsw.gov.au/threatenedspecies/index.htm

Outhet, D. and Young, C. (2004a). *Geomorphic reference reaches – field manual*. Parramatta: NSW Department of Infrastructure, Planning and Natural Resources, Sydney.

Outhet, D. and Young, C. (2004b). *Assessing geomorphic condition and trajectory – field manual*. Parramatta: NSW Department of Infrastructure, Planning and Natural Resources, Sydney.

Parsons, M., Thoms, M., Capon, T., Capon, S. and Reid, R. (2009). *Resilience and thresholds in river ecosystems,* Waterlines report, National Water Commission, Canberra.

Petts, G. E. and A. M. Gurnell (2005). Dams and geomorphology: Research progress and future directions. *Geomorphology* **71**, pp 27 – 47.

Peters, G. (2010). Review of HCVAE Trials. Report prepared for the Department of Environment, Water, Heritage and the Arts – Commonwealth of Australia. Riverness Protection and Restoration Services, Victoria.

Poff N.L., B. Richter, A.H. Arthington, S.E.Bunn, R.J. Naiman, E. Kendy, M. Acreman, C. Apse, B.P. Bledsoe, M. Freeman, J. Henriksen, R.B. Jacobson, J. Kennen, D.M. Merritt, J. O'Keeffe, J.D. Olden, K. Rogers, R.E. Tharme and A. Warner. (2010). The Ecological Limits of Hydrologic Alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology* **55**:147-170.

Pont D, Hugueny B, Beier U, Goffaux D, Melcher A, Noble R, Rogers C, Roset N, Schutz S. (2006) Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. *Journal of Applied Ecology* **43**, 70–80.

Price, P., Lovett, S. and Lovett, J. (2004) *'Managing riparian widths'*, Fact Sheet 13, Land and Water Australia, Canberra.

Pusey, B., Kennard, M., Hutchinson, M. and Sheldon, F (2009). *Ecohydrological regionalisation of Australia: A tool for management and science.* Technical report. Land and Water Australia.

Qld Government (2011). *Protocol for reviewing regional natural resource management plans (including targets) accredited with the NHT and NAPSWQ bilateral agreements*. Queensland Government.
http://www.regionalnrm.qld.gov.au/policies_plans_legislation/planning_guidance.html

Reeves, G. H.; Hohler, D. B.; Larsen, D. P.; Busch, D. E.; Kratz, K.; Reynolds, K.; Stein, K. F.; Atzet, T.; Hays, P.; Tehan, M. (2004). *Effectiveness Monitoring for the Aquatic and Riparian Component of the Northwest Forest Plan: Conceptual Framework and Options*. Gen.Tech. Rep. PNW-GTR-577. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p.

Richards, , C., Johnson, L. B. and Host, G. E. (1996). Landscape scale influences on stream habitats and biota. *Journal of Fisheries abd Aquatic Sciences*. **53**, 293-311.

Ryan, D., Badcock, C., Doyle, G., Muschal, M., and Mount, T. (2011). *Water Quality Guidelines for Regions within New South Wales: Preliminary Research and Development of Statistical Approaches*. NSW Office of Water, Sydney.

Ryder, D. S., Tomlinson, M., Gawne, B., and Likens, G. E. (2010). Defining and using 'best available science': a policy conundrum for the management of aquatic ecosystems. *Marine and Freshwater Research* **61**, 821–828.

Saintilan, N. and Overton, I. (2010). *Ecosystem response modelling in the Murray-Darling Basin*. CSIRO Publishing.

SA (2009). Our Plan, Our Future - *A guide to the regional natural resources management plan.* South Australian Murray-Darling Basin Natural Resources Management Board. Government of South Australia.

Sayers, J. (in prep). Final Report – Development of Reach Scale Hydrologic Indices and Habitat Evaluation. NSW Office of Water, Newcastle.

Shrubsole, D. (ed) (2004). Canadian Perspectives on Integrated Water Resources Management. Canadian Water Resource Association.

Spencer, C., Robertson, A. I. and Curtis, A. (1998). Development and testing of a rapid appraisal wetland condition index in south eastern Australia. *Journal of Environmental Management* **54,** 143 – 159.

Stein, J.L., Stein, J.A., and Nix, H. A, (2002). Spatial analysis of anthropogenic river disturbance at regional and continental scales: identifying the wild rivers of Australia. *Landscape and Urban Planning* **60** (2002) 1–25

Thomson, J. R., Taylor, M. P., Fryirs, K. A., Brierley, G. J. (2001). A geomorphic framework for river characterization and habitat assessment. *Aquatic Conservation: Marine and Freshwater Ecosystems* **11**, 373–389.

Tomlinson, M., and Davis, R. (2010). Integrating aquatic science and policy for improved water management in Australia. *Marine and Freshwater Research* **61**, 808–813.

Turak, E., Ferrier, S., Barrett, T., Mesley, E., Drielsma, M., et al. (2011). Planning for persistence of river biodiversity: exploring alternative futures using process-based models *Freshwater Biology* **56**, 39–56.doi:10.1111/J.1365-2427.2009.02394.X

US EPA (1998) *Guidelines for Ecological Risk Assessment*. Risk Assessment Forum US Environmental Protection Agency Washington DC.

US EPA (2002). *Biological Assessments and Criteria: criucial components of water quality programs.* United States Environmental Protection Agency. EPA 8222-F-02-006

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A, Liermann, C. R., and Davies, P. M. (2010). *Global threats to human water security and river biodiversity Nature*, **467** (7315), 555-561

Walker, B. H., and D. Salt. 2006. *Resilience thinking: sustaining ecosystems and people in a changing world*. Island Press, Washington, D.C., USA.

Wall, J. (2009). *Riverine Vegetation in the Namoi Catchment: An Assessment of Type and Condition.* Final Report prepared for the Cotton Catchment Communities CRC and Namoi Catchment Management Authority. Ecological Australia; Coffs Harbour.

Water Management Act (2000) (NSW) http://www.austlii.edu.au/au/legis/nsw/consol_act/

wma2000166/ (accessed 3 February 2012).

WCB (2009). *Priorities for Regional Collaboration In Coastal Planning and Natural Resource Management* - Final Report of the Priorities for Victoria's Western Coast Project. Western Coastal Board.

Werren, G. L. and Arthington, A. H. (2002). *The assessment of riparian vegetation as an indicator of stream condition, with particular emphasis on the rapid assessment of flow related impacts* (in) Franks, A., Playford, J. and Shapcott, A. (eds). Landscape Health of Queensland. Royal Society of Queensland, Brisbane, Brisbane: 194 – 222.Whittington, J. (2002) Assessing River Condition Using Existing Data - River management Series Part 2, CRCFE, Canberra.

Whittington, J. (2002) Assessing River Condition Using Existing Data - River management Series Part 2, CRCFE, Canberra.

World Bank (2006). *Evolution of Integrated Approaches to Water Resource Management in Europe and the United States: Some Lessons from Experience*. World Bank Analytical and Advisory Assistance (AAA) Program China: Addressing Water Scarcity Background Paper No. 2

WRC (2001). *Stressed Basins in Massachusetts*. The Commonwealth of Massachusetts, Water Resources Commission

Wright, J. F. (1994) *Development of RIVPACS in the UK and the value of the underlying database.* Limnetica 10 (1) 15-31.

Young, W. J., Chessman, B. C., Erskine, W. D. Raadick, T. A., Wimbush, D. J. Tillerad, J., Jakeman, A. J., Varley, I. and Verhoeven, T. J. (2004). *Improving expert panel assessments through the use of a composite river condition index – The case of the rivers affected by the Snowy Mountains hydro-electric scheme, Australia. River Research and Applications* **20**, 733 – 750.

Young R, Townsend C, and Matthaei C. (2004). *Functional indicators of river ecosystem health – an interim guide for use in New Zealand*. Ministry for the Environment, New Zealand

Appendix 1

Table A 1: Fragility rankings used in the analysis of likelihood of physical disturbance

River Style®	Fragility Classification for Slopes and Coast	Fragility Classification for Inland Plains
CVS - Floodplain pockets, gravel	Moderate	Moderate
CVS - Floodplain pockets, sand	Moderate	Moderate
CVS - Gorge	Low	Low
CVS - Headwater	Low	Low
CVS - Terrace Gorge	Low	Low
CVS T - Sinking	Low	Low
LUV CC - Anabranching	Moderate	Low
LUV CC - Anabranching, gravel	High	Moderate
LUV CC - Anabranching, swamp belt	Low	Low
LUV CC - Anastomosing	Low	Low
LUV CC - Bank confined, fine grained	Moderate	Low
LUV CC - Bank confined, gravel	Low	Low
LUV CC - Bank confined, sand	Moderate	Moderate
LUV CC - Channelised fill	Moderate	High
LUV CC - Channelised peat swamp	High	N/A
LUV CC - Low sinuosity, boulder	Moderate	Moderate
LUV CC - Low sinuosity, entrenched gravel	Moderate	Moderate
LUV CC - Low sinuosity, fine grained	Moderate	Low
LUV CC - Low sinuosity, gravel	Moderate	Moderate
LUV CC - Low sinuosity, sand	High	High
LUV CC - Low sinuosity, multi-channel, sand belt	High	High
LUV CC - Meandering, entrenched gravel	Moderate	Moderate
LUV CC - Meandering, fine grained	Moderate	Low
LUV CC - Meandering, gravel	High	High
LUV CC - Meandering, sand	High	High
LUV CC - Multi-channel, sand belt	High	High

River Style®	Fragility Classification for Slopes and Coast	Fragility Classification for Inland Plains
LUV CC - Tidal	Low	N/A
LUV CC - Wandering, gravel	High	High
LUV CC - Wandering, sand	High	High
LUV DC - Confluence wetland	High	High
LUV DC - Discontinuous sand bed	High	High
LUV DC - Lake delta	Low	Low
LUV DC - Tidal delta	Low	N/A
LUV DC - Variable lake delta	Low	Low
Urban Stream - Highly Modified	Low	Low
Water storage - dam or weir pool	Low	Low
PCVS - Bedrock controlled, fine grained	Moderate	Moderate
PCVS - Bedrock controlled, gravel	Moderate	Moderate
PCVS - Bedrock controlled, sand	Moderate	Moderate
PCVS - Dune controlled	High	High
PCVS - Dune controlled, anabranching	High	High
PCVS - Planform controlled, tidal	Moderate	Moderate
PCVS - Planform controlled, anabranching	Moderate	Moderate
PCVS - Planform controlled, anastomosing	Moderate	Moderate
PCVS - Planform controlled, low sinuosity, cobble	Moderate	Moderate
PCVS - Planform controlled, low sinuosity, fine grained	Moderate	Low
PCVS - Planform controlled, low sinuosity, gravel	Moderate	Moderate
PCVS - Planform controlled, low sinuosity, sand	High	High
PCVS - Planform controlled, meandering, fine grained	Moderate	Low
PCVS - Planform controlled, meandering, gravel	Moderate	Moderate
PCVS - Planform controlled, meandering, sand	High	High
PCVS - Planform controlled, wandering, sand	High	High
PCVS DC - Planform controlled, tidal delta	Moderate	N/A
SMG - Chain of ponds	High	High

River Style®	Fragility Classification for Slopes and Coast	Fragility Classification for Inland Plains
SMG - Cut and fill	High	High
SMG - Dune controlled, chain of ponds	High	High
SMG - Dune controlled, floodout	Moderate	Moderate
SMG - Floodout	High	Moderate
SMG - Lowland chain of ponds	High	High
SMG - Valley fill, clay	High	High
SMG - Valley fill, fine grained	High	High
SMG - Valley fill, gravel	High	High
SMG - Valley fill, sand	High	High

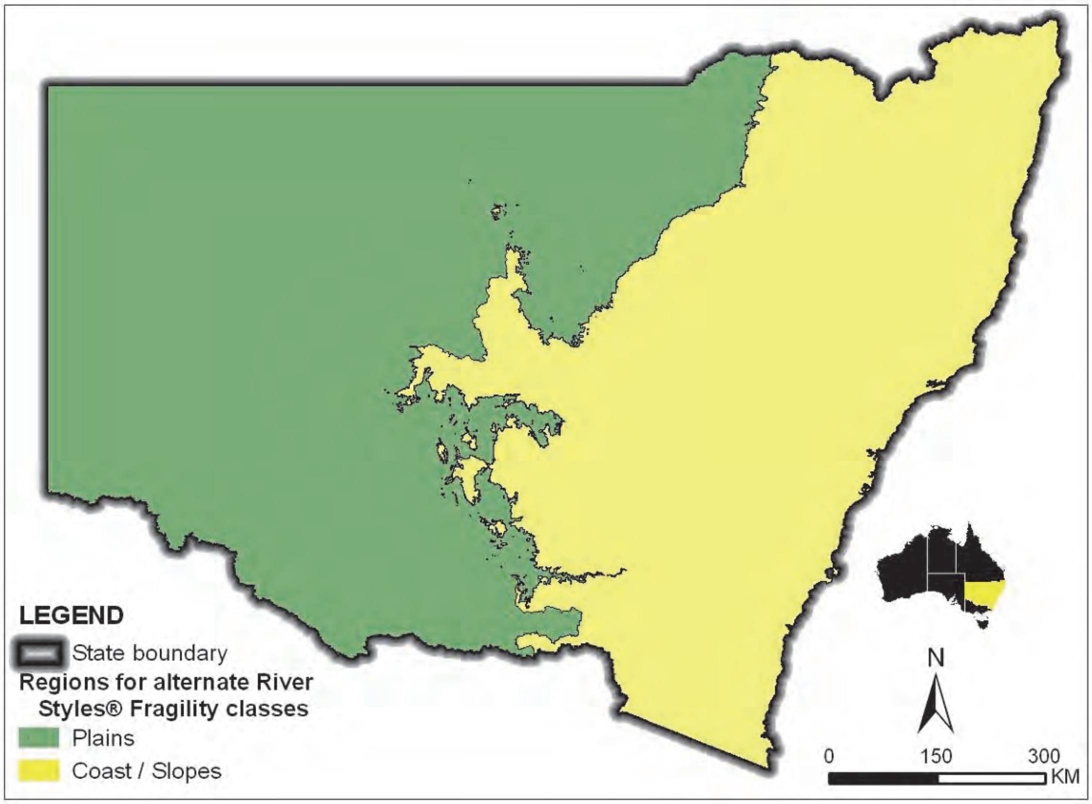

Figure A 1: Map showing where the fragility classification apply.

Appendix 2

The Process of Transferring Hydrologic Stress Attributes into the River Style® Layer

- The River Style® polylines are broken into 1.5km lengths (if they are longer than this), and this becomes the base layer that is to be used and attributed with the Hydrologic Stress (River Style® base layer).
- This River Style® base layer is converted into points 150m apart, attributed with Object ID of the 1.5km River Style lines.
- These points are then converted to a raster grid where the grid cell values are attributed with the Object ID.
- A process utilising the Spatial Analyst Tools\Hydrology\Pour Point tool within the ArcToolbox is used to identify cells where the IDs of upstream and downstream are the same is used, and where this in the case the cell value is changed to equal this ID, if it is not already.
- Another process also utilising the Pour Point tool is used to fill in gaps in the stream grid with the closed upstream or downstream Object ID, but not extrapolating more than 600m, is then used.
- The improved Object ID raster grid is converted to lines (referred to as network lines) based on the Object ID initially taken from the River Style® base layer. The extent is set to be the same as the flow direction grid and Hydrologic Stress layer to make the network line as similar to the Hydrologic Stress layer as possible as it helps in linking the layers.
- The Integrate function is used to line up the River Style® network lines with the Hydrologic Stress lines so the lines a coincident.
- The Hydrologic Stress grid hence is also coincident with the River Style® network line. This grid is converted to points attributed with the Hydrologic Stress value, which lie on the River Style® network line.
- The River Style® network lines are attributed with the minimum, maximum, average and standard deviation of hydrologic stress value points using the Spatial Join function.
- This information is used to select the best representation of Hydrologic Stress for each reach as the hydrologic stress value in some cases will vary along a river reach. This is done by;
    - exporting the attribute table of the River Style® network line as excel sheet
    - the difference between the minimum, maximum and average stress values are compared to the Standard Deviation of the points lying along the segmented or reach to select the most appropriate (Minimum, Maximum, or Average) using the following formula:

HS = IF (MAX-(SD/1.5)<AV, MAX, IF (MIN+(SD/1.5)>AV, MIN, AV))

which means,
If (Maximum-(Standard Deviation/1.5)<Average, Hydrologic Stress=Maximum, OR, If (Minimum+(Standard Deviation/1.5)>Average, Hydrologic Stress=Minimum, OTHERWISE Hydrologic Stress=Average

    - converting the excel file converted to database file, and finally using an Attribute Join to transfer the selected Hydrologic Stress back to the River Style® network line using the Object ID.
- The final step is to use an Attribute Join of the Object ID to link the River Style® network lines to the original River Style® polylines, hence attributing the 1.5km River Style® cartographic lines with the selected Hydrologic Stress value.

Appendix 3

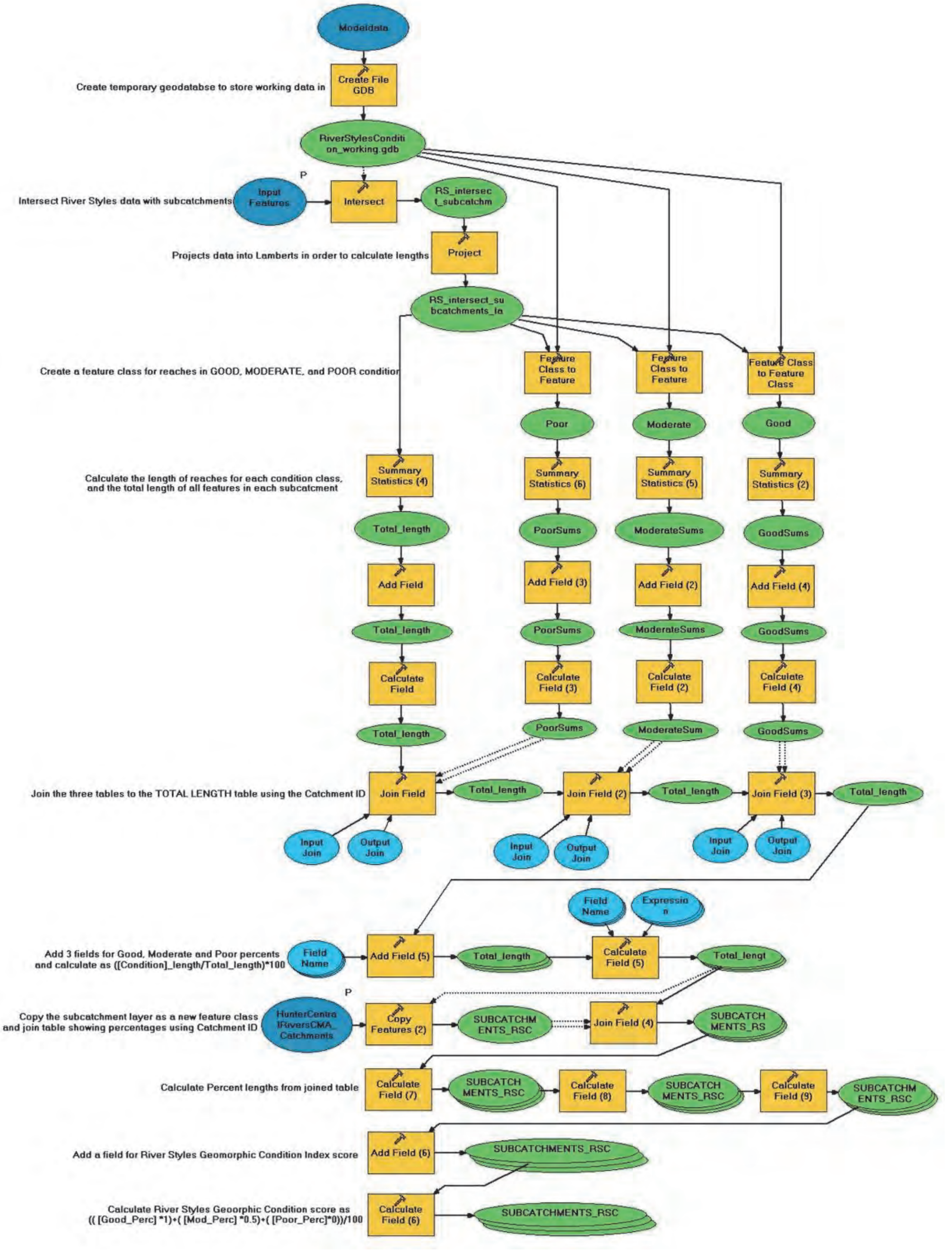

Figure A 2: Model showing the process to calculate River Styles® Geomorphic Condition input index (RSGC) – example from the Hunter Central Rivers CMA region

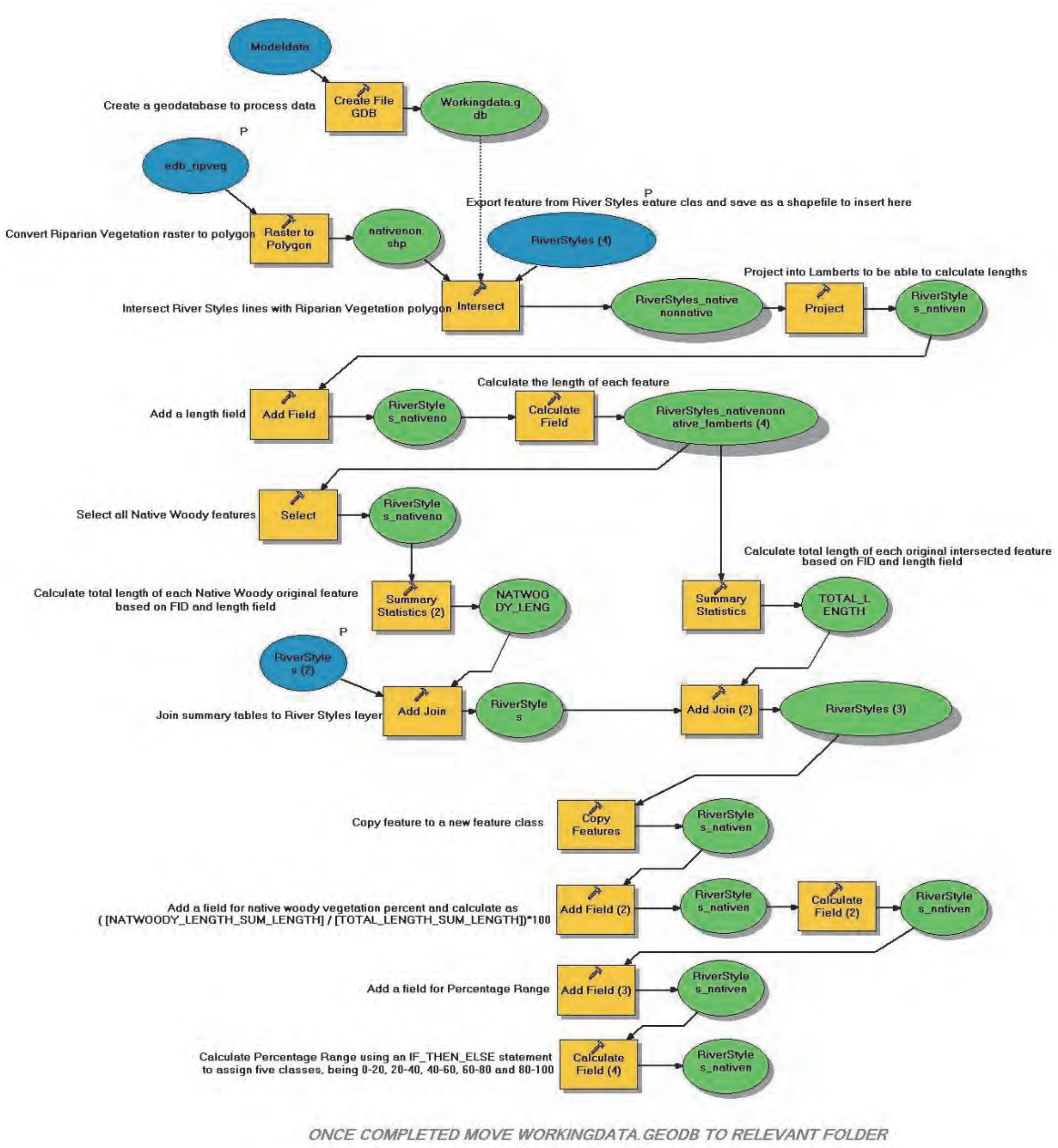

Figure A 3: Model Showing the process to calculate the percentage of Native Woody Riparian vegetation for River Styles® river reaches

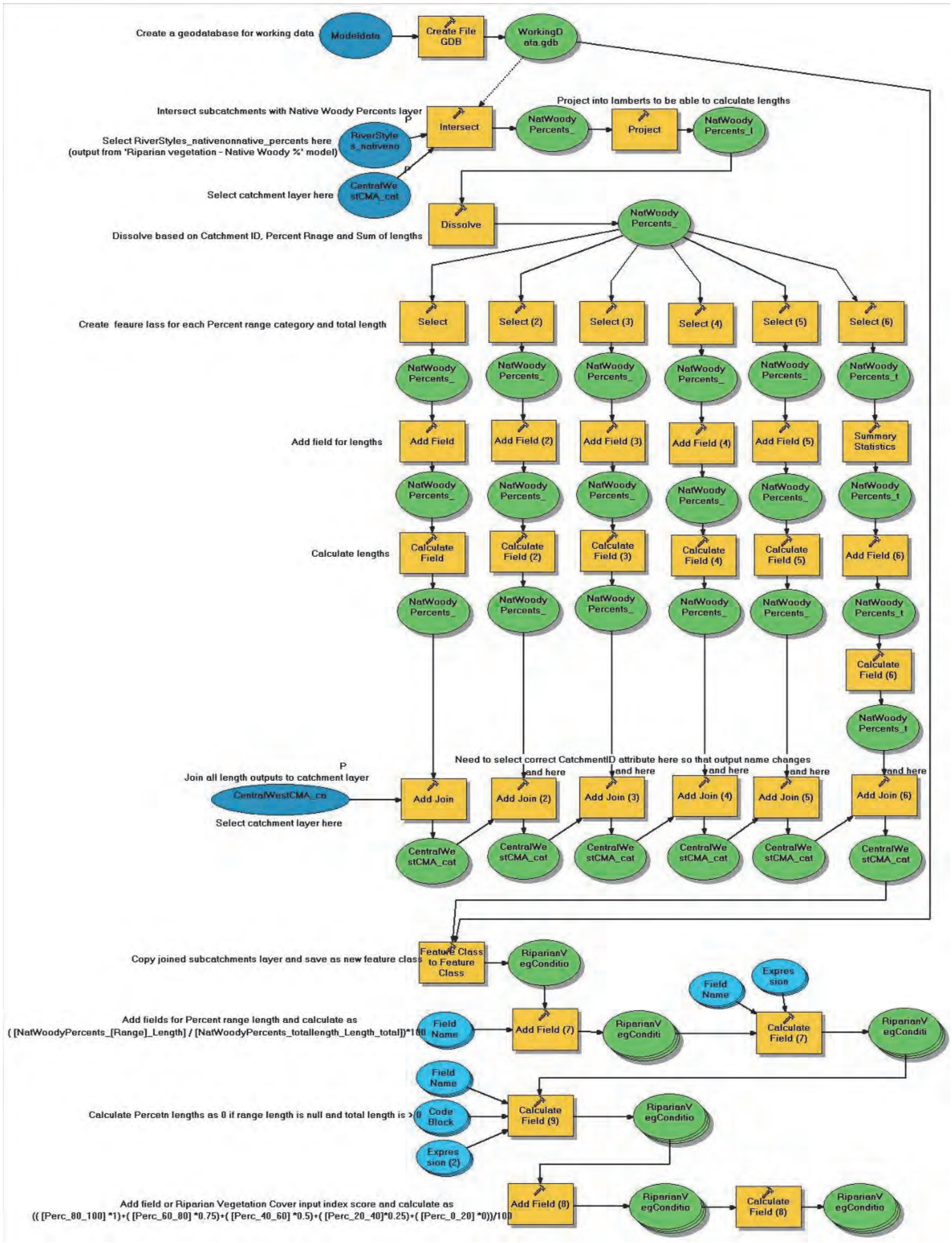

Figure A 4: Model showing the process to calculate the Riparian Vegetation Condition input index (RVC) – example from Central West CMA shown

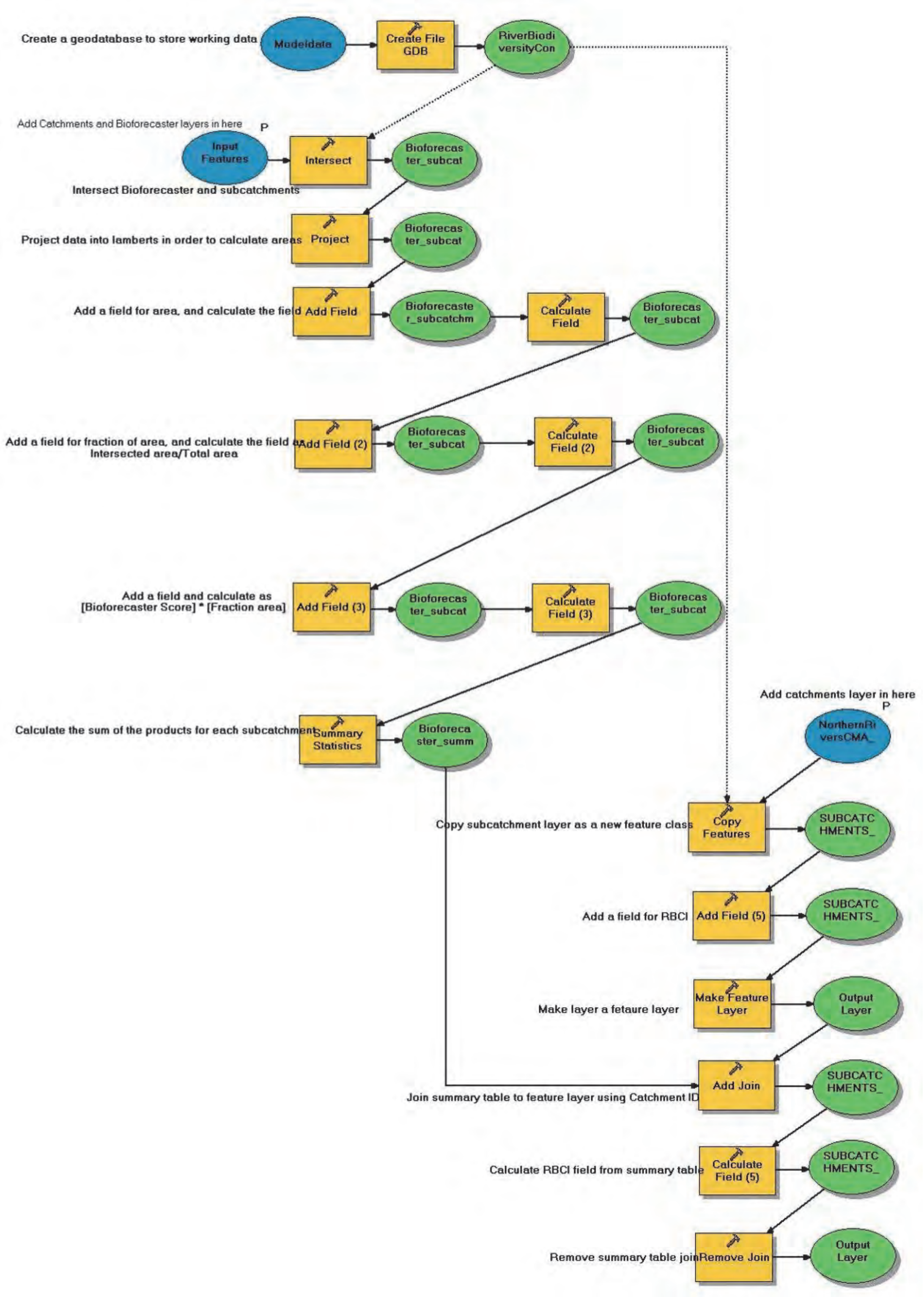

Figure A 5: Model showing the process to calculate the River Biodiversity Condition input index (RBCI) based on the River Biodiversity Forecaster data– example from Northern Rivers CMA shown

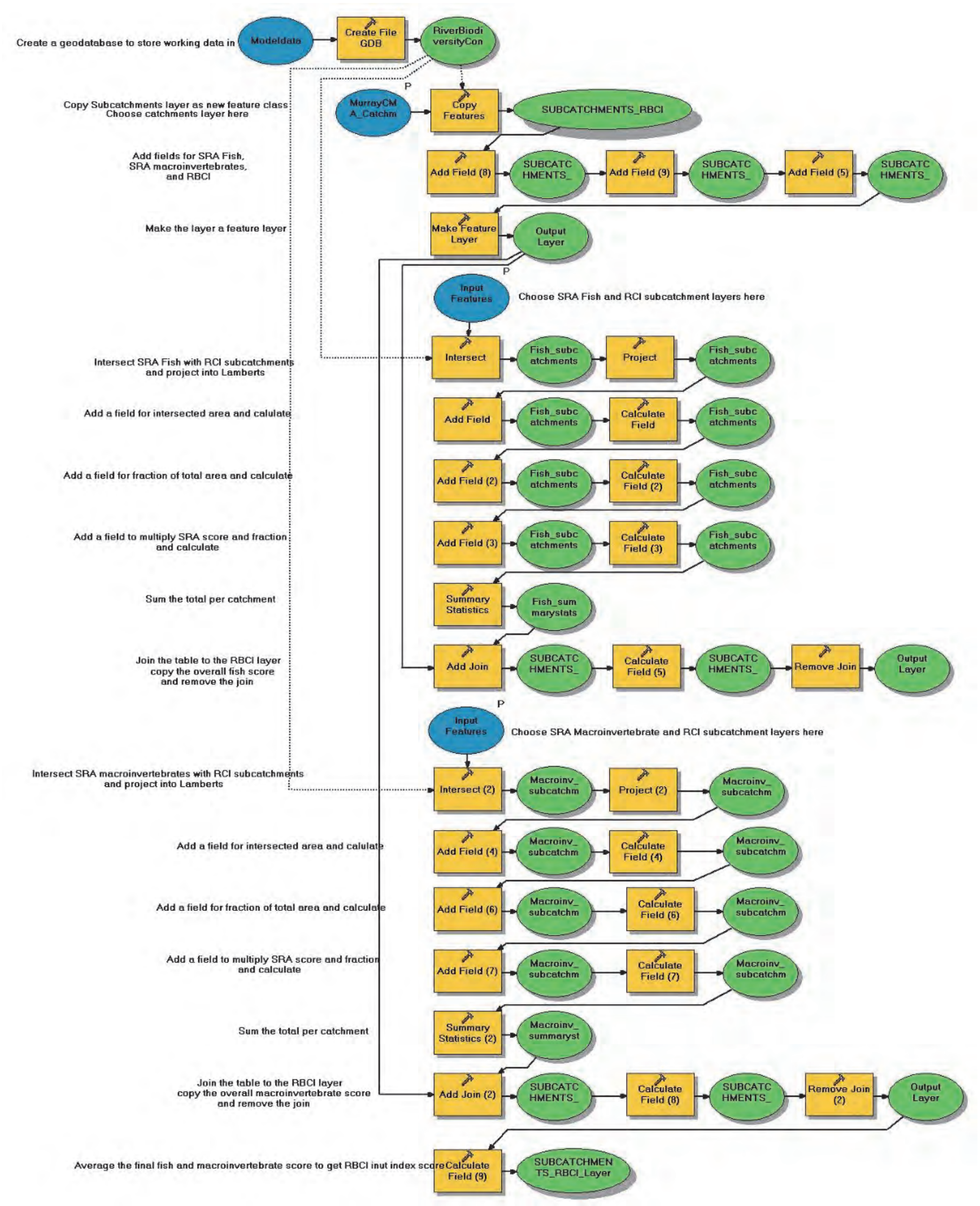

Figure A 6: Model showing the process to calculate the River Biodiversity Condition input index (RBCI) based on the SRA Fish and Macroinvertebrate data – example from Murray CMA shown.

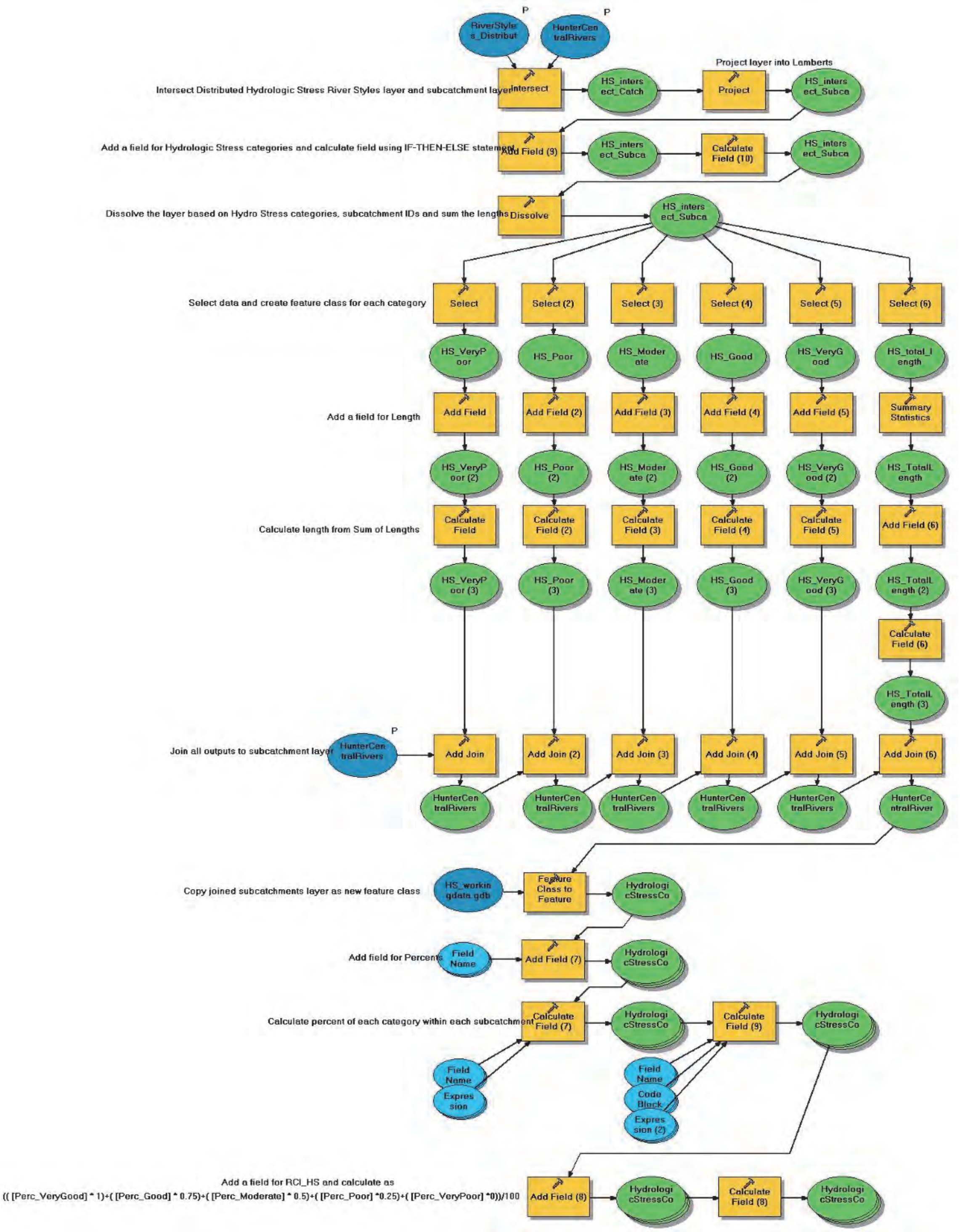

Figure A 7: Model Showing the process to calculate the Hydrologic Stress input index (HS) based on the Distributed Hydrologic Stress data - example from Hunter-Central Rivers CMA shown.

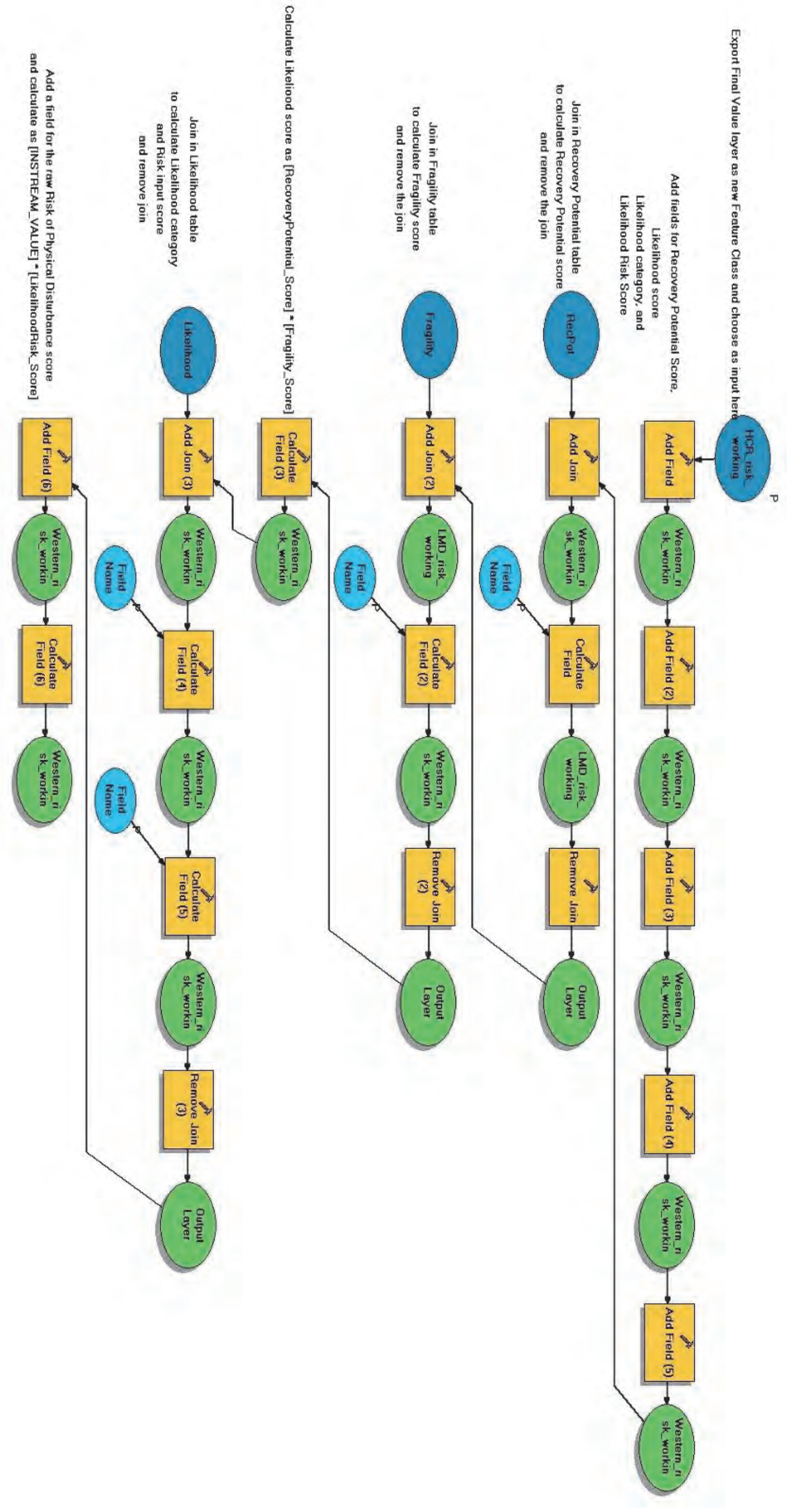

Figure A 8: Model showing the process to calculate the Raw Risk of Physical Disturbance to instream Value score - example from Hunter-Central Rivers CMA shown.

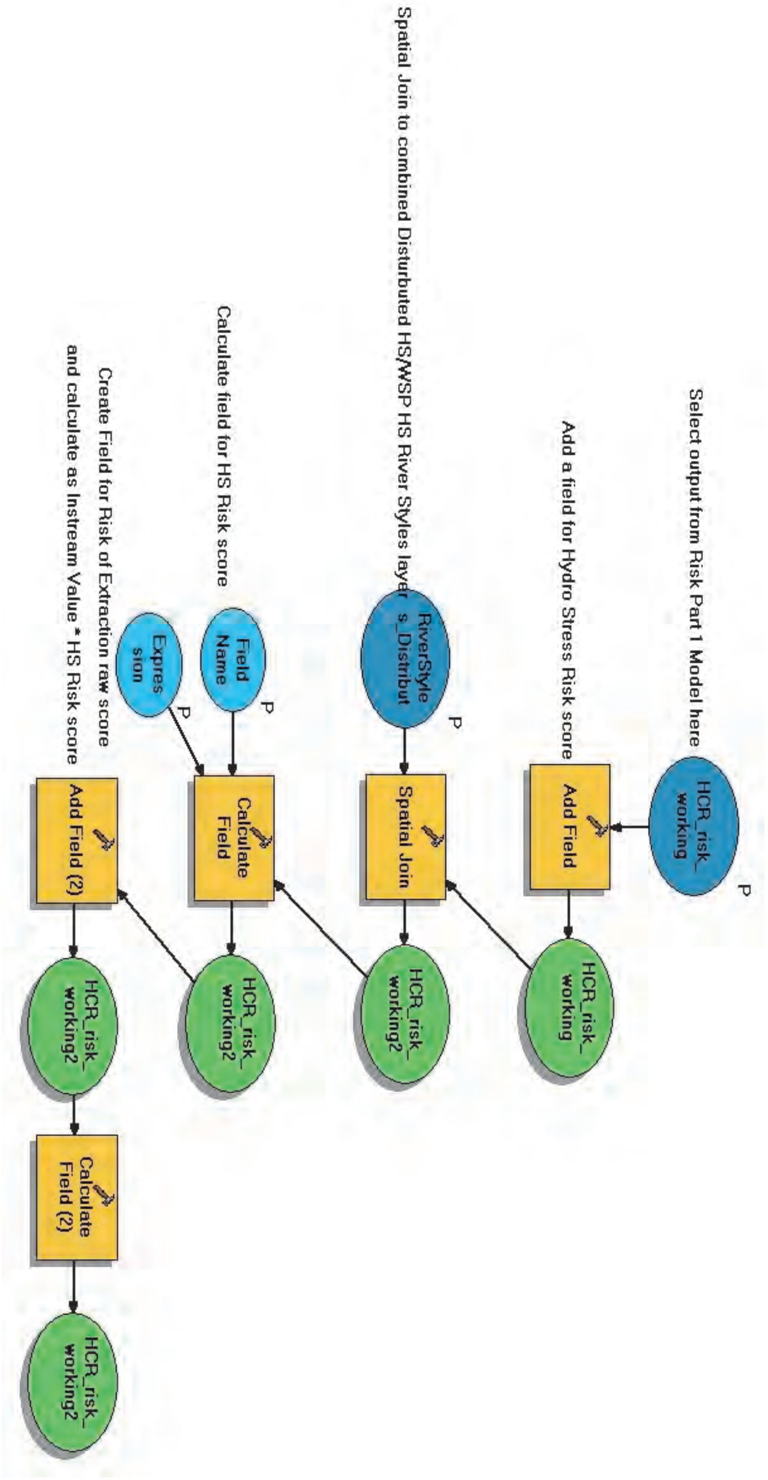

Figure A 9: Model showing the process to calculate the Raw Risk to Extraction to Instream Value score - example from Hunter-Central Rivers CMA shown.

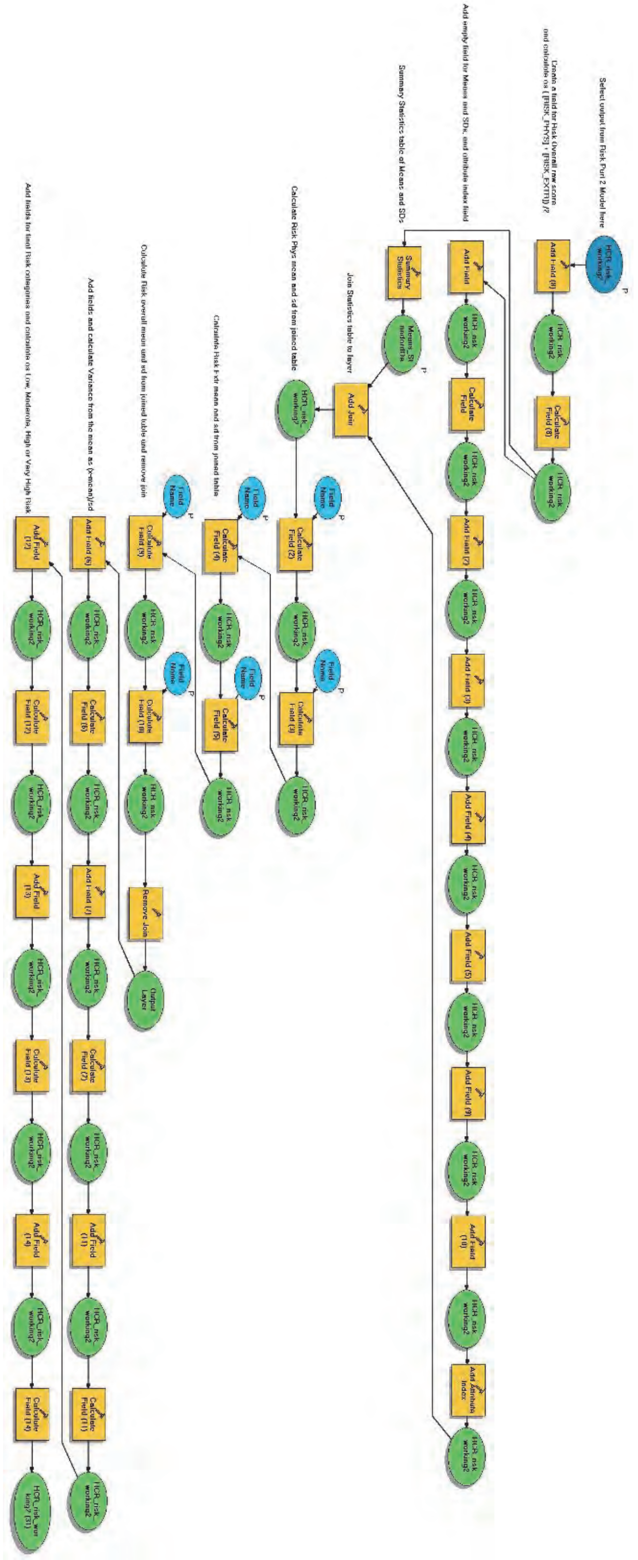

Figure A 10: Model showing the process to calculate the Final Risk to Instream Value score and final Risk categories - example from Hunter-Central Rivers CMA shown.