Department of Planning and Environment

dpie.nsw.gov.au

River Condition Index

Method Report

January 2023

Acknowledgement of Country

The Department of Planning and Environment acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past, present and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

Published by NSW Department of Planning and Environment

dpie.nsw.gov.au

River Condition Index

First published: January 2023

ISBN: 978-1-76058-689-8

Department reference number: PUB23/28

More information

Front Cover image Credit; Gunther Schmida, Mel Bradbury, Dan Coleman

For further information or questions please contact surfacewaterscience@dpie.nsw.gov.au

Copyright and disclaimer

Contents

Acknowledgements

The River Condition Index version 2 (2023) has been a team project by staff within the Knowledge Division of the NSW Department of Planning and Environment, Water Division. Project leadership was conducted by Surface Water Science staff John Brayan, David Workman and Kathryn Taffs. Technical component leads were Sharon Bowen, Fergus Hancock, Michael Healey, Warwick Mawhinney, Jon Sayers, with support from Matt Balzer, Jodie Dabovic, Jedda Lemon and Rory Williams. Spatial Unit staff Lucy Dobbs, Bilal Hossain and Matt Trappel completed the River Condition Index model and created the spatial product.

Data for the Riparian Vegetation Condition Index was provided by the NSW Department of Planning and Environment – Environment and Heritage Group - NSW State Vegetation Type Map

Data for the River Biodiversity Condition Index was provided by the NSW Department of Primary Industries– Fish Community Status

Data for the Catchment Disturbance Index was provided by the NSW Department of Planning and Environment – NSW Landuse Data

The River Condition Index

This document describes the methods used to update the River Condition Index (RCI) for New South Wales in 2023. The initial development (version 1) of the RCI (Healey et al. 2012) for New South Wales arose from a project funded by the National Water Commission to develop a framework for aligning water sharing plans with catchment action plans. During the first round of reporting for the State-wide Monitoring, Evaluation and Reporting 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 RCI was based on the National Water Commissions *Framework for Assessing River and Wetland Health* (FARWH) (Norris et al. 2007a), which was developed as the national standard. The RCI sub index which represents each FARWH category is shown in Figure 1. This report documents the data sources and methods used to update each RCI component and the development of the additional Water Quality Index.

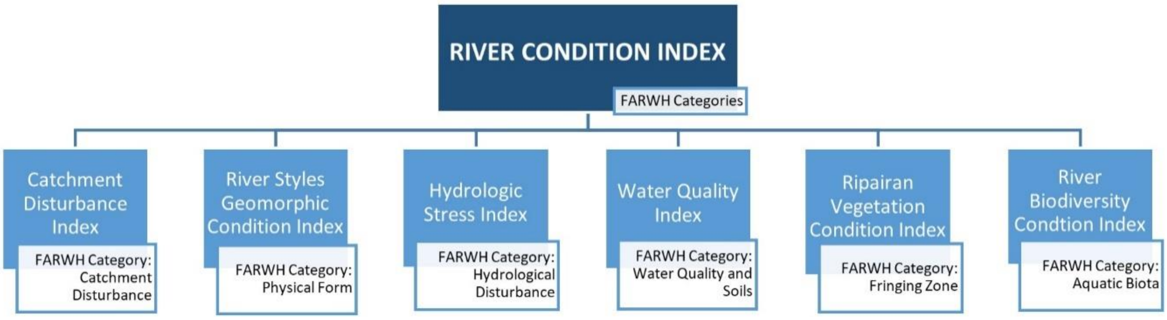


Figure 1 Indices used in the assessment of the RCI, with reference to the FARWH indices.

Interactions between River Condition Index components

Many of the indices within the RCI interact. (Figure 2). For example, catchment disturbance has a large influence on hydrologic stress, riparian vegetation and geomorphic stress. Changes to these indices consequently impact water-quality and biodiversity as well as interact with each other.

How indices interact, and the strength of these interactions, varies greatly. Hydrologic stress may affect riparian vegetation, geomorphic stress, water quality and biodiversity through increased occurrence of low flow periods. Riparian vegetation may affect geomorphic stress, water quality, biodiversity, and hydrologic stress through influencing riverbank support, nutrient cycling and habitat structure. Geomorphic stress may affect riparian vegetation, water quality, biodiversity and hydrologic stress through increased sedimentation and erosion, and reduced stability. All of these interactions play an important role in developing the final River Condition Index score.

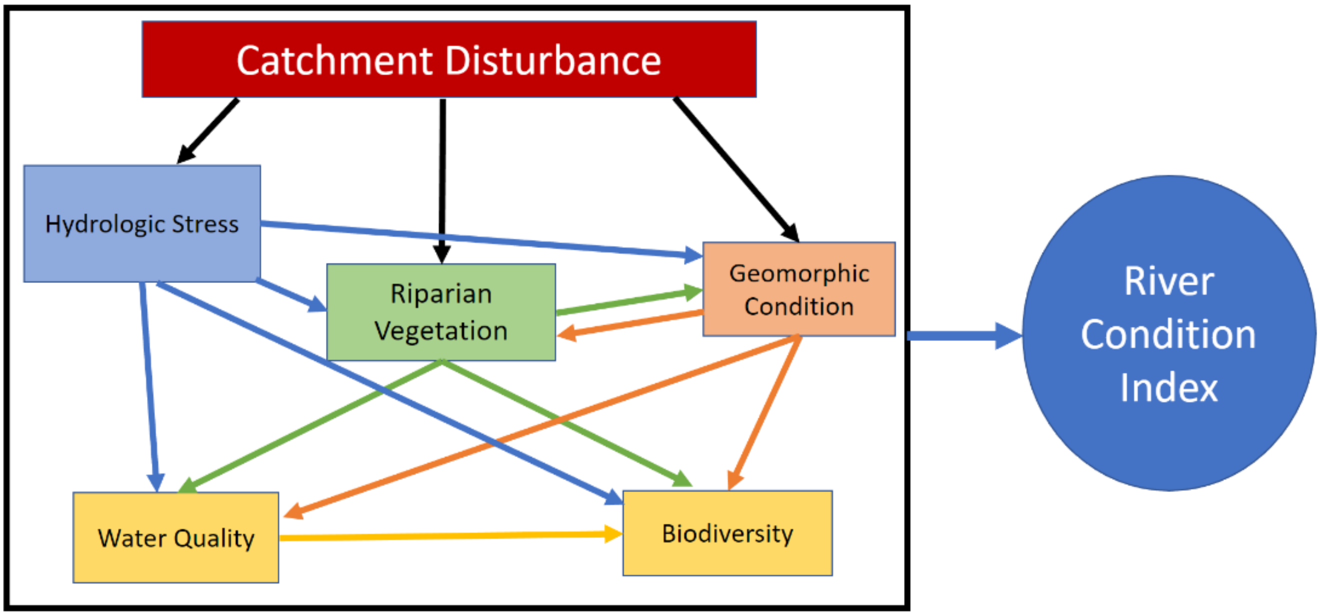


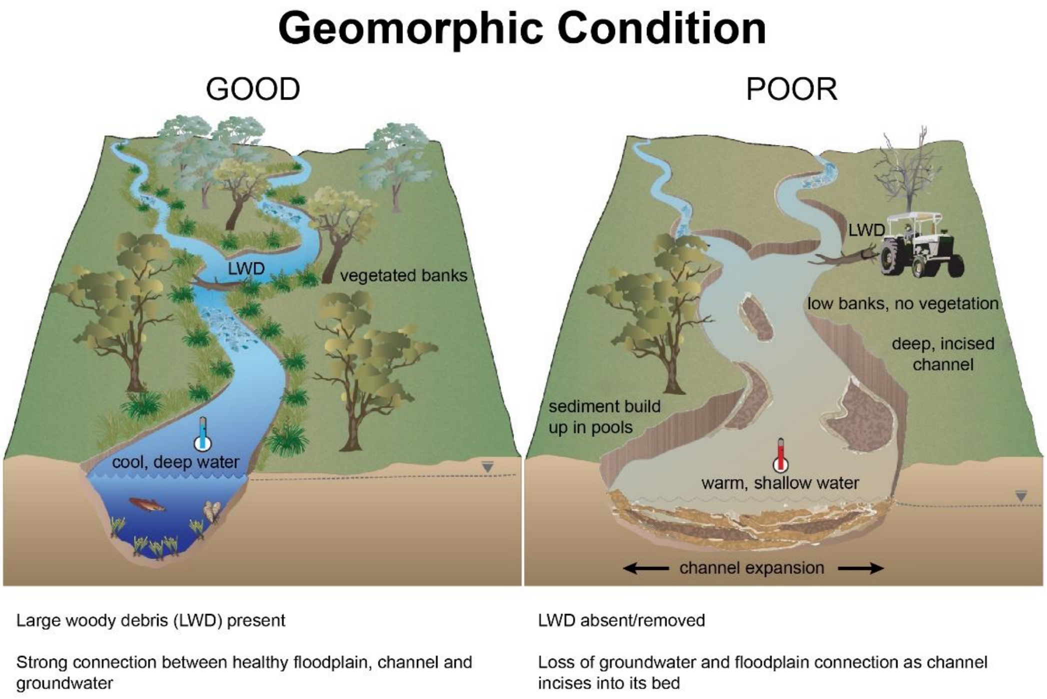
Figure 2 Relationships between the elements of the River Condition Index.

River Styles Geomorphic Condition Index

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 river 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 several riverine condition assessment programs (Anderson 1993; Ladson and White 1999; Reeves et al. 2004). River reaches in good condition have been found to be important for instream biodiversity (Chessman et al. 2006), ecological diversity and overall catchment condition (Figure 3). 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, fragility and recovery potential at the reach scale, relative to a reference condition for the given river 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 are 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.



Large woody debris (LWD) present

Strong connection between healthy floodplain, channel and groundwater

LWD absent/removed

Loss of groundwater and floodplain connection as channel incises into its bed

Most symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science

Figure 3 Good versus poor geomorphic condition.

River Styles Geomorphic Condition Methods

The original analysis for River Styles Geomorphic Condition calculated the percentage length of rivers in each River Styles condition category (Good, Moderate or Poor) in each sub-catchment. This was done by intersecting the River Styles spatial polylines with the sub-catchment polygons. The following formula was then used to generate a score for each sub-catchment. The formula is the same as Equation 45 in Norris et al. 2007b, and results in an overall condition score ranging between 0 and 1, with higher scores representing better condition.

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

Where RSGC = River Styles Geomorphic Condition score

The updated analysis has incorporated updated River Styles assessments from the NSW Department of Planning and Environment, Water. Using this updated version of the River Styles spatial layer, condition together with recovery potential were examined to determine 5 condition categories rather than 3 to make the analysis more detailed (**Error! Reference source not found.**).

Table 1 Condition categories used in the River Styles Geomorphic Condition assessment.

		CONDITION			
		Good	Moderate	Poor	None
RECOVERY POTENTIAL	Conservation	Very Good			
	High		Good		
	Rapid		Good		
	Strategic		Moderate	Poor	
	Moderate		Moderate	Poor	
	Low		Moderate	Very Poor	
	None				Very Poor

The incorporation of recovery potential provides a more accurate calculation of the geomorphic condition of a reach by including the trajectory or likelihood of the reach to improve in condition. That is, a river in moderate condition with high recovery potential is more likely to improve or maintain geomorphic condition compared to a moderate condition river with moderate or low recovery potential. The percentage length of each of the new condition categories in each sub-catchment was calculated by intersecting the River Styles spatial polylines with the sub-catchment polygons.

In the Murray and Murrumbidgee catchments irrigation channels have been previously mapped in the River Styles spatial layer. Some irrigation channels follow the path of natural watercourses, albeit highly modified, and have been included in the analysis. Other created irrigation channels, which were cut into the landscape for the specific purpose of transmitting water for irrigation and are disconnected from natural flows, were removed for the analysis. This was done to avoid skewing the data in a negative way, as these were not considered representative of the natural rivers in the Murray and Murrumbidgee catchments and have not been mapped or included in the analysis for other catchments.

The formula from the original RCI analysis is then used to calculate the River Styles Geomorphic Condition for each sub-catchment but extended to include 5 condition categories instead of 3. The formula results in an overall condition score ranging between 0 and 1, with higher scores representing better condition.

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

$$\textbf{Where RSGC} = \textbf{River Styles Geomorphic Condition score}$$

The range of final River Styles Geomorphic Condition scores was split into five classes as follows:

>0.8 – 1 = Very Good

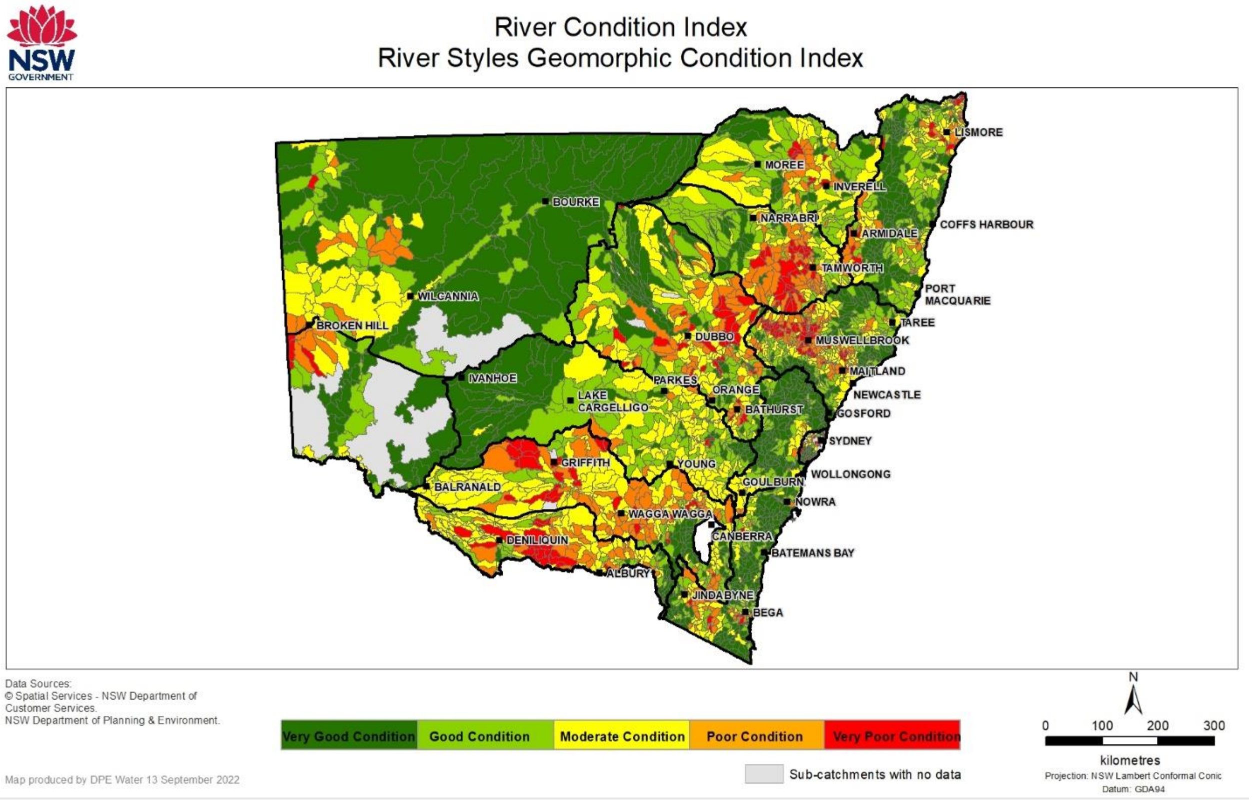
>0.6 – 0.8 = Good

>0.4 – 0.6 = Moderate

>0.2 – 0.4 = Poor

<=0.2 = Very Poor.

The state-wide map of this index is shown in Figure 4. Areas where there was insufficient data to calculate a score are shown in grey.



Data Sources:
© Spatial Services - NSW Department of Customer Services.
NSW Department of Planning & Environment.

Map produced by DPE Water 13 September 2022

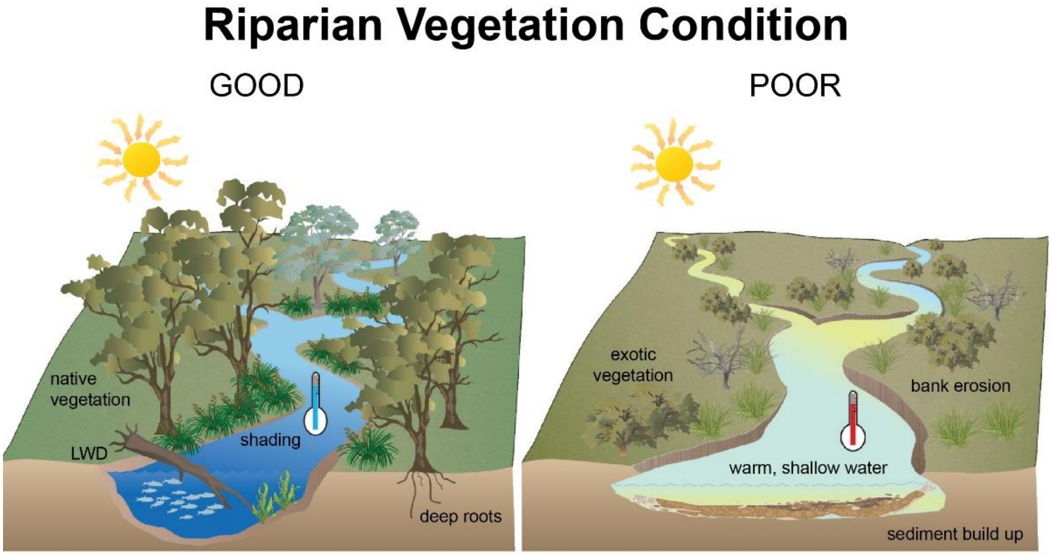
Figure 4 River Styles Geomorphic Condition Index.

Riparian Vegetation Condition Index

Riparian vegetation is important for the provision of a range of ecosystem services. It provides the structure and stabilising function for stream banks preventing erosion, buffers against stream flows, filters nutrients, moderates instream primary production, and provides habitat for aquatic and terrestrial biota (Spencer et al. 1998; Werren and Arthington 2002; Lovett and Price 2007, Riis et al., 2020). Riparian vegetation is under significant pressure from anthropogenic activities including vegetation removal, land-use change, water harvesting and stream flow regulation, invasive species, altered disturbance regimes, and water diversion (Riis et al. 2020). The removal of riparian vegetation also leads to the modification of river geomorphic structure (Brierley et al. 1999).

Riparian vegetation in NSW includes a diversity of Plant Community Types (PCTs) that include woody and non-woody vegetation types, from forests, woodlands, wetlands, grasslands, and rainforests. These types contribute to ecosystem services provided by riparian vegetation including; filtering and storage of sediment and pollutants, erosion control, flow regulation, provision of aquatic and terrestrial habitats, filtering of nutrient run off, regulation of microclimates and carbon sequestration (Riis et al., 2020). Consequently, all woody and non-woody vegetation types have been valued equally in this revised approach to the RCI described below.

Measures of landscape connectivity (or its inverse, fragmentation) are widely recognised in measures of vegetation condition. Better connectivity and larger patch sizes of native vegetation have been correlated with higher species diversity, improved colonisation by dispersing species, improved structure and function, and reduced edge effects (Lindenmayer and Fischer et al. 2006, Dabovic et al. 2019). In this version of the RCI, we include an assessment of fragmentation and patch size to derive an overall connectivity score, in addition to the extent of both woody and non-woody vegetation to measure riparian vegetation condition (Figure 5).



Good vegetation will contract and deepen the channel
Deep roots help maintain bank structure and stability, and reduce erosion
Large woody debris (LWD) provides habitat

Without vegetation, the channel will become wider and shallower
Absence or loss of vegetation increases channel instability and erosion
An absence of LWD reduces habitat

Most symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science

Figure 5 Good versus poor riparian vegetation condition.

The FARWH (Norris et al. 2007a) recognises the importance of including an assessment of fringing zone as a key index. The fringing zone index represents structural and condition features of the streamside zone, or the zone surrounding a wetland. While this index could contain features relevant to the physical form and aquatic biota indices, the zone is seen as such an important focus of management that it requires its own category.

Riparian Vegetation Condition Methods

The original Riparian Vegetation Condition analysis used various data sources depending on the available data in the region. Lower Murray Darling Catchment Management Authority and Western Catchment Management Authority had no available data. Sydney Metro and Namoi Catchment Management Authorities had conducted detailed assessments of riparian vegetation. The condition of riverine vegetation in the Namoi Catchment was assessed by EcoLogical (2009). In the case of the Sydney Metropolitan Catchment Management Authority, a detailed report had been completed on the mapping of river health and included an analysis of riparian vegetation condition (Earthtech, 2007). Both Catchment Management Authorities had vegetation metrics for river reaches that were able to be converted into five categories (very good, good, moderate, poor and very poor). The percentage length of each category within the sub-catchment was calculated by intersecting the river lines with the sub-catchment polygons, and then the final Riparian Vegetation Condition score for the sub-catchment was calculated using the following formula:

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

Where RVC = Riparian Vegetation Condition score

The remainder of the state used remote sensing data. Garlapati et al. (2010) produced spatial mapping products of riparian vegetation extent for 24 catchments in NSW for the NSW Office of Water using the NSW Interim Native Vegetation Extent dataset (DECC 2008). This dataset identified native woody vegetation within a 30m buffer from the river line. The percent of native woody vegetation on each river reach was calculated. The percentage cover of native woody vegetation was categorised into five groups: 0-20% (Very Poor), 20-40% (Poor), 40-60% (Moderate), 60-80% (Good), 80-100% (Very Good). The percentage length of each category within the sub-catchment was calculated, and then the final RVC score for the sub-catchment was calculated using the following formula:

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

Where RVC = Riparian Vegetation Condition score

For version 2 of the Riparian Vegetation Index, two main goals were acknowledged. Firstly, to achieve state-wide coverage with consistent datasets, and secondly, to improve the interpretation of riparian vegetation condition by including three metrics: native woody vegetation, native non-woody vegetation, and connectivity (Figure 6). Native non-woody vegetation and connectivity represent two new attributes included in this update of Riparian Vegetation Condition Index not used in version 1 of the RCI.

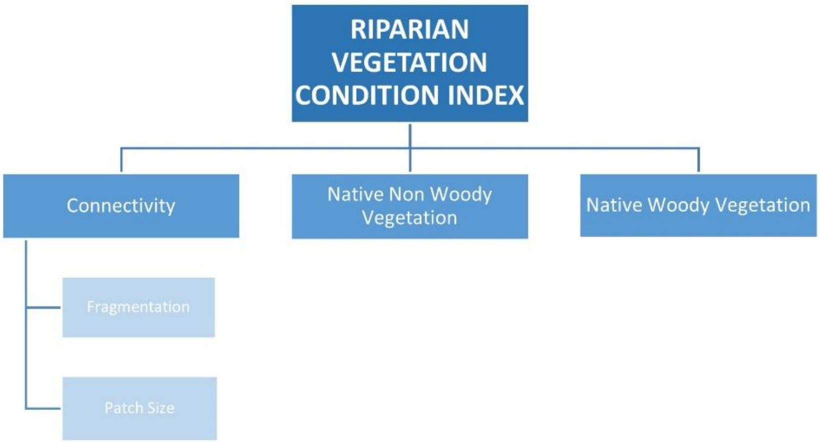


Figure 6 Inputs into the updated Riparian Vegetation Condition Index.

The updated Riparian Vegetation Condition analysis uses the NSW State Vegetation Type Map, provided by the NSW Department of Planning and Environment - Environment and Heritage Group (DPE 2022a). The State Vegetation Type Map is a regional-scale map of each of the three levels of the NSW vegetation classification hierarchy. It maps the distribution of each Plant Community Type, Vegetation Class and Vegetation Formation, across all tenures in NSW.

There are two separate map products:

- The State Vegetation Type Map extant map shows the distribution of the vegetation classification types within the limits of present-day native vegetation cover, across all of NSW.
- The State Vegetation Type Map pre-clearing map displays the likely distribution of types prior to the loss of native vegetation cover. The pre-clearing for central NSW is in preparation and due in 2023. This was not available for the current RCI update.

The State Vegetation Type Map is created and maintained using a method for regional-scale mapping of Plant Community Types. To develop the State Vegetation Type Map, the department uses on-ground survey, aerial and satellite photograph interpretation and landscape models to map the most likely Plant Community Types. While much of the State Vegetation Type Map is regional-scale information, some fine-scale mapping has been selectively included. Further fine-scale mapping will be included in the future, as well as updates and revisions as better information becomes available. If possible, the maps are checked on the ground.

The State Vegetation Type Map is designed to be routinely updated as better information becomes available. Annual map updates are coordinated with the maintenance of Plant Community Types by the department. Ongoing improvement of the State Vegetation Type Map by new or better information can be suggested through the *Provide Feedback* button in the NSW Sharing and Enabling Environmental Data Portal (SEED). Such updates will be useful for future editions of the Riparian Vegetation Condition Index.

From the State Vegetation Type Map, it is estimated that about 53% of the natural native vegetation that originally covered NSW remains today. Each Plant Community Type in NSW is given an estimate of percent clearing loss in eastern New South Wales, the State Vegetation Type Map is used to calculate the clearing loss of each mapped Plant Community Type.

Native woody and Native non-woody vegetation

Plant Community Type are the finest unit of vegetation community mapping in the NSW Vegetation Classification hierarchy; hence this is the level that the State-wide Vegetation Type Map is used in the Riparian Vegetation Condition index. Polygons of the State-wide Vegetation Type Map were identified as either 'native woody' or 'native non-woody' or 'non-native' according to the PCT attribution of that polygon. This was done as part of the High Priority Groundwater Dependent Ecosystem Mapping.

Each river reach (as identified in the River Styles layer) is buffered by 30 m either side, and the total area for each 30 m riparian buffer zone is calculated. The pre attributed PCT vegetation layer is intersected with the 30 m buffer zones, and the total area of native woody and native non-woody vegetation within each 30 m buffer zone is calculated. This enables the calculation of the percentage area for native woody and native non-woody vegetation within each 30 m buffer zone for each river reach.

Assigning Connectivity Score

A Connectivity score for each river reach (within the 30 m riparian buffer zone) is calculated using the metrics Patch size and Fragmentation, as explained below.

Patch size rating

For Patch size, the pre attributed Plant Community Type vegetation layer for the whole study area is dissolved (i.e., aggregated up to a higher classification level) to combine polygons with the same vegetation structure.

The size of each combined vegetation structure polygon (in hectares) is calculated to give total patch size. A weighted score (rating) is given depending on the size of the patch, with larger native vegetation patch size receiving a higher score. The patch size weighting scores in Table 2 are taken from the Diversity model in the Groundwater Dependent Ecosystems High Ecological Value Aquatic Ecosystems analysis (Dabovic et al., 2019)

Table 2 Weightings used for the derivation of the Vegetation Structure Patch Size index layer.

Vegetation Structure Patch Size	Rating
< 10 ha	0.00
10-25 ha	0.25
25-100 ha	0.50
100-500 ha	0.75
> 500 ha	1.00

An area weighted average is applied to get a single patch size index score for each river reach using all of the patch size index scores within the 30 m riparian buffer zone for each river reach:

$$\mathrm{PI} = \frac{(\mathrm{PS}_1 * \mathrm{A}_1) + (\mathrm{PS}_2 * \mathrm{A}_2)\ldots}{\text{Total Area of 30m buffer for the Reach}}$$

(where PI = patch size index, PS_1 = patch size index for area 1, A_1 = area of 30m buffer for patch score 1)

Fragmentation rating

For Fragmentation, the maximum length of any non-native vegetation patch within the 30 m buffer zone is identified. If a river reach has multiple non-native patches, only the largest patch is considered. A weighting score (rating) is given depending on the length of the patch. The weighting scores in Table 3 are taken from the Diversity model in the Groundwater dependent Ecosystem High Ecological Value Aquatic Ecosystem analysis (representing patch nearness) (Dabovic et al. 2019).

Table 3 Weightings used for the derivation of the Fragmentation index layer.

Non-native patch length	Rating
< 200 m	1.00
200- 1000 m	0.75
1000 - 3000 m	0.50
3000 - 10,000 m	0.25
> 10,000 m	0.00

Final Connectivity Score

The Fragmentation score and Patch Size score are averaged for each river reach to represent the final Connectivity score.

Riparian Vegetation Condition Score for each river reach

The three scores (Connectivity, Native Woody percent cover and Native Non-Woody percent cover) for each river reach are added together and divided by 2 (as 2 is the highest possible score), which gives a final score between 0 and 1 (where 1 is the best condition). This gives a riparian vegetation score for each river reach. The riparian vegetation scores for each river reach are converted into a category (Table 4).

Table 4 Categories used for the derivation of the Riparian Vegetation Condition index layer.

Riparian Vegetation reach score	Riparian vegetation condition category
≤ 0.2	Very Poor
> 0.2 - 0.4	Poor
> 0.4 - 0.6	Moderate
> 0.6 - 0.8	Good
> 0.8 - 1.0	Very Good

Riparian Vegetation Condition Score for each sub-catchment

The percentage of total stream length of each riparian vegetation condition category within each sub-catchment is calculated by intersecting the resulting Riparian Vegetation Condition River Reach layer with the sub-catchments layer. The Riparian Vegetation Condition input index score for each sub-catchment is determined from the percentage stream length of each riparian vegetation condition category within each sub-catchment, and is calculated as follows:

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

Where RVC = Riparian Vegetation Condition score

This index is scored using five categories; with better riparian vegetation condition reaches weighted more than reaches with lower riparian vegetation condition. The formula is based on Equation 45 in Norris et al. 2007b, and results in an overall condition score ranging between 0 and 1, with higher scores representing better condition.

The range of final Riparian Vegetation Condition scores was split into five classes as follows:

>0.8 – 1 = Very Good

>0.6 – 0.8 = Good

>0.4 – 0.6 = Moderate

>0.2 – 0.4 = Poor

<=0.2 = Very Poor.

The state-wide map of this index is shown in Figure 7. Areas where there was insufficient data to calculate a score are shown in grey.

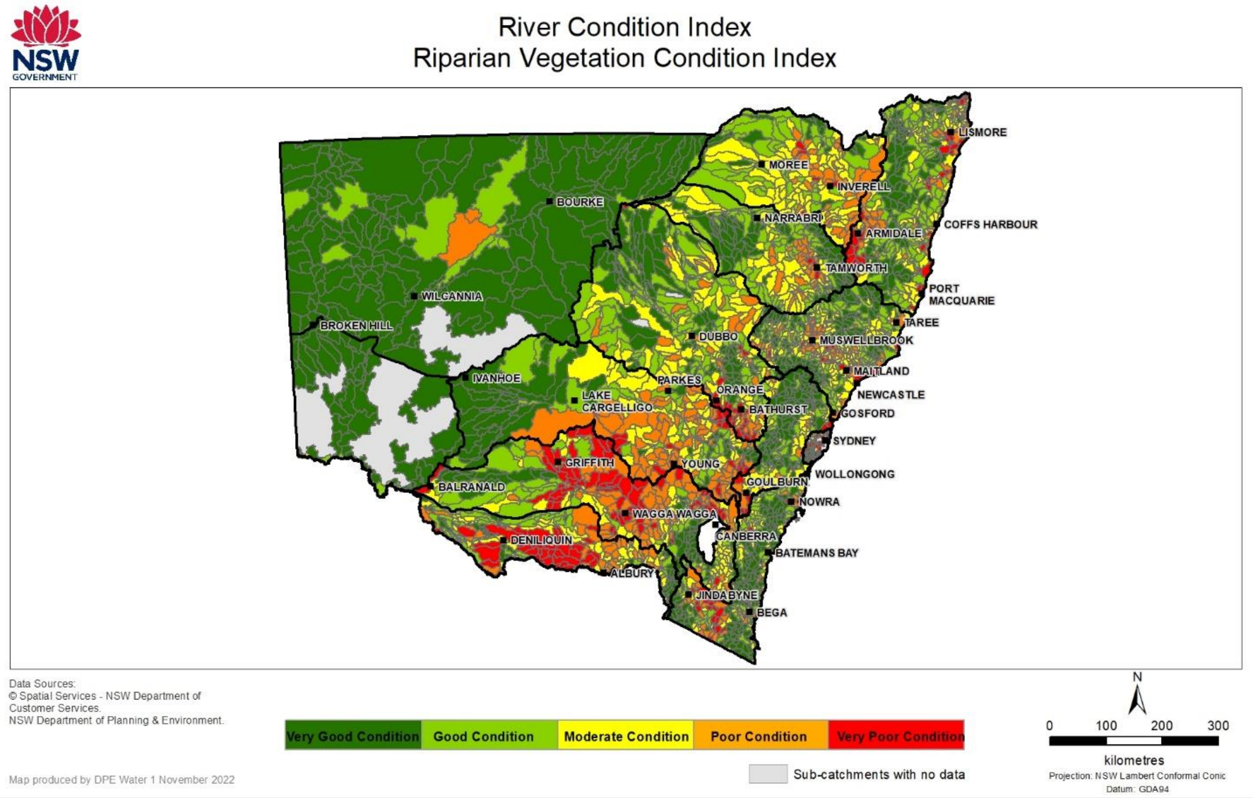


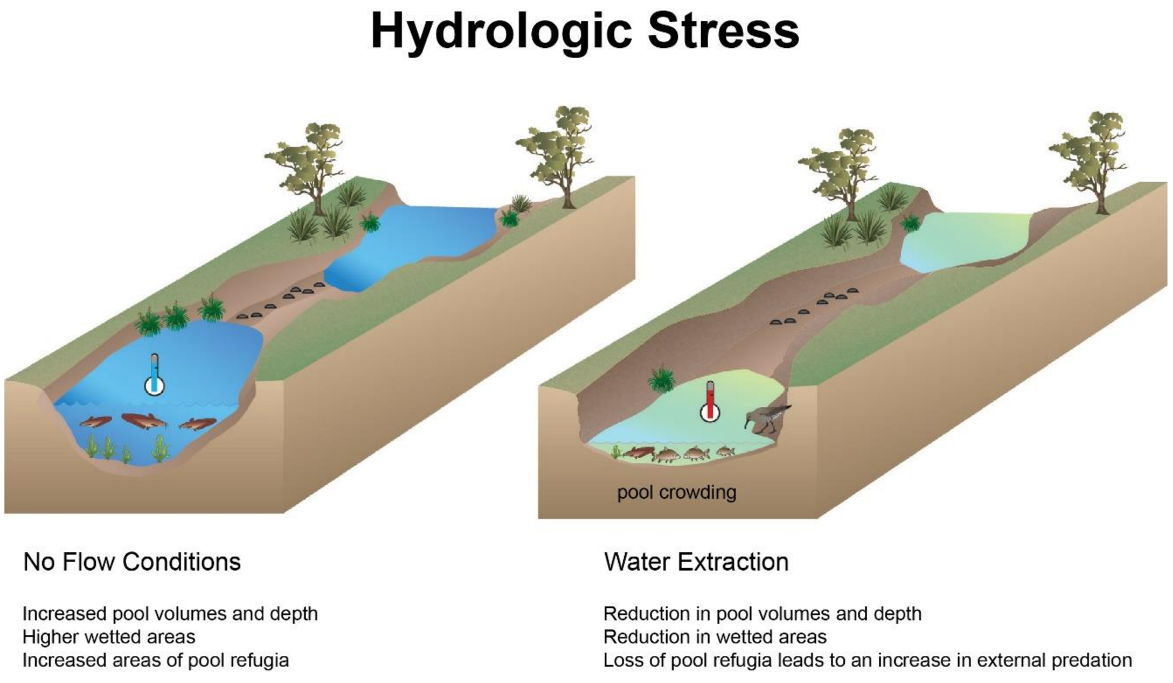
Figure 7 Riparian Vegetation Condition Index.

Hydrologic Stress Index

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. 2010). 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. 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 a measure to report alteration to flows within catchments or sub-catchments. 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).

The FARWH (Norris et al. 2007a) include a hydrological disturbance index as it recognises the importance to aquatic ecosystem function of the water regime, both surface and groundwater, depending on the ecosystem (Figure 8**Error! Reference source not found.**).



Most symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science

Figure 8 Hydrologic stress in low flow conditions and water extraction in low flow conditions.

Hydrologic stress methods

Three data sources were used to generate the Hydrologic Stress Index depending on data availability: Key Ecosystems Function metrics, Distributed Hydrologic Stress and Water Sharing Plan data as shown in Figure 9. Each data source is described below.

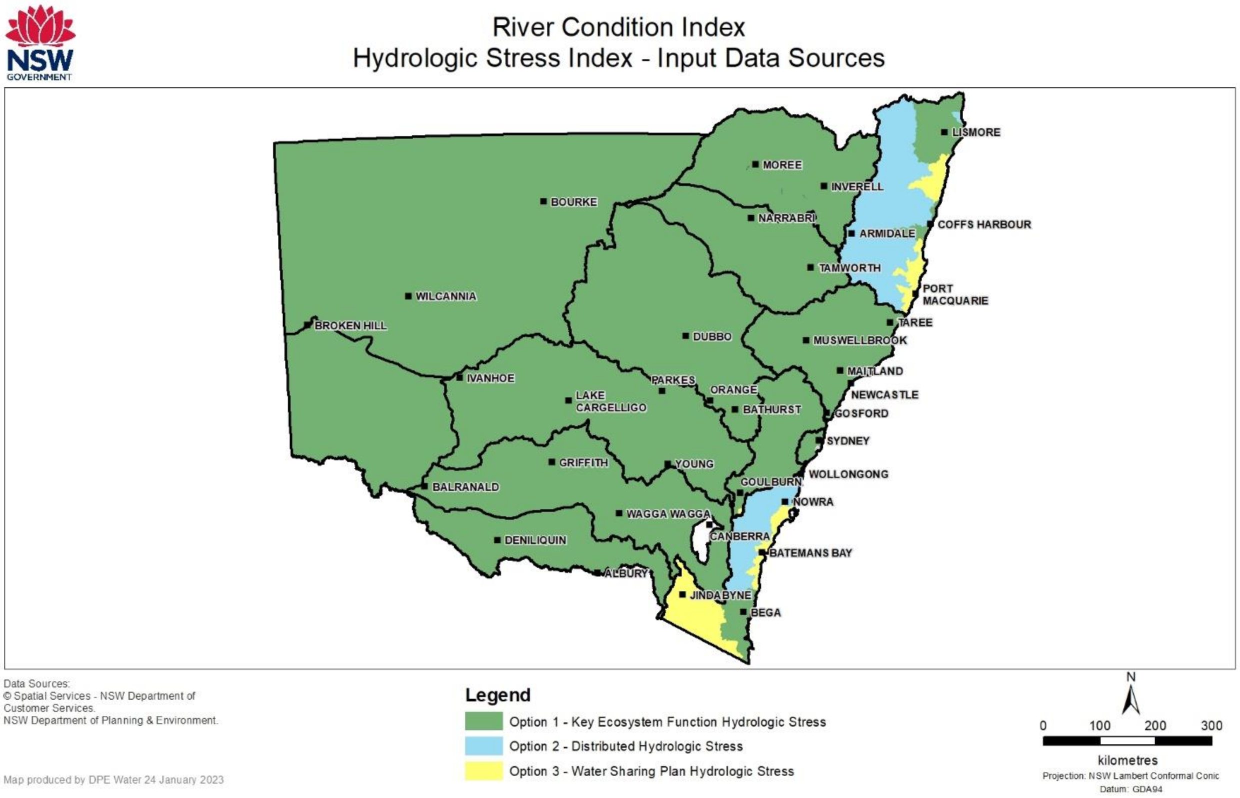


Figure 9 Input data sources for the Hydrologic Stress Index.

To report hydrologic stress for the RCI reporting catchments the hydrologic stress metrics that were derived for larger Water Sources and river reaches needed to be apportioned to the smaller RCI reporting catchments. For option 1 Key Ecosystem Function Hydrologic Stress and option 2 Distributed Hydrologic Stress the stress metrics are distributed along small river reaches and then summarised to provide a score for the RCI reporting catchments. In the case of option 3 Water Sharing Plan Hydrologic Stress the metrics are not distributed, but the RCI reporting catchments scores are assigned directly from the Water Source they fall within.

Option 1 Key Ecosystem Function Hydrologic Stress

The hydrologic stress is based on modelled streamflow sequences, that are used to calculate Key Ecosystems Function metrics. The Key Ecosystems Function metrics compare two flow sequences to identify the degree of flow alteration (relative to natural flows) and were developed for the Murray Darling Basin Authority (Alluvium, 2010). The metrics are designed to evaluate six ecologically important flow ranges: zero flows, low flows, freshes (in-bank flow events), and three high flow ranges (two near bank full, and a third just over-bank). The lower three flow ranges have multiple metrics (six for zero flows, two for low flows, and six for freshes), which are rolled up into single indicator for each of these three flow ranges. In all there are 17 metrics. The equations are listed below.

Zero flow event component metrics (both low and high flow season)

$$\text{Zero Years} = \frac{(\textbf{Natural number of zero years}) - (\textbf{Current Number of Zero Years})}{(\textbf{Natural Number of Zero Years})} \times 100$$

$$(\text{where Zero Years} = \text{Percentage change in the number of years with zero flow events})$$

$$\text{Zero Events/Year} = \frac{(\text{Natural no. of zero events/year}) - (\text{Current No. of Zero Events/year})}{(\text{Natural No. of Zero Events / year})} \times 100$$

$$(\text{where Zero Events/year} = \text{Percentage change in the number of zero events per year})$$

$$\text{Ave Duration of Zero Events} = \frac{(\text{Natural Ave Duration of zero events}) - (\text{Current Ave Duration of Zero Events})}{(\text{Natural Ave Duration of Zero Events})} \times 100$$

$$(\text{where Ave Duration of Zero Events} = \text{Percentage change in the Average duration of Zero flow events})$$

Low flow (baseflow) component metrics (both low and high flow season)

$$\text{80th percentile flow} = \frac{(\text{Natural 80th percentile flow}) - (\text{Current 80th percentile flow})}{(\text{Natural 80th percentile flow})} \times 100$$

$$(\text{where 80th percentile flow} = \text{Percentage change in the size of the } 80^{\text{th}} \text{ percentile flow})$$

Fresh event (spate) component metrics (both low and high flow season)

$$\text{Fresh Years} = \frac{(\text{Natural No. of Fresh years}) - (\text{Current No. of Fresh years})}{(\text{Natural No. of Fresh years})} \times 100$$

$$(\text{where Fresh years} = \text{Percentage change in the number of years with freshes})$$

$$\text{Fresh Events/year} = \frac{(\text{Natural No. of Fresh events/year}) - (\text{Current No. Fresh events/year})}{(\text{Natural No. of Fresh events/year})} \times 100$$

$$(\text{where Fresh events/year} = \text{Percentage change in the number of freshes/year})$$

$$\text{Ave duration of fresh events} = \frac{(\text{Natural Ave duration of fresh events}) - (\text{Current Ave duration of fresh events})}{(\text{Natural Ave duration of fresh events})} \times 100$$

$$(\text{where Ave duration of fresh events} = \text{Percentage change in the average duration of freshes})$$

Bank full to overbank flow events component metrics (all year)

$$\text{X year ARI flow} = \frac{(\text{Natural X year ARI flow}) - (\text{Current X year ARI flow})}{(\text{Natural X year ARI flow})} \times 100$$

$$(\text{where X year ARI flow Percentage change in the 1.5 year ARI flow, 2.5 year ARI flow, 5 year ARI flow})$$

Note 1. ARI or Average Reoccurrence Interval is a measure of probability of a peak flow. For example, the 2.5 year ARI flow is expected to be reached or exceeded in a 2.5 year period **on average**. It may be helpful to consider 2.5 year ARI flow as the flow that will be reached or exceeded 40 times in a 100 year period at probably irregular intervals.

In contrast, the first version of the hydrologic stress was a ratio of the peak daily demand and the 80th percentile flow. This earlier indicator was only able to consider the pressure on the low flow range, not higher flow ranges. Additionally, because it is not modelled it is not able to take the effect of Water Sharing Plan rules into account.

The metrics are calculated from modelled flow sequences generated at points in the river system, such as at the downstream end of unregulated water sources and at gauging stations along regulated river water sources. Interpolation between these points was used to estimate the metrics for each of the six flow ranges in reaches along the river system. Calculated metrics locations were identified on the Geofabric (BOM 2022) network streamlines. The interpolation used the network functionality of the Geofabric to identify where tributaries enter the river system and where licences extract water. This allows the interpolation to consider:

- tributary inflows, which improve the flow regime, and
- licenced entitlement, where water is taken altering the flow regime.

The first version used a digital elevation model to distribute the 80th percentile and the peak daily demands. The use of the Geofabric in this version improved speed and efficiency in producing the distributed layer. It also generated the metrics on a standard spatial framework that improves accessibility of the data, and compatibility of the data with other spatial datasets that use the Geofabric as the spatial framework.

Each river reach was allocated to a RCI reporting catchment by identifying the reporting catchment that the reach streamline's mid-point fell within. The scoring of the RCI reporting catchment was calculated by weighting each reach metric by the upstream drainage area of that reach and summing all the resulting products, then dividing by the sum of upstream drainage areas. The weighting influences the score proportionally to a stream's catchment. The biggest effect of this is in the most downstream RCI reporting catchments where a large river flows through. In these cases, the weighting highlights the metrics on the large rivers in comparison to the small tributaries, many just first and second order streams.

The metrics for RCI reporting catchment were converted into one of five ratings: very poor, poor, moderate, good, or very good. Because the metrics indicated if flow alteration had increased, by being positive, or decreased, by being negative, each of the ratings had a negative and positive range. Ranges are indicated in Table 5.

Table 5 Categories used for the derivation of the Hydrologic Stress index layer.

Hydrologic Stress score	Hydrologic Stress category
metric > 0.8, or metric < -0.8	Very Poor
0.6 > metric < 0.8, or-0.8 > metric < -0.6	Poor
0.4 > metric < 0.6, or -0.6 > metric < -0.4	Moderate
0.2 > metric < 0.4, or-0.4 > metric < -0.2	Good
0.2 > metric < -0.2	Very Good

Option 2 Distributed Hydrologic Stress

In areas where Risk Assessments have not yet been conducted (see Figure 9), the key ecosystem function metrics (option 1) are not available and alternative metrics have been generated from previous, less detailed, assessments of risk. In the case of option 2, the Hydrologic Stress derived for the first version of the RCI (Healey et al. 2012), where for river systems over 100 km^2 in area a Distributed Hydrologic Stress was derived. This index is the ratio of the peak daily demand and the 80th percentile flow (NOW 2011). This index is scored in the same way as the key ecosystem function metrics with reaches being allocated to RCI reporting catchments and weighting based on upstream catchment area (see above).

Option 3 Water Sharing Plan Hydrologic Stress

Where neither of the other options are available (Figure 9) the macro approach Water Sharing Plan Hydrologic Stress rating is used (NOW 2011). This metric is also the ratio of the peak daily demand and the 80th percentile flow but is not distributed along the rivers. Instead, it is assigned based on the water source that the River Condition Index catchment falls within.

Hydrologic Stress Index outputs

The state-wide map of the Hydrologic Stress index is shown in Figure 10.

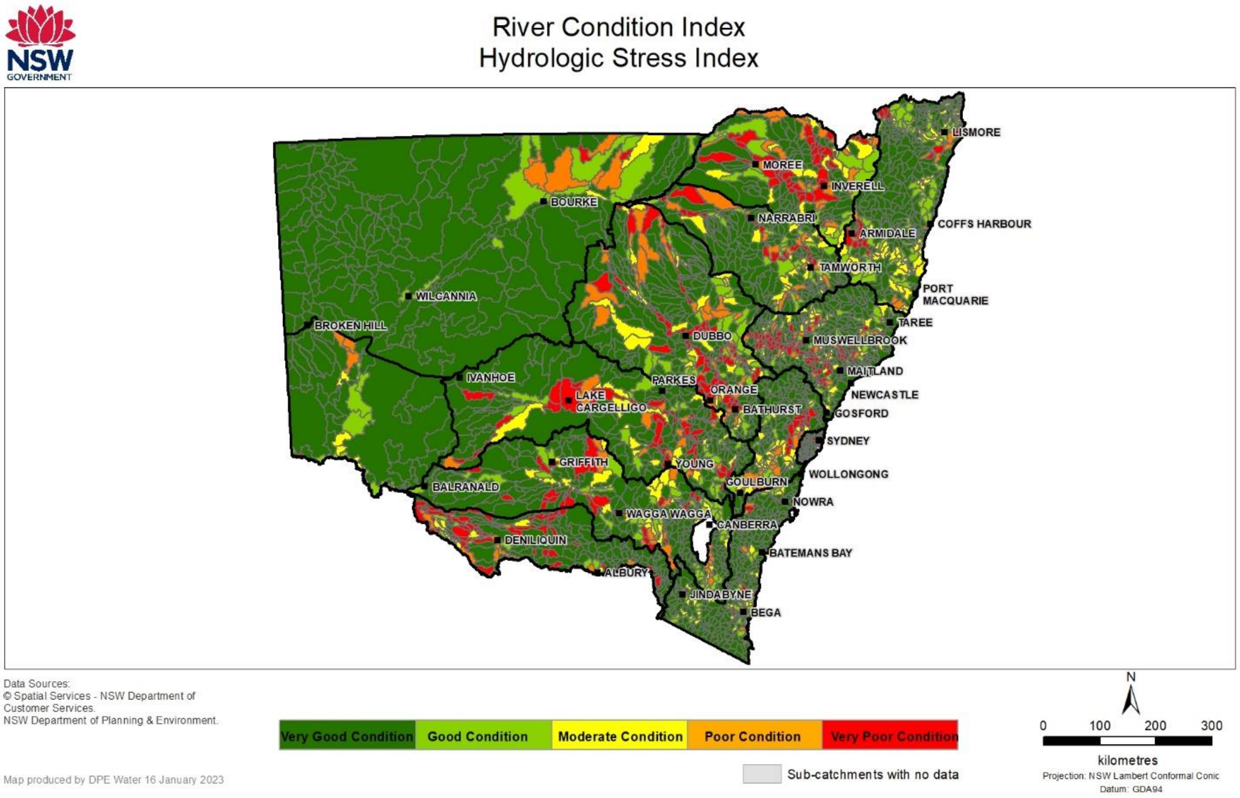
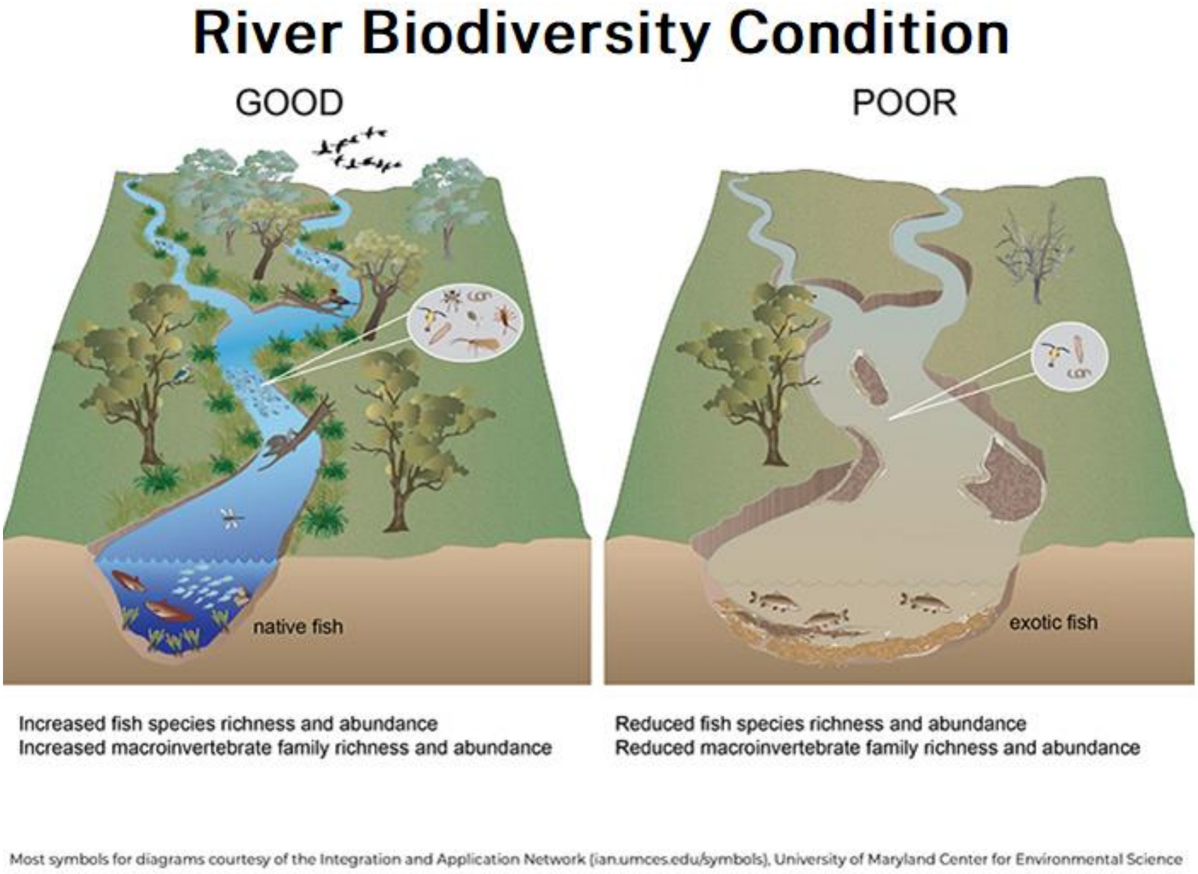


Figure 10 Hydrologic Stress Index.

River Biodiversity Condition Index

The FARWH (Norris et al. 2007a) identifies the importance of including an aquatic biota index to infer river condition to identify the influence of the physical environment on the biological community. Aquatic biota has been widely used as a sub-index 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 aquatic biotic indicators (e.g. fish, macroinvertebrates, frogs, reptiles, aquatic vegetation) are appropriate to incorporate into river condition assessments, with reduced river condition associated with loss of taxa (Norris and Thoms 1999). Aquatic species rely on healthy rivers and diverse habitats for survival and reproduction. These biotic indicators can help assess river condition. Reduced river condition is associated with loss of species (Figure 11).



Most symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science

Figure 11 Good versus poor river biodiversity condition.

River Biodiversity Condition Index Methods

In the original River Biodiversity Condition Index analysis (Healey et al. 2012), two datasets were used depending on available data in each study area:

1. Aquatic Biodiversity Forecaster Tool analysis (area weighted average of the Biodiversity Condition score) (Turak et al. 2011)
2. The Sustainable Rivers Audit macroinvertebrate and fish condition data (average of the two scores) (Davies et al. 2008).

These datasets have not been continued since version one of the RCI. In the updated analysis for River Biodiversity Condition Index, one consistent state-wide dataset is used instead, the Fish Community Status data obtained from DPI Fisheries (DPI 2016). This dataset was developed using a suite of indicator metrics developed for the Sustainable Rivers Audit process and later adapted for the NSW Monitoring Evaluation and Reporting Riverine Ecosystems theme. The metrics are aggerated to form three fish condition indicators of Expectedness, Nativeness and Recruitment and are used to produce an overall Fish Condition Index (DPI 2016). This dataset contains fish assemblage data collected from 646 sampling sites across NSW between 2009 and 2012 (DPI 2016).

Fish Community Status is a polyline spatial layer categorising fish community condition as Very Good, Good, Moderate, Poor or Very Poor (DPI 2016).

For the analysis of River Biodiversity Condition Index the categories are converted into scores (1 (very good), 0.75, 0.5, 0.25, 0 (very poor) respectively) as a reach scale index. The Fish Status reach scale index is converted into a sub-catchment scale habitat index by calculating the length-weighted mean of river reaches within a sub-catchment. Reach-scale indices are length-weighted so that longer reaches exert proportionally greater influence on the sub-catchment index than smaller reaches.

$$\mathbf{RBCI_b} = \frac{(\mathbf{FSI_{r1}} * \mathbf{L_{r1}}) + (\mathbf{FSI_{r2}} * \mathbf{L_{r2}}) \ldots}{\sum \mathbf{L_{r1}} + \mathbf{L_{r2}} \ldots}$$

(where $\mathbf{RBCI_b}$ = River Biodiversity Condition Index, $\mathbf{FSI_{r1}}$ = Fish Status index for reach 1 within the sub-catchment, $\mathbf{L_{r1}}$ = length of reach 1)

This results in an overall condition score ranging between 0 and 1, with higher scores representing better condition.

The range of final RBCI scores was split into five classes as follows:

> 0.8 – 1 = Very Good

> 0.6 – 0.8 = Good

> 0.4 – 0.6 = Moderate

> 0.2 – 0.4 = Poor

≤ 0.2 = Very Poor .

The state-wide River Biodiversity Condition Index is shown in Figure 12. Areas where there was insufficient data to calculate a score are shown in grey.

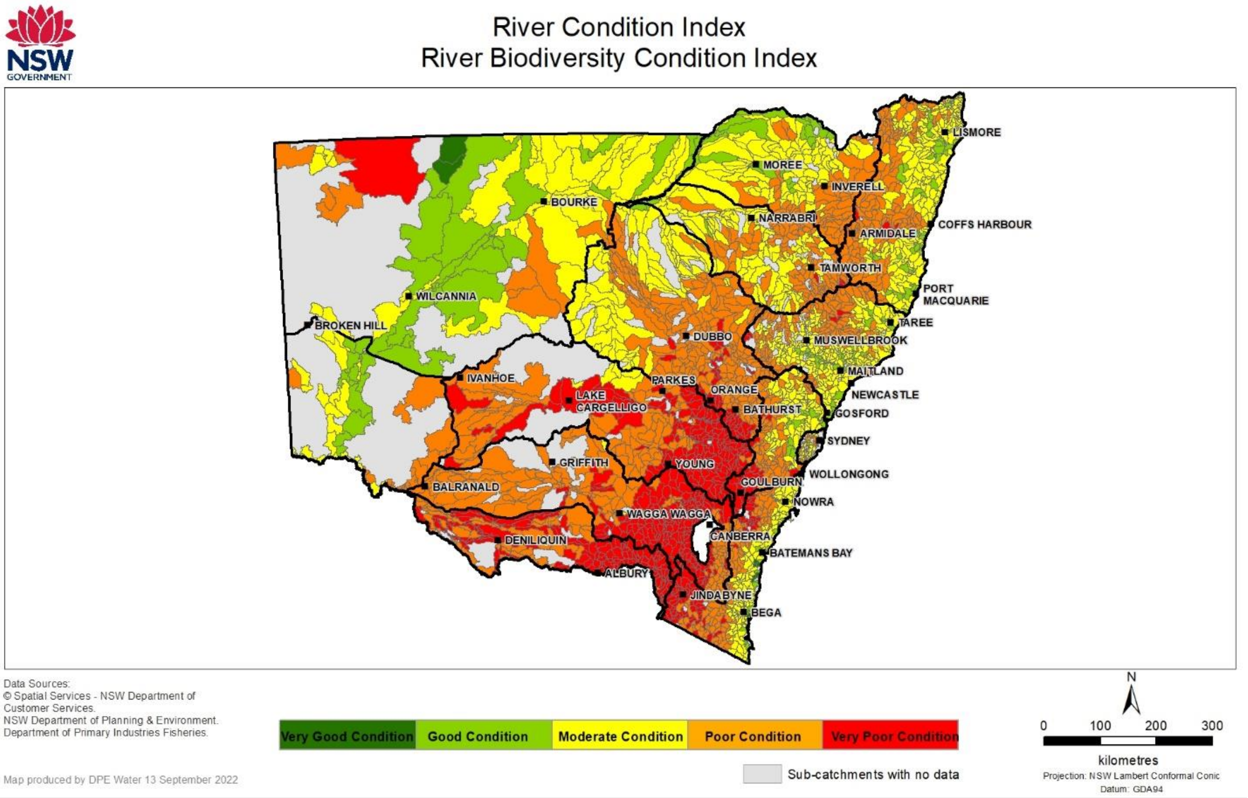


Figure 12 River Biodiversity Condition Index.

Water Quality Index

The FARWH (Norris et al. 2007a) recognises the importance of including a Water Quality Index to report on river condition and ecosystem health. The drivers for water quality are numerous and varied including land use, soil type, geology, altitude, climatic conditions, vegetation type and cover, diffuse and point source pollution sources and river regulation (Figure 13). In addition, there are chemical and biological processes that occur at a site that also affect its quality. Water quality can change from week to week. A Water Quality Index considers the effects of long-term changes in water quality characteristics on biota, such as changes in suspended sediment and nutrient concentrations or loads, and the effects of changes in salinity or toxicant levels (Norris et al 2007a). A water quality index has been included in this edition of the RCI but had not been developed for the previous version.

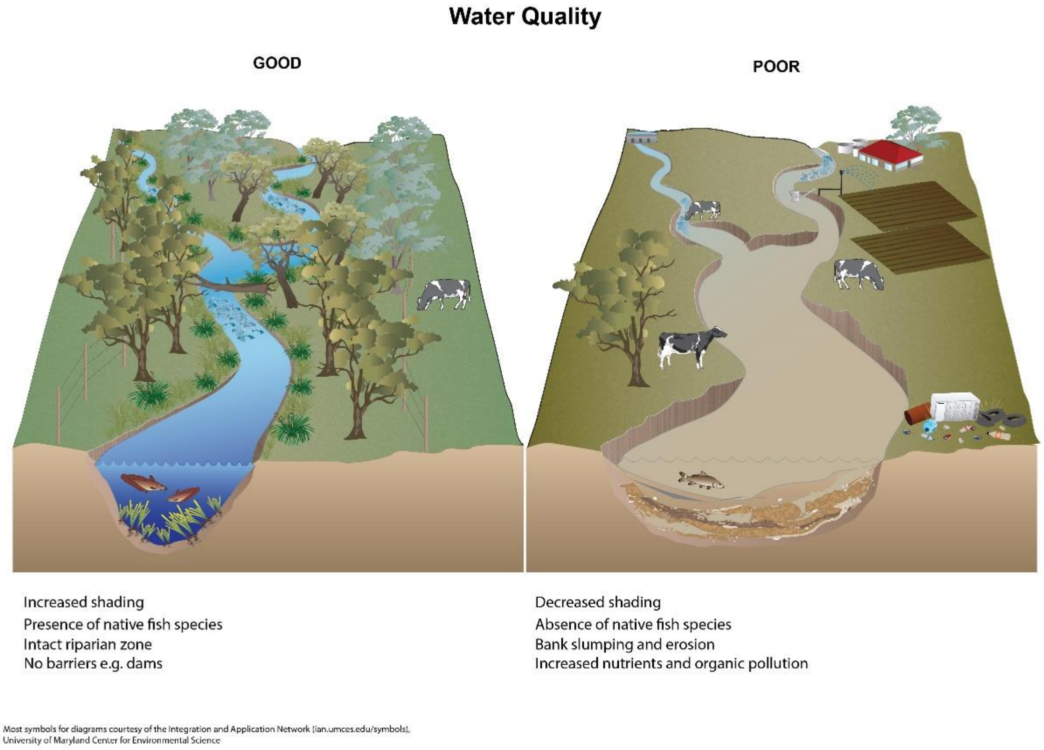


Figure 13 Good versus poor water quality.

Water Quality targets method

The National Water Quality Management Strategy (NWQMS) sets out the key principles to consider when managing water quality. Regionally specific water quality targets, matched to regional conditions, have been developed for New South Wales inland and coastal catchments using the reference condition approach (ANZG 2018). These regional targets have been used to assess the water quality results and calculate the Water Quality Index score.

Regionally specific targets apply across a larger spatial scale such as a drainage basin or climatic zone. These targets are more generic in nature and are suitable for application at any monitoring location within a defined area. Discrete regions can be defined as areas of similar drivers for water quality (land use, geology, topography, rainfall), similar water quality conditions, biological or ecological features. To develop water quality targets for the RCI, altitude boundaries have been proposed that align with the zone boundaries identified in the Sustainable Rivers Audit (Davies et al 2008) and selected for the Basin Plan application zones (Tiller and Newall 2010). The altitude boundaries are:

- Montane - greater than 700 m
- Uplands - between 200 and 700 m and
- Lowlands - less than 200 m inland and less than 150 m on the coast.

Ideally, targets would be derived from data collected before significant human disturbance or from reference or sites of least disturbed condition to quantify the natural water quality. Water quality data from a reference site are used to provide a suitable baseline or benchmark for comparison against data from an assessment site in a similar aquatic ecosystem or geographic unit. This benchmark is a value for a contaminant that, if not exceeded, indicates a low risk that the water quality and associated aquatic ecosystems will be unacceptably impacted (van Dam et al. 2019). Targets based on reference sites also recognise that the aquatic ecosystem has evolved in the presence of any naturally elevated concentrations of contaminants.

For modified ecosystems (like the majority of rivers of NSW) often the ‘best available’ reference site will be the only option. In Australia and New Zealand, the 80th percentile (and 20th percentile for lower limits of variables such as dissolved oxygen and pH) of the reference data is recommended for slightly to moderately disturbed systems (ANZG 2018). Available data from a more disturbed site, which is likely to have a broader range of contaminant concentrations than a site in reference condition, can be used to calculate the targets. This can be achieved by adjusting the percentiles used to derive the target, such as using the 25th and 75th percentiles.

Water Quality Index method

To calculate the Water Quality Index, a method based on a modified Canadian Council of Ministers of the Environment water quality index (Lumb et al. 2006) was identified, that incorporated both the frequency and exceedance of water quality targets. The method scales data from multiple sampling occasions and combines multiple parameter results to provide an overall single score for a monitoring site, with higher scores representing better overall water quality. The approach included nitrogen, phosphorus, turbidity, dissolved oxygen, pH and electrical conductivity results.

The indices representing the various measures of water quality should be equivalent (Norris et al. 2007a). For example, salinity could be an issue in one catchment and nutrients in another. For this reason, there has been no weighting of parameters. To account for temporal variability in water quality, a five-year data set (July 2016 to June 2021) has been used to calculate the Water Quality Index.

The Water Quality Index score is based on the *Frequency* and the *Amplitude* of exceedance of regional water quality targets. The index is calculated as:

$$\mathbf{WaQI} = \left(\frac{\sqrt{\mathbf{F1^2 + F2^2}}}{\mathbf{1.41421}}\right)$$

$$\textbf{Where WaQI} = \textbf{Water Quality Index score}$$

Where F1 (*Frequency*) is the number of failed results per total number of tests:

$$\mathbf{F1} = \left(\frac{\mathbf{Number\ of\ failed\ tests}}{\mathbf{Total\ number\ of\ tests}}\right)$$

And where F2 (*Amplitude*) is the amount a water quality result exceeds the target by. To calculate F2 requires three steps. Firstly, the number of times an individual result is greater than (or less than) the target, or *Excursion.*

Where the test value should not exceed the target or test objective (turbidity, nitrogen, phosphorus, electrical conductivity and upper limits for pH and dissolved oxygen), use:

$$\mathbf{Excursion} = \left(\frac{\mathbf{Failed\ test\ value\ i}}{\mathbf{Test\ objective}}\right) - \mathbf{1}$$

OR, when the test value should not fall below the targets (lower limit for pH and dissolved oxygen), use:

$$\mathbf{Excursion} = \left(\frac{\mathbf{Test\ objective}}{\mathbf{Failed\ test\ value\ i}}\right) - \mathbf{1}$$

The total amount the result does not comply with the target is calculated by summing the *Excursions* and dividing by the number of tests to give the *nse* (normalised sum of excursions):

$$\mathbf{nse} = \left(\frac{\sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{excursion\ i}}{\mathbf{number\ of\ tests}}\right)$$

The *nse* is then scaled to yield an F2 value between 0 and 100:

$$\mathbf{F2} = (\mathbf{nse} \div [\mathbf{0.01nse} + \mathbf{0.01}])$$

The final Water Quality Index output is a number between 0 and 1.0, where a score of 1.0 represents a site in reference condition. This value can be categorised according to the following to indicate the general water quality at a monitoring site. The assignment of Water Quality Index values to different categories is a subjective process which incorporates expert opinion and the public’s expectations of water quality. Rather than an even split in categories, as used in other layers for the RCI (i.e. 0.0-2.0, 2.0-4.0, 4.0-6.0, 6.0-8.0 and 8.0-1.0), the Water Quality Index category score range has been adjusted to be consistent with the high proportion of modified or disturbed catchments in NSW with a larger proportion of scores in the poor to very poor categories than good to very good (Table 6).

Table 6 Categories used for the derivation of the Water Quality index layer.

Water Quality Index Score	Water quality rating
0.0 - 0.29	Very Poor
0.3 - 0.59	Poor
0.6 - 0.79	Moderate
0.8 - 0.94	Good
0.95 - 1.0	Very Good

Converting point data to a sub-catchment score

To convert data from a monitoring point to an RCI sub-catchment score, the site index score is extrapolated upstream and downstream of the monitoring site until reaching a water quality zone boundary, a regulated river, major storage or another monitoring site.

Water quality data is reported using altitudinal zones within a given valley. Where there is only one monitoring site in an entire zone, the Water Quality Index score will be applied to all reaches in the zone. Where there are multiple monitoring sites in a zone, an average of site Water Quality Index scores will be applied to all reaches in that zone without a monitoring site.

In many cases the altitudinal zones are intersected by RCI sub-catchments. In this case the Water Quality Index score is multiplied by the percentage of river length of the RCI sub-catchment occupied. The products are then added to get an overall score for the RCI sub-catchment.

Rules developed for the extrapolation of point data to a catchment score are:

1. Site area of influence extends upstream and/or downstream until reaching a water quality zone boundary, a regulated river, major storage or another monitoring site – whichever comes first.
2. The site's area of influence extends up the main trunk of the river, as well as all the upstream tributaries unless there is another site on a tributary. In that case, the tributary's site has an area of influence that extends downstream until it reaches the main river, and upstream along the main trunk of the tributary as well as it's upstream tributaries. For regulated rivers the area of influence does not extend up into unregulated tributaries, only to the storage.
3. Where there are no sites on a tributary, the average Water Quality Index score of all other monitoring sites in that water quality zone is applied
4. Where an RCI sub-catchment extends across water quality zone boundaries, the Water Quality Index score from the two zones will be weighted using the percentage of river length in each zone.

A length weighted average of the river reach water quality scores is then applied to generate a Water Quality Index score between 0 and 1 for each sub-catchment:

$$\mathbf{WQI_b} = \frac{(\mathbf{WQI_{r1}} * \mathbf{L_{r1}}) + (\mathbf{WQI_{r2}} * \mathbf{L_{r2}}) \ldots}{\sum \mathbf{L_{r1}} + \mathbf{L_{r2}} \ldots}$$

(where $\mathbf{WQI_b}$ = water quality index, $\mathbf{WQI_{r1}}$ = water quality index for reach 1 within the basin, $\mathbf{L_{r1}}$ = length of reach 1)

This results in an overall condition score ranging between 0 and 1, with higher scores representing better condition.

The range of final water quality index scores was split into five classes as follows:

0.95 – 1 = Very Good

0.8 - 0.94 = Good

0.6 - 0.79 = Moderate

0.3 - 0.59 = Poor

0 – 0.29 = Very Poor.

The state-wide Water Quality Condition Index is shown in Figure 14. Areas where there was insufficient data to calculate a score are shown in grey.

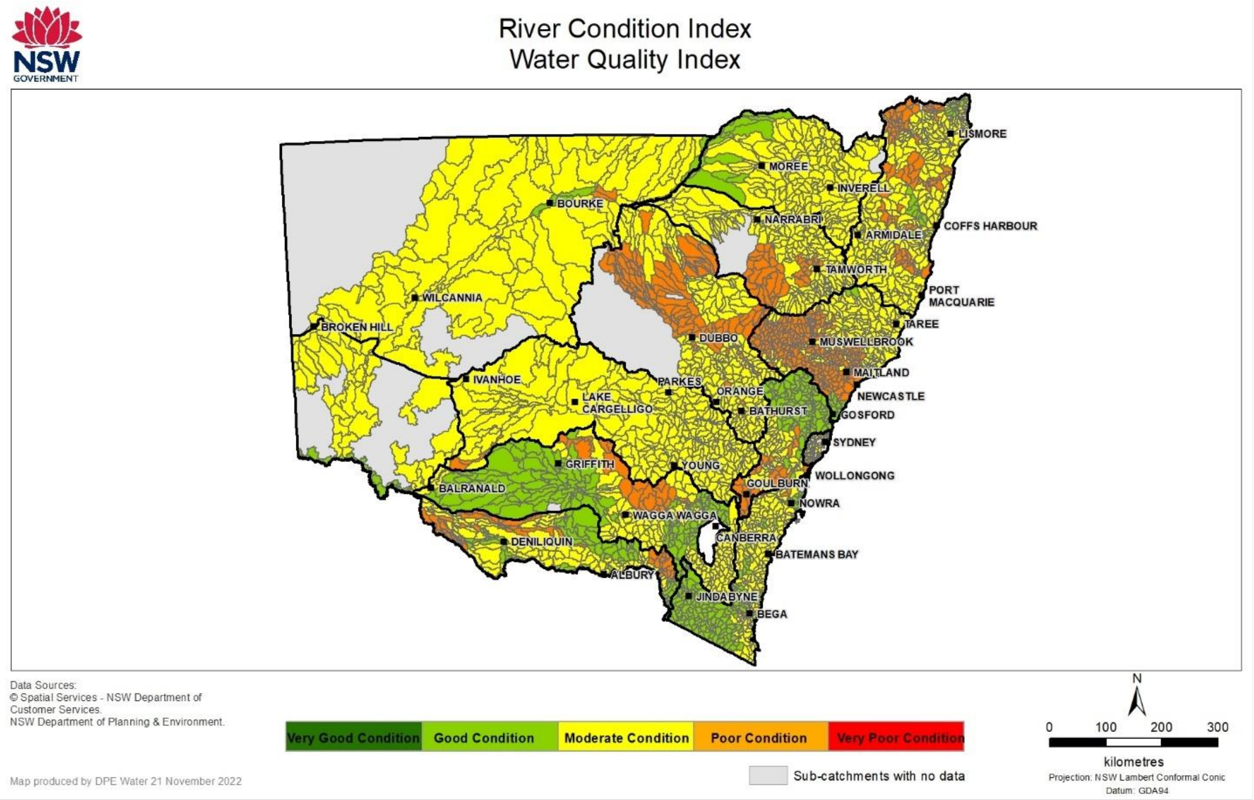
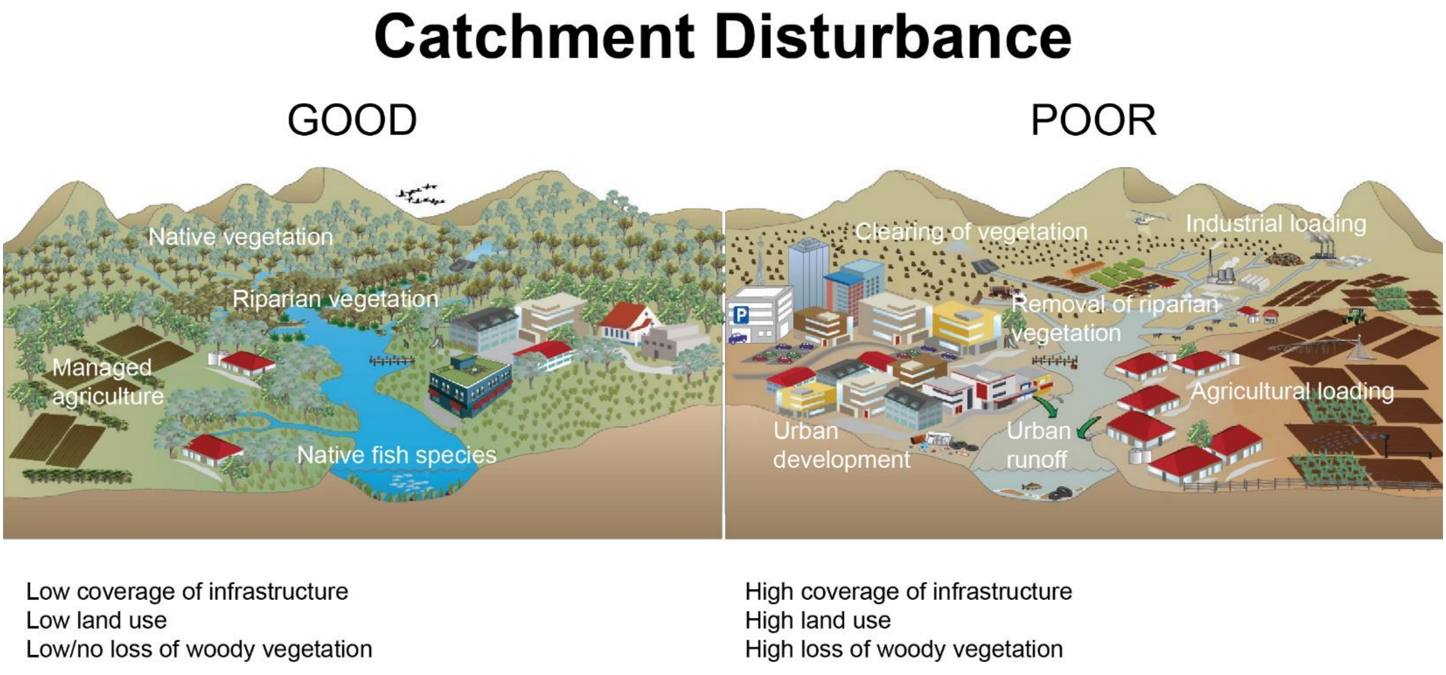


Figure 14 Water Quality Index

Catchment Disturbance Index

Catchment disturbance has a very important influence on river condition as recognised in the FARWH (Norris et al. 2007b). This index provides a measure of anthropogenic changes within a catchment area that have the potential to impact on river condition and biota (Figure 15).



Most symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science

Figure 15 Good versus poor catchment disturbance

The Catchment Disturbance Index incorporates Land Use data, Loss of Woody Vegetation (Land Cover Change), and Infrastructure data in order to characterise changes in the land surface within the catchment and hence represent catchment disturbance (Figure 16).

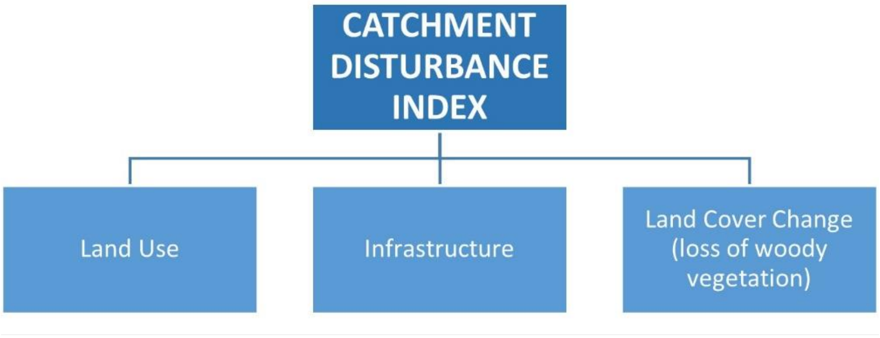


Figure 16 Inputs for the Catchment Disturbance Index.

Catchment Disturbance Index Methods

The process and formulas used to calculate the Catchment Disturbance Index have remained the same as the version one analysis (Healey et al 2012). The most recent spatial layers of land use, infrastructure and loss of woody vegetation have been used to update the index. The technique was adapted from Norris et al. (2007b).

Land use

The NSW Land use 2017 v1.2 has been used. The data (Table 7) was aggregated into categories that reflected the land use effects on aquatic biota and each category received a weighting to account for the different impacts of the various land use categories. The background to the weightings is provided in Norris et al. (2007a).

Table 7 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	
Cropping not included in intensive and irrigated agriculture	Cropping	0.48
Production forests, farm forestry, plantations	Production forestry	0.2
	Irrigated plantation forestry	
	Plantation 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	

The Land Use Index was assessed by the extent of each land use category within the sub-catchment adjusted by the associated weights, in accordance with Equation 8 of Norris et al. (2007b):

$$\mathbf{LU = 1 - \left((fLUI_1 * w_1) + (fLUI_2 * w_2) + (fLUI_3 * w_3) + (fLUI_4 * w_4) \ldots\right)}$$

(where LU = Land Use index, $\mathbf{fLUI_1}$ = fraction of the catchment of land use category 1, $\mathbf{w_1}$ = the weight for land use category 1, etc)

Infrastructure

The most recent data on the location of railways, pipelines, electricity transmission lines and roads were downloaded from GIS101 (a Department of Planning and Environment - Water spatial database) to assess the fraction of each Infrastructure category within each sub-catchment. The infrastructure polylines were buffered to represent the land impacted by that type of infrastructure (corridors/easements etc.) The buffer distances to determine corridors and easements for infrastructure were updated to reflect a more detailed analysis in the current study, as opposed to the broader definition of impacted land that was used in the original analysis. For example, road widths and transmission line buffer zones were identified and applied appropriately (Transgrid, 2021, 2022, AusNet Services 2022). The spatial resolution was also refined in the updated analysis. Weightings adopted for this attribute (Table 8) are described in detail in the section on Integration and aggregation in Norris et al. (2007a).

Table 8 Weightings used in the derivation of the infrastructure index layer.

Category	Infrastructure 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	0.00

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 from Norris et al. (2007a).

$$\mathbf{I = 1 - \left((f_{i1} * w_1) + (f_{i2} * w_2) + (f_{i3} * w_3) + (f_{i4} * w_4)\right)}$$

(where I = Infrastructure Index, $\mathbf{f_{i1}}$ = fraction of the catchment of infrastructure category 1, $\mathbf{w_1}$ = the weight for infrastructure category 1, etc)

Land Cover Change (State-wide Land cover and Tree Study method)

This index provides an assessment of the loss of woody vegetation based on the Statewide Land Cover and Tree Study method applied by the NSW Department of Planning and Environment - Environment and Heritage Group. Data from 2017, 2018 and 2019 was used to update the loss of woody vegetation data in this analysis.

The total area of 'Land Cover Change' for each sub-catchment is calculated. A weighting of 0.68 is 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 in Norris et al (2007a).

The final Land Cover Change index score for each sub-catchment is calculated in accordance with Equation 9 in Norris et al. (2007a).

$$\mathbf{LCC = 1 - \left(\frac{Area\ cleared * 0.68}{Total\ Area}\right)}$$

$$\textbf{(where LCC = Land Cover Change)}$$

Calculation of Catchment Disturbance Index

The three subindices (infrastructure, land use, and land cover change) are integrated into a single catchment disturbance index for each sub-catchment. No weighting is applied when the three measures are 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 is calculated in accordance with Equation 10 from Norris et al. (2007a) which results in a score ranging from 0 to 1, with 1 representing better condition:

$$\mathbf{CDI = Inf + LU + LCC - 2}$$

$$\textbf{(where CDI = Catchment Disturbance Index, Inf = Infrastructure index, LU = Land Use index, LCC = Land Cover Change)}$$

The range of final Catchment Disturbance Index scores was split into five classes as follows:

> 0.8 – 1 = Very Good

> 0.6 – 0.8 = Good

> 0.4 – 0.6 = Moderate

> 0.2 – 0.4 = Poor

≤0.2 = Very Poor

The state-wide map of this index is shown in Figure 17.

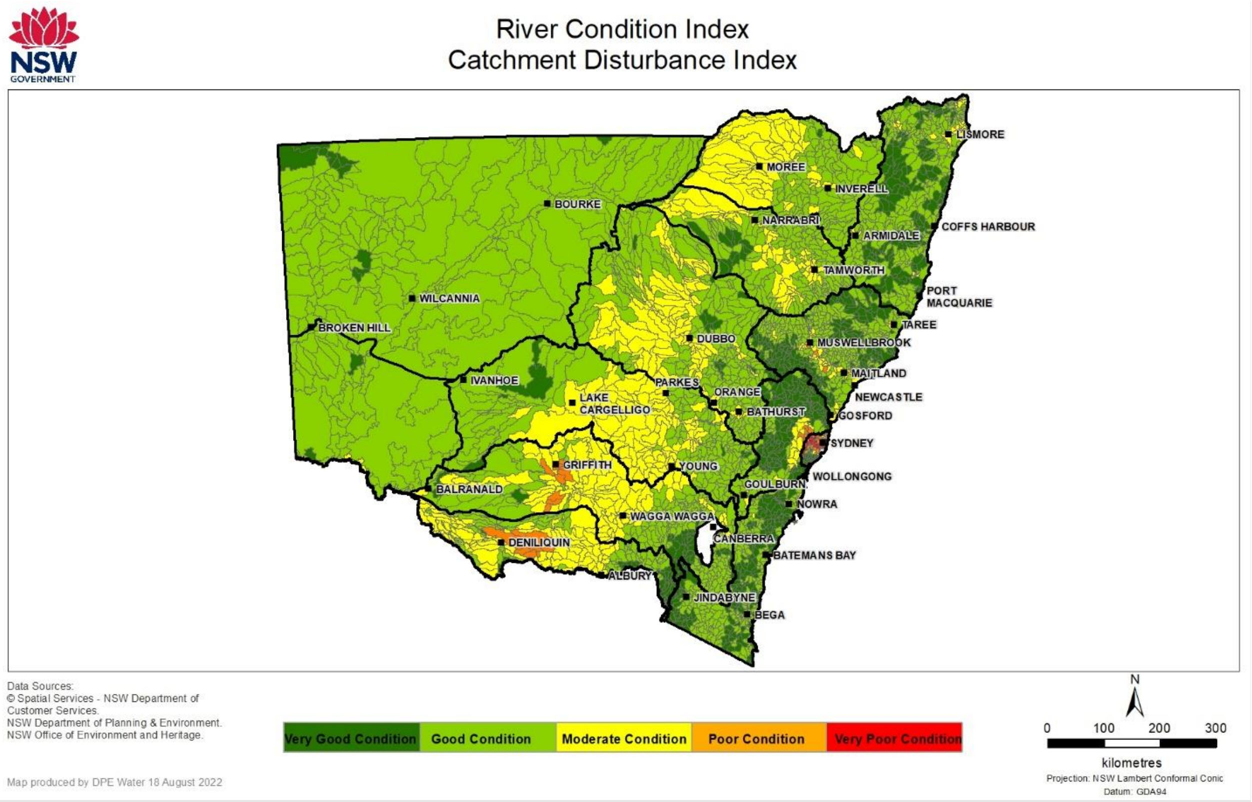


Figure 17 Catchment Disturbance Index.

River Condition Index

The RCI follows the method to integrate river condition metrics into a unified score that was developed by Norris et al. (2007a). In this method, the river condition sub-indices are standardised prior to being integrated into the RCI. This approach has been used in other Australian studies (eg. Young et al. 2004) with the outcome enabling sub-indices to be represented on a dimensionless 0 to 1 scale where 1 represents the best or reference condition.

All six input layers were combined into an overall RCI score and category for each sub-catchment using a standardised Euclidean distance formula. The standardised Euclidean distance formula was chosen in accordance with Table 3 in Norris et al. (2007a).

The formula used is:

$$\mathbf{RCI} = \mathbf{1} - \left(\frac{\sqrt{(\mathbf{1}-\mathbf{RVC})^2 + (\mathbf{1}-\mathbf{RSGC})^2 + (\mathbf{1}-\mathbf{HS})^2 + (\mathbf{1}-\mathbf{RBCI})^2 + (\mathbf{1}-\mathbf{WQI})^2 + (\mathbf{1}-\mathbf{CDI})^2}}{\sqrt{\mathbf{6}}} \right)$$

Where RVC = Riparian Vegetation Condition score, RSGC = River Styles Geomorphic Condition score, HS = Hydrologic Stress score, RBCI = River Biodiversity Condition Index score, WQI = Water Quality Index score and CDI = Catchment Disturbance Index Score.

Application of the method results in a score (range 0 – 1) for all sub-catchments with a higher score applying to sub-catchments in better condition. The range of final RCI scores was split into five classes as follows:

> 0.8 – 1 = Very Good

> 0.6 – 0.8 = Good

> 0.4 – 0.6 = Moderate

> 0.2 – 0.4 = Poor

≤ 0.2 = Very Poor

Any sub-catchments that did not have final metric scores for all 6 input layers due to lack of data (e.g., River Biodiversity Component Index scores) had their final RCI score calculated using only the inputs available. The RCI equation was adjusted to suit the number of input scores that were available. A minimum of four input scores was required to calculate the final score. For example, sub-catchments where River Biodiversity Condition Index scores were not available used the equation:

$$\mathbf{RCI{=}1{-}}\left(\frac{\sqrt{\mathbf{(1{-}RVC)^2{+}(1{-}RSGC)^2{+}(1{-}HS)^2{+}(1{-}WQI)^2{+}(1{-}CDI)^2}}}{\sqrt{\mathbf{5}}} \right)$$

The state-wide map of the RCI is shown in Figure 18. Areas where an overall RCI was unavailable were areas with less than 4 index components available.

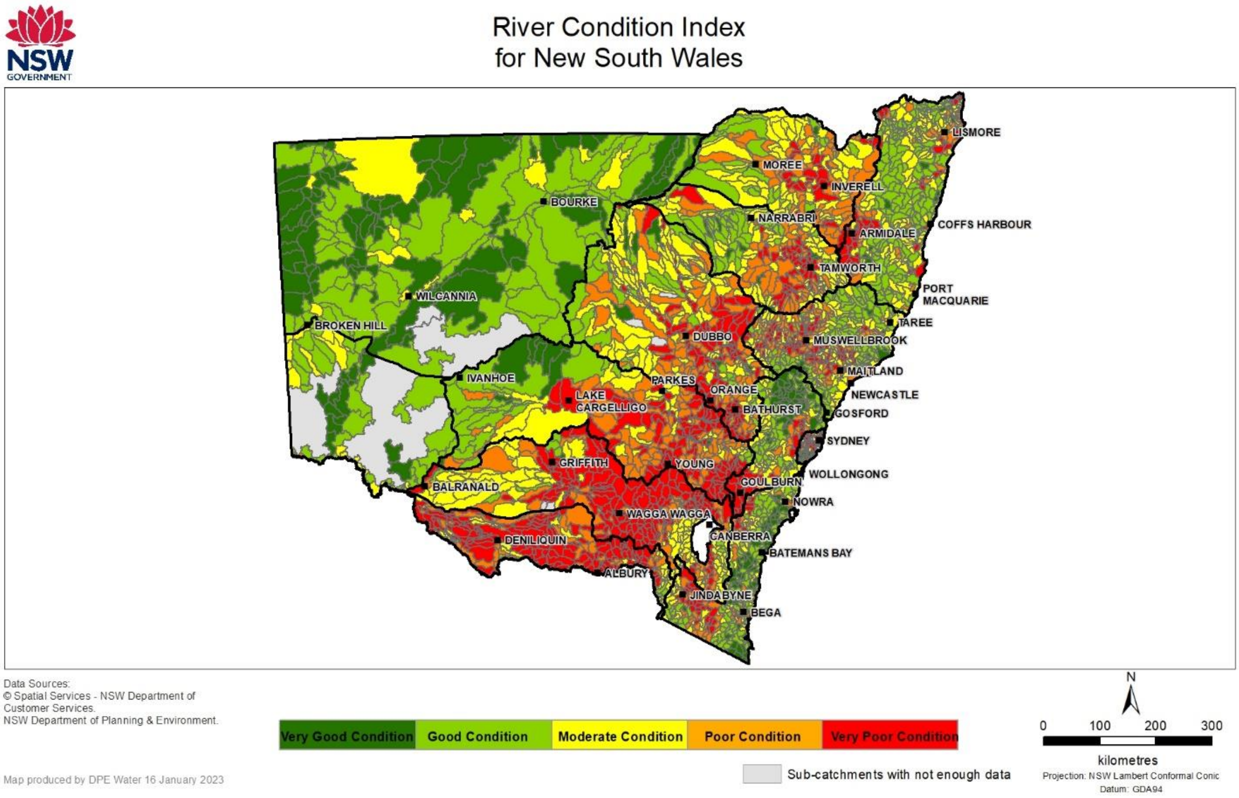


Figure 18 River Condition Index.

Assumptions and Limitations

This update to the RCI has several assumptions and data limitations that should be considered when utilising the information. Further development of the index as improved data becomes available will be necessary to continually improve the value, accuracy and use of the RCI. The following points should be considered.

1. The lack of state-wide and fit-for-purpose data, collected at the appropriate scale, to enable a high level of confidence in the outputs is a limitation of the RCI. The development of the RCI was undertaken utilising existing, available datasets. State-wide datasets were used where possible to enable a consistent measure across all catchment areas. Further investment and improvement of data sets (the biodiversity index in particular) will improve the RCI product.
2. The RCI represents average conditions (dependent on the age of the data components) and may not accurately show river condition changes associated with flow changes (including extraction) over seasonal and annual scales. The sensitivity of the RCI to variability will need to be tested and validated. In particular, the ability to identify changes that result from water resource management.
3. The RCI does not have the capacity to include the influence of extreme events (droughts, fires, floods) on river condition due to the nature of the data components and resourcing to acquire spatial data at a state-wide scale. For example, the Water Quality Index is calculated from a five-year average and hence extreme events will not be identified in the overall condition.
4. The hydrologic stress, or level of alteration, index is based on models of full development of current water license entitlements at specific points in the river systems. The hydrologic metrics generated at these points have been interpolated to estimate the alteration along all other reaches of the rivers. The interpolated estimates are not the same quality as the modelled metrics. Estimates may be improved in the future by: (a) increasing the number and improving the locations of modelled metrics, (b) as the interpolation considers licences, improvements can be made by linking to the licences river system layer, (c) introducing categories of licences, based on the flow ranges they impact, into interpolation algorithm, and refine the algorithm for each flow range to use this additional information, (d) generating modelled metrics for other scenarios to represent different levels of development and climate change.
5. The River Styles approach uses a qualitative approach to scoring geomorphic condition, which could make results subject to biases by operatives. Additionally, it is unlikely that River Styles data would be collected at a frequency of less than 10 years. As a result, some catchments may have older data than others, dependent on when the River Styles data was collected.
6. There are no regional benchmarks for riparian vegetation extent. It is assumed that a higher cover of native woody and native non woody species is better than a lower cover. This

assumption does not take into account different landscapes. For this reason, the development of riparian vegetation benchmarks for different landscapes would be beneficial to identify which areas have naturally higher cover of woody or non woody species.

7. There are limited Water Quality testing sites across NSW. Continued monitoring of water quality across more locations would lead to a more detailed analysis and would improve the accuracy of the Water Quality Index.
8. The Biodiversity Condition Index uses only fish data. Further investigation to include additional biotic data (such as macroinvertebrates, aquatic birds, water plants and frogs) needs to be undertaken. There are currently no funded, whole of State, river taxa or biodiversity condition assessment programs to provide ongoing data. The dataset contains fish assemblage data collected from 646 sampling sites across NSW between 2009 and 2012 (DPI 2016) and is not available for all streams and rivers across NSW. A more recent dataset as well as continued monitoring and additional sampling sites would improve the accuracy of the River Biodiversity Condition Index.
9. A sensitivity analysis to determine the influence of each index in the RCI input layers, particularly how weightings influence condition outcomes should be conducted to identify the scale at which change will be detected in the overall RCI.
10. No field assessment or validation of any of the RCI model outcomes have been undertaken to validate mapping outcomes. However, during development of the analysis, NSW Department of Planning and Environment staff review mapping products and local knowledge, and expert opinion gives a level of assessment that provides a check of the outcomes. Changes are made to the data if local knowledge indicates this is required.
11. 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.
12. An analysis comparing the first version of the RCI (2012) with the current version (2023) needs to be undertaken. By comparing results between the versions we can identify areas that have improved, regressed or maintained their overall condition. Ideally a statistical analysis would be beneficial to help understand results. Differences in datasets used needs to be considered.

References

Alluvium (2010). Key ecosystem functions and their environmental water requirements, Report by Alluvium for Murray-Darling Basin Authority, Canberra.

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

AusNet Services (2022), A guide to living with transmission line easements

Australian and New Zealand Governments (ANZG) (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra.

Arthington AH and Pusey BJ (2003). Flow restoration and protection in Australian Rivers. *River Research and Applications* **19** (5-6): 377-395.

BOM (2022) Australian Hydrological Geospatial Fabric (Geofabric)

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

Boulton AJ and Brock MA (1999). *Australian Freshwater Ecology: Processes and Management.* Gleneagles Publishing, Australia.

Brierley GJ and Fryirs KA (2005). *Geomorphology and River Management: Applications of the River Styles Framework.* Blackwell Publishing, Oxford, UK.

Bunn SE and Arthington AH (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* **30**: 492-507.

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 BC, Fryirs, KA and Brierley GJ (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

Dabovic J, Dobbs L, Byrne G, and Raine A (2019) A new approach to prioritising groundwater dependent vegetation communities to inform groundwater management in New South Wales, Australia. Australian Journal of Botany 67: 397-413.

Davies PE, Harris JH, Hillman, TJ and Walker KF (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 (Department of Environment and Climate Change) (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

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

DPE (Department of Planning and Environment) (2022a) NSW State Vegetation Type Map (version release number (C1.1.M1)

DPI (Department of Primary Industries) (2016). Fish communities and threatened species distributions of NSW. Second edition July 2016. NSW Department of Primary Industries.

Dudgeon D, Arthington AH, Gessner, MO, Kawabata Z, Knowler D, Leveque C, Naiman RJ, Prieur-Richard AH, Soto, D and Stiassny, ML. (2005). Freshwater biodiversity: importance, threats, status, and conservation challenges. *Biological Reviews* **18**: 163 – 182.

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.

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

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

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.

Ladson AR and White LJ (1999). *An Index of Stream Condition: Reference Manual.* Department of Natural Resources and Environment, Melbourne.

Lindenmayer DB and Fischer J (2006) Habitat Fragmentation and Landscape Change: An ecological and conservation synthesis, CSIRO Publishing, Melbourne.

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

Lumb A, Halliwell D, and Sharma T (2006). Application of CCME Water Quality Index to monitor water quality: A case study of the Mackenzie River Basin, Canada. Environmental Monitoring and Assessment 113: 411-429.

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

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.

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

NOW (NSW Office of Water) (2011) *Macro water sharing plans - the approach for unregulated rivers A report to assist community consultation Second edition*. NSW Office of Water, Sydney.

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

Norris RH and Thoms MC (1999). What is river health? *Freshwater Biology*. **41**: 197 – 209.

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.

Poff NL, Richter B, Arthington AH, Bunn SE, Naiman RJ, Kendy E, Acreman M, Apse C, Bledsoe BP, Freeman M, Henriksen J, Jacobson RB, Kennen J, Merritt DM, O'Keeffe J, Olden JD, Rogers K, Tharme RE and Warner A. (2010). The Ecological Limits of Hydrologic Alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology* **55**:147-170.

Reeves GH, Hohler DB; Larsen DP, Busch DE, Kratz K, Reynolds K, Stein KF, Atzet T, Hays P and 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.

Riis T, Kelly-Quinn M, Aguia FC, Manolaki P, Bruno D, Bejarano MD, Clerici N, Fernandes MR, Franco JC, Pettit N, Portela AP, Tammeorg O, Tammeorg P, Rodríguez-González PM and Dufour S (2020). Global Overview of Ecosystem Services Provided by Riparian Vegetation. BioScience 70: 501–514.

Spencer C, Robertson AI 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.

Thomson JR, Taylor MP, Fryirs KA and Brierley GJ (2001). A geomorphic framework for river characterization and habitat assessment. *Aquatic Conservation: Marine and Freshwater Ecosystems* **11**: 373–389.

Tiller D and Newall P (2010). Water quality summaries and proposed water quality targets for the protection of aquatic ecosystems for the Murray–Darling Basin. Report prepared for the Murray Darling Basin Authority.

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

Transgrid (2021). Study Corridor Identification Report. Central-West Orana Renewable Energy Zone Transmission. March 2021, Transgrid, Sydney

Transgrid (2022). Easement Guidelines Living and working with electricity transmission lines

Turak E, Ferrier S, Barrett T, Mesley E and Drielsma, M (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 (2002). *Biological Assessments and Criteria: crucial components of water quality programs.* United States Environmental Protection Agency. EPA 8222-F-02-006

van Dam RA, Hogan AC, Harford AJ and Humphrey CL. (2019). How specific is site-specific? A review and guidance for selecting and evaluating approaches for deriving local water quality benchmarks. *Integrated Environmental Assessment and Management* 15:5; 683-702.

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bun, SE, Sullivan CA, Liermann CR, and Davies PM (2010). *Global threats to human water security and river biodiversity Nature*, **467:** (7315), 555-561

Werren GL and Arthington AH (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.

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

Young WJ, Chessman BC, Erskine WD Raadick TA, Wimbush DJ, Tillerad J, Jakeman AJ, Varley I and Verhoeven TJ (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