WATER MANAGEMENT

Applying the High Ecological Value Aquatic Ecosystem (HEVAE) Framework for Riverine Ecosystems

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Cover image: Richmond River above Casino at Baileys Bridge. Source: M. Healey.

Executive summary

The NSW riverine High Ecological Value Aquatic Ecosystem (HEVAE) project aims to identify and define a range of instream values and levels of importance for freshwater river reaches in NSW. These values will assist in the prioritisation of areas for focused water management to benefit all water users, including the environment. The water management options include assessment of access and trade rules within water sharing plans (WSPs). The HEVAE product enables the NSW Department of Industry and its Lands and Water Division to better meet water management requirements under the *Water Management Act 2000* and Murray–Darling *Basin Plan 2012.*

The HEVAE Framework was developed by the Commonwealth Government as part of the Australian Aquatic Ecosystem Toolkit and has been adopted by the NSW Department of Industry as a progressive step to replace other NSW instream value assessments with a national approach.

Although the HEVAE Framework advocates using five key criteria (Aquatic Ecosystems Task Group 20102a), the NSW Department of Industry has adopted four criteria: diversity, distinctiveness, naturalness and vital habitat. Lack of data prevented inclusion of the fifth criterion (representativeness). Each of the four criteria relies on statewide availability of instream value data to enable the production of consistent spatial mapping outcomes. Mapping outputs were derived at the river reach scale and the overall HEVAE scores identify where the best instream values occur within a catchment. The overall riverine HEVAE outcomes can be examined to determine which particular individual values (e.g. a threatened fish species) are influencing the final HEVAE scores.

This report provides the rationale and describes the methods adapted from Commonwealth Government HEVAE Framework for instream value and for each of the four criteria used. Details are provided on the weightings used, and scoring approaches, providing the overall HEVAE scores for each river reach. This report also examines limitations of the methods and provides recommendations aimed at improving this first iteration of the HEVAE Framework for NSW freshwater rivers.

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1 Introduction

In Australia and overseas, river value assessment is a wide-spread practice, and has been implemented in many states and territories to focus resources on improving river health through strategic management practices (Bennett et al. 2002; Macgregor et al. 2011). In the last two decades, there has been a focus in NSW on assessing the values of rivers, commencing in 1988 with the water reforms utilising a stressed rivers assessment approach (DLWC 1998). In NSW, the macro water sharing plan (WSP) approach for unregulated rivers was developed in 1996 (NSW Office of Water 2010), and more recently, the development of the River Condition Index (RCI) (Healey et al. 2012).

Earlier versions of riverine instream (conservation) value assessment in NSW were undertaken as part of the approaches mentioned above. The data sets used, in these previous approaches, were collated by NSW Office of Water, Office of Environment and Heritage (OEH) and NSW Department of Primary Industries—Fisheries. These datasets and associated protocols were compiled to meet the then Office of Water's requirements under Section 7 of the *Water Management Act NSW (2000)* to assess the extent of risk from hydrologic stress (e.g. over-extraction of water) to instream values within each catchment water source. The data used in previous assessments is now largely outdated, although the requirements under Section 7 of the *Water Management Act NSW* (2000) are still required today. The Murray–Darling Basin Plan (MDBA 2012) also has key requirements for risk assessments to identify and address risks to river condition and water availability, prior to the development of water resource plans (WRPs). Additionally, since these water reforms, national approaches to classifying, or reporting on rivers have been developed (Norris et al. 2007a; Aquatic Ecosystems Task Group 2012a).

The Office of Water developed the RCI in 2011 to provide more accurate and precise spatial outcomes when assessing instream value and risk to these values from extraction. The peer-reviewed RCI also had an 'alignment framework' to enable shared use of common spatial tools to benefit the former catchment management authorities (CMAs) and the priority action plans they were developing (Healey et al. 2012).

The initial RCI package utilised the National Framework for Assessing River and Wetland Health (FARWH) (Norris et al. 2007a), but only for the condition assessment component. Instream value and risk assessment components were separate but interactive with the condition assessment. However, the instream value component used a mixture of spatial datasets across NSW and, catchment or region-specific datasets that did not have statewide consistency.

The NSW Department of Industry decided to adopt the High Ecological Value Aquatic Ecosystem (HEVAE) Framework (Aquatic Ecosystems Task Group 2012a) as a progressive step to replace other instream value frameworks previously used. This decision was based upon the need to have a reach-based ecological value identification system for river management in NSW. The HEVAE Framework has been considered a 'best practice' approach to identifying environmental assets (MDBA 2014a). Adopting the HEVAE Framework also allows for alignment with the Key Environmental Assets (KEAs) (Commonwealth of Australia 2012) that the previous instream value assessments did not achieve. The NSW Department of Industry has collated a range of attributes under four of the five recommended HEVAE criteria that align well with the Basin Plan KEA criteria (see Appendix 1).

One of the limitations of the previous macro WSP approach was that it only provided an assessment of values and risks at the water source scale. This was problematic because it failed to adequately identify where risks to instream values from extraction occurred at smaller scales and where more suitable water sharing rules could be placed to better manage the risks. Generating HEVAE instream values at the river reach level provides better opportunities for developing strategies (e.g. flow access rules) for WSPs and WRPs in Basin catchments. Adaptive management strategies could include installing management zones in water sources for more appropriate cease-to-pump rules and identifying knowledge gaps where future work should be targeted. More importantly, it provides a useful approach to exploring options for trade in water entitlements. This involves identifying where trade should not occur or be restricted, where trade limits should be established and how to improve trade of water entitlements which may increase economic benefits to regional communities.

The HEVAE instream values have formed a key part of the NSW Department of Industry's risk assessment process to meet Basin Plan requirements, as the 'consequence' component. Consequence can be considered as the instream values under threat from extraction or other water sharing activities; the consequence of losing a high-value asset is greater than losing a low-value one (NSW Office of Water 2010). Further information on this approach can be found in the Risk Assessment for the Gwydir Water Resource Plan Area (SW15) (NSW Department of Industry, 2018).

1.1 Aims of the project

The aims of the project were to:

1. develop and implement a method, using the Commonwealth Government HEVAE framework, that enabled the inclusion of the most up-to-date instream value or asset information to inform water planning needs in NSW
2. have a process that spatially enables the identification of contemporary instream value data at the river reach scale, that can then inform water sharing rules at different scales required (e.g. management zone or surface water source)
3. generate HEVAE outcomes to inform the risk assessment process and associated strategies in WSPs and WRPs, which are requirements under NSW legislation, as well as the Basin Plan
4. provide a robust method to assist in the setting of ecological objectives in WSPs and WRPs
5. provide defensible and logical outcomes that assist in objective water sharing (access and trade rules) decision-making.

1.2 Structure of the report

This report provides details on adapting the HEVAE approach to inform management decisions relating to the water management pressures on important instream values. The sections of the report are:

- Section 1—Introduction and project aims
- Section 2—Literature review
- Section 3—Methods used including criteria and attributes adopted, prioritisation, scoring, weighting and spatial application of the framework
- Section 4—Discussion, recommendations and limitations in implementing the HEVAE framework
- Section 5—References.

Additional information is provided in Appendix 1 (alignment between Basin Plan Key Environmental Assets and HEVAE criteria used in NSW application of the framework) and Appendix 2 (details on each attribute associated with each HEVAE criteria on flow-sensitivity weightings used, flow requirements, scoring and primary evidence).

2 Literature review

2.1 Instream ecological value assessment

In Europe, the System for Evaluating Rivers for Conservation (SERCON) was established to determine the conservation value of rivers in Britain (Boon et al. 1996). SERCON adopted six value criteria: Physical Diversity, Naturalness, Representativeness, Rarity, Species Richness, and a category known as ‘Special Features’ (Boon et al. 1996). The term ‘conservation value’ is considered the same as ‘ecological value’, with both using a broad range of criteria and indicators (Bennett et al. 2002).

Many waterway assessment methods have been undertaken in Australia and overseas that have focused on condition, conservation or ecological value assessment (Dunn 2000; Bennett et al. 2002). However, few have been universally adopted, despite some using similar criteria (Bennett et al. 2002). A survey of water natural resource managers and researchers in Australia by Dunn (2000) provided responses that endorsed five ecological criteria (naturalness, representativeness, physical diversity, species richness, and rarity) and a range of associated attributes to be adopted as a standard to measure ecological value of rivers. These same sets of criteria and attributes are adopted in Bennett et al. (2002).

A pilot project to determine the conservation value of rivers was undertaken in the Burnett catchment in Queensland (Phillips 2001). Results from this study contributed to the development of the Queensland Aquatic Biodiversity Assessment & Mapping Method (AquaBAMM) (Clayton et al. 2006). AquaBAMM was developed as a decision support tool to meet Queensland water policy and planning needs, and includes a geographic information system (GIS) platform to assist in result presentation and interpretation of the data, and the use of expert panels for aquatic and riparian flora, fauna and riverine ecology. AquaBAMM uses the five value criteria recommended by Dunn (2000) and Bennett et al. (2002), but also included the criterion connectivity (an attribute of flowing waters), with priority species and ecosystem indicators (Clayton et al. 2006).

The Commonwealth Government later developed Guidelines for Identifying High Ecological Value Aquatic Ecosystems (HEVAE) as part of its Aquatic Ecosystems toolkit (Aquatic Ecosystems Task Group 2012a). The HEVAE framework uses five key criteria applicable at a range of scales: diversity, distinctiveness, naturalness, vital habitat and representativeness. The HEVAE criteria are applicable across aquatic ecosystem types (rivers, wetlands, karst, floodplains, lacustrine and other groundwater-dependent ecosystems, salt-marshes, estuaries) at the regional level (Aquatic Ecosystems Task Group 2012a). The HEVAE framework has been trialled in a number of areas in Australia (Hale 2010; Kennard 2010; Aquatic Ecosystems Task Group 2012b).

The criteria to select key environmental assets in the Basin Plan were developed to broadly align with the draft criteria developed to identify High Conservation Value Aquatic Ecosystems (HCVAE): diversity, distinctiveness, vital habitat, evolutionary history, naturalness and representativeness (MDBA 2010). HCVAE was a precursor to the final HEVAE approach.

2.2 Diversity

Freshwater diversity is considered an important criterion when establishing the values of aquatic ecosystems and it has been used in a range of freshwater assessment programs in Australia and internationally (Dunn 2000; Bennett et al. 2002). Freshwater diversity has been described in the HEVAE framework (Aquatic Ecosystems Task Group 2012a, p.5) as:

> ‘The aquatic ecosystem exhibits exceptional diversity of species (native/migratory), habitats, and/or geomorphological features/processes.’

Diversity can include a range of related attributes including genetic diversity, habitat diversity and species diversity (Aquatic Ecosystems Task Group 2012a).

In the application of the framework to NSW, fish populations and communities are considered to be sensitive indicators of habitat quality in rivers because they are sensitive to many kinds of anthropogenic disturbances, including flow regulation, physical habitat alteration and fragmentation (Karr 1981; Pont et al. 2006: Koehn et al. 2014). Fish diversity has also been key components of river health assessment in the Murray–Darling Basin Australia (Davies et al. 2008).

Similar to fish, macroinvertebrates are also regarded as important biota of flowing-water ecosystems. Macroinvertebrates influence nutrient cycling and productivity, as well as being an important food source for fish (Wallace and Webster 1996). Altered flow regimes, water quality and other conditions can influence macroinvertebrate communities, making them useful in river condition assessments (Davies et al. 2008). Family-level resolution can be useful to discriminate taxonomic differences over wide geographic areas (Marchant et al.1995), and has been implemented in Australia-wide riverine assessments (Nichols et al. 2002; Chessman and Royal 2004; Davies et al. 2008).

2.3 Distinctiveness

Distinctiveness can also be referred to as 'rarity' (Boon et al. 1996; Macgregor et al. 2011) and is a characteristic of waterways value assessment that can include rare or threatened species, populations and communities, ecosystems and habitats and water chemistry (Bennett et al. 2002). Rarity is one of the key criteria used in aquatic ecological value assessment that is strongly influenced by legislation, specifically the *Environment Protection and Biodiversity Conservation Act 1999* (Dunn 2000; Macgregor et al. 2011). In the HEVAE framework (Aquatic Ecosystems Task Group 2012a), the distinctiveness (rarity) criterion is defined as:

- 'The aquatic ecosystem is rare/threatened or unusual; and/or
- The aquatic ecosystem supports rare/threatened/endemic species/communities/genetically unique populations; and/or
- The aquatic ecosystem exhibits rare or unusual geomorphological features/processes and/or environmental conditions, and is likely to support unusual assemblages of species adapted to these conditions, and/or are important in demonstrating key features of the evolution of Australia's landscape, riverscape or biota.'

Attributes associated with distinctiveness, have been applied in aquatic value assessments in Western Australia (including rare geomorphic features and threatened species—Macgregor et al. 2011), the Northern Territory (including threatened species—Kennard 2010) and Queensland (threatened species and ecosystems—Clayton et al. 2006).

2.4 Naturalness

Naturalness is a key criterion featuring in a number of national and international freshwater value assessments (Boon et al. 1996; Clayton et al. 2006; DPIW 2008; Ollero et al. 2011). Naturalness is most often referred to as an area that has not been disturbed or impacted by humans (Dunn, 2000; Bennett et al. 2002; Clayton et al. 2006).

In the HEVAE framework (Aquatic Ecosystems Task Group 2012a, p. 10), the naturalness criterion is described as:

> 'The ecological character of the aquatic ecosystem is not adversely affected by modern human activity.'

The geomorphic principles of naturalness and place are considered to underpin ecosystem integrity as a basis for effective river rehabilitation (Fryirs and Brierley 2009). Human impacts and strength of riverine connectivity determine the degree to which a river can respond to disturbance events and the trajectory of geomorphic recovery (Brierley and Fryirs 2005; Brierley et al. 2010). In the Hunter Valley, NSW, human-induced change to river form and morphology has occurred from modification to vegetation cover and hydrological regimes (Cook and Schneider 2006).

In Australia, attributes used to measure and/or report on naturalness (DPIW 2008; Kennard 2010; Macgregor et al. 2011) have included:

- changes in the flow regime (flow variability, abstraction, regulation) and sediment regime (land use, catchment clearance, urbanisation and mining sedimentation)
- indices of native of native aquatic biota (fish and macroinvertebrates)
- changes in riparian zone characteristics
- changes to geomorphic factors.

Hydrologic stress or modification of river flows to meet human needs is considered as an indicator of alteration to flows within catchments or sub-catchments. Hydrologic stress has been adopted as an assessment criterion in the United States (WRC 2001) and some areas in Australia (DLWC 1998; Ladson and White 1999; NLWRA 2002). Indicators of flow have also been used to describe the hydrological regime more recently in the Murray–Darling Basin (Davies et al. 2008). Hydrologic stress has been used as a support tool in NSW water planning needs in unregulated rivers for more than a decade (DLWC 1998; NSW Office of Water 2010). The NSW Department of Industry classified streams according to their hydrologic stress as a decision support tool for water trade and access rules for water sharing plan development (NSW Office of Water 2010).

Catchment disturbance impacts through land use change can cause complicated and long-lasting changes to stream ecosystems (Maloney and Weller 2011). Catchment disturbance has been recognised as an important factor that influences river condition, and was included in the national assessment of Australian rivers (NLWRA 2002). These impacts can include increased or decreased rates of flow, changes to the timing and seasonality of flow events, and increases in sediments and nutrients into waterways (NLWRA 2002). Catchment disturbance was included in the Australian framework for comparative assessment of the ecological condition of Australian rivers and wetlands, and included infrastructure, land cover change and land use as data sources (Norris et al. 2007b). These data sources were also used to assess the condition of NSW rivers (Healey et al. 2012) and these outcomes were adopted in the NSW riverine HEVAE methods.

Macroinvertebrate family occurrence data have been used in two major assessments of the condition of rivers in the Murray–Darling Basin (MDB) through the Sustainable Rivers Audit (SRA) (Davies et al. 2012). In both SRA 1 (Davies et al. 2008) and SRA 2 (Davies et al. 2012), the observed samples of macroinvertebrate families were compared to those expected (i.e. observed/expected or O/E), as determined from reference (more natural and/or less impacted) sites with outcomes related to specific bands or categories (Gray 2004; Davies et al. 2012). The SRA approach was an index of biological impact benchmarked against natural conditions, including natural spatial variations in community composition across the MDB (Harrison et al. 2011; Davies et al. 2012). The same approach to using macroinvertebrate O/E data was also used in reporting on the condition of rivers across NSW (Muschal et al. 2010).

National parks were included in the naturalness criterion (as part of the NSW application of HEVAE) as a landscape attribute that should reflect little change to their inherent values (being largely unmodified), and as such are highly valued natural systems (Bennett et al. 2002). However, some rivers may receive protection if they flow within a national park, although this protection will only apply to the area within the park and may not necessarily protect the values if upstream activities (e.g. logging) affect the river ecosystems (Dunn 2000). These types of reserves were initially established to protect their natural assets or values and maintain natural processes that occur within them (Burgman and Lindenmayer 1998). Reserve systems, such as national parks, although designed primarily for maintenance of terrestrial biota, may also provide significant value for aquatic systems (Kennard 2010). For example, a study on freshwater fish in India found that more species, increased abundances, larger individuals, and higher numbers of endangered fishes occurred within a protected area when compared to the unprotected area (Sarkar et al. 2013).

2.5 Vital habitat

In the HEVAE framework (Aquatic Ecosystems Task Group 2012a, p. 8), the vital habitat criterion is described as:

> ‘An aquatic ecosystem provides vital habitat for flora and fauna species if it supports:
>
> - Unusually large numbers of a particular native or migratory species; and/or
> - Maintenance of populations of specific species at critical life cycle stages; and/or
> - Key/significant refugia for aquatic species that is dependent on the habitat, particularly at times of stress.’

The term ‘vital habitat’ implies a range of ecological factors that are crucial in sustaining biota. For aquatic ecosystems, the quantity and quality of water as well as other instream physical and chemical factors that influence the maintenance and/or protection of instream biota would be considered ecological factors essential in the provision of vital habitat.

The use of vital habitat as a criterion in riverine ecosystem assessment is limited. In Australia, attributes associated with vital habitat as defined by the Aquatic Ecosystems Task Group (2012a), have sometimes been listed under the criterion ‘special features’ (Dunn 2000; Bennett et al. 2002; Clayton et al. 2006; Macgregor et al. 2011). Vital habitat (refugia and important waterbird sites) was listed as a key criterion in the review of the environmental water requirements in the northern Murray–Darling Basin (MDBA 2014a). Vital habitat is recognised as a key criterion for identifying an environmental asset within the Basin Plan for management under Commonwealth water sharing arrangements (Commonwealth of Australia 2012).

The HEVAE framework also states that

> *'vital habitat may be characterised by particular salinity, tidal regimes, hydrology, productivity, seasonal patterns of drying and wetting, or extent and nature of vegetative cover or substrate' (Aquatic Ecosystems Task Group 2012a, p. 8).*

Within schedule 8 of the Basin Plan Criterion 3, one of the associated attributes of vital habitat is that a

> 'water-dependent ecosystem is an environmental asset that requires environmental watering if it is essential for maintaining, and preventing declines of, native water-dependent biota' (Commonwealth of Australia 2012).

2.5.1 Wetlands

Directory of Important Wetlands in Australia (DIWA) are aquatic ecosystems recognised as being regionally, nationally and/or internationally important (Environment Australia 2001). DIWA include those listed as Ramsar wetlands (Environment Australia 2001). Many of the wetlands listed in the Australian Wetlands database are vital habitat for threatened and migratory species and maintain a range of biological diversity, particularly in times of drought (Environment Australia 2001; DEE 2016b). For an aquatic ecosystem to be included on the DIWA, it must meet one or more of six criteria (Environment Australia 2001). Ramsar wetlands of International Importance must meet at least one of nine criteria, several of which are related to vital habitat as defined in the HEVAE Framework. A number of the listing criteria in both the DIWA and Ramsar Convention relate to the definition of vital habitat under the HEVAE framework.

DIWA listing criteria that align with the Aquatic Ecosystems Task Group (2012a) definition of vital habitat include (Environment Australia 2001):

- 'It is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex';
- 'It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail';
- 'The wetland supports 1% or more of the national populations of any native plant or animal taxa'.

Three Ramsar listing criteria relating to vital habitat as defined in the HEVAE Framework include (Ramsar Convention 2009):

- Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.
- Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
- Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

2.5.2 Large woody habitat

Large woody habitat (LWH) can also be referred to as either large woody debris (LWD), coarse woody debris, or snags. LWH can be composed of logs and branches that are generally deposited within the river channel (Treadwell et al. 2007; Baldwin et al. 2014). LWH provides a range of functions as a vital habitat within rivers and streams including a surface area for microbial biofilms that mediate instream production and provides habitat for diverse macroinvertebrates (Boulton et al. 2014). For fish, LWH also provides microhabitats, mediates predator impacts and provides a velocity refuge (Crook and Robertson 1999). LWH also influences stream morphology, stability and sediment dispersal, thus influencing other instream habitats and biota (Brooks and Brierley 2002; Treadwell et al. 2007). LWH can, at times, be the only solid substrate for fish and macroinvertebrates to use for habitat, spawning and refuge (when the river bed and banks comprise fine, often unstable sediments) (Treadwell et al. 2007). The capacity of Australian streams to easily move LWH downstream from upstream sites appears to be limited (Treadwell et al. 2007). This is due to the dominance of low-gradient, low-energy rivers across Australia (some 97%) (Thoms and Sheldon 2000) and in NSW many are below 300 m (above sea level) (Gerhke 1997). In Australia, the movement of LWH appears to be mostly reliant on large, extreme flood events, while the majority of LWH recruitment in rivers can be from immediate on-site riparian input (Treadwell et al. 2007).

2.5.3 Dissolved organic carbon

Dissolved organic carbon (DOC), often referred to as dissolved organic matter, plays a key role in the dynamics of stream and river ecosystems, affecting processes such as metabolism (Boulton et al. 2014). DOC has a vital role in river systems as it has a direct influence on primary production. These influences include the balance between instream producers (autotrophs) and consumers (heterotrophs), and affects light and temperature regimes in water columns, bioavailability of toxic compounds, and acidity and nutrient uptake (Boulton et al. 2014; Stanley et al. 2012). Meyer and Tate (1983) conducted a study comparing cleared and non-cleared watersheds in North Carolina, USA. This study showed the importance of land use in affecting DOC-producing abilities of the vegetation and drainage of the land, with an overall decrease in stream DOC concentrations resulting from deforestation (Meyer and Tate 1983).

In Australia, an increasing understanding of the importance of carbon sources and the processing of carbon in lowland rivers during low-flow regimes has emerged (e.g. Oliver and Merrick 2006; Hadwen et al. 2009; Wallace and Furst 2016). Floodplain riparian areas in lowland rivers provide significant allochthonous energy sources such as leaf litter. The quality and quantity of leaf litter input (i.e. DOC) forms the first step in many of the river's trophic relationships (Schulze 1995). Evidence suggests that riparian trees such as *Eucalyptus camaldulensis* (river red gum) contribute large quantities of litter to large rivers and associated floodplains in south-eastern Australia (Francis and Sheldon 2002; Zander et al. 2007). Some of this litter falls directly into water bodies at times of low flow, but much of it remains on dry floodplains (Robertson et al. 1999) and in-channel surfaces (Thoms and Sheldon1997) until inundated by rises in river levels.

DOC can be provided by a range of sources in riverine ecosystems from in-stream (aquatic plants), terrestrial vegetation and the riparian zone (Robertson et al. 1999; Giling et al. 2014; Baldwin, 2018). However, in many rural settings, catchment clearing has removed many of the sources of DOC, and riparian vegetation is what often remains. Riparian vegetation is critical in all facets of the DOC regime along rivers, as a source, and in its effects on, in-stream processing and production and terrestrial-aquatic transfer (Stanley et al. 2012). For these reasons riparian woody vegetation has been selected as a surrogate measure influencing DOC availability in the NSW HEVAE methods.

During periods of high discharge, in-stream primary production is often very limited due to highly turbid conditions, with in-stream respiration often exceeding production (Thorp and Delong 1994), with lowland rivers reliant upon surrounding terrestrial inputs. Overall, the annual trend relating to DOC sources may be divided into periods of low flow (autochthonously driven) and periods of high flow (traditionally summer, with irrigation releases and summer rains). High episodic pulses of allochthonous organic matter tend to occur in response to the wetting and lateral connectivity of surrounding riparian vegetation and floodplain zones (Westhorpe and Mitrovic 2012). Westhorpe et al. (2010) determined that a more natural heterotrophic dominance could potentially occur when terrestrially derived DOC was rapidly assimilated into the aquatic food web (Whitworth et al. 2012; Baldwin et al. 2013). A study in the lower Namoi River looking at the relationship between discharge and DOC delivery suggested that 'environmental flows' should increase the amount of terrestrial DOC transported within the river in years with moderate and large flow events (Westhorpe and Mitrovic 2012).

2.6 Flow dependency and alteration to natural flow

Water is a resource in high demand globally, and various forms of extraction and interception have reduced natural freshwater river flows. Estimates of 65% of worldwide river flow and associated aquatic communities that rely on these flows are considered to be under moderate to high threat (Vörösmarty et al. 2010). Major alterations to natural hydrologic regimes in Australia have occurred through land-use change, river impoundment, surface and groundwater abstraction, and artificial transfers within and between basins (Arthington et al. 2012). The Murray–Darling drainage area has the most significant alteration in patterns of natural flow compared to other drainage areas in Australia (NWC 2012). Alteration to flow has been used as a measure of naturalness in other water prioritisation frameworks in Australia (DPIW 2008; Macgregor et al. 2011). The regulation of rivers in Australia is regarded as a key factor influencing the deterioration of river condition (Boulton et al. 2014; Arthington and Pusey 2003).

Flow dependency of instream ecosystems has been widely recognised in the approach to managing water extraction in the MDB (MDBA 2010). In 1997, a permanent cap on diversions from the MDB was introduced. The cap was aimed at maintaining and improving existing flow regimes to protect and enhance the riverine environment and to enable sustainable consumptive use of water (Whittington et al. 2000). The importance of natural flow variability was becoming better understood prior to the development of the Commonwealth *Water Act 2007*. Impacts on instream and floodplain processes, ecology and habitats were found to be largely due to changes caused by alteration to natural flow magnitude, variability, and rates of change, in particular altered seasonality of flow (Young 2001).

A major study into the health of the MDB rivers (the Sustainable Rivers Audit) incorporated flow metrics into the assessment process with the understanding that hydrology is a fundamental driver of riverine ecosystems (Davies et al. 2008; Davies et al. 2012). The Commonwealth *Water Act 2007* established the Murray–Darling Basin Authority (MDBA) to develop the Basin Plan with a focus on integrated management of the Basin's water resources. Key environmental objectives within the Basin Plan focus on supporting and protecting key instream biota, associated habitats and functions through improved river flows (MDBA 2012). Sustainable Diversion Limits (SDLs) were developed for each Basin catchment to reflect an Environmentally Sustainable Level of Take (ESLT) aimed at maintaining and improving the flow needs of key environmental assets and functions (MDBA 2011).

Alteration to natural flows of rivers and streams is recognised as a key threat to species, populations and communities, biological diversity and ecosystem function in aquatic ecosystems (OEH 2002; NSW Department of Primary Industries 2005). Water extraction, changes in drainage patterns, and instream structures are examples of a number of threats that can alter natural flow (OEH 2002; NSW Department of Primary Industries 2005). The identification of the flow regimes required by threatened and non-threatened biota and habitats provides information on the importance of hydrology to these ecosystems. Although many species, populations and communities listed under the *Threatened Species Conservation Act 1995* have alteration to natural flow listed as a key threat, further species could be determined to be impacted by altered flow in the future (OEH 2002; OEH 2015a). Various threat abatement actions have been listed to help manage the impact of river flow alteration, including implementing water reforms and the NSW *Water Management Act 2000*, and supporting water sharing planning and initiatives (OEH 2002).

3 Methods

The NSW application of the HEVAE Framework focuses on freshwater inland and coastal rivers above the tidal limit, and includes four of the five HEVAE criteria: diversity, distinctiveness, naturalness, and vital habitat. Due to the lack of current data available (e.g. river typing, aquatic bioregions, etc.), the criterion representativeness has yet to be included in the NSW riverine HEVAE methods. A process has not yet been developed to enable the river typing of river reaches in NSW to place reaches into representativeness categories.

The capacity to include and report on each HEVAE criterion is highly dependent on the availability of relevant data. The data needed to be at the appropriate scale and spatially enabled (i.e. has coordinate/site or area details) for incorporating into a geographical information system (GIS) model. The application of GIS modelling is a powerful decision support tool that is easily updated and interrogated, can manage multiple attribute layers, is transparent in its operation and can be easily maintained (Phillips 2001; Clayton et al. 2006).

Assessment of the availability of data for the attributes associated with the four criteria indicated enough useful data could be collated into the HEVAE framework to enable spatial outcomes to be derived at the river reach scale (Figure 1).

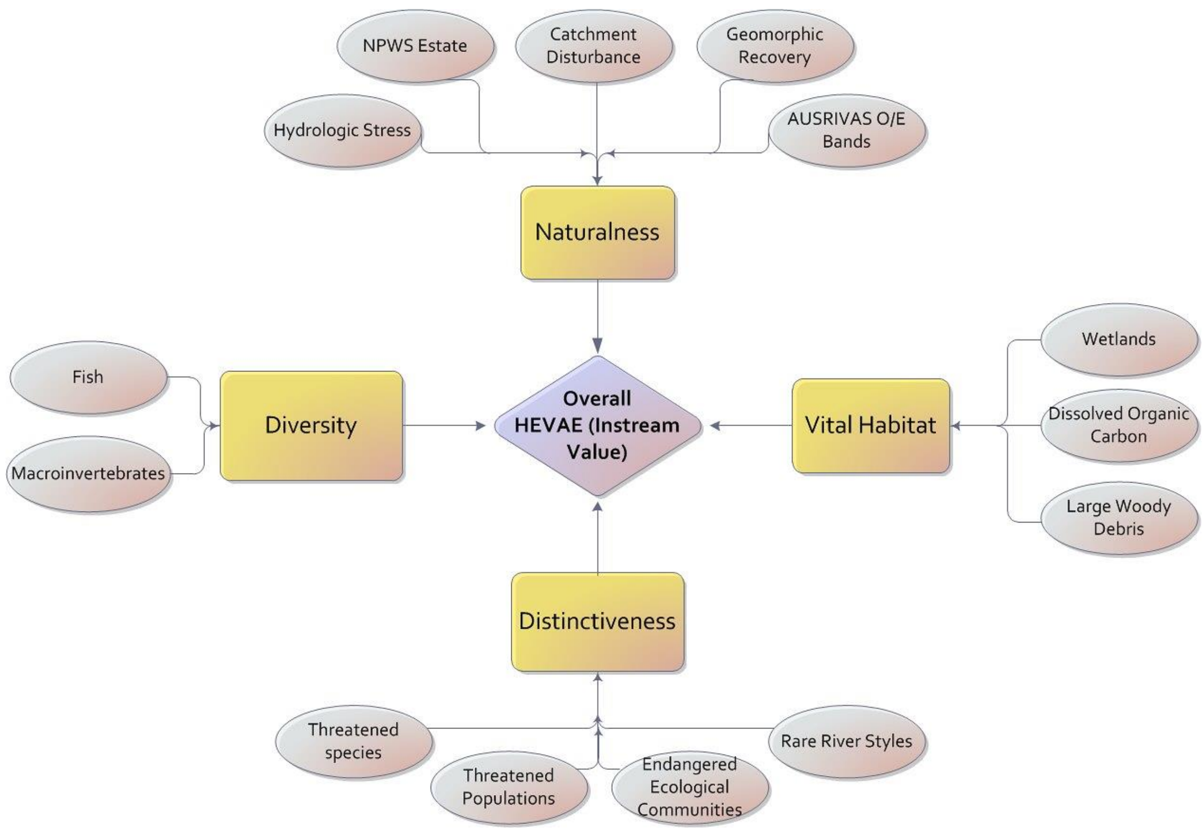

Figure 1: The four HEVAE criteria (yellow boxes) and associated attributes (indicators in grey ovals) used by NSW Department of Industry in the HEVAE assessment of NSW catchments.

3.1 Data sources

The HEVAE spatial model developed incorporates various data sources from NSW Department of Industry and partner agencies of NSW Department of Primary Industries—Fisheries and the Office of Environment and Heritage (OEH) (Table 1).

Table 1: Data sources used in each of the criteria

Criteria	Data Sources
Base layer in all criteria	• River Styles® (NSW Department of Industry) • Geofabric data layer (BOM)
Diversity	• Fish diversity data (NSW Department of Primary Industries—Fisheries) • AUSRIVAS macroinvertebrate data (Family level data) (OEH)
Distinctiveness	• Threatened species, populations and communities (recorded, known and predicted data) (OEH and NSW Department of Primary Industries—Fisheries) • Rare River Styles® (DoI Water)

Criteria	Data Sources
Naturalness	• Hydrologic stress and catchment disturbance (from River Condition Index) (NSW Department of Industry); • Natural Parks estate (OEH) • Observed/Expected (O/E) macroinvertebrate data (OEH) • River Styles Recovery Potential (DoI Water)
Vital Habitat	• Riparian Woody Extent raster dataset (DECC 2008) • River Styles® (NSW Department of Industry) • Ramsar/DIWA/SEPP14 (Coastal Wetlands) (OEH)

The following sections provide details on how the data were incorporated into the HEVAE model and what criteria they were used in.

3.2 Application of River Styles®

To ensure spatially enabled HEVAE outcomes can be reported in a consistent way at the water source scale in a WSP, the available data were attached to the River Styles® spatial layer (Healey et al. 2012). The River Styles® framework describes a set of procedures to document the geomorphic function and structure of rivers, the characterisation of different river types, and their biophysical linkages within a catchment setting (Brierley and Fryirs 2005). River Styles® mapping has been undertaken across all catchments in NSW to third- or fourth-order streams and higher. The River Styles® mapping at river reach level enables the outputs to be represented at the river reach, management zone, water source and catchment scale for water planning needs. First and second order streams were not mapped and are not included in the assessment. As River Styles® mapping is updated; first or second order streams may be included.

Site-based macroinvertebrate and fish data have been extended along river reaches using mapped river style and river geomorphic condition (see Section 3.4.1). River geomorphic condition is associated with the River Styles® framework, and has been assessed where NSW River Styles® mapping has occurred. Geomorphic condition is defined as a measure of the capacity of river sections to perform expected functions relative to similar reference river sections (Brierley and Fryers 2005; Cook and Schneider 2006). Good geomorphic condition indicates stable or undisturbed riverine settings (including the riparian zone) and the high potential for ecological diversity, similar to the pre-development intact state. Moderate geomorphic condition indicates localised degradation of river character and behaviour; however, patchy but effective riparian vegetation still occurs (Brierley and Fryers 2005; Cook and Schneider 2006). River reaches in good river geomorphic condition have been found to support increased aquatic macroinvertebrate and macrophyte diversity than moderate condition rivers sections (Chessman et al. 2006). Condition can also influence the structure and species diversity of freshwater mussels (Jones and Byrne 2010).

3.2.1 Diversity

In this initial assessment of riverine HEVAE, for inland catchments located in the Murray–Darling Basin and coastal catchments of NSW, fish diversity spatial data were obtained from NSW Department of Primary Industries—Fisheries (D. Gilligan pers. comm).

A diversity scoring system was developed that accounts for both species richness (the number of different native species present) and each species' abundance. The scoring system identifies sites which support the highest diversity of native fish species. Sites are then scaled to a percentage of the highest ranked site within the reporting region. The reporting region was the former NSW Catchment Management Authority (CMA) boundaries. These closely match the current Murray–Darling Basin Water Resource Plan boundaries.

For the calculation of species abundance, electrofishing fish data (collected by Fisheries NSW for 1 January 2002 to 31 December 2011) were standardised to catch per minute of electrofishing (power-on time) to account for variation in sampling effort across sites. Prior to analysis, sites were grouped to ensure similar sites were being compared. For the NSW-wide scale analysis, sites were grouped using the freshwater fish bioregionalisation model of Growns and West (2008), with an additional bioregion for sites within the Lake Eyre Basin–Bulloo catchments in northwest NSW. For CMA-scale analysis, sites were stratified into Lowland (3–400 m) and Upland (401–1,780 m) altitude bands within each CMA area, noting that sites within the Lake Eyre Basin drainage division were analysed separately from the Murray–Darling Basin portion of the Western CMA area.

To calculate the Biodiversity Score (or biodiversity score), each site within each group was ranked for each species in ascending order. Hence, sites where a species was absent had a rank of 0, and the site that had the highest abundance for that species had the highest rank. The ranks for each species were then summed across each sampling site to provide a ‘Sum of Ranks’. The site with the highest ‘Sum of Ranks’ was identified in each zone and then the Biodiversity Score of each site was expressed as a percentage of the ‘Sum of Ranks’ for the most highly ranked site in each zone.

A cluster analysis was then applied to the data for each bioregion or altitude band using the Getis-Ord Hot Spot Analysis tool in ArcGIS (Fischer and Getis 2010). The Getis-Ord statistic (Z score) identifies whether features with either particularly high values or particularly low values tend to cluster in a given area. This tool works by looking at each feature within the context of neighbouring features. If a feature's value is high, and the values for all of its neighbouring features are also high, it is considered a part of a ‘biodiversity hot spot’. The local sum for a feature and its neighbours is compared proportionally to the sum of all features; if the local sum is considerably different from the expected local sum, that difference is deemed to be too large to be the result of random chance. When this occurs, a statistically significant Z score is generated.

Future coastal and inland fish diversity analysis will include new fish community status data derived by NSW Department of Primary Industries—Fisheries (see Section 5.1 (6)).

For riverine macroinvertebrate data, a Microsoft Access database of the AUSRIVAS sample data (J. Miller pers. comm.) with spatial details for the NSW sampling sites was obtained from the NSW Office of Environment and Heritage (OEH). The macroinvertebrate data were initially collected under the Monitoring River Health program (Turak and Wardell 2002). Using this method, data were also collected under the Sustainable Rivers Audit program (Davies et al. 2008; Davies et al. 2012) from 2004 to 2012. The dataset includes inland and coastal macroinvertebrate sampling outcomes from 2006 to 2011 that supported the NSW Monitoring, Evaluation and Reporting program for riverine ecosystems (Muschal et al. 2010).

Macroinvertebrate Family-level data from the database provided by OEH formed the basis for calculating macroinvertebrate diversity. From this database, a GIS point layer was created based on site data and number of macroinvertebrate families.

3.2.2 Distinctiveness: threatened species, populations, endangered ecological communities, and rare River Styles®

Threatened species, populations and communities associated with riverine environments (flowing water) were identified for each catchment area. To determine the relevant river-flow dependent attributes for inclusion in a catchment/regional-scale assessment, an initial search was undertaken using three web-based tools and associated literature:

- Threatened species profile search for listing under the NSW *Threatened Species Conservation Act 1995* (TSC Act 1995) (OEH 2015a);
- Threatened and protected species—profiles and records viewer, for listing under the NSW *Fisheries Management Act 1994* (FM Act 1994) (NSW Department of Primary Industries 2015a; NSW Department of Primary Industries 2015b); and
- Commonwealth Government Protected Matters Search Tool, for listings under the *Environment Protection and Biodiversity Conservation Act 1999* (EP&BC Act 1999) (DoE 2015).

Of particular interest was the inclusion of species, populations, or communities, where alteration to natural flow was listed as a key threatening process. Appendix 3 lists the threatened species, endangered populations, and communities used in the distinctiveness criteria, as well as the flow weighting and criteria weighting. For threatened species, populations and Endangered Ecological Communities managed under the TSC Act 1995, site-based spatial data were obtained from several sources. Site records of threatened species stored in the Atlas of NSW Wildlife (OEH 2015b) were provided under creative commons licence agreements between OEH and NSW Department of Industry.

Site-based records from the Atlas of NSW Wildlife (non-fish data) were joined to geo-fabric sub-catchments. This was done because it was assumed there is a high probability that the species is likely to occur elsewhere within the geo-fabric sub-catchment. Site-based fish data were associated with River Styles® layer. Known and predicted Atlas of NSW Wildlife data were associated with Interim Bioregional Assessment (IBRA) subregions, and refined within these boundaries where specific altitude data was available indicating a habitat or distribution restriction on a species.

Catchment or regional recorded occurrence of vegetation-based EECs listed under the TSC Act 1995, were determined through assessment of plant community types within the NSW vegetation mapping program and associated spatial data (OEH 2016). Spatial data were provided by OEH (Bob Denholm pers. comm.).

Threatened fish species site-based spatial data were provided by NSW Department of Primary Industries—Fisheries (D. Gilligan and K. Danaher pers. comm.) and included two spatial data sets. One dataset was derived from electrofishing at sites across NSW (ProjectedCAPSummaryData270402) between 1 January 2002 and 31 December 2011 (a 10-year period). Data were standardised to catch per minute of electrofishing (power-on time) to account for variation in sampling effort across sites. To fill in sampling gaps across NSW, an additional data set (Observed and non-Electrofishing data 270412) was used. This data were based upon different sampling techniques to electrofishing (e.g. different trapping methods), including observational data. The second data set was supplemented with an additional spatial dataset (MACPEE.shp) with records for the sampling sites of Murray cod because Murray cod records were not listed in the Observed and non-Electrofishing data 270412 data set. All site-based data were converted to presence/absence data for each threatened fish species record regardless of sampling effort. A third dataset was based on the predicted distribution of threatened and recreationally important fish species (see dpi.nsw.gov.au/__data/assets/pdf_file/0007/669589/fish-communities-and-threatened-species-distributions-of-nsw.pdf)

The distribution of EECs listed under the *NSW Fisheries Management Act 1994* was available as spatial layers initially provided by NSW Department of Primary Industries—Fisheries.

Details on rare River Styles® are provided in section 3.4.2.3.

3.2.3 Naturalness

Recovery potential (see Brierley and Fryirs 2005) was derived from the NSW Department of Industry River Styles® data set, and each river reach was allocated a score based on a designated recovery potential (see also, section 3.4.3.1). Recovery potential forms part of the geomorphic attributes assessed as part of the River Styles® assessment of NSW Rivers. The categories of recovery potential indicate river reaches that may be in more natural condition than others that may be more degraded.

NSW Hydrologic stress data and catchment disturbance index scores were obtained from the NSW Department of Industry River Condition Index (RCI) data set (Healey et al. 2012). The catchment disturbance index (CDI) outcomes for NSW rivers were initially derived at a small watershed scale (polygons) using the geofabric data layer in the development of the RCI (Healey et al. 2012).

For inland Murray–Darling Basin catchments, site-based Observed/Expected (O/E) aquatic macroinvertebrate data were included in the state-wide macroinvertebrate (AUSRIVAS) dataset provided by OEH (J. Miller pers. comm. 2014) and contains the outcomes of OEH's routine AUSRIVAS sampling program from 1994 to 2013.

For coastal catchments, macroinvertebrate O/E values were also used. The coastal O/E data are a biodiversity condition assessment derived from a river biodiversity modelling tool developed by Turak et al. (2011). These data are not site-based but are predicted outputs that are then spatially assigned to fit NSW coastal sub-catchments (see Healey et al. 2012). The predicted O/E data provide catchment-wide outcomes for macroinvertebrates based on the influence of human-induced disturbances (Turak et al. 2011). In contrast the site-based O/E approach used in inland catchments only extends along river reaches in the same or better geomorphic condition (see Section 3.3).

The National Parks Estate spatial layer was provided by OEH.

3.2.4 Vital habitat

The DIWA wetland layer was obtained from the Directory of Important Wetlands in Australia (DIWA) Spatial Database (DEE 2016a). The data set covered all the aquatic ecosystems within the DIWA listing (Environment Australia 2001), plus various additions for river-associated wetlands listed after 2001.

Coastal vital habitat assessment also included coastal wetlands mapped under the NSW State Environmental Planning Policy (SEPP) No. 14. In past 200 years, more than 70% of NSW coastal wetlands have been lost, mainly through drainage and land reclamation (Finlayson 2000) rendering the remaining coastal wetlands as significant habitat along the NSW coastline (DECCW 2010). SEPP 14 was developed to ensure that further wetland loss would be considered in land development activities and prevent it where necessary. The SEPP 14 spatial layer was obtained from the NSW Department of Industry spatial database.

For all wetland layers, only those that were intersected by the River Styles® layer (and / or within a 200 m buffer) were used, to ensure non-riverine wetlands were not included. A 200 m buffer was chosen to ensure that wetlands influenced by overbank flooding were included.

The LWD and DOC layers (see section 2.5.3) were derived from the NSW Department of Industry River Styles® mapping, and the Riparian Woody Extent raster dataset (Garlapati et al. 2010). The Riparian Woody Extent raster dataset (Garlapati et al. 2010) was derived from the NSW interim native vegetation extent layer (DECC 2008).

3.3 Weightings, scoring and prioritisation

Weightings can be applied to value assessments to reflect the purpose of the assessment and the views of stakeholders (Bennett et al. 2002). Applying a weighting process allows the final scoring to better represent the importance or priority of the factors (attributes) used in a project or for specific management needs (Clayton et al. 2006; Macgregor et al. 2011; Hughey 2013).

During the development of ‘macro’ WSPs in NSW, specific weightings linked to the flow sensitivity (Table 2) of stream dependent species, populations and communities were applied to catchment assessments (DIPNR 2005; NSW Office of Water 2010). As one example, the flow sensitivity weightings were agreed upon through discussions with NSW agency experts who considered that the legislative requirements of threatened species, populations and communities provide an objective approach to water planning needs (DIPNR 2005; NSW Office of Water 2010). The same approach to applying weightings to the most flow-sensitive attributes has been adopted in the NSW HEVAE methods for NSW rivers. This has been done for consistency and to highlight river reaches with the most flow-sensitive HEVAE attributes. This allows NSW agencies to better target water management options or strategies to help manage their water requirements, in an objective manner. However, new flow sensitivity weightings were adopted where the scientific evidence indicated a change to the original macro WSP weightings was justified (Appendix 2).

For example, if a threatened species population of an endangered ecological community had alteration to natural flow listed as a key threat (OEH 2005), it received a new flow sensitivity weighting of 4. Previously, using the macro WSP approach, some of these attributes would have received a weighting of 3 or lower. Specific details on each attribute associated with each HEVAE criterion regarding their flow-sensitivity weightings, flow requirements, scoring and primary scientific evidence are provided in Appendix 2.

Prioritisation of areas for assessment or management enables strategic focus on issues of the highest importance. However, determining priority areas across a large scale can be problematic without appropriate spatial tools. For example in this process we use GIS tools to assist in synthesising, and display outcomes across large (e.g. catchment-scale) areas.

During the development of the NSW riverine HEVAE methods, five scale categories were used, as they provided for greater variability in spatial outcomes, and reduced the effect of clumping caused by using fewer categories. These categories were then used to prioritise river reaches for management action, with 1 being lowest priority, and 5 being highest. Prioritisation in waterway assessment often uses simple scoring systems where individual attributes and overall outcomes are placed into categories ranging from low to high (e.g. 1 is lowest and 5 is highest) (Macgregor et al. 2011; Healey et al. 2012).

Table 2: The original flow sensitivity weightings used in the NSW Macro Water Sharing Plan development process. ***Source: DIPNR (2005)***

Score/ weighting	Definition	Typical examples
4	Highly sensitive to extraction, with specific flow—less able to move to alternative refuge.	Fish, some frogs (tadpoles).
3	Moderately sensitive to extraction and/or flow—some ability to adjust to flow changes or to relocate.	Macroinvertebrates, frogs (tadpoles), turtles, wet flora.
2	Slightly sensitive to extraction and/or flow—can generally survive across a wider range of flow conditions, or can move elsewhere to seek refuge.	Waterfowl, migratory waders.
1	Low sensitivity to extraction and/or flow—secondary relationship to flow and extraction.	Riparian vegetation, birds that nest in riparian trees.

Note: These original weightings used in the Macro Water Sharing Plan approach have since been adjusted (see Appendix 2 for revised weightings).

3.4 Calculating and scoring HEVAE criteria for NSW rivers

The following details describe each of the four criteria, how they were included in the NSW riverine HEVAE methods and the weighting processes applied. Details on how each criterion was scored and the overall HEVAE outcomes are also described.

3.4.1 Diversity

For the purpose of the NSW riverine HEVAE methods and based on the availability of data, fish diversity and the number of macroinvertebrate families, were selected as the attributes to inform the HEVAE diversity criteria (Figure 1). Details on each attribute's flow-sensitivity weighting, association with flow, scoring and primary scientific evidence are provided in Appendix 2.

Fish biodiversity scores were transferred into the River Styles® spatial layer via an ArcGIS model. The fish biodiversity site data that fell within the high category of classification (very high, high and medium) (Table 3) were transferred onto the River Styles® layer with the separation of reaches based upon:

- the River Style® type (category) where the site intersected the river line; and
- extending the site-based fish biodiversity information to the extent of the same River Style® of the same or better geomorphic condition, upstream and downstream from a specific classification point.

All the fish biodiversity classes were then assigned fish biodiversity scores according to Table 3. Fish diversity scores ceased being extended upstream and downstream when the River Styles® reach category changed or if the geomorphic condition category changed to a lower category.

After transferring the fish point data into the River Styles® river reaches, the outcomes were checked to ensure the placement of site-based data was matched to the correct river reach.

Table 3: HEVAE scores applied to NSW Department of Primary Industries—Fisheries Fish Biodiversity Hotspot outcomes

Fish (Hotspot) Biodiversity Classes	Fish Biodiversity Scores
Extremely High	1
Very High	0.8
High	0.6
Others	0

Fish have a high sensitivity to flow alteration and therefore received the highest flow weighting of 4 (Department of Primary Industries 2015d).

The site-based aquatic macroinvertebrate Family data (i.e. number of families per site) was extended using the same approach described for fish diversity site data. The attributes of the River Styles® layer for the number of families were analysed to determine the standard deviation from the mean of the macroinvertebrate distribution. Based on the standard deviation analysis, the River Styles® reaches were assigned macroinvertebrate diversity scores (0 to 1) according to Table 4.

The scoring approach outlined in Table 4 distinguishes sites with the highest to lowest macroinvertebrate family diversity within each catchment, not among catchments. This approach aims to be able to express catchment-to-catchment variability in family numbers and differences in standard deviations above the mean.

Table 4: Diversity scores applied to OEH macroinvertebrate family data

No. of Macroinvertebrate Families	Macroinvertebrate Diversity score
Site associated with river reaches that have the maximum number (e.g. 23+ to 34+) of families in the catchment. Can be 2+ standard deviations above the mean, or in the case of the Intersecting Streams, 1+ standard deviations above the mean (this was to allow greater differentiation between sites, given they are all very similar).	1
Site associated with river reaches that have the next highest number (e.g. 22 to 33) of families in the catchment. Can be 1+ to 2 standard deviations above the mean, or in the case of the Intersecting Stream, 0.5 to 1 standard deviation above the mean.	0.75
Site associated with river reaches that have the next highest number (e.g. 19 to 28) of families in the catchment Can be 0 to 1 standard deviations above the mean, or in the case of the Intersecting Stream, 0 to 0.5 standard deviation above the mean.	0.5
All other reaches. Family numbers can range from <10 to 24.	0

Note: In Table 4, a different approach was adopted for the Intersecting Streams to account for the reduced number of Families detected at sampling sites in that region.

Broadly speaking, aquatic macroinvertebrates have a strong association with aquatic environments, but not as strong as fish. Most riverine macroinvertebrates only have a larval stage associated with aquatic environments, and/or adults can easily disperse to other aquatic habitats as required. Macroinvertebrates received the second highest flow-sensitivity weighting of 3 to indicate the biotic group's moderately strong sensitivity to flow. This weighting is based on previous work undertaken as part of the Macro WSP process (DIPNR, 2005). Some macroinvertebrates taxa have different strategies to survive low flow and drought conditions through either mobile adult stages (Boulton et al. 2014) or having desiccation-resistant eggs or larval stages, with some larvae burrowing into hyporheic sediments (Boulton et al. 2014; Stubbington et al. 2009). When flow resumes, recolonization by these types of macroinvertebrates can occur. Hence the application of a lesser flow-sensitivity weighting compared to fish. Further details are provided in Appendix 2.

3.4.1.1 Calculating overall diversity scores

The two final attributes of fish and aquatic macroinvertebrate diversity in two different line layers were then transferred into a single river style line layer within ARC GIS and the overall diversity score was calculated using the equations below. Final scores for both macroinvertebrate and fish diversity were standardised (i.e. equating the maximum score to 1) by dividing the weighted scores with the appropriate maximum weighted score for the valley, of either fish or macroinvertebrates (Equation 1). Overall final (combined) diversity scores were standardised to provide a score range between 0 to 1 (Equation 2). Standardisation was used to help group the data (Noy-Meir et al. 1975; Quinn and Keough 2002) to avoid skewing of the result in favour of 'data-rich' attributes (Macgregor et al. 2011) and to allow equal influence of each attribute in the analysis of each dataset (Kennard 2010).

Equation 1: Fish or macroinvertebrate standardised score

$$\textit{Fish or Macroinvertebrate Diversity Standardised Score} = \frac{\textit{Fish or Macroinvertebrate score x Flow response score}}{\textit{Maximum weighted score within fish or macroinvertebrates}}$$

Equation 2: Overall HEVAE diversity score

$$\textit{Overall HEVAE Diversity} = \frac{\textit{(Equation 1(Fish) + Equation 1 (Macroinvertebrate))}}{\textit{Maximum (Equation 1(Fish) + Equation 2 (Macroinvertebrate))}}$$

3.4.2 Distinctiveness

For the purpose of the NSW riverine HEVAE, distinctiveness incorporated available data related to threatened species, populations, endangered ecological communities and rare River Styles®. Including these datasets complies with the Aquatic Ecosystems Task Group (2012a) definition of distinctiveness, adopted by the NSW riverine HEVAE.

Within the NSW HEVAE methods, the distinctiveness criteria focused on:

1. the available spatial and non-spatial data related to threatened instream, riparian and floodplain within 200 m buffer of stream) species, populations and communities (Figure 1); and
2. rare River Styles® (these river sections were a combination of uncommon and threatened River Styles within a catchment or regional area—see Section 3.4.2.3 for more details).

Further details on each distinctiveness attributes, flow-sensitivity weighting, association with flow, scoring and primary scientific evidence are provided in Appendix 2.

3.4.2.1 Threatened species, populations and communities

Alteration to natural flow regimes was listed as a key threat for many threatened freshwater species, endangered population and endangered ecological communities (EECs) (OEH 2015a). In NSW rivers, alteration to natural flow was also identified as a key threatening process (KTP) under both the TSC Act 1995 (OEH 2015a) and the FM Act 1994 via reviews through the scientific committee process. Under the FM Act 1994, the KTP was defined as 'Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams' (NSW Department of Primary Industries 2015c). Threatened species, endangered populations and EECs that had an alteration to natural flow listed as a key threat, received the highest flow sensitivity weighting of 4.

Threatened species were broken into broad taxonomic groups such as fish, frogs, mammals, waterbirds, plants, and ‘other aquatic species’ to allow for characterisation into a flow-sensitivity weighting groups. ‘Other aquatic species’ represent a small subset of different but varied taxa that are still stream-dependent (e.g. turtles, crayfish).

With the exception of predicted fish distributions, and site-based fish data, other site-based threatened species records were assigned to the geofabric sub-catchment (polygon) in which they occurred. Geofabric sub-catchments are small watershed polygons developed by the Bureau of Meteorology (BOM 2012), and were used by NSW Department of Industry in the RCI (Healey et al. 2012). All stream river reaches that fell within a geofabric sub-catchment were tagged as ‘recorded’ and these were weighted as 1 as the distribution score (Table 5) for a threatened species Wildlife Atlas record.

Applying site-based threatened species records to a geofabric polygon was appropriate to accommodate the denaturing process of some site-based threatened species records. Some sensitive threatened species had specific site records denatured to prevent the actual location being known with the aim of protecting the habitat and species (DECCW 2009). Applying site-based records to these polygons also took into account the potential capacity for some threatened species to disperse and that the Wildlife Atlas site-based records did not account for species abundance in a given location (OEH 2012).

The next scale of resolution for threatened species data was derived by using the ‘known’ and ‘predicted’ outcomes for threatened species, endangered populations and/or EECs based on IBRA subregions (NPWS 2003). Subregions were determined by differences in biophysical attributes including geology and vegetation, and are useful because they provide more detailed information about the landscape and can be used for finer scale planning (Environment Australia 2000; NPWS 2003). When altitude was indicated as a factor controlling a species’ distribution, a digital elevation model (DEM) was applied to the IBRA subregions. This helped refine the known and predicted distributions of threatened species to more realistic scales, otherwise distributions could be overestimated in subregions containing both high and low elevations.

For vegetation EECs, OEH provided the most up-to-date regional vegetation data for each catchment (OEH 2016). Within the vegetation spatial attribute table and reports are details where vegetation-based EECs could be associated with vegetation type polygons (OEH 2016).

To enable the distribution weighting of recorded species to be applied to these types of EECs, it was assumed that the vegetation EEC polygons were recorded data and received a recorded distribution weighting of 1. The recorded distributions of EECs were only considered in the areas that are located within 200m buffer zones along the rivers (100 m each side). Therefore, the river layer was intersected with the recorded distribution layer with the setting of a 200 m buffer. Each vegetation-based EEC was scored as recorded, known or predicted. If the recorded vegetation data were not available for a catchment, known (score 0.5) and predicted data (score 0.25) were used. The implications are that vegetation scores will be lower in valleys where there is no recorded data.

For EECs managed under the FM Act 1994, only predicted distributions were considered because there was no process available to reliably associate the widespread distribution of these EECs with other spatial data such as using vegetation types with OEH-managed EECs.

Threatened fish distribution assessment was based on recorded (site survey) data, and predicted distributions of threatened fish (see dpi.nsw.gov.au/__data/assets/pdf_file/0007/669589/fish-communities-and-threatened-species-distributions-of-nsw.pdf). Site-based threatened fish data was scored as presence or absence and were associated with River Styles®. This was accomplished by extending the threatened fish score to similar upstream or downstream river reaches of the same River Style® in the same or better geomorphic condition.

This approach was undertaken because similar river style categories should have the same geomorphic features (e.g. pools with large woody debris (LWD) and or diverse bedrock structure and with riparian zones in good condition) in similar river reaches in which they were sampled. The application of this assessment also took into account the influence of natural instream geomorphic barriers that may influence the dispersal of threatened fish species.

3.4.2.2 Rare River Styles®

Geomorphic rarity is poorly identified in Australia (Brierley et al. 2002; Macgregor et al. 2011). Although there has been limited mention of the use of the River Styles® framework to identify rarity (Brierley et al. 2002; Macgregor et al. 2011), no research has categorised rivers across NSW based on rarity.

The definitions below were used to identify rare River Styles® in each catchment and follow some of the criteria listed in the HEVAE framework. These criteria include: generally limited in occurrence within a catchment, are vulnerable to threats, and demonstrate regional or catchment-based endism (Brierley et al. 2002).

Geomorphic rarity and threatened River Style® reaches were defined using:

- percentage ranking of river reaches classed as a single River Style®
- sub-class of river reaches identified as being highly fragile and susceptible to change
- sub-class of River Style® reaches which are of high, rapid or conservation geomorphic recovery potential and fall into a class of river reaches which are below a set threshold.

For this project, geomorphic rarity was defined as meeting thresholds of:

- uncommon river reaches of a certain River Style® being below 2% of total reach lengths per catchment under assessment
- low or uncommon distribution within the catchment, with high risk of disturbance or alteration to become another River Style® (especially to those possessing high fragility), designated as those with greater than 5% categorised as having strategic recovery potential
- low or uncommon River Style® reach lengths, with a high proportion located adjacent to strategic priority geomorphic recovery potential reaches, with a nominal threshold of 25% reaches located adjacent to, or within 2 river reaches of, strategic recovery potential, river reaches.

Threat to River Styles® was linked to rarity, in that those River Styles® which were determined as threatened in catchments in south east Australia, were also assessed for the relative rarity of reaches classified as being in conservation recovery potential. Threats to River Styles® apply predominantly to those styles classified as having a high fragility to disturbance (Cook and Schneider 2006).These styles are more susceptible to changes (e.g. channel incision in chain of ponds River Styles), which can reduce the integrity and habitat heterogeneity of these reaches. Threatened River Styles® are classed as possessing:

- River Styles® with high fragility with reach lengths in the conservation recovery potential class, occupying less than 10% of that specific style in the catchment
- River Styles® with moderate or low fragility with reach length in conservation recovery potential class, occupying less than 2% of total mapped reach length in the catchment
- River Styles® with high fragility, with greater than 25% of mapped reach lengths within two reaches of strategic recovery potential reaches
- River Styles® with moderate fragility, with greater than 50% of mapped reach lengths within two reaches of strategic recovery potential reaches.

The criteria for threatened River Style® reaches were derived on the assumption that high-fragility River Styles® are threatened by processes occurring adjacent to, as well as within, the target reach. Historically initial degradation in river channels in south eastern Australia was primarily in response to channel incision, followed by channel expansion (Erksine and White 1996, Brooks et al. 2003) which has a high likelihood of knick-point migration upstream and sediment slug release affecting downstream river reaches.

The determination of these geomorphic factors was catchment specific and relies on individual catchment-based assessments.

3.4.2.3 Distinctiveness weightings

Weightings were applied to distribution (i.e. recorded, known or predicted), status (listing type) and response to alteration of flow.

River or stream-flow sensitivity of each threatened species, endangered population and EEC was determined by assessment of the individual listing profiles and supporting published literature. Weightings ranged from four (most sensitive to flow alteration) to one (least sensitive to flow alteration) (Table 2). Further details supporting the selection of flow-sensitivity weightings for each distinctiveness attribute are provided in Appendix 2.

An unweighted distribution was applied to each threatened species, endangered population and EEC based on the confidence associated with each distribution data type (Table 5). It was assumed that the site-based data (i.e. recorded in a specific survey) was likely to be more accurate, and therefore more confidence could be placed in a record occurring at a given site. Hence this factor was scored the highest of the four distribution score options (Table 5). Details on site-based threatened fish and rare River Style® weightings are also provided in Table 5.

Table 5: Weightings applied to the range of distribution data for threatened species, endangered populations and EECs listed under the NSW threatened species legislation and Rare River Styles®

Distribution term/ Rare River Style	Weighting based on confidence in the data.	Comment
Recorded (in NSW Wildlife Atlas *or* recorded from site-based sampling by NSW Department of Primary Industries— Fisheries *or* recorded as a specific data set developed to represent a specific listing (e.g. spatial data coverage for EEC)	1.0	Records lodged in an agency database in either the Wildlife Atlas or directly sampled by NSW Department of Primary Industries— Fisheries. Site records provide a high degree of confidence in the data due to sampling technique, expertise of sampler(s) and reporting approach to survey outcomes, hence the highest weighting. Can be contemporary or older data. Record of occurrence (presence) may also represent a polygon to indicate area where listing occurs. Site records can include threatened species and endangered populations. Includes mapped EECs managed under the TSCA 1995 associated with mapped vegetation communities.
Two rare River Styles® categories		Rare River Styles® category considered to be both rare and threatened. Determined via evaluation of mapped and categorised geomorphic spatial data within each catchment.
Known (web profile)	0.5	Polygons derived from Internet profile web pages. May not be considered the most up-to-date or recent, and the 'known' indicates a confirmed record within a broader IBRA subregion, not a specific site (OEH 2012). Exact location within polygon unknown. Hence, a lower weighting is given as the locational accuracy of the record is lower due to no site-based location being provided.
One rare River Styles® category		Only rare River Style® categories (and not threatened) are determined to occur. Determined via evaluation of mapped and categorised geomorphic spatial data within each catchment.

Distribution term/ Rare River Style	Weighting based on confidence in the data.	Comment
Predicted (web profile)	0.25	Indicates that this threatened species or endangered population or entity could potentially occur in an IBRA sub-region due to occurrence of suitable habitat. Based on a predicted distribution layer stored in the TS Profiles Database (OEH 2012). A lower score is given as no measure or field validation is provided to indicate confidence in model outputs. EECs managed under the FMA 1994 were also considered to have a predicted distribution.
One threatened River Styles® category		Only a threatened River Styles® category (and not rare). Determined via evaluation of mapped and categorised geomorphic spatial data within each catchment.
None (not known)	0	No distribution details available or the absence of data. A very low level of confidence in the data.

3.4.2.4 Threatened status weighting

Threatened status listings were those associated with the level of threat determined by the relevant scientific committees that oversee the listing of state (TSCA 1995 and FMA 1994) and Commonwealth (EP&BCA 1999) threatened species, endangered population and EECs. Status listings can range from vulnerable to critically endangered (Table 6). Weightings were applied to the status-listing for instream or flow-dependent threatened species, endangered populations and EECs collated for the distinctiveness criterion to enable the most threatened or valued species to have a higher significance.

Priority weighting using threatened status has assisted with identifying waterways of high natural heritage value and national importance (Chadderton et al. 2004). Threatened status has also been used to determine consequence rankings in terrestrial ecosystem studies (Eco Logical Australia 2011). A similar process has been adopted in the NSW HEVAE methods, where an entity that is endangered receives a higher weighting than one that is listed as vulnerable. This was also the case where a species, population or EEC has the higher listing between the state and Commonwealth legislation. Weightings provide an additional basis for identifying priority river reaches for water management needs. The weightings used in the NSW approach are provided in Table 6.

Table 6: Weightings applied to state (Threatened Species Conservation—TSC—Act and Environmental Protection and Biodiversity Conservation—EPBC—Act) threatened status categories in the distinctiveness HEVAE criterion in NSW

	EPBC Status			
TSC Status	Critically Endangered	Endangered	Vulnerable	Not Listed
Critically Endangered	4	4	4	4
Endangered	4	3	3	3
Vulnerable	4	3	2	2
Not Listed	4	3	2	none

3.4.2.5 Calculating 'group' scores

Each threatened attribute (i.e. species, endangered population and/or EEC or rare River Style®) was placed into specific 'groups' (Figure 2) based on flow sensitivity weightings (Table 2). These attributes were then assigned a score based upon the status weightings within each flow-sensitivity category (Equation 3 and Tables 5 and 6).

The next step combines all attributes within each flow sensitivity group (e.g. fish, frog or EEC with a flow sensitivity of 4) found within each river reach. Each attribute is standardised (Equation 3). Standardisation of scores were undertaken to ensure that the result would be relative to each attribute (Fish, Frog, EEC, rare River Style®) within each one of the four flow sensitivity categories (Figure 2). The standardised scores of each attribute within each flow-sensitivity group were summed to provide a flow rating score (Equation 4). Finally, the overall flow-sensitivity category score for each river reach was calculated by multiplying the flow-rating score by the flow-response weighting score for each group and standardising this score (Equation 5).

Equation 3: Individual attribute standardised scores

Individual attribute score = $\dfrac{\textit{(Unweighted distribution score x Status weighting within the same flow-response group)}}{\textit{Maximum (Unweighted distribution score x Status weighting within the same flow-response}}$

Equation 4: Flow rating score

Flow-rating score = ∑ attribute 'x' Stand.score (within the same flow response group)

Equation 5: Group distinctiveness score

Attribute "group" distinctiveness score = $\dfrac{\textit{Flow rating score x Flow-response weighting score of that particular group}}{\textit{Maximum ((Flow rating score x Flow-response weighting score of that particular group) within each of the four flow-response groups)}}$

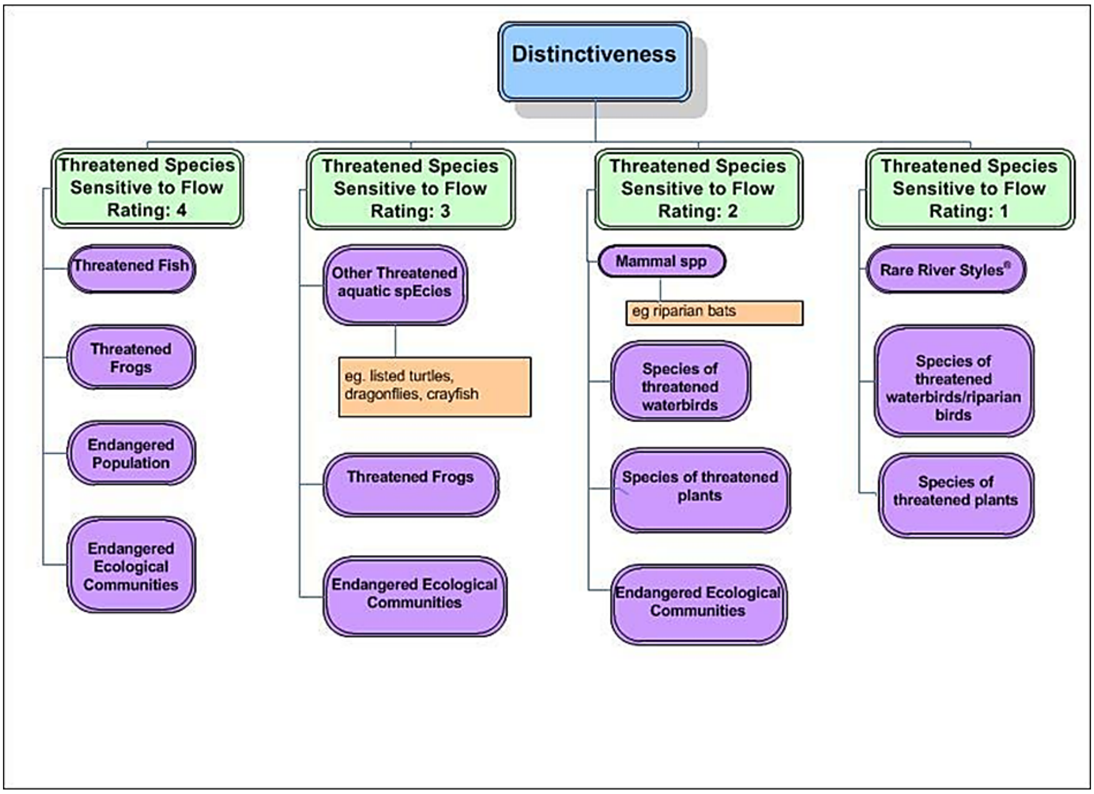

Figure 2: Example of how threatened attributes were placed into flow sensitivity groups

Note: Flow response groups were based on Table 2 (highest flow sensitivity = 4, lowest flow sensitivity = 1). Figure 2 is an example only, and does not list all species or populations used in the HEVAE assessment.

3.4.2.6 Calculating overall distinctiveness scores

Once each threatened species attribute ’group” distinctiveness score was determined, the overall distinctiveness score was calculated by summing up four ‘group’ distinctiveness scores and standardising the summed score (Equation 6). Standardisation of combined distinctiveness scores provides an overall distinctiveness score for each river reach between 0 and 1. Each overall distinctiveness score was associated with an individual River Style® river reach.

Equation 6: Overall HEVAE distinctiveness score

$$\textit{Overall distinctiveness score} = \frac{\sum \textit{group distinctiveness scores}}{\textit{Maximum (sum of group distinctiveness scores)}}$$

3.4.3 Naturalness

Naturalness, in the application of the NSW riverine HEVAE methods, focused on five attributes:

- Geomorphic condition (River Style® Value)
- Hydrologic Stress
- Catchment Disturbance Index
- Macroinvertebrate AUSRIVAS Observed/Expected (O/E) bands
- River reaches within National Park Estate.

In addition to the information provided below, details on each attribute’s flow-sensitivity weightings, flow requirements, scoring and primary scientific evidence are provided in Appendix 2.

3.4.3.1 Geomorphic condition

For the naturalness criterion, geomorphic condition was based on the mapped recovery potential of river reaches that were the closest to natural conditions (unimpaired or easily recoverable classifications). Recovery potential (i.e. trajectory of change) is defined as a measure of a stream reach's capacity to revert to good condition (Brierley and Fryirs 2005; Cook and Schneider 2006). The NSW Department of Industry has previously used six categories of recovery potential in geomorphic assessments (Cook and Schneider 2006).Two of these are likely to be most representative of no or little change and therefore reflect a state of naturalness.

Conservation recovery potential of a stream reach is indicative of stable geomorphic conditions with no recovery occurring or required (Cook and Schneider 2006). Rapid recovery potential of a stream reach is represented by moderate condition or upstream reaches in good geomorphic condition, with natural recovery occurring quickly (Cook and Schneider 2006).

Based on the logic above, the River Styles® data was allocated a score as follows; conservation recovery potential was scored highest (score = 1), rapid recovery potential scored next highest (score = 0.75) and all other categories of recovery potential were scored as 0.

3.4.3.2 Hydrologic stress

Hydrologic stress in the NSW HEVAE was derived from the RCI (Healey et al. 2012). Hydrologic stress was first specified 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 had already been calculated for each water source. The metric is 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 was applied to unregulated rivers in NSW where most extraction pressures are on low flows. The data used for the assessment of hydrologic stress across rivers in the NSW riverine HEVAE methods varied depending on availability (Figure 3).

Three core datasets were used:

- Distributed hydrologic stress assessment (most of NSW—green areas in Figure 3)
- Macro water sharing plan hydrologic stress data (yellow areas in Figure 3)
- Sustainable Rivers Audit (SRA) Hydrology Condition Index (pink areas in Figure 3).

Details on how the each measure of hydrologic stress is calculated are presented in Healey et al. (2012).

Additionally, in cases where a sub-catchment did not contain any active licences (based on the surface water licenses—NSW Office of Water 2010), the sub-catchment was assigned a 'very low stress' score of 1. In cases where more than 50%of the rivers in the sub-catchment were covered by the regulated water sources (NSW Office of Water 2010), the sub-catchment was assigned a score of 0.5, indicating 'very high stress'.

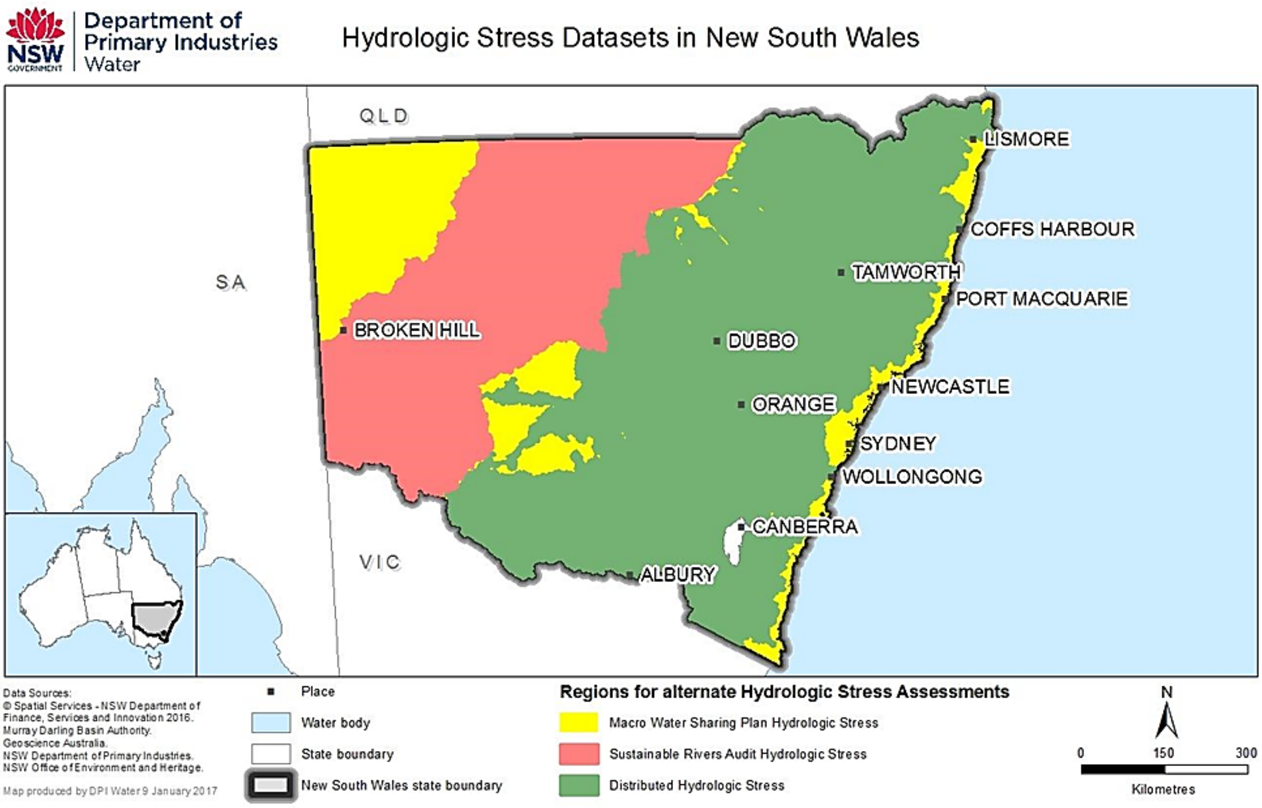

Figure 3: Locations of the hydrologic stress datasets across NSW rivers. Source: Healey et al. 2012

Scores were assigned to each river reach, with scores ranging from 0 (lowest contribution to naturalness or very high hydrologic stress) to 1 (highest contribution to naturalness or very low hydrologic stress). Details on the score categories applied to each river reach can be found in Appendix 2.

3.4.3.3 Catchment disturbance index (CDI)

CDI outcomes were derived from three sources:

i) infrastructure (e.g. roads, railways, utilities) density
ii) land-use index derived from the Australian Land Use mapping project (e.g. crop types, mining and urban uses, forest and plantations, grazing and managed resource areas)
iii) Land Cover Change Index based on loss of woody vegetation derived from the Statewide Land and Tree Study (SLATS) method (QLD Government, 2017) applied by OEH.

Each of the three CDI data sources were first calculated as individual sub-indices using the formulae recommended by Norris et al. (2007). The final CDI was calculated using the following formula from Norris et al. (2007):

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

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

This approach can reduce the final CDI score to a low value which was suitable when land use impacts were high and land condition was low, producing scores closer to or at 0. See Healey et al. (2012) for more details on each of the three data sources.

The overall CDI scores were transferred into the River Styles® layer. Scores applied to each river reach ranged from 0 (very high impact from catchment disturbance) to 1 (very low impact from catchment disturbance).

3.4.3.4 Macroinvertebrate AUSRIVAS O/E bands

The ‘AUSRIVAS Result’ dataset provided by OEH has a field called ‘Band’ which was used for assigning various O/E (observed/expected) Family-level model outputs to specific categories (Gray 2004). The numeric value of the field, called the OE50 score, was assigned a Band of A, B, C, D or X based on the O/E scores (Gray 2004). An OE50 score around 1 (range 0.85 to 1.15) equates to Band A, and indicated that the observed macroinvertebrate community was similar to the expected one. This was therefore equivalent to that of a reference (B and R) or undisturbed stream. Band B (O/E50 score range 0.55 to 0.84) indicated a degree of impairment to macroinvertebrate biodiversity relative to Band A and B, and R. An outcome lower than Band B suggested a much lower macroinvertebrate biodiversity was observed and the community was impoverished when compared to a reference site (Gray 2004).

In cases where score was higher than the range for Band A, the observed macroinvertebrate community was richer than the predicted or expected reference community and a Band category of ‘X’ was applied.

For the naturalness criteria in inland Murray–Darling Basin catchments, only the A, X and B AUSRIVAS bands were considered because these three O/E outcomes indicated either no or limited impairment of the macroinvertebrate communities. The other band letters (i.e. C and D) represented severely to extremely impaired communities compared to the reference condition and indicated a much lower degree of naturalness of the macroinvertebrate communities. For naturalness, macroinvertebrate communities were scored as:

- Naturalness Score = 1 for reaches with A or X bands
- Naturalness Score = 0.5 for reaches with B band
- All other reaches received a score of 0.

At times there may be some contrasting assessment outcomes for both macroinvertebrate diversity (see 3.4.1) and macroinvertebrate naturalness. A site may have been high in diversity (number of families is 35+) but may not have been a high band (X or A) of naturalness. Similarly, a site may have high naturalness (Band X or Band A) but may not have been high in diversity (number of families is fewer than 35). Examples of such outcomes are provided in Table 7.

Table 7: Examples of contrasting macroinvertebrate diversity and naturalness

Site	Diversity	Naturalness				Comments
ID	No of Families	O	E	O/E	Band	
101	40	20	80	0.25	D	High Diversity, low Naturalness
102	22	45	30	1.5	X	High Naturalness, low Diversity

The naturalness attribute score for inland site-based macroinvertebrate data was extended along the river line by associating it with specific River Style® river reaches as described in Section 3.4.1.

For coastal catchments where predicted sub-catchment O/E values were used, the O/E values already ranged between 0 (lowest condition) and 1 (highest condition). O/E scores ranging between 0.95 and 1.0 were considered as reference condition (Turak et al. 2011). Where the coastal sub-catchments intersected with the River Styles layer, the O/E score was applied to all river reaches in that sub-catchment.

3.4.3.5 River reaches within National Park Estate

For each river catchment, the NSW National Park Estate polygons were clipped into the layer. Where the National Park Estate polygon intersected a stream (with a 50 m buffer either side of the river line), a score of 1 was applied to the river reach indicating high naturalness associated with lack of human disturbance within the reserve boundary. The remaining river reaches were given scores of 0.

3.4.3.6 Naturalness weightings

Of the five naturalness attributes, four (geomorphic condition, hydrologic stress, catchment disturbance and National Park Estate) were applied with a flow-sensitivity weighting of 1 (low sensitivity to flow). Hydrologic stress implies a high level of flow alteration, and so the (attribute) scores already have the influence of flow sensitivity built in. River reaches with low hydrologic stress were automatically scored highest (score range from 0.8–1.0). Macroinvertebrate O/E scores were weighted the highest by a factor of 3 (moderately sensitive to flow) because most lotic larval stages having a significant reliance on river flow (Section 3.4.1). Further details are provided in Appendix 2.

3.4.3.7 Calculating attribute scores

Each naturalness attribute (i.e. geomorphic condition, hydrologic stress, catchment disturbance, macroinvertebrate O/E and National Park Estate) was standardised (Equation 7) by multiplying the unweighted distribution scores by the flow-sensitivity and dividing by the maximum score of all the attributes. Each score for each attribute was tagged to the appropriate River Style® river reach. Standardisation of scores was undertaken to ensure that the result will be relative to each attribute.

Equation 7: Standardised naturalness attribute score

$$\text{Standardised naturalness attribute score} = \frac{\text{Unweighted distribution score x flow response weighting}}{\text{Maximum (unweighted distribution score x flow response weighting)}}$$

3.4.3.8 Calculating overall naturalness scores

The overall standardised naturalness score was calculated by the total of each attribute score and dividing by the maximum of all the scores (Equation 8). Standardisation of each of the attribute scores provided an overall naturalness score for each river reach between 0 and 1. The final naturalness score was incorporated into the River Style® layer.

Equation 8: Overall HEVAE naturalness score

$$\text{Overall naturalness score} = \frac{\text{Sum of all standardised naturalness attribute scores } (A + B + C + D + E)}{\text{Maximum score } (A + B + C + D + E)}$$

3.4.4 Vital habitat

Vital habitat focuses on three attributes where statewide spatial data were available, and these included:

- wetlands (from Directory of Important Wetlands in Australia—DIWA)/Ramsar wetlands/SEPP14 — Coastal)
- large woody debris (LWD)
- dissolved organic carbon (DOC).

In addition to the information provided below, details on each attribute's flow-sensitivity weightings, flow requirements, scoring and primary scientific evidence are provided in Appendix 2.

3.4.4.1 Important wetlands

Wetlands are termed palustrine ecosystems in the HEVAE framework. This attribute is a composite of different listed aquatic ecosystems that meet the specific criteria for listing either in the Directory of Important Wetlands in Australia (DIWA) (Environment Australia 2001), or under the Ramsar Convention as a Wetland of International Importance. In addition aquatic ecosystems identified in the coastal region under SEPP14 are also included.

For each catchment, the DIWA/Ramsar/SEPP14 aquatic ecosystems were clipped within the catchment boundary. Individual catchment 'Vital Wetland' layers were generated by identifying which river reaches intersect with the wetland layer. If the river lines intersected a listed aquatic ecosystem within a 200 m buffer, they were included in the assessment. Those river reaches found to intersect listed aquatic ecosystems within the 200 m buffer were assigned a score of 1. Some of the listed systems were not intersected by the River Style® stream network because the layer did not include streams above third order or some River Styles® assessments missed mapping some lowland rivers. Any of the listed aquatic ecosystems located near these areas of incomplete River Styles® mapping did not receive a score.

3.4.4.2 Large woody habitat (LWH)

Riparian woody vegetation of 60% cover was selected from the riparian woody extent raster dataset (Garlapati et al. 2010) as a surrogate measure of both LWH and dissolved organic carbon (DOC). The spatial distribution of wood abundance along inland lowland sections of the Barwon–Darling River was significantly correlated with the percent tree cover in the adjacent riparian zone, with this relationship maximised at or just above 60% riparian tree cover (Matheson and Thoms, 2017).

The raster layer of riparian woody vegetation of 60% cover was transferred to the River Styles® layer, generated for other HEVAE attributes as discussed in detail above (see Section 3.3). The following steps were carried out to identify the proportion of vegetated (woody vegetation) length for each river reach:

- The Riparian Woody Extent raster dataset was simplified from eight types to two types: woody and non-woody. The definitions of the types (1 to 8) were provided in the metadata with three being woody and seven being non-woody (see Garlapati et al. 2010).
- The river (River Styles®) lines were buffered by 30 m to capture riparian woody raster outputs within this zone.
- In each river reach, the number of woody cells in the buffered river reaches was calculated, along with the total number of cells. This allowed the proportion of woody riparian zone per reach to be calculated (number of woody cells/total number of cells).

The identification of LWH was made by selecting river reaches that had greater than 60% woody riparian cover and the River Styles® that have specific characteristics related to laterally unconfined or partially confined valley settings. River Styles® of these types have either floodplain pockets or floodplain areas (Brierley and Fryirs 2005) where riparian vegetation occurs and can contribute to the supply of instream LWH (and also DOC). The locations of these River Styles® types were also areas where the energy of the river flow can dissipate and LWH that is transported during high flow events can be deposited. Riparian cover of 60% or greater was used based on the assumption that percentage coverage below this, contributes to lower LWH inputs (Matheson and Thoms, 2017). Therefore, the strategy was to conserve and value those riparian areas with the highest likely inputs of LWH, and where LWH was regarded as critical for habitat or geomorphology.

Reaches that had greater than 60% woody riparian cover and one of the following River Styles® received a LWH score of 1. All other reaches (less than 60% woody riparian cover and those greater than 60% woody riparian cover but not in the following 17 Common River Styles®) received a LWH score of 0.

Common River Styles® identified as potentially significant LWH habitat in all catchments included:

- PCVS—Planform controlled, meandering, fine grained
- PCVS—Planform controlled, low sinuosity, sand
- PCVS—Planform controlled, low sinuosity, fine grained
- PCVS—Planform controlled, meandering, sand
- LUV CC—Anabranching

- LUV CC—Anabranching, gravel
- LUV CC—Bank confined, sand
- LUV CC—Bank confined, fine grained
- LUV DC—Confluence wetland
- LUV DC—Lake delta
- LUV CC—Low sinuosity, fine grained
- LUV CC—Low sinuosity, gravel
- LUV CC—Meandering, fine grained
- LUV CC—Meandering, gravel
- LUV DC—Variable lake delta
- LUV CC—Wandering, gravel
- LUV CC—Wandering, sand.

3.4.4.3 Dissolved organic carbon (DOC)

Using the same three steps outlined in the LWH section (Section 3.4.4.2) above, significant DOC supply was identified by selecting river reaches that had greater than 60% woody riparian cover and River Styles® that were either laterally unconfined (scored 1) or partially confined (scored 0.5). Other River Styles® with less than 60% woody riparian cover received a score of 0. The use of these specific River Styles® types and their influence on the presence of riparian vegetation is justified in Section.3.4.4.2.

3.4.4.4 Vital habitat weightings

Initially, each of the three Vital Habitat attributes was applied a flow-sensitivity weighting of 1 (low sensitivity to flow). Following reassessment of the flow needs of listed aquatic ecosystems, the flow-sensitivity weighting for wetlands was changed from 1 to 4. This was appropriate given that alteration to natural flow is known to impact on the key MDB wetlands utilised by colonial waterbirds (Kingsford 2000; NPWS 2002; Bino et al. 2015). The impacts on waterbirds from changed flow regimes in key Basin wetlands was also a primary factor recognised for improvement under the Basin-wide environmental watering strategy (MDBA 2014b). LWH and DOC received a low flow sensitivity weighting of 2. Further details are provided in Appendix 2.

3.4.4.5 Calculating attribute scores

Each vital habitat attribute was standardised by multiplying the unweighted distribution scores by the flow-sensitivity weightings, and dividing by the maximum score of all the attributes (Equation 9). Each attribute score was associated with an individual River Style® river reach. Standardisation of scores was undertaken to ensure that the result will be relative to each attribute.

Equation 9: Standardised vital habitat attribute score

$$\textit{Standardised vital habitat attribute score} = \frac{\textit{Unweighted distribution score x Flow sensitivity weighting}}{\textit{Maximum score (unweighted distribution score x flow sensitivity weighting)}}$$

3.4.4.6 Calculating overall Vital Habitat scores

Overall vital habitat score was standardised by combining the attributes and dividing by the maximum score (Equation 10). Standardisation of each of the attribute scores provides an overall Vital Habitat score for each river reach between 0 and 1. The final Vital Habitat analysis was transferred onto the River Styles® layer to enable reach-based outputs.

Equation 10: Overall HEVAE Vital Habitat score

$$\text{Overall HEVAE Vital Habitat score} = \frac{\text{Attribute score } (A + B + C)}{\text{Maximum (attribute score } (A + B + C))}$$

3.5 Determining overall HEVAE outcomes

The final or overall HEVAE score was determined for each River Style reach by adding together the final scores for each criterion (naturalness, diversity, distinctiveness and vital habitat) and then standardising by dividing by the maximum combined HEVAE score for the whole catchment's river reaches to provide score outcomes between 0 (lowest) and 1 (highest) (Equation 11).

Equation 11: Overall HEVAE score

$$\text{Overall HEVAE score} = \frac{\text{Diversity score} + \text{distinctiveness score} + \text{naturalness score} + \text{vital habitat score}}{\text{Maximum (diversity score} + \text{distinctiveness score} + \text{naturalness score} + \text{vital habitat score)}}$$

A five-class system was adopted to display the four criteria and overall standardised score HEVAE outputs (Table 8). Using this type of classification is an accepted practice in waterway assessment (Bennett et al. 2002; Macgregor et al. 2011; Healey et al. 2012).

Table 8: Details on the five classes used to spatially display overall HEVAE or associated criteria in NSW rivers

Standardised score range	HEVAE Class
0.801–1.000	Very High Value
0.601–0.800	High Value
0.401–0.600	Medium Value
0.201–0.400	Low Value
0.000–0.200	Very Low Value

Each inland catchment or WSP area was modelled separately to enable each attribute within each criterion to be representative across the individual catchments. Due to their relatively small areas, adjacent coastal WSP areas were grouped based upon geological basement subregions and river geomorphic similarities to create sub regional zones. Using this process for coastal WSP areas enabled relative scorings of river reaches across equivalent catchment areas, and avoided the 'over-scoring' of reaches in very small WSP areas (e.g. Coffs Coast). These zones were grouped as follows:

- Far North: Tweed, Brunswick, Richmond/Wilson: falling entirely within the Mt Warning pluton or the underlying Clarence–Moreton Basin.
- Clarence–Coffs Coast: as the largest catchment in coastal NSW, it should be treated separately. It falls within the Central Complex-Upthrust Block subregions in its southern and eastern sections, and the New England granite batholith in the north-western section.
- Mid North Coast: Bellinger, Nambucca, Macleay: these catchments fall in the transition zone of the Eastern Fold Thrusts, Upthrust Blocks and Central Complex. They have some similarities, as sediment yield is similar from the highly altered geological domain, and have significant channel adjustments due to land-use activities.

- Lower North Coast: Hastings, Manning, Karuah/Great Lakes: these catchments lie in the southern section of the Tertiary uplift and contain large areas of National Parks, as well as coastal sandplain and dune-limited lakes.
- Hunter Basin, including all of the Hunter Valley and Central Coast catchments
- Sydney Basin: Hawkesbury–Nepean, Sydney Metropolitan, Shoalhaven and Wollongong Coast catchments overlying sedimentary rocks of the Sydney Basin
- Southern Rivers: Clyde, Deua–Moruya, Tuross, Bega, Snowy, Towamba; sharing similar catchment areas in conservation reserve areas (apart from the Bega) and similar levels of land use and hydrologic stress (except for the Snowy).

4 Results

The results provided in this section demonstrate the application of the NSW riverine HEVAE framework in a coastal (Hunter) and an inland (Gwydir) catchment in NSW. The Gwydir catchment is located in the northern MDB and the Hunter is located in the central coastal area.

In the Gwydir catchment, the five classes of HEVAE values were distributed across reaches in the headwaters, slopes and down to the lowland floodplains (Figure 4). However, some headwater reaches of the Gwydir have very low to low overall HEVAE scores that can be traced back through corresponding low criterion outcomes for these areas (Figure 4). The very high and high values were generally associated with the Gwydir River and associated Gwydir wetlands (Figure 4), largely due to the high number of threatened fish species, EECs and the Gwydir Ramsar site in the area.

In the Hunter Catchment, overall HEVAE values were unevenly distributed across the catchment (Figure 5) with a high proportion of very high and high values in the central coast area due to the SEPP 14 wetlands in the area and the high proportion of threatened species or EECs associated with the wetlands (Figure 5).

4.1 Diversity

The diversity criterion relied on combining site-based data from the two key data sets (fish and macroinvertebrates) and extending the diversity outcomes to river reaches of the same River Style® of the same or better geomorphic condition. This approach provided the least spatial variability of the five diversity categories (very low to very high) compared to the other HEVAE criteria (Figures 4 and 5). This may have been due to the lack of sampling points for fish and macroinvertebrates within a catchment, and the frequency with which River Style® types and condition can change. There was more sampling sites for macroinvertebrates inland than in the coast, hence the Hunter diversity scores are much lower than the Gwydir diversity scores (Figures 4 and 5).

4.2 Distinctiveness

Mapped outcomes for the distinctiveness criterion revealed substantial spatial variability (Figures 4 and 5) due to a combination of factors. Grouping of attributes into flow-sensitivity categories (Table 2) enabled the determination of where specific instream attributes are more vulnerable to alteration of flow than other attributes considered less sensitive. This gives us greater variability in the HEAVE results when a range of flow sensitivity weightings are applied, and allows us to focus on those areas where flow management interventions may provide the greatest benefit. A wider array of information was also incorporated within this criterion, ranging from site-based data for threatened species, populations and EECs through to broader outcomes for data associated with IBRA subregions. FM Act 1994 EECs also covered wide areas where many streams intersected respective distribution polygons. The availability of site-based data for attributes weighted the highest for distribution (recorded data) and flow-sensitivity in specific areas can produce clumping of spatial outcomes as seen, for example, in the eastern region of the Gwydir (distinctiveness value insert-map in Figure 4).

4.3 Naturalness

The naturalness criterion had the most number of input metrics that had data available across the entire catchment. As a result, this provided the greatest range of scores and coverage of results across river reaches (naturalness value insert-map in Figures 4 and 5). Of the five attributes assessed to determine naturalness (Figure 1), hydrologic stress, geomorphic recovery and catchment disturbance had the most complete spatial layer coverage across all river reaches in a catchment.

National Park Estate areas are not widespread within some catchments, limiting their influence on overall naturalness outcomes. Macroinvertebrate O/E scores also are not widely distributed across catchments due to site-based data being extended in a limited way along river reaches (as done for site-based diversity data). However, macroinvertebrate O/E data were weighted as 3, the second highest flow-sensitivity weighting but the highest weighting applied across all five naturalness attributes. This outcome, coupled with the highest outcomes for each of the other four attributes, influenced the higher naturalness scores in a river reach.

4.4 Vital habitat

The vital habitat criterion had the second smallest set of attributes utilised across all four HEVAE criteria. The lack of listed aquatic ecosystems within many catchments contributed to the limited spatial variability for vital habitat categories (Figures 4 and 5). Wetland attributes used in this criteria had the highest flow-sensitivity weighting of 4 compared to LWD and DOC attributes (weighted as 2), and this probably resulted in the reduced number of very high Vital Habitat river reaches in the Gwydir and Hunter catchments (vital habitat value insert-maps in Figures 4 and 5).

There was the greatest differentiation in medium and high score outcomes between uplands, the mid-slopes and lowlands in the Gwydir catchment. This was influenced by the presence of more site based threatened fish and the occurrence of the Ramsar listed Gwydir wetlands in the lowlands.

There were higher vital habitat river reaches mapped within the lowland zone in many catchments, including the Gwydir (Figure 4). This was largely due to the following factors:

- Specific River Style® types used to associate floodplain riparian vegetation occurrence may be too limited, implying that other River Styles® types should also be included. The types included were predominately found in lowland areas and not in upland areas.
- In many catchments, upland areas with the selected River Style® types do not have 60% riparian woody cover within 30 m of the bank due to vegetation clearance. These areas also lack of riparian vegetation recruitment.
- Accuracy of the River Style® mapping could be a contributing factor.

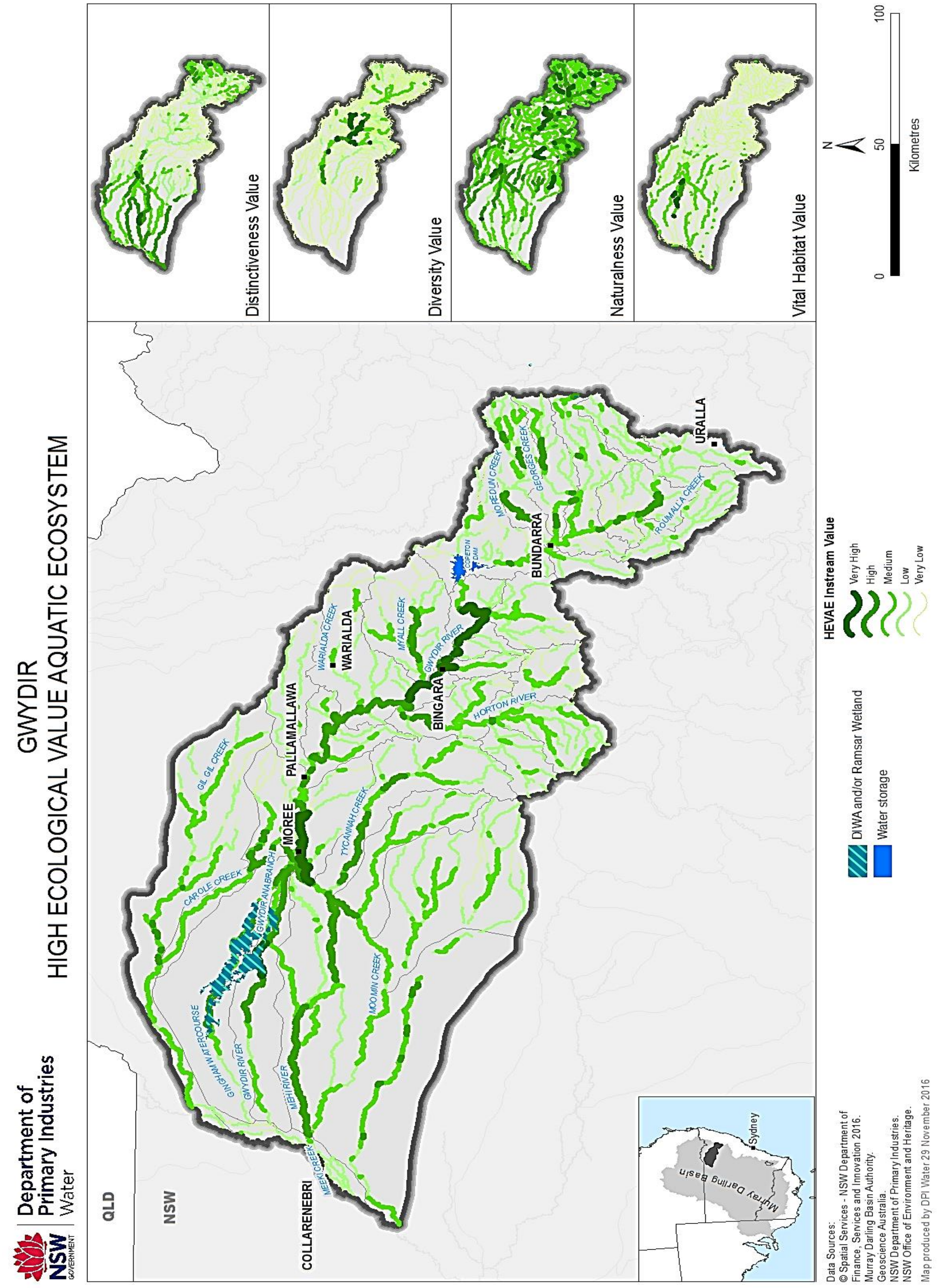

Figure 4: Overall HEVAE outputs for the Gwydir catchment, with associated criteria

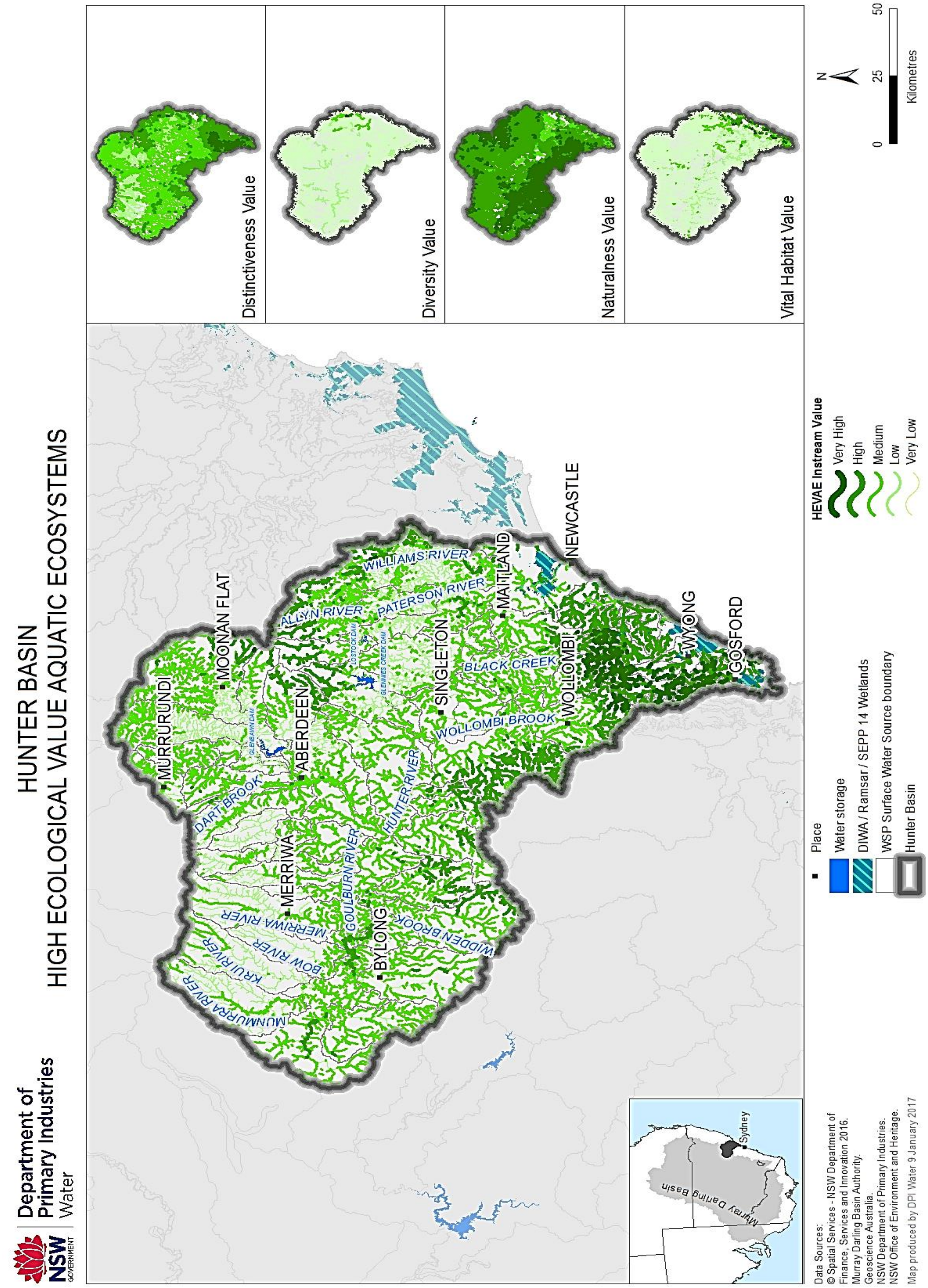

Figure 5: Overall HEVAE outputs for the Hunter catchment, with associated criteria

4.5 Limitations of applying the NSW datasets to the HEVAE method

No environmental assessment framework is without its limitations; the NSW riverine HEVAE methods are no different. Comprehensive spatial data were not available on the site-location or distribution of all the attributes used in this current NSW project. Thus, there is the chance that some spatial outcomes at the river reach scale may not be as accurate as the aims stated in Section 1.1 would always be desired. The limitations identified here, are referred to and addressed in the Recommendation section (see 5.1), with the aim to improve the next version of the HEVAE outputs. Limitations include:

1. Statewide data used in the diversity criterion were limited to two biotic groups (macroinvertebrates and fish), with no equivalent datasets available for other aquatic taxa. Spatial information on the diversity of aquatic habitats was also unavailable.
2. Most site-based data used in the diversity, distinctiveness and naturalness criteria were not consistently available or evenly distributed across all catchments. Site-based data for threatened aquatic species in the Atlas of NSW Wildlife were generally biased towards targeted site-specific surveys within national parks, other reserves or areas where development activity (e.g. mining, infrastructure development or land management alteration) has occurred or is occurring.
3. Extending site-based data to river reaches of the same River Style® of the same or better geomorphic condition was a conservative approach to estimating the range where a species or group of species might otherwise occur.
4. The use of low-resolution Landsat imagery to derive riparian vegetation extent data may have introduced errors reducing the accuracy of mapping riparian vegetation cover (Garlapati et al. 2010).
5. Some of the listed aquatic ecosystems (DIWA/Ramsar/SEPP14) may not have been included in the vital habitat assessment if River Styles® mapping was either incomplete or not undertaken for third-order streams or above. This may also be the case for other floodplain wetlands that are highly flow-dependent but located off-channel. Some of these aquatic ecosystems may also be vital habitat for riverine biota.
6. The data used for the vital habitat criterion in the coastal areas under-represents the actual habitat values and influences the overall HEVAE value scores.

It is important to remember that the initial, and many future outcomes derived from all criterion informing the HEVAE framework are not absolute in many cases. However, they do provide outcomes that allow for objective and pragmatic decision-making that will aid in the development of specific water management needs.

5. Discussion

The adaptation of the Commonwealth Government HEVAE framework for application to NSW rivers is a useful approach to synthesising a range of related information to help prioritise areas of importance for water management needs. The NSW riverine HEVAE methods provide a robust, spatially enabled, ecological-value data set at the river-reach scale for NSW rivers.

The draft High Conservation Value Aquatic Ecosystem (HCVAE) framework (a predecessor of HEVAE) was tested for several catchments within Australia prior to the finalisation of the framework. The finalisation of the framework also resulted in a change from ‘conservation’ value to ‘ecological’ value to allow for conservation and management issues to be removed from the framework (Aquatic Ecosystems Task Group 2012d). The number of criteria used in the final HEVAE framework was reduced from seven to five criteria by removing criterion 1 (International Recognition) and criterion 6 (Evolutionary History) as recommended in the HCVEA trial report (Peters 2010).

All the trials completed for testing the HCVEA framework, except the Northern Australia trial (Kennard 2010) and Tasmanian trial (DPIPWE 2010), used the Queensland AquaBAMM method (Clayton et al. 2006). The trial catchments/basins where AquaBAMM was used included the Lachlan, Condamine-Balonne, Barwon–Darling, Macquarie-Castlereagh and Lake Eyre Basin catchments (NSW Department of Primary Industries 2008a to c; Hale 2010). AquaBAMM was developed by the Queensland Government to enable assessment of conservation values at a catchment scale or at an individual wetland scale (Clayton et al. 2006). AquaBAMM uses a variety of spatially enabled datasets with data weighted based upon their importance to the indicators, and the indicators ranked by their importance to the criteria using expert opinion (Clayton et al. 2006; Fielder et al. 2011). HEVAE trials have also occurred in Cooper Creek (Negus et al. 2012).

NSW Department of Industry also used a weighting process for the NSW HEVAE methods based upon sensitivity to changes in flow regime (derived from either the literature or expert opinion) rather than the importance of an indicator to a criterion. Weighting of riverine attributes based on their sensitivity to flow, distribution and threatened status was a useful process to assist with river reach prioritisation and locating where the most important river reaches were located within a catchment. Prioritisation is an important part of the HEVAE framework to ensure NSW Department of Industry could consider appropriate water management rules to maintain or protect the HEVAE assets across locations. For the flow sensitivity weighting, although there was limited specific flow threshold data for some individual attributes, there was generally enough web-based or published evidence to defend weighting selections. Weightings have also been used in a New Zealand (Hughey 2013) and Australian (Macgregor et al. 2011) river value assessment to assist in determining the importance of river values over others.

An aquatic value assessment in northern Australia indicated weightings are best applied through expert opinion and statistical reasoning (Clayton et al. 2006; Kennard 2010). The flow-sensitivity weightings in the NSW riverine HEVAE methods used to support the macro WSP process were developed through the input of agency experts (DIPNR 2005; NSW Office of Water 2010) expert opinion and published literature. This approach provided the rationale for the use of the particular weightings. Outputs from NSW HEVAE methods for rivers has already been used in the management of river flow rules in some catchments (e.g. review of dealing rules in WSPs; update of the Hunter Unregulated WSP), so it was logical to apply flow-sensitivity weightings to ensure the management of water extraction is targeted to the HEVAE values at highest risk.

If no flow weightings had been used in the NSW riverine HEVAE methods, the distinctiveness results may not have been adequate to differentiate the most important flow-sensitive ecological assets. For example, waterbirds can disperse across the landscape in search of more favourable riverine habitat more readily than most fish or frog species (Kingsford et al. 2010), with the exception of colonial nesting waterbirds. Developing water management decisions in those types of river reaches where waterbirds were recorded to be more prevalent may not be effective prioritisation (with the exception of breeding sites). Furthermore, one or more threatened fish species found in other locations that are more 'sensitive' to flow could be overlooked if weightings were not applied.

The standardisation of datasets in the NSW riverine HEVAE methods was undertaken to help aggregate data collected in different ways. While it may have had the desired effect to help reduce all the data down to a similar basis for comparison, the standardisation process also had another influence on data-poor site outcomes within catchment areas. Where there was limited site-based data, which was a frequent outcome in many areas, we observed that the final HEVAE scores were “dragged down” during the standardisation process. There is limited ability to overcome the absence of site-based data in some areas, except to either collect more site-based data or develop predictive models for HEVAE criteria to overcome non-uniform data coverage (Kennard 2010). However, to improve the confidence in any outputs from the predictive models, a model validation process using true presence/absence data (Kennard 2010) for all HEVAE criteria and attributes would need to occur.

Weighting of riverine attributes based on their sensitivity to flow, distribution and threatened status was a useful process to assist with river reach prioritisation and locating where the most important river reaches were located within a catchment. Prioritisation is an important part of the HEVAE methods to ensure we could consider appropriate water management rules to maintain or protect ecological assets across locations. For example, the very high and high ratings of overall HEVAE were used as the highest priority for actions in the risk assessments recently used to satisfy Basin Plan requirements.

For the flow sensitivity weighting, although there was limited specific flow threshold data for some individual attributes, there was generally enough web-based or published evidence to attribute to weighting selections.

Weightings have been used in New Zealand (Hughey 2013) and Australian (Macgregor et al. 2011) river value assessments to assist in determining the importance of river values over others. Aquatic value assessment in northern Australia indicated that weightings were best applied through expert opinion and statistical reasoning (Clayton et al. 2006; Kennard 2010).

The use of HEVAE criteria maps, alongside the overall HEVAE results, provided a useful approach to drill down into datasets and examine possible attributes influencing outcomes. The use of separate criteria scores and maps provided a level of transparency when considering the overall HEVAE in any given area (Aquatic Ecosystems Task Group 2012a).

The HCVAE trials used spatial scales of 50 km^2 to 500 km^2 catchments (Lake Eyre Basin). No geomorphic data were used in the distinctiveness criterion and only very high and high AquaBAMM output categories were applied to the final HCVAE outputs (NSW Department of Primary Industries 2008a to c; Hale 2010). The Northern Australian and Tasmanian trials also used either catchment or regional scales (DPIPWE 2010; Negus et al. 2012). In contrast, the NSW riverine HEVAE methods use a spatial scale of river reach which allows for targeted management options, especially where there are varied extraction pressures within a water source. Using geomorphic characteristics such as geomorphic condition in the naturalness criterion provides additional information to encompass the physical and functional aspects of rivers.

The HCVAE trials also indicated that there were limited spatial/catchment units where all criteria were met for AquaBAMM (NSW Department of Primary Industries 2008a to c; Hale 2010). The NSW riverine HEVAE methods allow for all the criteria to be met because each indicator or attribute used in each criterion was developed based upon the data available. The only criterion that has not been developed in the NSW HEVAE methods is ‘representativeness’ due to the current lack of data that can be applied to potential indicators/attributes. Once there are suitable data available, this criterion will be added to the methods.

The HCVAE trials incorporated non-riverine environments such as non-riverine wetlands, karstic waters and springs. In this report, the NSW application of the HEVAE Framework has only been applied to riverine ecosystems and intersecting listed aquatic ecosystems (e.g. DIWA/Ramsar/SEPP 14 ecosystems), allowing weightings to be tailored for flow-sensitive aquatic species and ecological functions. A separate HEVAE method is being developed for those ecosystems that are groundwater-dependent and this will cover non-riverine environments.

5.1 Recommendations

It is anticipated that there will be ongoing activities to improve the NSW riverine HEVAE in rivers to resolve the identified limitations and address other elements of the framework. These ongoing activities include collaboration with other state and Commonwealth agencies and adopting outcomes and considerations of recommendations from relevant research. Inclusion of stakeholder opinions enables scoring of data-deficient criteria and can improve the transparency of the framework (Macgregor et al. 2011).

Recommendations to improve the riverine HEVAE methods for NSW include:

1. Develop a classification of river types (for example, using hydrology and River Styles®), and based on the ANAE framework(Aquatic Ecosystems Task group, 2012c). Mapping and classification of aquatic ecosystems is considered to be a first step undertaken prior to commencing HEVAE assessments (Aquatic Ecosystems Task Group (2012a). This approach helps to place natural ecosystems into relevant groups (Aquatic Ecosystems Task Group 2012c). Recommendations from the trials of the riverine HEVAE methods highlighted the need to include bioregionalisation and typology to improve ecosystem mapping and ensure ecosystem delineation is appropriate (Hale 2010; Kennard 2010). The approach used for threatened River Styles® also needs to be peer-reviewed.

   Developing an aquatic classification approach for NSW rivers is a requirement for developing attributes to support the yet to be included criterion of representativeness (see next recommendation). This would also allow stratification of analysis, whereby HEVAE scores are calculated and compared among similar river types or regions, rather than the current approach, which assesses values relative to each other across whole catchments (e.g. where tableland stream, are being scored relative to lowland rivers).

2. Developing and including the representativeness criterion and associated attributes into the NSW riverine HEVAE methods. The Aquatic Ecosystems Task Group (2012a) suggests that in applying the HEVAE framework, representativeness can be used in an assessment when all other criteria have been applied, and can act as a filter to determine if the highest ecological values have been identified. This is contingent upon the completion of recommendation 1.
3. For each of the attributes/metrics that apply to HEVAE, identify which components of the flow regime (Boulton et al. 2014) they are most limited by. For example, a Black Box (*Eucalyptus largiflorens*) EEC will be most sensitive to changes in over bank flows (Jensen et al. 2007). This will provide an improved basis to enable each asset to be weighted to components of the flow regime, rather than trying to achieve an overall flow weighting. This approach is justified as water management activities focus on rule-based outcomes across the flow regime of rivers.
4. Examine the influence of standardising the data for threatened species within each flow response group. There are currently several standardisation steps within the distinctiveness criterion which may be contributing to the overall spread of the value results (sensitivity analysis).
5. Examine other attributes that could be used to inform the vital habitat criterion to provide a more accurate representation for this criterion especially on the coast where the vital habitat values are under representing the actual conditions on the coast. Examples could be the inclusion of key pool refugia (drought security layer), or reaches important for fish passage, or hydrologic complexity data mapped by NSW Department of Primary Industries—Fisheries.
6. Utilise where available, or develop better, predictive models for biota such as macroinvertebrates, and other river-linked biota to improve spatial coverage of existing site-based datasets.

   Predictive models have been found to improve incomplete data coverage in aquatic ecological value assessments, and enhancing model validation processes will improve the confidence in the use of these techniques (Kennard 2010).

   NSW Department of Primary Industries—Fisheries have developed new predictive datasets on Fish Community Status and threatened fish distributions (Riches et al. 2016). The categories used for Fish Community Status outcomes will allow weightings to be assigned in a similar and consistent way to how weightings were assigned to the fish biodiversity categories used in the first iteration of the HEVAE method. The distribution data on threatened fish has been incorporated into the HEVAE methods for NSW.

   Whole-of-catchment predicted modelling outcomes that use macroinvertebrates and other environmental attributes may inform HEVAE outcomes in coastal areas. An Aquatic Biodiversity Forecaster model developed by Turak et al. (2011) produces predicted conservation priority scores that may be useful to inform the diversity criterion at a regional level.

   When a process is determined to enable the inclusion of each of these datasets in a meaningful way, they will be incorporated into inland and coastal HEVAE assessments. Developing new statewide predictive modelling outcomes for macroinvertebrates will be explored further in the development of the HEVAE model. This should be a collaborative effort with OEH as they have the lead role in undertaking the statewide AUSRIVAS program.
7. Develop predictive models that incorporate key flow-sensitivity metrics, point (site) sampling locations and modelled predictive distribution outcomes. This will assist in determining relationships between flow-sensitive biota and where risks occur to biota from specific flow changes. This will improve confidence in specifying locations for instream diversity and distinctiveness attributes and where specific flow regimes are important for optimising these attributes.
8. Determine where additional sampling of instream biota (e.g. macroinvertebrates, fish and other instream taxa) should occur to inform the riverine HEVAE methods. Existing sampling sites are sparse or biased to specific locations in certain areas within catchments and additional sampling

sites would greatly improve HEVAE outcomes for these areas. In addition, NSW Department of Industry intends to review its approach to using macroinvertebrate diversity.

9. Investigate the use of SPOT 5, Sentinel and LiDAR (Tickle et al. 2013; OEH, 2014) imagery to improve the accuracy of currently mapped woody riparian vegetation to reduce any significant errors associated with current riparian vegetation mapping.
10. Investigate the additional River Style® types that should be incorporated into the determination of riparian vegetation cover associated with LWD and DOC. Consider two River Styles® that require LWD to maintain channel/pool form and provide critical habitat, which should be taken into consideration. These are i) Planform-controlled, low-sinuosity, gravel-bed and ii) Planform-controlled, meandering gravel-bed.
11. Determine where River Styles® mapping needs to be undertaken to better associate with DIWA/Ramsar/SEPP 14 wetlands that may have been missed in the current vital habitat assessment.
12. Investigate how the HEVAE attributes and methods developed for NSW rivers can link with identifying riverine ecosystem functions (e.g. input of dissolved organic carbon—DOC; lateral connectivity). This will improve outcomes for the naturalness and representativeness criteria. It will also assist in reporting on Basin Plan (Schedule 9) requirements for WRPs.
13. Where possible, ensure that existing datasets have been updated if future iterations of the methods are undertaken. This will enable trend-reporting to occur, and may be useful to help in evaluating the success or otherwise of WSP rules. Revision of HEVAE and input data is aimed to occur to coincide with review timelines associated with NSW water planning needs. We suggest every five years.
14. Development of a defendable validation and sensitivity process to support spatial outputs. A range of literature/evidence has been collated to support the inclusion of each of the attributes in the HEVAE framework. However, no process has been formally developed to validate the spatial outputs for each of the HEVAE criteria at the river reach scale. The use of expert opinion and ground-truthing are two recommended approaches to validating the HEVAE method outcomes (Aquatic Ecosystems Task Group 2012a).
15. Explore the use of fish metrics in the Naturalness Criterion.

5.2 Conclusion

The development of the NSW riverine HEVAE methods has enabled the spatial representation of flow-sensitive ecological values at the river reach scale. This application of the HEVAE Framework provides a useful approach to identify specific river sections of highest priority for water management actions targeted to reduce the risk, or impact, to the values from water extraction.

The NSW riverine HEVAE framework was applied consistently across catchments and was successful in differentiating river sections based on their flow-sensitive ecological values. The NSW riverine HEVAE method provides the scores for the individual criterion whose summation generates the overall HEVAE outcomes. This enables examination of specific drivers of the scores and outcomes, and enhances transparency in the scoring process (Aquatic Ecosystems Task Group 2012a).

The NSW riverine HEVAE method is focused on determining outcomes to assist NSW water management activities for WSPs and WRPs under the Basin Plan. The outputs from the NSW HEVAE methods have already been used to inform the risk assessment process being undertaken as a requirement of the Basin Plan (NSW Department of Industry, 2018). The WRP risk assessment process uses the HEVAE scores to provide the consequence component of the risk matrix.

The HEVAE method developed to support NSW water management requirements is an adaptive and ongoing process, and to date, has only been applied to riverine ecosystems. As new information becomes available, it will be updated to reflect the most recent and relevant data. NSW Department of Industry is likely to include additional data to enhance application of the HEVAE criteria in the near future, including adopting the classification of stream types using the Interim Australian National Aquatic Ecosystem Classification Framework Aquatic Ecosystems Task Group (2012c; Brooks et al. 2014), and the addition of the representativeness criterion.

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Appendix 1

Table 1: Alignment between the Basin Plan (Schedule 8) Key Environmental Asset (KEA) criteria and the HEVAE criteria (Basin Plan 2012; Aquatic Ecosystem Task Group, 2012). The HEVAE assessment is being implemented to support NSW Water Sharing Plan development.

KEA Criteria (Schedule 8)	HEVAE Criteria/associated attributes
Criterion 1: The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it is: (a) A declared Ramsar wetland; or (b) With environmental watering, capable of supporting a species listed in or under the JAMBA, CAMBA, ROKAMBA or the Bonn Convention.	Vital Habitat: An aquatic ecosystem provides vital habitat for flora and fauna species if it supports: i) Unusually large numbers of a particular native or migratory species; and/or ii) Maintenance of populations of specific species at critical life cycle stages; and/or iii) Key/significant refugia for aquatic species that is dependent on the habitat, particularly at times of stress.
Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) Represents a natural or near-natural example of a particular type of water-dependent ecosystem as evidenced by a relative lack of post-1788 human induced hydrologic disturbance or adverse impacts on ecological character; or (b) Represents the only example of a particular type of water-dependent ecosystem in the Murray-Darling Basin; or (c) Represents a rare example of a particular type of water-dependent ecosystem in the Murray-Darling Basin.	Naturalness: The ecological character of the aquatic ecosystem is not adversely affected by modern human activity. Associated attributes: - Geomorphic recovery (conservation or rapid) potential of River Styles®; - Hydrologic stress (demand v's low flow percentile); - Catchment Disturbance Index (infrastructure density, land use index and land cover change); - Macroinvertebrate (AUSRIVAS) O/E bands (i.e. deviation from reference); and - River reaches in National Park Estate.
Criterion 3: The water-dependent ecosystem provides vital habitat Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) Provides vital habitat, including: (i) A refugium for native water-dependent biota during dry spells and drought; or (ii) Pathways for the dispersal, migration and movements of native water dependent biota; or (iii) Important feeding, breeding and nursery sites for native water dependent biota; or (b) Is essential for maintaining, and preventing declines of, native water-dependent biota.	Vital Habitat: An aquatic ecosystem provides vital habitat for flora and fauna species if it supports: i) Unusually large numbers of a particular native or migratory species; and/or ii) Maintenance of populations of specific species at critical life cycle stages; and/or iii) Provides key/significant refugia for aquatic species that are dependent on the habitat, particularly at times of stress. Associated attributes: - Vital wetlands (Ramsar/DIWA/SEPP14 (coastal) listed wetlands); - Dissolved Organic Carbon (DOC) input (suggested surrogate measure = river reaches of 60% woody riparian vegetation cover and measure of unconfined or partially confined River Style); and - Large Woody Debris (LWD) (suggested surrogate measure = river reaches of 60% woody riparian vegetation cover and specific River Styles®).

APPENDIX 1 ….. continued.

KEA Criteria (Schedule 8)	HEVAE Criteria/associated attributes
Criterion 4: Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) Supports a listed threatened ecological community or listed threatened species; or Note: See the definitions of listed threatened ecological community and listed threatened species in section 1.07. (b) Supports water-dependent ecosystems treated as threatened or endangered (however described) under State or Territory law; or (c) Supports one or more native water-dependent species treated as threatened or endangered (however described) under State or Territory law.	Distinctiveness: The aquatic ecosystem is rare/threatened or unusual; and/or The aquatic ecosystem supports rare/threatened/ endemic species/communities/genetically unique populations; and/or The aquatic ecosystem exhibits rare or unusual geomorphological features/processes and/or environmental conditions, and is likely to support unusual assemblages of species adapted to these conditions, and/or are important in demonstrating key features of the evolution of Australia's landscape, riverscape or biota. Associated attributes: - State and/or Commonwealth listed threatened species, endangered populations and endangered ecological communities; and - Rare River Styles®.
Criterion 5: The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it supports, or with environmental watering is capable of supporting, significant biological diversity. This includes a water-dependent ecosystem that: (a) Supports, or with environmental watering is capable of supporting, significant numbers of individuals of native water-dependent species; or (b) Supports, or with environmental watering is capable of supporting, significant levels of native biodiversity at the genus or family taxonomic level, or at the ecological community level.	Diversity: The aquatic ecosystem exhibits exceptional diversity of species (native/migratory), habitats, and/or geomorphological features/processes. Associated attributes: - Macroinvertebrate Diversity (No. of AUSRIVAS Families); and - Fish Diversity (Fish biodiversity hot spots assigned to specific River Styles® reach).

Appendix 2

Details on HEVAE criteria and attributes related to flow sensitivity, flow associations, scoring, and the evidence base used

The following table provides details on the flow-sensitivity weightings, associations with stream or river flow, spatial representation and scoring (including the evidence base examples of primary evidence) that supports the inclusion of the attributes associated with each HEVAE criterion. Attribute association with flow is a key factor, as the HEVAE attributes (instream values) inform the consequence component of the risk assessment process being developed by NSW Department of Industry. The risk assessment process supports the Water Sharing Plan (WSP) in NSW coastal river catchments and Water Resource Plan (WRP) development in NSW inland river catchments within the Murray–Darling Basin. Water sharing rules or strategies to manage the risk to instream values from water extraction will be developed to support each of these plans and it is critical that the ecological data being used have an association with river flow.

A description of each of the column headings in the table are as follows:

HEVAE Criterion: HEAVE criteria used in NSW Framework and as described in Section 2 of this report.

HEVAE Attribute: HEVAE attributes used in NSW Framework and as described in Section 2 of this report.

Flow-Sensitivity Weightings: Weightings considered to best represent the flow needs of attributes and whether they may be impacted by alteration to natural flow and/or water extraction.

Association with flow: Details on attribute flow requirements, obtained from primary evidence base.

Spatial representation/scoring: How specific attribute scores are applied to river reaches (additional details are provided in Section 2 of this report).

Other scoring: Additional scoring to assist with prioritisation of attributes at the river reach scale.

Example of Primary Evidence (related to flow-sensitivity weightings and attribute association with flow): Key (primary) reference material used and considered to be part of, but not limited to, the evidence to associate HEVAE attributes with flow requirements or impacts from flow alteration. For the Distinctiveness criterion, a spreadsheet was developed that lists the key flow-related evidence documented on state and Commonwealth threatened species websites (hence the listing of specific websites as evidence against attributes in this criterion). Generally, the threatened listing has a 'final determination' (state government) or a listing or conservation advice has the key details for threatened listings and reference material is also associated with these documents. Recovery plans for some of the threatened species are also provided for some but not all threatened listings and these also contain a range of useful evidence and additional reference material.

For all other HEVAE criteria and attributes, a database has been compiled to list additional key references associated with each of the HEVAE criteria and attributes. Reference (evidence) material is compiled using the Google and Google Scholar search engines with searches based on affirmative and rational statements. The evidence base is not considered to be complete and will be added to as new supporting evidence is obtained.

Table 2: The attributes associated with each HEVAE criterion and the evidence base that indicates their relationship to river flow

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
Diversity	*Fish Diversity*	Received the highest sensitivity weighting of 4.	Most riverine fish have a strong association with water and flow; hence the highest sensitivity weighting applies. Alteration to flow frequently listed as a key threat.	Site-based metric applies to all river reaches above and below site with the same or better geomorphic condition.	For the GetisOrd data - Fish Hotspot Classes and Fish Biodiversity Scores: Extremely High = 1 Very High = 0.8 High = 0.6 Others = 0	Iwasaki et al (2012) Baumgartner et al. (2014) NSW Department of Primary Industries (2015) Ellis, I., Cheshire, K., Townsend, A., Copeland, C. Danaher, K. and Webb, L. (2016). Fish and Flows in the Murray River Catchment – A review of environmental water requirements for native fish in the Murray River Catchment. NSW Department of Primary Industries, Queanbeyan
	Macroinvertebrate *(Family data)*	Aquatic macroinvertebrates received the second highest sensitivity weighting of 3, to indicate this biotic group's moderately strong sensitivity to flow (e.g. riffle-dwelling macroinvertebrates are sensitive to flow yet many pool- and edge-dwelling families are not. As pool- and edge-dwelling families make up a substantial proportion of the	Have a strong association with flow, but not as strong as fish. Most aquatic macroinvertebrates have a larval stage associated with aquatic environments.	Site-based metric applies to all river reaches above and below site with the same or better geomorphic condition.	No. of Families scoring: 2+ or 1+ SD above mean = 1 1+ to 2 or 0.5 to 1 SD above the mean = 0.75 0 to 1 or 0 to 0.5 SD above the mean = 0.5 <10 – 24 Families = 0	Armaninia et al. (2014) Boulton and Brock (1999) Buchanan et al. (2013) Davies et al. (2012) Stubbington et al. (2009)

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
		macroinvertebrate community, especially in lowland rivers).				
Distinctiveness	*Threatened Birds*	For threatened waterbirds a weighting of 2 was applied, or 1 for the Osprey (*Pandion cristatus*).	Although colonial-nesting waterbirds rely on flow events for breeding, waterbirds have the capacity to disperse to more favorable locations if wetlands and/or rivers conditions are not suitable. Hence the low weighting. Some non-colonial nesting species occupy riverine channels influenced by base-flow and freshes. Colonial nesting and wetland species rely upon bankfull and overbank flows to encourage breeding events.	The following details below apply to all HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria Site-based records applied to all river reaches above and below site with the same or better geomorphic condition. Metric applies to all streams that fall within the River Condition Index (RCI) geofabric sub-catchments where the record occurs. Recorded (NSW wildlife atlas record) = 1; Known (OEH model) = 0.5; Predicted (OEH model) = 0.25	The following details below apply to the majority of HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria Each threatened listing score based on status classification: Vulnerable = 2, Endangered = 3, Critically endangered = 4 and use higher of either State or Commonwealth classification (see Table 6 in report).	Bino et al. (2015) Kingsford et al. (2010) Roshier et al. (2001)
	Threatened Fish	Received the highest sensitivity weighting of 4.	Most riverine fish have a strong association with water and flow, hence the highest sensitivity weighting applies. Alteration to flow			Lintermans (2007) NSW Department of Primary Industries (2015) dpi.nsw.gov.au/fisheries/species-protection/conservation/wh

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
			frequently listed as a key threat.			at-current http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl
	Threatened Plants *(aquatic or riparian)*	Sensitivity weightings between 3 (moderately sensitive to flow change) and 1 (least sensitive). Aquatic plants received the higher weighting of 3; riparian plants impacted by alteration to flooding received a weighting of 2; and threatened plants with ambiguous flow threats received a weighting of 1.	Most riverine instream aquatic plants rely on flow and/or permanent water : riparian and floodplain vegetation rely on presence of water and flows/inundation for dispersal of seeds, and persistence / development of seedlings (Roberts & Marston, 2011); plants with less or no reliance on flow occur in drainage lines or depressions near floodplain.	The following details below apply to all HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria	The following details below apply to the majority of HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria	environment.nsw.gov.au/threatenedSpeciesApp/ http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl Roberts, J. and Marston, F. (2011) Water Regime for Wetland and Floodplain Plants: A Source Book for the Murray–Darling Basin, National Water Commission, Canberra.
	Threatened Frogs	Sensitivity weightings range between 4 (most sensitive) and 2 (least sensitive). Frogs with alteration to natural flow listed as a key threat received the higher	Instream breeding species have a clear reliance on specific flows, whereas floodplain dependent species reproduce often when flooding (and heavy	Site-based records apply to all river reaches above and below site with the same or better geomorphic condition. Metric applies to all rivers	Each threatened listing score based on status classification: Vulnerable = 2, Endangered = 3, Critically endangered = 4	Anstis (2013) http://www.environment.nsw.gov.au/threatenedSpeciesApp/ http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
		weighting of 4; species impacted by alteration to flooding received a weighting of 3; and species reliant upon soaks or drainage lines received a weighting of 2.	rainfall) inundates flood-runners and floodplains. Some species (eg *Assa spp. and Philoria spp.)* can occur in headwater areas above extraction and in soaks so they are not influenced as greatly by flow.	that fall within the RCI geofabric sub-catchments where record occurs. Recorded (atlas record) =1; Known (OEH model) = 0.5; Predicted (OEH model) =0.25	and use higher of State or Commonwealth classification (see Table 5 in report).	
HEVAE Criterion	**HEVAE Attribute**	**Flow-Sensitivity Weightings**	**Association with flow**	**Spatial representation / scoring**	**Other scoring**	**Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)**
	Threatened Mammals *Other aquatic species* (includes	Sensitivity weightings generally a 2 (slightly sensitive to extraction or can move elsewhere for better conditions). Sensitivity weightings range from 4 (highly sensitive) through to 3 (moderate sensitivity to	Generally riverine/riparian threatened bat species that can be influenced via indirect impacts on availability of aquatic food resources and/or habitat through flow alteration. Most aquatic crustaceans are reliant on instream habitat and suitable river flow to oxygenate the	The following details below apply to all HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria Site-based records apply to all river reaches above and below site with the same or better	The following details below apply to the majority of HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria Each threatened listing score based on status classification: Vulnerable = 2,	Law and Chidel (2002) Law and Urquhart (2000) http://www.environment.nsw.gov.au/threatenedSpeciesApp/ Gilligan et al. (2007) http://www.environment.nsw.gov.au/threatenedSpeciesApp/

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
	threatened River Snail (Notopala sublineata), turtles crayfish and dragonflies)	extraction /alteration to flow with some capacity to relocate).	water column. Most aquatic snails, turtles and macroinvertebrate larvae have similar reliance.	geomorphic condition. Metric applies to all streams that fall within the RCI geofabric sub-catchments where the record occurs. Recorded (atlas record) = 1; Known (OEH model) = 0.5; Predicted (OEH model) = 0.25	Endangered = 3, Critically endangered = 4 and use higher of State or Commonwealth classification (see Table 5 in report).	http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl http://www.dpi.nsw.gov.au/fisheries/species-protection/conservation/what-current
HEVAE Criterion	**HEVAE Attribute**	**Flow-Sensitivity Weightings**	**Association with flow**	**Spatial representation / scoring**	**Other scoring**	**Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)**
	Threatened Populations (generally fish, and one frog population (Tusked frog, *Adelotus brevis)*	Flow-sensitivity scores range from 4 (highly sensitive) through to 3 (moderate sensitivity to extraction /alteration to flow).	Fish have a strong association with water and flow, hence the highest sensitivity weighting applies. Alteration to flow is frequently listed as a key threat for fish. The frog, *Adelotus brevis* reproduces in streams			Anstis (2013) Lintermans (2007) NSW Department of Primary Industries (2015) dpi.nsw.gov.au/fisheries/species-protection/conservation/what-current environment.nsw.gov.au/threatenedSpeciesApp/

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
			(and ponds) and tadpoles occupy creeks.			
	Endangered Ecological Communities	Flow-sensitivity weightings between 4 (most sensitive) and 1 (least sensitive). EECs with alteration to natural flow listed as a key threat received the highest weighting of 4; EECs impacted by alteration to flooding received a weighting of 3, EECs that contain a small number of flood- reliant species received a weighting of 2, and EECs where there was uncertainty of their occurrence in a catchment, received a weighting of 1.	Some EECs either rely on river flows and/or flooding for the maintenance of flora and fauna that occur within them, in particular dispersal and recruitment requirements	The following details below apply to all HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria Site-based records apply to all river reaches above and below site with the same or better geomorphic condition. Metric applies to all rivers that fall within the RCI geofabric sub-catchments where the record occurs. Recorded (atlas record and/or OEH managed EEC associated with a vegetation community) = 1; Known (OEH model) = 0.5; Predicted (OEH model and/or NSW Department of Primary Industries— Fisheries EEC) = 0.25	The following details below apply to the majority of HEVAE attributes (except for Rare River Styles®) listed against the Distinctiveness criteria Each threatened listing score based on status classification: Vulnerable = 2, Endangered = 3, Critically endangered = 4 and use higher of State or Commonwealth classification (see Table 5 in report).	environment.nsw.gov.au/threatenedSpeciesApp/ environment.gov.au/cgi-bin/sprat/public/sprat.pl dpi.nsw.gov.au/fisheries/species-protection/conservation/what-current
HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation /	Other scoring	Example of Primary Evidence (related to

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
				scoring		flow sensitivity weightings and association of attributes with flow)
	Rare River Styles®	Rare River Styles® have the lowest flow sensitivity weighting of 1.	Although river geomorphology is influenced by a wide range of flow types, responses tend to be long-term adjustments and are considered to have low sensitivity to water extraction/flow alteration.	Applied to river reaches where rare River Styles® were identified to occur. Both rare and threatened River Styles® occur together = 1 Only rare river style occurs = 0.5 Only threatened river style occurs = 0.25	Rare River Styles® have no threatened status, and were weighted a 1 (no status) which is the lowest of the Distinctiveness attribute status weightings.	Brierley and Fryirs (2005) Brierley et al. (2010) Fergus Hancock (NSW Department of Industry Geomorphologist) pers. com.
Naturalness	*Geomorphic Condition* *(recovery potential)*	River Styles® with *conservation* or *rapid* recovery potential have the lowest flow sensitivity weighting of 1.	Impacts from water extraction or altered flow are minimal or absent. Conservation recovery potential of a stream reach is indicative of stable geomorphic conditions and generally no recovery is occurring or required. Rapid recovery potential of a stream reach is represented by moderate condition or upstream reaches in good geomorphic condition, with natural recovery occurring quickly.	Applied to river reaches where rare River Styles® of conservation or rapid recovery potential were identified to occur. Least altered or most natural recovery potential categories were weighted the highest. Conservation recovery potential was scored highest (= 1) and rapid recovery potential scored next highest (=0.75) in the HEVAE analysis. All other categories of Recovery Potential were scored as 0.		Brierley and Fryirs (2000) Brierley and Fryirs (2005) Cook and Schneider (2006)

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
HEVAE Criterion	**HEVAE Attribute**	**Flow-Sensitivity Weightings**	**Association with flow**	**Spatial representation / scoring**	**Other scoring**	**Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)**
	Hydrologic Stress	Hydrologic Stress has the lowest flow-sensitivity weighting of 1.	Hydrologic stress implies a high level of flow-sensitivity, and should therefore receive a higher weighting. This was not required as the initial scoring has the impact of flow sensitivity built in. High hydrologic stress river reaches are automatically scored highest (score range from 0.8 – 1.0).	Scores were apportioned to each river reach. Very Poor or high hydrologic stress (0-0.2), Poor (0.2-0.4), Moderate (0.4-0.6), Good (0.6-0.8) and Very Good or low hydrologic stress (0.8-1.0).		DLWC (1998) Ladson and White (1999) NLWRA (2002) Healey et al. (2012) NSW Office of Water (2010)
	Catchment Disturbance Index *(CDI)*	Catchment Disturbance has the lowest flow-sensitivity weighting of 1.	Three factors contribute to this attribute: infrastructure, land use and land cover change.	CDI data were available as a polygon layer and the attributes were transferred onto the River		Norris et al. (2007b) Norris et al (2007c) Healey et al. (2012)

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
			For the purpose of this process, CDIs are not considered as ecological factors altered by changes to natural flow, but they can influence flow within riverine systems, and represent a change to the naturalness of a catchment.	Style layer. Scores applied to each river reach ranged from 0 (very low impact from catchment disturbance) to 1 (very high impact from catchment disturbance).		
HEVAE Criterion	**HEVAE Attribute**	**Flow-Sensitivity Weightings**	**Association with flow**	**Spatial representation / scoring**	**Other scoring**	**Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)**
	Macroinvertebrate *(Observed / Expected (O/E))*	Macroinvertebrate O/E has the second highest flow sensitivity weighting of 3.	Have a strong association with aquatic environments, but not as strong as fish. Most aquatic macroinvertebrates have a larval stage associated with aquatic environments.	Scores were extended along the river line by associating it with specific River Style river reaches as per the method mentioned in the macroinvertebrate diversity section of this document (Section3.4.3.4) and in this table above.	Only the A, X and B AUSRIVAS bands are considered because the O/E outcomes indicate either no or limited degrees of impairment (i.e. departure from natural) of the macroinvertebrate communities.	Davies et al. (2012) Harrison et al. (2011) Nichols and Dyer (2013) Marsh et al. (2012)

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
					Macroinvertebrate communities are scored as follows: Naturalness Score = 1 for reaches with A or X bands Naturalness Score = 0.5 for reaches with B band; and Naturalness Score = 0 for all other reaches.	
	River Reaches within National Park	Reaches within National Parks have the lowest flow sensitivity weighting of 1.	The occurrence of the river flowing through a National Park is a strong indicator of the river reaches being unmodified or in a more natural state. This can be modified if extraction occurs in river reaches upstream of a National Park or reserve.	For each river catchment spatial layer, the National Park Estate polygons were clipped into the layer. Where the National Park estate polygon intersected a stream (with a 50 m buffer either side of the river line), a score of 1 was applied to the river reach. Remaining river reaches were given scores of 0.		Bennett et al. (2002) Dunn (2000)
HEVAE Criterion	**HEVAE Attribute**	**Flow-Sensitivity Weightings**	**Association with flow**	**Spatial representation / scoring**	**Other scoring**	**Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)**

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
Vital Habitat	*DIWA/RAMSAR Wetlands*	DIWA/Ramsar wetlands received the highest flow sensitivity of 4.	Key wetlands of national and international importance that are strongly influenced by the occurrence of bankfull and overbank flows (i.e. these are a subset of DIWA / Ramsar wetlands). They play an important ecological or hydrological role in the natural functioning of a major wetland system/complex, provide refugia, are key breeding hot-spots for a range of flora and fauna, and can have cultural and historical significance.	River Style river reaches found to intersect DIWAR/RAMSAR wetland polygons were attributed a score of 1; those wetlands that do not intersect DIWA/Ramsar wetland polygons received a score of 0.		Bino et al. (2015) Environment Australia (2001) NPWS (2002) Kingsford (2000) environment.gov.au/water/wetlands/ramsar
	Large Woody Habitat *(LWH)*	LWH received a low flow-sensitivity weighting of 2.	Important instream features that mediate instream geomorphic processes and instream production, and provide habitat for biota. These influences occur across different flow regimes. Can be redistributed during high energy flows. LWD unlikely to be	Identification of significant habitat likely to be a source of DOC was made by selecting river reaches that had greater than 60% woody riparian cover and either laterally unconfined or partially confined River Styles® (scored 1). Other River Styles® with less than		Boulton et al. 2014) Hughes and Thoms (2002) Matheson and Thoms, in prep Webb and Erskine (2003) Wohl and Jaeger (2009)

HEVAE Criterion	HEVAE Attribute	Flow-Sensitivity Weightings	Association with flow	Spatial representation / scoring	Other scoring	Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)
			directly sensitive to flow extraction.	and/or greater than 60% woody riparian cover received a score of 0.		
HEVAE Criterion	**HEVAE Attribute**	**Flow-Sensitivity Weightings**	**Association with flow**	**Spatial representation / scoring**	**Other scoring**	**Example of Primary Evidence (related to flow sensitivity weightings and association of attributes with flow)**
	Dissolved Organic Carbon	DOC sources received a low flow sensitivity weighting of 2.	While baseflow generates some DOC, flood conditions can generate up to 90 times more DOC. The range of flow regimes assist in the downstream distribution of DOC that, in turn influences instream production. Externally derived carbon inputs are predicted to rise with flows down a river network as a result of increased longitudinal inputs including increased riparian and floodplain connectivity.	Identification of significant DOC habitat was made by selecting river reaches that had greater than 60% woody riparian cover and either laterally unconfined River Style (which scored 1) or partially confined (which scored 0.5). Other River Style with less than 60% woody riparian cover received a score of 0.		Hadwen et al. (2009) Moran et al. (2014) Robertson et al. (1999) Schlesinger and Melack (1981) Westhorpe and Mitrovic (2014)

Appendix 3

Species, populations, and communities used in the distinctiveness criteria for each valley.

Table 3: Border Rivers

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weighting
Lowland Darling River endangered ecological community		EEC	Endangered Ecological Community	Not Listed	4	3
Eel Tailed Catfish	*Tandanus tandanus*	EP	Endangered Population	Not Listed	4	3
Olive perchalet	*Ambassia agassizii*	EP	Endangered Populations	not listed	4	3
Murray cod	*Maccullochella peelii*	Fish	not listed	Vulnerable	4	2
oxleyan pygmy perch	*Nannoperca oxleyana*	Fish	Endangered		4	3
Purple Spotted gudgeon	*Mogurnda adspersa*	Fish	Endangered Population	not listed	4	3
Silver Perch	*Bidyanus bidyanus*	Fish	Vulnerable	Critically endangered	4	4
Booroolong frog	*Litoria booroolongensis*	Frog	Endangered	Endangered	4	3
Glandular Frog	*Litoria subglandulosa*	Frog	Vulnerable	Not Listed	4	2
Stuttering Frog	*Mixophyes balbus*	Frog	Endangered	Vulnerable	4	3
Yellow Spotted tree frog	*Litoria castanea*	Frog	Critically endangered	Endangered	4/3 new	4
Sloanes Froglet	*Crinia sloanei*	Frog	Vulnerable	Not Listed	3	2

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weighting
Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregions		EEC	Endangered Ecological Community	Not listed	3	3
Marsh Club-rush sedgeland in the Darling Riverine Plains Bioregion		EEC	Critically endangered ecological community	Not Listed	3	4
Upland Wetlands of the Drainage Divide of the New England endangered ecological community		EEC	Endangered Ecological Community	Endangered	3	3
Tusked Frog pop	*Adelotus brevis- EP*	EP	Endangered Population	Not Listed	3	3
Bell' Turtle	*Elseya belli*	Other Aquatic	Endangered		3	3
Giant Dragonfly	*Petalura gigantea*	Other Aquatic	Endangered	Not Listed	3	3
Australian Painted snipe	*Rostratula australis*	Bird	Endangered	Endangered	2	3
Black-necked stork	*Ephippiorhynchus asiaticus*	Bird	Endangered	Not Listed	2	3
Blue-billed Duck	*Oxyura australis*	Bird	Vulnerable	Not Listed	2	2
Brolga	*Grus rubicunda*	Bird	Vulnerable	Not Listed	2	2
Cotton Pygmy-Goose	*Nettapus coromandelianus*	Bird	Endangered	Not Listed	2	3
Curlew sandpiper	*Calidris ferruginea*	Bird	Endangered	Critically endangered	2	4
Freckled duck	*Stictonetta naevosa*	Bird	Vulnerable	Not Listed	2	2
Magpie Goose	*Anseranas semipalmata*	Bird	Vulnerable	Not Listed	2	2

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weighting
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions		EEC	Endangered Ecological Community	Not listed	2	3
Greater Broad nosed bat	*Scoteanax rueppellii*	Mammal	Vulnerable	Not Listed	2	2
Southern myotis	*Myotis macropus*	Mammal	Vulnerable	Not Listed	2	2
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion		EEC	Endangered Ecological Community	Endangered	1	3
braid fern	*Platyzoma microphyllum*	Plant	Endangered	Not Listed	1	3
Cyperus conicus		Plant	Endangered	Not Listed	1	3
Shrub sida	*Sida rohlenae*	Plant	Endangered	Known	1	3
Torrington Pea	*Almaleea cambagei*	Plant	Endangered	Vulnerable	1	3
Warra Broad-leaved Sally	*Eucalyptus camphora subsp. relicta*	Plant	Endangered	Not Listed	1	3

Table 4: Gwydir

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
eel-tailed catfish	*Tandanus tandanus*	EP	Endangered Population	not listed	4	3
olive perchlet	*Ambassis agassizii*	EP	Endangered Populations	not listed	4	3
silver perch	*Bidyanus bidyanus*	Fish	Vulnerable	Critically	4	4

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
				endangered		
purple spotted gudgeon	*Mogurnda adspersa*	Fish	Endangered Population	not listed	4	3
Murray cod	*Maccullochella peelii*	Fish	not listed	Vulnerable	4	2
Booroolong frog	*Litoria booroolongensis*	Frog	Endangered	Endangered	4	3
yellow-spotted tree frog	*Litoria castanea*	Frog	Critically endangered	Endangered	4	4
Lowland Darling River aquatic ecological community		EEC	Endangered Ecological Community	not listed	4	3
river snail	*Notopala sublineata*	Other aquatic	Endangered	not listed	4	3
Marsh Club-rush sedgeland in the Darling Riverine Plains Bioregion		EEC	Critically endangered ecological community	not listed	3	4
Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregions		EEC	Endangered Ecological Community	not listed	3	3
Upland Wetlands of the Drainage Divide of the New England Tableland Bioregion		EEC	Endangered Ecological Community	Endangered	3	3
Bell's turtle	*Elseya belli*	Other aquatic	Vulnerable	Vulnerable	3	2
Australian painted snipe	*Rostratula australis*	Bird	Endangered	Endangered	2	3
black-necked stork	*Ephippiorhynchus asiaticus*	Bird	Endangered	not listed	2	3
blue-billed duck	*Oxyura australis*	Bird	Vulnerable	not listed	2	2

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Brolga	*Grus rubicunda*	Bird	Vulnerable	not listed	2	2
freckled duck	*Stictonetta naevosa*	Bird	Vulnerable	not listed	2	2
magpie goose	*Anseranas semipalmata*	Bird	Vulnerable	not listed	2	2
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions		EEC	Endangered Ecological Community	not listed	2	3
Tusked Frog population in the Nandewar and New England Tableland Bioregions	*Adelotus brevis*	EP	Endangered Population	not listed	2	3
greater broad-nosed bat	*Scoteanax rueppellii*	Mammal	Vulnerable	not listed	2	2
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion		EEC	Endangered Ecological Community	Endangered	1	3
braid fern	*Platyzoma microphyllum*	Plant	Endangered	not listed	1	3
Cyperus conicus	*Cyperus conicus*	Plant	Endangered	not listed	1	3
Torrington pea	*Almaleea cambagei*	Plant	Endangered	Vulnerable	1	3

Table 5: Namoi

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivty Weighting	Status
Lowland Darling River aquatic ecological community		EEC	Endangered Ecological Community		4	3
Tandanus tandanus	Eel Tailed Catfish	EP	Endangered Population		4	3
Ambassis agassizii	Western Olive Perchlet	EP	Endangered Population		4	3
Maccullochella peelii	Murray Cod	Fish		Vulnerable	4	2
Craterocephalus fluviatilis	Murray Hardyhead	Fish	Critically Endangered	Endangered	4	4
Bidyanus bidyanus	Silver Perch	Fish	Vulnerable	Critically endangered	4	4
Litoria daviesae	Davies' Tree Frog	Frog	Vulnerable	Not Listed	4	2
Litoria booroolongensis	Booroolong Frog	Frog	Endangered	Endangered	4	3
Notopala sublineata	River snail	Other aquatic	Endangered		4	3
Adelotus brevis- EP	Tusked Frog population in the Nandewar and New England Tableland Bioregions	EP	Endangered Population	Not Listed	3	3
Crinia sloanei	Sloane's Froglet	Frog	Vulnerable	Not Listed	3	2
Elseya belli	Bell's Turtle	Other Aquatic	Vulnerable	Vulnerable	3	2
Myriophyllum implicatum	Myriophyllum implicatum	Plant	Critically endangered	not listed	3	4

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivty Weighting	Status
Anseranas semipalmata	Magpie Goose	Bird	Vulnerable	Not Listed	2	2
Grus rubicunda	Brolga	Bird	Vulnerable	Not Listed	2	2
Limosa limosa	Black-tailed Godwit	Bird	Vulnerable	Not Listed	2	2
Oxyura australis	Blue-billed Duck	Bird	Vulnerable	Not Listed	2	2
Stictonetta naevosa	Freckled duck	Bird	Vulnerable	Not Listed	2	2
Irediparra gallinacea	Comb-crested Jacana	Bird	Vulnerable	Not Listed	2	2
Botaurus poiciloptilus	Australasian Bittern	Bird	Endangered	Endangered	2	3
Ephippiorhynchus asiaticus	Black-necked stork	Bird	Endangered	Not Listed	2	3
Rostratula australis	Australian Painted snipe	Bird	Endangered	Endangered	2	3
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions		EEC	Endangered Ecological Community	Not listed	2	3
Scoteanax rueppellii	Greater Broad-nosed Bat	Mammal	Vulnerable	Not Listed	2	2
Lepidium monoplocoides	Winged Peppercress	Plant	Endangered	Endangered	2	3
Euphrasia arguta	Euphrasia arguta	Plant	Critically Endangered	Critically endangered	2	4
Pandion cristatus	Eastern Osprey	Bird	Vulnerable	Not Listed	1	2
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands		EEC	Endangered Ecological Community	Endangered	1	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivty Weighting	Status
Bioregion						
Haloragis exalata subsp. velutina	Tall Velvet Sea-berry	Plant	Vulnerable	Vulnerable	1	2
Cyperus conicus	Cyperus conicus	Plant	Endangered	Not Listed	1	3
Sida rohlenae	Shrub Sida	Plant	Endangered	Known	1	3

6: Macquarie/Castlereagh

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Anseranas semipalmata	Magpie Goose	Bird	Vulnerable	Not Listed	2	2
Botaurus poiciloptilus	Australasian Bittern	Bird	Endangered	Endangered	2	3
Calidris ferruginea	Curlew Sandpiper	Bird	Endangered	Not listed /Critically endangered	2	3 now 4
Ephippiorhynchus asiaticus	Black-necked stork	Bird	Endangered	Not Listed	2	3
Grus rubicunda	Brolga	Bird	Vulnerable	Not Listed	2	2
Limosa limosa	Black-tailed Godwit	Bird	Vulnerable	Not Listed	2	2
Nettapus coromandelianus	Cotton Pygmy-Goose	Bird	Endangered	Not Listed	2	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Oxyura australis	Blue-billed Duck	Bird	Vulnerable	Not Listed	2	2
Pandion cristatus	Eastern Osprey	Bird	Vulnerable	Not Listed	1	2
Rostratula australis	Australian Painted snipe	Bird	Endangered	Endangered	2	3
Stictonetta naevosa	Freckled duck	Bird	Vulnerable	Not Listed	2	2
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions		EEC	Endangered Ecological Community	Not listed	2	3
Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregions		EEC	Endangered Ecological Community	Not listed	3	3
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion		EEC	Endangered Ecological Community	Endangered	1	3
Lowland Darling River aquatic ecological community		EEC	Endangered Ecological Community		4	3
Tandanus tandanus	Eel tailed catfish in the Murray/Darling Basin as an endangered population	EP	Endangered Population	not listed	4	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Ambassia agassizit	Olive Perchlet	EP	Endangered Populations	not listed	4	3
Maccullochella peelii	Murray Cod	Fish	not listed	Vulnerable	4	2
Mogunda adspersa	Purple spotted gudgeon	Fish	Endangered	not listed	4	3
Bidyanus bidyanus	Silver perch	Fish	Vulnerable	Critically endangered	4	4
Maccullochella macquariensis	Trout cod	Fish	Endangered	Endangered	4	3
Crinia sloanei	Sloane's Froglet	Frog	Vulnerable	Not Listed	3	2
Litoria aurea	Green & Golden Bell Frog	Frog	Endangered	Vulnerable	3	3
Litoria booroolongensis	Booroolong Frog	Frog	Endangered	Endangered	4	3
Litoria castanea	yellow-spotted tree frog	Frog	Critically endangered	Endangered	4	4
Litoria raniformis	Southern Bell	Frog	Endangered	Vulnerable	4	3
Scoteanax rueppellii	Greater Broad-nosed Bat	Mammal	Vulnerable	Not Listed	2	2
Notopala sublineata	River snail	Other Aquatic	Endangered	not listed	4	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Austrostipa wakoolica	A spear-grass	Plant	Endangered	Endangered	1	3

Table 7: Lachlan

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Lepidium monoplocoides	Winged Peppercress	Plant	Endangered	Endangered	**2**	**3**
Eleocharis obicis	Spike rush	Plant	Vulnerable	Vulnerable	**1**	**2**
Pilularia novae-hollandiae	Austral Pillwort	Plant	Endangered	Not Listed	**1**	**3**
Solanum karsense	Menindee nightshade	Plant	Vulnerable	Vulnerable	**3**	**2**
Carex klaphakei	Klaphake's Sedge	Plant	Endangered	Not Listed	**1**	**3**
Baloskion longipes	Dense cord rush	Plant	Vulnerable	Vulnerable	**1**	**2**
Austrostipa wakoolica	A spear-grass	Plant	Endangered	Endangered	**1**	**3**
Lowland Lachlan River EEC	Lowland Lachlan River EEC	EEC	Endangered Ecological Community	Not Listed	4	3
Crinia sloanei	Sloanes Froglet	Frog	Vulnerable	Not Listed	3	2
Litoria booroolongensis	Booroolong Frog	Frog	Endangered	Endangered	4	3
Litoria castanea	yellow-spotted tree frog	Frog	Critically endangered	Endangered	4	4
Litoria raniformis	Southern Bell	Frog	Endangered	Vulnerable	4	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Mixophyes balbus	Stuttering Frog	Frog	Endangered	Vulnerable	4	3
Myotis macropus	Southern Myotis	Mammal	Vulnerable	Not Listed	2	2
Scoteanax rueppellii	Greater Broad-nosed Bat	Mammal	Vulnerable	Not Listed	2	2
Euastacus armatus	Murray crayfish	other aquatic species	Vulnerable	not listed	3	2
Macquaria australasica	Macquarie Perch	Fish	Endangered	Endangered	4	3
Nannoperca australis	Southern pygmy perch	Fish	Endangered	not listed	4	3
Maccullochella peelii	Murray cod	Fish	not listed	Vulnerable	4	2
Bidyanus bidyanus	Silver perch	Fish	Vulnerable	Critically Endangered	4	4
Tandanus tandanus	Eel tailed catfish in the Murray/Darling basin	EP	Endangered Population	not listed	4	3
Ambassis agassizii	Western population Olive Perchlet	EP	Endangered Population	Not Listed	4	3
Botaurus poiciloptilus	Australasian Bittern	Bird	Endangered	Endangered	2	3
Rostratula australis	Australian Painted snipe	Bird	Endangered	Endangered	2	3
Oxyura australis	Blue-billed Duck	Bird	Vulnerable	Not Listed	2	2
Ephippiorhynchus asiaticus	Black-necked stork	Bird	Endangered	Not Listed	2	3
Grus rubicunda	Brolga	Bird	Vulnerable	Not Listed	2	2
Limosa limosa	Black-tailed Godwit	Bird	Vulnerable	Not Listed	2	2
Calidris ferruginea	Curlew Sandpiper	Bird	Endangered	Not listed/ Critically	2	3, now 4

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
				endangered		
Stictonetta naevosa	Freckled duck	Bird	Vulnerable	Not Listed	2	2
Anseranas semipalmata	Magpie Goose	Bird	Vulnerable	Not Listed	2	2
Pandion cristatus	Eastern Osprey	Bird	Vulnerable	Not Listed	1	2

Table 8: Murrumbidgee

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth Listing	Flow sensitivity Weighting	Status Weights
Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	EEC	Endangered Ecological Community		4	3
NSW Lower Murray River EEC	NSW Lower Murray River EEC	EEC	Endangered Ecological Community		4	3
Tandanus tandanus	Eel tailed catfish in the Murray/Darling basin	EP	Endangered Population	not listed	4	3
Bidyanus bidyanus	Silver Perch	Fish	Vulnerable	Critically endangered	4	4
Macquaria australasica	Macquarie Perch	Fish	Endangered	Endangered	4	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth Listing	Flow sensitivity Weighting	Status Weights
Maccullochella macquariensis	Trout Cod	Fish	Endangered	endangered	4	3
Mogurnda adspersa	Purple Spotted gudgeon	Fish	Endangered Population	not listed	4	3
Nannoperca australis	Southern pygmy perch	Fish	Endangered	not listed	4	3
Maccullochella peelii	Murray Cod	Fish	not listed	Vulnerable	4	2
Litoria booroolongensis	Booroolong Frog	Frog	Endangered	Endangered	4	3
Litoria castanea	yellow-spotted tree frog	Frog	Critically endangered	Endangered	4	4
Litoria raniformis	Southern Bell frog	Frog	Endangered	Vulnerable	4	3
Litoria verreauxii alpina	Alpine Tree Frog	Frog	Endangered	Vulnerable	4	3
Litoria aurea	Green & Golden Bell Frog	Frog	Endangered	Vulnerable	3	3
Solanum karsense	Menindee nightshade	Plant	Vulnerable	Vulnerable	3	2
Callitriche cyclocarpa	Western Water-starwart	Plant	Vulnerable	Not Listed	3	2
Crinia sloanei	Sloanes Froglet	Frog	Vulnerable	Not Listed	3	2
Anseranas semipalmata	Magpie Goose	Bird	Vulnerable	Not Listed	2	2
Botaurus poiciloptilus	Australasian Bittern	Bird	Endangered	Endangered	2	3
Grus rubicunda	Brolga	Bird	Vulnerable	Not Listed	2	2
Limosa limosa	Black-tailed Godwit	Bird	Vulnerable	Not Listed	2	2
Oxyura australis	Blue-billed Duck	Bird	Vulnerable	Not Listed	2	2
Rostratula australis	Australian Painted snipe	Bird	Endangered	Endangered	2	3
Stictonetta naevosa	Freckled duck	Bird	Vulnerable	Not Listed	2	2

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth Listing	Flow sensitivity Weighting	Status Weights
Calidris ferruginea	Curlew Sandpiper	Bird	Endangered	Not listed	2	3
Pseudophryne pengilleyi	Northern Corroboree frog	Frog	Critically endangered	Critically endangered	2	4
Pseudophryne corroboree	Southern Corroboree frog	Frog	Critically endangered	Critically endangered	2	4
Myotis macropus	Southern Myotis bat	Mammal	Vulnerable	Not Listed	2	2
Lepidium monoplocoides	Winged Peppercress	Plant	Endangered	Endangered	2	3
Pilularia novae-hollandiae	Austral Pillwort	Plant	Endangered	Not Listed	1	3
Amphibromus fluitans	Floating Swamp Wallaby-grass	Plant	Vulnerable	Vulnerable	1	2
Eleocharis obicis	Spike rush	Plant	Vulnerable	Vulnerable	1	2

Table 9: Murray – lower Darling

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Australasian Bittern	*Botaurus poiciloptilus*	Bird	Endangered	Endangered	2	3
Australian Painted snipe	*Rostratula australis*	Bird	Endangered	Endangered	2	3
Black-tailed Godwit	*Limosa limosa*	Bird	Vulnerable	Not Listed	2	2
Blue-billed Duck	*Oxyura australis*	Bird	Vulnerable	Not Listed	2	2
Brolga	*Grus rubicunda*	Bird	Vulnerable	Not Listed	2	2
Curlew Sandpiper	*Calidris ferruginea*	Bird	Endangered	Not listed	2	3
Freckled duck	*Stictonetta naevosa*	Bird	Vulnerable	Not Listed	2	2

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Magpie Goose	*Anseranas semipalmata*	Bird	Vulnerable	Not Listed	2	2
Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions		EEC	Endangered Ecological Community	Endangered	4	3
NSW Lower Murray River EEC		EEC	Endangered Ecological Community		4	3
Eel tailed catfish in the Murray/Darling basin	*Tandanus tandanus*	EP	Endangered Population	not listed	4	3
Olive perchlet	*Ambassia agassizii*	EP	Endangered Population		4	3
Flathead galaxia	*Galaxias rostratus*	Fish	Critically Endangered	not listed	4	4
Macquarie perch	*Macquarie australasica*	Fish	Endangered	Endangered	4	3
Murray Cod	*Maccullochella peelii peelii*	Fish	not listed	Vulnerable	4	2
Murray Hardyhead	*Craterocephalus fluviatilis*	Fish	Critically Endangered	Endangered	4	4
Silver perch	*Bidyanus bidyanus*	Fish	Vulnerable	Critically endangered	4	4
Southern pygmy perch	*Nannoperca australis*	Fish	Endangered	not listed	4	3
Trout Cod	*Maccullochella macquariensis*	Fish	Endangered	Endangered	4	3
Alpine Tree Frog	*Litoria verreauxii alpina*	Frog	Endangered	Vulnerable	4	3

Scientific Name	Common Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Booroolong Frog	*Litoria booroolongensis*	Frog	Endangered	Endangered	4	3
painted burrowing frog	*Neobatrachus pictus*	Frog	Endangered	Not Listed	3	3
Sloanes Froglet	*Crinia sloanei*	Frog	Vulnerable	Not Listed	3	2
Southern Bell frog	*Litoria raniformis*	Frog	Endangered	Vulnerable	4	3
Southern Corroboree frog	*Pseudophryne corroboree*	Frog	Critically endangered	Critically endangered	2	4
Spotted Tree Frog	*Litoria spenceri*	Frog	Critically endangered	endangered	4	4
Southern Myotis bat	*Myotis macropus*	Mammal	Vulnerable	Not Listed	2	2
Murray crayfish	*Euastacus armatus*	Other	Vulnerable		4	2
Austral Pillwort	*Pilularia novae-hollandiae*	Plant	Endangered	Not Listed	1	3
Floating swamp wallaby grass	*Amphibromus fluitans*	Plant	Vulnerable	Vulnerable	1	2
Menindee nightshade	*Solanum karsense*	Plant	Vulnerable	Vulnerable	3	2
Spike Rush	*Eleocharis obicis*	Plant	Vulnerable	Vulnerable	1	2
Square Raspwort	*Haloragis exalata subsp exalata*	Plant	Vulnerable	Vulnerable	1	2
Western Water-starwort	*Callitriche cyclocarpa*	Plant	Vulnerable	Not Listed	3	2
Winged Peppercress	*Lepidium monoplocoides*	Plant	Endangered	Endangered	2	3

Table 10: Barwon Darling

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Lowland Darling River endangered ecological community	Aquatic Ecological Community in the Natural Drainage System of the Lowland Catchment of the Darling River	EEC	Endangered Ecological Community	Not Listed	4	3
Western population Olive Perchlet	*Ambassia agassizii*	EP	Endangered Populations	not listed	4	3
Eel-tailed catfish	*Tandanus tandanus*	EP	Endangered Population	not listed	4	3
Silver perch	*Bidyanus bidyanus*	Fish	Vulnerable	Critically endangered	4	4
Purple spotted gudgeon	*Mogunda adspersa*	Fish	Endangered	not listed	4	3
Murray Cod	*Maccullochella peelii*	Fish	not listed	Vulnerable	4	2
Sloanes Froglet	*Crinia sloanei*	Frog	Vulnerable	Not Listed	3	2
Menindee nightshade	*Solanum karsense*	Plant	Vulnerable	Vulnerable	3	2
Marsh Club-rush sedgeland endangered ecological community	Marsh Club-rush sedgeland in the Darling Riverine Plains Bioregion	EEC	Critically endangered ecological community	Not Listed	3	4
Myriophyllum implicatum	*Myriophyllum implicatum*	Plant	Critically endangered	not listed	3	4
Australasian Bittern	*Botaurus poiciloptilus*	Bird	Endangered	Endangered	2	3
Australian Painted snipe	*Rostratula australis*	Bird	Endangered	Endangered	2	3
Black-necked stork	*Ephippiorhynchus asiaticus*	Bird	Endangered	Not Listed	2	3
Black-tailed godwit	*Limosa limosa*	Bird	Vulnerable	Not Listed	2	2
Blue-billed Duck	*Oxyura australis*	Bird	Vulnerable	Not Listed	2	2
Freckled duck	*Stictonetta naevosa*	Bird	Vulnerable	Not Listed	2	2

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weights
Magpie Goose	*Anseranas semipalmata*	Bird	Vulnerable	Not Listed	2	2
Brolga	*Grus rubicunda*	Bird	Vulnerable	Not Listed	2	2
Curlew sandpiper	*Calidris ferruginea*	Bird	Endangered	Critically endangered	2	4
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions		EEC	Endangered Ecological Community	Not listed	2	3
Winged Peppercress	*Lepidium monoplocoides*	Plant	Endangered	Endangered	2	3
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion		EEC	Endangered Ecological Community	Endangered	1	3
Cyperus conicus	*Cyperus conicus*	Plant	Endangered	Not Listed	1	3
Shrub Sida	*Sida rohlenae*	Plant	Endangered	Not Listed	1	3
Braid fern	*Platyzoma microphyllum*	Plant	Endangered	Not Listed	1	3

Table 11: Intersecting streams

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weighting
Lowland Darling River endangered ecological community	Aquatic Ecological Community in the	EEC	Endangered Ecological	Not Listed	4	3

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weighting
	Natural Drainage System of the Lowland Catchment of the Darling River		Community			
Eel Tailed Catfish	*Tandanus tandanus*	EP	Endangered Population	Not Listed	4	3
Western Population Olive Perchlet	*Ambassia agassizii*	EP	Endangered Populations	not listed	4	3
Murray Cod		Fish		Vulnerable	4	2
Silver Perch	*Bidyanus bidyanus*	Fish	Vulnerable	Critically endangered	4	4
Sloanes Froglet	*Crinia sloanei*	Frog	Vulnerable	Not Listed	3	2
Menindee nightshade	*Solanum karsense*	Plant	Vulnerable	Vulnerable	3	2
Australasian Bittern	*Botaurus poiciloptilus*	Bird	Endangered	Endangered	2	3
Australian Painted snipe	*Rostratula australis*	Bird	Endangered	Endangered	2	3
Black-necked stork	*Ephippiorhynchus asiaticus*	Bird	Endangered	Not Listed	2	3
Black-tailed godwit	*Limosa limosa*	Bird	Vulnerable	Not Listed	2	2
Blue-billed Duck	*Oxyura australis*	Bird	Vulnerable	Not Listed	2	2
Brolga	*Grus rubicunda*	Bird	Vulnerable	Not Listed	2	2
Curlew sandpiper	*Calidris ferruginea*	Bird	Endangered	Critically endangered	2	4
Freckled duck	*Stictonetta naevosa*	Bird	Vulnerable	Not Listed	2	2
Magpie Goose	*Anseranas semipalmata*	Bird	Vulnerable	Not Listed	2	2
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions		EEC	Endangered Ecological Community	Not listed	2	3

Common Name	Scientific Name	Distinctiveness Parameter	NSW Status	Commonwealth listing	Flow sensitivity Weighting	Status Weighting
Aponogeton queenslandicus	*Aponogeton queenslandicus*	Plant	Endangered	Not listed	2	3
Winged Peppercress	*Lepidium monoplocoides*	Plant	Endangered	Endangered	2	3
Nitella partita	*Nitella partita*	Plant	Endangered	Not listed	2	3
Nocoleche goodenia	*Goodenia nocoleche*	Plant	Endangered	Not listed	2	3
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion		EEC	Endangered Ecological Community	Endangered	1	3
Shrub sida	*Sida rohlenae*	Plant	Endangered	Not Listed	1	3