



Water Dependent Ecosystems of the NSW Northern Rivers

Mapping, assessment and prioritisation

Prepared for
Northern Rivers Catchment Management Authority

13 December 2013



DOCUMENT TRACKING

Item	Detail
Project Name	Water Dependent Ecosystems of the NSW Northern Rivers - mapping, assessment and prioritisation
Project Number	13COFNRM-0008
Project Manager	Julian Wall 0401 421 161
Prepared by	Julian Wall, Martin Stuart
Reviewed by	Liz Brown
Status	Final
Version Number	1
Last saved on	13 December 2013
Cover photo	Wetland types in the Northern River Catchment (P. Gilmour; L. Copeland 2013)

This report should be cited as 'Eco Logical Australia 2013. *Water Dependent Ecosystems of the NSW Northern Rivers - Mapping, Assessment and Prioritisation*. Prepared for Northern Rivers Catchment Management Authority.'

ACKNOWLEDGEMENTS

This document has been prepared by Eco Logical Australia Pty Ltd with support from Jai Sleeman, Northern Rivers Catchment Management Authority.

Disclaimer

This document may only be used for the purpose for which it was commissioned and in accordance with the contract between Eco Logical Australia Pty Ltd and Northern Rivers Catchment Management Authority. The scope of services was defined in consultation with Northern Rivers Catchment Management Authority, by time and budgetary constraints imposed by the client, and the availability of reports and other data on the subject area. Changes to available information, legislation and schedules are made on an ongoing basis and readers should obtain up to date information.

Eco Logical Australia Pty Ltd accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report and its supporting material by any third party. Information provided is not intended to be a substitute for site specific assessment or legal advice in relation to any matter. Unauthorised use of this report in any form is prohibited.

Contents

1	Introduction.....	1
1.1	Background.....	1
1.2	Project purpose and objectives	1
1.3	Caveats.....	1
1.4	Structure of the report.....	2
2	WAIT database.....	1
2.1	Context	1
2.2	Current status of WAIT for NRCMA	2
2.2.1	Data types.....	2
2.2.2	Impact data	2
2.3	Changes to WAIT database	3
3	Local Catchments.....	4
3.1	Definition.....	4
3.2	Context	4
3.3	Capture	4
3.4	Description of final layer	4
3.5	Assignment of Condition.....	6
3.5.1	Background.....	6
3.5.2	Method.....	6
3.5.3	Results.....	6
3.6	Assignment of vulnerability.....	7
3.6.1	Background.....	7
3.6.2	Method.....	7
3.6.3	Results.....	9
4	Water dependent ecosystems.....	12
4.1	Definition.....	12
4.2	Context	12
4.3	Spatial capture.....	12
4.3.1	Compilation of spatial data	12
4.3.2	Revision of WDE layer.....	12
4.3.3	Addition of other WDE classes	15
4.4	Final WAIT coverage	15
4.5	WDE fluctuation analysis.....	18
4.5.1	Background.....	18
4.5.2	Rainfall analysis.....	18

4.5.3	Image management.....	18
4.5.4	Results of analysis.....	19
4.6	WDE classification.....	22
4.6.1	Background.....	22
4.6.2	WDE regionalisation	22
4.7	WDE condition assessment.....	24
4.7.1	Results.....	25
4.8	WDE vulnerability assessment.....	28
4.8.1	Method.....	28
4.8.2	Results.....	28
5	Discussion.....	30
5.1	Limitations.....	30
5.1.1	Spatial data.....	30
5.1.2	Condition and vulnerability	30
5.2	Recommendations.....	30
5.2.1	Ongoing data management investment	30
5.2.2	Aquifers and floodplains	30
5.2.3	Groundwater dependent ecosystems.....	30
	References	31
	Appendix I. Land use classes	33
	Appendix II. Intactness	38
	Appendix III. Rules used to assign levels of ‘sensitivity’ and ‘resilience’ to local catchments....	39
	Appendix IV. Rules used to assign levels of ‘sensitivity’ and ‘resilience’ to WDEs.	42

List of Figures

Figure 1. Local catchments within Clarence-Moreton area of the Northern Rivers CMA region	5
Figure 2. Distribution of local catchments in the Clarence-Moreton region based on condition	8
Figure 3. Coal resource potential in the Northern Rivers CMA region	10
Figure 4. Distribution of local catchments in the Clarence-Moreton region based on habitat vulnerability to potential CSG extraction	11
Figure 5. Distribution of WDE types in Clarence-Moreton region	17
Figure 6. Landsat image tiles and dates	20
Figure 7. ‘Wetted surface’ signature for wet and dry periods in the Northern Rivers Catchment	21
Figure 8. Regionalisation applied to mapped WDEs in the NRCMA region	23
Figure 9. Distribution of WDEs in the Clarence-Moreton region based on condition	27
Figure 10. Proportion of each asset class in high, medium and low vulnerability, in relation to potential CSG impacts on habitat value	29

List of Tables

Table 1. Water assets in the WAIT database according to the “WaterBody_Type” field	3
Table 2. Number of assets for which an impact rating was established	3
Table 3. Criteria used to assign condition indices to local catchments	6
Table 4. Number and area of local catchments in 5 condition classes in the Clarence-Moreton region ...	7
Table 5. Asset vulnerability as a function of sensitivity and resilience	7
Table 6. Revised vulnerability scores based on coal potential	9
Table 7. Number of local catchments by sensitivity, resilience and vulnerability class (CSG extraction) .	9
Table 8. Area of local catchments by sensitivity, resilience and vulnerability class (CSG extraction)	9
Table 9. List of spatial datasets used to refine the WAIT geo-database	13
Table 10. Number and area of different types of WDEs in the Clarence-Moreton region	15
Table 11. Fields in the WAIT database for which updates were undertaken	16
Table 12: Landsat imagery and density slice intervals used to identify Water Dependant Ecosystems .	18
Table 13. WDE classes and types assigned to composite layer for NRCMA	22

Table 14. Criteria used to assign condition indices to WDEs	25
Table 15. Number of WDEs in five condition classes in the Clarence-Moreton region	26
Table 16. Asset vulnerability as a function of condition and resilience.	28
Table 17. Number of WDEs by sensitivity, resilience and vulnerability class (CSG extraction)	28

Abbreviations

ABBREVIATION	DESCRIPTION
BRG	Border Rivers-Gwydir
CMA	Catchment Management Authority
CSG	Coal seam gas
DE	Commonwealth Department of the Environment (formerly DSEWPaC)
DSEWPaC	Commonwealth Department of Sustainability, Environment, Water, Population and Communities (now DE)
DEM	Digital Elevation Model
ELA	Eco Logical Australia
NRCMA	Northern Rivers Catchment Management Authority
RAMSAR	The Convention on Wetlands of International Importance
RCI	River Condition Index
SEPP	State Environmental Planning Policy
WAIT	Water Asset Information Tool
WDE	Water Dependent Ecosystem

1 Introduction

1.1 Background

On 21st November 2011, the Prime Minister announced the establishment of a new Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining that will provide scientific advice to Governments in relation to coal seam gas (CSG) and coal mining proposals that are likely to have significant impacts on water resources.

A key role of the Committee is to scope and advise on Bioregional Assessments in areas where CSG and/or large coal mining developments are underway or planned. The Bioregional Assessments involve undertaking a scientific analysis of the ecology, hydrology and geology of an area for the purpose of assessing the potential risks to natural water resources in the area arising from the direct and indirect impacts of CSG or large coal mining developments.

The Commonwealth Department of the Environment (DE)¹ is coordinating the Bioregional Assessment process which is divided into two phases. Phase 1 involves collation of water asset data into a relational database called the Water Asset Information Tool (WAIT). Phase 2 involves implementation of the Bioregional Assessment using a process that is yet to be published.

In the northern coastal region of NSW, the Northern Rivers Catchment Management Authority (NRCMA) commenced Phase 1 of the Bioregional Assessment in August 2012, with collation of water dependent ecosystem (WDE) data, including rivers, streams, wetlands and other water assets, within the Clarence-Moreton system of north-eastern NSW (Cavanagh 2012).

1.2 Project purpose and objectives

This project completes the Phase 1 assessment within the Clarence-Moreton system by refining WDE mapping, undertaking condition and vulnerability assessment using a combination of local and regional inputs, and updating the WAIT database and associated spatial geo-databases.

1.3 Caveats

A key driver in defining the scope of the project was the limited timeframe, the spatial complexity of WDE dataset that was originally assembled by Cavanagh (2012), and the requirement to source and organise numerous datasets that were not incorporated in the original part of Phase 1. While as much data and information as possible on WDEs was included in the analyses, only existing and freely available resources were included. This meant that:

- only data that could be readily accessed (and quickly modified) to suit the purposes of the project were included in the spatial database, and contributed to the vulnerability analyses;
- where knowledge gaps existed, the vulnerability analyses were supported by generic rather than specific rule sets, and were guided by specialist knowledge.

¹ formerly Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC)

1.4 Structure of the report

This report is separated into the following sections:

- Section 2 provides a summary of the WAIT database
- Section 3 outlines the approach adopted to capture and integrate local catchments into the WAIT database, and describes the method used to assess condition and vulnerability of local catchments
- Section 4 summarises the various updates made to the WDE coverage in the WAIT database, and describes the method used to assess condition and vulnerability of WDEs
- Section 5 outlines limitations of the database and presents recommendations for future work.

2 WAIT database

2.1 Context

The WAIT database was developed by DE for Phase 1 of the Bioregional Assessments. It is designed to store various data about a catchment's water assets. It includes a module that allows a broad rating of vulnerability (high, moderate or low) to be entered in relation to the potential impact of major land use activities on flow pattern, habitat, water quality and water quantity.

For this project, vulnerability associated with coal mining and CSG extraction (but not other activities) were considered for the two new asset classes, local catchments and WDEs, where some information about WDEs had already been captured (Cavanagh 2012).

The following fields are included in the WAIT database:

General Fields

- | | |
|-------------------------------------------------------------|--------------------------------------------|
| • Asset ID | • Other_Relevant_Details |
| • Asset Name | • Management Authority |
| • NRM Region | • Current_landuse |
| • Description | • Tenure |
| • WaterBody_Type | • Condition |
| • Coordinates | • Is_map_available |
| • Nearest_Town | • Is_GISdata_available |
| • Mapsheet_100k_name | • Is_metadata_available |
| • Environmental Value | • File Identifier_in_ANZMetlitetool |
| • National Water Quality Management Strategy (NWQMS) values | • Dataset_resource_title_in_ANZMetlitetool |
| • Economic Value | • References |
| • Social Cultural Value | • Known_knowledge_gaps |
| • Hydrology | • Primary_contact_for_asset |
| • Geology_geomorphology | • Legal_protection |
| | • Notes |

Vulnerability fields

- Activity
- Impact
- Existing/potential hazard
- Mitigation in place
- Effect

2.2 Current status of WAIT for NRCMA

2.2.1 Data types

A working version of the WAIT database was provided by NRCMA in July 2013. This version was completed by BMT WBM Pty Ltd in late 2012 and contained the following spatial datasets (Cavanagh 2012):

- Named watercourses
- Wetlands
- Reservoirs, lakes and waterholes
- Estuaries
- Perch habitat
- Groundwater bore
- Groundwater dependent ecosystem (GDE)
- State Environmental Planning Policies (SEPP) Coastal Wetland and Littoral Rainforest

Table 1 shows the number of assets captured according to the “WaterBody_Type” field specified in the WAIT database. The number of assets assigned a condition rating (high, medium or low) is included in brackets. A total of 22,855 features were captured, of which 1,767 (mainly rivers and streams) included a condition rating.

It is apparent from Table 1 that several asset classes were not captured during the initial project, including aquifers, intertidal forested wetlands (e.g. Swamp Oak, Mangrove), intertidal marshes (i.e. saltmarsh) and Karst systems. Other features such as waterfalls, floodplains and local catchments were also absent.

Over 75% of water assets were not allocated a “waterbody_type” on account of the absence of an appropriate category. For example, no category was available in WAIT for the numerous groundwater bores, point GDEs and perch habitat polygons captured and included in the database.

2.2.2 Impact data

Cavanagh (2012) provides a summary of the approach used by BMT WBM Pty Ltd to generate an impact rating for each water asset, with respect to certain activities and effects². In summary, a rating was assigned to each asset using information about its sensitivity (based on condition) and its exposure to an activity (in this case coal mining or CSG extraction), where exposure was influenced by proximity to the activity and magnitude of the activity. Table 2 shows the number of assets for which an impact rating was generated by BMT WBM Pty Ltd. A total of 15,708 assets were assigned an impact rating for flow pattern, while 6,369 assets were assigned an impact rating for water quality. Almost all ratings were associated with CSG extraction. No asset was assigned an impact rating in relation to habitat or water quantity.

² The WAIT database includes CSG, coal mining and various other land use activities. It also includes four effects, namely flow pattern, habitat, water quality and water quantity.

Table 1. Water assets in the WAIT database according to the “WaterBody_Type” field

WaterBody_Type	Number of assets	Number of assets with condition rating
Aquifer	0	-
Coastal brackish/saline lagoons	389	12
Coastal freshwater lagoons	13	0
Coral reefs	0	-
Estuarine waters	262	16
Intertidal forested wetlands	0	-
Intertidal marshes	0	-
Intertidal mud/ sand or salt flats	0	-
Karst and other subterranean hydrological systems	0	-
Marine sub-tidal aquatic beds	0	-
Permanent freshwater lakes	98	0
Permanent freshwater marshes/pools	3,043	0
Permanent inland deltas	0	-
Permanent rivers/streams/creeks	1,739	1,739
Permanent saline/brackish/alkaline lakes	0	-
Permanent saline/brackish/alkaline marshes/pools	0	-
Permanent shallow marine waters	0	-
Rocky marine shores	0	-
Sand/ shingle or pebble shores	0	-
Seasonal/intermittent freshwater lakes	14	0
Seasonal/intermittent saline/brackish/alkaline lakes and flats	0	-
Seasonal/intermittent saline/brackish/alkaline marshes/pools	0	-
Seasonal/intermittent/irregular rivers/streams/creeks	0	-
Not allocated	17,297	0
ALL	22,855	1,767

Table 2. Number of assets for which an impact rating was established

Activity	Effect	No. assets
Coal mining	Flow pattern	77
Coal seam gas mining	Flow pattern	15,631
Coal seam gas mining	Water Quality	6,369
none	none	778
		22,855

2.3 Changes to WAIT database

Various changes were made to the WAIT database for this project, including addition and assessment of local catchments (Section 3) and rationalisation of WDEs that includes removal, retention and addition of various WDEs, and augmentation of descriptive data (Section 4).

3 Local Catchments

3.1 Definition

For the purpose of this project, a local catchment is defined as a geographical parcel of land circumscribed by an elevated watershed (ridgeline), that drains into an area of about a minimum 1,000 hectares (ha), and terminates at a confluence, terminal wetland/lake, or coastal margin. Most local catchments are named according to the stream or river to which they contribute surface flow, although some are unnamed creeks. Some local catchments constitute drainage plains or coastal margins, and most of the rivers and larger streams are represented by more than one local catchment (in which case they are separated into unique reaches). In general terms, local catchments represent the contributing areas of streams or reaches that are 3rd order and greater.

3.2 Context

Local catchments were delineated in the Clarence-Moreton section of the Northern Rivers CMA region³ for two reasons:

1. To provide an additional water asset class for upload to the WAIT database.
2. To contribute to condition assessment of WDEs (Section 4.7).

3.3 Capture

Manual digitising of local catchments was undertaken in ArcGIS with support of key spatial data including digital topographic map series, Digital Elevation Models (DEM), contours and hydrolines. Manual digitising required the operator to have a strong understanding of surface flow response (i.e. flow) in relation to topography. In some flat areas of the extensive coastal floodplains where 10 metres (m) contour lines were often separated by kilometres (km), the DEM alone was used to separate local catchments. In these circumstances, the reliability of the watershed position is only as useful as the apparent 'ridge' deciphered from the DEM. The boundaries of local catchments in the west of the NRCMA region were edge-matched with the eastern boundaries of local catchments captured in the Border Rivers-Gwydir (BRG) Catchment (ELA 2013) and the Namoi Catchment (ELA 2012).

3.4 Description of final layer

A total of 640 local catchments covering 21,880 km² were captured within the Clarence-Moreton part of the NRCMA region (Figure 1), including 483 named creeks (some larger creeks separated into reaches), 67 unnamed creeks, 58 river reaches, 16 coastal catchments (includes beaches and headlands), five brooks or gullies, and 11 other features (including channels and lakes). Local catchments were generally smaller and were located in more rugged terrain associated with escarpments and gorges.

The 58 local catchments that contain the reaches of main rivers total 4,500 km², and include the Barcoongere, Bobo, Boonoo Boonoo, Boyd, Brunswick, Cataract, Clarence, Coldstream, Corindi, Esk, Evans, Kangaroo, Koreelah, Little Nymboida, Mann, Maryland, Nymboida, Orara, Richmond, Rous, Sandon, Timbarra, Towallum, Tweed, Urumbulum, Wilsons and Wooli Wooli Rivers.

³ The Clarence-Moreton corresponds to the area captured in the WAIT database

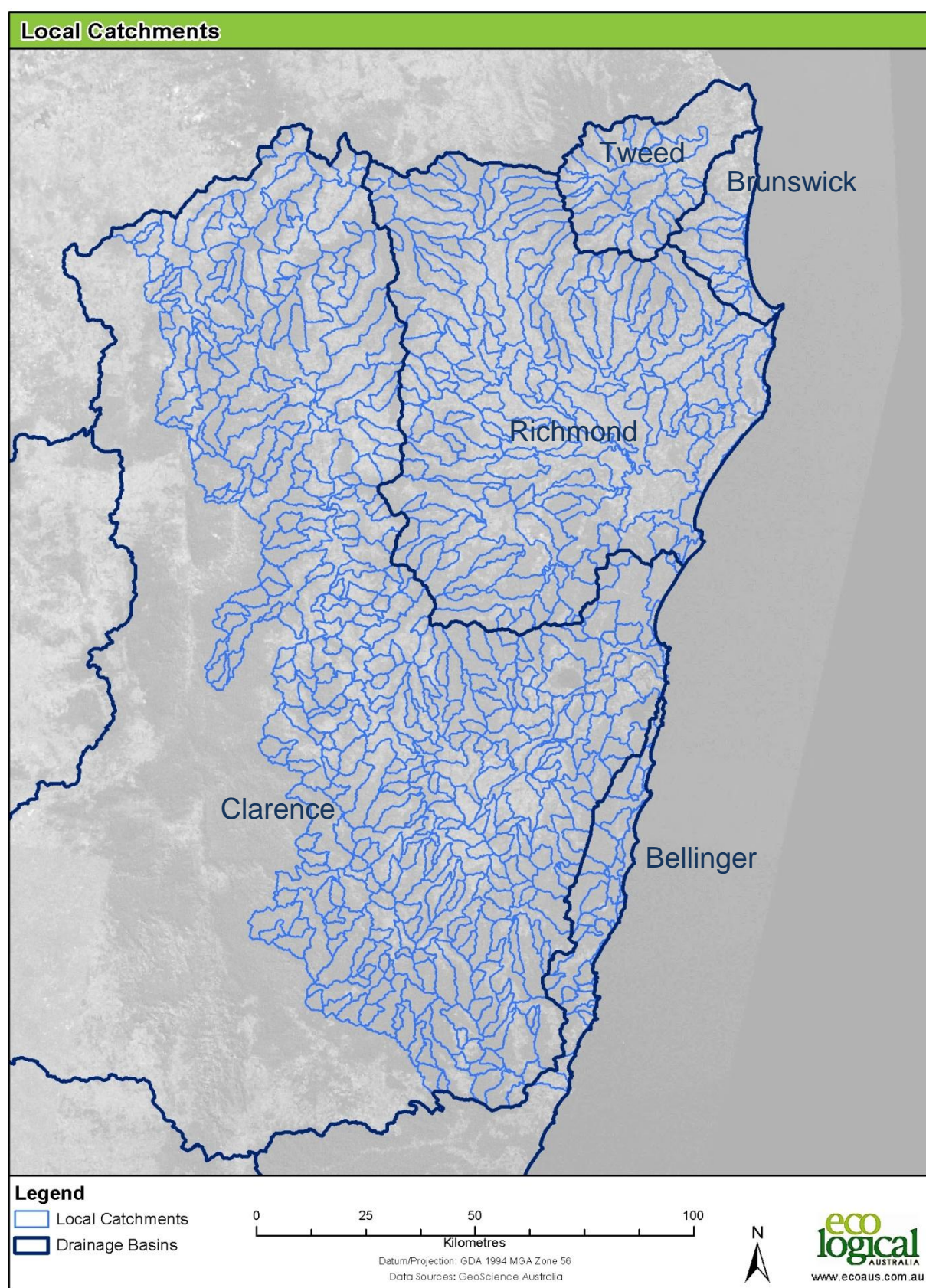


Figure 1. Local catchments within Clarence-Moreton area of the Northern Rivers CMA region

3.5 Assignment of Condition

3.5.1 Background

The condition of a local catchment is related primarily to the extent with which its surface vegetation cover and hydrology have been modified in the past. A local catchment that has been subject to little disturbance (e.g. a catchment located in National Park) is likely to be in better condition (in terms of biodiversity, clean water etc.) than a catchment which has been highly modified through agricultural development or urbanisation.

3.5.2 Method

A condition rating was derived for each local catchment by considering the following metrics:

- Percent of catchment within conservation reserve
- Percent of catchment within State Forest
- Percent of catchment subject to 'developed' and 'disturbed' land use (Appendix I)
- Vegetation intactness (Appendix II)
- Hydrological stress (Healey et al. 2012)

Table 3 lists the criteria and formulae used to calculate condition index. A condition index for protection status, vegetation intactness and land use was assigned to all 640 local catchments. A condition index for hydrostress was assigned to 347 of the 640 local catchments (data were not available for the small streams and coastal margins). A final condition metric was calculated as the average value (unweighted) of the four metrics. A final condition rating was assigned as follows.

Condition = very good $CI \geq 0.8$

Condition = good $CI = 0.6 - 0.79$

Condition = moderate $CI = 0.4 - 0.59$

Condition = poor $CI = 0.2 - 0.39$

Condition = very poor $CI = < 0.2$

Table 3. Criteria used to assign condition indices to local catchments

Condition Metric	Condition Index (CI) Formula
Protection status	$CI_{PS} = [1.0 * (\%reserve) + 0.5 * (\%SF)] / 100$
Vegetation intactness status	$CI_{II} = [intactness\ index]$
Land use	$CI_{LU} = [1.0 * (\%undeveloped) + 0.5 * (\%disturbed)] / 100$
Hydrostress	$CI_{HS} = hydrostress$
FINAL	$CI = average(CI_{PS} \ CI_{II} \ CI_{LU} \ CI_{HS})$

3.5.3 Results

The final condition index for local catchments ranged from 1.000 (shared by three local catchments in the Clarence Basin: Hianana Creek, Oorooroo Creek and Willowie Creek) and 0.133 (Belongil Creek on the coastal margin). The total number and area of catchments in each of the five condition classes is shown in Table 4 and the distribution of local catchment condition across the WAIT region is shown in Figure 2.

Table 4. Number and area of local catchments in five condition classes in the Clarence-Moreton region

Condition rating	Number of local catchments	Area of local catchments (ha)
Very good	85 (13%)	213,100 (10%)
Good	183 (29%)	732,900 (33%)
Moderate	234 (37%)	855,500 (39%)
Poor	124 (19%)	361,900 (17%)
Very poor	14 (2%)	24,100 (1%)
ALL	640	2,187,500

3.6 Assignment of vulnerability

3.6.1 Background

Vulnerability to impact is a function of an asset's *sensitivity* and its *resilience*. Sensitivity is the degree to which an asset is affected by 'pressures' (in this case activities associated with coal mining and CSG extraction), and resilience is the amount of change a system can undergo (i.e. its capacity to absorb disturbance) while retaining the same function, structure and feedbacks (Walker and Salt 2006). Determining an asset's capacity to absorb change or disturbance without moving to a new state often involves identifying thresholds (i.e. 'tipping points' from one stable state to another). Thresholds are typically related to core structural and functional elements of ecosystems, such as wetting-drying periods in wetlands, lateral and longitudinal connectivity in rivers, and carbon exchange between floodplains and rivers.

3.6.2 Method

A rating for vulnerability was derived from a matrix that cross-references levels of asset sensitivity to levels of asset resilience (Table 5). The vulnerability of an asset to coal or CSG extraction increases with increasing sensitivity and decreasing resilience.

To achieve the comparison in Table 5, sensitivity and resilience levels were generated for each local catchment using a set of rules and conditions relevant to each asset class. These are outlined in Appendix III.

Table 5. Asset vulnerability as a function of sensitivity and resilience.

	Resilience		
Sensitivity	High	Medium	Low
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium

Once all data were compiled, a final review was conducted in which vulnerabilities were revised downwards if all or part of the asset occurred outside the mapped extent of the potential coal or CSG gas resource, as depicted in Table 6. A map of coal resource potential in the NR catchment is provided in Figure 3.

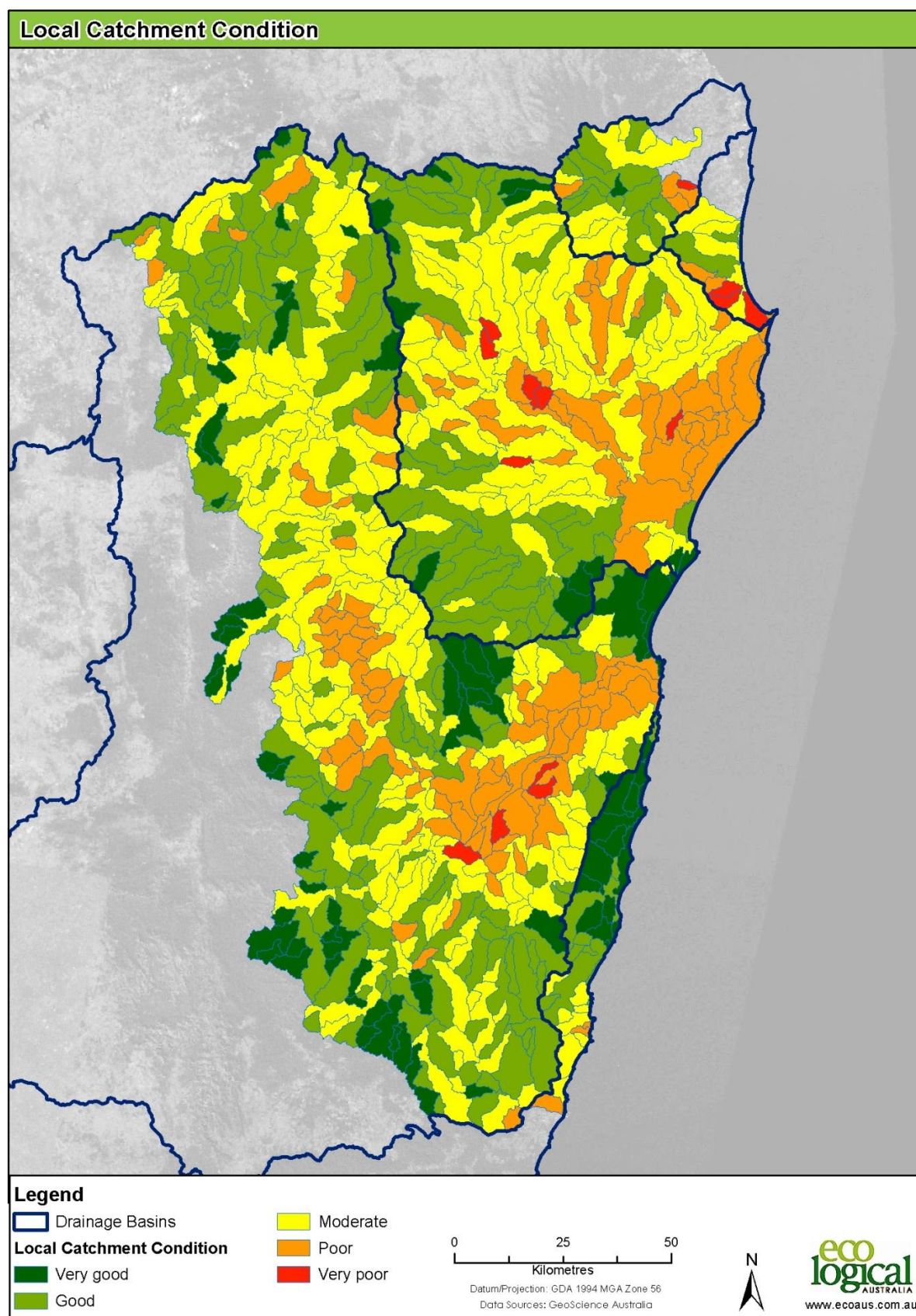


Figure 2. Distribution of local catchments in the Clarence-Moreton region based on catchment condition

Table 6. Revised vulnerability scores based on coal potential

Location of Local Catchment	Change to Vulnerability Status
Part or all within OCM / LWM areas	No change
All outside OCM / LWM areas	Moderate → Low; High → Low
Part or all within areas of high or moderate CSG potential	No change
None within areas of high or moderate CSG potential, but part within area of low CSG potential	Moderate → Low; High → Moderate
All within areas of no CSG potential	Moderate → Low; High → Low

3.6.3 Results

Results of sensitivity, resilience and vulnerability analysis in the context of potential CSG extraction are shown in Table 7 (number of assets) and Table 8 (area of assets). After reducing the vulnerability rating for local catchments that occur outside the region of CSG-potential, the total area of high vulnerability local catchments within the Clarence-Moreton region is as follows: 6% for flow pattern; 38% for habitat; 16% for water quantity; and 3% for water quality.

As the WAIT asset data are linked to a geo-database via unique identifier, it is possible to display sensitivity, resilience and vulnerability spatially. Figure 4 shows an example of local catchments mapped in terms of their vulnerability to CSG extraction.

Table 7. Number of local catchments by sensitivity, resilience and vulnerability class (CSG extraction)

Effect	Sensitivity			Resilience			Vulnerability*		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
Flow pattern	115	425	100	408	222	10	39	139	462
Habitat	431	101	108	312	166	162	163	203	274
Water Quantity	7	126	507	27	25	588	96	323	221
Water Quality	346	211	83	408	222	10	19	293	328

* values based on sensitivity-resilience pairing (Table 5) and location of local catchment in relation to CSG potential (Table 6)

Table 8. Area (km²) of local catchments by sensitivity, resilience and vulnerability class (CSG extraction)

Effect	Sensitivity			Resilience			Vulnerability*		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
Flow pattern	3,235	14,762	3,882	13,417	8,258	202	1,405	5,306	15,166
Habitat	18,028	1,945	1,904	9,545	5,653	6,678	8,259	7,293	6,325
Water Quantity	219	5,287	16,370	2,066	2,033	17,777	3,516	10,915	7,446
Water Quality	10,325	8,596	2,955	13,417	8,258	202	593	10,323	10,960

* values based on sensitivity-resilience pairing (Table 5) and location of local catchment in relation to CSG potential (Table 6)

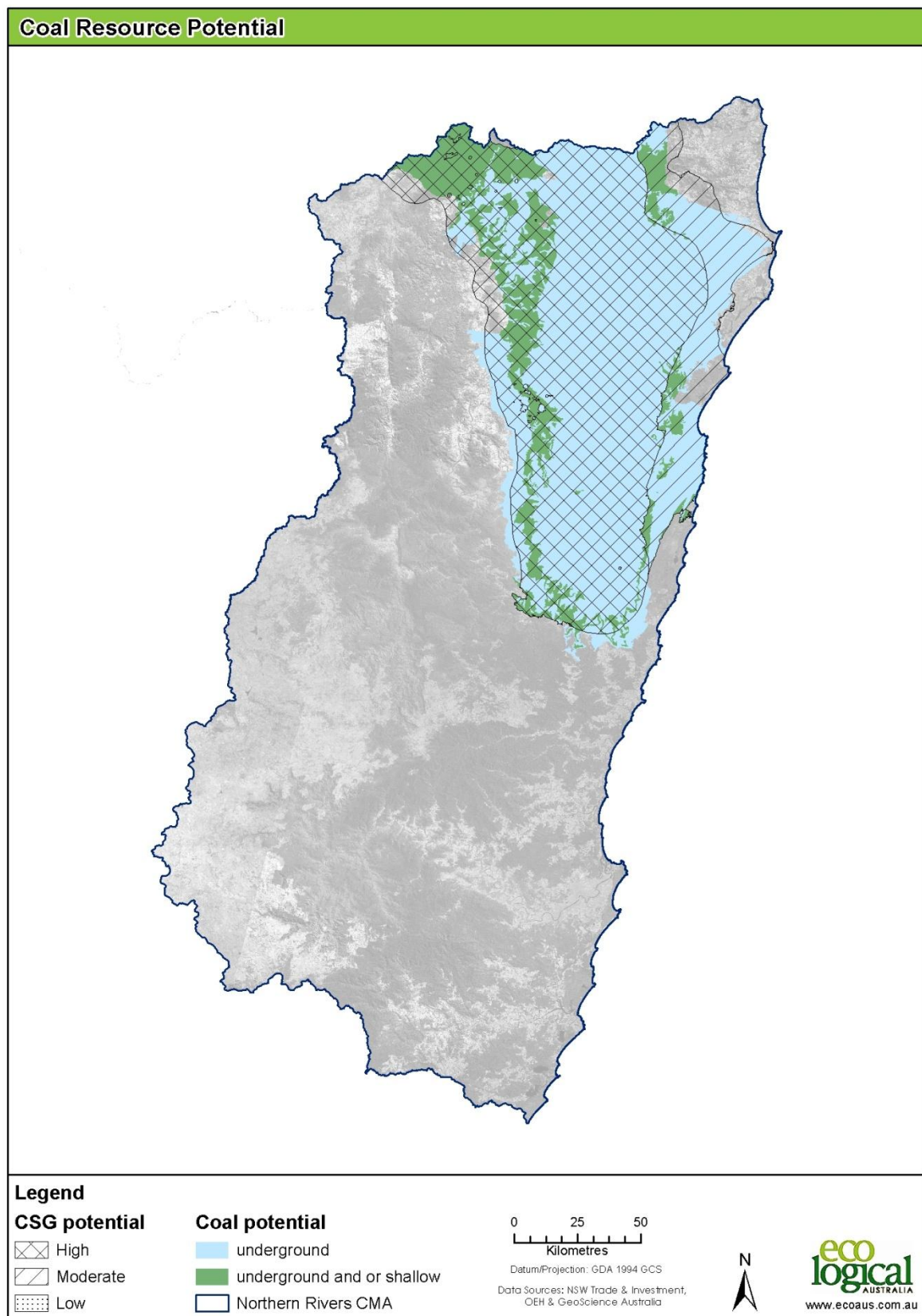


Figure 3. Coal resource potential in the Northern Rivers CMA region

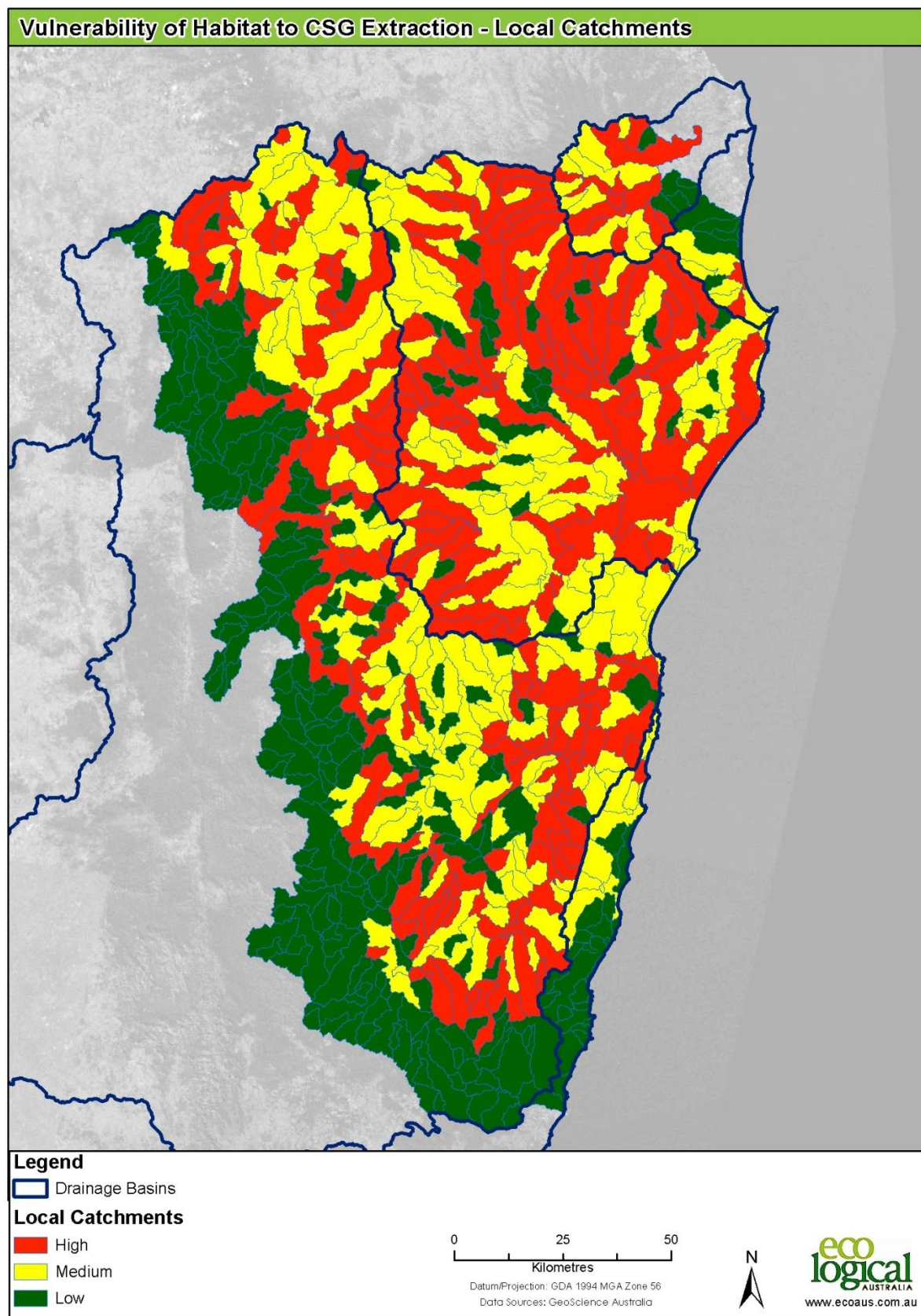


Figure 4. Distribution of local catchments in the Clarence-Moreton region based on habitat vulnerability to potential CSG extraction

4 Water dependent ecosystems

4.1 Definition

For the purpose of this study, a Water Dependent Ecosystem (WDE) includes any system in which lotic (flowing) water or lentic (non-flowing) water is prominent in the system. Lotic WDEs include estuaries, rivers, streams and waterfalls, while lentic WDEs include wetlands and lagoons, as well as GDEs and Karst systems.

4.2 Context

The scope of this contract was to update the WAIT database developed by BMT WBM Pty Ltd, and to derive a composite WDE surface for the whole NRCMA region. The following updates to the WAIT database were undertaken for this project:

- Deletion of groundwater bores, SEPP assets and perch habitat from the database (these were not considered to be natural water assets, but were considered to be values)
- Refinement of asset line work, including capture of unmapped WDEs via on-screen digitizing
- Addition of local catchments as a new asset class (Section 3)
- Addition of named waterfall, waterholes and caves as point layers
- Capture of additional forested wetlands, mangroves and saltmarshes (from various sources)
- Update of WDE names
- Update to contextual data via intersection with other layers
- Update of sensitivity and impact assessment with respect to 'habitat' value

Most of the data captured by BMT WBM Pty Ltd, including condition and vulnerability data, were retained in the database (other than bores, SEPP assets and perch habitat).

4.3 Spatial capture

4.3.1 Compilation of spatial data

A large number of spatial datasets were made available for this project. These are listed in two sections in Table 9, including WDE mapping (where wetlands and other WDEs were mapped specifically) and vegetation mapping (where wetlands and other WDEs were mapped within broader vegetation maps). Many of the datasets in Table 9 shared features that either aligned exactly or varied subtly in their spatial extent. All data were merged into a single composite wetland layer, building on data already captured by WBM BMT Pty Ltd within the WAIT area.

4.3.2 Revision of WDE layer

A 5 km x 5 km spatial grid was established, across which composite spatial WDE data were systematically scrutinised against background ADS40 aerial photographic imagery. Spatial polygons were retained, edited or in some cases deleted, and new polygons were captured where ADS40 data presented an obvious 'wetted' signature that was considered to represent a WDE. Topographic maps and a DEM surface were used to assist this process.

On completion of this process, place names extracted from the place names dataset (GNR_Placenames_NRCMA_260713; <http://www.gnb.nsw.gov.au/>) were appended to their respective polygons.

Table 9. List of spatial datasets used to refine the WAIT geo-database

Layer Name	Source
WDE mapping	
Sustainable wetlands	Burns <i>et al.</i> (2006)
NRAC wetlands	no report available
Groundwater_Dependent_Ecosystems_pts	no report available
dwe_priority_gde deccw_gde	Data compiled from various sources including the Environment Australia 'Directory of Important Wetlands' and Water Sharing Plans developed under the <i>Water Management Act 2000</i> .
NSW Topo data	Includes swamps, farm dams and other water features including on the NSW 1:25,000 topographic map series; http://www.lpi.nsw.gov.au/mapping_and_imagery/spatial_data/topographic_data
LGA 250k Hydro	Mapped hydroline data; http://www.ga.gov.au/topographic-mapping/digital-topographic-data.html
Clarence_Lowlands_Wetland_Clusters	no report available
DEC_upland_wetlands_poly	no report available
wca_clarence_saltmarsh_2010	no report available
Wetlands known to Nigel	unpublished NRCMA data
Montane lagoons	no report available
Waterbodies_nrcma_clip	no report available
Estuarine_vegetation_cca	http://www.planning.nsw.gov.au/?tabid=171
Sepp14_wetlands	http://sdi.nsw.gov.au/GPT9/catalog/nrdd/C/Coastal%20Wetlands%20%28State%20Environmental%20Planning%20Policy%20No.%2014%29%20-%20SEPP%2014.html
Important wetlands	"A Directory of Important Wetlands in Australia" Third Edition (EA, 2001), plus various additions for wetlands listed after 2001. http://www.environment.gov.au/metadataexplorer/full_metadata.jsp?docId=%7B0377A251-4E6C-48DF-95FC-720048F879B6%7D
All_combined_wetlands	OEH (2008).
Vegetation mapping	
BellingerRiverNP_1999_E_87	Austeco (1999a)
BillinudgelNR_1998_E_93	no report available
BongilBongil_Floyds_VIS_3857 BongilBongil_NP_veg_VIS_3856	Cameron <i>et al.</i> (2011)
BoonanghiNR_2002_E_138	no report available
cape_byron_NPWS_VISmap_169	Baker (2009)
CathedralRockNP_1994_E_173	no report available

Layer Name	Source
ChaelundiNP_1999_E_187	Austeco (1999b)
CooperabungCkNR_2002_E_220	no report available
CudgenNR_1998_E_229	no report available
DooraganNP_1997_E_253	Kendall and Kendall Ecological Services (1997)
GuyFawkesRvrNP_NW_2000_E_327	Watson <i>et al.</i> (2000)
GuyFawkesRvrNP_SE_1999_E_328	Austeco (1999c)
KillabakhNR_2003_E_381	no report available
MariaNP_2001_E_456	no report available
MarylandNP_2007_E_457	Hunter (2006)
nambucca_VISmap_500	Kendall (2003)
NewEnglandNP_2000_E_507	Clarke <i>et al.</i> (2000)
NymboiBinderayNP_1999_E_532	Austeco (1999d).
oxley_wild_rivers_VISmap_544	Unpublished report. NPWS Armidale Office.
RawdonCkNR_2002_E_560	no report available
RichmondRiverNR_2007_E_575	no report available
SkillionYarraNRs_2002_E_616	no report available
StottslidNR_2000_E_633	Stanisic, J. (2000).
tweed_LGA_VISmap_673	Kingston, <i>et al.</i> (2004).
VallaJagunNRs_2004_09_E_685	no report available
YarrahapinniNP_1942_E_3832	SWC (1997)
YarrahapinniNP_1997_E_3833	
Coastal Vegetation of North East NSW. VIS ID 3885	Metadata file identifier: 32A7B27F-22D4-4D6C-8672-AF08AE1B22C3
portveg2406_2013	Biolink (2013)
CoffsHarbourLGA12	OEH (2012)
Byron_FE_03	http://www.byron.nsw.gov.au/byron-shire-environmental-mapping
lismore_veg	http://canri.nsw.gov.au/nrdd/records/ANZNS1159000014.html
nambucca_VIS	Kendall and Kendall Ecological Services (2003)
tweed_LGA_VISmap_673	Ecograph 2004

4.3.3 Addition of other WDE classes

A comprehensive search of waterfall, waterhole and Karst data was undertaken to ensure that spatial point data representing these features were also uploaded to the WAIT database, as these are a key water asset. Aquifer data, also absent in the original layer, were not able to be sourced for this project.

4.4 Final WAIT coverage

On completion of the spatial review, a total of 11,070 WDEs were contained within the WAIT database for Northern Rivers. Of the original 22,855 features, 19,159 were removed (including Oxleyan Pygmy Perch habitat, Littoral Rainforest, groundwater bores, National Parks and Nature Reserves, and numerous multi-part polygons and slivers), while 7,374 were added (including local catchments, waterfalls, waterholes and unmapped wetlands).

Table 10 shows the number and area of different WDE types captured in the updated version of the WAIT database, while Figure 5 shows their distribution in the Clarence-Moreton region.

Table 10. Number and area of different types of WDEs in the Clarence-Moreton region

WDE class	Type	Number of assets	Area ha	Length km
Coastal sedgeland	Polygon	361	2,340	
Coastal wet heath	Polygon	392	6,380	
Estuary	Polygon	270	25,820	
Floodplain wetlands (ephemeral)	Polygon	1,536	16,620	
Floodplain wetlands (permanent)	Polygon	580	2,100	
Forested wetlands	Polygon	2,085	45,730	
Freshwater lakes (natural and semi-natural)	Polygon	1,046	2,150	
GDE	Point	1,272		
High altitude sphagnum heath	Polygon	1	10	
Local catchments	Polygon	639	2,187,600	
Mangrove	Polygon	47	70	
Riparian wetlands (non-floodplain)	Polygon	930	1,560	
Rivers/streams	Line	1,739		11,700
Saline lakes (fed by sea spray/drift)	Polygon	5	70	
Saltmarsh	Polygon	102	180	
Saltwater lagoons (fed by tidal water)	Polygon	17	4,500	
Waterfall	Point	37		
Waterhole	Point	11		
	Totals	11,070	NA (overlapping)	11,700

Various updates were made to descriptive fields in the WAIT database as part of the overview. Table 11 lists all fields in which updates were carried out.

Table 11. Fields in the WAIT database for which updates were undertaken

WAIT table	WAIT field
Water_Asset	ID
Water_Asset	AssetName
Water_Asset	NRM_region
Water_Asset	AssetID
Water_Asset	Description
Water_Asset	Coordinates_latitude_longitude
Water_Asset	coordinates_define
Water_Asset	Nearest_Town
Asset_MapSheet_names	Mapsheet_100k_name
Water_Asset	EnvironmentalValue
Water_Asset	EconomicValue
Water_Asset	ManagementAuthority
Asset_LandUse	Current_landuse
Water_Asset	Tenure
Water_Asset	Condition
Water_Asset	Is_map_available
Water_Asset	Is_GISdata_available
Water_Asset	Is_metadata_available
Water_Asset	References
Water_Asset	Notes
Water_Asset	Other_Relevant_Details
Vulnerability	ReferenceID
Vulnerability	Activity
Vulnerability	Existing_Potential
Vulnerability	Effect
Vulnerability	Impact

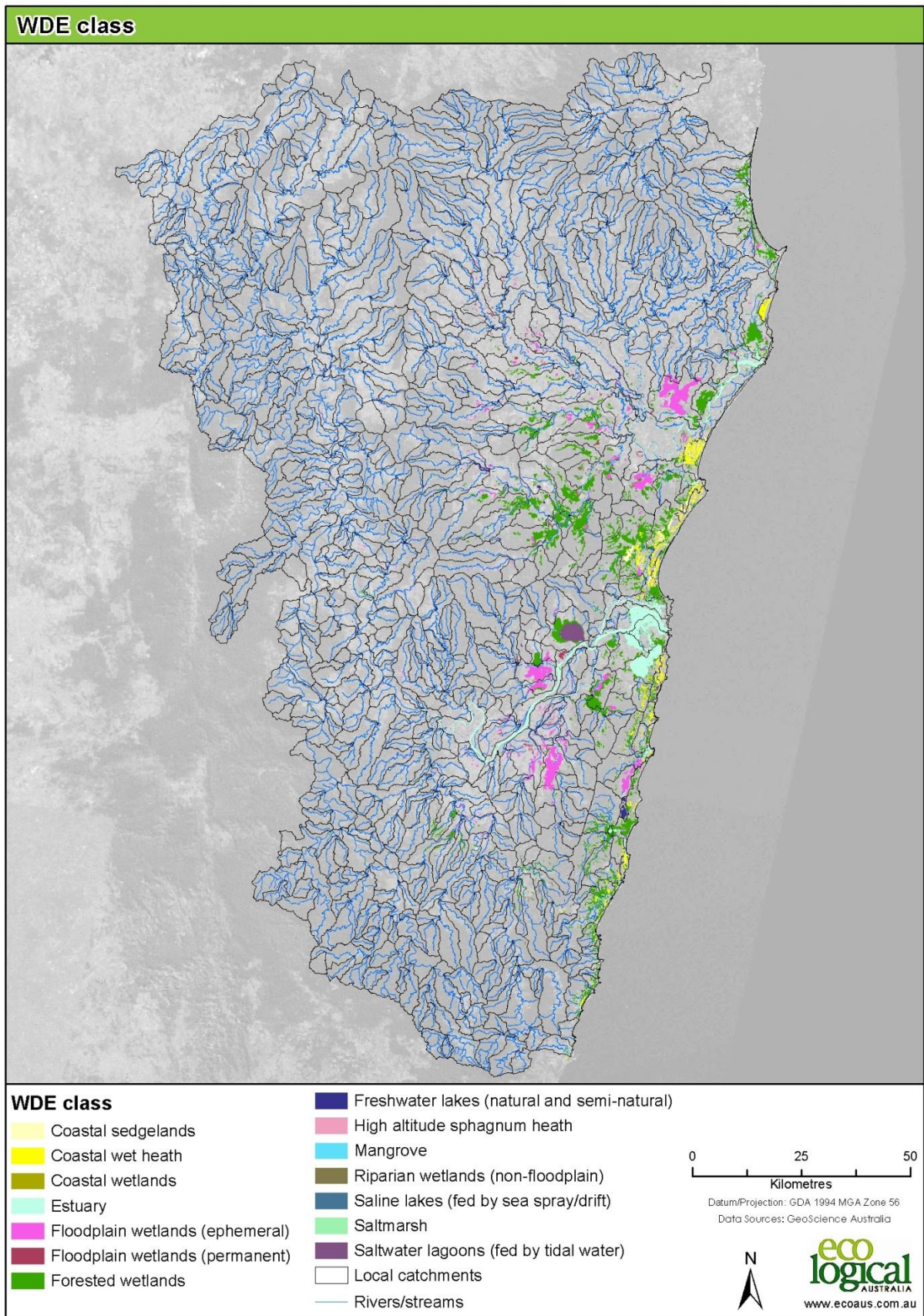


Figure 5. Distribution of WDE types in Clarence-Moreton region

4.5 WDE fluctuation analysis

4.5.1 Background

The purpose of this component was to derive maximum and minimum wetted extents of WDEs in the Northern Rivers catchment. Automated capture of wet and dry periods was undertaken within the Northern Rivers region footprint using density slicing of the mid-infrared Band 5 across a multi-temporal series of Landsat 5 TM (thematic mapper) images from periods of high flow and low flow, respectively. Where possible, the composite layer of inundated areas identified in the dry period density slice was used to inform the assignment of WDEs that were likely to be permanent and possibly groundwater dependent.

4.5.2 Rainfall analysis

Landsat images were selected following wetter and drier periods. Target analyses of monthly rainfall data taken from Armidale, Byron Bay, Casino, Coffs Harbour, Grafton and Port Macquarie were undertaken to provide information across the Northern Rivers CMA area. Monthly rainfall data were compared with historical monthly means to identify months that had below average and above average rainfall. Images were selected as close as possible to significant rainfall events to represent maximum wetted extent. Images were selected after prolonged dry periods to represent minimum wetted area and water body persistence.

4.5.3 Image management

Image acquisition

Landsat 5 TM (LT5) and Landsat 8 (LC8) imagery was acquired from the US Geological Survey *Glovis* website (<http://glovis.usgs.gov>). Imagery was selected to correspond wet or dry periods and contain minimal cloud cover. Four Landsat tiles were required to capture the whole catchment. In total nine images were acquired, two wet period images were required for Path 89 / Row 81 due to cloud cover in different areas of each image (Table 12; Figure 6).

Table 12: Landsat imagery and density slice intervals used to identify Water Dependant Ecosystems

Landsat Tile	Image date for dry period	Density slice intervals for dry periods	Image date for wet period	Density slice intervals for wet periods
P89 / R80	25 Aug 2004	Wet areas: 0-20 Dry areas: 20.01 - 255	16 Jan 2011	Wet areas: 0-33 Dry areas: 33.01 - 255
P89 / R81	29 Jun 2007	Wet areas: 0-20 Dry areas: 20.01 - 255	16 Jan 2011 (nw half) 10 Nov 2009 (sw half)	Wet areas: 0-33 Dry areas: 33.01 - 255
P89 / R82	4 Oct 2007	Wet areas: 0-20 Dry areas: 20.01 - 255	26 Apr 2013	Wet areas: 0 - 5 426 Dry areas: 5 426 – 55 513
P90 / R80	15 Jun 2005	Wet areas: 0-15 Dry areas: 15.01 - 255	10 Jun 2009	Wet areas: 0-33 Dry areas: 33.01 - 255

Image processing

Automated mapping of wet areas (open water and very moist soil) was undertaken within the Northern Rivers CMA area via density slicing of the mid-infrared band (Band 5 of Landsat 5 and Band 6 of Landsat 8). Density slice intervals were set through examination of the band histogram and the real-time evaluation of the area mapped as wet, with alteration to the density slice threshold. A mosaic of the wet area mapping was created for both the wet and dry periods.

Image refinement

The composite images were visually assessed and polygons drawn around wet areas to facilitate elimination of hill-shade and cloud-shadow. Contour and slope related information, plus inspection of the false colour imagery, were also used to assist in mapping refinement. Final wetted extent data were converted from raster to vector files, and a separate shapefile, for the wet and dry periods created.

4.5.4 Results of analysis

Figure 7 shows the wetted surface footprint within the Northern Rivers catchments, for wet and dry periods. The total extent of the wetted surface during seasonally high rainfall (wet period) was 76,300 ha, or 1.5% of the NRCMA area. In contrast, the total extent of the wetted surface during seasonally low rainfall (dry period) was 37,800 ha, equivalent to 0.8% of the NRCMA area.

When estuaries were eliminated from both footprints, the total wetted area in non-estuarine regions is observed to reduce from 53,710 ha in the wet period to 14,623 ha in the dry period. Any freshwater system coincident with the dry period footprint is likely to be a permanent rather than ephemeral system, and apart from larger rivers and streams, may be groundwater dependent.

Spatial intersection of WAIT data with the dry period wetted footprint resulted in the identification of 381 WDE features (excluding rivers, waterfalls, estuaries and GDEs) that were likely to be 'permanent' and possibly groundwater dependent. These were tagged in the comments field in the WAIT database.

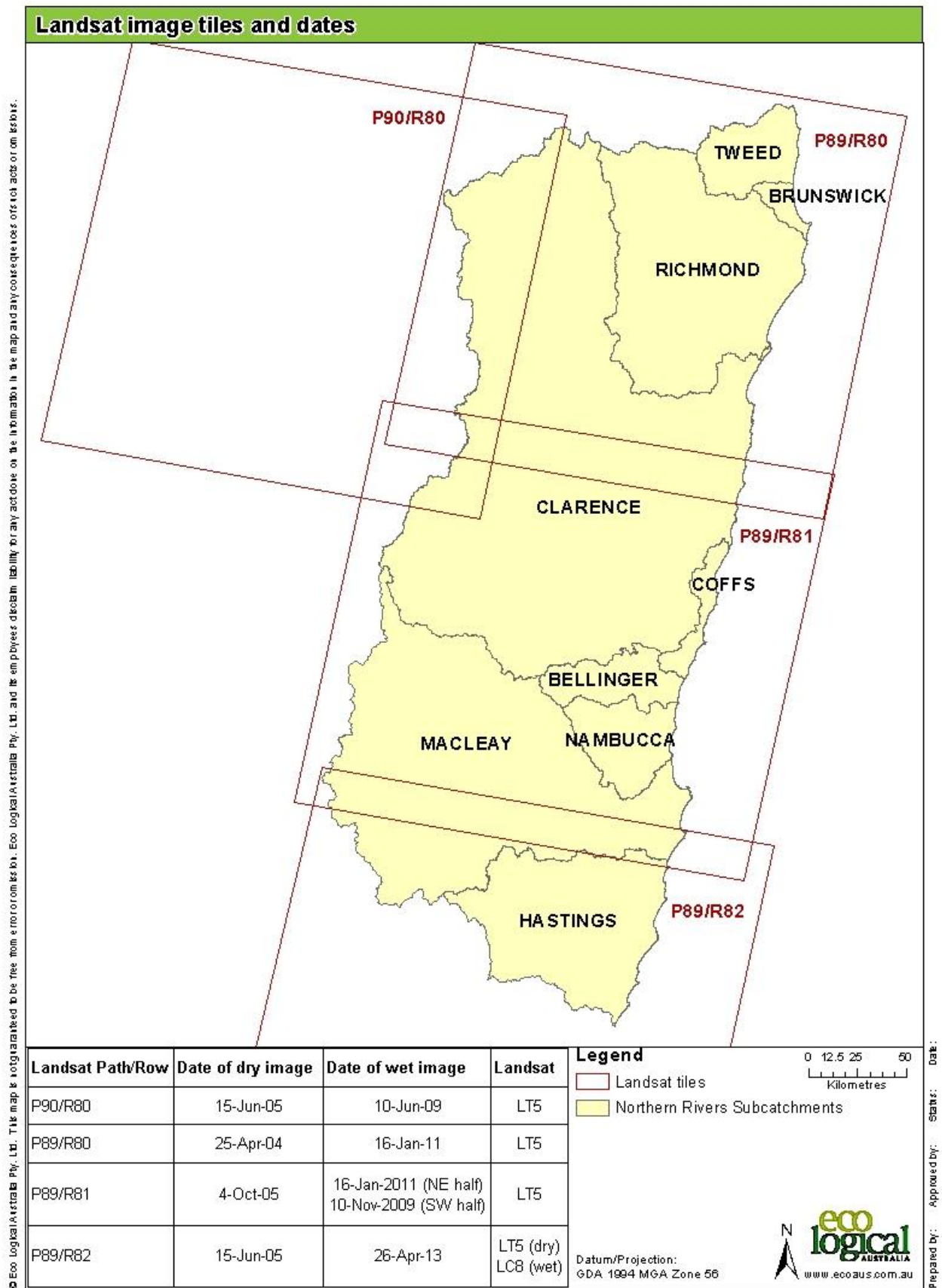


Figure 6. Landsat image tiles and dates

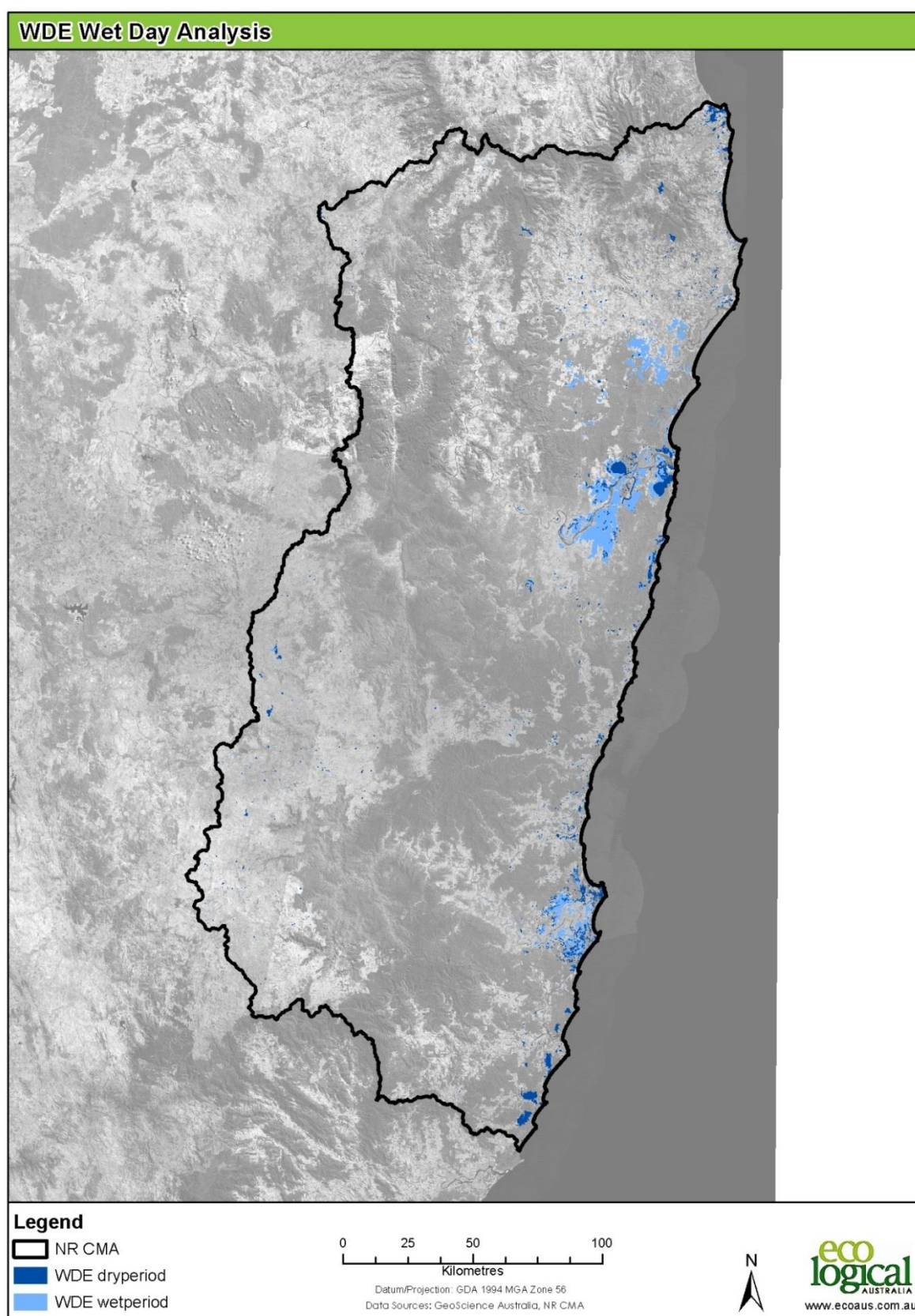


Figure 7. 'Wetted surface' signature for wet and dry periods in the Northern Rivers Catchment

4.6 WDE classification

4.6.1 Background

Eco Logical Australia worked in close consultation with the University of New England (UNE) to devise a simple WDE classification system that was able to be assigned consistently to the WDE map developed for the NRCMA region, and which facilitated condition assessment and prioritisation. Table 13 lists the WDE classes and types that were used. Specific colour signatures associated with topographic data were used to separate lagoons from wetlands in the spatial data, while a broad floodplain surface developed from the DEM was used to separate floodplain and non-floodplain systems.

Table 13. WDE classes and types assigned to composite layer for NRCMA

WDE Class	WDE type	Comment
Closed lagoon	Coastal floodplain lagoon	Spatial data sourced mainly from Bell <i>et al.</i> (2008)
	Coastal saline lagoon	
	Upland lagoon	
Estuary	Estuarine creek	
	Mangrove	
	Saltmarsh	
	Tidal channel (open water)	
	Tidal lagoon	
Riparian storage	Major storage (> 100 ha)	
	Other storage (5 – 100 ha)	
	Minor storage (0.5 – 5 ha)	
Wetland	Coastal floodplain wetland	Coastal floodplain and riparian wetland divided into permanent or ephemeral based on LandSat assessment (Section 4.5)
	Riparian wetland	
	Forested wetland	
Rivers/streams	Waterfall (point data)	Named waterfalls and waterholes captured for this project and input into the WAIT database
	Waterhole (point data)	

Two additional features – watercourses (line data) and GDEs (point data) – were assembled by WBM MBT Pty Ltd into the original WAIT database, but were not included in the WDE data for NRCMA on account of absence of spatial data beyond that already captured. Aquifer data were also absent from the composite WDE layer for NRCMA.

4.6.2 WDE regionalisation

WDEs were assigned to broad regions that comprised combinations of major drainage basins and IBRA bioregions. A total of 10 major regions were delineated; namely Bellinger, Brunswick, Clarence Upland, Clarence Coast, Hastings Upland, Hastings Coast, Macleay Upland, Macleay Coast, Richmond and Tweed (Figure 8). These were used to assist site selection for field condition assessment undertaken by UNE as part of a concurrent project.

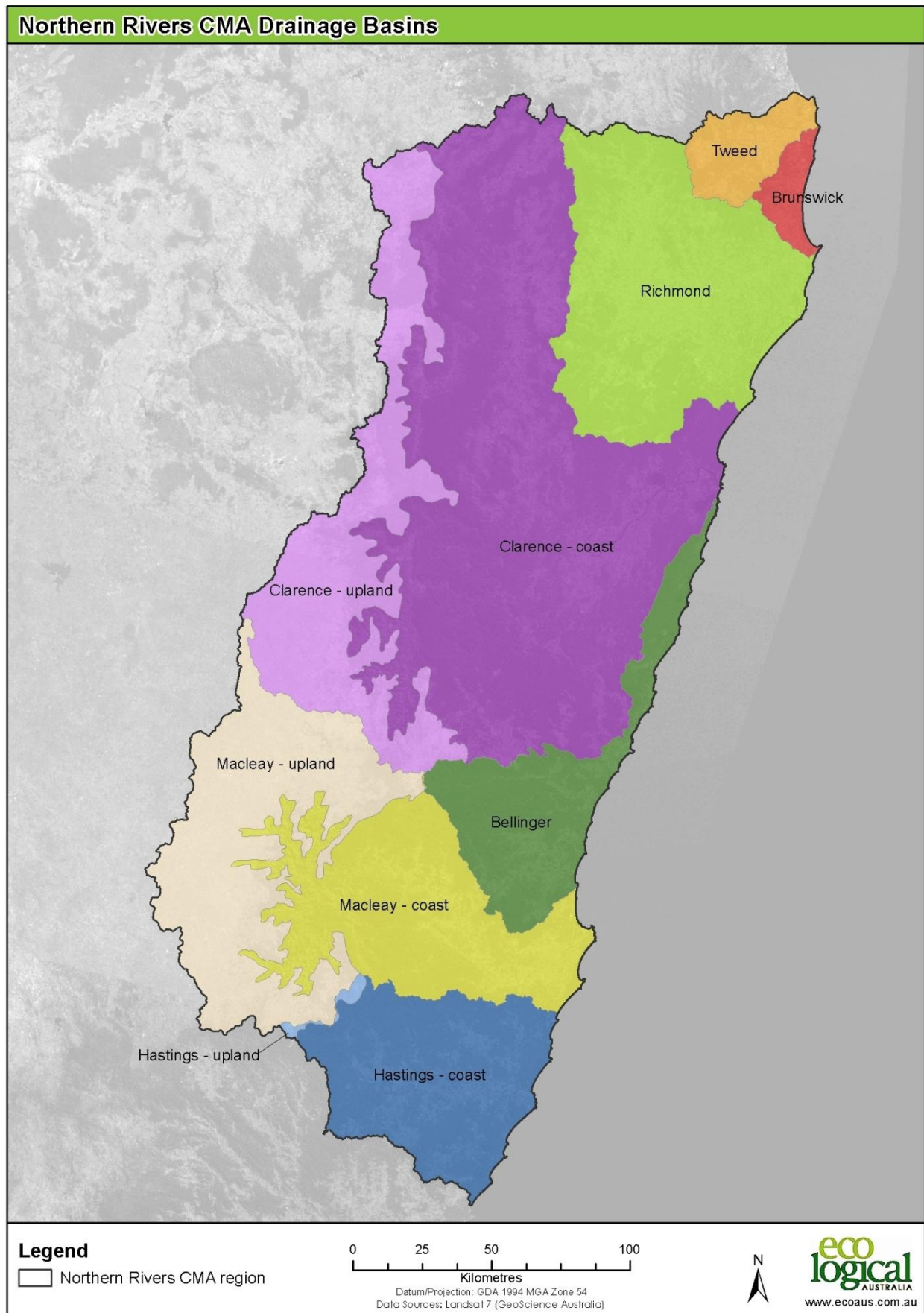


Figure 8. Regionalisation applied to mapped WDEs in the NRCMA region

4.7 WDE condition assessment

The condition of a natural WDE is a measure of its capacity to provide ecosystem services, for example clean water and healthy aquatic habitat. In general terms, a WDE in good condition is more vulnerable to a disturbance mechanism (e.g. mine runoff) as it has potentially more intrinsic value to forfeit, while a WDE in poor condition is less vulnerable to disturbance, as it has less intrinsic value to forfeit. A landscape-scale rapid condition rating of 'very good', 'good', 'moderate', 'poor' or 'very poor' (in line with requirements of the WAIT database) was assigned to each WDE in this project by applying a rule-set based on guidelines stipulated in the National Framework for the Assessment of River and Wetland Health (FARWH; Norris *et al.* 2007). Condition ratings already assigned to assets by BMT WBM Pty Ltd (Cavanagh 2012) were left unmodified. No field survey was undertaken for this condition assessment – it was desktop only.

The FARWH proposes six key components for assessing river and wetland health: catchment disturbance; hydrological change; water quality; physical form; fringing zone; and aquatic biota (Norris *et al.* 2007). The FARWH notes the inevitability that missing data will be encountered, and for this reason recommends that at least three of the six components be used to obtain an overall assessment. In the Northern Rivers region, a complete set of spatial data were developed from available NRM layers for the following metrics - catchment disturbance; physical form, and fringing zone – and these were used as the basis for desktop condition assessment for this project. Consistent catchment-wide data were not available for hydrological change, water quality or aquatic biota, so these were not used in the condition assessment.

A condition rating was derived for 7,373 WDEs in the WAIT database using the following desktop metrics:

Catchment disturbance metrics

- Percent of conservation reserve in local catchment containing asset
- Percent of native vegetation in local catchment containing asset
- Percent of 'developed' land in local catchment containing asset (Appendix I)

Physical form metrics

- Percent of asset in conservation reserve
- Percent of asset and 50 m buffer containing 'developed' land (Appendix I)

Fringing zone metrics

- Percent of fringing zone (50 m buffer) containing native vegetation

Table 14 lists the criteria and formulae used to calculate condition index. A final condition rating was assigned as follows.

Condition = very good	CI \geq 0.8
Condition = good	CI = 0.6 – 0.79
Condition = moderate	CI = 0.4 – 0.59
Condition = poor	CI = 0.2 – 0.39
Condition = very poor	CI = < 0.2

Table 14. Criteria used to assign condition indices to WDEs

Condition Metric	Condition Index (CI) Formula
Local catchment protection status	$CI_{LCP} = [\%reserve] / 100$
Local catchment native vegetation status	$CI_{LCNV} = [\%native\ vegetation] / 100$
Local catchment land use status	$CI_{LCLU} = [1.0 * (\%undeveloped) + 0.5 * (\%disturbed)] / 100$
Protection status	$CI_P = [\%reserve] / 100$
Land use status	$CI_{LU} = [100 - \%developed] / 100$
Native vegetation (fringing zone)	$CI_{FZ} = [\%native\ vegetation] / 100$
FINAL	$CI = \text{average } (CI_{LCP} \ CI_{LCNV} \ CI_{LCLU} \ CI_P \ CI_{LU} \ CI_{FZ})$

Condition ratings established above for estuaries (including tidal channels and tidal lagoons) were overwritten with condition ratings captured in Table 25 of the NSW Estuary and Coastal Lake Assessment (Roper *et al.* 2011). Condition ratings established for a number of wetlands were also updated based on recent field assessment by the University of New England (Ryder *et al.* 2013).

4.7.1 Results

For each WDE type, the total number of WDEs in each condition class is shown in Table 15. Just over half of all WDEs are in fair, good or very good condition. Sedgelands, wet heaths, forested wetlands, waterfalls, local catchments, non-tidal saline lakes, mangroves and saltmarshes are (collectively) in relatively good condition while estuaries, floodplain wetlands, freshwater lakes, riparian wetlands and rivers and creeks are (collectively) in relatively poor condition. Figure 9 show the distribution of WDES according to condition class.

Table 15. Number of WDEs in five condition classes in the Clarence-Moreton region

Description	Very good	Good	Moderate	Poor	Very Poor	<i>unassigned</i>
Coastal sedgelands	244	88	26	3		
Coastal wet heath	205	127	49	7	1	3
Estuary	9	7	52	184	18	
Floodplain wetlands (ephemeral)	19	78	469	882	86	2
Floodplain wetlands (permanent)	4	43	182	300	51	
Forested wetlands	502	446	635	449	48	5
Freshwater lakes (incl. semi-natural)	6	42	450	436	108	4
High altitude sphagnum heath				1		
Local Catchment	85	182	234	124	14	
Mangrove	2	15	19	11		
Riparian wetlands (non-floodplain)	18	62	358	479	7	6
River/creek		353	839	495	52	
Saline lakes (sea spray/drift)	3	2				
Saltmarsh	5	20	41	36		
Saltwater lagoons (tidal)	2	6	4	5		
Spring						1272
Waterfall		13	12	7		5
Waterhole		3	6			2
	1,104	1,487	3,376	3,419	385	1,299

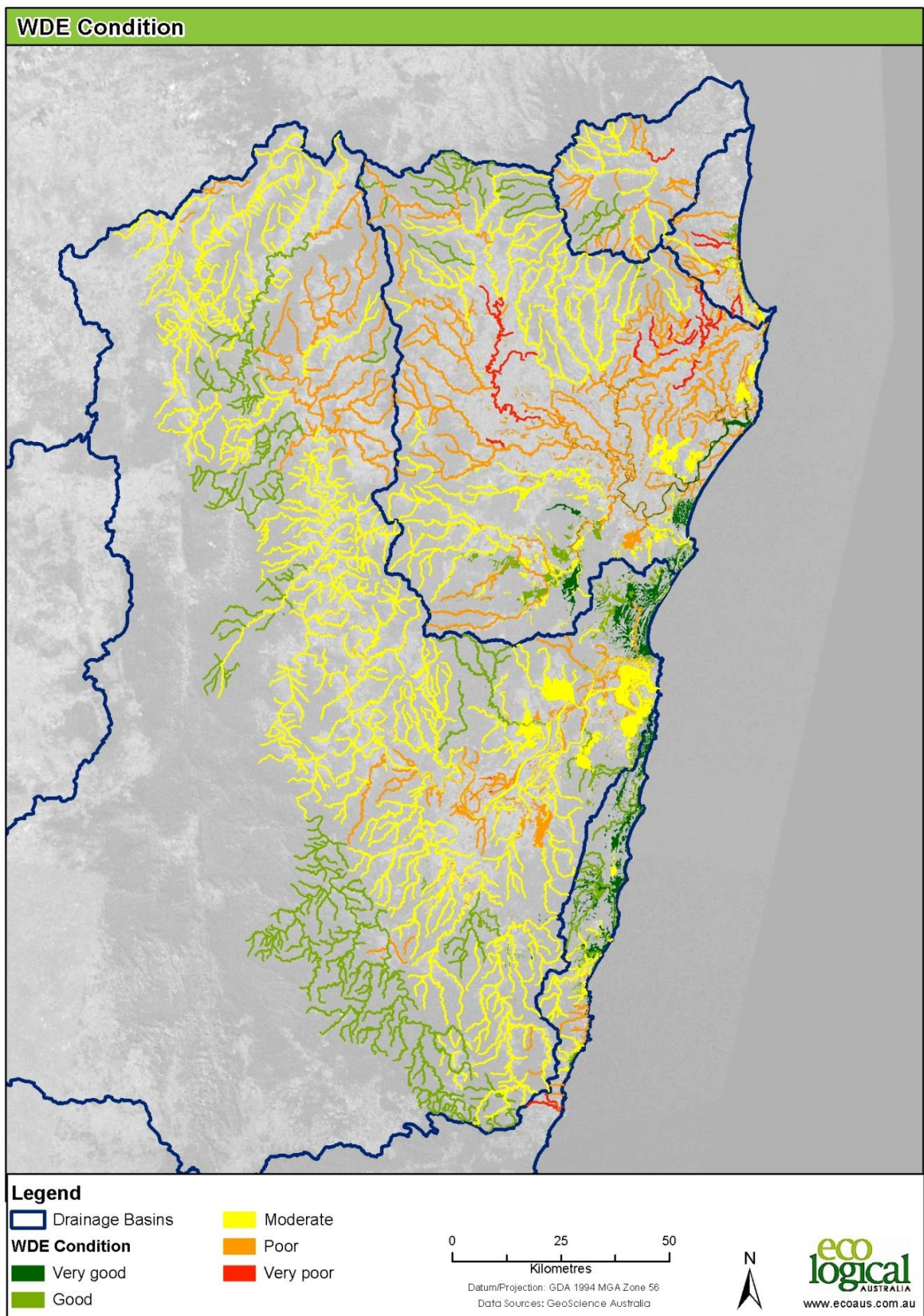


Figure 9. Distribution of WDEs in the Clarence-Moreton region based on condition

4.8 WDE vulnerability assessment

4.8.1 Method

Similar to the vulnerability assessment for local catchments, a rating for habitat vulnerability was derived for each WDE in the WAIT database using a matrix that cross-references levels of asset sensitivity to levels of asset resilience (Table 16). The vulnerability of assets to coal and CSG extraction increases with increasing sensitivity and decreasing resilience.

To achieve the comparison in Table 16, sensitivity levels were drawn from condition ratings (Section 4.7) while resilience levels were generated using a set of rules and conditions relevant to each asset class (refer to Appendix IV).

Table 16. Asset vulnerability as a function of condition and resilience.

	Resilience		
Sensitivity	High	Medium	Low
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium

Once all data were compiled, a final review was conducted in which vulnerabilities were revised downwards, if all or part of the asset occurred outside the mapped extent of the potential coal or CSG gas resource, as depicted in Table 6. A map of coal resource potential in the NR catchment is provided in Figure 3.

4.8.2 Results

Results of sensitivity, resilience and vulnerability analysis in the context of potential CSG extraction on habitat values are shown in Table 17. After reducing the vulnerability rating for WDEs that occur outside the region of CSG-potential, the total number of high vulnerability WDEs within the Clarence-Moreton region is 24%.

The proportion of each WDE asset class within high, medium and low vulnerability categories for CSG impacts on habitat is shown in Figure 10. While the majority of assets are low vulnerability, over 40% of coastal wetlands, floodplain wetlands and lagoons, forested wetlands, saline lakes and saltmarsh communities are medium to high vulnerability.

Table 17. Number of WDEs by sensitivity, resilience and vulnerability class (CSG extraction)

	Sensitivity			Resilience			Vulnerability*		
Effect	High	Medium	Low	High	Medium	Low	High	Medium	Low
Habitat	1,943	2,293	3,117	715	2,578	4,060	1,737	2,659	2,977

* values based on sensitivity-resilience pairing (Table 16) and location of local catchment in relation to CSG potential (Table 6)

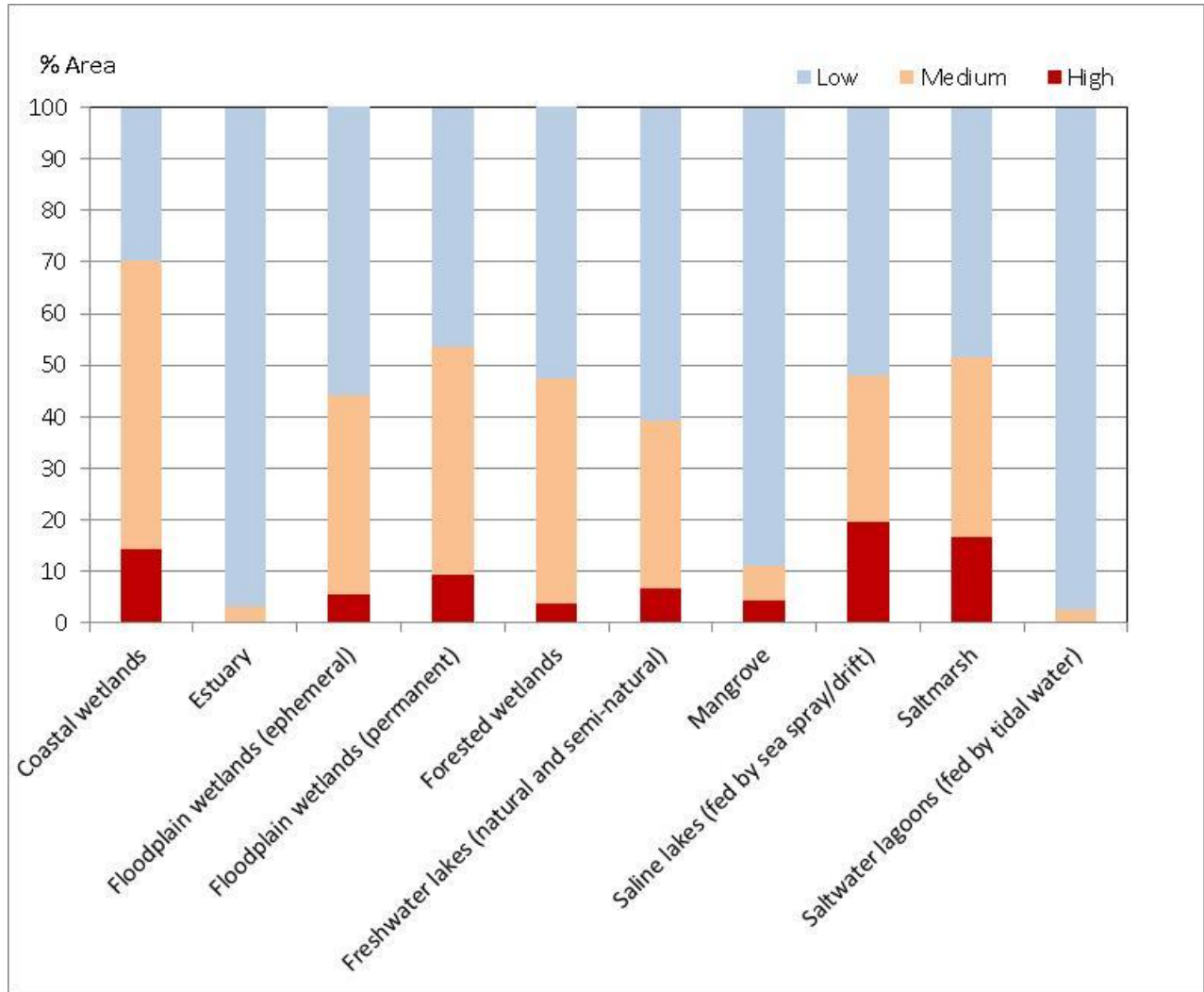


Figure 10. Proportion of each asset class in high, medium and low vulnerability, in relation to potential CSG impacts on habitat value.

5 Discussion

5.1 Limitations

5.1.1 Spatial data

A large number of spatial datasets associated with wetlands and forested wetlands are available in the Northern Rivers CMA region. Many are overlapping but with different spatial extents, as they have been created by a variety of organisations at different times and under different climatic seasons, and metadata are often absent. Of the various datasets, few were sourced for upload into the original WAIT database. Thus a large part of this project involved augmentation of spatial data with new data identified in Table 9, resulting in considerable time to manage overlapping polygons and slivers. While all reasonable care was undertaken in merging data, some spatial errors in the layer are likely to remain, particularly with respect to the spatial accuracy with which WDE boundaries were originally captured.

5.1.2 Condition and vulnerability

Condition and vulnerability assessment was undertaken using a desktop process in which various landscape metrics, available across the whole region, were applied to features as ‘surrogates’ of condition (where actual condition ratings were available from other sources, these were used instead). A limitation of this approach is that in some circumstances, actual condition may not reflect what might be expected when viewed in context of the surrounding landscape. For example, a wetland located in an urbanised or intensively cropped landscape may be in relatively good condition if targeted restoration and maintenance works are in place. Conversely, a wetland located in a relatively intact catchment may be in poor condition if heavily used as a watering point by stock. Thus an element of caution should be afforded when considering condition (and vulnerability) on an asset-by-asset basis.

5.2 Recommendations

5.2.1 Ongoing data management investment

This project represents the first, important step in collating data on natural water assets across the Clarence-Moreton catchment for the purposes of informing landscape level vulnerability to CSG / coal extraction. Due to data and time constraints, many values for the Environmental, Cultural, Economic and Hydrological characteristics of named assets were not completed. Therefore, it is recommended that an ongoing investment is allocated to build this data and knowledge to improve subsequent phases of Bioregional Assessment.

5.2.2 Aquifers and floodplains

A limitation of this project was the exclusion of aquifer and floodplain mapping. Both aquifers and floodplains are key water assets that should be considered in a Bioregional Assessment, in the context of the wide range of ecosystem services they provide. Delineation of these features should be considered.

5.2.3 Groundwater dependent ecosystems

A substantial number of GDE point localities that represent springs in the Alstonville area were retained in the database. However GDE mapping is incomplete as springs are absent in other parts of the catchment, and other GDEs (e.g. specific vegetation types) are not included. The status of GDE mapping in the catchment should be reviewed and lifted to a minimum, catchment-wide standard.

References

- Austeco (1999a). *Vegetation Report for Bellinger River National Park for use in Fire and Resource Management*. A consultancy report for NSW NPWS, Dorrigo district. Austeco Environmental Consultants, September, 1999.
- Austeco (1999b). *Vegetation Report for Chaelundi National Park for use in Fire and Resource Management*. A consultancy report for NSW NPWS, Dorrigo District. Austeco Environmental Consultants. September, 1999.
- Austeco (1999c). *Vegetation Report for Guy Fawkes River National Park for use in Fire and Resource Management*. A consultancy report for NSW NPWS, Dorrigo District. September, 1999.
- Austeco (1999d). *Vegetation Report for Nymboi-Binderay National Park for use in Fire and Resource Management*. A consultancy report for NSW NPWS, Dorrigo District. September, 1999.
- Baker, A. (2009). *Vegetation and Flora of Cape Byron State Conservation Area and Arakwal National Park*. Unpublished report to the DECC, Wildsite Ecological Services P/L.
- Bell, D.M., Hunter, J.T. and Haworth, R.J. (2008) Montane lakes (lagoons) of the New England Tablelands Bioregion. *Cunninghamia* 10(3): 475–492.
- Biolink (2013), *Vegetation of the Port Macquarie Hastings Local Government Area*. A report prepared for the Port Macquarie Hastings Council.
- Burns, C., Cibilic, A., and Smith, B. (2006) *NRCMA Wetland Mapping, Classification & Prioritisation Report*. WetlandCare Australia, Ballina, NSW, Australia.
- Cameron, M.A, Sheringham, P.R., Hunter, R.J. and Smith, M. (2011). *Survey and Mapping of the Vegetation of Bongil Bongil National Park*. Office of Environment and Heritage (NSW). Coffs Harbour.
- Cavanagh, D. (2012). *Baseline Identification and Assessment of Key Environmental Assets (Water Resources and Water Dependent Ecosystems)*. Report to Northern Rivers CMA. BMT WBM Pty Ltd.
- Clarke, P.J. Copeland, L.M., Noble, N.E., Bale, C.L. and Williams, J.B. (2000). *The Vegetation and Plant Species of New England National Park*. Botany, University of New England, Armidale.
- Environment Australia (2001). *A Directory of Important Wetlands in Australia*. Third Edition.
- Ecograph (2004). *Tweed Vegetation Management Strategy Volume 2 of 3 – Technical Reports*. Report prepared for Tweed Shire Council.
- Eco Logical Australia. (2012). *Assessing the cumulative risk of mining scenarios on bioregional assets in the Namoi Catchment: Development and trial of an interactive GIS tool*. Prepared for Namoi CMA.
- Eco Logical Australia. (2013). *Augmentation of the WAIT database for the Border Rivers and Gwydir Catchments: Addition of local catchment and floodplain data*. Prepared for Border Rivers/Gwydir CMA.
- Healey, M., Raine, A., Parsons, L., and Cook, N. (2012) *River Condition Index in New South Wales: Method development and application*. NSW Office of Water, Sydney.

- Hunter, J.T. (2006). *Vegetation and Floristics of Maryland National Park*. A Report to the New South Wales Parks and Wildlife Service.
- Kendall, P.A. (2003). *Nambucca Catchment Vegetation Study*. Report prepared for Nambucca Vegetation Sub-committee.
- Kendall and Kendall Ecological Services (1997). *Vegetation Survey of Dooragan National Park*. Report prepared for NSW NPWS, September 1997.
- Kendall and Kendall Ecological Services (2003). *Nambucca Catchment Vegetation Survey*. Report prepared for Nambucca Vegetation Sub-committee
- Kingston, M.B. and Storey, R.J. (2004). *Tweed Vegetation Management Plan – Draft Report*. Ecograph Ecological and Geographical Information Systems Consultants, Tweed Shire, NSW.
- Norris, R.H., Dyer, F., Hairsine, P., Kennard, M., Linke, S., Merrin, L., read, A., Robinson, W., Ryan, C., Wilkinson, S. and Williams, D. (2007). *Australian Water Resources 2005: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands*. National Water Commission. May 2007
- OEH. (2008). *Wetland Conserve and Repair Assessment*. Unpublished report.
- OEH (2012). *Development of a Fine-scale Vegetation Map for the Coffs Harbour Local Government Area. Volume 1: Project Report*. OEH on behalf of Coffs Harbour City Council and the Northern Rivers Catchment Management Authority.
- Roper, T., Creese, B., Scanes, P., Stephens, K., Williams, R., Dela-Cruz, J., Coade, G., Coates, B. and Fraser, M. (2011). *Assessing the Condition of Estuaries and Coastal Lake Ecosystems in NSW, Monitoring, Evaluation and Reporting Program*. Technical report series, Office of Environment and Heritage, Sydney.
- Ryder, D., Mika, S. and Richardson, M (2013). *Validation and sensitivity/risk assessment of the DSEWPac water asset condition data*. Final Technical Report to the NRCMA. University of New England, Armidale.
- Stanisic, J (2000). *Survey for Land Snail Thersites mitchellae in Northern New South Wales III. Investigation of Stotts Island locality*. Unpublished report prepared for NSW National Parks and Wildlife Service.
- SWC (1997). *Environmental Impact assessment for the proposed Restoration of Tidal inundation of Yarrahapini Wetland*. Unpublished report prepared by Shortland Wetland Centre consultancy.
- Walker, B. and Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Island Press, Washington DC.
- Watson, G. Elks, G. and Smith, A. (2000). *Guy Fawkes River National Park Vegetation Communities*. A report for the National Parks and Wildlife Service, Northern Tablelands Region, Glen Innes Area. Austeco Environmental Consultants, May 2000.

Appendix I. Land use classes

Overview

Land use classes in the state-wide land use surface were classified into three broad groups for the purpose of asset condition assessment and prioritisation. The three groups were: developed; disturbed; and intact. The following table lists the land use classes associated with each group.

LAND USE CLASSES in the 'DEVELOPED' GROUP

Abandoned orchard and vine lands; trees/vines not maintained and may be dying; regrowth of native shrubs and trees is occurring

Abandoned urban or industrial area and site is locked up e.g. Glen Alice

Abattoir

Aerodrome/airport

Airstrip (local/farmer, grass or bare surface, not sealed)

Alternate life style community under multiple occupancy

Aquaculture - fish, prawn, yabby or beach worm farm

Area recently under development for urban, commercial and/or industrial uses - infrastructure in place but no building activity

Areas irrigated with effluent from sewage disposal ponds

Bamboo plantation (for food)

Banana plantation

Banana plantation - irrigated

Building associated with horticultural industry (winery, packing shed)

Bulb production for flower trade

Canal (canal estate, navigation canal)

Caravan park or mobile home village

Cemetery

Communications facility

Cropping - continuous or rotation

Cropping - continuous or rotation - irrigated

Cut flowers & herbs

Cut flowers & herbs - irrigated

Defence facility

Derelict mining land

Dog kennel, dog run for greyhounds

Drainage channel (from irrigation system or a channel draining a swamp; base of channel is lined)

Effluent ponds from intensive animal industries

Electricity substation

Farm dam

Farm Infrastructure - house, machinery & storage sheds and garden areas

Flood chute (flood runners that are filled with water during and after floods) and designated floodway in irrigation districts, localities

Flood or irrigation structure

Flood refuge (constructed features located within flood prone areas)

Fly ash dam/spoil dump

LAND USE CLASSES in the 'DEVELOPED' GROUP

Fodder crop
 Fodder crop - irrigated
 Forest dominated by camphor laurel
 Government and private facilities - gaol, training centre, school, religious institutions & training centres, religious retreats
 Grassland areas (e.g. mown/slashed grass areas) within vineyards
 Horse stud and/or horse breeding facilities
 Industrial/commercial
 Intensive animal production
 Intensive animal production - beef feedlot
 Intensive animal production - dairy shed
 Intensive animal production - deer
 Intensive animal production - horse
 Intensive animal production - ostriches
 Intensive animal production - piggery
 Intensive animal production - poultry
 Irrigated pastures
 Irrigation dam
 Irrigation from abattoir and other industry
 Irrigation supply channel
 Landfill (garbage)
 Lantana, blackberry and other exotic weed infested grazing land
 Lemon Myrtle plantation
 Levee bank for urban area
 Marina
 Mine site
 Mine site within a State Forest
 Nursery
 Olives
 Olives - irrigated
 Orchard - tree fruits
 Orchard - tree fruits - irrigated
 Pecan, macadamia and other nuts
 Pecan, macadamia and other nuts - irrigated
 Poplar plantation
 Quarry
 Quarry - within a State Forest
 Research facility
 Reservoir
 Reservoir within a State Forest
 Residential
 Resort style private land use
 Riparian vegetation - exotic species (principally willow)

LAND USE CLASSES in the ‘DEVELOPED’ GROUP

River navigation structure
 Rural residential
 Rural residential within vineyard
 Saleyard
 Sawmill
 Sewage disposal ponds
 Shade house or glass house (includes hydroponic use)
 Softwood plantation
 Softwood plantation - nursery
 Softwood plantation and within a State Forest
 Sown, improved perennial pastures
 Sown, improved perennial pastures within a State Forest
 Sugar cane
 Surf club and/or coastal car parking facilities
 Tea and Coffee plantation
 Tea and Coffee plantation - irrigated
 Tea Tree Plantation
 Tea Tree Plantation - irrigated
 Temporary water storage area (e.g. rice farming - opportunistic storage of water in natural depressions)
 Tourist development
 Tree lot - exotic species
 Trig station or beacon
 Turf farming
 Turf farming - irrigated
 University or other tertiary institution
 Urban recreation
 Vegetables
 Vegetables - irrigated
 Vineyard - grape and other vine fruits
 Vineyard - grape and other vine fruits - irrigated
 Volunteer, naturalised, native or improved pastures, with previous evidence of cultivation
 Water supply pressure reservoir including water filtration plant

LAND USE CLASSES in the 'DISTURBED' GROUP

Degraded land (salt site, eroded area)

Drainage depression in cropping paddock

Drainage or water supply channel - base of channel is not lined

Drainage or water supply channel within a State Forest - base of channel is not lined

Energy corridor

Energy corridor within a State Forest

Eucalypts and other Australian native species for cut flower arrangements

Foreshores land to State Water dam

Foreshores or reserved land to water supply dam (Sydney Water, Hunter Water, SMHEA or Public Works Dam)

Grassland within mining lease

Grazing - Residual strips (block or linear feature) of native grassland within cultivated paddock. Strips contain scattered to isolated trees only

Hardwood plantation

Hardwood plantation within a State Forest

Lands fenced and treated for land degradation problems

Native shrub plantation (e.g. tea tree)

No identified use

Railway

Rainforest plantation

Recently cleared land (cleared of forest vegetation as yet not covered by crop or pasture)

Residential - with a woody vegetation cover of open forest

Restored mining lands

Restored sand mining area

River training work

Road or road reserve

Rural recreation. Blocks are isolated and not associated with an urban area

Rural residential - with a woody vegetation cover of open forest

Rural residential - with a woody vegetation cover of woodland

Rural residential - with more than 30% of ground area having regeneration of native tree species

Secondary grassland in forested areas

Sown, improved perennial pastures - with a woody vegetation cover of open forest

Sown, improved perennial pastures - with a woody vegetation cover of woodland

Tree lot

Volunteer, naturalised, native or improved pastures

Volunteer, naturalised, native or improved pastures - with more than 30% of ground area having exotic weeds

Volunteer, naturalised, native or improved pastures - with more than 30% of ground area having native shrub regeneration

Volunteer, naturalised, native or improved pastures within a State Forest

Windbreak or tree corridor

LAND USE CLASSES in the 'INTACT' GROUP

Beach
 Cliff/rock outcrop
 Coastal lake
 Coastal marsh/estuarine swamp
 Crown reserve
 Dunal swamp
 Estuarine waters
 Floodplain swamp
 Floodplain swamp - back swamp
 Floodplain swamp - billabong
 Foreshore protection - vegetated fore dune (coastal feature)
 Inland salt lake
 Lagoon or inland lake
 Land fenced for riparian management
 Mangrove
 Marine park
 Mudflat
 National park
 Native forest
 Native forest - filter strips in softwood plantation
 Native forest - logged
 Native forest - regeneration
 Native forest and within a State Forest
 Native woody shrub
 Nature reserve
 Prior stream
 Private conservation agreement
 River, creek or other incised drainage feature within a State Forest; includes cowals in western NSW
 River, creek or other incised drainage feature; includes cowals in western NSW
 Sand spit/estuarine sand island
 Small to medium forested or wilderness blocks with isolated residential buildings. (Rural residential but the forested or wilderness feature of the block is worth noting.)
 State forest
 Swamp
 Swamp - with a woody vegetation cover of closed forest
 Swamp - with a woody vegetation cover of open forest
 Swamp - with a woody vegetation cover of woodland
 Swamp - with more than 30% of ground area having regeneration of native tree species
 Volunteer, naturalised or improved pastures - with a woody vegetation cover of closed forest
 Volunteer, naturalised or improved pastures - with a woody vegetation cover of open forest
 Volunteer, naturalised or improved pastures - with a woody vegetation cover of open shrubland
 Volunteer, naturalised or improved pastures - with a woody vegetation cover of shrubland
 Volunteer, naturalised or improved pastures - with a woody vegetation cover of woodland
 Volunteer, naturalised, native or improved pastures - with more than 30% of ground area having regeneration of native tree species
 Wide road reserve or TSR, with some grazing

Appendix II. Intactness

The intactness of a landscape is its ‘naturalness’ and is influenced by the proportion of native vegetation remaining and its patchiness (number of patches per unit area). Intact landscapes have little or no degree of disturbance and exhibit high connectivity and a low degree of modification, while poorly intact landscapes have been highly disturbed and fragmented. Intactness is a reasonable (but not absolute) measure of vegetation condition, as roads and other easements that bisect contiguous areas of native vegetation can act as vectors for movement of alien species (thus increasing disturbance), and may also increase the risk of wildfire.

An intactness input layer was created for the local catchment condition assessment by applying the following equation to a 25 m grid cell layer at every point in the landscape that considered all surrounding vegetation within a 5 km buffer.

$$\text{Intactness} = \left[\frac{(\text{Native vegetation})_{\text{Area}}}{(\text{Total})_{\text{Area}}} \right]^{[1 + (0.01 * (\text{no. patches}))]}$$

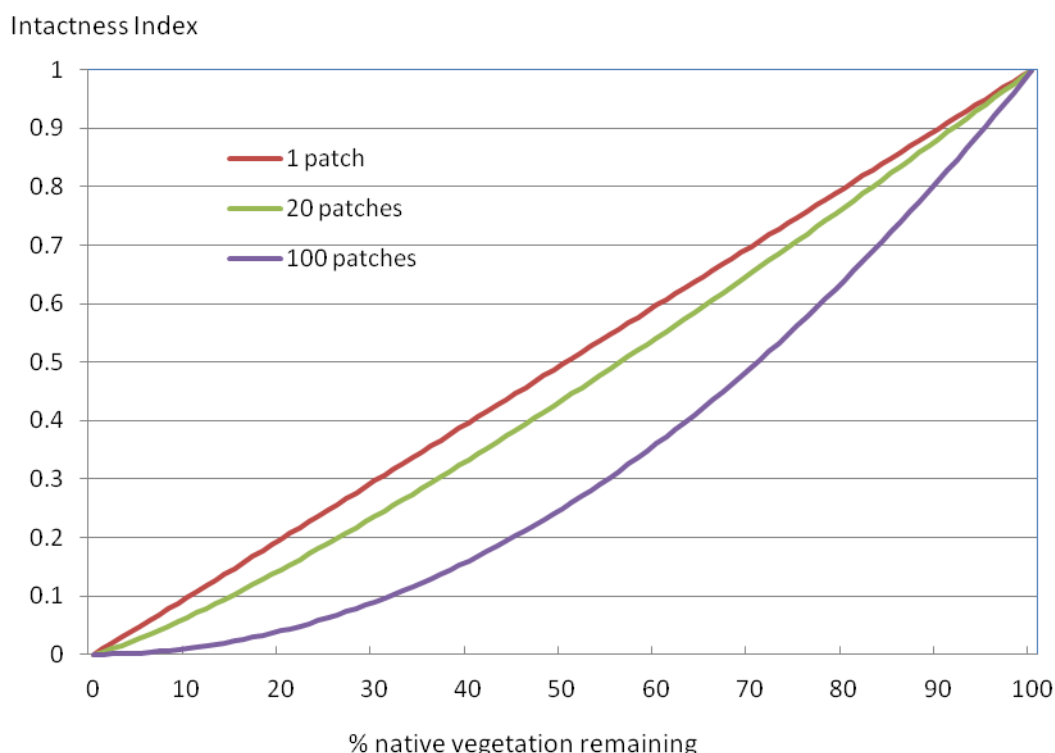
Where:

(Native vegetation)_{Area} = combined area of all native vegetation within the 5 km buffer

(Total)_{Area} = area of a circle of 5 km radius

No. of patches = number of patches in the 5 km radius (including those divided by easements)

The power factor increases with the total number of patches and is used to account for the impact of edge effects. Thus, the more the landscape has been cleared and the greater the number of remnant patches, the greater the relative loss of intactness in the landscape. This is demonstrated in the following illustration:



Appendix III. Rules used to assign levels of ‘sensitivity’ and ‘resilience’ to local catchments.

Outline

This Appendix outlines the rules used to assign a sensitivity and resilience rating and thus a vulnerability rating (high, medium or low) to each asset for each of four effects in the WAIT database – flow pattern, habitat, water quantity and water quality.

Algorithms

*Land Use Index = $[0 * \text{developed} + 0.5 * \text{disturbed} + 1.0 * \text{intact}] / \text{catchment area (ha)}$*

Where:

developed (ha) = area of developed land, including cropping, vineyards, horticulture, industry, urban, etc.

disturbed (ha) = area of semi-developed agriculture, mainly grazing on unimproved pasture; and

undisturbed (ha) = area of native vegetation, some of which is in conservation reserves, and some of which is grazed and/or logged.

EEC index = $[(\text{EEC (ha)} / \text{catchment area (ha)})]$

Where:

EEC (ha) = vegetation types that are likely to constitute EECs

Asset class = Local catchments

Effect = flow pattern

Sensitivity

Sensitivity = high if stream density ≥ 4.0 km per 100 ha (1 km^2) of catchment

Sensitivity = medium if stream density $2.0 - 4.0$ km per 100 ha (1 km^2) of catchment

Sensitivity = low if stream density < 2.0 km per 100 ha (1 km^2) of catchment

Resilience

Resilience = high if land use is non-intensive (land use index ≥ 0.700)

Resilience = medium if land use is semi-intensive (land use index $0.300 - 0.700$)

Resilience = low if land use is intensive (land use index < 0.300) or local catchments are largely impacted by major storages (i.e. upstream)

Resilience is reduced by a factor of one (e.g. from High to Medium) when local catchments are moderately impacted by major storages (i.e. storage upstream but significant flow from other catchments occurs).

Effect = habitat

Sensitivity

Sensitivity = high where EEC index ≥ 0.500 or number of vegetation types ≥ 10

Sensitivity = low where EEC index $= < 0.250$ and number of vegetation types < 7

Otherwise sensitivity = medium

Resilience

Resilience measured based on historical level of clearing in catchment, and proximity to the 30%, 70% and 100% clearing thresholds (specified in Namoi CAP).

Resilience = high where % vegetation cleared = $0 - 10\%$, $30 - 50\%$, $70 - 80\%$ (at least 20% from any threshold)

Resilience = medium where % vegetation cleared = $10 - 20\%$, $50 - 60\%$, $80 - 90\%$ (at least 10% from any threshold)

Resilience = low where % vegetation cleared = $20 - 30\%$, $60 - 70\%$, $90 - 100\%$ (within 10% of a threshold)

Effect = water quantity

Sensitivity

Sensitivity = high if water storages cover > 1% of catchment

Sensitivity = medium if water storages cover 0.1 - 1% of catchment

Sensitivity = low if water storages cover < 0.1% of catchment

Resilience

Resilience = high if local catchment supports a river reach 0.3 or higher

Resilience = medium if local catchment supports a river reach 1 or 2, or a lower reach of a major creek

Resilience = low for all other catchments

Effect = water quality

Sensitivity

Sensitivity = high if $\geq 70\%$ of riparian areas (50m buffer of drainage) are comprised of native vegetation

Sensitivity = medium if 30 - 70% of riparian areas (50m buffer of drainage) are comprised of native vegetation

Sensitivity = low if $< 30\%$ of riparian areas (50m buffer of drainage) are comprised of native vegetation

Resilience

Resilience = high if majority of land use is low intensity (land use index > 0.700)

Resilience = medium if majority of land use is semi-intensive (land use index = $0.300 - 0.700$)

Resilience = low if majority of land use is high intensity (land use index ≤ 0.300)

Appendix IV. Rules used to assign levels of ‘sensitivity’ and ‘resilience’ to WDEs.

Outline

This Appendix outlines the rules used to assign a resilience rating and, in combination with asset condition, a vulnerability rating (high, medium or low) to each asset for each of four effects in the WAIT database – flow pattern, habitat, water quantity and water quality.

Asset class = WDEs

(includes estuaries, saltmarshes, mangroves, floodplain wetlands and lagoons, upland lagoons, waterholes and waterfalls, streams and rivers, caves, and wetlands, but not GDEs)

Effect = habitat

Sensitivity

Sensitivity = high if condition = very good or good

Sensitivity = medium if condition = moderate

Sensitivity = low if condition = poor or very poor

Resilience

Resilience was calculated as a combination of asset area, percentage of fringing zone (50 m buffer) native vegetation, and average ‘intactness’ of the local catchment within which asset is located.

Habitat resilience as a function of area, fringing zone vegetation and intactness

Average intactness	% fringing zone vegetated	Asset area (ha)			
		0.5 – 2.0	2 - 10	10 - 100	> 100
< 0.3	< 30%	low	low	low	medium
	30 - 70%	low	medium	medium	high
	> 70%	medium	medium	high	high
0.3 – 0.7	< 30%	low	low	medium	medium
	30 - 70%	medium	medium	medium	high
	> 70%	medium	high	high	high
> 0.7	< 30%	low	medium	medium	high
	30 - 70%	medium	medium	high	high
	> 70%	high	high	high	high

**HEAD OFFICE**

Suite 4, Level 1
2-4 Merton Street
Sutherland NSW 2232
T 02 8536 8600
F 02 9542 5622

CANBERRA

Level 2
11 London Circuit
Canberra ACT 2601
T 02 6103 0145
F 02 6103 0148

COFFS HARBOUR

35 Orlando Street
Coffs Harbour Jetty NSW 2450
T 02 6651 5484
F 02 6651 6890

PERTH

Suite 1 & 2
49 Ord Street
West Perth WA 6005
T 08 9227 1070
F 08 9322 1358

DARWIN

16/56 Marina Boulevard
Cullen Bay NT 0820
T 08 8989 5601

SYDNEY

Level 6
299 Sussex Street
Sydney NSW 2000
T 02 8536 8650
F 02 9264 0717

NEWCASTLE

Suites 28 & 29, Level 7
19 Bolton Street
Newcastle NSW 2300
T 02 4910 0125
F 02 4910 0126

ARMIDALE

92 Taylor Street
Armidale NSW 2350
T 02 8081 2681
F 02 6772 1279

WOLLONGONG

Suite 204, Level 2
62 Moore Street
Austinmer NSW 2515
T 02 4201 2200
F 02 4268 4361

BRISBANE

PO Box 1422
Fortitude Valley QLD 4006
T 07 3503 7193

ST GEORGES BASIN

8/128 Island Point Road
St Georges Basin NSW 2540
T 02 4443 5555
F 02 4443 6655

NAROOMA

5/20 Cauty Street
Narooma NSW 2546
T 02 4476 1151
F 02 4476 1161

MUDGEES

Unit 1, Level 1
79 Market Street
Mudgee NSW 2850
T 02 4302 1230
F 02 6372 9230

GOSFORD

Suite 5, Baker One
1-5 Baker Street
Gosford NSW 2250
T 02 4302 1220
F 02 4322 2897

1300 646 131
www.ecoaus.com.au