Richmond Ecohealth Project 2014

Assessment of River and Estuarine Condition

Final Technical Report

June 2015

Darren Ryder, Sarah Mika, Max Richardson, John Schmidt and Ben Fitzgibbon

date. Strategy 12 seeks to identify unregistered sites and develop cultural management plans where appropriate to ensure on-going protection of cultural heritage around the estuary.

- Many of the major fisheries related issues (i.e. fish kills) are addressed by this plan by focussing on the source of issues, such as reducing environmental impacts of floodplain infrastructure (Strategy 4) and improving land management practices (Strategy 5). Other fisheries related issues are generally regulated by state government (principally Industry and Investment NSW) and the actions contained in Strategy 13 (Fishery Management) are related to improving community understanding of fisheries and aquaculture management in the local area and addressing specific concerns related to oyster harvest closures.

8. IMPLEMENTATION

The following table provides an overview of the recommended strategies, listing the key actions, responsibilities, location and indicative costs estimated over the ten year implementation period. The total cost of the CZMP implementation is estimated to be approximately $16.4 million over ten years.

Table 2: Overview of the CZMP implementation schedule

Action		Lead Organisation	Support Organisations	Management Zones	10 Year Cost ($'000)
FUNDAMENTAL MANAGEMENT STRATEGIES					
Strategy 1: Administration and Governance					
1.1	Review estuary governance and administration	EMC	BSC, LCC, RVC, RRCC, DECCW, I&I NSW, NRCMA, LPMA	Estuary-wide	**200**
Strategy 2: Climate Change Adaptation					
2.1	Planning for sea level rise and climate change impacts	EMC	BSC, LCC, RVC, RRCC, DECCW, I&I NSW, NRCMA, LPMA	Estuary-wide	**100**
Strategy 3: Monitoring and Evaluation					
3.1	EcoHealth monitoring program	EMC	BSC, LCC, RVC, RRCC, I&I NSW, DECCW, NRCMA, SCU	Estuary-wide	**2,000**
3.2	Develop catchment/water quality modelling tool to support decision making	EMC	BSC, LCC, RVC, RRCC, I&I NSW, DECCW, NRCMA, SCU	Estuary-wide	**45**
HIGH PRIORITTY					
Strategy 4: Floodplain Infrastructure Management					
4.1	Identify, prioritise and optimise drains and levees	RRCC	BSC, LCC, RVC, DECCW, I&I NSW	Estuary-wide	**3,420**
4.2	Review floodgate management protocols	RRCC	BSC, LCC, RVC, DECCW, I&I NSW	Estuary-wide	**55**

Table 2: CZMP Implementation Program

Action / Year	Lead Organisation	Ten year total	1	2	3	4	5	6	7	8	9	10
		$'000	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Action 1: Control of East Arm bank erosion and creation of sandy beach	BSC	**200**	25	175								
Action 2: Dredging of Main Section of Shaws Bay*	BSC	**400**	25	25	350							
Action 3: Review and upgrade stormwater treatment controls	BSC	**25**				25						
Action 4: Western foreshore improvements	BSC	**200**	20	100	80							
Action 5: Expansion of Pop Denison Park and improvement of access to the eastern foreshore	BSC	**350**		30	120	100	100					
Action 6: Development of Fenwick Drive foreshore area	BSC	**120**			20	50	50					
Action 7: Refurbishment of breakwall steps	Crown Lands	**150**					20	130				
Action 8: Modify conditions of mangrove maintenance permit	BSC	**-**	no additional cost									
Action 9: Weed management along northern side of the training wall	BSC	**22**	10	5	2	2	2	1				
Action 10: Education program – public health	BSC	**3**	3									
Action 11: Education program – estuarine vegetation	BSC	**-**	no additional cost									
Action 12: Education program – recreational fishing	Fisheries NSW	**-**	no additional cost									
Action 13: Education program – biological irritants	BSC	**3**	3									
Action 14: Foreshore signage	BSC	**5**	5									
Action 15: Beachwatch water quality monitoring (modified)	BSC	**10**	1	1	1	1	1	1	1	1	1	1
Action 16: Monitoring, Evaluation and Reporting Program	BSC	**18**		6			6			6		
Action 17: Hydrographic survey	BSC	**10**			5					5		
Action 18: Development of strategy to address inundation risk	BSC	**-**	no additional cost									
Action 19: Review of CZMP progress and monitoring of KPIs	BSC	**-**	no additional cost									
Action 20: 10 year review of CZMP	BSC	**50**										50
Total		**1,566**	**92**	**342**	**578**	**178**	**179**	**132**	**1**	**12**	**1**	**51**

Note: Years correspond to end of financial year i.e. 2016 is Year 1 (start 1st July 2015, end 30th June 2016) etc.

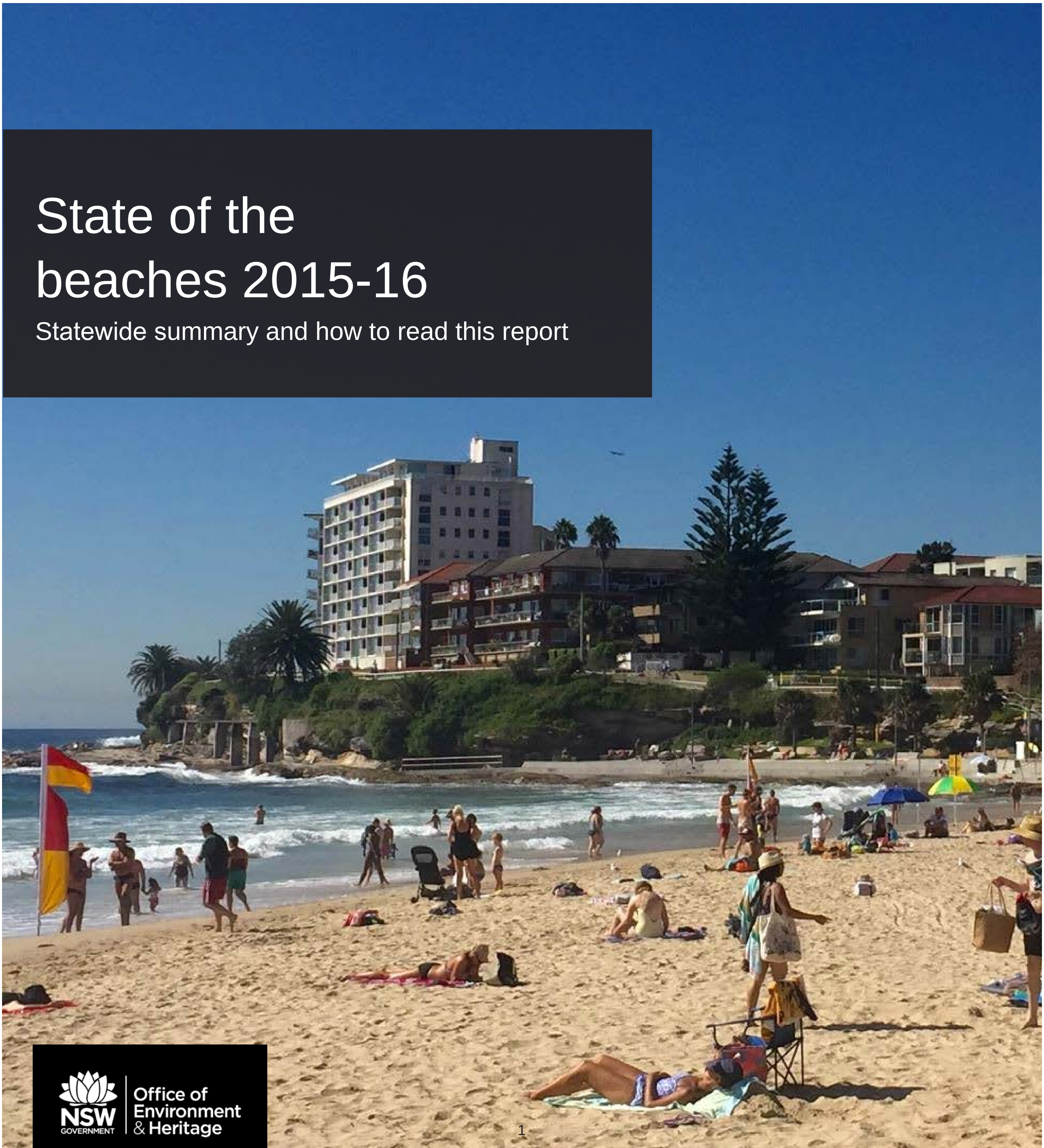
Shaded cells = Denotes the occurrence of actions with no additional costs allocated as part of this CZMP.

* The monetary value to address compensatory habitat requirements is not included in this figure. Up to $250,000 may be required in addition to the cost of works if suitable proposals in lieu of this requirement cannot be identified.

Beachwatch

State of the beaches 2015-16

Statewide summary and how to read this report



NSW Government
Office of Environment & Heritage

For technical information about this report contact:
Beachwatch, Office of Environment and Heritage NSW
59–61 Goulburn Street, Sydney
PO Box A290, Sydney South NSW 1232

Phone: (02) 9995 5344

Email: Beachwatch@environment.nsw.gov.au
Web: www.environment.nsw.gov.au/beach

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State of the Beaches

STATEWIDE SUMMARY 2015–2016

Beach monitoring in New South Wales

The water quality of beaches and other swimming locations is monitored under the NSW Government's Beachwatch programs to provide the community with accurate information on the cleanliness of the water and to enable individuals to make informed decisions about where and when to swim. Routine assessment also measures the impact of pollution sources, enables the effectiveness of stormwater and wastewater management practices to be assessed and highlights areas where further work is needed.

Swimming sites in New South Wales are graded as Very Good, Good, Fair, Poor or Very Poor in accordance with the National Health and Medical Research Council's 2008 *Guidelines for Managing Risks in Recreational Waters*. These Beach Suitability Grades provide a long-term assessment of how suitable a beach is for swimming. The grades are determined from the most recent 100 water quality results (two to four years' worth of data depending on the sampling frequency) and a risk assessment of potential pollution sources.

A guide on to how to read the report is provided on pages 16–19.

Rainfall impacts

Rainfall is the major driver of pollution to recreational waters, generating stormwater runoff and triggering discharges from the wastewater treatment and transport systems. Changes in rainfall patterns are reflected in beach water quality over time due to variation in the frequency and extent of stormwater and wastewater inputs.

The Beach Suitability Grades for 2015–2016 are based on water quality data collected over the last two to four years. Rainfall over this period has been diverse, beginning with sustained wet weather conditions and flooding in many areas along the NSW coast, followed by well-below average rainfall across the state, and ending with more wet weather conditions and heavy rainfall events including significant east coast lows:

- 2012–2013: high levels of rainfall recorded in many areas
- 2013–2014: driest summer in almost 30 years
- 2014–2015: above average rainfall, particularly on the coast
- 2015–2016: varied rainfall with wettest January on record for many coastal areas.

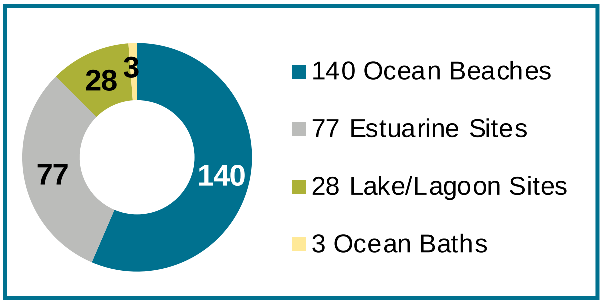
Beach Suitability Grades at 13 swimming sites were downgraded this year due to the inclusion of water quality data from the wet 2015–2016 summer and significant rainfall events. Some declines were from Very Good to Good grades, while others crossed the threshold from Good to Poor[1].

Statistics for 2015–2016:

9553
samples

248
sites

32
councils



4645
Twitter followers @BeachwatchNSW

52,782
Users environment.nsw.gov.au/beach

See How to Read this Report for explanations of graphs and Beach Suitability Grades.

Overall results for 2015–2016

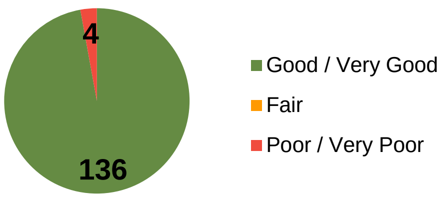
Percentage of sites graded as Very Good or Good:

81%	83%	83%	83%
2012–13	2013–14	2014–15	2015–16

In 2015–2016, 207 of the 248 monitored swimming locations were graded as Very Good or Good, indicating that they were suitable for swimming for most or almost all of the time. While overall this is an excellent result, many lake/lagoon and estuarine swimming locations did not perform as well as the ocean beaches, primarily due to limited flushing. Similar trends have been recorded in previous years.

As ocean beaches, estuarine beaches, lake/lagoon swimming sites and ocean baths have very different responses to rainfall-related impacts, the results for each type of swimming area are discussed separately.

Ocean beaches



In general, open ocean beaches in New South Wales exhibit excellent water quality with 97% of 140 monitored ocean beaches graded as Very Good or Good. This indicates that they were suitable for swimming for most or almost all of the time. This result is slightly higher than that recorded in 2014–2015, when 96% of ocean beaches were graded as Very Good or Good. The impacts of rainfall are least apparent at the ocean beaches, with tidal flushing rapidly dispersing and diluting pollution inputs.

Copacabana and Ocean beaches on the Central Coast and Boat Harbour at the northern end of Bate Bay in Cronulla were upgraded to Good from a Poor grade in 2014–2015.

Four ocean beaches were graded as Poor[1]:

- Terrigal Beach and Avoca Beach on the Central Coast
- Coogee Beach and Malabar Beach in Sydney.

Sites on the Central Coast can be impacted by more significant sources of contamination, such as discharges from lagoons, large creeks or estuaries, as well as substantial rainfall events. Terrigal Beach and Avoca Beach were also graded as Poor in 2014–2015. While water quality was generally suitable for swimming in dry weather conditions, elevated enterococci levels may be recorded following light rainfall.

Health risks

Contamination of recreational waters with faecal material from animal and human sources can pose significant health problems to beach users owing to the presence of pathogens (disease-causing micro-organisms) in the faecal material. The most common groups of pathogens found in recreational waters are bacteria, protozoans and viruses.

Exposure to contaminated water can cause gastroenteritis, with symptoms including vomiting, diarrhoea, stomach-ache, nausea, headache and fever. Eye, ear, skin and upper respiratory tract infections can also be contracted when pathogens come into contact with small breaks and tears in the skin or ruptures of the delicate membranes in the ear or nose.

Certain groups of users may be more vulnerable to the threat of microbial infection than others. Children, the elderly, people with compromised immune systems, tourists, and people from culturally and linguistically diverse backgrounds are generally most at risk.

Beach pollution forecasts

Beachwatch issues daily pollution forecasts to enable beachgoers to make informed decisions about where and when to swim. The forecasts are available before 7.30am during the swimming season (October to April) and before 8am between May and September, and cover swimming sites in the Sydney, Hunter, Central Coast and Illawarra regions.

Beach pollution forecasts can be accessed via the Beachwatch website, mobile website, email subscription, Twitter and Facebook.

environment.nsw.gov.au/beach

[1] Using the **Beach Suitability Grade** classification matrix, sites assigned a moderate Sanitary Inspection Category can only be rated as Good or Poor with no option of Fair grades. This can create the impression of a large change in water quality when in fact there need only be a slight increase in bacterial counts to push it over the threshold, with no significant increase in the risk to public health.

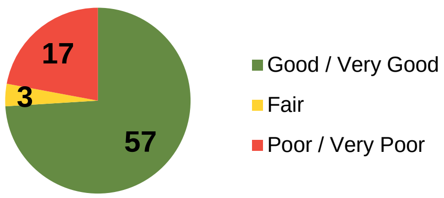
Malabar Beach and Coogee Beach were downgraded to Poor in 2015–2016 from Good in the previous year. Water quality was mostly good during dry weather conditions, however the impacts of rainfall are more apparent at these beaches.

While Coogee Beach generally had good water quality during dry weather, elevated bacteria levels were regularly measured following low levels of rainfall. Water quality was impacted by stormwater associated with frequent rainfall events during the assessment period, including the wettest January for Sydney since 1988. The impact of these events was enough to just breach the threshold from Good to Poor, however did not significantly increase the risk to public health from the previous year. With the inclusion of many wet weather results, Coogee Beach is now positioned at the top of the Poor grade instead of the bottom of the Good grade.

Malabar Beach has been monitored since 1989, with significant improvements in water quality since 2012–2013 due to the diversion of the large stormwater drain at the northern end of the beach. In 2015–2016, the beach was impacted by stormwater associated with significant rainfall events during the assessment period, including the wettest January for Sydney since 1988. This beach takes longer to recover from stormwater events than surrounding areas. Lower levels of flushing increase the time needed to disperse and dilute pollution inputs.

As a general precaution, swimming at ocean beaches should be avoided during and for up to one day after rainfall, or if there are signs of stormwater pollution such as discoloured water or floating debris.

Estuarine beaches



Fifty-seven (74%) of the 77 monitored estuarine beaches were graded as Very Good or Good, indicating the water quality was suitable for swimming for most of the time. These swimming sites were generally located in well-flushed sections of the estuaries or had few significant sources of pollution. This result is a decline on that recorded in 2014–2015 when 77% of estuarine beaches were graded as Good or Very Good. The overall fall in performance from the previous year was partly due to the inclusion of six estuarine beaches in Port Stephens, two of which were graded as Poor.

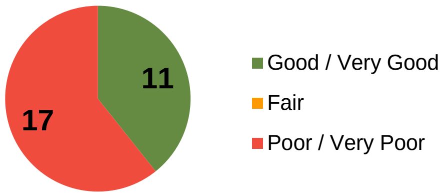
Three sites in Sydney (Gurney Crescent Baths, Clontarf Pool and Northbridge Baths) were graded as Fair. These sites generally had good microbial water quality in the assessment period, but the sanitary inspections identified risks from a number of potential sources of pollution including local stormwater runoff, upstream rivers and sewage overflows.

Sixteen (21%) of the estuarine beaches were graded as Poor. The water quality at these sites was often suitable for swimming during dry weather conditions, with elevated levels of enterococci recorded following rainfall. These sites were generally located in less well-flushed sections of the estuaries or had more significant sources of pollution.

As a general precaution, swimming at estuarine beaches should be avoided during and up to three days following rainfall or if there are signs of stormwater pollution such as discoloured water or floating debris.

Foreshores Beach in Botany Bay was graded as Very Poor, as it was in 2014–2015. The site is often suitable for swimming during dry weather conditions, but is very susceptible to pollution from the sewage overflows which discharge into Mill Pond Creek. To reduce the risk of illness, carefully follow the advisories in the Beachwatch pollution forecast and avoid swimming if there are signs of pollution such as discoloured water or floating debris.

Lake/lagoon swimming sites



Eleven of the 28 monitored lake and lagoon swimming sites (39%) were graded as Very Good or Good, an improvement on last year's 32%:

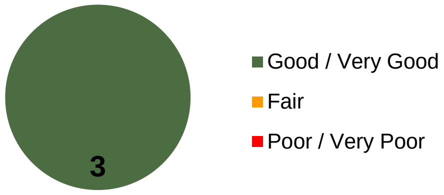
- seven locations in Lake Macquarie on the Central Coast
- Mogareeka Inlet north of Tathra on the South Coast
- Lake Ainsworth (East and South) in Ballina on the NSW North Coast
- Entrance Lagoon Beach in the Illawarra.

These swimming sites were suitable for swimming for most of the time.

Seventeen (61%) of the lake/lagoon swimming sites were graded as Poor. While many of these sites were suitable for swimming during dry weather conditions, elevated enterococci levels were frequently recorded following rainfall. Terrigal Lagoon was upgraded to Poor from Very Poor in 2014–2015. Water quality at Terrigal Lagoon has showed continual improvement since 2011. Narrabeen Lagoon (Birdwood Park) was downgraded to Poor from Good in 2014–2015. The entrance to the lagoon was closed for extended periods during the assessment period which impacted water quality at the nearby swimming site.

The water quality at coastal lake/lagoon sites often depends on how close the swimming area is to the ocean and whether the entrance is open to the ocean. When the entrance is open and the site is near that opening, the site can be well-flushed by clean ocean water and water quality is often of a high standard. If the site is not near the entrance, or the entrance is closed, the water quality of the site can be affected by contamination from stormwater runoff to the lake/lagoon. As a general precaution, it is recommended that swimming at lake and lagoon swimming sites be avoided during and up to three days following rainfall or if there are signs of stormwater pollution such as discoloured water or floating debris.

Ocean baths



All three monitored ocean baths were graded as Good: South Maroubra Rockpool in Sydney, Pearl Beach Rockpool in Gosford and Big Blue Pool on the South Coast, indicating that water quality is suitable for swimming for most of the time. Pearl Beach Rockpool was upgraded to Good in 2015–2016 from a Poor grade in the previous year.

The Beachwatch programs

Beachwatch

The Beachwatch program was established in 1989 to monitor Sydney's ocean beaches and was expanded to ocean beaches in the Hunter and Illawarra regions in 1996.

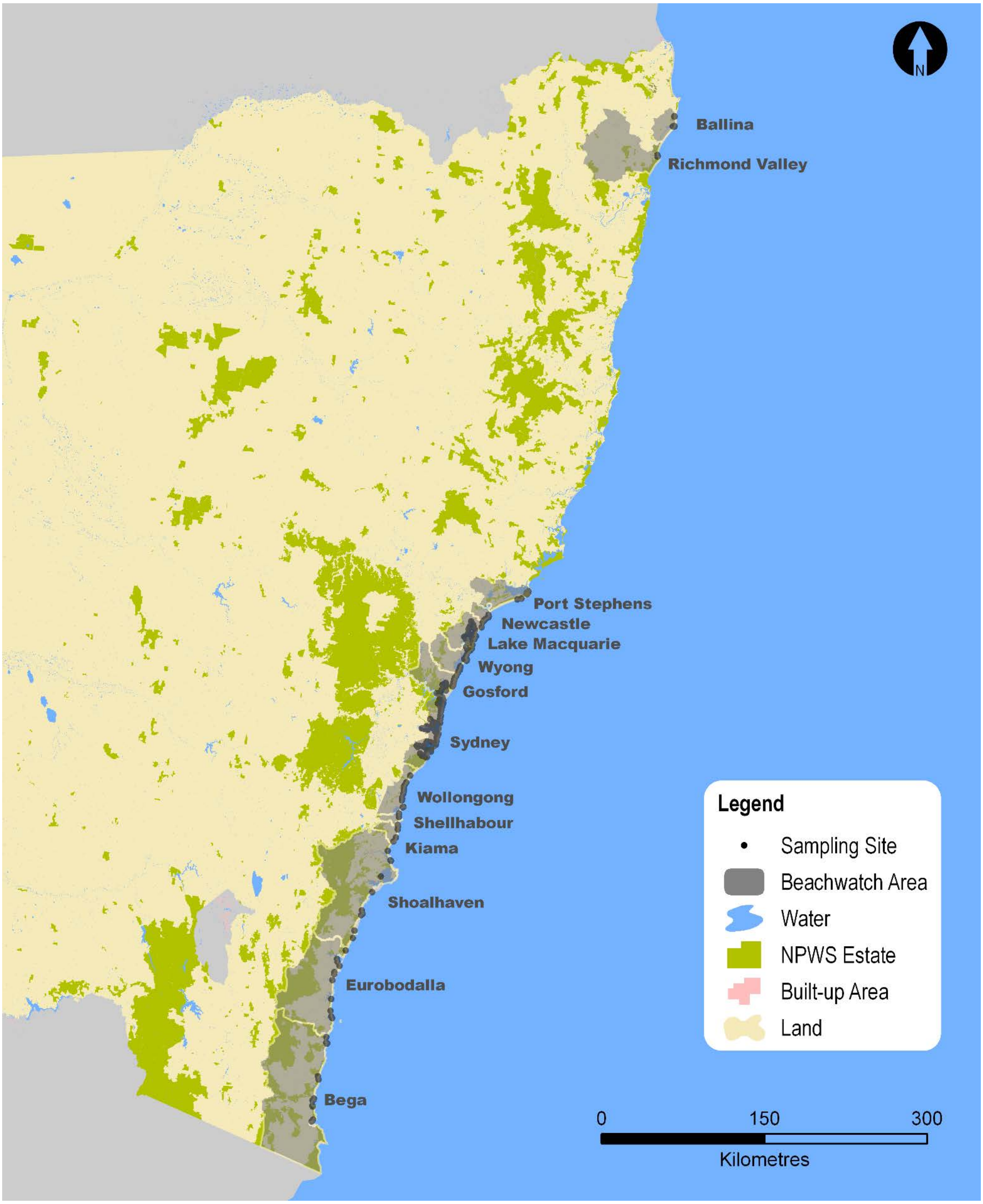
Monitoring of estuarine beaches commenced in 1994, with the addition of Sydney Harbour, Botany Bay and lower Georges River to the program. Pittwater was added in 1996 and most sites in Port Hacking were added in 1999.

Beachwatch Partnership Program

The Beachwatch Partnership Program was established as a pilot in 2002 and included 11 local councils along the NSW coast during 2015–2016:

Ballina Shire Council	Wollongong City Council
Richmond Valley Council	Kiama Municipal Council
Lake Macquarie City Council	Shoalhaven City Council
Wyong Shire Council	Eurobodalla Shire Council
Gosford City Council	Bega Valley Shire Council
Port Stephens Council	

The water quality sampling and laboratory analysis activities are fully funded by each local council. The Office of Environment and Heritage (OEH) provides quality assurance support and assistance with community reporting.



Sampling sites and areas monitored under the Beachwatch program

Beach Suitability Grades for North Coast region

North Coast region		Site Type	Beach Suitability Grade	Change	
Ballina Shire Council	Seven Mile Beach	Ocean beach	VG	●	Stable
	Lake Ainsworth East	Lagoon/lake	G	↑	Improved
	Lake Ainsworth South	Lagoon/lake	G	↑	Improved
	Lake Ainsworth West	Lagoon/lake	P	●	Stable
	Shelly Beach	Ocean beach	G	●	Stable
	Shaws Bay East	Estuarine	G	●	Stable
	Shaws Bay West	Estuarine	G	↑	Improved
	Shaws Bay North	Estuarine	P	↓	Deteriorated
	The Serpentine	Estuarine	G	●	Stable
	Lighthouse Beach	Ocean beach	VG	↑	Improved
Richmond Valley Council	Airforce Beach	Ocean beach	VG	●	Stable
	Main Beach	Ocean beach	VG	●	Stable
	Shark Bay	Ocean beach	VG	●	Stable
	Evans River	Estuarine	P	●	Stable

VG	Very Good	G	Good	F	Fair	P	Poor	VP	Very Poor

Beach Suitability Grades for Hunter region

Hunter region		Site type	Beach Suitability Grade	Change
Port Stephens Council	Zenith Beach	Ocean beach	VG	Stable
	Box Beach	Ocean beach	VG	Stable
	Fingal Beach	Ocean beach	VG	Stable
	One Mile Beach	Ocean beach	VG	Stable
	Bagnalls Beach	Estuarine	P	Stable
	Dutchmans Bay	Estuarine	G	Stable
	Birubi Beach	Ocean Beach	VG	Stable
	Karuah Tidal Pool	Estuarine	G	Stable
	Lemon Tree Passage Tidal Pool	Estuarine	G	Stable
	Little Beach	Estuarine	G	Stable
	Georges Reserve	Estuarine	P	Stable
City of Newcastle Council	South Stockton Beach	Ocean beach	VG	Stable
	Nobbys Beach	Ocean beach	VG	Stable
	Newcastle Beach	Ocean beach	VG	Stable
	Bar Beach	Ocean beach	VG	Stable
	Merewether Beach	Ocean beach	G	Stable
	Burwood North Beach	Ocean beach	G	Stable
	Burwood South Beach	Ocean beach	G	Stable
Lake Macquarie Council	Glenrock Lagoon Beach	Ocean beach	G	Stable
	Dudley Beach	Ocean beach	VG	Stable
	Redhead Beach	Ocean beach	VG	Stable
	Blacksmiths Beach	Ocean beach	VG	Stable
	Swansea Heads Little Beach	Ocean beach	G	Stable
	Caves Beach	Ocean beach	VG	Stable
	Eleebana (Lions Park)	Lagoon/lake	P	Stable
	Croudace Bay	Lagoon/lake	G	Stable
	Arcadia Vale	Lagoon/lake	G	Stable
	Belmont	Lagoon/lake	G	Stable
	Swansea	Lagoon/lake	P	Stable
	Cams Wharf	Lagoon/lake	P	Stable
	Catherine Hill Bay	Ocean beach	G	Stable
	Speers Point Park	Lagoon/lake	P	Stable
	Bolton Point	Lagoon/lake	P	Stable
	Toronto	Lagoon/lake	G	Improved
	Kilaben Bay	Lagoon/lake	P	Stable
	Wangi Point (Van Park)	Lagoon/lake	G	Stable
	Balcolyn	Lagoon/lake	G	Stable
	Sunshine	Lagoon/lake	G	Stable

VG Very Good · G Good · F Fair · P Poor · VP Very Poor

Beach Suitability Grades for Central Coast region

Central Coast Council		Site type	Beach suitability grade	Change
Former Wyong Shire Council	Frazer Beach	Ocean beach	VG	Stable
	Birdie Beach	Ocean beach	VG	Stable
	Budgewoi Beach	Ocean beach	VG	Stable
	Lakes Beach	Ocean beach	VG	Stable
	Hargraves Beach	Ocean beach	VG	Stable
	Jenny Dixon Beach	Ocean beach	VG	Stable
	Cabbage Tree Bay	Ocean beach	G	Stable
	Lighthouse Beach	Ocean beach	VG	Improved
	Gravelly Beach	Ocean beach	VG	Stable
	Soldiers Beach	Ocean beach	VG	Stable
	North Entrance Beach	Ocean beach	VG	Stable
	The Entrance Beach	Ocean beach	VG	Stable
	Blue Bay	Ocean beach	VG	Stable
	Toowoon Bay	Ocean beach	VG	Stable
	Shelly Beach	Ocean beach	VG	Stable
	Blue Lagoon	Ocean beach	VG	Stable
	Bateau Bay Beach	Ocean beach	VG	Stable
	Gwandalan	Lagoon/Lake	P	Stable
	Chain Valley Bay	Lagoon/Lake	P	Stable
	Lake Munmorah Baths	Lagoon/Lake	P	Stable
	Canton Beach	Lagoon/Lake	P	Stable
	The Entrance Channel	Estuarine	G	stable

VG Very Good | G Good | F Fair | P Poor | VP Very Poor

Central Coast Council	Swimming site	Site type	Beach suitability grade	Change
Former Gosford City Council	Forresters Beach	Ocean Beach	G	Stable
	Wamberal Beach	Ocean Beach	G	Stable
	Wamberal Lagoon	Lagoon	P	Stable
	Terrigal Beach	Ocean Beach	P	Stable
	Terrigal Lagoon	Lagoon	P	Improved
	North Avoca Beach	Ocean Beach	G	Stable
	Avoca Beach	Ocean Beach	P	Stable
	Avoca Lagoon	Lagoon	P	Stable
	Copacabana Beach	Ocean Beach	G	Improved
	Cockrone Lagoon	Lagoon	P	Stable
	MacMasters Beach	Ocean Beach	G	Stable
	Killcare Beach	Ocean Beach	G	Stable
	Patonga Creek	Estuarine	P	Stable
	Pearl Beach	Ocean Beach	G	Stable
	Pearl Beach Rockpool	Ocean Bath	G	Improved
	Umina Beach	Ocean Beach	G	Stable
	Ocean Beach	Ocean Beach	G	Improved
	Ettalong Channel	Estuarine	P	Stable
	Pretty Beach Baths	Estuarine	P	Stable
	Davistown Baths	Estuarine	P	Stable
	Woy Woy Baths	Estuarine	P	Stable
	Yattalunga Baths	Estuarine	P	stable

VG Very Good G Good F Fair P Poor VP Very Poor

Beach Suitability Grades for Sydney region

Sydney region (Northern)		Site type	Beach suitability grade	Change
Northern Beaches	Palm Beach	Ocean beach	VG	Stable
	Whale Beach	Ocean beach	VG	Stable
	Avalon Beach	Ocean beach	VG	Stable
	Bilgola Beach	Ocean beach	VG	Stable
	Newport Beach	Ocean beach	G	Stable
	Bungan Beach	Ocean beach	VG	Stable
	Mona Vale Beach	Ocean beach	VG	Stable
	Warriewood Beach	Ocean beach	G	Stable
	Turimetta Beach	Ocean beach	G	Stable
	North Narrabeen Beach	Ocean beach	G	Stable
	Narrabeen Lagoon	Lagoon	P	Deteriorated
	Bilarong Reserve	Lagoon	P	Stable
	Collaroy Beach	Ocean beach	G	Stable
	Long Reef Beach	Ocean beach	G	Stable
	Dee Why Beach	Ocean beach	VG	Stable
	North Curl Curl Beach	Ocean beach	G	Stable
	South Curl Curl Beach	Ocean beach	VG	Stable
	Freshwater Beach	Ocean beach	G	Stable
	Queenscliff Beach	Ocean beach	G	Stable
	North Steyne Beach	Ocean beach	G	Stable
	South Steyne Beach	Ocean beach	G	Stable
	Shelly Beach	Ocean beach	G	Deteriorated
Pittwater	Barrenjoey Beach	Estuarine	P	Deteriorated
	Paradise Beach Baths	Estuarine	G	Stable
	Clareville Beach	Estuarine	G	Stable
	Taylors Point Baths	Estuarine	G	Stable
	Bayview Baths	Estuarine	P	Stable
	Elvina Bay	Estuarine	VG	Improved
	North Scotland Island	Estuarine	G	Stable
	South Scotland Island	Estuarine	G	Stable
	The Basin	Estuarine	VG	Stable
	Great Mackerel Beach	Estuarine	VG	Stable

VG Very Good | G Good | F Fair | P Poor | VP Very Poor

Sydney region (Central)		Site type	Beach suitability grade	Change
City Beaches	Bondi Beach	Ocean beach	G	Stable
	Tamarama Beach	Ocean beach	G	Stable
	Bronte Beach	Ocean beach	G	Stable
	Clovelly Beach	Ocean beach	VG	Stable
	Gordons Bay	Ocean beach	G	Stable
	Coogee Beach	Ocean beach	P	Deteriorated
	Maroubra Beach	Ocean beach	VG	Stable
	South Maroubra Beach	Ocean beach	G	Stable
	South Maroubra Rockpool	Ocean baths	G	Stable
	Malabar Beach	Ocean beach	P	Deteriorated
	Little Bay Beach	Ocean beach	G	Stable
Sydney Harbour	Watsons Bay	Estuarine	G	Stable
	Parsley Bay	Estuarine	G	Stable
	Nielsen Park	Estuarine	VG	Stable
	Rose Bay Beach	Estuarine	G	Stable
	Murray Rose Pool	Estuarine	G	Stable
	Dawn Fraser Pool	Estuarine	G	Stable
	Chiswick Baths	Estuarine	G	Stable
	Cabarita Beach	Estuarine	G	Stable
	Woolwich Baths	Estuarine	G	Stable
	Tambourine Bay	Estuarine	G	Improved
	Woodford Bay	Estuarine	G	Stable
	Greenwich Baths	Estuarine	G	Stable
	Hayes St Beach	Estuarine	G	Stable
	Clifton Gardens	Estuarine	G	Stable
	Balmoral Baths	Estuarine	G	Stable
	Edwards Beach	Estuarine	G	Stable
	Chinamans Beach	Estuarine	G	Stable
	Northbridge Baths	Estuarine	F	Stable
	Davidson Reserve	Estuarine	P	Stable
	Gurney Crescent Baths	Estuarine	F	Stable
	Clontarf Pool	Estuarine	F	Stable
	Forty Baskets Pool	Estuarine	G	Stable
	Fairlight Beach	Estuarine	G	Stable
	Manly Cove	Estuarine	G	Stable
	Little Manly Cove	Estuarine	G	Stable

VG Very Good | G Good | F Fair | P Poor | VP Very Poor

Sydney region (Southern)		Site type	Beach suitability grade	Change
Southern Beaches	Boat Harbour	Ocean beach	G	Improved
	Greenhills Beach	Ocean beach	VG	Stable
	Wanda Beach	Ocean beach	VG	Stable
	Elouera Beach	Ocean beach	VG	Stable
	North Cronulla Beach	Ocean beach	VG	Stable
	South Cronulla Beach	Ocean beach	G	Stable
	Shelly Beach	Ocean beach	VG	Stable
	Oak Park	Ocean beach	VG	Stable
Botany Bay and lower Georges River	Silver Beach	Estuarine	G	Stable
	Como Baths	Estuarine	G	Stable
	Jew Fish Bay Baths	Estuarine	G	Stable
	Oatley Bay Baths	Estuarine	G	Stable
	Carss Point Baths	Estuarine	G	Stable
	Sandringham Baths	Estuarine	G	Stable
	Dolls Point Baths	Estuarine	G	Stable
	Ramsgate Baths	Estuarine	G	Stable
	Monterey Baths	Estuarine	G	Stable
	Brighton-Le-Sands Baths	Estuarine	G	Stable
	Kyeemagh Baths	Estuarine	G	Stable
	Foreshores Beach	Estuarine	VP	Stable
	Yarra Bay	Estuarine	P	Deteriorated
	Frenchmans Bay	Estuarine	G	Stable
Port Hacking	Congwong Bay	Estuarine	VG	Stable
	Jibbon Beach	Estuarine	G	Deteriorated
	Horderns Beach	Estuarine	G	Stable
	Gymea Bay Baths	Estuarine	P	Deteriorated
	Lilli Pilli Baths	Estuarine	G	Stable
	Gunnamatta Bay Baths	Estuarine	P	Deteriorated

VG Very Good · G Good · F Fair · P Poor · VP Very Poor

Beach Suitability Grades for Illawarra region

Illawarra Region		Site type	Beach suitability Grade		Change
Wollongong City Council	Stanwell Park Beach	Ocean beach	VG		Stable
	Coledale Beach	Ocean beach	VG		Stable
	Austinmer Beach	Ocean beach	VG		Stable
	Thirroul Beach	Ocean beach	G		Stable
	Bulli Beach	Ocean beach	G		Stable
	Woonona Beach	Ocean beach	VG		Stable
	Bellambi Beach	Ocean beach	G		Stable
	Corrimal Beach	Ocean beach	G		Stable
	North Wollongong Beach	Ocean beach	G		Stable
	Wollongong City Beach	Ocean beach	VG		Stable
	Coniston Beach	Ocean beach	VG		Stable
	Fishermans Beach	Ocean beach	VG		Stable
	Port Kembla Beach	Ocean beach	G		Stable
Shellharbour City Council	Entrance Lagoon Beach	Lagoon/lake	G		Stable
	Warilla Beach	Ocean beach	VG		Stable
	Shellharbour Beach	Ocean beach	VG		Stable
Kiama Municipal Council	Boyds Jones Beach	Ocean beach	G		Stable
	Bombo Beach	Ocean beach	G		Stable
	Surf Beach Kiama	Ocean beach	G		Stable
	Werri Beach	Ocean beach	VG		Stable
	Seven Mile Beach, Gerroa	Ocean beach	G		Stable

VG Very Good G Good F Fair P Poor VP Very Poor

Beach Suitability Grades for the South Coast region

South Coast Region		Site type	Beach suitability grade	Change
Shoalhaven City Council	Shoalhaven Heads Beach	Ocean beach	VG	Stable
	Tilbury Cove	Ocean beach	VG	Stable
	Warrain Beach	Ocean beach	VG	Stable
	Collingwood Beach	Ocean beach	G	Stable
	Cudmirrah Beach	Ocean beach	VG	Stable
	Mollymook Beach	Ocean beach	VG	Improved
	Rennies Beach	Ocean beach	VG	Stable
	Racecourse Beach	Ocean beach	G	Stable
	Bawley Point Beach	Ocean beach	VG	Improved
	Merry Beach	Ocean beach	VG	Stable
Eurobodalla Shire Council	Cookies Beach	Ocean beach	VG	Stable
	Caseys Beach	Ocean beach	VG	Stable
	Surf Beach	Ocean beach	G	Stable
	Malua Bay Beach	Ocean beach	VG	Stable
	Broulee Beach	Ocean beach	G	Deteriorated
	Bengello Beach	Ocean beach	G	Stable
	Shelley Beach	Ocean beach	G	Stable
	Tuross Main Beach	Ocean beach	G	Stable
	Brou Beach	Ocean beach	G	Stable
	Wagonga Inlet	Estuarine	G	Stable
	Narooma Main Beach	Ocean beach	VG	Stable
Bega Valley Shire Council	Camel Rock Beach	Ocean beach	VG	Stable
	Bruce Steer Pool	Estuarine	G	Stable
	Horseshoe Bay	Ocean beach	G	Stable
	Big Blue Pool	Ocean baths	G	Stable
	Beares Beach	Ocean beach	VG	Stable
	Mogareeka Inlet	Lagoon/lake	G	Stable
	Tathra Beach	Ocean beach	VG	Stable
	Short Point Beach	Ocean beach	G	Deteriorated
	Bar Beach	Estuarine	G	Stable
	Main Beach (Merimbula)	Ocean beach	G	Deteriorated
	Pambula Beach	Ocean beach	VG	Stable
	Pambula River Mouth	Estuarine	G	Stable
	Aslings Beach	Ocean beach	VG	Stable
	Cocora Beach	Ocean beach	G	Stable

VG Very Good | G Good | F Fair | P Poor | VP Very Poor

State of the Beaches
HOW TO READ THIS REPORT

Beach Suitability Grades

Beach Suitability Grades provide an assessment of the suitability of a swimming location for recreation over time and are based on a combination of sanitary inspection (identification and rating of potential pollution sources at a beach) and microbial assessment (water quality measurements gathered over previous years). There are five grades ranging from Very Good to Very Poor:

VG Very Good

Location has generally excellent microbial water quality and very few potential sources of faecal pollution. Water is considered suitable for swimming almost all of the time.

G Good

Location has generally good microbial water quality and water is considered suitable for swimming most of the time. Swimming should be avoided during and for up to one day following heavy rain at ocean beaches and up to three days at estuarine sites.

F Fair

Microbial water quality is generally suitable for swimming, but because of the presence of significant sources of faecal contamination, extra care should be taken to avoid swimming during and for up to three days following rainfall or if there are signs of pollution such as discoloured water or odour or debris in the water.

P Poor

Location is susceptible to faecal pollution and microbial water quality is not always suitable for swimming. During dry weather conditions, ensure that the swimming location is free of signs of pollution, such as discoloured water, odour or debris in the water, and avoid swimming at all times during and for up to three days following rainfall.

VP Very Poor

Location is very susceptible to faecal pollution and microbial water quality may often be unsuitable for swimming. It is generally recommended to avoid swimming at these sites.

Some of the Beach Suitability Grades in this report are provisional, as the information required for the analysis is incomplete due to limited bacterial data or limited information on potential pollution sources in a beach catchment.

Beach Suitability Grades are determined by using the following matrix:

The guidelines

The National Health and Medical Research Council's *Guidelines for managing risks in recreational water*[1] were adopted for use in New South Wales in May 2009. These guidelines have been adopted in all Australian states and territories and are supported by guidance notes developed by the Department of Health Western Australia[2].

[1]NHMRC 2008, *Guidelines for managing risks in recreational water*, National Health and Medical Research Council, Australian Government Publishing Service, Canberra, ACT.

[2]Department of Health, Western Australia 2007, *Microbial quality of recreational water guidance notes in support of chapter 5 of the National Health and Medical Research Council guidelines for managing risks in recreational water, 2006*, Department of Health, Western Australia and The University of Western Australia, October 2007. [Available at www.public.health.wa.gov.au/3/1287/2/publications.pm. Accessed on 6/06/16]

Enterococci

The national guidelines advocate the use of enterococci as the single preferred faecal indicator in marine waters. These bacteria are excreted in faeces and are rarely present in unpolluted waters. Enterococci have shown a clear dose–response relationship to disease outcomes in marine waters in the northern hemisphere. In accordance with the guidelines, Beachwatch tests for enterococci only. The enterococci density in water samples is analysed in the laboratory using method AS/NZS 4276.9:2007[3].

Enterococci are measured in colony forming units per 100mL of sample (cfu/100mL).

[3]AS/NZS 4276.9:2007, Water microbiology Method 9: Enterococci – Membrane filtration method (ISO 7899-2:2000, MOD), Standards Australia International Ltd, Sydney and Standards New Zealand, Wellington.

Matrix used to determine Beach Suitability Grades

		Microbial Assessment Category (MAC)			
		A	**B**	**C**	**D**
Sanitary Inspection Category	**Very Low**	Very Good	Very Good	Follow Up	Follow Up
	Low	Very Good	Good	Follow Up	Follow Up
	Moderate	Good	Good	Poor	Poor
	High	Good	Fair	Poor	Very Poor
	Very High	Follow Up	Fair	Poor	Very Poor

Microbial Assessment Category (MAC)

There are four Microbial Assessment Categories (A to D) and these are determined from the 95th percentile of an enterococci dataset of at least 100 data points. Each MAC is associated with a risk of illness determined from epidemiological studies. The risks of illness shown below are not those associated with a single data point but are the overall risk of illness associated with an enterococci dataset with that 95th percentile[4].

Category	Enterococci (cfu/100mL)	Illness risk*
A	≤40	GI illness risk: <1% AFR illness risk: <0.3%
B	41–200	GI illness risk: 1–5% AFR illness risk: 0.3–1.9%
C	201–500	GI illness risk: >5–10% AFR illness risk: >1.9–3.9%
D	>500	GI illness risk: >10% AFR illness risk: >3.9%

* GI = gastrointestinal; AFR = acute fever and rash

Sanitary Inspection Category (SIC)

The aim of a sanitary inspection is to identify all sources of faecal contamination that could affect a swimming location and assess the risk to public health posed by these sources. It is an assessment of the likelihood of bacterial contamination from identified pollution sources and should, to some degree, correlate with the bacterial water quality results obtained from sampling.

Through the sanitary inspection process[5], beaches are categorised to reflect the likelihood of faecal contamination. There are five categories: Very Low, Low, Moderate, High and Very High.

Calculating the MAC

The 95th percentile is a useful statistic for summarising the distribution of enterococci data at a site. It embodies elements of both the location of the distribution (how high/low the enterococci counts are) and the scale of the distribution (how variable the enterococci counts are).

The 95th percentile values for each of the four Microbial Assessment Categories were determined by the World Health Organization using enterococci data collected from swimming locations across Europe. These values will represent different probabilities of illness if the distribution of enterococci data from swimming locations in New South Wales differs from the European distribution.

In recognition of this issue, Dr Richard Lugg (Department of Health, Western Australia) has developed a Microsoft® Excel tool for calculating a modified 95th percentile that takes into account the distribution of data. This tool has been used to calculate the 95th percentile values presented in this report and has been adopted for use by other state governments in Australia.

The tool can be downloaded from: www.public.health.wa.gov.au/3/1287/2/publications.pm under Forms and Templates [accessed 06/06/16].

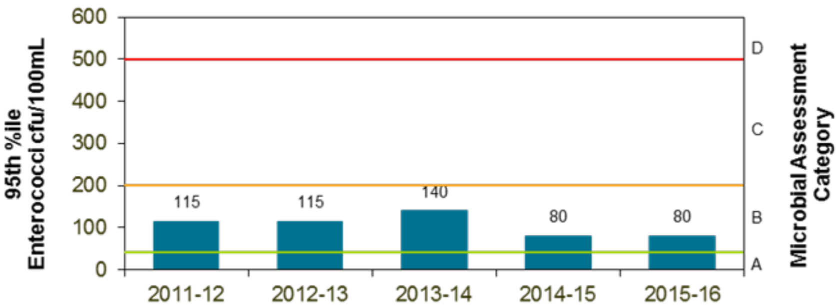
[4] Wyer MD, Kay D, Fleisher JM, Salmon RL, Jones F, Godfree AF, Jackson G and Rogers A 1999, An experimental health related classification for marine waters, *Water Research* 33(3), pp.715–722.

[5] Office of Environment and Heritage 2013, *Sanitary Inspections*, Office of Environment and Heritage, Sydney, NSW, viewed 25 May 2016, www.environment.nsw.gov.au/beach/sanitaryinspections.htm.

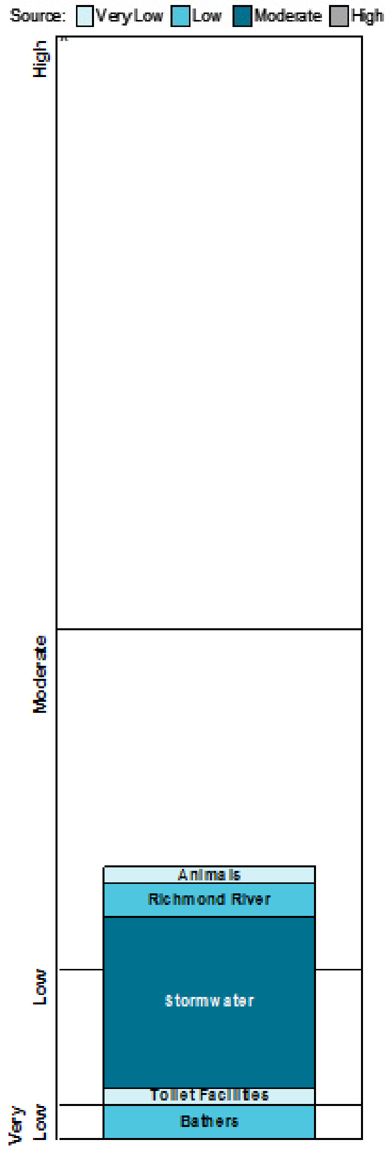
Explanation of graphs and charts on beach pages

Microbial Assessment Category (MAC) chart

On each beach page, the MACs for the last five years are displayed on a simple bar chart. The bars are labelled with the 95th percentile value for each year and the thresholds dividing the A, B, C and D categories are marked for reference.



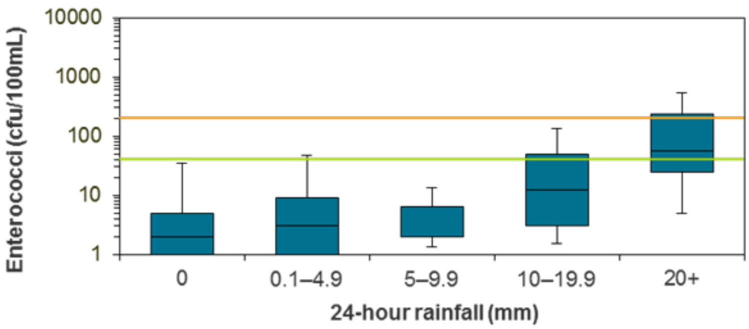
Sanitary Inspection Category (SIC) chart



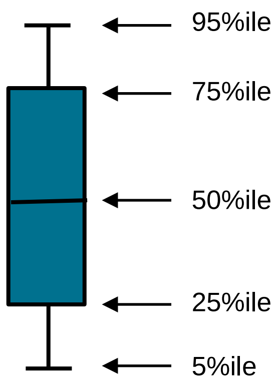
The results of the sanitary inspection for each swimming location are presented in a vertical bar chart, such as the one to the right. The graph shows the likelihood that each identified pollution source will contribute to faecal contamination at a swimming site, as indicated by the size and colour of the components of the bar, with the sum of these contributions being the overall likelihood, or Sanitary Inspection Category.

Response to rainfall plots

Trends in enterococci levels in response to rainfall are shown using a box plot (see below). For reference, enterococci levels of 40cfu/100mL and 200cfu/100mL are indicated with a green and orange line, respectively. The 40cfu/100mL level is referred to as the ‘safe swimming limit’. The enterococci data were obtained from the last five years of monitoring. Rainfall data were obtained from rain gauges situated close to the sample site and are 24-hour totals to 9am on the day of sampling. If there are fewer than five enterococci data points in a rainfall category, individual data points are presented instead of a box plot. At sites where many results are below the detection limit (1cfu/100mL), only the upper portion of the box plots will be visible.



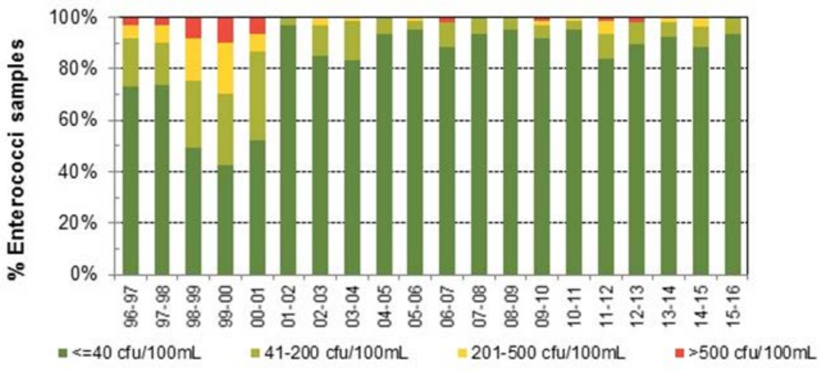
Each part of the box plot represents a significant percentile value of the sample population:



- 5% of the samples lie below the bottom whisker
- 25% of the samples lie below the bottom of the box
- half the samples are on each side of the middle line of the box (median or 50%ile)
- 75% of the samples lie below the top of the box
- 95% of the samples lie below the top whisker.

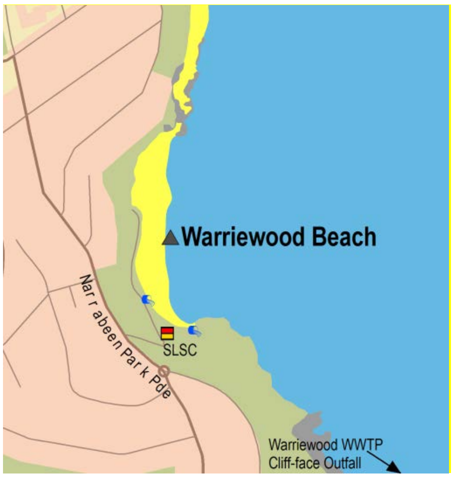
Historical enterococci data graphs

Trends in enterococci levels through time are presented for each swimming location as a bar graph. Each year's bar is colour coded to show the percentage of enterococci results up to 40cfu/100mL, between 41 and 200cfu/100mL, between 201 and 500cfu/100mL and greater than 500cfu/100mL. These categories reflect the Microbial Assessment Category thresholds and are coloured on the graph by dark green, light green, amber and red respectively.



Explanation of maps

A map of individual swimming locations is presented on each beach page. The scale of the maps is 1:15,000. Each map shows the location of the sampling site, land use and features such as surf lifesaving clubs. Potential pollution sources such as stormwater drains, sewage pumping stations, wastewater treatment plants, lagoons, rivers and creeks, are shown where accurate data is held.



Key to maps

- Sampling site
- Surf lifesaving club
- Wastewater treatment plant
- Storm sewage treatment plant
- Sewage pumping station
- Stormwater drain
- Water
- Baths
- National park
- Other park/reserve
- Built-up area
- Sand
- Land
- Roads
- Rock/cliff/reef
- Baths – netted area
- Breakwater/wharf

Quality assurance

State of the Beaches 2015–2016

The quality assurance program

To ensure that data reported by Beachwatch is accurate and reliable, quality assurance is included in all parts of the program:

- field sampling (equipment preparation, sample collection, sample storage and sample transport)
- laboratory analysis
- data management
- community reporting.

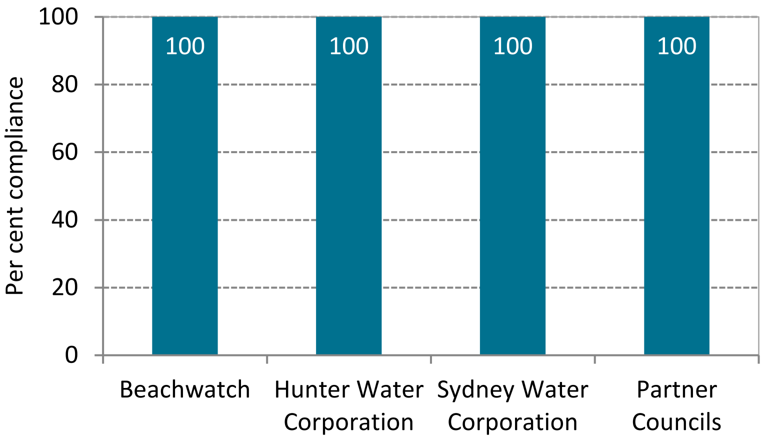
Field sampling

Hunter Water, Sydney Water and Beachwatch collect samples throughout the year and are audited quarterly. Councils in the Beachwatch Partnership Program usually sample for part or all of the swimming season (October to April) and are audited once during this period. Sample locations can be found on the individual beach maps.

Audits include an assessment of field officer performance according to established Beachwatch Programs sampling protocols, including aseptic sampling techniques, sample collection, sample storage and documentation of field observations. These protocols are based on internationally recognised methods for the collection of water samples in recreational bathing areas[1].

Beachwatch, Hunter Water Corporation, Sydney Water Corporation and the councils in the Beachwatch Partnership Program all achieved 100% compliance with sampling protocols.

Sampling quality assurance results for 2015–2016:



[1] *Standard methods for the examination of water and wastewater*, 20th edition, 1998. American Public Health Association, Washington DC.

100%

Sampling quality assurance

PASS

Laboratory quality assurance

Who samples where?

Beachwatch

Collects samples at 96 ocean and harbour beaches in Sydney.

Hunter Water Corporation

Collects samples at 17 ocean beaches in Port Stephens, Newcastle and Lake Macquarie.

Sydney Water

Collects samples at 18 ocean beaches in Wollongong, Shellharbour and Kiama.

Partner councils

Ballina Shire Council, Richmond Valley Council, Lake Macquarie City Council, Wyong Shire Council, Gosford City Council, Wollongong City Council, Kiama Municipal Council, Shoalhaven City Council, Eurobodalla Shire Council, Bega Valley Shire Council, Port Stephens Council.

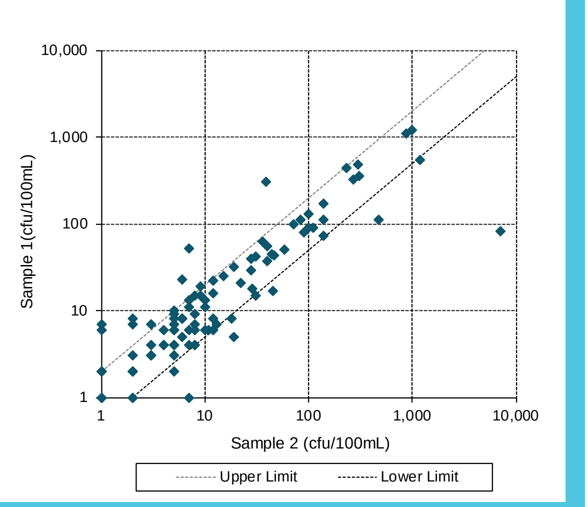
Collect samples at popular swimming locations in their respective local government areas.

Laboratory analysis

Beachwatch program

To assess the reliability of laboratory data, Beachwatch sends duplicate water samples to our contracted microbiological laboratory, which is accredited by the National Association of Testing Authorities (NATA). Duplicate samples are collected from the same site at the same time and the laboratory is unaware that the samples are collected from a single location. The results are expected to be similar.

Due to the inherent variability of bacterial levels in environmental samples, duplicate results that are within 0.3 log-units of each other (equivalent to a halving or doubling of density on a linear scale) are considered to be acceptable. Some enterococci results were outside this range. The majority of these were at very low bacterial densities which were below the safe swimming limit. Where higher values were outside this range, the site result was mostly higher than the replicate, indicating that results were rarely underestimated.

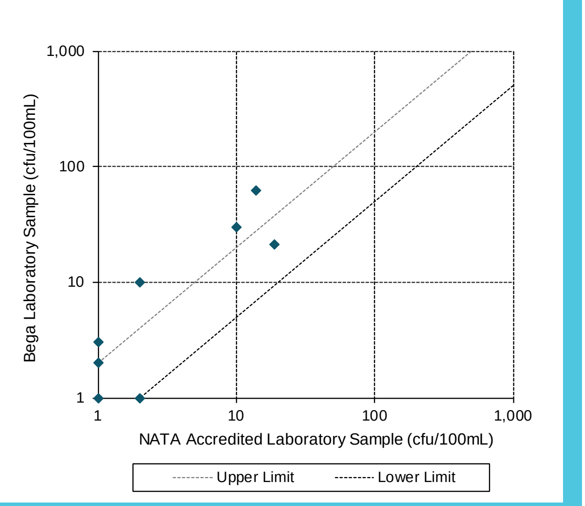


Distribution of duplicate enterococci results for the contracted laboratory, May 2015 to April 2016

Beachwatch Partnership Program

Council laboratories were invited to take part in proficiency testing in November 2015 to determine the reliability of data. Laboratories with NATA accreditation or which could provide evidence of regular proficiency testing were not included in the program as they already comply with strict assessments. This year Bega Valley Shire Council (Bega) and Wyong Shire Council (Wyong) were proficiency tested.

Bega collected two duplicate samples on four occasions during the summer season. Bega laboratory analysed one sample while the duplicate was sent to a NATA accredited laboratory for testing. Comparison of results showed that when enterococci were present, Bega laboratory frequently reported bacterial counts higher than that reported by the NATA accredited laboratory. Further investigation showed that contamination of council laboratory equipment was not the cause of the higher counts, as all sterile water samples processed during the season returned negative results for enterococci. This suggests Bega laboratory is overestimating the numbers of bacteria when present. As a result, water quality within Bega Valley Shire is likely to be of a higher standard than what has been reported.



Distribution of duplicate enterococci results for Bega and NATA accredited laboratories

The proficiency testing of Wyong was conducted by IFM Quality Services Pty Ltd. Samples were dispatched to the laboratory in November 2015, December 2015 and January 2016. The samples were presented in freeze dried form and required reconstitution prior to testing. Results were mostly good, and confidence can be placed in the accuracy of data from this laboratory and water quality results reported in the Wyong region. While they overestimated the number of bacteria in the first test, the following two tests produced excellent results.

Community reporting

Providing the community with current beach water quality information is a core function of the Beachwatch programs, so reporting has been incorporated into the quality assurance program. This enables Beachwatch to measure the accuracy, consistency of content (quality) and punctuality (timeliness) of all reports released. When necessary, this information is used to improve the reporting process.

There are two main types of Beachwatch reports: Beach pollution forecasts and star rating reports.

Beach pollution forecasts

Beach pollution forecasts provide advice to assist beach users on deciding when and where to swim. The forecasts are generated daily to report on the likelihood of bacterial contamination at swimming sites in the Hunter, Central Coast, Sydney and Illawarra regions. This information can be accessed by the public through the Beachwatch website (www.environment.nsw.gov.au/beach), and is reported on Twitter @BeachwatchNSW and Facebook (www.facebook.com/BeachwatchNSW). The information is also sent by email to subscribers, stakeholders and media.

The forecasts are based on telemetered rainfall data and any reported pollution incidents that could affect beach water quality. The forecasts include a prediction of the likelihood of pollution at ocean beaches and harbour swimming areas, as well as daily weather, tides and coastal conditions, based on the Australian Bureau of Meteorology's Metropolitan Forecast and Coastal Waters Forecast. During summer, forecast updates are also issued to advise of beach conditions such as dangerous surf, marine stingers, lagoon openings, closures and other information reported by council lifeguards.

Forecasts are audited weekly to assess the punctuality and quality of information reported. The punctuality of the forecasts and forecast updates to the website and by email is assessed to ensure the timeliness of our service. Lateness of forecasts was usually only by a few minutes and the result of technical problems. Formatting, spelling and punctuation are also checked to ensure the quality of the reports in emails and on the website.

Data management

Water quality results for swimming sites in the Sydney, Hunter and Illawarra regions are regularly forwarded electronically to Beachwatch Programs from the contracted laboratory, and by Hunter Water and Sydney Water laboratories. The water quality data are uploaded to the Beachwatch water quality database (BACTO) for storage and data evaluation.

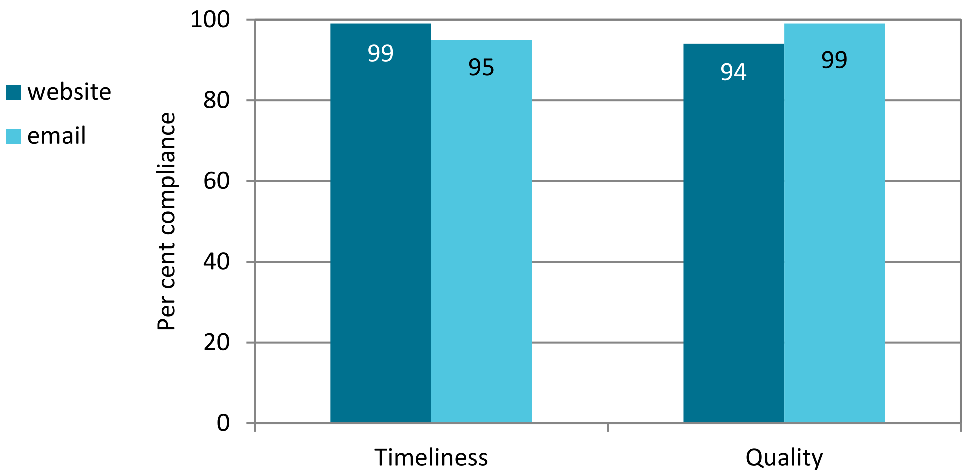
All partnership councils transferred water quality data to OEH on a regular basis, for centralised storage on the BACTO database. In some cases, data were emailed directly from the analysing laboratory.

Quality assurance procedures for the storage of data on the centralised database followed a rigorous protocol that was developed as part of the Beachwatch program. This includes data validation procedures to identify anomalous results.

Beachwatch data is uploaded to our website and can be downloaded online:

environment.nsw.gov.au/beach

Beach pollution forecasts quality assurance results for 2015–2016:



The results from the quality assurance audits are stored in an electronic database, with a weekly summary of any detected errors distributed to the field officers for their attention and action, if necessary.

The daily pollution forecast scenarios are analysed against bacterial data to track the accuracy of predictions. During 2015–2016, 93% of overall predictions were correct. While pollution forecasts at most beaches were accurate almost all of the time, a few beaches where water quality improved or declined during the assessment period, such as Malabar (77% accuracy) and Barrenjoey Beach (67% accuracy), lowered the overall accuracy. The prediction models for these sites has been readjusted to incorporate the changes in water quality to ensure that the accuracy of forecasts at these sites improves. The accuracy of ocean beach predictions was slightly higher than for estuarine beaches, owing to the catchment and site recovery times.

Star rating reports

The star ratings provide an indication of recent bacterial water quality results, based on NHMRC (2008) guidelines, with one star indicating poor water quality, through to a four star rating indicating excellent water quality. The star ratings are calculated using a spreadsheet, and are quality assured prior to reporting on the Beachwatch website, with any errors in calculations detected before publishing (www.environment.nsw.gov.au/beach/Reportstar.htm). Inaccuracies in reporting of star ratings only occurred on two occasions (23 February and 1 March 2016) for some swimming sites in Ballina due to human error in entering the data onto the Beachwatch website. Most star ratings are updated weekly throughout the year for swimming sites in Sydney, Hunter and Illawarra regions and during the summer season for regional partner councils where the frequency of sampling is reduced for some swimming sites that are not used during winter. All historical water quality data is available on the Beachwatch website (www.environment.nsw.gov.au/beachapp/report_enterococci.aspx).

Action		Lead Organisation	Support Organisations	Management Zones	10 Year Cost ($'000)
Strategy 5: Farm Management					
5.1	Scientific investigations: strategies for retention of water on backswamp areas	I&I NSW	BSC, LCC, RVC, EMC, DECCW, RRCC, SCU	Zones 7, 10, 11	**300**
5.2	Farm management planning	I&I NSW	BSC, LCC, RVC, EMC, DECCW, RRCC	Estuary-wide	**5,000**
5.3	Liaise with agriculture industry bodies to improve education and ensure estuary friendly practices are incorporated into industry guidelines	I&I NSW	RRCC, EMC	Estuary-wide	**90**
MEDIUM PRIORITY					
Strategy 6: Riparian Zone Management and Erosion					
6.1	Identify priority riparian areas and rehabilitate	EMC	BSC, LCC, RVC, LPMA, NRCMA	Estuary-wide	**2,300**
6.2	Riparian buffer establishment (planning)	BSC, LCC, RVC	LPMA	Estuary-wide	**30**
Strategy 7: Vegetation Management					
7.1	Retain, rehabilitate and conserve existing native floodplain vegetation	BSC, LCC, RVC	RRCC, LPMA, NRCMA, DECCW, FNCW	Estuary-wide	**930**
7.2	Aquatic weed management	FNCW, I&I NSW RRCC	BSC, LCC, RVC	Estuary-wide	**1,000**
Strategy 8: Education					
8.1	Estuary-wide community education and consultation program	EMC	BSC, LCC, RVC, RRCC, DECCW, I&I NSW, NRCMA, FNCW	Estuary-wide	**500**
Strategy 9: Waterway Usage					
9.1	Develop strategic plan for estuary usage	EMC	BSC, LCC, RVC, NSW Maritime, LPMA, DECCW, I&I NSW	Estuary-wide	**75**
9.2	Cost benefit analysis of dredging operations in lower estuary	BSC	LPMA, DECCW, I&I NSW, NSW Maritime	Zones 1,2	**20**
Strategy 10: Wastewater Management					
10.1	Sewerage system risk assessment and prioritisation study	DECCW	BSC, LCC, RVC	Estuary-wide	**25**
10.2	On-going on-site sewerage management inspections and improvements	BSC, LCC, RVC		Estuary-wide	not estimated
Strategy 11: Urban Runoff					
11.1	Stormwater Management	BSC, LCC, RVC	DECCW	Estuary-wide	not estimated

Action		Lead Organisation	Support Organisations	Management Zones	10 Year Cost ($'000)
LOW PRIORITY					
Strategy 12: Cultural Heritage					
12.1	Identification and recording of cultural sites available to council planners	DECCW	BSC, LCC, RVC	Estuary-wide	**100**
12.2	Cultural Site Management Plans	DECCW	BSC, LCC, RVC	Estuary-wide	**155**
Strategy 13: Fishery Management					
13.1	Ensure key research findings in the fishing and aquaculture sector are communicated to the public	I&I NSW	BSC, LCC, RVC, RRCC, SCU	Estuary-wide	Included in Strategy 8
13.2	Identify and manage contamination sources in the estuary to minimise oyster harvest closures	I&I NSW	BSC	Zones 1,2,4	**40**
Total					**16,385**

EMC: Estuary Management Committee; BSC: Ballina Shire Council; LCC: Lismore City Council; RVC: Richmond Valley Council; RRCC: Richmond River County Council; DECCW: Department of Environment, Climate Change and Water; I&I NSW: Industry and Investment NSW; SCU: Southern Cross University; LPMA: Land and Property Management Authority; NRCMA: Northern Rivers Catchment Management Authority.

The implementation of the plan will be supported by a process for reviewing the effectiveness of the plan and adapting it as required. This aspect of the project is essential for ensuring that the estuary management options identified become a reality and that the estuary is sustainably managed into the future.

Following public exhibition and consideration of submissions, the draft CZMP will be adopted by Richmond River County, Ballina Shire, Lismore City and Richmond Valley Councils. The draft CZMP will also be submitted to the Minister administrating the Coastal Protection Act 1979 for certification under the Act.

HAVE YOUR SAY

The EMS and CZMP are available for comment until 6 May 2011 and can be accessed at Council offices and from Richmond River County Council website: www.rrcc.nsw.gov.au.

A public meeting to present the Plan will be held on 28 March 2011, commencing at 5:30pm at the Richmond Room, Regatta Avenue, Ballina.

Submissions can be made via email to floodplain@rrcc.nsw.gov.au or:

By Post:

The General Manager
Richmond River County Council
PO Box 230
LISMORE NSW 2480
Attention: CZMP Richmond River Estuary

Drop Off in person:

Submission Box: The General Manager
Richmond River County Council
Level 4, 218-232 Molesworth St
LISMORE NSW 2480
Attention: CZMP Richmond River Estuary

ballina shire council

lismore city council

KYOGLE COUNCIL GATEWAY TO THE RAINFORESTS

Rous Water REGIONAL WATER SUPPLY

RICHMOND RIVER COUNTY COUNCIL Floodplain Services

Richmond Valley Council

Australian Government

NSW GOVERNMENT Local Land Services North Coast

NSW GOVERNMENT Office of Environment & Heritage

une University of New England

Aquatic Ecology and Restoration RESEARCH GROUP

Richmond Ecohealth Project 2014

Assessment of River and Estuarine Condition

Final Technical Report

June 2015

A/Prof. Darren Ryder, Dr Sarah Mika and Mr Max Richardson
School of Environmental and Rural Science, University of New England, Armidale, NSW, 2351

Mr John Schmidt
NSW Department of Environment and Heritage, 41 Belgrave St, Kempsey, NSW, 2440

Mr Ben Fitzgibbon
NSW Department of Environment and Heritage, Arakwal Depot, Tallow Beach Rd, Byron Bay, NSW, 2481

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Project contact:
Associate Professor Darren Ryder
School of Environmental and Rural Science
University of New England, Armidale, NSW, 2351
Email: darren.ryder@une.edu.au

Cover Photo: Terania Creek (M. Richardson, 2014).

Acknowledgements

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In particular, Max Osborne (NCLLS) and John Schmidt (OEH) have been the champions for Ecohealth and maintained progress for the program despite tumultuous times in government agencies. Ben Fitzgibbon supported project management and skippered the boat for estuary sampling. The people below provided significant support for the project including field sampling, local knowledge, landowner contacts and project support. We thank them all.

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Brian Eggis: Richmond Valley Council

Anthony Accret: Rous Water

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Andrew Page: NSW Department of Primary Industries, Fisheries (Marine Parks)

David Morand and Angus Ferguson: NSW Office of Environment and Heritage

Michael Wood and the Richmond Coastal Zone Management Plan Implementation Group

Phoebe Haslett, Paul Lisle, Adrienne Burns and Andrew Grigg: University of New England

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Glossary

Algal biomass	The mass of algae in a water body at a given time.
Aquatic macroinvertebrates	Larger aquatic invertebrates, functionally defined as those retained on a 500 µm sieve. Their body length usually exceeds 1mm.
Bank slumping	The mass movement of bank material after failure.
Chlorophyll *a*	A green pigment found in plants that allows them to photosynthesise. Chlorophyll *a* measurements are an indicator of the amount of phytoplankton and algae in a water body.
Dissolved oxygen (DO)	The concentration of gaseous oxygen (O_2) dissolved in an aqueous solution.
Geomorphic condition	An assessment of bank condition (e.g. slope, bank failure, exposed tree roots and undercutting), bed condition (active erosion and smothering of the bed substrate by high loads of fine sediment) and trampling by stock.
Ecohealth indicators	A selection of measurements that indicate if there are stresses to the habitat as a whole. Indicators include water quality (dissolved oxygen, salinity, acidity, turbidity, nutrients), riparian condition (vegetation composition, occurrence of riparian weeds, riparian habitat), geomorphic condition and composition of aquatic macroinvertebrate communities.
Oxides of nitrogen (NOx)	A series of gasses composed of nitrogen and oxygen, primarily NO, NO_2, N_2O and N_2O_5.
pH	The hydrogen ion concentration. Acidic solutions have a pH < 7, basic solutions have a pH > 7.
Riparian condition	The health of a riparian zone, based on an assessment of the occurrence of weeds, structure of riparian vegetation habitat (e.g. logs) and management regime.
Riparian zone	The area of land adjoining rivers and streams that has a direct influence on the water and aquatic ecosystems within those rivers and streams. It includes stream banks and a strip of land of variable width along the banks.
SIGNAL2	SIGNAL stands for “Stream Invertebrate Grade Number – Average Level”. SIGNAL2 is a scoring system for Australian macroinvertebrates based on their sensitivity to pollution.
Soluble reactive phosphorus (SRP)	The concentration of inorganic ions of phosphorus (predominately HPO_4^{2-} and PO_4^{3-}) in water. These ions are available to be used by aquatic biota.
Total nitrogen (TN)	The concentration of nitrogen in the water, both in organic and inorganic forms.
Total phosphorus (TP)	The concentration of phosphorus in natural or anthropogenic substances that contain, or decompose to produce phosphate ions.
Total suspended solids (TSS)	All particles suspended in water that do not pass through a 1.2 µm filter.
Turbidity	The cloudy appearance of water due to suspended material.

Glossary of Soil Terms

A horizon	The top soil layer containing the greatest concentration of organic material. Consists mainly of clay minerals and quartz with an absence of soluble minterals.
Anthroposol	Soils arising from human activities where soil horizons are profoundly modified, truncated or buried; the creation of new soil parent materials by mechanical means.
B horizon	The second soil layer comprising an illuvial concentration of silicate clay, iron, aluminium, humus, carbonates, gypsum or silica alone or in combination.
Dermosol	Soils having structured B2 horizons with a lack of textural contrast between A and B horizons.
Ferrosol	Soils with B2 horizons that are high in free iron oxide and that lack textural contrast between A and B horizons. Formed from basic or ultrabasic igneous rocks or alluvium derived from these.
Hydrosol	Soils other than organosols, podosols or vertosols in which the greater part of the soil profile is saturated for at least 2-3 months in most years.
Kandosol	Soils that lack strong textural contrast, have massive or weakly structured B horizons, have a maximum clay content exceeding 15% in the B2 horizon, and do not have a calcareous A horizon.
Kurosol	Soils with strong textural contrast between A horizons and strongly acid B horizons.
Podosol	Soils with B horizons dominated by the accumulation of organic matter, aluminium and/or iron.
Rudosol	Typically young soils with neglibile pedologic organization. These soils vary widely in texture and depth with many stratified and some highly saline.
Tenosol	Soils that have weak pedologic organization apart from the A horizon. These soils are diverse but includes soils having a peaty horizon or overlying a calcrete pan or hard, unweathered rock.
Vertosol	Clay soils (clay texture greater than 35%) with shrink-swell properties that exhibit strong cracking when dry and at depth, have slickensides and/or lenticular structure aggregates.

Summary

The development of a standardised means of collecting, analysing and presenting riverine, coastal and estuarine assessments of ecological condition has been identified as a key need for coastal Local Land Services and Local Councils who are required to monitor natural resource condition, and water quality and quantity in these systems. Forty-eight study sites were selected across the Richmond catchment; 23 freshwater sites and 25 estuarine sites and these were sampled monthly (estuarine) or bi-monthly (freshwater) over a 12 month period in 2014 to contribute to the assessment of the ecological condition of the catchment.

The Richmond catchment was divided into 5 hydrologic units for reporting; Richmond River main stem; Wilsons River; Eden and Iron Pot Creeks and Shannon Brook; Bungawalbin, Myrtle and Sandy Creeks; and Emigrant, Maguires and North Creeks. The project aimed to

- Assess the health of coastal catchments using standardised indicators and reporting for estuaries, and freshwater river reaches using hydrology, water quality, riparian vegetation and habitat quality, geomorphic condition and macroinvertebrate assemblages as indicators of ecosystem health in streams of the Richmond catchment, and
- Contribute scientific information to the development of a report card system for communicating the health of the estuarine and freshwater systems in the Richmond region.

Report Card

The Overall Grade for the Richmond catchment was D-, ranging from an F in the Wilsons River and upper Richmond estuary to a C in the headwater streams of the catchment. Twelve of the 17 river systems recorded a score of D or less. The upper freshwater reaches of the Richmond catchment had better water quality, aquatic macroinvertebrates and geomorphic condition than the lower freshwater reaches, but no better riparian condition. The upper estuary (upstream of Woodburn) was consistently in the poorest condition, with very high nutrient concentrations, turbidity and algal biomass. Scores were consistent among indicators within each system, highlighting that the issues with water quality, biota and physical condition are affecting short and long-term condition of the streams.

Geomorphic Condition

Geomorphic condition ranged from good to poor throughout the freshwater and estuarine reaches of the Richmond. The subcatchment-scale assessment of stream condition aligned with the site-scale geomorphic assessment, identifying the upper freshwater reaches as predominantly in good or moderate condition, particularly those in conservation reserves. Estuarine reaches were mostly in poor condition with evidence of active erosion.

The areas of poorest geomorphic condition were where the riparian zone had been completely cleared for cropping (sugarcane) extending to the top of bank. These areas were characterized by extensive and locally severe bank slumping, high bank slopes and exposed tree roots. Alternatively,

poor geomorphic condition was associated with cattle grazing and accessing the river in freshwater reaches.

Water Quality

Concentrations of all nutrients, Total Nitrogen (TN) and oxides of nitrogen (NOx), and Total Phosphorus (TP) and SRP (the form directly usable by aquatic algae and plants) exceeded the guideline value consistently across all sites throughout the study period. As such there was no seasonal pattern evident in nutrient concentrations.

The clear longitudinal pattern of increasing turbidity and nutrients with distance downstream highlights the need to improve riparian and bank condition throughout the catchment as a management priority. Improvement of water quality in the Richmond catchment therefore requires significant investment in reducing diffuse sources of fine sediments and their associated nutrients. Reducing stock access to the steep and fine-grained banks in the upper reaches would be an important step, as would vegetating those riparian zones to increase their buffering capacity for terrestrially derived nutrients.

Low dissolved oxygen concentrations were recorded a number of mid and lower catchment sites, and did reach levels that would influence the health and distribution of biota. Low flow conditions throughout the majority of the study period would have contributed to low DO concentrations. Low dissolved oxygen levels recorded in freshwater and estuary sites can lead to stress on biota and chemically reduced environments in the water column that are linked to release of phosphorus and subsequent algal blooms.

No low pH events (<4) were recorded during this study as we targeted base flow and not flood conditions. Sites in the upper Richmond (RR5) and Wilsons (WR1) estuaries recorded low pH values following high rainfall events. Sites within the Bungawalbin sub-catchment had consistently low pH values, reflecting both the altered land use and swamp vegetation present. North Creek had pH values that were consistently below the trigger value.

The poorest water quality was recorded from the sites closest to the tidal limit, highlighting their role as depositional environments for both freshwater and estuarine contaminants, and the importance of this zone as a focal point for future monitoring programs. Low DO concentrations, low pH and high Chlorophyll *a* (algal biomass) and nutrient concentrations were a feature of estuarine reaches. Focal reaches for future monitoring are from upstream of Tatham on the Richmond River and upstream of Lismore on the Wilsons River, as well as North Creek in the lower estuary.

Aquatic Macroinvertebrates

Because many macroinvertebrates live in a river reach for an extended period of time, they can integrate the impacts on the ecosystem over an extended period of time, rather than just at the time of sampling. Family level taxonomic richness ranged from 5 in lower Terenia and Bungawalbin Creeks to 30 in the upper Terania and Iron Pot Creeks. Similarly, the abundance of individuals ranged from a very low 14 individuals in Bungawalbin Creek (BC2) to 784 in the upper Richmond River (RR14) when both sample periods were combined.

Macroinvertebrate scores were low throughout the catchment. This reflects poor water quality and habitat conditions, particularly the geomorphic change to channels (U-shaped channels) and smothering of habitat with fine sediment. The potential for localized increases (e.g., upper Richmond, Rocky Creek) in macroinvertebrate condition suggest efforts to improve macroinvertebrate condition should target habitat restoration (e.g., riparian zone, woody and organic debris, macrophytes, riffles) and therefore food availability, disturbances such as sediment smothering, and water quality (nutrients and turbidity).

Riparian Condition

The area within a riparian zone contains valuable water resources, highly fertile soil and supports high levels of biodiversity as well as many social and economic functions. Riparian condition scores were poor throughout all regions of the Richmond River catchment, with 10 of the 17 river systems recording a score of D or lower.

The main stressors to riparian condition were the dominance of invasive weeds, disturbances from clearing and agriculture (e.g., sugarcane), and access by livestock. The dominance by exotic invasive weeds in estuarine reaches was predominantly Cockspur Coraltree and Coastal Morning Glory Vine. In freshwater reaches, Lantana, Privet, Wild Tobacco Bush and Cat's Claw Creeper were common. The influence of clearing and physical stressors (trampling and grazing) has reduced the recruitment of native vegetation in the riparian zone.

Strongly linked to riparian condition, the active restoration of riparian revegetation as a long term action for improving geomorphic condition must be a priority in the Richmond catchment. The poor geomorphic condition is directly linked to low scores in water quality, macroinvertebrates and riparian vegetation. Improving geomorphic condition, particularly in the mid and lower (including estuary) reaches will lead to an improvement in all other indicators.

Future Monitoring

There is limited evidence for reducing the number of sampling sites in freshwater reaches as the majority of systems with multiple sites showed a consistent longitudinal pattern, particularly in water quality indicators. Similarly, results from estuarine sites highlighted the need for multiple samples in the upper and lower estuary.

Retaining the suite of water quality variables and sampling procedures (water column profiles in sites >1 m depth) is recommended as all variables positively contributed to the understanding of issues at each site and the development of site-based scores for the report card. Season and site-based characteristics of freshwater reaches both affected the taxonomic composition and abundance of macroinvertebrates. Future macroinvertebrate sampling should include autumn and spring, but should consider further research into the link between geomorphic characteristics, condition and recovery potential. The riparian condition and separate geomorphic condition index make a major contribution to management priorities by identifying biological (weeds) and biophysical (bank erosion) drivers, and the sub-catchment scale provides a link to the spatial representativeness of condition. These should be retained for freshwater and estuary reaches as an annual survey.

The inclusion of monthly sampling for water quality in the estuarine reaches, and bimonthly sampling in freshwater reaches over a 12 month period has provided an integrated outcome of the catchment condition. Rainfall in the region during the 2014 sampling period was well below the long term mean. However, to ensure consistency over multiple years of sampling, the program is focused on non-flood sampling. This removes the opportunity to document the changes (particularly water quality) associated with high flows. A separate program using targeted indicators to assess the response and resilience of the lower Richmond to high flow events should be developed.

Partnerships

This project was a successful partnership among a number of Councils, government agencies and the University of New England. The inclusion of staff from Councils and Agencies increased the number of sites that could be sampled as part of the program, and facilitated education and training where possible. Continued partnerships are essential, and ensuring training for staff involved will maintain quality data and ensure project outcomes are maximized.

PART 1

ECOHEALTH PROGRAM AND OBJECTIVES

1.1 Background

The NSW Natural Resources Monitoring Evaluation and Reporting (MER) Strategy was prepared by the Natural Resources and Environment CEO Cluster of the NSW Government in response to the Natural Resources Commission standard and targets and was adopted in August 2006. The purpose of the Strategy is to refocus the resources of NSW natural resource and environment agencies and coordinate their efforts with CMAs (now LLS), Local Governments, landholders and other natural resource managers to establish a system of monitoring, evaluation and reporting on natural resource condition.

At this time there was no consistent monitoring of estuarine or freshwater ecological condition in NSW. Working groups were formed to consider the most appropriate indicators and sampling designs to enable a statewide assessment of the ecological condition of rivers and estuaries. This report outlines the approach taken by stakeholders in the Richmond River catchment to supplement the MER monitoring and is aligned with the objectives of regional Coastal Zone Management Plans.

1.2 Scope

Estuarine systems are focal points for the cumulative impacts of changed catchment land-use, and increasing urbanisation and development in coastal zones (Davis and Koop 2006). As a result, these ecosystems have become sensitive to nutrient enrichment and pollution, and degraded through habitat destruction and changes in biodiversity. The development of a standardised means of collecting, analysing and presenting riverine, coastal and estuarine assessments of ecological condition has been identified as a key need for coastal Local Land Services and Local Councils who are required to monitor and report on natural resource condition and water quality and quantity in these systems.

This project uses the Ecohealth framework that integrates the NSW Monitoring, Evaluation and Reporting (MER) Program currently monitoring NSW estuaries and coastal rivers on a bi- or tri-annual basis; NSW State of Environment (SoE) and State of Catchments (SoC) reports, EHMP Healthy Waterways program; proposed estuary report cards from the NLWRA (through WA Department of Water), NSW Estuary Management Policy and Coastal Zone Management Manual and relevant Estuary Management Plans; and sampling protocols developed by the CRC for Coastal Zone, Estuary and Waterway Management.

The Ecohealth Waterways Monitoring Program outlines a framework for the development of a catchment-based aquatic health monitoring program for rivers and estuaries in the North Coast LLS region with the aim of providing consistency in monitoring and reporting, and establishes the partnerships required for local and regional dissemination of outcomes. This project brings together major stakeholders in the coastal management of Northern NSW; State agencies (NC LLS, OEH, DPI), Local Councils and University researchers (UNE) to develop, refine, report and promote a standardised river and estuary health assessment tool for the Richmond catchment.

This report provides the initial baseline data for water quality, freshwater macroinvertebrates, riparian condition and geomorphic condition in the Richmond catchment. This framework facilitates an effective reporting mechanism to communicate water quality and resource condition information to the general public, stakeholders and managers through simple report cards. Additionally, this initial monitoring program in the Richmond catchment provides specific monitoring and management plans for the study area using the generic framework outlining a standardised (and tested) set of partnership, monitoring, data management and reporting protocols implemented in coastal catchments throughout the Northern Rivers region.

1.3 Project objectives

1. Assess the health of coastal catchments using standardised indicators and reporting for estuaries and freshwater river reaches using hydrology, water quality, macroinvertebrate assemblages, condition of riparian and aquatic vegetation, and geomorphic condition as indicators of ecosystem health in streams of the Richmond catchment;
2. Inform management priorities and actions throughout the Richmond catchment; and
3. Contribute scientific information to the development of a report card system for communicating the health of the estuarine and freshwater systems in the Richmond catchment.

1.4 Report structure

Part 2 of the report outlines the catchment characteristics of the Richmond region as context of the need for river and estuarine monitoring, and to provide the background to the study design and site selection processes:

2.1 **Study Area** provides information on the catchment characteristics of the rivers and estuaries of the Richmond region such as area, hydrology and land-uses.

2.2 **Study Design** provides the detailed description of the study design and protocols for site selection.

2.4 **Study Sites** provides brief site descriptions for the 48 study sites.

2.5 **Sampling Methods and Indicators** includes the range of water quality conditions measured, analysis of aquatic macroinvertebrate communities in freshwater sites, geomorphic measures of channel and bank characteristics, riparian features and local disturbance issues.

Part 3 of the report details the bi-monthly water chemistry and biophysical data collected from December 2013 to November 2014. Results for water chemistry, macroinvertebrates, riparian and geomorphic condition are reported for each of five major hydrological units (that is, the Richmond River main stem; Wilsons River; Eden and Iron Pot Creeks and Shannon Brook; Bungawalbin, Myrtle and Sandy Creeks; and Emigrant, Maguires and North Creeks (Figure 2.1). Water chemistry variables assessed include nutrients (nitrogen and phosphorus), chlorophyll *a* and suspended solids, as well as water column profiles for pH, salinity, dissolved oxygen and temperature. Exceedances of NSW MER or ANZECC guideline thresholds are identified.

Macroinvertebrate assemblages collected from freshwater sites in Autumn 2014 and Spring 2014 were used to assess long-term condition of in-channel habitats and health indicators using diversity, SIGNAL2 scores and percent EPT. The riparian condition assessment includes cover, structure and habitat, as well as identification of local-scale disturbances to riparian zones. The geomorphic condition assessment includes site-scale bank and bed condition, and management issues, as well as a sub-catchment scale assessment of geomorphic condition. Condition scores are calculated for water chemistry, aquatic macroinvertebrate community assemblages (freshwater sites), riparian condition and geomorphic condition. These form the basis of the report cards and are collated for the Richmond Catchment as a whole, Subcatchments (organized by hydrological units) and Sites.

The catchment, subcatchments and sites are organised accordingly:

3.1 Overall Richmond Catchment

3.2 Richmond River main stem
- Freshwater Reaches (includes Gradys Creek)
- Estuary Reaches

3.3 Wilsons River
- Wilsons River
- Leycester Creek
- Coopers Creek
- Terania Creek
- Byron Creek
- Wilson Creek

3.4 Eden and Iron Pot Creeks and Shannon Brook
- Eden Creek (includes Doubtful Creek)
- Iron Pot Creek
- Shannon Brook

3.5 Bungawalbin, Myrtle and Sandy Creeks
- Bungawalbin Creek (includes Myall Creek)
- Myrtle Creek
- Sandy Creek

3.6 Emigrant, Maguires and North Creeks
- Emigrant Creek
- Maguires Creek
- North Creek

Part 4 provides management recommendations for the future management of the instream and riparian condition in rivers and estuaries of the region, and identifies priorities for future monitoring within the Ecohealth framework.

PART 2

2 STUDY AREA, DESIGN AND SITE DESCRIPTIONS

2.1 Study area

The Richmond River Catchment, located in far northeast New South Wales (NSW) has a catchment area just over 7,000km^2, extending from the Queensland border in the north to the Clarence River Catchment at its south-eastern border. The Tweed and the Brunswick Catchments adjoin the north-east of the Richmond, with the Richmond coastline extending from south of Cape Byron in the north to Evans Head in the south (Figure 2.1).

The head waters of the Richmond River originate in the Border Ranges National Park, and flow south-west through floodplains entering the Pacific Ocean at Ballina. The main tributary of the Richmond River is the Wilsons River, which enters the Richmond on the coastal plain at Coraki. The tidal influence extends upstream of Tatham on the Richmond River and upstream of Lismore on the Wilsons River. Eden Creek, Shannon Brook and Bungawalbin Creek are significant tributaries draining the western and southern areas of the Richmond catchment (Figure 2.1).

The coastal catchment of the Evans River is connected to the Richmond River (via Rocky Mouth Creek) by a small canal (Tuckombil Canal) at Woodburn. The canal on Rocky Mouth Creek is managed to mitigate the severity of flooding in the mid reaches of the Richmond River, restrict poor water quality flowing from Rocky Mouth Creek into the Evans River under baseflow conditions, and prevent salt water intrusion into the upstream freshwater reaches of the Richmond River.

Approximately 11.5% (800km^2) of the Richmond catchment is protected within national parks and reserves, of which most are found in the Border Ranges in the north, as well as the Toonumbar and Nightcap National Parks. The Border Ranges, Toonumbar and Nightcap National Parks form part of the Gondwana Rainforests of Australia World Heritage Area. The lower Richmond River supports some extensive wetland complexes. The largest of these are Tuckean Swamp on the Richmond floodplain near Wardell. The lowland rainforest community, known as The Big Scrub once covered approximately 750km^2, but only one per cent (300ha) remains in the catchment. The small remnants of this rainforest community constitute one of the most diverse ecosystems in NSW, supporting more than 300 plant species and an equally diverse fauna community.

There are three water storage dams within the Richmond River Catchment. Iron Pot Creek is regulated by Toonumbar Dam (11,000ML capacity managed by State Water), draining a 98km^2 catchment area and supplying irrigation, stock, domestic, and town water. Rocky Creek Dam and Emigrant Creek Dam (14,000 and 830ML capacities, respectively) in the Wilsons River catchment are managed by Rous Water for town water for both Lismore and Ballina.

Figure 2.1 The Richmond catchment showing (a) its location in the Northern Rivers of NSW, (b) the location of Ecohealth sites (red circles), point source discharge such as sewage treatment plants, (c) the major hydrological units, and (d) LGAs within the catchment.

Lismore and Ballina are the largest urban centres in the catchment. Other towns include Casino, Lennox Head, Alstonville, and the smaller centres of Coraki, Nimbin, and Kyogle. Ballina Shire covers an area of 485km² with a shire population of 40,753 (2011 census, Figure 2.1d). The City of Lismore covers an area of almost 1,300km² with a population of 42,763 (2011 census). Tourism is an important part of the economy of the local government areas, with the total number of tourist visits increasing by over 90,000 in the last four years to 670,000 visits.

There are eight major point-source dischargers on the Richmond and Wilsons River (Figure 2.1b). These are predominantly sewage treatment plants at Kyogle, Casino, Coraki, Wardell, Ballina and Lismore, but also includes the Sugar Mill at Broadwater. There are also small sewage treatment works at Nimbin, Alstonville and Lennox Head.

The lithology of the Richmond Catchment is greatly varied, producing diverse soil types. Tertiary basalt dominates the upper northern reaches of the catchment (Figure 2.2). This has produced predominantly ferrosols throughout the northern reaches, upper Richmond River, and Wilsons River and tributries (Figure 2.3). Triassic quartz sandstones dominate in the Western headwaters of the catchment, giving rise to predominantly kurosols. A mix of Cretaceous conglomerates and lithic sandstones, siltstones and claystones, as well as Quaternary alluvium are found in the upper and mid reaches in the south of the catchment. These have produced a mix of kurosols and hydrosols, with some rudosols and tenosols in the upper south-western reaches. Quaternary coastal dunes dominate the geology in the lower reaches of the catchment, predominantly giving rise to hydrosols throughout these reaches. A mix of vertosols and dermosols are found throughout the mid reaches of the catchment where the dominant geology is Quaternary alluvium. Potential and actual acid sulfate soils are common throughout the tidal flat areas, especially in the lower reaches of Sandy and Bungawalbin Creeks.

Grazing (dairy and beef) is the dominant land use throughout the upper floodplains of the Richmond catchment (Figure 2.4). Cropping (mostly sugar cane) dominates the floodplains along the lower reaches of the Richmond River. In contrast, horticulture (tropical fruits, nurseries and turf growing) dominates the northern and some southern, mid and upper reaches of the Wilsons River and its tributaries. Tree and shrub cover and conservation areas are predominantly at higher elevations, towards the borders of the catchment. Urban areas are found throughout the catchment, with the majority in the upper northern catchment of the Willson River and its tributaries.

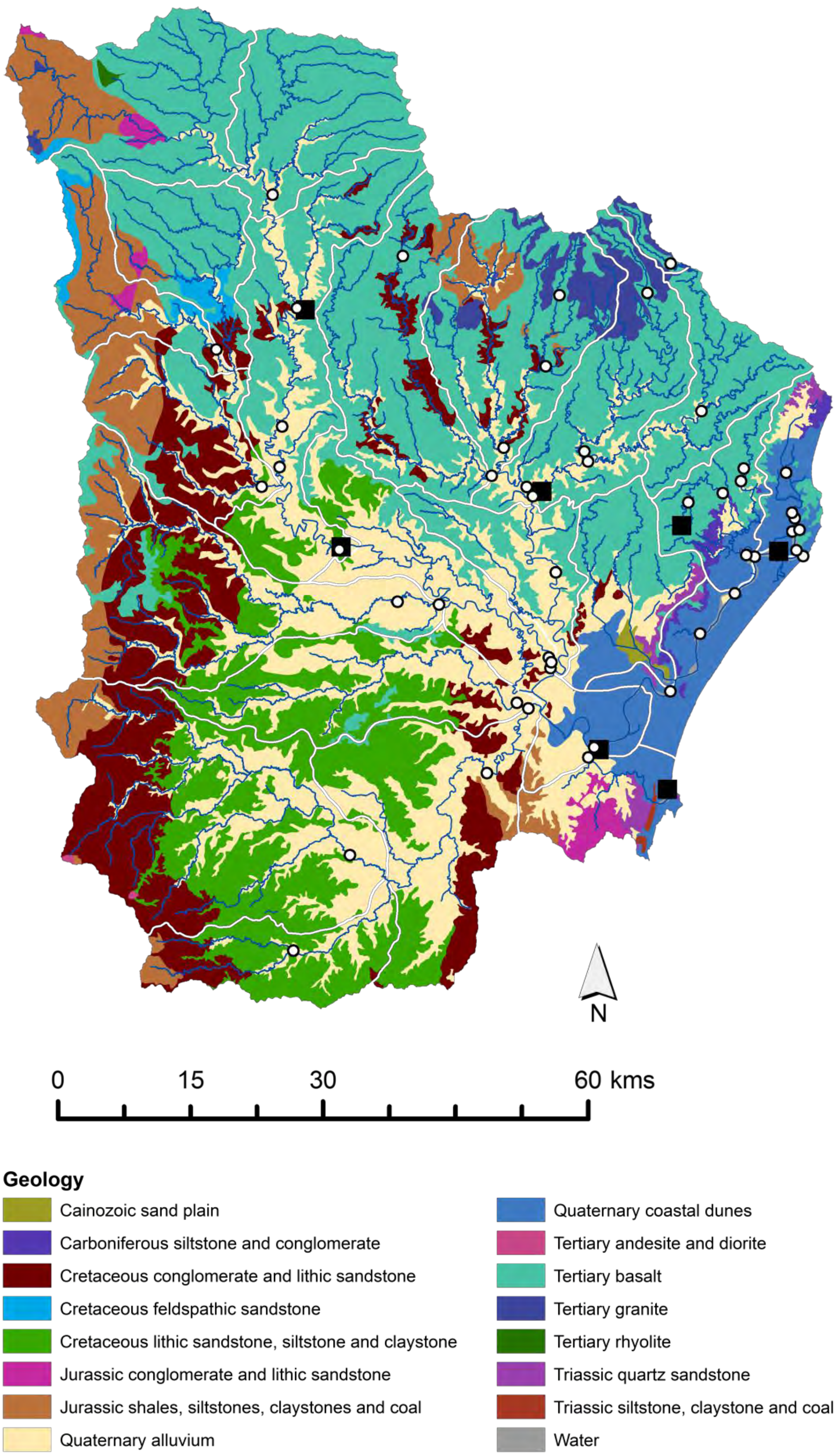


Figure 2.2 Geology of the Richmond catchment.

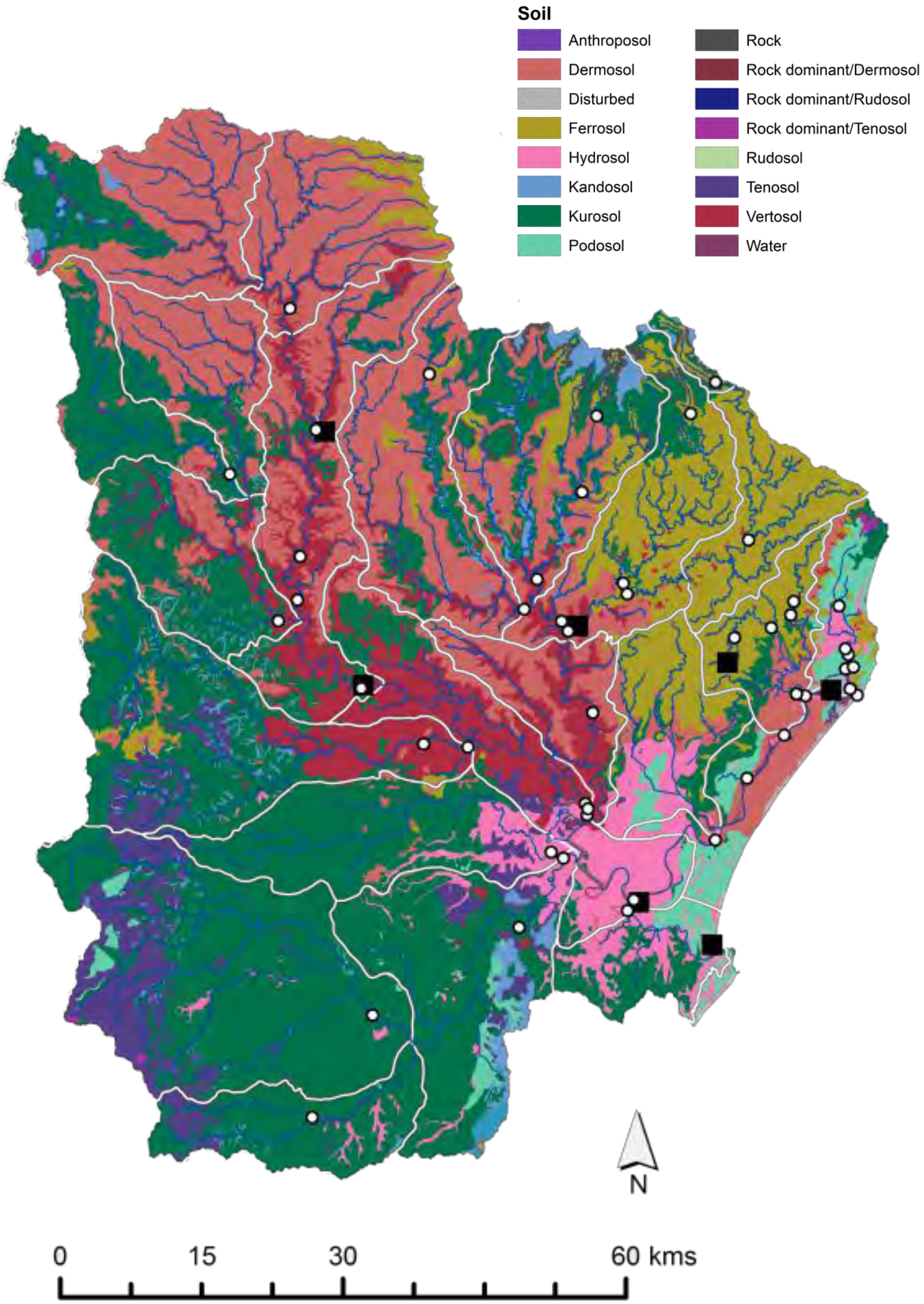


Figure 2.3 Soils of the Richmond catchment.

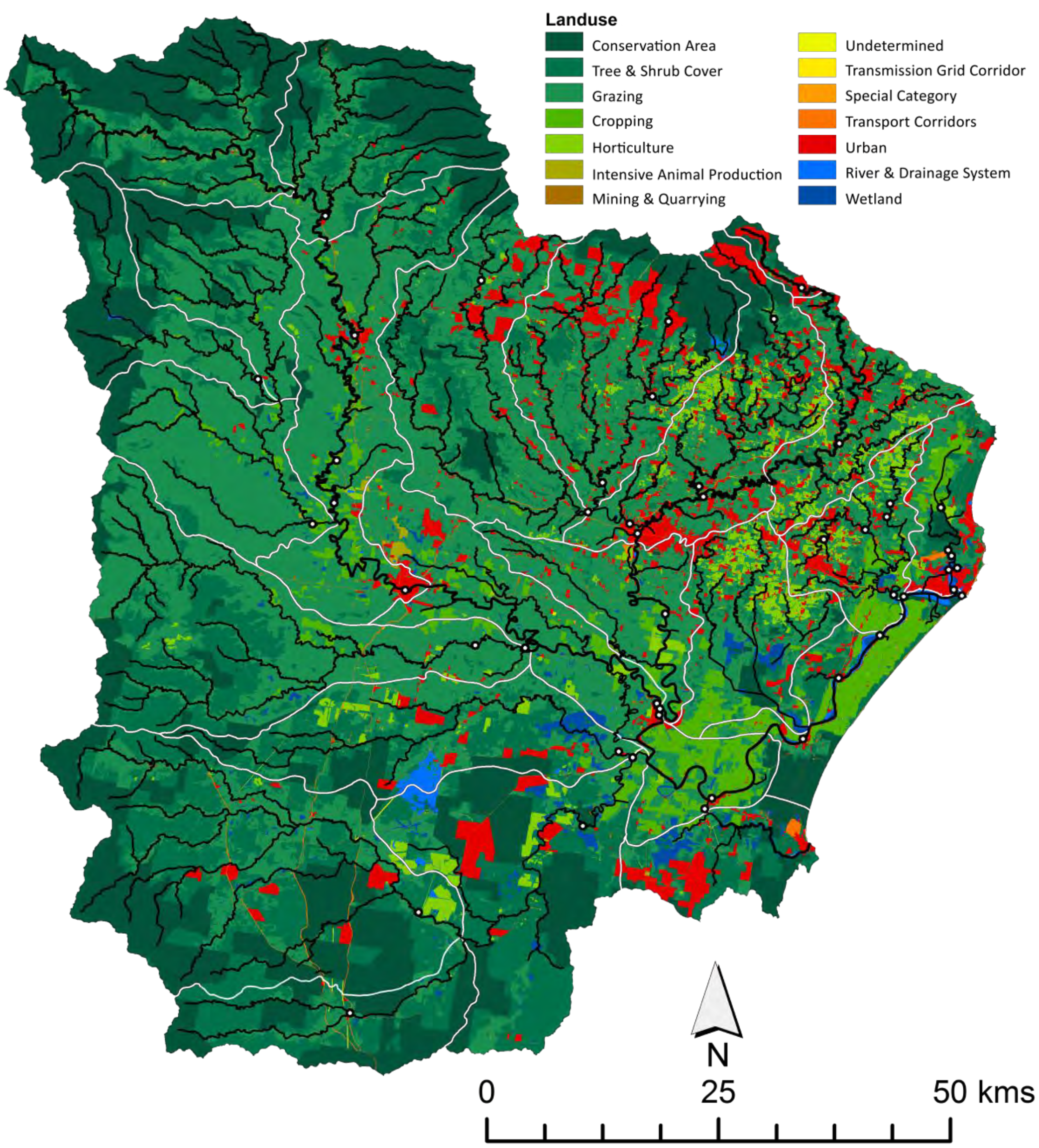


Figure 2.4 Landuse of the Richmond catchment.

Confined valley settings (CVS) account for 42% of the total stream length in the Richmond Catchment, followed by partly confined valley setting (PCVS, 32%), laterally unconfined valley setting – continuous channel (LUV CC, 23%) and swampy meadow group (SMG, 3%). Approximately 1% of the catchment's stream channels have not been classified (Figure 2.5). Of the total stream length, 18% are considered to be in good condition, 59% in moderate condition and 23% in poor condition. The stream channels in good condition are dominated by headwaters (67%) and meandering sand-bed channels (10%), while the stream channels in poor condition predominantly comprise planform controlled, meandering sand-bed channels (25%) and channelized fill (19%). The majority of the upper reaches of the Richmond main steam is planform controlled, low sinuosity gravel-bed, while the lower reaches and estuary comprise laterally unconfined, meandering, fine-grained channels (Figure 2.5).

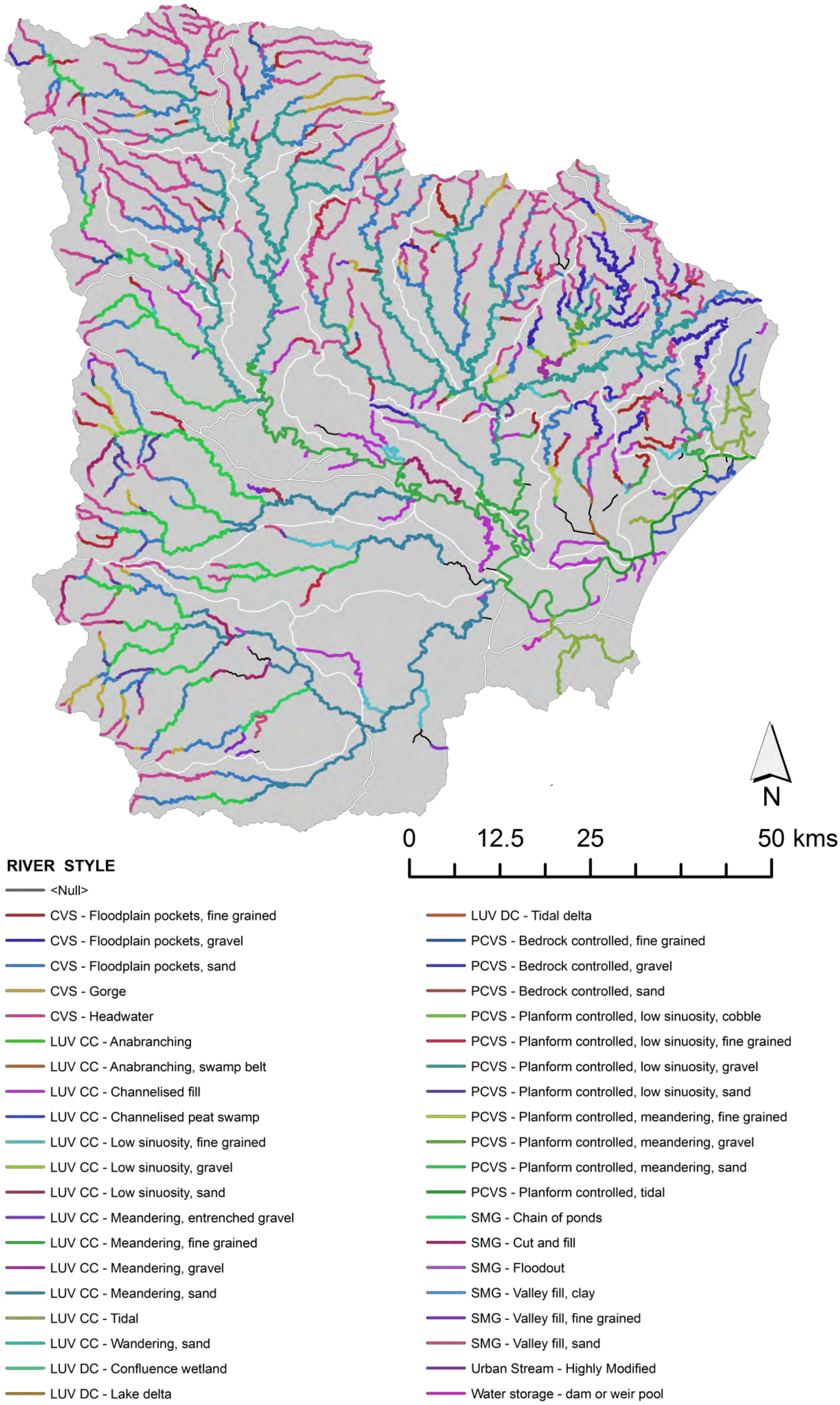


Figure 2.5 River Styles of the Richmond catchment**.**

2.2 Existing research

The aquatic ecology and biogeochemistry of the Richmond catchment has been extensively researched and documented and it is outside the scope of this project to provide an extensive literature review. However, key research themes in the Richmond catchment relevant to this project are summarized below with their most recent literature:

- *Estuarine acidification through draining of acid sulphate soils*. Episodic acidification (pH<5) is caused by the oxidation of sulfidic floodplain sediments and export of sulfuric acid and dissolved metals such as aluminium. In the Richmond estuary, acid discharge is controlled by the floodplain water balance, drainage of shallow acid groundwater and tidal floodgate operation. Leaching events have been linked to major fish kills, red spot disease in fish, and depletion of estuarine macrobenthic communities through the combination of soluble aluminium toxicity and low pH (Corfield 2000).
- *Coastal acid sulfate soils (CASS) may be hotspots for carbon dioxide and methane production*. More than 90% of carbon dioxide (CO_2) and methane (CH_4) emissions from wetland systems on Rocky Mouth Creek occurred during flood with the inundated wetland producing ~95% of CO_2-equivalent emissions over the floodplain (Gatland et al. 2014). Carbon dynamics were likely driven more by the drainage of surface floodwaters than groundwater seepage (Gatland et al. 2014). Similar results were seen in the lower Richmond Estuary and especially Tuckean Swamp, with an approximate 2-week lag between the onset of heavy rainfall and high rates of CO_2 evasion in the estuary (Ruiz-Halpem et al. 2015). Surveys of North Creek found CO_2 and CH_4 export varied over tidal and diel cycles, suggesting temporally intensive measurements are necessary for accurate estimations of CO_2 and CH_4 export (Maher et al. 2015).
- *Deoxygenation events associated with flooding causes fish kills*. Hypoxic floodwater is caused by the rapid microbial decomposition of introduced pasture and cropping plant species, although high suspended loads also reduce the dissolved oxygen concentration through the oxidation of organic compounds and sediments, and the reduction in water column photosynthesis (Dawson 2002). Mono-sulphide black oozes (MBOs) are also common to floodplain channels draining CASS and contribute to deoxygenation of receiving floodwaters (Bush et al. 2004). Floodplain drains have accelerated the transport of hypoxic floodwaters to the estuary, increasing the magnitude and duration of estuarine deoxygenation (Wong et al. 2010).
- *Intra- and inter-annual export of nitrogen and phosphorus in the Richmond River*. Nutrient concentrations were lowest during baseflow and increased between 2- to 5-fold during runoff events (McKee et al. 2000). Landuse and antecedent conditions strongly influenced nutrient concentrations, with terrestrially derived nonpoint source contributions contributing to elevated stream nutrient concentrations during rainfall (Logan et al. 2011). The Richmond catchment was significantly more variable than overseas temperate catchments, particularly with respect to phosphorus (Logan et al. 2011), suggesting it is difficult to model spatial and temporal nutrient exports (McKee et al. 2000).
- *Baseflow suspended sediment concentrations in the estuary*. During baseflow, there is little exchange of suspended sediment between the upper and lower estuarine reaches because of small freshwater inputs, with net sedimentation from marine inputs in the lower estuary

(Hossain et al. 2004). The major source of suspended sediment inputs into the Richmond estuary is fluvial inputs from the upper catchment (92-99% of the total yearly input), with more than 90% transported during runoff events (Hossain and Eyre 2002). The Richmond freshwater reaches and Wilsons River subcatchments contributed more than 93% of the suspended sediment load (Hossain et al. 2002).

2.3 Study design

The design of the Ecohealth freshwater/estuarine monitoring program for the Richmond catchment was based on the NSW Monitoring, Evaluation, Reporting (MER) protocols for Rivers and Estuaries (NSW OEH 2012), and aligned for reporting outcomes used in the South-East Queensland Ecosystem Health Monitoring Program (EHMP) methodologies, as well as previous ecosystem health assessments undertaken within the local region. The number and location of sample sites were designed to assess spatial and temporal variability of the Richmond catchment with statistical robustness.

Locations of 23 freshwater monitoring sites were selected to:

- Identify longitudinal change within the Richmond main stem and major tributaries;
- Assess end of system inputs from tributaries; and
- Compare River Styles, Condition and Recovery Potential, and elevation within and across subcatchments.

Locations of the 25 estuarine monitoring sites were selected to:

- Identify longitudinal change and potential point source (tributary) issues within the main stem of each river system and end of system flows;
- Compare River Styles, Condition and Recovery Potential, and elevation within and across subcatchments; and
- Locate ecological changes at the point of the tidal limit.

The design of the Ecohealth program in the Richmond required prioritisation of sites and sub-catchments to optimize available resources. To increase the spatial extent of sampling, a subset of sites were sampled bi-monthly (Table 2.1).

2.3.1 Sampling Schedule

Water chemistry was sampled bi-monthly or monthly, freshwater macroinvertebrates were sampled bi-annually in Autumn and Spring, and riparian condition and geomorphic condition were assessed once in January 2014 (Table 2.1).

Sampling events comprised a 4 or 5-day period for the full set of sites, or a 2-day period for the subset of sites (Table 2.2). Multiple freshwater and estuarine sites were sampled through both of these periods to ensure consistency in freshwater discharge and tidal regime. Estuarine sites were consistently sampled on an incoming high tide to maximize boat access to all sites. OEH supplied the boat captain and DPI Fisheries (Marine Parks) supplied the boat as in-kind support to the project. All freshwater sites and upper estuarine sites were sampled via road access. Field personnel comprised staff from UNE, Ballina Shire Council (North Creek and Chickiba Creek) and Richmond River County Council who were trained in Ecohealth sampling procedures.

TABLE 2.2 Sites comprising the full set and subset of sampling.

Site	Full set	Subset	Site	Full set	Subset	Site	Full set	Subset
RR1	*	*	NC1	*	*	LC1		*
RR2	*	*	NC2	*	*	LC2		*
RR3	*	*	NC3	*	*	LC3		*
RR4	*	*	NC4	*	*	COC1		*
RR5	*	*	NC5	*	*	COC2		*
RR6	*	*	WR1	*	*	MC1		*
RR7	*	*	WR2	*	*	MC2		*
RR8	*	*	WR3	*	*	TC1		*
RR9		*	WR4		*	TC2		*
RR10		*	BC1		*	IPC1		*
RR11		*	BC2		*	MYC1		*
RR12		*	BC3		*	RC1		*
RR13		*	EC1	*	*	RMC1		*
RR14		*	EC2		*	SB1		*
BYC1		*	EC3		*	SC1		*
CHC1	*	*	ED1		*	WC1		*

2.3.1.1 *Regional climate conditions*

Rainfall in the region during the 2013-2014 sampling period was well below the long term mean, with an annual total rainfall of 1208.4mm at Ballina, 1104.4mm at Lismore, and 743.4mm at Casino (Figure 2.6). Monthly total rainfall ranged from 2.8mm in September to 359.2mm in August at Ballina, 11.2mm in October to 316mm in November at Lismore, and 7mm in July to 196.4mm in both March and August at Casino.

Daily discharge at Old Grevillia, Wiangaree, Kyogle, and Casino reflected the variable rainfall for the Richmond Catchment (Figure 2.7). The highest mean monthly discharge of 1676.7ML/d (19.4 m^3/s) was recorded at Casino in March; this was only half the long term average for March (Figure 2.8). The lowest mean monthly discharge of 39.7ML/d (0.46m^3/s) for Casino was recorded in November. Discharge data for the upper Richmond at Old Grevillia is not available for dates after the 26th of May 2014. However, the highest mean monthly discharge for the first 6 months of sampling was 240.5ML/d (2.78m^3/s) recorded in March, with the lowest discharge of 6ML/d (0.069m^3/s) in January. The highest mean monthly discharges for The Richmond River at Wiangaree and Kyogle were 696.8ML/d (8.06m^3/s) and 834.1ML/d (9.65m^3/s) respectively, both recorded in March. The lowest mean monthly discharge for Wiangaree and Kyogle was 39.2ML/d (0.454m^3/s) and 34.2ML/d (0.396m^3/s) respectively, both recorded in November. These rainfall and discharge data demonstrate the below-average rainfall and resulting reduction in discharge throughout the sampling period. There were two significant peaks in both rainfall and discharge in March and August 2014 (Figure 2.9).

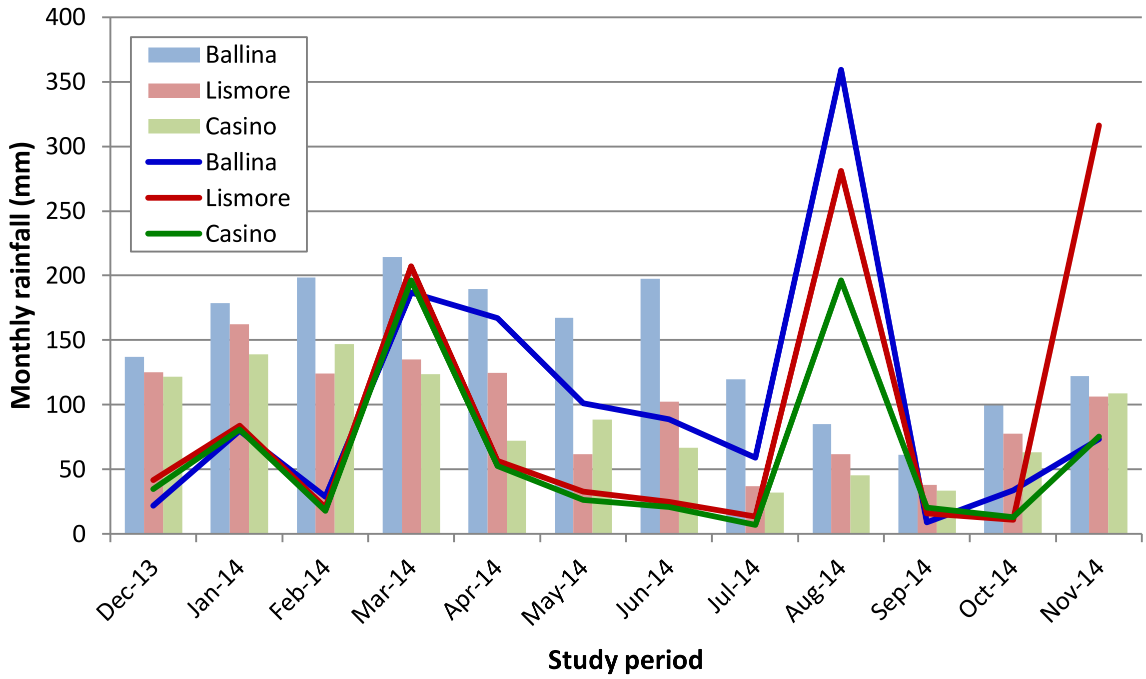


Figure 2.6 The long-term mean monthly total rainfall (columns, mm) and the monthly total rainfall during the sampling period (lines, mm) at Ballina (gauge 058198), Lismore (gauge 058214), and Casino (gauge 058208).

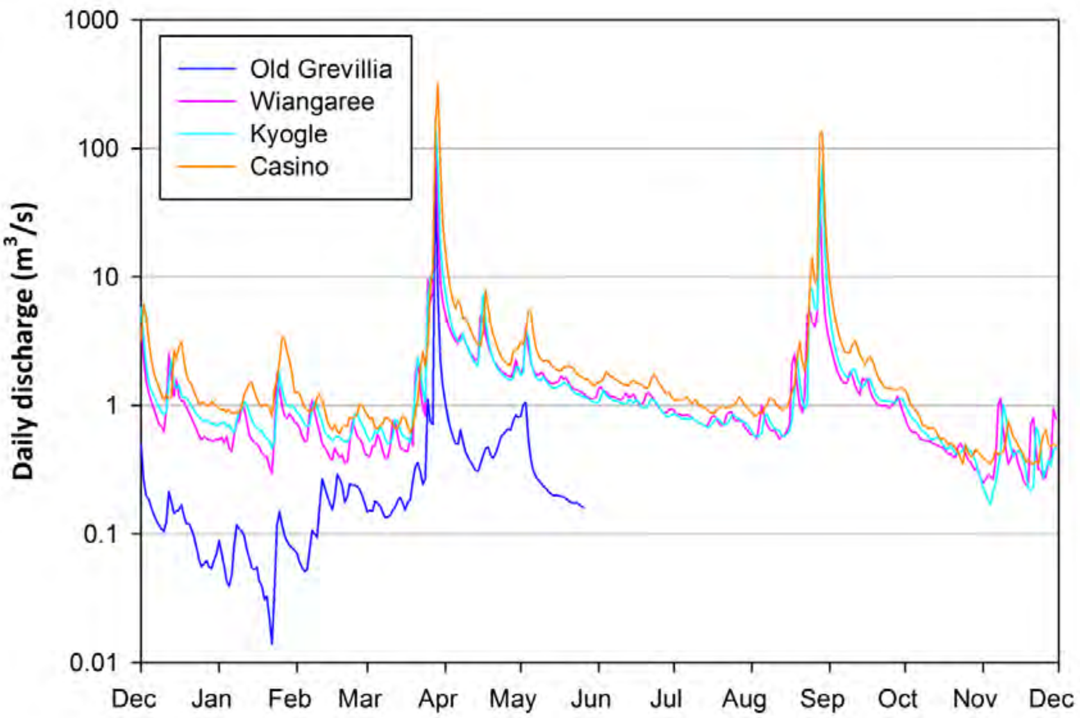


Figure 2.7 Daily discharge(m^3/s) in the Richmond River longitudinally downstream from Old Grevillia (gauge 203056), Wiangaree (gauge 203005), Kyogle (gauge 203900) to Casino (gauge 203004) from 1 December 2013 to 30 November 2014 (data from NSW Office of Water).

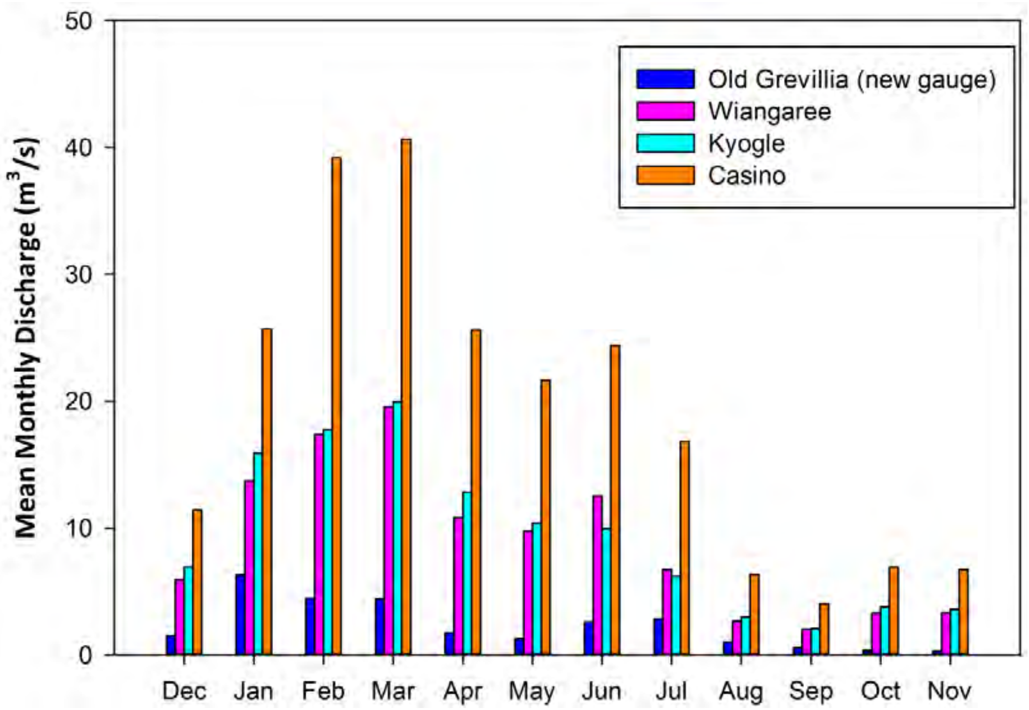


Figure 2.8 Long term mean monthly discharge (m^3/s) in the Richmond River longitudinally downstream from Old Grevillia (gauge 203056), Wiangaree (gauge 203005), Kyogle (gauge 203900) to Casino (gauge 203004, NSW Office of Water).

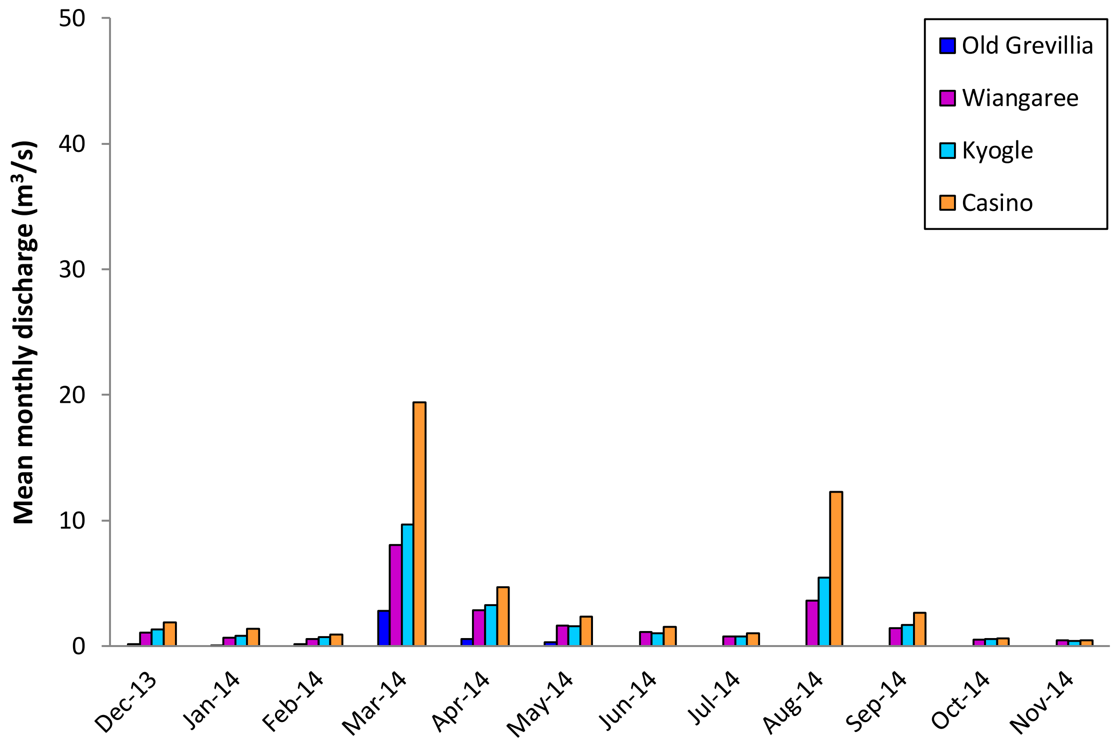


Figure 2.9 Mean monthly discharge (m^3/s) for the sampling period in the Richmond River longitudinally downstream from Old Grevillia (gauge 203056), Wiangaree (gauge 203005), Kyogle (gauge 203900) to Casino (gauge 203004, NSW Office of Water).

2.4 Study sites

Forty-eight study sites were selected across the Richmond catchment; 23 freshwater sites and 25 estuarine sites (Figure 2.1). The Richmond River Main Stem had 14 sites comprising 8 estuarine sites and 6 freshwater sites (Tables 2.3, 2.4). The eight estuarine sites were sampled monthly (i.e. 12 times).

The Wilsons River and its tributaries contained 13 sites, 4 estuarine sites on the Wilsons River, 3 sites on Leycester Creek (1 estuarine), 2 sites on Coopers Creek, 2 sites on Terania Creek, and 1 site each on Byron and Wilson Creeks (Tables 2.3, 2.4). With the exception of WR4, the estuarine sites on the Wilsons River were sampled monthly (12 sample times). All other sites were sampled bi-monthly (6 sampling times).

Eden and Iron Pot Creeks and Shannon Brook contained 1 site each, at the end of system (Tables 2.3, 2.4). These 3 sites were sampled bi-monthly (6 sampling times).

Bungawalbin, Myrtle and Sandy Creeks contained 5 sites that were sampled bi-monthly (6 sampling times). There were 3 sites on Bungawalbin Creek and one each to capture end of system inputs from Myrtle and Sandy Creeks (Tables 2.3, 2.4).

Emigrant, Maguires and North Creeks had 11 sites. North Creek had 5 estuarine sites, all sampled monthly. Chickiba Creek contained 1 estuarine site sampled monthly. There were 3 sites on Emigrant Creek, 1 of which was estuarine and sampled monthly (12 sampling times). The 2 freshwater sites on Emigrant Creek and the 2 sites on Maguires Creek were also sampled bi-monthly (6 sampling times). Maguires Creek contained 1 estuarine and 1 freshwater site (Tables 2.3, 2.4).

TABLE 2.3 Location of field sample sites in the Richmond catchment. Estuary sites are indicated by (*).

Name	Site Code	Easting (m E)	Northing (m S)	Elevation (m)
Richmond River 1	RR1*	556971	6805868	0
Richmond River 2	RR2*	551462	6805782	0
Richmond River 3	RR3*	549201	6801624	0
Richmond River 4	RR4*	545288	6797046	1
Richmond River 5	RR5*	541898	6790513	0
Richmond River 6	RR6*	533271	6784158	1
Richmond River 7	RR7*	528299	6793135	7
Richmond River 8	RR8*	528107	6794363	5
Richmond River 9	RR9	515673	6800369	7
Richmond River 10	RR10	504345	6806585	23
Richmond River 11	RR11	497594	6815971	35
Richmond River 12	RR12	497855	6820552	40
Richmond River 13	RR13	499548	6833998	55
Richmond River 14	RR14	496782	6846867	77
North Creek 1	NC1*	556207	6806507	0
North Creek 2	NC2*	555724	6808651	0
North Creek 3	NC3*	556015	6810148	5
North Creek 4	NC4*	555709	6810780	3
North Creek 5	NC5*	555021	6815334	6
Chickiba Creek 1	CHC1*	556544	6808845	4
Wilsons River 1	WR1*	528401	6793799	6
Wilsons River 2	WR2*	528925	6803998	8
Wilsons River 3	WR3*	526314	6812669	7
Wilsons River 4	WR4*	532562	6816588	17
Bungawalbin Creek 1	BC1*	525803	6788565	4
Bungawalbin Creek 2	BC2	521086	6781217	14
Bungawalbin Creek 3	BC3	499129	6761089	50
Emigrant Creek 1	EC1*	550518	6805984	0
Emigrant Creek 2	EC2*	549911	6814373	8
Emigrant Creek 3	EC3	550235	6815789	22
Leycester Creek 1	LC1*	525599	6813709	8
Leycester Creek 2	LC2	521647	6814980	8
Leycester Creek 3	LC3	511551	6839911	124
Coopers Creek 1	COC1	532144	6817729	12
Coopers Creek 2	COC2	539290	6835711	104
Maguires Creek 1	MC1*	547860	6813002	10
Maguires Creek 2	MC2	543935	6811958	104
Terania Creek 1	TC1	523009	6818141	8
Terania Creek 2	TC2	529309	6835476	145
Byron Creek 1	BYC1	545438	6822302	25
Eden Creek 1	ED1	495563	6813719	33
Iron Pot Creek 1	IPC1	490398	6829292	63
Myrtle Creek 1	MYC1	505568	6771930	36
Rocky Creek 1	RC1	527755	6827403	34
Rocky Mouth Creek 1	RMC1*	532593	6783013	4
Shannon Brook 1	SB1	510949	6800666	18
Sandy Creek 1	SC1	524487	6789194	4
Wilson Creek 1	WC1	541932	6839052	149

TABLE 2.4 Site photos and River Styles.

 **RR1 facing upstream:** PCVS – Planform controlled, tidal.	 **RR2 facing upstream:** PCVS – Planform controlled, tidal.
 **RR3 facing upstream:** LUV CC – Tidal.	 **RR4 facing upstream:** PCVS – Planform controlled, tidal.
 **RR5 facing upstream:** PCVS – Planform controlled, tidal.	 **RR6 facing upstream:** LUV CC – Meandering, fine grained.

TABLE 2.4 (continued) Site photos and River Styles.

 **RR7 facing upstream:** LUV CC – Meandering, fine grained.	 **RR8 facing downstream:** LUV CC – Meandering, fine grained.
 **RR9 facing downstream:** LUV CC – Meandering, fine grained.	 **RR10 facing downstream:** LUV CC – Meandering, fine grained.
 **RR11 facing downstream:** LUV CC – Meandering, fine grained.	 **RR12 facing downstream:** PCVS – Planform controlled, low sinuosity, gravel.

TABLE 2.4 (continued) Site photos and River Styles.	
 **RR13 facing upstream:** PCVS – Planform controlled, low sinuosity, gravel.	 **RR14 facing downstream:** PCVS – Planform controlled, low sinuosity, gravel.
 **NC1 facing upstream:** LUV CC – Tidal.	 **NC2 facing upstream:** LUV CC – Tidal.
 **NC3 facing upstream:** LUV CC – Tidal.	 **NC4 facing upstream:** LUV CC – Tidal.

TABLE 2.4 (continued) Site photos and River Styles.

 **NC5:** LUV CC – Tidal.	 **CHC1:** LUV CC – Tidal.
 **WR1 facing downstream:** LUV CC – Meandering, fine grained.	 **WR2 flow right to left:** PCVS – Planform controlled, low sinuosity, gravel.
 **WR3 facing downstream:** PCVS – Planform controlled, low sinuosity, gravel.	 **WR4 facing downstream:** PCVS – Planform controlled, low sinuosity, gravel.

TABLE 2.4 (continued) Site photos and River Styles.

<table>
<tr><td>
BC1 facing downstream: LUV CC – Meandering, sand.</td><td>
BC2 facing downstream: LUV CC – Meandering, sand.</td></tr>
<tr><td>
BC3 facing upstream: LUV CC – Meandering, sand.</td><td>
EC1 facing downstream: LUV CC – Meandering, fine grained.</td></tr>
<tr><td>
EC2 facing downstream: PCVS – Planform controlled, low sinuosity, gravel.</td><td>
EC3 facing downstream: CVS – Headwater.</td></tr>
</table>

TABLE 2.4 (continued) Site photos and River Styles.

	
LC1 facing downstream: PCVS – Planform controlled, low sinuosity gravel.	**LC2 facing downstream:** PCVS – Planform controlled, low sinuosity gravel.
	
LC3 facing downstream: CVS – Headwater.	**COC1 facing upstream:** LUV CC – Meandering, gravel.
	
COC2 facing downstream: CVS – Floodplain pockets, gravel.	**MC1 facing upstream:** PCVS – Planform controlled, low sinuosity, gravel.

<table>
<tr><th colspan="2">TABLE 2.4 (continued) Site photos and River Styles.</th></tr>
<tr><td>
MC2 facing downstream: CVS – Floodplain pockets, gravel.</td><td>
TC1 facing upstream: PCVS – Planform controlled, low sinuosity, gravel.</td></tr>
<tr><td>
TC2 facing downstream: CVS – Headwater.</td><td>
BYC1 facing upstream: PCVS – Planform controlled, low sinuosity, gravel.</td></tr>
<tr><td>
ED1 facing upstream: PCVS – Planform controlled, low sinuosity, gravel.</td><td>
IPC1 facing downstream: PCVS – Planform controlled, low sinuosity, gravel.</td></tr>
</table>

TABLE 2.4 (continued) Site photos and River Styles.	
 **MYC1 facing downstream:** LUV CC – Meandering, sand.	 **RC1 facing downstream:** CVS – Headwater.
 **RMC1 facing upstream:** LUV CC – Tidal.	 **SB1 facing downstream:** LUV CC – Meandering, sand.
 **SC1 flow from left to right:** LUV CC – Meandering, sand.	 **WC1 facing downstream:** CVS – Floodplain pockets, sand.

2.5 Sampling methods and indicators

The indicators chosen focus on the condition of the system to best identify the stressors and pressures that cause change in ecological condition. The selection of indicators (and groupings of indicators) represents elements of the structure, function and composition of riverine and estuarine ecosystems.

2.5.1 Water Quality Indicators

Assessing the impacts of land-use change on the ecological health of rivers and streams is an important issue for the management of water resources in Australia. Traditionally, these assessments have been dominated by the measurement of patterns in species distribution and abundance which contribute important information such as the status of threatened species and their habitat requirements. However, many goals of river management refer to concepts of sustainability, viability and resilience that require an implicit knowledge of ecosystem or landscape-level interactions and processes influencing these organisms or populations.

The water chemistry of rivers and estuaries can be an ideal measure of their ecological condition by providing an integrated response to a broad range of catchment disturbances (Table 2.5). Nutrients such as nitrogen, phosphorus, and carbon can play an integral role in regulating rates of primary production in these systems. However, anthropogenic changes to catchment land-use have led to increased supply of nutrients from diffuse or point sources, and altered light and turbidity regimes through increased suspended sediment loads and loss of riparian vegetation. These landscape-level processes define the supply of contaminants to a stream and provide the framework within which other processes operate at smaller spatial scales and shorter temporal scales to regulate their supply and availability.

TABLE 2.5 Water chemistry measurements taken monthly (subset) or bi-monthly (full set) at sites.

In situ measurements	Water quality samples for laboratory analysis
Water depth pH Temperature Salinity/Conductivity Dissolved oxygen Turbidity	Total nutrients (nitrogen and phosphorus) Dissolved nutrients (nitrate-nitrite, and phosphate) Chlorophyll *a* Total Suspended Solids (TSS)

2.5.2 Field and laboratory methods

At each sampling site, *in situ* water quality measurements were measured with the use of a Hydrolab Quanta water quality multi-probe (pH, Conductivity, Dissolved Oxygen (DO), Temperature, Turbidity). The following procedural steps are outlined to standardise the collection of these data and to identify quality control.

2.5.3 Water Quality Probe Calibration and Use

The water quality probe(s) were calibrated each day prior to use in the field. At each sample site, field measurements for the water column profile was taken at near surface (approx. 0.2m below surface), and at 1m intervals through the water column to a depth of 0.2m from the bottom (epibenthic). Measurements for each water quality parameter using the multi-probe were recorded at each interval. In freshwater sites that were less than 1m in depth, surface and epibenthic measurements were taken and maximum sampling depths noted. Data were recorded on proforma data recording sheets (Appendix 1).

2.5.4 Water Quality Sampling

Water samples were collected at each site for the determination of chlorophyll *a*, total and dissolved nutrients, and total suspended solids. Samples were collected at near surface (<0.2m) and obtained with the use of a hand held sampling device to ensure sample is taken at least 1.5m from the edge of the boat or riverbank. Samples were transferred to acid-washed and rinsed (thrice rinsed with sample water) 125mL containers. Duplicate samples for each parameter were taken from each site, and a third sample of each parameter was collected from a random subset of sites for quality assurance (QA) processing at an independent laboratory. The following procedures for sample collection and treatment are provided for each determination.

2.5.4.1 *Chlorophyll a*

Water column chlorophyll *a* is a measure of the photosynthetic biomass of algae/phytoplankton. These organisms are central to important nutrient and biogeochemical processes, and as such may respond to disturbance before effects on higher organisms are detected. This is because the higher organisms depend on processes mediated by algal communities. Consequently, they form the base of food webs supporting zooplankton, grazers such as crustaceans, insects, molluscs and some fish (Burns and Ryder 2001). The short generation time, responsiveness to environmental condition and the availability of sound, quantitative methodologies such as chlorophyll *a* make these measures of phytoplankton ideally suited as indicators of disturbance in aquatic systems. Information can be collected, processed and analysed at time scales relevant to both scientific and management interests.

In the field, a 1L bottle of water from 0.2m depth was collected using the hand held sampling device at each site, labelled, and placed on ice in an esky for transport to the laboratory. Sample processing was carried out within 48 hours of collection using the following steps;

1) Place a Whatman GF/C Glass Microfiber filter paper, using forceps, textured side up onto the filtration apparatus (EYELA Tokyo Rakahikai Coorperation Aspirator A-35) just prior to filtration.
2) Filter a sufficient amount of sample was filtered (100-1,000mL measured with a graduated cylinder), to produce a green colour on the filter paper, or until the flow through the filter

paper at ½ atmosphere pressure (approx. 7PSI) is reduced to a trickle. When approximately 10-15mL of the sample remained on the filter, 5-10 drops of the $MgCO_3$ powder were added to preserve the chlorophyll. The filter apparatus and graduated cylinder were then rinsed thoroughly using a squirt bottle with deionised water and the filter drained to remove all signs of moisture.

3) The sample volume filtered was recorded. The amount of water filtered is subject to the level of turbidity at the sampling site.
4) Using forceps, the filter paper was folded and carefully placed into the bottom portion of the prelabled culture tube that was then sealed, wrapped in aluminium foil, placed into a labelled ziplock bag and refrigerated below 4°C.
5) The filter paper was then placed in 10mL of 90% acetone. The solution was refrigerated for 24 hours. The samples were then centrifuged. The absorption spectra were recorded using a UV-1700 Pharmaspec UV-visible spectrometer at 665nm and 750nm.

2.5.4.2 *Total Suspended Solids*

Total suspended solids (TSS) is a direct measure of turbidity of the water. In the field, a pre-labelled 1-L bottle of water from 0.2m depth was collected at each site using the hand held sampling device, and the sample placed into a cool, dark esky.

TSS were measured by filtering a sufficient amount of sample (100-1,000mL measured with a graduated cylinder) through a Whatman GF/C Glass Microfiber filter paper, with a known weight, using a EYELA Tokyo Rakahikai Coorperation Aspirator A-35 at ½ atmosphere pressure (approx. 7PSI). The volume of filtered sample was recorded and used to calculate mg/L of TSS. The filter apparatus and graduated cylinder were thoroughly rinsed using a squirt bottle with deionised water and the filter drained to remove all signs of moisture. The filter paper with retained material was then placed into a foil envelope and dried in an oven at 50°C. They were reweighed after they dried to gain a measure of the weight of the TSS on each sample.

2.5.4.3 *Inorganic Nutrients*

For inorganic nutrients, two 125mL water samples were collected from 0.2m depth at each site using the hand held sampling device. Samples for total nitrogen and total phosphorus remained unfiltered and were transferred into pre-rinsed, pre-labelled, 125mL PET bottles and immediately placed in a cool, dark esky. Samples remained frozen until time of analysis. Duplicate samples for quality assurance processing at an independent laboratory remained frozen until analyzed. For organic nutrients, two 125mL water samples were collected from 0.2m depth at each site using the hand held sampling device. Approximately 125mL of water was passed through a Whatman GF/C filter paper (effective pore size 0.7µm) in the field and collected into pre-rinsed, pre-labelled, 125mL PET bottles and immediately placed in a cool, dark esky. Samples remained frozen until time of analysis. Duplicate samples for quality assurance processing at an independent laboratory remained frozen until analyzed.

Nitrogen was measured by digesting an unfiltered water sample in a digestion tube with 10mL of digestion mixture. This contained 40g of di-potassium-peroxodisulfate ($K_2S_2O_8$) and 9g of sodium hydroxide (NaOH) in 1000mL of Milli Q water. This sample was then digested in the autoclave for 20 minutes. Five mL of the sample was then placed into a 50mL acid-washed measuring cylinder and diluted to 50mL (Hosomi & Sudo 1986). Five mL of buffer solution was added: 100g of NH_4Cl, 20g sodium tetra borate and 1g EDTA to 1L with Milli Q water. Fifty mL of each sample was measured into a numbered jar. The samples were then filtered. Firstly, the cadmium reduction column was rinsed with 10% buffer solution, making sure the cadmium granules remained covered at all times by either the 10% buffer solution or the sample. The column was drained to 5mm above the cadmium granules, and 25mL of the first sample added. This was collected in a separate beaker as it drained through to rinse the column and was discarded. The column was then filled with the sample and 20mL was collected in the same sample jar. One mL of sulfanilamide solution was added and mixed thoroughly. After 2 minutes, 1mL of dihydrochloride solution was added and mixed. This was repeated for all water samples. After 10 minutes, the absorbance of each sample was measured using a UV-1700 Pharmaspec UV-visible spectrometer at 543nm. This colormetric determination of nitrogen can be used when nitrogen is in the range 0.0125 to 2.25μg/ml. Standards were also be prepared before analyzing the samples to calculate linear regression at 0μg/ml, 0.05μg/ml, 0.2μg/ml, 0.5μg/ml, 1μg/ml, 2μg/ml and 5μg/ml of known nitrogen concentration.

Phosphorus was measured by digesting an unfiltered water sample in a digestion tube with 10mL of digestion mixture. This contained 40g of di-potassium-peroxodisulfate ($K_2S_2O_8$) and 9g of sodium hydroxide (NaOH) in 1000mL of Milli Q water. This sample was then digested in the autoclave for 20 minutes. Twenty mL of sample was then added to a plastic SRP tube with 2mL of colour reagent: 20mL of ascorbic acid solution with 50mL of molybdate antimony solution. This was repeated for all water samples. After 8 minutes, the absorbance of each sample was measured using a UV-1700 Pharmaspec UV-visible spectrometer at 705nm. Standards were also be prepared before analyzing the samples to calculate linear regression at 0μg/ml, 0.05μg/ml, 0.2μg/ml, 0.5μg/ml, 1μg/ml, 2μg/ml and 5μg/ml of known nitrogen concentration.

2.5.4.4 *Laboratory QA/QC*

Quality control was maintained with the laboratory by the use of standard analytical methods, analysis of 5% random samples for QA/QC at the PMHC laboratories, and the regular calibration and maintenance of laboratory instrumentation. In addition, laboratory analyses of conductivity, turbidity and pH from stored water samples was used to confirm field measurements. An additional water chemistry sample was collected (via random number generator) from selected sites on each sample occasion and sent to an independent laboratory for analysis. These QA samples represented 5% of the total number of samples collected. Results confirmed no significant difference between results for N and P between laboratories.

2.5.4.5 *ANZECC and MER water quality guidelines*

The ANZECC Water Quality Guidelines (the guidelines) established in 1992 under the Commonwealth's National Water Quality Management Strategy (NWQMS), provide a scientifically informed framework for the water quality objectives required to maintain current and future water resources and environmental values (ANZECC, 2000). The ANZECC guidelines were created in response to growing understanding of the potential for water quality to be a limiting factor to social and economic growth. The guidelines were derived from reviewing water quality guidelines developed overseas. However; Australian guidelines were also incorporated where available (ANZECC, 1994).

The ANZECC *Australian Water Quality Guidelines for Fresh and Marine Waters* were released in 1992, and developed using two approaches:

1. An empirical approach which used the Precautionary Principle to create conservative trigger values from all available and acceptable national and international data. This method implemented data from only the most sensitive taxa in order to ensure the protection of these species.
2. The modeling of all available and acceptable national and international data into a statistical distribution with the confidence intervals of 90% and 50%.

Trigger values are conservative thresholds or desired concentration levels for different water quality indicators. When an indicator is below the trigger value there is a low risk present to the protection of that environment. However, when an indicator is above the trigger value, there is a risk that the ecosystem will not be protected. In cases where the trigger value is exceeded, further research and remediation of the risk identified should be conducted. Where a numerical value cannot be derived for a water quality indicator, a target load may be set, for example the salinity guideline; or a descriptive statement, for example for oil there should be no visible surface film; or an index of ecosystem health, for example percentage cover of an algal bloom. The Australian and New Zealand Environment Conservation Council (ANZECC) Guidelines (2000 and 2006) provide threshold values for freshwater and estuarine systems for pH, dissolved oxygen (DO), electrical conductivity (EC), salinity and nutrients such as nitrogen (N) and phosphorus (P). In addition, we used region-based trigger values for estuarine chlorophyll *a* and turbidity developed by DECCW as part of the MER program. A combination of ANZECC (2000,2006) and NSW MER developed trigger values were used to explore water quality across sites and sampling occasions (Table 2.6).

TABLE 2.6 ANZECC Guidelines (2000) and NSW MER - Min. and Max Values for freshwater (above and below 150m elevation) and estuarine systems of southeast Australia. * Revised MER trigger values for reference condition coastal systems were used.

Category	pH	DO (%)	EC (µScm)	Turbidity (NTU)	Chla (µgL)	NOx* (µgL)	SRP (µgL)	TN (µgL)	TP (µgL)
Freshwater sites >150m	6.5 – 7.5	80-110	30 - 350	25	4	25	15	250	20
Freshwater sites <150m	6.5 - 8	80-110	125 - 2200	50	4	40	20	500	50
Estuary sites	7 - 8.5	80-110	no ANZECC values	10	3.3	15	5	300	30

2.5.5 Macroinvertebrates

Aquatic macroinvertebrates are non-vertebrate aquatic animals (e.g., insects, crustaceans, snails and worms) that are visible to the naked eye and which live at least part of their life within a body of freshwater. Freshwater macroinvertebrates are important members of aquatic foodwebs. They feed on a wide range of food sources such as detritus (dead organic matter), bacteria, algal and plant material, and other animals. They in turn provide food for other animals such as fish and aquatic birds. Macroinvertebrates are useful as bio-indicators as many taxa are sensitive to stress and respond to changes in environmental conditions. Because many macroinvertebrates live in a river reach for an extended period of time, they integrate the impacts on the ecosystem over an extended period of time, rather than just at the time of sampling. In addition, many macroinvertebrates have widespread distributions, they are reasonably easy to collect and their taxonomy is reasonably well known.

Macroinvertebrates have been widely used in broad scale assessments of 'river health'. The most common approach adopted for environmental monitoring has involved the analysis of the taxonomic richness of macroinvertebrates. SIGNAL stands for 'Stream Invertebrate Grade Number – Average Level.' It is a simple scoring system for macroinvertebrate samples from Australian rivers. A SIGNAL score gives an indication of water quality in the river from which the sample was collected. Rivers with high SIGNAL scores are likely to have low levels of salinity, turbidity and nutrients such as nitrogen and phosphorus. They are also likely to be high in dissolved oxygen. When considered together with macroinvertebrate richness (the number of types of macroinvertebrates), SIGNAL can provide indications of the types of pollution and other physical and chemical factors that are affecting the macroinvertebrate community. SIGNAL Scores range from 1 (pollution tolerant) to 10 (pollution intolerant). Another classification system uses the EPT index. This index claims that although different insect taxa vary widely in their sensitivity to sedimentation, the taxa from the orders Ephemeroptera (E), Plecoptera (P), and Trichoptera (T) behave similarly. However, a taxonomic group can exhibit a great deal of heterogeneity, so an assessment method like the EPT may be insensitive to changes in species composition unless composition is altered along with overall taxa richness. Multimetric and multivariate approaches can increase a model's accuracy.

These models evaluate the sampled community by comparing observed conditions to what conditions or taxa are expected to occur in the absence of disturbance.

2.5.5.1 *Field and laboratory methods*

Macroinvertebrates were sampled bi-annually (Autumn and Spring 2014) at the freshwater sites to align with the MER protocols. Kick net samples (250µm mesh) that comprise 10 linear meters of each of pool, riffle and edge habitats were taken from each of the 23 freshwater sites on each of the two sampling occasions. Only those habitats present at the time were sampled. Invertebrates were immediately preserved in 70% ethanol on site and transported to the laboratory for analysis. Each sample was passed through 2mm, 1mm and 250µm sieves. All taxa from the 2mm and 1mm sieves were recorded, with material retained on the 250µm sieve sorted for a standardized 30-minute period. Macroinvertebrates were identified to Family/genera level and assigned a SIGNAL2 score for pollution tolerance, and EPT score calculated. Metrics of abundance, richness, diversity and composition were recorded. Data for each river, sites within rivers and season were collated to produce summary data on taxa richness, median signal score and EPT score.

2.5.6 Riparian and Mangrove/Seagrass condition assessment

2.5.6.1 *Riparian Assessment of freshwater sites*

A riparian zone is found where any body of water directly influences, or is influenced by adjacent land (Boulton & Brock 1999). Riparian zones are dynamic environments regularly influenced by freshwater, and characterised by strong energy regimes, considerable habitat diversity, a variety of ecological processes and multidimensional gradients (Naiman et al. 2005). The riparian land is an intermediary semi-terrestrial zone with boundaries that extend outward from the water's edges to the limits of flooding and upward into the canopy of the riverside vegetation (Naiman et al. 2005).

The area within a riparian zone contains valuable water resources, highly fertile soil and supports high levels of biodiversity. In regards to natural ecosystems and agricultural production, riparian land is often considered the most productive and fertile area in a landscape and hence they are considered to be a vital element of an ecosystem. Riparian zones contribute to numerous ecological functions as well as fulfill many social and economic functions, both directly and indirectly. The ecological functions of a riparian zone can be grouped into four main categories: nutrient flux, geomorphology, temperature and light, and litter input (Boulton & Brock 1999). Each of the four categories involves different attributes of the riparian zone and may encompass significantly different areas of channel bank.

2.5.6.2 *Rapid Assessment of Riparian Condition*

The sub-tropical rapid appraisal for riparian condition (STRARC) is a multi-metric index of riparian condition, which has been modified from the original Rapid Appraisal for Riparian Condition (RARC) (Jansen et al. 2004) and the adapted Tropical Rapid Appraisal of Riparian Condition (TRARC) (Dixon et al. 2006). The STRARC is comprised of 24 indicators which are grouped into four sub-indices which, when combined with equal weighting calculate to an overall index of riparian condition. The four sub-indices help to identify the general components that contribute to the condition of a site (Dixon et al. 2006). For the purposes of Ecohealth grading, the STRARC was modified to separate out geomorphic condition from riparian condition. Riparian sub-indices and their indicators are listed below in Table 2.7.

In summary the three riparian sub-indices describe:

1. The overall condition of the riparian vegetation (VEGETATION CONDITION).
2. The extent of habitat found within the riparian zone (HABITAT).
3. The amount of overall disturbance to the riparian zone (DISTURBANCES).

Vegetation condition

The percentage cover of each vegetation layer (midstorey, understorey, grass and organic litter) and the number of vegetation layers present is used as an indicator of the overall presence of riparian vegetation. This was chosen as it provides a well-rounded representation of the vegetation within the site and its distribution among different strata, as well as resilience to major flood events. The percentage of weeds within each stratum was measured as they pose threats to the ecological integrity and productivity of many Australia vegetation communities. The abundance of large trees was chosen as an indicator of riparian condition as the presence of such trees represents mature growth and undisturbed conditions. This is a particularly important indicator considering the history of logging and land clearing within the upper catchments. Vines were included as an indicator of riparian condition as they can contribute to the vegetation strata. However, it was desirable that the vines were natives as exotics tend to out-compete the original vegetation.

Habitat

Riparian zones occupy only a small fraction of the landscape, but they frequently have high levels of biodiversity. Habitats within riparian zones are an important characteristic of condition as they represent the presence of food, water, shelter from predators and harsh physical conditions, and safe sites for nesting and roosting. Organic litter is an indicator of habitat as it provides shelter for smaller invertebrates, nesting materials for birds and is a source of course particulate organic matter. Standing dead trees, fallen trees and large trees provide hollows in which approximately 15% of all Australian terrestrial vertebrate fauna use as habitat at some point in time (Gibbons & Lindenmayer 2002). Fallen trees and logs provide in-stream habitat for spawning sites and areas for fish to hide from predators, and to avoid intense sunlight and high current velocities (Crook and

Robertson 1999). Logs also provide habitat for biofilm and invertebrates that maintain essential links in the food web for fish (Ryder 2004).

TABLE 2.7 STRARC riparian sub-indices and their indicators (each given a score of 1-5 where 1 is poor and 5 is very good).

Sub-indices and their indicators	**Assessment (each given a score of 1-5)**
VEGETATION CONDITION	
- Midstorey cover	Percentage cover of vegetation 1.5-5m tall
- Midstorey weeds	Percentage of weeds in midstorey cover
- Understorey cover	Percentage cover of vegetation <1.5m tall
- Understorey weeds	Percentage of weeds in understorey cover
- Grass cover	Percentage cover of grass
- Grass weeds	Percentage of weeds in grass cover
- Organic litter	Percentage cover of leaves and fallen branches <10cm in diameter
- Organic weeds	Percentage of weeds in organic litter
- Vines	Present native, present exotic, absent
- Vegetation layers	Number of layers
- Canopy cover	Percentage cover of trees >5m tall
- Large trees	Number of large trees with >30cm trunk diameter at 1.3m from base
HABITAT	
- Organic litter	Percentage cover of leaves and fallen branches <10cm in diameter
- Organic weeds	Percentage of weeds in organic cover
- Standing dead trees	Number of standing dead trees >30cm trunk diameter at 1.3m from base
- Fallen trees	Number of fallen trees (i.e as a result of flooding)
- Large trees	Number of large trees with >30cm trunk diameter at 1.3m from base
- Reeds	Present native, present exotic, absent.
- Logs	Abundance of logs >10cm diameter
- Proximity	Nearest patch of native vegetation
DISTURBANCES	
- Tree clearing	Present, absent
- Fencing	Present, absent
- Livestock	Evidence of livestock
- Proximity	Nearest patch of native vegetation

Disturbances

Vegetation clearing and the presence of livestock continue to accelerate the deterioration of riparian condition. The presence of fencing indicates that there has been an attempt made to exclude livestock from the site. The evidence of livestock within a site was used as an indicator to determine whether fencing attempts had failed or if none existed then measured the extent of livestock disturbance. The vegetation surrounds was chosen as an indicator of disturbance as it is seen as an anthropogenic impact on riparian zones. Furthermore, the proximity of the nearest patch of native vegetation was noted in an attempt to measure the extent of tree clearing within the area in question.

Field methods

All 23 freshwater sites in the Richmond catchment were sampled in August 2014 using the STRARC method developed for the Ecohealth project. Data for each of the four indices were collected at the reach (200m) scale. Complete details of the STRARC methods are available in Southwell, E (2010) Development and application of a sub-tropical rapid assessment of riparian condition. Unpublished Honours Thesis, University of New England, Armidale NSW.

Mangrove cover/Seagrass/Saltmarsh

The cover of mangroves, seagrass and saltmarsh for each of the 25 estuarine sites was calculated using spatial datasets provided by NC LLS. The site location was used as a centroid from which the cover of mangroves was determined for a 500-m reach of river bank upstream and downstream from the central point on both sides of the river. These data were used to calculate total proportion of mangrove cover for the study reach. Maximum and minimum width of mangrove cover within the study reach was also calculated using the spatial data.

2.5.6.3 *Assessment of Geomorphic Condition*

Geomorphic condition was assessed at two spatial scales. Subcatchment scores and grades were calaculated using the entire stream network for each subcatchment using the River Styles data layer supplied by NC LLS. The proportions of total subcatchment stream length in Good, Moderate and Poor Condition were calculated and weighted (3, 2, and 1 for Good, Moderate and Poor, respectively). These were summed to a total score, divided by 3 and converted to proportions. The standard Ecohealth grading structure was applied to each subcatchment proportions.

Site-level geomorphic condition was assessed using the geomorphic indicators derived in the STRARC method. There were two sub-indices and their indicators are given in Table 2.8. Both bank and bed condition were assessed at freshwater sites and bank condition was assessed at estuarine sites. Similar to riparian indices, all site-level geomorphic indices were assessed on a scale of 1-5 where 1 is poor and 5 is very good. All indicators were equally weighted when calculating sub-indices. In summary, the two sub-indices describe:

1. The overall condition of the river banks (BANK CONDITION).

2. The overall condition of the river bed (BED CONDITION).

TABLE 2.8 STRARC geomorphic sub-indices and their indicators (each given a score of 1-5 where 1 is poor and 5 is very good) used for site-level geomorphic condition assessments.

Sub-indices and their indicators	Assessment (each given a score of 1-5)
BANK CONDITION	
- Exposed tree roots	Evidence of exposed tree roots
- Bank slumping	Evidence of bank slumping
- Pugging/trampling	Evidence of pugging and trampling
- Active erosion	Evidence of active erosion
BED CONDITION	
- Active erosion	Evidence of active erosion
- Pugging/trampling	Evidence of pugging and trampling
- Smothering fines	Evidence of smothering by fine-grained sediments

2.6 Ecohealth report cards

The calculation and reporting of Ecohealth grades involves the synthesis all available indicators each with trigger values recorded up to 12 times during the program. Scores are calculated for individual sites, but also must fulfill the broader aims of wider-scale reporting at river, sub-catchment, catchment and regional scales. To produce an Ecohealth grade, the value for each index – Water Quality, Macroinvertebrates, Riparian Condition and Geomorphic Condition– must be transformed into standardized scores that account for differing physical conditions and scales of measurement among indices and prevailing climate conditions. The result is a scoring system from 0 to 1, where 0 represents the most ‘unhealthy’ condition and 1 indicates a ‘healthy’ waterway.

2.7 Indicators

2.7.1 Water Quality

A guideline trigger value is formally defined as the value that is commonly used to assess the ecological condition of a waterbody. An exceedance indicates that a variable is outside the expected range. Triggers are likely to be recalculated periodically as additional data from reference systems becomes available. A combination of ANZECC (2000, 2006) and NSW MER developed trigger values were used to explore water quality across sites and sampling occasions (Table 2.6). For water quality variables with only upper limits for trigger values, the number of times each indicator recorded a value between 1-1.5 times, and greater than 1.5 times each collection was used to examine changes in water quality. Exceedance of trigger values by less than 0.5 times or between 1-1.5 times, and greater than 1.5 times each collection was used for variables that have both upper and lower thresholds.

Calculating non-compliance is the proportion of time that the measured values of the indicator are outside the adopted trigger values (number of samples non-compliant with trigger value divided by the total number of samples (expressed as a value between 0 and 1, with 0 equal to all values being compliant and 1 equal to all values non-compliant)). The result of this process is a score between 0 and 1 for each individual water quality parameter measured as part of Ecohealth monitoring. These scores are simply averaged to determine an overall score between 0 and 1 for Water Quality.

2.7.2 Macroinvertebrates

Regional trigger values must be developed from literature and past studies for taxa richness (number of families), SIGNAL2 Score (pollution tolerance index), EPT taxa (number of mayflies, stoneflies and caddisflies) for each study. In the absence of these, the default threshold values reported in Chessman (2003) can be used for SIGNAL2. Alternatively, it should be determined if one or more sites sampled during the Ecohealth program in a specific catchment can be used as a 'reference condition' for Family richness and EPT grade. In addition to a trigger value, a Worst Expected Value (WEV) must be calculated for Family Richness, SIGNAL2 and EPT score. The WEV scores are derived from either the 10^{th} and/or the 90^{th} percentile of data for all relevant available data, and represent a site that is the 'unhealthiest'. Calculation of a standardized score involves the comparison of each macroinvertebrate attribute against corresponding guideline value and WEV scenario.

2.7.3 Riparian Condition

The assessment of each site affords each indicator a maximum score out of five, where a score of 1 represented the worst possible condition and a score of 5 represents pristine condition. The scores recorded in the field were combined to produce summary scores for each sub-index and an overall condition index. The indicators are then grouped into the 3 sub-indices and summary scores for each grouping are calculated through simple averaging to produce a condition score out of 5 for each sub-index (i.e. riparian condition, habitat and disturbance). These scores are then summed to a total score out of 15, and through simple division are standardised to a score ranging from 0 to 1.

2.7.4 Geomorphic Condition

The assessment of each site affords each indicator a maximum score out of five, where a score of 1 represented the worst possible condition and a score of 5 represents pristine condition. The scores recorded in the field were combined to produce summary scores for both sub-indices and an overall condition index. The indicators are then grouped into the 3 sub-indices and summary scores for each grouping are calculated through simple averaging to produce a condition score out of 5 for each sub-index (i.e. bank condition and bed condition). These scores are then summed to a total score out of 10, and through simple division are standardised to a score ranging from 0 to 1.

2.8 Spatial Scales

The above process provides the methods for calculating standardized scores for each indicator used in a particular Ecohealth monitoring program for an individual site. Total scores for a site are simply calculated as an average of the 0 to 1 range of scores across all indicators. The scores can then be 'pooled' at spatial scales relevant to reporting requirements such as site, river, sub-catchment, freshwater or estuarine, catchment and region.

2.9 Calculating grades

The condition scores were grouped in ranges and given a corresponding grade (see Table 2.9). This scoring and grading system is based on the traditional format of a school report, with primary ratings ranging from a high of 'A', through intermediate ratings of 'B', 'C' and 'D', to the lowest possible score of an F. Secondary grades of + and – are included to provide greater resolution within a grade, and to better help show improvements over time.

TABLE 2.9 Standardised scores from 0-1 and corresponding Ecohealth grades.

Score	Grade	Condition	
≥0.95/1	A	Excellent	Environmental values met (The indicators measured meet all of the benchmark values for almost all of the year)
0.85/1	B	Good	Most environmental values met (The indicators measured meet all of the benchmark values for most of the year)
0.70/1	C	Fair	Some of the environmental values met (The indicators measured meet some of the benchmark values for some of the year)
0.55/1	D	Poor	Few of the environmental values met (The indicators measured meet few of the benchmark values for some of the year)
≤0.45/1	F	Very Poor	Very few of the environmental values met (The indicators measured meet very few of the benchmark values for almost all of the year)

PART 3

3 RESULTS

3.1 Richmond catchment

The Overall Grade for the Richmond catchment was D+ (Table 3.1, Figure 3.1), ranging from an F in the Wilsons River and upper Richmond estuary to a C in the headwater streams of the catchment. The upper freshwater reaches of the Richmond main stem had better water quality, aquatic macroinvertebrates and geomorphic condition than the lower freshwater reaches, but no better riparian condition (Table 3.1, Figure 3.2). Scores were consistent among indicators within each system, highlighting the issues with water quality, biota and physical condition are affecting short and long-term condition of the streams.

TABLE 3.1 Catchment and subcatchment Ecohealth grades for the Richmond.

SYSTEM	Water Quality	Aquatic Macroinvertebrates	Riparian	Geomorphic	Overall
Richmond River	F	D	D-	D+	D-
Upper Richmond FW	D+	B-	D	B	C
Lower Richmond FW	D-	F	D+	D+	D
Upper Richmond Estuary	F		F	F	F
Lower Richmond Estuary	F		D-	D-	D-
Rocky Mouth Creek	F		F	C-	D
Wilsons River	F		D-	C-	F
Leycester Creek	F	D	D-	C+	D
Coopers Creek	D+	C-	C+	D+	C-
Terania Creek	C-	D	C-	C+	C-
Byron Creek	D-	D-	F	C-	D-
Wilson Creek	C-	C	B-	C-	C
Eden Creek	D-	F	D+	C-	D
Iron Pot Creek	D+	C	C	C	C
Shannon Brook	F	D+	C-	D+	D-
Bungawalbin Creek	F	F	D+	B-	D
Myrtle Creek	D+	D+	B-	C	C
Sandy Creek	F	D-	D	C	D
Emigrant Creek	D-	C	D-	D+	D
Maguires Creek	D+	C	F	D+	D+
North Creek	D-		D	C	D+

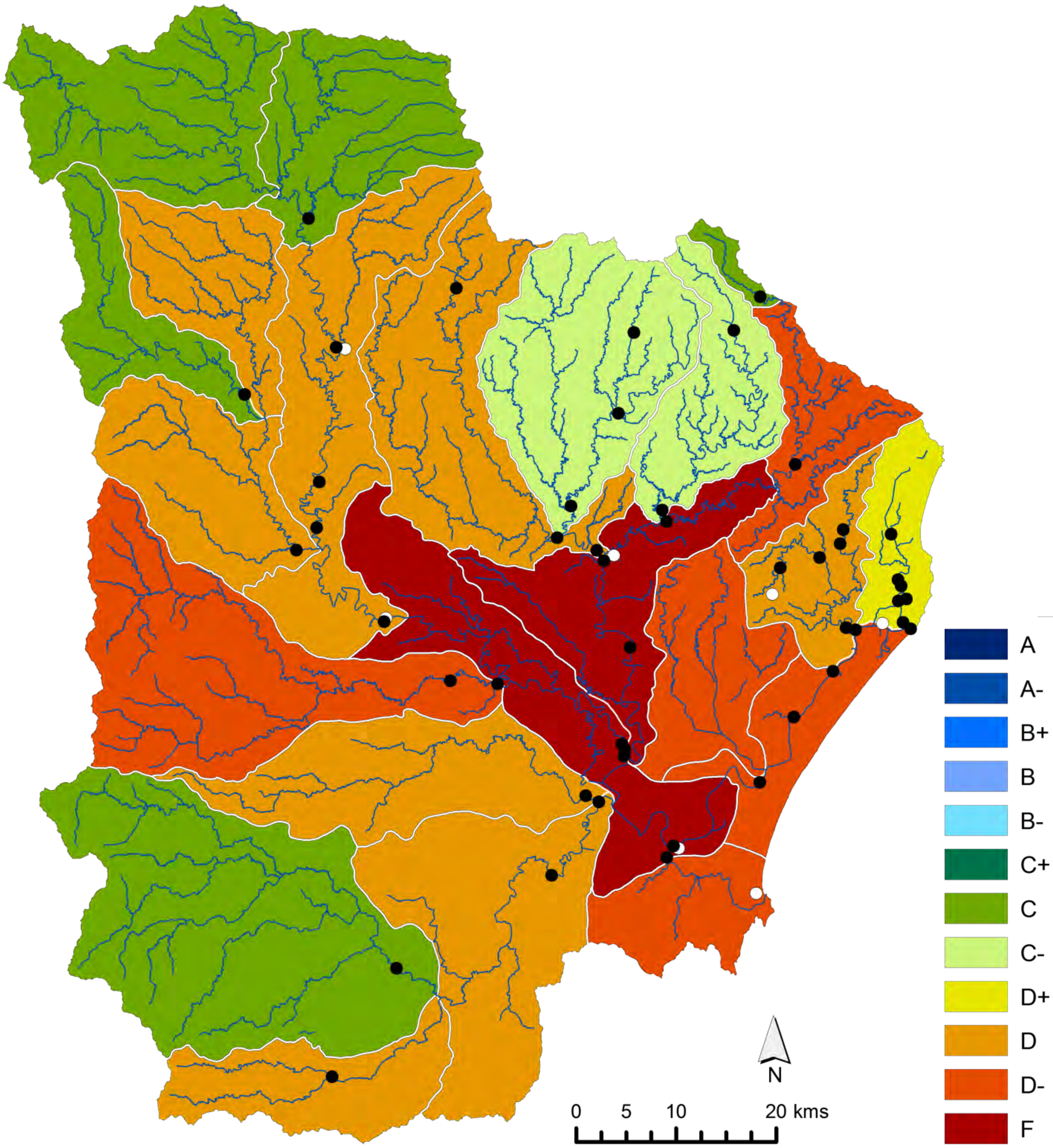
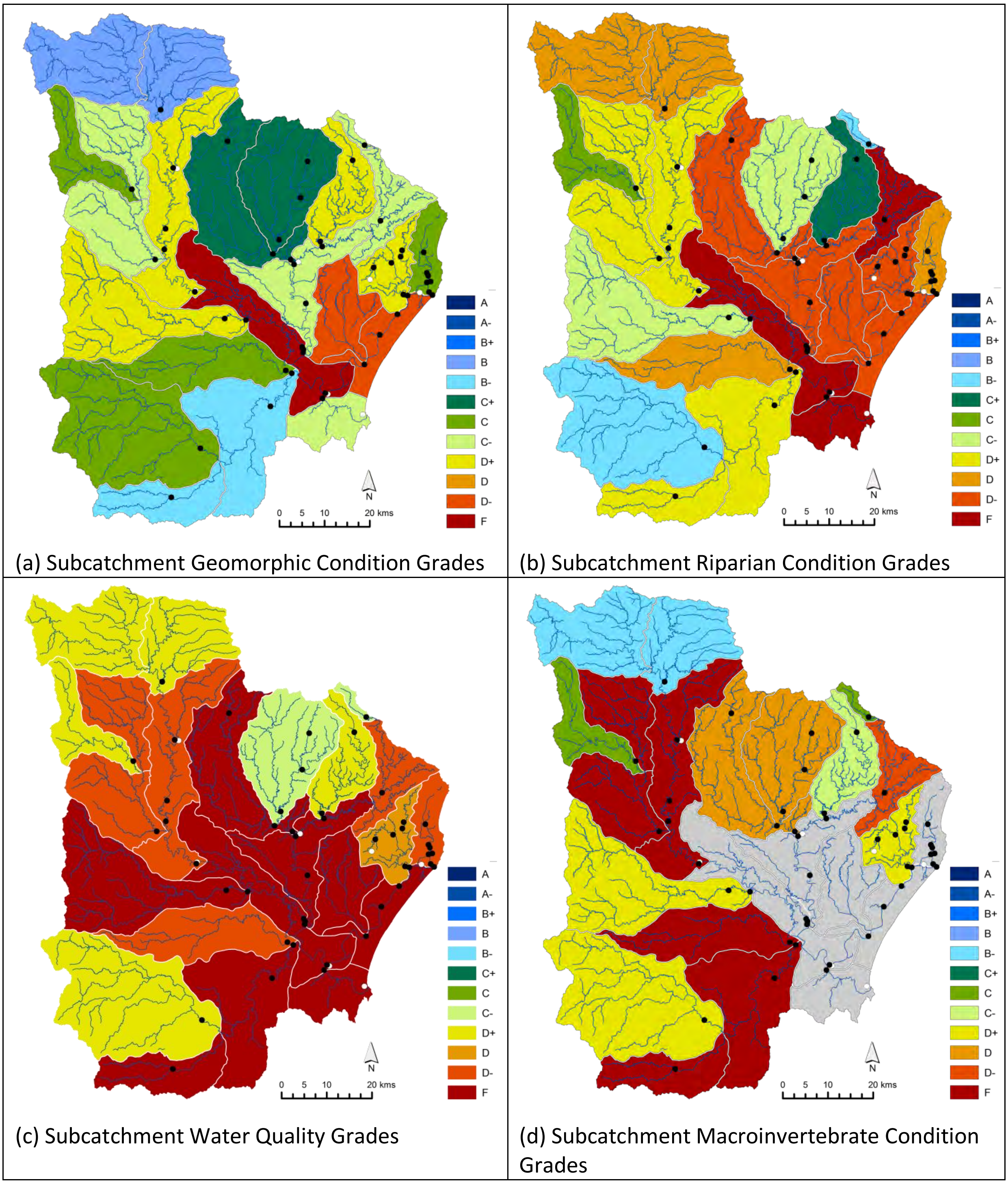


Figure 3.1 Overall Ecohealth grades for subcatchments in the Richmond.



(a) Subcatchment Geomorphic Condition Grades

(b) Subcatchment Riparian Condition Grades

(c) Subcatchment Water Quality Grades

(d) Subcatchment Macroinvertebrate Condition Grades

Figure 3.2 Subcatchment Ecohealth grades for (a) geomorphic condition, (b) riparian condition, (c) water quality and (d) aquatic macroinvertebrate communities. Aquatic macroinvertebrate communities were not assessed for estuarine reaches (greyed areas).

3.2 Richmond River main stem

The lowest grades were observed in the upper Richmond River estuary (Table 3.2). The areas of poorest geomorphic condition were where the riparian zone had been completely cleared for cropping (sugarcane) extending to the top of bank (Figure 3.3a). These areas were characterized by extensive and locally severe bank slumping. Alternatively, poor geomorphic condition was associated with cattle grazing and accessing the river in freshwater reaches (Figure 3.3b). In these reaches, the riparian zone comprised scattered mature River Oak trees and improved pasture with abundant exotic forbs. Trampling and pugging were common. The other main stressor to riparian structure was the dominance by exotic invasive weeds. In estuarine reaches, this was predominantly Cockspur Coraltree with Coastal Morning Glory Vine (Figure 3.3c). In freshwater reaches, Lantana, Privet, Wild Tobacco Bush and Cat's Claw Creeper were common (Figure 3.3d).

Water quality was very poor across the Richmond subcatchments. Turbidity consistently exceeded the estuarine trigger threshold, particularly in the upper estuary. Nutrient concentrations consistently were more than an order of magnitude higher than ANZECC trigger thresholds and exceedances were greatest in the upper estuary, leading to consistent exceedance of chlorophyll *a* concentrations indicating high algal biomass. Water quality was improved in freshwater reaches of the Richmond main stem, but remained poor, even in the upper catchment. Nutrient concentrations were consistently above ANZECC trigger thresholds for freshwater reaches and longitudinal increases in mean concentrations of total nitrogen and phosphorus correlated with increases in total suspended solids, suggesting significant diffuse sediment and nutrient inputs to the upper catchment are transported to the upper estuary.

Freshwater aquatic macroinvertebrate community scores were good at the most upstream site of the Richmond River at Wiangaree, characterized by gravel bed substrate, extensive macrophyte beds and some emergent littoral vegetation (Figure 3.3e). Site-scale processes (habitat, food resources) are highly significant for macroinvertebrate diversity and poor aquatic macroinvertebrate health was observed in the freshwater reaches below Kyogle where sites were characterized by little riparian shade or emergent littoral vegetation, and shallow runs with fine bed substrates that smothered available habitat (Figure 3.3f).

TABLE 3.2 Site-level Ecohealth grades for geomorphic condition, riparian condition, water quality, aquatic macroinvertebrate communities and overall site grades for the Richmond River main stem.

Sites	Geomorphic Condition	Riparian Condition	Water Quality	Aquatic Macroinvertebrates	Overall Site Grade
RR1	C+	D-	C-		C
RR2	C+	D	D		D+
RR3	C+	D-	F		D
RR4	C+	F	F		D
RR5	C	F	F		D-
RR6	C+	F	F		F
RR7	D+	F	F		F
RR8	F	F	F		F
RR9	C-	F	F		F
RR10	B-	C-	D-	D-	D+
RR11	C	C+	D	D+	C-
RR12	D	F	D-	F	D-
RR13	C-	F	D	F	D-
RR14	D+	D	D+	B-	C-
RMC1	C+	F	F		D-

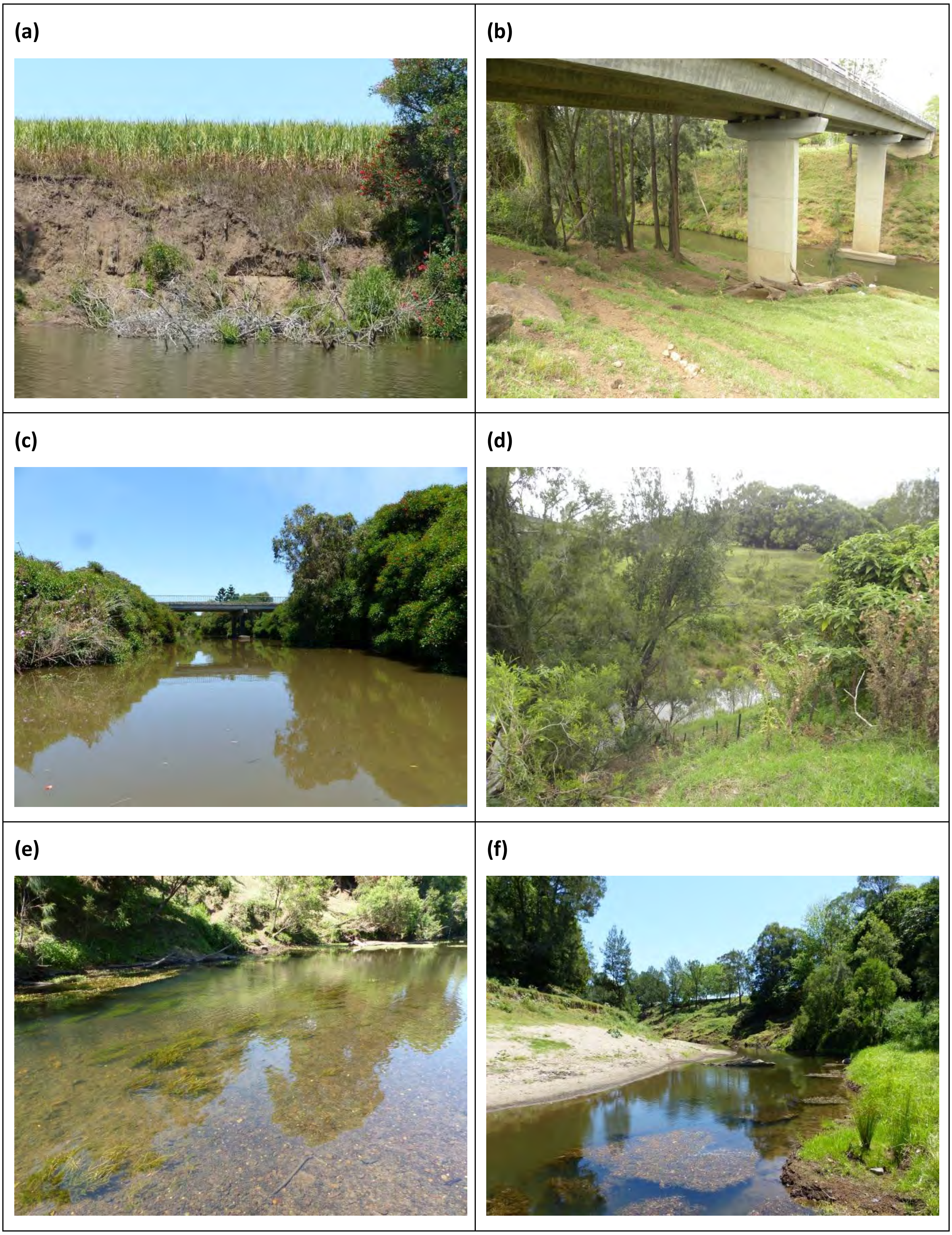


Figure 3.3 Sites on the Richmond Main Stem showing (a) cleared riparian zones adjacent to sugarcane crops (RR8), (b) poor geomorphic condition of banks and streambed associated with stock access (RR12), (c) dominant invasive weeds in estuarine reaches (RMC1), (d) invasive weeds in freshwater reaches (RR13), (e) good habitat for aquatic macroinvertebrate communities (RR14), and (f) poor habitat for aquatic macroinvertebrate communities (RR13).

3.2.1 Landscape Context

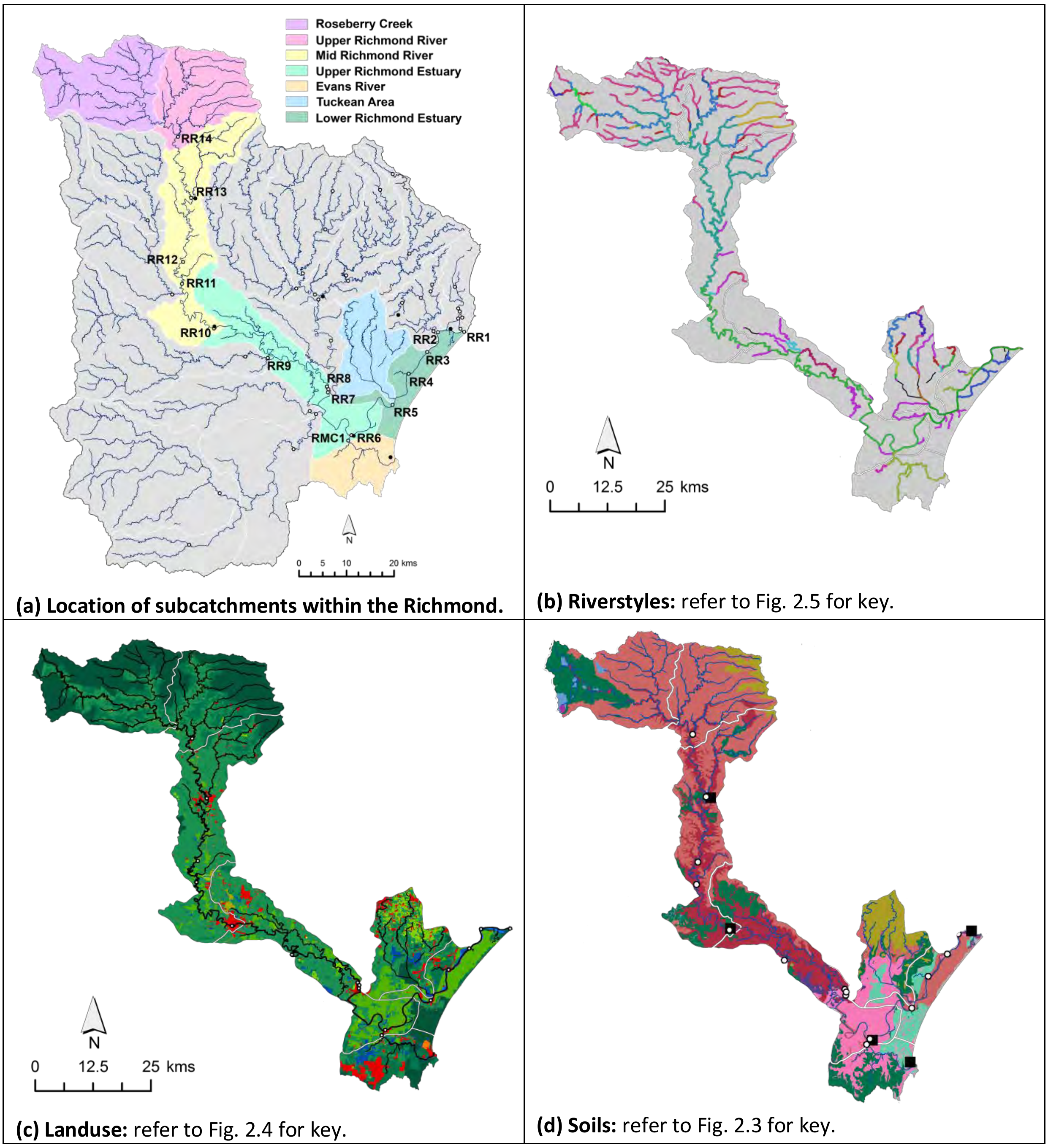
The upper freshwater reaches of the Richmond River main stem comprise the subcatchments of Roseberry Creek and the Upper Richmond River including Gradys Creek (Figure 3.4). The landscape unit of these upper freshwater reaches is escarpment and ranges (Alluvium 2012). Thus, 76% of the subcatchment geology comprises Tertiary basalts, resulting in 72% of the subcatchment's soils characterized as ferrosols, and 71% of the total stream length is in confined valley settings (with 44% of the total stream length as headwaters, Table 3.3). Landuse is predominantly national parks, conservation areas and state forests (51% of area), with 26% of the subcatchment area under grazing, mostly of native pastures (Table 3.3).

The lower freshwater reaches of the Richmond River main stem comprise midlands (hills of low elevation) and coastal floodplains (Figure 3.4). The midlands are characterized by gently undulating to moderately rolling low hills and narrow, non-tidal floodplains (Alluvium 2012). Thus, 51% of the subcatchment geology is basalt (the midlands) and 35% of the subcatchment area comprises Quaternary alluvium (on the coastal floodplains, Table 3.4). Soils are predominantly clay-rich vertosols and ferrosols (35% and 30% of area, respectively). Only 20% of the total stream length is in confined valley settings (12% headwaters). The dominant River Style is planform controlled, low sinuosity, gravel-bed streams (49% of total stream length). Conservation areas comprise only 4% of subcatchment area, with 76% of area under grazing, the most under native pastures (Table 3.4).

The upper Richmond estuary extends from downstream of Casino to Woodburn (Figure 3.4). The landscape is predominantly coastal floodplain. Quaternary alluvium comprises the majority (58%) of the subcatchment area, followed by coastal dunes (16%). Vertesols predominate (40%), but poorly drained hydrosols increase downstream (30%). Laterally unconfined continuous channels comprise 90% of the total stream length, with 52% of channels the meandering, fine-grained River Style (Table 3.5). Grazing is the dominant landuse (62%), with most of this under native pastures, but cropping is more common on the coastal floodplain areas (19%).

The lower Richmond estuary extends downstream from Woodburn to the estuary mouth at Ballina (Figure 3.4) and comprises coastal floodplain and coastal sandplains (Alluvium 2012). Hence, Quaternary coastal dunes (43%) dominate the subcatchment geology (Table 3.6). Hydrosols are the most common soil type (32%), followed by ferrosols (30%). Laterally unconfined valleys comprise 54% of the subcatchment area, and channelized fill (24%) is the most common River Style. Grazing of native pastures (53%), regenerating or residual native vegetation (15%) and National Parks (12%) are the dominant landuse (Table 3.6).

The landscape of the Evans River (Rocky Mouth Creek) subcatchment comprises coastal floodplain and coastal sandplain (Alluvium 2012). Thus, Quaternary alluvium and Quaternary coastal dunes are the dominant geology, with hydrosols (37%) and acidic kurosols (31%) dominating the soilscape (Table 3.7). Laterally unconfined tidal streams are the dominant River Style (89%). Regenerating or residual native vegetation (34%) and urban development (20%) are the most common landuse (Figure 3.4).



(a) Location of subcatchments within the Richmond.

(b) Riverstyles: refer to Fig. 2.5 for key.

(c) Landuse: refer to Fig. 2.4 for key.

(d) Soils: refer to Fig. 2.3 for key.

Figure 3.4 Subcatchments of the Richmond River main stem including Rocky Mouth Creek, showing (a) locations of Ecohealth sites, (b) River Styles, (c) landuse, and (d) soils. Data layers from NC LLS or OEH (Soils).

TABLE 3.3 Subcatchment description of the upper freshwater reaches of the Richmond River. Data from NC LLS and OEH.	
Area	716.97 km^2
Geology	76% Basalt; 16% Shales, siltstones, claystones and coal; 4% Quaternary alluvium; 3% Sandstone; 1% Granite; 1% Rhyolite;
Soils	72% Ferrosols; 17% Kurosols; 6% Vertosols; 4% Dermosols; <1% Rudosols and Tenosols
River Styles	44% CVS – Headwater; 21% PCVS - Planform controlled, low sinuosity, gravel; 17% CVS - Floodplain pockets, sand; 6% CVS – Gorge; 3% CVS - Floodplain pockets, fine grained; 3% PCVS - Planform controlled, meandering, sand; 2% PCVS - Planform controlled, low sinuosity, fine grained; 2% PCVS - Bedrock controlled, fine grained; 1% CVS - Floodplain pockets, gravel; 1% PCVS - Planform controlled, meandering, fine grained; <1% LUV CC - Meandering, fine grained; <1% LUV CC - Low sinuosity, fine grained
Landuse	41% National Park and Private conservation agreement; 23% grazing of native pasture; 20% rehabilitated and residual native cover; 10% State forest; 2% grazing of irrigated pasture; 1% plantation forest; 1% grazing of improved pasture; 1% urban and transport network
Major point source discharge	Nil
Tree Cover	51%

TABLE 3.4 Subcatchment description of the lower freshwater reaches of the Richmond River. Data from NC LLS and OEH.	
Area	456.22 km^2
Geology	51% Basalt; 35% Quaternary alluvium; 14% Sandstone
Soils	35% Vertosols; 30% Ferrosols; 18% Dermosols; 8% Kandosols; 7% Kurosols
Riverstyles	49% PCVS - Planform controlled, low sinuosity, gravel; 19% LUV CC - Meandering, fine grained; 12% CVS – Headwater; 7% CVS - Floodplain pockets, sand; 7% LUV CC - Channelised fill; 3% PCVS - Planform controlled, low sinuosity, fine grained; 1% CVS - Floodplain pockets, fine grained; 1% LUV CC - Low sinuosity, fine grained; 1% Water storage
Landuse	61% Grazing of native pastures; 12% Grazing of improved pasture; 8% Residual and rehabilitated native cover; 6% Cropping; 5% Urban and transport network; 4% National Park; 3% Grazing of irrigated pasture; 1% Horticulture; 1% State Forest
Major point source discharge	Kyogle Sewage Treatment System; Casino Wastewater Treatment Plant
Tree Cover	5%

TABLE 3.5 Subcatchment description of the upper Richmond estuary. Data from NC LLS and OEH.	
Area	390.02 km^2
Geology	58% Quaternary alluvium; 16% Coastal dunes; 13% Sandstone; 10 % Basalt; 2% Shales, siltstones, claystones and coal; 1% water
Soils	40% Vertosols; 30% Hydrosols; 12% Kurosols; 9% Dermosols; 4% Kandosols
Riverstyles	52% LUV CC - Meandering, fine grained; 29% LUV CC - Channelised fill; 10% SMG - Cut and fill; 7% LUV CC - Low sinuosity, fine grained; 1% LUV CC - Tidal
Landuse	53% Grazing on native pasture including degraded pasture; 19% Cropping; 6% urban and transport; 5% Grazing on improved pasture; 4% Grazing on irrigated pasture; 3% Residual and rehabilitated native cover; 3% farm dams and water ways; 2% Wetland; 1% horticulture; 1% farm buildings and intense livestock industries; 1% National park and conservation agreements; 1% plantation forest
Major point source discharge	Coraki Sewage Treatment Plant
Tree Cover	2%

TABLE 3.6 Subcatchment description of the lower Richmond estuary. Data from NC LLS and OEH.	
Area	390.96 km^2
Geology	43% Coastal dunes; 30% Basalt; 12% Quaternary alluvium; 7% Sandstone; 4% water; 3% Siltstone and conglomerate; 3% Sand plain
Soils	32% Hydrosols; 30% Ferrosols; 16% Podosols; 12% Kurosols; 4% Water
Riverstyles	24% LUV CC - Channelised fill; 16% PCVS - Planform controlled, tidal; 13% CVS - Floodplain pockets, gravel; 12% LUV CC - Meandering, fine grained; 9% LUV CC - Channelised peat swamp; 5% CVS - Floodplain pockets, fine grained; 5% LUV CC – Tidal; 4% PCVS - Planform controlled, low sinuosity, gravel; 4% PCVS - Planform controlled, meandering, fine grained; 3% CVS – Headwater; 3% LUV CC - Anabranching, swamp belt; 1% LUV CC - Low sinuosity, fine grained; 1% SMG - Valley fill, fine grained
Landuse	34% Grazing of natural pastures; 15% Regenerated or residual native cover; 12% National Park; 9% Cropping; 9% Horticulture; 9% Urban; 5% Farm dams and waterways; 4% Wetland; 1% Camphor Laurel Forest; 1% Grazing of improved pastures; 1% beach, foredunes and estuarine sand bars
Major point source discharge	Wardell Sewage Treatment Works; Broadwater Sugar Mill; Ballina Sewage Treatment Plant
Tree cover	13%

TABLE 3.7 Subcatchment description of the Evans River (Rocky Mouth Creek). Data from NC LLS and OEH.	
Area	156.74 km^2
Geology	32% Quaternary alluvium; 31% Sandstone; 25% Coastal dunes; 13% Shales, siltstones, claystones and coal
Soils	37% Hydrosols; 31% Kurosols; 18% Podosols; 8% Ferrosols; 4% Not Accessed; 1% Water
Riverstyles	89% LUV CC – Tidal; 11% Water storage
Landuse	34% residual and rehabilitated native cover; 20% urban; 20% National Park; 14% Grazing natural pastures; 7% Wetland; 2% Drainage including farm dams and water ways; 1% Cropping; 1% Grazing improved pastures; 1% State Forest
Major point source discharge	Nil
Tree cover	21%

3.2.2 Geomorphic Condition

Assessments of stream condition over the total stream lengths of each subcatchment and the Richmond catchment as a whole show that upper freshwater reaches are in predominantly good (47%) or moderate (52%) condition (Table 3.7). Upper estuarine reaches are mostly in poor condition (70%, Table 3.7). Stream channels in the Evans River (Rocky Mouth Creek) subcatchment are predominantly in moderate condition (89%). Overall, the Richmond main stem achieved a grade of D+ for subcatchment geomorphic condition, with freshwater reaches scoring a C and estuarine reaches scoring a D- (Table 3.7).

In concurrence with the subcatchment-scale assessment of stream condition, the site-scale geomorphic assessment found the lower estuary to be in better condition than the upper estuary (Table 3.8). At the site-scale, only bank condition could be assessed for estuarine reaches. Both banks at RR1 are extensively modified by rock break walls. At RR2 and RR3, the left bank is extensively reinforced by rock revetment. At RR2, the right bank is characterized by the intertidal mangrove flats of the Richmond River Nature Reserve. At RR3 immediately downstream of Pimlico Island, localised areas of active bank erosion occur on the right bank. Both banks at RR4 are extensively reinforced with rock revetment. Little bank instability was observed on either bank at RR5, or RR6; but active erosion is occurring in small, localized areas along both banks at RR7. Bank erosion is much more extensive upstream of Coraki (RR8): active slumping extends along the left bank where cane is grown to the top of the bank and the riparian zone comprises scattered trees and shrubs (Figure 3.3a). The right bank is currently grazed with localized areas of heavy trampling to the water's edge. Both banks at RR9 are currently grazed and have extensive areas of old slumping that are vegetated with grasses and forbs. There is some undercutting along the left bank below the high tide line, and localized but severe mass movement on the right bank associated with trees falling into the river (Figure 3.5a). Both banks at RMC1 appear stable with only minor active erosion in the intertidal zone (Table 3.8).

RR10 at Casino is the most downstream freshwater reach. Although the River Style of this reach is reported as meandering, fine-grained, there is extensive bedrock outcropping at the site. Both banks are heavily vegetated and stable. The channel bed alternates between bedrock and mobile sand patches. The left bank at RR11 is actively eroding, with extensive areas of undercutting and exposed tree roots. In the riffle at RR11, the cobble-bed contains significant fine sediments smothering habitat (Figure 3.5b). Both banks and the pool substrate are dominated by fine sediments. Both banks at RR12 are currently grazed and the site is characterized by deeply incised, fine-grained banks that have extensive areas of slumping associated with cattle trampling (Figure 3.3b, Table 3.8). There is extensive smothering of the streambed by fine-grained sediments. The right bank at RR13 (Kyogle) is actively grazed while the left bank is fenced. Significant bank slumping has occurred along the upstream end of the left bank; these areas are currently grassed but minor active erosion is visible. Bank stablisation works are evident along the left bank at the downstream end of the site. A large, sandy point bar comprises the right bank, but active erosion occurs extensively along the mid bank at the zone between point bar and cohesive bank (Figure 3.3f). The bed is predominatly fine-grained with substantial amounts of large woody debris as habitat. Both banks are actively grazed at RR14 (Wiangaree) and there is extensive, active bank erosion due to trampling (Table 3.8). Pugging is extensive along the water's edge of both banks and the gravel-bed channel contains significant amounts of highly active fine sediment (Table 2.4). The channel contains significant large woody debris but this appears to be due to flood transport, rather than *in situ* riparian erosion.

Both the subcatchment-scale and site-scale assessments found the upper estuary to be in the poorest geomorphic condition. This is partially due to bank instability caused by intertidal wetting and drying of fine-grained bank sediments at the tidal limit, but also strongly related to the more localized factors of landuse where the riparian zone has been largely cleared to crop to the top of vertical, fine-grained riverbanks. Likewise where sites in the upper freshwater reaches were in worse geomorphic condition than adjacent sites, this was also predominantly due to site-scale landuse, particularly cattle grazing of banks.

TABLE 3.7 Subcatchment-scale geomorphic condition calculated over the subcatchments' total stream length. Data from NC LLS.

Subcatchment	% Good Condition	% Moderate Condition	% Poor Condition	Geomorphic Grade
Richmond Main Stem	0	43	42	D+
Richmond Freshwater Reaches	0	52	21	C
Upper Freshwater	47	52	1	B
Lower Freshwater	8	52	40	D+
Richmond Estuary	1	35	64	D-
Upper Estuary	0	30	70	F
Lower Estuary	2	40	58	D-
Evans River (Rocky Mouth Creek)	0	89	11	C-

TABLE 3.8 Site-scale stream bed and stream bank geomorphic condition and overall site-scale geomorphic grade for the Richmond main stem.			
Site	**Bank Condition Grade**	**Bed Condition Grade**	**Overall Geomorphic Grade**
RR1	C+	*Estuary site – bed condition not assessed*	C+
RR2	C+	*Estuary site – bed condition not assessed*	C+
RR3	C+	*Estuary site – bed condition not assessed*	C+
RR4	C+	*Estuary site – bed condition not assessed*	C+
RR5	C	*Estuary site – bed condition not assessed*	C
RR6	C+	*Estuary site – bed condition not assessed*	C+
RR7	D+	*Estuary site – bed condition not assessed*	D+
RR8	F	*Estuary site – bed condition not assessed*	F
RR9	D+	*Estuary site – bed condition not assessed*	D+
RR10	B-	C+	B-
RR11	C	C+	C
RR12	D+	D	D
RR13	D+	C-	C-
RR14	D	D+	D+
RMC1	C	*Estuary site – bed condition not assessed*	C

(a) **(b)**

Figure 3.5 Sites on the Richmond Main Stem showing (a) localized mass failure of river banks (RR9), (b) fine-grained sediments smothering a cobble riffle (RR11).

3.2.3 Riparian Condition

Along the Richmond main stem, riparian condition was poorest in the upper estuary (Table 3.9). This was predominantly due to extensive woody weed invasions (VEGETATION, Table 3.10). From Broadwater (RR5) to downstream of Coraki (RR7), and Rocky Mouth Creek (RMC1), the dominant riparian community composition is Cockspur Coraltree (*Erythrina crista-galli*) shrubs heavily encroached by Coastal Morning Glory vine (Table 3.10). The instream vegetation assessment for estuarine reaches consisted of GIS-based assessments of seagrass (data from NC LLS). Although seagrass was observed in North Creek, it is in the shallow subtidal and intertidal zones, and boat-based sampling meant site locations were restricted to the deeper channels. The lack of large trees in the lower estuarine reaches was reflected in the absence of standing or fallen dead trees or logs in estuarine riparian zones (HABITAT, Table 3.9).

DISTURBANCE was indicated by site-scale landuse (fencing, grazing, clearing, etc), as well as a desktop assessment of the connectivity of riparian vegetation at the site to upstream and downstream riparian vegetation, and hillslope or floodplain vegetation. With the exception of RR11, all sites on the Richmond main stem experienced high levels of disturbance to the riparian zone (Table 3.9): both at the site-scale (e.g. grazing or cropping regime), and at the landscape scale (longitudinal and lateral connectivity to remnant vegetation). In the lower estuary, the clearing and loss of mangroves adjacent to residential areas was the predominant disturbance to riparian communities. In the upper estuary, clearing of the riparian zone for cropping (sugar cane), was the predominant disturbance.

While the riparian vegetation structure in freshwater reaches was generally better than in estuarine reaches (Table 3.10), this was mostly due to the absence of an exotic woody shrub layer through extensive grazing (VEGETATION, Table 3.9). Also, HABITAT scored better in freshwater reaches due to significant volumes of standing and fallen dead trees and logs. However, because this was generally associated with widespread clearing for grazing, riparian zones in freshwater reaches generally scored poorer for DISTURBANCE (Table 3.9).

It is worth noting that between Woodburn and Coraki (RR6 and RR7), riparian communities included abundant, very tall, mature eucalypt trees in good health and these trees were observed to be actively used by koalas and many birds including nesting sea eagles (Figure 3.6a). Although the dominant vegetation was the dense Cockspur Coraltree shrublayer and the Coastal Morning Glory vine layer, mature Weeping Bottlebrush (*Callistamon* sp.) were scattered through the invasive shrubs (Figure 3.6b). Improvement in the riparian structure of this reach would require weed control but not necessarily native revegetation. In contrast, the riparian zones of the upper freshwater reaches of the Richmond main stem have been extensively cleared of mature trees and are currently actively grazed. Improving the native riparian vegetation communities would necessitate restriction of stock access, weed control and likely revegetation given the lack of existing native vegetation.

TABLE 3.9 Site-scale riparian conditions for estuarine and freshwater reaches of the Richmond main stem.				
Site	**Vegetation**	**Habitat**	**Disturbance**	**Overall Riparian Grade**
RR1	F	D-	D+	D-
RR2	D+	F	D+	D
RR3	D	F	D	D-
RR4	D-	F	D	F
RR5	F	F	D	F
RR6	F	F	D	F
RR7	F	F	D	F
RR8	F	F	F	F
RR9	D+	F	F	F
RR10	C+	D	D+	C-
RR11	C+	B+	C	C+
RR12	D-	C+	F	F
RR13	D	D-	F	F
RR14	C-	B+	F	D
RMC1	D-	C-	F	F

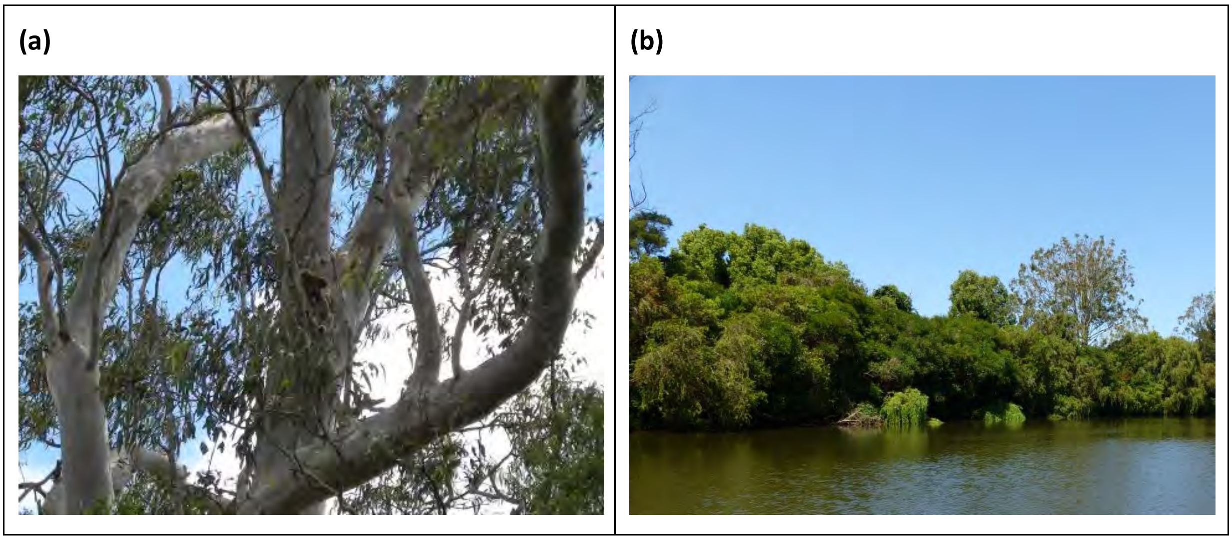


Figure 3.6 Sites on the Richmond Main Stem showing (a) mature eucalypt trees in the riparian zone provide habitat for koalas (between RR6 and RR7), (b) mature Weeping Bottlebrush are scattered through a riparian zone dominated by woody invasive weeds (between RR6 and RR7).

TABLE 3.10 Site-scale riparian vegetation and key stressors of the Richmond River main stem.

Site	Vegetation Community Description	Key Stressors
RR1	Rock break wall on left bank, coastal dune grassland on right bank.	Urbanisation on left bank.
RR2	Residential area with grass to water's edge on left bank and mangrove forest on right bank.	Clearing of riparian zone on left bank.
RR3	Cropping or grass to water's edge on left bank or narrow mangrove fringe with cropping behind on right bank.	Clearing of riparian zone.
RR4	Residential area on right bank with significant riparian clearing. Left bank is scattered eucalypt trees with abundant clumps of mangroves fringing the water's edge.	Clearing of riparian zone; some exotic woody shrubs scattered along the right bank.
RR5	Dense mangrove forest on right bank and scattered eucalypt trees with dense cockspur coraltrees (*Erythrina crista-galli*), *Cecropia* and coastal morning glory vine.	Dominance by exotic shrubs, lack of native regeneration; clearing of riparian zone on left bank.
RR6	Scattered tall eucalypt trees with dense cockspur coraltree shrub layer.	Exclusion of native regeneration by cockspur coraltrees
RR7	Scattered tall eucalypt trees with dense shrub layer of cockspur coraltrees and abundant coastal morning glory vine.	Smothering by coastal morning glory vine and exclusion of native regeneration by cockspur coraltrees.
RR8	Sugar cane with scattered cockspur coraltrees, *Callistamon* and river oaks on left bank and grazed grassland on right bank.	Extensive bank slumping and clearing on left bank and grazing pressure on right bank.
RR9	River oak with grassey understorey	Physical stressors include grazing. Several species of invasive woody shrubs common and exotic forbs present.
RR10	Abundant and regenerating river oak with scattered *Callistamon* shrub layer. Abundant small river oaks, bottle brush and sedges instream.	Extensive exotic weed invastion including vines and reeds. Significant dumping of rubbish persistent at site.
RR11	Tall, closed river oak forest with weeping bottlebrush shrub layer and lomandra understorey.	Exotic grasses, burrs and scattered wild tobacco bushes present. Significant and repeated dumping of rubbish at site.
RR12	Grassy open river oak and eucalypt forest.	Physical stressors include active bank erosion (loss of substrate) and grazing pressure.
RR13	River oak grassland with scattered *Callistamon* shrubs	Physical stressors include grazing pressure, trampling and loss of substrate (erosion). Castor oil plant and exotic grasses present.
RR14	River oak and tea tree shrubland with scattered river oak and eucalypt trees	Physical stressors include grazing pressure, trampling and loss of substrate (erosion). Invasive weeds include privet, lantana, wild tobacco bush, and cat's claw creeper.
RMC1	Dense cockspur coraltree shrubland with scattered eucalypts and silky oak trees	Invasive cockspur coraltree dominates, but coastal morning glory vine present.

3.2.4 Water Quality

The Richmond estuary generally had very poor water quality (Tables 3.11, 3.12, 3.13 and 3.14). Estuarine water quality was fair in the lower estuary (RR1 and RR2) due to marine flushing, and very poor from Pimlico Island (RR3) upstream to the tidal limit (RR8) including Rocky Mouth Creek (RMC1). These patterns were driven by physical properties such as the saturation of dissolved oxygen consistently well below the lower trigger threshold of 80% throughout the study period (Table 3.13). Low DO% was observed in the estuary at all depths. pH was consistently more alkaline than the upper trigger threshold of 8 for estuaries (Table 2.6), however, sampling at high tides consistently samples the more alkaline marine water entering the estuary. Turbidity was highly variable (Table 3.11), but consistently exceeded the estuarine trigger threshold of 10 NTU, particularly in the upper estuary from Woodburn to upstream of Coraki (Table 3.13). While turbidity decreased across the Richmond catchment during the below-average discharge in the second half of 2014, concentrations in the upper estuary remained above trigger thresholds despite low flows.

Nutrient concentrations were also consistently higher than ANZECC trigger thresholds by more than an order of magnitude (Table 3.11) and concentrations of bioavailable nitrogen and phosphorus in the estuary exceeded trigger thresholds on almost all sampling events (Table 3.14). Concentrations of total nitrogen and phosphorus were improved in the lower estuary with increased marine flushing, but exceeded trigger thresholds on almost all sampling occasions in the upper estuary (Table 3.14). Exceedances of total nutrients were likewise by substantial margins (Table 3.12). Chlorophyll *a* (chl-*a*) concentrations (algal biomass) in the mid estuary were consistently higher than the MER trigger threshold of 3.3 µg/L for estuaries (Table 3.12). However, chl-*a* concentrations in the upper estuary were consistently three times the MER trigger threshold (Table 3.12).

Water quality was better in freshwater reaches of the Richmond main stem, but remained poor. Overall water quality was very poor even high up in the catchment (e.g. RR14) and the consistency of data among sites and sampling times suggests significant non-point source pollution to the main stem (total suspended sediments and nutrients). DO% saturation fell below the lower trigger threshold of 80% during the drier second half of the study period as stream velocity decreased. A persistent algal bloom at RR10 (Casino) supersaturated DO during late spring 2014 (Table 3.13). pH was consistently above the upper ANZECC trigger threshold and this is likely due to the mafic geology (e.g. basalt) and soils contributing significant cations such as magnesium and calcium. Low-pH events in the Richmond catchment are associated with floods and as such, are underestimated by low-flow analyses reported in this study. Turbidity of freshwater reaches declined with the below-average discharge in the second half of 2014.

Nutrient concentrations were consistently above ANZECC trigger thresholds for freshwater reaches (Tables 3. 12, Table 3.14). Longitudinal increases in mean concentrations of total nitrogen and phosphorus correlated with increases in total suspended solids (Table 3.12), suggesting catchment inputs in the upper catchment are transported throughout the freshwater reaches to the upper estuary. Improvement of water quality in the Richmond catchment therefore requires significant investment in reducing diffuse sources of fine sediments and their associated nutrients (Table 3.15). Reducing stock access to the steep and fine-grained banks in the upper reaches would be an important step, as would vegetating those riparian zones to increase their buffering capacity for terrestrially derived nutrients.

TABLE 3.11 Ranges (and means) for temperature, pH, conductivity, salinity, DO% and turbidity.

Site	Times Sampled	Temperature (°C)	pH	Conductivity (µS/cm)	Salinity (PPT)	DO (%)	Turbidity (NTU)
RR1	12	19.10 – 23.22 (20.98)	7.63 – 9.19 (8.23)	54.4 – 56.1 (55.2)	35.72 – 36.98 (36.36)	77.4 – 119.7 (100.6)	0.3 – 7.3 (3.0)
RR2	12	17.30 – 23.95 (21.06)	7.46 – 9.95 (8.24)	12.84 – 55.60 (46.65)	7.40 – 36.57 (30.15)	82.0 – 107.0 (96.45)	0.8 – 17.6 (4.7)
RR3	12	16.37 – 24.82 (21.68)	7.32 – 9.10 (8.03)	7.41 – 52.6 (41.23)	4.05 – 34.56 (26.43)	81.3 – 104.1 (91.0)	2.6 – 139.0 (16.0)
RR4	12	15.48 – 12.60 (22.19)	7.13 – 8.91 (7.78)	1.59 – 40.1 (28.15)	0.81 – 25.67 (17.51)	67.5 – 100.1 (87.54)	4.0 – 146.0 (17.3)
RR5	12	15.53 – 27.05 (22.46)	6.85 – 8.70 (7.68)	0.553 – 33.8 (20.4)	0.26 – 21.01 (12.39)	57.6 – 93.0 (80.43)	4.3 – 54.4 (17.8)
RR6	12	14.47 – 26.82 (22.19)	7.17 – 9.18 (8.11)	0.15 – 10.6 (3.13)	0.07 – 5.98 (1.71)	60.1 – 106.7 (90.4)	10.1 – 41.6 (22.1)
RR7	12	14.57 – 27.43 (22.54)	7.37 – 9.39 (8.28)	0.136 – 0.518 (0.325)	0.07 – 0.25 (0.16)	68.0 – 99.4 (88.0)	9.6 – 36.9 (17.8)
RR8	12	14.37 – 27.74 (22.54)	7.51 – 9.40 (8.31)	0.163 – 0.540 (0.375)	0.08 – 0.26 (0.181)	65.6 - 103.9 (88.34)	8.0 – 34.5 (16.7)
RR9	6	13.52 – 28.35 (23.13)	7.5 – 8.7 (7.9)	0.425 – 0.563 (0.506)	0.21 – 0.28 (0.25)	60.3 – 93.1 (76.93)	11.0 – 39.4 (19.2)
RR10	6	14.66 – 35.19 (24.86)	7.76 – 9.23 (8.46)	0.348 – 0.444 (0.394)	0.17 – 0.21 (0.19)	84.3 – 204.6 (113.9)	84.3 – 204.6 (113.9)
RR11	6	11.60 – 29.63 (21.88)	7.37 – 8.91 (8.22)	0.274 – 0.384 (0.331)	0.13 – 0.18 (0.16)	83.3 – 99.0 (90.1)	5.8 – 177.0 (39.3)
RR12	6	17.17 – 30.37 (23.49)	7.34 – 8.89 (8.16)	0.216 – 0.353 (0.298)	0.09 – 0.17 (0.14)	68.1 – 109.8 (88.0)	4.3 – 117.0 (29.4)
RR13	6	11.80 – 28.41 (21.95)	7.35 – 8.98 (8.20)	0.144 – 0.298 (0.242)	0.07 – 0.14 (0.12)	107.3 – 110.2 (104.2)	4.6 – 49.7 (14.4)
RR14	6	11.75 – 27.23 (21.38)	7.54 – 9.45 (8.21)	0.014 – 0.260 (0.194)	0.02 – 0.12 (0.10)	72.8 – 110.5 (91.8)	3.6 – 22.7 (8.2)
RMC1	6	14.18 - 26.83 (23.00)	7.68 – 9.32 (8.07)	0.342 – 6.27 (2.45)	0.16 – 3.41 (1.29)	86.6 – 98.2 (91.9)	8.1 – 25.7 (16.5)

TABLE 3.12 Ranges (and means) for chlorophyll *a*, total suspended solids, total nitrogen, total phosphorus, bioavailable nitrogen and soluble reactive phosphorus.

Site	Chl-a (µg/L)	TSS (mg/L)	TN (µg/L)	TP (µg/L)	NOx (µg/L)	SRP (µg/L)
RR1	0.74 – 2.23 (1.16)	13.2 – 27.0 (17.9)	192 – 730 (407)	5 – 309 (41)	13 – 381 (170)	3 – 39 (15)
RR2	0.67 – 4.54 (2.29)	12.9 – 26.0 (18.6)	85 – 850 (441)	11 – 245 (51)	29 – 291 (155)	11 – 60 (30)
RR3	1.88 – 9.96 (4.06)	13.4 – 40.1 (20.2)	141 – 640 (405)	15 – 261 (65)	26 – 314 (144)	12 – 60 (31)
RR4	2.24 – 10.99 (4.97)	9 – 32.3 (18.7)	112 – 991 (512)	19 – 329 (91)	36 – 427 (173)	15 – 112 (43)
RR5	1.58 – 13.17 (5.53)	7.5 – 37.9 (19.2)	216 – 1057 (532)	21 – 327 (86)	22 – 426 (182)	13 – 95 (38)
RR6	3.07 – 27.50 (15.44)	9.29 – 31.45 (20.49)	341 – 974 (589)	41 – 399 (105)	24 – 330 (152)	5 – 108 (40)
RR7	1.56 – 31.24 (15.83)	6.06 – 20.89 (12.06)	368 – 1131 (648)	50 – 422 (124)	28 – 423 (186)	18 – 171 (58)
RR8	1.58 – 23.75 (13.77)	7.80 – 18.51 (12.10)	268 – 1595 (616)	17 – 419 (121)	28 – 2067 (310)	20 – 174 (54)
RR9	7.61 – 24.10 (16.48)	7.69 – 15.5 (12.68)	329 – 850 (610)	53 – 389 (131)	25 – 275 (132)	40 – 77 (48)
RR10	2.98 – 13.12 (6.74)	2.1 – 8.9 (4.9)	335 – 6914 (1594)	38 – 295 (133)	25 – 302 (109)	26 – 104 (54)
RR11	1.27 – 22.11 (6.52)	3.6 – 175.7 (34.4)	403 – 1007 (622)	58 – 294 (164)	19 – 242 (136)	36 – 188 (100)
RR12	0.50 – 8.75 (3.60)	2.4 – 131.8 (26.0)	203 – 741 (543)	55 – 300 (149)	22 – 226 (138)	37 – 99 (76)
RR13	1.03 – 6.09 (2.62)	2.3 – 60.0 (18.4)	199 – 828 (440)	42 – 321 (129)	31 – 406 (178)	27 – 81 (63)
RR14	0.96 – 2.32 (1.49)	1.5 – 18.0 (6.6)	177 – 907 (401)	40 – 174 (96)	27 – 370 (180)	28 – 65 (47)
RMC1	1.64 – 28.04 (12.54)	2.9 – 14.0 (9.5)	394 – 1218 (649)	40 – 380 (110)	13 – 278 (130)	13 – 42 (29)

TABLE 3.13 The number of times sampled and exceedances[1] for pH, conductivity, DO%, turbidity and chlorophyll *a*.						
Site	**Times Sampled**	**pH**	**Conductivity**	**DO %**	**Turbidity**	**Chl-a**
RR1	12	17 (27%) 0, 17	-	13 (30%) 5, 8	0	0
RR2	12	17 (28%) 0, 17	-	0	4 (7%)	2 (17%)
RR3	12	18 (26%) 0, 18	-	0	24 (35%)	5 (42%)
RR4	12	16 (23%) 0, 16	-	10 (14%) 10, 0	31 (44%)	8 (67%)
RR5	12	13 (19%) 4, 9	-	30 (43%) 30, 0	42 (61%)	11 (92%)
RR6	12	17 (26%) 0, 17	-	12 (18%) 12, 0	66 (100%)	10 (83%)
RR7	12	18 (26%) 0, 18	-	7 (10%) 7, 0	67 (99%)	11 (92%)
RR8	12	20 (33%) 0, 20	-	9 (15%) 9, 0	56 (93%)	11 (92%)
RR9	6	1 (17%) 0, 1	-	3 (50%) 3, 0	6 (100%)	6 (100%)
RR10	6	5 (83%) 0, 5	0	2 (33%) 0, 2	0	5 (83%)
RR11	6	4 (67%) 0, 4	0	0	1 (17%)	2 (33%)
RR12	6	4 (67%) 0, 4	0	1 (17%) 1, 0	1 (17%)	2 (33%)
RR13	6	5 (83%) 0, 5	0	3 (50%) 2, 1	0	1 (17%)
RR14	6	4 (67%) 0, 4	0	2 (33%) 1, 1	0	0
RMC1	6	4 (15%) 0, 4	-	0	23 (85%)	4 (67%)

[1] Numbers in black represent the total number and percent of exceedances. Numbers in blue and red represent the numbers of measurements lower than the minimum threshold and higher than the maximum threshold, respectively. The number of exceedances includes all depths sampled so may be greater than the number of times sampled. Turbidity and chlorophyll *a* only have maximum trigger thresholds.

TABLE 3.14 Exceedances[1] for total nitrogen, total phosphorus, bioavailable nitrogen, soluble reactive phosphorus, and the overall water quality grade.					
Site	**TN**	**TP**	**NOx**	**SRP**	**WQ Grade**
RR1	8 (67%)	2 (17%)	11 (92%)	11 (92%)	C-
RR2	9 (75%)	8 (67%)	12 (100%)	12 (100%)	D
RR3	9 (75%)	10 (83%)	12 (100%)	12 (100%)	F
RR4	9 (75%)	9 (75%)	12 (100%)	12 (100%)	F
RR5	8 (67%)	8 (67%)	12 (100%)	12 (100%)	F
RR6	12 (100%)	12 (100%)	12 (100%)	11 (92%)	F
RR7	12 (100%)	12 (100%)	12 (100%)	12 (100%)	F
RR8	11 (92%)	11 (92%)	12 (100%)	12 (100%)	F
RR9	6 (100%)	6 (100%)	6 (100%)	6 (100%)	F
RR10	3 (50%)	5 (83%)	3 (50%)	5 (83%)	D-
RR11	3 (50%)	6 (100%)	4 (67%)	6 (100%)	D
RR12	4 (67%)	6 (100%)	4 (67%)	6 (100%)	D-
RR13	3 (50%)	5 (83%)	4 (67%)	6 (100%)	D
RR14	2 (33%)	5 (83%)	5 (83%)	6 (100%)	D+
RMC1	6 (100%)	6 (100%)	5 (83%)	6 (100%)	F

[1] Numbers represent the total number and percent of exceedances. There are only maximum trigger thresholds for nutrients.

TABLE 3.15 Key stressors and management priorities for water quality in the Richmond River main stem.

Site	Stressor	Management Priority
RR1	High total nutrients and very high bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR2	High total nutrients and very high bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR3	High total nutrients and very high bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR4	High total nutrients and very high bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR5	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR6	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR7	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients). Investigate point-source discharge from Coraki sewage treatment plant.
RR8	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients). Investigate point-source discharge from Coraki sewage treatment plant.
RR9	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
RR10	Very high total and bioavailable nutrient concentrations; high chlorophyll-*a* concentrations; high turbidity.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients). Reduce point-source pollution from urban inputs at Casino. Investigate impacts of discharge from the Casino Wastewater Treatment Plant.
RR11	High nitrogen concentrations and very high phosphorus concentrations.	Investigate surrounding landuse and management for local inputs of phosphorus.
RR12	High nitrogen concentrations and very high phosphorus concentrations.	Investigate surrounding landuse and management for local inputs of phosphorus.
RR13	High nitrogen concentrations and very high phosphorus concentrations.	Investigate surrounding landuse and management for local inputs of phosphorus.
RR14	High nitrogen concentrations and very high phosphorus concentrations.	Investigate surrounding landuse and management for local inputs of phosphorus.
RMC1	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).

3.2.5 Aquatic Macroinvertebrates

Freshwater aquatic macroinvertebrate communities were healthiest (B-) at the most upstream site at RR14 (Wiangaree, Table 3.16). Abundance was more than twice that of any other site on the Richmond main stem, taxa richness was greatest (30 taxa), and EPT richness was greatest at 12 (Table 3.16). While stream velocity was typically slow (i.e. no riffle at the site), the substrate was gravel and although present, fine sediments did not smother the bed (Figure 3.3e). This contributed to the availability of habitat for EPT tax at the site, as did the extensive macrophyte beds (Table 2.4). Like RR14, RR11 was characterized by gravel bed substrate, extensive macrophyte beds and some emergent littoral vegetation. This contributed to a diverse range of habitats for aquatic macroinvertebrates and RR11 achieved a score of D+ (Table 3.16). However, turbidity was consistently higher at RR11 than RR14.

In the Richmond main stem, aquatic macroinvertebrate communities were poorest at RR13 (Kyogle) and RR12 (upstream of Casino). These sites were both characterized by little riparian shade or emergent littoral vegetation, and shallow runs with fine bed substrates (Figure 3.3f, Table 3.17). This results in less available habitat and food supplies for invertebrates and more variable water temperatures. Although RR10 (in Casino) contains significant instream vegetation, the substrate alternates between bedrock outcropping and sand patches. Furthermore, algal blooms were visible for much of the sampling period, as evidenced by the relatively high chlorophyll *a* concentrations for the site (Table 3.12).

TABLE 3.16 Taxa richness, total abundance, EPT richness, mean SIGNAL score and overall aquatic macroinvertebrate grade.

Site	Richness	Abundance	EPT Richness	SIGNAL Score	Macroinvertebrate Grade
RR1					
RR2					
RR3					
RR4					
RR5					
RR6					
RR7					
RR8					
RR9					
RR10	13	218	5	3.93	D-
RR11	19	320	7	4.52	D+
RR12	12	196	5	4.31	F
RR13	12	134	5	4.36	F
RR14	24	784	12	5.10	B-
RMC1					

TABLE 3.17 Key threats and management priorities for healthy aquatic macroinvertebrate communities in the Richmond River main stem.

Site	Stressor	Management Priority
RR1		
RR2		
RR3		
RR4		
RR5		
RR6		
RR7		
RR8		
RR9		
RR10	Urban pollution; loss of habitat from sand movement	Controlling coarse particulate pollutants; long-term control of upstream inputs of fine sediment
RR11	Pollution (dumping of rubbish); loss of habitat from siltation of bed substrate	Controlling coarse particulate pollutants; long-term control of upstream inputs of fine sediment
RR12	Loss of riparian shading; loss of emergent littoral vegetation; significant input of fine sediments	Reduce stock access to riparian zone; encourage regeneration of nativeriparian vegetation
RR13	Loss of riparian shading; loss of littoral vegetation; loss of habitat through siltation of stream bed	Revegetation of riparian zone
RR14	Loss of riparian shading; loss of emergent littoral vegetation; loss of habitat through trampling and significant input of fine sediments	Reduce stock access to riparian zone; encourage regeneration of native riparian vegetation
RMC1		

3.3 Wilsons River

Mid and lower estuarine reaches of the Wilsons River achieved an overall grade of “Very Poor” (Table 3.18). This was driven by the dominance of invasive exotic riparian vegetation and poor water quality. Generally, the upper reaches of the tributaries were in better condition than the lower reaches across all indicators. Upper Terania Creek (downstream of Nightcap National Park) was the best performing site in the Wilsons River subcatchment. Riparian condition declined quickly downstream and this was due firstly to dominance of several noxious invasive weeds or clearing associated with grazing in the riparian zones. Aquatic macroinvertebrate communities were most abundant and diverse in upper Terania and Rocky Creeks. This is likely due to the cobble substrates and pool-riffle sequences providing greater habitat diversity, higher stream velocities increasing stream oxygen concentrations, and better water quality generating the high richness of EPT taxa at TC2 and RC1.

Water quality was generally very poor, although water quality was better in upper reaches of most tributaries. Nutrient concentrations were very high throughout the Wilsons River and its tributaries with bioavailable nitrogen and phosphorus exceeding ANZECC trigger thresholds by more than an order of magnitude at many sites. Water quality declined longitudinally on all tributaries of the Wilsons River where multiple sites enabled this comparison. This was predominantly due to downstream increases in concentrations in bioavailable nutrients, especially bioavailable nitrogen.

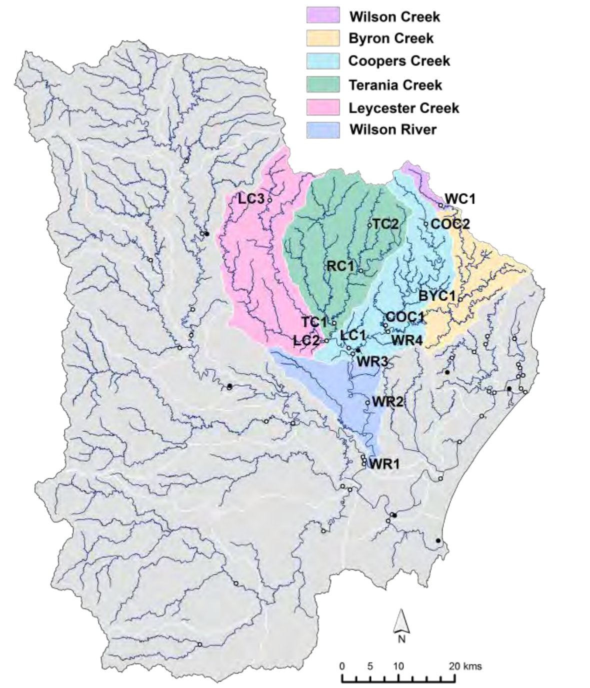
TABLE 3.18 Site-level Ecohealth grades for geomorphic condition, riparian condition, water quality, aquatic macroinvertebrate communities and overall site grades for the Wilsons River and tributaries.

Sites	Geomorphic Condition	Riparian Condition	Water Quality	Aquatic Macroinvertebrates	Overall Site Grade
WR1	D-	F	F		F
WR2	C-	F	F		F
WR3	C+	F	F		F
WR4	D	C	F		D
LC1	C+	D-	F		D-
LC2	D+	D-	D	F	F
LC3	C	D-	D	B-	C
TC1	D+	F	D	F	F
TC2	B-	B+	C	B+	B
RC1	B-	C+	C	B	B-
COC1	D+	D+	D	D+	D+
COC2	B-	B	C-	C	C+
WC1	B-	B-	C-	C	C+
BYC1	D+	F	D-	D-	D-

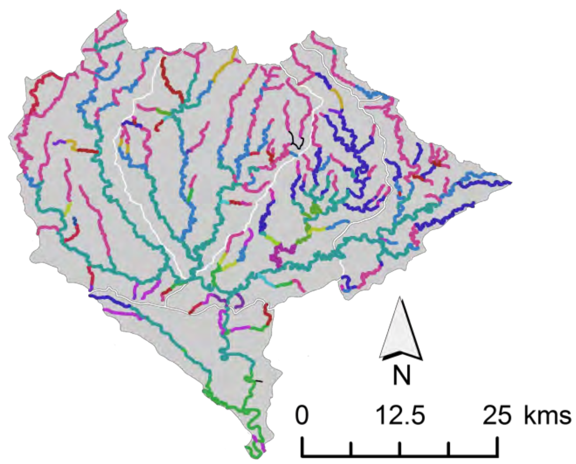
3.3.1 Landscape Context

The Wilsons River and its tributaries are dominated by the mountains, steep hills and deeply incised valleys comprising the Escarpment and Ranges landscape unit. Hence, in the Wilsons River subcatchment, Tertiary basalt comprises the upper 50% of subcatchment geology and Qaternary alluvium comprises the lower 50% of catchment geology, forming the non-tidal floodplains along the main stem of the Wilsons River (Table 3.19). Soils are predominantly volcanic in origin with very high clay contents (47% Vertosols, 43% Dermosols, Table 3.19). Confined valley settings comprise 9% of the subcatchment (floodplain pockets with gravel or fine-grained beds) and partially unconfined valley settings comprise the mid reaches (Figure 3.7) with planform controlled, low sinuosity, gravel-bed channels (33%, Table 3.19). The majority of stream channels are laterally unconfined meandering, fine-grained channels, or channelized fill, located on the low-gradient floodplains (57%, Table 3.19). Only 3% of the remnant coastal forests remain in the Wilsons subcatchment, with widespread clearing for grazing of native pastures (66%), highly intensive cropping, horticulture or improved pastures (19%), and urban and residential development (8%).

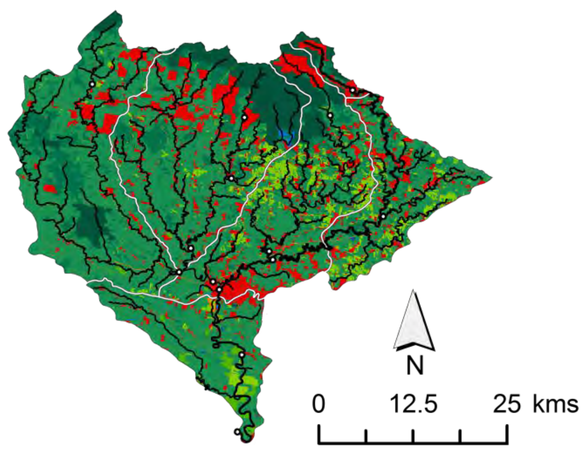
The tributaries of the Wilsons River are also dominated by the volcanic escarpments and ranges with deep, volcanic soils underlaying the upper reaches and valley margins (Figure 3.7, Tables 3.20, 3.21, 3.22, 3.23). Confined valleys dominate stream channels, and bed substrate is cobbles to gravel in upper reaches. Grazing is the dominant land use in all tributary subcatchments (Figure 3.7c), and extensive native tree cover remains in most subcatchments (Tables 3.20, 3.21, 3.22, 3.23).



Location of subcatchments within the Richmond.



Riverstyles: refer to Fig. 2.5 for key.



Landuse: refer to Fig. 2.4 for key.

Soils: refer to Fig. 2.3 for key.

Figure 3.7 Subcatchments of the Wilsons River, showing (a) locations of Ecohealth sites, (b) River Styles, (c) landuse, and (d) soils. Data layers from NC LLS or OEH (Soils).

TABLE 3.19 Subcatchment description of Wilsons River. Data from NC LLS and OEH.	
Area	289.85 km^2
Geology	50% Quaternary alluvium; 50% Basalt
Soils	47% Vertosols; 43% Dermosols; 6% Ferrosols; 1% Hydrosols; 1% Kurosols
Riverstyles	40% LUV CC - Meandering, fine grained; 33% PCVS - Planform controlled, low sinuosity, gravel; 16% LUV CC - Channelised fill; 6% CVS - Floodplain pockets, gravel; 3% CVS - Floodplain pockets, fine grained; 1% LUV CC - Anabranching
Landuse	66% grazing native pastures; 8% urban and rural residential; 7% Grazing improved pastures; 6% Cropping; 5% Horticulture; 3% residual or rehabilitated native cover; 2% farm dams and water ways; 1% Grazing irrigated pastures
Major point source discharge	East Lismore Sewage Treatment Works; South Lismore Sewage Treatment Plant
Tree cover	3%

TABLE 3.20 Subcatchment description of Leycester Creek. Data from NC LLS and OEH.	
Area	443.12 km^2
Geology	74% Basalt; 13% Sandstone; 8% Quaternary alluvium; 4% Shales, siltstones, claystones and coal
Soils	38% Ferrosols; 29% Dermosols; 21% Kurosols; 9% Vertosols; 3% Tenosols (Alluvial)
Riverstyles	36% PCVS - Planform controlled, low sinuosity, gravel; 34% CVS - Headwater 13% CVS - Floodplain pockets, sand; 7% PCVS - Planform controlled, low sinuosity, fine grained; 3% LUV CC - Channelised fill; 2% CVS - Floodplain pockets, fine grained; 1% CVS – Gorge; 1% LUV CC - Meandering, fine grained; 1% PCVS - Planform controlled, meandering, fine grained; 1% SMG - Valley fill, fine grained
Landuse	64% Grazing on native pasture; 14% Residual native cover and rehabilitated native cover; 8% Urban and rural residential; 4% State forest; 3% National Park and private conservation agreement; 3% Plantation forest; 2% Grazing on improved pastures; 1% Horticulture; 1% Farm dams and rivers
Major point source discharge	Nil
Tree cover	24%

TABLE 3.21 Subcatchment description of Terania Creek. Data from NC LLS and OEH.	
Area	422.44 km^2
Geology	56% Basalt; 17% Granite; 10% Quaternary alluvium; 10% Shales, siltstones, claystones and coal; 6% Sandstone; 1% water
Soils	42% Ferrosols; 39% Kurosols; 8% Dermosols; 6% Tenosols (Alluvial); 4% Vertosols
Riverstyles	33% CVS – Headwater; 29% PCVS - Planform controlled, low sinuosity, gravel; 23% CVS - Floodplain pockets, sand; 6% CVS - Floodplain pockets, fine grained; 4% CVS – Gorge; 1% CVS - Floodplain pockets, gravel; 1% LUV CC - Low sinuosity, fine grained; 1% LUV CC - Meandering, fine grained; 1% PCVS - Planform controlled, low sinuosity, fine grained; 1% PCVS - Planform controlled, meandering, gravel
Landuse	49% Grazing of natural pasture; 14% Urban or rural residential; 12% National Park or private conservation agreement; 11% residual or rehabilitated native cover; 4% State Forest; 3% Horticulture; 2% dams or natural water ways; 2% improved pastures; 1% plantation forests; 1% Camphor Laurel forest
Major point source discharge	Nil
Tree cover	29%

TABLE 3.22 Subcatchment description of Coopers Creek. Data from NC LLS and OEH.	
Area	227.88 km^2
Geology	70% Basalt; 18% Quaternary alluvium; 12% Granite
Soils	59% Ferrosols; 17% Kurosols; 14% Dermosols; 8% Vertosols; <1% Water
Riverstyles	28% PCVS - Planform controlled, low sinuosity, gravel; 27% CVS - Floodplain pockets, gravel; 13% CVS – Headwater; 6% LUV CC - Meandering, gravel; 5% PCVS - Planform controlled, meandering, gravel; 4% CVS - Floodplain pockets, sand; 4% PCVS - Planform controlled, meandering, fine grained; 4% LUV CC - Meandering, fine grained; 2% LUV CC - Channelised fill; 2% Urban Stream - Highly Modified; 1% CVS – Gorge; 1% PCVS - Planform controlled, low sinuosity, fine grained; 1% LUV CC - Low sinuosity, fine grained; 1% LUV CC - Low sinuosity, gravel; 1% SMG - Valley fill, fine grained; 1% Water storage - dam or weir pool
Landuse	48% Grazing on natural pasture; 19% Urban or rural residential; 9% Horticulture; 8% National Park or private conservation agreement; 4% Residual or rehabilitated native cover; 4% Camphor Laurel Forest; 2% Drainage system including farm dams and natural water ways; 2% Grazing on Improved pastures; 1% Grazing on Irrigated pastures; 1% State Forest; 1% Plantation forest
Major point source discharge	Nil
Tree cover	18%

TABLE 3.23 Subcatchment descriptions of Wilson and Byron Creeks. Data from NC LLS and OEH.	
Area	178.38 km^2
Geology	88% Basalt; 6% Quaternary alluvium; 6% Granite
Soils	88% Ferrosols; 9% Kurosols; 2% Dermosols; 1% Vertosols; <1% Hydrosols
Riverstyles	31% CVS – Headwater; 26% PCVS - Planform controlled, low sinuosity, gravel; 21% CVS - Floodplain pockets, gravel; 19% CVS - Floodplain pockets, sand; 2% CVS - Floodplain pockets, fine grained
Landuse	52% grazing on natural pasture; 18% urban and rural residential; 10% Horticulture; 7% Camphor laurel forest; 5% National Park and other private conservation areas; 3% Forest plantation; 2% Residual and rehabilitated cover; 2% Drainage system including farm dams and natural water ways; 1% improved pastures
Major point source discharge	Nil
Tree cover	17%

3.3.2 Geomorphic Condition

The subcatchment scale assessment of geomorphic condition over the entire stream length of the Wilsons River and its tributaries found most subcatchments were graded as “Fair”, with 80-94% of their stream length in moderate condition (Table 3.24). Coopers Creek was the exception, with 46% of its streams assessed as in poor condition. Where site-scale grades are lower than the subcatchment grade, this is usually driven by increased localized bank erosion associated with stock access, disturbed riparian vegetation and fords, rather than bed instability or smothering by fine sediments (Table 3.25).

Overall, the site-level assessments for the Wilsons River concurred with the subcatchment-scale assessment. The exception was WR4 at the tidal limit, where exposed tree roots were visible the length of the site due to undercutting and slumping of the banks. The gravel bed was blanketed by a deep layer of unconsolidated fine sediments that were colonized by extensive macrophyte beds and algal communities (Figure 3.8a). The deposition of fine sediments is expected at the tidal limit, and bank undercutting and slumping may also be accelerated by wetting and drying of the intertidal zone. Nonetheless, the site at WR4 was characterized by extensive active bank erosion with small, unvegetated gullies directly connected to the channel during runoff events.

The tributaries of the Wilsons River generally had good geomorphic condition in their upper reaches but were in poor condition in their lower reaches (Table 3.25). Typically, the upper reaches were confined valleys and the River Styles were either headwaters or floodplain pockets. The lower reaches were meandering, fine-graned channels in partially unconfined valley settings. These lower reaches were more likely cleared and grazed than the upper reaches. Byron Creek (BYC1) had poor geomorphic condition, particularly bank condition (Table 3.25). This site was actively grazed and the dense Camphor Laurel canopy combined with grazing pressure resulted in sparse ground cover on steep, deeply incised, fine-grained banks (Figure 3.8b).

The upper site on Terania Creek (TC2) was downstream of the creek's exit from Nightcap National Park and in very good condition. However, bridge works near the site during the second half of sampling caused localized disturbance to the banks and streambed.

TABLE 3.24 Subcatchment-scale geomorphic condition calculated over the subcatchments' total stream length. Data from NC LLS.

Subcatchment	% Good Condition	% Moderate Condition	% Poor Condition	Geomorphic Grade
Wilsons River	0	80	20	C-
Leycester Creek	15	82	3	C+
Terania Creek	15	80	5	C+
Rocky Creek	15	80	5	C+
Coopers Creek	14	40	46	D+
Wilson Creek	0	94	6	B
Byron Creek	0	94	6	B

TABLE 3.25 Site-scale stream bed and stream bank geomorphic condition and overall site-scale geomorphic grade for the Wilsons River and tributaries.

Site	Bank Condition Grade	Bed Condition Grade	Overall Geomorphic Grade
WR1	D-		D-
WR2	D		D
WR3	C		C
WR4	F		F
LC1	B-		B-
LC2	D+	D	D+
LC3	C	C	C
TC1	D+	D+	D+
TC2	B-	B-	B-
RC1	B-	B-	B-
COC1	D-	C-	D+
COC2	B-	C+	B-
WC1	B-	C+	B-
BYC1	D	C-	D+

(a)

(b)

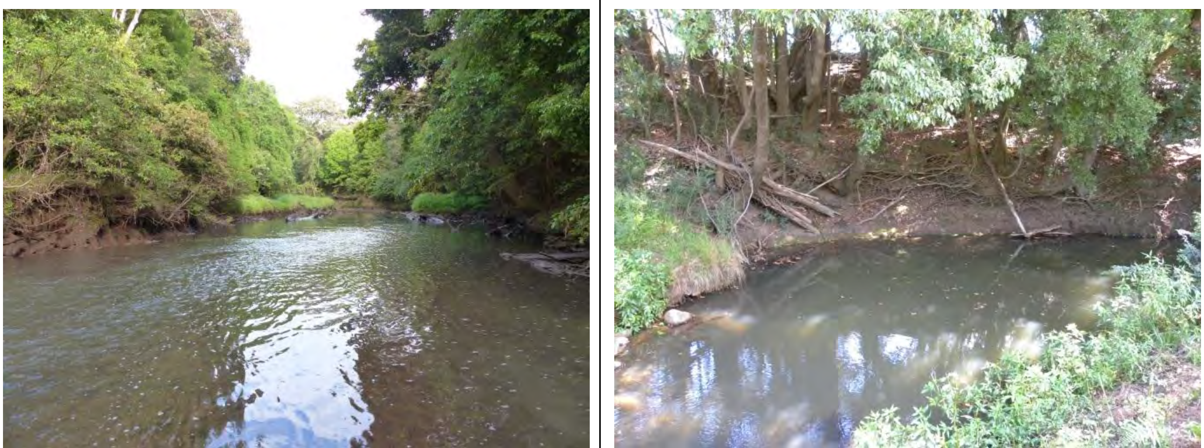


Figure 3.8 Sites in the Wilsons catchment showing (a) bank erosion and smothering of the streambed by fine-grained sediments (WR4), (b) poor bank condition at a heavily grazed site with sparse ground cover (BYC1).

3.3.3 Riparian Condition

Riparian condition was likewise better in the upper catchments of the tributaries and upper estuary of the Wilsons River. The lower and mid estuary of the Wilsons River were assessed have poor riparian condition. This was driven by relatively small numbers of large native trees, substantial invasion of exotic shrubs and vines (VEGETATION, Table 3.26), and in the lower reaches the lack of vegetation connectivity with remnants, both longitudinally (within the riparian zone) and laterally (with the floodplain or hillslopes, DISTURBANCE, Table 3.26). The lack of connectivity and current site-scale disturbances associated with clearing and grazing also reduced the grades for the lower sites on Leycester Creek and Terania Creek (Table 3.26).

TABLE 3.26 Site-scale riparian conditions for estuarine and freshwater reaches of the Wilsons River and its tributaries.

Site	Vegetation	Habitat	Disturbance	Overall Riparian Grade
WR1	D-	C	F	F
WR2	F	D	F	F
WR3	F	F	D	F
WR4	D-	C+	B	C
LC1	F	F	D	D-
LC2	D+	D-	F	D-
LC3	D-	D	F	D-
TC1	D+	F	F	F
TC2	B	B	A	B+
RC1	D+	B	B	C+
COC1	C+	D	D-	D+
COC2	C	A-	B+	B
WC1	C+	C	B+	B-
BYC1	D	F	F	F

TABLE 3.27 Site-scale riparian vegetation and key stressors of the Wilsons River and its tributaries.		
Site	**Vegetation Community Description**	**Key Stressors**
WR1	Cockspur Coraltree and Weeping Bottlebrush shrub with emergent Eucalypt trees and dense exotic vine layer.	Exotic vine is smothering native trees and shrubs; Coraltrees are excluding native regeneration.
WR2	Open Eucalypt forest with dense shrub layer and grassey understorey.	Direct grazing pressure and trampling reducing regeneration. Abundant exotic species including Camphor Laurel trees.
WR3	River Oak-Eucalypt-Campor Laurel open forest with exotic shrub understorey. Giant Reed in littoral zone.	Clearing through urban area, spread of garden weeds.
WR4	Dense Privet and Lantana scrub with emergent Camphor Laurel and scattered Eucalypt trees.	Exclusion of native species by Privet, Lantana and Camphor Laurel.
LC1	Scattered large trees with dense invasive exotic clumping bush and creeping ground-cover.Exotic grasses and forbs in the littoral zone.	Dominance of exotic species.
LC2	Scattered River Oak with grassey understorey and scattered Lomandra clumps.	Direct grazing pressure on regeneration of River Oak; erosion and trampling.
LC3	Tall open River Oak grassey forest on left bank and wet sclerophyll forest with vines on right bank.	Clearing on left bank and privet invasion on right bank.
TC1	Grasses and rushes with scattered Privet shrubs.	Tree and shrub layer almost absent; exotic grasses dominate.
TC2	Subtropical rainforest.	Invasion by exotics from surrounding farmland.
RC1	Dense Privet scrub (Narrow and Broad-leaved sp.) with scattered Castor Oil plants. Native rushes in litterol zone and channel.	Exclusion of native species by dense Privet scrub.
COC1	Water Gum and Lilly Pilly forest with abundant native vines and Privet.	Extensive bank erosion exposing tree roots and causing localized smothering of bed sediments.
COC2	Subtropical rainforest with Lantana understorey and abundant small privet bushes fringing the channel.	Invasion of Lantana and Privet.
WC1	Remnant wet sclerophyll forest with privet shrub layer and sedge understorey.	Loss of large trees, especially on right bank; exotic grasses and privet.
BYC1	Camphor Laurel canopy with scattered Lantana and Privet and grassey understorey.	Direct grazing pressure; trampling; dominance of invasive exotic species.

3.3.4 Water Quality

The Wilsons River had very poor water quality, although upper reaches of most tributaries had fair to poor quality water (Tables 3.29, 3.30 and 3.32). Estuarine reaches of the Wilsons River exceeded the upper ANZECC trigger threshold for turbidity on almost all sampling occasions (Tables 3.28, 3.30). Likewise, total and bioavailable nutrient concentrations consistently exceeded ANZECC trigger thresholds (Table 2.6): by more than double for total nitrogen, more than three times for total phosphorus, and an order of magnitude for bioavailable nitrogen and phosphorus (Table 3.29). Hence, concentrations of chlorophyll *a* (algal biomass) were more than four times the MER trigger threshold for estuarine systems over 80% of sampling events (Tables 3.29, 3.30).

Longitudinal decline in water quality was observed for all tributaries of the Wilsons River where subcatchments had multiple sites (Table 3.31). This was predominantly due to increasing concentrations in bioavailable nutrients in downstream reaches (Table 3.29). Concentrations of bioavailable nitrogen were particularly high in the tributaries of the Wilsons River: consistently exceeding the ANZECC trigger threshold by an order of magnitude (Table 3.29). DO% saturation fell below ANZECC trigger thresholds during the below-average flows experienced during the second half of 2014 (Table 3.30).

TABLE 3.28 Ranges (and means) for temperature, pH, conductivity, salinity, DO% and turbidity.

Site	Times sampled	Temperature (°C)	pH	Conductivity (µS/cm)	Salinity (PPT)	DO (%)	Turbidity (NTU)
WR1	12	14.55 – 27.57 (22.43)	7.38 – 9.43 (8.33)	0.137 – 0.497 (0.319)	0.07 – 0.24 (0.15)	68.8 – 100.9 (87.3)	10.0 – 37.9 (18.76)
WR2	12	15.10 – 28.13 (22.47)	7.14 – 8.83 (7.90)	0.155 – 0.341 (0.258)	0.08 – 0.16 (0.12)	64.0 – 93.9 (78.8)	8.8 – 60.5 (19.1)
WR3	12	13.81 – 27.95 (22.06)	6.86 – 8.88 (7.93)	0.139 – 0.360 (0.237)	0.07 – 0.20 (0.12)	68.2 – 107.1 (84.4)	13.2 – 51.6 (21.3)
WR4	6	11.24 – 25.43 (20.78)	7.12 – 8.40 (7.85)	0.119 – 0.161 (0.139)	0.06 – 0.08 (0.07)	77.1 – 95.2 (84.7)	6.6 – 16.6 (11.9)
LC1	6	12.92 – 26.66 (22.18)	7.39 – 8.79 (7.92)	0.260 – 0.367 (0.315)	0.12 – 0.18 (0.15)	59.0 – 89.5 (79.5)	12.7 – 23.9 (18.3)
LC2	6	11.7 – 26.55 (20.95)	7.48 – 8.86 (7.95)	0.457 – 0.620 (0.535)	0.22 – 0.30 (0.26)	60.1 – 95.4 (77.9)	9.0 – 44.2 (18.1)
LC3	6	10.42 – 25.14 (19.75)	7.76 – 9.06 (8.14)	0.251 – 0.401 (0.352)	0.12 – 0.19 (0.17)	72.6 – 92.1 (82.9)	2.4 – 27.2 (8.1)
TC1	6	12.30 – 26.10 (20.78)	7.26 – 8.71 (7.89)	0.141 – 0.214 (0.178)	0.07 – 0.10 (0.09)	74.8 – 99.8 (88.8)	8.6 – 90.8 (31.6)
TC2	6	11.68 – 22.94 (18.50)	7.18 – 8.58 (7.77)	0.059 – 0.078 (0.068)	0.03 – 0.04 (0.04)	82.2 – 98.9 (87.6)	3.9 – 9.7 (6.5)
RC1	6	10.66 – 24.78 (19.12)	7.53 – 8.89 (7.99)	0.096 – 0.120 (0.111)	0.05 – 0.06 (0.06)	72.1 – 99.7 (87.3)	2.4 – 8.3 (4.5)
COC1	6	11.47 – 28.80 (21.27)	6.71 – 8.29 (7.69)	0.093 – 0.221 (0.148)	0.05 – 0.10 (0.07)	70.8 – 95.5 (79.7)	4.2 – 24 (15.9)
COC2	5	11.95 – 25.44 (20.34)	6.76 – 8.40 (7.65)	0.079 – 0.148 (0.099)	0.04 – 0.07 (0.05)	70.4 – 90.5 (82.4)	3.9 – 13.1 (7.9)
WC1	6	12.44 – 25.78 (20.69)	6.83 – 8.94 (7.64)	0.080 – 0.094 (0.086)	0.04 – 0.05 (0.04)	65.5 – 106.3 (90.2)	4.6 – 12.5 (8.0)
BYC1	6	12.24 – 24.73 (19.94)	6.63 – 8.30 (7.50)	0.088 – 0.164 (0.133)	0.05 – 0.08 (0.07)	46.7 – 85.7 (65.4)	6.7 – 77 (23.5)

TABLE 3.29 Ranges (and means) for chlorophyll *a*, total suspended solids, total nitrogen, total phosphorus, bioavailable nitrogen and soluble reactive phosphorus.

Site	Chl-a (µg/L)	TSS (mg/L)	TN (µg/L)	TP (µg/L)	NOx (µg/L)	SRP (µg/L)
WR1	0.64 – 36.24 (14.15)	8.90 – 25.16 (14.02)	81 – 1362 (656)	26 – 444 (123)	35 – 656 (188)	14 – 177 (60)
WR2	1.17 – 31.38 (14.15)	7.16 – 51.54 (14.49)	199 – 1363 (761)	36 – 461 (134)	17 – 365 (140)	10 – 275 (54)
WR3	1.72 – 31.18 (16.01)	8.69 – 27.03 (16.47)	295 – 1049 (630)	27 – 370 (102)	21 – 307 (149)	11 – 116 (39)
WR4	1.53 – 21.74 (8.78)	4.00 – 17.50 (8.77)	232 – 891 (511)	40 – 236 (79)	25 – 226 (132)	17 – 55 (32)
LC1	2.75 – 27.09 (13.90)	9.60 – 25.89 (16.29)	359 – 964 (555)	49 – 276 (96)	22 – 221 (113)	13 – 45 (26)
LC2	0.95 – 27.57 (9.26)	1.60 – 19.39 (11.42)	302 – 995 (619)	48 – 192 (106)	17 – 214 (92)	16 – 84 (44)
LC3	0.43 – 3.44 (1.57)	1.20 – 17.60 (4.65)	601 – 1768 (855)	36 – 123 (71)	33 – 162 (95)	16 – 153 (64)
TC1	0.91 – 24.68 (6.64)	1.30 – 49.09 (16.84)	167 – 1016 (604)	51 – 108 (71)	25 – 305 (110)	16 – 49 (34)
TC2	0.67 – 1.76 (0.97)	0.70 – 3.70 (2.41)	277 – 1339 (754)	26 – 144 (55)	62 – 253 (140)	10 – 81 (30)
RC1	0.46 – 2.33 (1.47)	0.70 – 2.33 (1.51)	399 – 1098 (585)	18 – 93 (43)	56 – 1099 (318)	13 – 53 (24)
COC1	0.64 – 19.49 (8.67)	1.80 – 15.48 (8.07)	192 – 1229 (618)	32 – 219 (82)	53 – 325 (175)	19 – 63 (33)
COC2	0.74 – 5.90 (2.35)	2.00 – 10.00 (3.76)	329 – 722 (500)	19 – 130 (55)	73 – 249 (188)	14 – 35 (23)
WC1	0.94 – 14.06 (4.34)	2.10 – 7.30 (4.47)	68 – 973 (583)	24 – 114 (46)	95 – 253 (151)	6 – 31 (21)
BYC1	0.10 – 7.17 (2.88)	4.50 – 38.00 (10.90)	346 – 915 (693)	27 – 139 (219)	71 – 560 (219)	13 – 146 (48)

TABLE 3.30 The number of times sampled and exceedances[1] for pH, conductivity, DO%, turbidity and chlorophyll *a*.

Site	Times Sampled	pH	Conductivity	DO %	Turbidity	Chl-a
WR1		22 (31%) 0, 22	-	6 (9%) 6, 0	69 (99%)	10 (83%)
WR2	12	2 (17%) 0, 2	-	7 (58%) 7, 0	11 (92%)	10 (83%)
WR3	12	5 (42%) 1, 4	-	4 (33%)	12 (100%)	10 (83%)
WR4	6	0	-	2 (33%) 2, 0	4 (67%)	3 (50%)
LC1	6	1 (17%) 0, 1	-	3 (50%) 3, 0	6 (100%)	5 (83%)
LC2	6	2 (33%) 0, 2	0	3 (50%) 3, 0	0	3 (50%)
LC3	6	3 (50%) 0, 3	0	3 (50%) 3, 0	0	0
TC1	6	2 (33%) 0, 2	0	1 (17%) 1, 0	1 (17%)	3 (50%)
TC2	6	2 (33%) 0 ,2	0	1 (17%) 1, 0	0	0
RC1	6	2 (33%) 0, 2	0	1 (17%) 1, 0	0	0
COC1	6	3 (50%) 0, 3	0	3 (50%) 3, 0	0	4 (67%)
COC2	5	2 (40%) 0, 2	0	2 (40%) 2, 0	0	1 (20%)
WC1	6	2 (33%) 0, 2	0	2 (33%) 2, 0	0	2 (33%)
BYC1	6	2 (33%) 0, 2	0	5 (83%) 5, 0	1 (17%)	1 (17%)

[1] Numbers in black represent the total number and percent of exceedances. Numbers in blue and red represent the numbers of measurements lower than the minimum threshold and higher than the maximum threshold, respectively. The number of exceedances includes all depths sampled so may be greater than the number of times sampled. Turbidity and chlorophyll *a* only have maximum trigger thresholds.

TABLE 3.31 Exceedances[1] for total nitrogen, total phosphorus, bioavailable nitrogen, soluble reactive phosphorus, and the overall water quality grade.

Site	TN	TP	NOx	SRP	WQ Grade
WR1	10 (83%)	10 (83%)	12 (100%)	12 (100%)	F
WR2	11 (92%)	12 (100%)	12 (100%)	12 (100%)	F
WR3	10 (83%)	11 (92%)	12 (100%)	12 (100%)	F
WR4	4 (67%)	6 (100%)	6 (100%)	6 (100%)	F
LC1	6 (100%)	6 (100%)	6 (100%)	6 (100%)	F
LC2	4 (67%)	5 (83%)	4 (67%)	5 (83%)	D
LC3	6 (100%)	3 (50%)	5 (83%)	5 (83%)	D
TC1	3 (50%)	6 (100%)	4 (67%)	5 (83%)	D
TC2	4 (67%)	2 (33%)	6 (100%)	3 (50%)	C-
RC1	4 (67%)	2 (33%)	6 (100%)	2 (33%)	C-
COC1	3 (50%)	4 (67%)	6 (100%)	4 (67%)	D
COC2	2 (40%)	3 (60%)	5 (100%)	2 (40%)	C-
WC1	4 (67%)	2 (33%)	6 (100%)	3 (50%)	C-
BYC1	5 (83%)	3 (50%)	6 (100%)	5 (83%)	D-

[1] Numbers represent the total number and percent of exceedances. There are only maximum trigger thresholds for nutrients.

TABLE 3.32 Key stressors and management priorities for water quality in the Wilsons River and its tributaries.

Site	Stressor	Management Priority
WR1	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients). Investigate point-source discharge from sewage treatment plant in Coraki.
WR2	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
WR3	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients). Investigate point-source discharge from sewerage treatment works in Lismore.
WR4	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
LC1	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
LC2	High total nutrient concentrations particularly phosphorus; high chlorophyll-*a* concentrations; low DO%	Investigate sources of total nutrient inputs particularly phosphorus.
LC3	Very high total and bioavailable nutrient concentrations; very high chlorophyll-*a* concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
TC1	High total and bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
TC2	High total and bioavailable nutrient concentrations, particularly bioavailable nitrogen.	Investigate sources of bioavailable nitrogen.
RC1	High total and bioavailable nutrient concentrations, particularly bioavailable nitrogen.	Investigate sources of bioavailable nitrogen.
COC1	High total and bioavailable nutrient concentrations, particularly total and bioavailable nitrogen; low DO% during low-flows.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients); reduce stock access to stream channels.
COC2	Consistent exceedance of total and bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
WC1	Consistent high concentrations of bioavailable nitrogen and phosphorus.	Investigate sources of bioavailable nutrients.
BYC1	Very high concentrations of bioavailable nitrogen; high concentrations of total nutrients; consistent low DO%.	Reduce stock access to river to reduce localized inputs of nutrients.

3.3.5 Aquatic Macroinvertebrates

Aquatic macroinvertebrate grades were higher in the Wilsons River and its tributaries than the Richmond main stem (Table 3.33). The poorest macroinvertebrate communities were observed in the lower reaches of Leycester and Terania Creeks, where riparian disturbance and geomorphic condition were also poor. While upper Terania Creek (TC2, Table 3.33) had the most abundant and diverse macroinvertebrate communities in the whole of the Richmond catchment, lower Terania Creek (TC1) recorded one of the most depauperate communities in the Wilsons subcatchment. Only 17 individuals across 5 taxa (1 EPT) were found at TC1 (Table 3.33) across two sampling seasons. The channel at TC1 is a uniform U-shaped pool with little geomorphic complexity and fine-grained bank and bed sediments, so habitat diversity and food resources are very limited (Table 2.4).

Byron Creek (BYC1) also had poor aquatic macroinvertebrate communities (D-). This is likely driven by limited habitat availability given the site was dominated by a very-low velocity, deep pool with a mean DO saturation of 65% (Table 3.28). The banks are vertical fine-grained cohesive sediments with some active erosion and fine sediments dominate the streambed (Figure 3.8b). Riparian vegetation was dominated by Camphor Laurel, Privet and sparse grass so food and habitat availability is also likely limited (Table 3.34).

COC1 also had poor aquatic macroinvertebrates (D+, Table 3.33) despite being a cobble pool-riffle sequence with extensive macrophyte beds across the riffle. However, the riffle is very shallow and partially dewatered during low flows, to the extent that the macrophyte beds partially died. This is likely due to below average rainfall and runoff (Figure 2.6), and aquatic macroinvertebrate communities are likely to recover in increased baseflow given the habitat complexity of the site (Table 2.4).

TABLE 3.33 Taxa richness, total abundance, EPT richness, mean SIGNAL score and overall aquatic macroinvertebrate grade.

Site	Richness	Abundance	EPT Richness	SIGNAL Score	Macroinvertebrate Grade
WR1					
WR2					
WR3					
WR4					
LC1					
LC2	12	19	2	3.17	F
LC3	22	331	13	5.10	B-
TC1	5	17	1	3.40	F
TC2	30	739	17	5.45	B+
RC1	24	273	18	5.94	B
COC1	15	358	7	4.33	D+
COC2	19	428	11	5.50	C
WC1	25	262	13	4.88	C
BYC1	15	95	5	4.00	D-

TABLE 3.34 Key stressors and management priorities for healthy aquatic macroinvertebrate communities in the Wilsons River and its tributaries.

Site	Stressor	Management Priority
WR1		
WR2		
WR3		
WR4		
LC1		
LC2	Highly mobile, fine-grained bed sediments; lack of habitat availability; lack of riparian shading; lack of riparian vegetation.	Minimal active erosion at site so reduction of fine-sediments transported from upstream. Increase riparian tree cover.
LC3		Maintain site condition
TC1	Lack of riparian shading; lack of riparian vegetation; lack of habitat availability	Native revegetation of both banks.
TC2		Maintain site condition
RC1		Maintain instream condition; weed control for Privet.
COC1	Fine sediment smothering gravel bed sediments; significant algal colonization of bed substrate and macrophytes.	Reduce fine-sediment inputs from upstream; consider monitoring water extraction levels during very low flows.
COC2	Culvert restricted downstream velocity and discharge and created a pool upstream of road crossing.	Maintain site condition; consider effects of culvert on impounding low flows.
WC1		Maintain site conditions; continue with weed removal (and revegetation).
BYC1	Lack of habitat availability; low DO%.	Control stock access to stream; reduce Camphor Laurel canopy and Privet.

3.4 Eden and Iron Pot Creeks and Shannon Brook

Eden and Iron Pot Creeks and Shannon Brook had fair to poor geomorphic condition but below-average site-scale scores reflecting localized disturbances (trampling and pugging from cattle grazing and stock access to stream banks). Riparian condition was fair to poor. While all three riparian zones were densely vegetated, there were significant incursions of invasive woody weeds (such as Lantana and Privet) and exotic vines. Disturbances associated with cattle grazing lowered the site-level grades for Eden and Iron Pot Creeks, but landscape-scale disconnectivity to floodplain vegetation and surrounding riparian vegetation reduced riparian condition across sites.

Water quality was generally poor due to high concentrations of total and bioavailable nutrients. Aquatic macroinvertebrate communities ranged from fair to poor and this was largely due to site-scale differences in habitat heterogeneity. All sites were sand-bed channels and habitat availability remained low across the subcatchments.

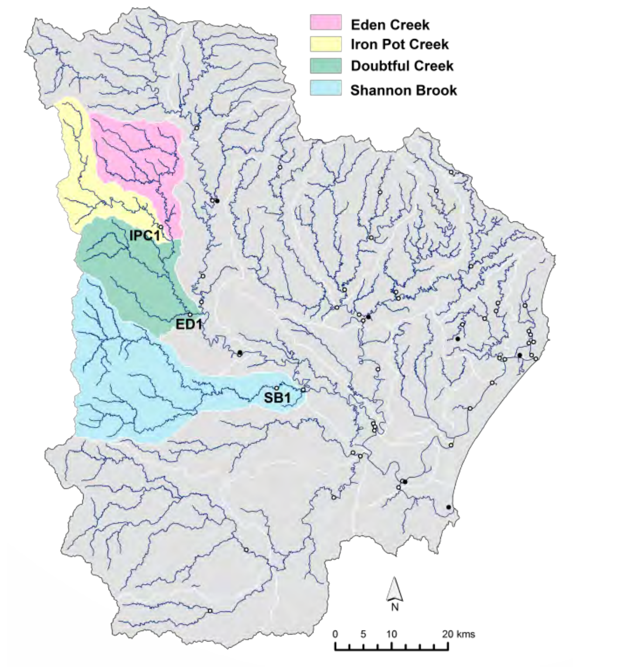
TABLE 3.35 Site-level Ecohealth grades for geomorphic condition, riparian condition, water quality, aquatic macroinvertebrate communities and overall site grades for Eden and Iron Pot Creeks and Shannon Brook.

Sites	Geomorphic Condition	Riparian Condition	Water Quality	Aquatic Macroinvertebrates	Overall Site Grade
ED1	D-	D+	D-	F	D-
IPC1	D	C	D+	C	C-
SB1	C+	C-	D+	D+	C-

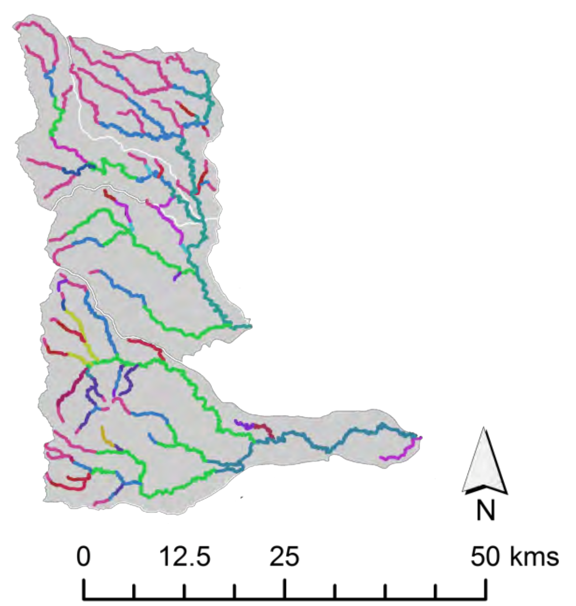
3.4.1 Landscape Context

The dominant landscape unit of Eden and Iron Pot Creeks and Shannon Brook are low elevation hills, although the eastern side of the Eden subcatchment is dominated by the Tertiary basalts of the escarpment and ranges. The major soil group is Kurosol with a strongly acidic B horizon (Tables 3.36, 3.37, 3.38). Headwaters in confined valleys were the most common River Style in Eden and Iron Pot subcatchments, but higher order streams across all three subcatchments were predominantly in partially unconfined valleys with planform controlled fine-grained sediments.

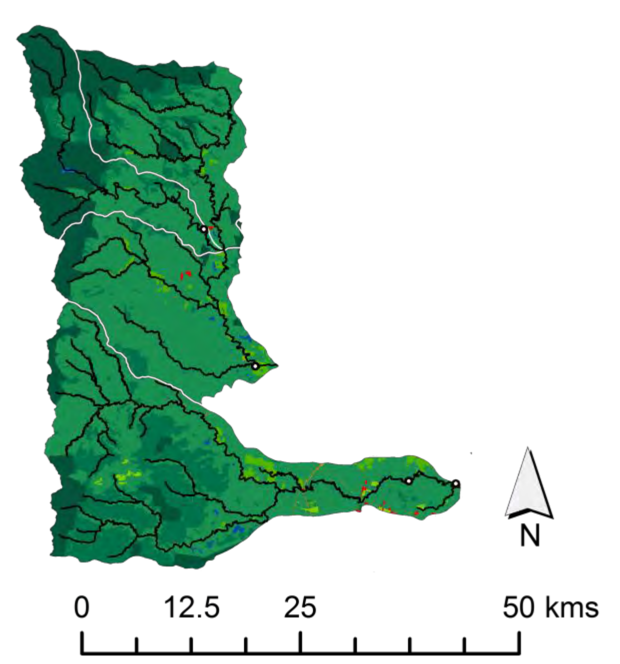
Grazing of native pastures was the dominant land use in Eden Creek and Shannon Brook subcatchments (67 and 57%, respectively, Tables 3.36, 3.38), but more than one-quarter of the area of both subcatchments was covered by forests. Forests in National Parks, State Forests, conservation areas or unprotected residual patches accounted for 69% of the subcatchment area of Iron Pot Creek (Figure 3.9).



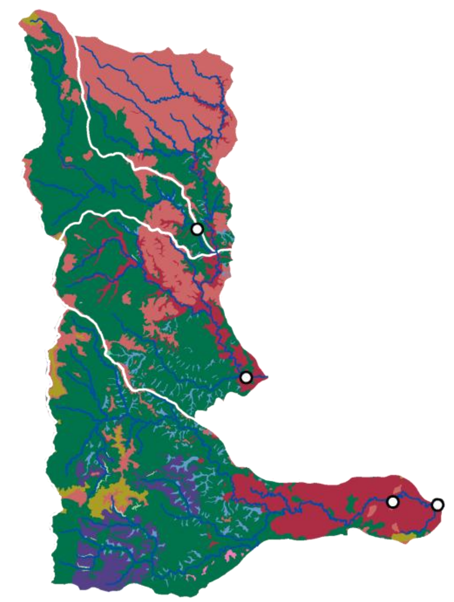
Location of subcatchments within the Richmond.



Riverstyles: refer to Fig. 2.5 for key.



Landuse: refer to Fig. 2.4 for key.



Soils: refer to Fig. 2.3 for key.

Figure 3.9 Subcatchments of Eden and Iron Pot Creeks and Shannon Brook, showing (a) locations of Ecohealth sites, (b) River Styles, (c) landuse, and (d) soils. Data layers from NC LLS and OEH (Soils).

TABLE 3.36 Subcatchment description of Eden Creek (including Doubtful Creek). Data from NC LLS and OEH.	
Area	510.15 km^2
Geology	42% Basalt; 27% Sandstone; 18% Shales, siltstones, claystones and coal; 14% Quaternary alluvium
Soils	54% Kurosols; 38% Ferrosols; 3% Vertosols; 3% Kandosols; 2% Dermosols
Riverstyles	29% CVS – headwater; 23% PCVS – Planform controlled, low sinuosity, gravel; 20% CVS – Floodplain pockets, sand; 18% PCVS – Planform controlled, meandering, sand; 4% LUV CC – Channelised fill; 3% CVS – Floodplain pockets, fine grained; 1% LUV CC – Low sinuosity, fine grained; 1% PCVS – planform controlled, low sinuosity, fine grained; <1% SMG – Valley fill, fine grained
Landuse	67% Grazing native pastures, including degraded pastures; 12% National Park and other small conservation areas; 5% Grazing improved and irrigated pasture; 4% State Forest; 2% cropping; 1% plantation; 9% Residual and rehabilitated native cover; <1% Urban, rural residential, farm dams, waterways, floodplain swamps, waste disposal by irrigation and quarry
Major point source discharge	Nil
Tree cover	26%

TABLE 3.37 Subcatchment description of Iron Pot Creek. Data from NC LLS and OEH.	
Area	192.78 km^2
Geology	54% Shales, siltstones, claystones and coal; 20% Sandstone; 15% Basalt; 8% Quaternary alluvium; 2% Granite
Soils	76% Kurosols; 23% Ferrosols; 1% Water; 1% Kandosols; <1% Dermosols
Riverstyles	37% CVS – Headwater; 21% PCVS - Planform controlled, meandering, sand; 14% CVS - Floodplain pockets, sand; 10% PCVS - Planform controlled, low sinuosity, gravel; 7% PCVS - Bedrock controlled, fine grained; 6% Water storage - dam or weir pool; 2%LUV CC - Channelised fill; 2% PCVS - Planform controlled, low sinuosity, fine grained; 1%LUV CC - Low sinuosity, fine grained
Landuse	37% National Park, private conservation and water reservoir foreshore conservation; 25% Grazing native pastures including degraded pastures; 18% State Forests; 14% Residual forest areas; 5% Grazing improved pastures; 1% farm dams, waterways and large reservoirs; <1% cropping
Major point source discharge	Nil
Tree cover	69%

TABLE 3.38 Subcatchment description of Shannon Brook. Data from NC LLS and OEH.	
Area	558.81 km^2
Geology	44% Sandstone; 30% Quaternary alluvium; 16% Shales, siltstones, claystones and coal; 9% Basalt
Soils	41% Kurosols; 18% Vertosols; 13% Rudosols and Tenosols; 12% Kandosols; 8% Ferrosols
Riverstyles	28% PCVS - Planform controlled, meandering, sand; 18% LUV CC – Meandering, sand; 12% CVS – Floodplain pockets, sand; 10% CVS – Headwater; 7% PCVS - Planform controlled, low sinuosity, sand; 6% PCVS - Planform controlled, meandering, fine grained; 6% PCVS - Planform controlled, low sinuosity, fine grained; 4% SMG – cut and fill; 2% LUV CC Channelised fill; 2% CVS – Floodplain pockets, fine grained; 2% SMG – Valley fill, fine grained; 2% LUV CC – Low sinuosity, sand; 1%CVS – Gorge; <1% LUV CC – meandering fine grained; <1% PCVS – Bedrock controlled, fine grained
Landuse	57% Grazing on native pasture including degraded pastures; 27% Residual and rehabilitated native forest; 4% National Park, Nature reserve and private conservation; 4% State Forest; 3% Grazing improved and irrigated pasture; 2% Cropping; 1% Farm dams and rivers; 1% Horticulture
Major point source discharge	Nil
Tree cover	35%

3.4.2 Geomorphic Condition

At a subcatchment scale, Eden and Iron Pot Creeks and Shannon Brook had fair to poor geomorphic condition (Table 3.39). However, streams in Iron Pot Creek were evenly split between good, moderate and poor condition, whereas both Eden Creek and Shannon Brook subcatchments contained less stream length in good condition (Table 3.39).

Site-scale assessments of geomorphic condition in Eden and Iron Pot Creeks recorded scores below the subcatchment averages (Table 3.40). In both cases, this was due to trampling and pugging from cattle grazing at the site. At IPC1, moderate bank slumping also contributed to the below-average score for bank condition. This caused significant localized smothering of the bed substrates by fine sediments which contribed to a poor bed condition grade (F, Table 3.40). At IPC1, bedrock outcropping comprised approximately 60% of the length of both banks. Hence, the 40% of bank length comprising fine sediments were sites of concentrated cattle trampling and major masss movement. In contrast, the site on Shannon Brook (SB1) was not actively grazed and the banks were densely vegetated. However, it is worth noting that the channel at SB1 contained significant loads of dumped household goods (mattresses and white goods) and car parts including a complete engine in the stream channel (Figure 3.10b).

TABLE 3.39 Subcatchment-scale geomorphic condition calculated over the subcatchments' total stream length. Data from NC LLS.				
Subcatchment	**% Good Condition**	**% Moderate Condition**	**% Poor Condition**	**Geomorphic Grade**
Eden Creek (including Doubtful Creek)	15	64	21	C-
Iron Pot Creek	36	34	30	C
Shannon Brook	14	50	36	D+

TABLE 3.40 Site-scale stream bed and stream bank geomorphic condition and overall site-scale geomorphic grade for Eden and Iron Pot Creeks and Shannon Brook.			
Site	**Bank Condition Grade**	**Bed Condition Grade**	**Overall Geomorphic Grade**
ED1	D+	F	D-
IPC1	D	D	D
SB1	B-	C+	C+

(a) **(b)**

Figure 3.10 Sites in Iron Pot Creek and Shannon Brook showing (a) poor geomorphic condition due to stock access (IPC1), and (b) rubbish dumped in the channel (SB1).

3.4.3 Riparian Condition

HABITAT indicators such as abundant standing and fallen trees and logs contributed to good habitat at ED1 and IPC1 (Table 3.41). Although all three sites contained dense riparian vegetation, there were significant incursions of invasive woody weeds (e.g. Privet, Lantana, Wild Tobacco Bush) and to a lesser extent, exotic vines. Low grades for DISTURBANCE at ED1 and IPC1 were partially due to the effects of grazing at these sites. However, all three sites had very poor lateral connectivity to floodplain vegetation, and to a lesser degree longitudinal connectivity to riparian vegetation. This is due to clearing for cropping (SB1) or grazing (ED1 and IPC1). Lantana was abundant along riparian zones in these subcatchments (Table 3.42)

TABLE 3.41 Site-scale riparian conditions for estuarine and freshwater reaches of Eden and Iron Pot Creeks and Shannon Brook.

Site	Vegetation	Habitat	Disturbance	Overall Riparian Grade
ED1	D+	B+	F	D+
IPC1	C	B+	D	C
SB1	C+	F	C-	C-

TABLE 3.42 Site-scale riparian vegetation and key stressors of Eden and Iron Pot Creeks and Shannon Brook.

Site	Vegetation Community Description	Key Stressors
ED1	River Oak open forest with scattered emergent Eucalypt trees. Lantana-dominated midstorey on both banks with abundant *Callistamon* and River Oak samplings. Willow abundant and heavy invasion of exotic vine on left bank. No grass or forb understorey.	Dominance of exotic invasive species such as Lantana and exotic vine.
IPC1	Closed River Oak, Eucalypt and Apple Gum forest with dense midstorey of Lantana, Camphor Laurel and Lilly Pilly. Fern understorey with Lomandra fringing the water's edge. Dense exotic vine on both banks.	Smothering by exotic vine; localized severe mass movement of fine-grained banks (loss of habitat); competitive dominance of Lantana in midstorey; direct grazing pressure.
SB1	Narrow strip of subtropical rainforest with exotic vines, and Lantana and Wild Tobacco abundant in midstorey.	Invasive exotic plant species and lack of connectivity with surrounding native vegetation (reducing natural regenerative capacity).

3.4.4 Water Quality

Water quality was generally poor in Eden and Iron Pot Creeks and Shannon Brook (Tables 3.43, 3.44, 3.45, 3.46 and 3.47). This was predominantly due to high concentrations of total and bioavailable nutrients (Table 3.46). Concentrations of total nitrogen and phosphorus exceeded the ANZECC trigger thresholds on most sampling occasions at all sites, the latter by at least double the threshold concentration at Eden Creek (ED1) and Shannon Brook (SB1, Table 3.44). Bioavailable nutrient concentrations consistently exceeded ANZECC trigger thresholds (Table 3.46): by three times the threshold concentration for nitrogen (Table 3.44). This was not correlated with turbidity, which generally remained below ANZECC trigger thresholds. DO% saturation fell below the lower trigger threshold of 80% during the very low flows observed in the second half of 2014 (Table 3.45). pH consistently was more alkaline than the upper ANZECC trigger threshold, likely due to the high proportion of alkaline geology (volcanics and siliciclastic sedimentary rocks) in these subcatchments (Tables 3.36, 3.37 and 3.38).

TABLE 3.43 Ranges (and means) for temperature, pH, conductivity, salinity, DO% and turbidity.							
Site	Times sampled	Temperature (°C)	pH	Conductivity (µS/cm)	Salinity (PPT)	DO (%)	Turbidity (NTU)
SB1	6	13.51 – 27.80 (21.10)	7.34 – 8.72 (7.93)	0.518 – 1.339 (1.045)	0.25 – 0.66 (0.51)	78.3 – 95.4 (87.0)	9.7 – 33.6 (17.5)
ED1	6	12.05 – 33.37 (23.16)	7.55 – 8.96 (8.22)	0.354 - 0.478 (0.412)	0.17 – 0.23 (0.20)	70.9 – 108.2 (87.9)	5.5 – 113.0 (28.7)
IPC1	6	11.06 – 29.63 (22.95)	7.50 – 9.45 (8.25)	0.243 – 0.323 (0.268)	0.12 – 0.15 (0.13)	71.0 – 110.4 (95.9)	5.8 – 16.6 (9.8)

TABLE 3.44 Ranges (and means) for chlorophyll *a*, total suspended solids, total nitrogen, total phosphorus, bioavailable nitrogen and soluble reactive phosphorus.						
Site	Chl-a (µg/L)	TSS (mg/L)	TN (µg/L)	TP (µg/L)	NOx (µg/L)	SRP (µg/L)
SB1	1.18 – 24.99 (8.45)	3.08 – 22.50 (8.95)	473 – 987 (667)	30 – 481 (185)	59 – 208 (120)	9 – 36 (18)
ED1	1.16 – 18.95 (5.70)	3.47 – 97.00 (24.08)	304 – 891 (615)	29 – 329 (118)	33 – 239 (140)	16 – 60 (36)
IPC1	1.03 – 3.63 (2.07)	0.30 – 9.10 (4.64)	366 – 1800 (784)	20 – 123 (56)	20 – 302 (141)	10 – 68 (35)

TABLE 3.45 The number of times sampled and exceedances[1] for pH, conductivity, DO%, turbidity and chlorophyll *a*.						
Site	Times Sampled	pH	Conductivity	DO %	Turbidity	Chl-a
SB1	6	2 (33%), 0, 2	0	1 (17%), 1, 0	0	3 (50%)
ED1	6	5 (83%), 0, 5	0	2 (33%), 2, 0	1 (17%)	2 (33%)
IPC1	6	5 (83%), 0, 5	0	2 (33%), 1, 1	0	0

[1] Numbers in black represent the total number and percent of exceedances. Numbers in blue and red represent the numbers of measurements lower than the minimum threshold and higher than the maximum threshold, respectively. The number of exceedances includes all depths sampled so may be greater than the number of times sampled. Turbidity and chlorophyll *a* only have maximum trigger thresholds.

TABLE 3.46 Exceedances[1] for total nitrogen, total phosphorus, bioavailable nitrogen, soluble reactive phosphorus, and the overall water quality grade.					
Site	TN	TP	NOx	SRP	WQ Grade
SB1	5 (83%)	4 (67%)	6 (100%)	2 (33%)	D+
ED1	4 (67%)	5 (83%)	5 (83%)	5 (83%)	D-
IPC1	4 (67%)	3 (50%)	5 (83%)	3 (50%)	D+

[1] Numbers represent the total number and percent of exceedances. There are only maximum trigger thresholds for nutrients.

TABLE 3.47 Key stressors and management priorities for water quality in Eden and Iron Pot Creeks and Shannon Brook.		
Site	**Stressor**	**Management Priority**
SB1	High total and bioavailable nutrient concentrations, particularly bioavailable nitrogen.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
ED1	High total and bioavailable nutrient concentrations, particularly bioavailable nitrogen; low DO% during low-flows.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients); reduce stock access to stream channels.
IPC1	High total and bioavailable nutrient concentrations, particularly bioavailable nitrogen.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients); reduce stock access to stream channels.

3.4.5 Aquatic Macroinvertebrates

Not surprisingly, aquatic macroinvertebrate communities were very poor at ED1 where substrate was highly mobile sand. The greatest diversity and abundance in these subcatchments was recorded at IPC1, where the bed habitat alternated between bedrock and sand. Extensive macrophyte beds and small pools also increased the habitat diversity at IPC1. The combination of bedrock and mobile sand patches at IPC1 is similar to RR10 (although bedrock and algal blooms are more extensive at the latter site), but aquatic invertebrate communities were more abundant and diverse at IPC1 than RR10.

TABLE 3.48 Taxa richness, total abundance, EPT richness, mean SIGNAL score and overall aquatic macroinvertebrate grade.					
Site	**Richness**	**Abundance**	**EPT Richness**	**SIGNAL Score**	**Macroinvertebrate Grade**
SB1	17	246	5	3.88	D+
ED1	12	277	7	5.00	F
IPC1	30	283	10	3.45	C

TABLE 3.49 Key stressors and management priorities for healthy aquatic macroinvertebrate communities in Eden and Iron Pot Creeks and Shannon Brook.		
Site	**Stressors**	**Management Priority**
SB1	Lack of available habitat through shallow channel with highly mobile sandy substrate.	Improve habitat complexity by maintaining mature riparian trees and instream wood loadings. Monitor rubbish dumping at this site.
ED1	Significant inputs of sandy fine sediments and highly mobile sandy substrate; shallow channel.	Reduce cattle access to river and maintain or improve riparian vegetation and instream wood loadings.
IPC1	Localised severe inputs of fine sediments smothering streambed and channel complexity (by infilling of small pools).	Weed control on exotic vine and Lantana to promote native midstorey; reduce cattle access to channel.

3.5 Bungawalbin, Myrtle and Sandy Creeks

Stream condition in Bungawalbin, Myrtle and Sandy Creeks was fair to good but below-average site scores reflect localized erosion (Table 3.50), or site-specific landuse. Riparian condition ranged from very good to poor with Myrtle and upper Bungawalbin Creek in good to fair condition. Noxious invasive weeds and disturbance significantly reduced riparian condition scores. Disturbance included active grazing pressure and evidence of clearing native vegetation, but also the lack of longitudinal and lateral connectivity to surrounding riparian, floodplain or hillslope vegetation.

Water quality was poor to very poor in Bungawalbin, Myrtle and Sandy Creeks where the ANZECC trigger thresholds for total and bioavailable nutrients were consistently exceeded, particularly for total phosphorus and bioavailable nitrogen. Chlorophyll *a* concentrations were consistently high, by more than double to five times the MER trigger thresholds. Aquatic macroinvertebrate communities were poor to very poor. Abundance and diversity were both very low, generally due to lack of habitat diversity in the shallow, sandy channels. Abundance and diversity of aquatic macroinvertebrates in spring was impacted by the very low flows observed during the latter half of 2014, when DO% saturation fell to below 28% - well below ANZECC trigger thresholds and a level that will influence the distribution of aquatic biota.

TABLE 3.50 Site-level Ecohealth grades for geomorphic condition, riparian condition, water quality, aquatic macroinvertebrate communities and overall site grades for Bungalwalbin, Myrtle and Sandy Creeks.

Sites	Geomorphic Condition	Riparian Condition	Water Quality	Aquatic Macroinvertebrates	Overall Site Grade
BC1	C-	D	F		F
BC2	C-	C-	D	F	D-
BC3	C-	C	D-	D-	D
MYC1	C+	B-	D+	D+	C
SC1	C+	F	F	D-	D

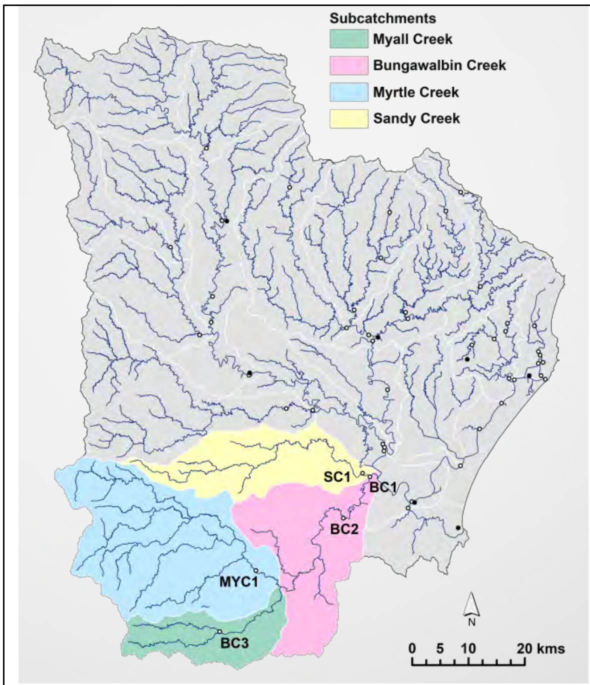
3.5.1 Landscape Context

The landscape units of the Bungawalbin, Myrtle and Sandy Creek subcatchments is dominated by low elevation hills, the Bungawalbin Plains and small areas of coastal floodplain (Alluvium, 2012). The geology of the low elevation hills are predominatly sandstones and siltstones (Tables 3.51, 3.52, 3.53). These standstones and siltstones underlie the Bungawalbin Plains. However, these plains are predominantly Quaternary alluvial landforms formed from the colluvia and alluvia of the sandstones (Figure 3.11d). The coastal floodplains at the lower reaches of Bungawalbin Creek are recent marine and estuarine sulfidic clays overlain by Quaternary alluvium.

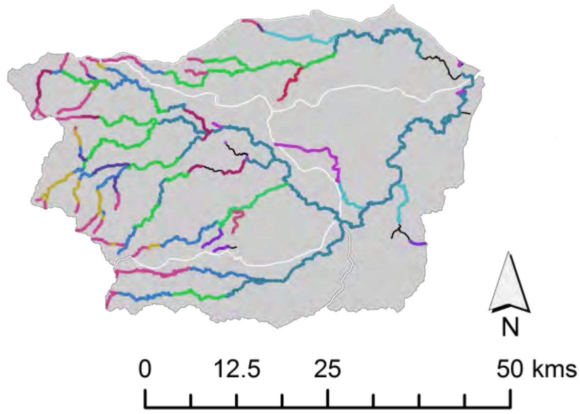
Poorly drained, dispersive Kurosols dominate the Bungawalbin Plains, with Hydrosols in stagnant, waterlogged areas of the Bungawalbin Plains and coastal floodplain (Tables 3.51, 3.52, 3.53). Potential acid sulphate soils are widely spread throughout the Bungawalbin Plains which have an elevation of 1m below sea level (Alluvium, 2012). Actual acid sulphate soils are present in the lower reaches of Sandy and Bungawalbin Creeks.

Partially unconfined valley settings dominate with planform controlled, sand and fine-grained sediments the dominant River Styles across the three subcatchments (Tables 3.51, 3.52, 3.53). Coarser substrates and confined valley settings comprise a significant proportion of total stream length in all three subcatchments, but these are located in low-order reaches arising from the low-elevation hills at the western extent of the subcatchments (Figure 3.11b).

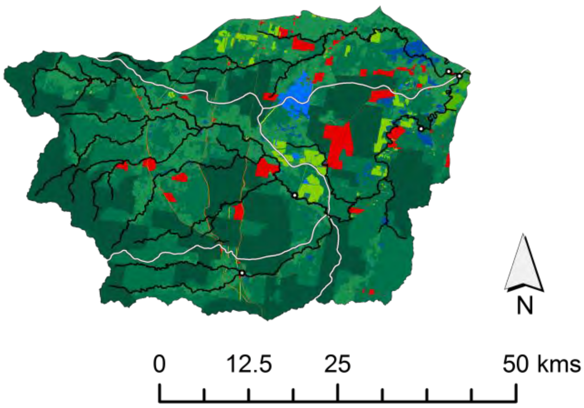
Native forests under multiple land tenures (national parks, state forests, plantations and rehabilitated residual forests) comprise 73% and 75% of Bungawalbin and Myrtle Creek subcatchments, respectively (Tables 3.51, 3.52). However, in Sandy Creek, grazing of native pastures is the dominant landuse, comprising 32% of area (Table 3.53).



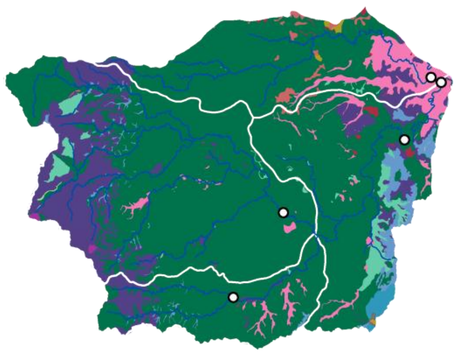
Location of subcatchments within the Richmond.



Riverstyles: refer to Fig. 2.5 for key.



Landuse: refer to Fig. 2.4 for key.



Soils: refer to Fig. 2.3 for key.

Figure 3.11 Subcatchments of Bungawalbin, Myrtle and Sandy Creeks, showing (a) locations of Ecohealth sites, (b) River Styles, (c) landuse, and (d) soils. Data layers from NC LLS and OEH (Soils).

TABLE 3.51 Subcatchment description of Bungawalbin and Myall Creeks. Data from NC LLS and OEH.	
Area	674.56 km^2
Geology	60% Sandstone; 36% Quaternary Alluvium; 4% Shales, siltstones, claystones and coal; <1% Basalt
Soils	48% Kurosols; 39% Hydrosols; 5% Rudosols and Tenosols; 4% Rudosols; 1% Podosols
Riverstyles	20% PCVS - Planform controlled, low sinuosity, gravel; 34% CVS – Headwater; 17% CVS - Floodplain pockets, sand; 10% LUV CC - Meandering, sand; 3% PCVS - Bedrock controlled, fine grained; 3% CVS - Floodplain pockets, fine grained; 8% CVS – Gorge; 1% PCVS - Planform controlled, low sinuosity, fine grained; 1% PCVS - Planform controlled, meandering, fine grained; 3% PCVS - Planform controlled, meandering, sand
Landuse	32% Residual and rehabilitated native forest; 28% State Forest; 13% Grazing natural pasture; 12% National Park; 4% Urban and Rural Residential; 3% Horticulture; 2% Farm dams, rivers and creeks; 2% Floodplain swamps; 1% Plantation Forest; 1% Utilities (transport and power); 1% Grazing improved pasture; 1% Cropping
Major point source discharge	Nil
Tree cover	73%

TABLE 3.52 Subcatchment description of Myrtle Creek. Data from NC LLS and OEH.	
Area	752.76 km^2
Geology	65% Sandstone; 29% Quaternary alluvium; 6% Shales, siltstones, claystones and coal; <1% andesite and diorite
Soils	53% Kurosols; 29% Rudosols and Tenosols; 11% Hydrosols; 3% Dermosols; 2% Rudosols
Riverstyles	22% PCVS – Planform controlled, meandering, sand; 21% LUV CC – Meandering, sand; 15% CVS Floodplain pockets, sand; 13% CVS – Headwater; 8% SMG – Cut and Fill; 7% CVS – Gorge; 5% SMG – Chain of ponds; 4% PCVS – Planform controlled, low sinuosity, sand; 2% SMG – Valley fill, fine grained; 2% SMG - Valley fill, sand; 1% LUV CC – Channelised Fill; 1% PCVS – Planform controlled, meandering, gravel
Landuse	32% residual or rehabilitated native cover; 31% State Forest; 8% National Park; 19% Grazing native pastures, graded pastures, pastures with significant regrowth; 3% softwood plantation; 2% rural residential; 1% Hardwood plantation; 1% Horticulture, particularly tea tree plantation; 1% Water ways, mainly farm dams; 1% Transport corridors; 1% Floodplain wetland
Major point source discharge	Nil
Tree cover	75%

TABLE 3.53 Subcatchment description of Sandy Creek. Data from NC LLS and OEH.	
Area	345.78 km^2
Geology	55% Sandstone, 42% Quaternary alluvium; 3% Basalt
Soils	44% Hydrosols; 30% Kurosols; 20% Kandosols; 4% Dermosols; <1% Rudosols and Tenosols
Riverstyles	38% PCVS Planform controlled, meandering sand; 26% LUV CC Meandering sand; 11% LUV CC Low sinuousity, fine grained; 11% CVS Headwater; 6% PCVS Planform controlled, low sinuosity, fine grained; 3% CVS Floodplain pockets, sand; 2% SMG Valley fill, sand; 1% PCVS Planform controlled, low sinuosity, sand; 1% LUV CC Channelised fill.
Landuse	32% grazing native pastures, 28% native forest, 12% State Forest, 7% softwood plantations, 4% urban or rural residential, 3% grazing improved pastures, 3% Tea Tree plantations, 3% farm dams, 3% floodplain swamps, 1% National Park, 1% transport corridors.
Major point source discharge	Nil
Tree cover	48%

3.5.2 Geomorphic Condition

Subcatchment-scale assessments of stream condition in Bungawalbin, Myrtle and Sandy Creeks were fair to good. Overall, the majority of stream channels are in moderate condition, with small percentages of poor condition recorded (Table 3.54). Site-scale assesssments of geomorphic condition generally agreed with subcatchment-scale assessments (Table 3.55). The low bank condition scores in the lower reaches of Bungawalbin Creek (BC1 and BC2) are due to localized areas of bank slumping at BC1, and undercutting exposing tree roots at BC2. The lower grade of D+ for bed condition at BC3 was predominantly driven by localized severe pugging and trampling associated with cattle accessing the stream. While not an indicator for geomorphic bed condition, it should be noted that the channel habitats at BC3 was highly diverse with many small pools. Sites assessed in Myrtle (MYC1) and Sandy Creeks (SC1) were in better geomorphic condition than the subcatchment average (Table 3.55). Both sites had little active erosion.

TABLE 3.54 Subcatchment-scale geomorphic condition calculated over the subcatchments' total stream length. Data from NC LLS.

Subcatchment	% Good Condition	% Moderate Condition	% Poor Condition	Geomorphic Grade
Bungawalbin Creek (including Myall Creek)	41	55	4	B-
Myrtle Creek	24	61	16	C
Sandy Creek	11	80	8	C

TABLE 3.55 Site-scale stream bed and stream bank geomorphic condition and overall site-scale geomorphic grade for Bungawalbin, Myrtle and Sandy Creeks.			
Site	Bank Condition Grade	Bed Condition Grade	Overall Geomorphic Grade
BC1	D	C	C-
BC2	D-	C+	C-
BC3	C-	D+	C-
MYC1	C	C+	C+
SC1	C+	C+	C+

3.5.3 Riparian Condition

Riparian condition ranged from very good to poor. Myrtle Creek (MYC1) and upper Bungawalbin Creek (BC3 at Whiporie) in good to fair condition were the best assessed riparian conditions in the subcatchments. Noxious invasive weeds reduced the scores for VEGETATION at all sites in Bungawalbin, Myrtle and Sandy Creek. The absence of standing or fallen dead trees reduced HABITAT scores. Poor disturbance scores in the lower Bungwalbin Creek (BC1) and Sandy Creek (SC1) was driven by active grazing pressure and clearing of the native vegetation, but also the lack of longitudinal and lateral connectivity of vegetation (Table 3.56). Riparian vegetation was continuous at BC2 and BC3, and riparian vegetation at both sites had good longitudinal and lateral connectivity to surrounding native forests.

TABLE 3.56 Site-scale riparian conditions for estuarine and freshwater reaches of Bungawalbin, Myrtle and Sandy Creeks.				
Site	Vegetation	Habitat	Disturbance	Overall Riparian Grade
BC1	D	D-	D	D
BC2	D	F	B+	C-
BC3	C	C	C-	C
MYC1	C-	B+	B+	B-
SC1	F	C+	D-	D

TABLE 3.57 Site-scale riparian vegetation and key stressors of Bungawalbin, Myrtle and Sandy Creeks.		
Site	**Vegetation Community Description**	**Key Stressors**
BC1	Scattered emergent Eucalypt trees with dense Cockspur Coraltree shrub layer containing abundant Tea trees and Castor Oil Bushes. Morning Glory vine abundant.	Invasive exotic species. Improve longitudinal and lateral connectivity of riparian vegetation.
BC2	Talled closed Water Gum – Paperbark forest with scattered Tea Tree- *Callistamon* shrubs.	Exotic grasses present in littoral zone.
BC3	Tall closed Eucalypt forest with *Callistamon* – Tea Tree shrub layer with scattered Lantana and Castor Oil Plant. Native grass understorey with exotic groundcover. Instream macrophytes include *Nyphoides*, Water Primrose, Water Couch and Knotweed. Exotic vine present through canopy and midstorey.	Direct grazing pressure and trampling; invasive exotic species.
MYC1	Low, closed dry sclerophyll forest with abundant regeneration. *Lomandra* and Parrot's Feather in litterol zone.	Increase in area covered by Parrot's Feather.
SC1	Clumps of River Oak trees with scattered Eucalypt trees and one Camphor Laurel tree. Shrub layer dominataed by Cockspur Coraltree and an exotic vine at water's edge. Grassey understorey interspersed with Lomandra.	Direct grazing pressure and trampling: invasive woody weeds and vines.

3.5.4 Water Quality

Water quality was poor to very poor in Bungawalbin, Myrtle and Sandy Creeks (Tables 3.58, 3.59, 3.60 and 3.61). The lower reaches of Bungawalbin and Sandy Creeks (BC1 and SC1, respectively) consistently exceeded the ANZECC trigger thresholds for total and bioavailable nutrients (Table 3.61): total phosphorus by more than double and bioavailable nitrogen by more than three times ANZECC trigger thresholds (Table 3.59). Phosphorus (total and available concentrations) were much lower in the upper Bungawalbin and Myrtle subcatchments with their higher proportion of sandstone. Chlorophyll *a* consistently exceeded MER trigger thresholds (Table 3.60), by more than double to five times the trigger thresholds (Table 3.59).

The estuarine reaches of Bungawalbin Creek (BC1) remained turbid for the duration of the sampling period (Tables 3.59, 3.60). DO% saturation fell well below ANZECC trigger thresholds on most sampling occasions, particularly during the below-average discharges observed during the latter half of 2014 where saturation fell below 28% (Tables 3.58, 3.60).

TABLE 3.58 Ranges (and means) for temperature, pH, conductivity, salinity, DO% and turbidity.

Site	Times sampled	Temperature (°C)	pH	Conductivity (µS/cm)	Salinity (PPT)	DO (%)	Turbidity (NTU)
BC1	6	14.84 – 28.61 (23.67)	6.91 – 9.12 (7.71)	0.207 – 0.733 (0.374)	0.10 – 0.36 (0.18)	50.1 – 95.5 (79.2)	11.8 – 43.0 (21.1)
BC2	6	12.18 – 26.70 (21.92)	6.36 – 8.11 (7.20)	0.139 – 0.191 (0.163)	0.07 – 0.09 (0.08)	41.6 – 75.2 (52.4)	16.8 – 32.1 (23.8)
BC3	6	9.91 – 27.62 (19.89)	6.32 – 8.02 (7.21)	0.203 – 0.240 (0.228)	0.10 – 0.12 (0.11)	27.8 – 60.4 (45.4)	5.1 – 22.1 (12.3)
MYC1	6	16.61 – 25.21 (20.22)	6.60 – 8.50 (7.60)	0.211 – 0.317 (0.280)	0.10 – 0.15 (0.13)	42.0 – 85.9 (62.1)	3.8 – 18.6 (9.1)
SC1	6	14.51 – 28.82 (23.41)	6.48 – 7.96 (7.26)	0.248 – 0.482 (0.346)	0.12 – 0.23 (0.17)	41.1 – 80.4 (54.5)	10.9 – 46.9 (24.5)

TABLE 3.59 Ranges (and means) for chlorophyll *a*, total suspended solids, total nitrogen, total phosphorus, bioavailable nitrogen and soluble reactive phosphorus.

Site	Chl-a (µg/L)	TSS (mg/L)	TN (µg/L)	TP (µg/L)	NOx (µg/L)	SRP (µg/L)
BC1	5.24 – 28.68 (15.1)	5.20 – 24.39 (12.65)	531 – 968 (710)	32 – 472 (131)	42 – 311 (157)	13 – 33 (23)
BC2	1.63 – 11.82 (6.32)	9.03 – 22.90 (14.78)	580 – 948 (774)	21 – 450 (102)	62 – 196 (141)	8 – 70 (21)
BC3	5.64 – 31.06 (15.72)	3.83 – 25.12 (11.27)	577 – 1052 (834)	14 – 109 (53)	24 – 353 (193)	5 – 100 (24)
MYC1	1.06 – 19.89 (8.46)	4.20 – 45.00 (15.49)	575 – 1223 (795)	18 – 74 (33)	40 – 293 (154)	5 – 56 (16)
SC1	5.15 – 16.36 (11.27)	2.71 – 33.04 (10.56)	411 – 1199 (704)	33 – 326 (119)	18 – 296 (119)	7 – 50 (27)

TABLE 3.60 The number of times sampled and exceedances[1] for pH, conductivity, DO%, turbidity and chlorophyll *a*.

Site	Number of measurements	pH	Conductivity	DO %	Turbidity	Chl-a
BC1	6	2 (33%) 1, 1	0	3 (50%) 3, 0	6 (100%)	6 (100%)
BC2	6	2 (33%) 1, 1	0	6 (100%) 6, 0	0	4 (67%)
BC3	6	2 (33%) 1, 1	0	6 (100%) 6, 0	0	6 (100%)
MYC1	6	2 (33%) 0, 2	0	4 (67%) 4, 0	0	4 (67%)
SC1	6	1 (17%) 1, 0	0	5 (83%) 5, 0	0	6 (100%)

[1] Numbers in black represent the total number and percent of exceedances. Numbers in blue and red represent the numbers of measurements lower than the minimum threshold and higher than the maximum threshold, respectively. The number of exceedances includes all depths sampled so may be greater than the number of times sampled. Turbidity and chlorophyll *a* only have maximum trigger thresholds.

TABLE 3.61 Exceedances[1] for total nitrogen, total phosphorus, bioavailable nitrogen, soluble reactive phosphorus, and the overall water quality grade.					
Site	**TN**	**TP**	**NOx**	**SRP**	**WQ Grade**
BC1	6 (100%)	6 (100%)	6 (100%)	6 (100%)	F
BC2	6 (100%)	1 (17%)	6 (100%)	1 (17%)	D
BC3	6 (100%)	3 (50%)	5 (83%)	1 (17%)	D-
MYC1	6 (100%)	1 (17%)	5 (83%)	1 (17%)	D+
SC1	5 (83%)	4 (67%)	5 (83%)	4 (67%)	F

[1] Numbers represent the total number and percent of exceedances. There are only maximum trigger thresholds for nutrients.

TABLE 3.62 Key stressors and management priorities for water quality in Bungawalbin, Myrtle and Sandy Creeks.		
Site	**Stressor**	**Management Priority**
BC1	High nutrient concentrations particularly total and bioavailable nitrogen; high chlorophyll-*a* concentrations	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
BC2	High nutrient concentrations particularly total and bioavailable nitrogen; low DO%	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients
BC3	High nutrient concentrations particularly bioavailable nitrogen; high chlorophyll-*a* concentrations; low DO%	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients); reduce stock access to channel.
MYC1	High nutrient concentrations particularly bioavailable nitrogen; low DO%	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients) upstream of site.
SC1	High total and bioavailable nutrient concentrations; high chlorophyll-*a* concentrations; low DO%	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients); reduce stock access to channel.

3.5.5 Aquatic Macroinvertebrates

Aquatic macroinvertebrate communities were poor to very poor across the subcatchments. The lack of habitat diversity at BC2 likely contributed to very low richness (6 taxa) and abundance (only 14 individuals). Habitat at this site consisted of deep, slow, highly turbid pools with soft sediments. Large woody debris forms an important component of habitat complexity at this site. The low SIGNAL score indicates that only taxa capable of living in polluted environments were observed at this site (Table 3.63). SC1 similarly lacks habitat heterogeneity and richness, EPT richness and abundance were similarly low at SC1 as BC2 (Table 3.63).

Richness and abundance were significantly greater upstream at BC3 and were the highest recorded across the subcatchments. The low EPT score reduced the overall site score for aquatic macroinvertebrates (Table 3.63). The low EPT richness was due to very flow flows disconnecting pools and the lack of habitat availability for EPT taxa inherent in sand-bed streams.

TABLE 3.63 Taxa richness, total abundance, EPT richness, mean SIGNAL score and overall aquatic macroinvertebrate grade.

Site	Richness	Abundance	EPT Richness	SIGNAL Score	Macroinvertebrate Grade
BC1					
BC2	5	14	0	2.83	F
BC3	19	226	2	2.96	D-
MYC1	15	116	5	3.61	D+
SC1	6	50	0	3.33	D-

TABLE 3.64 Key stressors and management priorities for healthy aquatic macroinvertebrate communities in Bungawalbin, Myrtle and Sandy Creeks.

Site	Stressor	Management Priority
BC1		
BC2	Lack of habitat diversity	Maintain instream wood loadings; reduce suspended sediment loads.
BC3	Very low flows	Maintain site conditions
MYC1	Invasion of Parrot's Foot	Irradicate Parrot's Foot before it becomes widespread.
SC1	Lack of habitat diversity	Maintain instream wood loadings; reduce suspended sediment loads.

3.6 Emigrant, Maguires, North and Chickiba Creeks

Catchment-scale geomorphic condition was assessed as poor for Emigrant and Maguires Creeks, and fair for North Creek. Site-scale assessments recorded slightly better scores than the subcatchment averages. High benthic silt loads were observed at the tidal limits of Emigrant and Maguires Creeks. Overall, riparian condition was poor or very poor due to the dominance of invasive exotic species in freshwater reaches and clearing of mangroves in the lower estuarine reaches of North Creek. Typically, estuarine sites scored well for longitudinal connectivity of riparian zones but connectivity with floodplain or hillslope vegetation was more fragmented in freshwater reaches due to extensive cropping, horticulture and urban development. Noxious invasive weeds such as Lantana and Privet dominate the riparian zones of freshwater reaches.

Aquatic macroinvertebrate communities were in good condition in the upper reaches of Emigrants and Maguires Creeks with habitat diversity good, pool-riffle sequences, and submerged and emergent instream vegetation present. However, water quality was fair to very poor across Emigrants, Maguires and North Creeks with exceedances of ANZECC trigger thresholds common across all sites for both total and bioavailable nutrients. North Creek was consistently acidic and DO% was consistently low.

TABLE 3.65 Site-level Ecohealth grades for geomorphic condition, riparian condition, water quality, aquatic macroinvertebrate communities and overall site grades for Emigrant, Maguires, North and Chickiba Creeks.

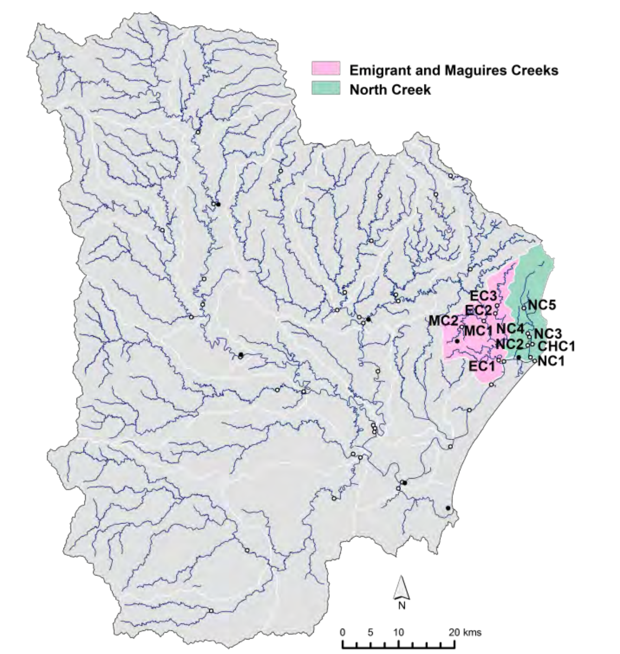
Sites	Geomorphic Condition	Riparian Condition	Water Quality	Aquatic Macroinvertebrates	Overall Site Grade
EC1	C	F	D-		D
EC2	C+	F	F		D-
EC3	C+	D+	C+	C	C+
MC1	C	F	D	C	D+
MC2	B-	F	C-	C	C
NC1	C+	F	C-		D+
NC2	B-	C-	C-		C
NC3	B-	C-	D-		C-
NC4	B-	C-	D-		C-
NC5	C	D-	F		D-
CHC1	B-	D	F		D+

3.6.1 Landscape Context

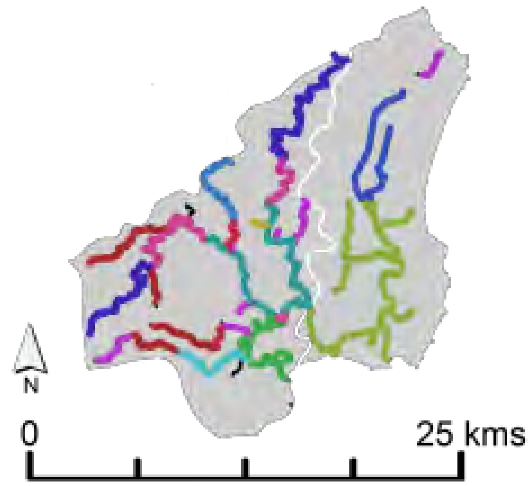
Emigrant, Maguires and North Creeks drain the volcanic Alstonville Plateau. Tertiary basalt has given rise to deep, red Ferrosols at higher elevations, and shallow dark Dermosols on the coastal hills (Figure 3.12d). The coastal margin is underlain by small areas of coastal floodplains where deep, clay-rich Dermosols overlie sulfidic grey clays (Hydrosols): Hydrosols are the dominant soil in Emigrant and Maguires Creeks (Table 3.66). Coastal sandplains lie between the Alstonville Plateau and northern coastal boundary of North Creek: here Hydrosols and Podosols dominate the backbarrier swamps, stream channels and tidal mangrove flats (Tables 3.66, 3.67). Localised acid sulfate soils are present in intertidal areas (Alluvium, 2012).

Confined and partially confined valleys drain the Alstonville Plateau, with coastal streams dominated by laterally unconfined fine-grained substrates, channelized fills, or tidal reaches (Tables 3.66, 3.67). While very little of the total stream length in Emigrant and Maguires subcatchments are tidal (<1%, Table 3.66), 72% of the total stream length in North Creek subcatchment is tidal, with the remainder channelized fill or channelized coastal peat swamps (Table 3.67).

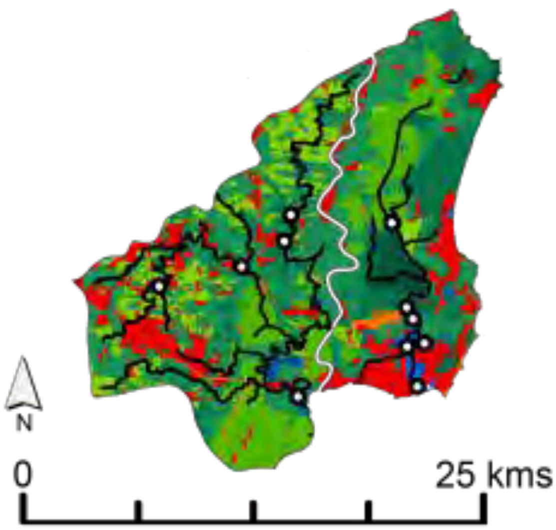
The soils on the Alstonville Plateau are among the most fertile of the North Coast (Alluvium, 2012), and 30% of the Emigrant and Maguires subcatchments are either intensive cropping or horticulture (Figure 3.12c, Table 3.66). Urban development also accounts for 15% of subcatchment area. In contrast, only 1% of subcatchment area in North Creek is used for cropping (Table 3.67). The dominant land tenure in North Creek is National Park (67%), but the subcatchment contains the large urban centre of Ballina.



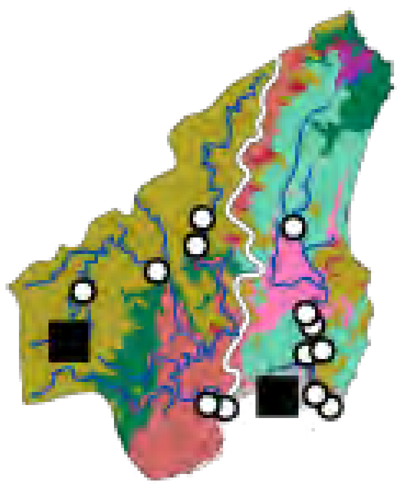
Location of subcatchments within the Richmond.



Riverstyles: refer to Fig. 2.5 for key.



Landuse: refer to Fig. 2.4 for key.



Soils: refer to Fig. 2.3 for key.

Figure 3.12 Subcatchments of Emigrant, Maguires, North and Chickiba Creeks, showing (a) locations of Ecohealth sites, (b) River Styles, (c) landuse, and (d) soils. Data layers from NC LLS and OEH (Soils).

TABLE 3.66 Subcatchment description of Emigrant and Maguires Creeks. Data from NC LLS and OEH.	
Area	160.25 km^2
Geology	65% Basalt; 18% Coastal dunes; 9% Siltstone and conglomerate; 7% Quaternary alluvium; <1% Sandstone
Soils	30% Hydrosols; 25% Podosols; 22% Ferrosols; 12% Kurosols; 5% Not Accessed; 2% Vertosols
Riverstyles	21% PCVS - Planform controlled, low sinuosity, fine grained; 20% CVS - Floodplain pockets, gravel; 15% CVS - Floodplain pockets, fine grained; 13% CVS – Headwater; 10% LUV CC - Meandering, fine grained; 9% LUV CC - Channelised fill; 6% LUV CC - Low sinuosity, fine grained; 6% CVS - Floodplain pockets, sand; 1% CVS – Gorge; 1% Water storage
Landuse	41% Grazing native pasture including degraded land; 15% Cropping; 15% Horticulture; 15% Urban development and transport network; 6% Camphor Laurel forest; 3% Rehabilitated and residual native cover; 2% Farms dams, canals and water ways; 1% Floodplain swamp; 1% Plantation forest;
Major point source discharge	Nil
Tree cover	10%

TABLE 3.67 Subcatchment description of North Creek (including Chickiba Creek). Data from NC LLS and OEH.	
Area	121.99 km^2
Geology	54% Coastal dunes; 21% Basalt; 10% Quaternary colluvium; 6% Siltstone and conglomerate; 5% Sandstone; 2% Quaternary alluvium
Soils	64% Ferrosols; 22% Hydrosols; 12% Kurosols; 1% Vertosols; 1% Water
Riverstyles	72% LUV CC – Tidal; 24% LUV CC – Channelised peat swamp; 4% LUV CC Channelised fill
Landuse	67% National Park; 27% Grazing of native pasture; 1% Residual native cover; 1% urban; 1% cropping (Sugar Cane); 1% water (farm dams, waterways, reservoirs)
Major point source discharge	Ballina sewage treatment plant (discharges to Fishery Creek which connects North Creek to the Richmond River).
Tree cover	68%

3.6.2 Geomorphic Condition

Catchment-scale geomorphic condition was assessed as poor for Emigrant and Maguires Creeks, and fair for North Creek (Table 3.68). No streams in these subcatchments were in good condition. Site-scale assessments were slightly better than the subcatchment average (Table 3.69). These were predominantly due to relatively stable banks (no obvious erosion).

Site location was significant for NC5 (at Ross lane) and Chickiba Creek (CHC1). Upstream of the road crossing at NC5, the creek is channelized for sugar cane drainage. However, the natural channel is more intact downstream of the road crossing and mangroves dominate the intertidal zone. Similarly at CHC1, one side of the road crossing is heavily modified while the other side of the road crossing is not. Site-scale assessments averaged over both geomorphic conditions.High benthic silt loads were observed at EC2 near the tidal limit of Emigrants Creek and MC1 (Table 3.69).

TABLE 3.68 Subcatchment-scale geomorphic condition calculated over the subcatchments' total stream length. Data from NC LLS.

Subcatchment	% Good Condition	% Moderate Condition	% Poor Condition	Geomorphic Grade
Emigrant and Maguires Creeks	0	69	31	D+
North Creek (including Chickiba Creek)	0	100	0	C

TABLE 3.69 Site-scale stream bed and stream bank geomorphic condition and overall site-scale geomorphic grades for Emigrant, Maguires, North and Chickiba Creeks.

Site	Bank Condition Grade	Bed Condition Grade	Overall Geomorphic Grade
EC1	C		C
EC2	C+	C	C+
EC3	B-	C+	C+
MC1	C+	C	C
MC2	B-	B-	B-
NC1	C+		C+
NC2	B-		B-
NC3	B-		B-
NC4	B-		B-
NC5	C		C
CHC1	B-		B-

3.6.3 Riparian Condition

Overall, riparian condition was poor or very poor in Emigrants, Maguires and North Creeks (Table 3.70). Poor scores for VEGETATION were due to the dominance of invasive exotic species in freshwater reaches and loss of mangroves in the lower estuarine reaches of North Creek. HABITAT scores were low due to the absence or scarcity of standing or fallen dead trees and logs (Table 3.70). DISTURBANCE scores were generally better as most freshwater reaches were fenced or residual native vegetation, and most estuarine reaches (except North Creek) retained extensive mangrove communities. Therefore, except for the lower estuarine reaches, sites scored well for longitudinal connectivity of riparian zones. Lateral connectivity with floodplain or hillslope vegetation was more fragmented, particularly in Emigrant and Maguires Creeks with the significant cropping, horticulture and urban landuses (each 15% of subcatchment area, Table 3.66).

The single greatest management challenge in freshwater reaches in Emigrants and Maguires Creeks is control of aggressive exotic woody shrubs such as Lantana and Privet. The capacity to increase riparian vegetation (mangroves) in the lower North Creek estuary is likely limited, so it is important to maintain the existing mangrove vegetation in the mid and upper estuary.

TABLE 3.70 Site-scale riparian conditions for estuarine and freshwater reaches of Emigrant, Maguires, North and Chickiba Creeks.

Site	Vegetation	Habitat	Disturbance	Overall Riparian Grade
EC1	F	F	D	F
EC2	F	F	C-	F
EC3	C	F	C	D+
MC1	F	F	C-	F
MC2	F	F	D	F
NC1	F	F	D+	F
NC2	D	C	C	C-
NC3	D+	D	C	C-
NC4	D+	D-	B	C-
NC5	F	F	C	D-
CHC1	D-	D	D+	D

TABLE 3.71 Site-scale riparian vegetation and key stressors of Emigrant, Maguires, North and Chickiba Creeks.		
Site	**Vegetation Community Description**	**Key Stressors**
EC1	Closed mangrove forest with scattered, emergent Eucalypt trees. The right bank has been extensively cleared for cropping and narrow, scattered clumps of fringing mangroves remain.	Clearing of riparian zone (right bank).
EC2	Scattered tall Eucalypt trees remain but the riparian zone is dominated by dense invasive exotic woody shrubs with significant Coastal Morning Glory vine. The understorey is exotic grasses.	Weed control of invasive exotic shrubs and vines.
EC3	Subtropical rainforest remnant but canopy dominated by Camphor Laurel trees, with Lantana and Privet widespread through midstorey. Abundant native aquatic plants occur instream (Knotweed, *Nymphoides*). Invasive exotic groundcovers such as Wandering Dew and Mile-A-Minute are abundant.	Weed control of Lantana and Privet in midstorey and invasive exotic groundcovers.
MC1	Camphor Laurel forest with privet midstorey. Native subtropical species do occur throughout midstorey. Understorey dominated by exotic grasses.	Weed control of Camphor Laurel and Privet. Revegetation of native subtropical species.
MC2	Narrow, scattered clumps of Camphor Laurel trees and Privet and Lantana understorey. Exotic grasses dominate the understorey.	Weed control and revegetation of native subtropical species.
NC1	Scattered single pine trees and low grassey understorey. Riparian zone removed on right bank but mangroves fringe left bank with scattered mature Eucalypt trees located at the terrestrial margin.	Maintain vegetation on left bank.
NC2	Narrow strip of fringing mangroves. Scattered mature Eucalypt trees at the terrestrial margin.	Maintain fringing mangroves.
NC3	Dense mangrove forest connected to Ballina Nature Reserve.	Maintain mangrove communities and connectivity to Ballina Nature Reserve.
NC4	With exception of immediately adjacent to airport runway, dense mangrove forests fringe the estuary and tall, closed Paperbark forest dominates the terrestrial margin and Ballina Nature Reserve.	Maintain vegetation communities. Control small patches of invasive reeds and groundcover at runway edges.
NC5	Cane field upstream of crossing and fringing, intertidal mangrove forest downstream of road crossing.	Maintain mangrove communities.
CHC1	Intertidal mangroves with occasionial River Oak saplings and mature Eucalypt trees. Bordered by residential area upstream of road crossing and farming downstream of crossing.	Maintain mangrove communities.

3.6.4 Water Quality

Water quality was fair to very poor across Emigrants, Maguires and North Creeks (Tables 3.72, 3.73, 3.74, 3.76). Estuarine water quality was very poor in Emigrants and Maguires Creeks, predominantly driven by concentrations of bioavailable nutrients consistently exceeding ANZECC trigger thresholds by more than four times for phosphorus and more than seven times for nitrogen (Tables 3.73, 3.75). Very high concentrations of chlorophyll *a* at EC2 were associated with an algal bloom early in the study period (Table 3.73).

Water quality in North Creek improved with increased tidal flushing. Nutrient concentrations typically decreased longitudinally downstream, although exceedances of ANZECC trigger thresholds were common across all sites for both total and bioavailable nutrients (Tables 3.73, 3.75). Significantly, pH was consistently more acidic than the lower trigger threshold (Table 3.74), with the lowest observation of 4.38 (Table 3.72). Likewise, DO% consistently fell below the ANZECC trigger threshold of 80% (Table 3.74), especially at the upper site NC5 (Table 3.72). Inputs of total suspended soils from NC5 were consistently high for an estuarine system and stayed in suspension for the length of the estuary (Table 3.73).

TABLE 3.72 Ranges (and means) for temperature, pH, conductivity, salinity, DO% and turbidity.

Site	Times sampled	Temperature (°C)	pH	Conductivity (µS/cm)	Salinity (PPT)	DO (%)	Turbidity (NTU)
EC1	12	17.49 – 24.90 (21.778)	7.44 – 9.19 (8.08)	10.03 – 53.4 (43.6)	6.87 – 35.12 (28.23)	66.5 – 108.5 (92.25)	2.7 – 20.8 (7.8)
EC2	6	13.50 – 26.28 (21.33)	5.90 – 7.63 (7.00)	0.108 – 6.16 (1.52)	0.05 – 3.34 (0.807)	46.4 – 91.3 (71.4)	4.3 – 31.3 (13.9)
EC3	6	13.56 – 26.89 (20.90)	6.69 – 8.11 (7.42)	0.105 – 0.139 (0.122)	0.01 – 0.07 (0.05)	48.3 – 103.1 (80.73)	3.9 – 8.5 (6.1)
MC1	6	13.70 – 27.89 (21.33)	6.52 – 8.10 (7.39)	0.062 – 0.143 (0.114)	0.03 – 0.07 (0.057)	66.9 – 103.5 (86.9)	4.6 – 29.7 (9.9)
MC2	6	13.8 – 26.8 (20.963)	6.42 – 8.20 (7.35)	0.118 – 0.144 (0.130)	0.06 – 0.07 (0.065)	48.7 – 98.7 (76.1)	3.8 – 32.3 (9.9)
NC1	12	17.97 – 23.01 (20.93)	7.63 – 9.21 (8.28)	39.4 – 56.1 (53.9)	24.42 – 37.6 (35.4)	79.5 – 111.5 (99.2)	0.6 – 8.6 (3.3)
NC2	12	16.05 – 25.80 (21.04)	7.52 – 8.31 (7.93)	9.24 – 55.1 (46.9)	4.98 – 36.4 (31.0)	88.4 – 106 (97.0)	1.2 – 28.2 (5.5)
NC3	11	17.08 – 27.30 (21.71)	6.74 – 8.18 (7.57)	1.60 – 54.0 (42.8)	0.81 – 35.7 (27.7)	68.4 – 100.5 (84.6)	3.1 – 25.9 (8.1)
NC4	11	16.97 – 25.55 (20.81)	6.32 – 8.10 (7.44)	1.45 – 54.8 (38.9)	0.51 – 36.3 (25.0)	66.8 – 93.8 (82.2)	3.1 – 24.8 (7.4)
NC5	12	15.7 – 27.1 (21.8)	4.38 – 8.05 (6.33)	0.222 – 50.4 (21.6)	0.00 – 54.0 (19.57)	57.6 – 79.1 (68.4)	2.0 – 41.9 (12.8)
CHC1	12	17.2 – 26.5 (22.31)	6.42 – 8.25 (7.55)	2.82 – 51.2 (41.2)	0.15 – 33.6 (26.63)	93.8 – 131.1 (113.2)	2 – 31 (8.4)

TABLE 3.73 Ranges (and means) for chlorophyll *a*, total suspended solids, total nitrogen, total phosphorus, bioavailable nitrogen and soluble reactive phosphorus.

Site	Chl-a (µg/L)	TSS (mg/L)	TN (µg/L)	TP (µg/L)	NOx (µg/L)	SRP (µg/L)
EC1	1.15 – 11.95 (3.94)	13.40 – 45.06 (20.50)	92 – 774 (391)	23 – 301 (68)	31 – 257 (106)	12 – 47 (25)
EC2	0.99 – 47.2 (19.7)	2.8 – 25.24 (10.30)	385 – 886 (623)	26 – 393 (105)	133 – 231 (162)	11 – 47 (22)
EC3	0.30 – 3.39 (1.97)	0.7 – 10 (3.07)	404 – 878 (597)	17 – 293 (77)	105 – 425 (199)	7 – 14 (12)
MC1	1.04 – 2.29 (1.70)	1.70 – 6.42 (3.50)	366 – 1091 (624)	22-342 (82)	54 – 311 (153)	6 – 57 (25)
MC2	0.23 – 4.72 (1.97)	1.10 – 3.80 (2.57)	313 – 1277 (803)	10 – 367 (79)	45 – 551 (219)	6 – 25 (13)
NC1	0.66 – 9.50 (2.15)	12.70 – 25.30 (17.57)	195 – 788 (341)	10 – 125 (39)	10 – 353 (115)	3 – 123 (21)
NC2	1.35 – 4.04 (2.10)	14.5 -31.4 (19.28)	69 – 1092 (454)	11 – 265 (50)	14 – 284 (97)	4 – 174 (28)
NC3	1.12 – 12.49 (3.87)	8.83 – 36.93 (19.87)	143 – 1009 (469)	15 – 220 (54)	31 – 318 (136)	6 – 43 (19)
NC4	1.51 – 12.61 (4.17)	11.88 – 27.34 (17.17)	172 – 950 (549)	21 – 96 (41)	13 – 251 (112)	6 – 48 (19)
NC5	1.95 – 19.8 (7.82)	5.00 – 36.00 (18.81)	325 – 1187 (654)	13 – 306 (62)	2 – 573 (164)	5 – 47 (16)
CHC1	1.32 – 9.36 (4.09)	3.20 – 36.10 (20.00)	245 – 2449 (695)	17 – 218 (60)	26 – 539 (136)	7 – 39 (17)

TABLE 3.74 The number of times sampled and exceedances[1] for pH, conductivity, DO%, turbidity and chlorophyll *a*.

Site	Times Sampled	pH	Conductivity	DO %	Turbidity	Chl-a
EC1	12	11 (26%) 0, 11	-	1 (2%) 1, 0	10 (23%)	5 (42%)
EC2	6	3 (50%) 3, 0	-	4 (67%) 4, 0	2 (33%)	5 (83%)
EC3	6	1 (17) 0, 1	3 (50%) 3, 0	2 (33%) 2, 0	0	0
MC1	6	1 (17%) 1, 0	-	3 (50%) 3, 0	1 (17%)	0
MC2	6	2 (33%) 1,1	3 (50%) 3, 0	3 (50%) 3, 0	0	1 (17%)
NC1		11 (28%) 0, 11	-	5 (13%) 2, 3	0	1 (8%)
NC2		0	-	0	2 (8%)	1 (9%)
NC3		5 (16%) 5, 0	-	6 (26%) 6, 0	4 (13%)	5 (42%)
NC4		3 (14%) 3, 0	-	7 (37%) 7, 0	2 (9%)	4 (40%)
NC5		19 (68%) 19, 0	-	2 (100%) 2, 0	10 (36%)	6 (50%)
CHC1		8 (31%) 8, 0	-	2 (67%) 0, 2	3 (12%)	6 (50%)

[1] Numbers in black represent the total number and percent of exceedances. Numbers in blue and red represent the numbers of measurements lower than the minimum threshold and higher than the maximum threshold, respectively. The number of exceedances includes all depths sampled so may be greater than the number of times sampled. Turbidity and chlorophyll *a* only have maximum trigger thresholds.

TABLE 3.75 Exceedances[1] for total nitrogen, total phosphorus, bioavailable nitrogen, soluble reactive phosphorus, and the overall water quality grade.

Site	TN	TP	NOx	SRP	WQ Grade
EC1	8 (67%)	7 (58%)	12 (100%)	12 (100%)	D-
EC2	6 (100%)	4 (67%)	6 (100%)	6 (100%)	F
EC3	3 (50%)	2 (33%)	6 (100%)	0	C+
MC1	6 (100%)	3 (50%)	6 (100%)	6 (100%)	D-
MC2	5 (83%)	1 (17%)	6 (100%)	1 (17%)	C-
NC1	5 (42%)	4 (33%)	11 (92%)	11 (92%)	C-
NC2	6 (55%)	3 (27%)	10 (91%)	10 (91%)	C-
NC3	11 (92%)	5 (42%)	12 (100%)	12 (100%)	D-
NC4	9 (82%)	4 (36%)	10 (91%)	11 (100%)	D-
NC5	12 (100%)	7 (58%)	11 (92%)	10 (83%)	F
CHC1	10 (83%)	9 (75%)	12 (100%)	12 (100%)	F

[1] Numbers represent the total number and percent of exceedances. There are only maximum trigger thresholds for nutrients.

TABLE 3.76 Key stressors and management priorities for water quality in Emigrant, Maguires, North and Chickiba Creeks.

Site	Stressor	Management Priority
EC1	Very high total and bioavailable nutrient concentrations.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
EC2	Very high total and bioavailable nutrient concentrations; very high chl-*a* concentrations; low DO%.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
EC3	Occasional high concentrations of bioavailable nitrogen.	Reduce non-point source pollution (fine sediments and terrestrially-derived nutrients).
MC1	High total and very high bioavailable nitrogenconcentrations.	Investigate sources of nitrogen to stream channel.
MC2	High total and very high bioavailable nitrogenconcentrations.	Investigate sources of nitrogen to stream channel.
NC1	High concentrations of bioavailable nutrients.	Investigate ways to improve quality of water exiting the cane fields.
NC2	Very high concentrations of bioavailable nutrients.	Investigate ways to improve quality of water exiting the cane fields. Investigate point-source discharge from Ballina sewage treatment plant.
NC3	Very high concentrations of bioavailable nutrients.	Investigate ways to improve quality of water exiting the cane fields.
NC4	Very high concentrations of bioavailable nutrients; acidic discharge from the upstream site draining cane fields; low DO%.	Investigate ways to improve quality of water exiting the cane fields.
NC5	Very high concentrations of bioavailable nutrients; acidic discharge from the upstream site draining cane fields; low DO%.	Investigate ways to improve quality of water exiting the cane fields.
CHC1	Very high concentrations of bioavailable nutrients; acidic discharge.	Investigate sources of nutrients from surrounding residential areas.

3.6.5 Aquatic Macroinvertebrates

Aquatic macroinvertebrate communities were in good condition in the upper Emigrants and Maguires Creeks (EC3 and MC2, respectively). Habitat diversity was good, with pool-riffle sequences, and submerged and emergent instream vegetation. Water quality was fair at both sites. EPT richness was low for cobble-bed streams, and this may be due to the below-average rainfall and very low flows through the second half of the study period (Table 3.77). A blue-green algal bloom was present at EC3 at the beginning of the study.

TABLE 3.77 Taxa richness, total abundance, EPT richness, mean SIGNAL score and overall aquatic macroinvertebrate grade.

Site	Richness	Abundance	EPT Richness	SIGNAL Score	Macroinvertebrate Grade
NC1					
NC2					
NC3					
NC4					
NC5					
CHC1					
EC1					
EC2					
EC3	22	222	7	4.54	C
MC1					
MC2	19	329	10	4.65	C

TABLE 3.78 Key stressors and management priorities for healthy aquatic macroinvertebrate communities in Emigrants and Maguires Creeks.

Site	Stressor	Management Priority
NC1		
NC2		
NC3		
NC4		
NC5		
CHC1		
EC1		
EC2		
EC3	Reduced flow minimizing habitat availability; water quality (algal bloom)	Maintain stream condition; further investigation required.
MC1		
MC2	Reduced flow minimizing habitat availability; water quality	Maintain stream condition; further investigation required.

PART 4

4 SUMMARY OF MAIN FINDINGS, MANAGEMENT ISSUES AND RECOMMENDATIONS

4.1 Main Findings

4.1.1 Geomorphic Condition

- Geomorphic condition ranged from good to poor throughout the freshwater and estuarine reaches of the Richmond. The subcatchment-scale assessment of stream condition aligned with the site-scale geomorphic assessment, identifying the upper freshwater reaches were predominantly in good or moderate condition, particularly those in conservation reserves. Estuarine reaches were mostly in poor condition with evidence of active erosion.
- The areas of poorest geomorphic condition were where the riparian zone had been completely cleared for cropping (sugarcane) extending to the top of bank. These areas were characterized by extensive and locally severe bank slumping, high bank slopes and exposed tree roots. Alternatively, poor geomorphic condition was associated with cattle grazing and accessing the river in freshwater reaches.

Recommendations

- Strongly linked to riparian condition, the active restoration of riparian zone vegatation as a long term action for improving geomorphic condition must be a priority in the Richmond catchment. The poor geomorphic condition is directly linked to low scores in water quality, macroinvertebrates and riparian vegetation. Improving geomorphic condition, particularly in the mid and lower (including estuary) reaches will lead to an improvement in all other indicators.

4.1.2 Riparian Condition

Riparian land is an intermediary semi-terrestrial zone with boundaries that extend outward from the water's edges to the limits of flooding and upward into the canopy of the riverside vegetation. The area within a riparian zone contains valuable water resources, highly fertile soil and supports high levels of biodiversity as well as many social and economic functions. An assessment of the riparian condition was undertaken on the 23 freshwater sites in 2014.

- Riparian condition scores were poor throughout all regions of the Richmond River catchment, with 10 of the 17 river systems recording a score of D or lower.
- The main stressors to riparian condition were the dominance of invasive weeds, disturbances from clearing and agriculture (e.g., sugarcane), and access from livestock.

- The dominance by exotic invasive weeds in estuarine reaches was predominantly Cockspur Coraltree and Coastal Morning Glory Vine. In freshwater reaches, Lantana, Privet, Wild Tobacco Bush and Cat's Claw Creeper were common.
- The influence of clearing and physical stressors (trampling and grazing) has reduced the recruitment of native vegetation in the riparian zone.

Recommendations

- Restoration of the riparian revegatation must be a priority in the Richmond catchment. The lack of streambank vegetation is linked to poor bank condition and localized erosion, sediment deposition and benthic habitat smothering throughout rivers, reduced habitat for biota, and poor water quality (evidenced by high nutrients and turbidity throughout the year).

4.1.3 Water Quality

- Concentrations of Total Nitrogen (TN) and oxides of nitrogen (NOx), and Total Phosphorus (TP) and SRP (the form directly usable by aquatic algae and plants) exceeded the guideline value consistently across all sites throughout the study period. As such there was no seasonal pattern evident in nutrient concentrations.
- Nutrients displayed a consistent longitudinal pattern of increasing concencentrations with distance downstream in all subcatchments, clearly identifying the role of upstream connectivity in contributing to the poor water quality in the estuary.
- Concentrations of Chlorophyll *a* (algal biomass) exceeded the guideline value throughout the Richmond catchment. High concentrations evident as persistent algal blooms were recorded consistently in the upper estuarine reaches of the Richmond and Wilsons Rivers, mirroring the reaches with the highest nutrient concentrations.
- Low dissolved oxygen concentrations were recorded at a number of mid and lower catchment sites, and did reach levels that would influence the health and distribution of biota. Low flow conditions throughout the majority of the study period contributed to low DO concentrations. Low dissolved oxygen levels recorded in freshwater and estuary sites can lead to stress on biota as well as chemically reduced environments in the water column that are linked to release of phosphorus and subsequent algal blooms.
- No low pH events (<4) were recorded during this study as we targeted base flow and not flood conditions. This was despite sampling across both flood and ebb tides. Sites in the upper Richmond (RR5) and Wilsons (WR1) estuaries recorded low pH values following high rainfall events. Sites within the Bungawalbin sub-catchment had consistently low pH values, reflecting both the altered land use and swamp vegetation present. North Creek had pH values that were consistently below the trigger value.

Recommendations

- Total and available nitrogen was consistently high throughout the catchment and should be a focus for future water quality monitoring. The highest concentrations of nutrients were not associated with increased flows (freshes) in the Wilsons or Richmond Rivers, suggesting the channels contain high loads of nutrients at all times, either transported with sediment in high flows or released during low oxygen conditions under low flows. Reducing nutrient concentrations in the channel may require a reduction in catchment inputs over the long term.

- The clear longitudinal pattern of increasing turbidity and nutrients with distance downstream highlights the need to improve riparian and bank condition throughout the catchment as a management priority. Improvement of water quality in the Richmond catchment therefore requires significant investment in reducing diffuse sources of fine sediments and their associated nutrients. Reducing stock access to the steep and fine-grained banks in the upper reaches would be an important step, as would vegetating those riparian zones to increase their buffering capacity for terrestrially derived nutrients.
- The poorest water quality was recorded from the sites closest to the tidal limit, highlighting their role as depositional environments for both freshwater and estuarine contaminants, and the importance of this zone as a focal point for future monitoring programs. Low DO concentrations, low pH and high Chlorophyll *a* (algal biomass) and nutrient concentrations were a feature of estuarine reaches. Focal reaches for future monitoring are from upstream of Tatham on the Richmond River and upstream of Lismore on the Wilsons River, as well as North Creek in the lower estuary.

4.1.4 Aquatic Macroinvertebrates

Aquatic macroinvertebrates are non-vertebrate aquatic animals that are visible to the naked eye and which live at least part of their life within a body of freshwater. Because many macroinvertebrates live in a river reach for an extended period of time, they integrate the impacts on the ecosystem over an extended period of time, rather than just at the time of sampling. Macroinvertebrates were collected from 23 freshwater sites in Autumn and Spring 2014.

- Family level taxonomic richness ranged from 5 in lower Terenia and Bungawalbin Creeks to 30 in the upper Terania and Iron Pot Creeks. Similarly, the abundance of individuals ranged from a very low 14 individuals in Bungawalbin Creek (BC2) to 784 in the upper Richmond River (RR14) when both sampling periods were combined.
- SIGNAL2 scores ranged from a maximum of 5.94 in Rocky Creek (RC1) to just 3.17 in Leycester Creek (LC2). The consistently low scores throughout the 23 freshwater sites indicates the long-term degradation of water quality and instream habitat. The dominance of very tolerant waterbugs such as Chironomidae (midges), Atyidae shrimps and Notonectidae/Corixidae (waterbugs) (SIGNAL scores of 1-3) at the majority of other sites contributed to lower scores.

Recommendations

- Macroinvertebrate scores were low throughout the catchment. This reflects poor water quality and habitat conditions, particularly the geomorphic change to channels (U-shaped channels) and smothering of habitat with fine sediment. The potential for localized increases in macroinvertebrate condition (e.g., upper Richmond, Rocky Creek) suggest habitat restoration (e.g., riparian zone, woody and organic debris, macrophytes, riffles) and therefore food availability, disturbances such as sediment smothering, and water quality (nutrients and turbidity) must be targeted to improve macroinvertebrate condition.

4.2 Future Monitoring

The 2014 Richmond Ecohealth program was spatially intensive with 45 sites, but less temporally intensive with 6 sample dates over the 12 month period. The program also incorporated field sampling from teams from the Office of Environment and Heritage, Ballina Shire Council and Richmond River County Council. Suggested major outcomes from these analyses are:

4.2.1 Spatial Resolution

There is limited evidence for reducing the number of sampling sites in freshwater reaches as the majority of systems with multiple sites showed a consistent longitudinal pattern, particularly in water quality indicators. Similarly, results from estuarine sites highlighted the need for multiple samples in the upper and lower estuary.

- *Recommendation*: maintaining a minimum of one site within freshwater reaches of each of the major subcatchments is recommended. The intention of multiple sites within each river systems is to detect longitudinal trends in water quality and biotic variables. If only one site remains in each subcatchment, the ability to spatially identify reaches of management interest will be reduced.
- *Recommendation*: maintaining sampling at the most downstream freshwater reach in each major subcatchment is recommended as this site represents the cumulative impacts from throughout the upstream catchment, and is generally gauged to allow the calculation of nutrient and sediment loads exported from each catchment.
- *Recommendation:* the optimum combination from the above recommendations is to retain the most downstream site in each subcatchment, one site in the dominant River Style of each subcatchment, and strategic upland sites (e.g., RR14, RC1, TC2) to establish a local reference condition.

4.2.2 Indicators

- *Recommendation*: Retaining the suite of water quality variables and sampling procedures (water column profiles in sites >1 m depth) is recommended as all variables positively contributed to the understanding of issues at each site and the development of site-based scores for the report card. The inclusion of TP and TN and exclusion of SRP and NOx in future sampling would be the main way to reduce costs. This would have minimum impact on the Ecohealth grades for each site, but impacts on the ability to understand drivers of condition.
- *Recommendation*: Season- and site-based characteristics of freshwater reaches both affected the taxonomic composition and abundance of macroinvertebrates. Future macroinvertebrate sampling should include autumn and spring, but should consider further research into the link between geomorphic characteristics, condition and recovery potential.
- *Recommendation*: The riparian condition and separate geomorphic condition index make a major contribution to the management priorities by identifying biological (weeds) and biophysical (bank erosion) drivers, and the sub-catchment scale provides a link to the spatial representativeness of condition. These should be retained for freshwater and estuary reaches as an annual survey.

4.2.3 Temporal resolution

- The inclusion of monthly sampling for water quality in the estuarine reaches, and bimonthly sampling in freshwater reaches over a 12 month period has provided an integrated outcome of the catchment condition. Rainfall in the region during the 2014 sampling period was well below the long term mean.
- *Recommendation*: This project has highlighted the importance of sampling within defined hydrologic periods (80^{th} percentile flows), and the potential for both low and high flows to influence site condition. Sampling one out of every four years in the Richmond catchment may not best reflect the long-term condition of the sites as much as the influence of short-term climate conditions. It is recommended to continue to target sampling to specific flow conditions ($>80^{th}$ percentile) in defined time periods (seasonal) over a multi-year timeframe. This will facilitate the capture of data from all sites under similar flow conditions and replicated temporal periods (seasons) within the four year reporting period (e.g., 1 sample/season, 4 seasons/year, for 3 years = 12 sample times). This recommendation removes the potential influence of flow extremes that may be encountered within a shorter 12 month period. Impact of floods on ecological condition and flood-recovery would require a separate sampling program.
- *Recommendation*: As stated above, to ensure consistency over multiple years of sampling the program is focused on non-flood sampling. This removes the opportunity to document the changes (particularly water quality) associated with high flows. A separate program using targeted indicators to assess the response and resilience of the lower Richmond to high flow events should be developed.

4.2.4 Partnerships

- This project was a successful partnership among a number of Councils, government agencies and the University of New England.
- *Recommendation:* The inclusion of staff from Councils and Agencies increased the number of sites that could be sampled as part of the program, and facilitated education and training where possible. Continued partnerships are essential, and ensuring training for staff involved will maintain quality data and ensure project outcomes are maximized.

5 REFERENCES

Alluvium (2012). River Styles assessment and mapping in the Northern Rivers CMA area. Report by Alluvium for the NSW Office of Water and Northern Rivers Catchment Management Authority.

Australian and New Zealand Environment and Conservation Council (ANZECC) (2000, 2006). Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Sydney.

Boulton, A.J. and Brock, M.A. (1999) Australian Freshwater Ecology: processes and management. Gleneagles Publishing, Adelaide.

Bush, R.T., L.A. Sullivan, D. Fyfe and S. Johnston. (2004). Redistribution of monosulfidic black oozes by floodwaters in a coastal acid sulfate soil floodplain. Soil Research 42: 603-607.

Chessman, B.C. (2003). New sensitivity grades for Australian river macroinvertebrates. Marine and Freshwater Research 54: 95.103.

Corfield, J. (2000). The effects of acid sulphate run-off on a subtidal estuarine macrobenthic community in the Richmond River, NSW, Australia. ICES Journal of Marine Science 57: 1517-1523.

Crook, D. A. & Robertson, A. I. (1999). Relationships between riverine fish and woody debris: implications for lowland rivers. Marine and Freshwater Research 50: 941–953.

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

Davis J.R & Koop, K. (2006). Eutrophication in Australian Rivers, Reservoirs and Estuaries – A Southern Hemisphere Perspective on the Science and its Implications. Hydrobiologia 559: 23-76.

Dawson, K. (2002). Fish kill events and habitat losses of the Richmond River, NSW Australia: an overview. Journal of Coastal Research SI 36: 216-221.

Dixon, I and Douglas, M. (2006). A field guide to assessing Australia's tropical riparian zones. Tropical Savannas CRC, Darwin.

Gatland, J.R., Santos, I.R., Maher, D.T., Duncan, T.M. and Erler, D.V. (2014). Carbon dioxide and methane emissions from an artificially drained coastal wetland during a flood: implications for wetland global warming potential. Journal of Geophysical Research: Biogeosciences 119: 1689-1716.

Gibbins, P. and Lindenmeyer, D. (2002) Tree hollows and wildlife conservation in Australia. CSIRO Publishing Australia.

Hosomi, M. & Sudo, R. (1986). Simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulfate digestion. International Journal of Environmental Studies 27: 267-275.

Hossain, S. and B.D. Eyre. (2002). Suspended sediment exchange through the sub-tropical Richmond River Estuary, Australia: a balance approach. Estuarine, Coastal and Shelf Science 55: 579-586.

Hossain, S., B.D. Eyre and D. McConchie. (2002). Spatial and temporal variations of suspended sediment responses from the subtropical Richmond River catchment, NSW, Australia. Soil Research 40: 419-432.

Hossain, S., B.D. Eyre and D. McConchie. (2004). Dry season suspended sediment concentration and sedimentation in the Richmond River estuary, northern NSW, Australia. Australian Journal of Soil Research 42: 203-211.

Jansen, A., A.I. Robertson, L. Thompson and A. Wilson. (2004) Development and application of a method for the rapid appraisal of riparian condition. River Management Technical Guideline No. 4, Land and Water Australia.

Koop, K. 2006. Eutrophication in Australian Rivers, Reservoirs and Estuaries – A Southern Hemisphere Perspective on the Science and its Implications. Hydrobiologia 559: 23-76.

Logan, B., K.H. Taffs, B.D. Eyre and A. Zawadski. (2011). Assessign changes in nutrient status in the Richmond River estuary, Australia, using paleolimnological methods. Journal of Paleolimnology 46: 597-611.

Maher, D.T., K. Cowley, I.R. Santos, P. Macklin and B.D. Eyre. (2015) Methan and carbon dioxide dynamics in a subtropical estuary over a diel cycle: insights from automated in situ radioactive and stable isotope measurements. Marine Chemistry 168: 69-79.

McKee, L., B. Eyre and S. Hossain. (2000) Intra- and interannual export of nitrogen and phosphorus in the subtropical Richmond River catchment, Australia. Hydrological Processes 14: 1787-1809.

Moore, S.K. and Suthers, I.M. (2006). Evaluation and correction of subresolved particles by the optical plankton counter in three Australian estuaries with pristine to highly modified catchments. Journal of Geophysical Research, 111: C05S04, doi: 10.1029/2005/JC002920.NSW Office of Environment and Heritage 2012. Sampling, data analysis and reporting protocols Estuary health assessments, Sydney.

Naiman, R.J., Décamps, H. & McClain, M.E. (2005) Riparia: ecology, conservation, and management of streamside communities. Elsevier Academic Press, California.

NSW Office of Environment and Heritage (2012). Sampling, data analysis and reporting protocols Estuary health assessments, Sydney.

Ruiz-Halpern, S., D.T. Maher, I.R. Santos and B.D. Ehre. (2015). High CO_2 evasion during floods in an Australian subtropical estuary downstream from a modified acidic floodplain wetland. Limnology and Oceanography 60: 42-56.

Ryder, D. (2004). Response of epixylic biofilm metabolism to water level variability in a regulated floodplain river. Journal of the North American Benthological Society 23: 214-223.

Suthers, I. M., C. T. Taggart, D. Rissik and M. E. Baird (2006). Day and night ichthyoplankton assemblages and zooplankton biomass size spectrum in a deep ocean island wake. Marine Ecology Progress Series 322: 225-238.

Suthers, I.M., Tang, E., Ryder, D.S. & Everett, J. (2012). Zooplankton size frequency distribution (the “size spectrum”) for integrating water quality and as an ecosystem measure. Report to Port Macquarie Hastings Council (PMHC).

Wong, W.N.L., S.G. Johnston, R.T. Bush, L.A. Sullivan, C. Clay, E.D. Burton and P.G. Slavich. (2010). Spatial and temporal changes in estuarine water quality during a post-flood hypoxic event.

Zhou, M and D. Huntley (1997). "Population dynamics theory of plankton based on biomass spectra." Marine Ecology Progress Series 159: 61-73.

6 APPENDIX 1 – Water quality field data sheets

Ecohealth Water Quality Data Sheet

Date:_________________________________

Site Name:____________________________ Site ID:_________________________

Location: Easting__________________ Northing____________ Datum _________

Decimal degrees - Lat _________ Long____________Elevation _______

Field Personnel ____

Start Time (24 hr) ________________________ End time (24hr) _________________

High Tide Time/Height _____________________ Low Tide Time/Height ____________

Equipment: (Make/Model)_______________________ Serial/ID number________________

Calibrated by: __________________________ Calibration Log Complete? Y N

Air Temp _________________________

Weather Conditions

Water Surface: ☐ flat ☐ choppy ☐ rough

Wind: ☐ nil ☐ light ☐ moderate

Rainfall: ☐ nil ☐ light ☐ moderate ☐ heavy in last ☐ 24 hours ☐ 2-5 days

Sky: ☐ sunny ☐ overcast

Depth (m)	Temp (C)	pH	Cond (mS/cm)	Salinity (ppt)	DO (mg/L)	DO (% sat)	Turb (NTU)
0.1							
1.0							

Ecohealth Water Quality Data Sheet

Secchi Depth (m)	
Maximum depth (m)	
Water Velocity (m.sec^{-1}) – *freshwater sites only*	

Duplicate TN/TP sample	Yes	No	Sample ID:	
Duplicate SRP/NOx sample	Yes	No	Sample ID:	
Duplicate ICP sample	Yes	No	Sample ID:	
Chl a volume filtered (mL)			Sample ID:	
TSS volume filtered (mL)			Sample ID:	

Samples Forwarded to (Lab Name): ____

Chain of custody form completed: Y N

Comments
