ADDENDUM to the Richmond River Estuary Processes Study

For Richmond River County Council

AUSTRALIAN WETLANDS PTY LTD

PROJECT NUMBER: BB074

11/05/2009

Australian Wetlands

70 Butler Street Byron Bay NSW 2481 P + 61 2 6685 5466 F + 61 2 6680 9406
byron@wetlands.com.au
www.wetlands.com.au

PO Box 409
Brunswick Heads 2483
(02) 66801 995
aber@aber.com.au
www.aber.com.au

ABER

Table of Contents

List of Figures

List of Tables

Introduction and Summary

As part of the Richmond River Estuary Management Study, some further research was undertaken with regard to water quality impacts and monitoring, geomorphological conditions, riparian vegetation conditions and fauna. These data are presented as an Addendum to the Richmond River Processes Study (2006) and provide information towards management of the issues within the identified Management Zones of the Richmond River estuary.

1. Riparian Vegetation Assessment

1.1 Background

Riparian vegetation is classified as *vegetation that is found on the banks of a river or stream, and any vegetation on land that adjoins, directly influences or is influenced by a body of water*. Riparian vegetation plays a crucial role in maintaining bank stability and control of bed erosion in streams, which can be directly linked to water quality issues. It can reduce the amount of sediment and associated pollutants entering the stream. Research suggests that stream and river banks that are sparsely vegetated, erode at a much higher rate than those banks that are densely vegetated (Water Quality Monitoring 2004). A well vegetated streambank is resistant to streambank erosion due to the extra stability provided by the roots and other plant material, and because it can reduce flow velocity at the edges of the stream. Riparian vegetation also plays a role in increasing biodiversity and serves to provide habitat for native fauna. Loss of riparian vegetation, through clearing, livestock grazing or recreational uses, means that these benefits are lost and the overall condition of the stream can decline.

Assessment of vegetation health and the prioritisation of sites was adapted for this study from Owers (2002) and the Rapid Assessment Method (RAM) described in the *Riparian and In-stream Rehabilitation Plan for the Lower Freshwater Reaches of Currumbin Creek* (Australian Wetlands 2006). The assessment has been used successfully on other projects by the project team. This method was a similar but more rigorous assessment method than the one described within the *Tallebudgera Creek Riparian Vegetation Study* (GCCC, 2002).

A broad scale desktop study of aerial photography was used to assess the riparian widths and longitudinal connectivity for the estuary to the tidal limit (Appendix 1). This assessment also provided information on obvious changes in vegetation for on-ground assessment.

The on-ground survey of sites incorporated existing on-ground work sites and areas with potential for high profile demonstration sites for riparian rehabilitation. The desktop assessment was used to assist in identifying suitable sites for on-ground assessment.

Digital photographs were taken at the upstream midpoint of the site facing downstream and downstream facing upstream. Each photo point was noted using GPS coordinates, to identify the extent of the reach.

The field assessment recorded responses to variables in the Riparian Assessment Matrix described below with a brief description of the key features of each site. A list of dominant weed and native species was compiled for each site.

The results of the assessment including GPS locations are contained in a Riparian Assessment Matrix, described in the following section.

1.2 Riparian Rapid Assessment Method (RAM)

Details of the riparian RAM implemented are provided below. Two parameter types were recorded in this assessment, those based on riparian vegetation extent and quality, and those based on rehabilitation potential of the reach and threatening processes on site.

The assessment of condition and extent of riparian vegetation incorporated the following parameters:

1. Longitudinal connectivity (API)
2. Width of riparian vegetation (API)
3. Native vegetation cover
4. Site weed control issues
5. Habitat quality assessment

1. **Longitudinal connectivity** measured the length of vegetation >5m wide along the stream for both banks. Four criteria were mapped 1. Longitudinal connectivity >100m, width 50->100m, 2. Longitudinal connectivity > 100m, width 10-50m, 3. Longitudinal connectivity <100m, width 0-10m, 4. Longitudinal connectivity >100m, width 0-10m.

2. The **width of riparian vegetation** was also assessed from aerial photography and measured using tools within Google earth. Width was ground-truthed using the flowing criteria: small channel < 10 m wide, (riparian vegetation width: 0 = <5 m vegetation, 5 = > 5 - <50m vegetated, 10= >100m. Large Channel ≥ 10 m wide: 0 =riparian width (rw)<1/2 channel width (CW), 2 = rw ½ to 1 x CW, 4 = rw 1- 2 x CW, 6= rw 3-4 x CW, 8 = rw 4 x CW., 10=rw10xCW

3. **Native vegetation cover** was measured by a percentage score of overall cover in the canopy and understorey and percentage of native cover in the canopy and understorey. This also gives a corresponding score for % weed cover in the canopy

and understorey. Percentage cover and percentage native was classed using the following categories. 0=0, 1=1%, 2=2-10%, 3=11-30%, 4=31-60%, 5=61-100%.

4. **Site weed control issues measured the severity of weeds to indicate the recovery potential of the site.**
   The severity of weeds score (%): High 0 = > 31-100%, Med 5 = 10-30%, Low 10 = <10% or no threat. Dominant weeds in each of the canopy, mid and understorey layers were recorded. Any weeds from the priority weeds list of the Far North Coast County Council (FNCCC), were recorded and the number present on site was used as a rating: score 10 = no priority weeds, 5 = 1 priority weed, 0 = > 2 priority weeds. The priority weeds included the following: Cockspur Coral, Duranta, Groundsel, Water Lettuce, Honey Locust, Hymenachne, Chinese Tallow, Glush Weed, Cats Claw Creeper, Alligator Weed, Chinese Celtis, Water Hyacinth, Camphor Laurel, Salvinia, Broad-leaved Pepper and Alumen Grass.

5. **The habitat quality assessment** measures parameters that identify the values of established riparian habitat for mammals, reptiles and other fauna. The parameters and rating used was:
   - Vegetation community age class 0 = no riparian vegetation or isolated stag trees, 1= seedlings/ planting <5 yo with/without stag trees, 2 = regrowth 10yo, 3 = regrowth >10yo 4 = regrowth with stag trees, 5 =4 old growth >30 yo (Note: stag trees are isolated remnant individuals)
   - Tree hollows present, 0 = none, 5 present.
   - Leaf litter class, 0 = none, 3 =1-60%, 5 =>60%
   - Fallen logs/habitat structure, diversity, 0 =none, 3 = small debris, 5 = abundant
   - Seed/fruiting trees: 0 = none, 3 = 1-4 trees, 5 = > 5 trees
   - In-stream habitat (in freshwater large woody debris (LWD) or overhang branches etc) Mangrove pneumatophores >1m wide, 0 = none, 3 = <50 % site with habitat features, 5 = > 50 % of site with habitat features.

1.3 Results and Assessment

The on-ground field assessments and general field and mapping observations were used to provide a vegetation assessment overview based on management zones. The assessment results for each site and the site details are described below and the field results are shown in Tables 1.1 and 1.2. The sums of each assessed condition provide a relative indication of the importance of the condition at each site. From these on-ground field assessments and from general field and mapping observations, a vegetation assessment overview based on management zones has been provided.

A list of weed species observed at each Field Site is also provided in Table 1.3. A photographic Archive is provided for each management zone in Appendix 2.

Table 1.1 Longitudinal connectivity, vegetation width and cover assessment of on-ground riparian site assessment. Refer to Section 2.2 for details on scoring.

SITE	Site Location	GPS	Management Zone No.	Management Zone name	**1. LONGITUDINAL CONNECTIVITY**	Bank 1	Bank 2	**TOTAL SCORE**	**2.. WIDTH OF RIPARIAN VEGETATION**	*Channel width (CW) m*	Vegetation width (m)	Vegetation width (m)	**TOTAL SCORE**	**3. VEGETATION COVER**	*Canopy*	% cover class	% native	*Understorey*	% cover class	% native	**TOTAL SCORE**
NC1	Nth Cr Road	28 50' 21.21"S, 153 34' 43.26"E	1	North Creek		5	5	**10**		*20m*	**0**	**6**	**6**			4	5		3	2	**14**
NC2	Upstream Ross Lane	28 47'12.76"S, 153 33' 50.14"E	1	North Creek		0	0	**0**		*<10m*	0	0	**0**			0	0		5	0	**5**
EC3	Emigrant Cr	28 50' 01.53"S, 153 30' 48.50"E	2	Emigrant/ Maguires		5	0	**5**		*>50m*	4	0	**4**			3	4		4	2	**13**
SB4	Sth Ballina Beach Road	28 52' 52.62"S, 153 33' 34.82"E	4	Sth Ballina		5	5	**10**		*5m*	5	5	**10**			5	5		5	0	**15**
SB5	Empire Vale	28 54' 46.58"S, 153 30' 30.60"E	4	Sth Ballina		0	0	**0**		*<10m*	0	5	**5**			3	5		5	0	**13**
SB6	Carney Lane River Dr	28 57' 6.07"S, 153 28' 29.80"E	4	Sth Ballina		5	0	**5**			0	0	**0**			3	4		5	0	**12**
SB7	Near Pimblico Is	28 54' 49.43"S, 153 29' 19.35"E	2	Emigrant/ Maguires		0	5	**5**		*>20m*	0	1	**1**			3	4		3	3	**13**
BC8	Wardell Bridge	28 57' 16.25"S, 153 27' 56.07"E	3	Back Channel		0	0	**0**			0	0	**0**			3	4		4	4	**15**

SITE	Site Location	GPS	Management Zone No.	Management Zone name	**1. LONGITUDINAL CONNECTIVITY**	Bank 1	Bank 2	**TOTAL SCORE**	**2.. WIDTH OF RIPARIAN VEGETATION**	*Channel width (CW) m*	Vegetation width (m)	Vegetation width (m)	**TOTAL SCORE**	**3. VEGETATION COVER**	*Canopy*	% cover class	% native	*Understorey*	% cover class	% native	**TOTAL SCORE**
T 10/11	Broadwater Road	28 59' 50.68"S, 153 24' 11.22"E	10	Tuckean		0	0	**0**		*>50m*	0	0	**0**			4	4		5	3	**16**
T12	BAG BARRAGE	28 58' 51.75"S, 153 24' 15.98"E	10	Tuckean		5	5	**10**		*>20m*	4	4	**8**			5	5		5	4	**19**
KB 13/14	Kilgin Drain to RR	29 01'31.58"S 153 22 '30.24" E	9	Kilgin /Buckendoon		0	5	**5**		*>50m*	0	0	**0**			0	0		2	0	**2**
KB15	Woodburn opp town	29 4' 6.42"S, 153 20' 34.57"E	9	Kilgin /Buckendoon		0	0	**0**		*>50m*	0	0	**0**			1	5		5	0	**11**
KB18	OAKLAND RD NEAR SCHOOL RD	29 4' 38.55"S, 153 20' 4.10"E	9	Kilgin /Buckendoon		0	0	**0**		*>50m*	0	0	**0**			2	2		4	1	**9**
RC17	Rocky Mouth Creek	29 02' 40.25"S, 153 20' 09.24"E	7	Rocky Mouth Creek		0	0	**0**		*<10m*	0	0	**0**			3	1		5	0	**9**
E19	TUCKOMBIL CANAL	29 05' 05.52"S, 153 20'16.79"E	6	Evans River		0	0	**0**		*>20m*	0	0	**0**			2	4		5	3	**14**
SB20	Swan Bay	29 3' 40.89"S, 153 17' 16.87"E	8	Swan Bay		5	5	**10**		*>20m*	2	0	**2**			4	4		5	4	**17**
UPRW	Coraki	28 59' 6.10"S,	12	Upper		0	0	**0**		*>20m*	0	0	**0**			2	4		5	0	**11**

SITE	Site Location	GPS	Management Zone No.	Management Zone name	1. LONGITUDINAL CONNECTIVITY	Bank 1	Bank 2	TOTAL SCORE	2.. WIDTH OF RIPARIAN VEGETATION	*Channel width (CW) m*	Vegetation width (m)	Vegetation width (m)	TOTAL SCORE	3. VEGETATION COVER	*Canopy*	% cover class	% native	*Understorey*	% cover class	% native	TOTAL SCORE
R21/22	downstream boat ramp	153 17' 14.37"E		Richmond/ Wilson River																	
UPRW R23	WYRALLA RD BRIDGE TO CORAKI	28 53' 29.78"S, 153 17' 49.75"E	12	Upper Richmond/ Wilson River		5	0	**5**		*>20m*	0	0	**0**			4	1		5	0	**10**
UPRW R24	WYRALLA RD UPPER	28 52' 06.87"S, 153 16' 14.12"E	12	Upper Richmond/ Wilson River		5	5	**10**		*>20m*	2	2	**4**			4	3		3	0	**10**
UPRW R25	LECESTER CR	28 47' 45.44"S, 153 14' 24.09"E	12	Upper Richmond/ Wilson River		0	5	**5**		*15m*	0	1	**1**			4	3		5	0	**12**
BU26	Bora Bungawalby n Creek	29 2' 42.08"S, 153 15' 3.72"E	11	Lower Bungawalbyn		5	0	**5**		*10m*	5	0	**5**			5	5		4	4	**18**
BU27/ 28	Sandy Creek	29 1' 32.61"S, 153 15' 5.76"E	11	Lower Bungawalbyn		5	5	**10**		*<10m*	5	5	**10**			4	3		5	0	**12**
UPRW R	Tomki Tatham	28 55' 30.09'S, 153 09' 39.64"E	12	Upper Richmond/		0	0	**0**		*>15 m*	0	0	**0**			3	5		5	0	**13**

SITE	Site Location	GPS	Management Zone No.	Management Zone name	**1. LONGITUDINAL CONNECTIVITY**	Bank 1	Bank 2	**TOTAL SCORE**	**2.. WIDTH OF RIPARIAN VEGETATION**	*Channel width (CW) m*	Vegetation width (m)	Vegetation width (m)	**TOTAL SCORE**	**3. VEGETATION COVER**	*Canopy*	% cover class	% native	*Understorey*	% cover class	% native	**TOTAL SCORE**
29/30	Bridge			Wilson River																	
UPRW R31	Casino Weir	28 52' 4.56"S, 153 2' 33.21"E	12	Upper Richmond/ Wilson River		5	0	**5**		*20m*	2	0	**2**			4	5		5	0	**14**
UPRW R32	Wilson R Trinity	28 48' 0.09"S, 153 17' 9.39"E	12	Upper Richmond/ Wilson River		0	5	**5**		*<5m*	0	0	**0**			4	2		5	0	**11**

Table 1.2 Weed control issues and habitat quality assessment of on-ground riparian site assessment.
Refer to section 11.2 for information on scoring.

SITE		GPS	Management Zone	Management Zone name	SITE WEED CONTROL	canopy weeds	mid storey	understorey	FNCC Priority weeds on site	TOTAL SCORE	HABITAT QUALITY ASSESSMENT	Veg community age class	Tree hollows present	Leaf litter class	Fallen logs	Seed/ fruiting trees	In-stream habitat (LWD overhang branches etc)	Habitat connectivity in-stream/ pools/ riffles, water flow	TOTAL SCORE
NC1	Nth Cr Road	28 50' 21.21"S, 153 34' 43.26"E	1	North Creek		10	10	0	5	**25**		2	0	3	0	3	5	10	**23**
NC2	Upstream Ross Lane	28 47'12.76"S, 153 33' 50.14"E	1	North Creek		10	10	0	10	**30**		0	0	0	0	0	0	0	**0**
EC3	Emigrant Cr	28 50' 01.53"S, 153 30' 48.50"E	2	Emigrant/ Maguires		10	10	0	10	**30**		2	5	3	3	3	3	10	**29**
SB4	Sth Ballina Beach Road	28 52' 52.62"S, 153 33' 34.82"E	4	Sth Ballina		10	10	10	10	**40**		4	5	5	5	5	5	0	**29**
SB5	Empire Vale	28 54' 46.58"S, 153 30' 30.60"E	4	Sth Ballina		5	5	0	10	**20**		3	5	0	0	3	3	5	**19**
SB6	Carney Lane River Dr	28 57' 6.07"S, 153 28' 29.80"E	4	Sth Ballina		0	0	0	0	**0**		1	5	0	3	3	5	5	**22**
SB7	Near Pimblico Is	28 54' 49.43"S, 153 29' 19.35"E	2	Emigrant/ Maguires		5	5	5	10	**25**		2	5	3	3	5	5	10	**33**
BC8	Wardell	28 57' 16.25"S,	3	Back Channel		10	3	10	10	**33**		3	5	3	3	3	3	10	**30**

SITE		GPS	Management Zone	Management Zone name	SITE WEED CONTROL	canopy weeds	mid storey	understorey	FNCC Priority weeds on site	TOTAL SCORE	HABITAT QUALITY ASSESSMENT	Veg community age class	Tree hollows present	Leaf litter class	Fallen logs	Seed/ fruiting trees	In-stream habitat (LWD overhang branches etc)	Habitat connectivity in-stream/ pools/ riffles, water flow	TOTAL SCORE
	Bridge	153 27' 56.07"E																	
T 10/11	Broadwater Road	28 59' 50.68"S, 153 24' 11.22"E	10	Tuckean		10	0	0	5	**15**		4	5	3	3	5	5	10	**35**
T12	BAG BARRAGE	28 58' 51.75"S, 153 24' 15.98"E	10	Tuckean		10	5	0	10	**25**		4	5	3	3	5	5	5	**30**
KB 13/14	Kilgin Drain to RR	29 01'31.58"S 153 22 '30.24" E	9	Kilgin/ Buckendoon		0	0	0	5	**5**		0	0	0	0	0	3	5	**8**
KB15	Woodburn opp town	29 4' 6.42"S, 153 20' 34.57"E	9	Kilgin/ Buckendoon		0	0	0	0	**0**		0	0	0	0	3	3	10	**16**
KB18	OAKLAND RD NEAR SCHOOL RD	29 4' 38.55"S, 153 20' 4.10"E	9	Kilgin/ Buckendoon		0	0	0	0	**0**		0	0	3	3	3	3	10	**22**
RC17	Rocky Mouth Creek	29 02' 40.25"S, 153 20' 09.24"E	7	Rocky Mouth Creek		0	0	0	0	**0**		0	0	0	0	0	3	5	**8**
E19	TUCKOMBIL CANAL	29 05' 05.52"S, 153 20'16.79"E	6	Evans River		0	0	10	5	**15**		2	5	3	3	3	3	5	**24**
SB20	Swan Bay	29 3' 40.89"S, 153 17' 16.87"E	8	Swan Bay		0	0	0	0	**0**		2	5	3	3	3	5	10	**31**

SITE		GPS	Management Zone	Management Zone name	SITE WEED CONTROL	canopy weeds	mid storey	understorey	FNCC Priority weeds on site	TOTAL SCORE	HABITAT QUALITY ASSESSMENT	Veg community age class	Tree hollows present	Leaf litter class	Fallen logs	Seed/ fruiting trees	In-stream habitat (LWD overhang branches etc)	Habitat connectivity in-stream/ pools/ riffles, water flow	TOTAL SCORE
UPRW R21/22	Coraki downstream boat ramp	28 59' 6.10"S, 153 17' 14.37"E	12	Upper Richmond/ Wilson River		10	5	0	0	**15**		1	0	0	0	3	3	10	**17**
UPRW R23	WYRALLA RD BRIDGE TO CORAKI	28 53' 29.78"S, 153 17' 49.75"E	12	Upper Richmond/ Wilson River		5	0	0	0	**5**		0	0	0	0	5	3	10	**18**
UPRW R24	WYRALLA RD UPPER	28 52' 06.87"S, 153 16' 14.12"E	12	Upper Richmond/ Wilson River		0	0	0	0	**0**		2	5	3	3	3	3	10	**29**
UPRW R25	LECESTER CR	28 47' 45.44"S, 153 14' 24.09"E	12	Upper Richmond/ Wilson River		10	0	0	5	**15**		3	5	0	3	5	5	10	**31**
BU26	Bora Bungawalbyn Creek	29 2' 42.08"S, 153 15' 3.72"E	11	Lower Bungawalbyn		0	0	5	0	**5**									
BU27/ 28	Sandy Creek	29 1' 32.61"S, 153 15' 5.76"E	11	Lower Bungawalbyn		5	0	0	0	**5**									

SITE		GPS	Management Zone	Management Zone name	SITE WEED CONTROL	canopy weeds	mid storey	understorey	FNCC Priority weeds on site	TOTAL SCORE	HABITAT QUALITY ASSESSMENT	Veg community age class	Tree hollows present	Leaf litter class	Fallen logs	Seed/ fruiting trees	In-stream habitat (LWD overhang branches etc)	Habitat connectivity in-stream/ pools/ riffles, water flow	TOTAL SCORE
UPRW R 29/30	Tomki Tatham Bridge	28 55' 30.09'S, 153 09' 39.64"E	12	Upper Richmond/ Wilson River		10	5	0	0	**15**		2	5	0	0	3	3	10	**23**
UPRW R31	Casino Weir	28 52' 4.56"S, 153 2' 33.21"E	12	Upper Richmond/ Wilson River		10	5	0	5	**20**		2	5	0	3	5	3	10	**28**
UPRW R32	Wilson R Trinity	28 48' 0.09"S, 153 17' 9.39"E	12	Upper Richmond/ Wilson River		0	0	0	0	**0**		0	0	0	0	3	3	10	**16**

Table 1.3 Weed species noted in the on-ground site assessment.

		NC1	NC2	EC3	SB4	SB5	SB6	SB7	BC8	T11	T12	KB14	KB15	KB18	RC17	E19	SB20	BU28	UPRWR21	UPRWR23	UPRWR24	UPRWR25	UPRWR26	UPRWR30	UPRWR31	UPRWR32	Sites present
Ageratina adenophora	Crofton Weed																										0
Ageratina riparia	Mist Flower																										0
Ageratum houstonianum	Blue Billy Goat Weed																					X		X	X	X	4
Ambrosia artemisiifolia	Annual Ragweed	X																				X					2
Anredera cordifolia	Madeira Vine							X							X							X			X	X	5
Asclepias curassavica	Redhead Cotton Bush	X																									1
Asparagus aethiopicus	Asparagus Fern	X					X	X																			3
Asparagus plumosus	Climbing Asparagus																X	X		X	X	X	X	X		X	8
Axonopus compressus	Carpet Grass	X	X				X															X					4
Baccharis halimifolia	Groundsel								X																		1
Bidens pilosa	Farmers Friend	X	X	X	X	X						X		X	X						X	X		X	X	X	13
Urochloa mutica	Para Grass		X					X		X	X	X		X	X				X	X							9
Bryophyllum delagoense	Mother of Millions																										0
Cabomba caroliniana	Cabomba																										0
Canna x generalis	Canna Lily							X																			1
Cardiospermum grandiflorum	Balloon Vine									X							X		X	X		X		X	X	X	8
Celtis sinensis	Japanese Hackberry																									X	1
Chloris gayana	Rhodes Grass		X			X	X													X		X					5
Chrysanthemoides monilifera	Bitou Bush						X																				1
Cinnamomum camphora -	Camphor Laurel	X	X				X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	19
Cocos plumosus	Cocos	X																									1

		NC1	NC2	EC3	SB4	SB5	SB6	SB7	BC8	T11	T12	KB14	KB15	KB18	RC17	E19	SB20	BU28	UPRWR21	UPRWR23	UPRWR24	UPRWR25	UPRWR26	UPRWR30	UPRWR31	UPRWR32	Sites present
Colocasia esculanta	Elephant ears																										0
Commelina benghalensis	Hairy Commelina		X	X			X								X							X				X	6
Conyza albida	Fleabane	X	X																								2
Cuphea carthagenensis	Cuphea																										0
Cynodon dactylon	Common Couch			X	X	X	X			X					X		X	X	X			X				X	11
Desmodium uncinatum	Silverleaf Desmodium																										0
Eichhornia crassipes	Water Hyacinth																X										1
Elodea canadensis	Elodea																										0
Erechtites valerianifolia	Soft Top																										0
Erythrina crista-galli	Coral Tree						X	X		X		X	X	X	X	X	X	X	X	X	X	X	X			X	16
Erythrina sykesii	Coral Tree													X													1
Eugenia uniflora	Brazilian Cherry																										0
Gleditsia tricanthos	Honey Locust																							X			1
Gomphocarpus fruiticosus	Narrow Leaf Cotton Bush																										0
Ipomoea alba	White Ipomea																X			X	X						3
Ipomoea cairica	Coastal Morning Glory	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X		X	X	X	X	X		X	21
Ipomoea indica	Morning Glory							X		X										X						X	4
Koelreuteria paniculata	Golden Rain Tree																									X	1
Lantana camara	Lantana	X			X	X				X				X	X							X	X	X			9
Ligustrum lucidum	Large Leaved Privet																									X	1
Ligustrum sinense	Small Leaved Privet																			X	X	X			X	X	5
Macroptilium atropurpureum	Siratro									X																	1

		NC1	NC2	EC3	SB4	SB5	SB6	SB7	BC8	T11	T12	KB14	KB15	KB18	RC17	E19	SB20	BU28	UPRWR21	UPRWR23	UPRWR24	UPRWR25	UPRWR26	UPRWR30	UPRWR31	UPRWR32	Sites present
Megathyrsus maximus	Guinea Grass																										0
Melinis minutiflora	Molasses Grass																										0
Morus alba	Mulberry																			X		X			X	X	4
Myriophyllum aquaticum	Parrots Feather																										0
Nymphaea capensis	Cape Waterlily																										0
Nymphaea zanzibarensis	Water Lilly																										0
Ochna serrulata	Ochna																										0
Oxalis sp.	Oxalis																										0
Paspalum dilatatum	Paspalum																										0
Paspalum sp.	Paspalum Grass																										0
Paspalum urvillei	Vasey Grass	X	X	X		X	X						X	X	X	X				X		X					11
Paspalum wettsteinii	Broad-leaved Paspalum									X												X					2
Passiflora subpeltata	White Passionfruit	X																									1
Pennisetum alopecuroides	Swamp Foxtail																X										1
Pennisetum clandestinum	Kikuyu Grass		X			X	X						X		X		X			X	X	X					9
Pennisetum sp.	Bana Grass																										0
Persica sp.	Peach																										0
Phyllostachys aurea	Golden Bamboo																										0
Psidium guajava	Yellow Guava																				X						1
Ricinus communis	Castor Oil												X							X				X	X		4
Rivina humilis	Coral Berry														X				X	X						X	4
Salvinia molesta	Salvinia																										0
Schefflera actinophylla	Umbrella Tree																										0

		NC1	NC2	EC3	SB4	SB5	SB6	SB7	BC8	T11	T12	KB14	KB15	KB18	RC17	E19	SB20	BU28	UPRWR21	UPRWR23	UPRWR24	UPRWR25	UPRWR26	UPRWR30	UPRWR31	UPRWR32	Sites present
Schinus terebinthifolius	Broad-leaf Pepper Tree																								X		1
Senecio madagascariensis	Fireweed																										0
Senna pendula var. glabrata	Easter cassia	X		X	X	X	X	X		X				X	X											X	10
Setaria sphacelata	Setaria												X	X	X	X				X	X	X					7
Sida rhombifolia	Paddy's Lucerne													X	X	X						X	X				5
Solanum mauritianum	Wild Tobacco																					X					1
Solanum seaforthianum	Blue Potato Vine									X										X							2
Sorghum halepense	Johnson Grass																		X	X		X		X			4
Sphagneticola trilobata	Singapore Daisy							X																			1
Tagetes minuta	Stinking Roger																										0
Tecoma stans	Yellow Tecoma																					X					1
Tradescantia albiflora	Wandering Jew									X								X		X		X				X	5
Trifolium repens	White Clover	X																									1
Vachellia farnesiana	Mimosa Bush																	X									1

Zone 1 - North Creek/Newrybar

On-ground sites NC1, NC2

The riparian vegetation along North Creek was mostly greater than 50m wide with a high native cover in the canopy (>30% - 60%). The dominant species in the lower estuarine zones were Swamp Oak (*Casuarina glauca)* and Tuckeroo (*Cupaniopsis anacardioides*) on the banks, with mangroves including Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) at the water's edge.

The Ballina Nature Reserve covers a large section of North Creek. Extensive saltmarsh areas were found in the lower reaches of the creek. Although the canopy weed cover was low, the understorey weed cover was >90% in some areas. Threatening weeds include Ground Asparagus (*Asparagus aethiopicus)* with vines such as Coastal Morning Glory (*Ipomoea cairica*) and White Passionfruit (*Passiflora subpeltata*). These weeds were preventing regeneration in the understorey and reducing habitat for reptiles. These reaches have a high recovery potential if weeds and pasture grasses were controlled as there was an abundant seed source available for regeneration.

In the higher reaches above Ross Lane, the Creek has been channelized by historical drainage union works. With the exception of pasture grasses and a few patches of regrowth upstream, riparian vegetation is almost non-existent on the channel. The current landuse, predominantly cane farming, limits expansion of the riparian vegetation along this part of the creek.

Zone 2 - Emigrant/Maguires Creek

On-ground sites EC3

The lower estuarine areas of Emigrant Creek have good mangrove areas. The riparian width varies from wide 50m to <10m where landuse or roads come close to the creek edge. The dominant species were similar to North Creek with Swamp Oak (*Casuarina glauca)* and Tuckeroo (*Cupaniopsis anacardioides*) on the banks, and mangroves such as Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) dominating the water's edge. The major issues for riparian management in this area were urban and infrastructure encroachment and recreational landuse (e.g. vehicles causing damage to saltmarsh and creek banks).

Zone 3 - Back Channel

On-ground sites BC8

The Back Channel management zone includes the riverbank near Wardell. The northern bank of the river has a healthy mature (>10yo) corridor of mangroves and riparian vegetation with 30-60% native cover in the canopy and understorey. On the southern side, the riparian vegetation was very narrow to non-existent in places. Priority weeds were not evident. The riparian v2egetation on the southern side includes remnant mangroves and saltmarsh. The major issues affecting the recolonisation of mangroves are boat wash and encroaching landuse.

Zone 4 - South Ballina/Empire Vale

On-ground sites SB4, SB5, SB6, SB7

The South Ballina management area includes the Ballina Nature Reserve along South Ballina Beach Road. Mangroves were extensive in this reach. Several large floodgates feed into the river along the zone. The flood-gated area at Empire Vale has been identified as a potential riparian rehabilitation site as it is a refuge area for fish in flood times. The dominant canopy vegetation was Forest Red Gum (*Eucalyptus tereticornis*) and Hoop Pine (*Araucaria cunninghamii*), with mangroves along the main channel. The riparian vegetation was less than 30% cover but predominantly native with few weeds. Major weeds were Coastal Morning Glory (*Ipomoea cairica),* Lantana *(Lantana camara)* and Senna *(Senna pendula var. glabrata),* with pasture grasses and herbs such as Farmers Friend *(Bidens pilosa).* The riparian zone along the river was approximately 50m wide in this area, but became narrower to non-existent towards the locality around Keith Hall Road.

Native tree planting at Carney Lane was becoming established but further planting and weed control will be required. On the western bank, near Pimlico Island, a very narrow native riparian zone is threatened by weeds, particularly vines like Coastal Morning Glory (*Ipomoea cairica).*

Major issues for riparian management centre on boat wash and loss of native vegetation to weeds, as well as encroaching urban, agricultural and infrastructure landuses.

Zone 5 – Rileys Hill

This is a relatively small management zone with boat launch facilities, urban dwelling and agriculture (predominantly sugar cane). The riparian vegetation varied from some coverage (riparian width >10m) with some remnant native vegetation near to very limited. The dominant species along banks were Swamp Oak (*Casuarina glauca)* and Tuckeroo (*Cupaniopsis anacardioides*) on the banks, with mangroves including Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*). Common Reed (*Phragmites australis*) and Cumbungi (*Typha orientalis*) provide habitat along the bank toe in places. The understorey vegetation was degraded with few native species. Landuse activities and road infrastructure were encroaching on the riparian zone.

Other issues for riparian management were boatwash and clearing of the existing vegetation. The opportunities for improvement of riparian vegetation in this management zone are varied and depend on site access and landuse limitations. Brolgas were observed in grazing paddocks in this zone.

Zone 6 - Evans River

On-ground sites E19

Vegetation along the Evans River is extensive in some areas but around the Tuckombil Canal, downstream of the Pacific Highway, there is no riparian canopy. Upstream of the Pacific Highway, the dominant canopy tree was Forest Red Gum (*Eucalyptus tereticornis*) along with Swamp Oak (*Casuarina glauca*) and Hoop Pine (*Araucaria cunninghamii*). There were no mid-storey species. Water couch (*Paspalum distichum*) colonised the edges of the banks.

The major weed species was Cockspur Coral Tree (*Erythrina crista-galli*). There is opportunity to manage bank erosion around the Tuckombil Canal using low riparian vegetation that can tolerate inundation. Revegetaion would require landholder support or need engagement with the RTA during the construction of the new route of the Pacific Highway.

RRCC has recently had a report completed on the management of the Tuckombil Canal and they have resolved to place the Tuckombil Canal Management Report on public exhibition and proceed to public consultation on the basis of a fixed weir.

Zone 7 - Rocky Mouth Creek

On-ground sites RC17

The vegetation along the riparian zone of Rocky Mouth Creek was dominated by a weedy canopy of Cockspur Coral Tree (*Erythrina crista-galli*). Camphor Laurel (*Cinnamomum camphora*) was also a major canopy weed along Rocky Mouth Creek. The canopy cover was less than 30% with almost no native species. The existing remnant native canopy vegetation included some Forest Red Gum (*Eucalyptus tereticornis*), with Black Tea-tree (*Melaleuca bracteata)* in the mid-storey. The toe of the bank was colonised by native species such as *Bolboschoenus* sp. and Common Reed (*Phragmites australis*). Pasture grasses dominated the understorey. Other major weeds included Senna *(Senna pendula var. glabrata)* and Madeira Vine (*Anredera cordifolia*).

Good opportunities for revegetation exist around the mouth of Rocky Mouth Creek in Woodburn and with landholders along the creek.

Zone 8 - Swan Bay

On-ground sites SB20

Riparian vegetation on the northern bank of Swan Bay extending to the start of Swan Bay Road, was dominated by native riparian species. The canopy cover was over 30% and up to 60% with a high percentage (60%) of native species. The dominant native canopy was Swamp Oak (*Casuarina glauca)* and Tuckeroo (*Cupaniopsis anacardioides*). The major mid-storey species included the threatened species Sweet Myrtle (*Gossia fragrantissima),* and more common Green Native Cascarilla *(Croton verreauxii)* and Foambark *(Jagera pseudomes).* The understorey vegetation was heavily grazed by cattle and was dominated by pasture grasses and native species such as Basket Grass (*Oplismenus undulatus*) and Swamp Foxtail (*Pennisetum alopecuroides*). Smartweed (*Persicaria stigosa*), Cumbungi (*Typha orientalis*) and *Bolboschoenus* sp. colonised the edges of the oxbow.

Serious weeds were evident in the Swan Bay area. Water Hyacinth (*Eichhornia crassipes*) covered less than 10% over the water surface. This lower coverage was possibly due to control measures or flooding and flushing of the Oxbow. Cockspur Coral Tree (*Erythrina crista-galli*) was the main canopy and mid-storey weed. Several vines were encroaching on the remnant vegetation. These were Coastal Morning Glory, (*Ipomoea cairica*), White Morning Glory (*Ipomoea alba*), Climbing Asparagus (*Asparagus plumosus*) with large areas of Balloon Vine (*Cardiospermum grandiflorum*).

The Swan Bay region has major potential for rehabilitation. Existing remnant vegetation provides a useful reference community for edge plantings. Control of aquatic weeds will allow the oxbow to function as a valuable wetland for resident and migratory birds. Grazing may be used as a weed control method but at a lighter regime than the present one.

Zone 9 - Kilgin Buckendoon

On-ground sites KB14, KB15, KB18

The riparian vegetation of the Kilgin Buckendoon management zone varied from some coverage (riparian width >10m) with remnant native vegetation near Dungarubba Creek, to highly degraded near Kilgin Drain and along the channel to Woodburn. The native canopy cover was < 10% for most of this area of the channel.

The dominant species along banks were Swamp Oak (*Casuarina glauca)* and Tuckeroo (*Cupaniopsis anacardioides*) on the banks, with mangroves including Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*). Hoop Pines (*Araucaria cunninghamii*) were also noted in the riparian zone and close to the waters edge in some places. Common Reed (*Phragmites australis*) and Cumbungi (*Typha orientalis*) provide habitat along the bank toe in places. The understorey vegetation was degraded with few native species. The dominant landuse throughout this area was cane farming with some Macadamia plantations and cattle grazing. Landuse was impacting on riparian vegetation in some places.

Cockspur Coral Tree (*Erythrina crista-galli*) appears to be increasing and was the dominant canopy weed along this riparian management zone. Other dominant weeds were Castor Oil Plant (*Ricinus communis*), and Para grass (*Urochloa mutica*), along the bank edges.

Other issues for riparian management were boatwash and current clearing of the existing vegetation. The opportunities for improvement of riparian vegetation in this management zone were high as there was existing remnant vegetation to provide structural cover and seed sources. The bank has high visibility and good access for works although in places the extent of rehabilitation works will be limited by road infrastructure. Potential demonstration sites exist at Dungarubba Creek, Oakland Road and Woodburn on the opposite bank to the main town.

Zone 10 - Tuckean

On-ground sites T11, T12

Sites surveyed in the Tuckean covered the Baggotville Barrage to the mouth of the riverbank and along the Broadwater Road. The riparian vegetation in the Tuckean was often greater than 50m wide with a high native cover in the canopy (>-60% - 100%). Upstream of the Barrage, the Tuckean Nature Reserve covers a large area and mangroves were noted to be recolonising the upstream area. The vegetation downstream of the barrage was diverse with fresh and saltwater species co-existing. The dominant species along banks were Broad-leaved Paperbark (*Melaleuca quinquenervia*), Swamp Oak (*Casuarina glauca)* and Tuckeroo (*Cupaniopsis anacardioides*) on the banks, with mangroves including Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*). The understorey vegetation along the banks included Water Ribbons (*Triglochin procera*), Cumbungi (*Typha orientalis*), River Lily (*Crinum penduncelatum*) and Sea Rush (*Juncus kraussii*). An extensive cover of Cape Waterlily (*Nymphaea capensis*) was evident both up and downstream of the Barrage. The vegetation downstream of the barrage provides significant estuarine habitat and should be highly valued.

The riparian vegetation along the main channel near Broadwater Road was highly diverse but narrow and threatened by climbing weeds in places. The main canopy tree was Forest Red Gum (*Eucalyptus* *tereticornis*) with Tuckeroo (*Cupaniopsis anacardioides*) on the banks. Mangroves, including Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) and Common Reed (*Phragmites australis*) were colonising the toe of the bank in many places. The riparian vegetation included remnant rainforest species such as Hard Quandong (*Elaeocarpus obovatus*), Green Native Cascarilla (*Croton verreauxii)*, Clerodendron (*Clerodendron floribundum),* Rapanea *(Myrsine variabilis)* and *Exocarpus latifolius.*

Several water weeds, transported to the site by flood waters, were evident near the bank. These were Parrots Feather *(Myriophyllum aquaticum*), Water Hyacinth *(Eichhornia crassipes),* Salvinia *(Salvinia molesta),* Water Lettuce *(Pistia stratiotes*), Duckweed (*Lemna* sp). and *Azolla* sp*.* The rotting biomass of these weeds in the brackish conditions of the estuary may present potential blackwater and low dissolved oxygen issues.

Zone 11 - Lower Bungawalbyn

On-ground sites BU26/27/28

The results of committed riparian management were evident in the riparian vegetation of the Bungawalbyn catchment. Weed control around the mouth of Bora Creek and along Bungawalbyn Creek has been successful. The width of the riparian zone was less than 10 m for much of the area but the riparian canopy cover was over 60-100%. The percentage of native species in the canopy was over 90%. The riparian vegetation was fenced with an electric fence for cattle at the study site. The weed species that were present in low abundance were seedlings and mature plants of Climbing Asparagus (*Asparagus plumosus)*, Cockspur Coral Tree (*Erythrina crista-galli*) and Coastal Morning Glory Vine (*Ipomoea cairica*) was evident in places.

Weed control and planting along Sandy Creek has also been successful with a canopy cover of up to 60% native and a high diversity evident. The major canopy species was Forest Red Gum (*Eucalyptus tereticornis*), with Whalebone Tree (*Streblus brunonianus*), Rough-leaved Elm (*Aphananthe philippinensis*), and Sally Wattle (*Acacia melanoxylon*). The River Lilly (*Crinum penduncculatum*), Marsh Club-rush (*Bolboschoenus fluviatilis*) and Creek Mat Rush (*Lomandra hystrix*) were colonising along the toe of the bank. The high diversity on the Bungawalbyn provides important reference sites for future riparian rehabilitation. There is scope for further riparian rehabilitation activities in this area.

The dominant weed species in this zone was Mimosa Bush (*Vachellia farnesiana*).

The Bora Creek Management Plan has recently been completed and will assist with weed management and riparian revegetation strategies.

Zone 12 - Upper Richmond/Wilsons River

On-ground sites UPRWR21/22, UPRWR23, UPRWR24, UPRWR25, UPRWR26, UPRWR30, UPRWR32, UPRWR32

The Upper Richmond and Wilsons River estuary management zone includes Leycester Creek, the Wilsons River from Lismore to Coraki and the Richmond River from Casino to Coraki.

Leycester Creek is mainly cleared of riparian vegetation with some remnant areas near site UPRWR25. The remaining vegetation in this section is dominated by River Oak (*Casuarina cunninghamiana*) and Weeping Bottlebrush (*Callistemon viminalis*) with rainforest elements in the mid-storey. The dominant mid-storey species include Whalebone Tree (*Streblus brunonianus*), Red Kamala (*Mallotus philippensis*) and Cudgerie (*Flindersia schottiiana*). The understorey was dominated by pasture grasses and herbaceous weeds with some native grasses, including Basket Grass (*Oplismenus* spp.). The threatened species Thorny Pea (*Desmodium acanthocladum*) was also found. The toe of the bank was largely unvegetated but *Baumea articulata* and other sedges were colonising in a few places. This site has high regeneration potential with a percentage cover class of up to 60% in the canopy with 30% native species. The major weed species in the canopy were Mulberry (*Morus alba*), Camphor Laurel (*Cinnamomum camphora*) and Coral Tree (*Erythrina crista-galli*), which all pose a serious threat to the remaining native species if left uncontrolled. Other serious weeds on the site were Balloon Vine (*Cardiospermum grandiflorum*), Climbing Asparagus (*Asparagus plumosus*) and Coastal Morning Glory (*Ipomoea cairica*). Bank exposure in places was severely impacting erosion of the bank and causing slumping in places. Vegetation has been compromised.

Wilsons River above Lismore

The riparian vegetation along the Wilsons River above Lismore at the Trinity Sports Field, was dominated by a canopy of Camphor Laurel (*Cinnamomum camphora*) and Coral Tree (*Erythrina sykesii*). The native canopy cover was less than 10%, consisting of Silky Oak (*Grevillea robusta*) and Red Kamala (*Mallotus philippensis*). Several native species were present in the mid and understorey, including Whalebone (*Streblus brunonianus*), Small-leaved Tuckeroo (*Cupaniopsis parvifolia*), Rough-leaved Elm (*Aphananthe philippinensis*), Twin-leaved Coogera (*Arytera distylis*) with the threatened species, Thorny Pea (*Desmodium acanthocladum*). The major weeds were Madeira Vine (*Anredera cordifolia*), Coral Berry (*Rivina humilis*) and Senna (*Senna pendula*).

Wilsons River downstream from Lismore

Downstream from Lismore, the Wilsons River riparian corridor was sparse with a canopy cover of less than 10% in many places. The dominant native species were Forest Red Gum (*Eucalyptus tereticornis),* Weeping Bottlebrush *(Callistemon viminalis)* with some River Oak (*Casuarina cunninghamiana).* The percentage of native species in the canopy varied between 1% and 30%. The major weed species in the canopy were Mulberry (*Morus alba*), Camphor Laurel (*Cinnamomum camphora*) and Coral Tree (*Erythrina crista-galli*) which all pose a serious threat to the remaining native species if left uncontrolled. Other serious weeds on the site were Balloon Vine (*Cardiospermum grandiflorum*), Climbing Asparagus (*Asparagus plumosus*) and Coastal Morning Glory (*Ipomoea cairica*). Other serious understorey weeds included Para Grass (*Urochloa mutica*) and Johnson Grass (*Sorghum halepense*).

Upper Richmond River

The riparian corridor along the Richmond River to Casino was similar to the Wilson River. The dominant native species were Forest Red Gum (*Eucalyptus tereticornis),* Weeping Bottlebrush *(Callistemon viminalis)* with some River Oak (*Casuarina cunninghamiana).* Other native trees included Creek Lilly Pilly (*Acmena smithii*) and Twin-leaved Coogera (*Arytera distylis*) .The percentage of native species in the canopy varied between 1% and 30%. The understorey was dominated by pasture grasses and herbaceous weeds with some native grasses including Basket Grass (*Oplismenus* spp.). The major weed species in the canopy were Mulberry (*Morus alba*) Camphor Laurel (*Cinnamomum camphora*) and Coral Tree (*Erythrina crista-galli*), which all pose a serious threat to the remaining native species if left uncontrolled. Other serious weeds on the site were Balloon Vine (*Cardiospermum grandiflorum*), Climbing Asparagus (*Asparagus plumosus*) and Coastal Morning Glory (*Ipomoea cairica*).

Other serious understorey weeds included Para Grass (*Urochloa mutica*) and Johnsons Grass (*Sorghum halepense*). This area is reported to have Honey Locust (*Gleditsia tricanthos*) and *Hymenachne* sp. which are both potentially serious invasive weeds of the lower estuary in the future.

The Richmond River at Casino has similar vegetation although some very useful regeneration work has been completed. This site has high potential as a focus site for revegetation works to demonstrate the appropriate species for slowing bank erosion.

1.4 Summary

The riparian vegetation of the Richmond River Estuary is degraded for much of the area. The width of the bank vegetation is often <5 m and few native trees remain. Serious weed invasion is occurring on the banks as there is no natural vegetation to inhibit the growth of weeds. The major weeds are Camphor Laurel and Cockspur Coral Tree.

In some places, particularly North Creek and the lower Estuary, there is some remnant vegetation with good native canopy and mid-storey trees. The understorey is largely dominated by pasture grasses leaving little opportunity for seedling regeneration and nutrient cycling, suggesting that the current vegetation is not providing viable riparian function.

Potential demonstration sites exist in all the management zones. In the Swan Bay, Bungawalbyn, and Kilgin/Buckendoon/Dungarubba management zones potential demonstration sites are at Dungarubba Creek, Oakland Road and Woodburn on the opposite bank to the main town. Good opportunities for revegetation exist around the mouth of Rocky Mouth Creek in Woodburn and with landholders along the creek.

Current Landcare groups are actively involved in riparian vegetation management and enhancement in many of the management zones and Richmond Landcare Inc oversees many of the funded projects. These groups along with private landholder have made notable contributions to riparian vegetation improvements in the study area.

2. Geomorphological Assessment

2.1 Context of the Richmond River Estuary and Catchment

The geology of the Richmond River catchment is comprised primarily of Tertiary-Quaternary Sediments (river gravels, alluvium, sand and clay as well as beach and dune sands) and Tertiary Volcanics (Lismore Basalt) which overlay Palaeozoic Neranleigh-Fernvale Metasediments. In addition, there are several scattered outcrops of Mesozoic sediments, including the Walloon Coal Measures, Kangaroo Creek Sandstone and the Tabulam Group (Redcliff Coal Measures). These Mesozoic sediments include rock types such as sandstone, siltstone, claystone, shale, conglomerate and coal (Brunker *et al*. 1972; Hanlon *et al*. 1970).

The five main soil types in the catchment are; red basaltic (kraznozem), chocolate, alluvial, podzolic and coastal heath soils. The red and chocolate soils have developed from Tertiary Basalts in elevated areas of high rainfall, the podzolic soils have developed from Mesozoic Sediments and the coastal heath soils have formed from Quaternary Sediments. Alluvial soils contain sediments from all geologic groups (Donnelly, 1997).

The Richmo2nd River catchment covers an area of approximately 6900 km^2 which includes three main tributaries, the Wilsons River, the Richmond River and Bungawalbyn Creek (Hossain *et al*. 2002) and the floodplain (Donnelly 1997). Approximately 20% of the catchment has slopes exceeding 15°; 40% has slopes between 3° and 15°; with the remaining area comprised of flat land with extensive floodplains (WBM 2006; Hossain *et al*. 2001). Only 22% of the Wilsons River subcatchment is forested, compared with 42% of the Richmond River and 75% of the Bungawalbyn Creek sub-catchments (Hossain et al. 2002).

With the exception of the Bungawalbyn Creek subcatchment and the Border Ranges, the majority of the Richmond catchment has been extensively cleared of native vegetation with a significant number of natural water courses (tributaries) having been highly modified for agricultural drainage and/or flood mitigation purposes. Changes in the landuse patterns such as deforestation and agricultural activities in the upper catchments, development on the lower floodplains, and urbanisation in the lower coastal catchments, has significantly increased the supply of sediment to the river system (Hossain *et al*. 2004). Landuse, population density, geology and soils vary considerably across the catchment (McKee *et al*. 2001), and landuse changes in the subcatchments indicate a potential increase of suspended sediment load of about 6-fold since European settlement (Hossain *et al*. 2002).

Loose rock protection is present along most of the Richmond riverbank as far upstream as Wardell. Upstream from Wardell, bank erosion contributes substantially to downstream sediment loading. On the lower Richmond River floodplain, bank erosion does not significantly contribute to the sediment supply, nor do tributary streams other than for fine clays and silts during high rainfall run off events. The main contributors to bank instability are boat wake and locally generated wind waves (WBM 2006).

The straightening of existing river or tributary meander in areas of where drainage regimes have been altered, results in heightened erosion of banks, as it steepens the gradient of the channel and thus increases water velocity (Ladson 2008). The natural meander of water courses has been largely disregarded by agricultural land management practices, leading to significant increases in sediment transport downstream.

The catchment is characterised by net seaward-directed sediment transport, associated with the predominantly high river discharge and relative absence of available accommodation space for sediment deposition (WBM 2006). Consequently, fine suspended sediment, and coarse sediment (as bed-load), is moved downstream along the bottom of the deltaic channels, due to unimpeded river flow. Where flow is impeded by built structures such as weirs and dams, sediment becomes trapped under normal flow regimes and there is often significant infilling from sediment build up.

The Richmond River estuary can be described as a bar built, micro-tidal, mature wave dominated delta (Roy *et al*. 2001; Hossain *et al*. 2004; Hashimoto et al. 2006). The tidal influence extends to Boatharbour in the Wilsons River, to Casino in the Richmond River and 15km upstream in Bungawalbyn Creek (Hossain *et al*. 2001). Fine and coarse sediment enters the estuary from the catchment, subject to climatic conditions and the volume of river input. Seasonal and climate factors dominate the function of deltas, with episodic high-flow events causing intense flushing, sedimentation, and erosion in the main channels and floodplain (Eyre *et al*. 1998).

Suspended sediment transport through the estuary is controlled by many factors including river flow, tidal flows, tidal range, salinity, density, circulation and wind (Hossain *et al*. 2004). Freshwater discharge appears to be a major influence on sediment transport, deposition and export to the continental shelf (Hossain *et al*. 2001). Increasing amounts of sediment being received by estuarine ecosystems is increasing the economic burden on local communities as high standards of water quality are expected and there are escalating costs to remove sediment and maintain channels for navigation and flood mitigation purposes (Eyre *et al*. 1998).

1.2 Methodology for Field Site Assessment

2.2.1 Geomorphic Stability Assessment

Methodology developed by Rosgen (1996) and adapted after Dilworth (2008), was used to assess geomorphic stability at the same sites the vegetation assessment was carried out. Scores were given that related to stability characteristics, shown in Table 2.1, at the same sites where the vegetation assessment was complete.

Table 2.1 Scoring system used to assess geomorphic stability.

Stability	*Characteristics*	*Score*
Stable	Geomorphic structures of the channel unaltered or largely unchanged from pre-European disturbance state, and geomorphic form processes (sediment transport) are in equilibrium with existing channel geometry. High sediment transport competence. Usually bedrock controlled and not subject to or likely to be subject to bed level adjustment.	10-8
Moderately Unstable	Stable convex stream banks with intact bank toes stable. Isolated incidences of bed and bank erosion may be present but can easily be addressed by restoring riparian vegetation, and bank protection.	8-5
Unstable	Both bed level and/or lateral adjustments are active in-stream. Vertical stream banks indicate major bank erosion, which is associated with active bed level adjustments (minor head cuts) are common.	5-3.5
Highly Unstable	The channel is entrenched and highly unstable with ongoing vertical and/or lateral bed and bank erosion. Stream banks are vertical to concave and numerous bed level adjustments are evident.	3.5-0

1.2.2 Geomorphic Condition

Methodology developed by Lambert *et al*. (1999) and adapted after Dilworth (2008), was used to define the geomorphic conditions of each site assessed. The scoring was based on the conditions described in Table 2.2.

Table 2.2 Condition assessment used to classify the geomorphology.

Geomorphic Condition	*Characteristic*	*Score*
Near Intact	The geomorphic structure is largely unchanged from pre-disturbance state. Riparian vegetation is usually unchanged. Geomorphic form characteristics and processes are in equilibrium. The aquatic waterway is providing critical aquatic habitat refuge.	10-8
Geomorphic Condition	Characteristic	Score
Good	Geomorphic structure is largely unchanged from pre-disturbance state, however, vegetation cover and composition may be significantly altered. Characteristics and processes are in equilibrium. The aquatic waterway is providing critical aquatic habitat refuge.	8-6.5
Moderately impacted	Geomorphic form characteristics and processes have been disturbed in the past and remain out of equilibrium. The waterway has not adjusted to prevailing conditions and is experiencing on-going changes. Aquatic habitat refuge is still provided however the condition is degraded.	6.5-4.5
Degraded	The channel has become entrenched laterally and vertically expanded to its most degraded condition. The channel is disconnected from the floodplain. Geomorphic form and characteristics are processes are degraded. Limited aquatic refuge habitat is provided.	4.5-0

1.2.3 Geomorphic recovery potential

Methodology developed by Lambert et al. (1999) and after Dilworth (2008), was used to determine a score for recovery potential. Table 2.3 outlines the characteristic used in the scoring.

Table 2.3 Scoring system used to assess recovery potential at sites.

Recovery Potential	*Characteristics*	*Score*
Conservation	River structure and vegetation associations are relatively intact. Management strategies should aim to maintain, or improve the current River Style.	10-8
Strategic	Sites or reaches which are sensitive to disturbance triggering upstream geomorphic degradation, lateral or vertical expansion of the channel. These areas may deliver an oversupply of sediment to downstream reaches. Proactive management strategies are the most effective means of conservation. Attention should be placed on bed level adjustments.	8
High Recovery	These reaches have high inherent natural recovery potential and will respond well to improved land management and assisted regeneration.	8-6
Moderate Recovery	These moderately degraded sites/reaches have reasonable potential to recover and can be rehabilitated at reasonable cost. River structure and vegetation associations require improvement. Bed and bank rehabilitation	6-4

		strategies may be required to stabilise the waterway.	
Degraded reaches		These highly degraded sites/reaches have little natural recovery potential (i.e. the water way shows signs of continued geomorphic degradation). Extensive bed and bank stabilisation works are required at considerable cost over a long period of time.	4-0

2.3 Results and Assessment

The observations made during a catchment tour together with a literature review and the results of the on-ground site assessment, were used to provide a geomorphic status assessment for each management zone. The results of the on-ground site assessment are provided in Table 2.4. Table 2.5 provides a summary of the issues in each zone. Some relevant photographs are provided in Figures 2.1 and 2.2.

Additionally, photograph Archives for each management zone and at specific on-ground sites are available in Appendix 2.

Table 2.4 Geomorphic Assessment Scoring.

SITE		GPS	Management Zone Number	Management Zone name	BANK AND BED STABILITY	Geomorphic stability	Creek and Bank Condition	Recovery Potential	TOTAL SCORE
NC1	Nth Cr Road	28 50' 21.21"S, 153 34' 43.26"E	1	North Creek		5.5	5.5	7.5	**18.5**
NC2	Upstream Ross Lane	28 47'12.76"S, 153 33' 50.14"E	1	North Creek		5.5	5.5	7.5	**18.5**
EC3	Emigrant Cr	28 50' 01.53"S, 153 30' 48.50"E	2	Emigrant/ Maguires		5.5	5.5	7.5	**18.5**
SB4	Sth Ballina Beach Road	28 52' 52.62"S, 153 33' 34.82"E	4	Sth Ballina		5.5	5.5	7.5	**18.5**
SB5	Empire Vale	28 54' 46.58"S, 153 30' 30.60"E	4	Sth Ballina		5.5	5.0	6.0	**16.5**
SB6	Carney Lane River	28 57' 6.07"S, 153 28'	4	Sth Ballina		6.0	5.5	5.5	**17.0**

SITE		GPS	Management Zone Number	Management Zone name	BANK AND BED STABILITY	Geomorphic stability	Creek and Bank Condition	Recovery Potential	TOTAL SCORE
	Dr	29.80"E							
SB7	Near Pimblico Is	28 54' 49.43"S, 153 29' 19.35"E	2	Emigrant/ Maguires		4.5	5	4.5	**14.0**
BC8	Wardell Bridge	28 57' 16.25"S, 153 27' 56.07"E	3	Back Channel		4.5	5	4.5	**14.0**
T 10/11	Broadwater Road	28 59' 50.68"S, 153 24' 11.22"E	10	Tuckean		3	5.5	5.5	**14.0**
T12	BAG BARRAGE	28 58' 51.75"S, 153 24' 15.98"E	10	Tuckean		7.5	6.5	8.5	**22.5**
KB 13/14	Kilgin Drain to RR	29 01'31.58"S 153 22 '30.24" E	9	Kilgin/ Buckendoon		3.5	4.5	3	**11.0**
KB15	Woodburn opp town	29 4' 6.42"S, 153 20' 34.57"E	9	Kilgin/ Buckendoon		4.5	2	8	**14.5**
KB18	OAKLAND RD NEAR SCHOOL RD	29 4' 38.55"S, 153 20' 4.10"E	9	Kilgin/ Buckendoon		4.5	3	7.5	**15.0**
RC17	Rocky Mouth Creek	29 02' 40.25"S, 153 20' 09.24"E	7	Rocky Mouth Creek		6.5	6	7	**19.5**
E19	TUCKOMBIL CANAL	29 05' 05.52"S, 153 20'16.79"E	6	Evans River		4	4	6.5	**14.5**
SB20	Swan Bay	29 3' 40.89"S, 153 17' 16.87"E	8	Swan Bay		7	7	7	**21.0**
UPRWR21/22	Coraki downstream boat ramp	28 59' 6.10"S, 153 17' 14.37"E	12	Upper Richmond/ Wilsons River		5.5	5	7.5	**18.0**
UPRWR23	WYRALLA RD BRIDGE	28 53' 29.78"S, 153 17'	12	Upper Richmond/ Wilsons River		6	5	6	**17.0**

SITE		GPS	Management Zone Number	Management Zone name	BANK AND BED STABILITY	Geomorphic stability	Creek and Bank Condition	Recovery Potential	TOTAL SCORE
	TO CORAKI	49.75"E							
UPRWR24	WYRALLA RD UPPER	28 52' 06.87"S, 153 16' 14.12"E	12	Upper Richmond/ Wilsons River		4	6	7	**17.0**
UPRWR25	LECESTER CR	28 47' 45.44"S, 153 14' 24.09"E	12	Upper Richmond/ Wilsons River		5.5	5	6.5	**17.0**
BU26	Bora Bungawalbyn Creek	29 2' 42.08"S, 153 15' 3.72"E	11	Lower Bungawalbyn		7.5	7	8	**22.5**
BU27/28	Sandy Creek	29 1' 32.61"S, 153 15' 5.76"E	11	Lower Bungawalbyn		8.0	7	8	**23.0**
UPRWR 29/30	Tomki Tatham Bridge	28 55' 30.09'S, 153 09' 39.64"E	12	Upper Richmond/ Wilsons River		4.5	5	5.5	**15.0**
UPRWR31	Casino Weir	28 52' 4.56"S, 153 2' 33.21"E	12	Upper Richmond/ Wilsons River		5.5	5.5	4	**15.0**
UPRWR32	Wilson R Trinity	28 48' 0.09"S, 153 17' 9.39"E	12	Upper Richmond/ Wilsons River		4.5	5.0	5	**14.5**

Zone 1 - North Creek/Newrybar

On-ground sites NC1, NC2

Geology

The upper catchment flows east from the coastal ridge at Newrybar which is a region underlain with Tertiary Volcanics (Lismore Basalts), down onto the coastal plain which is comprised of Quaternary Sediments (river gravels, alluvium, sand and clay, as well as beach and dune sands). In the northern most portion of this catchment (Midgen Creek), the upper catchment flows from a region consisting of Neranleigh-Fernvale Metasediments. The majority of the North Creek catchment including tributaries of Birrung Creek, Newrybar drain, Deadmans Creek, Roberts Creek, and Chickiba Creek, drain through lower lying swampy areas comprised mainly of Quaternary Sediments (Brunker *et al*. 1972).

Natural Land Cover

Most of the coastal sub-catchment has been modified from its natural state for agricultural use as well as urban coastal development on some upland ridgelines. The management zone has been extensively drained and cleared with a network of connecting artificial drainage systems adjacent to the coastal heath which has been selectively retained along the beach dune systems.

Current Land Use

The North Creek/Newrybar management zone has been cleared for grazing (cattle) and horticultural purposes in the upper reaches, and drained for agricultural purposes (predominantly sugar cane), on the lower lying areas. Dredging and expanding urban development is occurring in this area.

Soils

The North Creek/Newrybar management zone is made up of alluvial, red basaltic (kraznozem), podzol soil types, and coastal heath sands (Donnelly 1997).

Stream Pattern

The stream pattern can be described as dendritic in the upper region and both centripetal (unaltered) and distributary (altered with drainage) in the middle and lower reaches (Grotzinger *et al*. 2007).

Bank Stability

The upper reaches are lacking in riparian vegetation due to clearing for grazing which has lead to bank erosion and transportation of sediment downstream. The coastal sand plain is characterised by extensive drainage channels in which siltation (transported from upstream) is actively removed and often dumped as spoil along the banks as part of management practices to keep drains open. Riparian vegetation is non-existent along drainage channels due to the need for efficient drainage and access, as well as the practice of maximising land area for crop production. The middle section of North Creek passes through Ballina Nature Reserve and as such has extensive riparian vegetation resulting in good bank stability and erosion control. The lower estuary area has some loose rock protection, adjacent to urban settlement, where meander channels are undercutting the shoreline (WBM 2006) (eg. Figures 12.1F).

Sediment Transport/Movement

The opportunity for sediment transport and movement is evident in the upper boundaries of the management zone due to past land clearing practices and a lack of riparian vegetation. The sediment is transported downstream in "slugs" during times of high rainfall making its way into the lower estuary (Hossain *et al*. 2001). Here, the sediment is trapped and is accreting in expanding mangrove forests. From the ocean side, marine sands are developing shoals around the Missingham Bridge area.

Zone Specific Issues

Major issues for the North Creek/Newrybar management zone include a lack of suitable riparian vegetation in the upper reaches which provides increased opportunity for bank instability and sediment mobilisation. Current agricultural practices for sugar cane farming provide a source of unconsolidated sediment as drain clearance spoil is readily transported downstream in high rainfall events.

- Lack of suitable riparian vegetation in upper reaches leading to bank instability.
- Drainage modification for agriculture.
- Agricultural practices remove drainage vegetation and sediment which is often deposited along the bank.

- Stock access to upper catchment watercourses.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on farmed agricultural land.
- Recreational boating and fishing access in lower catchment.
- Sheet and rill erosion on cleared land.
- Catchment and marine sediment movement resulting in estuary shoaling.
- Increasing channel width and decreasing channel depth in the lower catchment.

Zone 2 - Emigrant/Maguires Creek

On-ground sites EC3

Geology

Maguires Creek drains the eastern portion of the Alstonville plateau which is a region of Tertiary volcanic rock named Lismore Basalt. Off the edge of the plateau, the creek passes through exposed sections of ancient Palaeozoic strata identified as Neranleigh-Fernvale Metasediments, then flows down onto the coastal plain which is comprised of Quaternary Sediments (river gravels, alluvium, sand and clay). Tributaries of Maguires Creek include Willowbank Creek, Branch Creek and Houghlahans Creek. Maguires Creek joins Emigrant Creek 2km north west of West Ballina. Emigrant creek begins just east of Newrybar and cuts through Lismore Basalts, some minor outcrops of Neranleigh-Fernvale Metasediment at Tintenbar, before flowing onto the coastal plain at Cumbulum. Tributaries of Emigrant Creek include Sandy Flat Creek, (Brunker *et al*. 1972).

Natural Land Cover

Basalt areas were originally covered in rainforest which was known as the Big Scrub. Most of the management zone has been modified from its natural state for agricultural use as well as urban development on upland areas (eg. Alstonville). The management zone has been extensively cleared, originally for dairying, but in more recent times much of the upland area has been converted to horticulture which is mainly Macadamia Nut production. Natural vegetation cover has been removed with only the occasional isolated pocket of remnant vegetation remaining as an example of the once broad and rich species mix.

Current Land Use

The management zone has been extensively cleared for grazing (cattle) and horticultural purposes (WBM, 2006). Some areas are no longer used for agricultural production and are regenerating original forest vegetation cover, but with an increased mix of exotic weed species.

Soils

The management zone is made up of alluvial, red basaltic (kraznozem) and podzol soil types (Donnelly, 1997).

Stream Pattern

The stream pattern of Maguires Creek can be described as radial from the Alstonville plateau and parallel in the areas of pronounced localised relief. The stream pattern of Emigrant Creek can be described as parallel in the upland areas and both catchments are centripetal in the middle and lower reaches (Grotzinger *et al*. 2007). Emigrant Creek Dam is located in the middle to upper reaches of Emigrant Creek, at Knockrow, and was commissioned in late 1953. It should be noted that since construction there have been significant effects downstream in relation to altered flow regimes and sediment movement. In more recent times, significant effort has been put into catchment revegetation around the Emigrant Creek Dam. Marine dominated shoaling occurs at the confluence with Richmond River.

Bank Stability

The upper reaches of the management zone are lacking in riparian vegetation due to clearing for grazing which has in turn lead to extensive erosion of banks and transportation of sediment downstream (WBM 2006). With a more recent change from grazing to horticulture some landholders have replanted riparian corridors resulting in bank stabilisation and improved stream management. Areas that are not currently used for agricultural production tend to have naturally regenerating riparian zones, however, the species mix is often predominantly exotic (i.e. Camphor Laurel). The coastal sand plain is characterised by extensive existing riparian corridors dominated by Mangrove species.

Sediment Transport/Movement

The past land clearance for grazing would have contributed significantly to the sediment load. With the change in land use to predominantly horticultural activity exposed soils and landforms will depend on crop style and farm management practices. Sediment contributions to the system also occur during the establishment of the chosen crop. The opportunity for sediment transport and movement is most evident in the steeper upper boundaries of the management zone with a lack of riparian vegetation. The sediment is transported from higher elevations downstream in “slugs” during times of high rainfall and accumulates in the lower energy drainage network of the coastal floodplain. This is evidenced by expanding mangrove forests and extensive shoaling in estuarine and tidal channels (WBM 2006).

Zone Specific Issues

A major issue for the Emigrant/Maguires Creek management zone is a lack of riparian vegetation in the steeper upper areas of the drainage network where higher stream velocities readily erode banks leading to increased sediment transport and deposition lower down in the catchment.

- Lack of suitable riparian vegetation in upper reaches leading to bank instability.
- Interruption of natural flow regime with construction of Emigrant Creek Dam.
- Sheet and rill erosion on cleared land.
- Potential mobilisation of chemicals due to horticultural management practices.
- Stock access to upper catchment watercourses.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on farmed agricultural land.
- Recreational boating and fishing access in lower catchment.
- Bulk sediment movement resulting in downstream estuary shoaling.

Zone 3 -Back Channel

On ground sites BC8

Geology

The Back Channel management zone drains the eastern portion of the Blackwall Range which is a complex geological feature comprised of predominantly Mesozoic sediment (sandstone, siltstone, claystone and conglomerate) which is named the Tabulum Group. There are some minor Lismore Basalt caps above these sedimentary layers at higher elevations and significant outcrops of Neranleigh-Fernvale Metasediments below, adjacent to the coastal plain. The coastal plain is comprised of Quaternary Sediments including river gravels, alluvium, sand and clay (Brunker *et al*. 1972). The area is drained by a number of minor water courses such as Bingal Creek and areas under agriculture are networked with a constructed drainage system.

Natural Land Cover

Basalt areas were originally covered in rainforest which have now been cleared for agriculture. Steeper slopes in the management zone remain forested with a strip of farmed land at the base of the Blackwell Range down onto the coastal plain. The centre portion of the coastal plain remains as Crown Reserve, and is predominantly low-lying swampland and scrub. The proposed route for the Pacific Highway upgrade runs through the farmed land between the Blackwell Range and Crown Reserve.

Current Land Use

The management zone has been partially cleared on lower slopes and sections of the coastal plain for cropping (sugar cane), especially those areas adjoining the Richmond River. Higher slopes are utilised for cattle grazing and minor horticultural activities. To the north west of Wardell a significant area (~1km^2) is being mined for mineral sands.

Soils

The management zone is made up of red basaltic (kraznozem), podzol and alluvial soil types (Donnelly 1997).

Stream Pattern

The natural stream pattern can be described as centripetal which connects with a series of modified distributary channels within agricultural cropping areas. Many of the modified watercourse channels connect directly to the Richmond River (Grotzinger *et al*. 2007).

Bank Stability

The eastern range escarpment is incised with a series of steep flowing and eroded water courses which connect to Bingal Creek. The upper reaches have retained riparian vegetation which diminishes significantly in the lower reaches and in areas under agricultural production on the coastal plain. Drainage networks with the extensive Crown Reserve retain natural vegetation cover. Bank stability along this section of the Richmond River is artificially maintained with a series of loose rock walls, especially around the town of Wardell (WBM 2006).

Sediment Transport/Movement

As the Blackwall Range is primarily sedimentary strata it is more susceptible to erosion, and as such, higher sediment loads should be anticipated from this area as a natural process. Consequently, it is particularly important to retain riparian vegetation on the upper steep slopes which will help minimise and manage the erosion of unconsolidated sediment.

Zone Specific Issues

A major issue for the Back Channel management zone is in the upper reaches where steep gullies leading to the Blackwall Range pass through geological substrate that has a high potential for erosion. It is especially important to maintain vegetation cover in this area.

- Lack of riparian vegetation in agricultural areas of both the lower and middle reaches leading to bank instability.
- Drainage modification to facilitate improved agricultural production.
- Agricultural practices remove drainage vegetation and sediment which is deposited along the bank.
- Sedimentary substrate of the upper reaches is particularly vulnerable to erosion on cleared land.
- Recreational boating and fishing access on the Richmond River.
- Sheet and rill erosion on cleared land.
- Stock access to upper and mid catchment watercourses.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on farmed agricultural land.
- Uncertainty associated with erosion implications of the Pacific Highway upgrade and flooding.

Zone 4 -South Ballina/Empire Vale

On ground sites SB4, SB5, SB6, SB7

Geology

The South Ballina/Empire Vale management zone is drained by minor tributaries, Mosquito Creek, Empire Vale Creek, Reedy Creek, Boundary Creek and Everson's Creek, all of which have been extensively modified for use as drainage channels for agriculture. Most of the management zone is comprised of Quaternary Sediments of which the eastern portion is predominantly beach and dune sands and the western portion is comprised of river alluvium. East of Broadwater is Cook's Hill which is the only elevated portion in the zone and is comprised of ancient Palaeozoic metamorphic rock types, group named as Neranleigh-Fernvale Metasediment (Brunker *et al*. 1972).

Natural Land Cover

The management zone was originally covered with low lying swampland, coastal heath, and portions of littoral rainforest in the lee of the beach hind dunes. Richmond River Nature Reserve is in the lower estuarine area of this zone.

Current Land Use

The area has been extensively sand mined along the coastal dune systems and cleared between back dunes and the river for agriculture (sugar cane). A small southern section east of Broadwater is not under agriculture and is predominantly heath land.

Soils

The management zone is made up of mainly alluvial and coastal heath soil types (Donnelly 1997) with a small section of podzolic soil east of Broadwater.

Stream Pattern

The natural stream pattern is now essentially only modified distributary channels within agricultural areas and most channels connect directly to the Richmond River (Grotzinger *et al*. 2007).

Bank Stability

Most of the drainage network for the management zone is maintained by farm management practices which require free flowing movement of groundwater away from areas of crop production. Banks are inherently unstable due to the use of machinery for their modification and construction and this results in unnatural steep sides as a means to maximise cropping area and agricultural production. Feasibility studies are currently being conducted through NSW NPWS in order to manage erosion issues at Mobbs Bay. The erosion at Mobbs Bay has been exasperated by a slumping in the sub-tidal barrier over the last 15 or so years.

Sediment Transport/Movement

High rainfall events will result in significant sediment mobilisation due to most drainage channels being devoid of natural riparian vegetation (WBM 2006). This can lead to the easy movement of unconsolidated sandy sediment and loam soil types during periods of high flow rates.

Zone Specific Issues

As the zone is relatively flat and wholly contained within the Lower Richmond River Floodplain management issues are primarily concerned with drainage and flood mitigation.

- Lack of natural riparian vegetation in agricultural areas resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Recreational boating and fishing access on the Richmond River.
- Drainage modification for flood mitigation (including levee construction and flood gates).
- Sheet and rill erosion on cleared (agricultural) land.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on farmed agricultural land.
- Drainage modification to facilitate improved agricultural production.
- Mobbs Bay shore erosion issues.

Zone 5 -Rileys Hill

Geology

Rileys Hill management zone is drained by unnamed minor tributaries, some of which drain the northern portion of Broadwater National Park. Most of the management zone is comprised of Quaternary Sediments (alluvium, sands and clay) but Rileys Hill, which is the only elevated portion of the management zone, is an outcrop of Mesozoic sediment (Tabulam Group, including sandstone, shale and conglomerate) (Hanlon *et al*. 1970).

Natural Land Cover

The management zone was originally covered with low lying swampland, adjacent to the river, heath on the sand plain, and a portion of woodland on the elevated ridge of Rileys Hill.

Current Land Use

The area has been extensively cleared along the river floodplain for agriculture (sugar cane) and residential development on Rileys Hill. A significant portion of the management zone is part of Broadwater National Park.

Soils

The zone is made up of mainly alluvial and coastal heath soil types (Donnelly 1997) with a small section of podzolic soil at Rileys Hill.

Stream Pattern

The natural stream pattern is now essentially only modified distributary channels within agricultural areas and most channels connect directly to the Richmond River (Grotzinger *et al*. 2007).

Bank Stability

Other than drainage originating in Broadwater National Park most of the drainage network for the management zone is maintained by farm management practices which require free flowing movement of groundwater away from areas of crop production. Banks are inherently unstable due to a lack of vegetation and the use of machinery for their construction and modification. This results in unnatural steep sides as a means to maximise cropping area and agricultural production. The main Richmond River bank retains a fringe of mangroves for most of the management zone.

Sediment Transport/Movement

High rainfall events will result in sediment mobilisation due to most drainage channels being devoid of natural riparian vegetation and constructed in loamy soils with unconsolidated sediment. Significant sections of the floodplain zone are impacted by major flood events in the Richmond River (WBM 2006).

Zone Specific Issues

Issues associated with a reliance on a modified and constructed drainage network, in association with measures for flood mitigation, are the primary concerns within the management zone.

- Lack of natural riparian vegetation in agricultural areas resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Drainage modification to facilitate improved agricultural production.
- Agricultural practices remove drainage vegetation and sediment which is often deposited along the bank.
- Recreational boating and fishing access on the Richmond River.
- Drainage modification for flood mitigation (including levee construction and flood gates).
- Sheet and rill erosion on cleared (agricultural) land.

- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on farmed agricultural land.

Zone 6 - Evans

On ground sites E19

Geology

The Evans management zone is not contained by catchment boundaries and geologically is situated primarily on Quaternary Sediments (i.e. alluvium, sands and clay), although the Evans River passes through outcrops of Mesozoic Sediments, including the Tabulam Group and the Redcliff Coal Measures, at a river constriction known as Iron Gates. The Evans headland is a complex geological area that includes Palaeozoic Metasediments. Quaternary beach sands and dune complexes extend north from the river mouth (Hanlon *et al*. 1970).

Natural Land Cover

The majority of the management zone is part of either Broadwater National Park (north) or Bunjalung National Park (south) and typifies the original heath land and swamp vegetation of the area. Coastal woodland can be found on low ridgelines of Mesozoic sediment that traverse sections of the Parks.

Current Land Use

The western portion of the management zone (adjacent to Woodburn) has been cleared along the river floodplain for agriculture, mainly sugar cane and some cattle grazing. The township of Evans Head extends across the floodplain and headland at the mouth of the Evans River.

Soils

The management zone is made up of predominantly alluvial soil types closer to the Rivers and sandy coastal heath in the rest of the area (Donnelly 1997).

Stream Pattern

Sawpit Creek, Brady arm Creek, Oyster Creek and Rocky Mouth Creek drain the elevated ridgelines of Mesozoic Sediments south of the Evans River with a centripetal stream pattern. The Tuckombil Canal was constructed around 1900 and connects Rocky Mouth Creek, a tributary of the Richmond River, with the upper reaches of the Evans River. This has major implications for bank stability and movement of sediment, especially during times of flood and/or high flow regimes. The purpose of the Tuckombil Canal construction was to alleviate flooding in the mid Richmond area. The section of Rocky Mouth Creek (from Tuckombil Canal to the Richmond River) can be subject to flow reversal dependant upon flow regimes and river levels. Control of water through the canal is by means of a temporary concrete fixed weir, replacing the fabridam about seven years ago (B. Eggins, pers.comm. 2009).

Bank Stability

The drainage network in the cleared areas of the management zone is maintained by farm management practices. The main Richmond River bank has virtually no (or extremely ineffective) riparian vegetation for most of the management zone. The increased flow regime during times of flood has had a detrimental effect on much of the bank stability for the Evans River. Some banks appear to have receded many tens of metres since 1953 (WBM 2002). Property owners are encouraged to fence off river banks from stock access, with grant funding being provided through local government.

Sediment Transport/Movement

Floodwaters originating from the upper Richmond catchment are redirected through the Tuckombil Canal resulting in significant detrimental impacts on the Evans River System. Therefore, upstream high rainfall events will result in additional sediment mobilisation from beyond the natural catchment and with a lack of natural riparian vegetation along the canal and upper reaches compound the usual erosion and deposition issues. Sections of the Evans River floodplain will be impacted by “overflow” flood events from the Richmond River (WBM 2002).

Zone Specific Issues

The major issue for the Evans management zone is alteration of natural flow regimes following construction of the Tuckombil Canal and the impact of higher flows increasing bank erosion along the length of the main river channel.

- Lack of natural riparian vegetation in agricultural areas resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Agricultural practices remove drainage vegetation and sediment which is often deposited along the bank.
- Recreational boating and fishing access on the Evans River and Richmond River.
- Bank erosion is mainly the result of the higher energy associated with flooding from the Richmond River through Tuckombil Canal.
- Some banks have also been weakened by the removal of riparian vegetation, mainly for flood mitigation purposes.
- The increase in flows is causing bank erosion and the downstream bulk transport and deposition of channel sands in the Evans River, upstream of Iron Gates.
- The sediment derived from bank erosion is gradually transported downstream mainly by flood flows and is causing significant shoaling between Iron Gates and Elm Street bridge. A sedimentation study in 1986 shows the material in the Evans is marine derived and it is natural shoaling. The Tuckombil canal and Evans were eroding at the same pace as other streams and rivers.
- Natural meander readjustment of the Evans River channel is working to increase depth as a result of altered flow regimes.
- Erosion from flow reversal and redirection of floodwater in lower Rocky Mouth Creek during peak flood conditions. There is some scouring just downstream of the tidal structure (GHD 2006).
- Sheet and rill erosion on cleared land along lower Rocky Mouth Creek and around Woodburn.
- Control and alteration of flow regimes by means of a Fabridam at the head of Tuckombil Canal.

Figure 2.1: Examples of major geomorphologic issues in the Richmond River Floodplain.
A. Drainage modification for agriculture (Management Zone 9), B. Drainage modification with steep sided banks (Management Zone 11), C, D, E and F. Examples of bank slumping and erosion caused from removal of riparian vegetation (Management Zone 12).

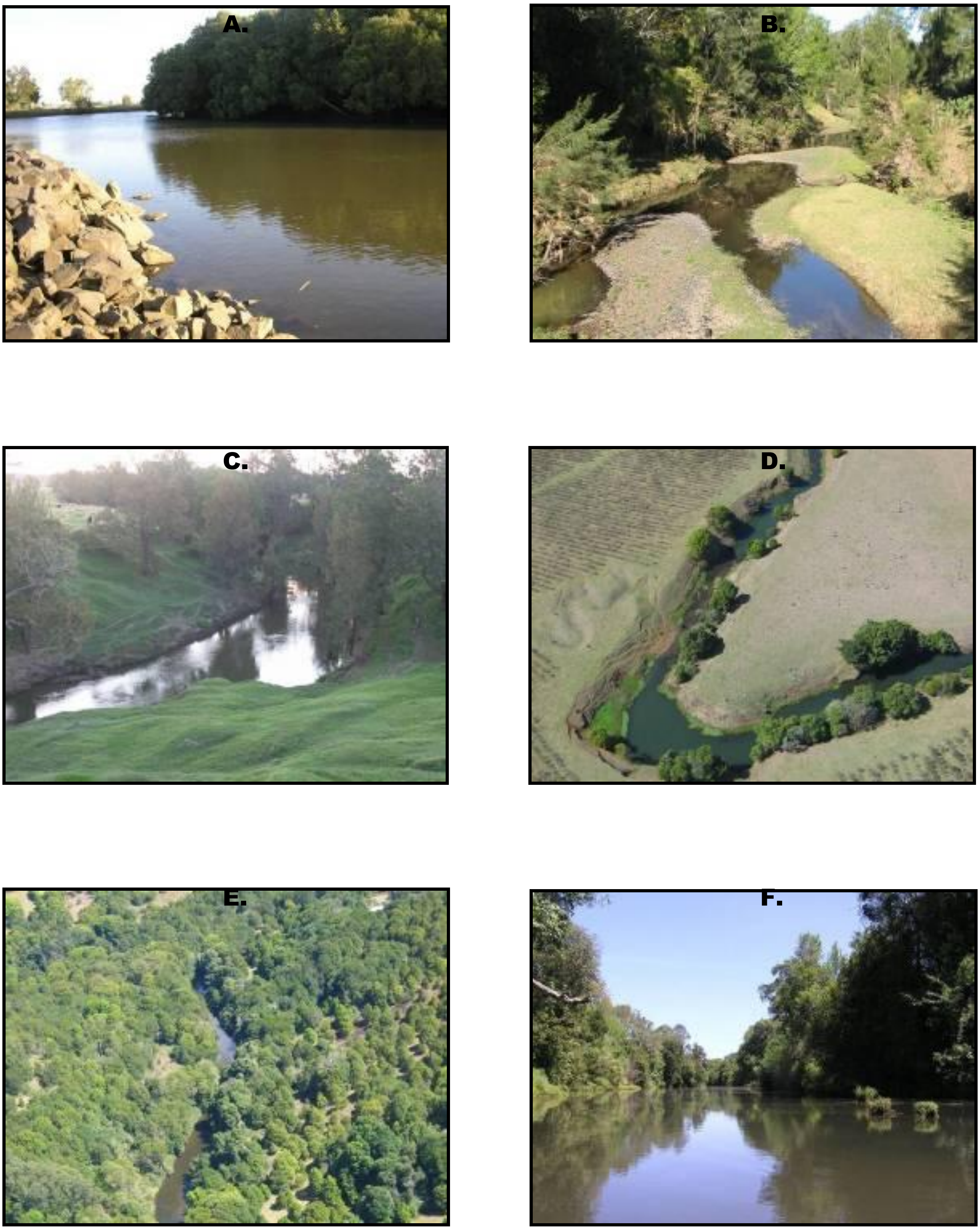


Figure 2.2 Examples of major geomorphologic issues in the Richmond River Floodplain.
A. Loose rock bank protection (Management Zone 1); B. In channel sediment build up; C. Cattle access to watercourse; D. Denuded section of bank and encroaching agriculture; E. Stream section with healthy riparian vegetation; F. River section with healthy riparian vegetation.

Note: Photographs B to F are from Management Zone 12 and taken by NSW Fisheries, but are representative of the issues for the majority of Management Zones.

Zone 7 -Rocky Mouth Creek

On ground sites RC17

Geology

Rocky Mouth Creek management zone is situated primarily on Quaternary Sediments (i.e. alluvium, sands and clay), with the upper catchment around the Mooninba Range comprised of Mesozoic Sediments including the Tabulam Group and the Walloon Coal Measures (Hanlon *et al*. 1970).

Natural Land Cover

Most of the management zone has been cleared of its original vegetation which was originally low lying swamp and wetland forests with open woodland on elevated ridges.

Current Land Use

The river floodplain is used for agriculture, mainly sugar cane and some cattle grazing, and is recognised as a hot spot for acid sulphate soils (Ferguson and Eyre 1995).

Soils

The management zone is made up of predominantly alluvial soil types with podzolic soils on elevated slopes and ridges (Donnelly 1997).

Stream Pattern

The stream pattern of the tributaries of Rocky Mouth Creek can be described as largely modified distributary drainage channels. Former dendritic water courses such as Swampy Creek are no longer connected to the natural drainage network and have been modified through agricultural land use. The lower reaches of Rocky Mouth Creek between the Richmond River at Woodburn and the Tuckombil Canal can be bi-directional, controlled by a “Fabridam” (inflatable rubber barricade) that prevents the intermixing of Evans River and Rocky Mouth Creek waters, except during flood events (Grotzinger *et al*. 2007).

Bank Stability

The drainage network in the cleared areas of the management zone is maintained by farm management practices. The main Richmond River bank has virtually no (or extremely ineffective) riparian vegetation for most of the zone. Rocky Mouth Creek has sections of riparian vegetation but the majority of the creek banks are unstable, having been cleared to allow for cattle access and maximisation of land for cropping.

Sediment Transport/Movement

The flow characteristics of Rocky Mouth Creek are influenced by the flow in the Tuckombil Canal. In times of flood, water will back up in Rocky Mouth Creek and as the majority of sediment transport occurs during flood events it can be expected that some sediment movement will be diverted into the Evans River system via Tuckombil Canal as drained flood overflow (WBM 2002).

Zone Specific Issues

Extensive drainage for agriculture across the zone and alteration of flow regimes through the connection of lower Rocky Mouth Creek with the Tuckombil Canal are the major management issues.

- Lack of natural riparian vegetation across upper, middle and lower reaches in agricultural areas resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Agricultural practices remove drainage vegetation and sediment which is often deposited along the bank.
- Bank erosion resulting from higher energy associated with flood redirection from the Richmond River through Tuckombil Canal.
- Some banks have been weakened by the removal of riparian vegetation, mainly for flood mitigation purposes along the Richmond River.
- Stock access to watercourses on grazing properties.
- Sheet and rill erosion on cleared land.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on agricultural land.
- Drainage modification to improve opportunities for agriculture.

Zone 8 -Swan Bay

On ground sites SB20

Geology

Swan Bay management zone includes a major anabranch of the Richmond River and is connected via a small channel to the main river. The zone is comprised entirely of Quaternary Sediments (i.e. river alluvium) (Hanlon *et al*. 1970).

Natural Land Cover

The management zone was originally covered with mid floodplain mixed vegetation, dominated by low lying wetland species.

Current Land Use

The area has been almost entirely cleared for agriculture, principally sugar cane and cattle grazing.

Soils

The management zone is solely river sourced alluvial soil types (Donnelly 1997).

Stream Pattern

All water courses flowing into the anabranch are modified distributary drainage channels. The anabranch is slowly infilling with sediment as it becomes further disconnected from the river system with only low energy water movement. Flood sourced sediment is transported across and into the management zone during major flood events (Grotzinger *et al*. 2007).

Bank Stability

The drainage network for the management zone is maintained by farm management practices. The main Richmond River bank retains a very thin (and mostly ineffective) fringe of riparian vegetation for much of the zone. Consequently, the river bank is unstable and erodes during flood events (WBM 2006).

Sediment Transport/Movement

High rainfall results in significant sediment mobilisation due to most drainage channels being devoid of natural riparian vegetation and this can lead to easy movement of the unconsolidated alluvial soil. Most sections of the floodplain within the zone will be impacted by overflow floodwaters from the Richmond River.

Zone Specific Issues

Major issues include drainage modification for agriculture and flood mitigation and sediment infill of the Swan Bay anabranch.

- Lack of natural riparian vegetation in agricultural areas resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Infilling due to isolation from river system.
- Sheet and rill erosion on cleared land.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on agricultural land.
- Drainage modification to improve opportunities for agriculture.
- Stock access to watercourses.

Zone 9 -Kilgin/Buckendoon/Dungarubba

On ground sites KB14, KB15, KB18

Geology

The management zone is almost exclusively Quaternary Sediments (i.e. river alluvium), with the exception of Newbys Hill and McPherson Trig Station at Bungawalbyn. These are two small elevated outcrops of Mesozoic Sediments which are further identified as Walloon Coal Measures and Kangaroo Creek Sandstone rock substrate (Hanlon *et al*., 1970; Brunker *et al*. 1972).

Natural Land Cover

Virtually all the management zone has been drained and cleared of its original vegetation which was originally low lying wetland forests and floodplain woodlands. Only small fragments of original vegetation remain as slightly elevated isolated remnants.

Current Land Use

The river floodplain is exclusively used for agriculture, mainly sugar cane and some cattle grazing on elevated areas.

Soils

The management zone is made up of mainly alluvial soil types (Donnelly 1997), except for the two elevated knolls at Bungawalbyn which have a podzolic soil profile.

Stream Pattern

The stream pattern within the zone can be described as mainly modified distributary drainage channels (eg. Figure 11.1A). Former dendritic water courses, such as Dungarubba Creek, have been altered and now exist as part of the agricultural drainage network (Grotzinger *et al*. 2007).

Bank Stability

The drainage network throughout cleared areas of the management zone is maintained by farm management practices. The main Richmond River bank has minimal riparian vegetation in some areas and is subject to erosion (WBM 2006). The majority of the drainage banks have been cleared to allow maximum utilisation of land for cropping and grazing, and consequently can be regarded as unstable at times of high flow.

Sediment Transport/Movement

Sediment transport and movement is greatly influenced by the extent of fallow agricultural land at the time of higher rainfall events. The extensive drainage network facilitates the ready transport of sediment away from ploughed paddocks and often directly into the river system. During flooding sediment is easily moved and distributed across the floodplain area in accordance with currents and the extent of inundation (WBM 2006).

Zone Specific Issues

The major issue for the Kilgin/Buckendoon management zone is a lack of natural riparian vegetation and farm management practices which maintain most watercourses as open drains.

- Lack of natural riparian vegetation in agricultural areas resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Agricultural practices remove vegetation and sediment from drains which is often deposited along the bank.
- Recreational boating and fishing access on the Richmond River.
- Some banks have also been weakened by the removal of riparian vegetation, mainly for flood mitigation purposes along the Richmond River.
- Stock access to watercourses on grazing properties.
- Sheet and rill erosion on cleared land.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on agricultural land.
- Drainage modification to improve opportunities for agriculture.

Zone 10 -Tuckean

On ground sites T11, T12

Geology

Tuckean management zone is almost exclusively Quaternary Sediments (i.e. alluvium, river gravels, sand and clay), but is fringed with lower elevated outcrops of Mesozoic Sediments including the Tabulum Group, Walloon Coal Measures and Kangaroo Creek Sandstone. These layered sediments are found in low ridges to the east, north and west of the drainage floodplain and higher elevations in these areas are capped with Tertiary Basalts (Hanlon *et al*. 1970; Brunker *et al*. 1972).

Natural Land Cover

Most of the management zone has been extensively drained and cleared of its original floodplain and swampland vegetation to provide for agricultural production. However, the lower lying centre of the zone has retained some natural and regenerating vegetation within the Tuckean Nature Reserve. Much of the Reserve is a mix of floodplain and swampland vegetation bisected by major drainage channels.

Current Land Use

The Tuckean has a mix of cropping (sugar cane), mainly around the southern and western margins, with cattle grazing being predominant to the north and alongside the Nature Reserve in the west and east.

Soils

The management zone is made up of mainly alluvial soil types (Donnelly 1997), with podzolic soils on elevated portions to the west at Tuckurimba, north at Cedar Island, and east along the Blackwall Range.

Stream Pattern

The stream pattern of watercourses can be described as modified distributary drainage channels throughout the bulk of the floodplain area that connects through to Bagotville at the head of the Tuckean Broadwater. A barrage at Bagotville restricts tidal movement and ingress of saltwater beyond the Broadwater. A centripetal network of streams originally drained the Tuckean Basin, however, natural drainage patterns are now only evident in the upper reaches of Stibbards Creek, Tucki Tucki Creek, Marom Creek, Youngman Creek, Gum Creek, and Yellow Creek, all of which are now connected to major drainage channels (Grotzinger *et al*. 2007). The Tuckean is regarded as a hotspot for Acid Sulphate Soils as a consequence of lowering water tables via extensive drainage modification (Ferguson and Eyre 1995).

Bank Stability

The drainage network in the cleared areas of the management zone is maintained by farm management practices. Major drainage channels within Tuckean Nature Reserve retain clearance spoil on the banks and consequently are not naturally vegetated. Drainage channels are generally steep sided, poorly stabilised and subject to erosion during periods of high flow. The majority of the drainage banks have been cleared to allow maximum utilisation of land for cropping, stock access, and ease of maintenance. Bank stability along the Tuckean Broadwater is poor due to flow constrictions at the Bagotville Barrage which channel water and provide higher energy for increased erosion downstream. Much of the land area is subject to flooding.

Sediment Transport/Movement

In high rainfall events the drainage network facilitates the ready transport of sediment away from ploughed paddocks and grazing areas to be deposited along the major channels of the Tuckean Basin. This requires regular clearance and maintenance, especially as waters slow toward the Barrage in all but the greater flood events. During flooding beyond the drainage channels sediment is easily moved and distributed across the basin area in accordance with currents and the extent of inundation (WBM 2006).

Zone Specific Issues

Management of the Tuckean is an ongoing problem centred on the positive and negative consequences of the Bagotville Barrage. Primarily, siltation is an issue within the agricultural drainage network and erosion is a concern downstream of the barrage.

- Lack of natural riparian vegetation in agricultural areas of the middle and upper reaches, resulting in bank instability.
- Drainage modification with steep sided unnatural banks.
- Agricultural practices remove drainage vegetation and sediment which is often deposited along the bank.
- Some banks have also been weakened by the removal of riparian vegetation, mainly for flood mitigation purposes, upstream of the Bagotville Barrage.
- Drainage modification to improve opportunities for agriculture.
- Increased bank erosion as a result of high flow channelling through the Bagotville Barrage.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on agricultural land.
- Interruption to the natural flow regime with the construction of the Baggotville Barrage.
- Sheet and rill erosion on cleared land.
- Stock access to watercourses on grazing properties.
- Agricultural encroachment on wetland vegetation.
- ASS hot spot.

Zone 11 -Lower Bungawalbyn

On ground sites BU28

Geology

The Swan Bay/Lower Bungawalbyn management zone is a mix of Quaternary Sediments (i.e. river alluvium, gravels, sand and clay) on the lower floodplain, and Mesozoic Sediments (Kangaroo Creek and Grafton Formation Sandstones) on higher elevations and upper tributary catchments. Some small Tertiary Basalt caps are present in the Ellangowan district and the management zone is separated from the Coastal sub-catchment in the south east by the Richmond Range, an extensive and elevated area of Grafton Formation Sandstone (Hanlon *et al*. 1970; Brunker *et al*. 1972).

Natural Land Cover

Much of the management zone has retained its original vegetation in an extensive network of State Forests. Although the forests have been managed and supplemented with selected plantation eucalypt species they can still be regarded as a retention of a more representative natural vegetation cover (for the particular soil types and geological substrate) than any other management zone of the Richmond Floodplain. However, lower reaches of the zone, around Bungawalbyn and Bora Ridge, have been cleared for agriculture. Original vegetation of these areas would have included a higher swampland and floodplain species mix.

Current Land Use

The river floodplain in lower reaches and along the major watercourses has some agricultural use with cropping and cattle grazing. However, the majority of the management zone is NSW State Forest, including Bungawalbyn, Ellangowan, Myrtle, Whiporie, Giberagee, and Doubleduke State Forests. Some large sections of these forests are maintained and managed as plantations.

Soils

The management zone is made up of primarily alluvial soil types (Donnelly 1997), and podzolic soils on the elevated Sedimentary substrates.

Stream Pattern

The drainage pattern of streams are centripetal and remain largely natural except for drainage modification to suit agricultural practice in the lower reaches, close to the Richmond River around Bungawalbyn and Bora Ridge. Major connecting streams of Bungawalbyn Creek include Sandy Creek to the north, Myrtle Creek to the south west, with Myall Creek and Scrubby Creek to the south (Grotzinger *et al*. 2007). Each of these tributaries drain large areas of State Forest. Much of the land area is subject to flooding.

Bank Stability

The drainage network within agricultural cropping areas of the Lower Bungawalbyn Creek is maintained by farm management practices. Due to a catchment of lower gradient landforms bank heights are more moderate than the other Richmond River sub-catchments and consequently banks are generally more stable, however, bank instability is still present (eg. Figure 2.1). This is especially so with the areas of State Forest where extensive natural and riparian vegetation is maintained.

Sediment Transport/Movement

The Lower Bungawalbyn management zone is an area of the greater Bungawalbyn Creek sub-catchment of the Richmond River Basin where sediment transport and movement is substantially less due to flatter topography and extensive vegetation cover within State Forest estate (Hossain *et.al.* 2002). Podzolic soils and sandy alluvium are less susceptible to transport in high rainfall events when stream gradients are low and natural vegetation maintains bank stability.

Zone Specific Issues

Recognition of a geological substrate with a high potential for erosion is a major issue for the Lower Bungawalbyn management zone. Despite gentler slopes and lower landforms in upper and mid reaches it is particularly important to maintain suitable riparian zones along watercourses which will minimise erosion potential. The low lying nature of the zone results in substantial flooding.

- Lack of natural riparian vegetation in agricultural areas (particularly the lower reaches) resulting in bank instability.
- Agricultural practices remove drainage vegetation and sediment which is often deposited along the bank.
- Some banks have also been weakened by the removal of riparian vegetation, mainly for flood mitigation purposes on lower reaches adjacent to the Richmond River.
- Some exposed and sandy unconsolidated soils with high potential for erosion in areas of cleared landscape, generally agricultural areas.
- Stock access to watercourses on grazing properties.
- Sheet, rill, and gully erosion on cleared land.
- Unsuitable drainage and watercourse obstructions (bridges, crossings, pipes) which cause flow restrictions on agricultural land.
- Drainage modification to improve opportunities for agriculture.
- ASS
- Blackwater source after flooding events.

Zone 12 - Upper Richmond/Wilson Management Zone

On ground sites UPRWR21/22, UPRWR23, UPRWR24, UPRWR25, UPRWR26, UPRWR30, UPRWR32, UPRWR32

Geology
The Upper Richmond/Wilson management zone is a mix of Quaternary Sediments (i.e. river alluvium, gravels, sand and clay) on the lower floodplain, and Tertiary Basalts on higher elevations and fringing ridgelines (Brunker *et al*. 1972).

Natural Land Cover
Most of the management zone has been cleared of its original vegetation which was primarily low lying wetland forests and woodlands on the floodplain, grading through to dense areas of rainforest on the basalt soils and southerly aspects of higher elevations. Only small fragments of original vegetation remain, usually as isolated and unconnected remnants in elevated areas. Some significant areas such as Tucki Tucki Nature Reserve, are retained on northerly and western aspects of some floodplain bordering ridgelines.

Current Land Use
The river floodplain has a dual agricultural use with cropping (mainly sugar cane) on the lower reaches of the Wilson's River and Pelican Creek sub-catchment at North Codrington, and cattle grazing in upper reaches on both the floodplain and surrounding slopes. The floodplain of the Richmond River between Coraki and Tatham also has dual agricultural use with a mix of both cropping and cattle grazing.

Soils

The management zone is made up of primarily alluvial soil types (Donnelly 1997), and basalt derived kraznozem and chocolate soils on elevated and surrounding slopes.

Stream Pattern

Except for the lower reaches around North Codrington and South Gundurimba there is minimal drainage alteration to facilitate agricultural cropping. The stream pattern of the minor tributaries that flow into the Wilson's River below Lismore, plus Pelican Creek, can be described as centripetal. Some minor streams south of Lismore are maintained as drains within grazing properties and also as a drainage network in areas adjacent to urban and industrial development. A farm drainage network is also maintained along both banks of the Richmond to Tatham. Only one named tributary, Walsh's Creek (also centripetal in stream pattern), enters the main river channel at Codrington (Grotzinger *et al*. 2007).

Bank Stability

The drainage network within agricultural cropping areas of the Lower Richmond and Wilson's Rivers is maintained by farm management practices. The main Wilson's River bank has minimal riparian vegetation in most areas and the connecting minor streams are generally totally cleared and stabilised by grazing pasture only. Pelican Creek retains some form of riparian vegetation for approximately half its length but has exposed banks through areas of agricultural cropping. The Richmond River has typically high steep banks and minimal riparian vegetation. Significant sections of the bank are devoid of any vegetation as a result of clearing for cattle access and erosion during past flood events (WBM 2006).

Sediment Transport/Movement

The Upper Richmond/Wilson management zone is an area of mid-catchment for the Richmond River Basin where sediment transport and movement is influenced by the extent of fallow agricultural land at the time of higher rainfall events. During floods and as a consequence of elevated landforms in the upper regions of both the Wilson's River and Richmond River sub-catchments suspended sediment loads have been estimated at greater than 93% compared to the Bungawalbyn Creek sub-catchment which has flatter topography and extensive forest coverage (Hossain *et.al.* 2002). The drainage network facilitates the ready transport of sediment away from both ploughed and grazing paddocks and into the river system. With the higher energy of flooding sediment is easily moved and distributed across the floodplain area in accordance with currents and the extent of inundation.

Zone Specific Issues

Cattle access to steep sided drainage channels and the main riverbank create a management concern as regularly used tracks remain unvegetated and are further eroded in times of flood. Most of the typically steep banks of the zone are cleared of riparian vegetation and are vulnerable to erosion during high flow flood events.

- Lack of natural riparian vegetation in agricultural areas of upper and middle reaches resulting in bank instability.
- Recreational boating and fishing access on the Richmond and Wilsons River.
- Sections of unstable and unvegetated banks as a result of stock access to watercourses.
- High steep banks susceptible to ongoing erosion during high flow conditions.

- Sheet, rill, and gully erosion on cleared land.
- Drainage modification to improve opportunities for agriculture.

2.4 Summary Statement

As could be expected, the issues occurring within each of the 12 management zones are primarily the direct consequence of anthropogenic activity which began with permanent European settlement of the Richmond River Basin from around 1842. Extensive land clearance, initially for the timber industry, but also to facilitate the establishment of broad scale farm based agricultural enterprises has set the scene for an altered landscape which is more susceptible to fluvial erosion processes in a high rainfall region.

The cumulative effects of a largely cleared landscape are most evident along the steeper slopes of upper catchments and the upper to mid floodplain where erosion scarps and bank slumping are common in areas no longer bordered by natural riparian vegetation. Mass movement of eroded sediment is most evident in the lower floodplain where siltation and infilling of channels has progressively restricted navigation for boating and exacerbated the spread of floodwaters following high rainfall events.

Drainage modification for farming (particularly sugar cane), roads and flood mitigation measures have had a marked effect on the natural flow regime. In these areas, there is no longer the capacity for streams to establish natural meanders in response to landscape gradients and natural rates of flow. Consequently, drainage patterns are established to suit farming practices and in addition to hydrologic changes, can promote erosion of fallowed soil during high rainfall events, direct to the main river system.

The major management issues for the Richmond River Floodplain are highlighted in the summary table (Table 2.5) which shows sheet and rill erosion, drainage modification for agriculture, water course obstructions, and a lack of suitable riparian vegetation (within at least one portion of each zone) as the common elements across all Management Zones. The establishment of suitable vegetation for riparian corridors and natural vegetation for stabilisation of denuded banks would result in a significant reduction in bank erosion and sediment displacement.

Table 2.5 Management Zone Issues.

MANAGEMENT ISSUES	*MANAGEMENT ZONE*											
	1-North Ck Newrybar	2 – Emigrant/	3 –Back Channel	4 –South Ballina/	5 –Rileys Hill	6 -Evans	7 –Rocky Mouth Ck	8 –Swan Bay	9 –Kilgin/ Buckendoo	10 - Tuckean	11 –Lower Bungawalb	12 –Upper Richmond/
Lack of suitable riparian vegetation (upper reaches)	X	X				X	X			X		X
Lack of suitable riparian vegetation (middle)			X				X	X	X	X		X
Lack of suitable riparian vegetation (lower reaches)			X	X	X		X				X	
Drainage modification for agriculture	X		X	X	X	X	X	X	X	X	X	X
Drainage modification with steep sided banks				X	X	X	X	X	X	X		
Drainage and bank modification for flood mitigation				X	X	X	X	X	X	X	X	
Agricultural practices removing drainage sediment	X		X	X	X	X	X	X	X	X	X	
High flow erosion susceptibility increasing bank erosion						X				X		X
Water course obstructions (constructed flow restrictions)	X	X	X	X	X		X	X	X	X	X	
Erosion from flow redirection during flood conditions						X	X					
Interruptions to natural flow regime (e.g. dam construction)		X				X				X		
Sheet and rill erosion on cleared land	X	X	X	X	X	X	X	X	X	X	X	X
Mobilisation of chemicals from horticultural activity		X										
Geological substrate with high potential for erosion			X								X	
Downstream bulk sediment movement resulting in shoaling	X	X				X						
Increasing channel width and decreasing channel depth	X					X						
Stock access to watercourses	X	X					X	X	X	X	X	X
Recreational boating and fishing access (wave erosion)	X	X	X	X	X	X	X	X	X			X
Natural meander readjustment after altered flow regime						X						
In-filling due to isolation from the river system								X				

3. Water Quality Impacts

The Richmond River is predisposed to water quality challenges due to its relatively small catchment area (6979km^2) and large floodplain (990km^2) with a very small water surface area (19km^2). It is a poorly flushed system with a tidal pinch near Pimilco which results in poor water exchange upstream from this area. The upper catchment areas have largely been cleared and the land use is now predominantly agriculture. This change in land use has contributed to high TSS and nutrient loadings from these areas. Additionally, there are eight sewage treatment plants in the study area and several more in the catchment area, which manage waste from the larger urban areas including Ballina, Lismore, Casino, Wardell, Alstonville, Nimbin, Dunoon, and Coraki. Stormwater runoff from these urban areas also enters the Richmond River. The large expanse of rural residential living within the area also results in a significant number of on-site sewage treatment facilities. The labyrinth of road networks and the lack of hard surfaces on some of these also contributes to TSS loading.

The hydrology of the large floodplain has largely been modified through drainage channels and changes in vegetation types. The exposure of Acid Sulfate Soils (ASS) has occurred as a result of floodplain drainage and other activities that altered the ground water hydrology. Flood waters can become acid when draining occurrs from large areas of ASS. Blackwater events are significant post flooding in the Richmond River Estuary and Eyre et al. (2006) have determined that at 25˚ the Richmond River floodplain has the potential to deoxygenate 12.5 x 10^3 mL of saturated freshwater. This scale of deoxygenation is sufficient to completely deoxygenate floodwater stored on the flood plain within 3 to 4 days. Historical information suggests that flood water can persist on the floodplain for around 6 days and in some places for several weeks. Both black water events and acid water event have contributed to fish kills in the Richmond River. There are also potential health risks related to mosquito borne infections after flood events and while water is still stored on the floodplain. Healthy, ecologically balanced wetlands systems can minimise mosquito infestation.

It will be important for the Management Plan to provide actions that build resistance in the Richmond River so the extreme effects flood events do not result in a collapse of the environmental services the river provides. Future climate change scenarios in this region predict more frequent and intense storm activity which will potentially result in more storm surge, erosion and flood events. Richmond River must be able to recover between events to ensure its long term health. Currently, it is not known when a critical threshold will be reached in the Richmond River where recovery does not occur but evidence suggests that fish kills are becoming more severe and more frequent.

The development of a Water Quality Monitoring Strategy for the Richmond River estuary as part of the Management Study and Plan, provides the basis for an integrated approach to this facet of the estuary (see Appendix 3).

3.1 Data review

A detailed review of existing water quality data from the Richmond River floodplain and estuary (ABER 2008) has been used to characterise water quality and key processes in each of the management zones. Summary statistics (boxplots) have been presented showing the temporal variation in water quality at each site.

3.2 Flow weighted assessments

The results of water quality data review have been synthesised for low (<10%ile flow), median and high flow (>90%ile flow) scenarios into a risk assessment matrix. This is to recognise the important distinction between processes affecting water quality under different flow scenarios.

3.3 Catchment modelling

An E2 catchment export model of the Richmond River catchment recently developed by the Department of Environment and Climate Change (DECC) was used to provide estimates of hydraulic and pollutant loadings from a total of 49 subcatchments (Figure 3.1). Runoff was estimated by scaling measured river flow from available stations in upper sub-catchments to total catchment area (source NSW DWE).

3.4 Estuarine response model

An estuarine response model (ERM) of the Richmond River Estuary has been developed to estimate the relative impact of management zone exports on the health of the Richmond River Estuary. It is also used to assess critical thresholds (guidelines) for primary water quality drivers (e.g. light climate and nutrient concentrations) necessary for maintaining key ecosystem processes.

The model is based on a modified 1D box model approach, comprising 13 boxes from the mouth at Ballina to the upper limit of salt penetration at Coraki. The transport / mixing sub-model accounts for variation in the principle drivers of estuarine biogeochemical processes:

1. morphology and depth
2. freshwater inflows
3. tidal mixing
4. water residence times (eg Figure 3.2)
5. nutrient and TSS inputs
6. light climate

The biological response sub-model predicts the growth and biomass of phytoplankton and benthic microalgae, as well as rates of bacterial breakdown of organic matter. The net impacts on important water quality parameters such as dissolved oxygen are then estimated.

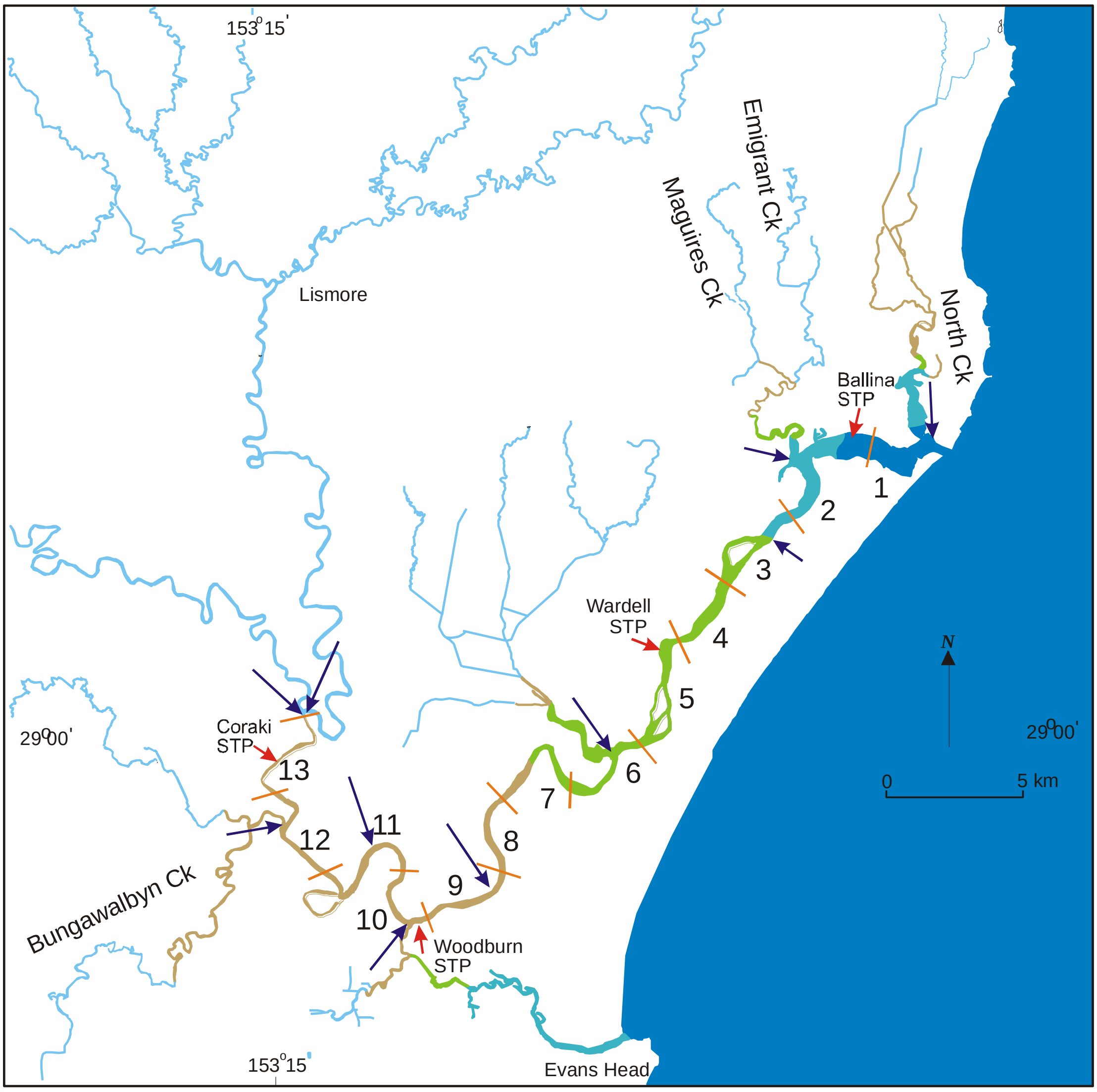


Figure 3.1; The location of box boundaries in the Richmond River estuary ecosystem response model (ERM), showing inputs of freshwater (blue arrows) and STP effluent inputs (red arrows).

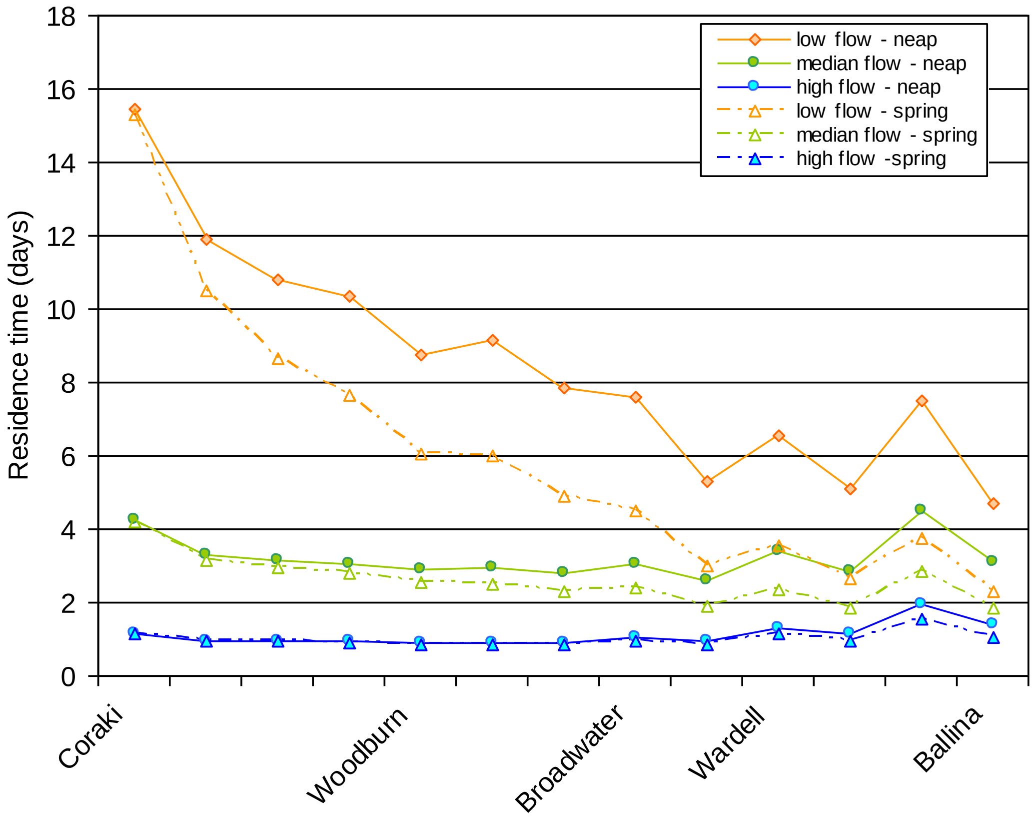


Figure 3.2 ERM estimations of water residence times in each of the 13 boxes along the Richmond River estuary for mean low flow, median and mean high flow conditions during neap and spring tides.
(*neap = a less than average tide occurring at the first and third quarters of the moon*)

3.5 In-stream and downstream impacts

All management zones include significant streams and aquatic habitat which form ecological extensions of the main Richmond River estuary. These waterways are herein referred to as "in-stream", and associated water quality and threats for in-stream habitats are assessed as distinct from the "downstream" impacts / threats of management zone exports on the main Richmond River estuary. This recognises the ecological importance of smaller tributaries despite their relatively small impact on receiving water quality. In addition, the quality of exports from these in-stream waterways is commonly largely attenuated / modified by internal biogeochemical processes. As such, the maintenance of these processes that may be location-specific, is important to mediating downstream impacts.

3.6 Internal processes

The water quality assessment identifies key reaches / waterways within management zones where internal processes are an important consideration in the maintenance of good water quality and ecosystem health. The main concepts underpinning this analysis are outlined below.

3.6.1 Productivity and ecosystem function

The relative importance of pelagic (water column) and benthic (sediments) habitat is assessed in relation to each components contribution to internal primary productivity (i.e. photosynthesis) within each reach. Where possible this has been quantified using the ecosystem response model. The balance between pelagic and benthic productivity is an important feature of estuarine ecosystems, influencing the type of foodchains present and also the internal recycling of nutrients.

3.6.2 Internal nutrient recycling

Internal deposition and recycling of materials (i.e. water quality constituents) within the waterway can significantly alter water quality. For example, the development of phytoplankton blooms can completely remove all inorganic nutrients from the water column (even in highly enriched systems), and cause large fluctuations in dissolved oxygen. Bio-available nutrients can be released as organic matter (e.g. phytoplankton) is broken down by bacteria in the water column and sediments. A certain proportion of re-mineralised nutrients can be lost due to burial, or in the case of nitrogen, lost to the atmosphere via denitrification.

The relative importance of internal processes increases with water residence times (or “flushing times”), which in turn broadly increase as a function of 1) decreasing antecedent rainfall totals, and 2) distance upstream from the estuary mouth. Channel morphology and impediments to tidal exchange also impact on water residence times.

3.6.3 Light climate

The amount of light reaching the water surface (which is influenced by riparian vegetation cover), and the light attenuation properties of the water and its constituents (as measured by secchi depth) are fundamental controls over the productivity and nutrient recycling characteristics of the system. Both pelagic and benthic compartments can become light limited in turbid water. When sediments become light limited, production by benthic microalgae approaches zero and benthic processes become dominated by bacterial breakdown of organic matter. In extreme cases of eutrophication, this can exert a significant oxygen demand on the overlying water and cause hypoxia.

3.6.4 Eutrophication

The term eutrophication refers to an increase in the rate of organic matter supply in aquatic ecosystems. This can be caused by nutrient enrichment stimulating algal blooms, or large loadings of organic matter or BOD. Eutrophication can significantly alter the quality of pelagic and benthic habitat due to the occurrence of hypoxia and high concentrations of toxic nutrients (e.g. nitrite), and in extreme cases cause permanent shifts in divers ecological communities towards simpler, microbial dominated assemblages.

3.7 Summary

The E2 modelling results provide very useful information that helps inform the management needs for each management zone.

Additionally, Table 3.2 describes the in-stream and downstream contributions of loading from each of the management zones under three different flow conditions.

The assessment approach in Table 3.2 is an informed semi-quantitative method of enabling a snapshot understanding of management issues associated with water quality impacts. Information from both Tables 3.1 and 3.2 as well as previous data analyses and interpretation (ABER 2008) are used to inform the following discussion of each management zone.

Also a photographic archive of management zones is presented in Appendix 2.

4. Fauna

The Richmond River estuary forms part of the greater Moreton Bioregion which is recognised as having high biodiversity. This is because of the high variability in habitat with influences from both tropical climates to the north and temperate climates to the south.

Before the commencement of agricultural practices in the Richmond River catchment and other areas, much of the lower catchment consisted of extensive wetlands. To enable agricultural production, wetlands were drained and cleared of native vegetation. This reduced large amounts of habitat for native fauna, compressing their range significantly and excluding some species altogether. It is estimated that 106,000ha of terrestrial vegetation has been cleared since European settlement in the Richmond valley (SoE 2000 Richmond Valley Council 2003).

This period of change for the area also resulted in the mobilisation of acid sulfate soils that underlay much of the floodplain. Mobile chemicals resulted in reactions and processes that created conditions that were toxic to fish and other aquatic life (eg fish kills). Sometimes acidic water enters the estuary, while at other times black water enters from large stagnant waterbodies upstream. Both these conditions have major impacts on aquatic fauna and other connected species.

The Richmond River Estuary Processes Study (WBM 2006) identified likely impacts on aquatic fauna (including plankton, algae, invertebrates and fishes) from variations in water quality. Similar impacts are likely up the foodchain for marine birds and mammals. It is important to reiterate the connectivity of the estuary to other regions, especially in terms of organisms that travel larger distances, are migratory or have larger home ranges.

There is considerable community value placed on marine mammals such as whales, dolphins and dugongs, as well as many species of bird that inhabit both the estuary and the greater surrounding region. Improvements in the condition of the estuary will increase the available habitat for these species in the future and reduce the risks to their continued existence (see various newspaper articles in Appendix 4).

4.1 Threats to fauna

Apart from the abovementioned water quality changes and threats there are also barriers to movement that threaten ordinary life functions of aquatic mammals and other fauna. The estuary areas provide extremely important feeding and breeding grounds for fish, birds and other fauna. Wetlands are biodiversity hotspots, with large numbers of insects and therefore insect-eating fauna (eg birds, bats, flying foxes, reptiles, etc.).

One of the most important threats is the loss of connectivity between biomes (ie ocean to floodplains to rainforests to mountains). The importance of corridors that allow genetic connectivity and passage for many different species, cannot be over-emphasised.

Environmental issues identified by the NSW NPWS (2008) that threaten flora and fauna, include:

- Climate change and water,
- Pollution and contamination,
- 2Pests and weeds, and
- Waste.

The list of Key Threatening Processes in NSW identified by the NSW NPWS Scientific Committee that are relevant to this Study are:

- Alteration to the natural flow regimes of rivers, streams, floodplains & wetlands - key threatening process listing
- Cane toad - key threatening process listing
- Clearing of native vegetation - key threatening process listing
- Death or injury to marine species following capture in shark control programs on ocean beaches - key threatening process listing
- Entanglement in or ingestion of anthropogenic debris in marine and estuarine environments - key threatening process listing
- Exotic vines and scramblers - key threatening process listing
- Human-caused climate change - key threatening process listing
- Invasion of native plant communities by bitou bush and boneseed - key threatening process listing
- *Lantana camara* - key threatening process listing
- Loss of Hollow-bearing Trees - key threatening process determination

- Predation by feral cats - key threatening process listing
- Predation by the European red fox - key threatening process listing
- Predation by the plague minnow (*Gambusia holbrooki*) - key threatening process listing
- Removal of dead wood and dead trees - key threatening process listing

5.2 Endangered Species

The NSW *Threatened Species Act* (2003) identifies 41 threatened species as occurring or likely to occur in the Richmond River estuary or nearby. Of these, 33 were listed as vulnerable and 8 as endangered. Priority actions for recovery of these species have been developed (NPWS Threatened Species Unit 2005). The listed endangered species are provided in Table 4.1 below (NSW NPWS 2008):

Table 4.1: NPWS Endangered Species listing for Northern Rivers CMA region and marine region.

Common Name	*Scientific Name*
Birds	
Beach Stone-curlew	*Esacus neglectus*
Gould's Petrel	*Pterodroma leucoptera leucoptera*
Little Tern	*Sterna albifrons*
Southern Giant-Petrel	*Macronectes giganteus*
Wandering Albatross	*Diomedea exulans*
Mammals	
Blue Whale	*Balaenoptera musculus*
Dugong	*Dugong dugon*
Reptiles	
Loggerhead Turtle	*Caretta caretta*

5.3 Vulnerable Species

Vulnerable species that are known to occur or are likely within the study area are provided in Table 4.2 (NSW NPWS 2008).

Table 4.2: Vulnerable species list (NSW NPWS database 2005).

Common Name	Scientific Name
Birds	
Antipodean Albatross	*Diomedea antipodensis*
Black-browed Albatross	*Thalassarche melanophris*
Black-tailed Godwit	*Limosa limosa*
Black-winged Petrel	*Pterodroma nigripennis*
Broad-billed Sandpiper	*Limicola falcinellus*
Flesh-footed Shearwater	*Puffinus carneipes*
Gibson's Albatross	*Diomedea gibsoni*
Great Knot	*Calidris tenuirostris*
Greater Sand-plover	*Charadrius leschenaultii*
Grey Ternlet	*Procelsterna cerulea*
Kermadec Petrel	*Pterodroma neglecta*
Lesser Sand-plover	*Charadrius mongolus*
Little Shearwater	*Puffinus assimilis*
Masked Booby	*Sula dactylatra*
Northern Giant-Petrel	*Macronectes halli*
Osprey	*Pandion haliaetus*
Pied Oystercatcher	*Haematopus longirostris*
Providence Petrel	*Pterodroma solandri*
Sanderling	*Calidris alba*
Shy Albatross	*Thalassarche cauta*
Sooty Albatross	*Phoebetria fusca*
Sooty Oystercatcher	*Haematopus fuliginosus*
Sooty Tern	*Sterna fuscata*
Terek Sandpiper	*Xenus cinereus*
White Tern	*Gygis alba*
White-bellied Storm-petrel	*Fregetta grallaria*
Mammals	
Australian Fur-seal	*Arctocephalus pusillus doriferus*
Humpback Whale	*Megaptera novaeangliae*
New Zealand Fur-seal	*Arctocephalus forsteri*
Southern Right Whale	*Eubalaena australis*
Sperm Whale	*Physeter macrocephalus*
Reptiles	
Green Turtle	*Chelonia mydas*
Leathery Turtle	*Dermochelys coriacea*

5.4 Recovery Plans

Recovery Plans exist for the Gould's Petrel and the Little Tern, both listed as Endangered under NSW legislation. There are Threat Abatement Plans under development for many species and areas, including Bitou bush and Boneseed, and predation by plague minnow and red fox.

5.5 Summary

There are many species of wildlife present within the estuary, in both aquatic and terrestrial ecosystems. Species are resident, transitory and migratory for the area. The condition of the estuary reflects directly on its capacity to provide adequate habitat for wildlife. For example, in the past Dugongs were frequent in the waterways, however, with the reduction in sea grass and the increase in boat traffic and other impacts, Dugongs have not been recorded within the estuary for some years.

Recommendations towards reductions in threats to fauna have been addressed in Part 2, the Richmond River Estuary Management Plan, for each Management Zone as appropriate. Appropriate actions may be included in other activities such as riparian revegetation, weed control, boat speed control, improvements to water quality, etc.

5. References

ABER (2008) Review of water quality data from the Richmond River Estuary. r. t. R. R. C. Council. Lismore.

Australian Water Resources, 2005. Regional Water Resource Assessment – Combined Water Management Areas Richmond River. Accessed 04/07/08, from http://www.water.gov.au/RegionalWaterResourcesAssessments/SpecificGeographicRegion/TabbedReports.aspx?PID=NSW_SW_203xNSW Department of Water and Energy, website.

Australian Wetlands (2006) *Riparian and In-stream Rehabilitation Plan for the Lower Freshwater Reaches of Currumbin Creek.* Report for Gold Coast City Council.

Brunker R.L., Cameron R.G., Tweedale G. and Reiser R., 1972. Tweed Heads 1:250 000 Geological Sheet SH/56-03, 1st edition. Geological Survey of New South Wales, Sydney

Dilworth (2008

Donnelly, R. 1997. A review of historical nutrient exports from the Richmond River catchment, northern NSW. Southern Cross University.

Eyre, B., Hossain, S. and McKee, L. 1998. *A suspended sediment budget for the modified subtropical Brisbane River estuary, Australia.* Estuarine, Coastal and Shelf Science **44:** 311-346.

Ferguson, A. J. P. and B. D. Eyre (1995). Local and Regional Impacts of Acid Runoff from Acid Sulfate Soil Environments in the Richmond River Estuary. Lismore, Southern Cross University.

Grotzinger, J., Jordan, T. H., Press, F. and Siever, R. 2007. Understanding Earth (5th edition). W.H. Freeman and Company, New York.

Hanlon, F. N., Lloyd, A. C., McElroy, C. T., Rasmus, P. L., Rayner, E. O. and Rose, G. 1970. Maclean 1: 250 000 Geological Sheet SH/56-07, 1st edition. Geological Survey of New South Wales, Sydney.

Hashimoto et al. 2006

Hossain, S., Eyre, B. and McConchie, D. 2001. *Suspended sediment transport dynamics in the subtropical micro-tidal Richmond River estuary, Australia.* Estuarine, Coastal and Shelf Science **52**: 529-541.

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

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

Hossain *et al*. 2004

Key Threatening Processes in NSW identified by the NSW NPWS Scientific Committee NSW NPWS (2008) NPWS Threatened Species Unit 2005 website

Ladson, A. 2008. Hydrology: An Australian Introduction. Oxford University Press, Australia.

Lambert *et al*. (1999

McKee, L. J., Eyre, B. D., Hossain, S. and Pepperell, P. R. 2001. *Influence of climate, geology and humans on spatial and temporal nutrient geochemistry in the subtropical Richmond River catchment, Australia.* Marine and Freshwater Research **52**:235-248.

Owers, G. (2002) Mapping and evaluation of the condition of the riparian zones of the Bungawalbyn catchment. Honours Thesis, School of Environmental Science and Management, Southern Cross University, Lismore.

Rosgen (1996)

Rosicky, M.A., Sullivan, L.A., Slavich, P.G. and Hughes, M. (2004) *Soil properties in and around acid sulphate soil scalds in the coastal floodplains of New South Wales, Australia*. Australian Journal of Soil Research, **42**: (5-6)515-525

Roy, P. S., Williams, R. J., Jones, A. R., Yassini, R., Gibbs, P. J., Coates, B., West, R. J., Scanes, P. R., Hudson, J. P., and Nichol, S. 2001. *Structure and function of south-east Australian estuaries*. Estuarine, Coastal and Shelf Science **53**:351-384

State of the Environment Report (2000) Richmond Valley Council.

Water Quality Monitoring: A Toolkit for Water Quality Monitoring for Local Government. (2004). Development of Toolkit funded by NSW State Government, a Stormwater Trust Initiative.

WBM Oceanics Australia (WBM), 2006. Richmond River Estuary Processes Study Final Report. Prepared for the Richmond River County Council.

WBM Oceanics Australia (WBM). 2002. Evans River Estuary Management Study and Plan. Prepared for Richmond Valley Council.

WBM (2006). Richmond River Estuary Processes Study. R.R.C. Council. Lismore.

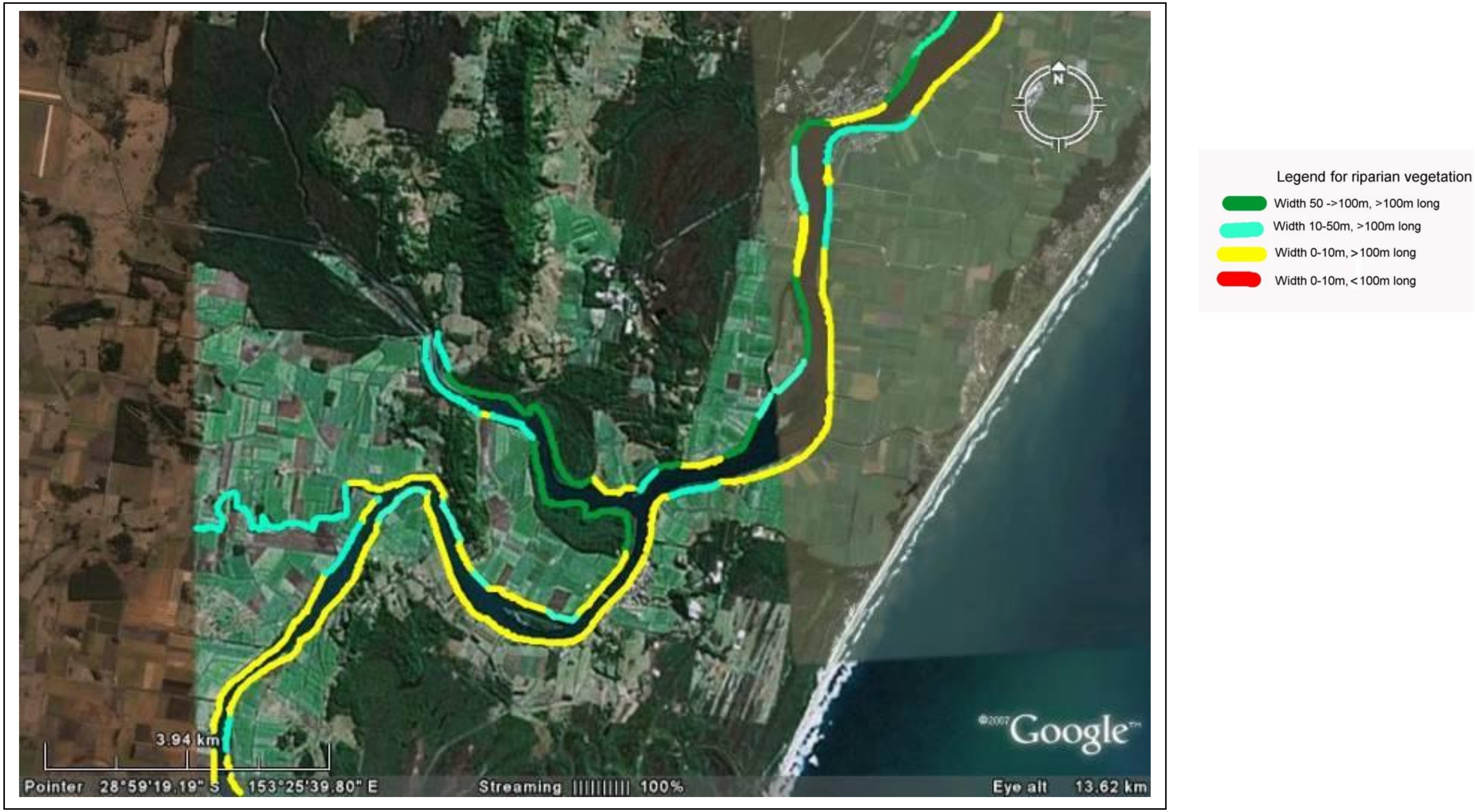
6. Appendices

1 – Riparian vegetation assessment maps
2 – Photographic archive of assessment points for water quality, riparian vegetation and geomorphology
3 – Newspaper articles

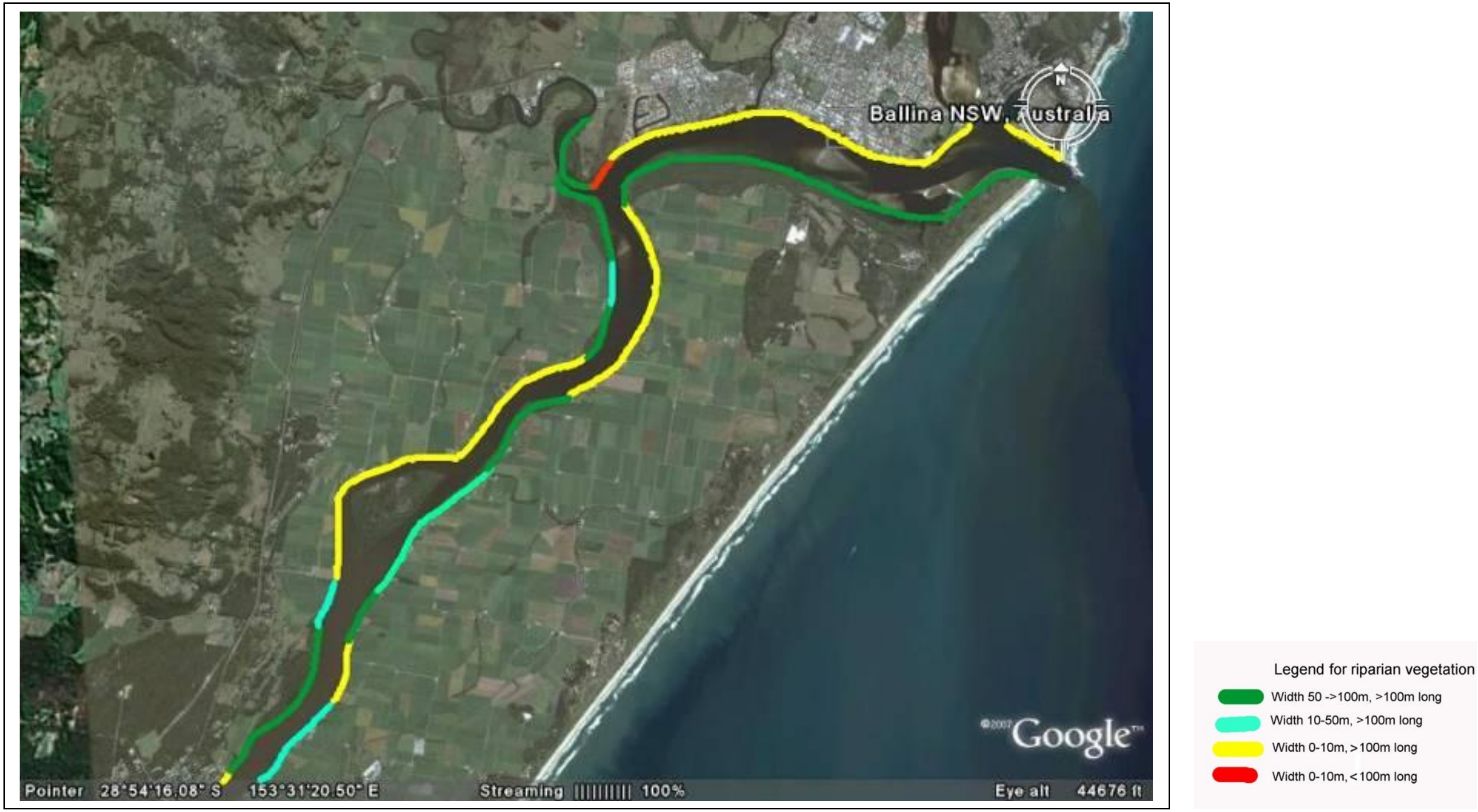
Appendix 1 – Riparian Vegetation Assessment Maps

Using aerial photography and on-ground assessment, the following maps have been compiled to depict riparian vegetation width, with green being the widest (50-100m)and blue next widest (10-50m). Yellow areas show width less than 10m over a distance greater than 100m and red areas are less than 10m wide and less than 100m long.

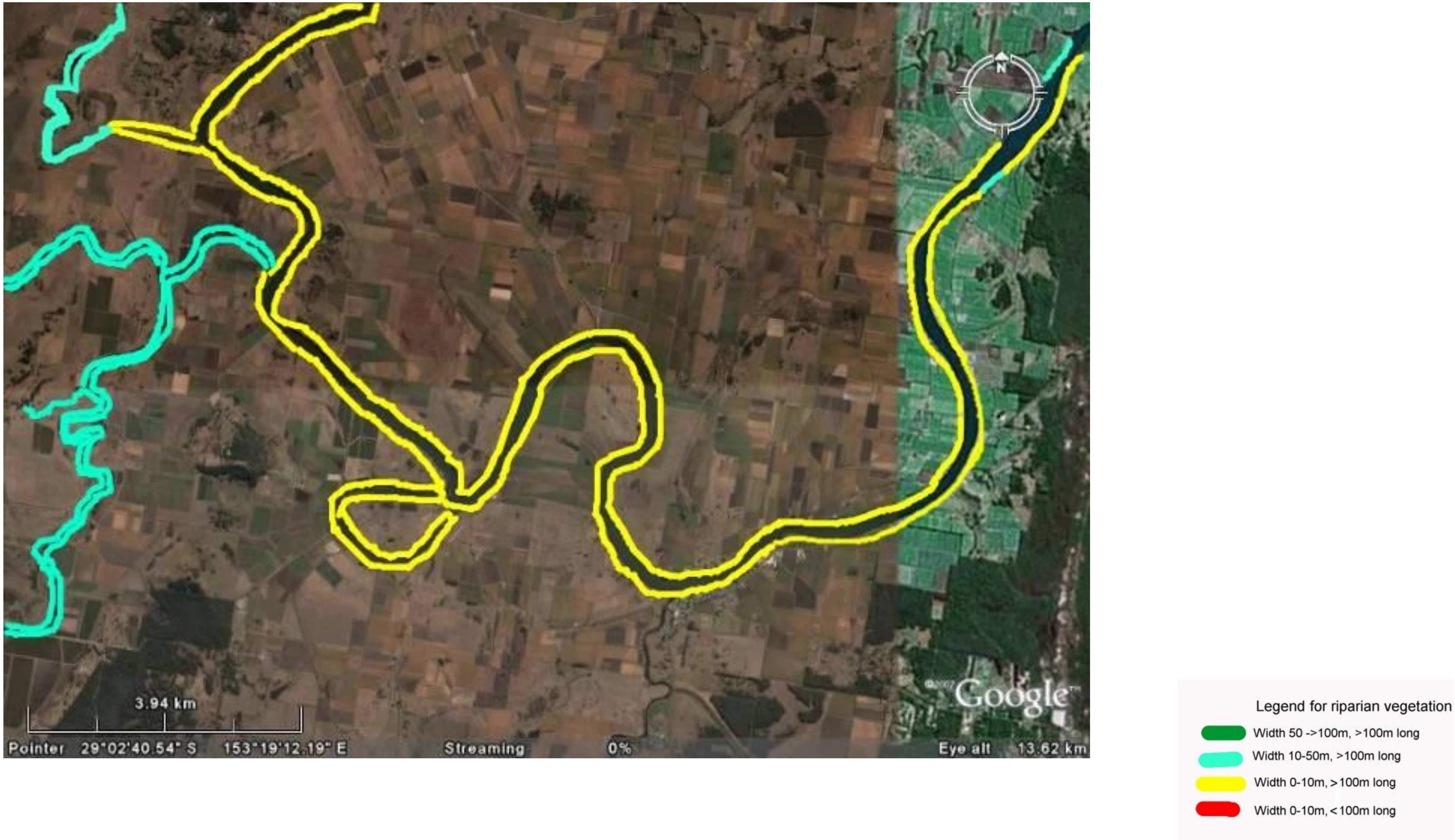
Figure 0.1: Desktop riparian assessment of the North Creek and Emigrant Creek area.



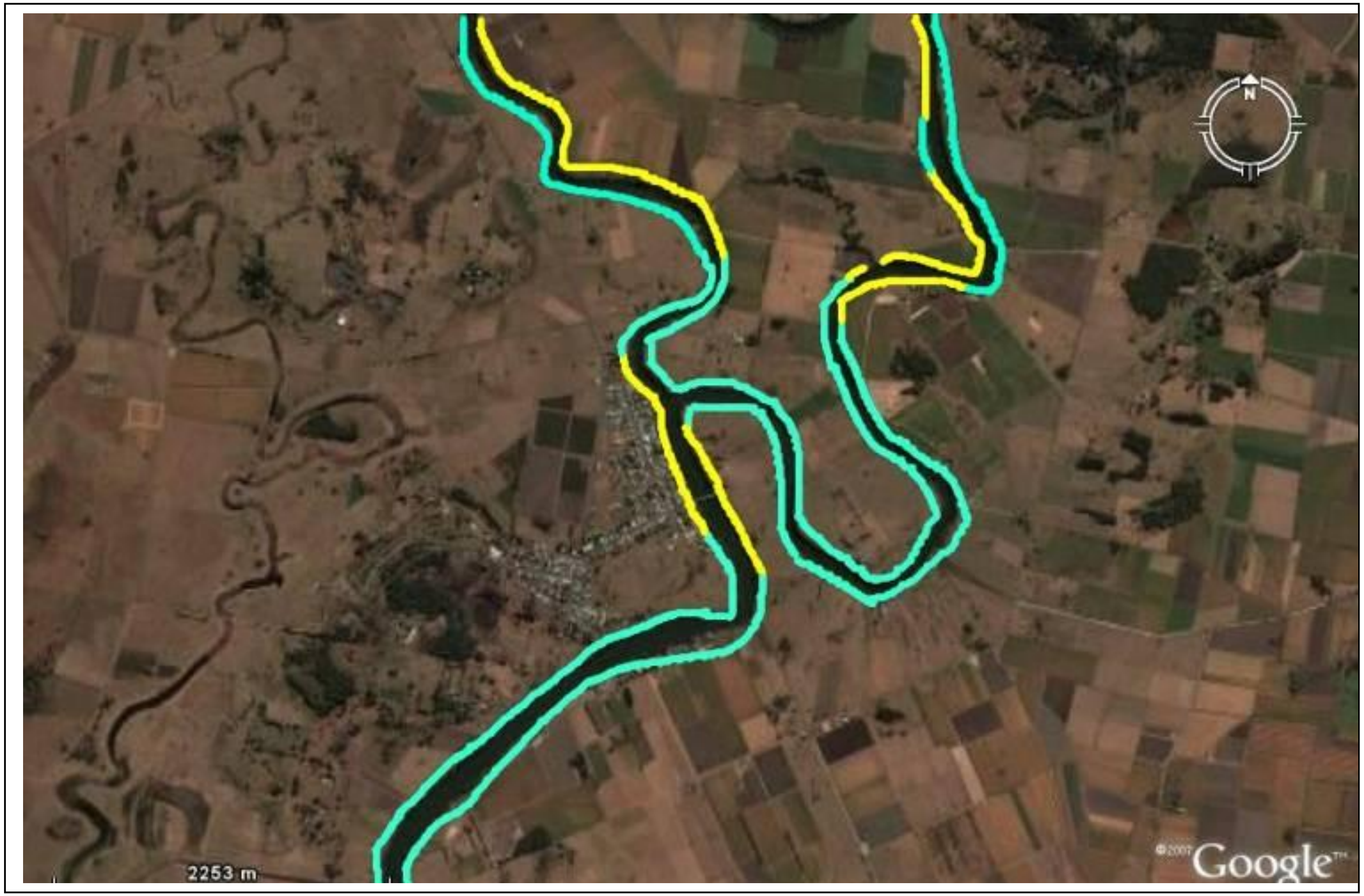
Tuckean – riparian vegetation width and longitudinal connectivity.



North Creek and Emigrant Creek – riparian vegetation width and longitudinal connectivity



Swan Bay and Bungawalbyn riparian desktop assessment.



Coraki area riparian desktop assessment.

Riparian desktop assessment upstream from Coraki.

Appendix 2 – Photographic Archive for water quality, riparian vegetation assessment and geomorphological assessment points

Photographic Archive of each management zone, including riparian site photographs.

Zone 1 – North Creek


Mangrove regrowth near Ballina Fair


Sediment deposition and mangrove communities lower North Creek


Seagrass and mangroves lower North Creek


Public access to foreshore near Missingham Bridge. Note the shoaling from marine derived sediments in the background and rock retaining wall.

	
Recreational fishing in North Creek	Floodplain area and T-tree plantation in the background of picture adjacent to eroding shoreline in North Creek

	
Wet pastures near NC2	Sugar cane at Ross Lane near NC2
	
An Estuary Management Plan was adopted by Ballina Council for Shaws Bay in 2000	Plumes from flood events can extend some distance out to sea.
	
Flood waters at the mouth of North Creek during February 2008.	Fish kill clean up in Ballina Keys February 2008 (Photo: NSW Fisheries)

Figure : Site NC1 and NC2

Zone 2 –Emigrant/Maguires Creek

Macadamia plantation on the floodplain near Teven in background. Note bank erosion Maguires Creek.

Development of macadamia plantation on land previously farmed for sugar cane. Teven/Tintenbar.

Confluence of Maguires Creek and Houghlahans Creek near Teven Golf Course. Note erosion scarp.

Tyres dumped near Pimlico Island. Perhaps crude attempts at bank stabilisation.

Bank slumping and weed infestation at Teven Bridge, Maguires Creek.

Dirt road and exposed bank at the causeway over Pearces Creek, Pearces Creek Hall Road.

	
Degraded wetland near the site of the Teven interchange of the Pacific Highway upgrade.	Water Hyacinth deposition and dead fish near Byrnes Point ferry after the fish kill in February 2008.

	
Google image of the site	Mangrove recruitment
	
Pimlico Island	Drainage into Richmond River
	
Bank slumping and rock retainment.	View of the shoreline.

Figure : Site SB7

Zone 3 –Back Channel

	
Wardell Bridge (Pacific Highway)	Tea-tree plantation
	
Vegetation clearing	

	
Google image of the site	River bank at Royal Hotel Wardell
	
Transport of water hyacinth during flood events occurs in the Richmond River.	Erosion control at Wardell

Figure : Site BC8 (Northern bank at Wardell).

Zone 4 –South Ballina/Empire Vale

	
Vegetation die back and erosion at Mobbs Bay (Photo: Michael Wood)	Prickly Pear infestation at Mobbs Bay (Photo: Michael Wood)
	
Construction of recreational facilities at Woodburn. The 2008 flood results in bank undercutting of the bank below the steps.	Broadwater Sugar Mill
	
Mangrove Removal on Plenkovich Road	Mangrove colonisation in areas around drains

	
Google Image of the site	Improvement in water quality will result in aquatic habitat values.
	
Over hanging vegetation provides good habitat for aquatic life.	A collaborative water quality project is currently underway at this site.
	
A good riparian zone exists here that is not confined by the road. Weed management is required.	Well structured riparian vegetation.

Figure: Images taken from Site SB5.

Google image of the site

Drain at Carney Lane

Mangroves mixed with grasses

Rover bank vegetation

Steep banks at the drain entrance to the river.

Opportunity exists for some vegetation enhancement.

Figure: Images taken from Site SB6

	
Mangroves at site SB4	Opportunities for riparian revegetation in the channel at site SB4.
	
Bank slumping resulting in mangrove destablilisation at Wardell. Site BC8 (Southern Bank opposite Wardell)	The extent of bank slumping at this site is significant. Site BC8 (Southern Bank opposite Wardell)

Figure : Images from sites SB4 and BC8 (Southern bank opposite Wardell).

Zone 5 –Rileys Hill

	
Improvement works could be conducted on the boat ramp at Rileys Hill (north side)	Steep bank at the boat ramp (south side)
	
Wetlands on private property with habitat value.	A pair of Brolgas was observed in the same wet pasture site on 9/4/08 and later on the 25/09/08.
	
Works being conducted to elevate land adjacent to the river	Tea-tree (mid ground) and sugar cane (far background) are both grown at Rileys Hill.

Zone 6 –Evans

	
Riparian vegetation north of Woodburn limited by the current highway	Opportunity exists for high profile riparian revegetation and weed management along the river bank at Woodburn.
	
Bank erosion on Tuckombil Canal (Site E19).	Tuckombil Canal joining the Richmond River to the Evans River (Site E19)
	
Coral Tree invasion on the lower river bank at Tuckombil Canal (Site E19)	Limited riparian vegetation at the Tuckombil Canal site (Site E19)

Figure : An overview of images from Management Zone 6 –Evans and on ground assessment site E19

Zone 7 –Rocky Mouth Creek

	
Google image showing the area of site RC17	
	
Narrow riparian zone being used as a horse paddock at site RC17. Note the coral tree weed abundance. This landowner expressed interest in riparian revegetation	Weed infestation along Rocky Mouth Creek site RC17

Figure : An overview of images from Management Zone 7 –Rocky Mouth Creek and on ground assessment site RC17.

Zone 8-Swan Bay

	
Google image of the Swan Bay area	
	
Riparian zone near Swan Bay showing extensive coral tree growth and exotic vines.	Richmond River in April 2008 after heavy rains near Swan Bay.
	
Sand extraction from the Richmond River near Swan Bay	Riparian vegetation at Swan Bay.

	
Terrestrial and aquatic vegetation at site	Shore line reeds
	
Wetland habitat with some weed aquatic weed issues	Mixed species of aquatic plants

Figure : Images from site SB20

Zone 9-Kilgin Buckendoon

<table>
<tr><td></td><td></td></tr>
<tr><td>Kilgin Canal</td><td>Some large native eucalyptus on the riparian zone.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Some areas of riparian vegetation exist with notable native trees. Extent is limited by the road in places.</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Vegetation clearing resulting in bank erosion</td><td>Large improvements to riparian zone can be made in high profile areas like Council managed</td></tr>
</table>

	parks. (Woodburn west bank)

	
Riparian vegetation clearing (April 2008) destroyed native trees including Tuckeroos.	Good riparian vegetation cleared for unknown reasons (April 2008).
	
Dungarubba Creek restoration project	The boat ramp at Dungarubba Recreational Reserve needs improvement
	
Dungarubba Drain feeds into Dungarubba Creek restoration project	Riparian farming

	
Kilgin School Canal entrance to the Richmond River	Recent fill dumping and vegetation clearing at the Kilgin School Drain entrance (April 2008)
	
Richmond River at site KB13/14	Aquatic plants in the drain
	
Muddy sediments at the drain entrance	Vegetation on the toe of the bank

Figure : Images from site KB 13/14

Google image of this site

Extensive grazed riparian area note coral tree

Hugh potential exists for revegetation with limited weed removal required. Need land holder support for this site.

Weed invasion in grazing paddock

Cattle grazing in the riparian zone

Some good riparian vegetation upstream from this site.

Figure : Images from site KB15

Google image of this site

Bank slumping on opposite bank

Limited riparian vegetation at this site (opposite Bank)

Floating weeds and sparse riparian vegetation

Rocks used to retain bank and tree pruning is evident.

Riparian vegetation on Oakland Road bank

Figure : Images from site KB18

Zone 10 - Tuckean

	
Upstream from the Baggotville Barrage	The Tuckean is utilised by wetland birds.
	
Variable riparian vegetation along the channels	Mangrove fern at the Baggotville Barrage

	
The Baggotville Barrage	

	
Google earth image of the site	Good riparian vegetation structure
	
Rock revetment and mangrove colonisation.	Interesting depositional area near the cutting edge of the bank. Note aquatic weeds.
	
Stormwater runoff and floodplain drainage at this site	Good native riparian trees

Figure : Images from site T11

	
Google image of the site	Rocky outcrop on the northern side of the barrage inhibits immediate erosion. Downstream erosion is notable (background)
	
Abundant water lilies on the estuary side of the barrage.	Southern side of the barrage on the estuary side
	
Northern side of the barrage	

Figure : Images from site T12

Zone 11-Bungawalbyn

	
Drainage channel through pasture	
	

	
Riparian revegetation	

	
Drain management	Asparagus fern regrowth
	
Steep banks with some good native trre growth. The width of the riparian zone is limited.	

Figure : Images from site BU26

<table>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Active riparian revegetation</td><td>Landholder commitment to riparian vegetation enhancement.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Figure : Images from site BU27/28

Zone 12 –Upper Richmond/Wilsons River

	
Confluence of Leycester Creek and Wilsons Rivers at Lismore	Cattles access to streams enhances erosion, Wilsons River near Eltham.
	
Pelican Creek	Near the sale yards at Leycester Creek
	
Confluence of the Richmond and Wilsons River at Coraki	Exposed banks and bank slumping at Lismore.

	
Wyrallah boat ramp	Large area of exposed bank at the Wyrallah boat ramp
	
An interesting wetland site occurs near site 24.	Foreshore works in Lismore has been conducted as part of the levee construction.
	
Jabiru Geneebeinga wetlands are near Casino. Opportunities exists to protect further wetland refuge areas.	Turbidity is compromised during rainfall events in the Wilsons Creek at Bangalow, far upstream from the study area.

	
Camphor Laurel a large woody weed prominent in the management zone. Although a noxious weed they provide structural support for the riparian zone.	Cattle fencing and riparian revegetation on the Wilsons River.
	
Coral tree infestation along the Wilsons River near Lismore. Some structural support is provided b these weeds.	Riparian weed issues, Wilsons River.
	
Severe bank slumping, Wilsons River.	Slumping causing tree fell into the River, Wilsons River.

	
	Water extraction at the Lismore Source has the potential to compromise downstream water quality.

	
A google image of the site	Cattle access to the river on opposite bank at Coraki
	
Public space on the river bank at Coraki	Fishing at the boat ramp in Coraki
	
View from the bridge downstream from Coraki	Fill dumping at the playground in the river side park, Coraki.

Figure : Images from site 21/22

	
A google image of this site	Some serious weed issues at this site
	
River extraction on the opposite bank at this site.	Post flood mud deposition at this site
	
Play ground and BBQ facilities are at this site. Some tree planting (background) and grass swales are used to divert rainwater to the river.	I view from the bridge at this site.

Figure : Images from site 23

A google image of this site.


Grazing occurs at this site


Riparian grazing land with coral tree infestation on the river bank.


Some structural vegetation occurs at this site among intermittent exposed river bank areas.


Private riparian land

Figure : Images from site 24

	
A google image of the site.	Dairy cattle access to the river has been controlled at this site.
	
	Some weed management would benefit this site.
	
Willing landowner at this site provide possible	Downstream view at this site

further riparian management. Upstream of site	

Figure : Images from site 25

	
A google image of this site	Downstream from the bridge
	
Upstream of the bridge	The swing ropes indicate that primary contract recreation occurs at this site.
	
Weed issues at this site	Opportunities for riparian vegetation enhancement.

Figure : Images from site 29/30

	
A google image of this site	The Manyweathers Weir at Casino.
	
Riparian vegetation went some way to helping stabilise banks in recent flooding (2008).	Rocky substrate occurs at the foot bridge downstream from the weir. Some notable riparian plant has occurred along the path and Lomandra help stablilise the bank in the foreground.

Figure : Images from site 31

A google image of the site locality

Downstream of the site

Undercutting of banks

Upstream of the site

Site vegetation and bank view.

Some threatening vines

Figure : Images from site 32

Appendix 3 – Water Quality Monitoring Strategy

Richmond Estuary Monitoring Strategy (REMS)

The Richmond River is predisposed to water quality challenges due to its relatively small catchment area (6979km^2) and large floodplain (990km^2) with a very small water surface area (19km^2). It is a poorly flushed system with a tidal pinch near Pimilco which results in poor water exchange upstream from this area. The upper catchment areas have largely been cleared and the land use is now predominantly agriculture. This change in land use has contributed to high TSS and nutrient loadings from these areas. Additionally, there are eight sewage treatment plants in the study area and several more in the catchment area, which manage waste from the larger urban areas including Ballina, Lismore, Casino, Wardell, Alstonville, Nimbin, Dunoon, and Coraki. Stormwater runoff from these urban areas also enters the Richmond River. The large expanse of rural residential living within the area also results in a significant number of on-site sewage treatment facilities. The labyrinth of road networks and the lack of hard surfaces on some of these also contributes to TSS loading.

The hydrology of the large floodplain has largely been modified through drainage channels and changes in vegetation types. The exposure of Acid Sulfate Soils (ASS) has occurred as a result of floodplain drainage and other activities that altered the ground water hydrology. Flood waters can become acid when draining occurrs from large areas of ASS. Blackwater events are significant post flooding in the Richmond River Estuary and Eyre et al. (2006) have determined that at 25˚ the Richmond River floodplain has the potential to deoxygenate 12.5 x 10^3 mL of saturated freshwater. This scale of deoxygenation is sufficient to completely deoxygenate floodwater stored on the flood plain within 3 to 4 days.

Historical information suggests that flood water can persist on the floodplain for around 6 days and in some places for several weeks. Both black water events and acid water event have contributed to fish kills in the Richmond River. There are also potential health risks related to mosquito borne infections after flood events and while water is still stored on the floodplain. Healthy, ecologically balanced wetlands systems can minimise mosquito infestation.

Overview

The aim of this strategy is to provide an optimised, cost-efficient way to:

- Monitor ecosystem health along the estuary (including tidal pools) and tributary waterways on the floodplain,
- Monitor the main drivers of ecosystem health,
- Assess the performance of sub-catchment management initiatives in improving ecosystem health, and
- Interpret data within a functional catchment export-estuarine response model framework that can be used as a predictive risk assessment tool.

Integrated catchment-wide monitoring

The Richmond River estuary is the unifying element for environmental management across all local government areas (LGAs). Each LGA attempts to maintain good water quality throughout their particular part of the catchment and estuary, however, the ultimate goal is to improve the ecosystem health of the Richmond estuary. Monitoring strategies should, therefore, not only cover particular localised issues, but also place these into the wider system context (i.e. how does each LGA impact on the estuary as a whole).

At present, there is monthly water quality monitoring data collected from each of the constituent councils. This data will be used to assist with future monitoring, however, a coordinated approach will provide more robust results.

Centralised approach

Disparate LGA water quality monitoring programs across the Richmond River catchment would be best served by centralising and standardising the collection, storage and analysis of samples to a catchment-wide monitoring strategy. This allows for a standardised approach to sampling protocols, analysis, quality assurance and database management ensuring high quality data. It is important that the strategy is consistent with state-wide monitoring efforts (e.g. the Monitoring, Evaluation and Reporting program currently being undertaken by DECC).

Organisation

The strategy should be ideally overseen by a single authority (e.g. Richmond River County Council), and include regular consultation with contributing stakeholders. It is anticipated that the strategy could be run by one full-time Water Quality Officer. Time weighting for duties would include:

- Sample collection 0.3
- Sample analysis 0.3
- Data management 0.2
- Reporting and Liaison 0.2

The position would require field, laboratory and data analysis skills. Data quality can be improved keeping the chain of custody from sample collection, storage, analysis to data management with one person. Data would be made available using existing reporting framework for Councils.

Monitoring locations

The choice of monitoring locations will be determined by a trade-off between costs / logistics and information gained. A core set of main channel sample locations should be maintained along the estuarine gradient and tidal pool in order to provide assessment of system-wide water quality, and a context for gauging impacts of sub-catchment inputs. Ideally, these should include representatives from each reach.

Sampling locations within each sub-catchment unit should include as a minimum a site at the catchment outlet, sites relevant to current management initiatives, and major secondary sub-catchments (e.g. a minimum requirement for the Bungawalbyn / Sandy Creek management unit would be sites in both creeks upstream of their confluence and one site downstream of their confluence). Ideally, a site representative of the primary water quality stressor (e.g. the Bora Codrington drain) should be included. It is anticipated that the strategy would utilise car and boat based sampling to cover the minimum of sites throughout the catchment and estuary.

Boat-based sampling is preferable for estuarine monitoring due to the ability to:

- choose ecologically-relevant sites rather than be constrained by accessibility considerations,
- collect mid-stream samples (away from bank disturbance effects),
- take depth profiles which provide valuable information about stratification,
- allow samples to be collected at a standard state of tide along the estuarine gradient, thereby improving the quality of the data and power of interpretation.

Car-based sampling is required to cover most of the catchment outlet sites. Problems associated with bank-based sampling can be overcome using various remote sampling aids (e.g. extension poles for probes and collection containers), or utilising bridges where appropriate.

Indicative sites have been identified (Figures 8.1 to 8.4) according to:

- strategic location at key catchment outlets,
- ability to monitor indicators pertinent to management zone issues, and
- ability to monitor indicators relevant to ecosystem health within a reach.

A total of 36 car-based and 15 boat-based sites have been identified, which is approximately 3 car-based and 1 boat-based sample per management zone (note that not all management zones contain equal numbers of sites – number of sites per zone was commensurate with the magnitude of the zones issues).

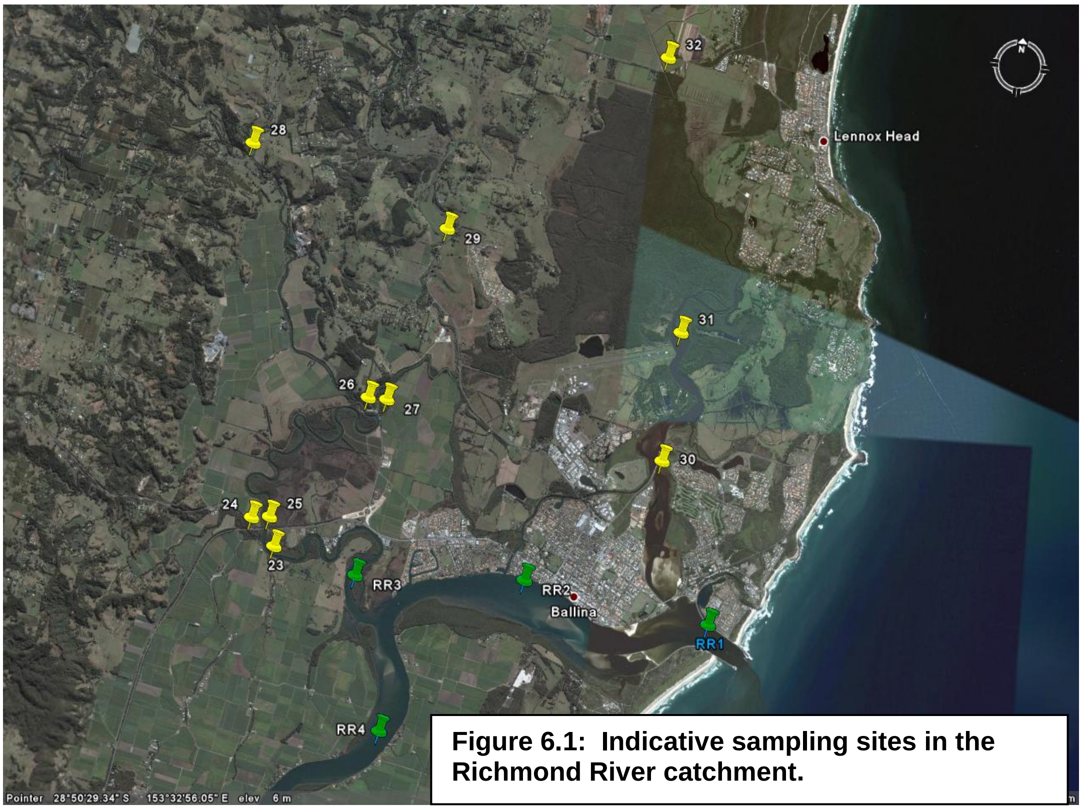


Figure 6.1: Indicative sampling sites in the Richmond River catchment.

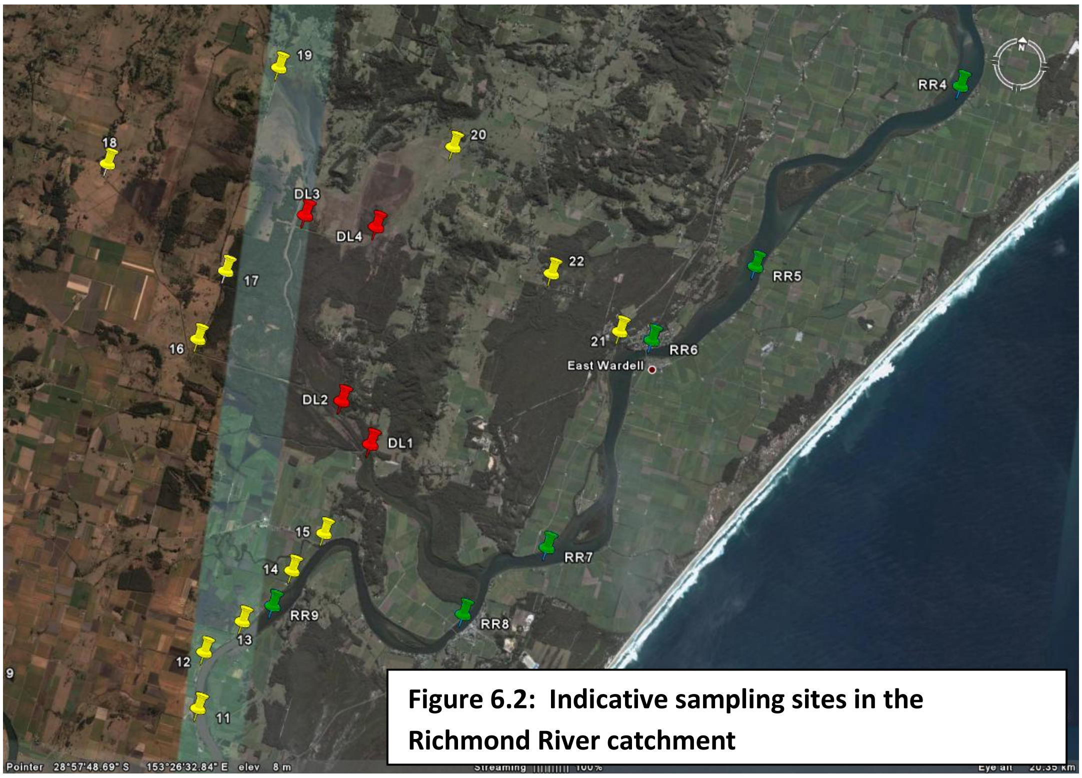


Figure 6.2: Indicative sampling sites in the Richmond River catchment

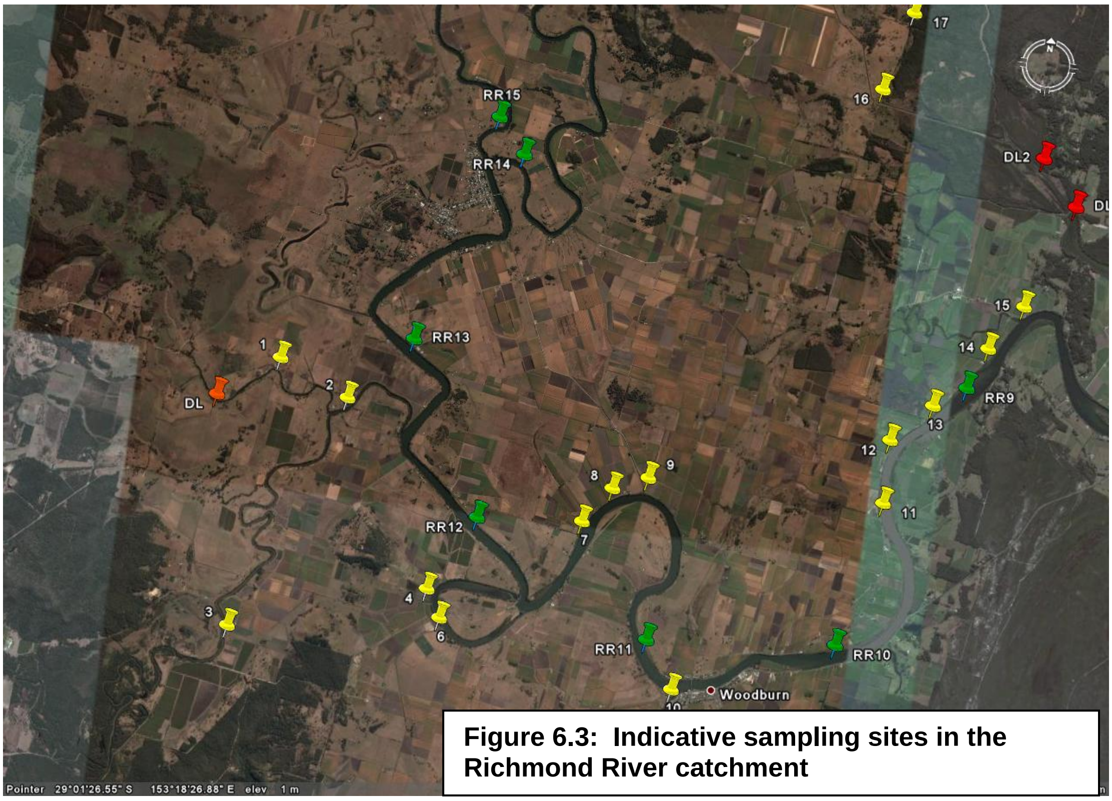


Figure 6.3: Indicative sampling sites in the Richmond River catchment

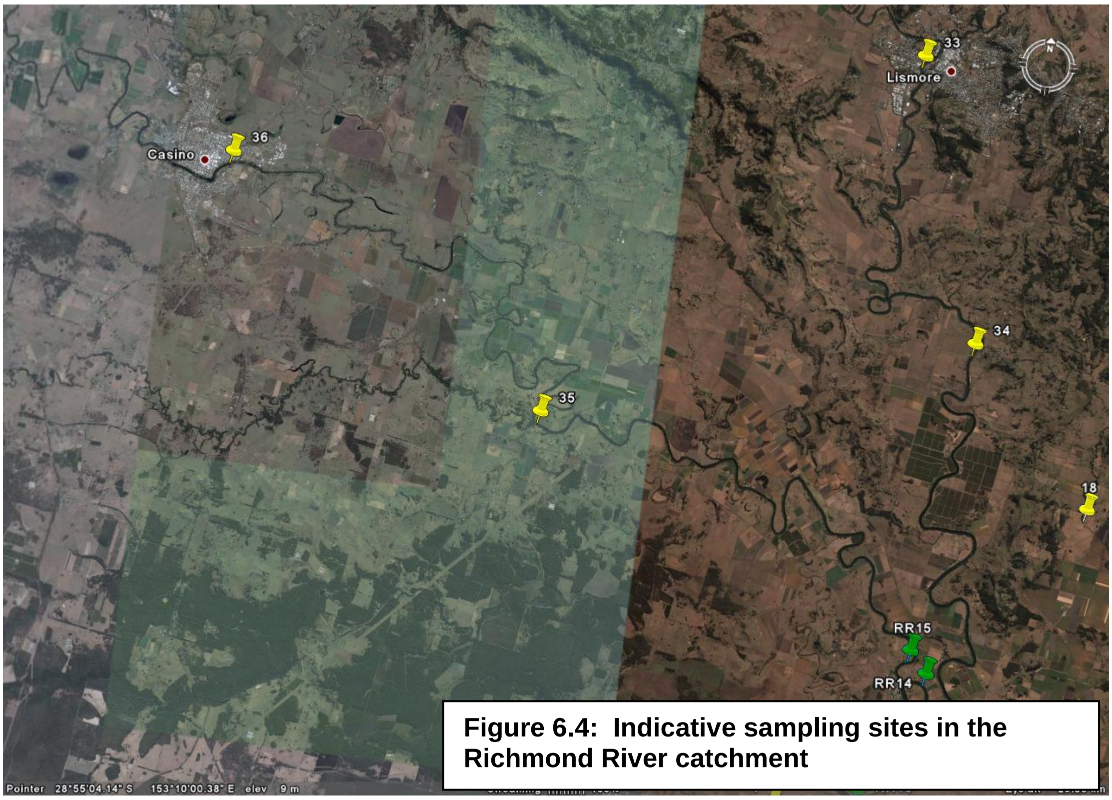


Figure 6.4: Indicative sampling sites in the Richmond River catchment

Monitoring frequency

A minimum routine frequency of monthly samples across all locations is required to properly ascertain seasonal trends due to temperature and broader wet/dry seasonal changes, however, it is insufficient to assess the magnitude / persistence of extreme water quality events (e.g. hypoxia) alone. The power of a monitoring strategy to accurately constrain environmental trends increases with the sampling frequency, which needs to consider the time frame of processes which impact on water quality.

Monthly samples will commonly miss the extremes of water quality variation in response to high flow events, and will only provide a coarse measurement of impacts arising from in-stream processes (e.g. algal blooms and subsequent hypoxia). Fortnightly samples are most likely to represent the minimum sampling frequency needed to describe temporal variation in internal processes and reduce the standard error of estimations. In addition, a flow weighted component to the strategy (e.g. revert to weekly samples after major rainfall events) would greatly improve understanding of catchment exports and ecosystem responses to these inputs to the estuary.

Water quality parameters

A full suite of physico-chemical parameters (temperature, conductivity, dissolved oxygen, pH, faecal coliforms and turbidity) should be measured at each site regardless of what other parameters are measured. These provide vital information pertinent to ecosystem health, e.g. salinity regime (and therefore relative freshwater influence), acidity and trophic status (e.g. hypoxia).

The choice of additional water quality parameters should be addressed on a site by site basis, depending on the primary water quality stressors (e.g. ASS runoff and blackwater) relevant to the site. Catchment outlet sites should include collection of samples for organic dissolved and particulate nutrients and inorganic dissolved nutrients, as well as total suspended solids and chlorophyll-*a.*

Quality assurance protocols

A full record sheet should be maintained for every sample collected (see example record sheet attached as Appendix 1).

Due to the uncertainty introduced to data through poor calibration, it is essential that calibration, according to instrument specifications and using certified high quality standards and reference waters, is carried out pre- and post-sampling. These results should be reported in the Richmond River Water Quality Database (RRWQDB) to allow subsequent quality assessments to be made on data. All data should be entered into the RRWQDB as soon as possible and checked for consistency. Any unexplained anomalies in the data should be addressed immediately to ascertain whether the anomaly reflects a methodological artefact or bona fide environmental trend. These results will be available to all extension officers in real time.

Analytical protocols

To ensure the recovery of good quality data (and hence return for sampling costs), it is critical that all laboratory analysis is NATA certified, and is carried out using the current best-practice methods for marine, estuarine and freshwater water samples. In particular, it is recommended that a low level analysis protocol for inorganic and total nutrients be developed that accounts for interferences due to variable salinity of samples. All analyses should include standard reference materials, and regularly cross check laboratory performance by sending replicate samples to other approved laboratories for analysis.

Data management

Data from the Richmond River Estuary Water Quality Monitoring Strategy (RREWQMS) would be stored centrally in the RRWQDB originally developed by WBM Oceanics as part of the Richmond River Estuary Processes Study. The database currently stores data in Microsoft Access format and provides statistical interpretation via Microsoft Excel and a graphical interface using MapInfo. There is scope for upgrading the current system to make it more user friendly and tailoring outputs to integrate seamlessly with the catchment export and estuarine modelling tools (see below).

In situ data-loggers

These provide valuable information on water quality variation in response to tidal variations, floodgate management, and critical thresholds for the outflow of backswamp runoff. In particular, well-maintained loggers provide crucial feedback on the effectiveness of drain management initiatives (e.g. sills) as long as the data period spans the full range of climatic extremes.

The network of loggers currently maintained in the Tuckean Swamp / Broadwater provides a good system overview by spanning the gradient from the upper, middle, and lower backswamp through to the broadwater. There are major issues associated with *in situ* dataloggers, which must be addressed to maximise the recovery of good quality data:

- Probes should be referenced to AHD to allow proper assessment of tidal impacts and critical levels;
- Probe drift due to biogeochemical fouling should be minimised by regular servicing and calibration,
- If probes are set at a fixed height above the channel bed, an assessment of stratification in the waterway and the potential artefacts likely caused, should be undertaken.

Data analysis and interpretation

Well coordinated REMS could;

- Provide measurable performance indicators for sub-catchment management initiatives (see zone specific indicators in Part 2),
- Improve the diagnostic power of monitoring to detect environmental changes,
- Improve understanding of the Richmond River ecosystem and its likely response to climate change and catchment management scenarios, and
- Meet LGA requirements for environmental audits and reporting.

Catchment export and estuarine response models

The Department of Environment and Climate Change (DECC) has recently completed a comprehensive E2 catchment export model of the entire Richmond River catchment. The model includes up-to-date landuse assessments for each sub-catchment and allows the estimation of pollutant loads from each sub-catchment and testing of landuse change scenarios on loads. This catchment export model has been coupled to an estuarine response model (ERM) of the Richmond estuary which estimates the relative impact of management zone exports on the health of the Richmond estuary. It is also used to assess critical thresholds (guidelines) for primary water quality drivers (e.g. light climate and nutrient concentrations) necessary for maintaining key ecosystem processes.

The model is based on a modified 1D box model approach, comprising 13 boxes from the mouth at Ballina to the upper limit of salt penetration at Coraki. The transport / mixing sub-model accounts for variation in the principle drivers of estuarine biogeochemical processes:

- morphology and depth
- freshwater inflows
- tidal mixing
- water residence times
- nutrient and TSS inputs
- light climate

The biological response sub-model predicts the growth and biomass of phytoplankton and benthic microalgae, as well as rates of bacterial breakdown of organic matter. The net impacts on important water quality parameters such as dissolved oxygen are then estimated.

Interpretation of routine monitoring data

Data collected routinely as part of the proposed REMS can be easily interpreted in the catchment export-ERM framework to give an indication of ecosystem health status against a set of system-specific health guidelines. Catchment outlet data can be used to calibrate and update export coefficients in the E2 model to give more realistic estimations of loads.

Key monitoring sites and assessment parameters

The following series of Tables provide key monitoring sites and parameters for the assessment of inputs and ecosystem health in Management Zones 1 to 4 and 7 to 12, described in the Richmond River Estuary Management Study and Plan (Australian Wetlands 2009).

ZONE 1 – North Creek	Phys-chem	Secchi	nutrients	BOD	Chlorophyll-*a*	TSS
Input sites						
Newrybar Swamp at Ross Lane	X		X	X		X
Ballina STP	X		X	X	X	X
Ballina urban runoff	X		X	X		X
In-stream health sites						
Upper North Creek estuary	X	X	X		X	X
Mid North Creek estuary	X	X	X		X	X
Lower North Creek estuary	X	X	X		X	X
Lower Richmond estuary	X	X	X		X	X

ZONE 2 – Emigrant / Maguires Creek	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Emigrant Ck at Cumbalum	X		X	X	X	X
Maguires Ck at Teven	X		X	X	X	X
Uralba Ck at highway	X		X	X	X	X
Pimlico Ck at highway	X		X	X	X	X
In-stream health sites						
Emigrant Ck at confluence	X	X	X		X	X
Maguires Ck at confluence	X	X	X		X	X
Emigrant estuary at Pacific Highway	X	X	X		X	X
Lower Emigrant estuary	X	X	X		X	X
Lower Richmond estuary at Byrnes Pt	X	X	X		X	X
Lower Richmond estuary at Pimlico	X	X	X		X	X

Zone 3 – Back Channel	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Bingal Ck at Wardell Rd	X		X	X	X	X
Pacific highway upgrade sites	X		X	X	X	X
Instream health sites						
Bingal Ck at confluence	X	X	X		X	X
Mid Richmond estuary at RR5	X	X	X		X	X
Mid Richmond estuary at RR6	X	X	X		X	X
Mid Richmond estuary at RR7	X	X	X		X	X

Zone 4 – South Ballina / Empire Vale	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Empire Vale Ck at Reedy Ck Rd	X		X	X	X	X
In-stream health sites						
Empire Vale Ck at outlet	X	X	X	X	X	X
Lower Richmond estuary at RR1	X	X	X		X	X
Lower Richmond estuary at RR2	X	X	X		X	X
Mid Richmond estuary at RR4	X	X	X		X	X
Mid Richmond estuary at RR5	X	X	X		X	X
Mid Richmond estuary at RR6	X	X	X		X	X
Mid Richmond estuary at RR7	X	X	X		X	X
Mid Richmond estuary at RR8	X	X	X		X	X

Zone 7 – Rocky Mouth Creek	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Rocky Mouth Ck at tide gates	X	X	X	X	X	X
In-stream health sites						
Rocky Mouth Ck at fabridam	X	X	X	X	X	X
Rocky Mouth Ck at Woodburn	X	X	X	X	X	X
Upper Richmond estuary at RR10	X	X	X		X	X
Upper Richmond estuary at RR11	X	X	X		X	X

Zone 8 – Swan Bay	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Northern drain	X	X	X	X	X	X
Southern drain	X	X	X	X	X	X
In-stream health sites						
Swan Bay	X	X	X	X	X	X
Upper Richmond estuary at RR11	X	X	X		X	X
Upper Richmond estuary at RR12	X	X	X		X	X

Zone 9 – Kilgin / Buckendoon / Dungarubba	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Oakland Rd drain1	X		X	X	X	X
Oakland Rd drain2	X		X	X	X	X
Oakland Rd drain3	X		X	X	X	X
Kilgin Rd drain1	X		X	X	X	X
Kilgin Rd drain2	X		X	X	X	X
Kilgin Rd drain3	X		X	X	X	X
Kilgin Rd drain4	X		X	X	X	X
Kilgin Rd drain5	X		X	X	X	X
Instream health sites						
Mid Richmond estuary at RR8	X	X	X		X	X

Upper Richmond estuary at RR9	X	X	X		X	X
Upper Richmond estuary at RR10	X	X	X		X	X
Upper Richmond estuary at RR11	X	X	X		X	X
Upper Richmond estuary at RR12	X	X	X		X	X

Zone 10 - Tuckean	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Yellow Ck at Justilius Rd	X		X	X	X	X
Marom Ck at Tuckean Island Rd	X		X	X	X	X
Tucki Ck at Mathieson Ln	X		X	X	X	X
Instream health sites						
Tucki Drain at Tuckean Island Rd	X	X	X		X	X
Nature Res. Drain at Tuckean Island Rd	X	X	X		X	X
Main drain at Baggotville Barrage	X	X	X		X	X
Mid Richmond estuary at RR7	X	X	X		X	X
Mid Richmond estuary at RR8	X	X	X		X	X

Zone 11 – Lower Bungawalbyn	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Bungawalbyn Ck at Neileys Lagoon Rd	X		X	X	X	X
Instream health sites						
Bungawalbyn Ck at Boggy Ck Rd	X	X	X	X	X	X
Sandy Ck at Myall Ck Rd	X	X	X	X	X	X
Bungawalbyn Ck at Coraki-Woodburn Rd	X	X	X	X	X	X
Upper Richmond estuary at RR12	X	X	X	X	X	X
Upper Richmond estuary at RR13	X	X	X	X	X	X

Zone 12 – Upper Richmond / Wilsons	Phys-chem	secchi	nutrients	BOD	Chl-a	TSS
Input sites						
Wilsons River at South Lismore	X	X	X	X	X	X
Richmond River at Casino	X	X	X	X	X	X
Instream health sites						

Wilsons River at Whyrallah	X	X	X	X	X	X
Richmond River at Tatham	X	X	X	X	X	X
Wilsons River at Coraki	X	X	X	X	X	X
Richmond River at Coraki	X	X	X	X	X	X
Upper Richmond estuary at RR13	X	X	X	X	X	X