A part of BMT in Energy and Environment

BMT WBM

Upper Hawkesbury River Bank Erosion, Foreshore Structure and Weed Mapping

Reference: R.N20133.001.01.docx

Date: November 2013

Upper Hawkesbury River Bank Erosion, Foreshore Structure and Weed Mapping

Prepared for:	Hawkesbury City Council
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

Offices

Brisbane
Denver
London
Mackay
Melbourne
Newcastle
Perth
Sydney
Vancouver

Document Control Sheet

BMT WBM Pty Ltd 126 Belford Street BROADMEADOW NSW 2292 Australia PO Box 266 Broadmeadow NSW 2292 Tel: +61 2 4940 8882 Fax: +61 2 4940 8887 ABN 54 010 830 421 www.bmtwbm.com.au	**Document:**	R.N20133.001.01.docx
	Title:	Upper Hawkesbury River Bank Erosion, Foreshore Structure and Weed Mapping
	Project Manager:	Luke Kidd
	Author:	Luke Kidd
	Client:	Hawkesbury City Council
	Client Contact:	Suzanne Stuart
	Client Reference:	
Synopsis:	**This report documents water-based field data collection, mapping and analysis of foreshore erosion, structures and weeds along the Hawkesbury River between Yarramundi and Wisemans Ferry. This study has been prepared to facilitate the development of management options for the Coastal Zone Management Plan also being prepared by BMT WBM.**	

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0 1	12 Sep 2013 19 Nov 2013	MF MF	M Peters	LJK LJK	Luke Kidd

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
Hawkesbury City Council	1	1									
BMT WBM File	1	1									
BMT WBM Library											

Contents

List of Figures

List of Tables

1 Introduction

1.1 Study Background

BMT WBM is preparing a Coastal Zone Management Plan (CZMP) for the Upper Hawkesbury River on behalf of Hawkesbury City Council (Council). Significant work has been undertaken already through previous initiatives to document pressures, issues and values for the Upper Hawkesbury River. The first step in preparing the CZMP was to ground truth existing information into a Synthesis Report and to move forward with prioritising the issues and values and developing targeted, specific and achievable options (BMT WBM, 2013). The field data inspection and background data review contained in that report indicated that bank erosion and foreshore structures (particularly retaining walls) are a significant issue throughout much of the Upper Hawkesbury River Estuary, and within Councils jurisdiction to manage.

Gap analysis and recommendations for further work identified that up-to-date mapping of structures and erosion zones would be measurable in the short-term, provide immediate benefits and be worthy of inclusion in the CZMP. An updated map of foreshore structures and erosion would serve as a baseline to measure the success of the CZMP, which is likely to include actions to reduce the construction of inappropriate (or ecologically insensitive) foreshore structures. Terrestrial weeds are also a significant issue in the study area particularly those deemed to be noxious or cause significant environmental harm.

To this end, a complementary study to map foreshore erosion, structures and *Arundo donax* (a significant environmental weed for the study area) was undertaken during preparation of the CZMP. This study focusses on the three key data gaps noted above (which are considered to be manageable in the future) and is presented in this report as follows:

Section 1 introduces the study.

Section 2 provides a summary of existing information and analysis available for the study.

Section 3 provides an overview of the field data collected and baseline mapping.

Section 4 details the results of data analysis.

Section 5 provides general discussion around field observations and results of the data analysis.

Section 6 provides concluding remarks of the study.

Section 7 contains a list of references used during the study.

1.2 Study Area

The study area includes an 80 km stretch of the Hawkesbury River between Wisemans Ferry and Yarramundi (the tidal limit of the river) as shown in Figure 1-1. This stretch of the Hawkesbury River is frequently used by the public for recreational boating as well as commercial vessels operating in the region. Organised events such as the annual ‘Bridge to Bridge’ ski race and other boat races occur in the study area and further downstream.

Water level in the river is subject to tidal influences (tide range of 1 metre or more). At low tide, water depth can be less than 0.5 metres and at some locations boats have been reported to run aground. Sediment build-up at some locations affects navigation especially upstream of Bridge Street, Windsor. Sediment slugs and exposed shoals restrict the navigational channel to one boat width in some locations. Floods are often responsible for ‘resetting’ the system and shifting accumulated sediment and other debris downstream.

To facilitate field data collection and mapping tasks, the study area was broken up into three zones (refer Figure 1-2):

- **Zone A** – Yarramundi to Windsor;
- **Zone B** – Windsor to Sackville; and
- **Zone C** – Sackville to Wisemans Ferry.

While the above zones were defined to assist with the presentation of maps and other data, they also coincide with notable topographical changes some of which can be readily observed in the field, e.g. channel shape, ground elevation, the contributing upstream catchment area, land use, soil landscape / geology as well as key estuarine processes and usage of the water way.

A brief description of the study zones is provided below in the following sections.

1.2.1 Yarramundi to Windsor

The Yarramundi to Windsor Reach (Zone A) defines the upstream segment of the Hawkesbury River between South Creek and Steading Creek (approximately 17.4 km in length). This segment of river is situated entirely within the Hawkesbury Local Government Area (LGA) and both sides of the river have therefore been included in the field mapping. The river is wide and shallow with numerous shoals restricting navigability to only those boats with a small draft. This segment of river is notably less meandering than the other downstream river reaches, although an eight knot speed limit does apply.

The tidal limit of the Hawkesbury River occurs at Yarramundi, approximately 140 km upstream of the river mouth (Krogh *et al*., 2009). Near the tidal limit, the Hawkesbury River receives tributary inflows from the Grose River (at Yarramundi) and the Nepean River (further upstream of Yarramundi), and experiences moderate freshwater tidal influence (Gruber *et al.,* 2010). The channel form and bank stability of the upper estuary at this location are largely influenced by the recurring low flows in the main stream of the Hawkesbury River (Kimmerikong, 2005). The altered flow regime impacts on sediment and bank dynamics, which is readily observable in this reach of the study area.

Near Windsor the channel has large meanders and the floodplain widens out (up to 6 km at some locations) providing high storage capacity for overbank flows (with the exception of those higher relief areas on the northern side of the river between North Richmond and Freemans Reach). This section is also characterised by lagoons and floodplain swamp wetlands with low elevations as a result of more rapid sedimentation in the main channel compared to the smaller tributaries. Land use is predominantly agriculture (turf farming) but also includes low density residential development in North Richmond and rural residential properties along the river.

1.2.2 Windsor to Sackville

The Windsor to Sackville reach (Zone B) defines the middle segment of the Hawkesbury River between South Creek and Sackville Ferry (approximately 28.4 km in length). This segment of river is situated predominately within the Hawkesbury Local Government Area (LGA). The Cattai National Park is located on the eastern side of the Hawkesbury River about 17 km upstream of the Sackville Ferry. The Hills LGA boundary incorporates properties located on the eastern side of the Hawkesbury River between of Cattai Creek (including the National Park) and Wisemans Ferry, which have not been included in the field mapping.

In Zone B, the river is wide, deep and has no boating speed limits with the exception of the 8 knot speed limit which begins approximately 300 metres downstream of South Creek and within 100 metres of the ferry crossing at Sackville. Land use along this segment of the river includes agriculture (turf farming) which mostly occurs upstream of Cattai Creek where the floodplain can extend 2 km or more from the river at some locations.

Downstream of Cattai Creek, the floodplain is confined by high relief terrain that surrounds the river on both sides reducing the floodplain width to about 700 metres or less. Land use is predominantly rural and large properties fronting the river are common. Remnant bushland is notably greater, less fragmented and often much closer to the river than areas upstream.

Several ski parks are also situated in this part of the study area including Butterfly Farm and Ski Park, Sackville Ski Gardens, Hawkesbury Riverside Tourist Park, Riverside Ski Park, Kallawatta Ski Park, Hawkesbury Water Leisure Park and Golf Course and the Pacific Park Waterski Gardens. Those river front properties are primarily used for aquatic recreation activities such as boat launching and retrieval, foreshore picnicking and walking and swimming. Other rural properties in the area are primarily used as farms for cattle grazing and other similar land use.

1.2.3 Sackville to Wisemans Ferry

The Sackville to Wisemans Ferry reach (Zone C) defines the remainder of the study area (approximately 34.6 km in length). Like Zone B, this segment of the river is wide, deep and has no boating speed limits with the exception of 8 knot speed limits within 100 metres of the ferry crossing at Portland and Wisemans Ferry. The Cumberland Reach to Wisemans Ferry is notably deeper than the upstream reaches, and influenced by strong tidal currents and inflows from the Colo River (BMT WBM, 2013). The western foreshore of the river belongs to the Hawkesbury LGA and has therefore been included in the field mapping. The entire length of foreshore on the eastern side of the river is under the jurisdiction of the Hills Shire Council.

The Hawkesbury River is also naturally wider downstream of its confluence with tributary river systems including the Colo River and the Macdonald River. The floodplain however is small (typically less than 400 metres wide) and essentially non-existent where hard surface foreshore habitat (e.g. steep sandstone cliff faces) encounter the river. Land use is confined to the small floodplain which also includes river front properties used for cattle grazing, hobby farms and a range of recreational based activities.

Native bushland is present on both sides of the river and the surrounding terrain is steep. Ski parks are also common in this part of the study area (more so than Zone B) which include Caradon Ski Park, Bundarra Ski Gardens, Dargle Water Ski Resort, Pondarosa Ski Resort, St George Ski Park, Riveria Ski Park and others.

1.3 Study Aims

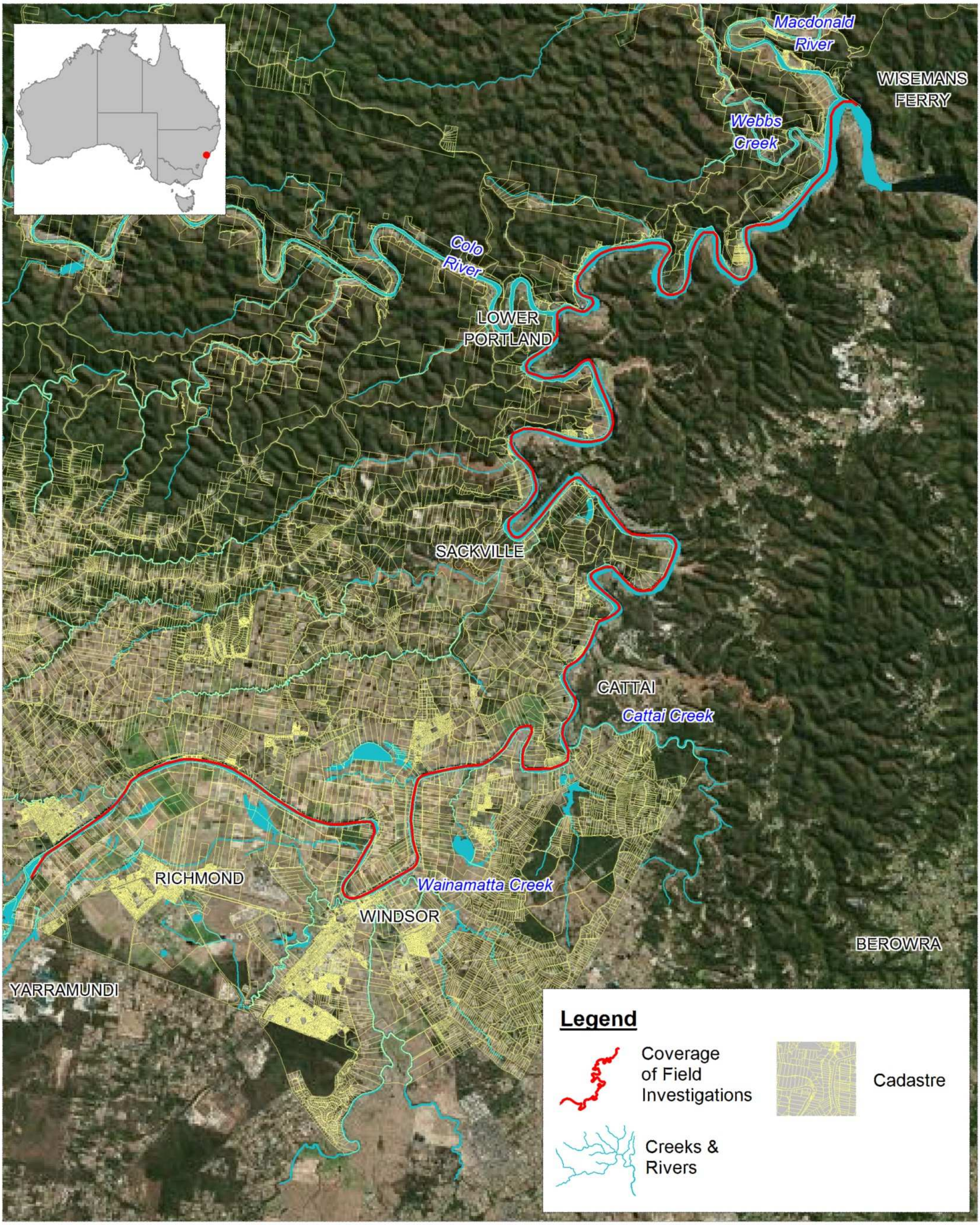
With the exception of site reconnaissance and field data collection undertaken in the early stage of the project, the investigation is primarily desktop based and presents spatial data to quantify and characterise the extent of bank erosion, foreshore structures and *Arundo* in the Upper Hawkesbury River.

The aim of the present study is to assist Council with the collation of new spatial datasets for establishing a baseline upon which further data collection and mapping of the study area may be compared.

In addressing the study aims, the following tasks have been undertaken:

1. Water-based field data collection of bank erosion, foreshore structures and *Arundo* along the Hawkesbury River between Yarramundi and Wisemans Ferry;
2. Collation of field data and preparation of spatial datasets for presentation and analysis in a GIS;
3. Mapping, analysis, interpretation and reporting of spatial datasets and other existing datasets relevant to the study; and
4. Discussion of the results of the field data with key findings of relevant studies and reports.

The study provides a basis for Council to seek future funding for rehabilitation of the Estuary and to provide important information that can be used to focus management options in appropriate locations for the most effective outcomes.



Title:

Study Area, Upper Hawkesbury River

Figure: 1-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

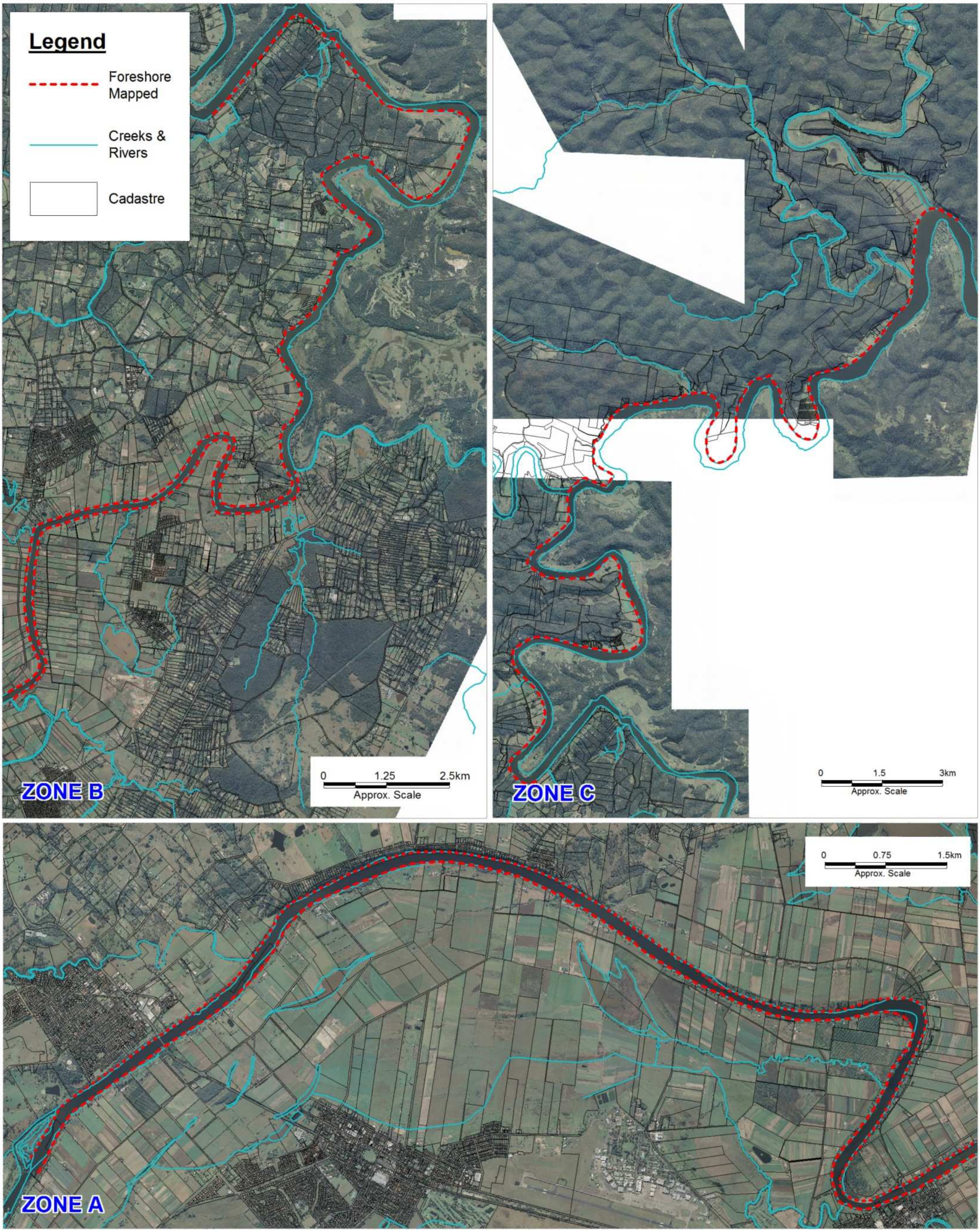
0 3.75 7.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\DRG_001_130719_StudyArea.wor



Title:
Study Area Zones

Figure: 1-2

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\DRG_002_130719_StudyZones.wor

2 Available Information and Analysis

2.1 Overview

The Upper Hawkesbury River has been the subject of numerous environmental investigations undertaken by various government agencies and engineering consultants. The studies have included investigation and assessment of tidal hydrodynamics, water quality, environmental and ecological impacts and the preparation of management plans. The studies document a range of estuarine and catchment related processes, highlighting issues relating to increased sediment and nutrient loads, reduced sediment transport and increased sedimentation and shoaling (reduced navigability particularly in the upper reaches of the study area).

The following provides a concise summary of information and existing analysis particularly relevant to the current study.

2.2 Information Synthesis Report

The Information Synthesis Report provides a review of available information relating to the present condition of the Upper Hawkesbury River Estuary. It provides an overview of the key processes operating in the study area giving a snapshot description of geomorphology, tides, freshwater flows, ecology and water quality. Interactions between these processes and how they come together to form the complex ecosystem of the Upper Hawkesbury River Estuary is discussed.

Of particular relevance to this study is the review of background data and consultation which identifies opportunity for further data collection to inform a more complete and holistic CZMP. The focus of the gap analysis and assessment undertaken by BMT WBM was to identify opportunities to collect information and to provide recommendations for additional data which could be collected rapidly and assist the immediate management of the estuary for maximum environmental benefit. By addressing data gaps where possible, the need for further research or data collection in the future CZMP may be avoided.

The gap analysis and recommendations highlighted three key data gaps / issues, namely:

- Bank erosion;
- Foreshore structures; and
- Terrestrial weeds.

BMT WBM (2013) explains that bank erosion and foreshore structures (particularly walls) are a significant issue throughout much of the Upper Hawkesbury River Estuary, and within Councils jurisdiction to manage. Terrestrial weeds are also a significant issue particularly the emerging weed commonly known as Giant Reed or Elephant Grass.

The following provides background to these key issues which are to be examined as part of the current study.

2.2.1 Bank erosion

The drowned river valley morphology of the Upper Hawkesbury River means that slopes adjacent to the waterway are steep, and the actual intertidal area is very narrow. Between Windsor and

Wisemans Ferry, the influence of geology on conservation is striking. The wide flat banks around Windsor are cleared, cultivated, usually weed infested and often eroding, whereas further downstream, where the imposing sandstone cliffs occur, the vegetation is predominantly native, and probably not dissimilar to conditions 200 years ago.

Causes of bank erosion include wind, wind waves, boat wash, uncontrolled access for farm animals, sediment starvation and slumping (Kimmerikong, 2005). This is exacerbated by the lack of riparian vegetation. Riparian land use also has an effect the volume and velocity of surface runoff which at some locations (e.g. stormwater outlets) causes localised scour in the river channel and erosion of riverbanks. Land use may increase the steepness of riverbanks, sediment and nutrient inputs, and reduce the connectivity between the river and adjacent riparian zones. Bank erosion is also common around foreshore structures which can redirect flows causing “end effect” erosion to adjacent riverbanks.

2.2.2 Foreshore structures

The Upper Hawkesbury River Estuary and its upstream tributaries have been crucial to human settlements for a very long time. Human activities have modified virtually every process operating in and around the study area. The extent to which the catchment and waterway has changed from natural conditions renders these influences irreversible.

The Upper Hawkesbury River Estuary is utilised extensively for a range of different activities. Water skiing and wakeboarding are very dominant waterway uses between Windsor and Wisemans Ferry. Due to the predominantly private ownership of riparian areas, public recreation along the Hawkesbury Estuary is very limited. Publically owned reserves for the study area are limited, and in areas where the riverbank is publically owned, adjacent private landholders have often encroached onto public land with, for example, buildings, barbeques, access ways and gardens.

Human influences include water based development or foreshore structures such as jetties, stairs/ladders, bank protection works and boat ramps. If improperly designed, structures such as these can exacerbate natural bank erosion and/or create gross pollutants/waterway hazards as components break-off during high river flow conditions (e.g. a flood). These structures can also impact on fish habitat and passage and reduce the waterway available to professional trawling activities. In some cases, foreshore structures such as retaining walls and rock protection may be preferred over natural riverbanks if they better suit human uses of the surrounding land and/or are designed to protect property and infrastructure from bank recession caused by natural and/or human impacts on the environment.

2.2.3 *Arundo*

In general, the movement of water up and down the estuary (hydrodynamics) provides transport for seeds and plant fragments. Hydrodynamics also has an important role in the dispersal of weeds through the estuary. Weeds travel downstream with freshwater flows and tidal flows also redistribute weed species on a daily basis (both upstream and downstream).

Both terrestrial and aquatic weeds are a significant issue for the study area although the availability of data is limited. The area between Penrith and Windsor is noted as being a chief concern with respect to aquatic weeds. Site selective aquatic weed data collection has been undertaken by

SKM (as part of the replacement flows project done by Sydney Water) for the Upper Hawkesbury River near Yarramundi although these data are not the primary concern of the current study.

The use of remote sensing techniques to map infestations of aquatic weeds within the river has been attempted (e.g. Williams and Thiebaud, 2007), however, the completeness of data obtained is unknown and is more likely to provide generalised small scale mapping outputs rather than site specific details such as the work done by SKM. Hawkesbury River County Council is also working on developing GIS weed mapping capabilities (C Dewhurst 2013, pers. comm., 3 June 2013).

A variety of terrestrial weeds including Willows (mainly Black and Crack), Lantana, Balloon Vine, Bamboo, Castor Oil, Camphor Laurel and Wild Tobacco common to the study area are shown in Figure 2-1. Several environmental weeds, i.e. weeds that are not declared noxious under the *Noxious Weeds Act 1993* but still pose a threat to environmental health are also present in the study area which is listed in Appendix C (Hawkesbury City Council, 2013).

Of particular importance to the study area is the introduction and spread of the giant reed (*Arundo donax*). *Arundo* responds strongly to fertiliser, prefers well-drained soils above the mean water level in freshwater streams, and it is generally most abundant and dominant in open sites (full sun) where the original native vegetation has been recently damaged or removed (Queensland Primary Industries, 2009). Although not formally listed as a noxious weed, *Arundo* is a high priority widespread weed impacting on biodiversity in the Hunter-Central Rivers catchment (Environment and Heritage, 2013) and requires attention to reduce further spread in the Hawkesbury region.

Council is aware that the spread of *Arundo* has increased and that up-to-date mapping will assist in the prioritisation and targeting of rehabilitation efforts. A rapid targeted and coordinated approach will be required if the introduction of this weed to the study area is to be managed.


a.


b.


c.


d.


e.


f.


g.

a. Black Willow

b. Lantana

c. Balloon Vine

d. Bamboo

e. Castor Oil

f. Camphor laurel

g. Wild Tobacco

Figure 2-1 Terrestrial Weeds Common in the Study Area

2.3 Other Relevant Studies and Data

The following provides a concise review of other background information and data relevant to the mapping project.

2.3.1 Estuarine habitat mapping and geomorphic characterisation

Estuarine habitat mapping and geomorphic characterisation of the Lower Hawkesbury River and Pittwater estuaries was undertaken by Industry & Investment NSW (Astles, West and Creese, 2010). The project was designed to provide information to better understand the distribution of estuarine habitats and the potential threats to these habitats from human activity.

Results presented in Part A of their report (Data Consolidation and Mapping) are of most relevance to addressing data gaps examined in this report. Although the work is not directly applicable to the current study, it does highlight the importance of addressing data gaps to establish a more comprehensive coverage and understanding of estuary condition. Recommendation that spatial mapping of human activities be constructed and incorporated into habitat maps (to enable the location of habitats to be overlaid with the location of their potential threats) is consistent with the broader aims of the current study and the preparation of the CZMP.

The study consisted of mapping the estuarine habitats and undertaking an ecological risk assessment of human activities on those habitats. The Lower Hawkesbury Estuary was broken up into generalised geomorphic zones which included Berowra Creek, Broken Bay, Cowan Creek, Mangrove Creek, Mooney Mooney Creek, Mullet Creek, Patonga Creek, Pittwater, Hawkesbury River – Fluvial Delta and Hawkesbury River – Riverine Channel. The riverine channel geomorphic zone includes the Upper Hawkesbury River between Wisemans Ferry and Yarramundi (i.e. the area considered by this study).

Overall, their study is wide ranging but does include consideration of foreshore development as a human activity with the potential to impact on estuarine habitats. Erosion and sedimentation are discussed in relation to dredging and foreshore development, which can destabilise subtidal habitats. The study also highlights that:

- Foreshore development can pose an intolerable level of risk to estuarine habitats and that the level of risk posed can be reduced if issues are managed. Understanding the extent of the interactions (intensity and location) between human activities and surrounding habitats is important. It therefore stands to reason that management actions should be formulated where the interactions are most intense and/or the greatest risk of environmental degradation is expected;
- Riverside settlement in the riverine channel comprised 2.1 km of recreational parks and 4.6 km of housing/riverside settlement. Stressors of foreshore development includes a change of hardness and slope of shore, increased access to shoreline, clearance of natural vegetation, change of flow and tidal regimes, pollutant deposition and accumulation. Stressors are responsible for impacts on a range of estuarine habitat including potential outcomes such as erosion/accretion, sediment destabilisation, accumulation of pollutants, increased turbidity and changed tidal exchange and hydrodynamics; and
- Jetties and marinas have previously been mapped to a very limited extent in the NSW Lands DCDB and the DTDB databases although the coverage was inconsistent and missing many of

the jetties now present within the Estuary. The total number of jetties mapped in the Estuary was 1371 with the majority found in Pittwater (677). A comparatively smaller number of jetties (61) were mapped in the Hawkesbury River Riverine Channel.

2.3.2 RMS water-based structure mapping

During the background data review, water-based structure mapping undertaken by the Roads and Maritime Services (RMS) (former Waterways Authority) was identified. The informal mapping / audit undertaken between 2007 and 2010 recorded 1248 locations along the Hawkesbury River between Yarramundi and Singletons Mill as well as the lower reach of the Colo River and Macdonald River.

Each location was categorised as either a:

- Boat ramp (total of 432 sites);
- Waterway structure i.e. jetties/pontoons (total of 178 sites); or
- Irrigation intake i.e. pipes/pumps (total of 638 sites).

The raw data provided by the RMS included the GPS coordinates (longitude/latitude and Easting/Northing) and a unique ID number. Structure mapping data is presented in Figure 2-2, Figure 2-3, Figure 2-4 for Zone A, Zone B and Zone C respectively.

The data provides some insight into the coverage and density of the above structure categories in the study area, however, in the absence of other data e.g. the date of each sighting, the condition of structures and other commentary, the period over which the data were collected, and the order in which sightings were gathered, it is difficult to obtain any meaningful indication of change or trend. Furthermore, since these data were collected changes have occurred on the water where compliance was either met or the item was removed. Similarly, other structures/boat ramps or pump systems are likely to have been erected since the informal audit took place, and as such it is difficult to confirm the reliability of the dataset.

Nevertheless, these data do provide a record of where structures have been recorded in the study area and may be used to provide broad guidance on where management efforts should be focussed. Irrigation infrastructure such as pumps and pipes were not included in the current field data collection although such data are likely to be of interest to the Sydney Catchment Authority (SCA).

Legend

Cadastre

Creeks & Rivers

Boat ramp	(14)
Irrigation	(145)
Waterway Structure	(4)

Title:

Waterway Structures Recorded by the Roads and Maritime Service in Zone A

Figure: **2-2**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

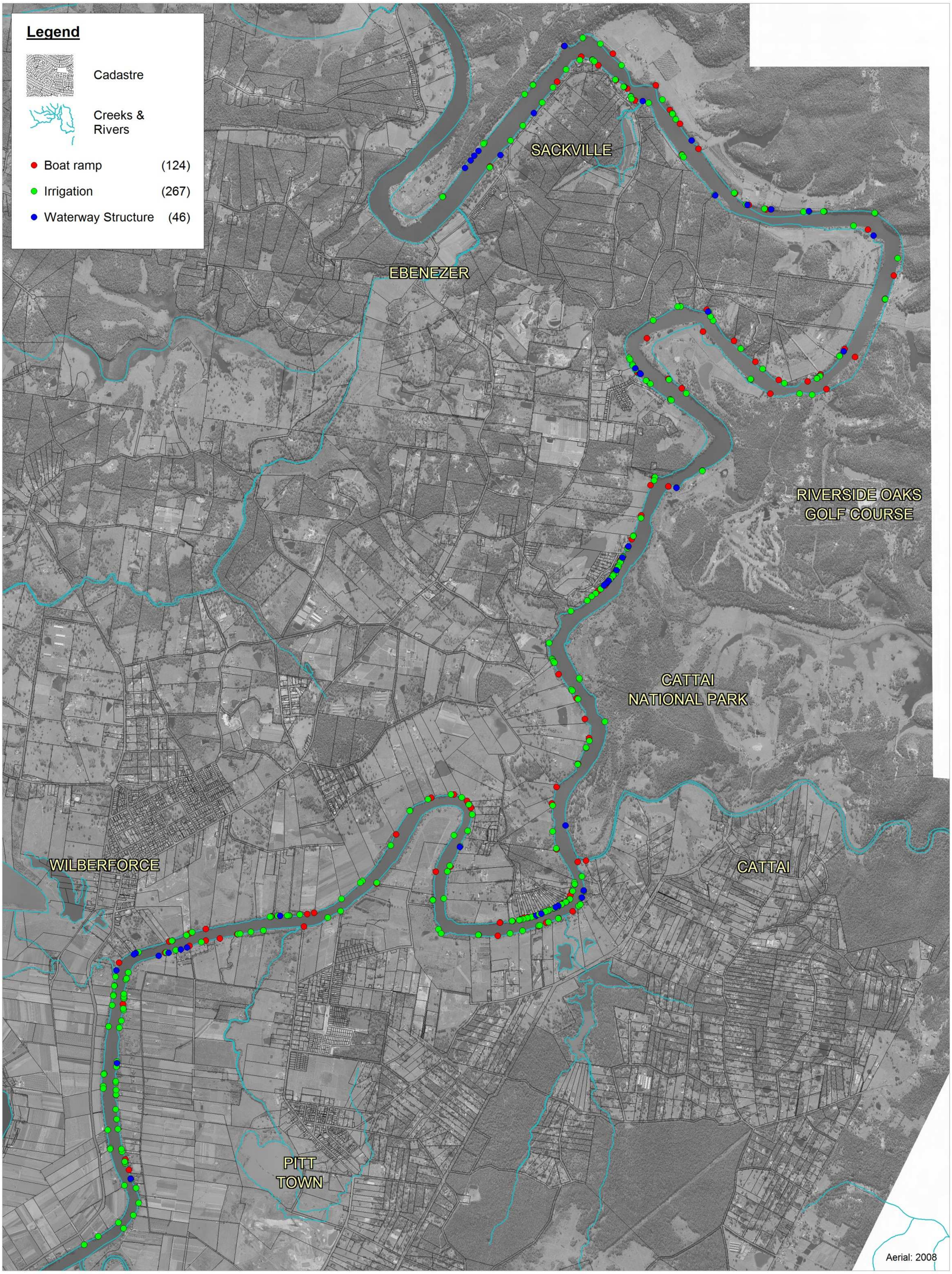
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_015_130909_RMS_Structures_Zone A.WOR



Title:
Waterway Structures Recorded by the Roads and Maritime Service in Zone B

Figure: **2-3**

Rev: **A**

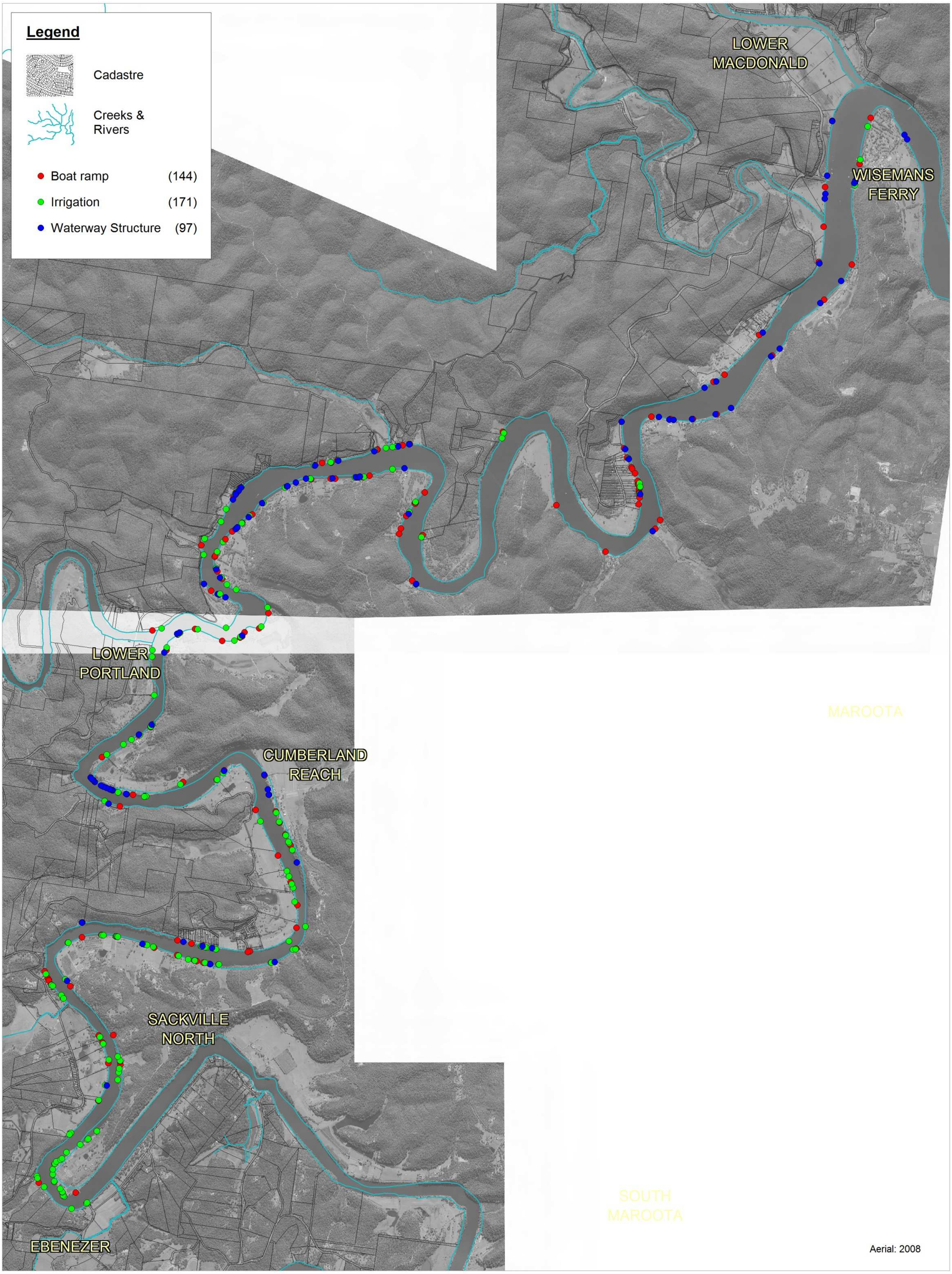
BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.75 1.5km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_016_130910_RMS_Structures_Zone_B.WOR



Title:

Waterway Structures Recorded by the Roads and Maritime Service in Zone C

Figure: **2-4**

Rev: **A**

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_017_130910_RMS_Structures_Zone_C.WOR

2.3.3 Environmentally friendly seawalls

A guide to improving the environmental value of seawalls and seawall-lined foreshores in estuaries has been prepared by the Sydney Metropolitan Catchment Management Authority and Department of Environment and Climate Change NSW (2009). The guideline aims to illustrate the environmental consequences of building traditional seawalls and to explain how seawalls differ from natural estuarine foreshores. The guidelines also provide those involved in designing, approving, building or upgrading seawalls in estuaries with a range of options to improve the environmental value of seawalls and seawall-lined foreshores.

The guideline highlights that:

- Seawalls have become a dominant foreshore feature of urban estuaries, and the demand to build more and the need to repair existing seawalls is expected to increase in a bid to protect low-lying foreshore infrastructure from sea level rise associated with climate change. Seawalls present in the study area are no exception with many in a deteriorated condition;
- In the past, little consideration was given to the intertidal habitats that were destroyed or fragmented through the creation of seawalls, or how seawalls could be designed to more closely mimic natural shores. Traditional vertical seawalls have limited potential to provide habitat and other environmental services and are therefore poor surrogates. Research has shown that concrete seawalls do not support the same diversity of species as sandstone seawalls;
- Traditional seawalls provide a hard and homogeneous substrate of rock or concrete, often in areas of an estuary where natural hard substrate may be absent or sparse. Seawalls offer little variety or complexity of habitat types, particularly those habitats that retain water or moisture during low tide, thus reducing species diversity;
- Seawalls act as buffers against shoreline erosion, however, their construction means that intertidal vegetation is removed or will eventually die off through prevention of tidal inundation. When a hard structure is built where there is potential for wave action or strong currents, erosion is generally exacerbated at the toe or ends of the structure;
- There are a number of options for improving the environmental value of existing seawalls so they have greater habitat potential than traditional designs which include:
  - Establishing estuarine vegetation such as mangroves or reeds directly in front of seawalls;
  - Providing a native riparian vegetation buffer landward of the seawall;
  - Providing artificial reef habitat immediately in front of seawalls; and
  - Providing variation of texture and form on the seawall surface.
- Similarly, when a new seawall is planned, the guideline promotes the following key design principles:
  - Decide whether a seawall is even needed, or whether other, more environmentally favourable options could be used, e.g. native vegetation and temporary wave barriers;
  - Maximise the incorporation of native riparian and estuarine vegetation into the structure;

- Maximise habitat diversity and complexity by incorporating microhabitats e.g. pools, crevices, boulders and ledges, and by maximising surface roughness and texture;
- Create low-sloping seawalls or incorporate changes of slope to maximise habitat surface area.

A variety of foreshore structures including jetties, stairs/ladders, bank protection works (seawalls) and boat ramps are common in the study area. If improperly designed these structures may exacerbate natural bank erosion and/or create gross pollutants/waterway hazards. The guidelines above are considered particularly relevant for the study area and should be further considered as part of any targeted management actions relating to the restoration of existing or construction of new seawalls and other related foreshore infrastructure.

3 Field Data and Baseline Mapping

3.1 Overview

The primary focus of the field data collection task was to obtain details of the location, spatial extent and properties of bank erosion and structures within the study area. Additionally, *Arundo* was also identified during the field data collection and included in baseline mapping and data analyses.

The following sections provide a summary of the methods used for field data collection, the collation and organisation of raw data into GIS and the mapping of baseline field datasets.

3.2 Field Data Collection

3.2.1 General

A rapid assessment of foreshore erosion, structures and *Arundo* was undertaken over three consecutive days (30 July to 1 August 2013). The field data collection methodology was based on a high level study that required a considered approach. That is, the manner in which similar features were to be combined (i.e. not all features could be recorded individually) and/or excluded from the assessment was important. For example, structures such as irrigation pumps/water lines, stormwater pipe and floodgates were observed in the study area but not recorded; terrestrial weeds are common throughout the study area although mapping all species would be a considerable task and the focus of a separate more detailed study; and the degree to which river banks are actively eroding also varies throughout the study area and could also be the subject of a separate study.

In order to focus field data collection efforts, Council identified that mapping *Arundo* would provide a valuable baseline dataset that could be used to apply for funding and to assist with its removal and reduce further spread. Similarly, mapping the location of foreshore structures and ‘hot-spot’ bank erosion sites (i.e. those sections of riverbank that could be the focus of bank restoration works and which could be addressed in the future by the CZMP) was considered to be most useful to Council.

3.2.2 Approach to data collection

A water-based approach was adopted for recording features along the banks of the river situated within the Hawkesbury Local Government Area. Other tributaries and creeks connecting with the Hawkesbury River such as the Colo River and Macdonald River were not included. Field work was undertaken by BMT WBM staff with assistance provided by the Roads and Maritime Service (RMS) and Council.

Field data sheets (refer Appendix A) were used to document site observations and maintain a record of field data collection activities. A hand-held GPS device was used to record the location of particular points of interest (i.e. bank erosion, foreshore structures and *Arundo*). Start and end coordinates were obtained to mark out segments of the river bank where more than one structure was present or where bank erosion and/or *Arundo* were continuous.

Site photos were obtained for each field data entry as well as any other notable points of interest. In some cases, several photos were taken to record the variety of structures and the variability of conditions along a segment of river noted on each field data sheet. In general, field data sheets were used to document the date and time of each record, the study area zone that the feature is located within (i.e. A, B or C), the name of photos and GPS coordinates (Easting, Northing) for the feature(s). Additional attributes (or categories) relevant to bank erosion, foreshore structures and *Arundo* were also recorded as summarised in Table 3-1.

3.3 Data Collation

Spatial and attribute data were linked with site photos and organised into a Google Earth Data Compendium (refer to CD in Appendix B). The data compendium provides a complete record of all site photos and observations collected for bank erosion, foreshore structures and *Arundo* in the study area. Screenshot examples from the data compendium are shown in Figure 3-1.

3.4 Baseline Mapping

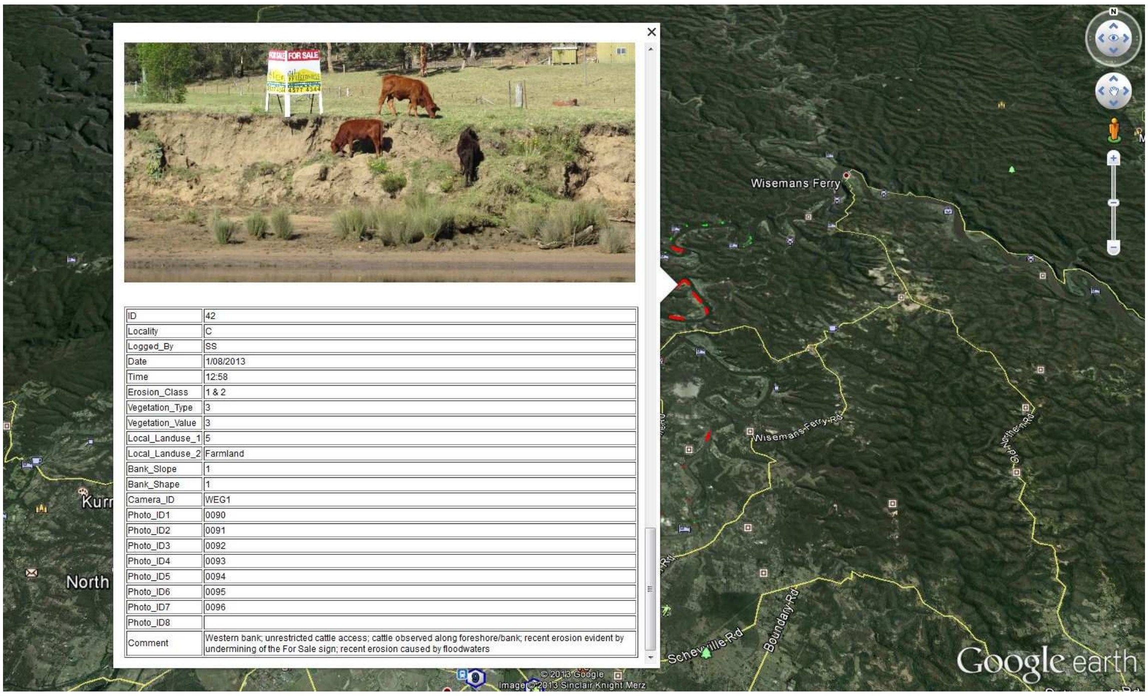
A combination of data collected during the field investigations and high resolution aerial photography were used to confirm and digitise the location and extent of features recorded in the field notes and site photos. Baseline maps showing the location of bank erosion, foreshore structures and *Arundo* (map variables) in each of the study area zones (with the exception of *Arundo* which has been mapped for Zone B and Zone C only) is presented in Figure 3-2 to Figure 3-9.

Each map shows the location (as a point) or extent (as a polyline) of map variables and a unique ID number that refers to attribute data summarised in their respective tables (see Table 3-2 for Bank Erosion, Table 3-3 for Foreshore Structures and Table 3-4 for *Arundo*).

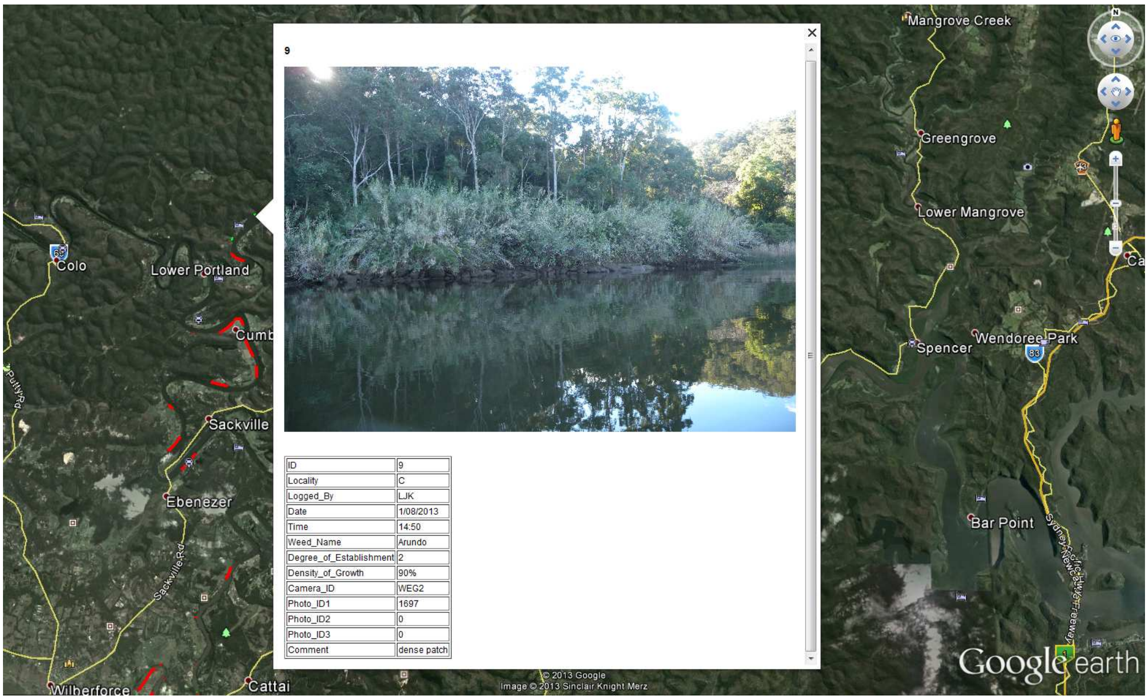
Polylines have been used to define continuous segments of the river bank where *Arundo* and bank erosion were observed. Similarly, a collection of structures were mapped as a polyline with points used to show individual structures that were isolated or could not be shown easily on small scale maps.

Table 3-1 Feature, Attributes and Values

Feature	*Attribute*	*Value*
Bank Erosion	Class	High
		Moderate
		Low
	Vegetation Condition	Natural
		Mixed
		Cleared
		Absent
	Vegetation Value	High
		Moderate
		Low
		Insignificant
	Land Use	Bushland
		Ski/caravan park
		Turf farm
		Housing/residential
		Other
	Bank Slope	Vertical (e.g. 80-90 degrees)
		Steep (e.g. 60-80 degrees)
		Moderate (e.g. 30-60 degrees)
		Low (e.g. 10-30 degrees)
		Flat (e.g. <10 degrees)
	Bank Shape	Concave
		Convex
		Stepped
		Wide lower bench
		Undercut
Structures	Type of Structure	Jetty / fixed
		Pontoon / floating
		Boat ramp
		Gabion wall
		Rock protection / riprap
		Timber retaining wall
		Rock retaining wall
		Concrete retaining wall
		Other
	Condition of Structure	New
		Old
		Degraded
	Number of Structures (if grouped)	(e.g. 5)
Weed (*Arundo*)	Density of Growth	0 – 100%



a

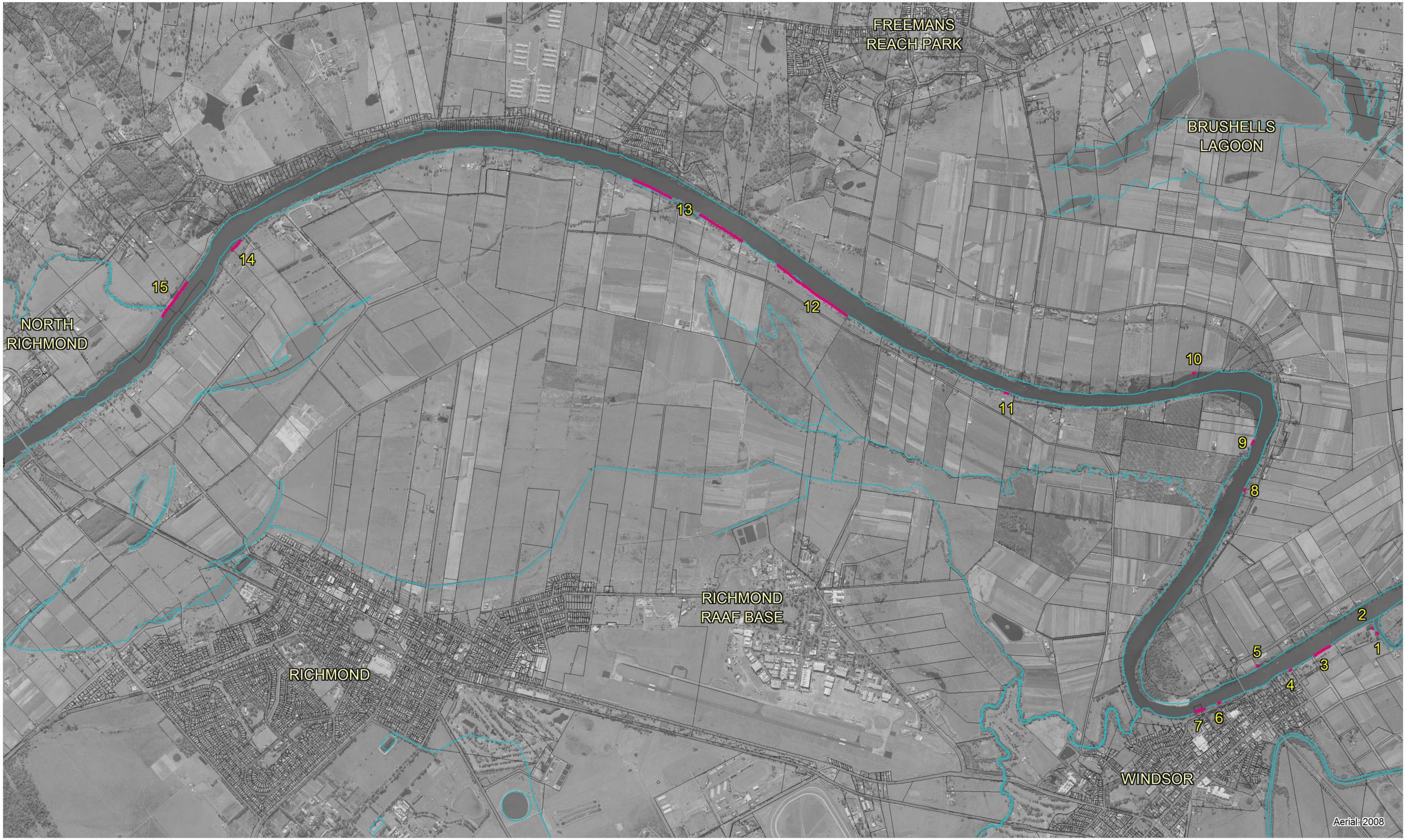


b

Figure 3-1 Google Earth Data Compendium (a) Bank Erosion (b) *Arundo*

Table 3-2 Baseline Map Data (Bank Erosion)

ID	Erosion Class	Bank Slope	Bank Shape	Local Land Use	Vegetation Condition	Vegetation Value
1	High	Vertical	Concave	Governor Phillip Park	Mixed	Low
2	Moderate	Steep	Concave	Governor Phillip Park	Mixed	Low
3	High	Moderate	Concave	Governor Phillip Park	Mostly Absent	Low
4	High	Steep	Concave	Residential	Mostly Absent	Insignificant
5	Moderate	Steep	Convex	Rural – Farming	Mostly Absent	Insignificant
6	Moderate	Vertical	Concave	Public Recreation	Natural	Moderate
7	Moderate	Steep	Convex	Public Recreation	Mixed	Low
8	High	Steep	Concave	Turf Farm	Mostly Absent	Insignificant
9	High	Moderate	Concave	Turf Farm	Mixed	Moderate
10	Moderate	Steep	Convex	Turf Farm	Cleared	Insignificant
11	High	Steep	Convex	Rural – Residential	Cleared	Low
12	Moderate	Steep	Concave	Rural – Residential	Cleared	Low
13	High	Steep	Convex	Rural – Residential	Mostly Absent	Low
14	High	Moderate	Concave	Rural – Residential	Mostly Absent	Low
15	High	Steep	Convex	Rural – Farming	Mixed	Low
16	Moderate	Moderate	Convex	Rural – Residential	Mixed	Insignificant
17	Moderate	Moderate	Concave	Rural – Farming	Mostly Absent	Low
18	High	Vertical	Convex	Rural – Farming	Mostly Absent	Insignificant
19	High	Steep	Concave	Rural – Farming	Mostly Absent	Insignificant
20	High	Steep	Concave	Rural – Farming	Mostly Absent	Insignificant
21	Moderate	Steep	Concave	Rural – Residential	Mostly Absent	Insignificant
22	High	Steep	Concave	Rural – Residential	Mostly Absent	Low
23	Moderate	Steep	Concave	Rural – Residential	Cleared	Low
24	High	Vertical	Concave	Rural – Residential	Mostly Absent	Low
25	Moderate	Steep	Concave	Rural – Residential	Cleared	Low
26	Moderate	Steep	Concave	Rural – Residential	Mixed	Low
27	High	Vertical	Undercut	Rural – Residential	Cleared	Low
28	High	Steep	Concave	Rural – Residential	Mixed	Moderate
29	High	Vertical	Concave	Rural – Farming	Natural	High
30	High	Steep	Concave	Rural – Residential	Cleared	Low
31	Moderate	Moderate	Concave	Rural – Residential	Cleared	Low
32	High	Vertical	Concave	Bushland	Natural	High
33	Moderate	Moderate	Concave	Rural – Farming	Mostly Absent	Insignificant
34	High	Steep	Concave	Ski Park	Cleared	Low
35	Moderate	Steep	Concave	Rural – Residential	Mixed	Moderate
36	Low	Steep	Concave	Rural – Farming	Mixed	Moderate
37	High	Steep	Concave	Rural – Residential	Cleared	Low
38	Moderate	Vertical	Concave	Rural – Farming	Mixed	Moderate
39	Moderate	Vertical & Steep	Concave	Rural – Farming	Mostly Absent	Insignificant
40	High & Moderate	Vertical	Concave	Rural – Farming	Cleared	Low
41	High & Moderate	Vertical	Concave	Rural – Farming	Cleared	Low
42	High	Vertical	Concave	Ski Park	Cleared	Low
43	High	Vertical	Concave	Ski Park	Cleared	Low
44	Moderate	Vertical & Steep	Concave	Ski Park	Cleared	Low



Legend

Cadastre

Continuous Segment of Bank Erosion

Creeks & Rivers

Title:

Baseline Mapping of Bank Erosion in Zone A

Figure: 3-2

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

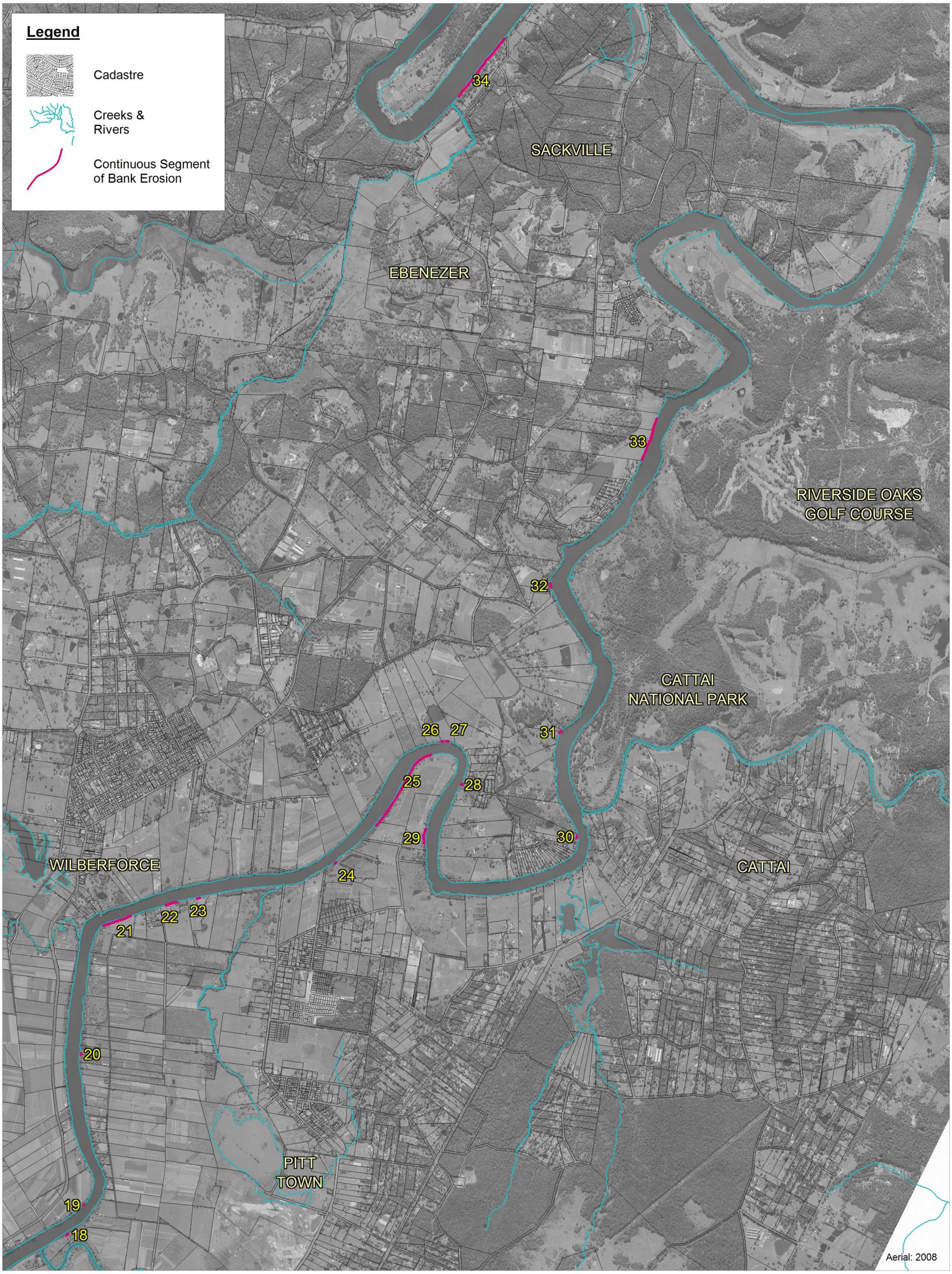
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_003_130822_BankErosion_Zone A.WOR



Title:

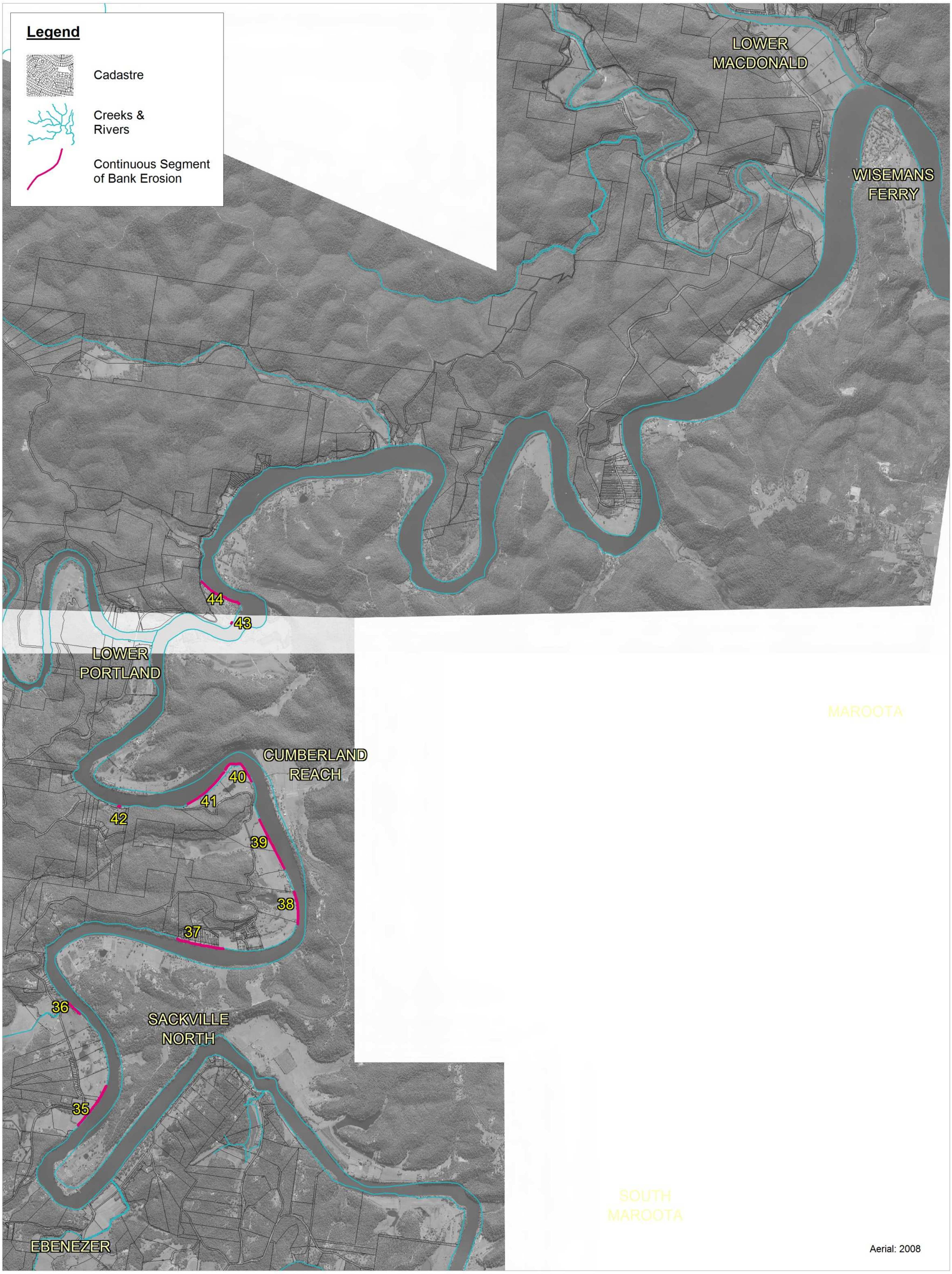
Baseline Mapping of Bank Erosion in Zone B

Figure: 3-3

Rev: A

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_004_130822_BankErosion_Zone B.WOR



Title:

Baseline Mapping of Bank Erosion in Zone C

Figure: **3-4**

Rev: **A**

N

0 1 2km

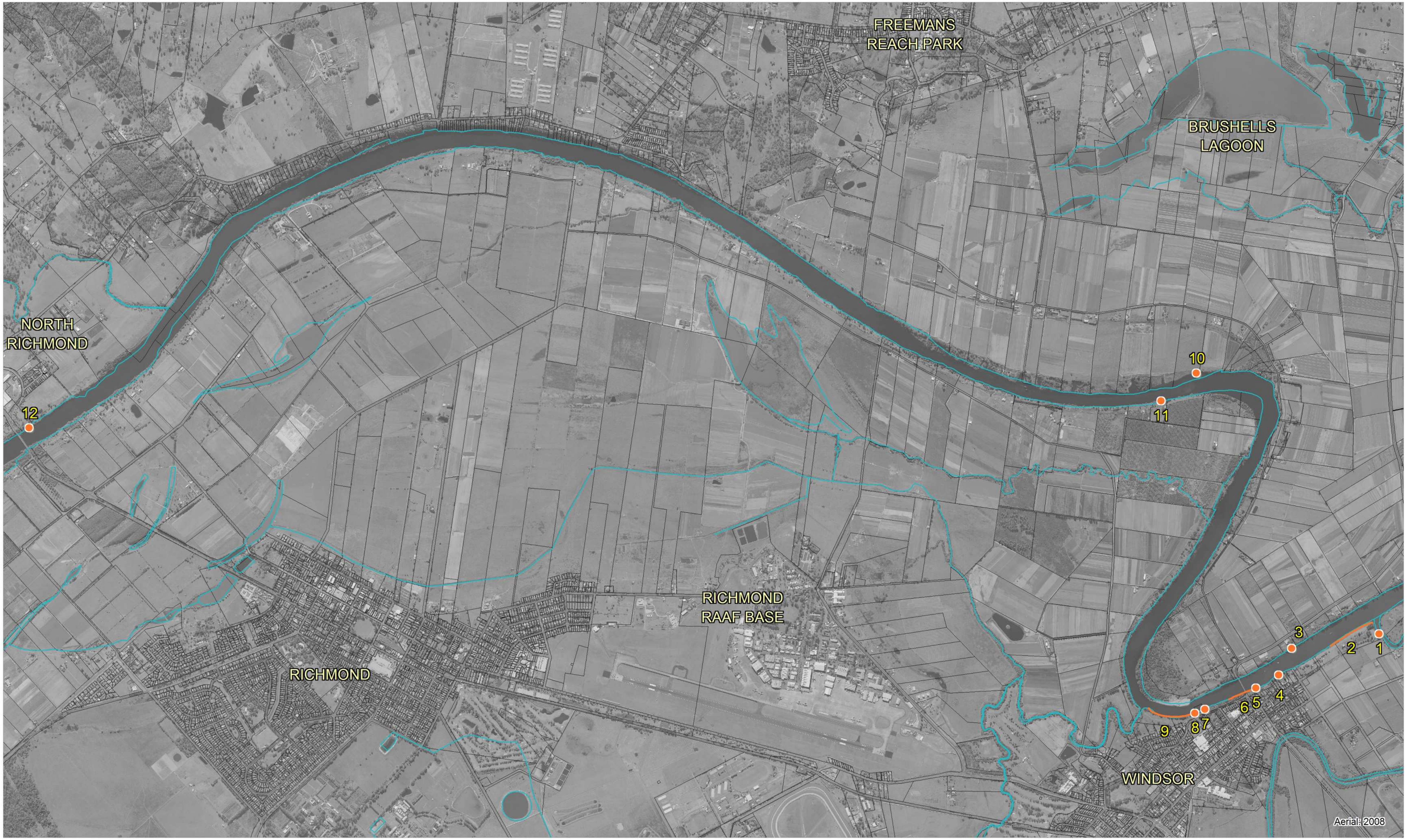
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_005_130822_BankErosion_Zone C.WOR

Table 3-3 Baseline Map Data (Foreshore Structures)

ID	Type of Structure(s) Present	Number of Structures	Condition of Structure(s)	ID	Type of Structure(s) Present	Number of Structures	Condition of Structure(s)
1	Jetty	1	new	41	Boat ramp; concrete retaining wall	2	old
2	Riprap	1	old	42	Boat ramp; jetty; riprap; rock retaining wall	4	old
3	Timber retaining wall	1	old	43	Boat ramp; rock retaining wall	2	old
4	Boat ramp; riprap	2	old	44	Boat ramp; rock retaining wall	2	old
5	Jetty; riprap	2	new	45	Jetty	1	old
6	Gabion wall; riprap	2	old	46	Boat ramp; jetty; rock retaining wall; timber retaining wall	~10	old
7	Gabion wall	2	old	47	Riprap; stairs/ladder	2	old
8	Other	1	old	48	Gabion; stairs/ladder	2	new
9	Riprap	1	old	49	Rock retaining wall; timber retaining wall; stairs/ladder	3	old
10	Jetty	1	degraded	50	Boat ramp; jetty; rock, timber and concrete retaining walls; stairs/ladder	~50	old & degraded
11	Jetty; timber retaining wall	2	new	51	Rock retaining wall	1	old
12	Jetty	1	old	52	Rock retaining wall; stairs/ladder	1	old
13	Jetty	1	old	53	Boat ramp	1	old
14	Jetty	1	old	54	Jetty	1	old
15	Boat ramp; concrete retaining wall; rock retaining wall	3	new	55	Boat ramp; riprap; concrete retaining wall; rock retaining wall	4	old
16	Timber retaining wall	1	old	56	Boat ramp; jetty; pontoon; concrete retaining wall; rock retaining wall	5	new & old
17	Boat ramp; rock retaining wall	2	old	57	Rock retaining wall	1	old
18	Concrete retaining wall; rock retaining wall	2	old	58	Jetty; pontoon; rock retaining wall	3	old
19	Jetty; pontoon; concrete retaining wall; timber retaining wall	3	new	59	Boat ramp; jetty; rock retaining wall; timber retaining wall	~20	new, old & degraded
20	Boat ramp; jetty	2	old	60	rock retaining wall; timber retaining wall	2	old
21	Boat ramp; timber retaining wall; rock retaining wall	3	old	61	Boat ramp; rock, timber, concrete and tyre retaining walls	~10	new & old
22	Boat ramp; rock retaining wall	2	old	62	Boat ramp; riprap; rock retaining walls	2	old
23	Boat ramp; rock retaining wall	2	old	63	Jetty; pontoon; tyre retaining wall	2	old
24	Boat ramp; rock retaining wall	2	old	64	Rock retaining wall; timber retaining wall	8	new & old
25	Rock retaining wall	1	old	65	Timber retaining wall; stairs/ladder	6	new & old
26	Jetty	1	old	66	Rock retaining wall; timber retaining wall; pontoon; stairs/ladder	~15	old & degraded
27	Boat ramp; rock retaining wall	4	new	67	Concrete retaining wall; stairs/ladder	2	old
28	Timber retaining wall; rock retaining wall; stairs	~50	old & degraded	68	Boat ramp; riprap; rock retaining wall; concrete retaining wall; stairs/ladder	~15	old
29	Boat ramp; timber retaining wall; stairs/ladder	~15	old	69	Jetty; rock retaining wall	2	old
30	Boat ramp; rock retaining wall	~20	old	70	Jetty	2	old
31	Boat ramp; rock retaining wall	4	new	71	Jetty; pontoon; concrete retaining wall	4	old
32	Pontoon; rock retaining wall	2	old & degraded	72	Boat ramp; jetty; pontoon; timber retaining wall	2	old
33	Boat ramp; rock retaining wall	2	old	73	Boat ramp; jetty; pontoon; gabion; rock, timber, concrete retaining walls	~50	old
34	Boat ramp; rock retaining wall	2	new	74	Jetty; pontoon; rock retaining wall	3	old
35	Boat ramp; rock retaining wall; timber retaining wall; pontoon; stairs	~25	old	75	Jetty; concrete retaining wall; rock retaining wall	~30	new & old
36	Boat ramp; rock retaining wall	2	old	76	Jetty; pontoon; rock retaining wall	3	new
37	Boat ramp; rock retaining wall	2	old	77	Jetty	1	old
38	Boat ramp; jetty; timber retaining wall; stairs/ladders	~18	old	78	Jetty	1	old
39	Boat ramp; rock retaining wall	2	old	79	Jetty	1	old
40	Jetty	1	degraded				



Legend

Cadastre

Group of Structures

Creeks & Rivers

Individual Structure

Title:

Baseline Mapping of Foreshore Structures in Zone A

Figure: **3-5**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

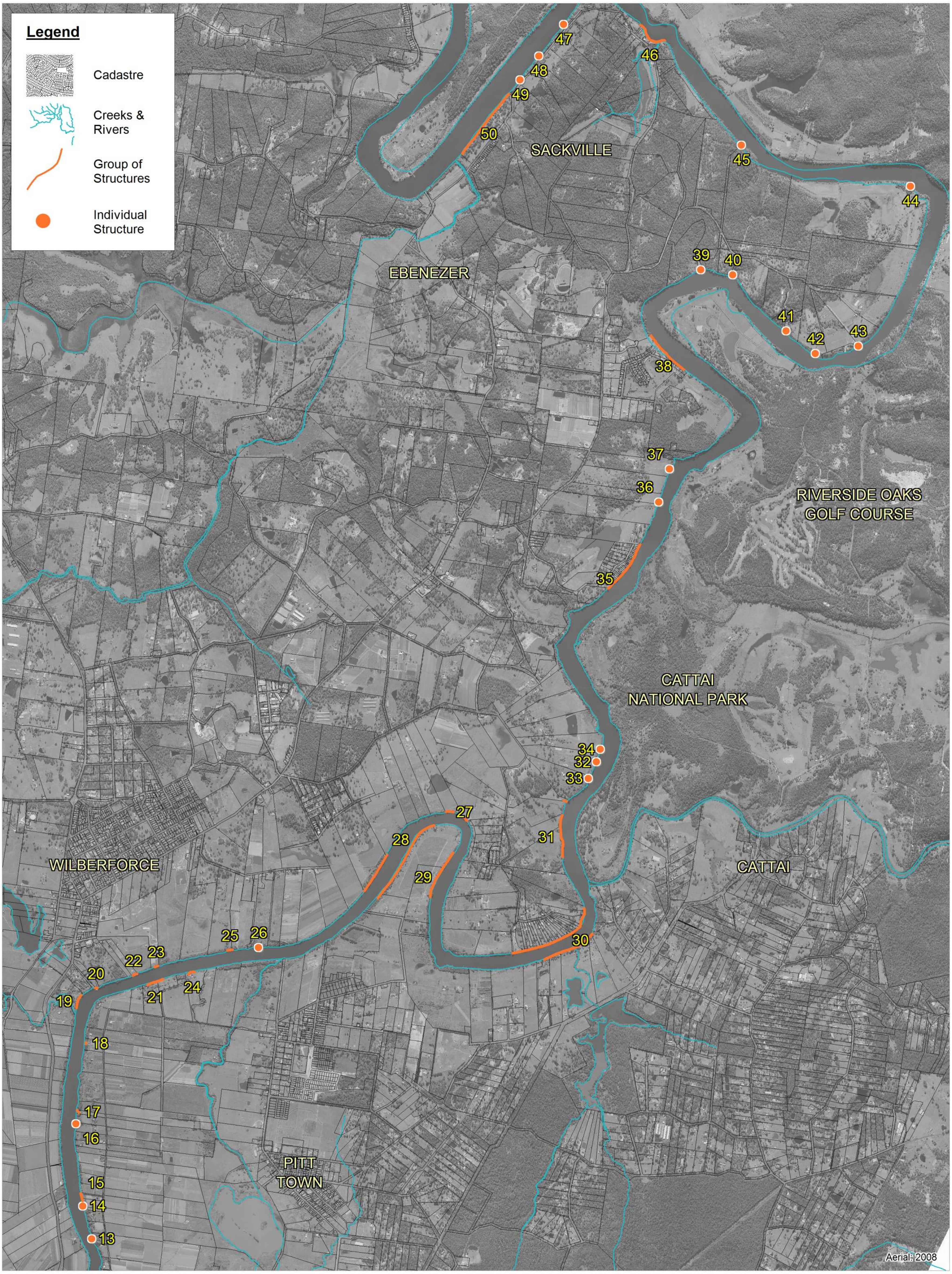
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_006_130821_ForeshoreStructures_Zone A.WOR



Title:

Baseline Mapping of Foreshore Structures in Zone B

Figure: 3-6

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

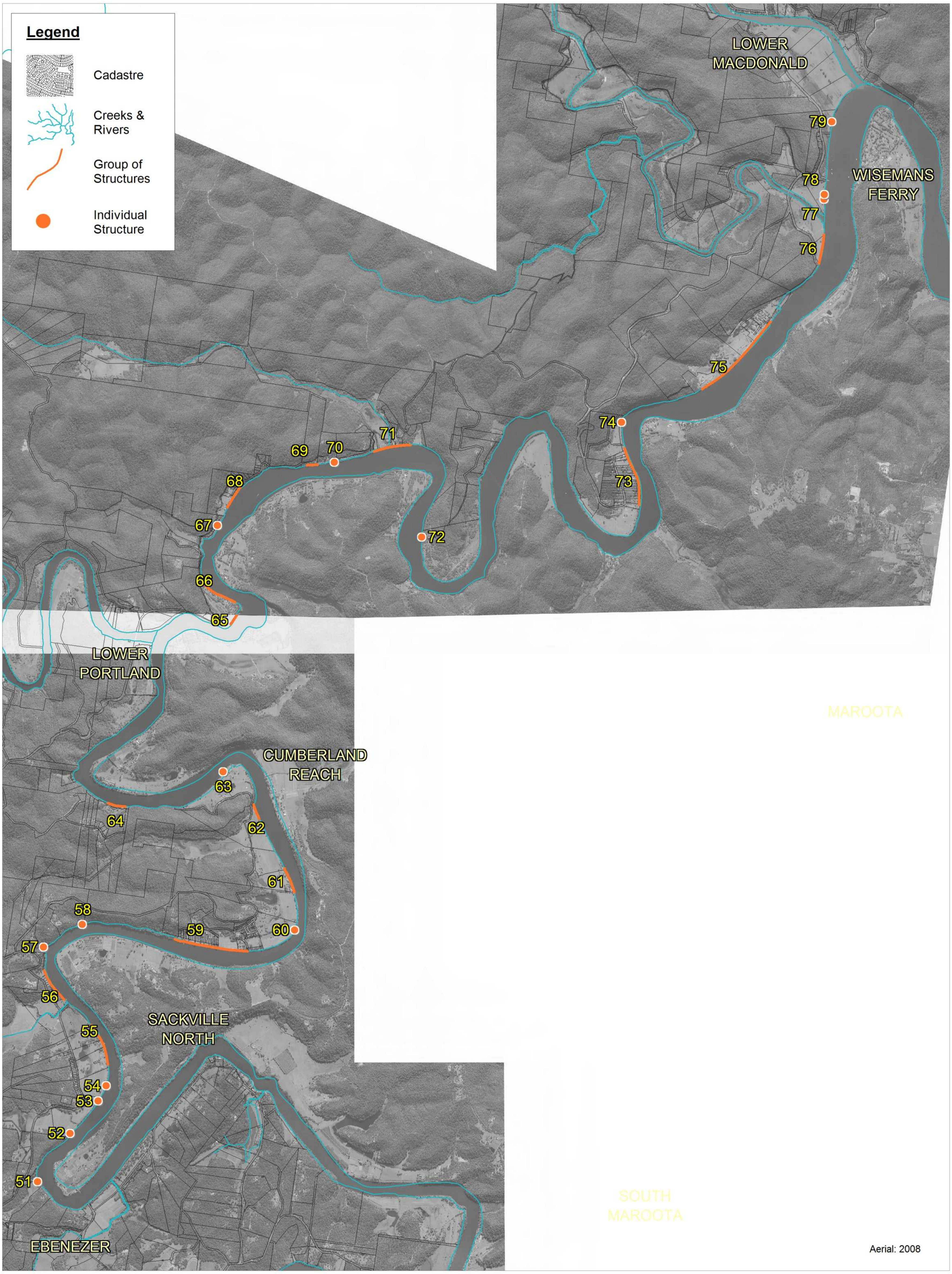
N

0 0.75 1.5km

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_007_130821_ForeshoreStructures_Zone B.WOR



Title:

Baseline Mapping of Foreshore Structures in Zone C

Figure: 3-7

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 1 2km

Approx. Scale

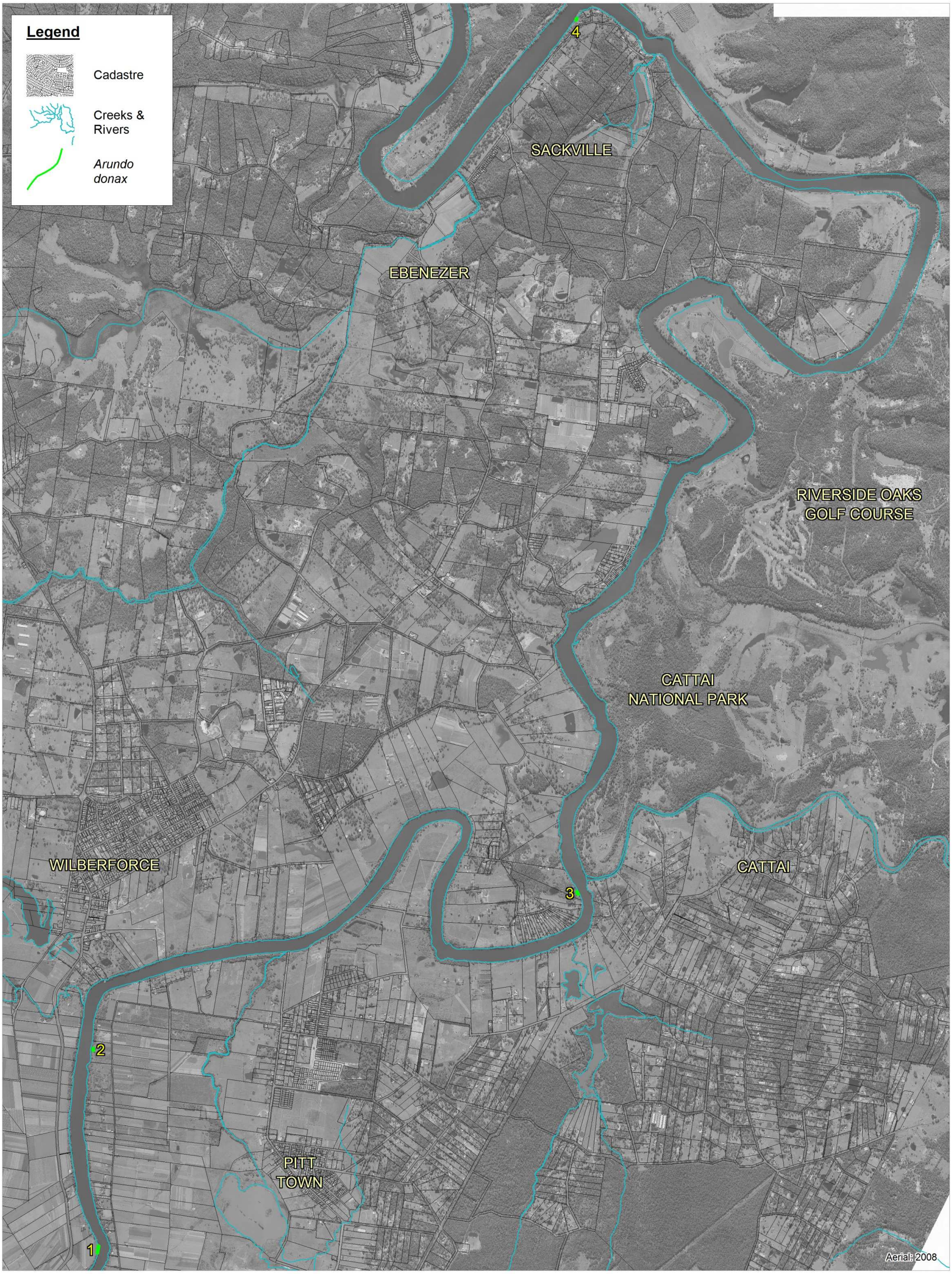
BMT WBM

www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_008_130821_ForeshoreStructures_Zone C.WOR

Table 3-4 Baseline Map Data (*Arundo*)

ID	*Density of Growth (%)*	*Comments*
1	55	Along western river bank
2	100	Along eastern river bank
3	100	Along western river bank
4	100	Small patch; mixture of weeds surrounding including Bamboo, Lantana, Balloon Vine
5	100	Small patch at downstream end of Pondarosa Ski Resort
6	15	Western river bank downstream of the Colo River confluence
7	70	Long segment of western river bank infested
8	90	Small dense patch
9	25	Widespread; mixed with Bamboo
10	40	Small patch; Lantana also present
11	25	Three large patches with Lantana present
12	100	
13	100	Small patch
14	50	Two large patches
15	30	Two patches – one small and the other larger



Title:
Baseline Mapping of Arundo in Zone B

Figure: **3-8**

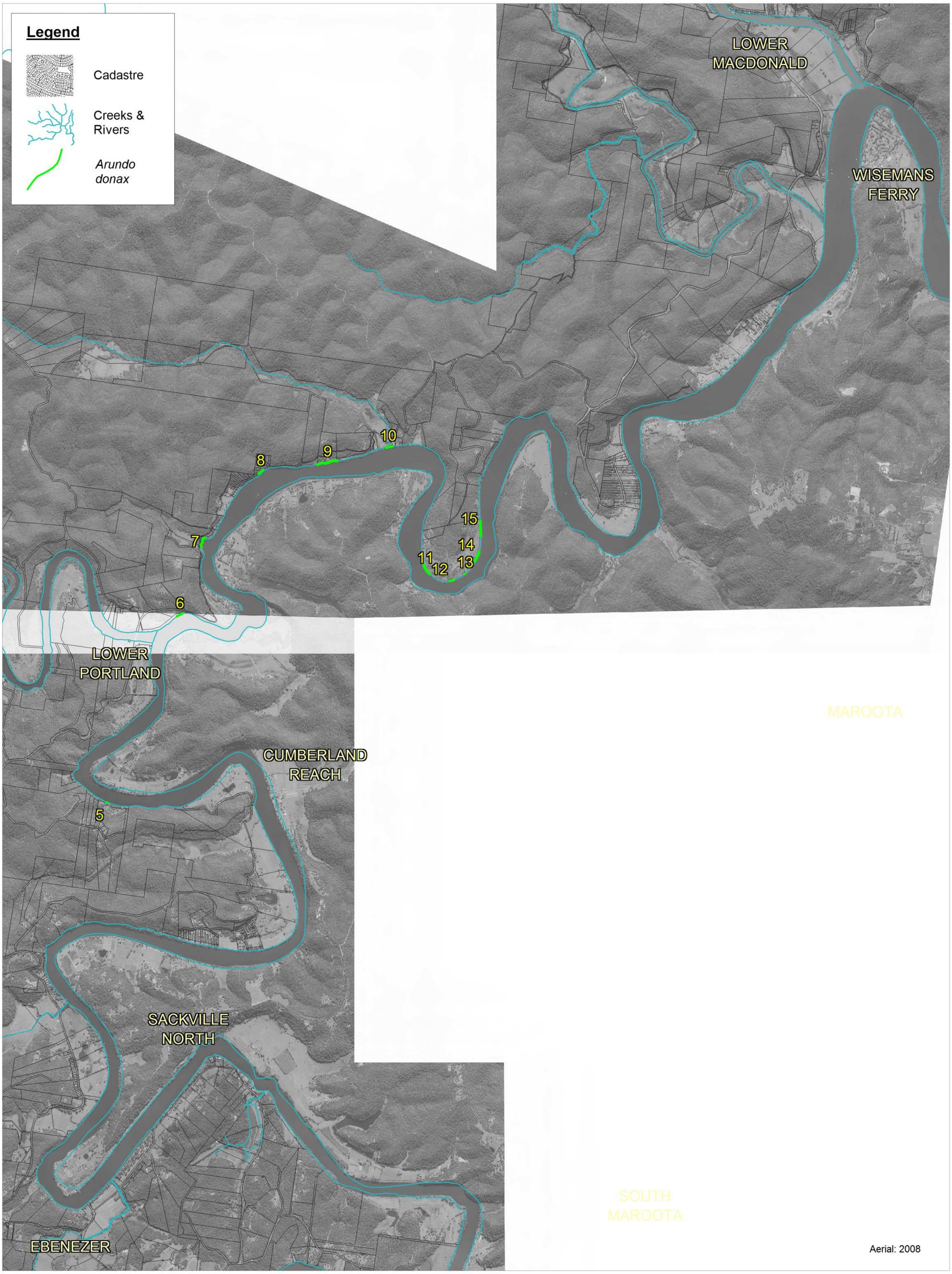
Rev: **A**

N

0 0.75 1.5km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_009_130822_Arundo_Zone B.WOR



Title:

Baseline Mapping of Arundo in Zone C

Figure: **3-9**

Rev: **A**

N

0 1 2km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_010_130822_Arundo_Zone C.WOR

4 Analysis of Data

4.1 Overview

The following analysis of data is based on a preliminary, high-level study that provides broad guidance on key data gaps identified during the preparation of the CZMP.

Data presented in the baseline maps (refer Section 3) which show the location and extent of bank erosion, foreshore structures and *Arundo* in the study area have been summarised to provide insight and extract further information that may be of use to the CZMP.

Tables, pie charts and thematic maps are presented to summarise data collated for bank erosion, foreshore structures and *Arundo*. Thematic maps have been prepared to assist with illustrating the spatial relationships that exist between bank erosion categories and the location of the bank erosion sites in the study area.

4.2 Bank Erosion

4.2.1 Summary data

Bank erosion was observed in all study area zones. A summary of bank erosion data is presented in Table 4-1, which shows the length of riverbank mapped, the number of bank erosion sites, the total length of bank erosion and the average length of bank erosion per km of riverbank.

Table 4-1 Summary of Bank Erosion Data

Locality	*Length of Riverbank Mapped (km)*	*Number of Bank Erosion Sites*	*Length of Bank Erosion (m)*		*Average Length of Bank Erosion per km of Riverbank (m)*
			Total	*Average*	
A	34.72[1]	17	2344	138	68
B	39.25[2]	17	2809	165	72
C	34.58[3]	10	4229	423	122
Overall	108.55	44	9382	213	86

[1] includes riverbank on both sides of the river
[2] includes riverbank on both sides of river upstream of Cattai Creek only
[3] includes riverbank on the western side of the river only

The summary results above show that the total length of riverbank erosion is approximately 9.4 km. In Zone A and Zone B, the total number of bank erosion sites observed was 17 each and the total length of bank erosion was similar, i.e. 2.3 km and 2.8 km respectively. On average, the length of bank erosion in Zone A and Zone B was 138 metres and 165 metres respectively, which equates to an average length of erosion (per km of riverbank) of about 70 m in both zones.

In Zone C, the number of bank erosion sites was less than Zone A and Zone B (i.e. 10 compared with 17) however the total length of bank erosion was greater (approximately 4.2 km). The average length of bank erosion in Zone C was approximately three times greater than Zone A and 2.6 times greater than Zone B, and the average length of erosion (per km of riverbank) is about 120 metres.

Overall, bank erosion in Zone C accounts for almost half of the total length of river bank erosion observed in the study area. This result indicates that large segments of riverbank are eroding at fewer sites when compared to results obtained for Zone A and Zone B (which both have shorter segment of bank erosion but at a greater number of locations).

4.2.2 Break-up by category

The summary of bank erosion data above provides information relating to the number of bank erosion sites and the average length of riverbank each occupies in each study area zone. The following section provides further information relating to the categories (attribute data) assigned to each bank erosion site during field data collection. Pie charts are used to show the number of occurrences of each category in the study zones (Zone A, Zone B and Zone C) as a well as the study area wide (overall) breakup.

Categories relevant to bank erosion are presented below and include:

- Erosion class (i.e. high, moderate, low) (refer Figure 4-1);
- Bank slope (i.e. vertical, steep, moderate) (refer Figure 4-2);
- Adjacent land use (i.e. bushland, ski park, turf farm, residential, farmland, public open space) (refer Figure 4-3);
- Vegetation condition (i.e. natural, mixed, cleared, absent) (refer Figure 4-4); and
- Vegetation value (i.e. high, moderate, low) (refer Figure 4-5).

Overall, the results show that the erosion class assigned to the majority of bank erosion sites was considered to be high (55%) or moderate (43%). In Zone A and Zone B, the erosion class was high for 50% and 65% of the erosion sites respectively. In Zone C, a single site was identified to have a low erosion class with the remaining nine sites assigned a moderate (50% of sites) or high (40% of sites) erosion class.

Overall, about 85% of erosions sites were considered to be vertical or steep with the remainder classified as moderate. Bank slope in Zone A was mostly steep (59%) with some moderate slopes (29%) and vertical banks (12%) also present. Results for Zone B are similar to those obtained for Zone A although there were a greater proportion of vertical banks than moderate slopes. Bank slope for erosion sites in Zone C was either vertical (70%) or steep (30%).

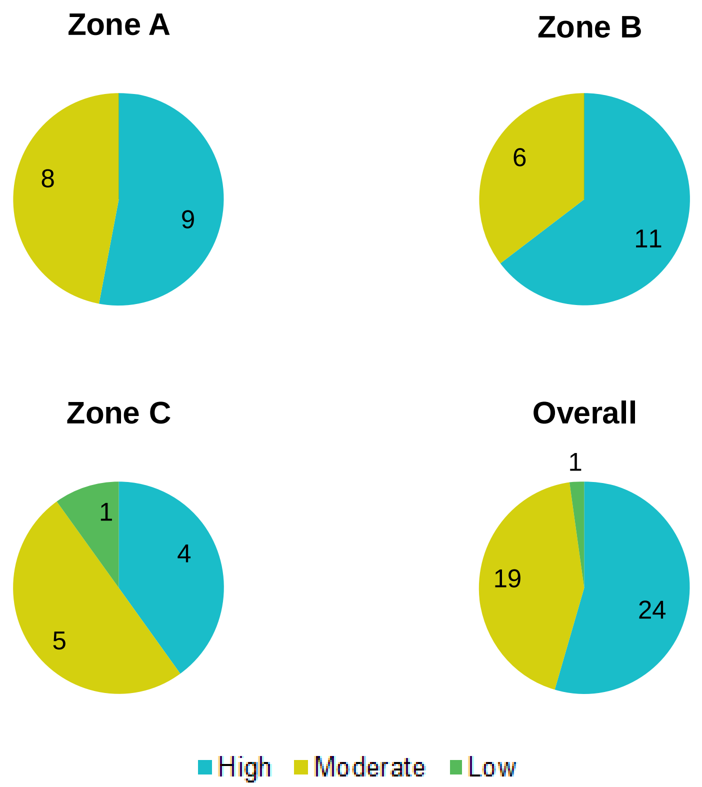


Figure 4-1 Break-up of Sites by Erosion Class

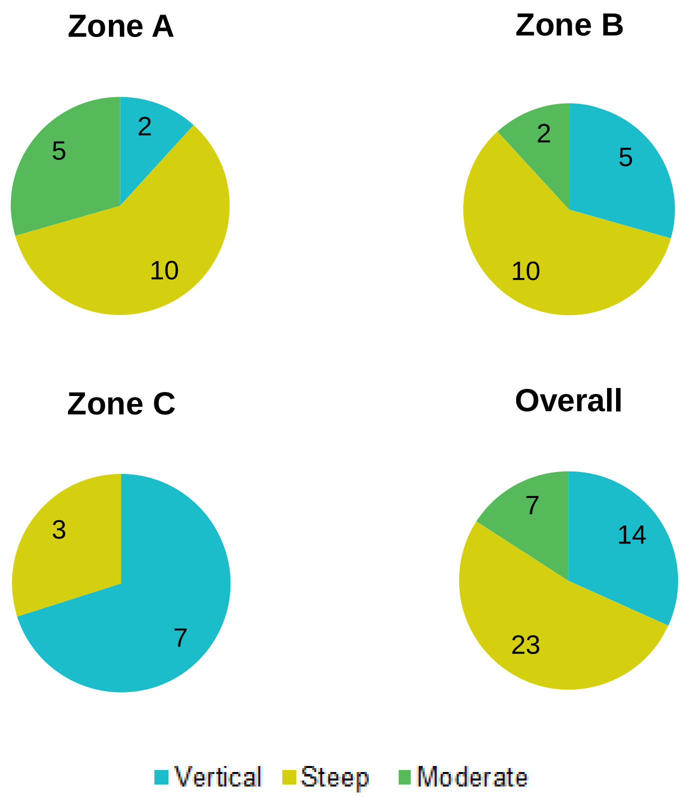


Figure 4-2 Break-up of Sites by Bank Slope

The break-up of erosion sites based on adjacent land use shows that overall residential, farmland and public open space are most common (36%, 27% and 18% respectively). Bushland, ski parks and turf farms account for the remainder (~18%) of bank erosion sites identified in the study area. In Zone A, public open space and residential land use is most common (71%) with turf farms and other farmland present at the remaining bank erosion sites. In Zone B, the majority of bank erosion was located near residential (59%) and farming (29%) land use. The remaining bank erosion sites occurred near bushland and a ski park. In Zone C, bank erosion is situated mostly near farmland (50%) and ski parks (30%) with the remaining sites (20%) adjacent to residential and public open space areas.

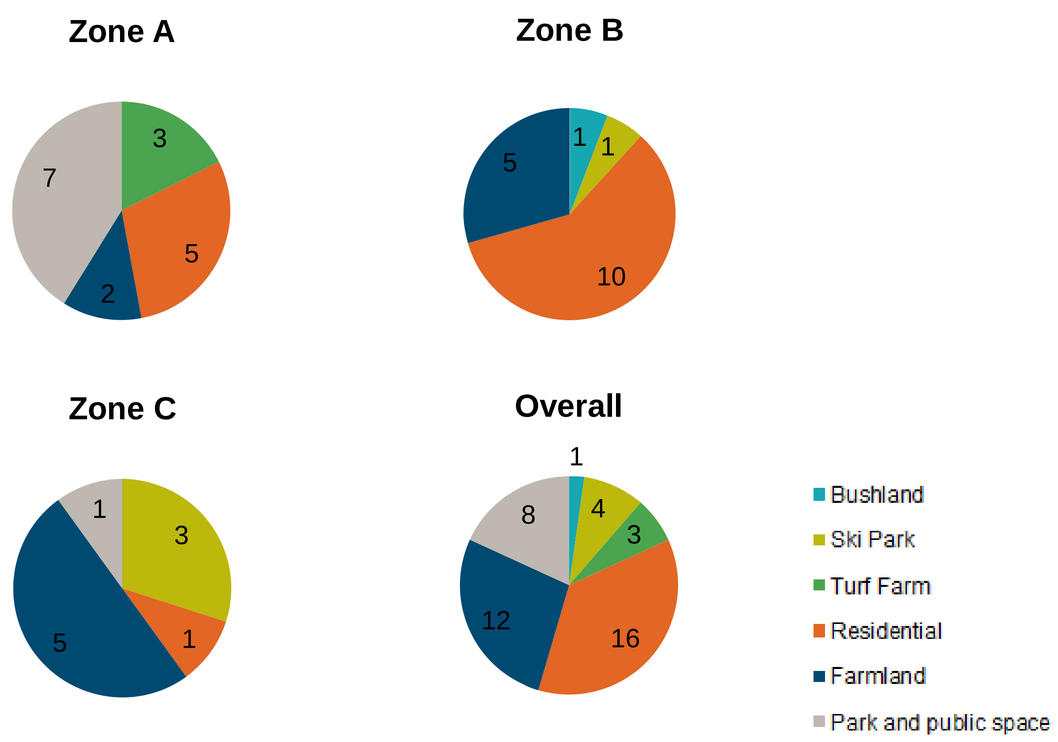


Figure 4-3 Break-up of Sites by Adjacent Land Use

The break-up of bank erosion sites based on the condition of riparian vegetation shows that across the study area vegetation is mostly cleared (39%) or absent (34%) from the riverbank. Approximately 20% of bank erosion sites included remnant vegetation including a mixture of native trees, shrubs and weeds. Only 7% of bank erosion sites were observed with natural riparian vegetation that has not been cleared or infested with terrestrial weeds. The results also show that the break-up of bank erosion sites based on the condition of riparian vegetation was similar in all three study zones. Absent or cleared vegetation was common (70% or more bank erosion sites) with the remainder of sites containing mixed and in a few cases natural (undisturbed) riparian vegetation. The condition of riparian vegetation and its value (or importance) is closely related to one another. Riparian vegetation at the majority of bank erosion sites in the study area was low (64%) or insignificant (20%) corresponding to vegetation being cleared / absent. Consequently, only a few riparian vegetation sites were considered to have a moderate or high value where natural or mixed vegetation were present (e.g. Zone A and Zone B).

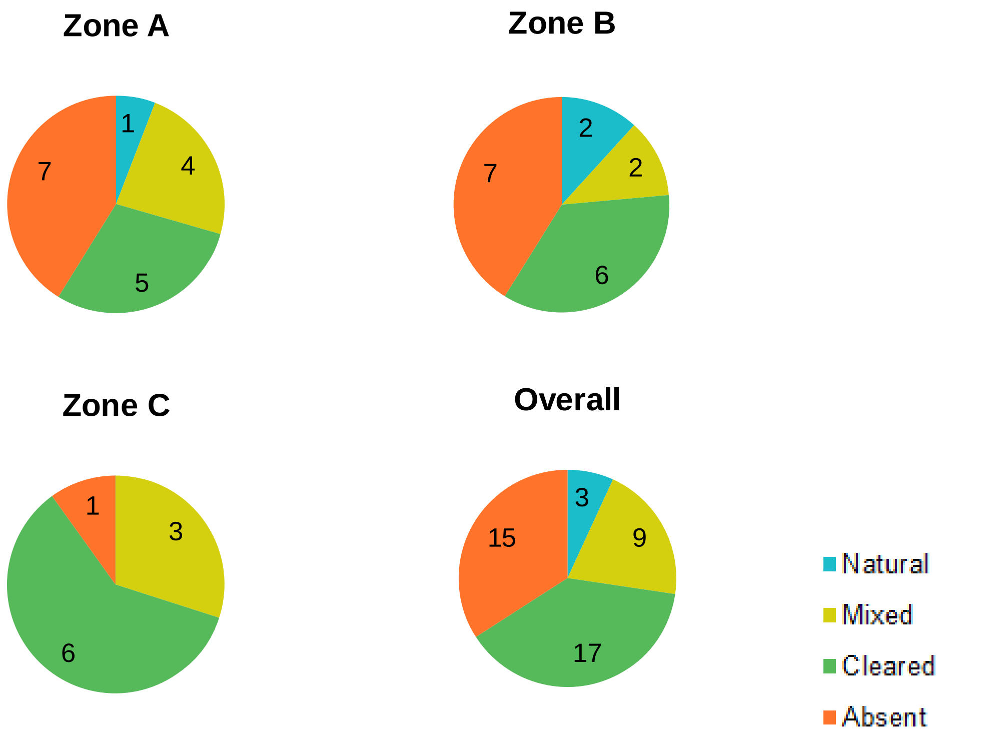


Figure 4-4 Break-up of Erosion by Condition of Riparian Vegetation

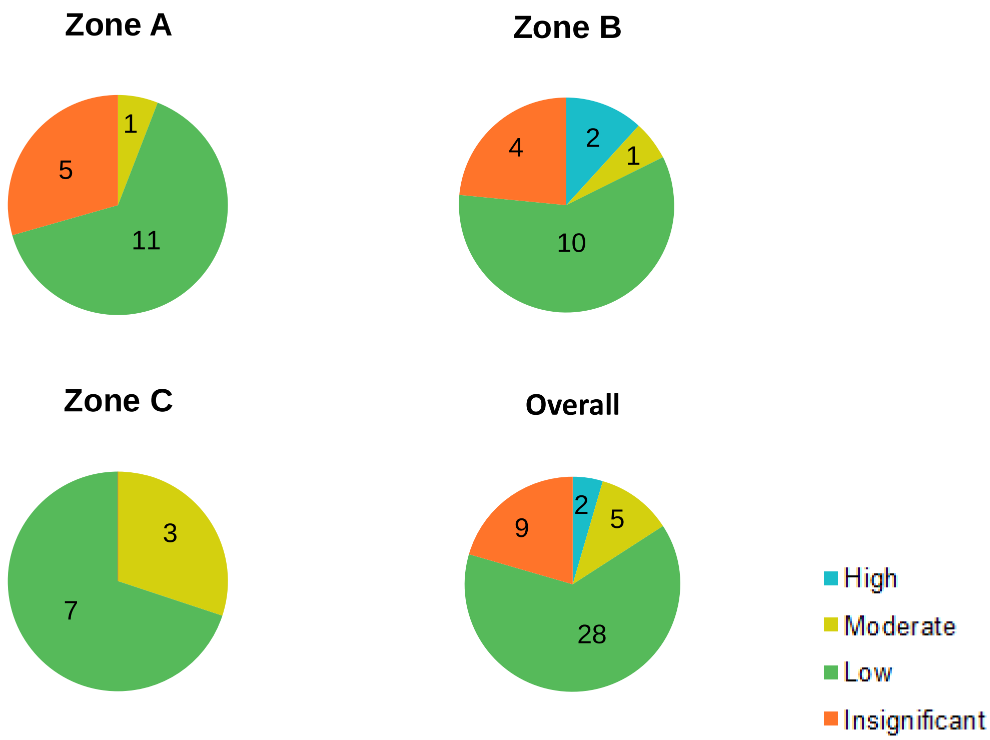


Figure 4-5 Break-up of Sites by Value of Riparian Vegetation

4.2.3 Thematic maps

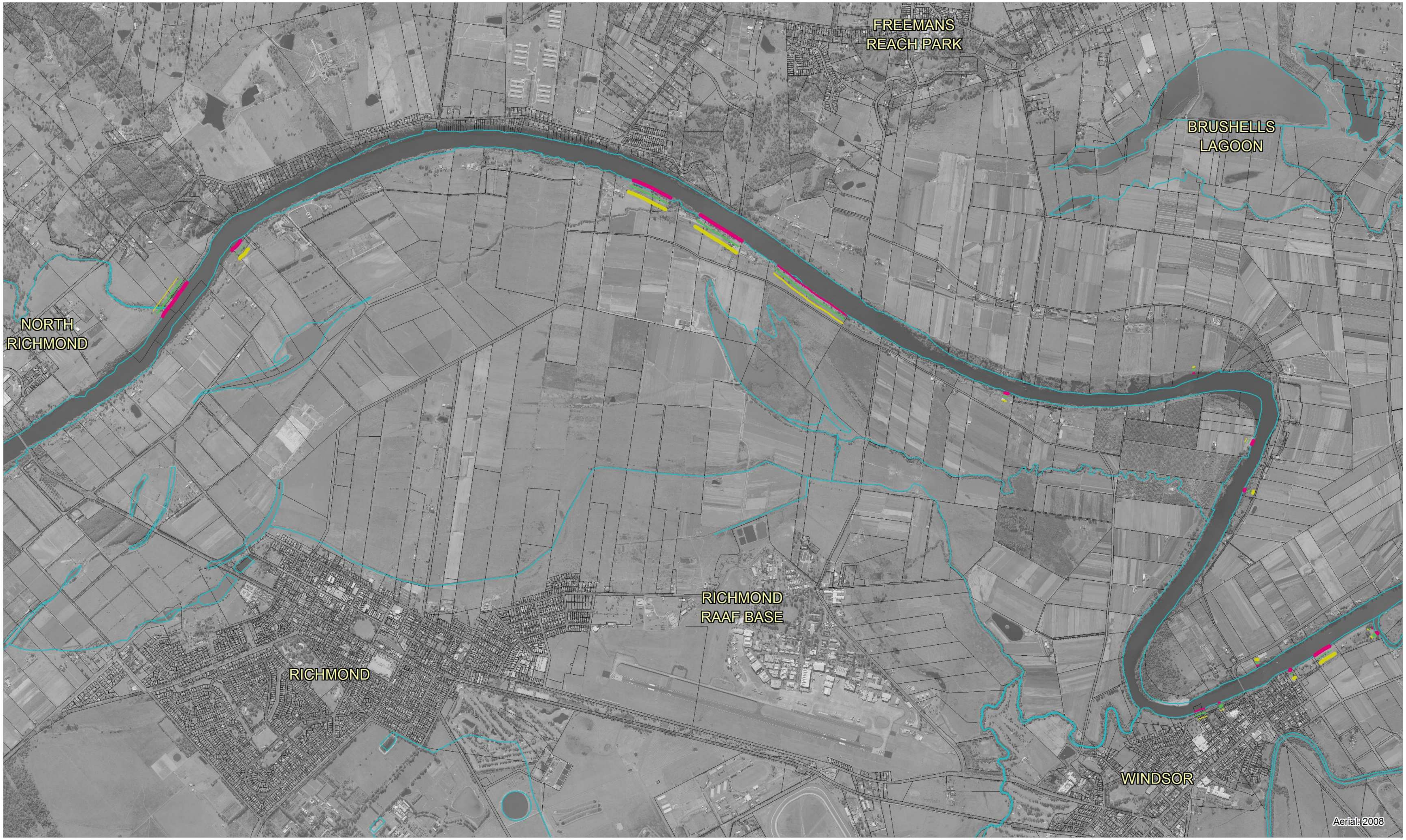
The break-up of bank erosion sites is presented below in a series of thematic maps, which show the association between related categories (e.g. erosion class, bank slope, vegetation condition) in each study area zone. Maps for Zone A, Zone B and Zone C are shown in Figure 4-6, Figure 4-7 and Figure 4-8 respectively.

Just like the baseline maps, polylines have been used to define continuous segments of the river bank where bank erosion were observed. Each map shows three coloured lines at each bank erosion site corresponding to the erosion class (red), bank slope (green) and vegetation condition (yellow). Line thickness was assigned so that 'hot spot' bank erosion sites with active erosion, steep banks and little or no vegetation are shown as bold lines which are easily identifiable. Conversely, sites where bank erosion and slope was less, and/or vegetation was well defined appear as thin lines and are therefore comparatively less prominent.

The maps below show notable areas of bank erosion in all three study area zone, which are often clustered in proximity to one another or near tight bends or segments of the river that meander. Notable areas of 'hot-spot' bank erosion occur:

- Along Freemans Reach in Area A;
- Along the segment of river between Wilberforce and Cattai Creek, opposite Riverside Oaks Golf Course and upstream of Sackville Ferry in Area B; and
- Along the Cumberland Reach and downstream of the Colo River in Area C.

Bank erosion frequently coincides along riverbanks where vegetation is cleared or absent (see Figure 4-9a). Instances where the bank erosion class is high or moderate but vegetation is well established (mixed or native) are evident however such cases are localised and most likely caused by flooding in the study area (refer Figure 4-9b). Sites where bank erosion has occurred in the past but riparian vegetation has since been established as a result of riverbank restoration projects were also observed (refer Figure 4-9c).



Legend

Cadastre

Creeks & Rivers

Erosion Class		Bank Slope		Vegetation Type	
High	(9)	Vertical	(2)	Absent	(7)
Moderate	(8)	Steep	(10)	Cleared	(5)
		Moderate	(5)	Mixed	(4)
				Natural	(1)

Title:
Thematic Mapping of Bank Erosion in Zone A

Figure: **4-6**

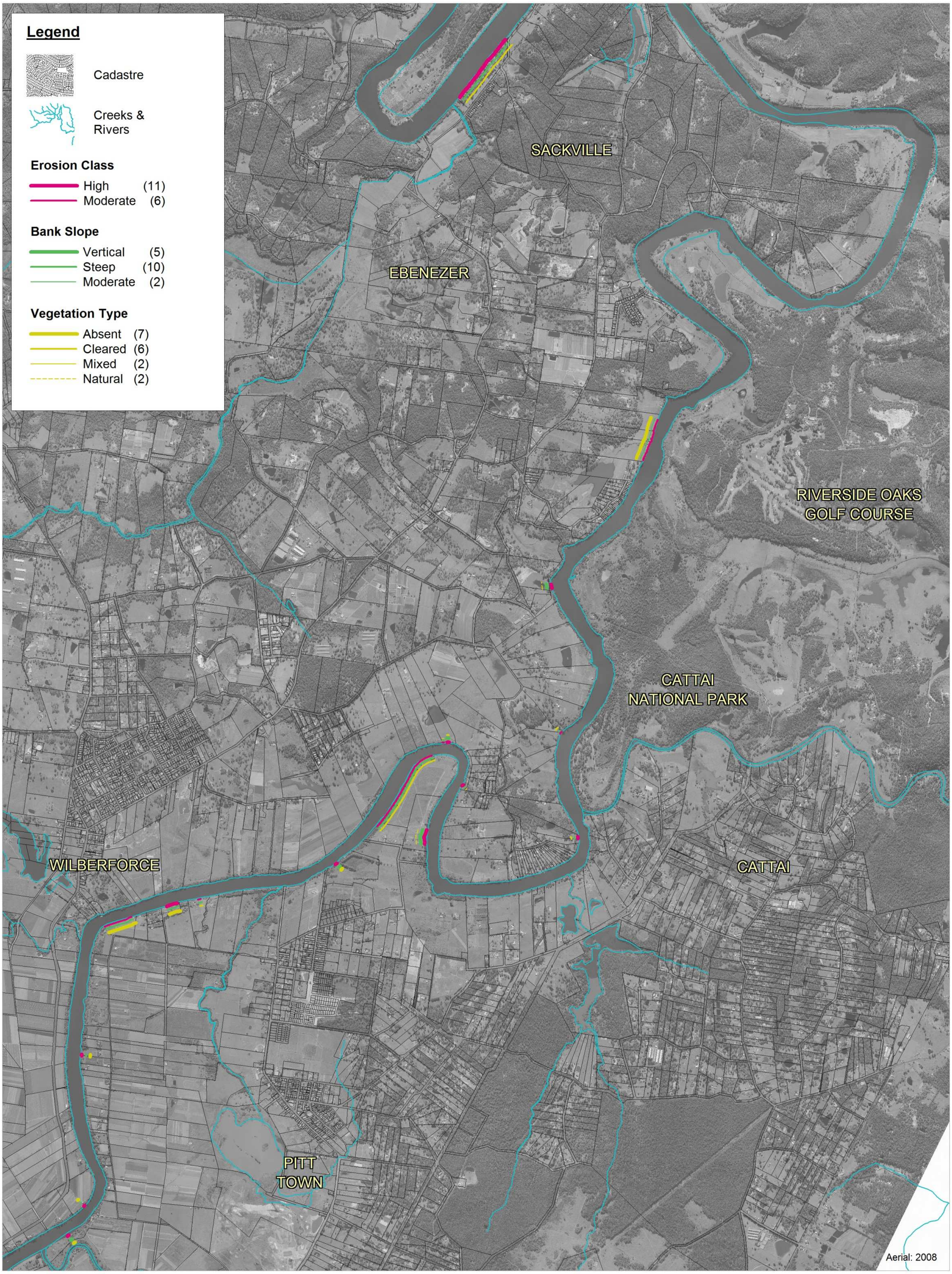
Rev: **A**

N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_011_130902_BankErosion_Zone A _Thematic.WOR



Title:

Thematic Mapping of Bank Erosion in Zone B

Figure: 4-7

Rev: A

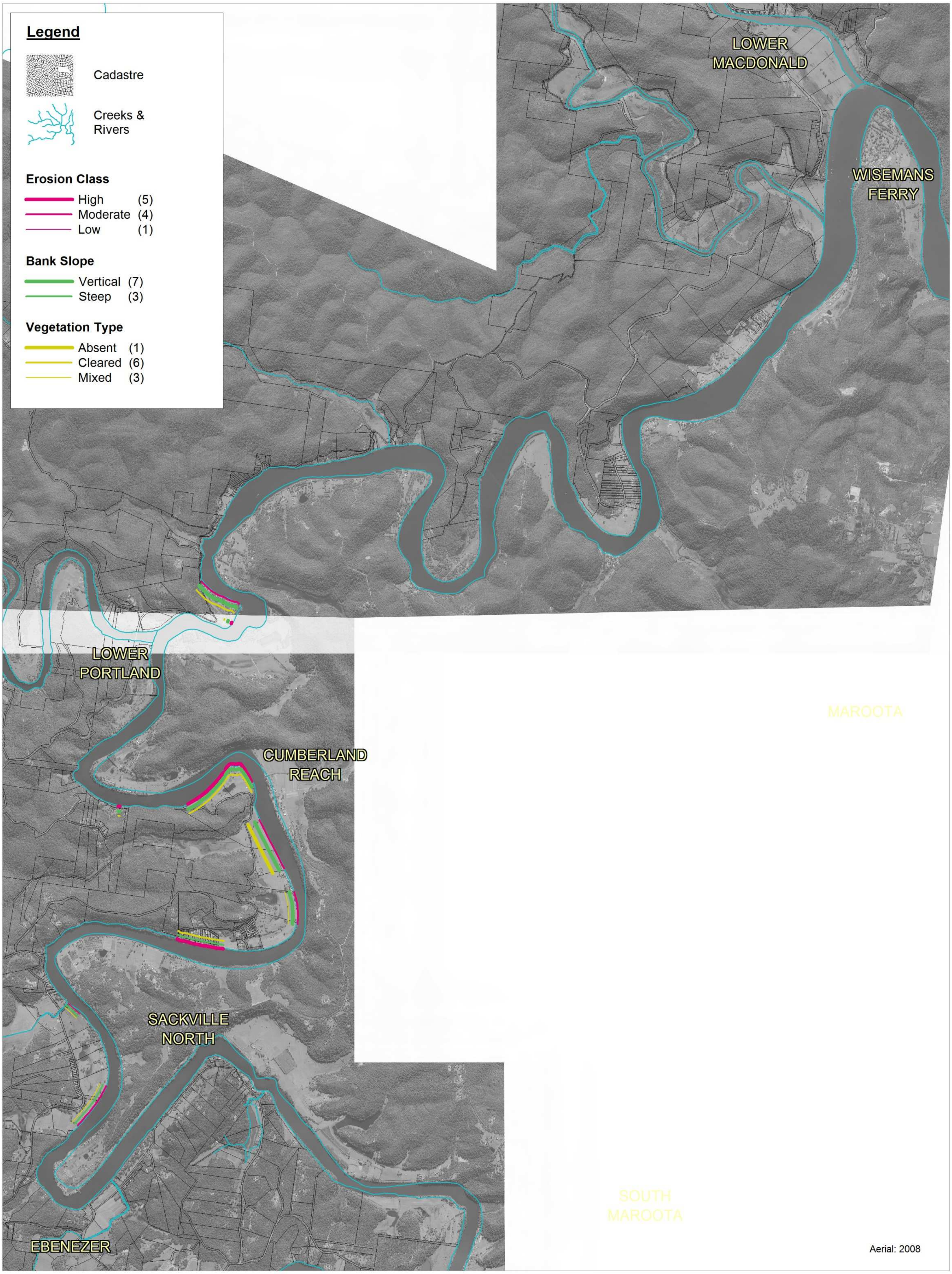
N

0 0.75 1.5km

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_012_130902_BankErosion_Zone B _Thematic.WOR



Title:

Thematic Mapping of Bank Erosion in Zone C

Figure: **4-8**

Rev: **A**

N

0 1 2km

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : K:\N20133_HawkesburyRiverForeshoreErosion&StructureMapping\MI\Workspaces\Figures\DRG_013_130902_BankErosion_Zone C_Thematic.WOR

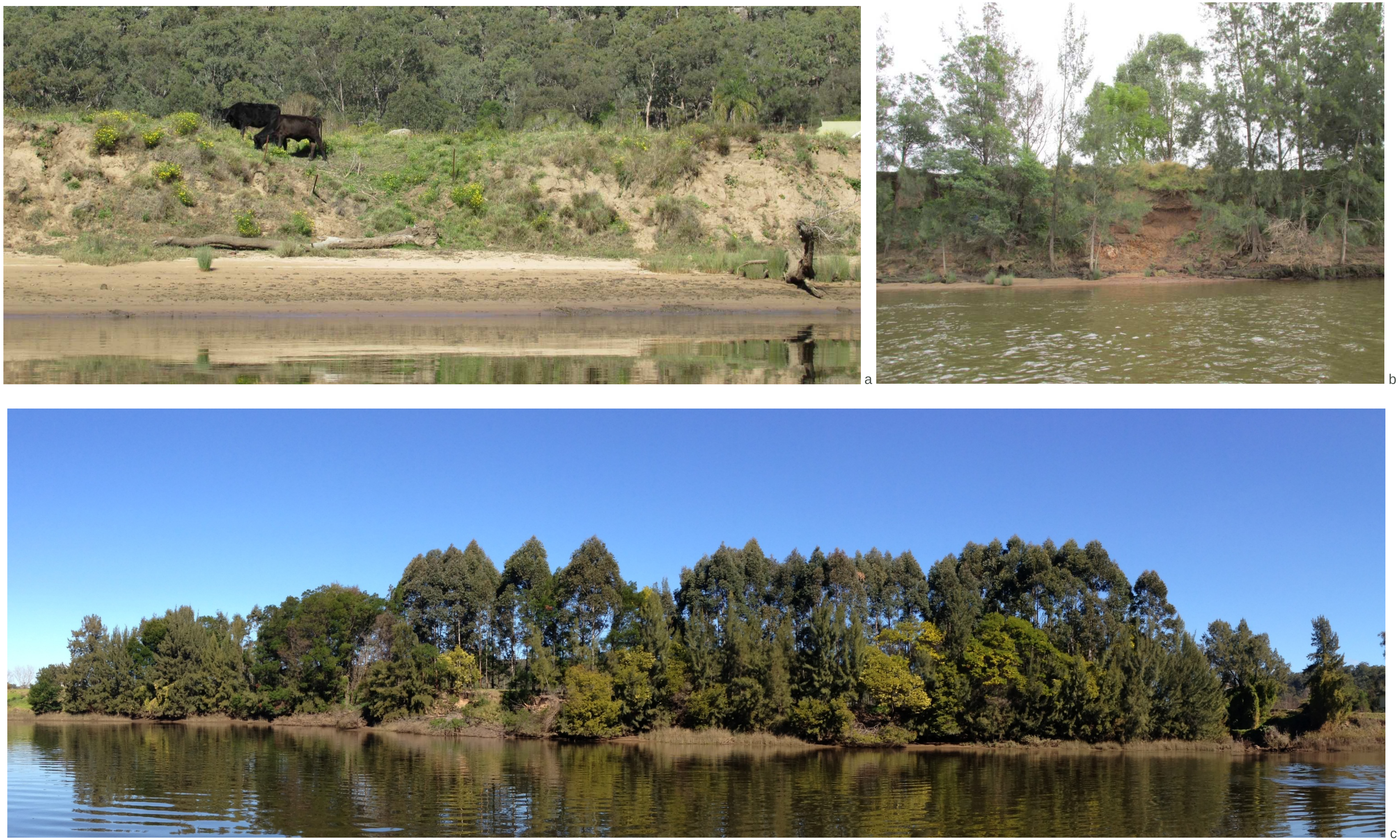


Figure 4-9 Examples Bank Erosion Sites (a) vegetation absent (b) after flooding (c) riverbank restoration

4.3 Foreshore Structures

4.3.1 Summary data

Foreshore structures were observed in all study area zones. A summary of foreshore structure data is presented in Table 4-2, which shows the length of riverbank mapped, the approximate number of foreshore structures recorded and the number of structures per kilometre of riverbank.

Table 4-2 Summary of Foreshore Structure Data

Locality	*Length of Riverbank Mapped (km)*	*Approximate Number of Structures Recorded*	*Approximate Number of Structures per km of Riverbank*
A	34.72[1]	17	0.5
B	39.25[2]	265	6.8
C	34.58[3]	193	5.6
Overall	108.55	475	4.4

[1] includes riverbank on both sides of the river
[2] includes riverbank on both sides of river upstream of Cattai Creek only
[3] includes riverbank on the western side of the river only

The summary results above show that almost 500 structures were observed and that on average, the study area contains between 4 and 5 structures per kilometre of riverbank. In Zone A, the number of foreshore structures observed was 17 or about 1 structure per km of river. In Zone B and Zone C, the number of structures was considerably greater (265 and 193 structures respectively), which equates to about 6 or 7 structures per kilometre of riverbank.

Overall, the number of structures in Zone A is negligible when compared Zone B and Zone C. Structures in Zone B account for more than half (56%) of the total number of structures observed in study area, and when combined, Zone B and Zone C encompass 96% of foreshore structures estimated in the study area.

4.3.2 Break-up by category

The summary of foreshore structure data above provides information relating to the number of structures in each study area zone. The following section provides further information relating to the categories assigned to each structure (or group of structures) during field data collection. Pie charts are used to show the frequency of each category in the study zones (Zone A, Zone B and Zone C) as a well as the study area wide (overall) breakup.

Categories relevant to foreshore structures are presented below and include:

- Structure type (e.g. jetty, pontoon, boat ramp, gabion, rock protection, retaining wall) (refer Figure 4-10);
- Retaining wall material (i.e. timber, rock, concrete, tyre) (refer Figure 4-11); and
- Structure condition (i.e. new, old or degraded) (refer Figure 4-12).

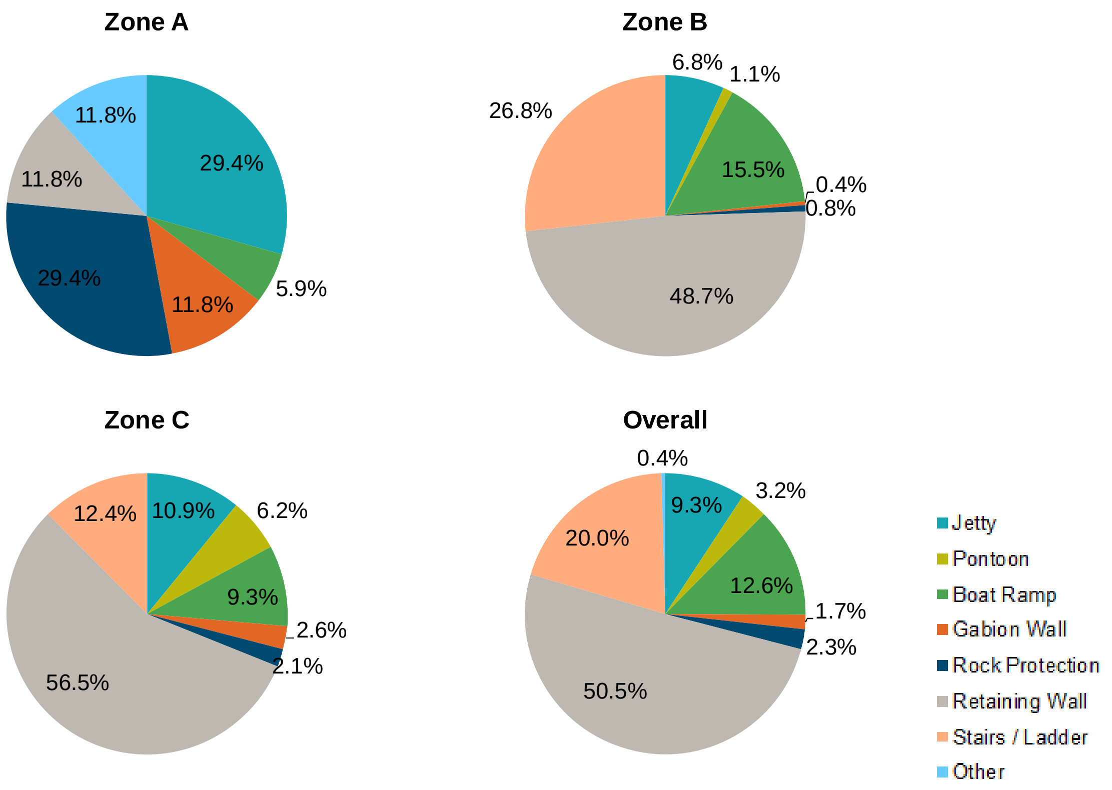


Figure 4-10 Break-up of Structures by Type

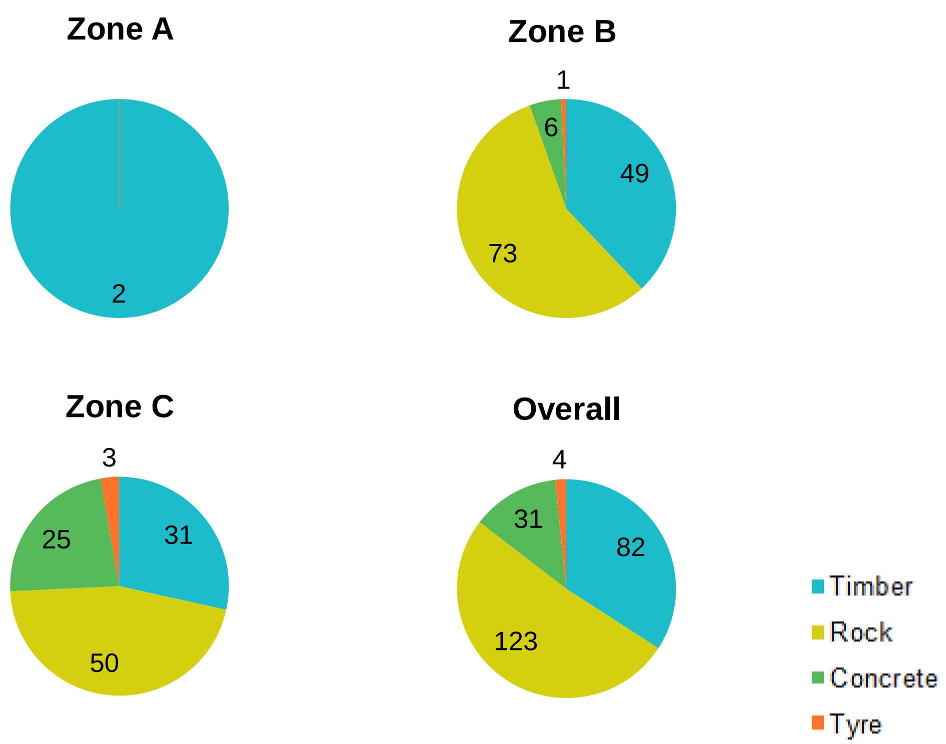


Figure 4-11 Break-up Retaining Walls by Material Type

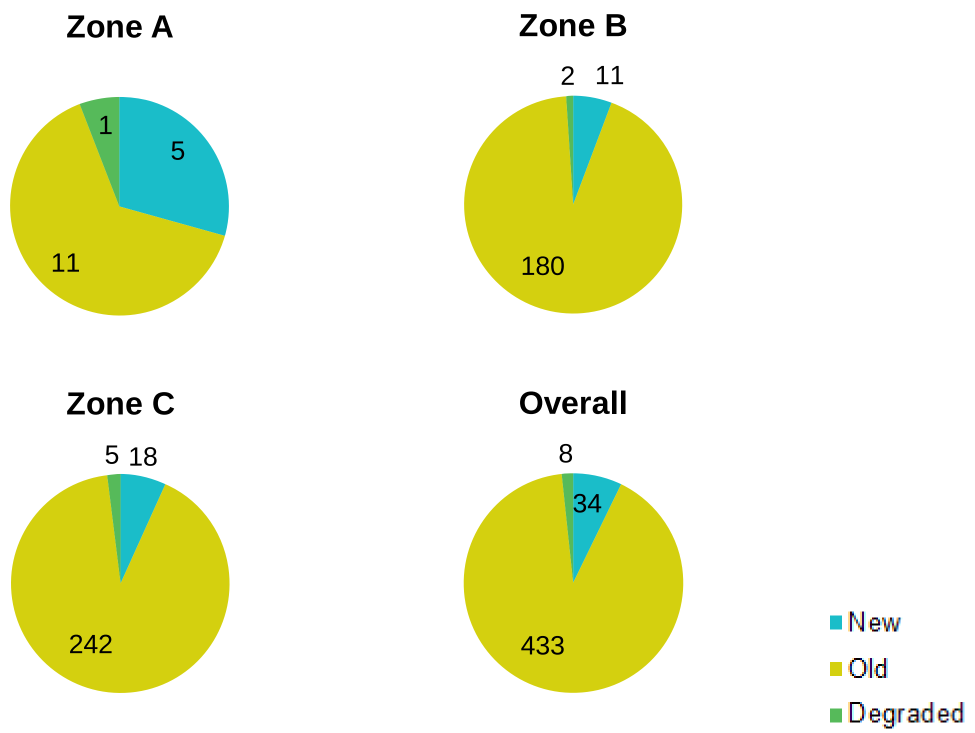


Figure 4-12 Break-up of Structures by Condition

Overall, the results show that retaining walls are the most common structure type in the study area accounting for approximately 50% of all structures followed by stairs/ladders (20%), boat ramps (12.6%) and jetties (9.3%). Pontoons (3.2%), rock protection (2.3%) and gabion walls (1.7%) are the least common structures across the study area on the whole. In general, this break-up is consistent for Zone B and Zone C as the majority of structures in the study area are situated one of these two regions. However, in Zone A, the break-up of structure types is notably different from Zone B and Zone C with rock protection and jetties combined accounting for 60% of the structures. Gabion walls, retaining walls and boat ramps made up the remainder of structures observed. Stairs / ladders and pontoons were not observed in Area A.

Retaining walls are the most common structure type observed in the study area (particularly downstream of Windsor). The break-up of retaining walls by material type reveals that rock (e.g. sandstone) is most common (51%) followed by timber (34%), concrete (13%) and then tyre (<2%). In general, this break-up is consistent for Zone B and Zone C although when comparing between these two zones, rock retaining walls were observed more frequently in Zone B and concrete retaining walls in Zone C.

The condition for the overwhelming majority (91%) of structures observed is old (assumed to be installed more than 3 years ago). A few new structures (7% overall) and degraded structures (<2% overall) were observed in the study area.

4.4 Arundo

Arundo was observed in Zone B and Zone C only (i.e. Zone A was not included in the field assessment). A summary of data collected for these two zones is presented in Table 4-3, which shows the length of riverbank mapped, the total number of *Arundo* sites recorded, the equivalent length of riverbank with *Arundo* (based on recorded density of growth) and the percentage of riverbank with *Arundo* over the length of riverbank.

Table 4-3 Summary of *Arundo* Site Data

Locality	Length of Riverbank Mapped (km)	Number of Arundo Sites	Length of Riverbank with Arundo (m)	Equivalent Length of Riverbank (Length*Density) (m)	Approximate Percentage of Riverbank length with Arundo (%)
B	39.25[1]	4	136	105	0.3
C	34.58[2]	11	1202	515	1.5
Overall	73.83	15	1338	620	0.8

[1] includes riverbank on both sides of river upstream of Cattai Creek only
[2] includes riverbank on the western side of the river only

The summary results above show that the total length of riverbank colonised by *Arundo* is approximately 1.3 km. In Zone B, the length of riverbank with *Arundo* is about 140 metres with the remainder (1200 metres) located between Sackville and Wisemans Ferry (Zone C). The average length of riverbank colonised by *Arundo* is approximately 25 metres, whereas in Zone C, the average length is almost 50 metres. The equivalent length of riverbank colonised by *Arundo* is also greater (about 5 times) in Zone C than Zone B.

The approximate density of growth for each *Arundo* sighting is shown in Figure 4-13. The chart shows that dense continuous patches of *Arundo* cover up to 50 metres of riverbank at some locations although patches of less than 30 metres are more common. Depending on the degree of establishment, the average density of growth along a segment of riverbank can vary considerably. The density of growth for *Arundo* sighted between longer segments of riverbank (i.e. between 100 metres and 300 metres) was estimated between 20% and 70%. This result suggests that colonisation tends to be clustered and present as a series of patches that gradually disperse along the riverbank and join up with one another to form a continuous dense patch.

Overall, the majority of *Arundo* sightings occur in Zone C and downstream of the Colo River which is also significantly colonised by this weed. *Arundo* has colonised less than 1% of the riverbank length in Zone B and Zone C which is small, however, this represents more than 600 metres of riverbank that would need to be managed across 15 sites with variable weed growth/establishment and site access.

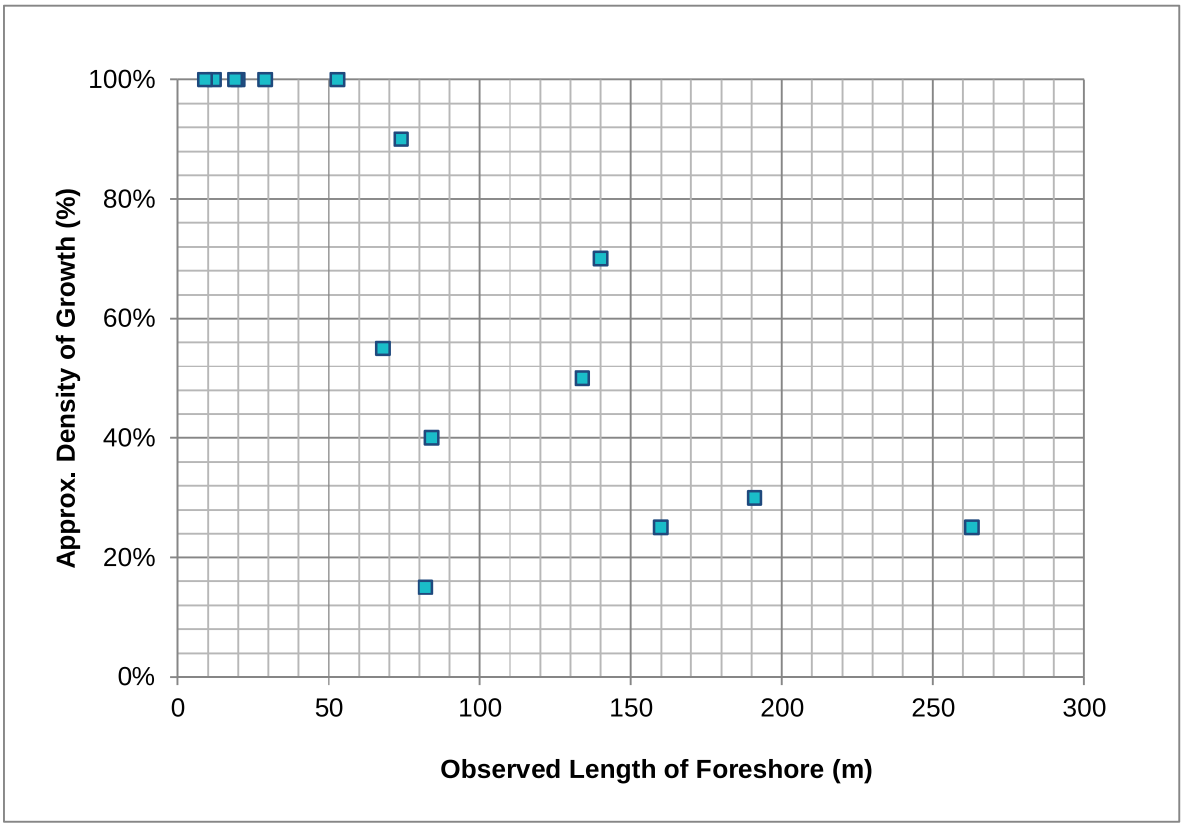


Figure 4-13 Foreshore Length vs Density of *Arundo* Growth

5 Discussion

The following provides general discussion around field observations and results of the data analysis outlined above.

5.1 Bank Erosion

During the field investigations bank erosion was observed in all study area zones. The majority of bank erosion sites identified and mapped are 'hot-spot' locations where significant segments of riverbank have receded or been lost entirely due to bank scour and mass failure resulting in steep or vertical banks. Overall, bank erosion is more common in the upstream reaches of the study area where riverbanks are not well protected by riparian vegetation and where development and structures are most common. Unsurprisingly, bank erosion was largely absent in the lower reaches of the study area (i.e. downstream of Colo River confluence) where hard surface natural foreshore habitat (e.g. steep sandstone cliff faces) is common.

Bank erosion mapped as part of this study is likely to have occurred as a result of short-term cumulative impacts on riverbank condition caused by several factors including:

- saturation of banks from off-stream sources;
- redirection and acceleration of flow around infrastructure;
- obstructions, debris or vegetation within the stream channel;
- inundation of bank soils followed by rapid drops in flow after flooding;
- removal or disturbance of protective vegetation from stream banks as a result of trees falling from banks or through poorly managed stock grazing, clearing or fire;
- bank soil characteristics such as poor drainage or seams of readily erodible material within the bank profile; and
- wave action generated by wind or boat wash.

It is difficult to solely attribute one of the above factors to the cause of bank erosion in the study area as almost all of them are expected to occur at one time or another. In some cases significant processes such as flooding can trigger dramatic and sudden changes in rivers and streams (Queensland Primary Industries, 2006). Recent flooding in the study area is partly responsible for the bank erosion observed particularly at locations where the riverbank is exposed due to the lack of riparian vegetation.

Land use and stream management can also trigger erosion responses. The responses can be complex, often resulting in accelerated rates of erosion and sometimes affecting stability for decades. Over-clearing of catchment and stream bank vegetation, poorly managed sand and gravel extraction, and stream straightening works are examples of management practices which result in accelerated rates of bank erosion (Queensland Primary Industries, 2006).

In the study area, the majority of bank erosion sites have minimal riparian vegetation and where present is often of low or insignificant value (e.g. weeds). At some locations, terrestrial weeds covering the riverbank are the only form of vegetative protection available during high river flow conditions and as such their removal would require a considered approach. That is, any targeted clearing of weeds should be undertaken in a manner that maintains some form of bank protection (e.g. roots, dead tree stumps) during the re-establishment of local native trees, shrubs and ground covers. Past bank rehabilitation observed near West Portland Road (see Bank Erosion Site 36) demonstrate that such efforts can be achieved and with beneficial results.

Unfenced paddocks with cattle and other livestock grazing over the riverbank is also an issue that needs to be addressed to protect establishing riparian vegetation from being destroyed, and to maintain bank stability, form and function. Bank erosion sites are also closely associated with the foreshore structures such as those present at ski parks which have localised impact on flows causing redirection and acceleration which can exacerbate bank erosion and/or cause adjacent ‘soft’ banks to be damaged.

5.2 Foreshore Structures

A variety of foreshore structures were observed in the study area. Upstream of Windsor, structures are much less abundant than other downstream localities where numerous ski parks and private riverfront properties are situated and the greatest density of structures is found.

The site reconnaissance revealed that the majority of structures are old but still functional with only a small fraction considered to be degraded or in disrepair. Some of the structures were also likely to have been constructed without the necessary approvals (i.e. Development Application) although this is not easily monitored / regulated and has not been confirmed during the study.

The maintenance of existing foreshore structures appears ad-hoc and their construction inconsistent both in terms of design and construction materials. For example, retaining walls are the most common foreshore structure accounting for more than half of all structures recorded in the study area. Materials used for their construction (e.g. concrete, rock, timber and in some cases old tyres) is often dependent on material available to the owner at the time of construction and does not follow any standard practice or guideline. Indeed, about three quarters of the structures observed in the study area are for the purpose of bank stabilisation and protection, and the majority of these are constructed using rock.

Based on site observations, foreshore structures are typically clustered together and associated with ski parks and river front properties. Opportunities for improving the environmental value of existing retaining walls by establishing estuarine vegetation directly in front of seawalls, providing a native riparian vegetation buffer landward of the seawall, providing artificial reef habitat immediately in front of seawalls and providing a varied surface for habitat are abundant. The mapping and analysis reveals that the greatest density of retaining walls is found between Sackville and Wisemans Ferry (where there are numerous ski parks) and may offer suitable sites for retrofitting environmentally friendly seawall design principles and improving the overall aesthetic of the area.

5.3 Weeds (*Arundo*)

In general, terrestrial weeds are widespread in the study area and posing a threat to natural bushland areas along rivers and creeks. During field investigations, weeds were readily observed along the riverbank and tended to be prominent near development and where clearing / tree felling was undertaken. Terrestrial weeds were less common in a few notable areas surrounding the Cattai Creek Nature Reserve and between Wisemans Ferry and Lower Portland where sandstone river banks and dense native bushland are well established. Although terrestrial weeds are unsightly and have negative impacts on the establishment and growth of native vegetation, strategic monitoring and removal is required to minimise further spread and to ensure that any bank rehabilitation efforts (including bank stabilisation) are effective in the longer-term.

Arundo has only established itself in the study area over the past five years, and is already considered to be a significant environmental weed. If not managed, *Arundo* can spread uncontrollably and cause significant environmental, social and economic impacts to waterways which have already occurred in parts of the Hunter-Central Rivers catchment. A rapid targeted and coordinated approach will be required if the introduction of this weed to the study area is to be managed.

Council is aware that the spread of *Arundo* has increased and that up-to-date mapping will assist in the prioritisation and targeting of rehabilitation efforts. The data presented in this study provide a baseline upon which to monitor the spread of the species and review any perceived changes in weediness (i.e. an increase in the density or extent of growth). This study may also be used by Council to demonstrate preliminary surveillance and mapping of infested areas and to assist with funding applications for ongoing management and removal of the species.

6 Conclusion

The aim of the study is to collate new spatial datasets for establishing a baseline upon which further data collection and mapping of the study area may be compared. Central to this study was a rapid assessment of foreshore erosion, structures and *Arundo* along the Hawkesbury River between Yarramundi and Wisemans Ferry. Water-based field data collection was undertaken over three consecutive days which established a baseline of existing conditions that can be used in the development of management options for the CZMP being prepared for Council.

Field data and mapping presented in this study has not previously been obtained for the study area, and as such provides new insight into the location, extent and condition of bank erosion and foreshores structures which are both key data gaps. Preliminary mapping of *Arundo* also provides a new dataset that has not previously been collated by Council (or other stakeholders in the region), and provides a central mapping resource and basis to apply for funding to assist with its removal and reduce further spread in local waterways.

A summary of the investigation including the key conclusions and recommendations derived from the modelling are provided below:

- High bank erosion sites are commonly associated with residential and ski park developments where there is also a higher density of foreshore and waterway structures;
- On the whole, structures are old and in some cases degraded. Only a few structures would be considered new (less than 3 years old). This may suggest that development assessment and compliance activities are having an increasing influence on preventing new structures. Structures tend to be constructed in isolation to one another and designed to protect the foreshore of private properties without any regard for the adjacent land use and/or riverbank condition. There is a significant opportunity within the CZMP to implement options to improve the appropriateness of future structures through development assessment and provision of information to potential proponents;
- The condition of riparian vegetation is mostly cleared or absent from the riverbank, which also is closely connected with the occurrence of bank erosion. Riparian vegetation at the majority of bank erosion sites in the study area is low or insignificant corresponding to vegetation being absent, cleared, weed infested or a combination of all three;
- *Arundo* has colonised more than 600 metres of riverbank across 15 sites. The density / extent of growth (weediness) varies between sites and the majority of sightings occur downstream of the Colo River. It is likely that the source(s) of Arundo originate in the Colo and Macdonald River catchments, which is supported by abundant sightings along the lower reaches of those two rivers. A concerted effort is required to identify the source of *Arundo* and to minimise further spread of the weed throughout the study area;
- Data presented in this report provide a basis for informing the development of management options during the preparation of the CZMP. Hot-spot locations of bank erosion and foreshore structures have been mapped which can be used to identify who Council will need to work with in implementing intervention and adaptation options and to prioritise sites. Knowledge of the types of structures can be used in the design of policy and targeted information on the design and rehabilitation of structures into the future; and

- Continued monitoring and comparison against baseline conditions will be required to establish both spatial and temporal trends. Annual field data collection campaigns may be worthwhile in this regard. For example, additional site reconnaissance could be undertaken to identify new *Arundo* patches and/or to revisit known sites to ascertain if the weed is invading or spreading to new areas. Similarly, the length of bank erosion at key sites could be monitored to understand if bank stability is deteriorating, improving or remaining unchanged.

7 References

Astles, K., G. West and R.G. Creese, 2010. Estuarine habitat mapping and geomorphic characterisation of the lower Hawkesbury river and Pittwater estuaries. Industry & Investment NSW – Fisheries Final Report Series No. 117 ISSN 1837-2112, April 2010.

BMT WBM, 2013. Upper Hawkesbury River Information Synthesis Report. Prepared for Hawkesbury City Council, May 2013.

Environment and Heritage, 2013. High priority widespread weeds impacting on biodiversity in the Hunter-Central Rivers catchment. Accessed on 10 September 2013 from http://www.environment.nsw.gov.au/resources/pestsweeds/cma_weeds_HCR.pdf

Gruber, R., Ferguson, A. and Haine, B. (2010) Final Report. Nutrient Transformation and Attenuation within Tidal Rivers. Research Project 2007/RD/0018 (July 2008 – July 2010). NSW Department of Environment Climate Change and Water.

Hawkesbury City Council, 2013. Environmental Weeds in the Hawkesbury LGA. Accessed on 15 August 2013 from http://www.hawkesbury.nsw.gov.au/environment/natural-environment/vegetation,-noxious-weeds/environmental-weeds-in-the-hawkesbury-lga

Kimmerikong, 2005. Scoping Study Hawkesbury Nepean River Estuary Management Final Report.

Krogh. M., A. Wright and J. Miller, 2009. Hawkesbury-Nepean River Environmental Monitoring Program. Final Technical Report. NSW Department of Environment and Climate Change.

Queensland Primary Industries, 2009. River Fact Sheet Series R2. What causes bank erosion?, March 2006.

Sydney Metropolitan Catchment Management Authority and Department of Environment and Climate Change NSW, 2009. Environmentally Friendly Seawalls. A Guide to Improving the Environmental Value of Seawalls and Seawall-lined Foreshores in Estuaries. ISBN 978 1 74232 254 4 DECC 2009/328, June 2009.

Williams, R.J. and I. Thiebaud, 2007. An Analysis of Changes to Aquatic Habitats and Adjacent Land-use in the Downstream Portion of the Hawkesbury Nepean River over the Past Sixty Years. NSW Department of Primary Industries - Fisheries Final Report Series No. 91 ISSN 1449-9967, August 2007.

Appendix A Field Data Sheets

Weed Mapping Record Sheet

BMT WBM

Client:	Hawkesbury City Council	Identification [Species / Common Name]:	
Locality:		Degree of Establishment:	
Logged by:		Noxious? [Y / N]:	
Date / Time:		Density of growth:	

Site Details

e.g. general site details / other information/notes

Notes:
Area A = Yarramundi - Windsor
Area B = Windsor - Sackville
Area C = Sackville - Wisemans Ferry

Photo Log		GPS Coordinates
Camera ID:	UTM56	Easting:
Photo ID:	UTM56	Northing:

Site Sketch

Degree of Establishment: New growth = 1
Old growth = 2

Density of Growth: High [50-100%] = 1
Moderate [10-50%] = 2
Low [10%] = 3

Structure Mapping Record Sheet

BMT WBM

Client:	Hawkesbury City Council	Type of structure:	
Locality:		Number of structures (if grouped):	
Logged by:		Condition of Structure [New / Old / Degraded]:	
Date / Time:			

Site Details

e.g. general site details / other information/notes

Notes:
- Area A = Yarramundi - Windsor
- Area B = Windsor - Sackville
- Area C = Sackville - Wisemans Ferry

Photo Log / GPS Coordinates

Photo Log		GPS Coordinates
Camera ID:	UTM56	Easting:
Photo ID:	UTM56	Northing:

Site Sketch

Type of Structures:	Jetty / fixed = J	Timber retaining wall = TW
	Pontoon / floating = P	Rock retaining wall = RW
	Boat ramp = B	Concrete retaining wall = CW
	Gabion wall = G	
	Rock protection / riprap = R	
	Other = O	

Erosion Mapping Record Sheet

BMT WBM

Client:	Hawkesbury City Council	Erosion Class:	
Locality:		Vegetation [Type / Value]:	
Logged by:		Local Landuse:	
Date / Time:		Bank Properties [Slope / Shape]:	

Site Details

e.g. general site details / surrounding landscape

Notes:

Area A = Yarramundi - Windsor
Area B = Windsor - Sackville
Area C = Sackville - Wisemans Ferry

Photo Log		GPS Coordinates
Camera ID:	UTM56	Easting:
Photo ID:	UTM56	Northing:

Site Sketch

Erosion Class:	High = 1	Land Use:	Bushland = 1	Bank Slope:	Vertical (80-90 deg) = 1	Bank Shape:	Concave = 1
	Moderate = 2		Ski/caravan park = 2		Steep (60-80 deg) = 2		Convex = 2
	Low = 3		Turf farm = 3		Moderate (30-60 deg) = 3		Stepped = 3
			Housing/residential = 4		Low (10-30 deg) = 4		Wide low er bench = 4
			Other = 5		Flat (<10 deg) = 5		Undercut = 5

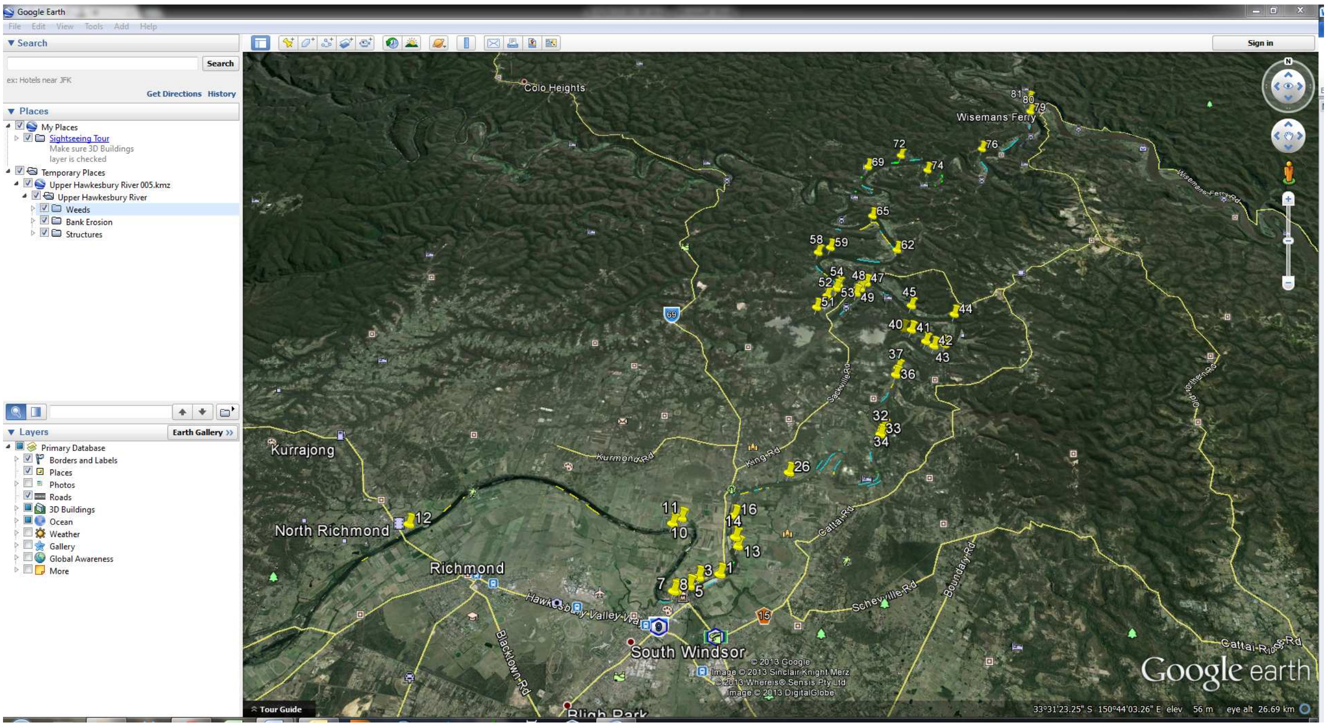
Veg. Type:	Natural Riparian Vegetation = 1	Veg. Value:	High importance / conservation value = 1
	Mixed riparian vegetation fringing altered land use = 2		Moderate importance / native veg. in good condition = 2
	Cleared vegetation w ith provate infrastructure / gardens = 3		Low importance / common land = 3
	Cleared land =4		Insignificant / w eed infested = 4

Appendix B Google Earth Data Compendium

Raw data collected during the field investigations including site coordinates, attribute data and photos are linked together in a data compendium. The data compendium provides a complete record of all site photos and observations collected for bank erosion, foreshore structures and *Arundo* observed in the study area during the field investigations.

The data compendium (KMZ file) has been created using Google Earth. A KMZ file is a compressed version of a KML file. Google Earth can open KML and KMZ files if these files have the proper file name extension (.kml or .kmz).

To view the data, start Google Earth (http://www.google.com/earth/index.html), and open the file ‘UpperHawkesburyRiverDataCompendium.kmz’ contained on the DVD.



Google Earth Data Compendium of Raw Field Data

Appendix C Environmental Weeds in the Hawkesbury

Environmental Weeds in the Hawkesbury

Environmental Weeds are plants that, although not recognised as noxious under the Noxious Weeds Act, still pose a threat to the environmental health of our local region. These weeds pose a particular threat to natural bushland areas and along rivers and creeks. The following is a list of locally occurring environmental weeds.

Common Name	Scientific name	Habit	Habitat
African Love Grass	*Eragrostis curvula*	Grass	Roadsides, pastures
African Olive	*Olea europaea subsp africanus*	Tree	Fertile soils
Blue Heliotrope	*Heliotropium amplexicaule*	Herb	Sunny, disturbed areas
Blue Periwinkle	*Vinca major*	Herb	Moist, fertile soils
Bridal Creeper	*Myrsiphyllum asparagoides*	Herb	Fertile, well-drained soil
Balloon Vine	*Cardiospermum grandiflorum*	Vine	River and creek banks
Black Willow	*Salix nigra*	Tree	River and creek banks
Box Elder	Acer negundo	Tree	River and creek banks
Buddleja	*Buddleja madagascariensis*	Shrub	Moist areas in sun
Cape Ivy	*Delairea odorata*	Vine	Moist areas in sun
Castor Oil Plant	*Ricinus communis*	Tree	Roadsides, Fill
Cats Claw Creeper	*Macfadyena unguis-cati*	Vine	Moist fertile soil
Fennel	*Foeniculum vulgara*	Herb	Roadsides, Wastelands
Fireweed	*Senecio madagascariensis*	Herb	Roadsides, Pastures
Giant Reed	*Arundo donax*	Reed	Riverbanks
Honey Locust	*Gleditsia triacanthos*	Tree	Roadsides, riverbanks
Honeysuckle	*Lonicera japonica*	Vine	Moist sheltered areas
Jasmine	*Jasminum polyanthum*	Vine	Moist sheltered areas
Lantana	*Lantana camara*	Shrub	Widespread
Large-leaved Privet	*Ligustrum lucidum*	Tree	Moist, nutrient rich sites
Madeira Vine	*Anredera cordifolia*	Vine	Moist, fertile soils
Micky Mouse Plant	*Ochna serrulata*	Shrub	Moist, fertile soils
Morning Glory	*Ipomea indica*	Vine	Moist, fertile soils
Moth Vine	*Araujia sericifolia*	Vine	rich soils
Paddy's Lucerne	*Sida rhombifolia*	Herb	Sunny, disturbed areas
Radiata Pine	*Pinus radiata*	Tree	Cooler climates
Small leaved Privet	*Ligustrum sinense*	Tree	Moist, nutrient rich sites
Tree of Heaven	*Ailanthus altissima*	Tree	Riverbanks, Wastelands
Turkey Rhubarb	*Acetosa sagittata*	Vine	Sunny, damp, disturbed
Wandering Jew	*Tradescantia albiflora*	Herb	Moist, fertile soils
Wild Tobacco	*Solanum mauritianum*	Tree	Roadsides, disturbed areas

(Note: Many Noxious weeds are also considered to be environmental weeds. Please see the Noxious Weeds List for additional weeds that pose a threat to agriculture, the environment or the community).

BRW.
CLIENT
CHOICE
AWARDS
2013
australia's best professional service firms
WINNER

BMT WBM

BMT WBM Bangalow	6/20 Byron Street Bangalow 2479 Tel +61 2 6687 0466 Fax +61 2 66870422 Email bmtwbm@bmtwbm.com.au Web www.bmtwml.com.au
BMT WBM Brisbane	Level 8, 200 Creek Street Brisbane 4000 PO Box 203 Spring Hill QLD 4004 Tel +61 7 3831 6744 Fax +61 7 3832 3627 Email bmtwbm@bmtwbm.com.au Web www.bmtwml.com.au
BMT WBM Denver	8200 S. Akron Street, #B120 Centennial Denver Colorado 80112 USA Tel +1 303 792 9814 Fax +1 303 792 9742 Email denver@bmtwbm.com Web www.bmtwbm.com
BMT WBM London	1st Floor, International House St Katherine's Way London E1W1TW Email london@bmtwbm.co.uk Web www.bmtwbm.com.au
BMT WBM Mackay	Suite 1, 138 Wood Street Mackay 4740 PO Box 4447 Mackay QLD 4740 Tel +61 7 4953 5144 Fax +61 7 4953 5132 Email mackay@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Melbourne	Level 5, 99 King Street Melbourne 3000 PO Box 604 Collins Street West VIC 8007 Tel +61 3 8620 6100 Fax +61 3 8620 6105 Email melbourne@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Newcastle	126 Belford Street Broadmeadow 2292 PO Box 266 Broadmeadow NSW 2292 Tel +61 2 4940 8882 Fax +61 2 4940 8887 Email newcastle@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Perth	Suite 6, 29 Hood Street Subiaco 6008 Tel +61 8 9328 2029 Fax +61 8 9486 7588 Email perth@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Sydney	Level 1, 256-258 Norton Street Leichhardt 2040 PO Box 194 Leichhardt NSW 2040 Tel +61 2 8987 2900 Fax +61 2 8987 2999 Email sydney@bmtwbm.com.au Web www.bmtwbm.com.au
BMT WBM Vancouver	Suite 401, 611 Alexander Street Vancouver British Columbia V6E 3W1 Canada Tel +1 604 683 5777 Fax +1 604 608 3232 Email vancouver@bmtwbm.com.au Web www.bmtwbm.com