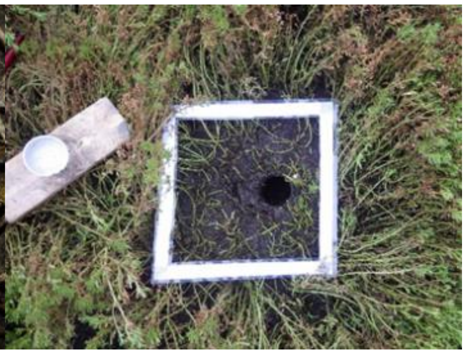

Yanco-Billabong Creek Broad-scale Wetland Monitoring Project: Frog communities of the Yanco-Billabong creek system.

Walcott, A., Wolfenden, B., Hall, A. and Wassens S.

Walcott, A., Wolfenden, B., Hall, A. & Wassens, S. (2018) Yanco-Billabong Creek Broad-scale Wetland Monitoring Project: Frog communities of the Yanco-Billabong creek system. Final Report prepared for Murray Local Land Services. Institute of Land Water and Society, Charles Sturt University, Albury

Acknowledgements

The project team respectfully acknowledges the traditional owners of the land on which this work was conducted, their Elders past, present and future, their Nations of the Murray-Darling Basin, and their cultural, social, environmental, spiritual and economic connection to their lands and waters. In particular, we acknowledge the Wiradjuri people, traditional owners of the land on which this research is focused.

The project team also thank the team of people who contributed to the project including: Anthony (Rex) Conallin, Szofia Palfi, Carmen Amos (OEH) and Robert Cook. We are grateful to the landholders who granted us access to wetlands as well as their interest, cooperation and support. We would also like to thank Jim Parrett from Rural and Environmental Services for assisting with site selection and landholder contact details. All research methods were conducted in accordance with Charles Sturt University's Animal Care and Ethics Committee guidelines, approval number: 15/075.

Contents

Executive summary

Limited information is available on the biota of the Yanco-billabong creek system, particularly for aquatic animals and plants, and this information is critical to making informed, evidence-based natural resource management decisions. This project has been developed in partnership with Charles Sturt University and Murray Local Land Services to increase knowledge of the ecology and ecological function of wetlands through the Yanco-Billabong creek system. This final report synthesises the research activities and outcomes achieved for the Yanco-Billabong Creek Wetland monitoring Project between April 2017 and April 2018.

Fifteen wetlands were selected across the system for their potentially high conservation value via consultation with Jim Parrett (Rural & Environmental Services). Wetland boundaries for 18 candidate wetlands were delineated using high resolution digital terrain models (spatial analysis). Subsequently, wetland areas were estimated and stratified according to depth classes, a useful tool for the delivery of environmental water and other natural resource management activities. Rapid habitat assessment described over and under story vegetation allowing for classification of the different wetland types occurring throughout the system.

Broad scale frog surveys were conducted on two occasions in 2017. First in October, following a small delivery of environmental water and again in early December, following very heavy rainfall. Frogs were very widespread, identified at 14 of the 15 wetlands (all wetlands which held at least residual water during the surveys). Overall, eight frog species were identified across the system: spotted marsh frog, barking marsh frog & eastern sign-bearing froglet, eastern banjo frog, Sudell's frog, inland banjo frog, Peron's tree frog; and one threatened species, the southern bell frog. A key finding of this study was observation of the southern bell frog which was heard calling in low numbers at two wetlands along the mid-Yanco creek. Also, higher frog species diversity (number of frog species) was related to a higher diversity of microhabitat types (e.g. submerged vegetation, tall standing emergent vegetation).

Frog calling activity, a proxy for breeding activity, was also monitored on an hourly basis from 25th October 2017 until 7th February 2018. Daily calling by the same frog species varied considerably between the two sites considered and this likely reflected the strong influence of hydrology on resident frog species breeding. The findings of this study suggest that Bundure provided an important breeding habitat for the endangered southern bell frog, as well as a range of other frog species during the monitoring period. Based on the findings of this study, natural resource management actions which improve/sustain aquatic vegetation diversity and provide aquatic habitats which persist during spring and summer (and longer to cater for southern bell frog metamorphosis) could sustain and even improve frog occupancy in this system.

A single waterbird survey was conducted alongside the day time frog surveys in December 2017. Overall, 17 waterbird species were identified, in addition numerous (90-100) inactive nests (likely cormorant species) were identified. Further surveys are required following wetland inundation to better understand waterbird diversity in the system.

Inland wetlands are attributed with being the earth's largest stores of terrestrial carbon and in this way are considered important for offsetting the impacts of greenhouse gas emissions. Multiple factors influence the capacity for wetlands to sequester carbon. Hydrology controls the amount and type of vegetation that grows in wetlands as well as the rate at which the organic matter of these plants produce accumulates within the soil over time. Using the wetland maps stratified according to depth, the relationship between carbon stores (soil and standing stock) and wetland depth (a proxy for hydrological regime) was assessed (from May 2017). Carbon stock 'hotspots' were identified and extended to the lower reaches of the catchment which are likely to have suffered the compounding effects of lower water volumes. The results of this pilot study suggest that wetland soils more frequently inundated, stored significantly higher proportions of carbon. Further analysis of soil carbon stable isotopes was conducted to determine whether the source of carbon also differed among wetlands, or sites within wetlands, with different hydrological regimes. For example, we might expect sites that are more frequently inundated will have a higher proportion of soil carbon contributed by wetland plants, and so the composition of soil carbon isotopes may reflect changes in carbon sources. Stable isotope $\delta^{13}C$ ‰ analysis also revealed a relationship with wetland depth, showing that deeper (more frequently inundated) sites within wetlands were more enriched in ^{13}C. It isn't clear whether this trend reflects alternative source materials at drier sites that have a contrasting isotopic signature, or if the less depleted signature is the result of microbial processing. These findings are an important consideration when assessing the potential environmental impacts of future management decisions that result in reduced water delivery to this system. Based on the findings of this pilot study, the delivery of water to these hotspots is recommended and emphasised. These findings demonstrate key differences in the amount and type of soil carbon accumulated by different wetlands in the Yanco Creek system and provide a benchmark for which future reassessment can be compared against to quantify the benefits of rehabilitation.

Summary of key findings & outputs

This project provides baseline knowledge on a range of floodplain wetland characteristics including important implications for natural resource management of the system.

- Maps for 18 wetlands were produced which delineate wetland boundaries and describe local wetland topography. The stratified maps guided wetland soil carbon collection and can be used to estimate water volumes required to inundate the wetlands, a useful tool to inform future environmental watering strategies. These maps have already been used to guide LLS funding of pest and weed control within a 500 metre buffer of wetland extent.

- High carbon storage was estimated for key wetlands and the results of this pilot study suggest that wetland soils more frequently inundated, stored significantly higher proportions of carbon.

- Two frog surveys were conducted in October and December 2017, which provide baseline data for the wetland dependent taxa residing in the system.

    - a small population of threatened frog species (the southern bell frog) breeding in the mid Yanco creek system, which was communicated (via memo) to environmental water managers for timely consideration of this flow dependent species

    - seven other frog species were identified across the system: spotted marsh frog, barking marsh frog & eastern sign-bearing froglet, eastern banjo frog, Sudell's frog, giant banjo frog and Peron's tree frog

    - a higher diversity and abundance of frog species were observed at wetlands with a higher diversity of microhabitat types (structural complexity). However, further work would be required to extend this link to wetland carbon due to the number of sites that were dry in December.

  - a summary of the key findings was presented at the Murrumbidgee Environmental Water Advisory Group (EWAG) meeting in Wagga on 14th of March 2018

All findings were made directly available to the Yanco-Billabong community to communicate the floodplain assets within their region and the benefits of flooding (natural and environmental) to maintaining these important wetland systems.

- summary letters were sent to the participating Landholders following each field trip
- Interactive presentations (and learning resources) to school groups at the 'Creative Catchment Kids program: Who lives in the Water? Billabong-Yanco Creek Gala Event' and general public at the 'Wetland Wonders of the Yanco, Billabong and Colombo Creeks information night' (both held by the Murray Local Land Services).

Introduction

The Yanco Creek is a significant environmental, economic and social asset of the Murray Local Land Services (LLS) region. Like other systems in the Murrumbidgee catchment, the hydrology of the Billabong-Yanco creek has changed immensely due to water extraction and regulation. Delivery of environmental water to help maintain and improve these water-dependent creek and wetland communities has been an objective for the Commonwealth Environmental Water Office. Despite its significance, limited information is available on the biota of the Yanco-billabong creek system, particularly for aquatic animals and plants, and this information is critical to making informed, evidence-based natural resource management decisions. This project has been developed in partnership with Charles Sturt University, NSW Office of Environment & Heritage and Murray Local Land Services to increase knowledge of the ecology and ecological function of wetlands through the Yanco-Billabong creek system. This final report synthesises the research activities and outcomes achieved for the Yanco-Billabong Creek Wetland monitoring Project between April 2017 and April 2018.

Wetlands are highly diverse, hosting a wide variety of plants and animals. The biology of ephemeral wetlands is largely shaped by the frequency and duration of wetland inundation and changes to these patterns can contribute to the loss of individual species or entire ecosystems. Protecting wetlands requires ongoing efforts to understand the biology of wetland species and their relationship with water regimes. Broad scale surveys are needed to better understand the water requirements of both individual wetlands and wetland systems as a whole. Such understanding can be used to natural resource manager to objectively prioritise actions, such as the delivery of environmental water.

Wetlands are well known to be very productive, meaning they contain an abundance of food that supports high numbers of wetland-adapted animals. The source of this productivity lies in the carbon and nutrients that are released from soils and into the water when a wetland is inundated. Wetland soils accumulate carbon from both trees (leaves, bark or wood) and grasses, or from aquatic plants and algae. How much carbon accumulates in the soil over time, and which of these two sources (terrestrial or aquatic plants) dominates, can change depending on how often and how long the wetland is inundated. Gaining insight into the amount and sources of carbon in wetland soils and how this relates to wetland inundation, and ultimately, the species diversity and abundance (e.g. frogs and waterbirds) it can support will provide important knowledge for direct natural resource management considerations.

Frogs are considered important ecological indicator as their life cycle depends on both aquatic and surrounding riparian and terrestrial habitat, as well as their role of predator and food source in the greater food chain. Different species have different habitat and breeding requirements, wetland inundation and duration is particularly influential as the timing of which can either support or prevent successful breeding outcomes for species, with tadpoles requiring water to persist for their complete development (and at the right time). Subsequently, frog species diversity and composition, as well as changes in these measures can thus provide important insight into wetland ecosystems.

The aim of this study was to collect baseline physico-chemical and biological data for the floodplain wetlands of the Yanco-Billabong creeks system to inform natural resource management of the system using frogs as biological indicators. Fifteen wetlands were selected across the system for their potentially high conservation value via consultation with Jim Parrett (Rural & Environmental Services). A broad-scale assessment of the Billabong-Yanco creek wetlands commenced in May 2017. High annual rainfall during 2016 resulted in widespread inundation of the wetlands in the system, many of which had been dry (especially in the downstream reaches) for extended periods due to changed water flows (landholder communication). At the time of soil carbon collection (May-June), most wetlands retained some water, but at relatively low levels. While some environmental water was delivered to the system, wetland water levels declined across the system, the Rhyolla wetlands remained dry from May 2017 (at latest). Two frog surveys were conducted in 2017, first in October when most wetlands retained at least moderate water levels and again in December when water levels had dried considerably but very heavy rainfall in the preceding days resulted in local flooding of some sites, particularly in the upper reaches of the system.

Project objectives:

1. Undertake a wetland classification and inventory (delineate wetland extent and depth classes)

2. Provide a baseline for wetland carbon stocks and identify carbon stock 'hotspots' (estimate the level of carbon stored in the wetlands and identify wetlands with relatively high stores)

3. Identify the origin (terrestrial or aquatic plants) of soil carbon stocks via isotopic analysis

4. Frog species occupancy and diversity across the system (identify frog species occurring across the system and identify how this compares with previous records)

5. Frog calling activity (assess hourly call records collected from October 2017 until February 2018 to identify temporal trends in frog species calling, a proxy for reproduction)

6. Implications for natural resource management (based on the findings of the study, identify key implications for natural resource management)

Objective 1: Wetland classification and inventory

Introduction

Each wetland has its own unique physical characteristics, which, along with its hydrology, influence the formation of the dominant plant and animal communities. An understanding of the local topography and the bathymetry of an inundated wetland area underpins any explanation of ecological responses to water management. Wetland vegetation provides crucial habitat structure and function for resident animal communities. For frogs, vegetation influences what species can reside in a wetland with different frog species displaying different habitat requirements, e.g. tree dwelling species require standing timber or tall standing vegetation. Thus, as a first step of this project, topography, area and habitat characteristics were described for each of the wetlands (figure 1.1).

Objectives

1. Produce wetland maps and estimate wetland area

2. Produce wetland maps to stratify carbon sampling (according to depth)

3. Rapid habitat assessment to describe key structural characteristics and dominant vegetation

Methods & Results

Wetlands boundary and area

Using high resolution digital terrain models, boundaries of 18 candidate wetlands were produced and wetland area determined (Table 1). Maps of the wetland areas are provided in Appendix 1, and a selection of photographs of the wetlands are provided in Appendix 2. The wetlands were further stratified into depth classes to guide the stratified random sample collection of soil samples (Appendix 1).

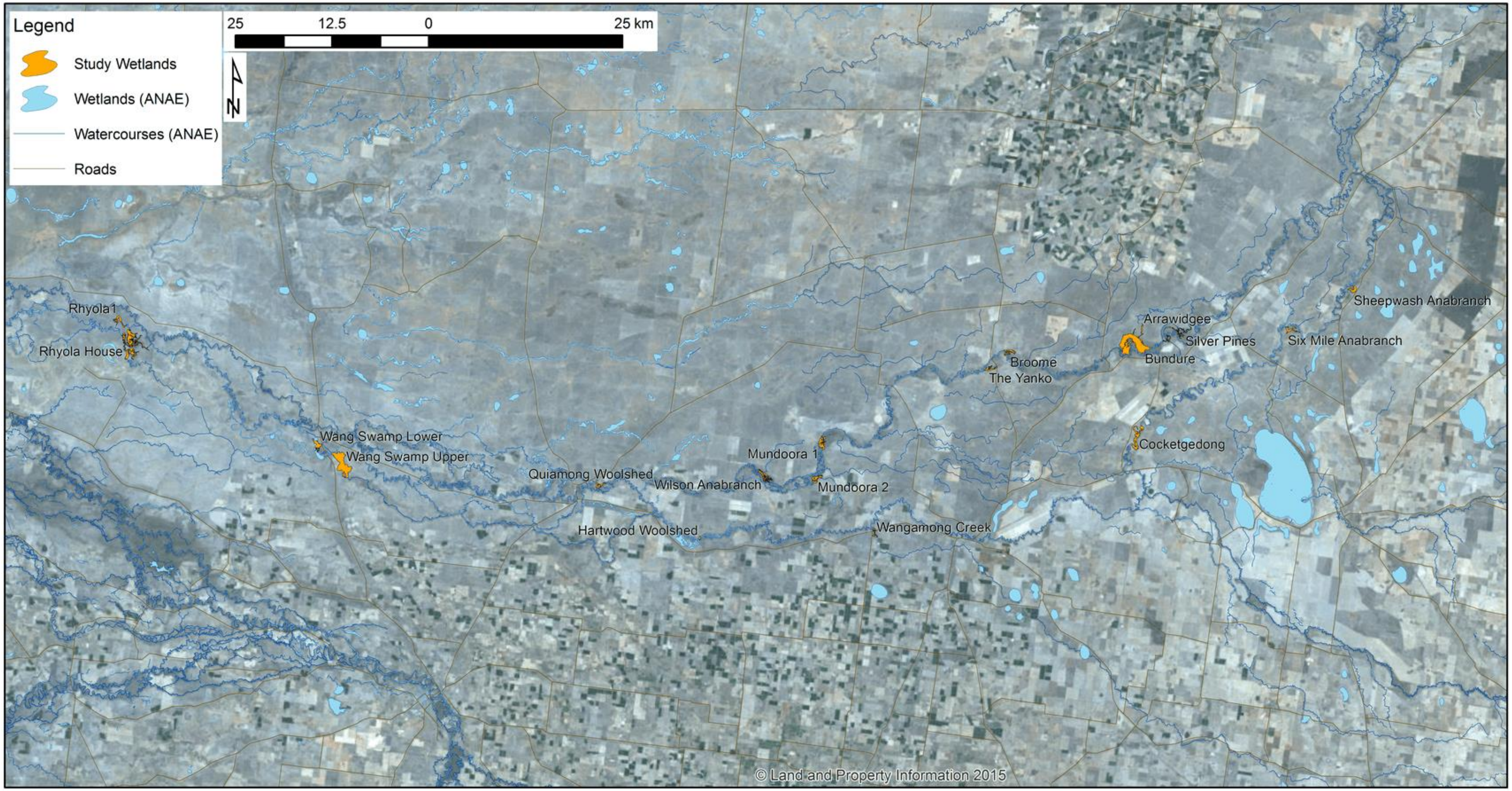

Figure 1.1. Overview map of selected study wetlands within the Yanco creek system.

Table 1.1 General wetland classification and area estimated using high resolution digital terrain models. * indicate wetlands which were not sampled for soil carbon

Study wetland Name	Latitude	Longitude	Area (ha)	Dominant vegetation community
Arrawidgee *	-35.12883	146.02492	16.23	Mapped, not surveyed
Broome	-35.14386	145.79745	43.40	River red gum - Open
Bundure	-35.13235	145.98412	514.54	River red gum - Open
Cocketgedong	-35.23705	145.98061	123.33	River red gum - typha
Six Mile Anabranch (Coonong)	-35.11944	146.19322	38.47	River red gum - Black box- open
Hartwood	-35.35123	145.35207	8.25	River red gum - Open
Mundoora 1 *	-35.23642	145.53009	75.79	Mapped, not surveyed
Mundoora 2 *	-35.28767	145.51676	53.90	Mapped, not surveyed
Quiamong	-35.29050	145.21484	35.18	River red gum - Open
Rhyola House	-35.11361	144.55113	50.37	Black box - Atriplex
Rhyola 1	-35.07999	144.53600	294.15	Black box - Atriplex
Sheepwash Anabranch	-35.07068	146.28834	38.18	River red gum - typha
Silver Pines*	-35.11417	146.05553	44.78	River red gum - Open
Wangamong Creek	-35.34375	145.60191	18.48	Black Box- Nitre goosefoot- typha
Wanganella Swamp Lower	-35.23180	144.81607	61.49	Nitre goosefoot-cane grass
Wanganella Swamp Upper	-35.24667	144.84421	342.98	Nitre goosefoot-cane grass
Wilson Anabranch	-35.27962	145.44365	65.55	River red gum - Open
The Yanko	-35.15907	145.76544	32.60	River red gum - Black box- open

Wetland habitat characteristics

Wetland vegetation communities were evaluated through rapid assessment of three 10 metre belt transects, with the percentage cover of each structural component (e.g. submerged, free floating, attached floating or emergent) and dominant species recorded through rapid assessment of riparian and wetland vegetation. Water quality (temperature (˚C), conductivity (mS/cm), dissolved oxygen (mg/L), pH and turbidity (NTU)) was measured using a hand held multi-parameter water quality meter (U-50 Series, HORIBA Ltd., Kyoto, Japan) at three points within each waterbody at a depth of at least 30 cm, or wherever possible in shallow waters. The meter was calibrated according to manufacturer specifications.

The Alluvium (2013) study classifies the Yanco creek system into six reaches, each reach considered to have relatively homogenous hydrological, structural and ecological characteristics. While the wetlands selected in this study were not selected on this basis, the results of this project are discussed in terms of this reach classification. According to the (Alluvium, 2013) study, the selected wetlands fell within the following system reaches (Table 1.2).

Table 1.2. Classification of the wetlands studied according to (Alluvium, 2013).

System reach as per (Alluvium, 2013)	Site code	Site name
Mid-Yanco	BROO	Broome
	BUND	Bundure
	WILS	Wilson's anabranch
	YANK	The Yanko
Colombo	CCKT	Cocketgedong
	CNNG	Coonong (otherwise known as six mile anabranch)
	SHEE	Sheepwash anabranch
Mid-Billabong	HART	Hartwood
	WANG	Wangamong creek (TSR)
Forest (regulated sub-reach)	FRST	Forest creek (TSR)
Forest (unregulated sub-reach)	WANL	Wanganella swamp lower
	WANU	Wanganella swamp upper
	RHYO	Rhyolla
	RYLH	Rhyolla house
Lower-Billabong	QUIA	Quiamong

Average water quality metrics varied between the wetlands within a normal range for freshwater wetlands (temperature: 20-26°C, conductivity: 0.06-0.36 mS/cm, DO: 64-124%, pH: 6.81-7.75, Turbidity: 85-355 NTU). None of the wetlands were hypoxic during the surveys, that is, all wetlands contained dissolved oxygen levels which were sufficient for aquatic animal function (table 1.3).

Most of the wetlands held moderate to high water levels throughout the surveys (figure 1.1). Lower Wanganella swamp (unregulated Forest creek reach) completely dried following the October surveys and the Rhyolla wetlands (unregulated Forest creek reach) remained dry throughout both surveys. High aquatic vegetation coverage was recorded at Sheepwash anabranch and Cocketgedong (Colombo reach), Wangamong (mid-Billabong) and Bundure (mid Yanco reach). The lack of aquatic vegetation recorded for Wanganella lower and the Rhyolla wetlands related to the lack of water reaching and persisting in the lower reaches.

Table 1.3 Water quality measured at each of the wetlands, averaged from three replicate readings per survey (in association with the frog surveys, October and December 2017). Gaps in the data occur when the wetland was dry and Lower Wanganella swamp (WANL) was only surveyed once due to wetland drying.

Reach	site	No. surveys	Temperature (°C)	Conductivity	DO%	DOmg	pH	Turbidity	Depth (m)
Mid-Yanco	BROO	2	21.59	0.07	108.85	9.36	7.01	233.92	0.23
Mid-Yanco	BUND	2	21.16	0.08	98.97	8.55	7.09	150.50	0.26
Mid-Yanco	WILS	2	26.07	0.15	120.22	9.53	7.36	239.17	0.25
Mid-Yanco	YANK	2	20.19	0.10	86.18	7.57	6.90	352.33	0.27
Colombo	CCKT	2	21.35	0.09	71.68	6.22	6.84	100.50	0.34
Colombo	CNNG	2	24.03	0.09	110.35	9.09	7.11	85.58	0.48
Colombo	SHEE	2	20.49	0.06	114.23	10.01	7.27	207.67	0.39
Mid-Billabong	HART	2	23.46	0.13	113.93	9.76	7.34	355.50	0.32
Mid-Billabong	WANG	2	20.78	0.18	64.48	5.64	6.81	234.33	0.33
Forest (reg.)	FRST	2	21.51	0.14	95.33	8.22	7.20	298.83	0.28
Forest (unreg.)	WANL	1	21.74	0.29	124.15	10.62	6.94	107.84	0.21
Forest (unreg.)	WANU	2	23.28	0.36	109.35	9.19	7.75	143.60	0.25
Forest (unreg.)	RHYO	0	-	-	-	-	-	-	-
Forest (unreg.)	RYLH	0	-	-	-	-	-	-	-
Lower-Billabong	QUIA	0	21.60	0.16	120.73	10.29	7.29	229.50	0.34

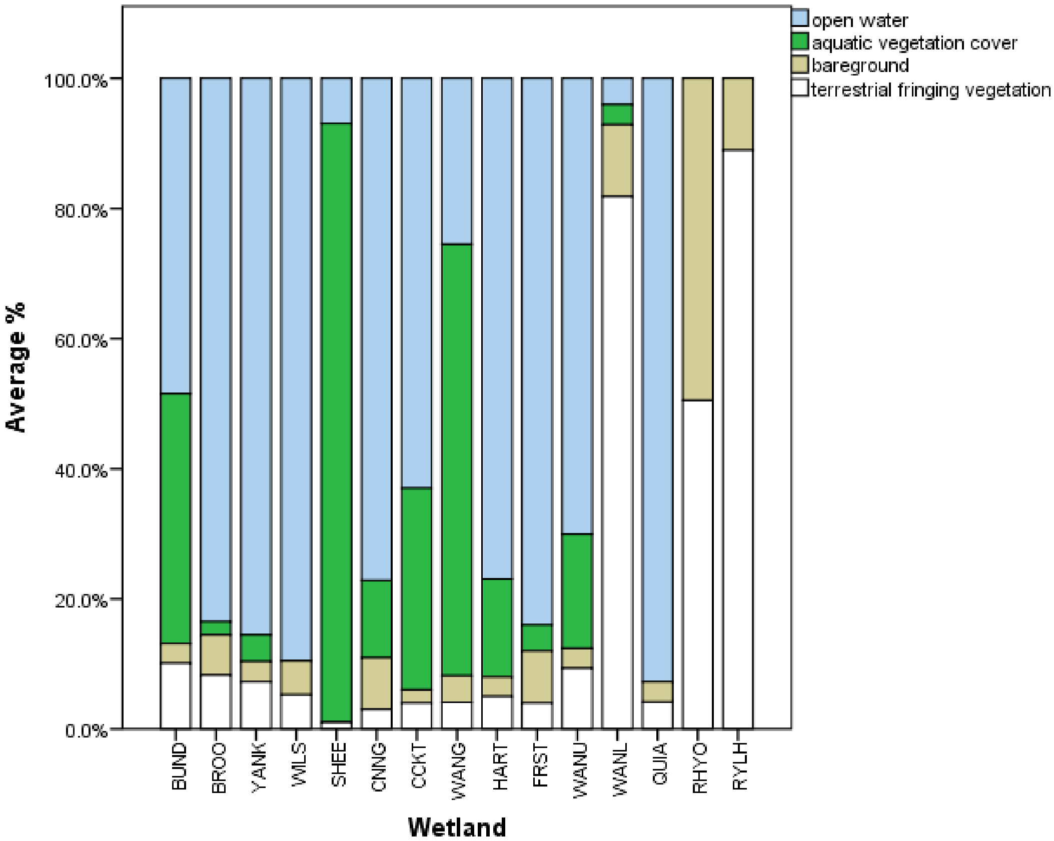

Figure 1.2. General wetland habitat characteristics, average percent open water, aquatic vegetation, bare ground and terrestrial fringing vegetation.

The sites which contained the highest percentage of aquatic vegetation (figure 1.2: Bundure, Wangamong, Sheepwash anabranch and Cocketgedong,), also displayed a high diversity of aquatic vegetation types (figure 1.3). Tall emergent species such as cumbungi were common; short emergent species included short spike rush, *Eleocharis sp*. (covering a vast area at sheepwash anabranch), water couch, juncus and slender knotweed; low growing species included water primrose and common starwort; submerged species included ribbon weed and milfoil; and free floating species included azolla. Lignum was also common in the lower reaches of the catchment.

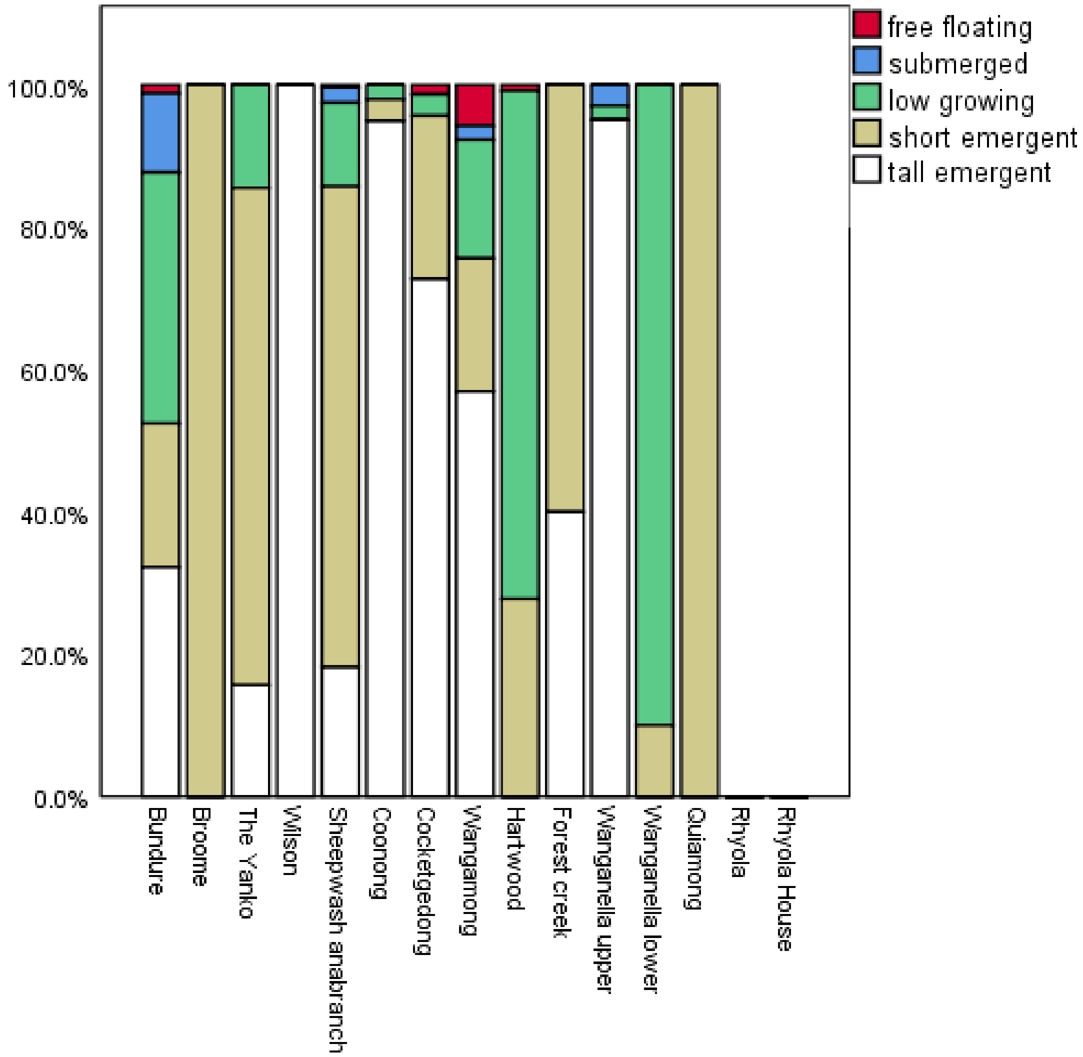

Figure 1.3. Where present, average percentage of each aquatic vegetation type (free floating, submerged, low growing, short and tall emergent) per wetland. N.b. the total percentage of aquatic vegetation varied significantly across the wetlands (see figure 1.2 for overall percentage).

Discussion

Overall, the Yanco –Billabong systems support a number of high quality ox-bow lagoons and wetland depressions, which although smaller than those on the main Murrumbidgee River Channel, support wetland plant communities with similar diversity and composition. The shallow nature of many of the lagoons in this system may also contributes to a higher percentage cover of aquatic species, with a comparably high diversity aquatic species when compared to those in the mid-Murrumbidgee. This is evidenced by the range of aquatic plant growth forms (types) at high quality sites including Sheepwash anabranch and Wangamong (plate 1),

Plate 1 Diverse, high quality aquatic plant communities at Wangamong (top) and sheepwash anabranch (bottom)

Objective 2: Frog species occupancy and calling

Introduction

Wetland inundation can shape frog communities directly through the availability of free standing water for tadpoles and indirectly by influencing vegetation communities and water quality. Frogs respond to the availability of water at both long and short time frames. Over long time frames, the frequency of inundation determines how often frog species can breed, as well as their capacity to survive during dry periods (availability of persistent refuge habitat). Over short time frames, breeding is also driven by the seasonal timing and duration of water availability.

Different frog species breed at different times of year in response to distinct cues e.g. seasonal rainfall, temperature and inundation. Tadpole development times also vary, for example, eastern sign bearing froglets can develop rapidly, under ideal conditions completing metamorphosis within weeks whereas southern bell frogs require 4-6 months to fully metamorphose. The majority of frog species in Australia require free standing water for their entire larval development phase. Subsequently, repeated failure of complete metamorphosis can result in local declines and extinctions. While wetlands which hold water for longer/permanent durations are important for species with longer tadpole development phases, such habitats also provide optimal habitat for tadpole predators such as fish.

Vegetation plays an important role in providing protection from predators and climate, as well as scaffolding for egg masses. Vegetation influences the suitability of habitat for frogs as different species have different habitat requirements. For example, tree dwelling species such as Peron's tree frogs require standing timber or tall standing vegetation, while eastern sign-bearing froglets require fringing vegetation along the banks of wetlands. A higher proportion of wetland vegetation and a higher diversity of vegetation species can therefore provide habitat for a wider range of frog species (Shulse et al., 2012). Poor water quality can also impact growth and survival of tadpoles, both directly and through its effect on other organisms e.g. their food source (Relyea, 2005, Hatch and Blaustein, 2000).

Given their dependence on both aquatic and surrounding riparian and terrestrial habitat, frogs are considered important indicators of wetland health. Frog species diversity and composition, as well as changes in these measures can thus provide important insight into wetland ecosystems. For most species, male frogs call to attract their female counterparts, with species displaying their own unique call. This behaviour also provides the opportunity to measure calling (attempted breeding activity) in response to natural resource management actions (e.g. environmental watering) on a much finer temporal scale (hourly, daily) via acoustic monitoring.

Current knowledge of the frog species residing throughout the Yanco-Billabong system is lacking with only a limited number of records available for part of the system, as per NSW Wildlife Atlas (OEH). In this section, frog species diversity and abundance (using survey observations as a proxy) are described for the Yanco, Billabong and Colombo creek systems. The observations of this study are also compared with historical records available for the study region as a way to describe the likelihood of absence by other species previously recorded. Daily frog species calling activity is also described at a subset of the wetlands to compare how the different wetland habitats supported frog species breeding over a broader temporal scale.

Survey methods

Frog surveys

Frogs were surveyed after dark, along two timed 10 minute transects conducted along the water edge and through surrounding terrestrial habitats within 10 metres of the water. The number of calling individuals for each species was recorded along the two transects (2 counts total). Five minutes of sweep netting was completed within shallow, vegetated (where available) areas of each wetland, during each survey to gain an idea of whether breeding activity indicated by calling activity resulted in tadpoles and what other taxa occurred in the wetlands. Vegetation communities were evaluated through rapid assessment of three 10 metre belt transects, with the percentage cover of each structural component (e.g. submerged, free floating, attached floating or emergent) and dominant species recorded through rapid assessment of riparian and wetland vegetation. Water quality (temperature (˚C), conductivity (mS/cm), dissolved oxygen (mg/L), pH and turbidity (NTU)) was measured using a hand held multi-parameter water quality meter (U-50 Series, HORIBA Ltd., Kyoto, Japan) at three points within each waterbody at a depth of at least 30 cm, or wherever possible in shallow waters. The meter was calibrated according to manufacturer specifications.

Acoustic monitoring

Call recorders, SM3 bioacoustic recorders (Wildlife Acoustics, Inc.: Maynard, USA) were deployed at four of the sites, spread along the system. Recordings were made at hourly intervals for a duration of 5 minutes (per hour). Species call recognition models developed using the software program SongScope were used to automatically extract when each of the species called during the entire hourly dataset (October 2017 – February 2018) at each of the sites. Calling data was then validated and reduced to number of calls per day, allowing for identification of peak calling activity.

Results

Frog diversity and abundance

Eight frog species were identified throughout the system including: three ground dwelling species, spotted marsh frog (*Limnodynastes tasmaniensis*)(14 of 15 sites), barking marsh frog (*Limnodynastes fletcheri*) (7 of 15 sites) and eastern sign-bearing froglet (*Crinia parinsignifera*) (12 of 15 sites); three burrowing species, eastern banjo frog (*L. dumerilii*) (7 of 15 sites), Sudell's frog (*Neobatrachus sudelii*) (5 of 15 sites) and inland banjo frog (*Limnodynastes interioris*) (1 of 15 sites); one tree dwelling species, Peron's tree frog *(Litoria peronii)*(13 of 15 sites); and one threatened species, the southern bell frog (*Litoria raniformis*) (2 of 15 sites).

Overall, there was no significant difference in the number of species recorded between the five reaches (between 3 and 7 species detected per reach). However, forest (unregulated section, the Rhyolla wetlands) was very dry and supported fewer species (Figure 2.1). Highest frog species diversity was recorded at Bundure (mid Yanco reach) and Wanganella upper (unregulated Forest creek reach). Importantly, Bundure and Broome in the mid Yanco, supported southern bell frogs which are an endangered species and are known to be very sensitive to wetland condition.

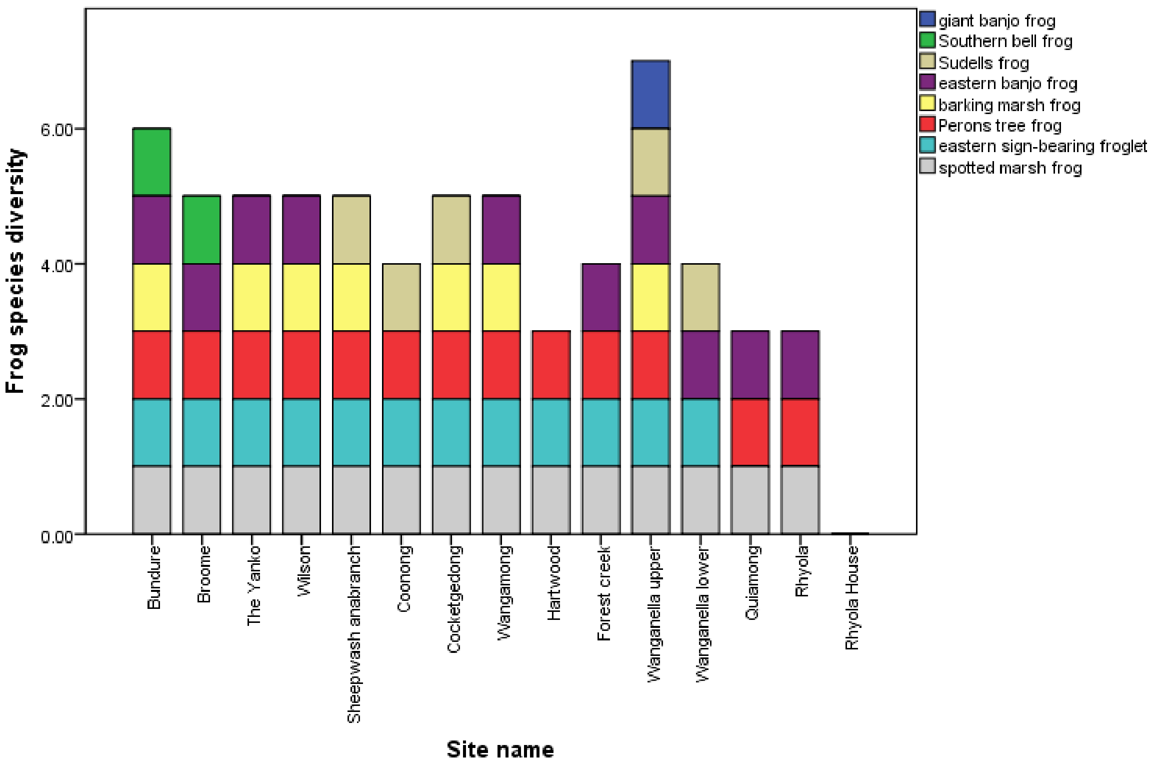

Figure 2.1. Summary of the frog species detected at each of the 15 wetlands surveyed.

There was a significant relationship between frog species diversity and aquatic vegetation complexity (number of aquatic functional groups) (figure 2.2). Frog species diversity increased with increasing vegetation type (structural) complexity ($F=6.1$, $p<0.05$, $R^2=0.32$).

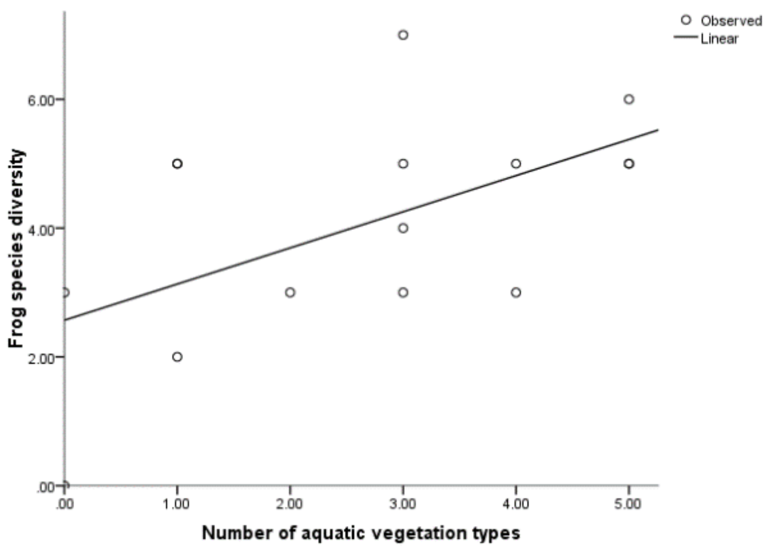

Figure 2.2. Linear relationship between frog species diversity and the number of different aquatic vegetation types (e.g. floating, submerged, emergent).

Evidence of frog breeding

Egg masses and tadpoles were observed at six of the 15 sites surveyed via sweep netting during both the October and December surveys. Marsh frog tadpoles were the most commonly observed species (detected at one third of sites) while eastern sign-bearing froglet and Peron's tree frog tadpoles were only observed at one and two sites (respectively).

Table 2.1 Evidence of frog breeding (egg masses and tadpoles) observed during the October and December 2017 surveys.

Site	Common name	Scientific name	Egg masses	Tadpoles	Stage of development (tadpoles)
BROO	marsh frogs	*Limnodynastes spp.*	6		
CCKT	Peron's tree frog	*Litoria peronii*		1	29
SHEE	eastern sign-bearing froglet	*Crinia parinsignifera*		9	28
	marsh frogs	*Limnodynastes spp.*		34	28-33
WANG	marsh frogs	*Limnodynastes spp.*	6		
	Peron's tree frog	*Litoria peronii*		1	29
WANL	marsh frogs	*Limnodynastes spp.*	20		
WANU	marsh frogs	*Limnodynastes spp.*	6		

Daily frog calling between October 2017 and February 2018

Call recorders were deployed and data extracted from two sites (Bundure and Wanganella lower) and set to record for 5 minutes every hour, from the 25th October 2017 until 7th of February 2018. Overall, frog calling was higher at Bundure where moderate to high water levels persisted, compared with lower Wanganella swamp which was dry by December 2017 (figure 2.3). Furthermore, a higher diversity of frog species called for longer durations at the permanently available Bundure site.

Peron's tree frog was the most active calling species at Bundure, calling on 95% of the recording days whereas spotted marsh frogs called most frequently at lower

Wanganella (82% of the recording days). At Bundure, southern bell frogs, barking marsh frogs and spotted marsh frogs called on 40- 60% of the recording days, and eastern sign-bearing froglets called on 13% of the recording days. In comparison, at lower Wanganella (aside from spotted marsh frogs), the three other resident frog species called for much shorter periods of time within the monitoring period (Peron's tree frog: 9%, Eastern sign-bearing froglet: 16% & barking marsh frogs: 18%).

Southern bell frogs called at Bundure on 43 of the 106 recording days. Calling by this species occurred on (roughly) a daily basis for three distinct periods during the overall monitoring with between 2-3 week breaks between (calling occurred from (1) 25/10/27 until 12/11/17, (2) 25/11/17 until 12/12/17 and (3) 16/1/17 until 3/2/2018) (figure 2.3).

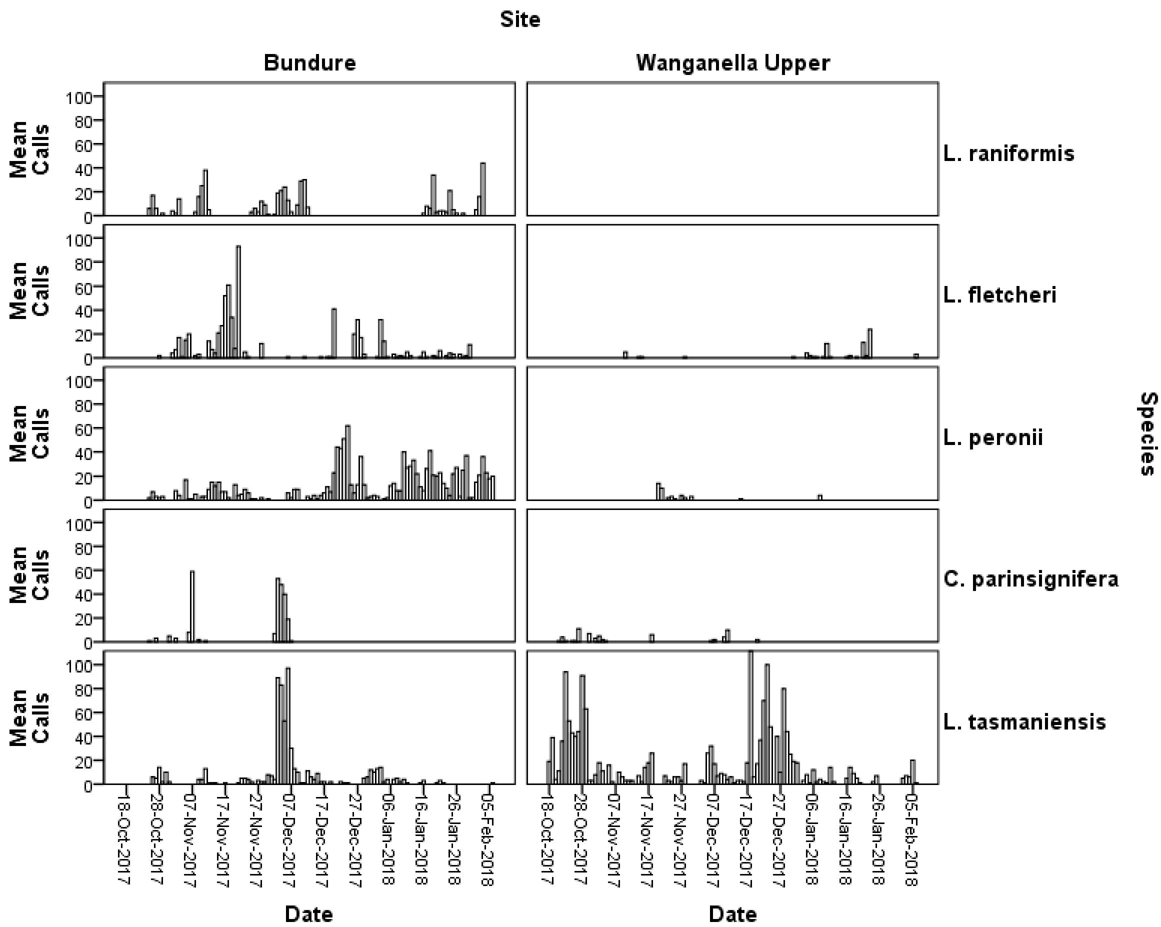

Figure 2.3. Daily frog species calling at Bundure and lower Wanagnella swamp between 25th October, 2017 and 7th February 2018.

Discussion

Frog diversity and abundance

Frogs were identified at all wetlands except for Rhyolla wetlands (RYLH) which was dry during both the October and December surveys. Many frog species will move to alternative aquatic habitats such as nearby farm dams and creeks when wetlands are dry so it is quite likely that frogs will recolonise this wetland when it fills. However, in the absence of nearby aquatic habitats, extended dry phases can lead to local declines and even extinctions (Mac Nally et al., 2014). Aside from the endangered southern bell frog, the frog species observed are known to be widespread and common in the broader, south east Australian landscape. The high numbers of spotted marsh frogs, eastern sign-bearing froglets and Peron's tree frogs (where standing timber available), is similar to nearby regions e.g. (Healey et al., 1997, Hazell et al., 2004, Hazell et al., 2001, Wassens and Maher, 2011, Mac Nally et al., 2009). These species are known to be habitat generalists meaning that they can live in a wide range of habitats within their distributional range.

A key finding of this study was observation of the Southern bell frog, with small populations of calling individuals observed at two sites along the mid-Yanco creek (at Bundure and nearby Broome). The southern bell frog is listed as endangered in NSW (Biodiversity Act 2016) and Vulnerable federally (EPBC Act 1999), although populations occur through rice growing areas in the nearby Coleambally Irrigation Area. Southern bell frogs breed in spring and summer and show preference for shallow, warm water with abundant aquatic vegetation and their tadpoles have a long development period of 4-6 months. Our surveys were not intensive enough to detect breeding activity by southern bell frogs at these two wetlands although the presence of calling individuals suggests that breeding may occur if hydrological conditions are suitable.

The very heavy rainfall preceding the December surveys allowed for observation of three burrowing species across the system (eastern banjo frog, giant banjo frog and Sudell's frog), these species emerge from underground following heavy rainfall to breed and are typically less dependent on riverine inundation of wetlands. The availability of aquatic habitat is also important to observing frogs. Subsequently, a much lower number of frog species and individuals were observed at the two

Rhyolla wetlands, in the unregulated Forest creek system, likely due to the lack of available aquatic habitat. Although not identified during these surveys, another burrowing species, the crucifix frog *(Notaden bennetti)* was observed by a landholder along the Nile creek (Oakville 676 Mabins Well Road Conargo), further north within the Billabong Yanco region.

Apart from the wetlands within the unregulated Forest creek reach, the other four system reaches contained at least some wetlands where frog species diversity and abundance was observed to be high (using the survey records as a proxy).

Frog species diversity

A higher diversity of frog species were observed at wetlands with a higher diversity of aquatic vegetation types (e.g. submerged vegetation, tall standing emergent vegetation). Aquatic vegetation is important to frogs as it provides food, protection from predators. Different frog species display different habitat requirements, e.g. tree frogs require tall standing timber or vegetation whereas ground dwelling species require ground level vegetation for refuge. In this way a higher diversity of habitats fosters higher diversity of frog species.

Evidence of breeding

Evidence of frog breeding was only observed in the very early stages of development (egg mass to minor hind limb bud development) at six of the sites, and for three species, marsh frogs (spotted or barking marsh frogs), Peron's tree frogs and eastern-sign bearing froglets. Comparatively high numbers of tadpoles were observed at Sheepwash anabranch suggesting this site, characterised by high amounts of spike rush, is a key breeding site for frogs.

It is important to note that while sweep netting provide some indication of the presence of tadpoles and other taxa, such as fish, it is generally does not detect rarer species in larger wetlands (Wassens et al., 2016). Alternative survey methods including fyke netting which have a higher likelihood of detecting tadpoles are recommended for future surveys, particularly at wetlands likely to support southern bell frogs.

Three introduced fish species (mosquito fish, carp and gold fish) were identified across the system, with mosquito fish observed at 11 of the 15 sites. Adult carp were also commonly observed, spawning in the shallow waters, although again, the sweep net survey method was unlikely to provide a representative understanding of the larger system, particularly larger bodied fish. Fish species, particularly exotic species are known to be veracious predators of tadpoles.

Daily frog calling between October 2017 and February 2018

Call recorders were deployed at Bundure and lower Wanganella. Calling (a proxy for breeding) varied considerably between the two sites and this likely reflected the differing hydrologies. For example, Bundure held water for the entire monitoring period, while at lower Wanganella swamp, water levels were very low between October and December (2017) and largely remained dry until conclusion of the monitoring period (February 2018). Subsequently, Bundure supported repeated breeding attempts (indicated by calling activity) for each of the resident species considered (Peron's, spotted marsh, barking marsh, eastern sign-bearing froglet and southern bell frog) during the monitoring period. Higher levels of calling by Peron's tree frog and southern bell frogs at this site also reflected the species preferences for more persistent aquatic habitat. In contrast, fewer breeding attempts were made by resident frog species at lower Wanganella and these typically occurred over shorter time frames. During the December surveys, following heavy rainfall, numerous spotted marsh frogs called from very shallow, rain-filled pugs made by cattle – the only source of water remaining in this wetland, reflecting their highly opportunistic breeding strategy. However, some of the calling by spotted marsh, barking marsh and Peron's tree frogs during December, January and February may be misleading as this site was dry when visited in early December 2017 and early February 2018. The calling detected may instead be heard from species using a nearby dam as a refuge. The calls during this time were generally quite distant and the acoustics of this site permitted the long distant travel of sound (sparse low growing vegetation). The hydrograph at Warriston Weir showed irrigation oversupply flows in January and March and this may have provided some aquatic habitat needed to cue these species to breed.

While other species occurred at both sites, e.g. the eastern banjo, giant banjo and sudells frogs, their call data has not yet been extracted due to time constraints. The acoustic monitoring allowed us to identify two frog species (barking marsh and Peron's tree frogs) which weren't observed during the two visual encounter surveys of lower Wanganella swamp, highlighting the value of this additional survey method for identifying seasonally active species in highly variable (ephemeral) systems.

Calling by southern bell frogs

The pattern of calling by the southern bell frog at Bundure is of particular interest. This species displayed consistent daily calling for roughly 2.5 weeks at a time, punctuated with two to four weeks of no calling activity. The observed patterns of non-calling may by behavioural, or may reflect the migration of this species to alternative habitats (Wassens et al., 2008). Regardless, the repeated calling activity which was observed throughout the duration of the monitoring period highlights the importance of maintaining aquatic habitat at this site during this time of year. To foster successful tadpole development aquatic habitats would also need to extend for their entire tadpole development time (4-6 months).

Comparison with NSW Wildlife Atlas records

Within the general region studied, southern bell frogs have only previously been recorded due east of Sheepwash anabranch at Buckingbong State Forest in 1979. For the other seven species recorded in this study, relatively few records have been made within the region studied, however the available records are consistent with the findings of this study. Four frog species previously recorded in the (general) area but not during this study, all are normally associated with rain fed wetland systems rather than persistent creeks and wetlands which were the target of this study. These were the common eastern froglet (*Crinia signifera*), Sloane's froglet (*Crinia sloanei*), Crucifix frogs (*Notaden bennetti)* and wrinkled toadlet (*Uperoleia rugosa*). The absence of the eastern froglet may be explained by the timing of surveys which probably missed the calling season of this species (known to call from March to October following rain). Only one record of Sloane's froglet is available in Buckingbong State Forest, 2005. Sloane's is listed as threatened species in NSW (Biodiversity Act 2016). It is typically breeds in small rain fed depressions, temporary wetlands and occasionally small farm dams. As was the case for eastern froglet our surveys fell well outside the normally breeding period for this species which typically occurs from June to September. Crucifix frogs are known to occur across the broader region, however, this species is notoriously difficult to detect only calling on one to two favourable nights (warm nights following heavy rain) and so these surveys may have just missed the narrow opportunity to observe this species. As previously mentioned, a crucifix frog was observed (photograph) by a landholder within the broader study area (Colin Bull, along the Nile creek). The wrinkled toadlet has also previously been recorded due east of the wetlands studied, near Lake Urana as recently as 2014 (and Buckingbong SF in 1979).

Objective 3: Wetland carbon

Introduction

Wetlands are among the most diverse and productive ecosystems on earth, supporting a large part of the world's biodiversity and providing a range of ecosystem services (Junk et al., 2013). Collectively, the world's wetlands are also one of the largest carbon sinks, accounting for an estimated 350-535 gigatonnes of carbon, representing an estimated 20-25% of the world's organic carbon (Mitra et al., 2005). As collectors of atmospheric carbon, wetlands play a crucial role in regulating carbon dioxide levels, offsetting the impacts of greenhouse gas emissions (Mitra et al., 2005). Soil carbon is a key determinant of the character and fertility of soils and is therefore broadly studied to understand soil health (Lal 2016). Carbon-rich soils are a key characteristic of wetlands, providing a range of essential services in both the dry and wet phase of the hydrological cycle including the regulation of water quality and the provision of nutrients for plants and animals (Cook et al 2009). Wetlands with higher soil carbon levels also retain more moisture and nutrients than degraded systems where these materials are instead shed into adjacent river networks (Finlayson et al. 2011), and are more tolerant of drying caused by either flow diversions or drought (Colloff and Baldwin 2010). However, with the global loss of at least 50% of wetlands since 1900 (Davidson, 2014) and the subsequent liberation of their accumulated carbon stores (Pendleton et al., 2012), protecting and/or restoring wetlands is needed to preserve global biodiversity and atmospheric stability (Mitra et al., 2005).

Wetlands are formed through the combined influences of hydrology and geomorphology and over time, they accrue organic materials through the growth, senescence and decomposition of terrestrial and aquatic vegetation. There are many factors that influence the amount and rate carbon sequestration by wetlands. Carbon is supplied to wetland soils in the form of non-living organic matter, initially derived from photosynthesis by plants (woody trees, shrubs, macrophytes and algae). This material is subsequently consumed by wetland biota, cycling between living biomass and non-living carbon stocks until it is either flushed out of the system by flow or lost to the atmosphere as a gas (e.g. carbon dioxide or methane; Kayranli et al. (2010)). In healthy wetlands, the balance between supply and decomposition favours the accumulation of organic matter in soil profiles with incomplete decomposition in anaerobic soils common to most wetlands (Kayranli et al., 2010). Vegetation condition and hydrology form two key drivers that regulate rates of supply and decomposition. Land clearing and the loss of flooding adversely impact the condition, health and character of wetlands. However, there is a limited understanding as to how hydrological regimes influence carbon stores, particularly for ephemeral wetlands.

This study seeks to benchmark the amount and composition of soil carbon across 15 wetlands in the Yanco Creek system. Future changes to carbon stores, through either ongoing degradation or recovery efforts, can be evaluated against this existing dataset.

Key objectives:

1. Determine carbon stock within the top 10cm of wetland soils
2. Identify differences in the composition of carbon in wetland soils
3. Determine whether hydrology or other covariates influence the amount and type of carbon

Methods

The field sampling protocol was adapted from the Wetland Carbon Monitoring Program Manual (Carnell et al., 2016a). Between the 25th of May and 16th of June 2017, five soil cores were collected from 15 wetlands, located across the Yanco-Billabong creek system (75 soil samples in total). Soil collection was stratified according to wetland elevation classes, with the five replicate soil cores collected across a range of depth classes at each wetland. At each of the soil carbon sample points, standing stock carbon was also measured via collection of all overlying vegetation and debris within a 25 cm quadrat – and later drying in the laboratory. A rapid visual assessment of vegetation type, proportion and height was also conducted for each quadrat.

As described by Carnell et al. (2016a), a 5 cm (inner-diameter) PVC pipe was hammered into the soil until the target depth was reached. A soil core depth of 10 cm was chosen based on the slow accretion rates known for the broader region

(Carnell et al., 2016a). This depth is expected to favour the 'contemporary carbon' in the soil profile that is most likely to reflect recent patterns of hydrology and land management as well as future management interventions. A rubber plug was applied to the top of the PVC pipe core to create a vacuum seal aiding core extraction. The core was then placed in a plastic bag to prevent moisture loss until later laboratory analysis. All samples were analysed by the Environmental and Analytical Laboratories, Charles Sturt University in Wagga Wagga.

Small amounts of soil were also collected from within the core for stable isotope analysis by running a small stainless steel measuring spoon along the extracted soil cores circumference (following an initial sweeping of the soil surface to prevent contamination) and samples were stored in sterile 15 ml vials. Clean, disposable nitrile gloves were used to prevent soil contamination. Samples were later dried at 70°C overnight to prevent microbial decay. Dried samples were then delivered to the Stable Isotope Laboratory, Australian National University, for analysis of C&N isotopes + N%-C% via the Dumas method of molecular weight determination.

Laboratory processing

Dry bulk density and total organic carbon analyses were completed by the Environmental and Analytical Laboratories, Charles Sturt University in Wagga Wagga. Bulk density was measured by drying the samples until a constant mass and then weighing to the nearest 0.001g. The same method was applied to the vegetation and overlying debris samples. Dry weight was used to calculate the sediment bulk density (weight (g)/volume (cm^3)). For the vegetation and overlying debris samples it was assumed that a high proportion of the sample would be carbon and so this was taken as a measure/indication of total carbon. For the 75 soil samples, total carbon (TC) was also determined via Loss on Ignition (at 550^0C).

Carbon stock calculations

Total sedimentary carbon stock calculations were adopted from Carnell et al. (2016a). However, because soil % carbon and soil LOI were comparatively low in the present study, the raw soil organic percent carbon values were used in subsequent analysis. We recommend that further studies in the Yanco Creek wetlands avoid using soil LOI as a surrogate for organic carbon concentration. Soil carbon density (g C cm^{-3}) was calculated by multiplying the dry bulk density by the percent carbon data provided by the stable isotope analysis. This total carbon density was then scaled up to estimate mega grams of carbon per hectare (Mg ha^{-1}; Carnell et al. (2016a). We note that one mega gram is the equivalent to one metric tonne.

Data analysis

Interpretation of results focuses primarily on describing the existing extent of measured variables so that future changes can be evaluated against this benchmark. Although there were no a-priori predictions, we tested for patterns in the data as an aid to explaining observed differences in measured variables among wetlands and relative sample depth. Differences among wetlands (n=15) were compared using a one way analysis of variance with sites within wetlands (n=5) as the term. For significant main effects, differences among wetlands were further were tested using a Tukey HSD pairwise comparison. Where necessary, data were square-root transformed to meet the assumptions of normality and homogeneity of variance prior to analysis. Differences among relative sample depth, which is confounded by wetland (i.e. depths are unequally spread across wetlands) and unbalanced (there are unequal samples among the different categories of depth) were tested separately using a non-parametric Kruskal-Wallis test.

Results

Standing stock vegetation, dry bulk density, and carbon

Standing stock vegetation ranged between 0 and 101.2 g C m^{-2} and differed significantly among wetlands ($F_{(14,61)}$=3.8327, P<0.01). Posthoc comparisons shows that values were significantly greater at Silver Pines than Coonong, Hartwood, Quiamong, Ryola, Ryola House, Sheepwash, Wanganella Upper, the Yanko, and Wangamong (Figure 3.1). Overall, standing stock vegetation appears higher in the mid-Yanco Creek wetlands than other reaches. There was no consistent relationship between standing stock vegetation and soil organic matter content (Figure 3.2).

Overall, soil dry bulk density (DBD) results ranged between 0.49 to 1.6 g cm^{-3}, averaging 1.14 (± 0.03) g cm^{-3}. Total percent organic matter (LOI) ranged between 2.9 and 23.4% of sample dry weight with a mean of 9.61% (±4.8) and % carbon between 0.5 and 8.4% of sample dry weight, averaging 3.1% (±2.3). As expected, dry bulk density was negatively correlated with both LOI and % carbon, with the least organic matter in sediments with a DBD of around 1.6-1.7 g cm^{-3}. Percent carbon (range 0.45-8.43; $F_{(14,58)}$=2.6498, P<0.01), nitrogen (range 0.1-0.9; $F_{(14,58)}$=2.3652, P=0.01) and the per hectare <10cm carbon stock (Mg C ha^{-1}; F=1010, P<0.01) differed significantly among wetlands. However, posthoc comparisons for all variables show only weak differences among wetlands, suggesting that organic matter stocks, and associated variables, vary more within wetlands than among them.

The nitrogen isotopic ratio ($\delta^{15}N$) was highly variable, and did not differ significantly among the surveyed wetlands ($F_{(14,60)}$=0.629, p=0.830). Carbon isotopes ($\delta^{13}C$) differed significantly among wetlands ($F_{(14,53)}$=5.3226, p<0.01) with the least depleted values from Wangamong (mid-Billabong Creek) and the most depleted from Wilson (mid-Yanco Creek; Figure 3.3). Note that post-hoc comparisons are made complicated by missing values where the analytical method was unable to determine usable data.

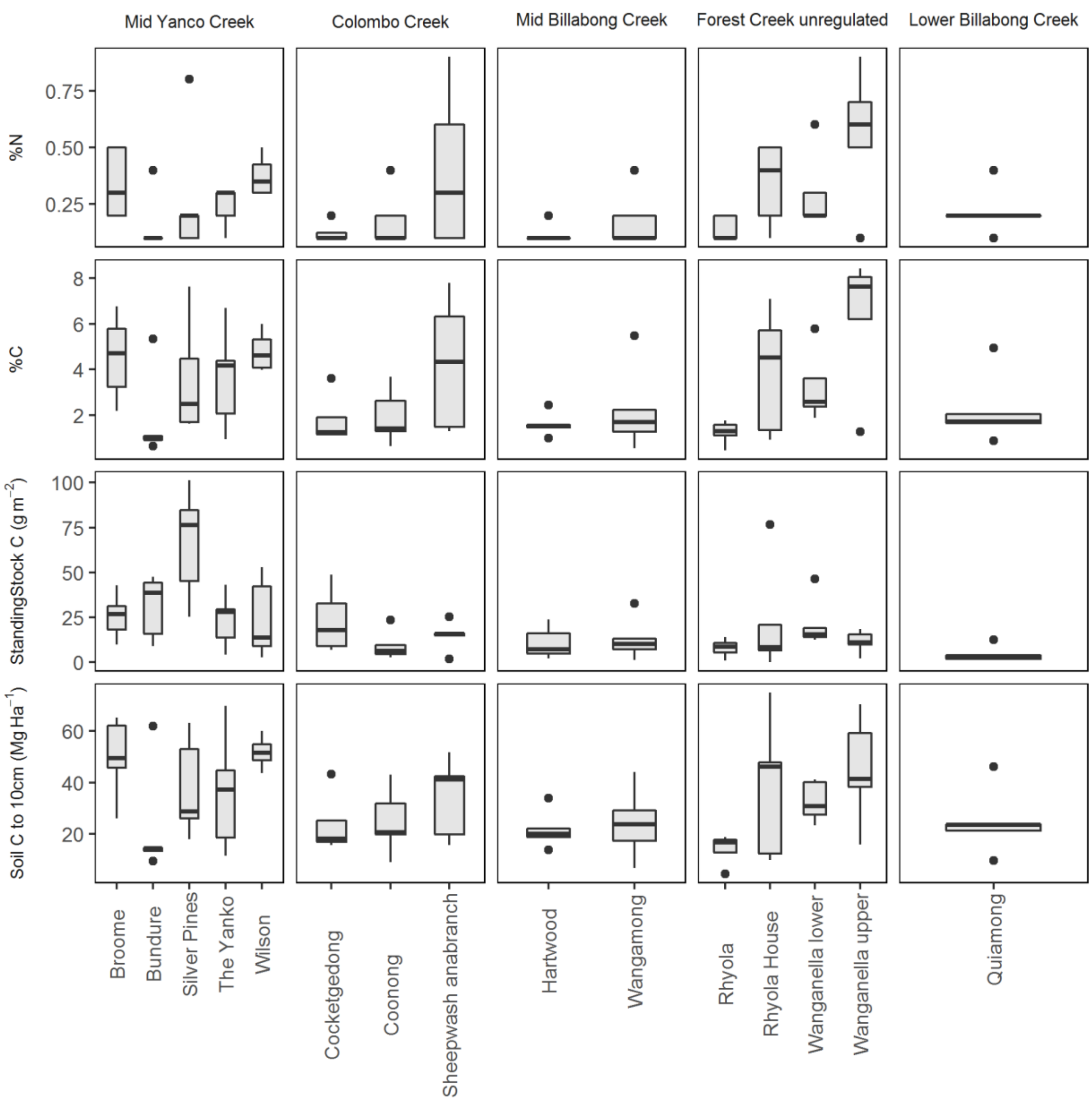

Figure 3.1 A box and whisker diagram showing average soil organic matter and carbon data for <10cm (15 wetlands; n=5) grouped according to reaches as per Alluvium (2013).

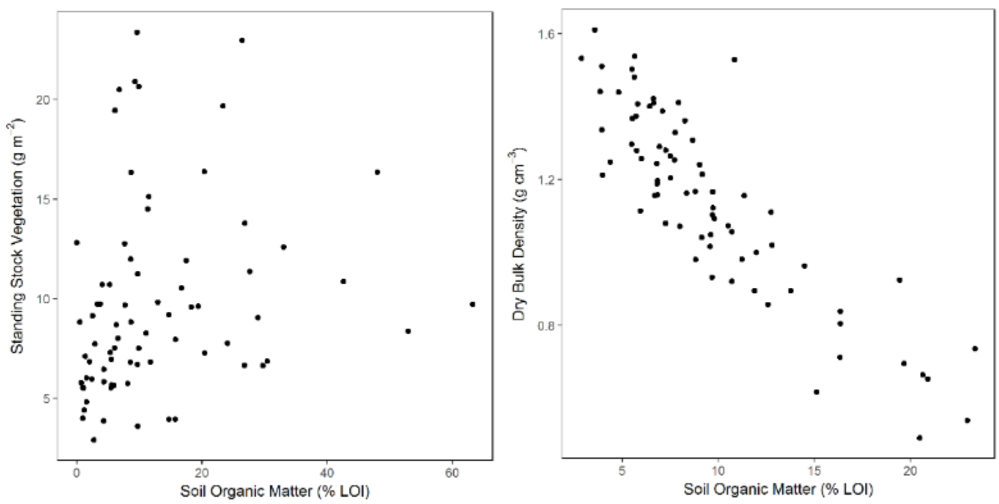

Figure 3.1 Scatterplots of soil organic matter (as % loss on ignition) vs a) standing stock vegetation and; b) soil dry bulk density. Data are all 75 data points collected during the study.

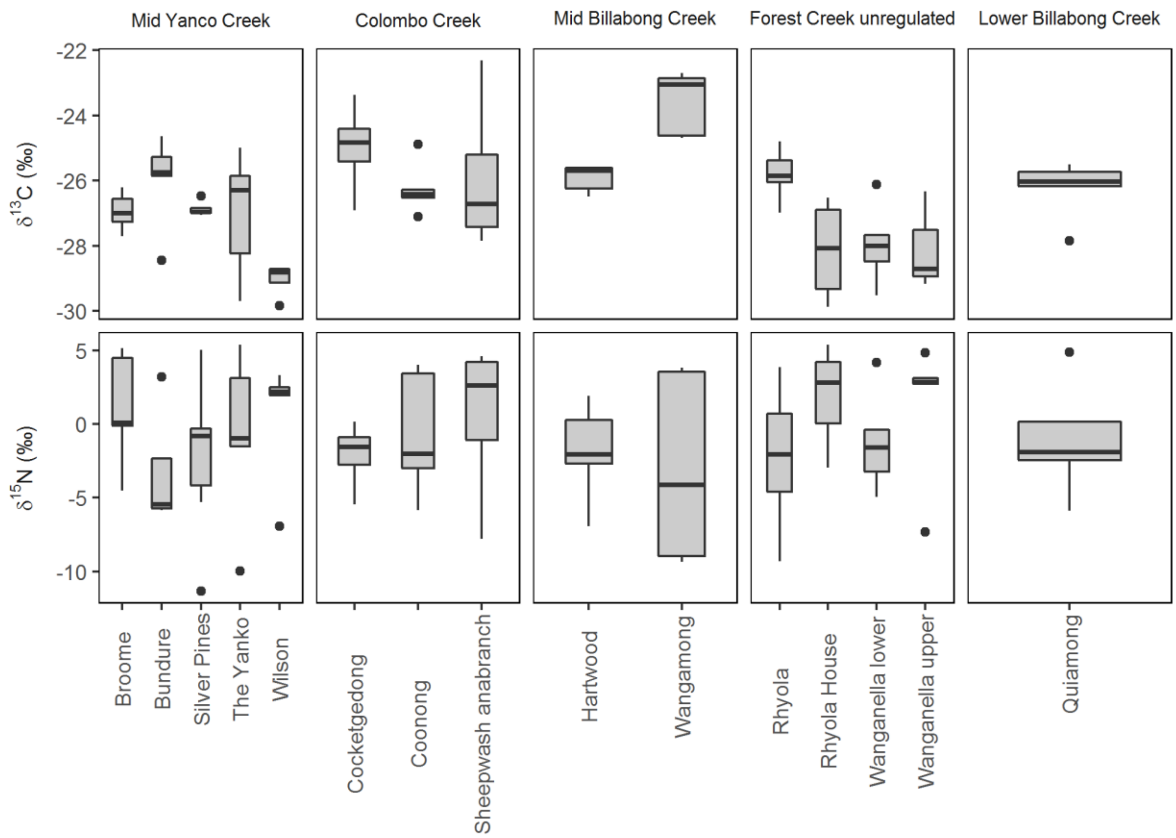

Figure 2.3 A box and whisker diagram showing average soil stable isotope data for <10cm (15 wetlands; n=5) grouped according to reaches as per Alluvium (2012).

Table 3.1 Summary of the mean (± SE) organic carbon metrics (carbon mass and stable isotope ratios) recorded for each wetland. Data are the mean of 5 samples collected from each wetland. *Reach classification as per (Alluvium, 2013).

Reach*	**Wetland name**	**Wetland area (Ha)**	**% LOI**		**% Carbon**		**Standing Stock Carbon (g m^{-2})**		**Soil C density (mg cm^{-3})**		**Total carbon stock (<10 cm depth; Mg)**	**δ^{13}C ‰**		**δ^{15}N ‰**	
Mid Yanco Creek	Broome	43.40	9.8	±1.3	4.5	±0.8	16.1	±3.5	49.7	±6.9	2157.6	-26.95	±0.2	1.02	±1.7
	Bundure	514.54	7.0	±1.2	1.8	±0.8	19.3	±4.9	22.8	±9.8	11728.8	-25.99	±0.6	-3.23	±1.7
	Silver Pines	44.78	10.8	±1.8	3.6	±1.1	41.8	±7.5	37.8	±8.6	1691.6	-26.86	±0.1	-2.23	±2.2
	The Yanko	32.60	10.2	±1.2	3.7	±1.0	14.8	±4.2	36.3	±10.2	1184.4	-27.01	±0.8	-0.80	±2.6
	Wilson	65.55	12.1	±3.0	4.8	±0.4	15.0	±6.1	51.7	±3.3	3390.3	-29.03	±0.2	0.60	±1.8
Colombo Creek	Coonong	38.47	6.4	±1.3	1.9	±0.5	5.8	±2.3	24.9	±5.7	959.3	-26.24	±0.3	-0.69	±1.9
	Sheepwash anabranch	38.18	12.1	±3.7	4.2	±1.2	9.1	±2.3	34.2	±6.9	1304.9	-25.90	±1.2	0.50	±2.3
	Cocketgedong	12.333	6.4	±0.7	1.8	±0.6	14.4	±4.9	23.8	±6.4	294.2	-24.99	±0.7	-2.11	±1.1
Mid Billabong Creek sub-reach 4b	Hartwood	8.25	6.5	±0.6	1.6	±0.2	6.7	±2.4	21.7	±3.3	179.4	-25.92	±0.1	-1.91	±1.5
	Wangamong	18.48	8.5	±2.0	2.2	±0.8	8.0	±3.3	24.3	±6.1	448.6	-23.59	±0.4	-3.01	±2.8
Forest Creek (unregulated)	Wanganella lower	61.49	10.3	±1.8	3.3	±0.6	13.4	±3.9	32.6	±3.4	2003.0	-27.95	±0.5	-1.21	±1.5
	Wanganella upper	342.98	16.6	±3.3	6.3	±1.3	7.1	±1.7	45.0	±9.3	15447.0	-28.07	±0.8	1.24	±2.1
	Rhyola	294.15	8.5	±0.4	1.2	±0.2	4.9	±1.3	14.1	±2.6	4152.8	-25.81	±0.3	-2.28	±2.2
	Rhyola House	50.37	12.1	±1.1	3.9	±1.2	14.1	±8.7	38.3	±12.1	1928.6	-28.14	±0.8	1.90	±1.5
Lower Billabong Creek	Quiamong	35.18	6.7	±0.7	2.2	±0.7	2.9	±1.2	24.9	±5.9	874.7	-26.25	±0.4	-1.05	±1.7

Wetland depth comparisons

Data were further analysed to test for the influence of relative wetland depth, which for this study is expected to correlate with the likelihood of inundation. Samples from each wetland were divided into one of four groups, according to the relative depth at which they were collected (Group 1: lowest elevation - inundated often; Group 2: moderate elevation - inundated regularly; Group 3: higher elevation - inundated occasionally; Group 4: outside area of analysis - most likely to be highest elevation - inundated only during flood conditions).

We found significant differences in $\delta^{13}C$ ‰ among depth classes ($\chi^2(3) = 14.9119$, $p < 0.01$). Pairwise tests reveal significantly more depleted $\delta^{13}C$ ‰ in the lowest depth class relative to the three shallower classes (pairwise: $p=0.16$, $p<0.01$ and $p<0.01$, respectively) while depth classes 2-4 did not differ significantly. Examination of the data (Figure 3.5) shows that samples containing the most carbon only occurred in the lower depth class. Similarly, total soil carbon per hectare also differed significantly among depth classes ($\chi^2(3) = 10.523$, $p=0.01$) although for this variable significant differences were only found between the lowest depth/elevation class and class 3 (pairwise $p<0.01$) and class 4 (pairwise $p=0.04$). Much of this pattern appears to be driven by the high variability of data in depth class 2 (Figure 3.5).

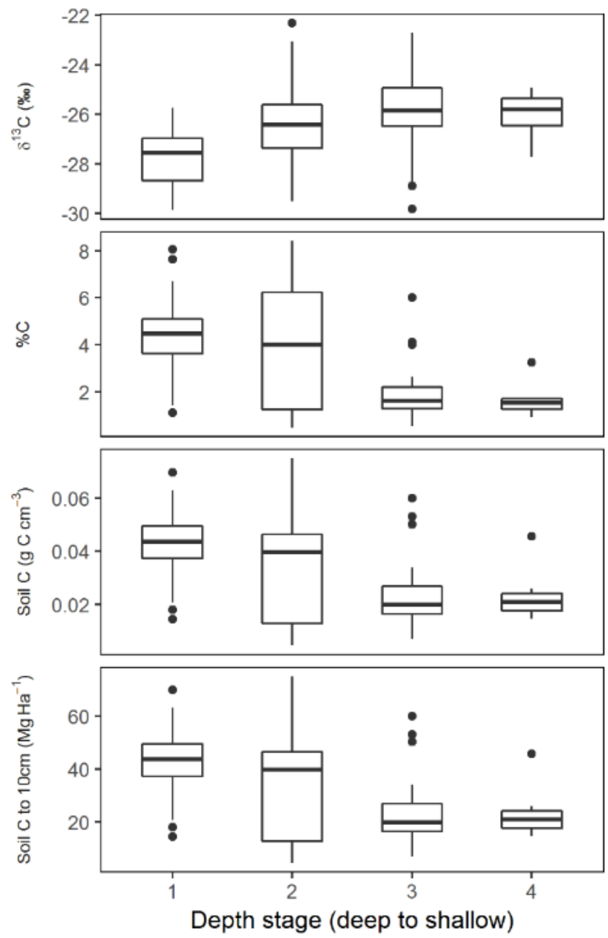

Figure 3.3 A box and whisker diagram showing the mean, range and variability of soil carbon data for <10cm (n=75 cores) grouped according to wetland depth, an indicator of hydrology (x-axis). 1: lowest elevation class, inundated often; 2: moderate elevation, inundated occasionally; 3: higher elevation, inundated occasionally; 4: outside the area of analysis, but taken to be the highest class.

Discussion

This pilot study provides a preliminary benchmark of the carbon stocks occurring within the top 10 centimetres of soil for 15 wetlands in the Yanco-Billabong creek system. The findings of this study suggest that these wetlands alone provide substantial carbon stocks, approximately 172,577 tonnes of organic matter representing a total carbon storage of 47,745 tonnes for the surveyed sites (note that tonnes are the equivalent of 'mega grams'). As described by Carnell et al. (2016a), such estimates have a high value in terms of their capacity to sequester carbon and offset CO_2 emissions.

Carbon accumulation and potential sources

Although we found little evidence of differences in soil accumulation among wetlands, much of the variability in the data occurred within individual wetlands. These early results indicate that the apparent depth of the sample point within each wetland was a more important driver of differences among samples than differences among wetlands or reaches. Samples that were located deeper within wetlands tended to have more carbon, and this carbon was generally more depleted in ^{13}C than samples from shallower locations. This pattern has been observed for other wetlands and has been attributed to longer periods of inundation (Luo et al. 2016).

Carbon on earth generally occurs as one of two different isotopes, carbon 12 and carbon 13, the latter being slightly 'heavier' and only accounting for around 1.1% of all the carbon on earth (G D Farquhar et al., 1989). These isotopes generally occur in a fixed ratio, as is the case for carbon dioxide found in the atmosphere and carbon-rich sediments. This basic ratio is taken to be the 'zero' value against which data from isotopic studies are evaluated (i.e. $\delta^{13}C$ 0 ‰). During photosynthesis, where atmospheric carbon dioxide is used to form organic carbon, plants have a tendency to filter out the heavier carbon 13 isotope. Some types of plants (called C_3 photosynthesisers) do this more strongly than others, and so the carbon they produce is more 'depleted' in ^{13}C (i.e. this organic matter has a more negative $\delta^{13}C$ ‰ value) than other types of plants (i.e. C_4 photosynthesisers).

The rationale for studying carbon stable isotopes in soils stems from potential differences and/or changes in the carbon isotopic ratio of different carbon source materials. For example, river red gum leaves are reported to have $\delta^{13}C$ ratios of ~-30‰ (see Bunn and Boon (1993), Burns and Walker (2000)). Some common wetland macrophytes can have similar $\delta^{13}C$ ratios (e.g. -27 for leaves from *Phragmites spp* – Burns and Walker (2000); -28.72 for *Eleocharis sphacelata* - Illes et al. 2010). Isotopic ratios for individual species can also be variable, changing over time (e.g. Bunn et al. (1997)). The $\delta^{13}C$ ratio is sometimes used to differentiate between C_4 and C_3 plants, with C_4 plants having a much more $\delta^{13}C$ enriched ratio of > -19 ‰ (e.g. Murphy and Bowman (2009)). Wetland management and restoration that favours a change in the amount or type of carbon source material (for example a net shift from aquatic macrophytes to terrestrial grasses) might therefore be reflected in a net shift in the isotopic ratio of soil carbon over time, particularly if that change relates to the addition or loss of carbon from a C_4, rather than C_3, source.

The data for the wetlands of Yanco Creek suggests less frequently flooded soils contain less organic matter, and that the carbon comprising those soils is from a less ^{13}C-depleted source. Without data for the individual potential sources we are currently unable to suggest the cause of this change. There are no exhaustive lists of common isotopic ratios for plants and animals of Australian wetlands, and because of potential spatial and temporal variation it is common practice for those ratios to be determined for individual studies. It is important to note that the processes that deplete soil organic matter can also reduce soil organic matter and increase $\delta^{13}C$. Menchichetti et al. (2015) found similar patterns in a long-term study of agricultural soils across Europe, and they speculated that such changes could be the result of microbial processes. It is likely that both processes operate in the Yanco-Billabong Creek system simultaneously.

Carbon stocks and hotspots

The data in the present study reveals lower total organic matter (average 9.6 %) and carbon (average 3.1) than Carnell et al. (2016b) who reported % carbon values between 0 and 55.85 % (averaging 7.72%) in floodplain wetlands. Although the average calculated by Carnell et al. (2016b) is based on a greater depth range (down to a depth of 140 cm) their study found that carbon % generally (but not always) decreased beyond a depth of 14 cm, the raw density data can be conservatively compared between the two studies. However, we also note that (Carnell et al., 2016b) sampled a wide range of wetland types across Victoria, with none classed as ephemeral wetlands (i.e. those that have a distinct drying phase, rather than permanent wetlands). Baldwin et al. (2015) studied soils of the less frequently inundated (ephemeral) wetlands in the Yanga National Park floodplain in the Lower Murrumbidgee (largely open river red gum (*E. camaldulensis*) forest), reporting an average LOI (i.e. soil organic matter) between 6.4 and 9.5%. Similarly, Reid et al. (2007) found soil LOI values were all <20% in a billabong adjacent to the Murray River. The data from the present study shows that the Yanco wetlands have carbon stocks similar to other wetlands in the region.

When scaled up to a total carbon load by wetland area, larger sites predictably contribute more to the overall carbon pool. Bundure had one of the lowest average soil carbon density of 1.8 %, but was also one of the largest sites (514.54 ha), so contributed 25% of the cumulative total carbon load accounted for by this study. Wanganella Upper, which is slightly smaller, stands out from the other wetland as a carbon hotspot because it both covers a large area (342.98 ha) and contains the highest average carbon density (6.3%), contributing 32% of the cumulative total carbon load. Given the large estimated carbon store already present in the Yanco Creek system and the potential relationship with inundation, careful consideration of future hydrological management could dramatically increase the size and value of this carbon store.

Objective 4: Waterbird diversity

Brief summary of the findings

Water bird surveys were conducted alongside the December frog surveys by Carmen Amos (NSW OEH). With a single 20 minute survey (morning or afternoon) conducted at each site. In total, 17 waterbird species were identified across the Yanco, Billabong and Colombo Creek systems (table 4.1). Pacific black ducks were the most widespread species, detected at 12 of the 15 wetlands. The next most common species were Grey teal and Sacred kingfisher, both detected at 10 wetlands; and Australian reed-warbler's at half of the sites. Overall waterbird diversity was highest at Wanganella upper, followed by Bundure and Cocketgedong, with four or less species recorded at the remaining wetlands (figure 4.1), No waterbirds were recorded at the sites Rhyolla (RHYO & RYH) and lower Wanganella swamp which were dry at the time of survey.

Waterbird breeding was observed at two of the wetlands with small broods of Pacific black ducks and purple swamphens observed at Wangamong creek (TSR), and juvenile pelicans at Wanganella upper. At Wilson's anabranch, approximately 90 to 100 inactive cormorant nests were observed, which were likely to have been established during the natural inundation in 2016-17. This observation indicates Wilson's anabranch as a previously important waterbird breeding site. Although not a wetland bird, the white-fronted chat is listed as vulnerable in NSW (*Biodiversity Act 2016*). Major threats to this species include predation (cats, foxes and rodents) and habitat modification, particularly associated with hydrological modification which is common throughout their broader geographic distribution. Further surveys are required following wetland inundation to better understand waterbird diversity in the system.

Table 4.1 Water bird species observed by Carmen Amos (OEH) during the December frog surveys. * indicates non-waterbird species listed as vulnerable in NSW (*Biodiversity Act 2016*).

Waterbird species	Number of sites observed
Australian Pelican	3
Australian Reed-Warbler	7
Australian Wood Duck	3
Black-fronted Dotterel	1
Black-tailed Native-hen	3
Dusky Moorhen	1
Eurasian Coot	1
Grey Teal	10
Little Grassbird	3
Little Pied Cormorant	1
Pacific Black Duck	12
Peregrine Falcon	1
Purple Swamphen	4
Sacred Kingfisher	10
Whistling Kite	1
White-bellied Sea-Eagle	1
White-faced Heron	4
*White-fronted Chat	1

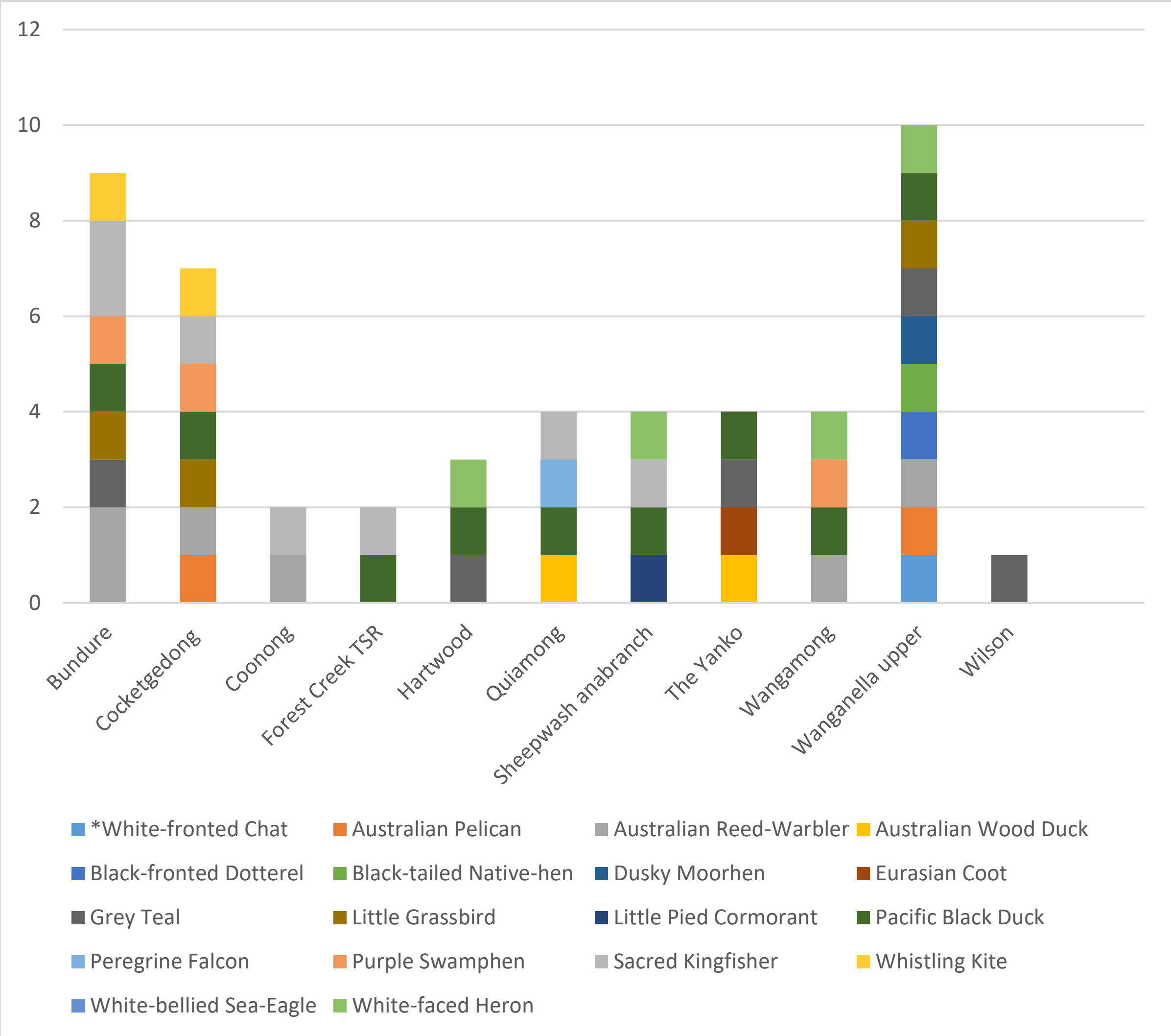

Figure 4.1 Water bird species richness across the 14 survey sites (Note that the two wetlands at Rhyolla (RHYO & RYH) and lower Wanganella swamp are excluded because no waterbirds were recorded.

Synthesis of findings & recommendations

This study provides an important benchmark of this diverse system against which, future changes can be evaluated against.

Frogs

The findings of this study suggest that the wetlands of the Yanco-Billabong creek system provide significant frog habitat. Surveys were conducted during conditions conducive to breeding activity (following heavy rainfall in early December) and so we are reasonably confident that most of the resident species were detected in this study. Wetlands with higher frog species diversity typically had more complex aquatic habitat characteristics, that is, a higher number of different types of aquatic vegetation (e.g. emergent, floating, submerged) corresponding with structural diversity. Based on this relationship, water delivery and wetland management actions which aim to improve the proportion and diversity of aquatic vegetation available in wetlands could improve levels of frog species occupancy throughout the system. For example, the Alluvium (2013) study describes the water requirements of the different water-dependent plant groups common throughout the catchment. Subsequently, catering to the water requirements of multiple plant groups (i.e. areas of temporary and more permanent water supply) along with stock exclusion/management is recommended to improve and sustain habitat complexity.

A key finding of this study was observation of the endangered southern bell frog, with small populations of calling individuals observed at two sites along the mid-Yanco creek. Reduced water flows and loss of wetland habitats have likely contributed to the decline of this species which was historically widespread across south eastern Australia. Subsequently, water delivery actions in the lower Murrumbidgee have improved populations of this species (Wassens, 2016) and so similar strategies could be applied in this system. Water delivery actions which provide aquatic breeding habitat for the southern bell frog, including increasing flows in spring and summer to ensure that water remains in wetlands long-enough to support tadpole growth and development (4-6 months) is recommended to sustain this small population. We also recommend that further surveys be conducted to confirm successful recruitment (i.e. recently metamorphosed individuals), demographic structure (size of individuals) and location of refuge habitats for this species. Generation of such data is important to secure southern bell frog populations in the Yanco creek system and inform future management interventions and environmental watering strategies (e.g. water depth and longevity).

Frog calling activity, at two of the sites provided insight into species breeding activity under different hydrological conditions. Calling by the same frog species varied considerably between the two sites considered and this likely reflected the different hydrologies of the sites. The wetland which permanently held water (at least in parts of the waterbody), Bundure, supported high levels of breeding activity (indicated by calling). At this site, multiple species displayed several peak calling events during the monitoring period. In contrast, frog calling at lower Wanganella swamp declined with wetland drying, the distant calls detected during the dry phase likely originating from a small dam refuge nearby. The southern bell frog (only heard at Bundure) called for three distinct periods suggesting that the hydrology of this site supported breeding by this species. While permanently available wetlands bear the risk of fish colonisation (predators of tadpoles), the provision of aquatic habitat during (at least) a larger portion of the monitoring period studied here (spring-summer) could extend the number and diversity of frog species breeding across the system (as observed at Bundure). We recommend continuous acoustic monitoring (5 minutes per hour) over a longer period of time (e.g. July until April) to gain more detailed information on temporal frog calling responses to hydrological regime. Using frogs as a flagship species, the insight gained could facilitate effective management of wetlands and dependant aquatic fauna. For example identifying when the different frog species are most active allows for water delivery to be timed to best meet their breeding, growth and development phases.

Carbon

The surveyed wetlands of Yanco-Billabong Creek system contain a vast 172,577 tonnes of soil carbon in the upper 10cm of the soil profile. It isn't known whether these soils would have yielded a higher density and loading of soil carbon prior to anthropogenic disturbance. However, considering the known impacts of land clearing, agricultural development and altered hydrology on soil carbon sequestration, it is reasonable to assume that soil carbon has declined and with it soil health and fertility.

There are no guidelines that tie specific measures of wetland soil carbon with ecosystem health or the loss of ecosystem services, particularly for ephemeral wetlands in southeastern Australia. Elsewhere, nearby natural or restored systems have been used as reference states for evaluation (e.g. Yu et al. 2017). For the Yanco Creek wetlands, we have no comparative data to tell us whether the observed range of soil carbon characteristics indicate poor health, although we now have evidence that broadly ties increasing soil carbon with wetland inundation frequency and/or duration. We conservatively expect that a more natural inundation regime (i.e. increased frequency and duration of floodplain inundation) for the Yanco Creek wetlands will decrease soil bulk density, increase percent soil organic matter and carbon density, and reduce soil $\delta^{13}C$ ratios. Recent evidence suggests that frequent, short duration inundation can adversely affect wetland soils and that longer duration flows (months) are required for increased flooding to benefit soil carbon accumulation (Baldwin et al. 2014, Luio et al. 2016), and this should be considered carefully when planning the restoration of flows to the Yanco Creek wetlands. Further work may be needed to determine the optimal inundation regimes, or if potential complementary activities such as revegetation and stock management, are required to support soil carbon outcomes.

Soil carbon responses to management are likely to be detectable over a period of 5-10 years, and so we recommend follow-up monitoring after this time, preferably at the same time of year to control for any unmeasured seasonal effects. In the absence of rehabilitation, follow-up sampling after 5 years will show whether soil carbon is changing over broad timescales, telling us whether the system is in a state of decline, no-change or improvement. Additional stable isotope samples could be collected at any stage to determine the sources of carbon contributing to the observed differences associated with wetland depth. Such a program would need to sample across both the dry and wet phases of the wetland hydrological cycle.

Waterbirds

Rapid, one off assessment of waterbirds was undertaken by NSW OEH in December 2017. By this time, water levels were often low and this is reflected in the relatively low diversity of waterbirds recorded. Interestingly, 90 to 100 inactive cormorant nests were observed at Wilson's anabranch, suggesting this as an important breeding site when aquatic habitat is available). Evidence of waterbird breeding was also observed (chicks and juveniles) at three of the sites which retained higher water levels. While not a waterbird species, the white-fronted chat is listed as vulnerable, a predominant threat being habitat modification.

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APPENDICES

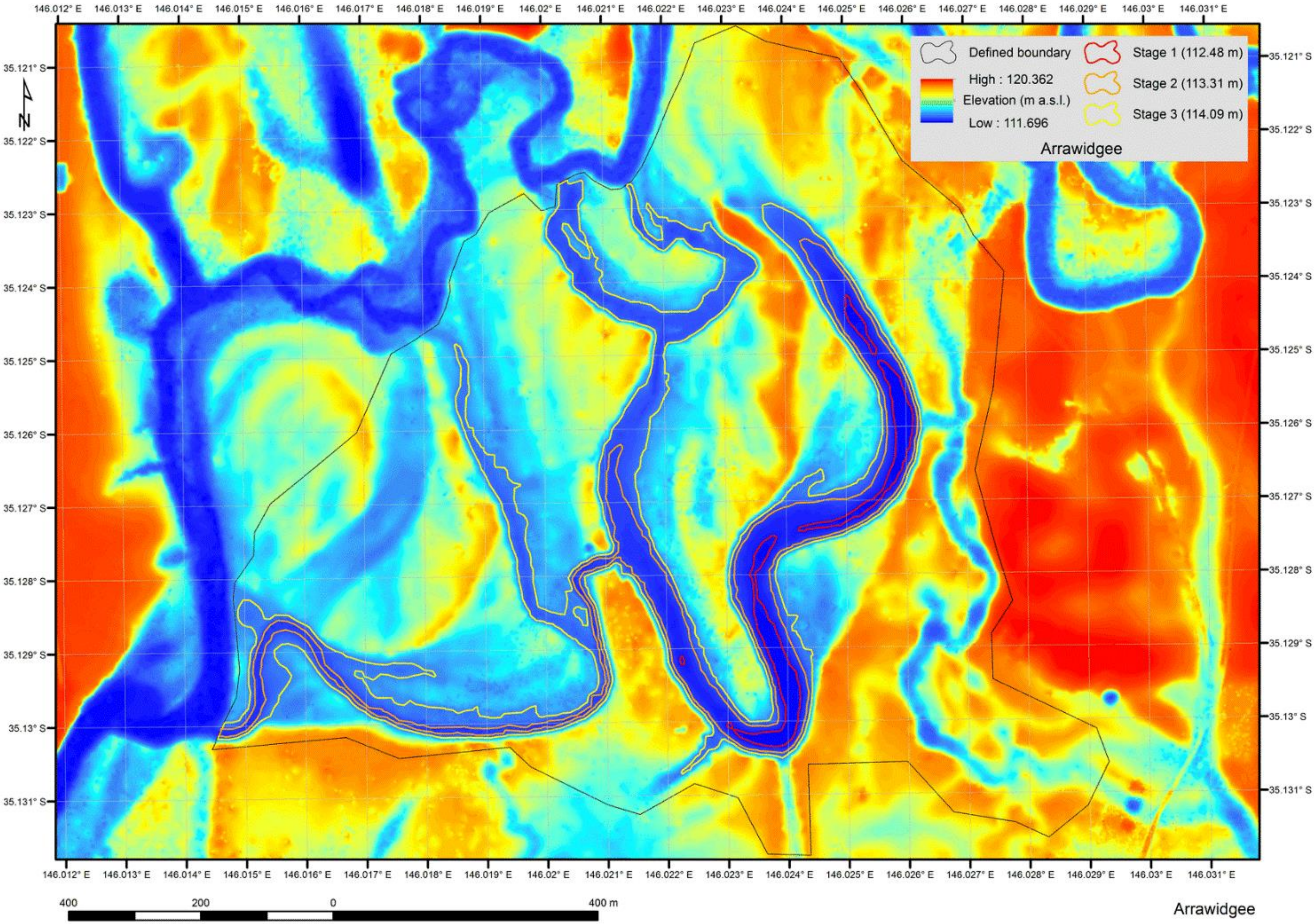
Appendix 1: Wetland maps

Two maps are presented for each site. The first map for each site presents the digital terrain map (DTM). An equalisation contrast stretch has been applied to the DTM data in these images to maximise the spatial variability in the display; the colour scale is therefore not necessarily linear and can exaggerate minor elevation differences. The second map for each site presents remotely sensed imagery of the wetlands sourced from NSW Land & Property Information (http://maps.six.nsw.gov.au/arcgis/services).

In the maps, the 'defined boundary' represents the spatial limits placed on the wetland area. Boundaries of inundation stages are provided based on an analysis of the DTM with the defined boundaries. Each stage represents a natural break in the inundated area with respect to water volume. For each subsequent stage, significantly larger volumes of water are required for further water level increases than was required within the previous stage. The boundary with the highest stage number represents the outer wetland boundary.

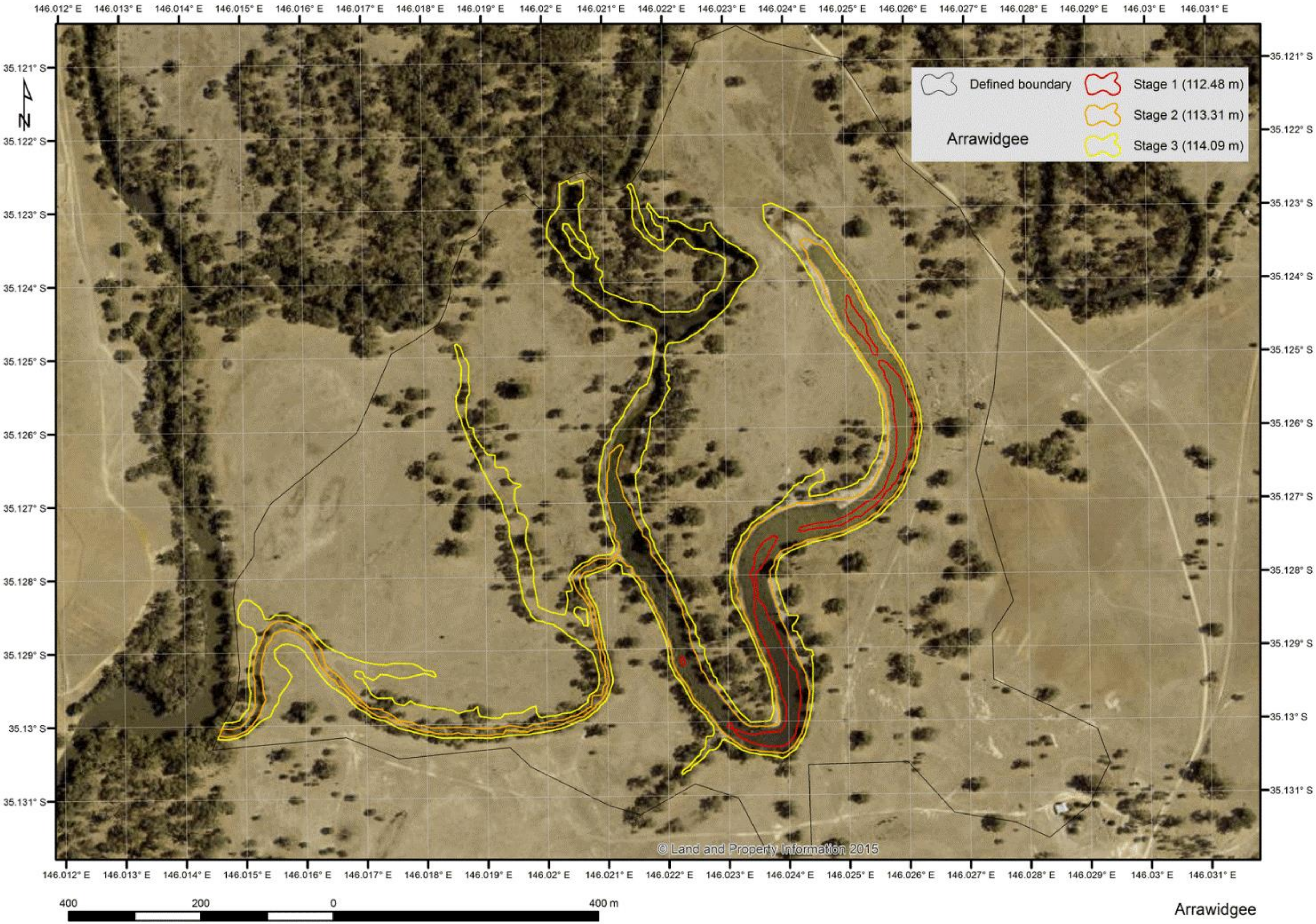
Locations of soil sample sites so far established are provided within each map.

The coordinate system for all spatial data and maps is Geocentric Datum of Australia 1994 (GDA94).



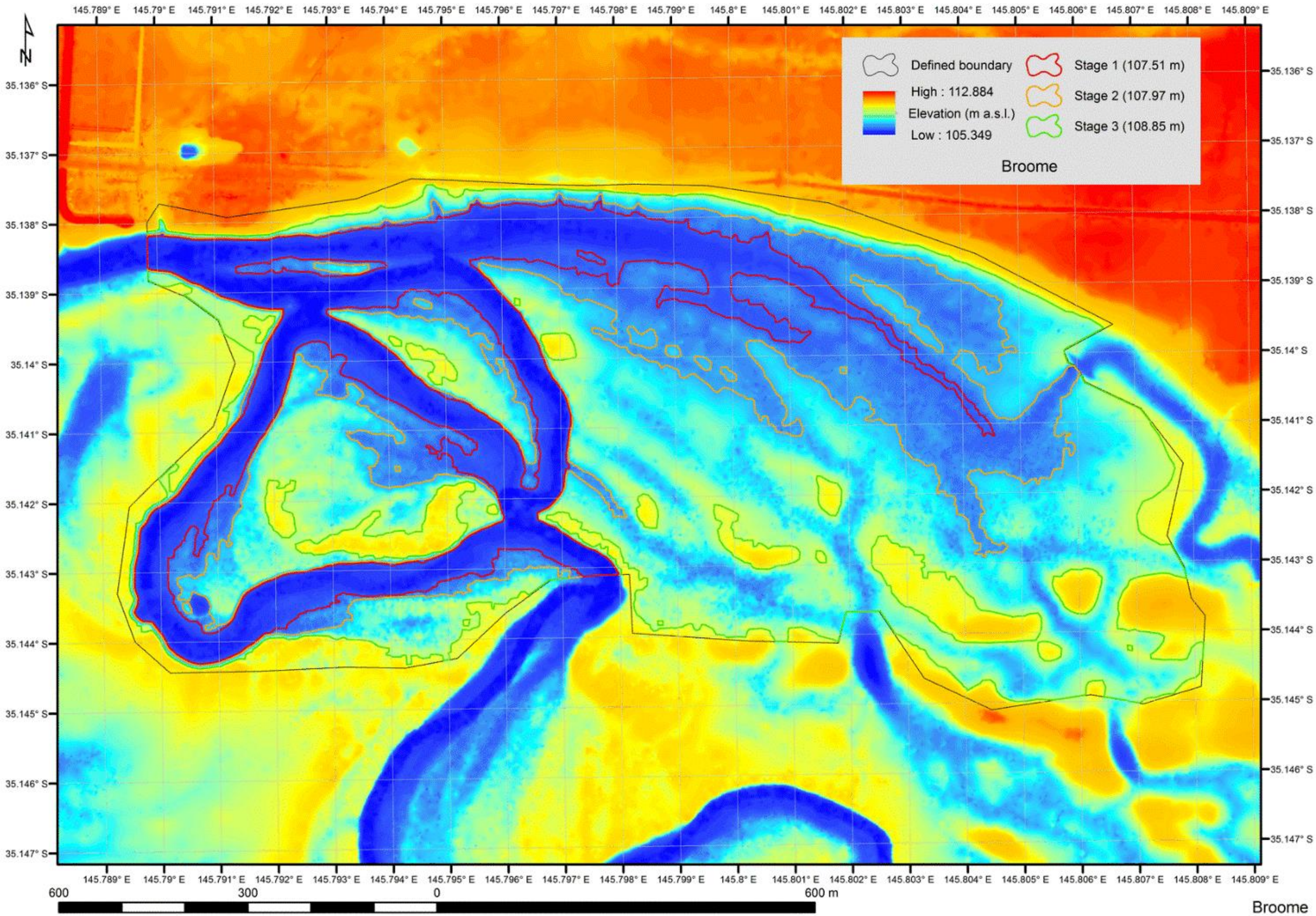
Defined boundary
High : 120.362
Elevation (m a.s.l.)
Low : 111.696
Stage 1 (112.48 m)
Stage 2 (113.31 m)
Stage 3 (114.09 m)
Arrawidgee
N
400
200
0
400 m

Arrawidgee



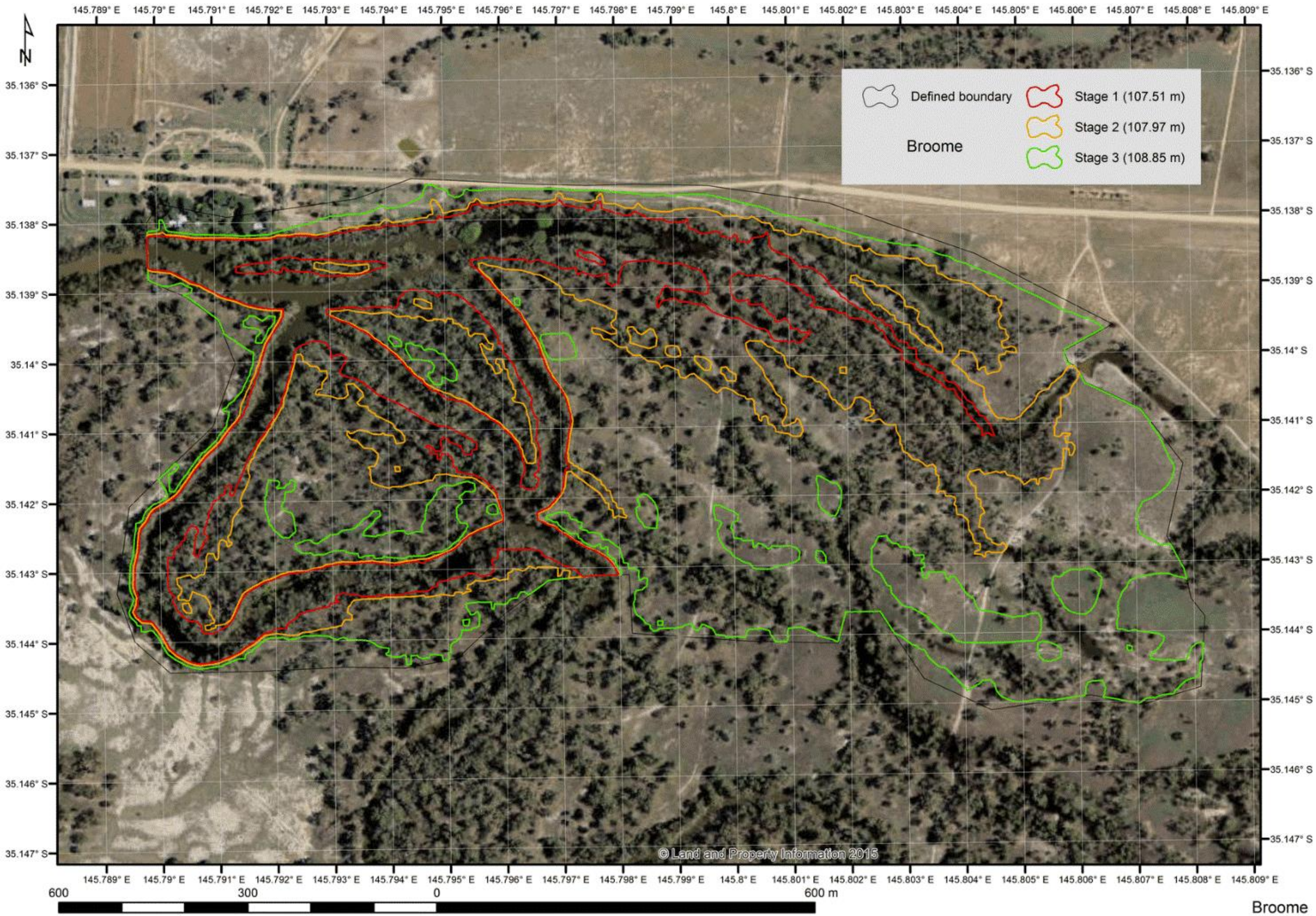
Defined boundary
Stage 1 (112.48 m)
Stage 2 (113.31 m)
Stage 3 (114.09 m)
Arrawidgee
© Land and Property Information 2015
400
200
0
400 m

Arrawidgee



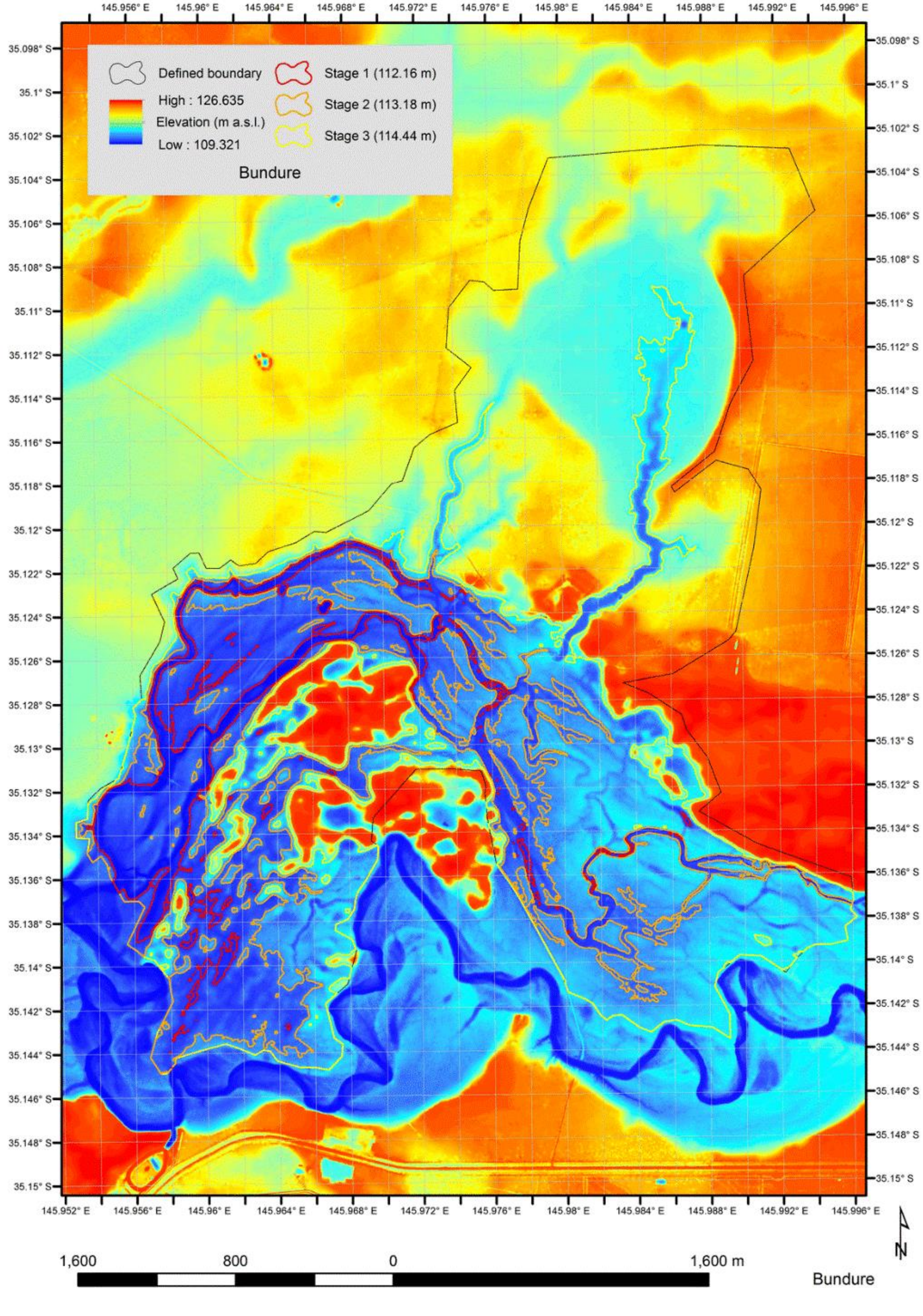
Defined boundary
Stage 1 (107.51 m)
High : 112.884
Stage 2 (107.97 m)
Elevation (m a.s.l.)
Low : 105.349
Stage 3 (108.85 m)
Broome
600
300
0
600 m

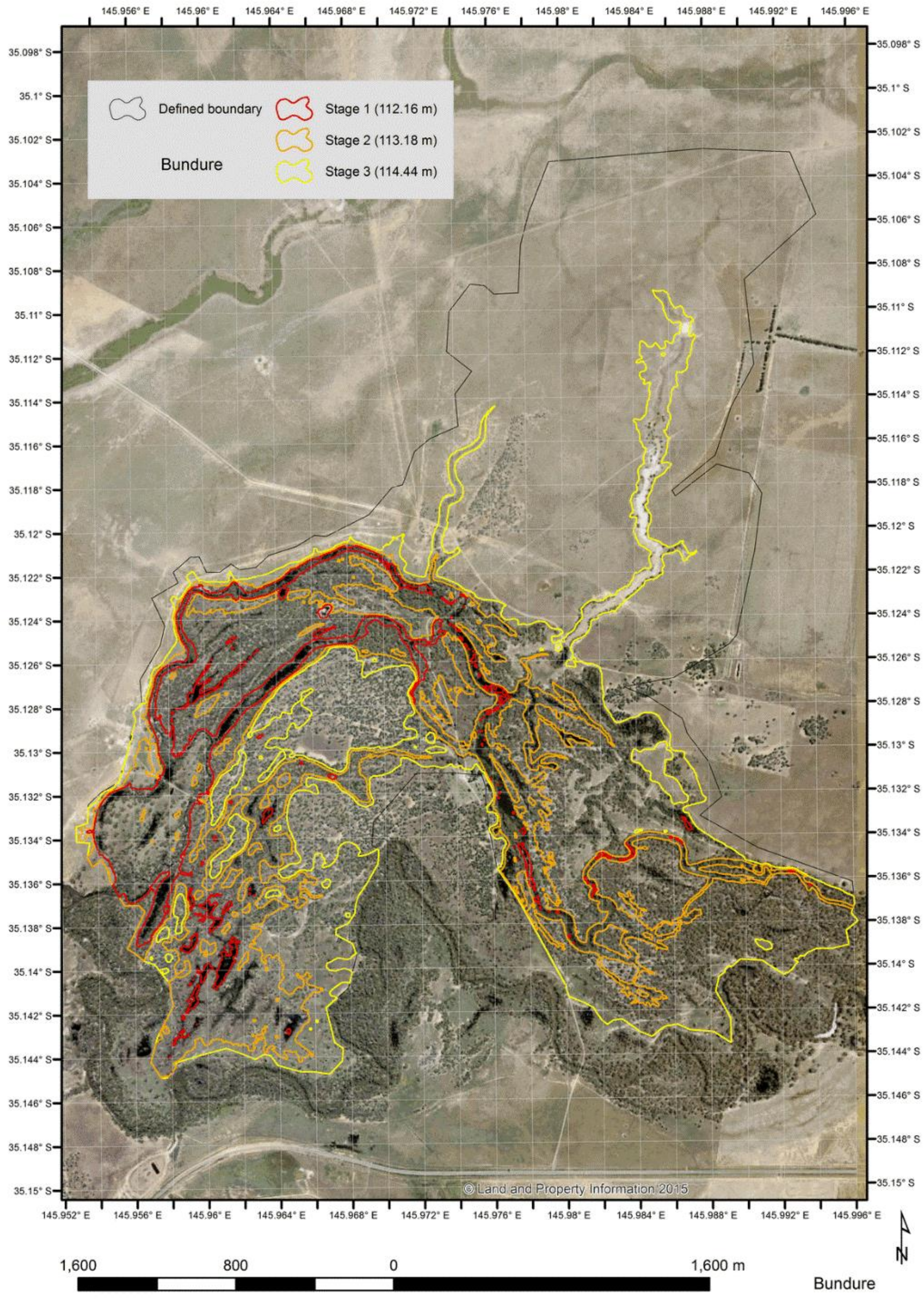
Broome



Defined boundary
Stage 1 (107.51 m)
Stage 2 (107.97 m)
Stage 3 (108.85 m)
Broome
© Land and Property Information 2015
600
300
0
600 m

Broome


Defined boundary
Stage 1 (112.16 m)
High : 126.635
Stage 2 (113.18 m)
Elevation (m a.s.l.)
Low : 109.321
Stage 3 (114.44 m)
Bundure
1,600
800
0
1,600 m
Bundure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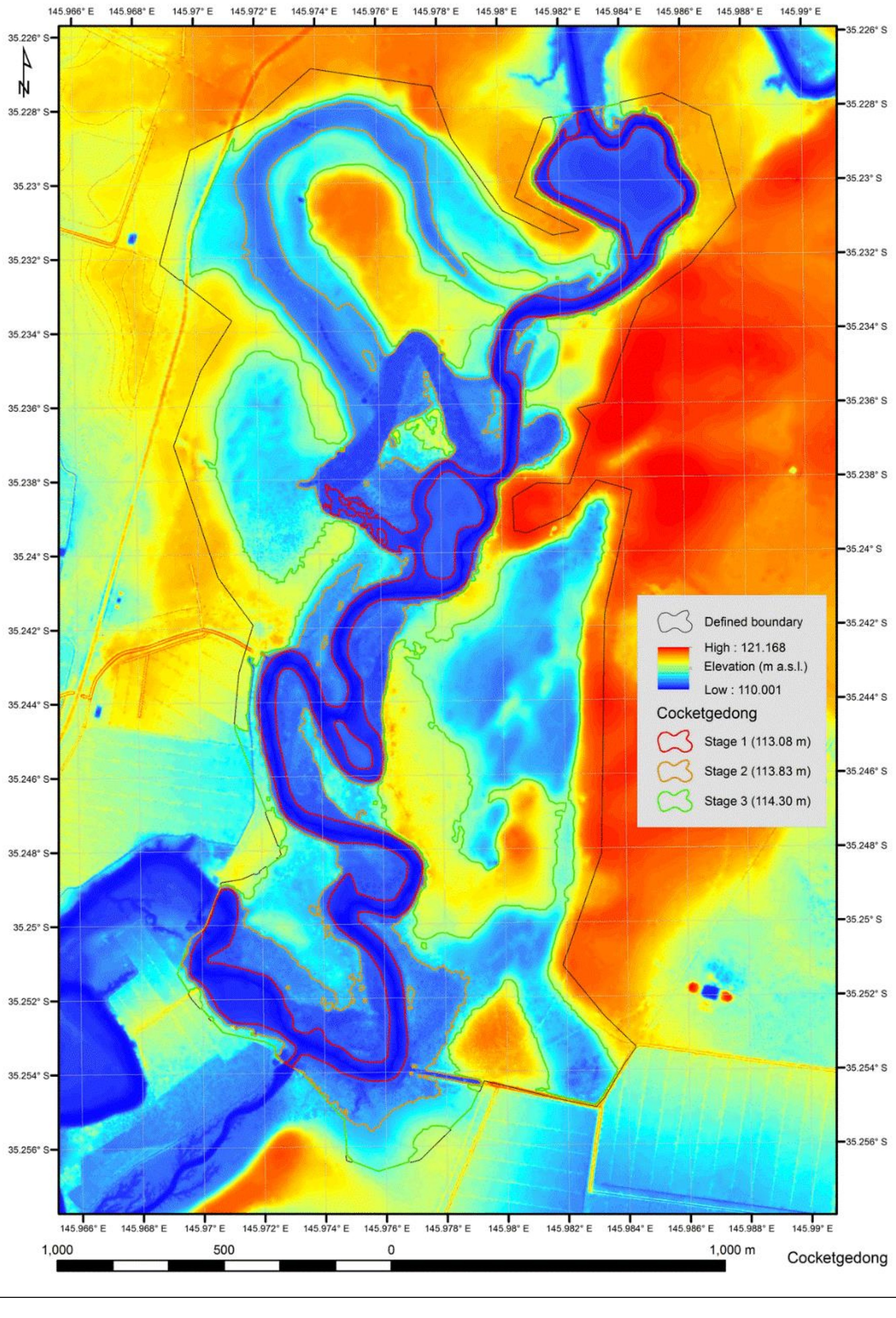
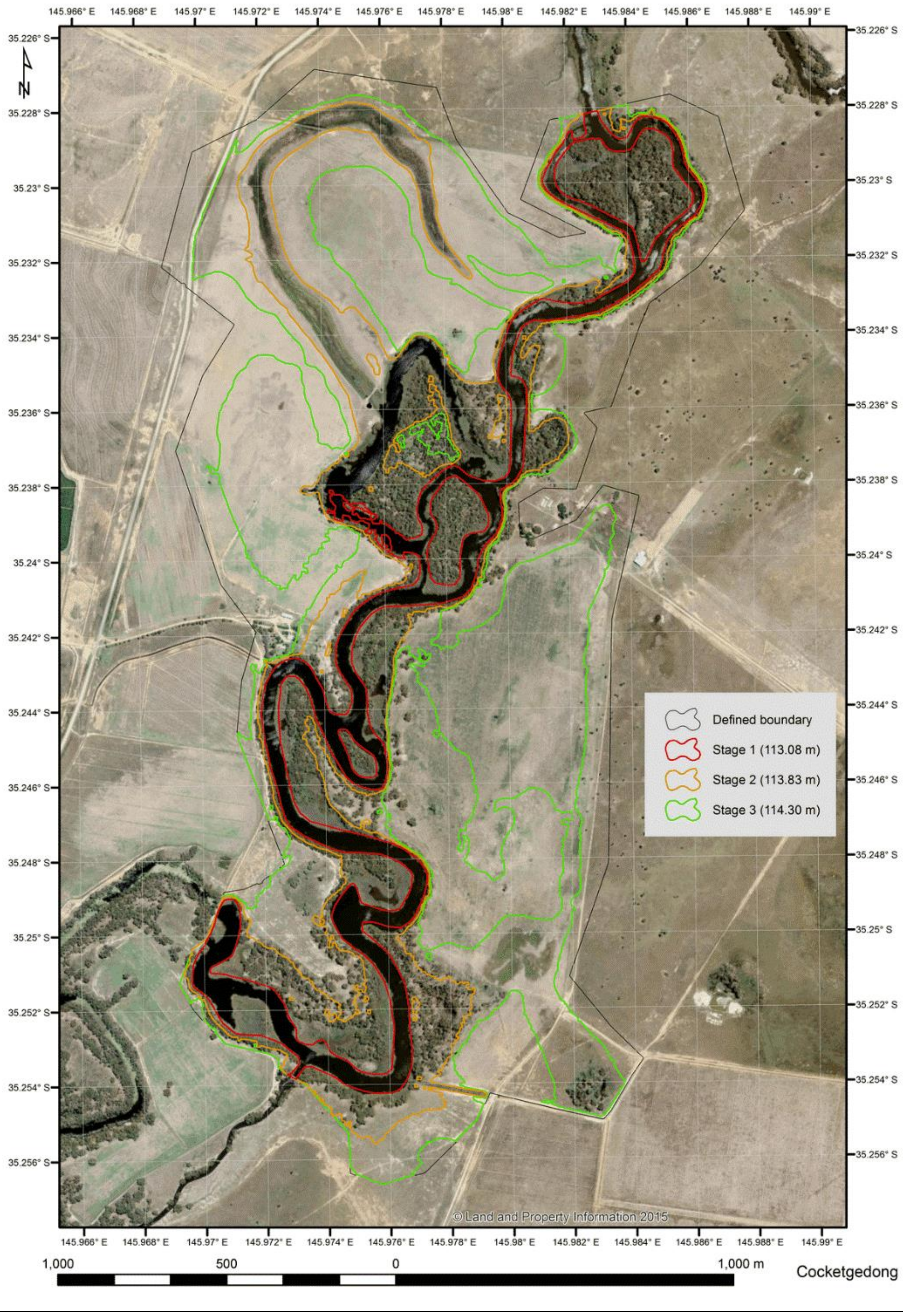
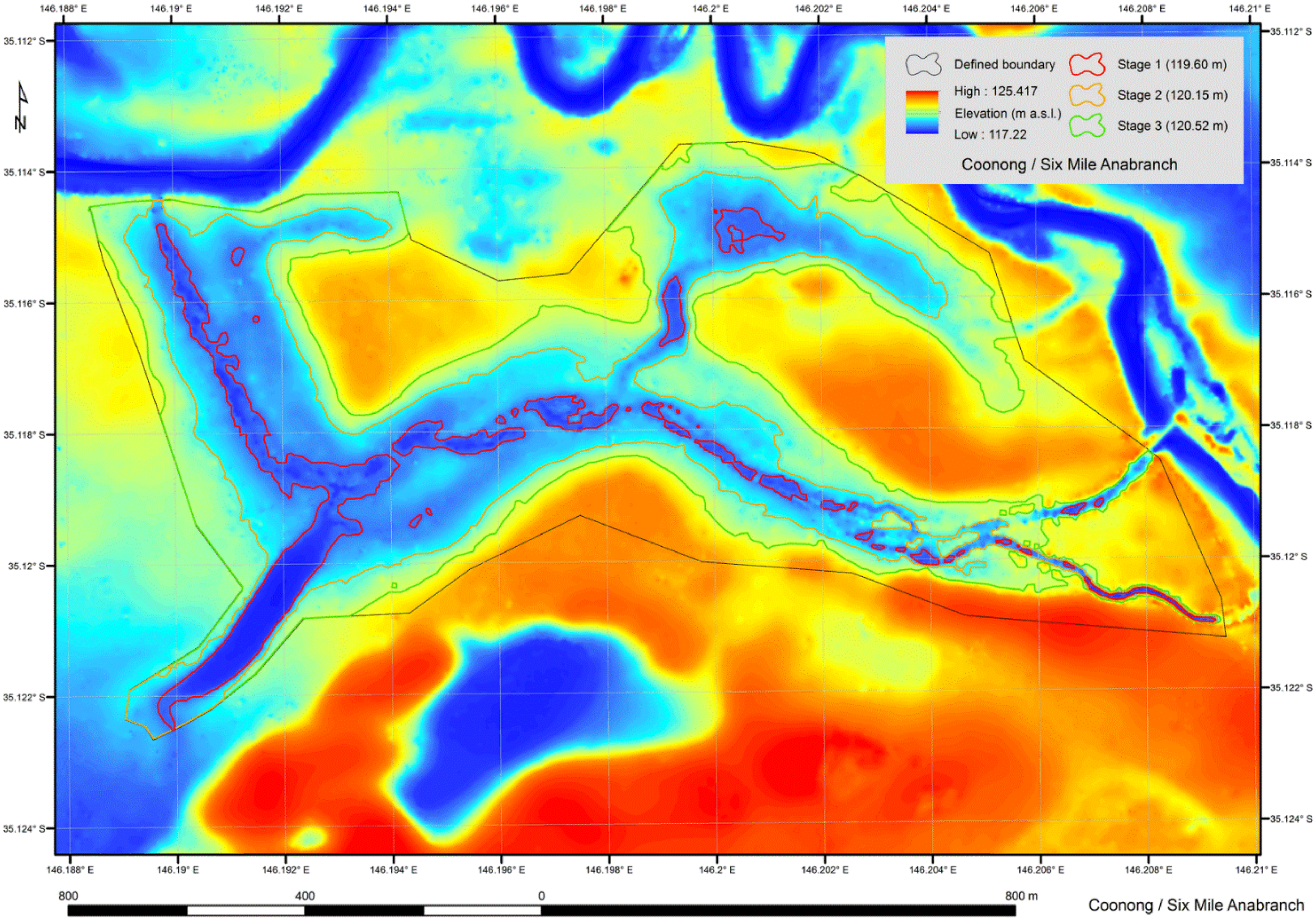
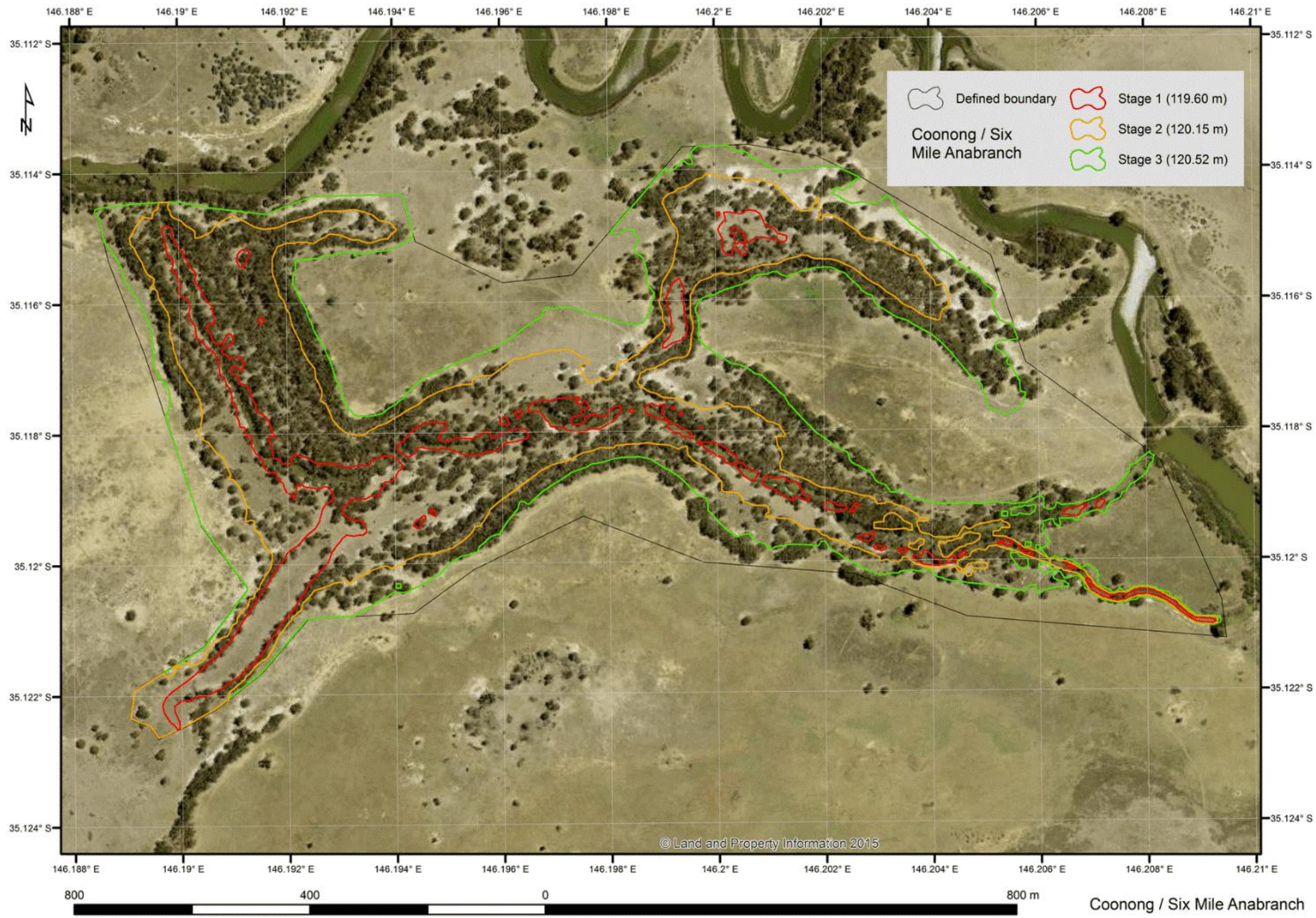
Stage 1 (112.16 m)
Stage 2 (113.18 m)
Stage 3 (114.44 m)
Bundure
© Land and Property Information 2015
1,600
800
0
1,600 m
N
Bundure



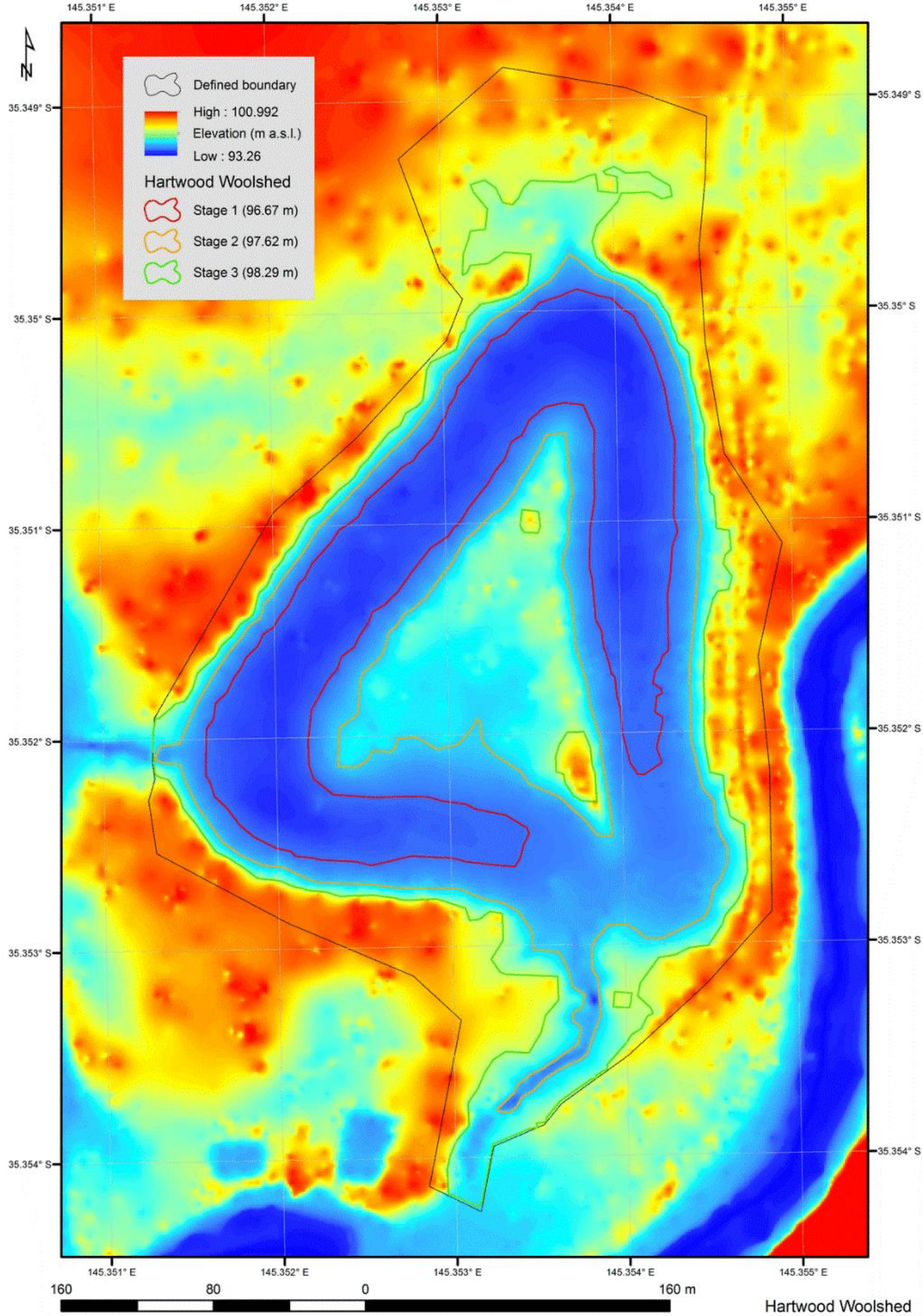
Defined boundary
High : 121.168
Elevation (m a.s.l.)
Low : 110.001
Cocketgedong
Stage 1 (113.08 m)
Stage 2 (113.83 m)
Stage 3 (114.30 m)
1,000
500
0
1,000 m
Cocketgedong

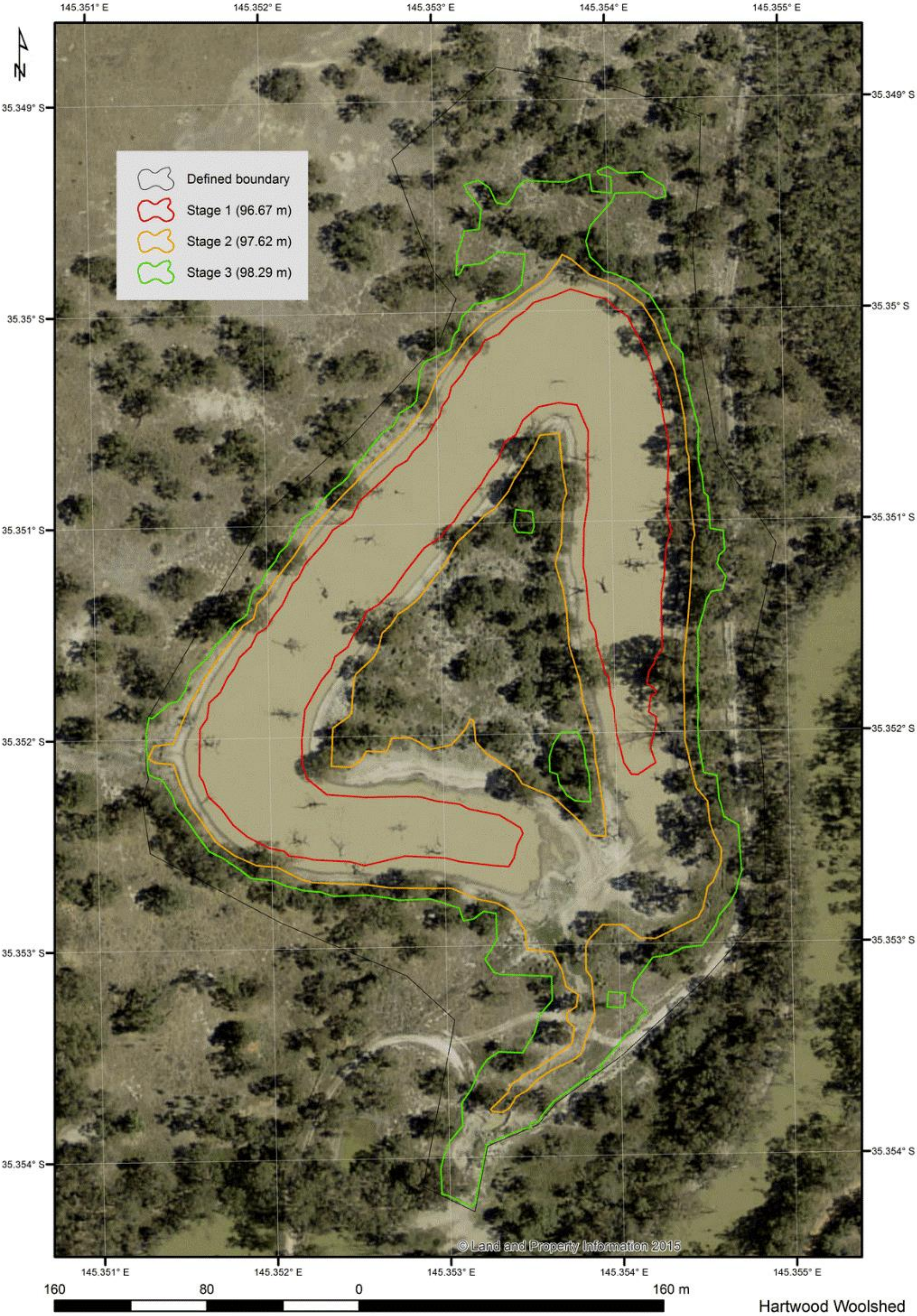

Defined boundary
Stage 1 (113.08 m)
Stage 2 (113.83 m)
Stage 3 (114.30 m)
© Land and Property Information 2015
1,000
500
0
1,000 m
Cocketgedong


Defined boundary
High : 125.417
Elevation (m a.s.l.)
Low : 117.22
Stage 1 (119.60 m)
Stage 2 (120.15 m)
Stage 3 (120.52 m)
Coonong / Six Mile Anabranch
800
400
0
800 m

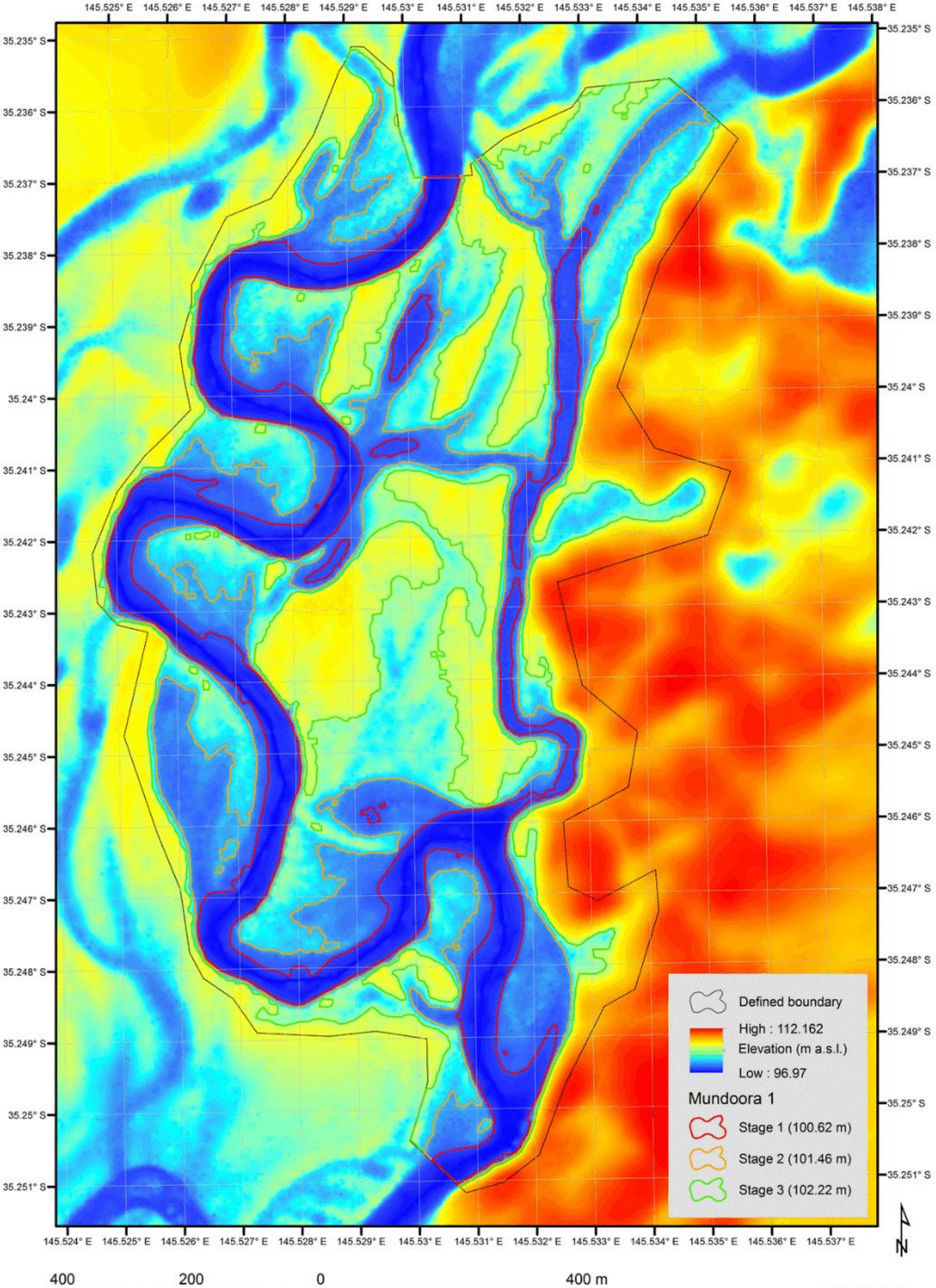


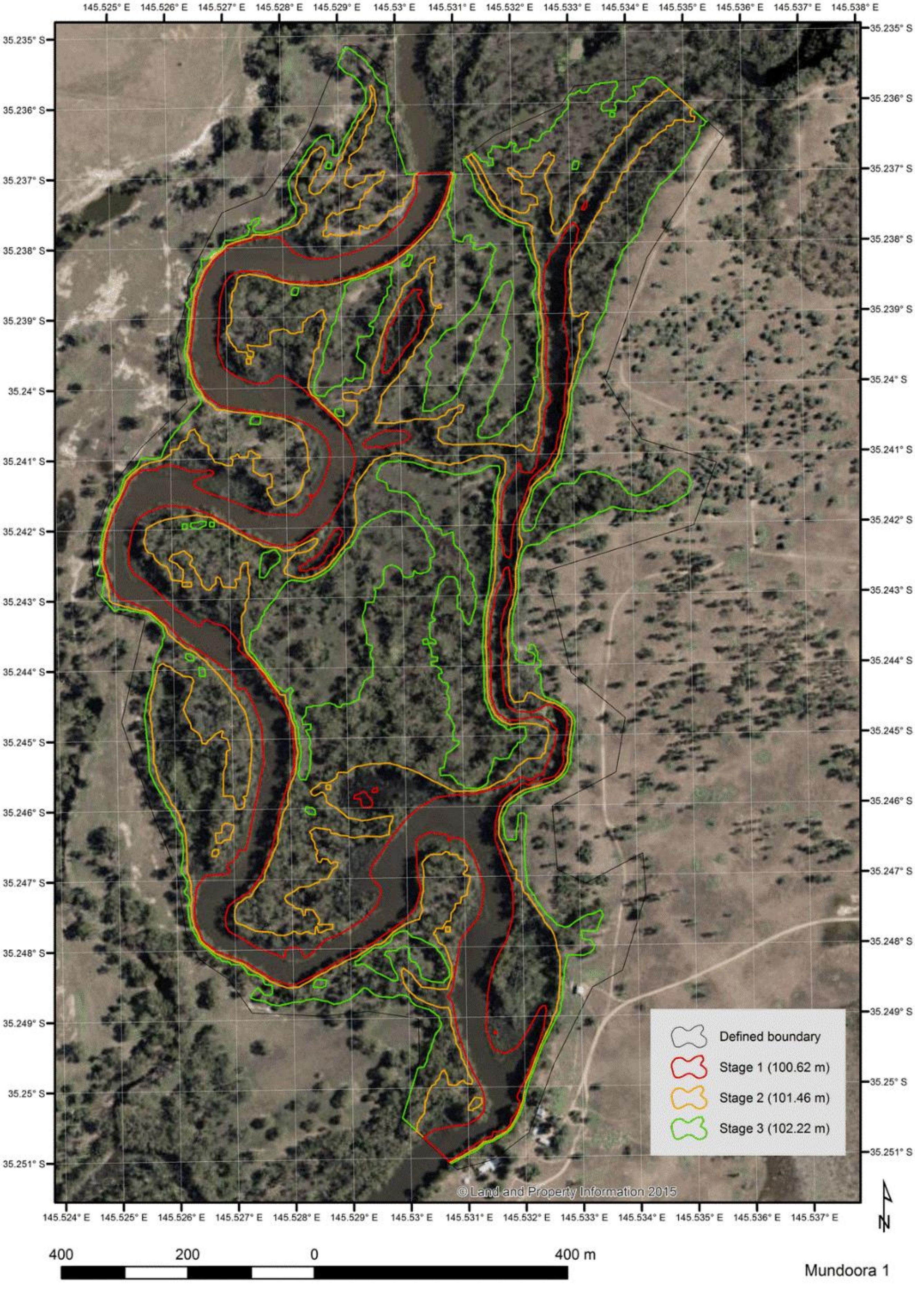
Coonong / Six Mile Anabranch

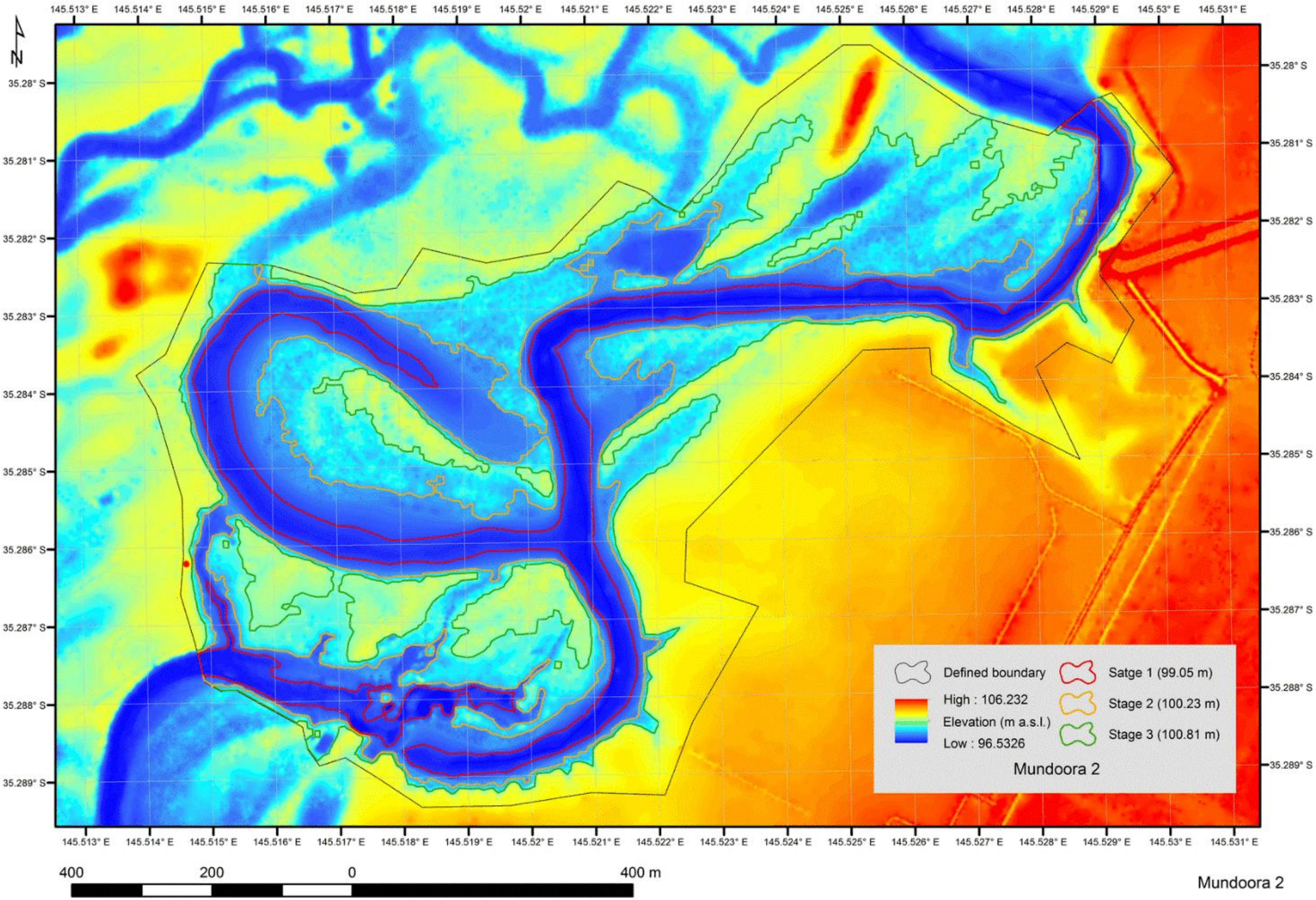

Defined boundary
High : 100.992
Elevation (m a.s.l.)
Low : 93.26
Hartwood Woolshed
Stage 1 (96.67 m)
Stage 2 (97.62 m)
Stage 3 (98.29 m)
145.351° E
145.352° E
145.353° E
145.354° E
145.355° E
35.349° S
35.35° S
35.351° S
35.352° S
35.353° S
35.354° S
160
80
0
160 m
Hartwood Woolshed



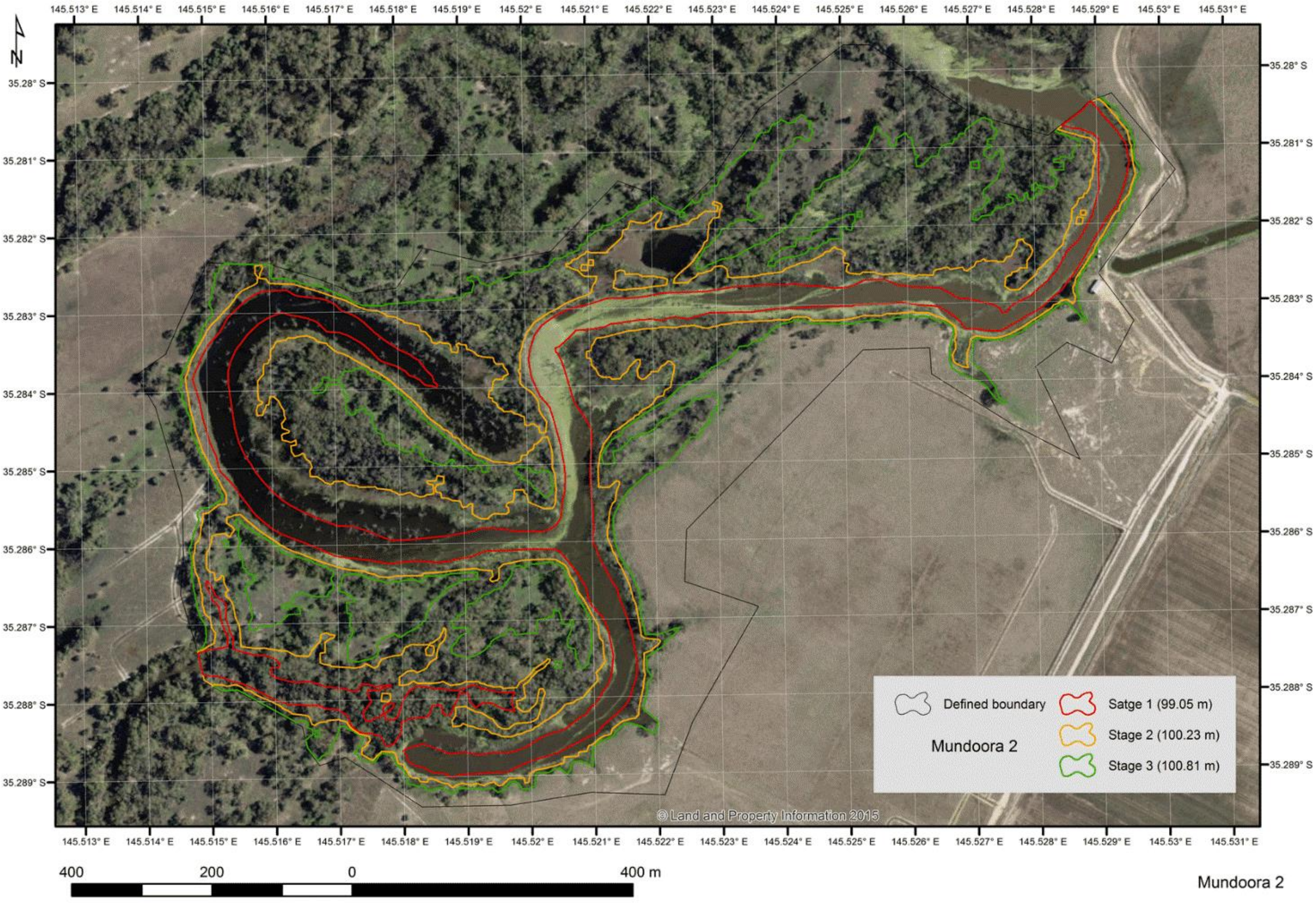
Hartwood Woolshed


Defined boundary
High : 112.162
Elevation (m a.s.l.)
Low : 96.97
Mundoora 1
Stage 1 (100.62 m)
Stage 2 (101.46 m)
Stage 3 (102.22 m)
400
200
0
400 m
Mundoora 1

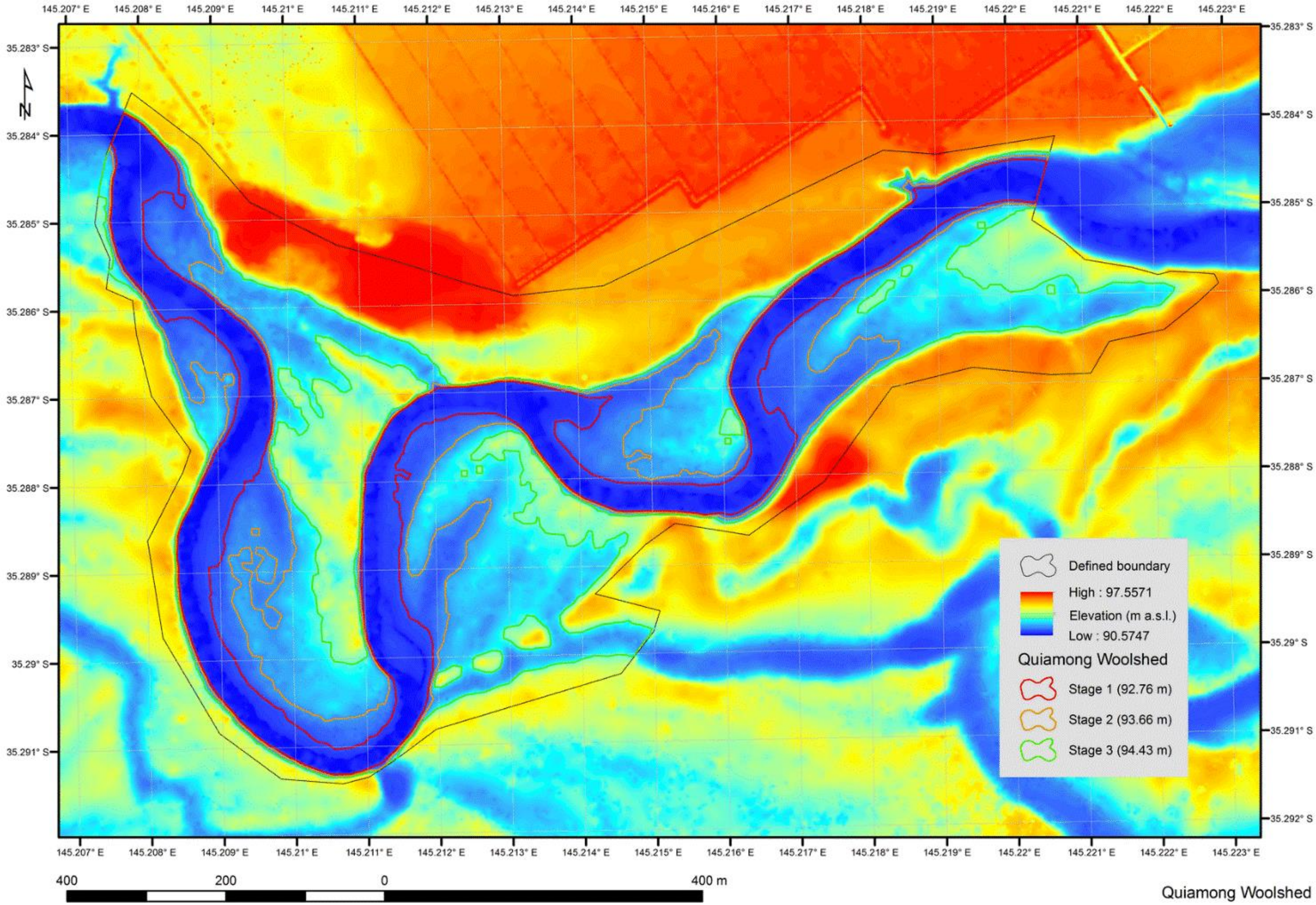

Defined boundary
Stage 1 (100.62 m)
Stage 2 (101.46 m)
Stage 3 (102.22 m)
© Land and Property Information 2015
400
200
0
400 m
Mundoora 1


Defined boundary
Satge 1 (99.05 m)
High : 106.232
Stage 2 (100.23 m)
Elevation (m a.s.l.)
Stage 3 (100.81 m)
Low : 96.5326
Mundoora 2
400
200
0
400 m

Mundoora 2



Defined boundary
Satge 1 (99.05 m)
Stage 2 (100.23 m)
Stage 3 (100.81 m)
Mundoora 2
© Land and Property Information 2015
400
200
0
400 m


Defined boundary
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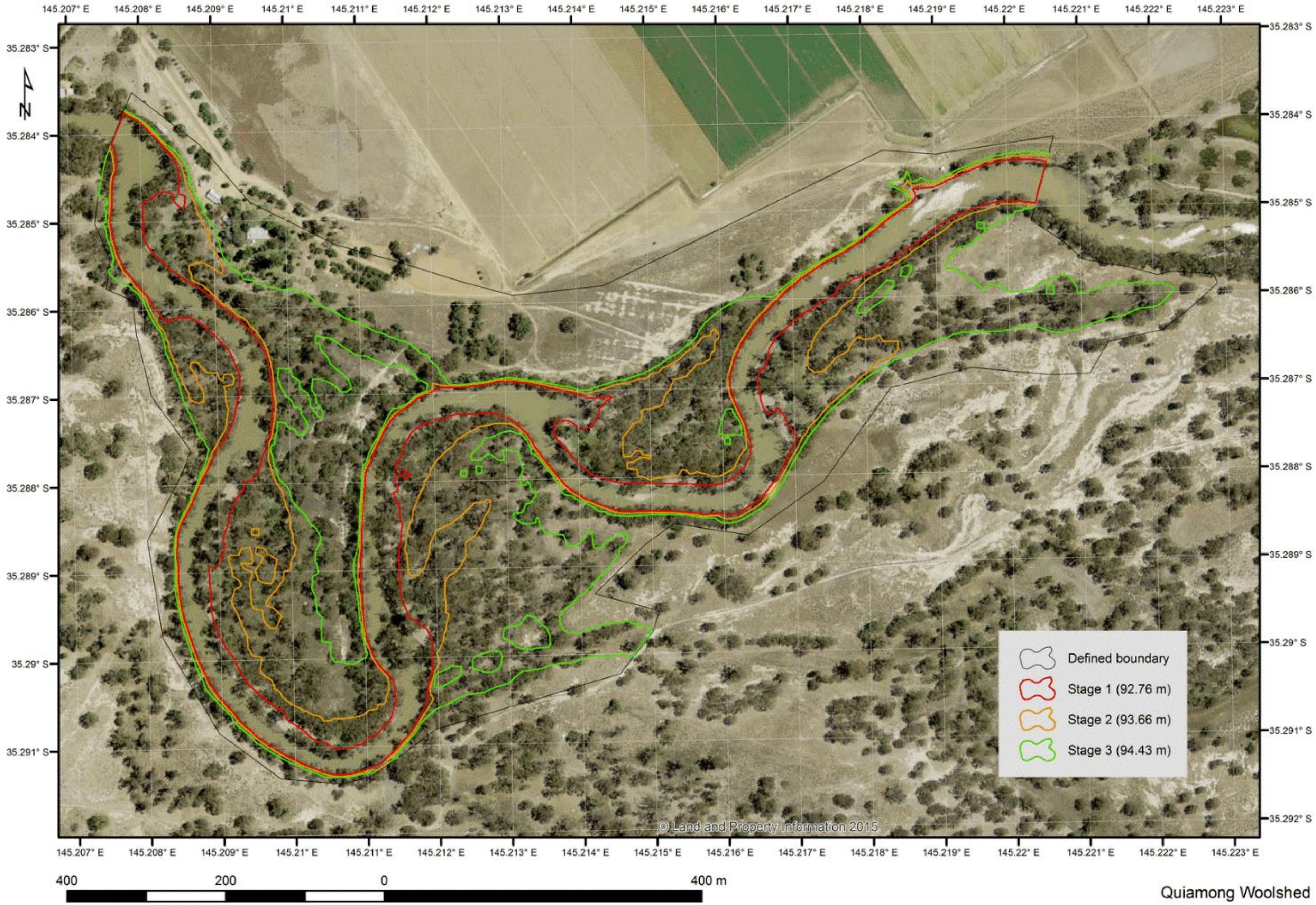
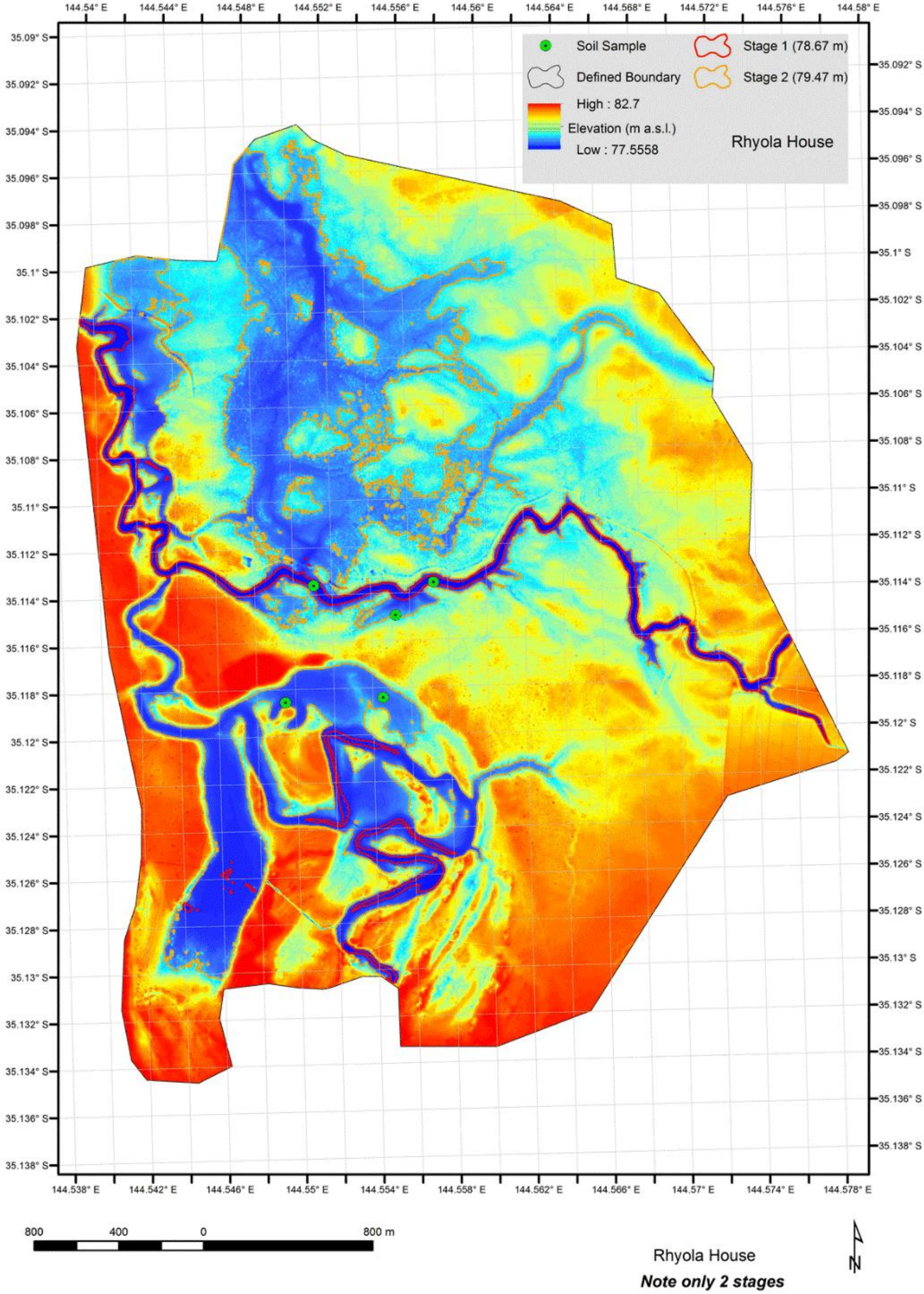
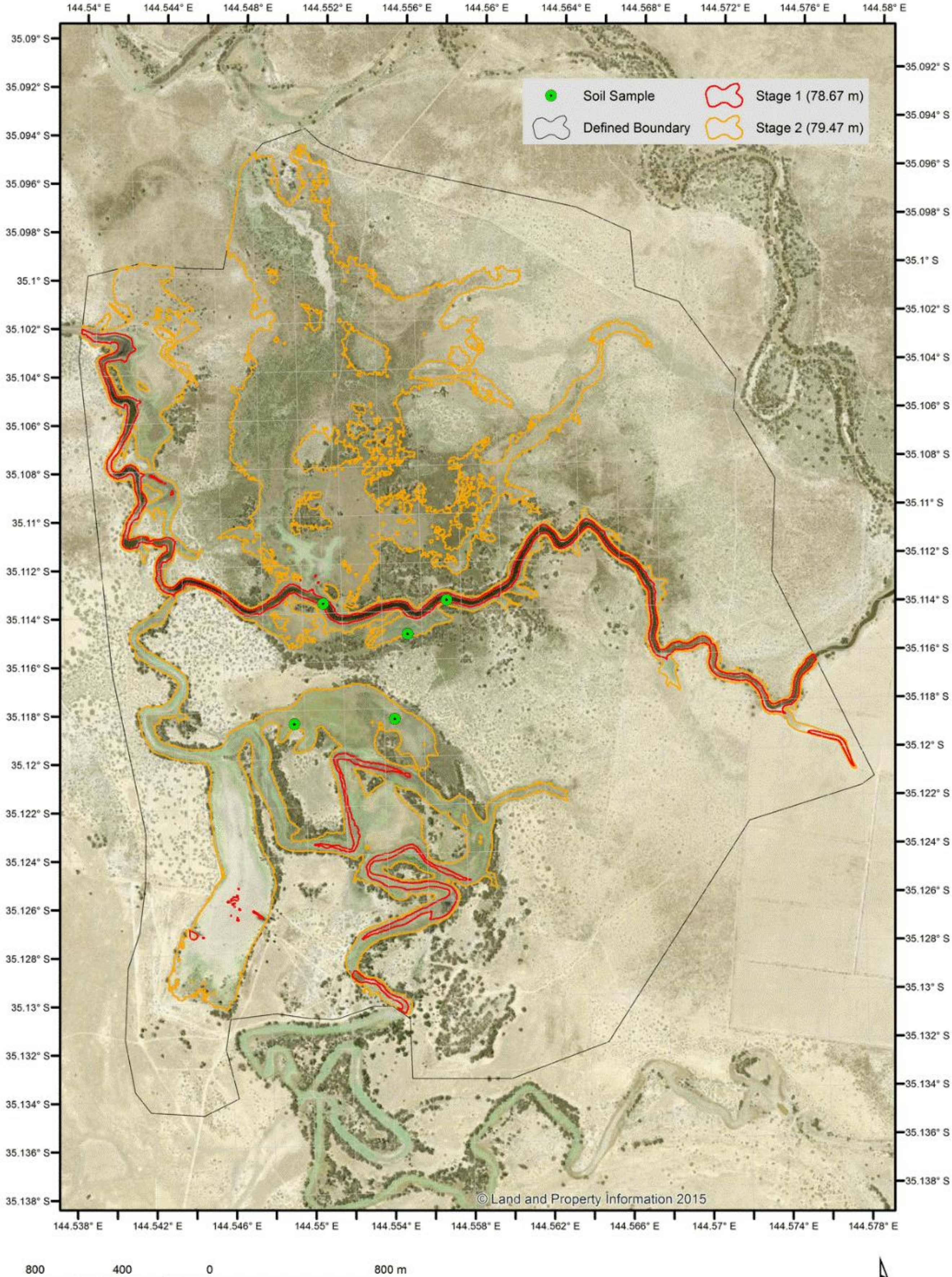
Elevation (m a.s.l.)
Low : 90.5747
Quiamong Woolshed
Stage 1 (92.76 m)
Stage 2 (93.66 m)
Stage 3 (94.43 m)
400
200
0
400 m


Defined boundary
Stage 1 (92.76 m)
Stage 2 (93.66 m)
Stage 3 (94.43 m)
© Land and Property Information 2015
400
200
0
400 m



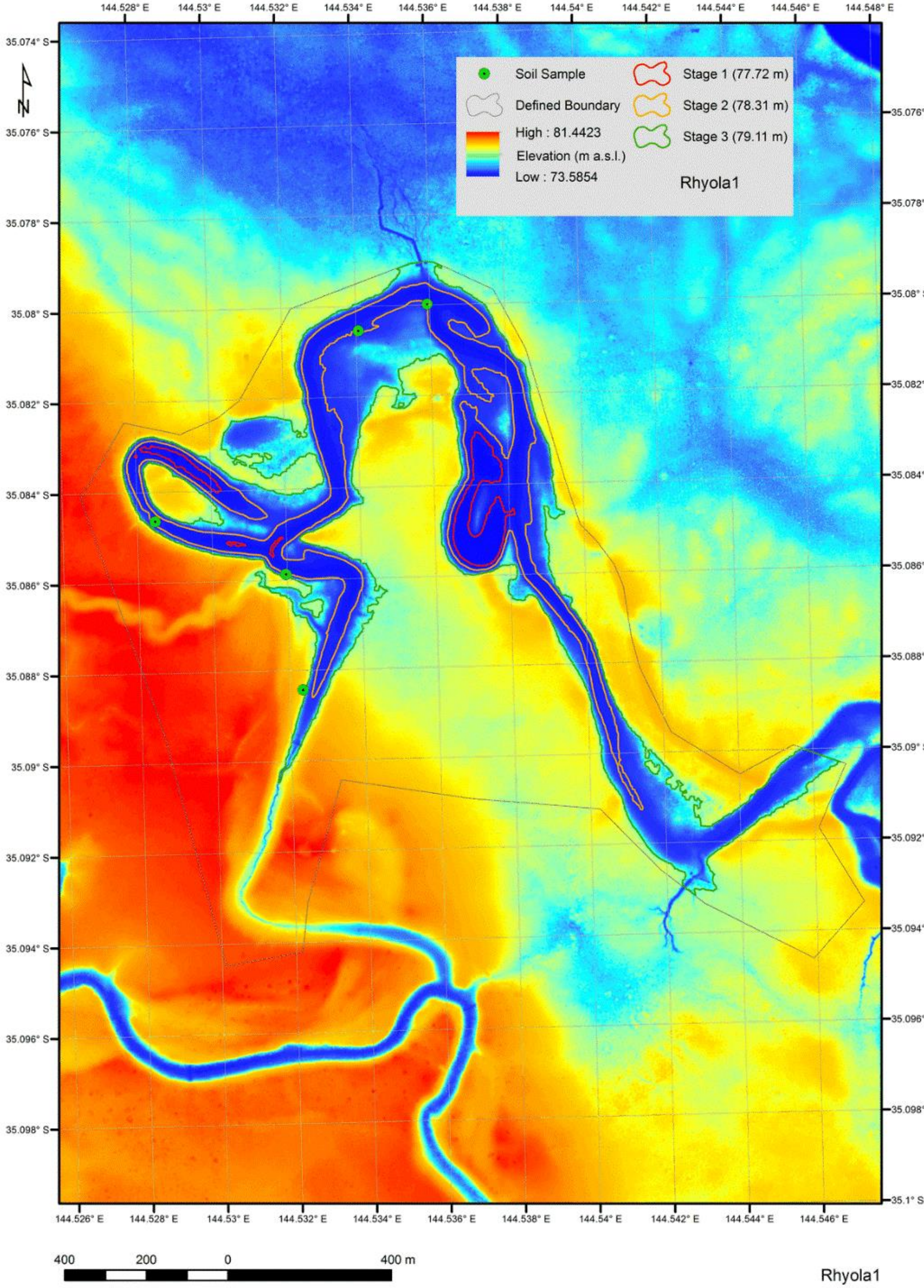
Rhyola House

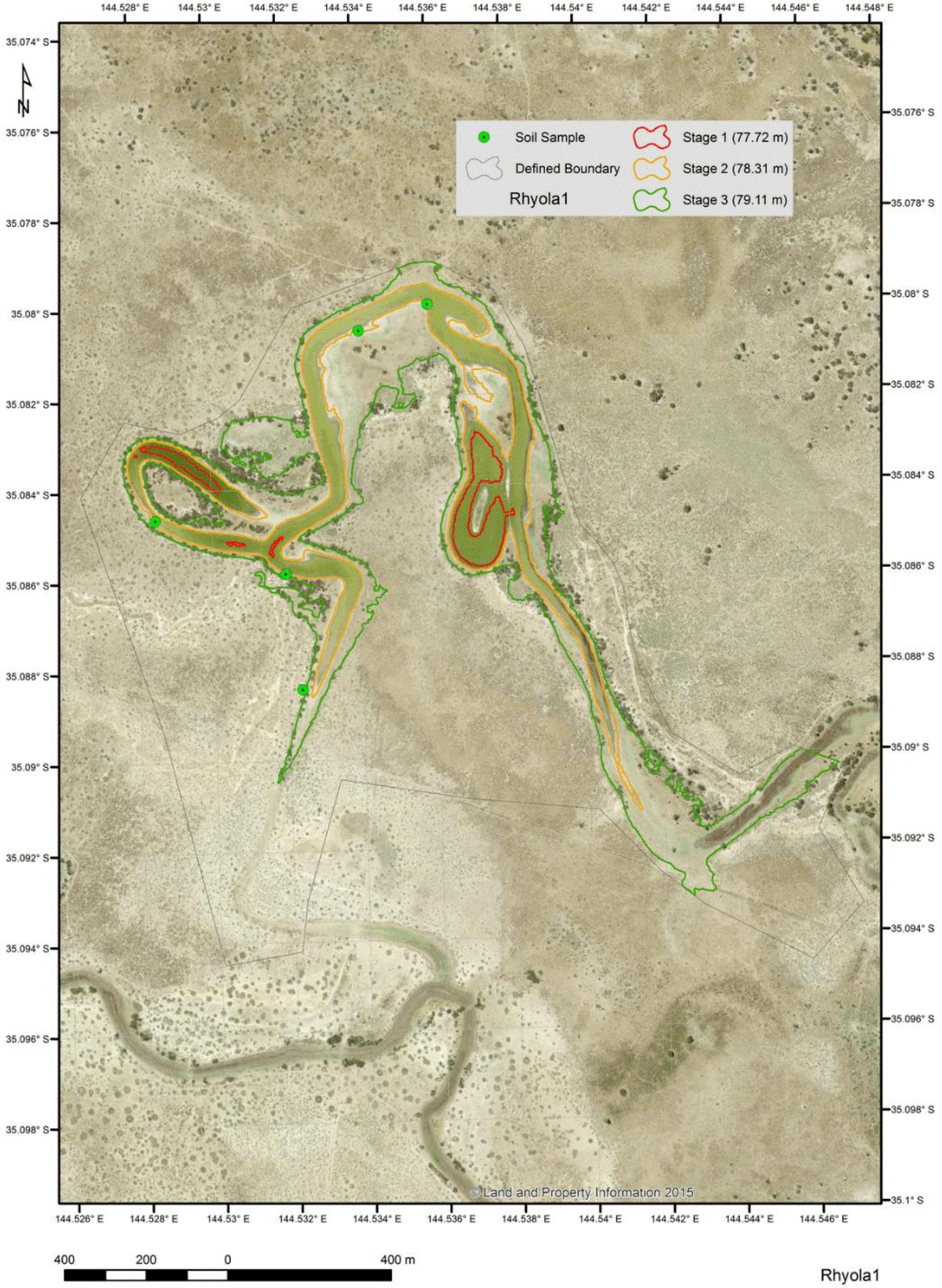
Note only 2 stages



Rhyola House

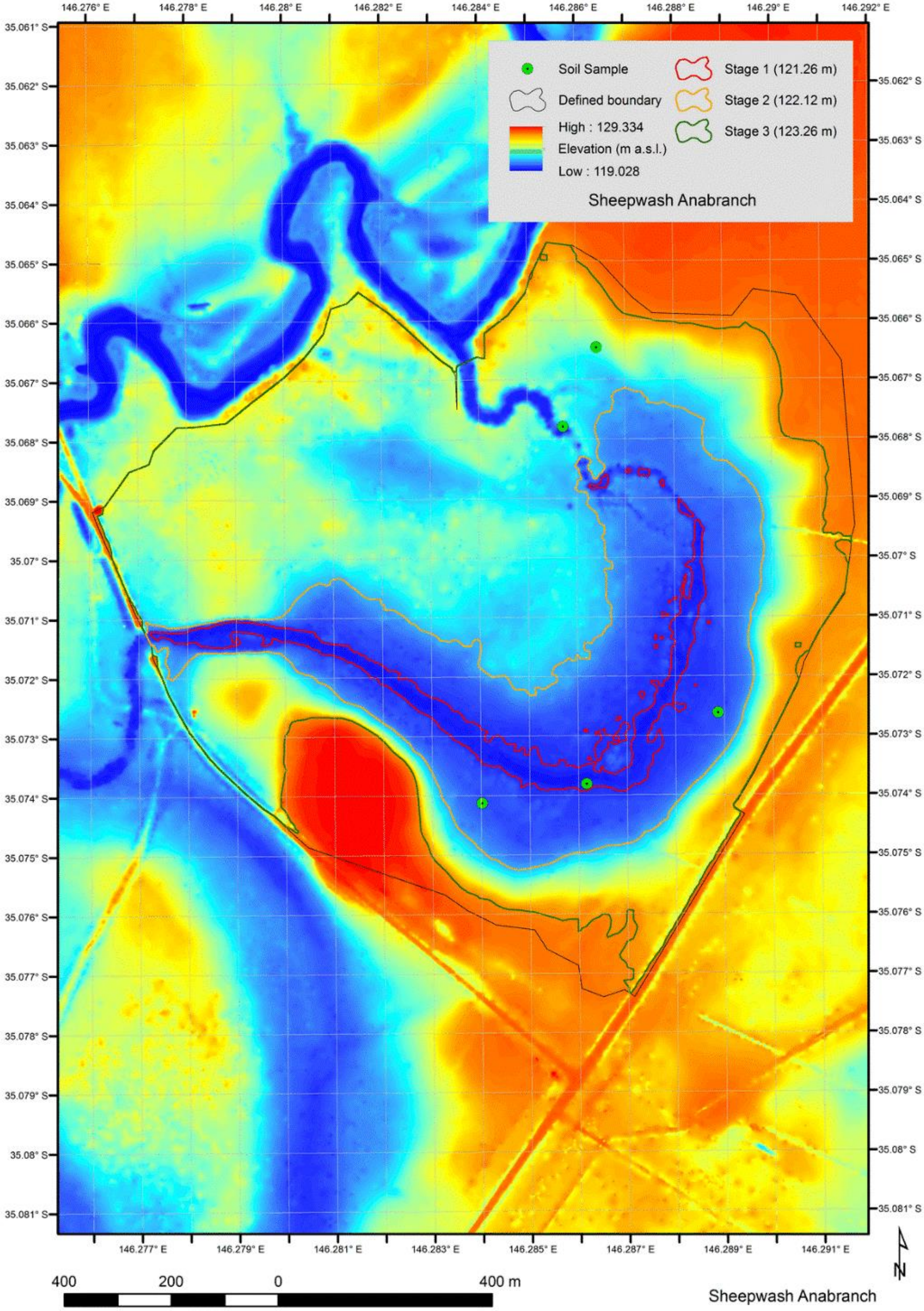
Note only 2 stages

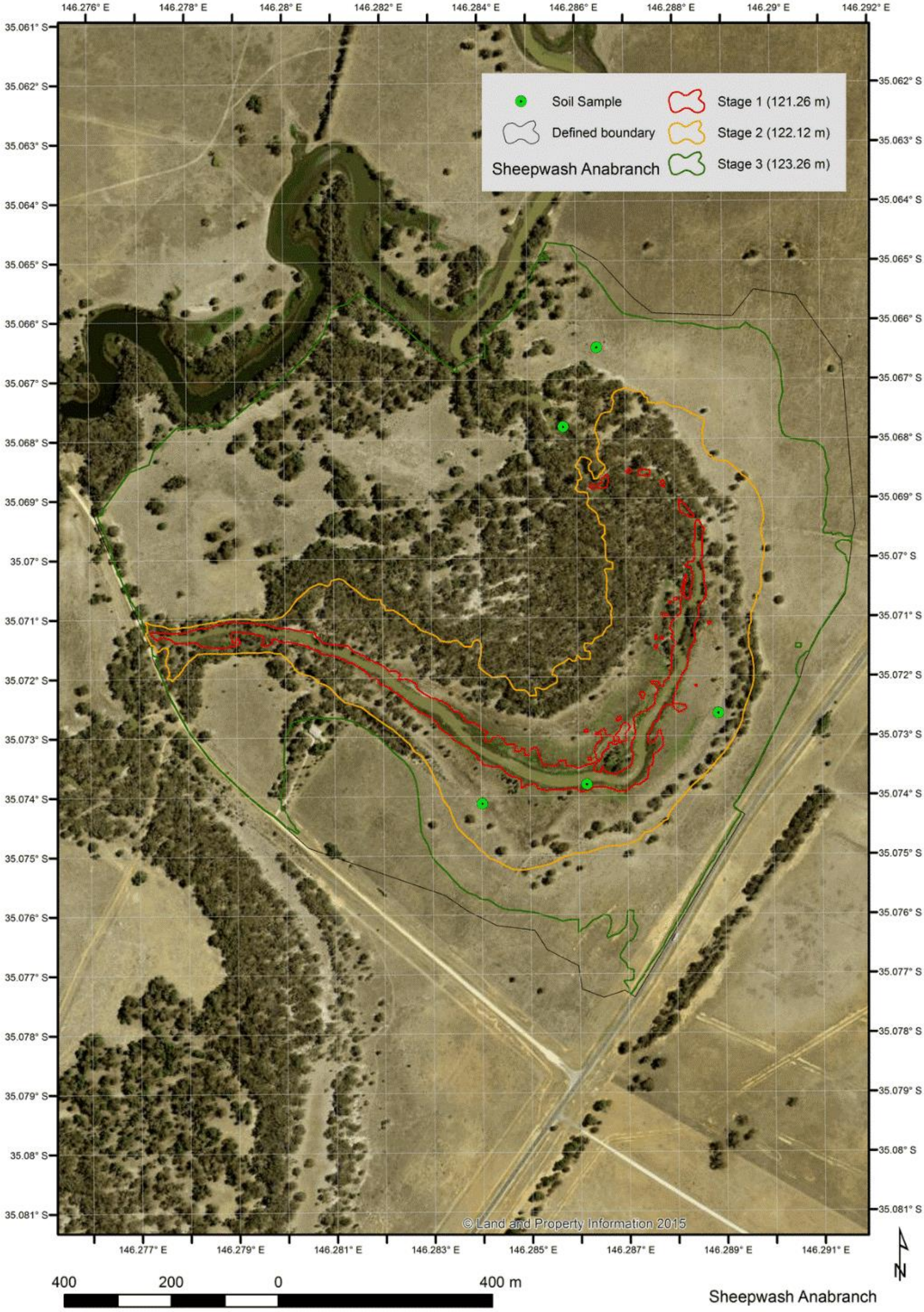

Soil Sample
Defined Boundary
High : 81.4423
Elevation (m a.s.l.)
Low : 73.5854
Stage 1 (77.72 m)
Stage 2 (78.31 m)
Stage 3 (79.11 m)
Rhyola1
N
144.528° E
144.53° E
144.532° E
144.534° E
144.536° E
144.538° E
144.54° E
144.542° E
144.544° E
144.546° E
144.548° E
144.526° E
35.074° S
35.076° S
35.078° S
35.08° S
35.082° S
35.084° S
35.086° S
35.088° S
35.09° S
35.092° S
35.094° S
35.096° S
35.098° S
35.1° S
400
200
0
400 m
Rhyola1



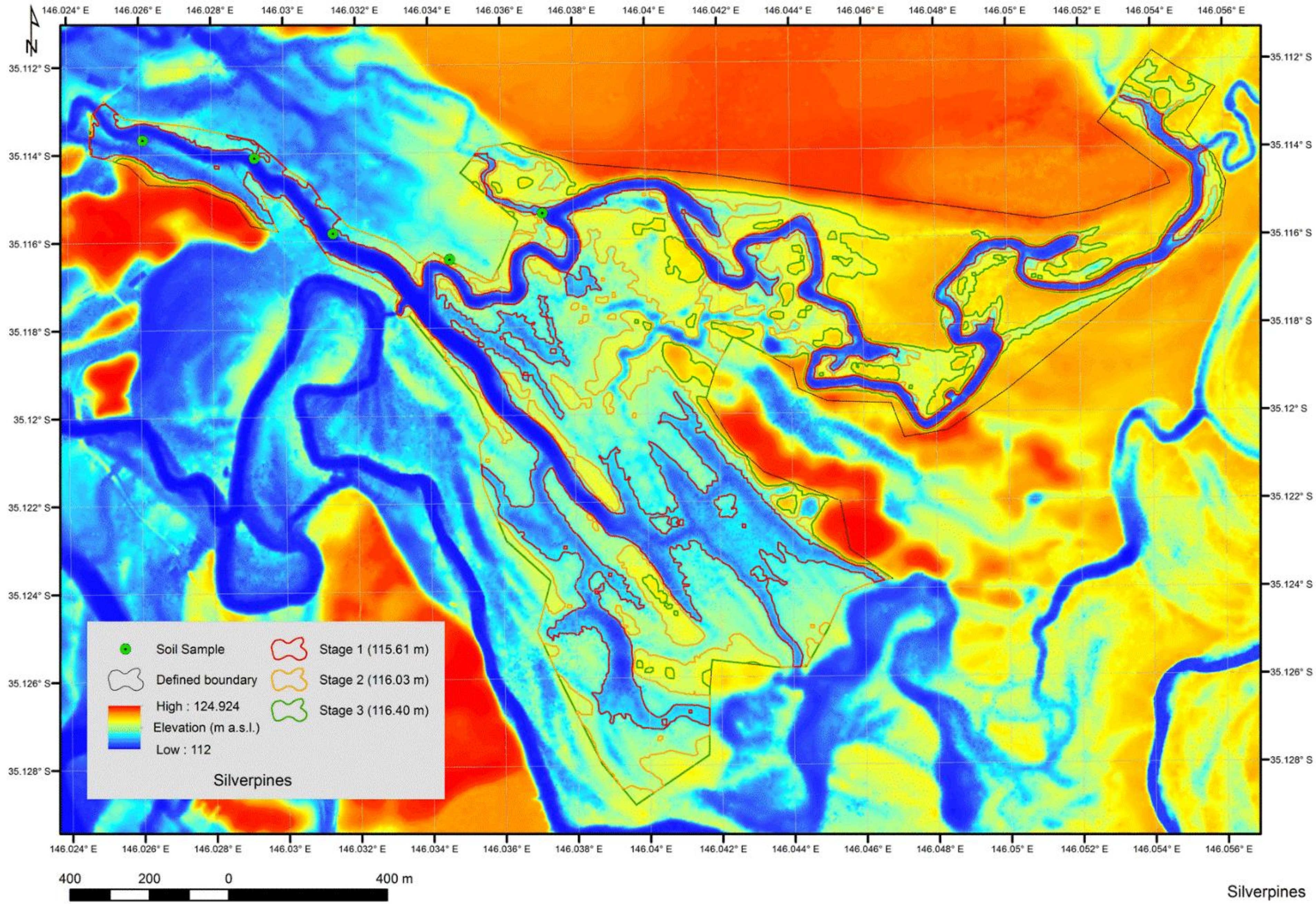
Soil Sample
Defined Boundary
Rhyola1
Stage 1 (77.72 m)
Stage 2 (78.31 m)
Stage 3 (79.11 m)
© Land and Property Information 2015
400
200
0
400 m

Rhyola1

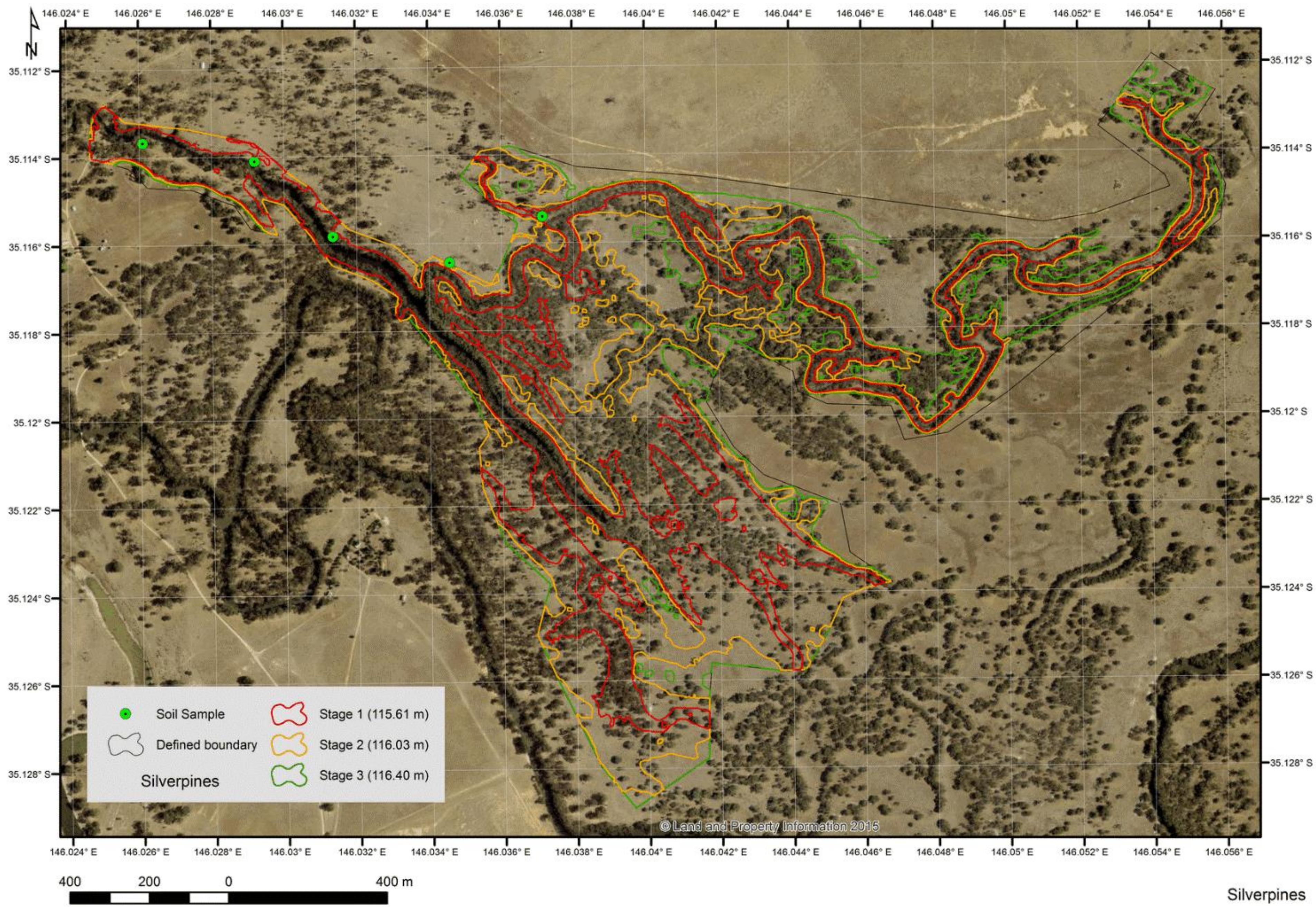

Soil Sample
Defined boundary
High : 129.334
Elevation (m a.s.l.)
Low : 119.028
Stage 1 (121.26 m)
Stage 2 (122.12 m)
Stage 3 (123.26 m)
Sheepwash Anabranch
400 200 0 400 m
N
Sheepwash Anabranch



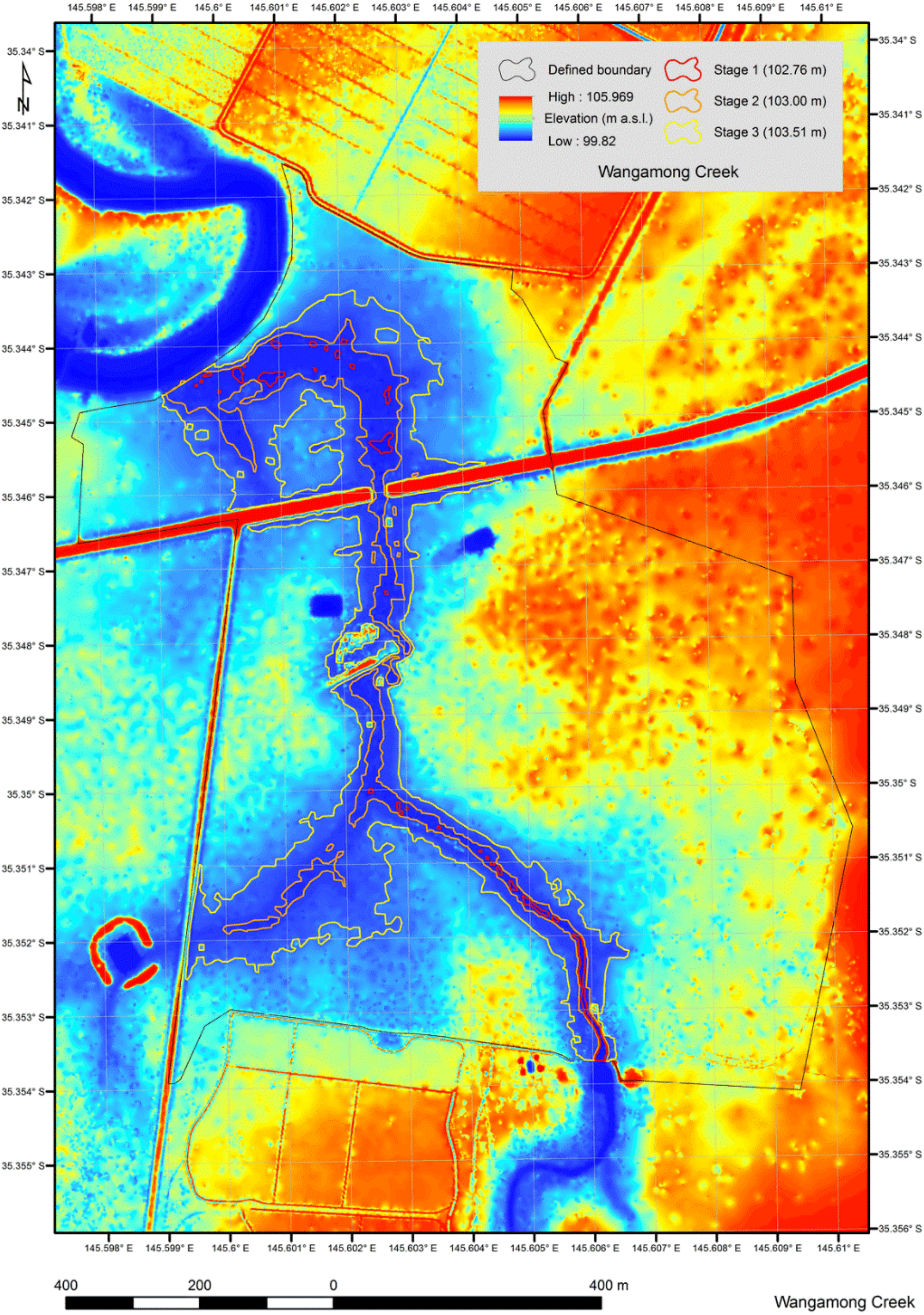
Soil Sample
Defined boundary
Sheepwash Anabranch
Stage 1 (121.26 m)
Stage 2 (122.12 m)
Stage 3 (123.26 m)
146.276° E
146.278° E
146.28° E
146.282° E
146.284° E
146.286° E
146.288° E
146.29° E
146.292° E
146.277° E
146.279° E
146.281° E
146.283° E
146.285° E
146.287° E
146.289° E
146.291° E
35.061° S
35.062° S
35.063° S
35.064° S
35.065° S
35.066° S
35.067° S
35.068° S
35.069° S
35.07° S
35.071° S
35.072° S
35.073° S
35.074° S
35.075° S
35.076° S
35.077° S
35.078° S
35.079° S
35.08° S
35.081° S
© Land and Property Information 2015
N
400
200
0
400 m
Sheepwash Anabranch



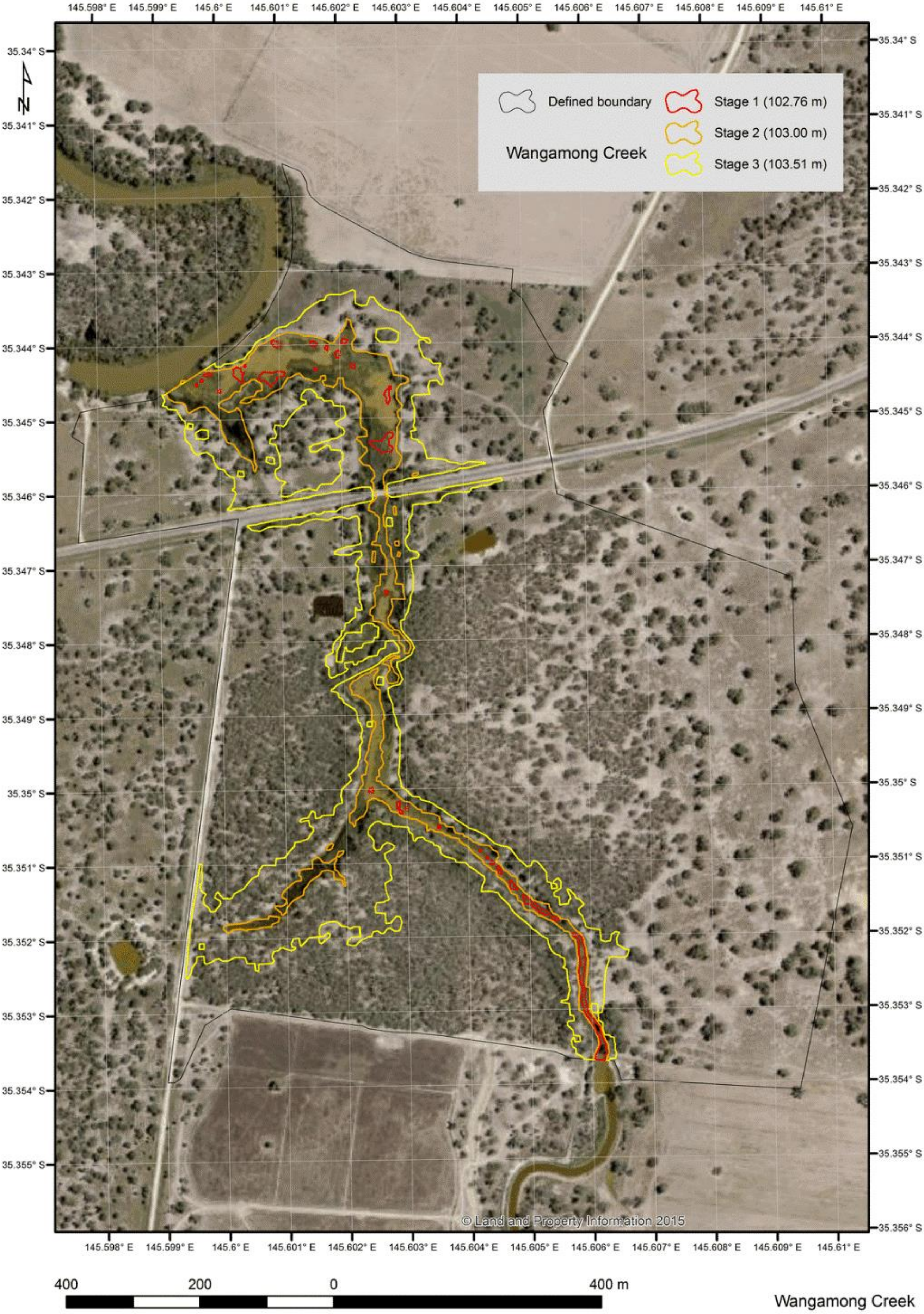
Soil Sample
Defined boundary
High : 124.924
Elevation (m a.s.l.)
Low : 112
Stage 1 (115.61 m)
Stage 2 (116.03 m)
Stage 3 (116.40 m)
Silverpines
400 200 0 400 m



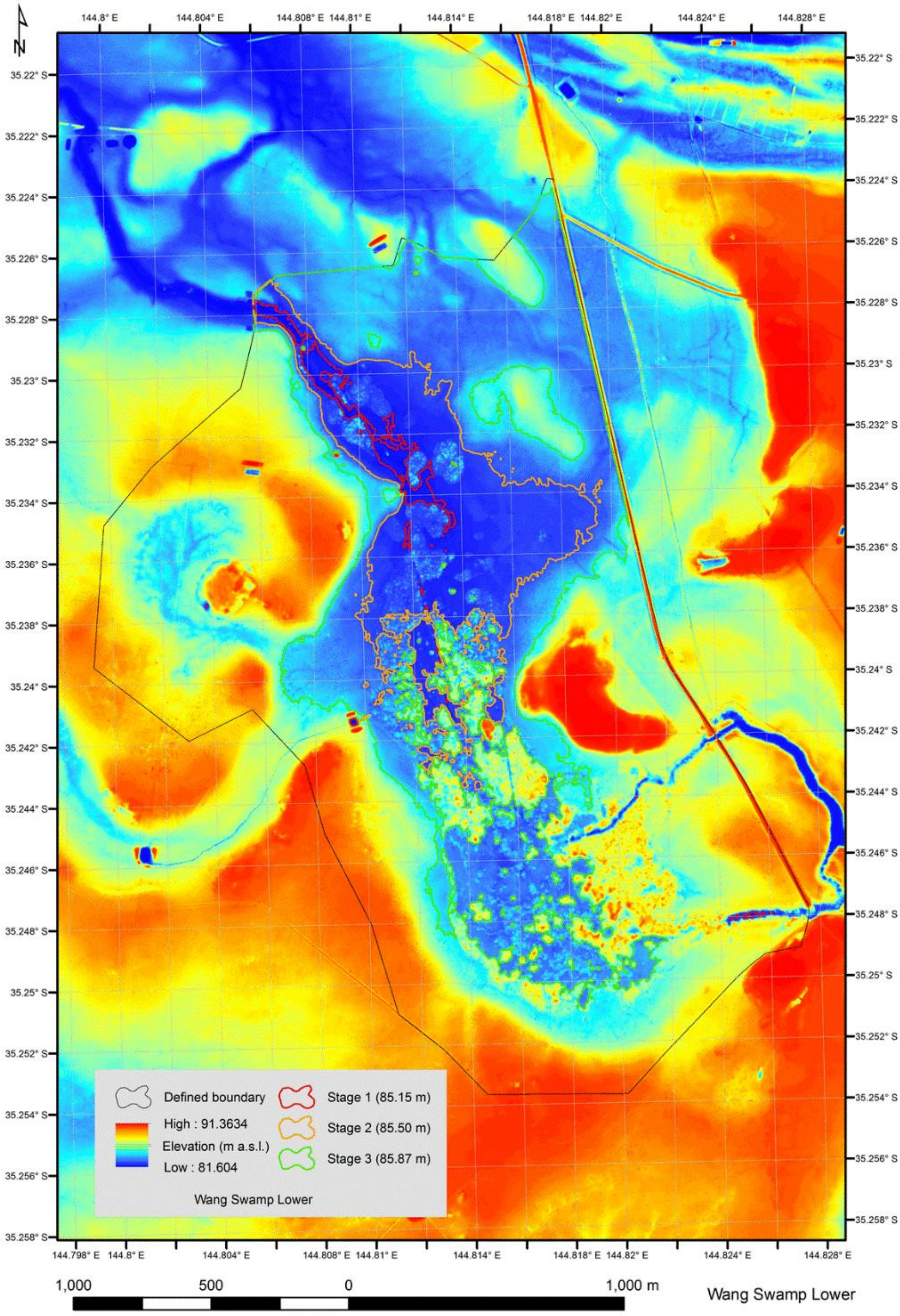
Soil Sample
Defined boundary
Silverpines
Stage 1 (115.61 m)
Stage 2 (116.03 m)
Stage 3 (116.40 m)
© Land and Property Information 2015
N
146.024° E
146.026° E
146.028° E
146.03° E
146.032° E
146.034° E
146.036° E
146.038° E
146.04° E
146.042° E
146.044° E
146.046° E
146.048° E
146.05° E
146.052° E
146.054° E
146.056° E
35.112° S
35.114° S
35.116° S
35.118° S
35.12° S
35.122° S
35.124° S
35.126° S
35.128° S
400 200 0 400 m

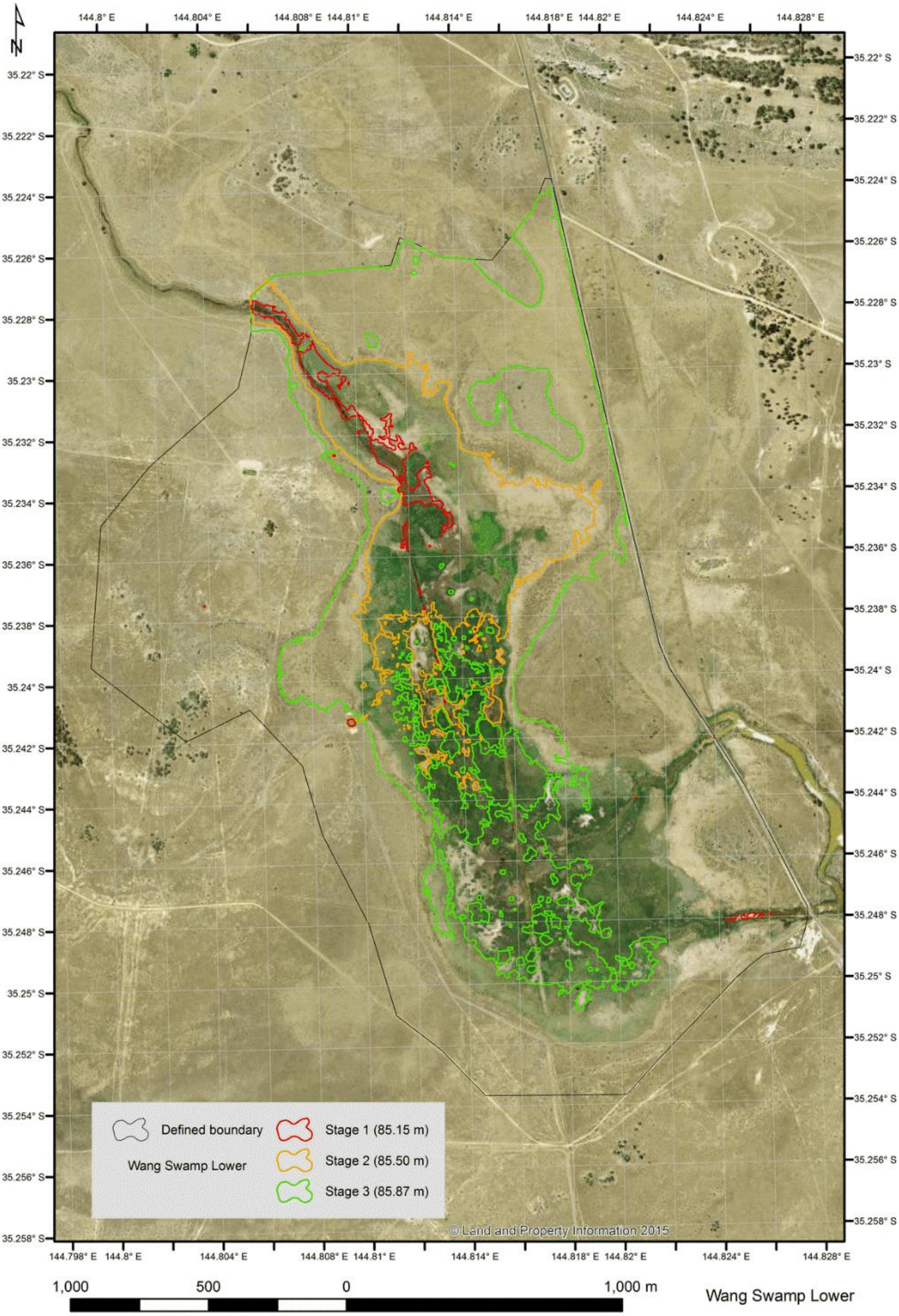


Wangamong Creek

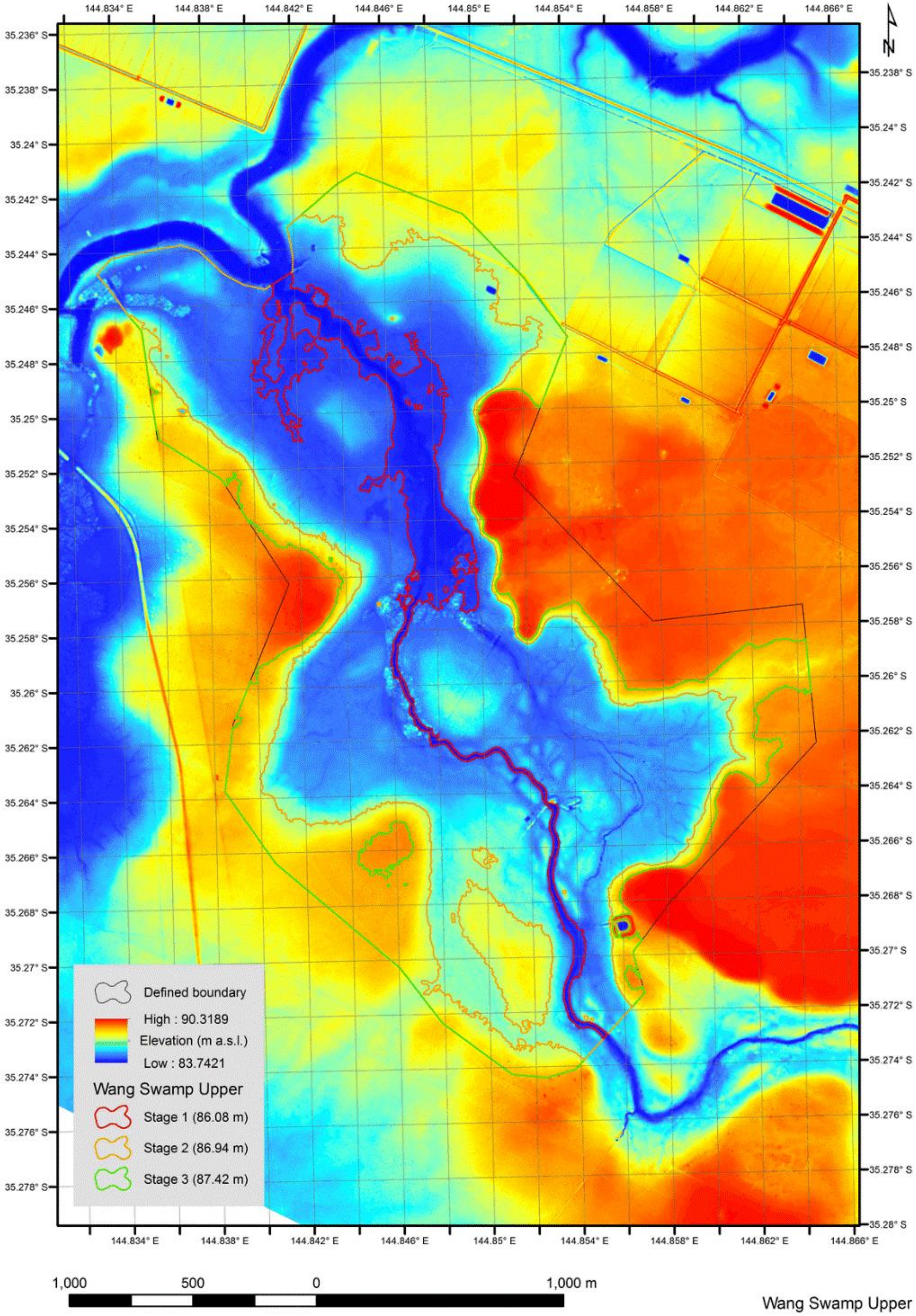


Wangamong Creek

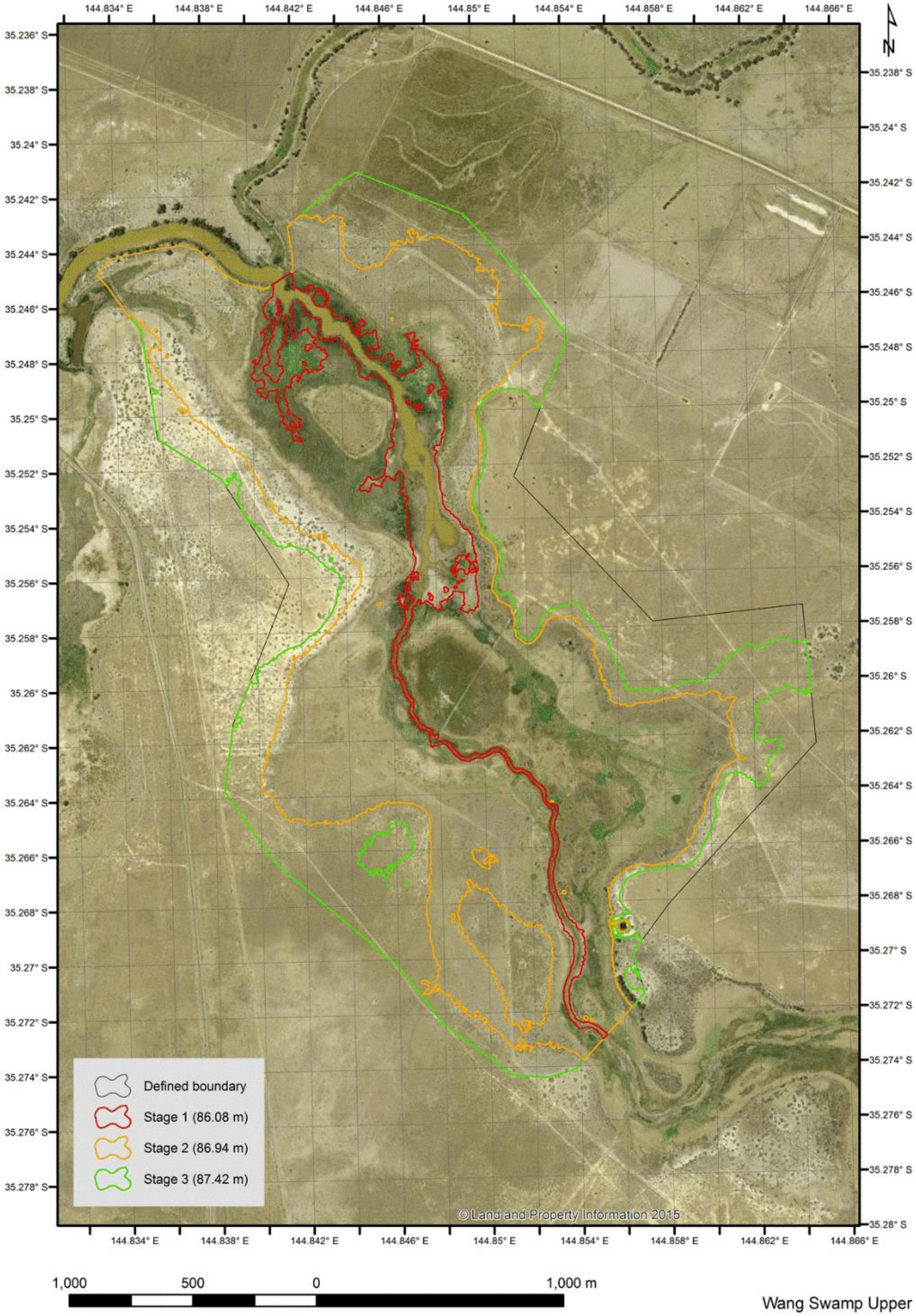

Defined boundary
High : 91.3634
Elevation (m a.s.l.)
Low : 81.604
Stage 1 (85.15 m)
Stage 2 (85.50 m)
Stage 3 (85.87 m)
Wang Swamp Lower
1,000
500
0
1,000 m
Wang Swamp Lower



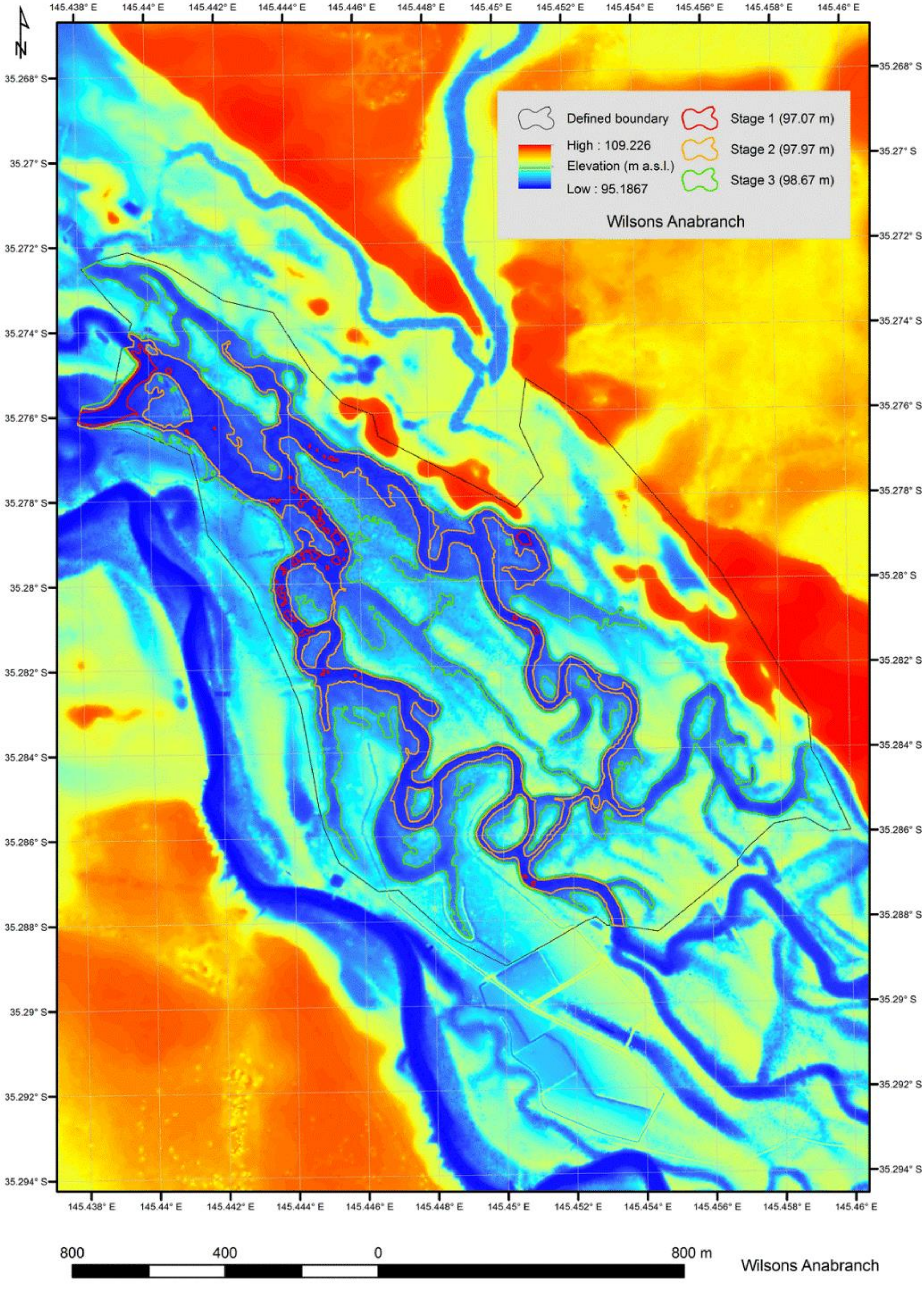
Wang Swamp Lower

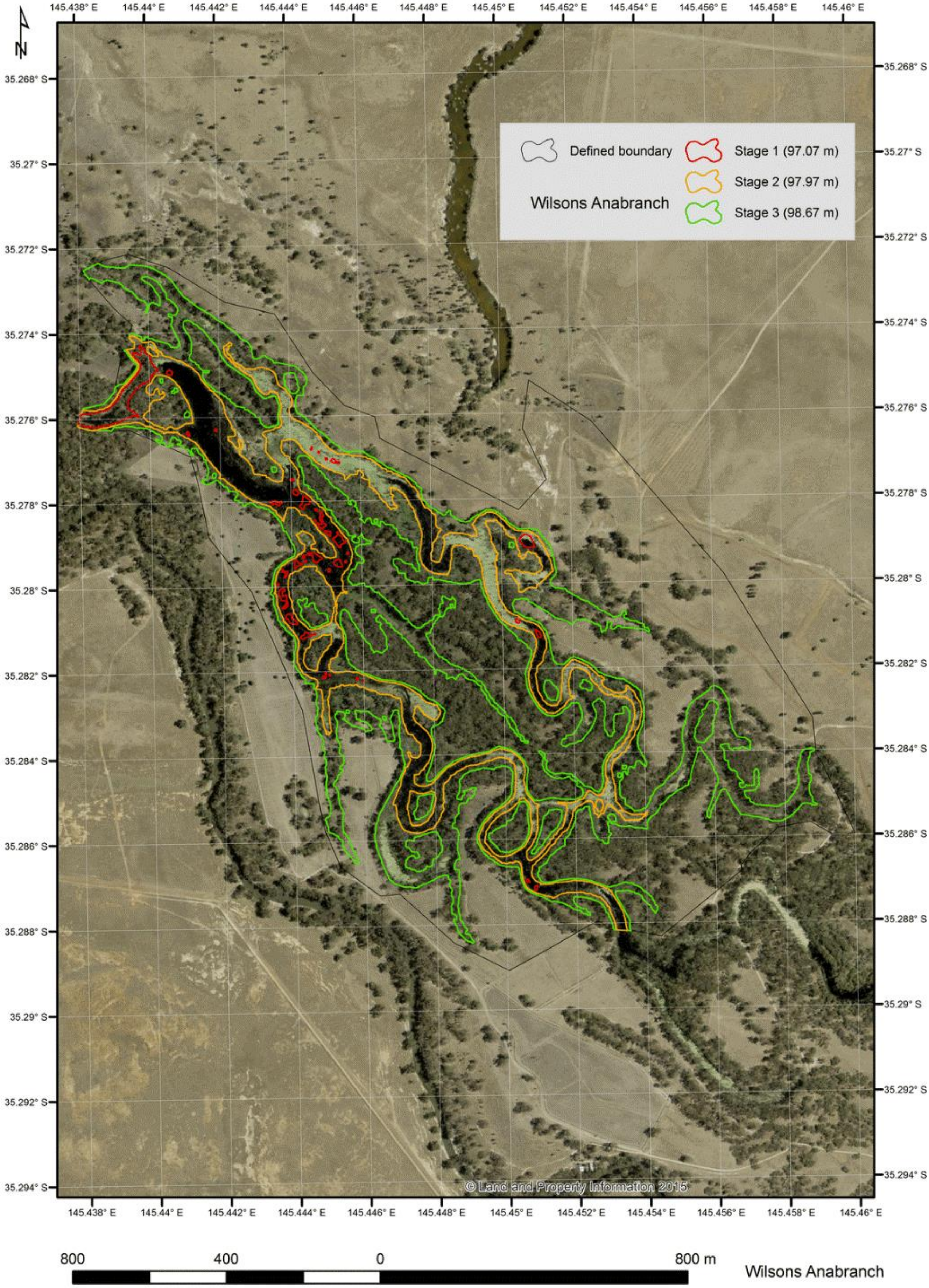


Wang Swamp Upper

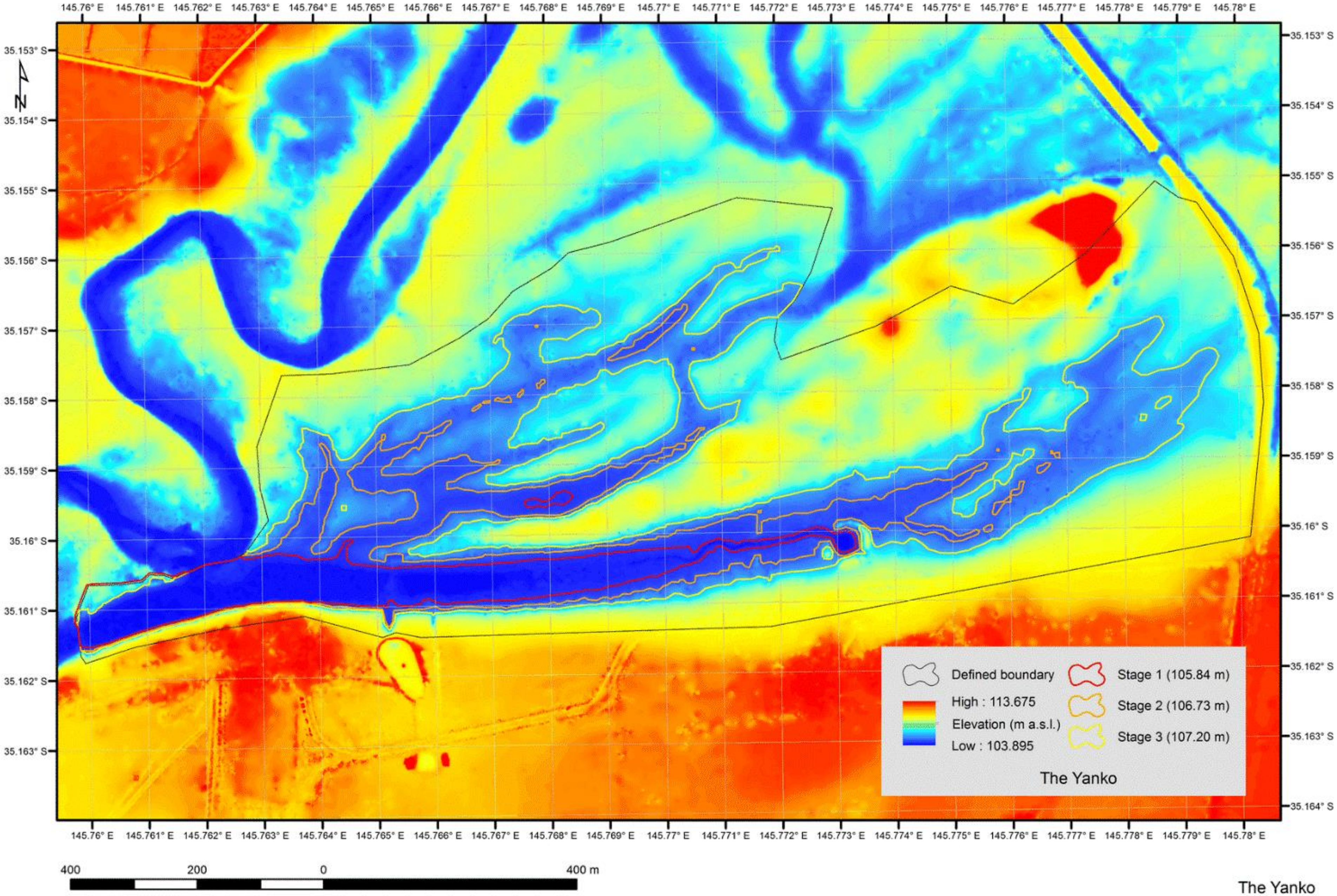


Wang Swamp Upper

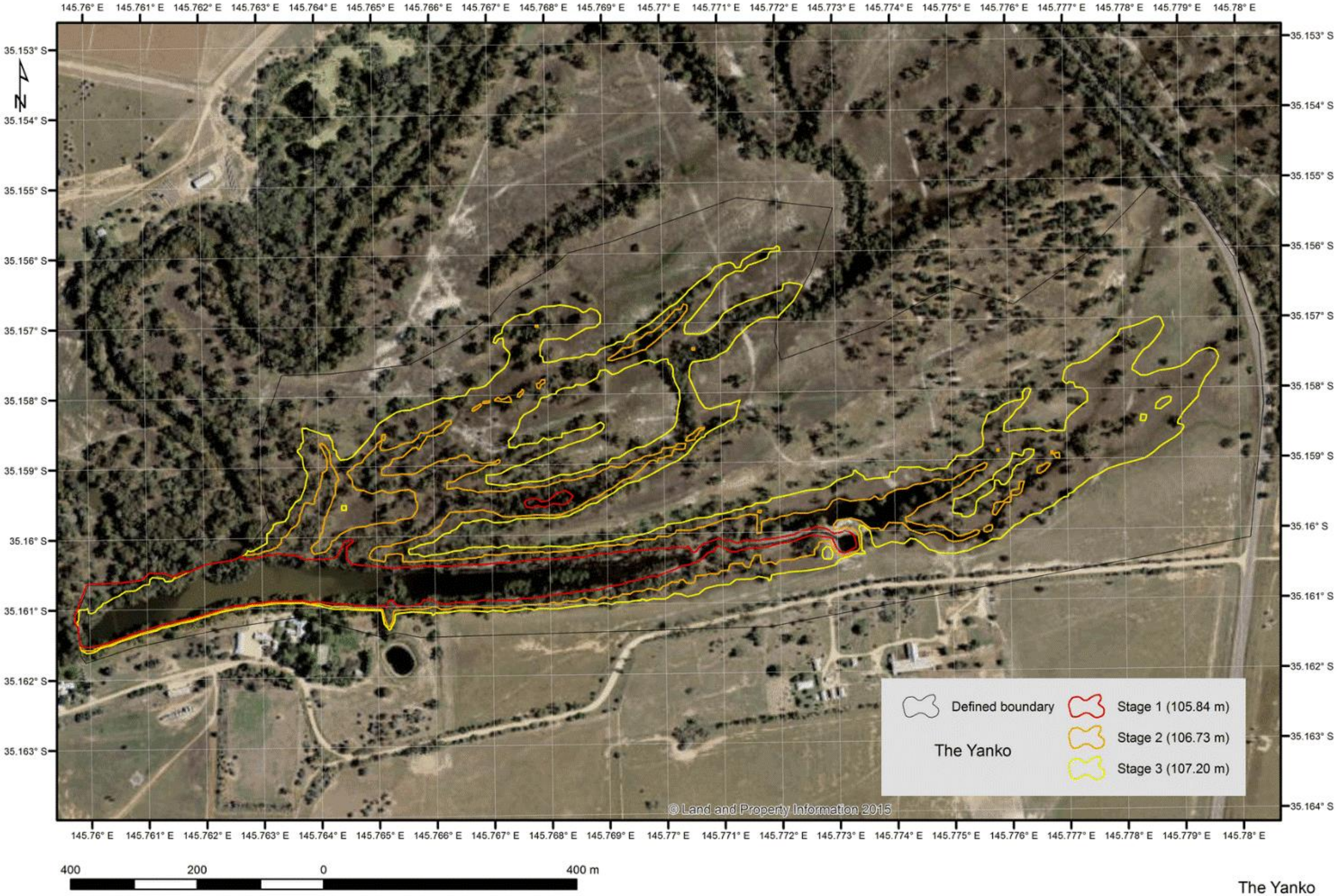

Defined boundary
High : 109.226
Elevation (m a.s.l.)
Low : 95.1867
Stage 1 (97.07 m)
Stage 2 (97.97 m)
Stage 3 (98.67 m)
Wilsons Anabranch
800
400
0
800 m
Wilsons Anabranch



Wilsons Anabranch


Defined boundary
Stage 1 (105.84 m)
High : 113.675
Stage 2 (106.73 m)
Elevation (m a.s.l.)
Stage 3 (107.20 m)
Low : 103.895
The Yanko
400
200
0
400 m

The Yanko


Defined boundary
Stage 1 (105.84 m)
Stage 2 (106.73 m)
Stage 3 (107.20 m)
The Yanko
© Land and Property Information 2015
400
200
0
400 m

Appendix 2: Wetland photos

Photos of each of the wetlands surveyed, photos taken during the initial May surveys. Please see photo library for more photos.

Broome	
Bundure	

Cocketgedong	
Coonong	

Hartwood	
Quiamong	
The Yanko	

Wangamong creek	
Wanganella lower	
Wanganella upper	

Wilson's anabranch	
Rhyola House	

Wilson's anabranch	
Silver Pines	
Sheepwash Anabranch	

Appendix 3: Wetland habitat description

Table A1.1. Rapid frog habitat assessment in % cover (October and December surveys 2017). Percentages presented are averaged from three transects per survey while tree canopy and dead standing timber counts were only estimated during the initial survey.

System reach	Site code	Open water	Inundated veg.	open water + inundated veg.	Bare ground	Dry vegetation	Free floating aquatic	Submerged aquatic	Low growing aquatic	Short emergent	Tall emergent	Structural diversity	Canopy cover	Dead standing timber	Aquatic vegetation (summary)	Hydrology during surveys
Mid-Yanco	BROO	81	2	82	6	8	0	0	0	100	0	1	15	22	Predominantly leaf litter and coarse woody debris, small amount azolla & juncus	Flooded early December (heavy rain)
	BUND	48	38	86	3	10	1	11	35	20	32	5	23	9	Areas with high amounts of cumbungi, shallower areas with a diversity of water primrose, ribbon weed, water couch, short spike rush and slender knotweed	Flooded early December (heavy rain)
	WILS	86	0	86	5	5	0	0	0	0	33	1	10	51	Small amounts of cumbungi (fringing) only	Receding water levels by December
	YANK	83	4	87	3	7	0	0	12	58	13	3	13	8	Small amount of slender knotweed, water primrose, juncus, umbrella sedge, dead seedlings and leaf litter	Flooded early December (heavy rain)
Colombo	CCKT	63	31	94	2	4	1	0	3	23	73	4	25	0	High amounts of cumbungi and leaf litter (bank), small amounts of couch, azolla and juncus	No significant change (steep banks)
	CNNG	78	12	90	8	3	0	0	2	3	95	3	9	0	Some couch and small amounts of juncus	Flooded early December (heavy rain)
	SHEE	7	93	99	0	1	0	2	11	63	17	5	6	32	Vast area of short spike rush, cumbungi, persicaria, dock sp., water primrose, milfoil, nardoo etc.	Flooded early December (heavy rain)

Table A1.1. continued

System reach	Site code	Open water	Inundated veg.	open water + inundated veg.	Bare ground	Dry vegetation	Free floating aquatic	Submerged aquatic	Low growing aquatic	Short emergent	Tall emergent	Structural diversity	Canopy cover	Dead standing timber	Aquatic vegetation (summary)	Hydrology during surveys
Mid-Billabong	HART	77	15	92	3	5	1	0	72	28	0	4	12	8	Small amounts of juncus, water primrose, ribbon weed. Lignum & salt bush.	No significant change (regulated by levee bank)
Mid-Billabong	WANG	25	65	90	4	4	6	2	17	19	58	5	12	7	High amounts of cumbungi, spike rush, water primrose, azolla, couch, some milfoil, curled dock & juncus	Flooded early December (heavy rain)
Forest (regulated)	FRST	84	4	88	8	4	0	0	0	60	40	2	20	1	Predominantly leaf litter covered banks	No significant change (steep banks)
Forest (unreg.)	WANL	4	3	8	11	81	0	0	45	5	0	3	1	14	Lignum, when water was present, small amount of submerged aquatic	Dried by December
Forest (unreg.)	WANU	68	17	85	3	9	0	3	2	0	97	3	0	11	Predominantly cumbungi with small amounts of submerged aquatic (e.g. milfoil), lignum	Retained some water in December
Forest (unreg.)	RHYO	0	0	0	49	50	0	0	0	0	0	0	7	22	Apart from lignum, no aquatic vegetation due to wetland drying	Dry throughout
Forest (unreg.)	RYLH	0	0	0	11	89	0	0	0	0	0	0	4	11	Apart from lignum, no aquatic vegetation due to wetland drying	Dry throughout
Lower-Billabong	QUIA	90	0	90	3	4	0	0	0	33	0	1	20	9	Predominantly leaf litter covered banks	No significant change (steep banks)

Table A1.2 Incidental observations of non-amphibian aquatic organisms caught during five minute sweep netting surveys (targeting tadpoles) at each of the wetlands.

Common name	**Scientific name**	**No. sites observed**
Carp	*Cyprinus carpio*	3
Mosquito fish	*Gambusia holbrooki*	11
Goldfish	*Carassius auratus*	1
Carp gudgeon	*Hypseleotris spp.*	2
Australian smelt	*Retropinna semoni*	1
Shrimp	*Paratya spp.*	9
Yabby	*Cherax destructor*	3

Appendix 4: Frog species observations

Table A1.3. Total frog species observations (visual and call observations) from the October and December (2017) frog surveys.

System reach	Site	*Eastern sign-bearing froglet*	*Eastern banjo frog*	*Barking marsh frog*	*Inland banjo frog*	*Spotted marsh frog*	*Peron's tree frog*	*Southern bell frog*	*Sudell's frog*	Grand Total	Species diversity (count)
Mid-Yanco	BROO	36	10			63	8	1		118	5
	BUND	48	12	54		176	11	7		308	6
	WILS	2	1	10		13	3			29	5
	YANK	23	8	1		15	13			60	5
Colombo	CCKT	38		1		21	26		35	121	5
	CNNG	25				19	8		1	53	4
	SHEE	125		32		256	105		4	522	5
Mid-Billabong	HART	100				130	30			260	3
	WANG	40	1	98		210	8			357	5
Forest (regulated)	FRST	1				7	10			18	3
Forest (un-regulated)	WANL	35				113			1	149	3
	WANU	39	1	16	1	126	6		3	192	7
	RHYO		1			1	4			6	3
	RYLH									0	0
Lower-Billabong	QUIA					1	3			4	2
No. sites observed		12	7	7	1	14	13	2	5		
Total no. species observations (all sites)		512	34	212	1	1151	235	8	44		
Proportion of total observations		0.233	0.015	0.096	0.000	0.524	0.107	0.004	0.020		

Appendix 5: Carbon sample collection co-ordinates

Table A1.4. Geographic co-ordinates for carbon sample collection

Sample no.	Replicate	Site	S	E
1	Bundure 1	Bundure	-35.13235	145.9841
2	Bundure 2	Bundure	-35.13332	145.9588
3	Bundure 3	Bundure	-35.13002	145.9569
4	Bundure 4	Bundure	-35.12243	145.9742
5	Bundure 5	Bundure	-35.12389	145.9755
6	Wangamong 1	Wangamong	-35.34375	145.6019
7	Wangamong 2	Wangamong	-35.34393	145.6007
8	Wangamong 3	Wangamong	-35.34534	145.6030
9	Wangamong 4	Wangamong	-35.34485	145.5999
10	Wangamong 5	Wangamong	-35.34530	145.6007
11	The Yanko 1	The Yanko	-35.15907	145.7654
12	The Yanko 2	The Yanko	-35.16042	145.7666
13	The Yanko 3	The Yanko	-35.16032	145.7697
14	The Yanko 4	The Yanko	-35.15965	145.7737
15	The Yanko 5	The Yanko	-35.15952	145.7762
16	Cocketgedong 1	Cocketgedong	-35.23705	145.9806
17	Cocketgedong 2	Cocketgedong	-35.23415	145.9817
18	Cocketgedong 3	Cocketgedong	-35.24645	145.9754
19	Cocketgedong 4	Cocketgedong	-35.24453	145.9768
20	Cocketgedong 5	Cocketgedong	-35.24160	145.9771
21	Wilson 1	Wilson	-35.27962	145.4437
22	Wilson 2	Wilson	-35.27613	145.4443
23	Wilson 3	Wilson	-35.27687	145.4454
24	Wilson 4	Wilson	-35.27807	145.4478
25	Wilson 5	Wilson	-35.27503	145.4400
26	Coonong 1	Coonong	-35.11944	146.1932
27	Coonong 2	Coonong	-35.11911	146.1953
28	Coonong 3	Coonong	-35.11892	146.2013
29	Coonong 4	Coonong	-35.11971	146.2022
30	Coonong 5	Coonong	-35.12058	146.2037
31	Quiamong 1	Quiamong	-35.29050	145.2148
32	Quiamong 2	Quiamong	-35.28852	145.2131
33	Quiamong 3	Quiamong	-35.28901	145.2113
34	Quiamong 4	Quiamong	-35.28968	145.2126
35	Quiamong 5	Quiamong	-35.28984	145.2086
36	Broome 1	Broome	-35.14386	145.7975
37	Broome 2	Broome	-35.13965	145.7989
38	Broome 3	Broome	-35.13860	145.8006
39	Broome 4	Broome	-35.14168	145.8040

40	Broome 5	Broome	-35.14132	145.8073

Table A1.4 continued

Sample no.	Replicate	Site	S	E
41	Wanganella upper 1	Wanganella upper	-35.24667	144.8442
42	Wanganella upper 2	Wanganella upper	-35.24774	144.8460
43	Wanganella upper 3	Wanganella upper	-35.25302	144.8454
44	Wanganella upper 4	Wanganella upper	-35.25401	144.8442
45	Wanganella upper 5	Wanganella upper	-35.25600	144.8449
46	Wanganella lower 1	Wanganella lower	-35.23180	144.8161
47	Wanganella lower 2	Wanganella lower	-35.23276	144.8117
48	Wanganella lower 3	Wanganella lower	-35.23437	144.8139
49	Wanganella lower 4	Wanganella lower	-35.23030	144.8089
50	Wanganella lower 5	Wanganella lower	-35.22998	144.8109
51	Hartwood 1	Hartwood	-35.35123	145.3521
52	Hartwood 2	Hartwood	-35.35282	145.3523
53	Hartwood 3	Hartwood	-35.34941	145.3536
54	Hartwood 4	Hartwood	-35.35054	145.3528
55	Hartwood 5	Hartwood	-35.34996	145.3542
56	Rhyola 1	Rhyola	-35.07999	144.5360
57	Rhyola 2	Rhyola	-35.08054	144.5341
58	Rhyola 3	Rhyola	-35.08587	144.5320
59	Rhyola 4	Rhyola	-35.08464	144.5286
60	Rhyola 5	Rhyola	-35.08843	144.5324
61	Rhyola House 1	Rhyola House	-35.11361	144.5511
62	Rhyola House 2	Rhyola House	-35.11855	144.5495
63	Rhyola House 3	Rhyola House	-35.11843	144.5546
64	Rhyola House 4	Rhyola House	-35.11494	144.5553
65	Rhyola House 5	Rhyola House	-35.11357	144.5573
66	Silver Pines 1	Silver Pines	-35.11644	146.0346
67	Silver Pines 2	Silver Pines	-35.11540	146.0372
68	Silver Pines 3	Silver Pines	-35.11583	146.0314
69	Silver Pines 4	Silver Pines	-35.11410	146.0292
70	Silver Pines 5	Silver Pines	-35.11367	146.0261
71	Sheepwash anabranch 1	Sheepwash anabranch	-35.06646	146.2864
72	Sheepwash anabranch 2	Sheepwash anabranch	-35.06779	146.2858
73	Sheepwash anabranch 3	Sheepwash anabranch	-35.07262	146.2889
74	Sheepwash anabranch 4	Sheepwash anabranch	-35.07381	146.2862
75	Sheepwash anabranch 5	Sheepwash anabranch	35.07413	146.2840

Appendix 6: Survey co-ordinates for the rapid habitat and frog surveys

Table A1.5. Geographic co-ordinates for the vegetation surveys (GDA94). Frog surveys also covered these co-ordinates (20 minute walking transects along the water's edge).

Site code	Site	T1		T2		T3	
		S	E	S	E	S	E
SILV	Silver Pines	NA	NA	NA	NA	NA	NA
WILS	Wilson	-35.2746	145.4406	-35.2748	145.4411	-35.2751	145.4414
WANU	Wanganella upper	-35.2455	144.8425	-35.2461	144.8434	-35.2472	144.8447
WANL	Wanganella lower	-35.2294	144.8078	-35.2305	144.8083	-35.2316	144.8093
WANG	Wangamong	-35.3449	145.6000	-35.3449	145.5997	-35.3447	145.5991
BROO	Broome	-35.1381	145.7986	-35.138	145.7978	-35.1378	145.7966
BUND	Bundure	-35.1237	145.9738	-35.1231	145.9733	-35.1226	145.9727
CCKT	Cocketgedong	-35.2451	145.9761	-35.2445	145.976	-35.2435	145.9762
FRST	Forest creek TSR	-35.3254	145.2884	-35.3254	145.2887	-35.3251	145.2891
YANK	The Yanko	-35.1604	145.7691	-35.1604	145.7687	-35.1602	145.7667
HART	Hartwood	-35.3505	145.3545	-35.3509	145.3545	-35.3500	145.3543
SHEE	Sheepwash anabranch	-35.0744	146.2865	-35.0740	146.2877	-35.0725	146.2890
RYLH	Rhyola House	-35.1107	144.5517	-35.1109	144.5501	-35.1103	144.5492
RHYO	Rhyola	-35.0830	144.5293	-35.0840	144.5309	-35.0844	144.5324
QUIA	Quiamong	-35.2884	145.2144	-35.2884	145.2152	-35.2880	145.2138
CNNG	Coonong	-35.1196	146.2022	-35.1191	146.2017	-35.1188	146.2005