Inland Waters & Catchment Ecology

Chowilla Icon Site – Floodplain Vegetation Monitoring 2022 Interim Report

J.M Nicol, K.A. Frahn, J. Fredberg, S.L. Gehrig, K.B Marsland and J.T. Weedon

SARDI Publication No. F2010/000729-13
SARDI Research Report Series No. 1170

SARDI Aquatic and Livestock Sciences
PO Box 120 Henley Beach SA 5022

March 2023

Government of South Australia
Department of Primary Industries and Regions

Government of South Australia
Department for Environment and Water

Australian Government

MURRAY–DARLING BASIN AUTHORITY

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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This publication may be cited as:
Nicol, J.M., Frahn, K.A., Fredberg, J., Gehrig, S.L., Marsland, K.B. and Weedon, J.T. (2023). Chowilla Icon Site – Floodplain Vegetation Monitoring 2022 Interim Report. South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2010/000279-13. SARDI Research Report Series No. 1170. 79pp.

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Date: 24 March 2023

Distribution: MBDA, DEW, SARDI Aquatic and Livestock Sciences, Parliamentary Library, State Library and National Library

Circulation: OFFICIAL

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ACKNOWLEDGEMENTS

The authors thank Todd Wallace, Rebecca Crack, Mark Hassam, Kate McNicol, Richard Watts, Mark Schultz, Erin Lenon, Terry Minge, Grace Hodder and Luke Vial (DEW) for field assistance. Matt Gibbs (DEW) and Andrew Keogh (MDBA) for providing modelled natural flows and inundation extents for the Chowilla Floodplain. Todd Wallace, Tony Herbert, Richard Watts, Brad Hollis, Nick Souter, Mark Schultz, Erin Lenon, Alison Stokes, Jan Whittle, and Luke Vial (DEW), Chris Bice, Rod Ward, Sandra Leigh, Leigh Thwaites, Philippa Wilson, Brenton Zampatti and Juan Livore (SARDI) are thanked for comments on early drafts of this report. This project was funded by The Living Murray initiative. The Living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian and Commonwealth governments, coordinated by the Murray-Darling Basin Authority. This project has been managed by the Department of Environment and Water (DEW), through the Chowilla Icon Site staff.

EXECUTIVE SUMMARY

The Chowilla Floodplain is the largest remaining area of undeveloped floodplain habitat in the lower Murray-Darling Basin (MDB). Nonetheless, it has suffered ecological degradation due to reduced magnitude, duration, and frequency of flooding as a result of river regulation, water extraction, rising saline ground water, grazing by domestic stock and feral animals and (in recent years) overabundant native herbivores. In 2002 it was designated as one of The Living Murray (TLM) initiative's Icon Sites (Murray-Darling Basin Authority 2011b) and management actions are being undertaken with the aim of attaining a series of site-specific ecological objectives. These include the following vegetation-specific objectives:

- Objective 5: improve the area and diversity of grass and herblands;
- Objective 6: improve the area and diversity of flood dependent understorey vegetation; and
- Objective 8: limit the extent of invasive (increaser) species, including weeds.

A series of quantitative targets were developed through the TLM Condition Monitoring Plan refinement project (2014) to be the subject of monitoring programs and aid assessment of the aforementioned objectives in temporary wetland and floodplain habitats at Chowilla. Five vegetation targets relate to the assessment of Objectives 5 and 6 and take into consideration the abundance of flood dependent and amphibious species, frequency of occurrence of these species, species richness and the maximum interval between occurrences. These targets include:

1. In temporary wetlands, a minimum of 40% of cells (from monitoring quadrats) either inundated or containing, native flood dependent or amphibious taxa once every two years on average with maximum interval no greater than 4 years. Native flood dependent and amphibious species richness ≥20;
2. In temporary wetlands, a minimum of 80% of cells either inundated or containing native flood dependent or amphibious taxa once every four years on average with maximum interval no greater than 6 years. Native flood dependent and amphibious species richness ≥40;
3. On the floodplain, a minimum of 20% of cells containing native flood dependent or amphibious taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness ≥15;
4. On the floodplain, a minimum of 40% of cells containing native flood dependent or amphibious taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness ≥25; and
5. On the floodplain, a minimum of 65% of cells containing native flood dependent or amphibious taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness ≥40.

Four targets were developed to aid assessment of Objective 8 and take into consideration the abundance of exotic species including the proclaimed pest plant *Xanthium occidentale* across the floodplain and in temporary wetlands. These targets include:

1. In temporary wetlands, a maximum of 1% of cells containing *Xanthium occidentale* in any given survey.
2. In temporary wetlands, a maximum of 10% of cells containing exotic taxa in any given survey;
3. On the floodplain, a maximum of 1% of cells containing *Xanthium occidentale* in any given survey; and
4. On the floodplain, a maximum of 5% of cells containing exotic taxa in any given survey.

The aim of this study was to monitor and assess vegetation condition at the Chowilla Icon Site against the site-specific objectives and ecological targets. Since 2018 the opportunity has been taken to also include:

- an assessment of grazing pressure to gain an indication of a non-hydrological influence (grazing) on vegetation; and
- an analysis of the attainment of the floodplain native vegetation targets predicted under modelled natural flows to determine whether the floodplain native vegetation targets could be achieved under natural conditions and are realistically achievable.

Throughout this monitoring program (2006–2022), variable flow in the MDB and site-specific management interventions within Chowilla, have resulted in variable patterns of inundation both spatially and temporally. In 2006 the MDB was in extended drought and overbank flows had not inundated large areas of floodplain since 1996. Low flows characterized the flow regime in the lower Murray River between 2006–2010, but in spring 2006 and spring 2009, site-scale environmental watering (pumping) and inundation occurred at discrete wetlands (i.e. Coppermine Complex and Gum Flat). A prolonged natural overbank flow, and extensive floodplain inundation, occurred from spring 2010 to autumn 2011, and a shorter, but higher overbank flood occurred in late spring 2016. Several in-channel flow pulses were also experienced from 2011 to 2022. The Chowilla Environmental Regulator was also operated five times over this period, namely: spring 2014 (inundation height = 2.75 m above normal pool level, inundation area = 2,142 ha); spring 2015 (inundation height = 1.5 m above normal pool level, inundation area = 535 ha); winter-spring 2016 (inundation height = 3.4 m above normal pool level, inundation area 7,653 ha); spring 2018 (inundation height = 2.24 m above normal pool level, inundation area 2,250 ha) and spring 2021 (inundation height = 3.24 m above normal pool level, inundation area 6,736 ha).

A network of sites was established in areas of herbland and grassland in 2006 and the vegetation surveyed to provide a baseline. These sites have been re-surveyed on an annual basis to monitor medium-term vegetation changes and assess the aforementioned site-specific ecological objectives. Between 2013 and 2022, an additional 59 sites in temporary wetlands that were part of a previous intervention monitoring program were added to the network to gain a better understanding of floodplain and temporary wetland condition at Chowilla. In addition, vertebrate grazing intensity was estimated at each site from 2018 to 2022 by recording the frequency of scats.

The predicted attainment of the floodplain native vegetation targets under natural flows was undertaken by comparing the potential number of quadrat cells containing flood dependent or amphibious species and species richness with that observed under current conditions. The maximum flow across the South Australian border for each year between 2005 and 2022 was modelled using MSM BIGMOD (MDBA) for natural conditions. The inundation extent for the Chowilla Floodplain corresponding to the maximum natural flow was calculated using the MIKE FLOOD model (MDBA), and a polygon of the modelled maximum inundation for each year was overlaid on the position of the sites to determine which sites were inundated in the 12 months prior to the survey.

Forty-six species from 20 families (predominantly Chenopodiaceae and Asteraceae) were recorded from floodplain sites (established in 2006). With the inclusion of the temporary wetland sites surveyed in 2022, plant species richness increased to 65 species from 23 families (also predominantly Chenopodiaceae and Asteraceae).

The five most frequently encountered taxa in 2022 were *Sclerolaena brachyptera, Sclerolaena divaricata,* Open water, *Atriplex* spp. and *Disphyma crassifolium*; accounting for 46% of observations. Of the 5175 quadrat cells surveyed, approximately 8% were found to be devoid of vegetation.

At a similarity of 30%, cluster analysis identified seven distinct groups of the 115 sites surveyed across the Chowilla Floodplain in 2022 and Indicator Species Analysis produced a list of significant representative taxa for each group listed below:

1. “Terrestrial” (32.2%);
2. “Flood responders-1” (22.6%);
3. Open water” sites were inundated and devoid of vegetation (19.1%);
4. “Flood responders-2” (12.2%);
5. “Bare soil” sites were predominantly characterised by empty cells (8.7%);
6. “Amphibious” (4.3%); and
7. “Azolla” (0.9%).

Grazing intensity inferred through scat counts was variable indicating the floodplain sites were more heavily grazed than temporary wetlands for 2022; however, areas of high scat frequency were observed at Lake Littra and Coombool Swamp. Overall scat frequency was significantly higher at floodplain sites than wetland sites for all years. Across the floodplain and temporary wetlands scat frequency was significantly lower in 2018, 2021 and 2022 compared to 2019 and 2020 (when there was no significant difference). Grazing intensity varied among the different communities identified by cluster analysis with the rank order of scat frequency across the different communities: Terrestrial > Flood responders-1 = Flood responders-2 = Amphibious > Bare soil > Open water = ‘Azolla’.

At floodplain sites in 2022, there was an increase in species richness compared to 2021, which was likely due to regulator operation in spring 2021 and vertebrate grazer control. The plant community on the floodplain was transitioning towards a community similar to the one observed after watering. Species richness decreased at the temporary wetland sites due to several sites being inundated and devoid of vegetation.

Current management practices (i.e., site-scale watering and regulator operation) and natural flooding have resulted in three out of the five targets for native understorey floodplain vegetation being achieved over the previous 16 years (Table 1). In 2017, more than 65% of cells in sites 1 to 85 contained amphibious or flood dependent taxa and in 2015, 2017 and 2022 more than 80% of cells at sites 86 to 144 contained amphibious or flood dependent taxa (or were inundated). However, as native flood dependent and amphibious species richness was below 40 for both habitats and the target not achieved.

Table 1: Success of attaining floodplain and temporary wetland native vegetation targets between 2006 and 2022.

Floodplain:	Minimum of 20% of cells containing native flood dependent or amphibious taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness ≥15.	Achieved
	Minimum of 40% of cells containing native flood dependent or amphibious taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness ≥25.	Achieved
	Minimum of 65% of cells containing native flood dependent or amphibious taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness ≥40.	Not achieved
Temporary wetlands:	Minimum of 40% of cells either inundated or containing native flood dependent or amphibious taxa once every two years on average with maximum interval no greater than 4 years. Native flood dependent and amphibious species richness ≥20.	Achieved
	Minimum of 80% of cells either inundated or containing native flood dependent or amphibious taxa once every four years on average with maximum interval no greater than 6 years. Native flood dependent and amphibious species richness ≥40.	Not achieved

Targets for exotic species for the floodplain were achieved each year except in 2011, 2012 and 2017 (after the 2010-11 and 2016 floods) and the target for *Xanthium occidentale* on the floodplain was achieved every year. However, exotic species were abundant in temporary wetlands and the target in this habitat was only achieved in 2017 when most sites were inundated and devoid of vegetation. Furthermore, the *Xanthium occidentale* target was not achieved in temporary wetlands in 2022 (Table 2).

Table 2: Success of attaining floodplain and temporary wetland exotic species and *Xanthium occidentale* targets between 2006 and 2022.

	Target			
Year	**Floodplain exotics**	**Floodplain *Xanthium***	**Temporary wetland exotics**	**Temporary wetland *Xanthium***
2006	Achieved	Achieved	NA	NA
2007	Achieved	Achieved	NA	NA
2008	Achieved	Achieved	NA	NA
2009	Achieved	Achieved	NA	NA
2010	Achieved	Achieved	NA	NA
2011	Not achieved	Achieved	NA	NA
2012	Not achieved	Achieved	NA	NA
2013	Achieved	Achieved	Not achieved	Achieved
2014	Achieved	Achieved	Not achieved	Achieved
2015	Achieved	Achieved	Not achieved	Achieved
2016	Achieved	Achieved	Not achieved	Achieved
2017	Not achieved	Achieved	Achieved	Achieved
2018	Achieved	Achieved	Not achieved	Achieved
2019	Achieved	Achieved	Not achieved	Achieved
2020	Achieved	Achieved	Not achieved	Achieved
2021	Achieved	Achieved	Not achieved	Achieved
2022	Achieved	Achieved	Not achieved	Not achieved

Modelling predicted that for most years more sites would be inundated under natural flows than under the current regime, except in 2006-07 and 2009-10 when Coppermine Complex and Gum Flat were watered, 2014-15, 2015-16 and 2018-19 when the regulator was operated and in 2020-21 when Gum Flat was watered. Under modelled natural conditions between 2006 and 2022, ≥20% of cells were predicted to contain amphibious or flood dependent species on six occasions. Under current conditions, this occurred on nine occasions, four of which were due to watering interventions. Amphibious or flood dependent species were present in 40% of cells three times between 2006 and 2022 with a maximum interval of five years under both modelled natural and current conditions (Figure 19). However, on each of these occasions under modelled natural conditions 70%, 70% and 73% of cells in 2011, 2012 and 2017, respectively, were predicted to have flood dependent or amphibious species present.

Keywords: Floodplain understorey, The Living Murray, Condition monitoring, Chowilla monitoring, Chowilla Floodplain.

1. INTRODUCTION

The Chowilla Floodplain, located on the lower River Murray at the borders of South Australia, New South Wales and Victoria, is the largest remaining area of undeveloped floodplain habitat in the lower Murray-Darling Basin (MDB). It is unique for its large area of contiguous floodplain habitat and wide variety of aquatic environments including fast and slow flowing anabranches, temporary billabongs and permanent backwaters (O'Malley and Sheldon 1990). The area supports a diversity of species across many taxonomic groups and has been recognised as a wetland of international significance under the Ramsar convention (O'Malley and Sheldon 1990) and an Icon Site under the Murray-Darling Basin Authority's (MDBA) *The Living Murray* (TLM) initiative.

Prior to river regulation in the MDB, the lower River Murray experienced greater variability in flow, and in turn, water level. Small to medium sized floods occurred more frequently prior to river regulation, and as such, the Chowilla Floodplain was historically inundated more frequently (to some extent every one to two years), for longer duration and to greater depths (Maheshwari *et al.* 1995).

Vegetation on the Chowilla Floodplain includes *Eucalyptus largiflorens* (black box) woodlands, *Eucalyptus camaldulensis* var. *camaldulensis* (river red gum) woodlands, *Atriplex* spp. (saltbush) shrublands, and a range of aquatic and riparian vegetation types associated with the various temporary and permanent wetlands (O'Malley 1990). The majority of vegetation studies of the Chowilla Anabranch system prior to 2005 focused on the *Eucalyptus camaldulensis* and *Eucalyptus largiflorens* overstorey communities, with an emphasis on the impact of groundwater depth and salinity on tree condition (e.g. Jolly *et al.* 1993; 1994; McEwan *et al.* 1995; Walker *et al.* 1996; Akeroyd *et al.* 1998; Doble *et al.* 2004; Overton and Jolly 2004). Prior to The Living Murray condition and intervention monitoring programs, there were sporadic investigations of the understorey vegetation of the system; O'Malley (1990) and Roberts and Ludwig (1990; 1991) undertook extensive surveys of the floodplain and permanently inundated wetlands, respectively, whilst there has been a series of site-specific monitoring and research investigations at Pilby Creek (e.g. Stone 2001; Siebentritt 2003).

1.1. Objectives

This monitoring program commenced in 2006 and represents the longest continuous monitoring program of the understorey plant community on the Chowilla Floodplain and at any floodplain site in the South Australian River Murray Corridor. The monitoring program was established to assess the four understorey vegetation objectives identified in The Chowilla Floodplain Environmental Water Management Plan (Murray-Darling Basin Authority 2012), namely:

Objective 5 - "improve the area and diversity of grass and herblands";

Objective 6 - "improve the area and diversity of flood dependent understorey vegetation";

Objective 7 - "maintain or improve the area and diversity of grazing sensitive plant species"; and

Objective 8 - "limit the extent of invasive (increaser) species, including weeds".

A series of targets for temporary wetlands and the floodplain were developed to assess Objectives 5, 6 and 8 (Objective 7 was not assessed because it does not relate to water management). Five targets assess the combined Objectives 5 and 6, and consider the abundance of flood dependent and amphibious species, the frequency of occurrence of these species, species richness and the maximum interval between occurrences:

1. In temporary wetlands a minimum of 40% of cells (from monitoring quadrats) either inundated or containing native flood dependent or amphibious taxa once every two years on average, with maximum interval no greater than 4 years. Native flood dependent and amphibious species richness ≥20;
2. In temporary wetlands a minimum of 80% of cells either inundated or containing native flood dependent or amphibious taxa once every four years on average, with maximum interval no greater than 6 years. Native flood dependent and amphibious species richness ≥40;
3. On the floodplain a minimum of 20% of cells containing native flood dependent or amphibious taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness ≥15;
4. On the floodplain a minimum of 40% of cells containing native flood dependent or amphibious taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness ≥25; and
5. On the floodplain a minimum of 65% of cells containing native flood dependent or amphibious taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness ≥40.

Four targets were developed to assess Objective 8 and take into consideration the abundance of exotic species and the proclaimed pest plant in South Australia *Xanthium occidentale* across the floodplain and in temporary wetlands in any given survey:

1. In temporary wetlands a maximum of 1% of cells containing *Xanthium occidentale* in any given survey;
2. In temporary wetlands a maximum of 10% of cells containing exotic taxa in any given survey;
3. On the floodplain a maximum of 1% of cells containing *Xanthium occidentale* in any given survey; and
4. On the floodplain a maximum of 5% of cells containing exotic taxa in any given survey.

Assessment of these objectives and targets requires both baseline data and ongoing monitoring, particularly after large flood events or management interventions.

Monitoring undertaken in 2022 builds upon data collected from 2006 to 2021 and provides information regarding the change in plant communities over that time. The survey period includes a period of record low inflows, targeted environmental watering (usually pumping water into temporary wetlands), two large unregulated floods, several smaller in-channel flow pulses and floodplain inundation via the operation of the Chowilla Environmental Regulator on five occasions (at different heights and durations). Therefore, this monitoring program has collected information regarding the change in floodplain understorey vegetation in response to different inundation histories, including desiccation, targeted environmental watering, and increased water levels and areas of inundation due to natural flooding and regulator operation.

The surveys from 2013 onwards included temporary wetlands that were previously monitored under the intervention monitoring program (Nicol *et al.* 2010b; Nicol 2012).

The aim of this study was to monitor and assess vegetation condition at the Chowilla Icon Site against site specific objectives and associated ecological targets.

Since 2018, the opportunity has been taken to also include:

- assessment of grazing pressure to gain an indication of a non-hydrological influence (grazing) on vegetation; and
- analysis of the attainment of the floodplain native vegetation targets predicted under modelled natural flows to determine whether the floodplain native vegetation targets could be achieved under natural conditions and are realistically achievable.

This interim report describes: the methods used to establish the monitoring sites, including survey design; results from the 2022 survey; quantitative and qualitative comparisons of the changes in floristic composition between 2006 and 2022; evaluation of achievement of TLM targets; assessment of vertebrate grazing pressure; and comparison of the attainment of TLM targets under current conditions and modelled natural flows.

2. METHODS

2.1. Hydrology

From 1996 to 2010, the MDB experienced the most severe drought in recorded history (van Dijk *et al.* 2013). Below average stream flows, coupled with upstream extraction and river regulation, resulted in reduced inflows to South Australia (van Dijk *et al.* 2013), which prior to August 2010 were insufficient to inundate the floodplain (Murray-Darling Basin Authority 2011a) (Figure 1). From June 2010 to May 2011, total inflow volumes were among the highest on record and patterns of inflows were atypical compared to historical flows (Murray-Darling Basin Authority 2011a) (Figure 1). During this period, flow into South Australia peaked at 93,000 ML/day in February 2011 (Figure 1). Flows of this magnitude inundate around 70% of the Chowilla Floodplain area (Overton *et al.* 2006, Overton and Doody 2010) and under natural conditions typically last for around three months as unregulated events (Sharley and Huggan 1995), but the 2010-11 high flows and floodplain inundation persisted for ~11 months (Figure 1).

Flows remained high throughout winter and spring 2011 with flows of 41,000 ML/day in August 2011 and remained above 15,000 ML/day throughout the summer. Two smaller flood events peaking at 60,000 ML/day and 50,000 ML/day (flow into South Australia) occurred in April and October 2012 (Figure 1) resulting in inundation of low-level floodplain. Following this, flow declined and from January to August 2013 was maintained at entitlement flows (<10,000 ML/day), before a small unregulated flow peaking at 23,500 ML/day in October 2013 (Figure 1). From December 2013 to June 2014, flow to South Australia remained at entitlement (Figure 1). There was a small flow of 16,000 ML/day in July 2014, after which flows decreased to 5,000 ML/day in September 2014, before increasing again to 7,000–11,000 ML/day between October 2014 and March 2015 (due to delivery of environmental water and return flows from upstream watering interventions), and then returning to entitlement (Figure 1). These flows were confined to the channel and insufficient to inundate large areas of floodplain; nevertheless, some low-lying temporary wetlands were flooded between 2012 and 2015.

In 2016, flows to South Australia remained <12,000 ML/day until mid-July when flow increased slowly, peaking at 95,000 ML/day on November 30th, inundating 14,358 ha of the Chowilla Floodplain, after which flow (and water level: Figure 2) decreased rapidly. By February 2017, flow was approximately 10,000 ML/day and remained around this level for the rest of the year (Figure 1). At the peak of the late 2016 overbank flood 116 monitoring sites; 60 (80%) floodplain sites and 57 (100%) temporary wetland sites were inundated (Appendix 1). Flows were generally below 12,000 ML/day throughout 2017, except for the first half of January when flows were receding from the overbank flood, and a small in-channel pulse peaking at 17,600 ML/day in mid-November (Figure 1), which was insufficient to inundate significant areas of floodplain or temporary wetlands (Figure 2). Similar to 2017, flows remained low (typically <12,000 ML/day) throughout 2018, 2019 and early 2020, except for a small flow pulse (due to environmental flows) of 15,561 ML/day in October 2019 (Figure 1). Flows also were low in 2020 and early 2021 (typically entitlement flows) with the exception of a small flow pulse (due to environmental flows) peaking at 17,917 ML/day in late November 2020 (Figure 1). In 2021, flows remained at or near entitlement until August 2021 when a natural in channel flow pulse commenced peaking at 37,656 ML/day in late December (Figure 1). Flows remained at above entitlement past the end of April 2022 (Figure 1).

In spring 2014, the Chowilla Environmental Regulator was operated for the first time. Water levels were raised to 19.1 m AHD upstream of the regulator in October 2014, increasing water levels by approximately 2.75 m (Figure 2). An associated raising of Lock and Weir 6 to 19.67 m AHD (42 cm above normal pool level) was also undertaken. The combined actions resulted in inundation of 2,142 ha of low-lying floodplain (including 12 floodplain sites) and most temporary wetlands including Werta Wert Wetland, Coppermine Complex, Lake Limbra, Twin Creeks, Punkah Depression, Punkah Floodrunner and Monoman Horseshoe (including 55 temporary wetland sites). Water levels were held at this height for two weeks before being drawn down and returning to normal pool levels by December 2014.

The Chowilla Regulator was operated for a second time in spring 2015 to a low level, generating a small within channel increase in water level. Water levels were gradually raised to 17.85 m AHD upstream of the regulator in November 2015, increasing water level by 1.5 m (Figure 2). This action resulted in inundation of 535 ha of low-lying floodplain (including two floodplain sites) and temporary wetlands (five monitoring sites). Water levels were held at this height for five days before being drawn down and returning to normal levels by December 2015.

A large-scale operation of the Chowilla Regulator was undertaken in spring 2016. Water levels were raised to 19.75 m AHD (3.4 m above normal pool level) at the regulator and to 19.84 m AHD (59 cm above normal pool level) at Lock 6 (Figure 2). This resulted in the inundation of approximately 7,650 ha of floodplain and temporary wetlands at its peak in late-September 2016. Regulator operation inundated a total of 90 monitoring sites (35 floodplain and 55 temporary wetland). Inundation maintained by the subsequent natural flood (Appendix 1) during which water levels peaked at 19.96 m AHD in early-December (Figure 2).

The Chowilla Regulator was operated for the fourth time in spring 2018 to a medium level. Water levels were raised to 18.59 m AHD (2.24 m above normal pool level) at the regulator and to 19.47 m AHD (22 cm above normal pool level) at Lock 6 (Figure 2). This resulted in inundation of approximately 2,250 ha of floodplain and temporary wetlands at the peak in early October 2018. Regulator operation inundated a total of 36 monitoring sites (eight floodplain and 28 temporary wetland) (Appendix 1).

A large-scale operation of the Chowilla Regulator was undertaken in spring 2021. Water levels were raised to 19.59 m AHD (3.24 m above normal pool level) at the regulator and to 19.69 m AHD (44 cm above normal pool level) at Lock 6 (Figure 2). This resulted in inundation of approximately 6,736 ha of floodplain and temporary wetlands at the peak in mid-October 2021. Regulator operation inundated a total of 78 monitoring sites (24 floodplain and 54 temporary wetland) (Appendix 1).

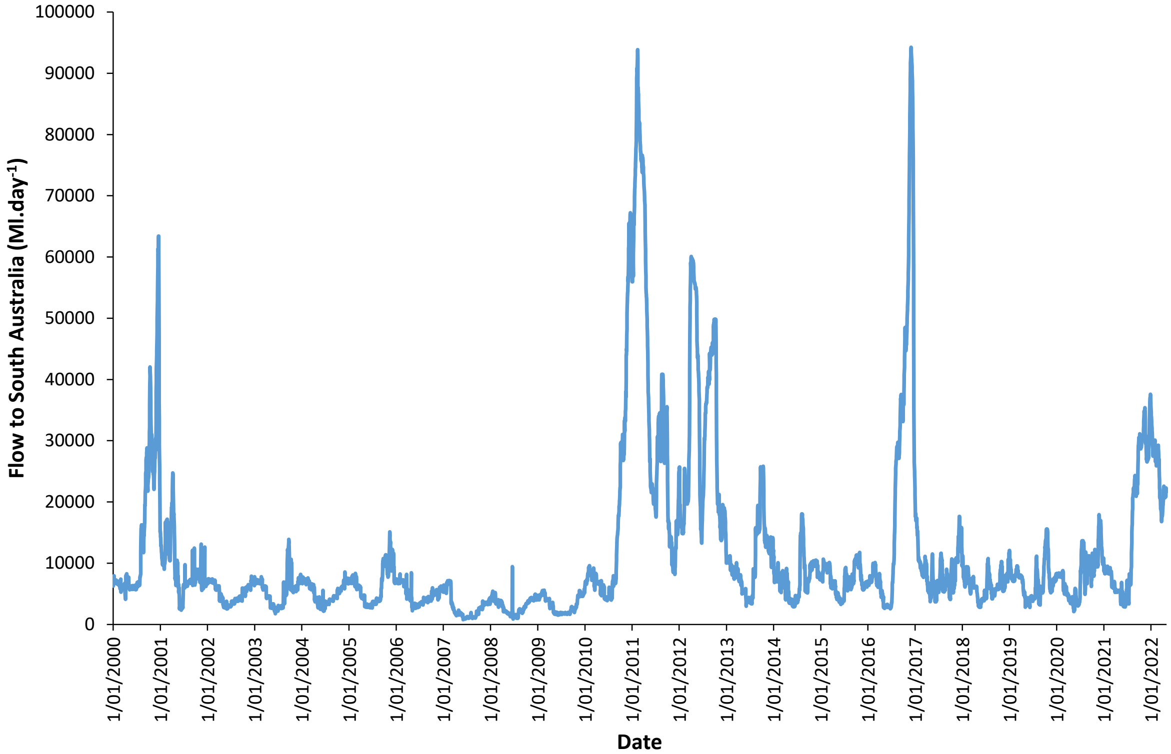

Figure 1: River Murray flow (mean daily discharge) to South Australia from January 2000 to April 2022 (DEW 2022b).

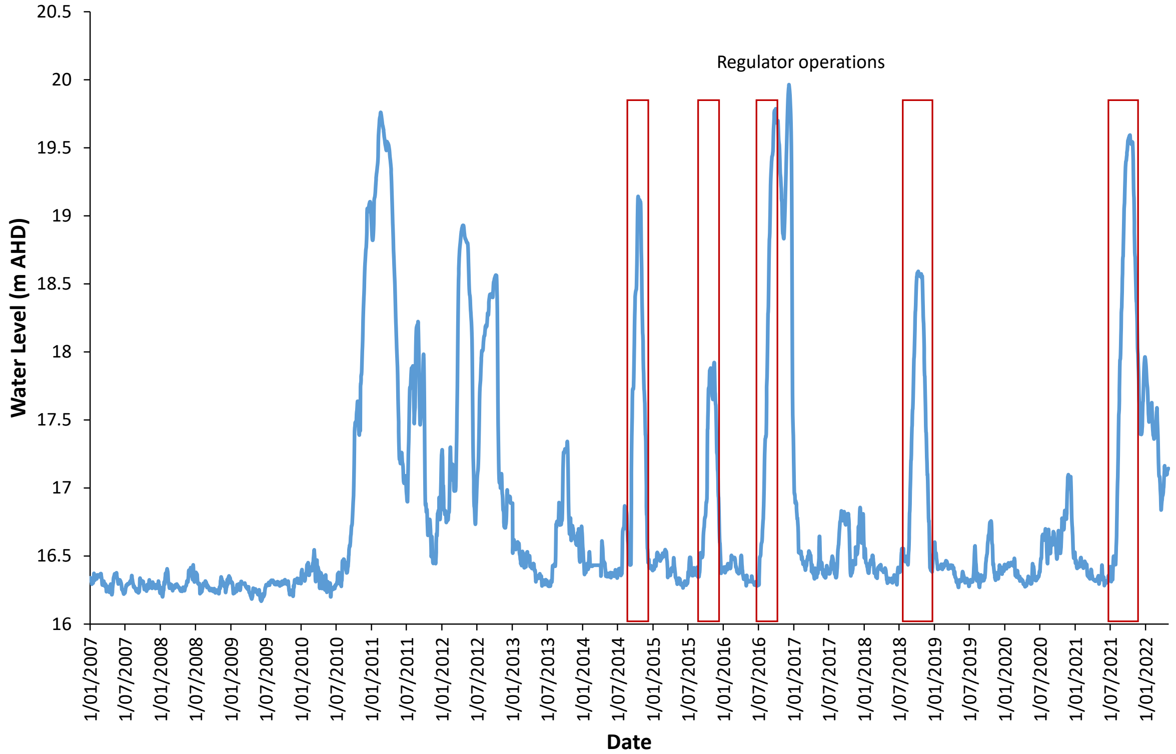

Figure 2: Water level in Chowilla Creek upstream of the Chowilla Environmental Regulator from January 2007 to April 2022 (DEW 2022a), red boxes denote regulator operations.

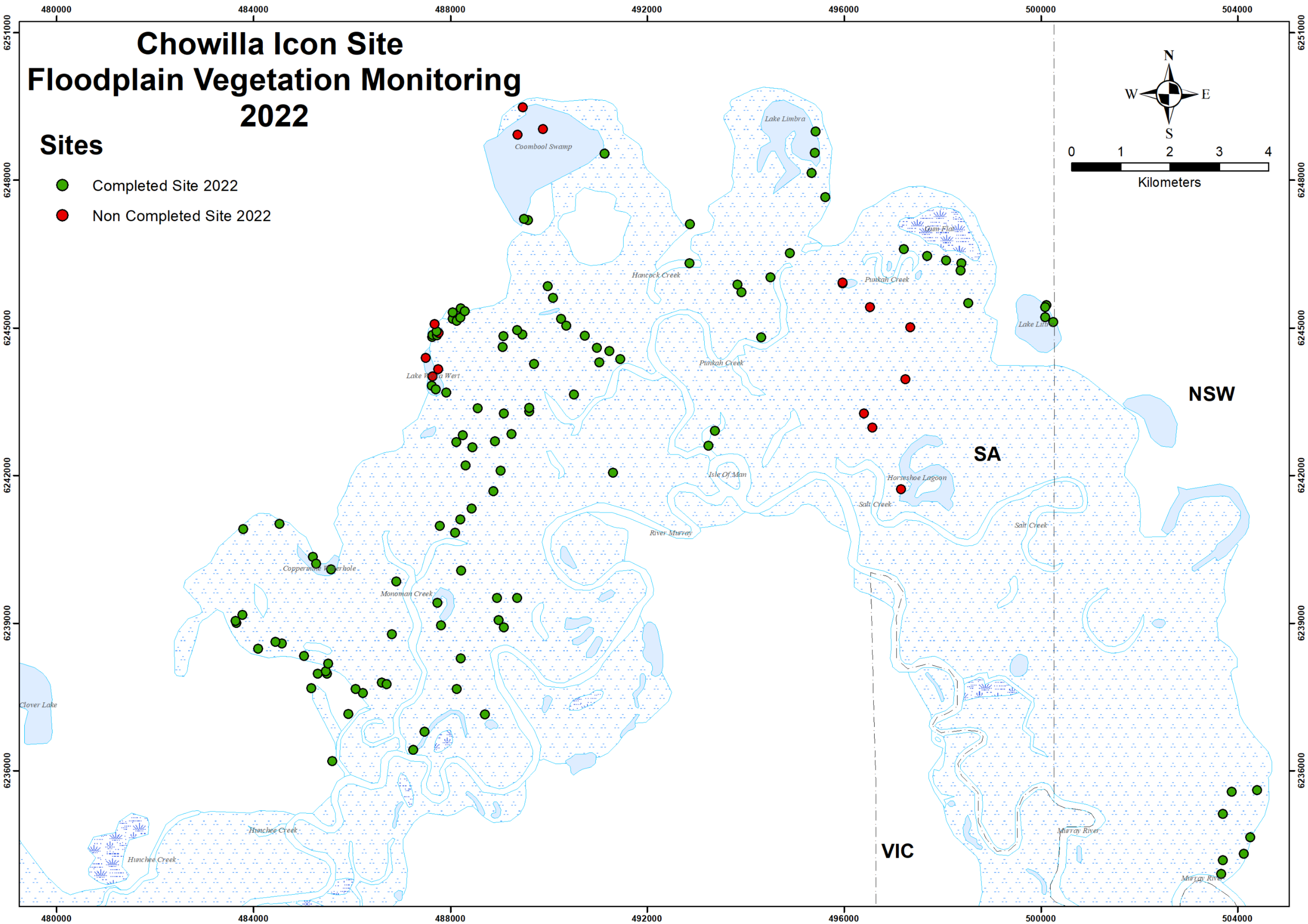

Figure 3: Map of the Chowilla Floodplain showing condition monitoring sites (green dots indicate sites surveyed in 2022 and red dots indicate sites not surveyed in 2022).

2.2. Vegetation surveying protocol

Vegetation survey methods were consistent with those used for other vegetation monitoring projects in the South Australian River Murray upstream of Wellington (e.g. Nicol 2010; Nicol *et al.* 2013; 2015a; 2015b). The maintenance of consistent methods and ongoing monitoring will facilitate comparison of data across studies to enable a greater understanding of floodplain vegetation dynamics across the lower River Murray and with broader hydrology.

The sites surveyed in this report followed those established in 2006, incorporating areas of herbland and grassland across the Chowilla Floodplain (Weedon and Nicol 2006). Sites were chosen such that they:

- were located in areas that would be inundated by overbank flows;
- had no tree overstorey;
- were accessible by 4WD vehicle during dry conditions; and
- covered a range of vegetation types and grazing histories.

Sites were re-surveyed in February 2007, 2008, 2009, 2010, 2012, 2013, 2014, 2015, 2016, 2017, 2018,2019, 2020, 2021 and 2022. Due to the 2010/11 overbank flood, access to the Chowilla Floodplain was not possible until July 2011. In 2008, three additional sites on islands and the New South Wales section of the floodplain were added. Two sites established in 2006 (53 and 54) were excluded from 2009 onwards as the construction of a fence made them inaccessible (Appendix 1). In 2010, 2011, 2012, 2015, 2016, 2017, 2018, 2019 and 2022 sites on Punkah Island were inaccessible due to high water levels in Punkah Creek or damage to the ford and in 2011, 16 sites (including the sites on Punkah Island) were inaccessible due to high river levels. In 2013, five of the original floodplain sites were inaccessible and therefore not surveyed. In spring 2013, Gum Flat was watered with six sites inundated, and thus, could not be surveyed in 2014. In 2016, 17 established sites (including those on Punkah Island) were unable to be surveyed; sites 50, 96 (Punkah Depression), 98 (Punkah Flood Runner), 118 (Pipeclay Billabong) and 129 (Brandy Bottle Lagoon) were inundated, whilst sites 84, 85, 88, 89 and 90 (Kulcurna) were inaccessible. In 2017, 48 sites were inundated in February, and devoid of vegetation but were included in the analysis. In 2018, a total of 12 sites were not surveyed including the sites on Punkah Island. Four floodplain sites and one in Woolshed Creek on the western end of the floodplain were also not surveyed. In 2019, 13 floodplain sites were not surveyed including the eight sites on Punkah Island and five sites were inaccessible. In temporary wetlands, two sites in the Central Basin of Werta Wert Wetland were not accessible due to deep mud (risk of bogging and damage to site) and a further nine were inundated but surveyed and found to be devoid of vegetation (Appendix 1). In 2020, all sites were surveyed, except two sites in Coombool Swamp that were inaccessible due to watering and one floodplain site that is only accessible by boat (Figure 3, Appendix 1). All inundated sites (except the two in Coombool Swamp) were assessed. In 2021 sites in New South Wales were not surveyed due to travel restrictions brought about by the COVID-19 pandemic and 12 sites in Werta Wert Wetland were inaccessible due to watering (Figure 3, Appendix 1). In 2022, in addition to the sites located on Punkah Island, five sites in Werta Wert Wetland and three in Coombool Swamp were inaccessible due to watering (Figure 3, Appendix 1).

Since 2013 a total of 59 temporary wetland sites have been added to the condition monitoring program. However, they may not all be surveyed each year depending on accessibility and inundation (Appendix 1). These additional sites were previously monitored as part of an intervention monitoring program (Nicol *et al.* 2010b; Nicol 2012). The only sites from the intervention monitoring program that have not been surveyed at least once as part of the condition monitoring program are the two sites in Punkah Island Horseshoes (Figure 3, Appendix 1). However, since the 2016 flood, Punkah Island Horseshoes were connected at normal pool level (and permanently inundated) and will not be included in the condition monitoring program.

At each site, three 15 m x 1 m quadrats were surveyed. Quadrats were arranged in a straight line parallel to elevation contours, 50 m apart. Each quadrat was divided into 15, 1 x 1 m cells. The presence of each species that had live plants rooted within each cell was recorded to give a total score out of 15 for each quadrat. Cells that were not inundated and contained no live plants were recorded as bare soil and inundated cells containing no live plants as open water. To gain a better indication of species richness, all species observed within 50 m of each site are also recorded. Since 2018, the frequency of scats in each quadrat was also recorded in this manner to gain an indication of vertebrate grazing intensity. The types of scats were not recorded but included 1) native herbivores: emu (*Dromaius novaehollandiae*), kangaroos (western grey; *Macropus fuliginosus* and red; *Macropus rufus*) and euros (*Macropus robustus*) and feral and 2) domestic herbivores: sheep (*Ovis aries*), goats (*Capra aegagrus hircus*), pigs (*Sus scrofa*) and rabbits (*Oryctolagus cuniculus*).

2.3. Plant identification and nomenclature

Plants were identified using keys in Jessop and Toelken (1986), Cunningham *et al.* (1992), and Jessop *et al.* (2006). In some cases, due to immature individuals or lack of floral structures, plants were identified to genus only. Nomenclature follows the Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2022). A comprehensive list of all species surveyed, their functional classification, growth form, life history strategy and conservation status are presented in Appendix 2.

2.4. Data analysis

For the 2022 survey, the plant communities present (a snapshot for that year) were compared using Group Average Clustering (McCune *et al.* 2002) performed on pooled data (species scores were averaged from the three quadrats at each site). A cut-off score of 30% similarity was used to determine the cluster groups based on species presence and their abundances. To identify the representative species for each group, Indicator Species Analysis (Dufrene and Legendre 1997) was performed on the unpooled data using the groupings of sites derived from the cluster analysis. All multivariate analyses used Bray-Curtis (1957) distances to construct the similarity matrices and were undertaken using the package PCOrd 5.12 (McCune and Mefford

2006). The locations of the quadrats were also mapped to allow presentation of the spatial distribution of the vegetation groups.

Differences in scat frequency between the floodplain (sites 1–85) and wetland (sites 86–143) habitats from 2018 to 2022 were analysed with two factors univariate PERMANOVA (Anderson and Ter Braak 2003). Differences between scat frequency and the plant communities identified by the cluster analysis for 2022 were also analysed using single factor univariate PERMANOVA (Anderson and Ter Braak 2003), using the package PRIMER version 7.0.12 (Clarke and Gorley 2015). Euclidean distances were used to calculate the similarity matrices for all univariate PERMANOVA analyses and α was corrected for multiple comparisons using the Bonferroni correction (corrected $\alpha = 0.05/n$ comparisons).

Changes in floristic composition of floodplain sites (sites 1–85) from 2006 to 2022 were analysed using non-metric multi-dimensional scaling (nMDS) ordination using the package PRIMER version 7.0.12 (Clarke and Gorley 2015). In addition, plants were classified into functional groups based on the framework developed by Nicol *et al.* (2010) and the proportion of broad functional groups (terrestrial, salt tolerant, flood dependent, amphibious and bare soil) present each year were plotted.

2.5. Comparison of attainment of The Living Murray targets under current and modelled natural flows

A comparison of 1) the number of quadrat cells containing flood dependent or amphibious plant species; and 2) native flood dependent and amphibious species richness was made between current conditions (empirical data) and predictions under modelled natural flows for the floodplain (sites 1–85). The maximum flow across the South Australian border for each year between 2005 and 2021 was modelled for natural conditions (all regulating structures and water extraction removed) using MSM BIGMOD by the Murray-Darling Basin Authority (MDBA). The inundation extent for the Chowilla Floodplain corresponding to the maximum natural modelled flow was calculated using the MIKE FLOOD model (MDBA). A polygon of the modelled maximum inundation extent under natural flows for each year was overlaid on the position of the sites to determine which sites were modelled to have been inundated in the 12 months prior to the survey.

Empirical data collected through this monitoring program between 2006 and 2017 showed that 75% of cells contained native flood dependent or amphibious taxa when inundated in the previous 12 months and this was used to calculate the potential number of cells that would have contained flood dependent or amphibious species for each survey under modelled natural flows.

Multiple regression analyses performed on the same data yielded two predictors of potential species richness under modelled natural flow; 1) the number of quadrat cells containing amphibious or flood dependent species; and 2) the number of sites inundated in the previous 12 months. These data; however, exhibited different relationships with species richness (Figure 4, Figure 5). The association between flood dependent and amphibious species richness, and the number of cells containing the aforementioned species, was best described by a positive linear relationship (Predicted species richness = 0.0188 x no. cells containing native flood dependent or amphibious species: R^2=0.73) (Figure 4). In contrast, the association between flood dependent and amphibious species richness, and the number of sites inundated in the previous 12 months, was best described by an exponential rise to maximum relationship (Predicted species richness = 36.3323 x (1-exp(-0.0667 x no. sites inundated in the previous 12 months)): R^2=0.84) (Figure 5).

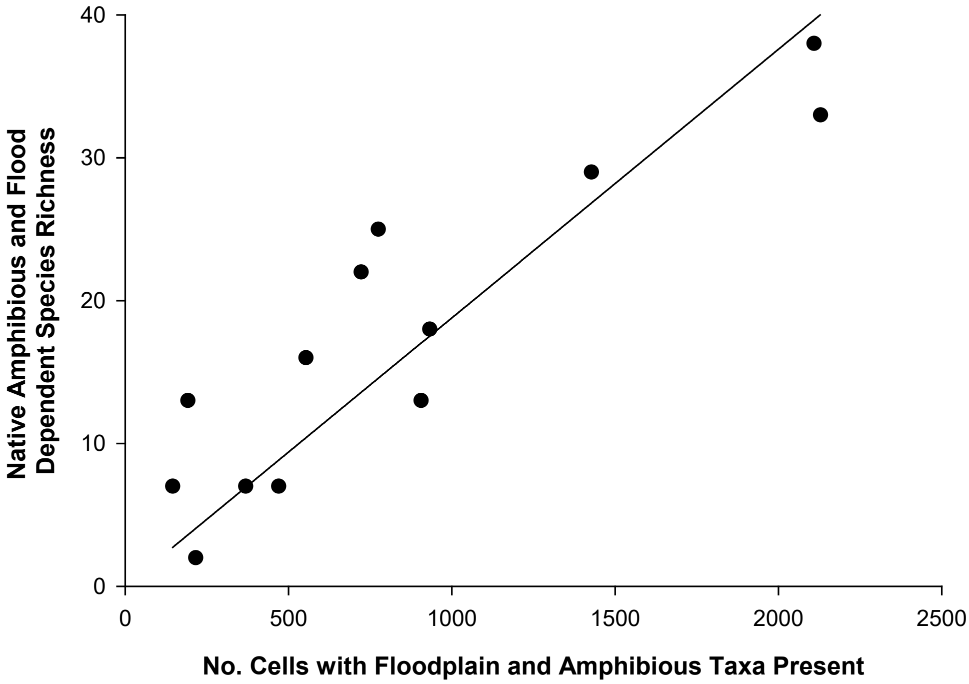

Figure 4: Relationship between the number of cells containing flood dependent and amphibious species and species richness for floodplain sites (1 to 85) from 2006 to 2017 condition monitoring data.

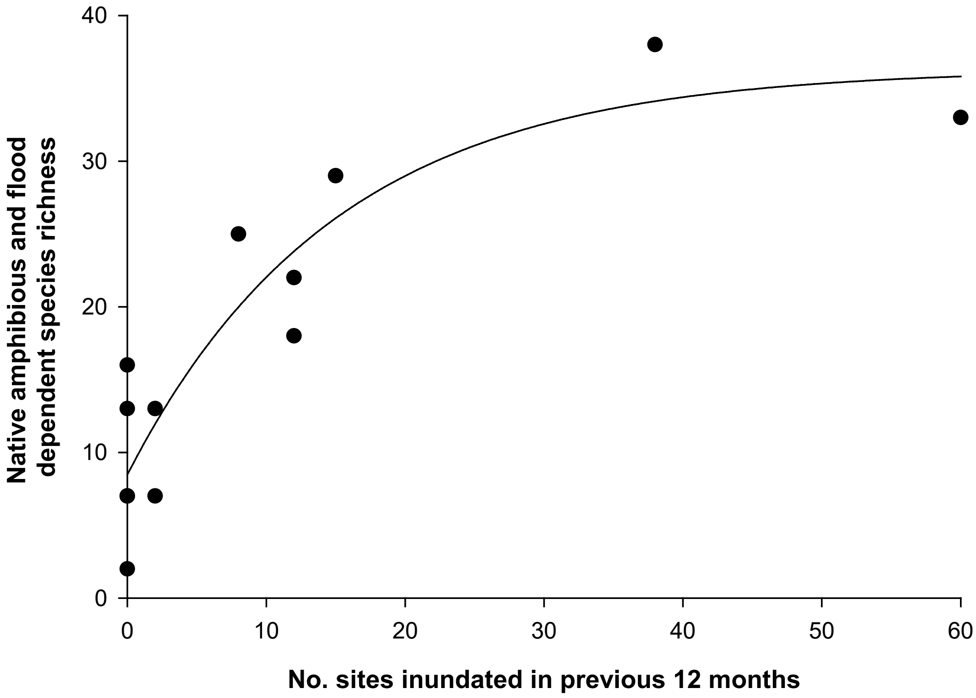

Figure 5: Relationship between the number of sites inundated in the previous 12 months and species richness for floodplain sites (1 to 85) from 2006 to 2017 condition monitoring data.

RESULTS

3.1. 2022 snapshot of plant communities

In 2022, 46 species from 20 families (predominantly Chenopodiaceae and Asteraceae) were recorded from floodplain sites (established in 2006). With the inclusion of the temporary wetland sites surveyed in 2022, plant species richness across the Chowilla Floodplain increased to 65 species from 23 families (also predominantly Chenopodiaceae and Asteraceae).

The five most frequently encountered taxa were *Sclerolaena brachyptera, Sclerolaena divaricata,* Open Water, *Atriplex* spp. and *Disphyma crassifolium*; accounting for 46% of observations. Of the 5175 quadrat cells surveyed, approximately 8% were found to be devoid of vegetation.

Cluster analysis (30% similarity) identified seven distinct groups (Figure 6) of sites surveyed in 2022 and Indicator Species Analysis (Table 3) produced a list of significant representative taxa for each group.

Figure 7 presents the spatial distribution of sites and plant communities based on groupings identified from cluster analysis listed below:

1. “Terrestrial” (32.2%);
2. “Flood responders-1” (22.6%);
3. Open water” sites were inundated and devoid of vegetation (19.1%);
4. “Flood responders-2” (12.2%);
5. “Bare soil” sites were predominantly characterised by empty cells (8.7%);
6. “Amphibious” (4.3%); and
7. “Azolla” (0.9%).

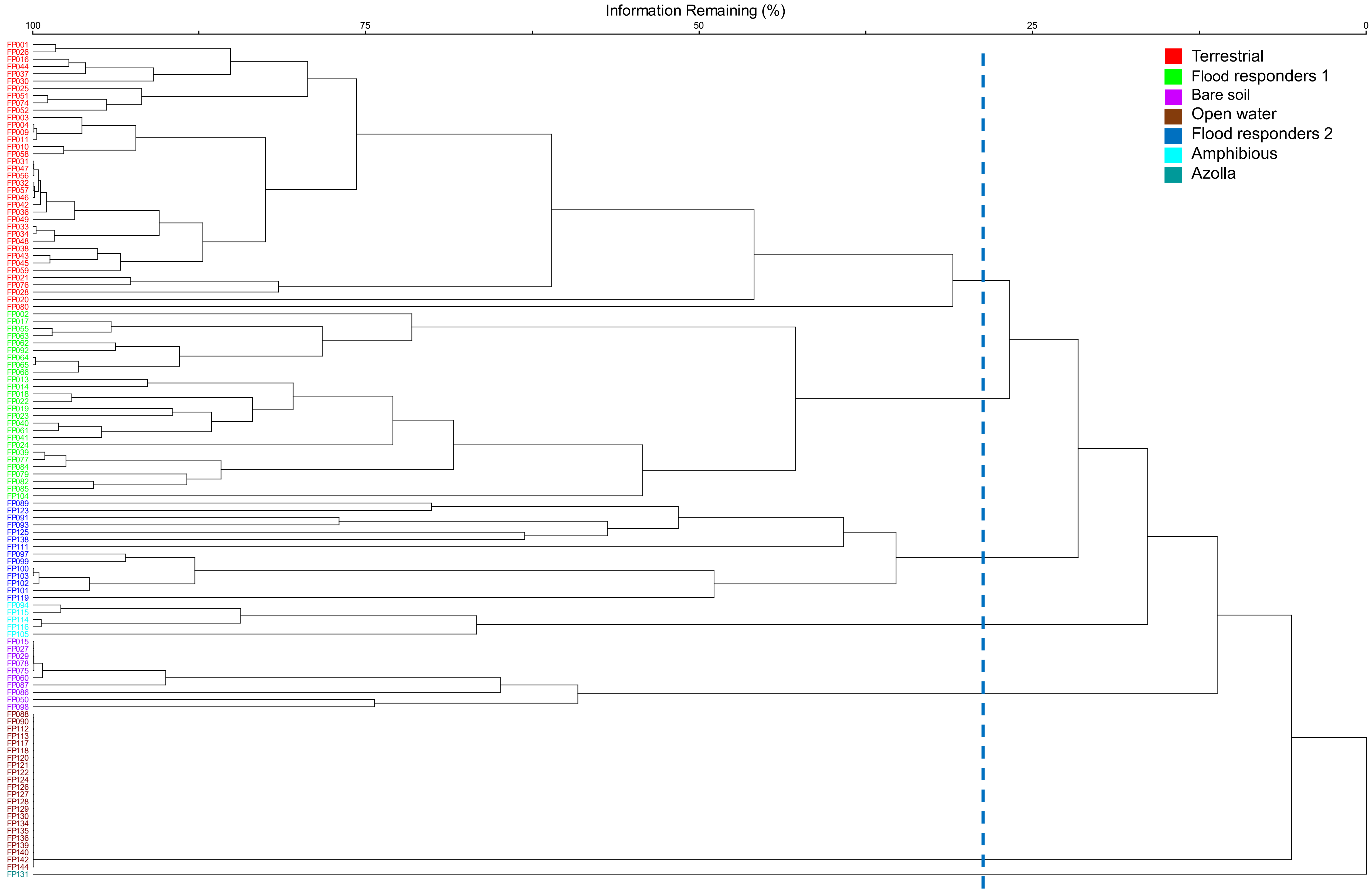

Figure 6: Dendrogram showing group average clustering of vegetation survey sites from the 2022 survey. Dashed line shows division of sites into vegetation groups at 30% similarity.

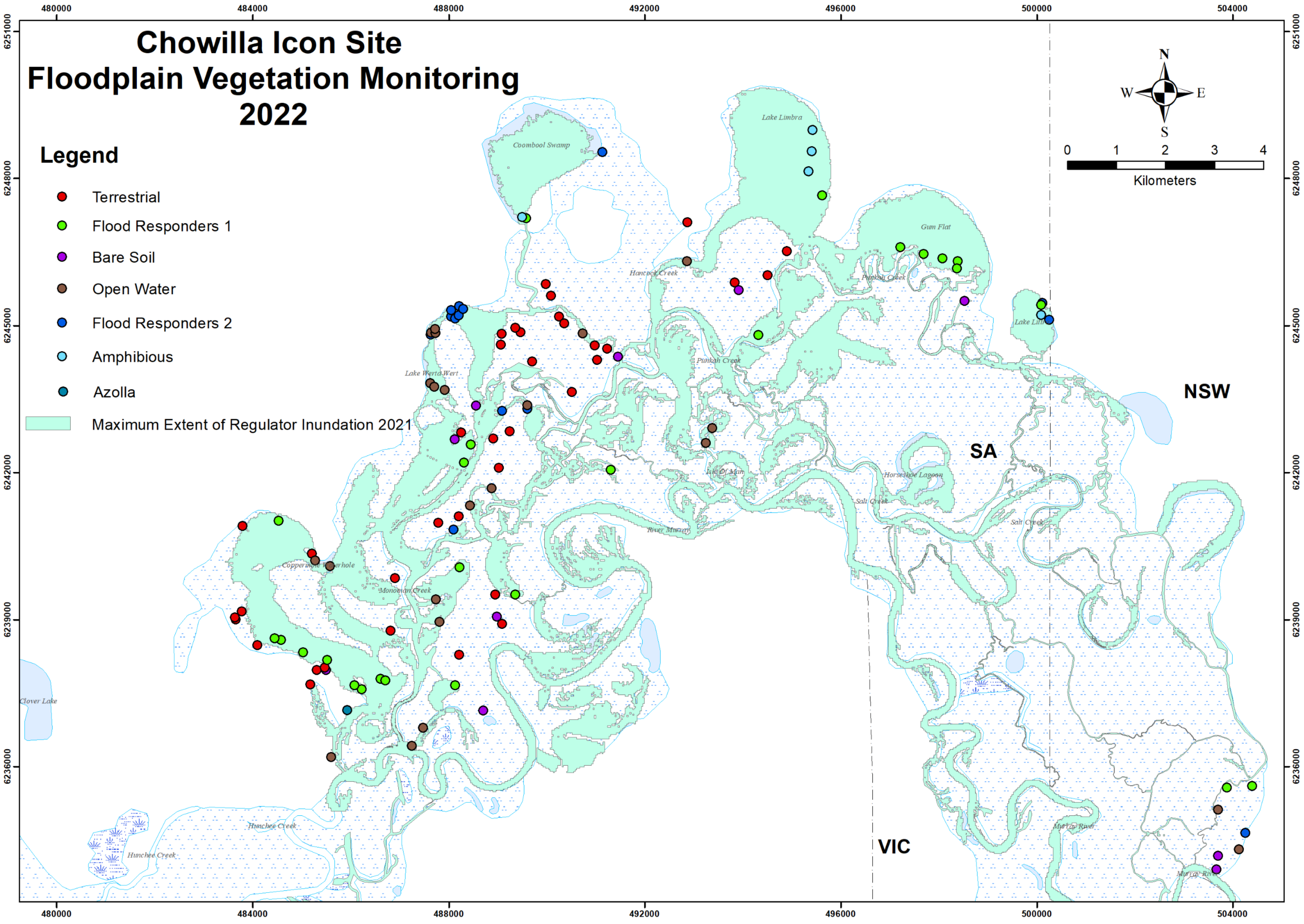

Figure 7: Spatial distribution and plant communities of the 125 sites across the Chowilla Floodplain for the 2022 survey. Colours reflect the 2022 dendrogram groupings (Figure 6).

Table 3: Indicator Species Analysis (Dufrene and Legendre 1997) based on unpooled data (*n* = 375) from the 2022 vegetation survey. Group indicates group in which taxon had highest indicator value. P-value derived from Monte-Carlo test of significance (permutations=10,000). Significant (*P*<0.05) taxa are highlighted (*denotes exotic taxon).

Taxon	Group	*P*
Abutilon theophrasti	Flood responders 2	0.0616
Acacia stenopylla	Flood responders 2	0.4419
Alternanthera denticulata	Flood responders 1	0.0034
Ammania multiflora	Flood responders 2	0.0306
Atriplex spp.	Flood responders 1	0.0006
Atriplex suberecta	Flood responders 2	0.0928
Azolla pinnata	Azolla	0.0002
Bare soil	Bare Soil	0.0002
Brachyscome paludicola	Flood responders 2	0.06
Calotis cuneifolia	Flood responders 2	0.8652
Calotis hispidula	Flood responders 1	0.0164
Centipeda minima	Flood responders 2	0.0002
Chenopodium nitrariaceum	Terrestrial	1
Craspedia sp.	Flood responders 1	0.0708
Cyperus difformis	Flood responders 1	0.163
Cyperus gymnocaulos	Flood responders 2	0.0426
Disphyma crassifolium ssp. *clavellatum*	Terrestrial	0.0002
Dittrichia graveolens	Flood responders 1	0.4753
Duma florulenta	Flood responders 1	0.4595
Duma horrida	Bare Soil	0.4333
Dysphania pumilio	Flood responders 2	0.0412
Eindia nutans	Flood responders 1	0.6749
Eleocharis acuta	Flood responders 1	0.1368
Enchylaena tomentosa	Bare Soil	0.1352
Eragrostis dielsii	Flood responders 2	0.0558
Eucalyptus camaldulensis	Flood responders 2	0.0444
Euchiton involucratus	Flood responders 2	0.0362
Euphorbia drummondii	Flood responders 2	0.0764
Frankenia pauciflora	Flood responders 2	0.118
Glinus lotoides	Flood responders 2	0.06
Glycyrrhiza acanthocarpa	Flood responders 2	0.0168
Haloragis aspera	Flood responders 2	0.0528
*Heliotropium curassavicum**	Flood responders 2	0.1072
*Heliotropium europaeaum**	Flood responders 2	0.0002
Iseotopis graminifolia	Flood responders 2	0.0506
Lachnagrostis filiformis	Flood responders 2	0.2769
Maireana spp.	Terrestrial	0.0454
Marselia drummondii	Amphibious	0.1114
Mesembryanthemum crystallinum	Flood responders 1	0.6773
Mukia maderaspatana	Flood responders 2	0.1692
Myriophyllum verrucosum	Amphibious	0.0018
Open water	Open water	0.0002
Osteocarpum acropterum	Flood responders 1	0.6821
Persicaria lapathifolia	Flood responders 1	0.6807
*Phyla canescens**	Flood responders 2	0.1338
Phyllanthus lacunaris	Flood responders 1	0.2917
Polygonum plebeium	Flood responders 2	0.0604
Pseudognaphalium luteoalbum	Flood responders 2	0.0568
Rhagodia spinescens	Flood responders 1	0.6237
Salsola australis	Terrestrial	0.1398
Sclerolaena brachyptera	Terrestrial	0.0002
Sclerolaena divaricata	Flood responders 1	0.0002
Sclerolaena stelligera	Terrestrial	0.0002
Setaria jubiflora	Flood responders 1	0.2545
Solanum lacunarium	Terrestrial	0.7858
Spergularia marina	Flood responders 2	0.072
Sphaeromorphaea littoralis	Flood responders 2	0.007

Taxon	Group	*P*
Sporobolus mitchellii	Flood responders 1	0.0022
Stemodia florulenta	Flood responders 2	0.011
Tecticornia pergranulata	Amphibious	0.0006
Tecticornia triandra	Terrestrial	0.0892
Tetragonia tetragonoides	Flood responders 1	0.0822
Teucrium racemosum	Flood responders 1	0.3823
Thyridia repens	Amphibious	0.0002
Unknown Coombool	Flood responders 2	0.2496
*Verbena supina**	Flood responders 2	0.0524
*Xanthium occidentale**	Flood responders 2	0.0026

3.2. Grazing intensity

Grazing intensity (as inferred from scat frequency) was highly variable across the Chowilla Floodplain and showed no clear spatial patterns (Figure 8). Areas not inundated by regulator operation; however, typically had higher scat frequencies (Figure 8). Scat frequency was significantly higher at floodplain sites than wetland sites for all years, in particular in 2022 due to most wetlands being either inundated or recently inundated (Table 4, Figure 9a). Furthermore, scat frequency was significantly lower in 2018, 2021 and 2022 (for both habitats) compared to 2019 and 2020 (when there was no significant difference) (Figure 9a). PERMANOVA detected a significant interaction between habitat and year from 2018 to 2022 indicating that the change in scat frequency through time showed different patterns between the floodplain and temporary wetlands. This was particularly the case for 2022, with the lowest frequency recorded for temporary wetlands (Table 4, Figure 9a).

Table 4: PERMANOVA results comparing scat frequency between the floodplain and temporary wetlands 2018–2022.

Factor	df	*Pseudo-F*	*P*
Habitat	1,1799	242.71	0.001
Year	3,1799	47.48	0.001
Habitat x Year	3,1799	3.72	0.004

There were significant differences in scat frequency between plant communities as defined by the cluster analysis (PERMANOVA *Pseudo* $F_{6,335}$ = 23.22; P = 0.001). Pairwise comparisons suggested significant differences among most plant community comparisons with the exception of Flood responders-1, Flood responders-2 and Amphibious; and Open water and 'Azolla' (Table 5, Figure 9). The rank order of scat frequency across the different plant communities was: Terrestrial > Flood responders-1 = Flood responders-2 = Amphibious > Bare soil > Open water = 'Azolla' (Table 5, Figure 9).

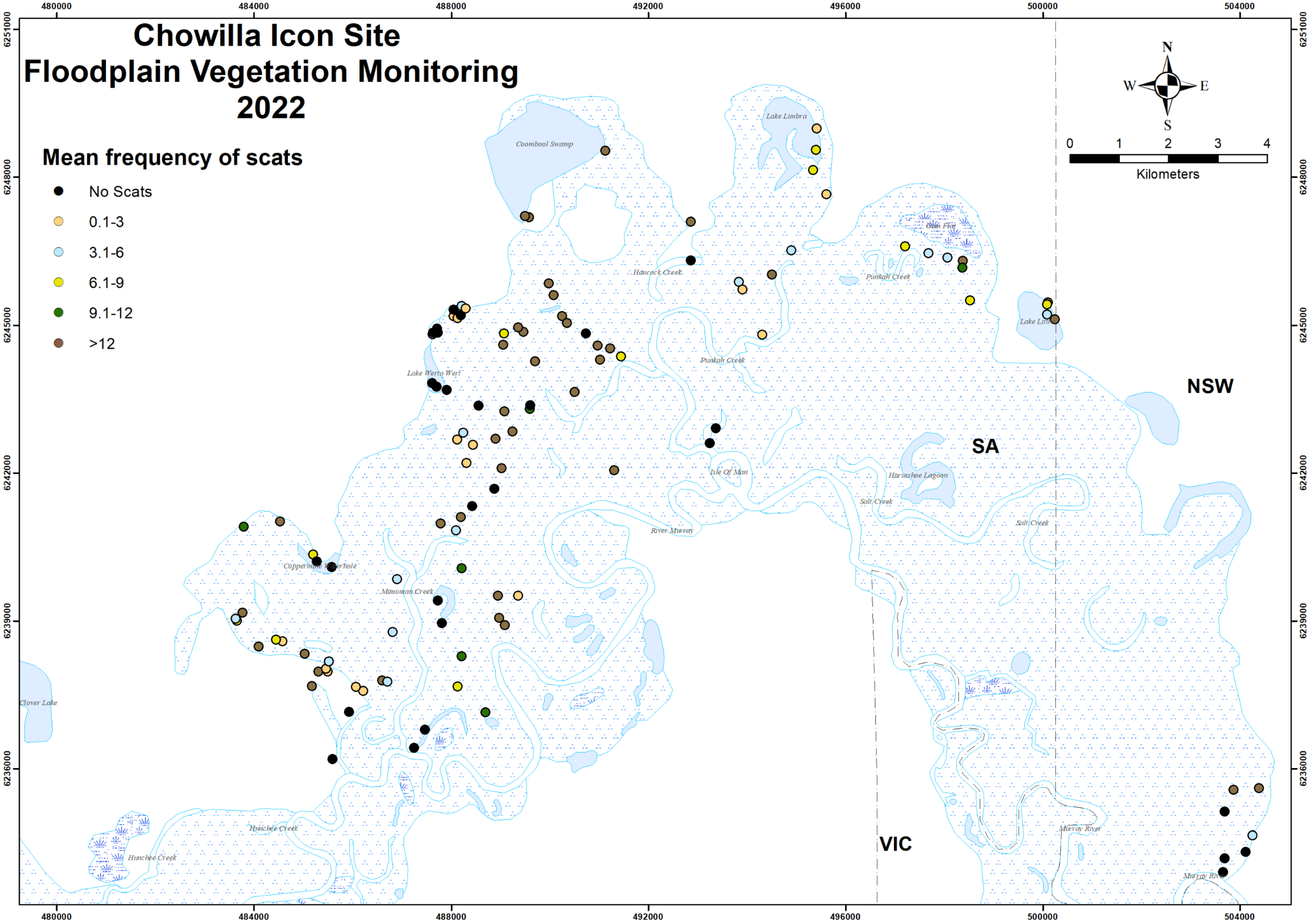

Figure 8: Mean frequency of scats at each site (mean of three quadrats) surveyed in 2022.

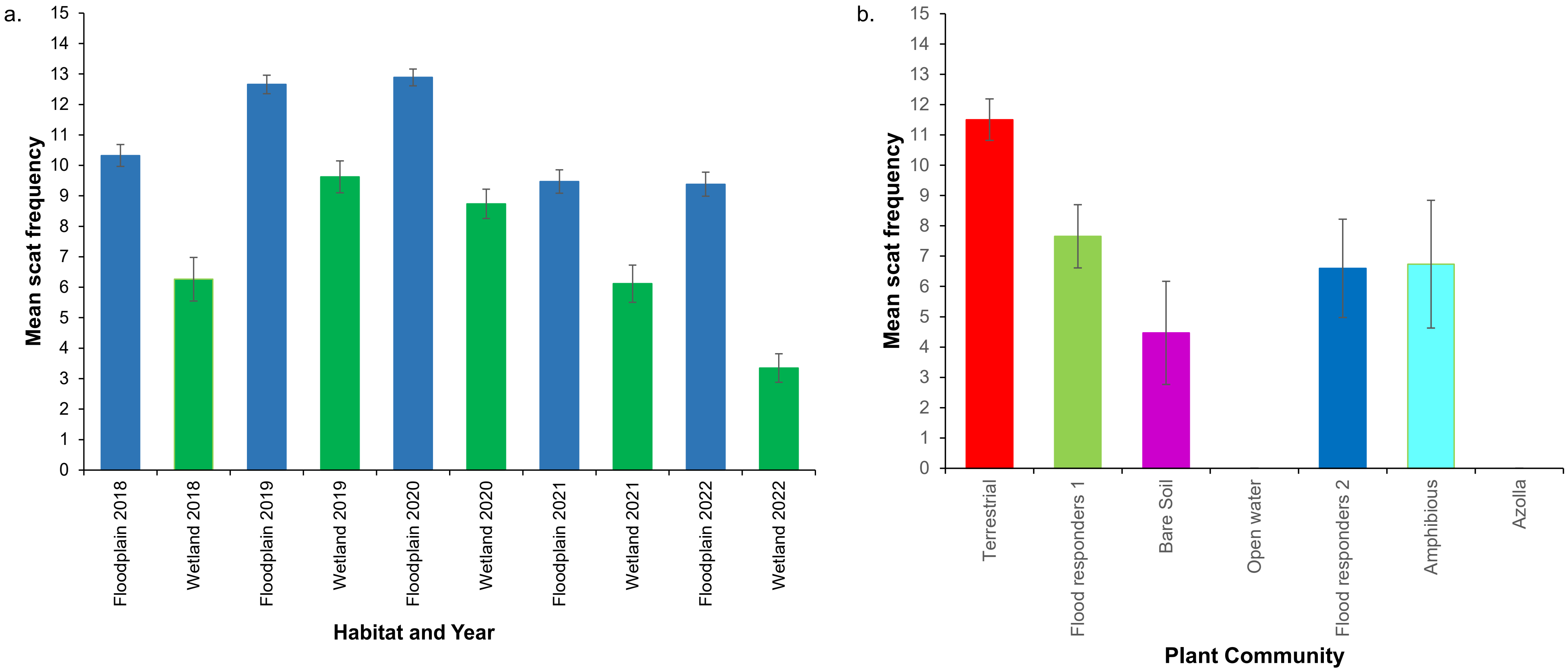

Figure 9: Mean frequency of scats for a. the different habitats (floodplain or temporary wetland) 2018–2022 and b. plant communities identified by the dendrogram groupings in 2022 (Figure 6). Colours for the plant community columns reflect the 2022 dendrogram groupings and error bars = ±1 SE

Table 5: Matrix showing PERMANOVA pairwise comparisons of scat frequencies between plant communities identified by cluster analysis (NS = not significant, * denotes P = 0.05 – 0.01 ** denotes P = 0.01 – 0.001, *** denotes P< 0.001; α was Bonferroni corrected for multiple comparisons).

	Terrestrial	Flood responders 1	Bare Soil	Open water	Flood responders 2	Amphibious	Azolla
Terrestrial							
Flood responders 1	**						
Bare Soil	***	**					
Open water	***	***	***				
Flood responders 2	***	NS	*	***			
Amphibious	***	NS	*	***	NS		
Azolla	***	***	***	NS	***	***	

3.3. Change in the plant community from 2006 to 2022

Between 2006 and 2009, species richness generally declined across the Chowilla Floodplain (Figure 10) except for a rise in species richness in 2007. This peak of 48 taxa followed the first watering of Coppermine Complex and Gum Flat in spring 2006, but in subsequent years species richness steadily declined, such that by 2009, only 17 taxa were recorded (Figure 10). Re-watering of the same areas in spring 2009 resulted in higher species richness in the 2010 survey (42 taxa), similar to that recorded in 2007 (Figure 10). In 2011 (66 taxa), following overbank flooding, species richness increased by more than 50% compared to 2010, but in 2012 had declined slightly (50 taxa) (Figure 10). In 2013, species richness declined again (30 taxa), increased to 37 taxa in 2015 in response to the regulator operation in spring 2014, but declined to 21 in 2016 (Figure 10). In 2017, there was a >200% increase in species richness (57 taxa) due to regulator operation and natural flooding; however, this response was lower than following the previous overbank flood in 2011. In 2018, there was a sharp decrease with species richness falling to 30. This decrease in species richness was similar to decreases recorded between 2012 and 2013 (Figure 10). In 2019, in response to the mid-level regulator operation in spring 2018, there was an increase in species richness from 30 to 36; however, the response was short-lived with species richness declining to levels similar to during the Millennium drought in 2020 (Figure 10). Species richness almost doubled (40 taxa) in 2021 (Figure 10), which corresponded with watering of gum flat in spring 2020 and increased further to 46 in 2022 after regulator operation (Appendix 1).

In temporary wetlands, plant species richness was higher than the floodplain sites, and increased between 2013 and 2016, but decreased in 2017 due to most sites being inundated (Figure 10). Temporary wetlands generally contained a higher number of amphibious and flood dependent species than the floodplain (Figure 6, Figure 7 and Table 3) due to watering interventions (e.g. pumping) undertaken at these sites, and longer and more frequent inundation by regulator operations and high flows. The increase in plant species richness between 2013 and 2016 was primarily due to an increase in the number of sites surveyed each year and the decrease in 2017 due to most sites being inundated and devoid of vegetation. In 2018, none of the temporary wetlands were inundated and there was an increase in species richness recorded across these sites (Figure 10). In 2019, there was a decrease in species richness (Figure 10) with some wetlands still inundated by regulator operation; however, many of the wetlands not inundated by regulator operation were dominated by bare soil (Figure 6, Figure 7 and Table 3). Despite many sites in temporary wetlands remaining dominated by bare soil in 2020 (Figure 6 and Figure 7), species richness increased (Figure 10). All of the wetlands inundated in 2019 had dried and flood dependent species recruited; furthermore, *Myriophyllum verrucosum* and *Nitella* sp. were present at the inundated sites in Coombool Swamp and Lake Littra (Figure 6 and Figure 7). Species richness in wetlands was the highest recorded for the condition monitoring program in 2021 (Figure 10), despite almost all sites in Werta Wert being inaccessible due to inundation and other wetlands (except Monoman Depression and Punkah Floodrunner) not being watered since 2019 or earlier (Appendix 1). There was a slight decrease in species richness in 2022 (Figure 10) after regulator operation (Appendix 1); however, many sites were inundated in February 2022 and devoid of plants (Figure 6 and Figure 7).

Combined species richness of the floodplain and temporary wetland sites remained relatively constant between 2013 and 2016 (the lowest being 54 species recorded in February in 2014 and the highest 58 in February 2015), but increased in 2017 due to the 2016 regulator operation followed by late 2016 overbank flood (Figure 10). Many of the same species were present in the floodplain sites inundated by the regulator operations in spring 2014 and 2016, and the flood in 2016 that were present in the wetland sites between 2013 and 2016. There was a decrease in combined richness in 2018; however, it was the second highest recorded (despite the decrease in floodplain sites) due to the increase in the number of species present in temporary wetlands (Figure 10). There was a further decrease in overall species richness in 2019 to the equal lowest recorded (54 species) primarily due to a decrease in species richness in temporary wetlands (Figure 10). Species richness in 2020 was also the equal lowest on record (54 species); however, this was due to a sharp decline in species richness across the floodplain sites, while that of temporary wetlands increased (Figure 10). In 2021 species richness across all sites was the second highest recorded (66 taxa) due to increases in floodplain and wetland species richness compared to 2020 (Figure 10). Species richness in 2022 was similar to 2021 with the increase on the floodplain offsetting the decrease in temporary wetlands (Figure 10).

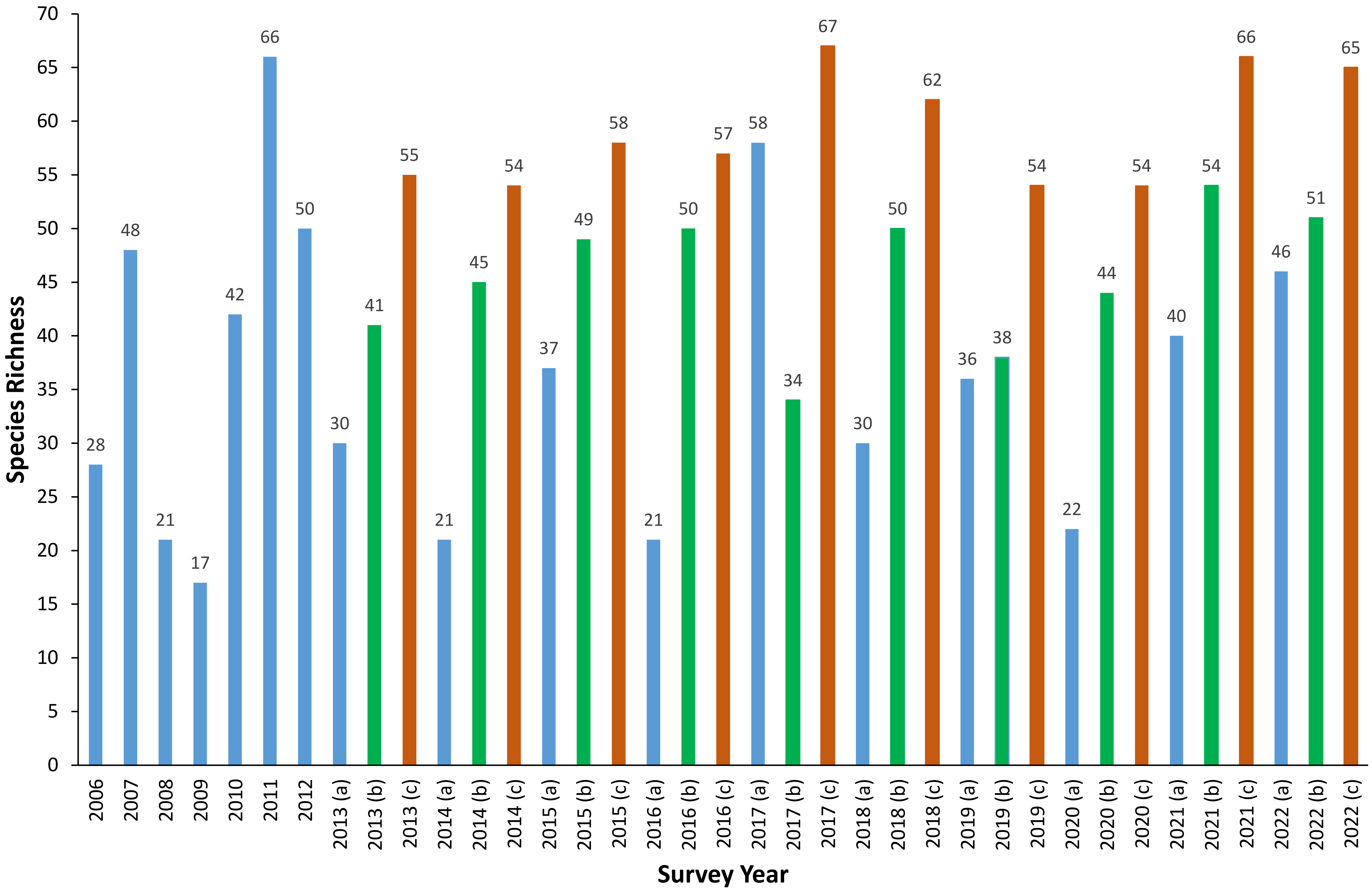

Figure 10: Changes through time in species richness (number of taxa) of the Chowilla Floodplain from 2006 to 2022. 2013(a), 2014(a), 2015(a), 2016(a) 2017(a), 2018(a), 2019(a), 2020(a), 2021(a) and 2022 (a) denotes floodplain only sites 1–85, 2013(b) denotes temporary wetland sites (86–118), 2014(b) denotes temporary wetland sites (86–126), 2015(b) denotes temporary wetland sites (86–129), 2016(b) denotes temporary wetland sites (86–143), 2017(b) denotes temporary wetland sites (86–143), 2018(b) denotes temporary wetland sites (86–143), 2019(b) denotes temporary wetland sites (86–143), 2020(b) denotes temporary wetland sites (86–144), 2021(b) denotes temporary wetland sites (86–144) and 2022(b) denotes temporary wetland sites (86–144). 2013(c) denotes floodplain and temporary wetland sites (1–118), 2014(c) denotes floodplain and temporary wetland sites (1–126), 2015(c) denotes floodplain and temporary wetland sites (1–129), 2016 (c) denotes floodplain and temporary wetland sites (1–143), 2017(c) denotes floodplain and temporary wetland sites (1–143), 2018(c) denotes floodplain and temporary wetland sites (1–143), 2019(c) denotes floodplain and temporary wetland sites (1–143), 2020(c), 2021(c) and 2022(c) denotes floodplain and temporary wetland sites (1–144).

In 2006, the floodplain understorey was mostly comprised of plant taxa from salt tolerant and terrestrial functional groups; however, following the first site-specific watering of Coppermine Complex and Gum Flat (spring 2006) there was an increase in amphibious and flood dependent taxa, and a concomitant decrease in terrestrial taxa and bare soil recorded during the 2007 survey (Figure 11). In 2008, the number of observations of bare soil and salt tolerant taxa increased, while flood dependent and terrestrial taxa decreased and amphibious taxa were not recorded (Figure 11). Similarly in 2009, the observations of salt tolerant taxa increased further, terrestrial and bare soil remained consistent, and both flood dependent and amphibious taxa were not observed (Figure 11). Re-watering of the Coppermine Complex and Gum Flat (spring 2009) resulted in an increase in flood dependent and amphibious taxa in 2010 (Figure 11). Overbank flooding in 2010/11 was associated with a further decline in bare soil, terrestrial and salt tolerant taxa, a moderate increase in amphibious taxa and a large increase of flood dependent taxa (Figure 11). In 2012, the number of observations of terrestrial and salt tolerant taxa and bare soil increased, while the observations of amphibious and flood dependent taxa decreased compared to the previous year (Figure 11). In 2013, a comparison of the original floodplain sites (sites 1–85), suggests the proportion of bare soil increased, while terrestrial and salt tolerant species remained consistent and flood dependent and amphibious taxa all decreased. Nonetheless, with the inclusion of the additional temporary wetland sites (sites 1–118), the proportion of bare soil and flood dependent taxa increased, amphibious species remained consistent, while terrestrial and salt tolerant species decreased (Figure 11).

In 2014, for the floodplain sites (1–85), there was an increase in the proportion of salt tolerant species and a decrease in all other functional groups, except for bare soil, which remained in similar proportions to 2013 (Figure 11). The proportions of functional groups in the floodplain sites (1–85) were similar to the proportions observed in the 2008 surveys (Figure 11). With the inclusion of the temporary wetlands sites (1–126), there was a marked decrease in amphibious and flood dependent species, while the proportion of terrestrial species remained the same and the bare soil and salt tolerant taxa increased, compared to 2013 (Figure 11).

In 2015, following the first regulator operation in spring 2014, there was a decrease in bare soil and an increase in flood dependent species at all sites (1–129), and floodplain sites (1–85) compared to 2014 (Figure 11). The proportion of flood dependent species was higher when temporary wetland sites were included compared to just the floodplain sites (1–85) in 2014 and 2015 (Figure 11). Nevertheless, salt tolerant and terrestrial taxa were the dominant groups in 2015 (Figure 11) given that the regulator operation in spring 2014 was only a low-mid level, short duration (2 weeks at peak) event resulting in 2,142 ha (approximately 12%) of low elevation floodplain being inundated. The survey was also undertaken in February 2015 and it is acknowledged that the regulator operation was followed by intense grazing pressure from kangaroos and feral goats, which along with the hot dry conditions, muted the vegetation response detected at the time of the survey.

In 2016, there was a decrease in the proportion of observations of bare soil at sites one to 85 despite it being the most abundant taxon recorded (Figure 11). The proportion of salt tolerant and terrestrial plant taxa was similar to 2015, but there was an increase in flood dependent species (Figure 11). Across all sites in 2016, there was an increase in the proportion of amphibious and flood dependent species and decrease in all other functional groups compared to 2015 (Figure 11). This was due to an increase in the number of temporary wetland sites surveyed in 2016, most of which remained inundated during the 2015 survey following the regulator operation in spring 2014.

At sites one to 85 in 2017, there was an increase in flood dependent and amphibious plant taxa, and corresponding decrease in bare soil and salt tolerant taxa compared to the 2016 survey in association with regulator operation in spring 2016 and subsequent natural flooding inundating 59 sites (Figure 11). There was a similar pattern across all sites with a higher proportion of amphibious taxa, and lower proportion of salt tolerant taxa present when the temporary wetland sites were included (Figure 11). In 2018, there was a decrease in flood dependent and amphibious taxa and a corresponding increase in bare soil and terrestrial and salt tolerant taxa at sites one to 85. When the temporary wetland sites were added there were still increases in bare soil and salt tolerant and terrestrial taxa compared to 2017; however, there were higher proportions of amphibious and flood dependent species compared to the floodplain sites (Figure 11).

In 2019, at sites one to 85 there was a further increase in the proportion of bare soil with a similar pattern when the temporary wetland sites were included (Figure 11). Similarly salt tolerant taxa, declined over the same period with an increase in terrestrial species (Figure 11). Flood dependent and amphibious species increased across sites one to 85 but when the temporary wetland sites were included there was a decrease in flood dependent taxa compared to 2018 with similar proportions of amphibious species (Figure 11). In 2020 there was a further increase in the proportion of quadrat cells with an absence of plants, with this year recording the highest number of cells with no plants (for floodplain and temporary wetlands sites) with over two thirds of the cells from floodplain sites being devoid of vegetation (Figure 11). There was also an increase in salt tolerant taxa and decrease in terrestrial, flood dependent and amphibious species (Figure 11). With temporary wetlands included there was still a large increase in bare soil with 49% of surveyed cells devoid of vegetation (Figure 11). Compared to 2019, there was a decrease in terrestrial and flood dependent species but an increase in amphibious taxa (Figure 11).

In 2021, there was a large decrease in the proportion of quadrat cells devoid of vegetation and a corresponding increase of salt tolerant and terrestrial species abundance at floodplain sites. There was also a decrease in the proportion of cells containing flood dependent and amphibious taxa (Figure 11). When the temporary wetlands were included, there was a similar decrease in proportion of quadrat cells devoid of vegetation and increase in salt tolerant and terrestrial species. There was a similar proportion of cells containing flood dependent species in 2020 and 2021 but a decrease in cells with amphibious taxa (Figure 11).

In 2022 there was a decrease in bare soil and salt tolerant taxa and corresponding increase in terrestrial, flood dependent and amphibious species at floodplain sites (Figure 11). When the temporary wetland sites were included, there was a similar pattern of change as observed at the floodplain sites since 2021, but with a higher proportion of flood dependent and amphibious taxa and lower proportion of terrestrial species (Figure 11).

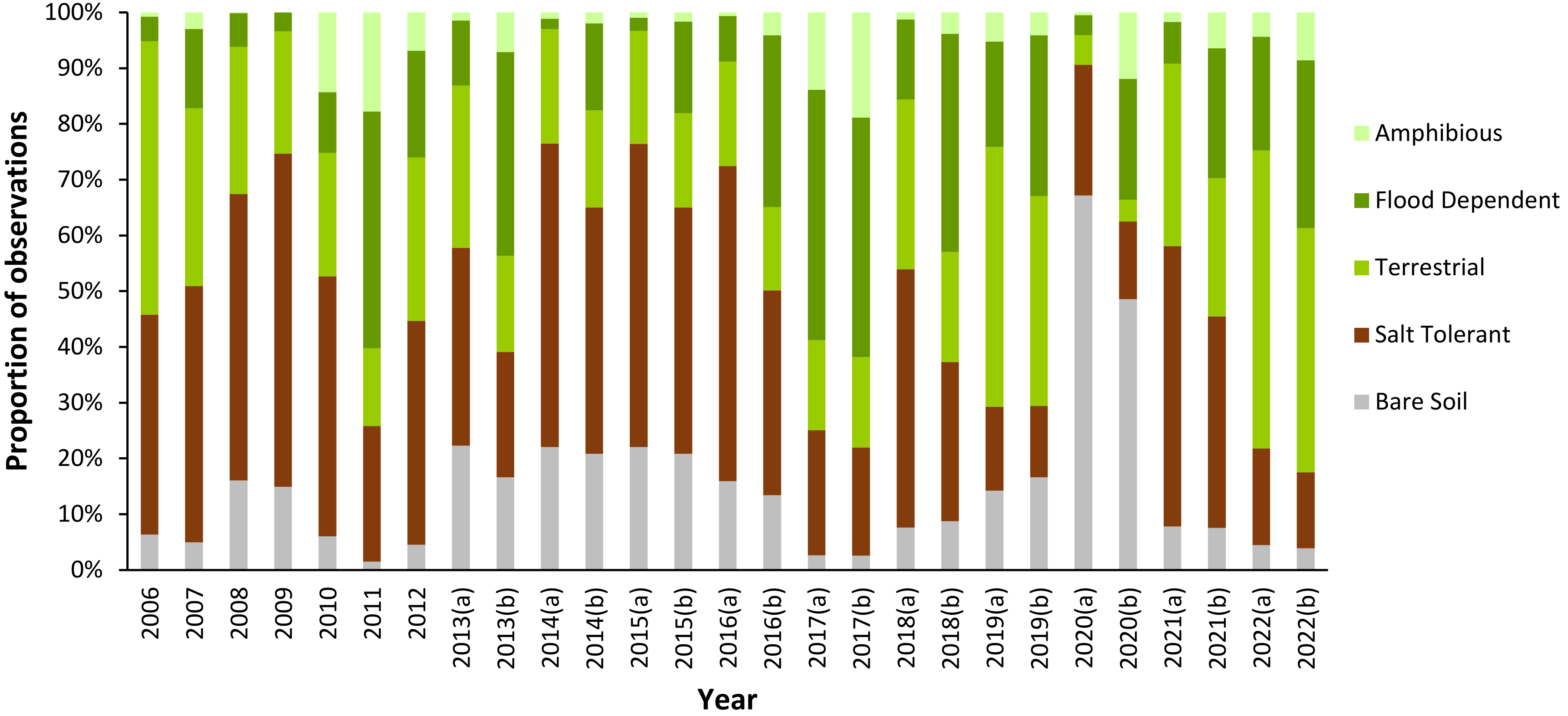

Figure 11: Changes in the percentage of observations of vegetation functional groups of the Chowilla Floodplain from 2006 to 2022. 2013(a), 2014(a), 2015(a), 2016(a), 2017(a), 2018(a), 2019(a), 2020(a), 2021(a) and 2022(a) denotes floodplain sites 1–85; 2013(b) denotes floodplain and temporary wetlands sites (1–118), 2014(b) denotes floodplain and temporary wetland sites (1–126), 2015(b) denotes floodplain and temporary wetland sites (1–129), 2016(b), 2017(b), 2018(b), 2019(b) denotes floodplain and temporary wetland sites (1–143), 2020(b), 2021(b) and 2022(b) denotes floodplain and temporary wetland sites (1–144).

NMS ordination (Figure 12) shows the trajectory for plant communities at floodplain sites (1–85) from 2006 to 2022. The largest changes in floristic composition occurred between 2010 and 2011, and 2016 and 2017 following natural flooding (and a preceding regulator operation in 2016) and 2019 and 2020. Without further flooding or interventions, the plant community became more similar to the communities present in 2008 and 2009, and in 2015 it was more similar to the community present in 2008 and 2009 compared to after flooding or watering (Figure 12). Although the regulator was operated in spring 2014 the event was of a moderate scale that resulted in the inundation of 2,142 hectares (approximately 12%) of the floodplain with peak water levels maintained for only two weeks. However, this intervention inundated 12 sites compared to eight and ten inundated by watering interventions in spring 2006 and 2009 respectively.

In 2016, the plant community was similar to the community present during the Millennium Drought in years when no large-scale watering interventions were undertaken (Figure 12). The regulator operation undertaken in spring 2015 was a low level in-channel rise (17.85 m AHD) that raised water levels within the creeks by 1.5 m. This resulted in the inundation of 535 ha along riparian zones and two floodplain sites, one of which was still inundated in February 2016 and not surveyed. The large change between 2016 and 2017 was due to regulator operation and subsequent overbank flood in spring 2016; however, the floristic composition was different compared to 2011 (Figure 12), primarily due to lower species richness in 2017. In 2018, there was also a large change in the plant community that was transitioning towards one similar to those observed at the end of the Millennium drought and 2016 (Figure 12). This trend continued in 2019 despite operation of the regulator to 2.24 m above normal pool level inundating eight sites in spring 2018 (Figure 10). There was a large change in floristic composition between 2019 and 2020 (Figure 12), which was due to a decline in species richness and a large increase in the occurrence of bare soil (Figure 11). There was also a large change in floristic composition between 2020 and 2021 due to the decrease in bare soil and increase in species richness (Figure 10, Figure 11), with the community similar to the one present during the Millennium following pumping of Gum Flat (Figure 12). There was a small change in floristic composition between 2021 and 2022 after a large-scale operation of the regulator (Figure 12). The change was due to an increase in species richness (Figure 10) and further decrease in bare soil and decrease in salt tolerant taxa (Figure 11) and was similar to the community post watering in 2010 and 18 months after a large flood in 2012 (Figure 12).

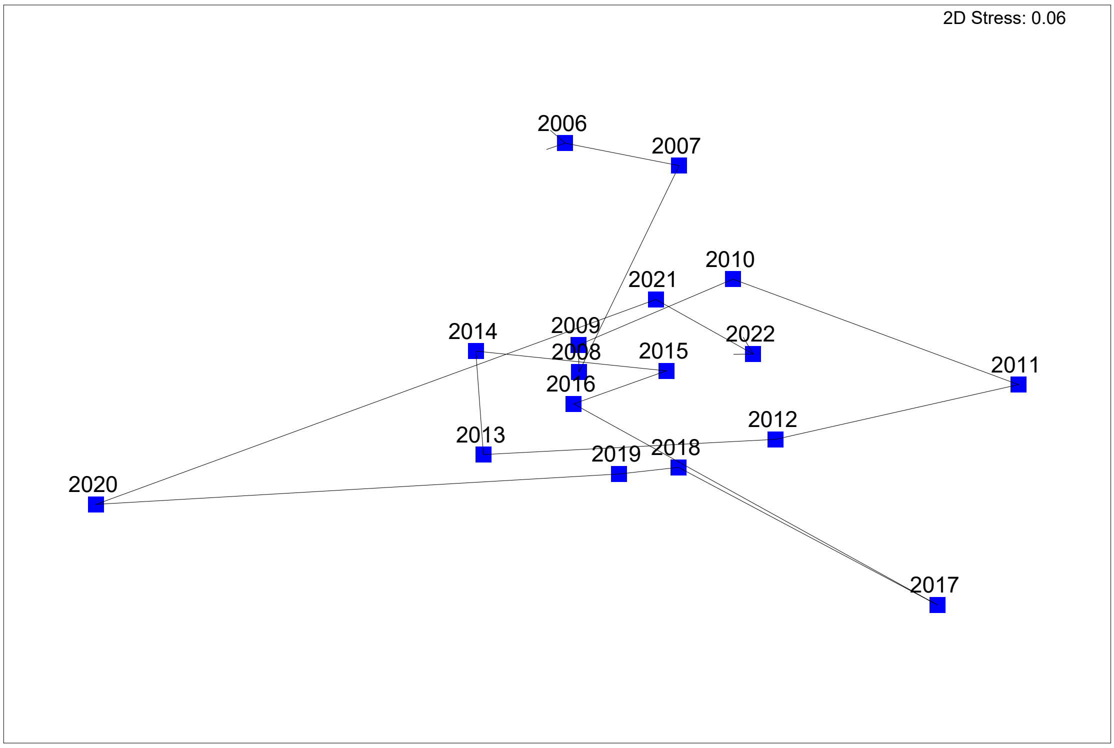

Figure 12: NMS ordination comparing the plant communities of Chowilla Floodplain sites 1–85 from 2006 to 2022.

3.4. The Living Murray targets

<u>Native taxa - floodplain sites</u>

Between 2006 and 2022 at the floodplain sites (1–85), 20% or more of the cells contained amphibious or flood dependent species on nine occasions: 2007, 2010, 2011, 2012, 2015, 2017, 2018, 2019 and 2022 with the maximum interval being two years (Figure 13). In 2007 and 2010, Gum Flat and Coppermine Complex were watered; 2011, 2012 and 2017 surveys followed overbank flooding; the 2015, 2016, 2019 and 2022 surveys followed regulator operation in the previous spring. In 2018, flood dependent species that recruited after the regulator operation and subsequent overbank flow in late 2016 persisted at some sites.

Amphibious or flood dependent species were present in 40% or more of cells on three occasions; in 2011, 2012 and 2017 (following natural overbank flooding) with a maximum interval of five years (Figure 13). In 2017 68% of cells contained flood dependent or amphibious species (Figure 13); however, the target was not met because species richness of native flood dependent and amphibious species did not exceed 40 (Figure 14, Table 6).

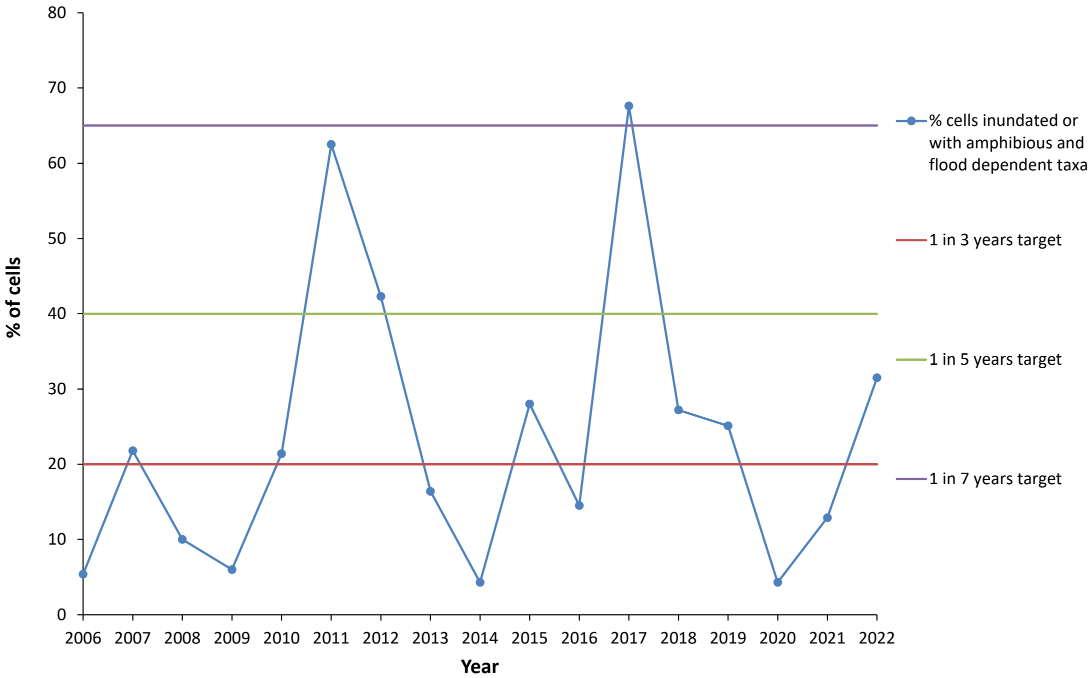

Figure 13: Percentage of cells with native amphibious or flood dependent species present at floodplain sites (sites 1 to 85) between 2006 and 2022.

Figure 14 shows presents the richness of native flood dependent and amphibious taxa between 2006 and 2022. Eight out of the nine occasions when the percentage of cells containing flood dependent or amphibious taxa exceeded 20% (2007, 2010, 2011, 2012, 2015, 2017, 2019 and 2022) (Figure 13) the native flood dependent and amphibious species richness was >15; therefore, the target was met (Figure 14, Table 6). Similarly, when more than 40% of cells from floodplain sites contained amphibious or flood dependent species (2011, 2012 and 2017), >25 native flood dependent and amphibious species were recorded; hence, the target was achieved (Figure 14, Table 6). Native amphibious and flood dependent species richness has never exceeded 40; therefore, the one-in-seven year target has not been achieved throughout the condition monitoring program (Figure 14, Table 6).

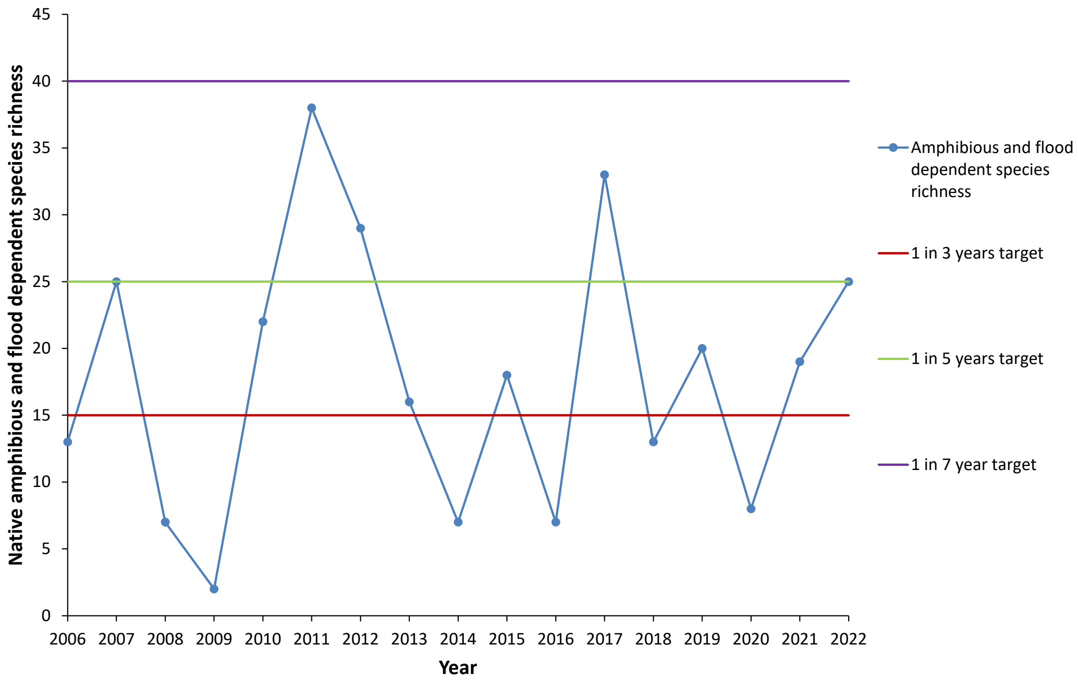

Figure 14: Species richness of amphibious and flood dependent species at floodplain sites (sites 1 to 85) between 2006 and 2022.

Native taxa - temporary wetland sites

Between 2013 and 2022, >40% of quadrat cells at temporary wetland sites (86–144) were inundated or contained amphibious or flood dependent species during every survey (Figure 15). In the 2015 (after the first operation of the regulator), 2017 (after regulator operation and overbank flooding) and 2022 surveys (after a large scale operation of the regulator) >80% of quadrat cells were either inundated or contained amphibious or flood dependent taxa (Figure 15).

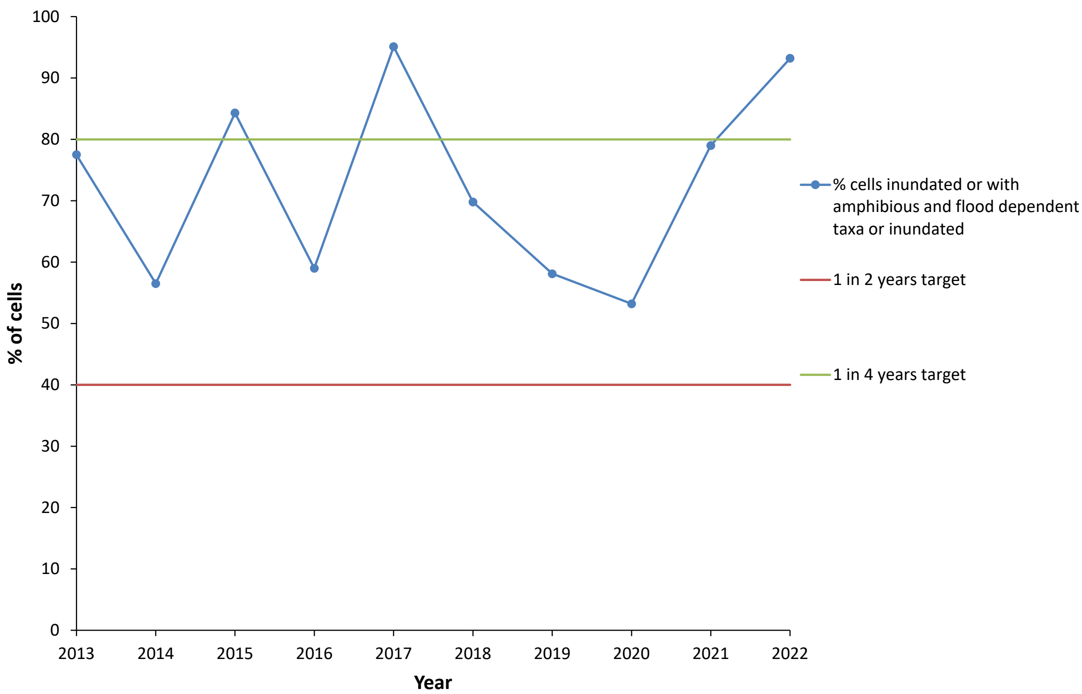

Figure 15: Percentage of cells with amphibious or flood dependent species present at temporary wetland sites (sites 86 to 144) between 2013 and 2022.

Between 2013 and 2022, >20 native flood dependent and amphibious species were present at temporary wetland sites during each survey (Figure 16), indicating the one-in-two-year target has been achieved (Table 6). Despite over 80% of cells being inundated or containing floodplain or amphibious species in 2015, 2017 and 2022 (three times in the previous nine surveys) (Figure 15), there were less than 40 species present (Figure 16). Therefore, the one-in-four-year target for temporary wetlands has not been achieved (Table 6).

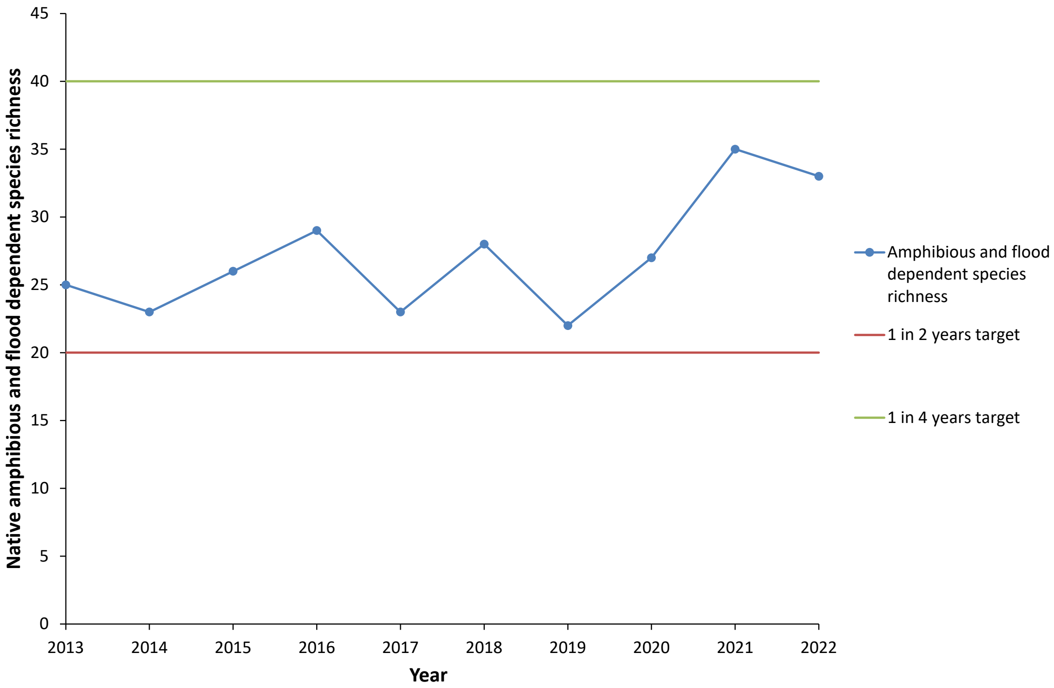

Figure 16: Species richness of native amphibious and flood dependent species at temporary wetland sites (sites 86 to 144) between 2013 and 2022.

Table 6: Success of attaining floodplain and temporary wetland native vegetation targets between 2006 and 2022.

Floodplain:	Minimum of 20% of cells containing native flood dependent or amphibious taxa once every three years on average with maximum interval no greater than 5 years. Native flood dependent and amphibious species richness ≥15.	Achieved
	Minimum of 40% of cells containing native flood dependent or amphibious taxa once every five years on average with maximum interval no greater than 7 years. Native flood dependent and amphibious species richness ≥25.	Achieved
	Minimum of 65% of cells containing native flood dependent or amphibious taxa once every seven years on average with maximum interval no greater than 10 years. Native flood dependent and amphibious species richness ≥40.	Not achieved
Temporary wetlands:	Minimum of 40% of cells either inundated or containing native flood dependent or amphibious taxa once every two years on average with maximum interval no greater than 4 years. Native flood dependent and amphibious species richness ≥20.	Achieved
	Minimum of 80% of cells either inundated or containing native flood dependent or amphibious taxa once every four years on average with maximum interval no greater than 6 years. Native flood dependent and amphibious species richness ≥40.	Not achieved

Exotic taxa - floodplain sites

Over the study period, with the exception of 2011, 2012 and 2017, <5% of cells from floodplain sites (usually <1%) contained exotic species (Figure 17). Therefore, the exotic species target was met every year except in 2011, 2012 and 2017 after overbank flooding (Figure 17, Table 7). *Xanthium occidentale* was uncommon on the floodplain and the number of cells with this species present never exceeded 1%; hence, this target was achieved every year between 2006 and 2021 (Figure 17, Table 7).

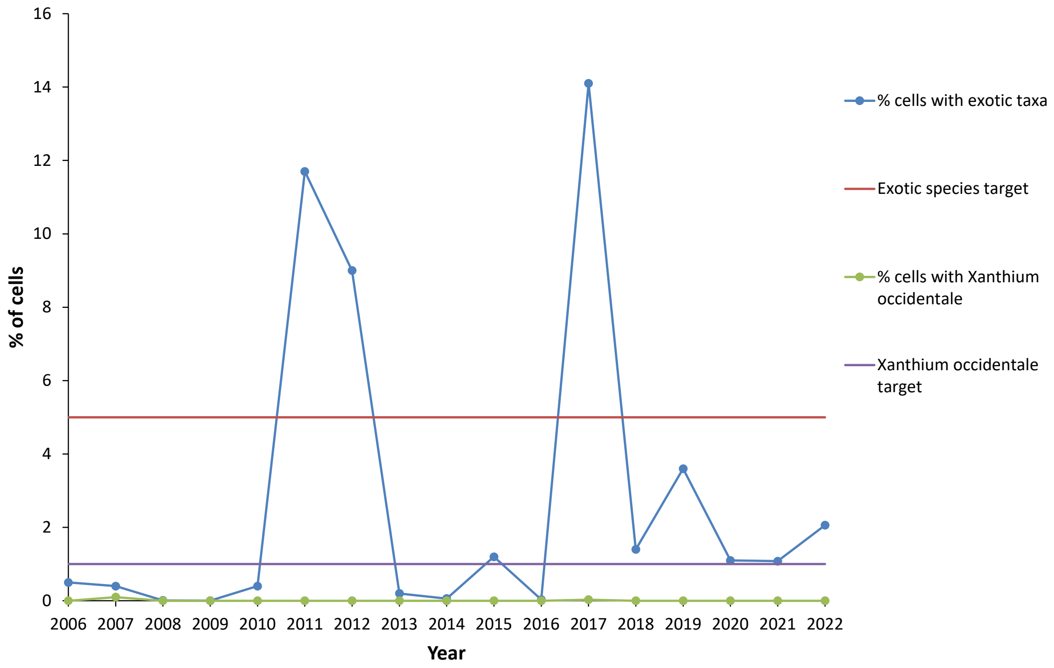

Figure 17: Percentage of cells with exotic species and *Xanthium occidentale* present at floodplain sites (sites 1 to 85) between 2006 and 2022.

Exotic taxa – temporary wetland sites

Between 2013 and 2022, in temporary wetlands, the number of cells containing exotic species was >10% every year except 2017 (due to most sites being inundated); hence, the target has only been achieved once (Figure 18, Table 7). Prior to 2022 *Xanthium occidentale* was uncommon and the number of cells where this species was present never exceeded 1% between 2013 and 2021; however, in 2022 this species was more abundant and present in more than 1% of cells (Figure 18). Therefore, the target not achieved in 2022 (Figure 18, Table 7).

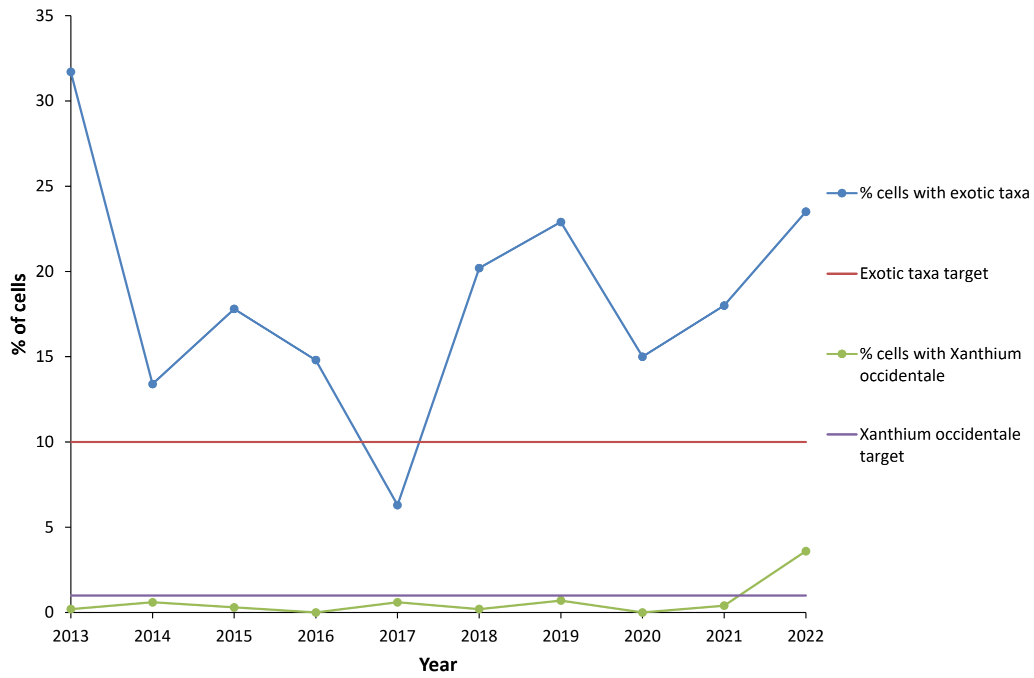

Figure 18: Percentage of cells with exotic species and *Xanthium occidentale* present at temporary wetland sites (sites 86 to 144) between 2013 and 2022.

Table 7: Success of attaining floodplain and temporary wetland exotic species and *Xanthium occidentale* targets between 2006 and 2022.

	Target			
Year	**Floodplain exotics**	**Floodplain *Xanthium***	**Temporary wetland exotics**	**Temporary wetland *Xanthium***
2006	Achieved	Achieved	NA	NA
2007	Achieved	Achieved	NA	NA
2008	Achieved	Achieved	NA	NA
2009	Achieved	Achieved	NA	NA
2010	Achieved	Achieved	NA	NA
2011	Not achieved	Achieved	NA	NA
2012	Not achieved	Achieved	NA	NA
2013	Achieved	Achieved	Not achieved	Achieved
2014	Achieved	Achieved	Not achieved	Achieved
2015	Achieved	Achieved	Not achieved	Achieved
2016	Achieved	Achieved	Not achieved	Achieved
2017	Not achieved	Achieved	Achieved	Achieved
2018	Achieved	Achieved	Not achieved	Achieved
2019	Achieved	Achieved	Not achieved	Achieved
2020	Achieved	Achieved	Not achieved	Achieved
2021	Achieved	Achieved	Not achieved	Achieved
2022	Achieved	Achieved	Not achieved	Not achieved

Comparison of native taxa at floodplain sites under modelled natural and current observed conditions

A comparison of modelled natural and observed conditions demonstrates that in most years a larger number of sites would have been inundated under natural conditions. There were; however, some exceptions: in 2006-07 and 2009-10 Coppermine Complex and Gum Flat were watered by pumping, which inundated eight and ten sites respectively, compared to modelled natural flow that was insufficient to inundate any sites. In 2014-15, 14 sites were inundated by regulator operation compared to five indicated as inundated under modelled natural conditions. Additionally, in 2015-16 and 2018-19 regulator operation inundated two sites and eight sites, respectively and watering of Gum Flat by pumping in 2020-21 inundated five sites, compared to no sites under natural conditions for all three of these years (Table 8, Appendix 3).

Under modelled natural conditions between 2006 and 2022, ≥20% of cells were predicted to contain amphibious or flood dependent species on six occasions: 2006, 2011, 2012, 2013, 2016 and 2022 with the maximum interval four years (Figure 19). Under observed conditions (Figure 13), this occurred on eight occasions, five of which (2007, 2010, 2015, 2019 and 2022) were due to watering interventions (pumping and regulator operation). Amphibious or flood dependent species were present in 40% of cells three times between 2006 and 2022 (2011, 2012 and 2017) with a maximum interval of five years under both modelled natural and current conditions (Figure 19). However, on each of these occasions under modelled natural conditions 70%, 70% and 73% of cells in 2011, 2012 and 2017, respectively, were predicted to have flood dependent or amphibious species present (Figure 19). In 2022 the actual and predicted (under natural conditions) percentage of cells with native amphibious or flood dependent taxa was similar (Figure 19) despite 10 extra sites that would have been inundated under natural conditions (Table 8).

Table 8: Comparison of modelled natural and current peak daily flow to South Australia from the 2005-06 to 2021-22 water years and the number and percentage of sites inundated (*denotes sites were watered by pumping; # denotes sites were inundated by regulator operation). Maps of modelled maximum extent for each year and monitoring sites are presented in Appendix 3.

	Modelled Natural				**Current**			
Water Year	**Date of Peak Flow**	**Peak Flow (Ml day^{-1})**	**No. sites inundated**	**% sites inundated**	**Date of Peak Flow**	**Peak Flow (Ml day^{-1})**	**No. sites inundated**	**% sites inundated**
2005-06	8/11/2005	69,219	25	32	12/11/2005	15100	0	0
2006-07	1/01/2006	36,882	0	0	27/04/2006	8443	8*	10*
2007-08	13/08/2007	34,925	0	0	15/02/2007	7169	0	0
2008-09	26/10/2008	26,250	0	0	18/06/2008	9423	0	0
2009-10	14/11/2009	29,425	0	0	31/12/2009	6048	10*	13*
2010-11	31/10/2010	99,368	70	93	18/12/2010	67218	46	61
2011-12	8/02/2011	95,060	70	93	13/02/2011	93872	46	61
2012-13	2/05/2012	78,859	32	43	3/04/2012	60070	17	23
2013-14	14/10/2013	61,644	17	23	12/10/2013	25841	5*	7*
2014-15	31/08/2014	45,401	4	5	6/08/2014	18062	14#	19#
2015-16	24/09/2015	27,875	0	0	29/10/2015	11752	2#	3#
2016-17	23/11/2016	163,230	68	97	30/11/2016	94246	56	80
2017-18	20/10/2017	34,906	0	0	9/12/2017	17,642	0	0
2018-19	19/09/2018	28,028	0	0	1/01/2019	12,081	8#	12#
2019-20	19/09/2019	25,748	0	0	19/10/2019	15,561	0	0
2020-21	30/11/2020	38,240	0	0	25/11/2020	17,926	5*	7*
2021-22	23/09/2021	74,500	34	49	28/12/2021	37,567	24#	35#

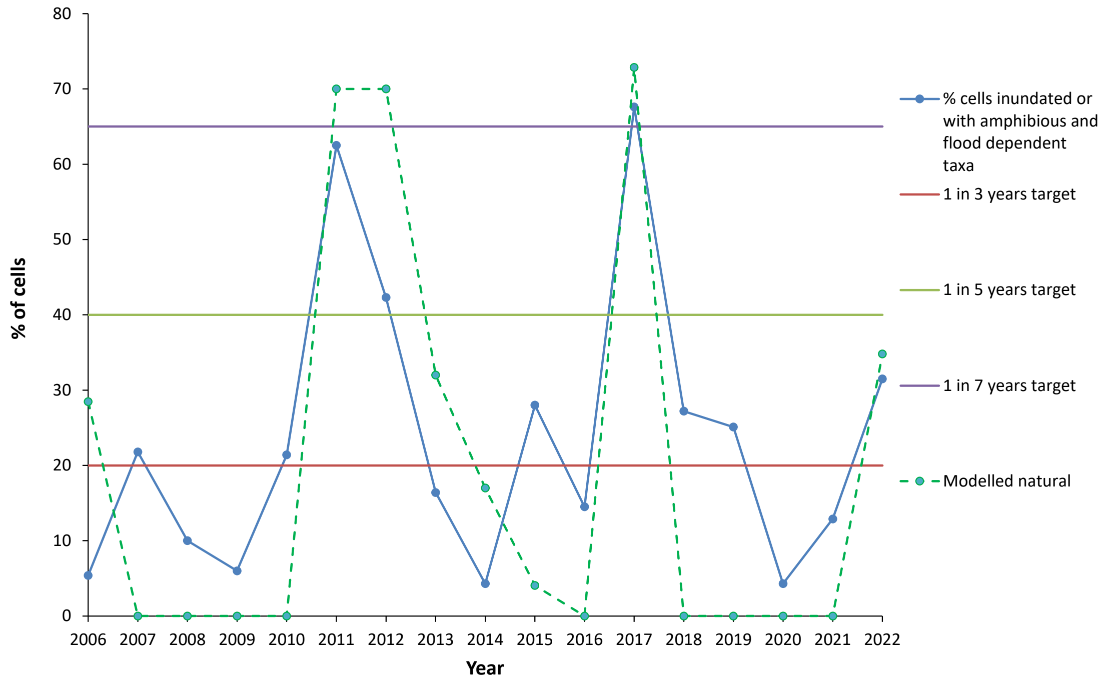

Figure 19: Percentage of cells with amphibious or flood dependent species present at floodplain sites between 2006 and 2022 (blue line) and predicted percentage of cells with flood dependent and amphibious species present under modelled natural conditions (dashed green line) at floodplain sites for the same period.

Predicted plant species richness under modelled natural flows varied considerably depending on which prediction method was used i.e. 1) the number of cells containing floodplain or amphibious species or 2) the number of sites inundated in the previous 12 months (Figure 20).

Between 2006 and 2022, under current conditions, ≥15 native flood dependent and amphibious plant species were recorded on nine occasions, six of which (2007, 2010, 2015, 2019, 2021 and 2022) were due to watering interventions (pumping and regulator operation), and ≥25 species were recorded on four occasions (due to flooding) (Figure 14).

When the number of quadrat cells containing flood dependent or amphibious plant species is used as the predictor, ≥15 species were predicted on six occasions and ≥25 and ≥40 species on three occasions (Figure 20). In comparison, when the number of sites inundated in the previous 12 months was used as the predictor, ≥15 species were predicted on eight occasions, with ≥25 species on seven occasions, but no instances of ≥40 were predicted (Figure 20). The actual native flood dependent or amphibious taxa richness in 2022 was close to mid-way between the two modelled natural predicted values (Figure 20).

Under modelled natural conditions based on the predicted occurrence of native flood dependent or amphibious plant taxa and using the number of quadrat cells containing flood dependent or amphibious species as the predictor for species richness, all targets would be achieved. However, if the number of sites inundated in the previous 12 months was used to predict flood dependent and amphibious species richness only the one-in-three and one-in-five year targets would be achieved (Figure 19, Figure 20).

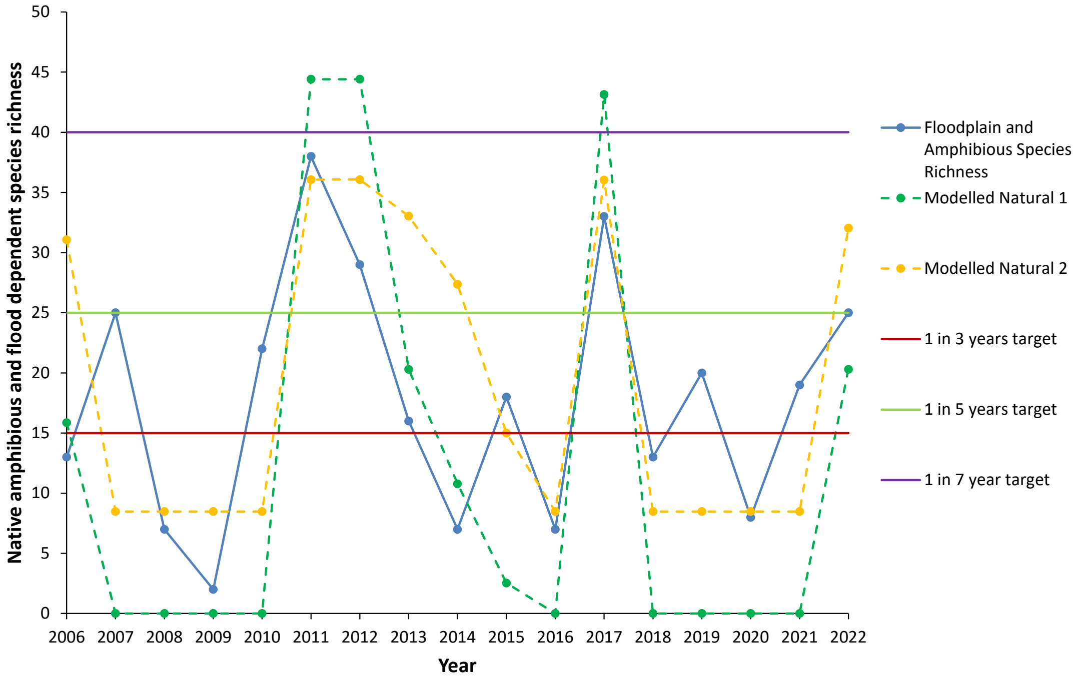

Figure 20: Species richness of native amphibious and flood dependent species at floodplain sites between 2006 and 2022 (blue line) and predicted flood dependent and amphibious species richness under modelled natural conditions at floodplain sites for the same period (Modelled Natural 1 = predicted using number of cells containing native flood dependent or amphibious taxa; Modelled Natural 2 = predicted using number of sites inundated in the previous 12 months).

4. DISCUSSION

4.1. Floodplain and temporary wetland vegetation dynamics

The floodplain vegetation condition monitoring program for the Chowilla Icon Site has provided comprehensive spatial coverage of open habitats across the floodplain with a broad range of flood and managed inundation frequencies. Initial sampling in 2006 provided baseline data, while follow up surveys have provided information regarding medium-term vegetation dynamics and the impacts of watering, natural flooding, regulator operation and changes in land management practices. Ultimately, these data are informing the management of the Chowilla Floodplain.

To gain a better understanding of floodplain and temporary wetland condition in Chowilla, 58 sites initially surveyed as part of an intervention monitoring program (Nicol *et al.* 2010b; Nicol 2012) are now included in the condition monitoring network. This has greatly improved spatial coverage and capacity to accurately detect spatio-temporal change in plant communities. To assess medium to long-term vegetation changes, all sites should continue to be re-surveyed on an annual basis if accessible.

Analysis of data collected from floodplain sites since 2006 (sites 1–85) showed that between 2018 and 2020, the plant community remained dominated by salt tolerant taxa with an increase in bare soil. The plant community across these sites was becoming more similar to that observed during the Millennium drought; however, the large number of quadrat cells with no plants present in 2020 resulted in a community different from the one observed during the drought. This was partially due to the absence of large-scale inundation (engineered or natural) required for the recruitment of flood dependent and amphibious species. However, it is likely the large numbers of vertebrate herbivores present throughout the system also contributed to the large amount of bare soil in 2020. Scat frequencies were significantly higher in 2019 and 2020 compared to 2018 and, whilst scats were not recorded prior to 2018, the number of vertebrate herbivores (in particular kangaroos) are present in higher number than during the drought (J. Nicol *pers. obs.*).

In contrast, the floodplain plant community in 2021 was dominated by terrestrial and salt tolerant taxa with a marked decrease in quadrat cells that were devoid of vegetation. This change was likely brought about by the successful efforts to control vertebrate herbivores across the Chowilla Floodplain and was reflected in the lower scat frequency recorded in 2021. Furthermore, Gum Flat was watered by pumping in spring 2020, inundating five sites and increasing species richness for the 2021 survey, which resulted in the plant community being most similar to the communities recorded in 2007 and 2010 following similar large-scale pumping. The further increase in species richness and proportion of amphibious and flood dependent species in 2022 was probably due to regulator operation inundating 24 sites and ongoing herbivore management reducing grazing pressure.

Since 2012, temporary wetland sites have been inundated more often than floodplain sites, either via regulator operations, site-specific pumping or flooding. In February

2019 nine sites were inundated (five of the six in the central basin of Werta Wert Wetland, two sites in Coppermine Waterhole and two in Pipeclay Billabong) (Appendix 1). In addition, sites in Werta Wert Wetland (northern and southern basins), Monoman Island Horseshoe, Lake Limbra, Hancock Creek, Twin Creeks and Chowilla Oxbow were inundated by regulator operation (Appendix 1). The sites inundated during the 2019 survey had dried by February 2020 and were generally dominated by flood dependent species as expected. In February 2020 11 sites were inundated (sites in Chowilla Island Loop, Punkah Depression, Punkah Floodrunner, Lake Littra and Coombool Swamp) with a further six located on the edges of Coombool Swamp and Lake Littra that were recently exposed (Appendix 1). In contrast to previous years, when inundated sites were typically devoid of vegetation, the inundated sites in Lake Littra and Coombool Swamp were dominated by submergent (*Nitella* sp.) and amphibious (*Myriophyllum verrucosum*) species. In contrast to many amphibious species, *Myriophyllum verrucosum* is adapted to recruit during the inundated phase of temporary wetlands. *Myriophyllum verrucosum* seeds will germinate whilst inundated (Nicol 2004) and charophyte spores require inundation for germination (e.g. Casanova 2011). It is not known why there was recruitment of the aforementioned taxa in these particular wetlands and not in others that were watered. Sites on the edges of Coombool Swamp and Lake Littra were similar to sites inundated in 2019 and dominated by flood dependent species in 2020. The remainder of the temporary wetland sites not inundated in the previous 12 months were dominated by bare soil and salt tolerant species.

In 2021, 13 wetland survey sites were inundated, nine in Werta Wert Wetland, two in Pipeclay Backwater, one in Punkah Floodrunner and one in Monoman Depression (Appendix 1). All sites in the southern basin of Werta Wert Wetland were inaccessible and not surveyed and the inundated sites in the central and northern basins were devoid of vegetation. The sites in Pipeclay Backwater were also inaccessible but Punkah Floodrunner and Monoman Depression were able to be surveyed. Punkah Floodrunner was devoid of vegetation but a diverse amphibious community was present in Monoman Depression. It is unclear why plants were present in Monoman Depression but not the other inundated sites in 2021; however, when surveyed the water depth in Monoman Depression was shallow (<5 cm). Furthermore, species such as *Damasonium minus* and *Setaria jubiflora*, which had not been previously recorded in the condition or intervention monitoring (Nicol *et al.* 2010; Nicol 2012) programs were present. In 2022 all wetland sites were inundated by regulator operation in spring 2021 and most had dried by February 2022. Similar to 2021, all sites in the southern basin of Werta Wert Wetland were inaccessible and the inundated sites in the central basin were devoid of vegetation. However, sites on the edge of the central basin and all sites in the northern basin of Werta Wert Wetland were surveyed and dominated by amphibious and flood dependent taxa. Similar to Werta Wert Wetland, almost all wetland sites not inundated in February 2022 were dominated by amphibious and flood dependent species due to recent inundation by regulator operation. Submergent species and *Myriophyllum verrucosum* were absent at sites inundated in February 2022, with all inundated sites being devoid of vegetation except one site in Chowilla Island Loop, which was dominated by the floating species *Azolla pinnata*. It is unclear why submergent species were absent; however, regulator operation typically results in shorter hydroperiods (except in wetlands with structures designed to hold back floodwaters) compared to pumping. Most of the sites where submergent species and *Myriophyllum verrucosum* were present in 2021 were dry also in 2022.

During vegetation surveys from 2018 to 2022, grazing intensity was measured semi-quantitatively by recording the frequency of scats in each quadrat, which gave an indication of the combined grazing pressure by kangaroos, euros, sheep, goats, pigs and emus. However, the provenance (i.e. species identification) and age of scats was not determined, and thus, it was not possible to differentiate the impacts of different grazers or whether the grazing was recent. Ideally, scats within each quadrat would be identified, separated based on species and weighed to give a more quantitative estimate. Furthermore, moisture content of scats could be determined to give an indication of scat age and used to infer recent grazing pressure. Nevertheless, recording the frequency of scats provided a rapid and repeatable assessment of grazing intensity appropriate for the current investigation that was comparable between years, plant communities and broad habitat types (temporary wetlands and the floodplain).

Scat frequency showed that grazing pressure was consistently higher on the floodplain (which includes Coppermine Complex and Gum Flat) than in temporary wetlands (Figure 9) for the five years these data have been collected. Nevertheless, some temporary wetlands such as Lake Littra and Coombool Swamp may be grazing hot spots (Figure 8). In both habitats there was a significant increase in scat frequency between 2018 and 2019, suggesting there was an increase in grazing pressure, and no significant change between 2019 and 2020, but a significant decrease in 2021 (Figure 9). This decrease corresponded with a major effort to reduce vertebrate grazing pressure on the Chowilla Floodplain, which was reflected in the lower scat frequencies in the 2021 survey in the wetland and floodplain habitats (Figure 9). There was a further decrease in scat frequency between 2021 and 2022 in wetland habitats, which was probably due to inundation and scats either getting removed from wetlands or not being recorded because they could not be seen. In contrast there was no difference in scat frequency at floodplain sites with the highest frequencies typically at sites that were not inundated and dominated by terrestrial taxa. The high abundance of bare soil in 2020 is likely due to high vertebrate grazing pressure and the subsequent decrease in 2021 and 2022 was likely a result of the grazing control.

Scat frequency also suggested that vertebrate grazers prefer different plant communities (Figure 9). Results suggested the ‘Terrestrial’ community was most heavily grazed (Figure 9); however, in 2022 the regulator operation may have influenced the spatial distribution of scats. The terrestrial community was present at sites that were not inundated in 2022; therefore, scats were not removed from the floodplain or redistributed by inundation. Nevertheless, sites dominated by bare soil had significantly lower scat frequencies than sites dominated by terrestrial taxa, and they also were typically not inundated by regulator operation. Sites dominated by amphibious and flood dependent taxa had a significantly higher scat frequency than sites dominated by bare soil but lower than sites with predominantly terrestrial species, despite these sites being inundated by regulator operation. Scats were unable to be counted at inundated sites (Figure 9). Results from 2022 suggest that, despite inundation playing a role in the distribution of scats on the floodplain, vertebrate grazers spend more time in vegetated areas.

4.2. The Living Murray Targets

The TLM condition monitoring plan refinement project developed quantitative targets that can be assessed with data collected throughout the condition monitoring program. The one-in-three year target for the floodplain was able to be achieved through a combination of watering, regulator operation and the 2010-11 and 2016 floods. The one-in-five year target was achieved in 2011, 2012 and 2017, supported by the spring 2016 regulator operation and subsequent overbank flooding. In 2017, however, had the overbank flood not occurred, the target may have been achieved by regulator operation alone as it inundated 48% of sites (Appendix 1). Between 2006 and 2022, the one-in-seven year target was not achieved. In 2017, >65% of cells contained flood dependent or amphibious taxa, but the target was not achieved because native floodplain and amphibious species richness was below the target of 40.

Floristic composition following the 2016, 2018 and 2021 regulator operations suggest that the one-in three and one-in-five year targets for the floodplain could be achieved in the future by mid to high-level regulator operations; however, the one-in-seven year target likely requires large natural floods. Nevertheless, the two overbank floods over the monitoring program did not result in the one-in-seven year target being achieved and suggests this target may need refinement, in particular the metrics relating to native floodplain and amphibious species richness. The target of 40 native floodplain or amphibious species may be unrealistic for the seven year target given the design of the monitoring program, which aimed to maximise statistical power to detect changes in vegetation through time and in response to management. The relatively small total area surveyed using this method, in comparison with studies designed to catalogue biodiversity (e.g. O'Malley 1990), would result in rare species not being recorded. For example, *Pseudoraphis spinescens* was observed in Coppermine complex and Werta Wert Wetland in 2014 and 2017, and in Punkah Creek Depression in 2015, but was not detected in any condition monitoring surveys. Furthermore, the condition monitoring program focusses on open areas and does not include woodlands that may result in some species not being recorded. Nevertheless, 137 native flood dependent and amphibious species have been recorded on the Chowilla Floodplain since 1989 (Nicol *et al.* 2010a). Recording all species present in a 50 m radius around sites did result in an increase in the number of species recorded at the site scale; however, these species were recorded at other sites (in quadrats) resulting in no additional species being recorded at the whole of site scale.

The 2022 condition monitoring survey resulted in the 10th year of annual monitoring data being collected for temporary wetland sites. Over 40% of cells were either inundated or contained native amphibious or flood dependent species with a species richness >20 in each year. The achievement of the one-in-two-year target was due to watering interventions, flooding and regulator operations. However, these interventions have not resulted in the one-in-four-year target being achieved (due to the native flood dependent and amphibious species richness being <40) despite over 80% of cells being either inundated or containing amphibious or flood dependent taxa in 2015, 2017 and 2022. Similar to the one-in-seven-year target for the floodplain, this target may require further refinement with respect to species richness, but (similar to the floodplain sites) recording all species in a 50 m radius of sites did not result in additional species being recorded at the whole of site scale.

Exotic taxa are uncommon on the floodplain, with the target for the floodplain being achieved every year except in 2011, 2012 and 2017. The increased recruitment of exotic species was likely due to natural flooding in 2010/11 and 2016, which provided conditions suitable for the recruitment of many pest plant species in areas that were inundated (Nicol 2007). Furthermore, it is likely that pest plant propagules were transported to the Chowilla Floodplain in floodwater (e.g. Nilsson *et al.* 1991). With regard to management, there are no practical actions to control weeds on the Chowilla Floodplain due to the large spatial scale of the Icon Site and proximity to a watercourse preventing the use of herbicides.

Despite flooding facilitating the recruitment of exotic plants, the benefits of natural flooding to the riverine ecosystem (e.g. Holland *et al.* 2013; Bice *et al.* 2014) outweigh any negative impacts from pest plants. Pest plants are more abundant in temporary wetlands, with exotic species being present in >10% of cells each year except 2017 (when most sites were inundated and devoid of live plants). This has resulted in this target being achieved only in 2017 and there is not yet sufficient data to determine medium to long-term trends in pest plant abundances. As with the floodplain, there is little that can be done with regards to management. Despite high abundances of other exotic species, the proclaimed pest plant *Xanthium occidentale* was generally absent from floodplain and temporary wetland sites until 2022. The target was not achieved for the first time in temporary wetlands with this species recorded in more than 1% of cells. There was anecdotal and observational evidence that *Xanthium occidentale* was present in higher-than-normal abundances throughout the South Australian River Murray corridor in spring/summer 2021/22, which was reflected in abundances in temporary wetlands on the Chowilla Floodplain.

The attainment of The Living Murray targets has been determined for the floodplain since 2006 and temporary wetlands since 2013 and whilst data collected for the condition and intervention monitoring programs was examined, the targets were formulated largely by expert opinion. Nevertheless, analysis of modelled natural inundation, the number of quadrat cells predicted to contain flood dependent or amphibious species, and predicted species richness, showed that it is likely the floodplain native vegetation targets would be achieved under natural conditions. Whilst it is unlikely that management interventions and environmental flows will result in attainment of the one-in-seven-year target they do result in attainment of the one-in-three and one-in-five-year targets. Nevertheless, the modelled predictions support the validity of the targets.

The calculations used to predict the number of cells containing flood dependent or amphibious plant taxa and species richness under modelled natural flow, whilst based on data from the Chowilla Floodplain, were simple and should not necessarily be viewed as accurate. It is likely that the predicted number of cells containing flood dependent or amphibious species under natural conditions is an underestimate, as more frequent inundation would probably result in more than 75% of inundated cells containing these species. The relationship held true for 2018 to 2021 when data from sites one to 85 (which was not used to formulate this relationship) showed that 75% of sites inundated in the previous 12 months contained flood dependent or amphibious taxa. In 2022; however, the predicted percentage of cells containing floodplain or amphibious species was similar to the observed value despite ten less quadrats being inundated. In 2022, 89% of cells inundated in spring 2021 contained floodplain or amphibious species. This provides evidence that watering sites consecutively may increase the abundance of floodplain and amphibious taxa as Gum Flat was watered by pumping in spring 2020 inundating five sites, which were inundated the following spring by the regulator operation. Over the condition monitoring program this is the only instance where multiple floodplain sites have been watered in consecutive years (although sites in Gum Flat and Coppermine complex were inundated in consecutive years by watering in 2009 and flooding in 2010) (Appendix 1). Furthermore, the modelled percentage of cells containing floodplain and amphibious species assumes that there are no flood dependent or amphibious species present if the quadrat cell was not inundated in the previous 12 months, which is not always the case as reflected in the 2018 to 2021 survey results that followed a dry period.

The two different functions proposed to predict native flood dependent and amphibious species richness under natural flows, suggested strong relationships as determined by regression analysis; however, this needs to be viewed with caution. The simple linear relationship between the number of quadrat cells containing flood dependent or amphibious species and species richness, when using the predicted number of quadrat cells containing these species under natural flows, results in species richness being zero when no sites were inundated in the previous 12 months. It will also predict that species richness will increase as the number of cells containing these species increases, which may reflect the data collected from the Chowilla Floodplain over the past 15 years but does not recognise there is a finite number of flood dependent and amphibious species. The exponential relationship between the number of sites inundated in the previous 12 months, and native flood dependent and amphibious species richness resembles a typical species area relationship and assumes there is a finite number of flood dependent and amphibious species. The relationship derived from 13 years' data suggests that the maximum number of flood dependent and amphibious species that will be present is around 37, which is just over one quarter of the total number of these species recorded on the Chowilla Floodplain since 1989 (Nicol 2010a). Therefore, it is likely that the linear relationship between native flood dependent and amphibious species richness and the number of quadrat cells underestimates species richness during dry periods and the exponential relationship between the number of sites inundated in the previous 12 months underestimates species richness after floods.

4.3. Management recommendations and future research and monitoring

Observational and monitoring data suggests that regulator operation and pumping improves understorey vegetation condition based on species richness and abundance of native flood dependent and amphibious taxa. In recent years, these interventions, in conjunction with overbank flooding and flow pulses, have resulted in most understorey vegetation targets being achieved. A high-level regulator operation in 2022 will not result in meeting additional targets in the short-term; however, it should not be ruled out if there is sufficient flow as the opportunity may not arise in following years. Furthermore, it will result in floodplain sites being watered in consecutive years and the benefits that result from multiple watering or floods.

Seed bank investigations on the Chowilla Floodplain (Kelly 2017, Skinner 2017, Gibbs *et al.* 2020) and a comparison of the response to flooding between the Pike (unwatered) and Chowilla (watered) floodplains showed that understorey vegetation is resilient and may not require interventions for long-term survival (Holland *et al.* 2013). However, this does not mean interventions such as regulator operations; weir pool raisings and pumping do not provide benefit. Interventions are required to improve the condition of woody floodplain vegetation and provide a source of feed for native grazers often not available on the adjacent uplands (an ecosystem service the floodplain has likely always provided).

The Living Murray Chowilla Floodplain condition monitoring program has produced a robust mid to long-term dataset that has documented the changes in floristic composition through time and in response to flooding and interventions. Datasets of this nature are critical to evaluate ecological response to management interventions and inform adaptive management. Other monitoring and research are required to better understand the biological processes and physicochemical factors that ultimately drive changes, and the function of understorey vegetation (e.g. as a resource) in the landscape. Future research and monitoring activities to inform management of the site include:

- Continuation of the condition monitoring program to gain further information regarding the medium to long-term floodplain and temporary wetland vegetation dynamics and report on TLM targets;
- Continuation of recording scat frequency within quadrats to estimate grazing intensity, which could be coupled with exclusion experiments to gain a better understanding of the impacts of native and exotic vertebrate herbivores;
- Investigate modelling target achievement under natural conditions for temporary wetlands;
- Explore modelling target achievement under the “do nothing” scenario to compare under current conditions and modelled natural flow for floodplain sites;
- Refinement of relationships between species richness and occurrence of native flood dependent and amphibious species under modelled natural flows;
- Investigation of relationships between vegetation and soil properties (e.g. salinity, soil moisture, water potential, texture);
- Refinement of grazing pressure estimates by determining provenance and age of scats;
- Investigation of short-term longevity of understorey watering/flooding response to determine optimal interval between watering and vegetation surveys;
- Investigation of energetic benefits to consumers (e.g. trophic upsurge) from managed events; and

- Investigation of species propagule survival following passage through the gut of different grazers.

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APPENDICES

Appendix 1: Site GPS coordinates (UTM format, map datum WGS 84), year survey site established (N/A = no longer included in analysis, I/A = inaccessible due to reasons other than inundation), site description and inundation history across survey period (W = watered, F = flooded, WF = watered + flooded that year).

Site #	Easting	Northing	Year Established	Description	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
1	485198	6240345	2006	Floodplain						F						WF					W
2	484523	6241019	2006	Floodplain		W			W	F				W	W	WF		W			W
3	483784	6240912	2006	Floodplain						F						WF					
4	483645	6239006	2006	Floodplain																	
5	483016	6239192	2006	Floodplain													I/A	I/A	I/A	I/A	I/A
6	484742	6236011	2006	Floodplain													I/A	I/A	I/A	I/A	I/A
7	484859	6236000	2006	Floodplain													I/A	I/A	I/A	I/A	I/A
8	485543	6236491	2006	Floodplain													I/A	I/A	I/A	I/A	I/A
9	483624	6239042	2006	Floodplain																	
10	483764	6239169	2006	Floodplain						F						WF					
11	484087	6238477	2006	Floodplain																	
13	486211	6237577	2006	Floodplain						F				W		WF		W			W
14	486064	6237665	2006	Floodplain						F						WF					W
15	485487	6237975	2006	Floodplain												WF					
16	485298	6237971	2006	Floodplain												WF					
17	485021	6238331	2006	Floodplain					W	F				W		WF		W			W
18	484572	6238585	2006	Floodplain					W	F				W		WF		W			W
19	484438	6238618	2006	Floodplain		W			W	F				W		WF		W			W
20	485169	6237680	2006	Floodplain						F						WF					
21	485459	6238026	2006	Floodplain												WF					
22	485513	6238180	2006	Floodplain		W			W	F				W		WF		W			W
23	486597	6237792	2006	Floodplain		W			W	F				W		WF		W			W
24	486698	6237764	2006	Floodplain										W		WF		W			W
25	486805	6238779	2006	Floodplain												WF					
26	486896	6239849	2006	Floodplain												WF					
27	488116	6242678	2006	Floodplain						F						WF					
28	488241	6242818	2006	Floodplain						F						WF					
29	488551	6243371	2006	Floodplain						F						WF					
30	489071	6244832	2006	Floodplain						F						F					
31	489052	6244608	2006	Floodplain						F						WF					
32	489693	6244265	2006	Floodplain						F						F					
33	488193	6241105	2006	Floodplain						F						F					
34	487778	6240977	2006	Floodplain						F						F					
36	488897	6242699	2006	Floodplain						F						F					
37	489238	6242844	2006	Floodplain												F					
38	489017	6242097	2006	Floodplain																	W
39	489350	6239512	2006	Floodplain						F						WF					W

Site #	Easting	Northing	Year Established	Description	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
40	488303	6242207	2006	Floodplain						F				W		WF					W
41	488438	6242575	2006	Floodplain						F				W		WF					W
42	489973	6245851	2006	Floodplain												F					
43	490075	6245613	2006	Floodplain																	
44	490242	6245188	2006	Floodplain						F						F					
45	490345	6245049	2006	Floodplain																	
46	489458	6244864	2006	Floodplain						F						F					
47	489351	6244956	2006	Floodplain						F						F					
48	490503	6243645	2006	Floodplain						F						F					
49	491017	6244303	2006	Floodplain						F						F					
50	491442	6244363	2006	Floodplain						F					W	WF					W
51	490966	6244592	2006	Floodplain						F						WF					
52	491223	6244572	2006	Floodplain												WF					
55	495612	6247657	2006	Floodplain						F				W		WF		W			W
56	494893	6246522	2006	Floodplain						F						F					
57	494499	6246028	2006	Floodplain												F					
58	492860	6247105	2006	Floodplain																	
59	493830	6245882	2006	Floodplain						F						F					
60	493910	6245725	2006	Floodplain						F						F					
61	494310	6244810	2006	Floodplain						F						WF					W
62	497206	6246599	2006	Floodplain		W			W	F			W	W		WF				W	W
63	497618	6246464	2006	Floodplain		W			W	F			W			WF				W	W
64	498069	6246375	2006	Floodplain		W			W	F			W			WF				W	W
65	498376	6246311	2006	Floodplain		W			W	F			W			WF				W	W
66	498394	6246168	2006	Floodplain					W	F			W			WF				W	W
67	497154	6241724	2006	Floodplain					I/A	I/A	I/A			I/A	I/A	I/A	I/A	I/A			I/A
68	496397	6243263	2006	Floodplain					I/A	I/A	I/A			I/A	I/A	I/A	I/A	I/A			I/A
69	496572	6242971	2006	Floodplain					I/A	I/A	I/A			I/A	I/A	I/A	I/A	I/A			I/A
70	497243	6243954	2006	Floodplain					I/A	I/A	I/A			I/A	I/A	I/A	I/A	I/A			I/A
71	497342	6245017	2006	Floodplain					I/A	I/A	I/A			I/A	I/A	I/A	I/A	I/A			I/A
72	496523	6245423	2006	Floodplain					I/A	I/A	I/A			I/A	I/A	I/A	I/A	I/A			I/A
74	489083	6238916	2006	Floodplain																	
75	488969	6239062	2006	Floodplain						F						F					
76	488205	6238287	2006	Floodplain												F					
77	488122	6237666	2006	Floodplain										W		F					W
78	488692	6237147	2006	Floodplain																	
79	488209	6240070	2006	Floodplain						F				W		F					W
80	488942	6239515	2006	Floodplain												F					
82	491300	6242057	2006	Floodplain						F						F					
83	498893	6236615	2008	Floodplain						F						I/A	I/A	I/A	I/A	I/A	I/A
84	503870	6235576	2008	Floodplain											I/A	F					
85	504385	6235609	2008	Floodplain						F					I/A	F					

Site #	Easting	Northing	Year Established	Description	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
86	503659	6233903	2013	Kulcurna Black Box 1	W					F						F					
87	503689	6234181	2013	Kulcurna Black Box 2	W					F						F					
88	504119	6234315	2013	Kulcurna Red Gum 1	W			W	W	WF					I/A	F					
89	504251	6234648	2013	Kulcurna Red Gum 2	W			W	W	WF					I/A	F					
90	503690	6235129	2013	Kulcurna Red Gum 3	W			W	W	WF					I/A	F					
91	500102	6245461	2013	Littra Edge 1	W		W		W	WF			W			WF			W		W
92	500083	6245421	2013	Littra Middle 1	W		W		W	WF			W			WF			W		W
93	500246	6245118	2013	Littra Edge 2	W		W		W	WF			W			WF			W		W
94	500085	6245221	2013	Littra Middle 2	W		W		W	WF			W			WF			W		W
95	498520	6245504	2013	Punkah Floodrunner 1	W			W		WF						WF			W	W	W
96	495966	6245906	2013	Punkah Depression 1	W			W		WF					W	WF		W	W		W
97	495966	6245919	2013	Punkah Depression 2	W			W		WF						WF		W	W		W
98	488042	6245182	2013	Werta Wert North Middle 1	W		W		W	WF						WF		W		W	W
99	488124	6245143	2013	Werta Wert North Edge 2	W		W		W	WF			W	W		WF		W		W	W
100	488041	6245317	2013	Werta Wert North Edge 6	W		W		W	WF			W	W		WF		W		W	W
101	488193	6245206	2013	Werta Wert North Middle 2	W		W		W	WF			W	W		WF		W		W	W
102	488205	6245395	2013	Werta Wert North Edge 1	W		W		W	WF			W	W		WF		W		W	W
103	488289	6245341	2013	Werta Wert North Middle 3	W		W		W	WF			W	W		WF		W		W	W
104	489573	6247193	2013	Coombool Edge 1					W	WF	W					WF			W		W
105	489491	6247218	2013	Coombool Middle 1					W	WF	W					WF			W		W
106	488999	6247637	2013	Coombool Edge 2					W	WF	W					WF			W		I/A
107	489213	6247649	2013	Coombool Middle 2					W	WF	W					WF			W		I/A
108	489355	6248928	2013	Coombool Middle 3					W	WF	W					WF			W		I/A
109	489467	6249484	2013	Coombool Edge 3					W	WF	W					WF			W		I/A
110	489870	6249043	2013	Coombool Middle 4					W	WF	W					WF			W		I/A
111	491123	6248539	2013	Coombool Edge 4					W	WF	W					WF			W		W

Site #	Easting	Northing	Year Established	Description	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
112	487726	6239416	2013	Chowilla Oxbow 1	W			W		WF						WF		W			W
113	487804	6238952	2013	Chowilla Oxbow 2	W			W		WF						WF		W			W
114	495334	6248147	2013	Limbra 1					W	WF						WF		W			W
115	495397	6248559	2013	Limbra 2					W	WF						WF		W			W
116	495413	6248992	2013	Limbra 3					W	WF						WF		W			W
117	492857	6246312	2013	Hancock Creek 2						F						WF		W			W
118	493241	6242604	2013	Pipeclay Backwater 2				W		WF					W	WF		W		W	W
119	488091	6240839	2013	Monoman Depression 1	W			W		WF						WF				W	W
120	485268	6240209	2014	Coppermine 1				W		WF						WF		W			W
121	485568	6240091	2014	Coppermine 2				W		WF						WF		W			W
122	488420	6241325	2014	Monoman Island 1	W		W			WF						WF		W			W
123	489759	6243272	2014	Twin Creek 1			W			WF						WF		W			W
124	489596	6243373	2014	Twin Creek 2			W			WF						WF		W			W
125	489076	6243250	2014	Twin Creek 3			W			WF						WF		W			W
126	488868	6241674	2014	Monoman Island 2	W		W			WF						WF		W			W
127	487240	6236425	2015	Chowilla Island Loop 1	W			W		WF						WF		W	W		W
128	487464	6236797	2015	Chowilla Island Loop 2	W			W		WF						WF		W	W		W
129	490728	6244838	2015	Brandy Bottle Lagoon	W			W		F					W	WF		W			W
130	485587	6236197	2016	Woolshed Creek 1				W		WF	W	W	W	W		WF	I/A	I/A			W
131	485919	6237151	2016	Woolshed Creek 2				W		WF	W	W	W	W		WF		W			W
132	487496	6244391	2016	Werta Wert South Edge 6	W		W		W	WF	W	W	W	W		WF		W		W	W
133	487634	6244017	2016	Werta Wert South Edge 7	W		W		W	WF	W	W	W	W		WF		W		W	W
134	487611	6243827	2016	Werta Wert South Middle 1	W		W		W	WF	W	W	W	W		WF		W		W	W
135	487698	6243755	2016	Werta Wert South Middle 2	W		W		W	WF	W	W	W	W		WF		W		W	W
136	487905	6243689	2016	Werta Wert South Middle 3	W		W		W	WF	W	W	W	W		WF		W		W	W
137	487743	6244165	2016	Werta Wert South Edge 2	W		W		W	WF	W	W	W	W		WF		W		W	W

Site #	Easting	Northing	Year Established	Description	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
138	487621	6244818	2016	Werta Wert Centre Edge 2	W		W		W	WF	W	W	W	W		WF		W		W	W
139	487627	6244854	2016	Werta Wert Centre Middle 3	W		W		W	WF	W	W	W	W		WF		W		W	W
140	487722	6244850	2016	Werta Wert Centre Middle 1	W		W		W	WF	W	W	W	W		WF		W		W	W
141	487754	6244899	2016	Werta Wert Centre Edge 5	W		W		W	WF	W	W	W	W		WF		W		W	W
142	487709	6244930	2016	Werta Wert Centre Middle 2	W		W		W	WF	W	W	W	W		WF		W		W	W
143	487669	6245078	2016	Werta Wert Centre Edge 8	W		W		W	WF	W	W	W	W		WF		W		W	W
144	493367	6242911	2018	Pipeclay Backwater 1				W		WF	W	W	W	W	W	WF		W		W	W

Appendix 2: Species list, functional classification, life history strategy, conservation status (state conservation status from listings in Barker et al. 2005 (*denotes exotic species, **denotes proclaimed pest plant in South Australia, ***denotes weed of national significance, # denotes listed as rare in South Australia, ^ denotes listed as vulnerable in South Australia, ^^denotes listed as endangered in South Australia).

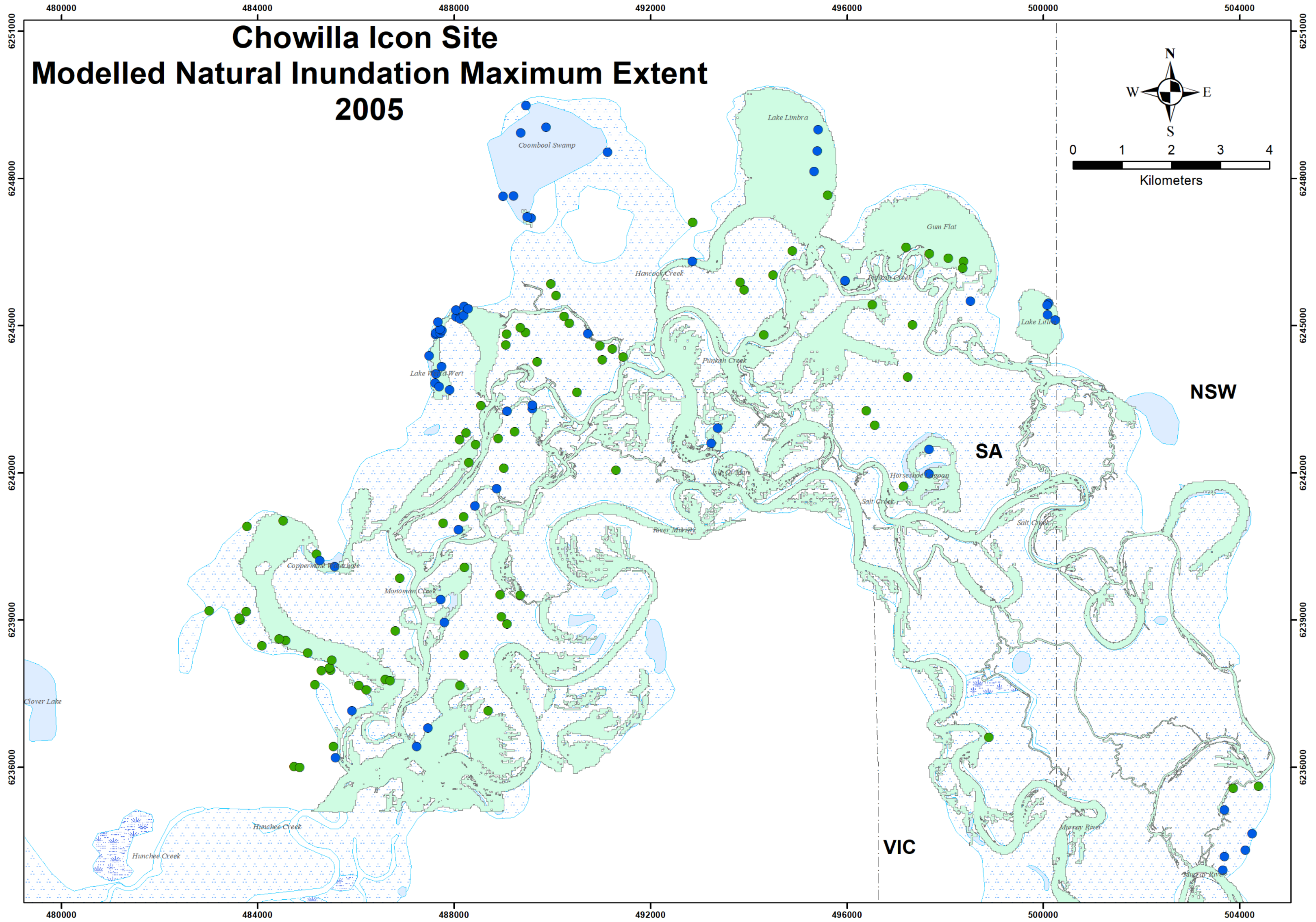
Taxon	Common Name	Family	Status	Life history strategy/growth form	Functional group
*Abutilon theophrasti**	Velvetleaf, China Jute, Buttonweed, Pie-Marker, Indian mallow	Malvaceae	Exotic, Naturalised	Annual herb	Amphibious
Alternanthera denticulata	lesser joyweed	Amaranthaceae	Native	Annual herb	Flood dependent
Ammannia multiflora	jerry-jerry	Lythraceae	Native	Annual herb	Amphibious
*Asphodelus fistulosus***	onion weed	Liliaceae	Exotic, Proclaimed SA Plant	Annual/Perennial	Terrestrial
Atriplex spp.	saltbush	Chenopodiaceae	Native	Perennial	Terrestrial
Atriplex suberecta	lagoon saltbush	Chenopodiaceae	Native	Perennial	Flood dependent
Austrobryonia micrantha	desert cucumber	Cucurbitaceae	Native	Perennial	Flood dependent
Bolboschoenus caldwellii	Marsh clubrush	Cyperaceae	Native	Perennial	Amphibious
Brachyscome paludicola#	swamp daisy	Asteraceae	Native, Rare in South Australia	Perennial herb	Flood dependent
Brachyscome dentata	swamp daisy	Asteraceae	Native	Perennial herb	Flood dependent
Calotis cuneifolia	purple (or blue) burr-daisy	Asteraceae	Native	Perennial herb	Flood dependent
Calotis hispidula	bogan flea, hairy burr-daisy, bindyi	Asteraceae	Native	Annual herb	Flood dependent
Calotis scapigera#	tufted burr-daisy	Asteraceae	Native, Rare in South Australia	Perennial herb	Flood dependent
*Centaurium tenuiflorum**	branched centaury	Gentianaceae	Exotic, Naturalised	Annual herb	Terrestrial
Centipeda minima ssp. *minima*	speading sneezeweed	Asteraceae	Native	Annual herb	Flood dependent
Chenopodium nitrariaceum	nitre goosefoot	Chenopodiaceae	Exotic	Annual herb	Terrestrial
Damasonium minus	starfruit	Alismataceae	Native	Perennial herb	Amphibious
Disphyma crassifolium ssp. *clavellatum*	round pigface	Aizoaceae	Native	Perennial	Salt tolerant
Dysphania pumilio	clammy goosefoot, small crumbweed	Chenopodiaceae	Native	Annual/Perennial	Flood dependent
*Citrullus amarus**	bitter melon, wild (or camel) melon	Cucurbitaceae	Exotic, Naturalised	Annual herb	Terrestrial
Cotula australis	common cotula	Asteraceae	Native	Annual/Perennial herb	Amphibious
Craspedia chrysantha	bachelors buttons, common billybuttons	Asteraceae	Native	Annual herb, sometimes Biennial	Terrestrial
Crassula helmsii	swamp crassula	Crassulaceae	Native	Perennial herb	Amphibious
*Crassula sieberana^^*	Australian stonecrop	Crassulaceae	Native, Endangered in South Australia	Annual/Perennial	Amphibious
Cyperus difformis	variable flat-sedge, dirty Dora	Cyperaceae	Native	Annual sedge	Amphibious
Cyperus gymnocaulos	spiny flat-sedge, spiny sedge	Cyperaceae	Native	Perennial sedge	Amphibious
*Dittrichia graveolens**	stinkwort, stink-weed	Asteraceae	Exotic, Naturalised	Annual herb	Flood dependent
Duma florulenta	lignum	Polygonaceae	Native	Perennial shrub	Amphibious
Duma horrida#	spiny lignum	Polygonaceae	Native, Rare in South Australia	Perennial shrub	Amphibious
Eleocharis acuta	common spike-rush	Cyperaceae	Native	Perennial sedge	Amphibious
Enchylaena tomentosa var. *tomentosa*	ruby saltbush, barrier saltbush	Chenopodiaceae	Native	Perennial shrub	Terrestrial
Enneapogon nigricans	black-heads, niggerheads	Poaceae	Native	Perrennial grass	Flood dependent
Eragrostis australasica	cane-grass, bamboo-grass	Poaceae	Native	Perennial grass	Amphibious
Eragrostis dielsii	Mallee lovegrass	Poaceae	Native	Perennial grass	Flood dependent

Taxon	Common Name	Family	Status	Life history strategy/growth form	Functional group
Eremophila divaricata	spreading emubush	Scrophulariaceae	Native	Perennial shrub	Terrestrial
Eremophila scoparia	broom emubush, silver emubush, scotia bush	Scrophulariaceae	Native	Perennial shrub	Terrestrial
*Erigeron bonariensis**	flaxleaf fleabane, tall fleabane	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial
*Erodium cicutrium**	common storks bill	Geraniaceae	Exotic, Naturalised	Annual/Biennial herb	Flood dependent
Eucalyptus camaldulensis var. *camaldulensis*	red gum, river red gum	Myrtaceae	Native	Tree	Amphibious
Euphorbia drummondii	caustic weed	Euphorbiaceae	Native	Perennial herb	Flood dependent
Frankenia pauciflora var. *gunnii*	common (or southern) sea-heath	Frankeniaceae	Native	Perennial herb	Salt tolerant
Glinus lotoides	hairy carpet-weed	Aizoaceae	Native	Annual/Perennial herb	Flood dependent
Glycyrrhiza acanthocarpa	liquorice	Fabaceae	Native	Annual herb	Flood dependent
Goodenia gracilis^	slender goodenia	Goodeniaceae	Native, Vulnerable in South Australia	Annual/Perennial herb	Flood dependent
Gunniopsis septifraga	green pigface	Aizoaceae	Native	Annual herb	Flood dependent
Haloragis aspera	rough raspwort	Haloragaceae	Native	Perennial herb	Flood dependent
Haloragis glauca	grey raspweed, grey raspwort	Haloragaceae	Native	Perennial herb	Flood dependent
*Heliotropium curassavicum**	smooth heliotrope	Boraginaceae	Exotic, Naturalised	Annual/Perennial herb	Flood dependent
*Heliotropium europaeum**	potato weed, heliotrope, common heliotrope	Boraginaceae	Exotic, Naturalised	Annual herb	Flood dependent
Helminthotheca echiodes *	ox-tongue	Asteraceae	Exotic, Naturalised	Annual/Biennial herb	Terrestrial
*Hypochaeris glabra**	smooth catsear, glabrous catsear	Asteraceae	Exotic, Naturalised	Annual herb	Terrestrial
Isoetopsis graminifolia	grass cushions, grass buttons	Asteraceae	Native	Annual herb	Flood dependent
Isolepis hookeriana		Cyperaceae	Native	Annual herb	Amphibious
Lachnagrostis filiformis	blown grass, fairy grass	Gramineae	Native	Perennial grass	Flood dependent
Leiocarpa brevicompta	flat Billy-buttons	Asteraceae	Native	Annual herb	Terrestrial
Limosella australis	Australian mudwort, austral mudwort	Scrophulariaceae	Native	Perennial herb	Amphibious
Ludwigia peploides	Water primrose, clove-strip	Onagraceae	Exotic, Naturalised		Amphibious
*Lycium ferocissimum****	African box thorn	Solanaceae	Exotic, Weed of National Significance	Perennial shrub	Terrestrial
Maireana spp.	bluebush	Chenopodiaceae	Native	Perennial shrub	Terrestrial
*Malva parviflora**	small flowered marshmallow	Malvaceae	Exotic, Naturalised	Annual/Perennial herb	Terrestrial
Marsilea drummondii	nardoo	Marsileaceae	Native	Annual herb	Amphibious
Medicago spp.*	burr-medic	Fabaceae	Exotic, Naturalised	Annual herb	Terrestrial
Mentha australis	slender mint	Lamiaceae	Native	Perennial herb	Amphibious
*Mesembryanthemum crystallinum**	Common iceplant	Aizoaceae	Exotic, Naturalised	Annual/biennial herb	Terrestrial
Mollugo cerviana	Wire-stem chickweed	Aizoaceae	Native	Ephemeral/Annual herb	Flood dependent
Myosurus australis	mousetail	Ranunculaceae	Native	Annual herb	Flood dependent
Nitella sp.	stonewort	Characeae	Native	Alga	Submergent
*Nothoscordum borbonicum**	onion weed	Liliaceae	Exotic, Naturalised	Annual herb	Flood dependent
Osteocarpum acropterum	water weed, babbagia	Chenopodiaceae	Native	Perennial herb	Salt tolerantz
Persicaria lapathifolia	pale (or pink) knotweed	Polygonaceae	Native	Perennial herb	Amphibious
*Phyla canescens**	lippia, fog fruit	Verbenaceae	Exotic, Naturalised	Perennial herb	Terrestrial

Taxon	Common Name	Family	Status	Life history strategy/growth form	Functional group
Phyllanthus lacunaris	lagoon spurge, Caraweena clover	Euphorbiaceae	Native	Annual/Perennial herb	Flood dependent
Plantago cunninghamii	sago weed	Plantaginaceae	Native	Annual herb	Flood dependent
Plantago turrifera	small sago weed	Plantaginaceae	Native	Annual herb	Flood dependent
*Polygonum aviculare**	wireweed, hogweed, (prostrate) knotweed.	Polygonaceae	Exotic, Naturalised	Annual herb	Terrestrial
Polygonum plebium	small knotweed	Polygonaceae	Native	Annual herb	Flood dependent
*Polypogon monspeliensis**	annual beard-grass, beard-grass.	Poaceae	Exotic, Naturalised	Annual grass	Amphibious
Pseudognaphalium luteoalbum	jersey cudweed	Asteraceae	Native	Annual herb	Flood dependent
Rhaghodia spinescens	spiny saltbush, berry saltbush	Chenopodiaceae	Native	Perennial shrub	Terrestrial
*Rorippa palustris**	yellow cress, marsh watercress	Brassicaceae	Exotic, Naturalised	Annual/Biennial herb	Flood dependent
Rumex bidens	mud dock	Polygonaceae	Native	Perennial	Amphibious
Salsola australis	buckbush, rolypoly, soft roly-poly, prickly saltwort	Chenopodiaceae	Native	Annual herb	Salt tolerant
Scleroblitum atriplicinum	purple (or starry or purple-leaved) goosefoot,	Chenopodiaceae	Native	Annual herb	Flood dependent
Sclerolaena brachyptera	short-winged copperburr, hairy bassia,	Chenopodiaceae	Native	Annual herb	Salt tolerant
Sclerolaena divaricata	tangled copperburr, pale poverty bush	Chenopodiaceae	Native	Perennial shrub	Terrestrial
Sclerolaena stelligera	star-fruit bassia, star copperburr, starred bluebush	Chenopodiaceae	Native	Perennial sub-shrub	Salt tolerant
Senecio cunninghamii	bushy groundsel	Asteraceae	Native	Perennial shrub	Flood dependent
Senecio runcinifolius	tall groundsel	Asteraceae	Native	Perennial herb	Flood dependent
Setaria jubiflora	Warrego summer grass	Poaceae	Native	Perennial grass	Amphibious
Sida ammophila	sand sida	Malvaceae	Native	Perennial shrub	Terrestrial
Solanum lacunarium	lagoon Nightshade	Solanaceae	Native	Perennial herb	Flood dependent
*Solanum nigrum**	black-berry nightshade, black nightshade	Solanaceae	Exotic, Naturalised	Perennial shrub	Terrestrial
*Spergularia marina**	salt sand-spurrey	Caryophyllaceae	Exotic, Naturalised	Annual/Biennial/Perennial herb	Salt tolerant
Sphaeromorphaea australis	spreading nut-heads	Asteraceae	Native	Annual/Perennial herb	Flood dependent
Sporobolus mitchellii	rats-tail couch, short rats-tail grass	Poaceae	Native	Perennial grass	Flood dependent
Stemodia floribunda	blue-rod	Scrophulariaceae	Native	Perennial herb	Flood dependent
*Symphyotrichum subulatum**	Wild aster, bushy starwort	Asteraceae	Exotic, Naturalised	Annual herb	Amphibious
*Taraxacum officinale**	dandelion	Asteraceae	Exotic, Naturalised	Perennial herb	Terrestrial
Tecticornia pergranulata	N/A	Chenopodiaceae	Native	Perennial herb/shrub	Amphibious
Tecticornia triandra	desert glasswort	Chenopodiaceae	Native	Perennial shrub	Salt tolerant
Tetragonia tetragonioides	New Zealand spinach, Warragul cabbage	Aizoaceae	Native	Annual/Perennial herb	Flood dependent
Teucrium racemosum	grey germander	Lamiaceae	Native	Perennial herb	Flood dependent
Thyridia repens	creeping monkey flower, Maori musk	Scrophulariaceae	Native	Perennial herb	Amphibious
Trachymene cyanopetala	purple trachymene, purple parsnip	Apiaceae	Native	Annual herb	Flood dependent
Typha domingensis	narrow-leaved Cumbungi	Typhaceae	Native	Perennial rush	Amphibious
*Verbena supina**	trailing verbena	Verbeneaceae	Exotic	Perennial herb	Flood dependent
Wahlenbergia fluminalis	river bluebell	Campanulaceae	Native	Perennial herb	Flood dependent
*Xanthium occidentale***	Noogoora burr, cockleburr	Asteraceae	Exotic, Proclaimed SA Pest Plant	Annual herb	Flood dependent

Appendix 3: Modelled maximum inundation extent of the Chowilla Floodplain under modelled natural flows in a) 2005-06, b) 2006-07, c) 2007-08, d) 2008-09, e) 2009-10, f) 2010-11, g) 2011-12, h) 2012-13, i) 2013-14, j) 2014-15, k) 2015-16, l) 2016-17, m) 2017-18, n) 2018-19, o) 2019-20 and p) 2020-21 water years (green dots represent floodplain sites (1–85) and blue dots temporary wetland sites (86–145).

a)



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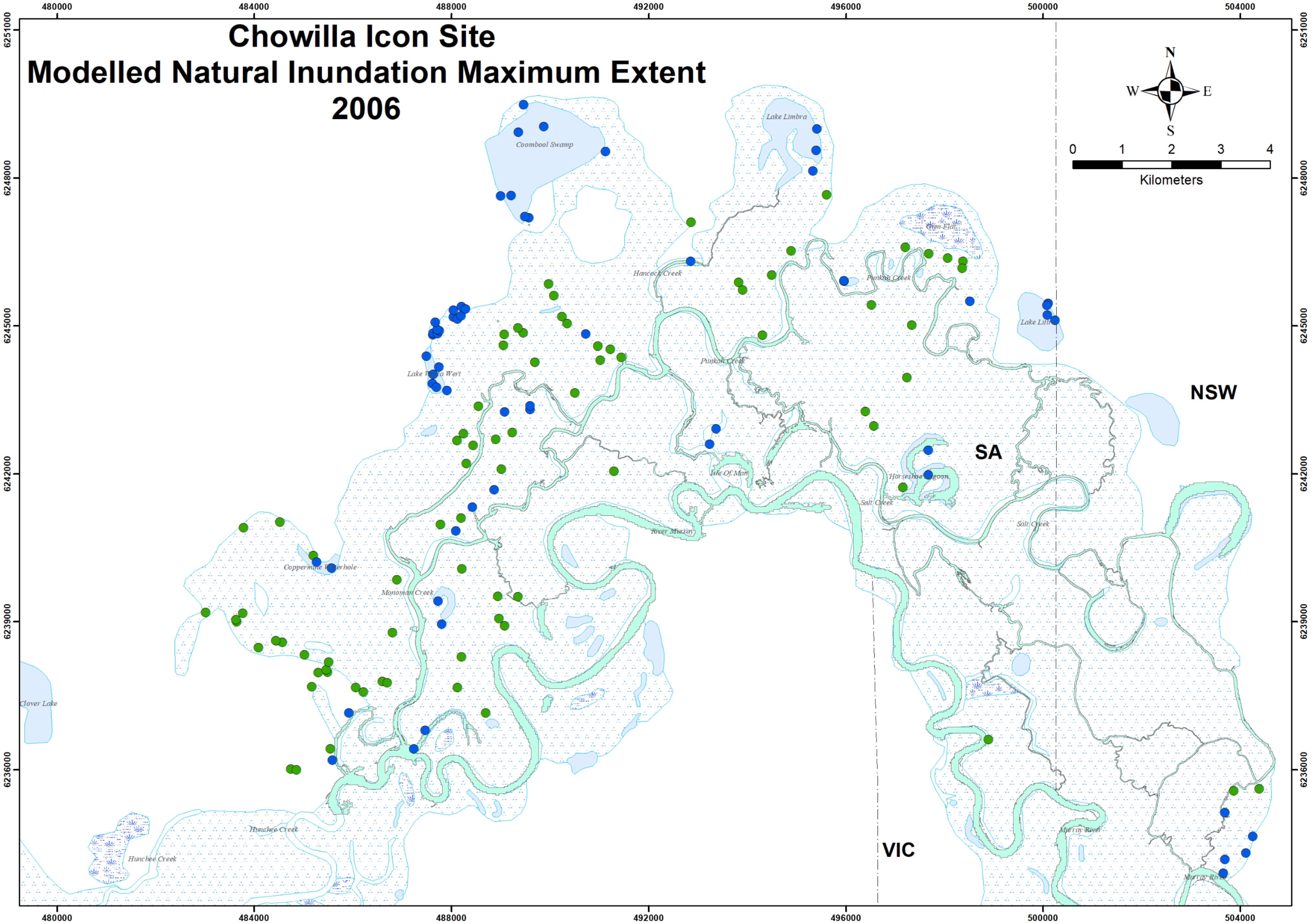
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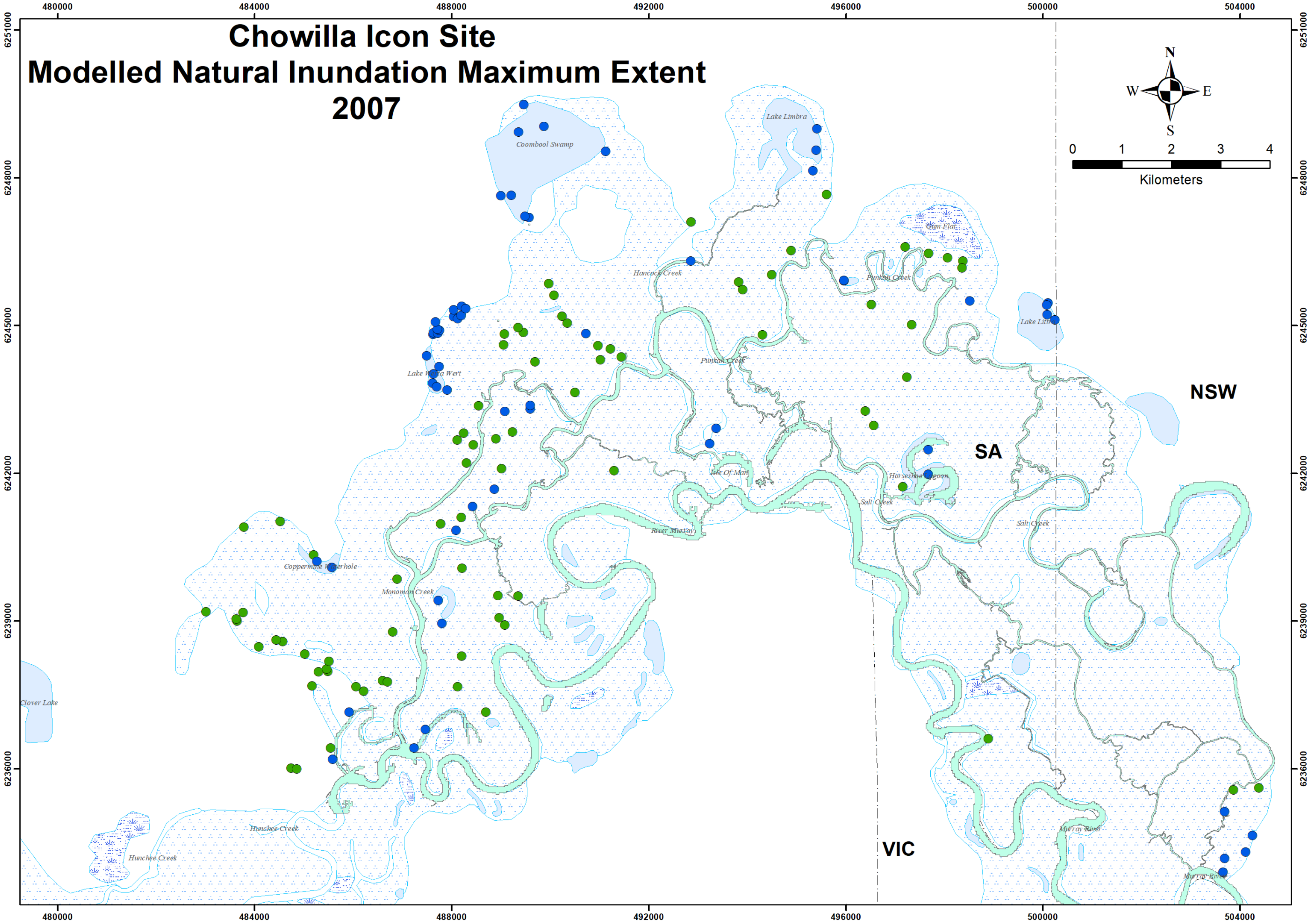
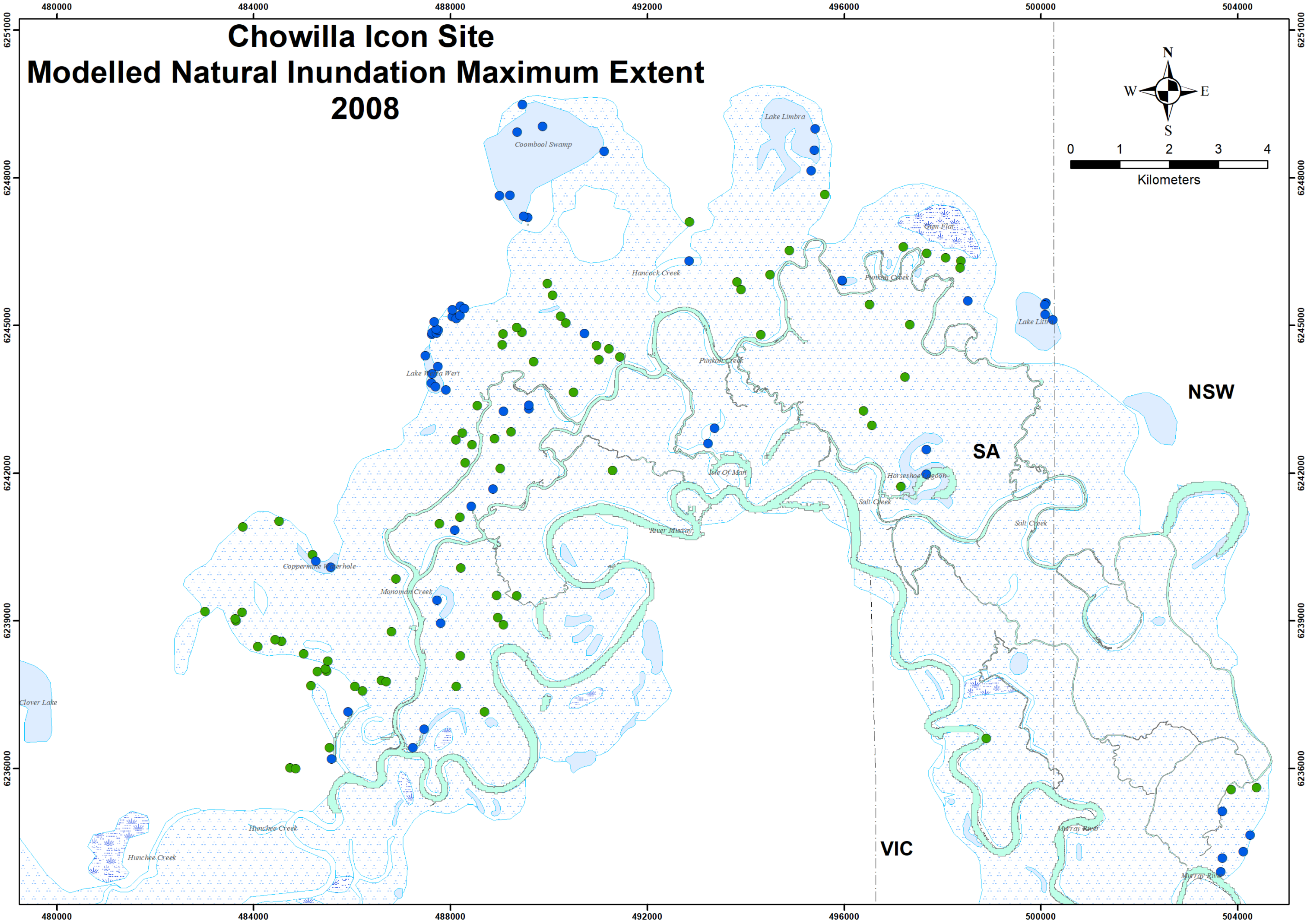
Modelled Natural Inundation Maximum Extent
2006
480000
484000
488000
492000
496000
500000
504000
6251000
6248000
6245000
6242000
6239000
6236000
N
W
E
S
0
1
2
3
4
Kilometers
Coombool Swamp
Lake Limbra
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
NSW
SA
VIC

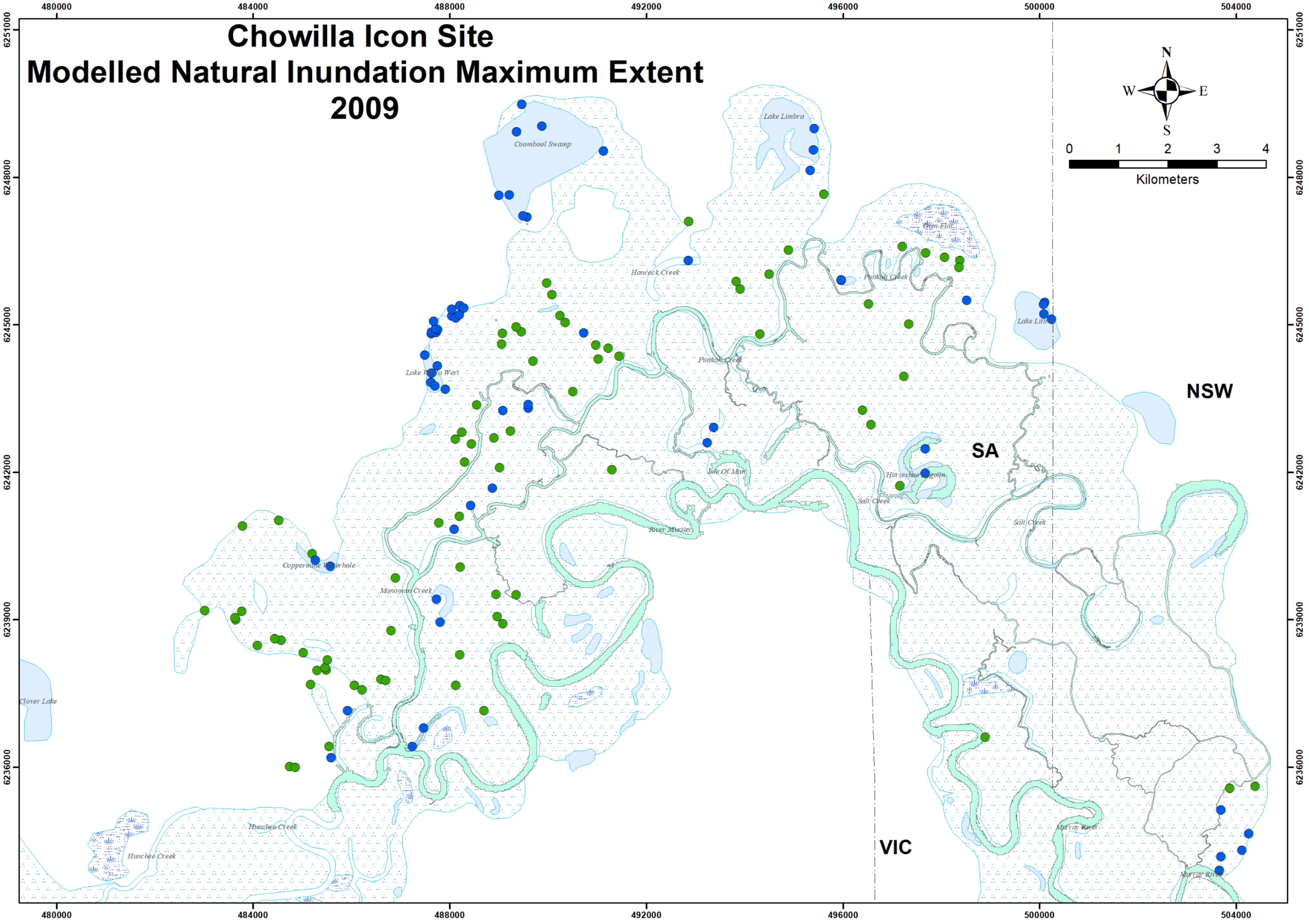
c)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2007
N
S
E
W
0 1 2 3 4
Kilometers
NSW
SA
VIC
Coombool Swamp
Lake Limbra
Hancock Creek
Punkah Creek
Lake Littra
Lake Limbra West
Coppermine Waterhole
Monoman Creek
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Clover Lake
Hunchee Creek
Murray River
480000
484000
488000
492000
496000
500000
504000
6251000
6248000
6245000
6242000
6239000
6236000

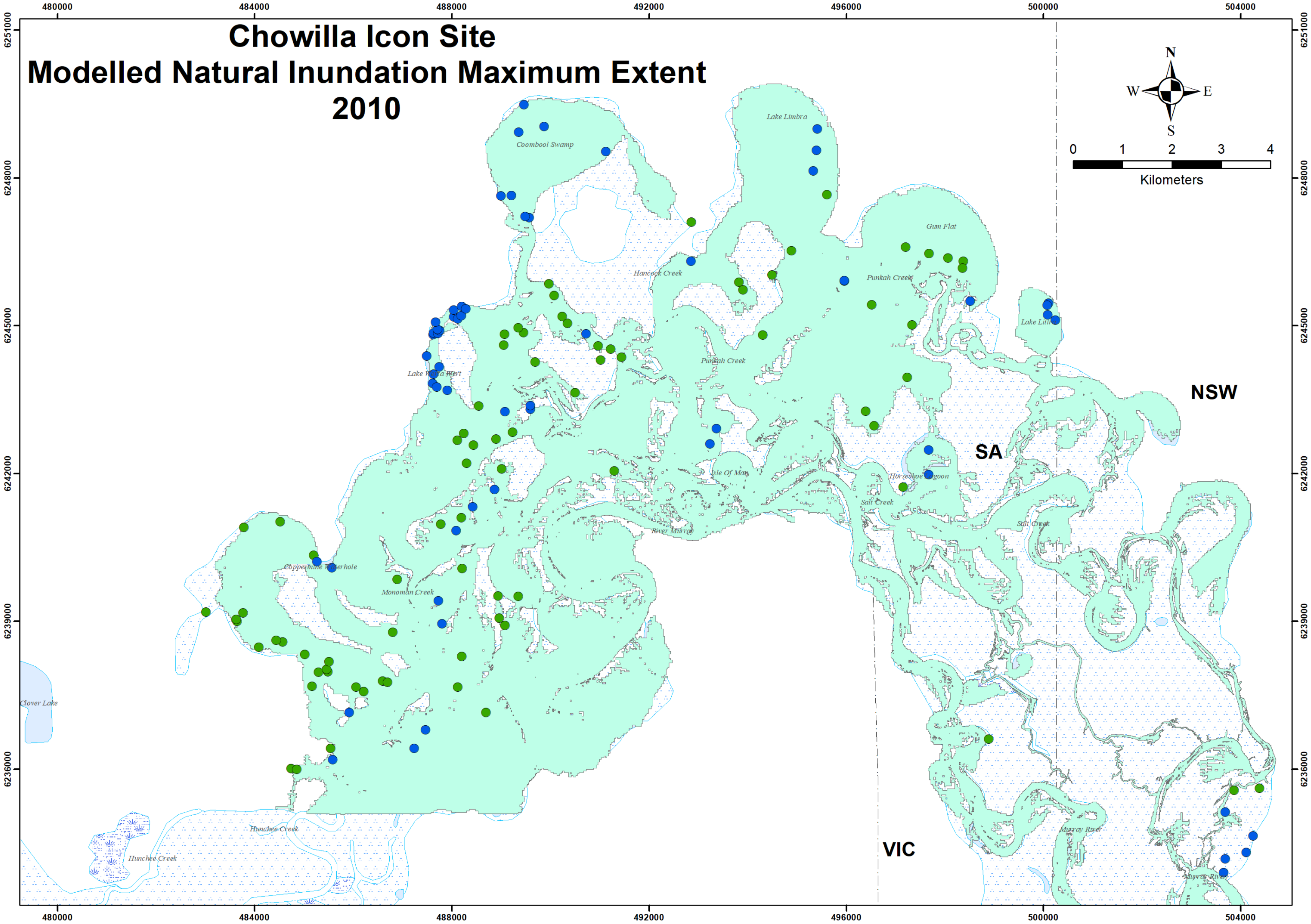
d)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2008
N
S
W
E
0 1 2 3 4
Kilometers
NSW
SA
VIC
Coombool Swamp
Lake Limbra
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool
Lake Waila Weit
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
480000
484000
488000
492000
496000
500000
504000
6251000
6248000
6245000
6242000
6239000
6236000

e)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2009
N
W
E
S
0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
480000
484000
488000
492000
496000
500000
504000
6251000
6248000
6245000
6242000
6239000
6236000

f)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2010
N
S
W
E
0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Gum Flat
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
480000
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488000
492000
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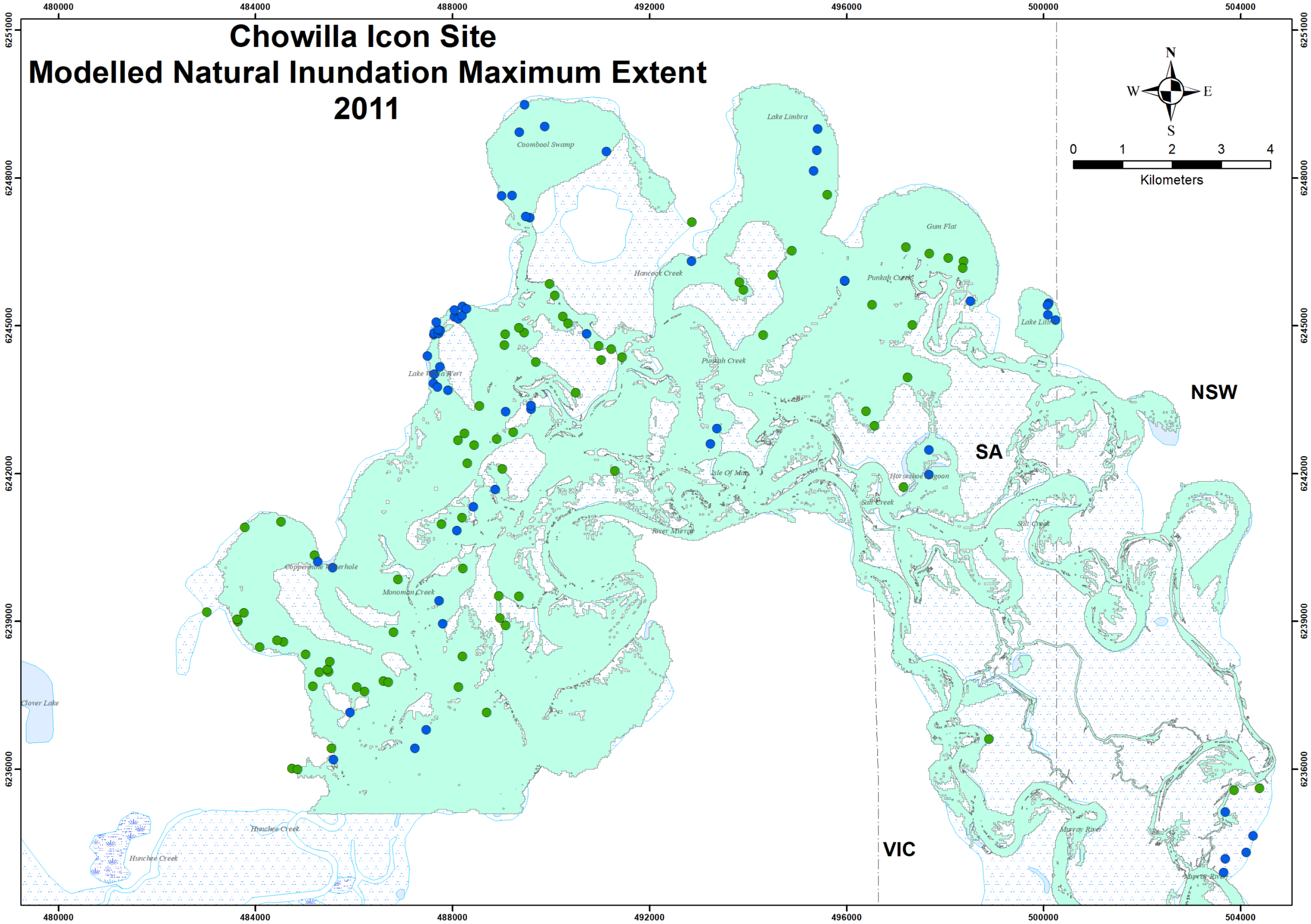
504000
6251000
6248000
6245000
6242000
6239000
6236000

g)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2011
N
S
W
E
0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Gum Flat
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool
Coppermine Waterhole
Monoman Creek
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Clover Lake
Hunchee Creek
Murray River
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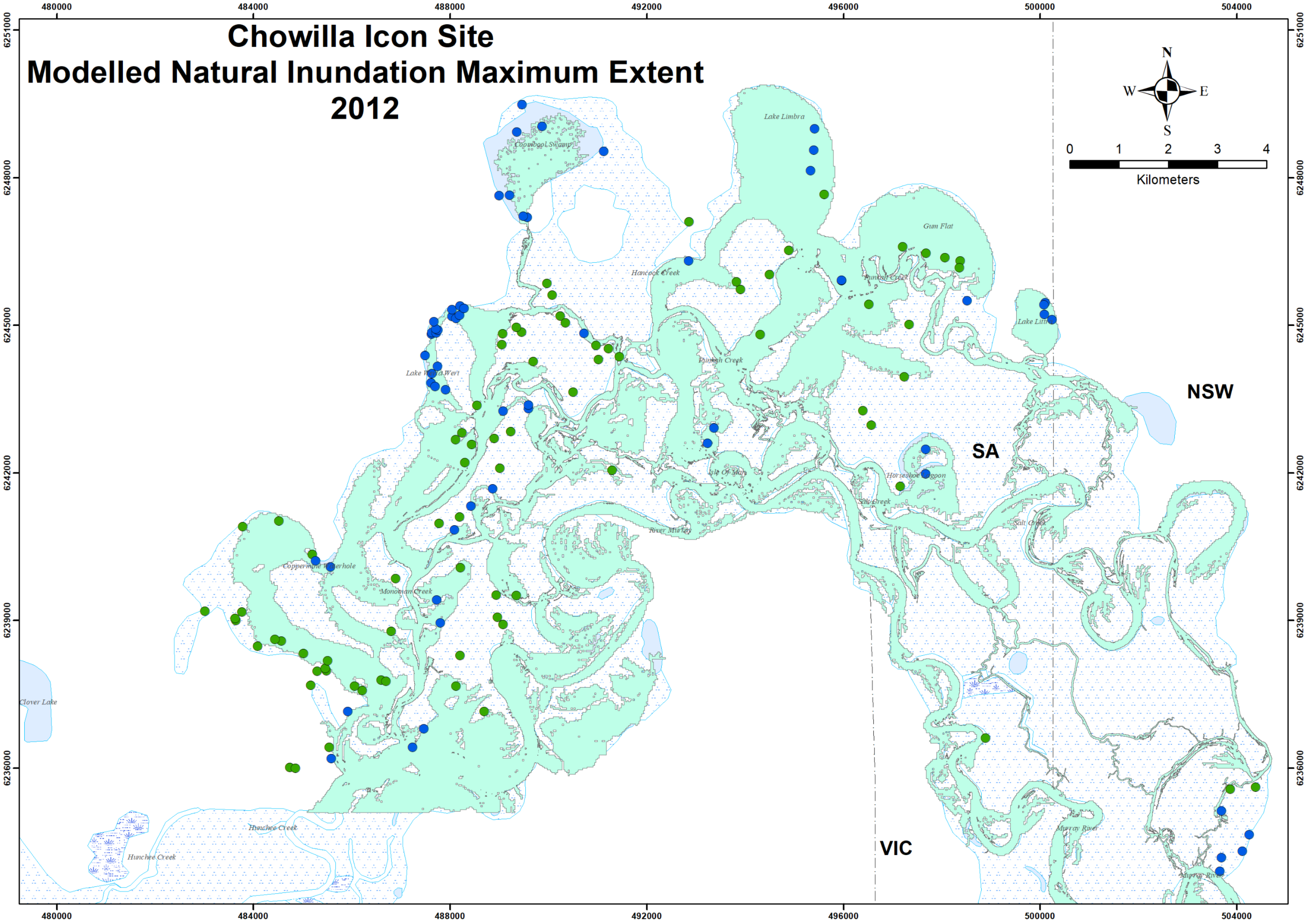
h)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2012
N
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E
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0 1 2 3 4
Kilometers
480000
484000
488000
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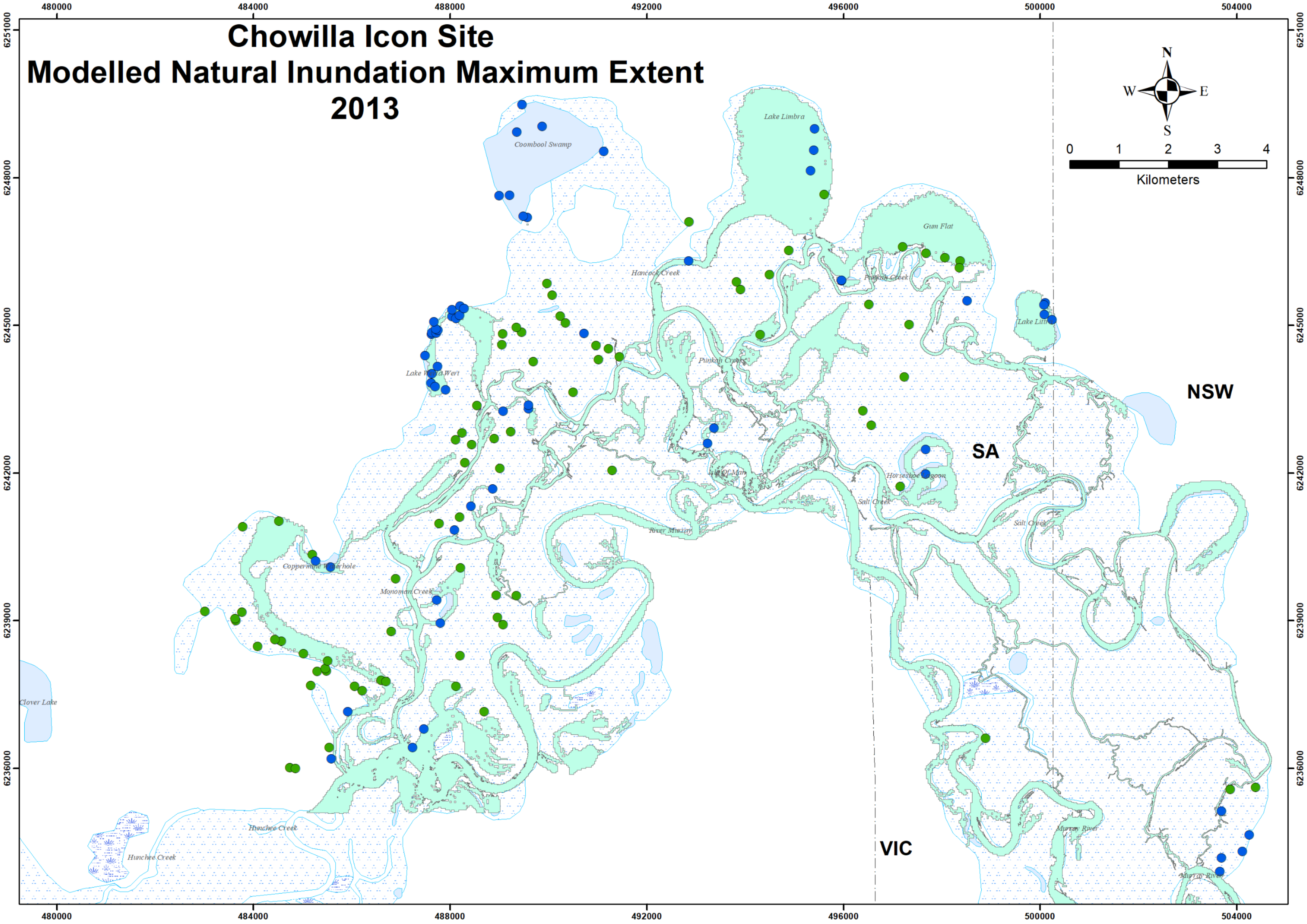
496000
500000
504000
6251000
6248000
6245000
6242000
6239000
6236000
Lake Limbra
Gum Flat
Hancock Creek
Punkah Creek
Pipeclay Creek
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
NSW
SA
VIC

i)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2013
N
S
W
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0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Gum Flat
Hancock Creek
Pipeclay Creek
Pipeclay Creek
Lake Littra
Lake Woolpolool Wert
Horseshoe Lagoon
Salt Creek
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Hunchee Creek
Murray River
Murray River
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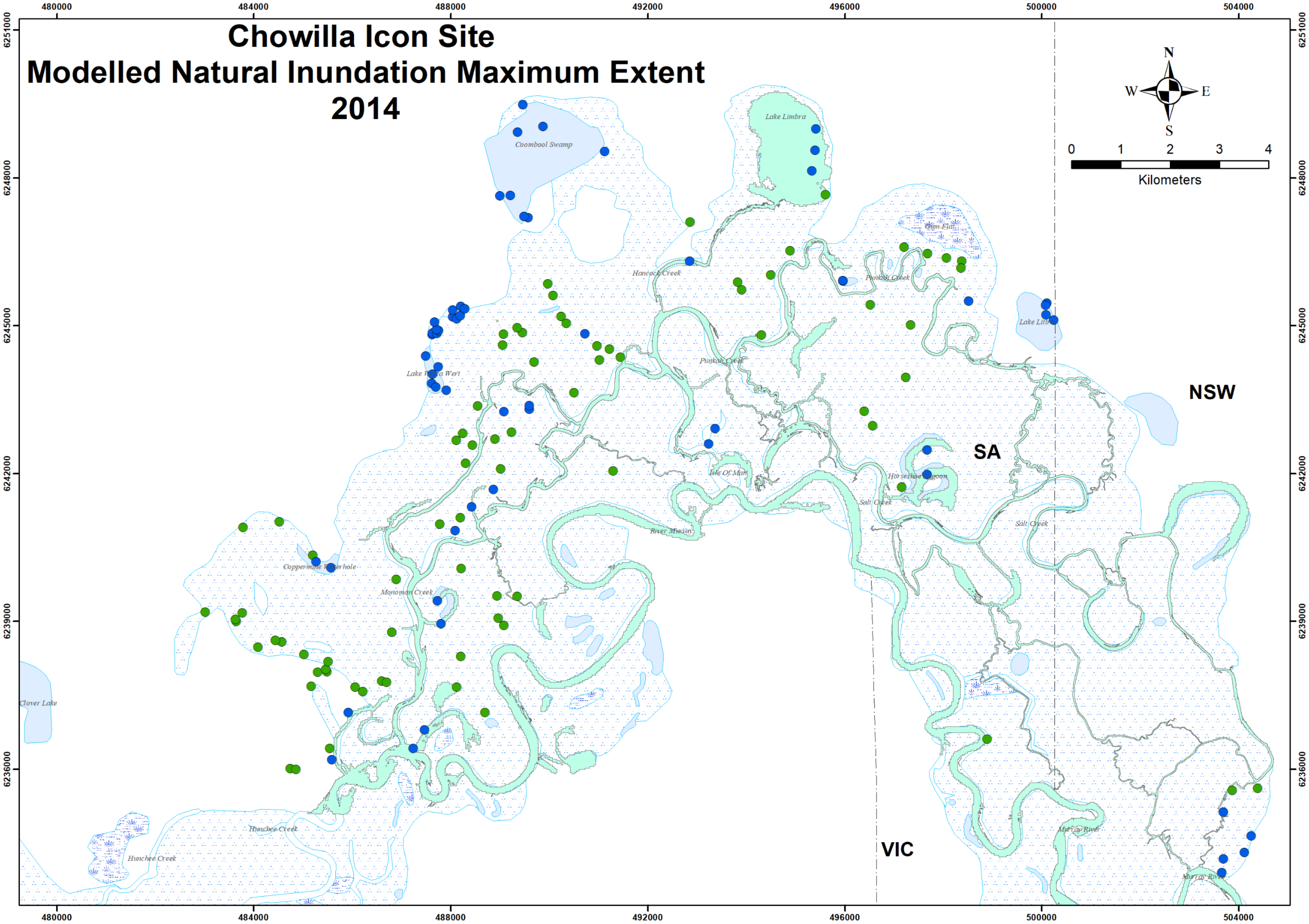
Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2014
N
W
E
S
0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
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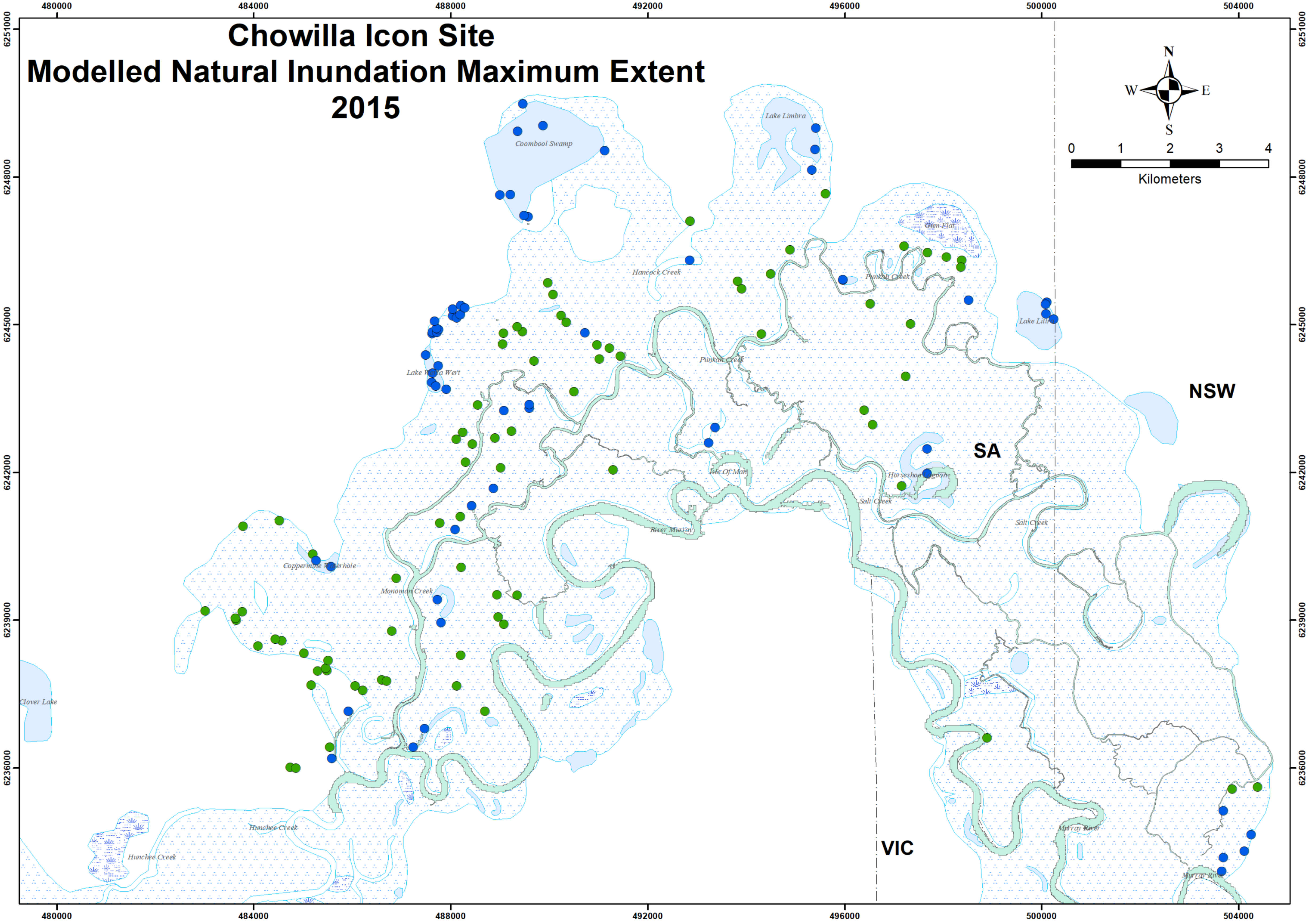
Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2015
N
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E
S
0 1 2 3 4
Kilometers
NSW
SA
VIC
Coombool Swamp
Lake Limbra
Hancock Creek
Pipeclay Creek
Punkah Creek
Lake Littra
Lake Woolpolool
Isle Of Man
Horseshoe Lagoons
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
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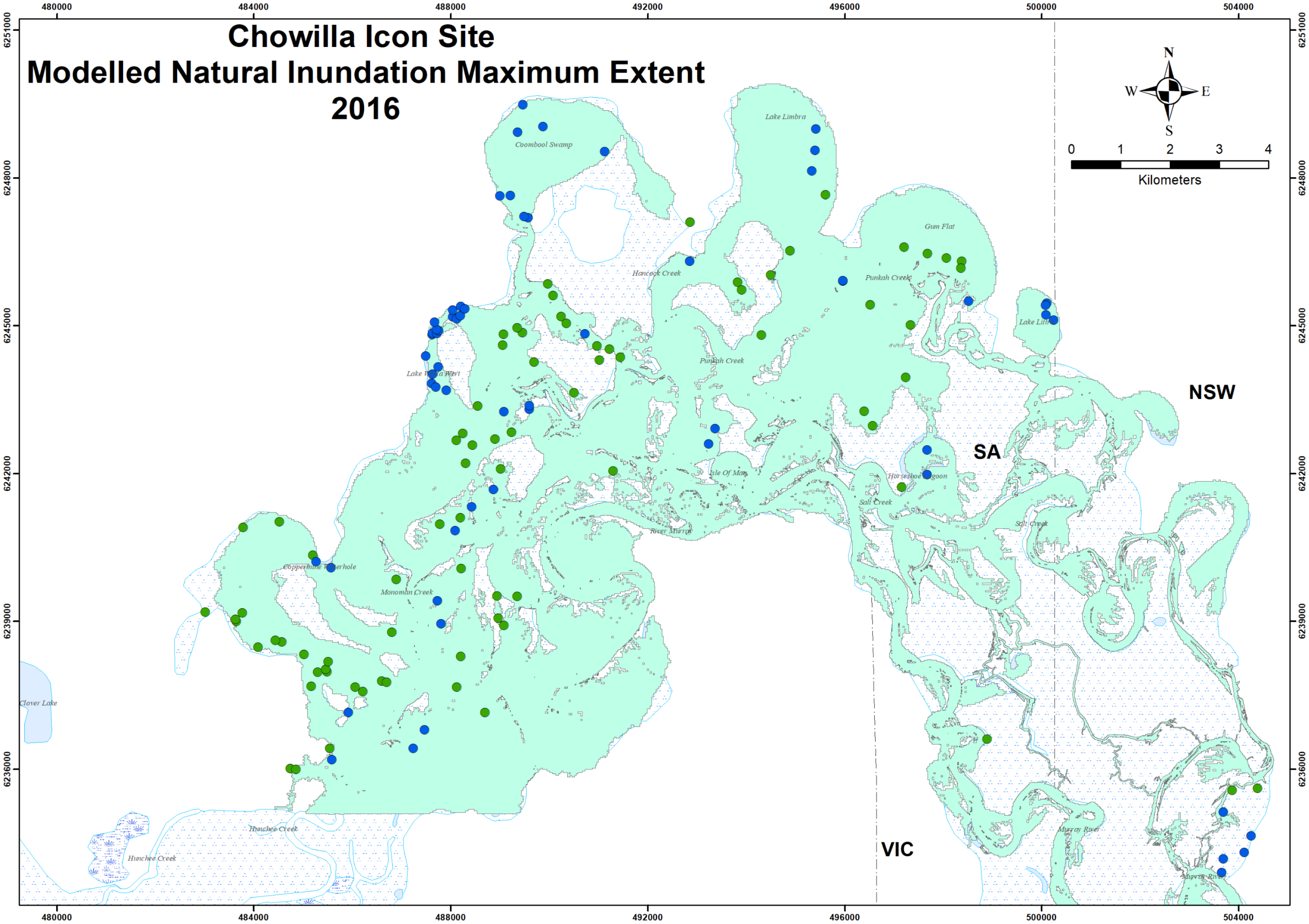
Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2016
N
S
W
E
0 1 2 3 4
Kilometers
NSW
SA
VIC
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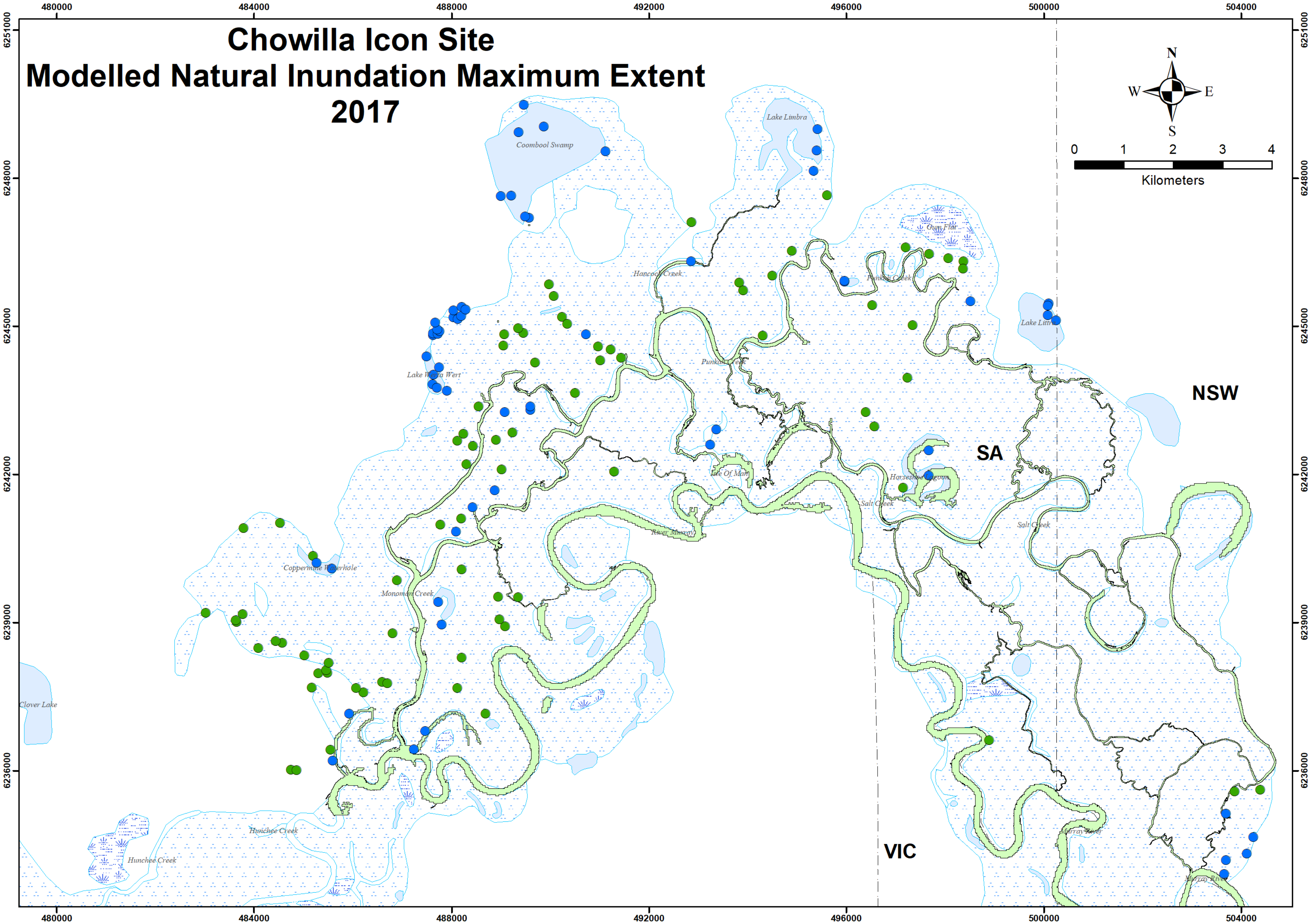
488000
492000
496000
500000
504000
6251000
6248000
6245000
6242000
6239000
6236000
Coombool Swamp
Lake Limbra
Gum Flat
Hancock Creek
Punkah Creek
Lake Littra
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Monoman Creek
Clover Lake
Hunchee Creek
Murray River

m)


Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2017
N
W
E
S
0
1
2
3
4
Kilometers
NSW
SA
VIC
Coombool Swamp
Lake Limbra
Lake Littra
Hancock Creek
Punkah Creek
Lake Woolpolool Wert
Coppermine Waterhole
Monoman Creek
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Clover Lake
Hunchee Creek
Murray River
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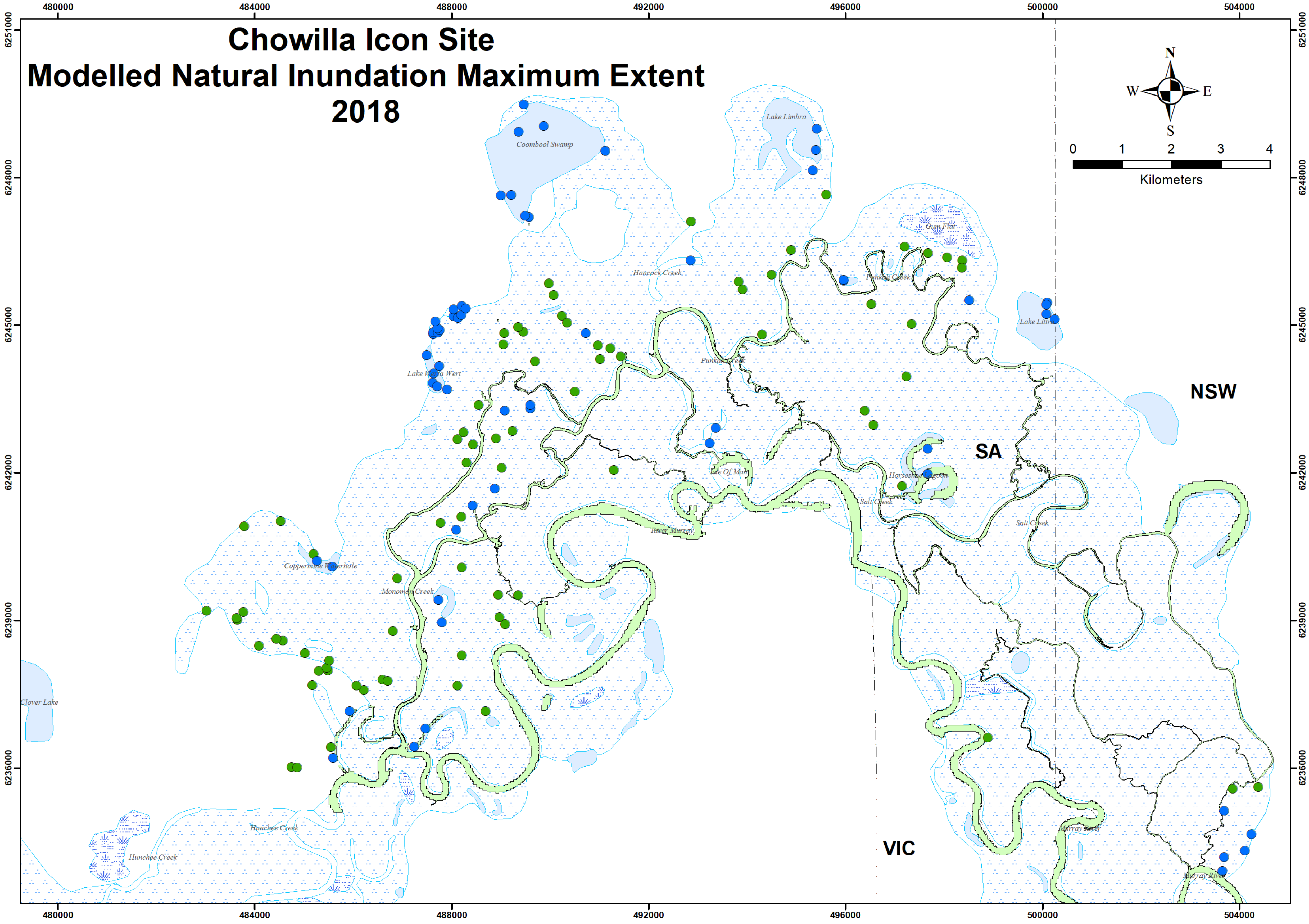

Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2018
N
S
W
E
0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Hancock Creek
Lake Littra
Punkah Creek
Lake Woolpolool Wert
Coppermine Waterhole
Monoman Creek
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Clover Lake
Hunchee Creek
Murray River
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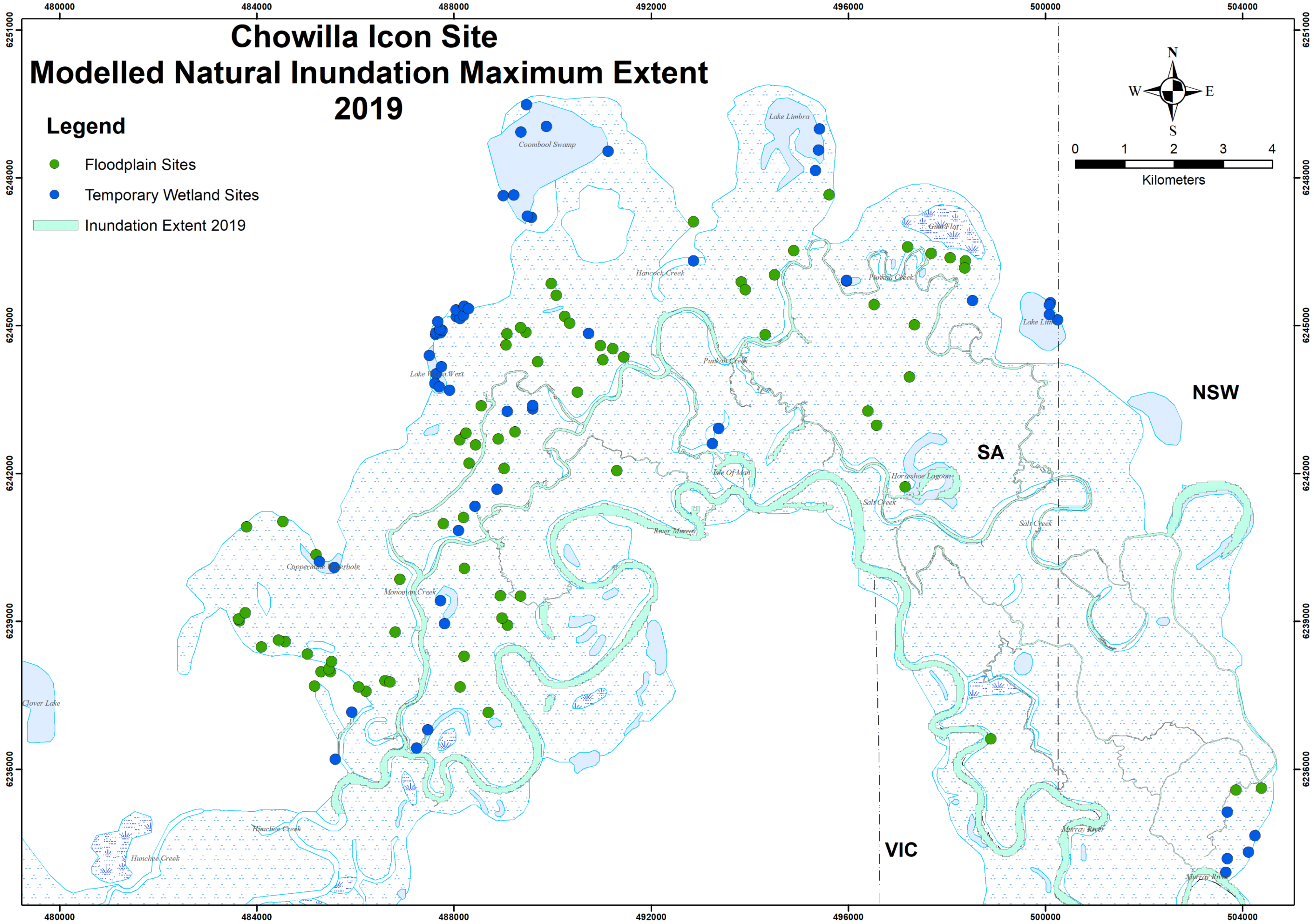

Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2019
Legend
Floodplain Sites
Temporary Wetland Sites
Inundation Extent 2019
N
S
W
E
0 1 2 3 4
Kilometers
NSW
SA
VIC
Lake Limbra
Coombool Swamp
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
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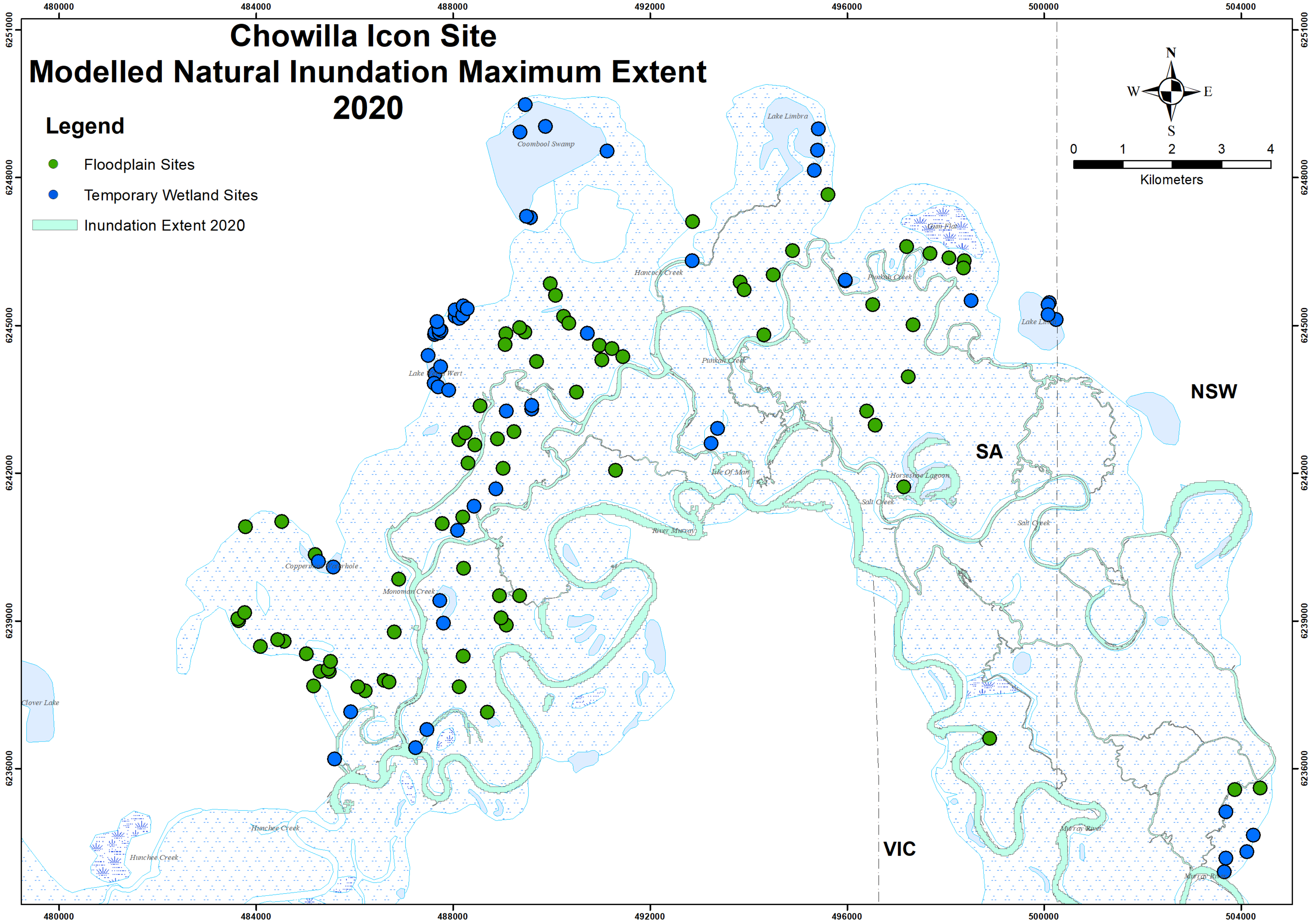
Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2020
Legend
Floodplain Sites
Temporary Wetland Sites
Inundation Extent 2020
N
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Kilometers
NSW
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