Inland Waters & Catchment Ecology

Chowilla Icon Site – Floodplain Vegetation Monitoring 2019 Interim Report

Jason Nicol, Kate Frahn, Josh Fredberg, Susan Gehrig, Kelly Marsland and James Weedon

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

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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 and water abstraction, rising saline ground water and grazing by domestic stock. It was designated as one of The Living Murray (TLM) initiative's icon sites 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,
- 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 to be the subject of monitoring programs and aid assessment of the aforementioned objectives in temporary wetland and floodplain habitats at Chowilla. Five targets relate to 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:

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.
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 and the South Australian proclaimed pest plant *Xanthium occidentale* across the floodplain and in temporary wetlands:

1. In temporary wetlands, a maximum of 1% of cells containing *Xanthium strumarium* 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.
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 (2006–2019), variable flow in the MDB and site specific management interventions within Chowilla, have resulted in spatio-temporally variable patterns of inundation. When monitoring sites were established in 2006 the MDB was in extended drought and overbank flows had not inundated large areas of floodplain since 1996. Low flows characterised 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). An extensive and prolonged overbank flow, and subsequent floodplain inundation, occurred from spring 2010 to autumn 2011 and another shorter, but higher overbank flood occurred in late spring 2016. Several in-channel flow pulses were also experienced from 2011 to 2019. The Chowilla Environmental Regulator was also operated four times over this period, namely: spring 2014 (inundation height = 2.75 m above normal pool height, inundation area = 2,142 ha); spring 2015 (inundation height = 1.5 m above normal pool height, inundation area = 535); winter-spring 2016 (inundation height = 3.4 m above normal pool height, inundation area 7,653 ha); and spring 2018 (inundation height = 2.24 m above normal pool height, inundation area 2,250 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 2018, an additional 58 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 in 2018 and 2019 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 2018 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.

Empirical data collected between 2006 and 2017 showed that 75% of cells inundated in the previous 12 months contained native flood dependent or amphibious taxa. This relationship was used to calculate the potential number of cells containing these for each survey under modelled natural flows. Two predictors of potential species richness under modelled natural flow were identified; the number of quadrat cells containing amphibious or flood dependent species, and the number of sites inundated in the previous 12 months. Positive linear relationships best described associations between flood dependent and amphibious species richness, and the number of cells containing the aforementioned species (Predicted species richness = 0.0188 x no. cells containing native flood dependent or amphibious species: R^2=0.73) (Figure 4). In contrast, an exponential rise to maximum relationship best described the association between flood dependent and amphibious species richness, and the number of sites inundated in the previous 12 months (Predicted species richness = 36.3323 x (1-exp(-0.0667 x no. sites inundated in the previous 12 months: R^2=0.84).

The 14th annual floodplain vegetation condition monitoring survey was undertaken in February 2019. A total of 36 species, from 17 families (predominantly from the Chenopodiaceae and Asteraceae) were recorded from the floodplain sites (established in 2006). With the inclusion of the temporary wetland sites surveyed in 2019, species richness across the Chowilla Floodplain increased to 54 species from 21 families (also predominantly from the Chenopodiaceae and Asteraceae).

The five most frequently encountered taxa were bare soil, *Sporobolus mitchellii*, *Sclerolaena stelligera, Disphyma crassifolium* and *Atriplex* spp*.*; accounting for 48% of observations. Of the 8,719 observations, approximately 16% were found to be devoid of vegetation.

At a similarity of 30%, cluster analysis identified seven distinct groups of the 126 sites surveyed in 2019 and Indicator Species Analysis produced a list of significant representative taxa for each group. Plant community based on groupings identified from cluster analysis listed below:

1. “Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.” sites were predominantly characterised by the terrestrial taxa *Atriplex* spp*., Disphyma crassifolium, Sclerolaena brachyptera, Sclerolaena stelligera* and *Maireana* spp. (23.2% of sites),
2. “Sclerolaena divaricata/ Sporobolus” were dominated the terrestrial species *Sclerolaena divaricata* and flood dependent *Sporobolus mitchellii* (16.0%),
3. “Bare soil” were predominantly characterised by empty cells (31.2%),
4. “Flood responders 1” were dominated by the flood dependent species *Ammania multiflora, Centipeda minima, Glinus lotoides,* and the exotic *Heliotrpoium europaeaum* (12.8%),
5. “Flood responders 2” were dominated by the flood dependent species *Brachyscome basaltica, Glycyrrhiza acanthocarpa, Stemodia florulenta* and *Wahlenbergia fluminalis* (6.4%),
6. “Tecticornia pergranulata” sites were dominated by the samphire *Tecticornia pergranulata* (3.2%).
7. “Open water” sites were inundated and devoid of vegetation (7.2%)

Indications of grazing intensity inferred through scat counts was variable with the floodplain sites more heavily grazed than temporary wetlands; however, Coombool Swamp, Chowilla Island Loop and Lake Littra were grazing hot spots. Grazing intensity varied among in the different communities identified by cluster analysis with ‘Atriplex spp./Disphyma/ Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.’, ‘Sclerolaena divaricata/ Sporobolus’ and Flood responder 2 communities having the highest scat frequencies and the ‘Tecticornia pergranulata’ and Flood responders 1 communities the lowest.

At floodplain sites in 2019, there was an increase in species richness compared to 2018 due to an increase in flood dependent and terrestrial species, but there was also an increase in bare soil. Despite the increase in flood dependent taxa data indicates that the plant community on the floodplain is transitioning towards a community similar to the one observed during the drought in the absence of watering. In contrast, species richness decreased at the temporary wetland sites due to the lack of recent watering at most sites and an increase in bare soil.

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 13 years (Table 1). More than 65% of cells in sites 1 to 85 and more than 80% of cells at sites 86 to 143 contained amphibious or flood dependent taxa (or were inundated) in 2017, but because native flood dependent and amphibious species richness was below 40 for both habitats the target was not fully achieved.

Table 1: Success of attaining floodplain and temporary wetland native vegetation targets between 2006 and 2019.

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 targets for *Xanthium occidentale* on the floodplain and in temporary wetlands were 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 (Table 2).

Table 2: Success of attaining floodplain and temporary wetland exotic species and *Xanthium occidentale* targets between 2006 and 2019.

	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

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, and 2014-15, 2015-16 and 2018-19 when the regulator was operated. Under modelled natural conditions between 2006 and 2019, 20% or more of quadrat cells were predicted to contain amphibious or flood dependent species on five occasions with the maximum interval four years. This occurred on six occasions under current conditions. Amphibious or flood dependent species were present in 40% of cells three times between 2006 and 2019 with a maximum interval of five years under both natural and current conditions. However, on each of these occasions under natural conditions over 65% of cells were predicted to have flood dependent or amphibious species present.

Predicted species richness under modelled natural flows varied depending on whether the number of cells containing floodplain or amphibious species or the number of sites inundated in the previous 12 months was used as the predictor. More than 15 native flood dependent and amphibious species were recorded on eight occasions between 2006 and 2019, but on four occasions this was due to watering interventions. When the number of quadrat cells containing flood dependent or amphibious species was used as the predictor more than 15 species were predicted on five occasions and when the number of sites inundated in the previous 12 months was used more than 15 species was predicted on six occasions. However, when the number of quadrat cells containing floodplain or amphibious species was used as the predictor, the flood dependent and amphibious species richness was predicted to be greater than 40 in 2011, 2012 and 2017. In contrast, the predicted flood dependent and amphibious species richness did not exceed 40 when the number of cells inundated in the previous 12 months was used.

Under modelled natural conditions based on the predicted occurrence of flood dependent or amphibious 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 under natural conditions. When 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. However, both functions used to predict amphibious and flood dependent species richness under natural conditions need to be viewed with caution and require further investigation.

The predictions of occurrence of flood dependent and amphibious species and species richness under natural conditions showed that that the targets (despite being developed largely using expert opinion) are realistic benchmarks for vegetation condition.

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 undeveloped area of 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 and Sheldon 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",

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 take into consideration 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.
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 South Australian proclaimed pest plant *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.
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 2019 builds upon data collected from 2006–2018 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, two large unregulated flow events, several smaller flow pulses and operation of the Chowilla Environmental Regulator on four occasions, at four different heights and durations. Therefore, this monitoring program has collected information regarding the change in floodplain understorey vegetation in response to different inundation histories, such as 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 2019 survey; quantitative and qualitative comparisons of the changes in floristic composition between 2006 and 2019; 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 2011) (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 2011) (Figure 1). Inflows from June until the end of November 2010 were the highest since 2000, but not unusual historically. Inflows during summer 2010-11; however, were the highest on record for the southern basin (~6,700 GL); more than double the previous highest record of ~2,980 GL in the summer of 1992-93 (Murray-Darling Basin Authority 2011).

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), with the delineation between floodplain and highland based upon the extent of the 1956 flood (Overton and Doody 2010). Large flows with maximums of ~100,000 ML/day 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). Hence, for the first time in more than ten years, flows not only watered red gum (*Eucalyptus camaldulensis*) woodland and wetland areas, but also reached higher elevation black box (*Eucalyptus largiflorens*) woodlands (Murray-Darling Basin Authority 2011).

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. Another two flow pulses 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 and 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.

For most of 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). The resultant water level rise 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 and early 2019 (Figure 1).

The Chowilla Environmental Regulator was operated for the first time in spring 2014. Water levels were raised to 19.1 m AHD upstream of the regulator by 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. These 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 levels by December 2014.

The Chowilla Regulator was operated for a second time in spring 2015 to a low level to generate a within channel increase in water levels. Water levels were gradually raised to 17.85 m AHD upstream of the regulator in November 2015, increasing water levels 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 (including 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 inundation of approximately 7,650 ha of floodplain and temporary wetlands at the peak in late-September 2016. Regulator operation inundated a total of 90 monitoring sites (35 floodplain and 55 temporary wetland), with 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).

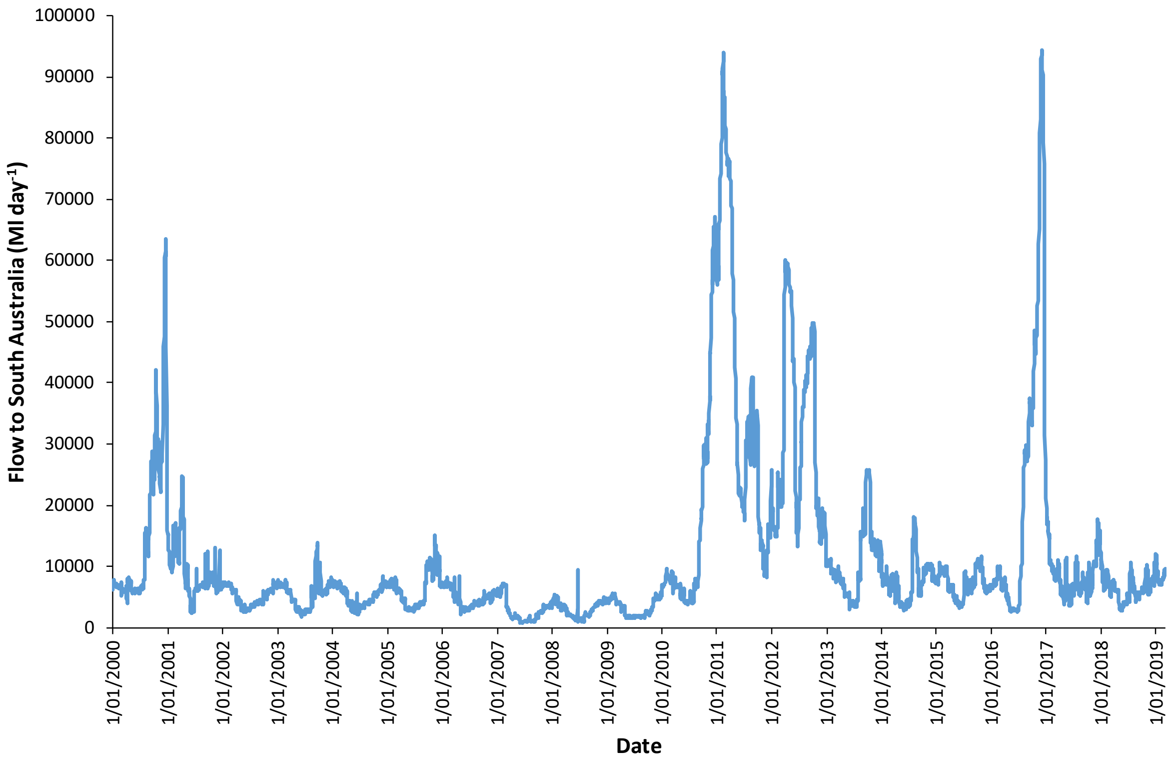

Figure 1: River Murray flow to South Australia from January 2000 to March 2019 (DEW 2019b).

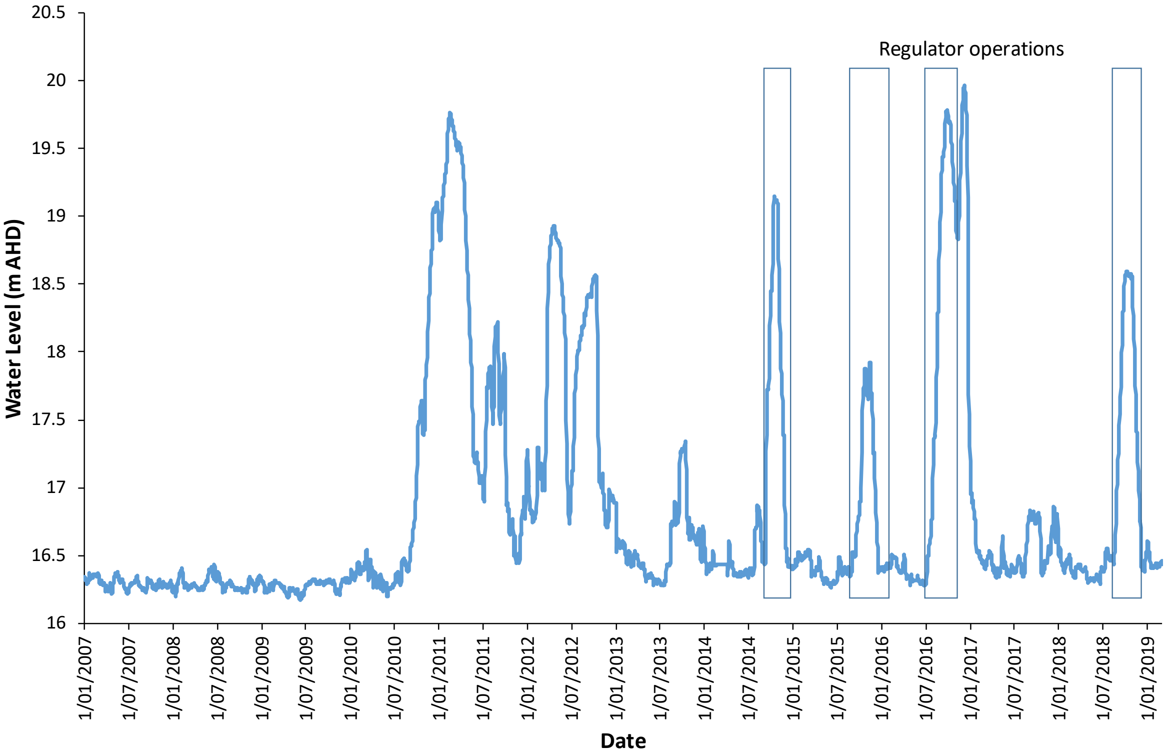

Figure 2: Water level in Chowilla Creek upstream of the Chowilla Environmental Regulator from January 2007 to March 2019 (DEW 2019a).

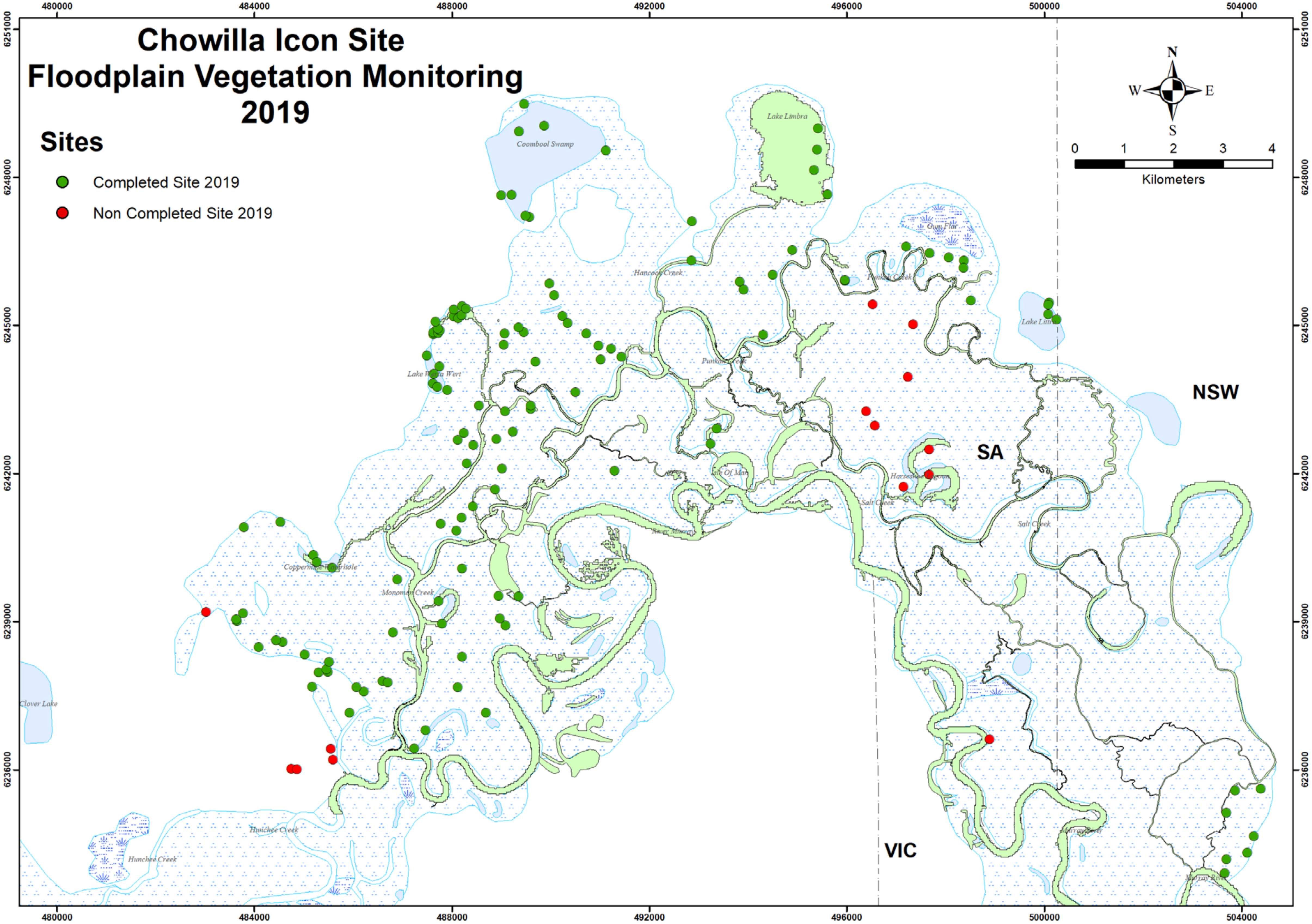

Figure 3: Map of the Chowilla Floodplain showing condition monitoring sites (green dots indicate sites surveyed in 2019 and red dots indicate sites not surveyed in 2019) and inundation extent of regulator operation in spring 2018.

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.

In February 2006, a series of sites were established in 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 and 2019. 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 and 2019 sites on Punkah Island were inaccessible due to high water levels in Punkah Creek or damage to the ford and in 2011 a total of 16 sites (including the sites on Punkah Island) were inaccessible due to high river levels. In 2013, a total of 5 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, a total of 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, a total of 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 not surveyed. In 2019 a total of 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 (see further details in Appendix 1)

In 2013, 34 additional sites were included in the network to gain a better understanding of temporary wetland (as well as floodplain) condition at Chowilla. These included sites within temporary wetlands such as Lake Littra, Werta Wert Wetland, Hancock Creek, Kulcurna (flood runners), Lake Limbra, Coombool Swamp, Punkah Depression, Punkah Flood Runner, Monoman Depression, Chowilla Oxbow and Pipeclay Billabong (Figure 3, Appendix 1). In 2014, another seven temporary wetland sites were added, in Twin Creeks, Monoman Island

Horseshoe and Coppermine Waterhole (in 2013 these sites had been either wet or inaccessible) (Appendix 1). An additional three sites were added in 2015 in Brandy Bottle Lagoon and Chowilla Island Loop (having been inaccessible or inundated prior to 2014) (Appendix 1). Another 14 sites were added in 2016 in the central and southern basins of Werta Wert Wetland and Woolshed Creek, which had been previously inundated (Appendix 1). The second site in Pipeclay Billabong was not inundated in 2018 and has now been surveyed. A total of 59 temporary wetland sites have now been included in the network since 2013; however, they may not all be surveyed each year depending on accessibility and inundation (Appendix 1). The only sites from the intervention monitoring program (Nicol *et al.* 2010b; Nicol 2012) 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).

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. In 2018 and 2019, 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 identified but included the native animals: emu (*Dromaius novaehollandiae*), kangaroos (western grey; *Macropus fuliginosus* and red; *Macropus rufus*) and euros (*Macropus robustus*) and feral and domestic species: 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 (2019). 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 2019 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). Finally, the locations of the quadrats were 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 and the different plant communities as identified by the cluster analysis were 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 α = 0.05/*n* comparisons).

Changes in floristic composition of floodplain sites (sites 1 to 85) from 2006 to 2019 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 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 one to 85). The maximum flow across the South Australian border for each year between 2005 and 2018 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 containing flood dependent or amphibious species for each survey under modelled natural flows.

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. However, these data 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).

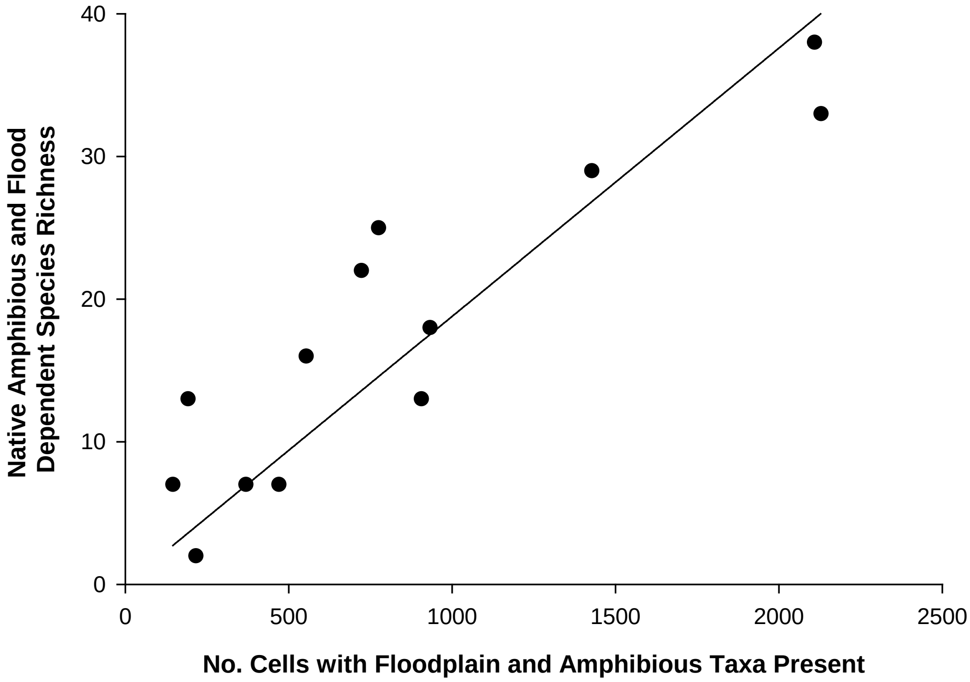

Figure 4: Relationship between the number of cells containing flood dependent and amphibious species and species richness for floodplain sites (1 to 85) from 2006 to 2017 condition monitoring data.

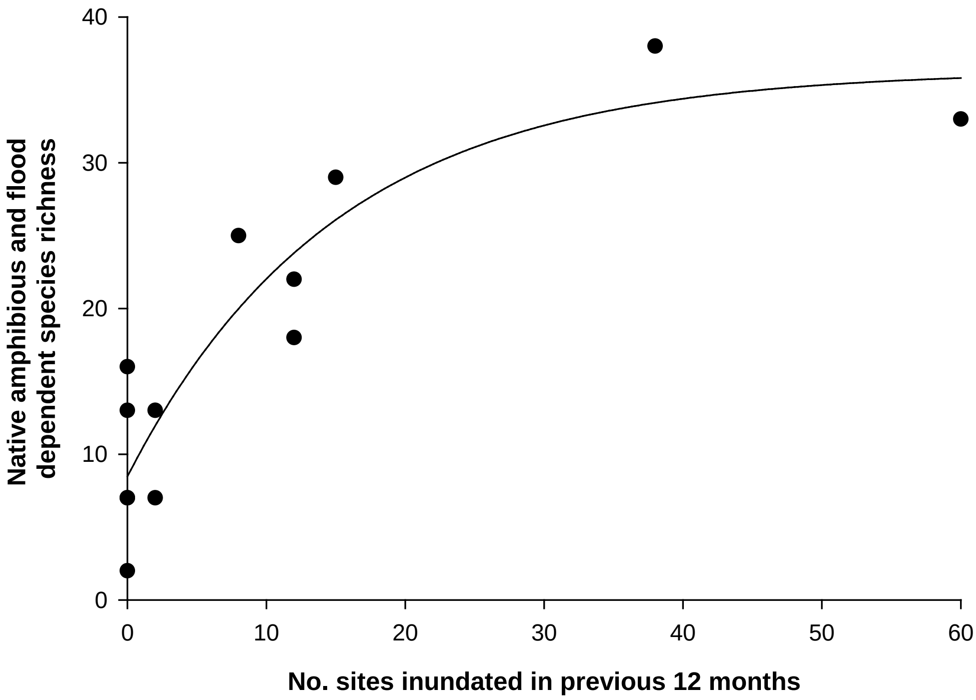

Figure 5: Relationship between the number of sites inundated in the previous 12 months and species richness for floodplain sites (1 to 85) from 2006 to 2017 condition monitoring data.

RESULTS

3.1. 2019 snapshot of plant communities

In 2019, 36 species from 17 families (predominantly from the Chenopodiaceae and Asteraceae) were recorded from floodplain sites (established in 2006). With the inclusion of the temporary wetland sites surveyed in 2019, species richness across the Chowilla Floodplain increased to 54 species from 21 families (also predominantly from the Chenopodiaceae and Asteraceae).

The five most frequently encountered taxa were bare soil, *Sporobolus mitchellii*, *Sclerolaena stelligera, Disphyma crassifolium* and *Atriplex* spp.; accounting for 48% of observations. Of the 8,719 observations, approximately 16% were found to be devoid of vegetation.

At a similarity of 30%, cluster analysis identified seven distinct groups (Figure 6) of the 126 sites surveyed across the Chowilla Floodplain in 2019 and Indicator Species Analysis (Table 3) produced a list of significant representative taxa for each group. Figure 7 shows the spatial distribution and plant community based on groupings identified from cluster analysis listed below:

8. "Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp." sites were predominantly characterised by the terrestrial taxa *Atriplex* spp*., Disphyma crassifolium, Sclerolaena brachyptera, Sclerolaena stelligera* and *Maireana* spp. (23.2% of sites),
9. "Sclerolaena divaricata/ Sporobolus" were dominated the terrestrial species *Sclerolaena divaricata* and flood dependent *Sporobolus mitchellii* (16.0%),
10. "Bare soil" were predominantly characterised by empty cells (31.2%),
11. "Flood responders 1" were dominated by the flood dependent species *Ammania multiflora, Centipeda minima, Glinus lotoides,* and the exotic *Heliotropium europaeaum* (12.8%),
12. "Flood responders 2" were dominated by the flood dependent species *Brachyscome basaltica, Glycyrrhiza acanthocarpa, Stemodia florulenta* and *Wahlenbergia fluminalis* (6.4%),
13. "Tecticornia pergranulata" sites were dominated by the samphire *Tecticornia pergranulata* (3.2%).
14. "Open water" sites were inundated and devoid of vegetation (7.2%)

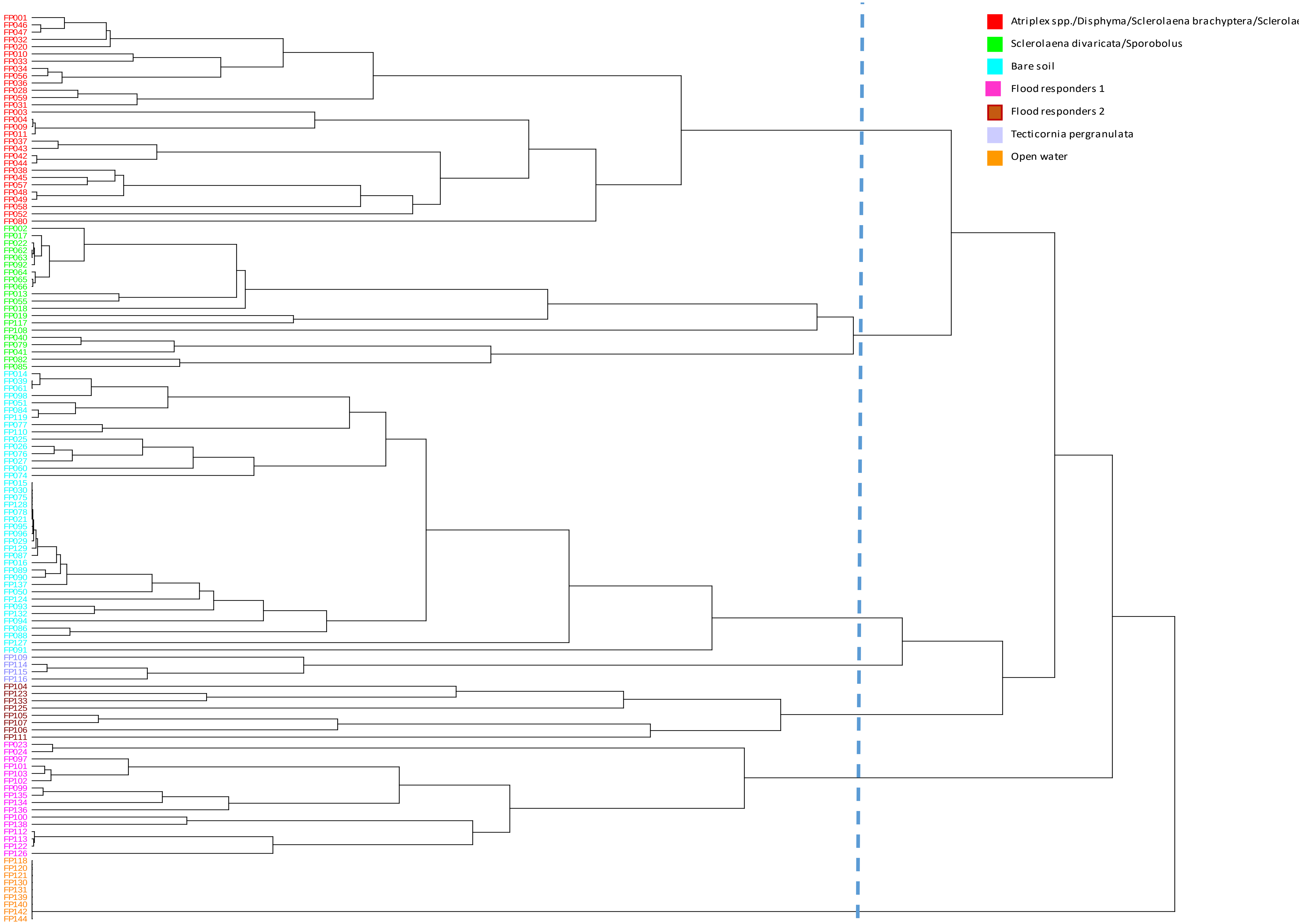

Figure 6: Dendrogram showing group average clustering of vegetation survey sites from the 2019 survey. Dashed line shows division of sites into vegetation groups at 30% similarity.

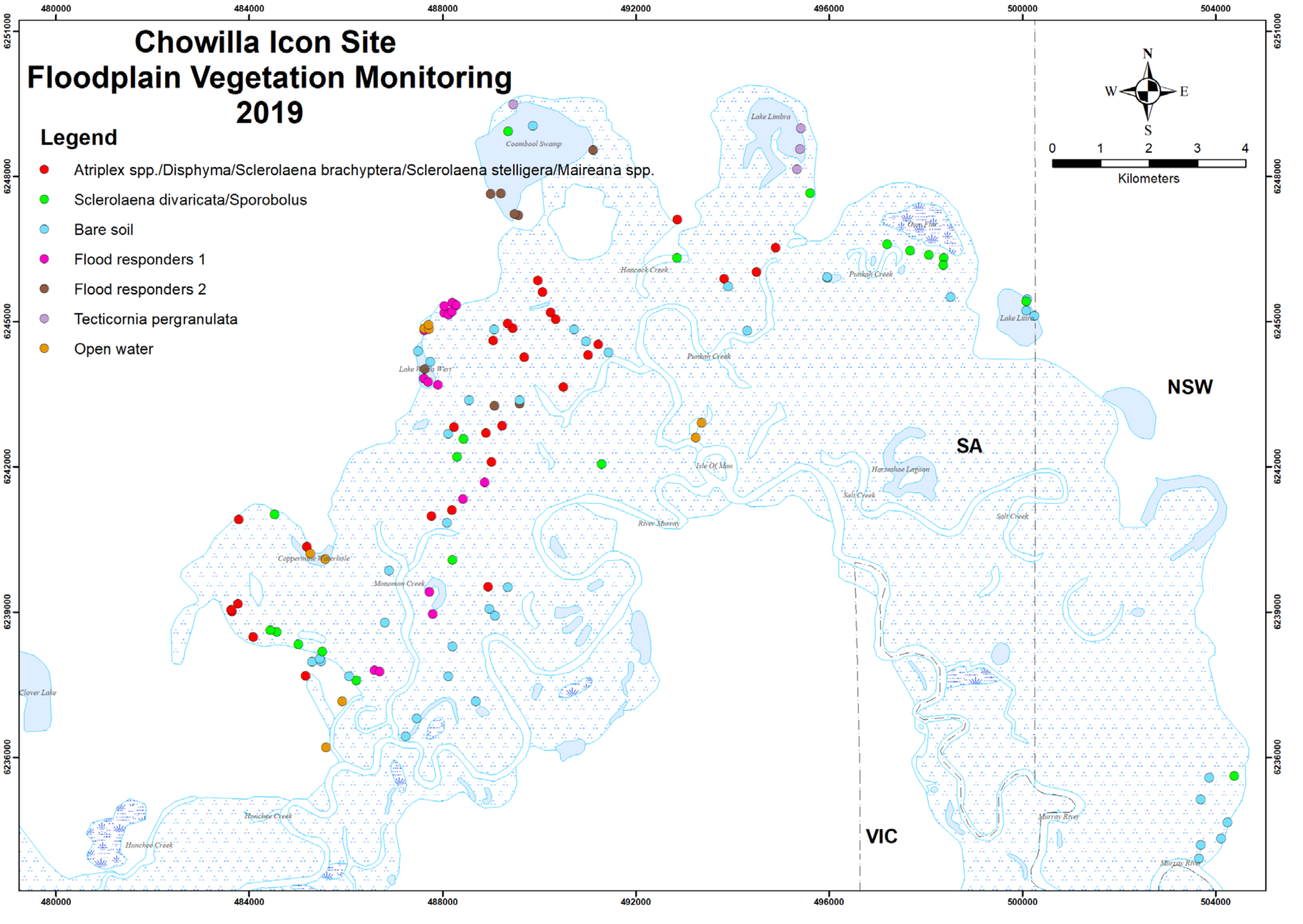

Figure 7: Spatial distribution and plant communities of the 126 sites across the Chowilla Floodplain for the 2019 survey. Colours reflect the 2019 dendrogram groupings (Figure 6).

Table 3: Indicator Species Analysis (Dufrene and Legendre 1997) based on unpooled data (*n*=378) from the 2019 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; **denotes proclaimed pest plant in SA).

Taxon	Group	*P*
*Abutilon theophrasti**	Flood responders 1	0.0824
Alternanthera denticulata	Flood responders 1	0.7506
Ammania multiflora	Flood responders 1	0.0102
Atriplex spp.	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.0594
Atriplex suberecta	Flood responders 1	0.1312
Austrobryonia micrantha	Flood responders 1	0.3049
Bare soil	Bare soil	0.0002
Bolboschoenus caldwellii	Flood responders 1	0.3091
Brachyscome basaltica	Flood responders 2	0.0066
Calotis hispidula	Sclerolaena divaricata/ Sporobolus	0.4565
Centipeda minima	Flood responders 1	0.0002
Chamaesyce drummondii	Flood responders 2	0.2611
Chenopodium nitrariaceum	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.6807
*Citrullus lanatus**	Flood responders 1	0.0912
Cyperus difformis	Flood responders 1	0.091
Cyperus gymnocaulos	Flood responders 2	0.6125
Disphyma crassifolium ssp. *clavellatum*	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.0002
*Dittrichia graveolens**	Bare soil	0.4643
Duma florulenta	Sclerolaena divaricata/ Sporobolus	0.0932
Duma horrida	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.3871
Eleocharis acuta	Flood responders 1	0.1536
Enchylaena tomentosa	Bare soil	0.169
Eragrostis australasica	Bare soil	1
Eragrostis dielsii	Bare soil	1
Eremophila divaricata	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.6797
Eucalyptus camaldulensis	Flood responders 1	0.6759
Frankenia pauciflora	Flood responders 2	0.0036
Glinus lotoides	Flood responders 1	0.0002
Glycyrrhiza acanthocarpa	Flood responders 2	0.0054
Haloragis aspera	Flood responders 2	0.1026
*Heliotropium curassavicum**	Bare soil	0.1686
*Heliotropium europaeaum**	Flood responders 1	0.0002
Iseotopsis graminifolia	Flood responders 1	0.0864
Maireana spp.	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.0038
Marselia dummondii	Flood responders 1	0.1304
Myriophyllum verrucosum	Flood responders 1	0.3049
Open water	Open water	0.0002
*Phyla canescens**	Flood responders 2	0.6877
Phyllanthus lacunaris	Flood responders 1	0.3049
Polygonum plebeium	Flood responders 1	0.1268
Rhagodia spinescens	Bare soil	0.7325
Salsola australis	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.6935
Sclerolaena brachyptera	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.0002
Sclerolaena divaricata	Sclerolaena divaricata/ Sporobolus	0.0006
Sclerolaena stelligera	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.0002
Senecio cunninghamii	Bare soil	1
Sphaeromorphaea australis	Flood responders 1	0.1432

Taxon	Group	*P*
Sporobolus mitchellii	Sclerolaena divaricata/ Sporobolus	0.0002
Stemodia florulenta	Flood responders 2	0.0002
Tecticornia pergranulata	Tecticornia pergranulata	0.0002
Tecticornia triandra	Atriplex spp./ Disphyma/Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.	0.023
Thyridia repens	Tecticornia pergranulata	0.3889
Unknown-Coombool	Tecticornia pergranulata	0.125
*Verbena supinum**	Flood responders 1	0.0886
Wahlenbergia fluminalis	Flood responders 2	0.0066
*Xanthium occidentale***	Flood responders 2	0.1152

3.2. Grazing intensity

Grazing intensity (as inferred by the frequency of scats) was highly variable across the Chowilla Floodplain and showed no clear spatial patterns (Figure 8). However, there were areas of high frequency of scats such Coppermine Complex, Gum Flat, Coombool Swamp, Kulcurna (New South Wales section of the floodplain) and Lake Littra (Figure 8). Despite high scat frequencies at some temporary wetlands, overall scat frequency was significantly higher at floodplain sites than wetland sites (PERMANOVA *Pseudo* $F_{1,347}$ = 28.23; P = 0.001) (Figure 9).

There were significant differences in scat frequency between plant communities as defined by the cluster analysis (PERMANOVA *Pseudo* $F_{6,347}$ = 35.50; P = 0.001). There were no significant differences between ‘Atriplex spp./Disphyma/ Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.’ and ‘Sclerolaena divaricata/ Sporobolus’, and ‘Atriplex spp./Disphyma/ Sclerolaena brachyptera/ Sclerolaena stelligera/ Maireana spp.’ and Flood responders 2 (Table 4, Figure 9). In addition, there was no significant difference between ‘Tecticornia pergranulata’ sites and bare soil, and ‘Tecticornia pergranulata’ sites and Flood responders 2 (Table 4, Figure 9). Scat frequency was significantly different between all other plant communities (Table 4, Figure 9).

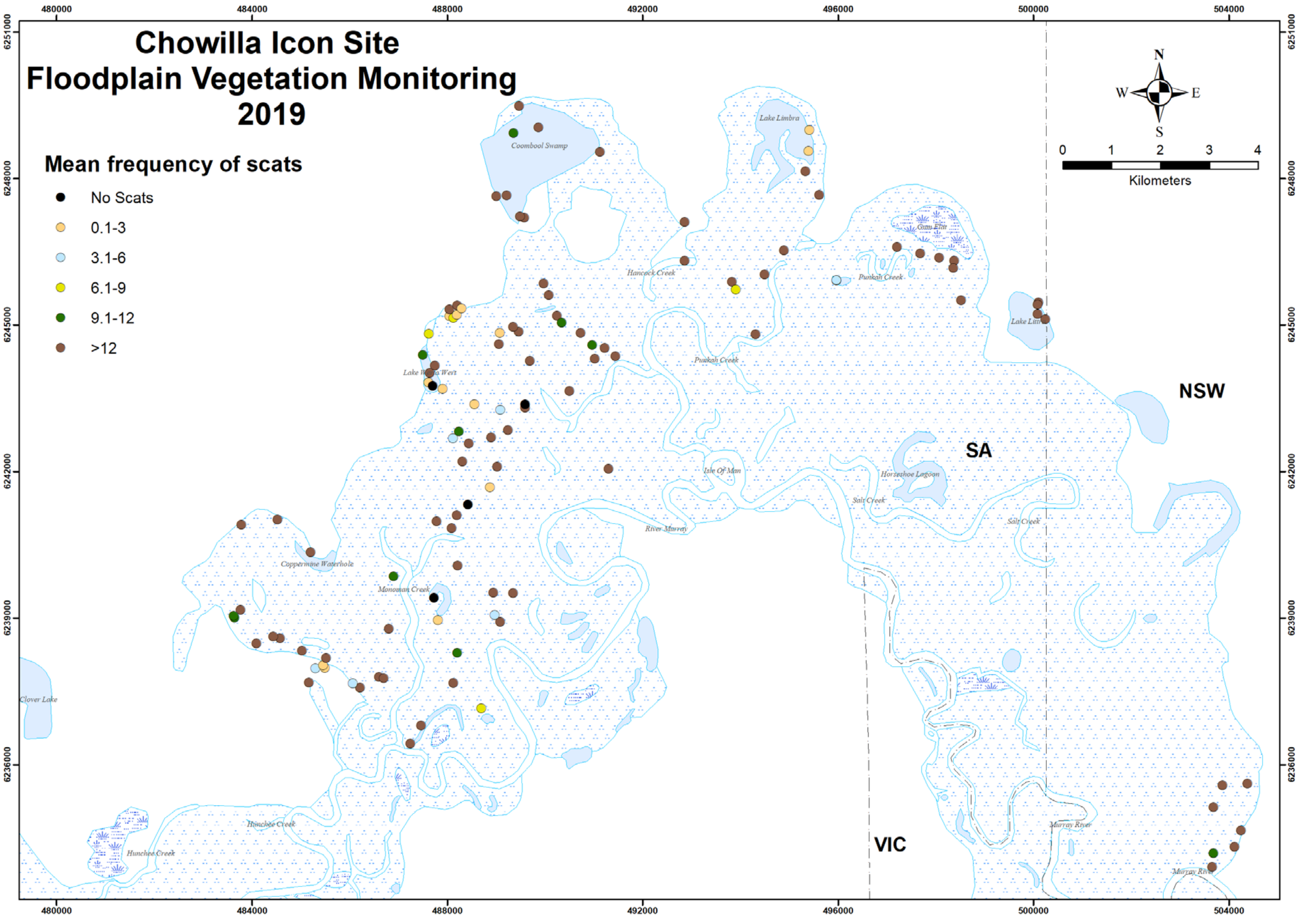

Figure 8: Mean frequency of scats at each site (mean of three quadrats) surveyed in 2019.

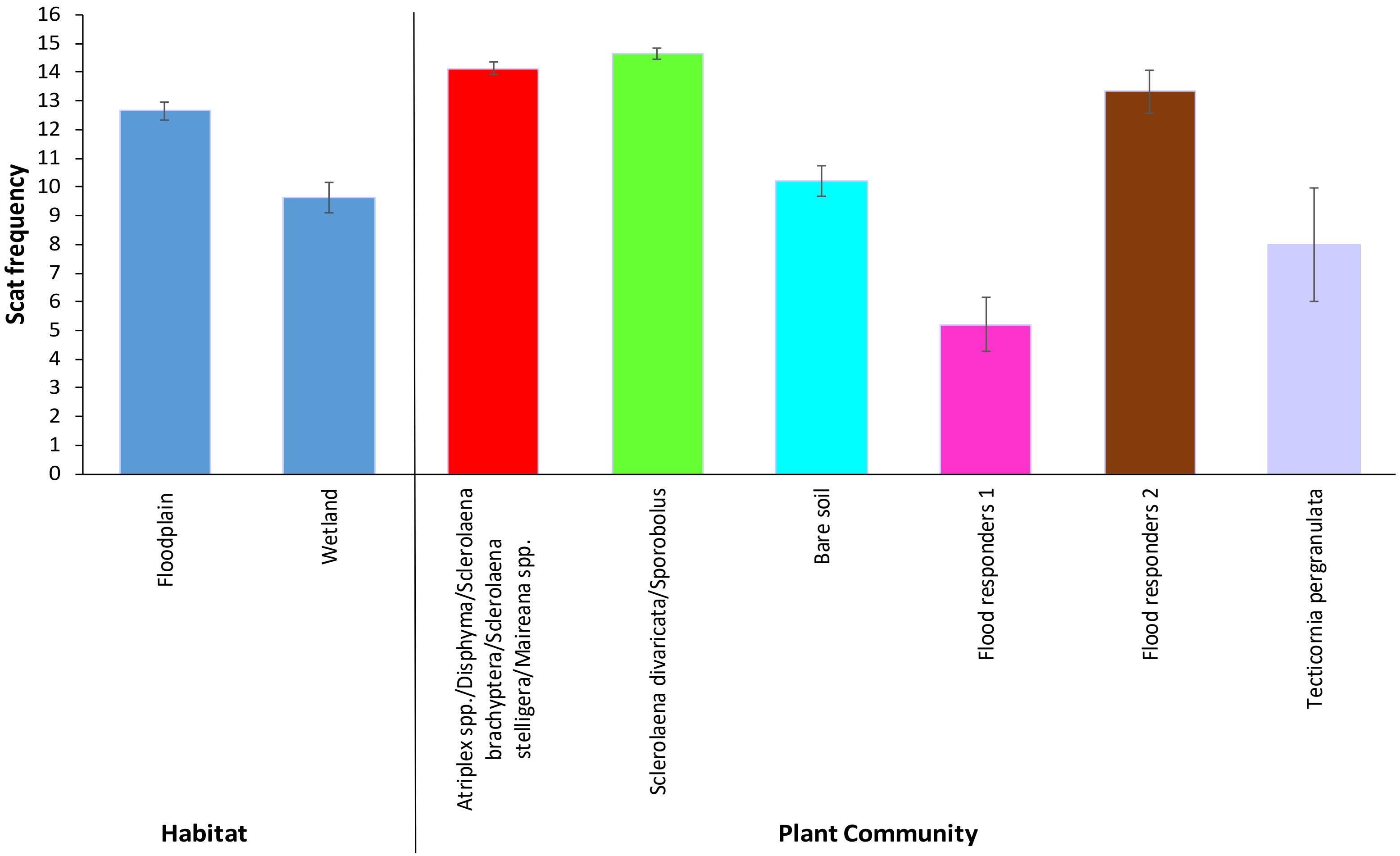

Figure 9: Mean frequency of scats for the different habitats (floodplain or temporary wetland) and plant communities identified by the dendrogram groupings (Figure 6). Colours for the plant community columns reflect the 2019 dendrogram groupings and error bars = ±1 SE

Table 4: 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).

	Atriplex spp./Disphyma/Sclerolaena brachyptera/Sclerolaena stelligera/Maireana spp.	Sclerolaena divaricata/Sporobolus	Bare soil	Flood responders 1	Flood responders 2	Tecticornia pergranulata
Atriplex spp./Disphyma/Sclerolaena brachyptera/Sclerolaena stelligera/Maireana spp.						
Sclerolaena divaricata/Sporobolus	NS					
Bare soil	***	***				
Flood responders 1	***	***	***			
Flood responders 2	NS	*	***	***		
Tecticornia pergranulata	***	***	NS	NS	**	

3.3. Change in the plant community from 2006 to 2019

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 similar to the numbers recorded in the 2007 survey (42 and 48 taxa, respectively) (Figure 10). In 2011, following overbank flooding, species richness increased by more than 50% compared to 2010 (66 and 42 taxa, respectively), but in 2012 species richness 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 more than two-fold increase in species richness (57 taxa) due to the regulator operation and natural flooding; however, this 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 (Figure 10).

In temporary wetlands, 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 (pumping) undertaken at these sites, and longer and more frequent inundation by regulator operations and high flows. The increase 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 the regulator operation; however, many of the wetlands not inundated by regulator operation were dominated by bare soil (Figure 6, Figure 7 and Table 3)

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 late 2016 overbank flood and regulator operation (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).

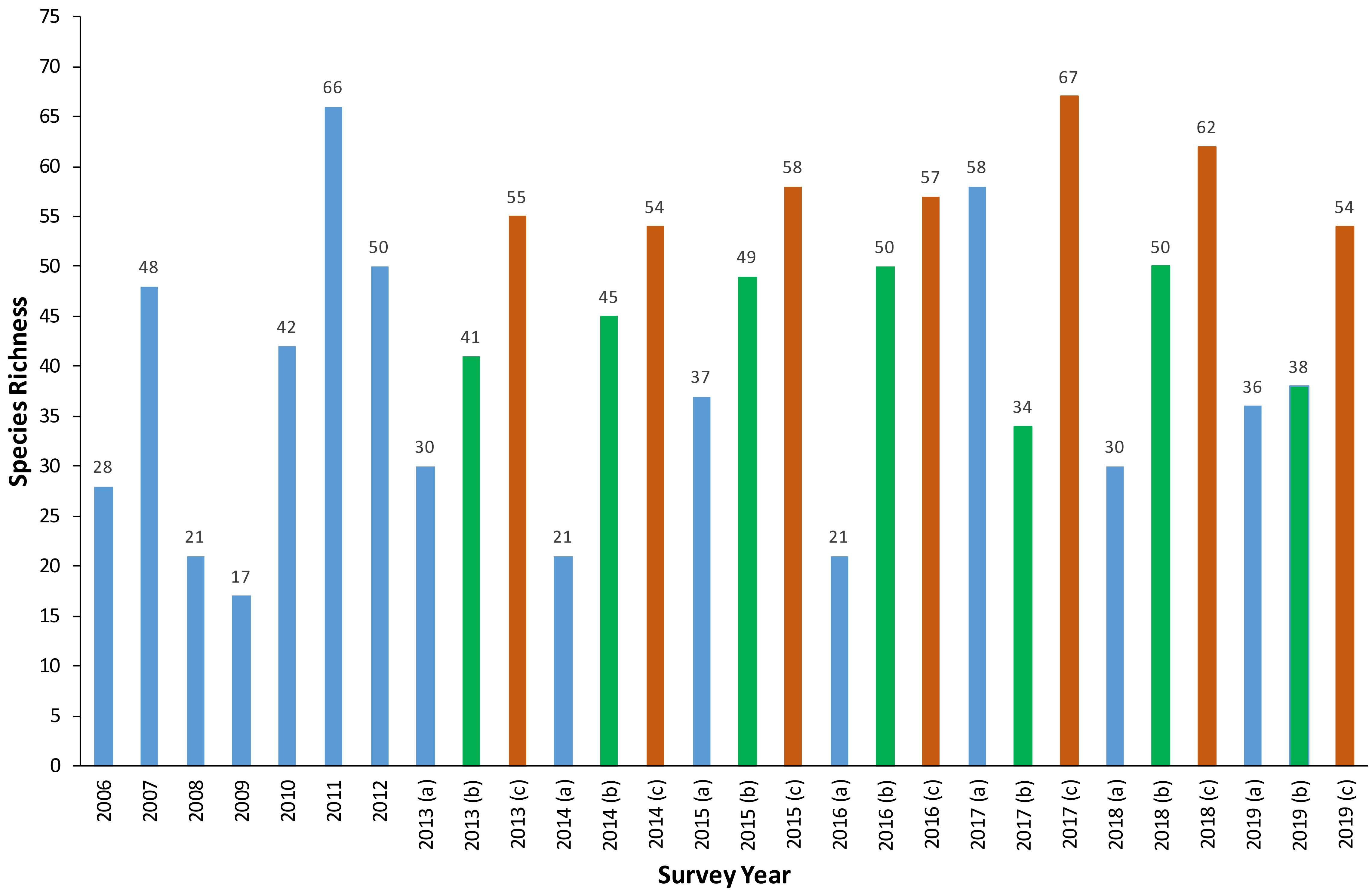

Figure 10: Changes through time in species richness (number of taxa) of the Chowilla Floodplain from 2006 to 2019. 2013(a), 2014(a), 2015(a), 2016(a) 2017(a), 2018(a) denotes floodplain only sites 1–85, 2013(b) denotes temporary wetland sites (86–118), 2014(b) denotes temporary wetland sites (86–126),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

In 2006, the floodplain understorey was mostly comprised of 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 resulted in 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, if a comparison is made between the original floodplain sites (sites 1–85); the proportion of bare soil increased, while terrestrial and salt tolerant species remained consistent and flood dependent and amphibious taxa all decreased. However, 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 sites one to 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 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 taxa, and corresponding decrease in bare soil and salt tolerant taxa compared to the 2016 survey due 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 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).

At sites one to 85 there was a further increase in the proportion of bare soil in 2019, 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).

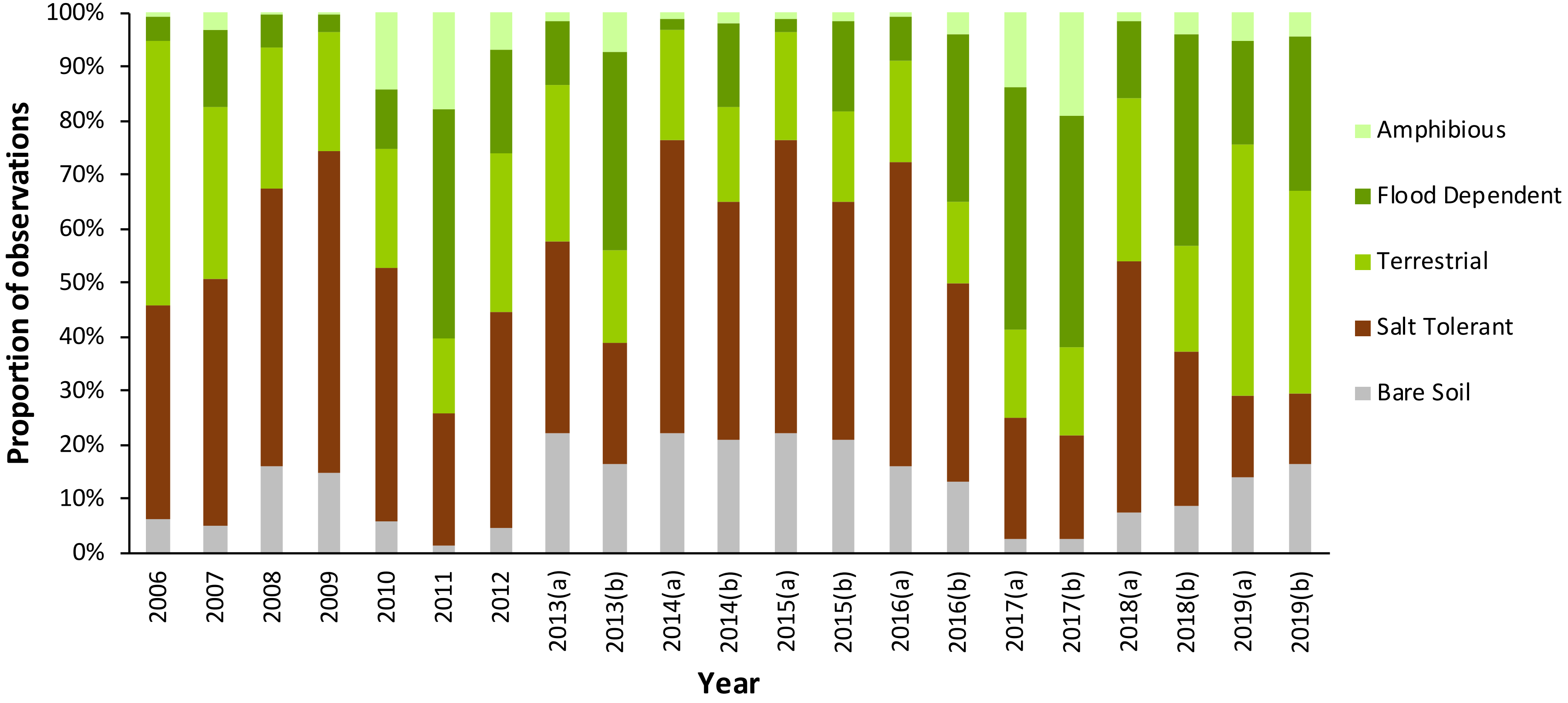

Figure 11: Changes in the percentage of observations of vegetation functional groups of the Chowilla Floodplain from 2006 to 2018. 2013(a), 2014(a), 2015(a), 2016 (a), 2017 (a) and 2018 (a) denotes floodplain sites 1–85; 2013(b) denotes floodplain and temporary wetlands sites (1–118), 2014(b) denotes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

NMS ordination (Figure 12) shows the trajectory for plant communities at floodplain sites (sites one to 85) from 2006 to 2019. 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). 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. Although the regulator was operated in spring 2014 the event was of a moderate scale that resulted in 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 the 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 (Figure 10).

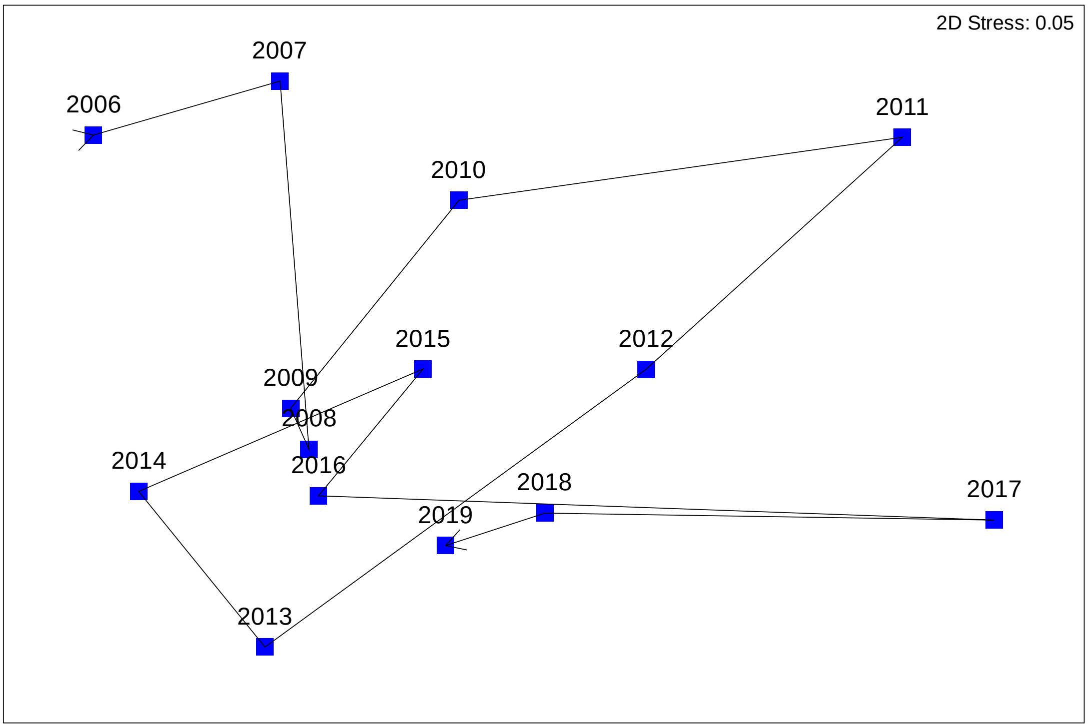

Figure 12: NMS ordination comparing the plant communities of Chowilla Floodplain sites 1–85 from 2006 to 2019.

3.4. The Living Murray targets

Native taxa - floodplain sites

At the floodplain sites (1–85) between 2006 and 2019, 20% or more of the cells contained amphibious or flood dependent species on seven occasions: 2007, 2010, 2011, 2012, 2015, 2017, 2018 and 2019 with the maximum interval two years (Figure 13). In 2007 and 2010, Gum Flat and Coppermine Complex were watered, 2011, 2012 and 2017 followed overbank flooding, the 2015, 2016 and 2019 surveys followed regulator operation in the previous spring and 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 three times between the period 2006 to 2019, in 2011, 2012 and 2017 (following 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 5).

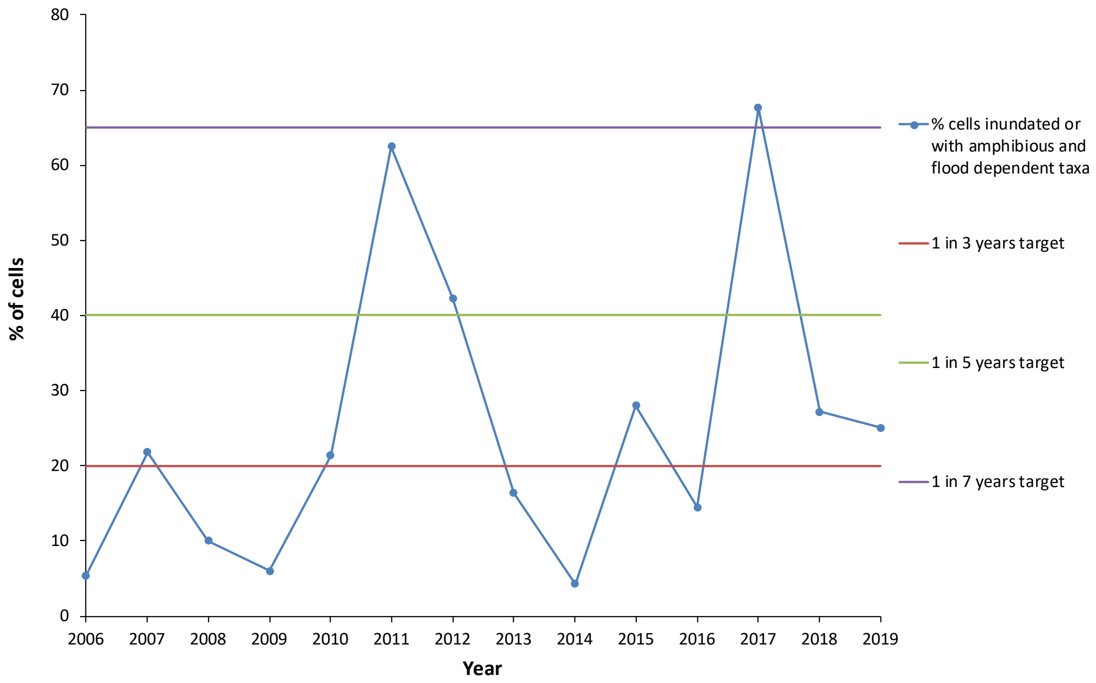

Figure 13: Percentage of cells with native amphibious or flood dependent species present at floodplain sites (sites 1 to 85) between 2006 and 2019.

Figure 14 shows species richness of native flood dependent and amphibious species between 2006 and 2019. Six out of the seven occasions when the percentage of cells containing flood dependent or amphibious taxa exceeded 20% (2007, 2010, 2011, 2012, 2015, 2017 and 2019) (Figure 13) the native flood dependent and amphibious species richness >15; therefore, the target was met (Figure 14, Table 5). 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 5). Native amphibious and flood dependent species richness has never exceeded 40; therefore, the one-in-seven year target has never been achieved during the condition monitoring program (Figure 14, Table 5).

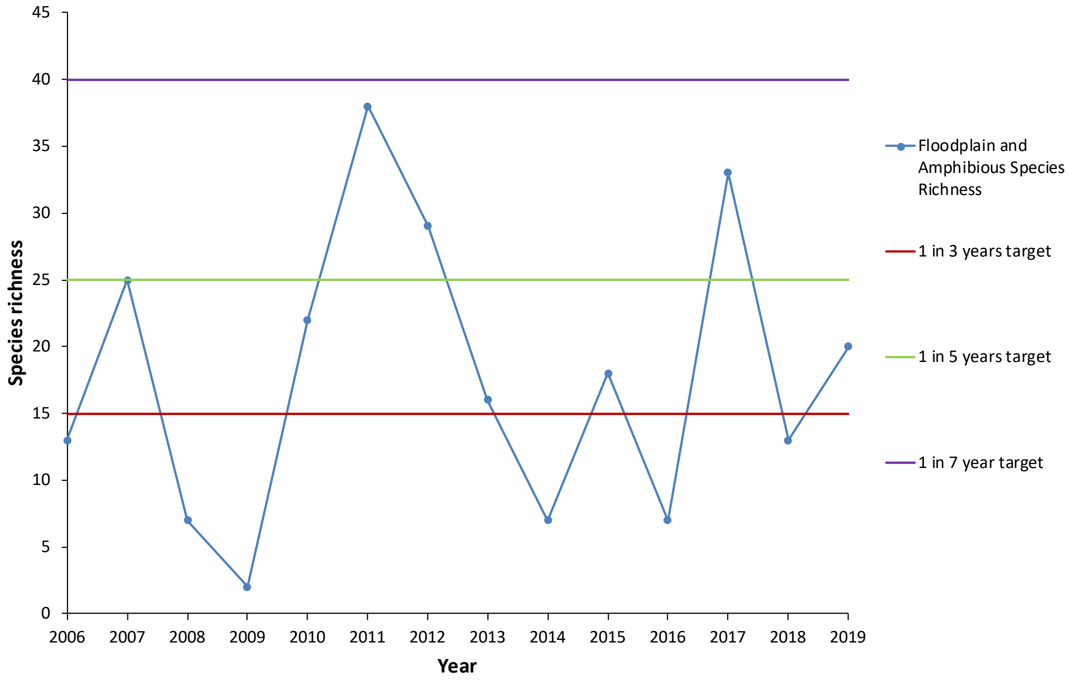

Figure 14: Species richness of amphibious and flood dependent species at floodplain sites (sites 1 to 85) between 2006 and 2019.

Native taxa - temporary wetland sites

Over 40% of quadrat cells at temporary wetland sites (86 to 143) were inundated or contained amphibious or flood dependent species every survey between 2013 and 2019 (Figure 15). In 2015 (after the first operation of the regulator) and 2017 (after regulator operation and overbank flooding) over 80% of quadrat cells were either inundated or contained amphibious or flood dependent taxa (Figure 15).

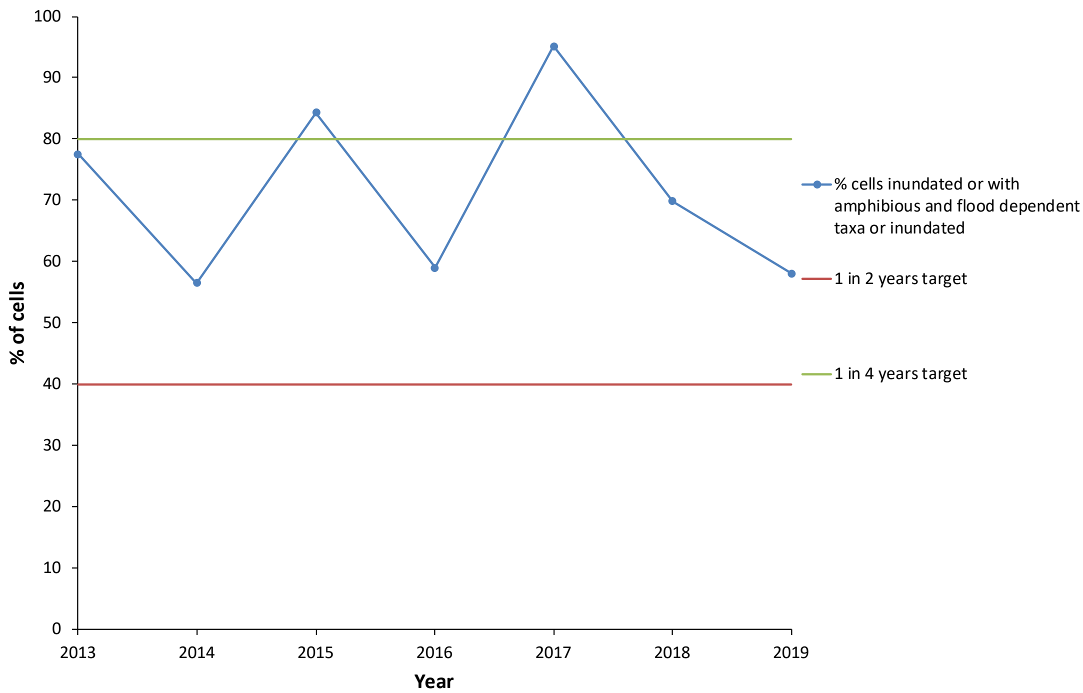

Figure 15: Percentage of cells with amphibious or flood dependent species present at temporary wetland sites (sites 86 to 143) between 2013 and 2019.

Over 20 native flood dependent and amphibious species were present each survey in temporary wetland sites each year between 2013 and 2019 (Figure 16), which means that the one-in-two-year target has been achieved (Table 5). Despite over 80% of cells being inundated or containing floodplain or amphibious species in 2015 and 2017 (twice in the previous seven 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 5).

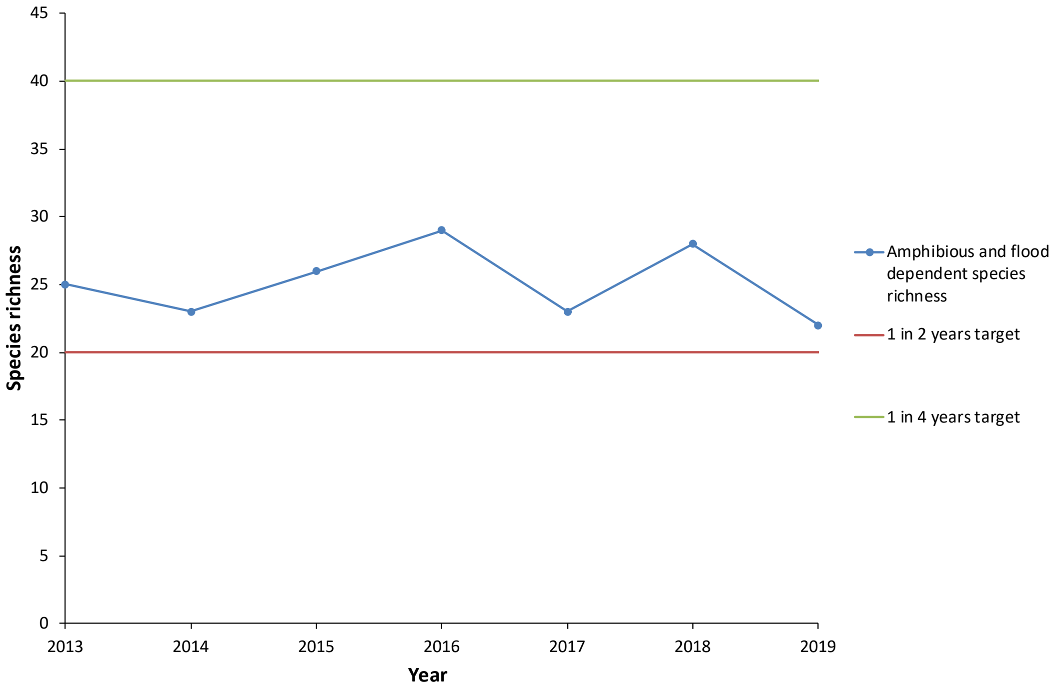

Figure 16: Species richness of amphibious and flood dependent species at temporary wetland sites (sites 86 to 143) between 2013 and 2019.

Table 5: Success of attaining floodplain and temporary wetland native vegetation targets between 2006 and 2019.

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

With the exception of 2011, 2012 and 2017, <5% of cells from floodplain sites (usually <1%) have 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 6). *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 2019 (Figure 17, Table 6).

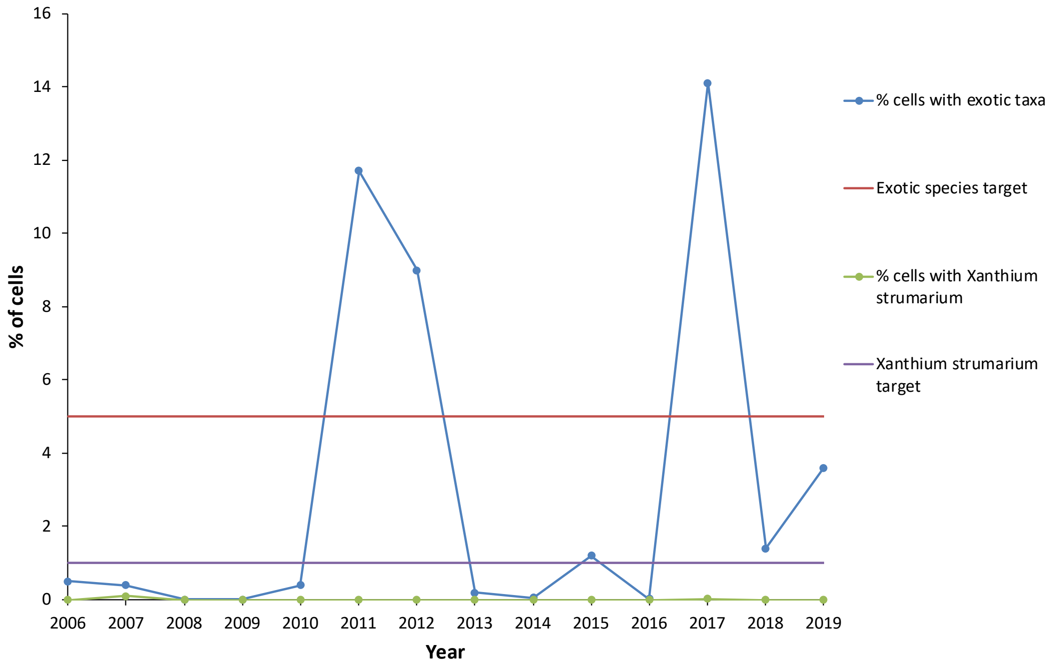

Figure 17: Percentage of cells with exotic species and *Xanthium occidentale* present at floodplain sites (sites 1 to 85) between 2006 and 2019.

Exotic taxa – temporary wetland sites

In temporary wetlands, the number of cells containing exotic species was >10% every year between 2013 and 2019, except in 2017 (due to most sites being inundated); hence, the target has only been achieved once (Figure 18, Table 6). *Xanthium occidentale* was uncommon and the number of cells where this species was present never exceeded 1% between 2013 and 2018; hence, this target was achieved every year (Figure 18, Table 6).

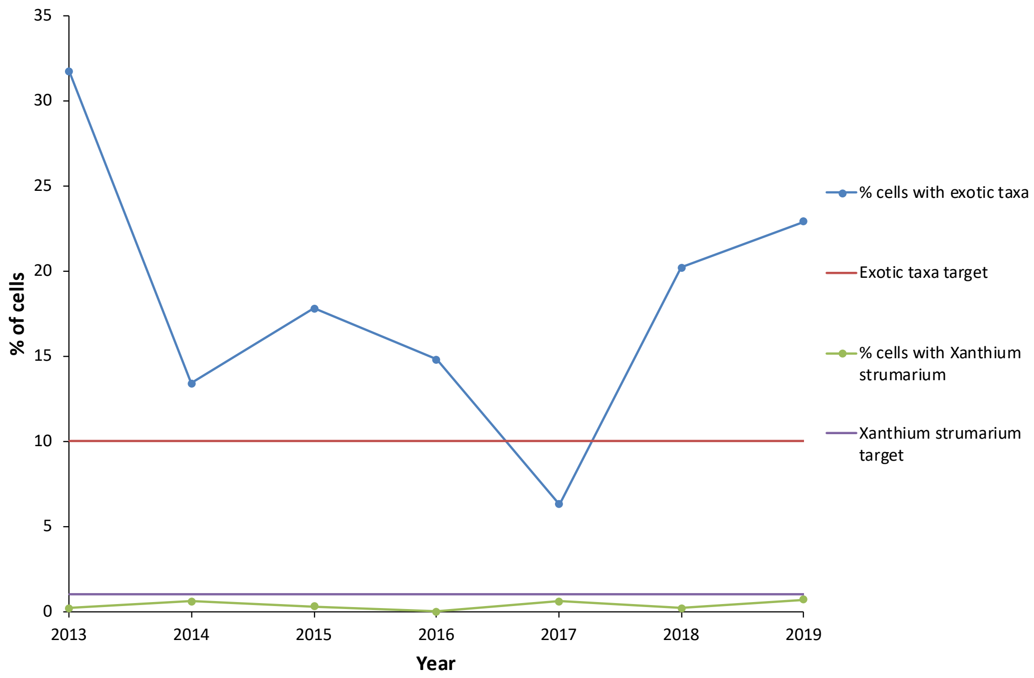

Figure 18: Percentage of cells with exotic species and *Xanthium occidentale* present at temporary wetland sites (sites 86 to 143) between 2013 and 2019.

Table 6: Success of attaining floodplain and temporary wetland exotic species and *Xanthium occidentale* targets between 2006 and 2018.

	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

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.

However, there were 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, in 2015-16 regulator operation inundated two sites and in 2018-19 eight sites compared to no sites under natural conditions (Table 7, Appendix 1, Appendix 3).

Under modelled natural conditions between 2006 and 2019, 20% or more of the cells were predicted to contain amphibious or flood dependent species on five occasions: 2006, 2011, 2012, 2013 and 2016 with the maximum interval four years (Figure 19). Under observed conditions (Figure 13), this also occurred on eight occasions which on four occasions (2007, 2010, 2015 and 2019) was due to watering interventions (pumping and regulator operation). Amphibious or flood dependent species were present in 40% of cells three times between 2006 and 2017 (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).

Table 7: Comparison of modelled natural and current peak daily flow in the River Murray into South Australia from the 2005-06 to 2018-19 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#

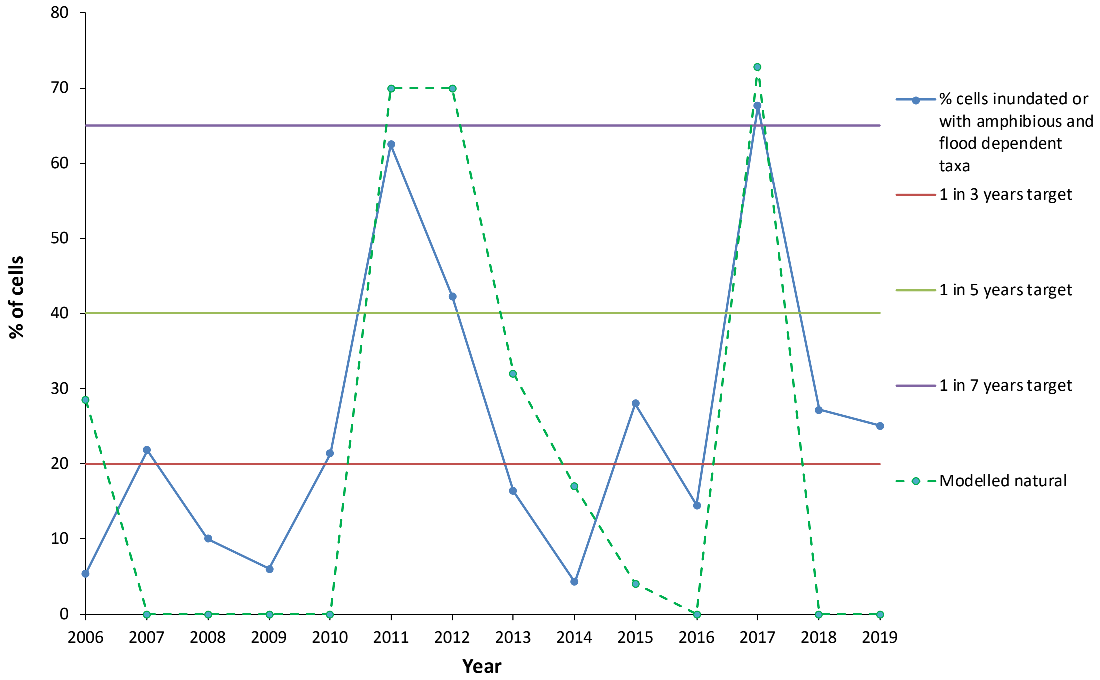

Figure 19: Percentage of cells with amphibious or flood dependent species present at floodplain sites between 2006 and 2019 (blue line) and predicted percentage of cells with flood dependent and amphibious species present under modelled natural conditions (dashed green line) at floodplain sites for the same period.

Predicted 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 was used as the predictor (Figure 20).

Under current conditions, 15 or more native flood dependent and amphibious species were recorded on eight occasions between 2006 and 2019, which on four occasions (2007, 2010, 2015 and 2019) was due to watering interventions (pumping and regulator operation) and 25 or more species on four occasions (due to flooding) (Figure 14).

When the number of quadrat cells containing flood dependent or amphibious species is used as the predictor, 15 or more species were predicted on five occasions and 25 or more and 40 or more 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 or more species were predicted on six occasions, with 25 or more species on four occasions, but 40 or more species was not predicted (Figure 20).

Under modelled natural conditions based on the predicted occurrence of native flood dependent or amphibious 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).

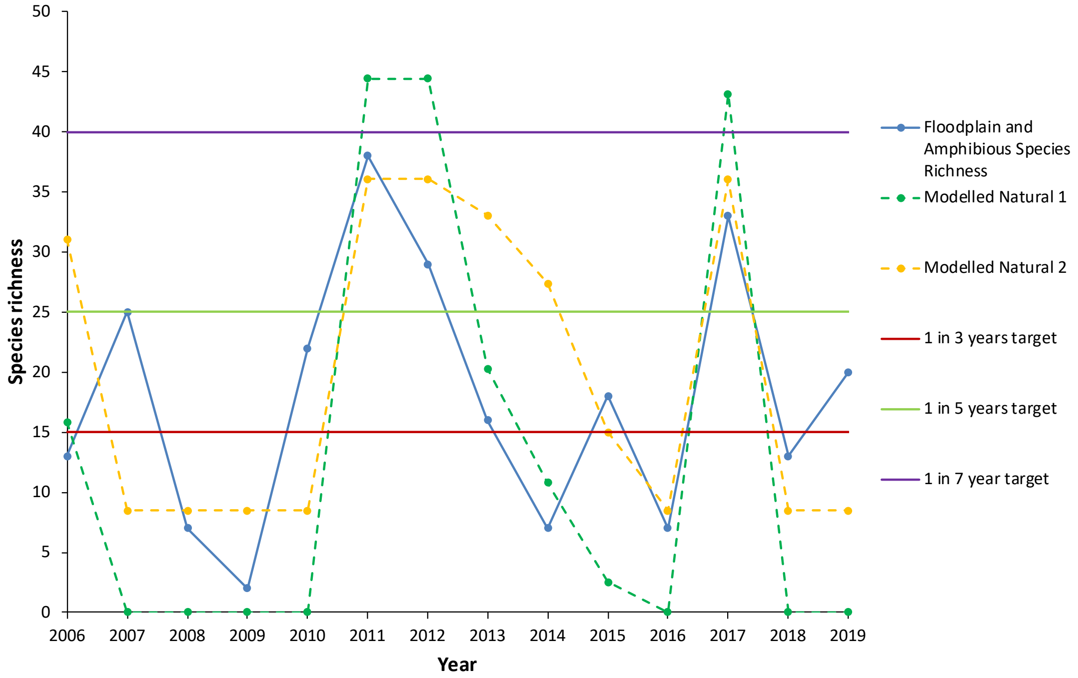

Figure 20: Species richness of native amphibious and flood dependent species at floodplain sites between 2006 and 2019 (blue line) and predicted flood dependent and amphibious species richness under modelled natural conditions at floodplain sites for the same period (Modelled Natural 1 = predicted using 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 and regulator operation. 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. In order to monitor 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 one to 85) showed that between 2018 and 2019, the plant community remained dominated by terrestrial and salt tolerant taxa with an increase in bare soil. The plant community across these sites is becoming more similar to that observed during the Millennium drought. This result was expected due to the absence of large-scale inundation (engineered or natural) required for the recruitment of flood dependent and amphibious species.

Since 2012, temporary wetland sites have been inundated more often than floodplain sites, either via regulator operations, site-specific pumping or natural flooding. No sites were inundated in February 2018, but 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) (Figure 7). 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 (Figure 3). These sites were dominated by amphibious and flood dependent species, with the exception of Lake Limbra (dominated by *Tecticornia pergranulata*) (Figure 7). The remainder of the temporary wetland sites were not inundated and the abundance of bare soil, terrestrial and salt tolerant species increased between 2018 and 2019 (Figure 7)

Grazing intensity was measured semi-quantitatively in 2019 during the vegetation survey 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.

Scat frequency showed that grazing pressure was probably higher on the floodplain (which includes Coppermine complex and Gum Flat) than in temporary wetlands (Figure 9); however, some temporary wetlands such as Lake Littra, Chowilla Island Loop and Coombool Swamp may be grazing hot spots (Figure 8). At the time of the survey, these wetlands were densely vegetated, with large numbers of kangaroos and emus present (J. Nicol *pers. obs.*). Scat frequency was patchy in Werta Wert Wetland sites, despite abundant vegetation, and was generally low across the remaining temporary wetlands (most of which were sparsely vegetated) (Figure 7 and Figure 8).

Scat frequency also suggested that vertebrate grazers prefer different plant communities (Figure 9). Results suggested that the 'Atriplex spp./Disphyma/Sclerolaena brachyptera/Sclerolaena stelligera/Maireana spp.', 'Sclerolaena divaricata/Sporobolus' and Flood responders 2 communities were more heavily grazed than other plant communities (Figure 9). 'Atriplex spp./Disphyma/Sclerolaena brachyptera/Sclerolaena stelligera/Maireana spp.' and 'Sclerolaena divaricata/Sporobolus' communities were abundant across floodplain sites and the Flood responder 2 community in temporary wetlands not inundated in the previous 12 months (in particular Coombool Swamp) (Figure 7). *Atriplex* spp., *Maireana* spp., *Sporobolus mitchellii*, and several dominant species in the Flood responders 2 community (*Brachyscome basaltica, Glycyrrhiza acanthocarpa* and *Wahlenbergia fluminalis*) are palatable to domestic stock (Cunningham *et al.* 1992). In addition, *Sporobolus mitchellii* plants present in quadrats commonly show signs of heavy grazing (J. Nicol *pers. obs.*).

4.2. The Living Murray Targets

The TLM condition monitoring plan refinement project developed quantitative targets that can be assessed against data collected through the condition monitoring program. The one-in-three year target for the floodplain was able to be achieved by 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; however, it may have been achieved by regulator operation alone in 2017 because the spring 2016 operation inundated 48% of sites (Appendix 1). The one-in-seven year target has not been achieved between 2006 and 2019, despite >65% of cells containing flood dependent or amphibious taxa in 2017, because native floodplain and amphibious species richness was below the target of 40.

The 2016 and 2018 regulator operations showed 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 operation; however, the one-in-seven year target 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 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 2019 condition monitoring survey resulted in the seventh 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 and 2017. 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 probably 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). There is little in regards to practical management actions to control weeds due to the size of the Chowilla Floodplain 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 more than 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 the high abundances of other exotic species, the proclaimed pest plant *Xanthium occidentale* was generally absent from floodplain and temporary wetland sites with this species recorded in less than 1% of cells during each survey.

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 one in three and one 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 taxa and species richness under modelled natural flow, whilst based on data from the Chowilla Floodplain, were simple and should not be viewed as necessarily 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. However, the 2018 and 2019 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. Furthermore, it 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 and 2019 survey results that followed such a dry period.

The two different functions proposed to predict native flood dependent and amphibious species richness under natural flows, whilst both being highly significant relationships as determined by regression analysis, need 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 cells containing these species increases, which may reflect the data collected from the Chowilla Floodplain over the past 13 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 the previous 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. Collecting species richness data over a larger area than the quadrats over time may provide a better function to model flood dependent and amphibious species richness under natural conditions.

4.3. Management recommendations and future research and monitoring

Observational and monitoring data shows 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 2019 is not necessary to achieve targets; however, it should not be ruled out if there is sufficient flow as the opportunity may not arise in following years.

Seed bank investigations on the Chowilla Floodplain (Kelly 2017, Skinner 2017) and a comparison of the response to flooding between the Pike (unwatered) and Chowilla (watered) floodplains showed that the understorey vegetation is resilient and probably does 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 probably provided before river regulation).

The Living Murray Chowilla Floodplain condition monitoring program has produced an excellent 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 valuable to evaluate interventions and inform managers when to undertake interventions to slow or arrest decline in condition. Other monitoring and research is required to better understand the underlying biological processes and physicochemical factors that 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 exclosure experiments to gain a better understanding of the impacts of native and exotic vertebrate herbivores;
- Refinement of relationships between species richness and occurrence of native flood dependent and amphibious species under modelled natural flows;

- Investigate relationships between vegetation and soil properties (e.g. salinity, soil moisture, water potential, texture);
- Refine grazing pressure estimates by determining provenance and age of scats;
- Investigate short-term longevity of understorey watering/flooding response to determine optimal interval between watering and vegetation surveys;
- Investigate energetic benefits to consumers (e.g. trophic upsurge) from managed events; and
- Determine which species propagules' will survive 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
1	485198	6240345	2006	Floodplain						F						WF		
2	484523	6241019	2006	Floodplain		W			W	F				W	W	WF		W
3	483784	6240912	2006	Floodplain						F						WF		
4	483645	6239006	2006	Floodplain														
5	483016	6239192	2006	Floodplain													I/A	I/A
6	484742	6236011	2006	Floodplain													I/A	I/A
7	484859	6236000	2006	Floodplain													I/A	I/A
8	485543	6236491	2006	Floodplain													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
14	486064	6237665	2006	Floodplain						F						WF		
15	485487	6237975	2006	Floodplain												WF		
16	485298	6237971	2006	Floodplain												WF		
17	485021	6238331	2006	Floodplain					W	F				W		WF		W
18	484572	6238585	2006	Floodplain					W	F				W		WF		W
19	484438	6238618	2006	Floodplain		W			W	F				W		WF		W
20	485169	6237680	2006	Floodplain						F						WF		
21	485459	6238026	2006	Floodplain												WF		

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
22	485513	6238180	2006	Floodplain		W			W	F				W		WF		W
23	486597	6237792	2006	Floodplain		W			W	F				W		WF		W
24	486698	6237764	2006	Floodplain										W		WF		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														
39	489350	6239512	2006	Floodplain						F						WF		
40	488303	6242207	2006	Floodplain						F				W		WF		
41	488438	6242575	2006	Floodplain						F				W		WF		
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		

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
49	491017	6244303	2006	Floodplain						F						F		
50	491442	6244363	2006	Floodplain						F					W	WF		
51	490966	6244592	2006	Floodplain						F						WF		
52	491223	6244572	2006	Floodplain												WF		
55	495612	6247657	2006	Floodplain						F				W		WF		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		
62	497206	6246599	2006	Floodplain		W			W	F			W	W		WF		
63	497618	6246464	2006	Floodplain		W			W	F			W			WF		
64	498069	6246375	2006	Floodplain		W			W	F			W			WF		
65	498376	6246311	2006	Floodplain		W			W	F			W			WF		
66	498394	6246168	2006	Floodplain					W	F			W			WF		
67	497154	6241724	2006	Floodplain					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
69	496572	6242971	2006	Floodplain					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
71	497342	6245017	2006	Floodplain					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
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		

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
78	488692	6237147	2006	Floodplain														
79	488209	6240070	2006	Floodplain						F				W		F		
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
84	503870	6235576	2008	Floodplain											I/A	F		
85	504385	6235609	2008	Floodplain						F					I/A	F		
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	WF		
91	500102	6245461	2013	Littra Edge 1	W		W		W	WF			W			WF		
92	500083	6245421	2013	Littra Middle 1	W		W		W	WF			W			WF		
93	500246	6245118	2013	Littra Edge 2	W		W		W	WF			W			WF		
94	500085	6245221	2013	Littra Middle 2	W		W		W	WF			W			WF		
95	498520	6245504	2013	Punkah Floodrunner 1	W			W		WF						WF		
96	495966	6245906	2013	Punkah Depression 1	W			W		WF					W	WF		W
97	495966	6245919	2013	Punkah Depression 2	W			W		WF						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
98	488042	6245182	2013	Werta Wert North Middle 1	W		W		W	WF						WF		W
99	488124	6245143	2013	Werta Wert North Edge 2	W		W		W	WF			W	W		WF		W
100	488041	6245317	2013	Werta Wert North Edge 6	W		W		W	WF			W	W		WF		W
101	488193	6245206	2013	Werta Wert North Middle 2	W		W		W	WF			W	W		WF		W
102	488205	6245395	2013	Werta Wert North Edge 1	W		W		W	WF			W	W		WF		W
103	488289	6245341	2013	Werta Wert North Middle 3	W		W		W	WF			W	W		WF		W
104	489573	6247193	2013	Coombool Edge 1					W	WF	W					WF		
105	489491	6247218	2013	Coombool Middle 1					W	WF	W					WF		
106	488999	6247637	2013	Coombool Edge 2					W	WF	W					WF		
107	489213	6247649	2013	Coombool Middle 2					W	WF	W					WF		
108	489355	6248928	2013	Coombool Middle 3					W	WF	W					WF		
109	489467	6249484	2013	Coombool Edge 3					W	WF	W					WF		
110	489870	6249043	2013	Coombool Middle 4					W	WF	W					WF		
111	491123	6248539	2013	Coombool Edge 4					W	WF	W					WF		
112	487726	6239416	2013	Chowilla Oxbow 1	W			W		WF						WF		W
113	487804	6238952	2013	Chowilla Oxbow 2	W			W		WF						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
114	495334	6248147	2013	Limbra 1					W	WF						WF		W
115	495397	6248559	2013	Limbra 2					W	WF						WF		W
116	495413	6248992	2013	Limbra 3					W	WF						WF		W
117	492857	6246312	2013	Hancock Creek 2						F						WF		W
118	493241	6242604	2013	Pipeclay Backwater 1				W		WF					W	WF		W
119	488091	6240839	2013	Monoman Depression 1	W			W		WF						WF		
120	485268	6240209	2014	Coppermine 1				W		WF						WF		W
121	485568	6240091	2014	Coppermine 2				W		WF						WF		W
122	488420	6241325	2014	Monoman Island 1	W		W			WF						WF		W
123	489759	6243272	2014	Twin Creek 1			W			WF						WF		W
124	489596	6243373	2014	Twin Creek 2			W			WF						WF		W
125	489076	6243250	2014	Twin Creek 3			W			WF						WF		W
126	488868	6241674	2014	Monoman Island 2	W		W			WF						WF		W
127	487240	6236425	2015	Chowilla Island Loop 1	W			W		WF						WF		W
128	487464	6236797	2015	Chowilla Island Loop 2	W			W		WF						WF		W
129	490728	6244838	2015	Brandy Bottle Lagoon	W			W		F					W	WF		W
130	485587	6236197	2016	Woolshed Creek 1				W		WF	W	W	W	W		WF	I/A	I/A
131	485919	6237151	2016	Woolshed Creek 2				W		WF	W	W	W	W		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
132	487496	6244391	2016	Werta Wert South Edge 6	W		W		W	WF	W	W	W	W		WF		W
133	487634	6244017	2016	Werta Wert South Edge 7	W		W		W	WF	W	W	W	W		WF		W
134	487611	6243827	2016	Werta Wert South Middle 1	W		W		W	WF	W	W	W	W		WF		W
135	487698	6243755	2016	Werta Wert South Middle 2	W		W		W	WF	W	W	W	W		WF		W
136	487905	6243689	2016	Werta Wert South Middle 3	W		W		W	WF	W	W	W	W		WF		W
137	487743	6244165	2016	Werta Wert South Edge 2	W		W		W	WF	W	W	W	W		WF		W
138	487621	6244818	2016	Werta Wert Centre Edge 2	W		W		W	WF	W	W	W	W		WF		W
139	487627	6244854	2016	Werta Wert Centre Middle 3	W		W		W	WF	W	W	W	W		WF		W
140	487722	6244850	2016	Werta Wert Centre Middle 1	W		W		W	WF	W	W	W	W		WF		W
141	487754	6244899	2016	Werta Wert Centre Edge 5	W		W		W	WF	W	W	W	W		WF		W
142	487709	6244930	2016	Werta Wert Centre Middle 2	W		W		W	WF	W	W	W	W		WF		W
143	487669	6245078	2016	Werta Wert Centre Edge 8	W		W		W	WF	W	W	W	W		WF		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).

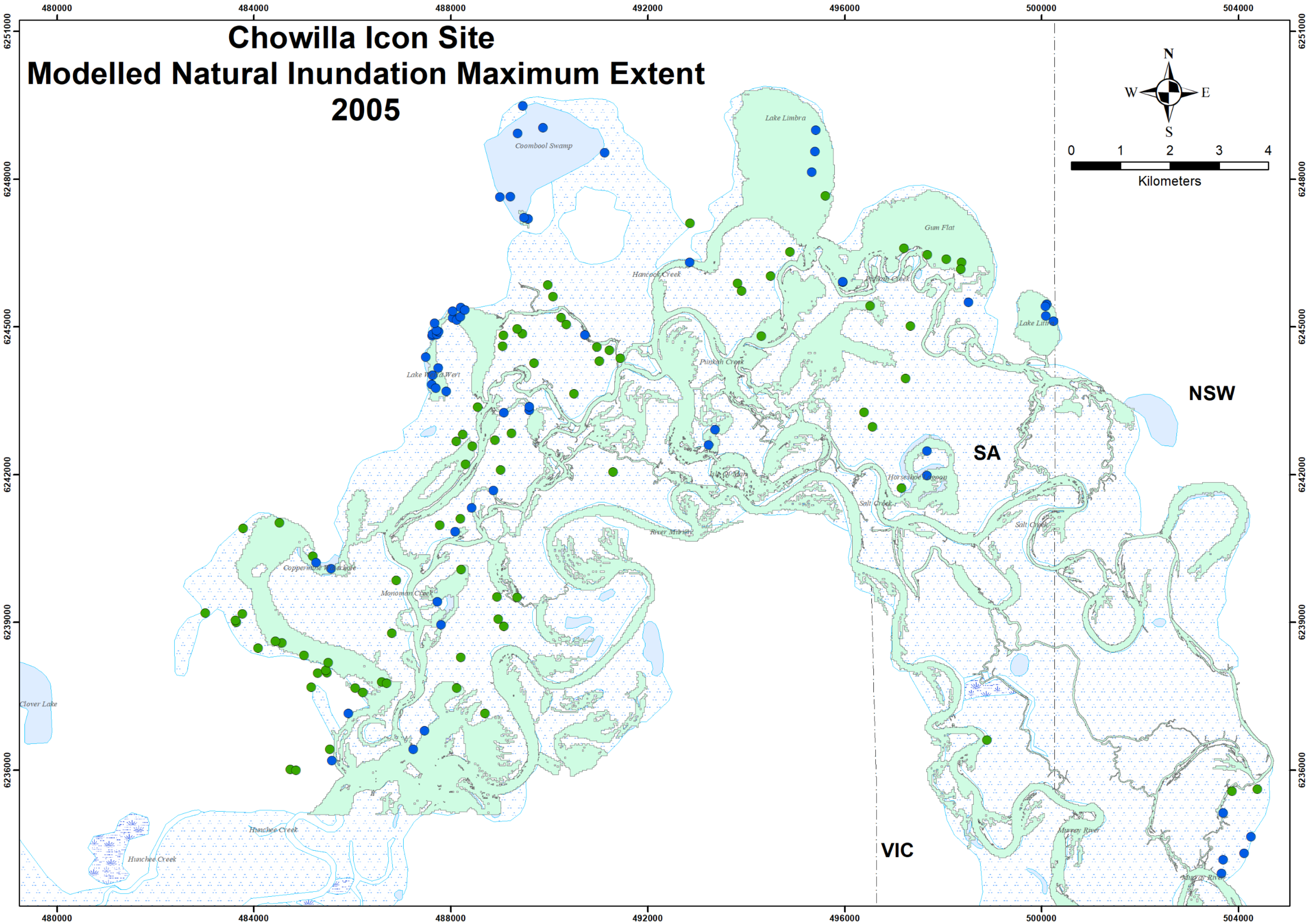
Taxon	Common Name	Family	Status	Life history strategy/growth form	Functional group
*Abutilon theophrasti**	Velvetleaf, China Jute, Buttonweed, Pie-Marker, Indian mallow	Malvaceae	Exotic, Naturalised	Annual herb	Amphibious
Alternanthera denticulata	lesser joyweed	Amaranthaceae	Native	Annual herb	Flood dependent
Ammannia multiflora	jerry-jerry	Lythraceae	Native	Annual herb	Amphibious
*Asphodelus fistulosus***	onion weed	Liliaceae	Exotic, Proclaimed SA Plant	Annual/Perennial	Terrestrial
*Aster subulatus**	Wild aster, bushy starwort	Asteraceae	Exotic, Naturalised	Annual herb	Amphibious
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 basaltica#	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
Chamaesyce drummondii	caustic weed	Euphorbiaceae	Native	Perennial herb	Flood dependent
Chenopodium nitrariaceum	nitre goosefoot	Chenopodiaceae	Exotic	Annual herb	Terrestrial
Dysphania pumilio	clammy goosefoot, small crumbweed	Chenopodiaceae	Native	Annual/Perennial	Flood dependent
Disphyma crassifolium ssp. *clavellatum*	round pigface	Aizoaceae	Native	Perennial	Salt tolerant
*Citrullus lanatus**	bitter melon, wild (or camel) melon	Cucurbitaceae	Exotic, Naturalised	Annual herb	Terrestrial
*Conyza bonariensis**	flaxleaf fleabane, tall fleabane	Asteraceae	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

Taxon	Common Name	Family	Status	Life history strategy/growth form	Functional group
Eragrostis australasica	cane-grass, bamboo-grass	Poaceae	Native	Perennial grass	Amphibious
Eragrostis dielsii	Mallee lovegrass	Poaceae	Native	Perennial grass	Flood dependent
Eremophila divaricata	spreading emubush	Scrophulariaceae	Native	Perennial shrub	Terrestrial
Eremophila scoparia	broom emubush, silver emubush, scotia bush	Scrophulariaceae	Native	Perennial shrub	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
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
Helichrysum luteoalbum	jersey cudweed	Asteraceae	Native	Annual 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	Ephermeral/Annual herb	Flood dependent
Myosurus australis	mousetail	Ranunculaceae	Native	Annual herb	Flood dependent
*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
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
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
*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 supine**	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 and n) 2018-19 water years (green dots represent floodplain sites (1–85) and blue dots temporary wetland sites (86–143).

a)



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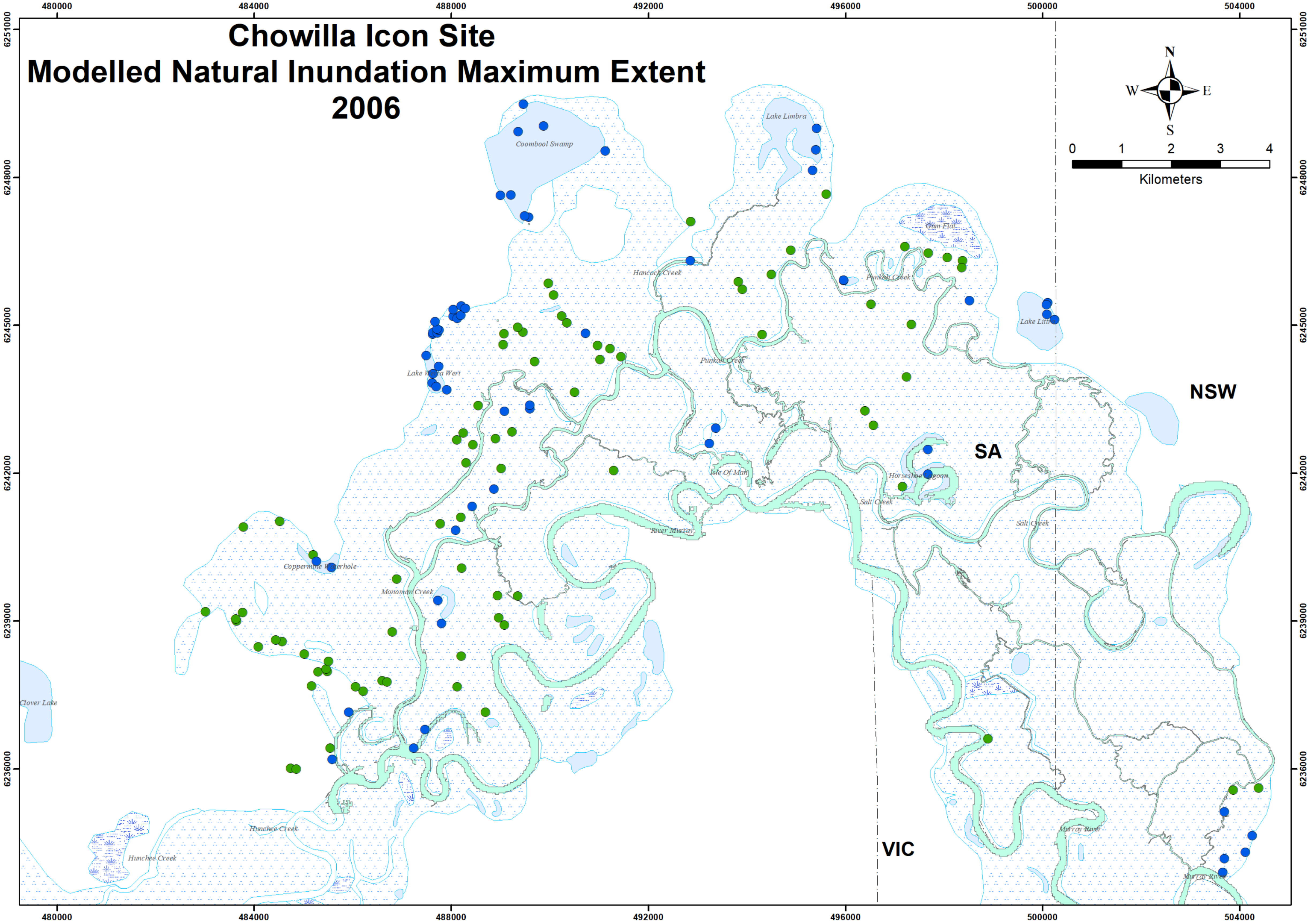

Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
2006
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Kilometers
NSW
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VIC
Coombool Swamp
Lake Limbra
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
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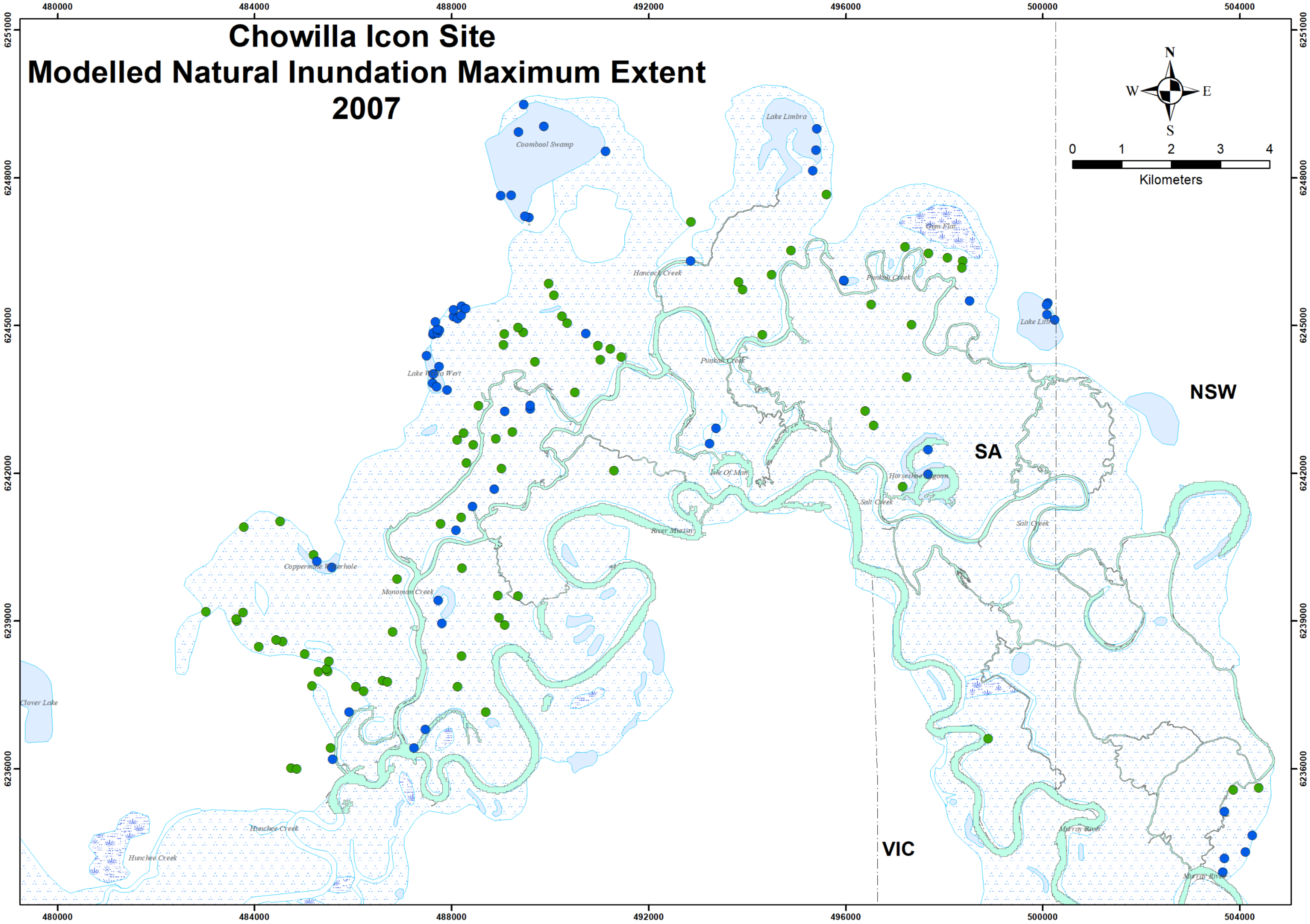
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Modelled Natural Inundation Maximum Extent
2007
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Kilometers
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Coombool Swamp
Lake Limbra
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
Murray River
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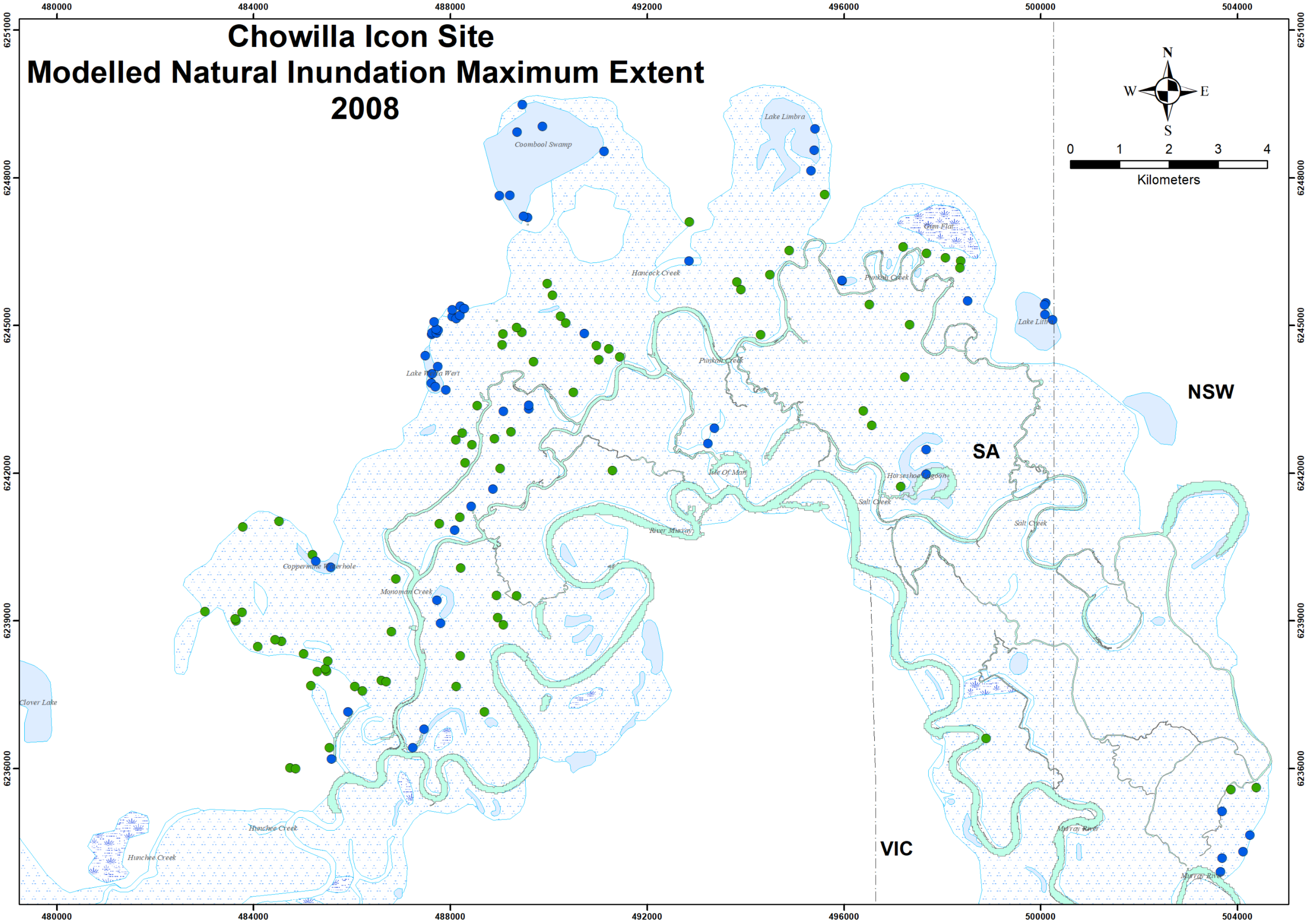
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Modelled Natural Inundation Maximum Extent
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Kilometers
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Coombool Swamp
Lake Limbra
Hancock Creek
Pipeclay Creek
Lake Littra
Lake Limbra West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Punkah Creek
Murray River
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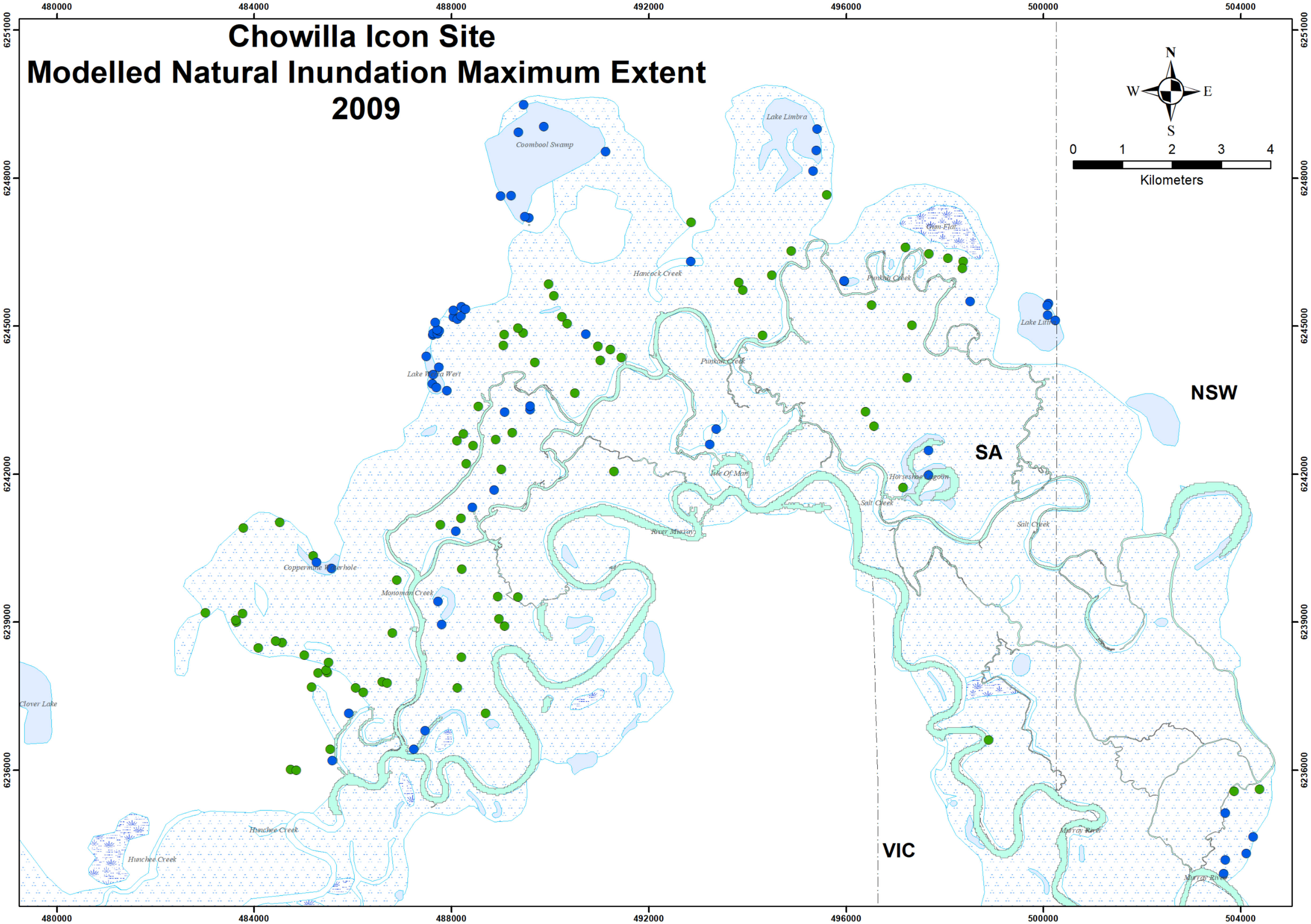
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Modelled Natural Inundation Maximum Extent
2009
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Kilometers
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Lake Limbra
Coombool Swamp
Hancock Creek
Punkah Creek
Lake Littra
Lake Woolpolool West
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
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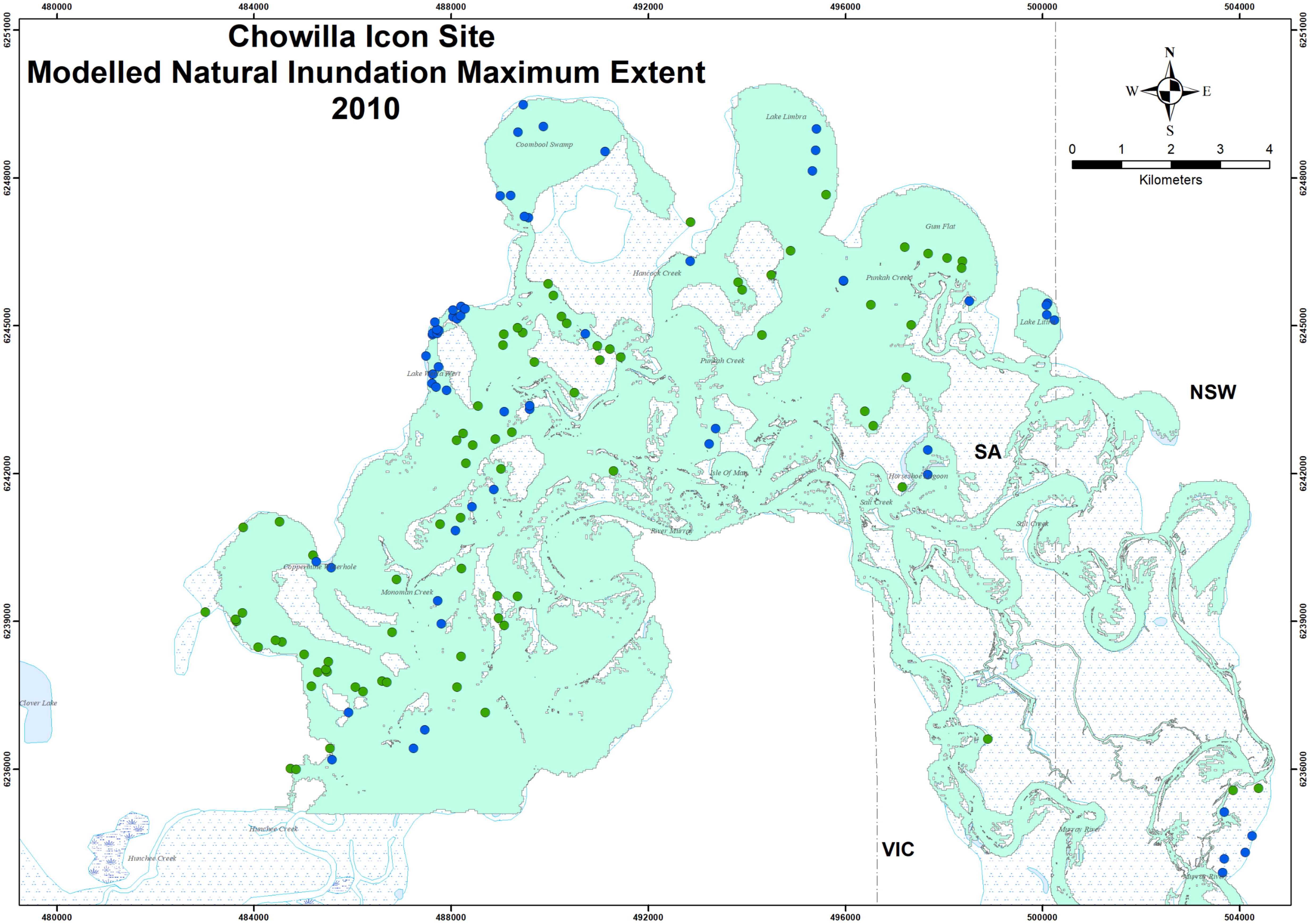
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Modelled Natural Inundation Maximum Extent
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Gum Flat
Hancock Creek
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Lake Littra
Lake Woolpolool
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Coppermine Waterhole
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Clover Lake
Hunchee Creek
Murray River

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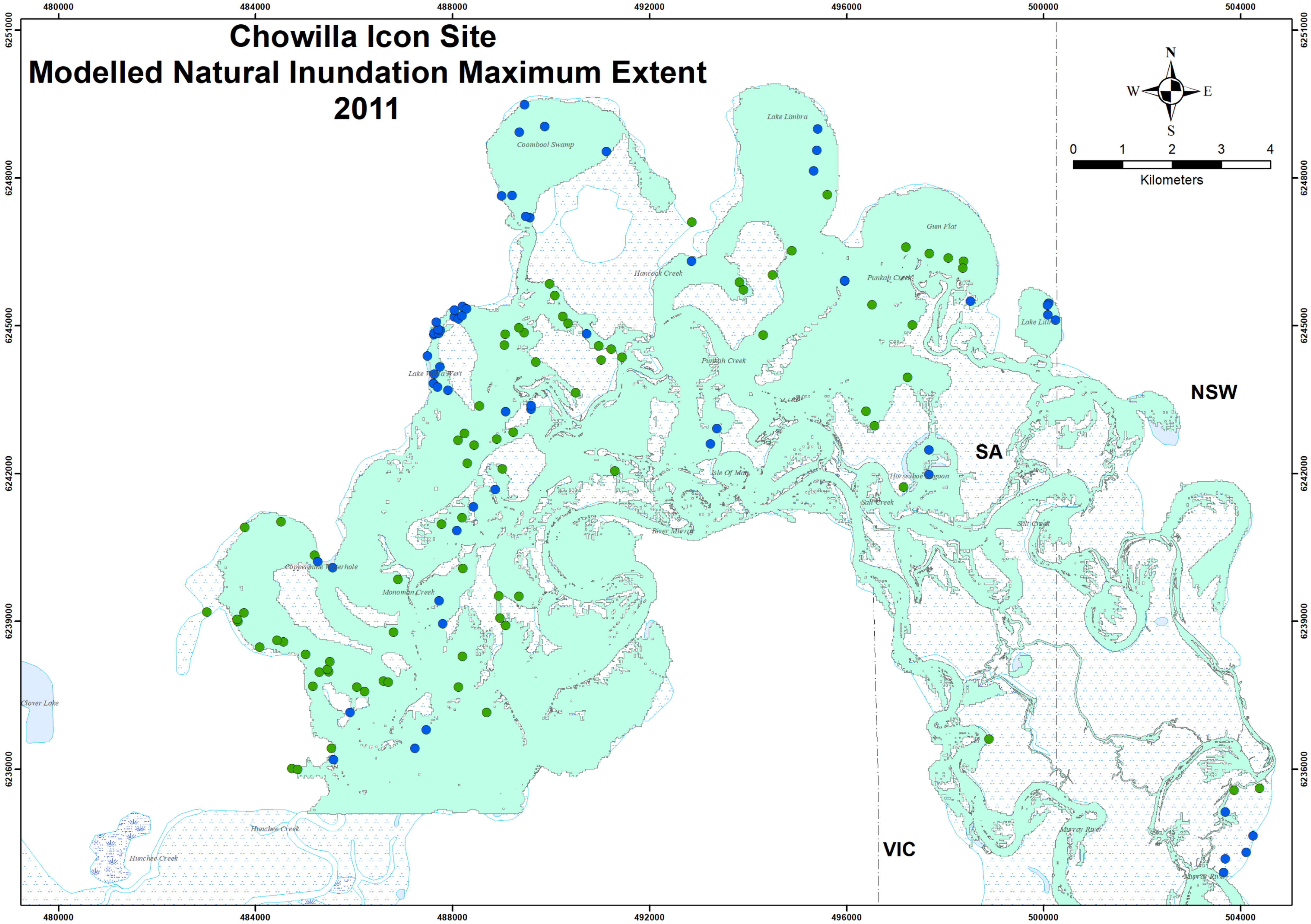
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Coombool Swamp
Gum Flat
Hancock Creek
Punkah Creek
Lake Littra
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
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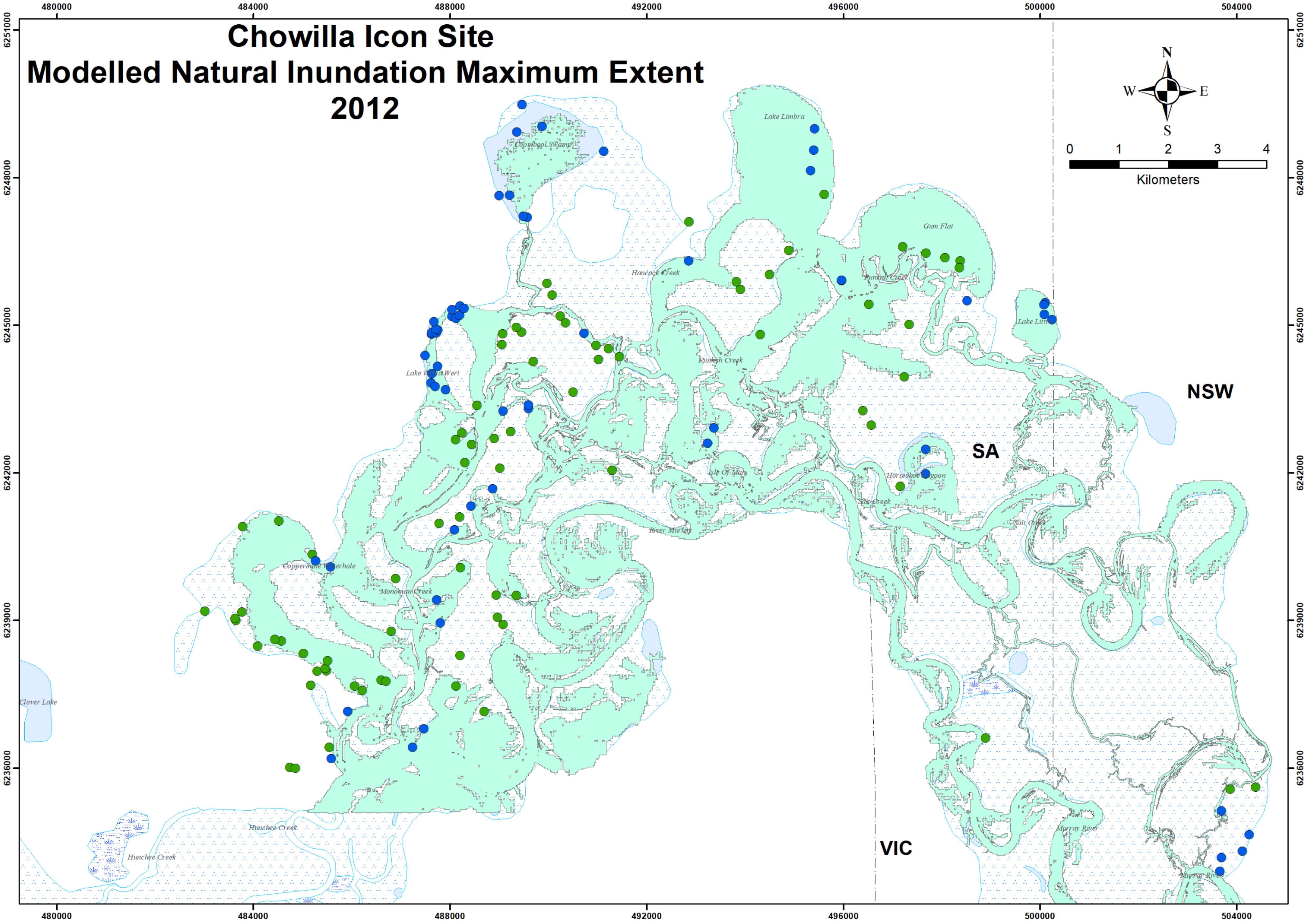
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Modelled Natural Inundation Maximum Extent
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Lake Limbra
Gum Flat
Coppermine Swamp
Hancock Creek
Punyelroo Creek
Lake Littra
Pipeclay Creek
Lake Woolpolool
Lake Merreti Weir
Isle Of Man
Horseshoe Lagoon
Salt Creek
River Murray
Coppermine Waterhole
Monoman Creek
Clover Lake
Hunchee Creek
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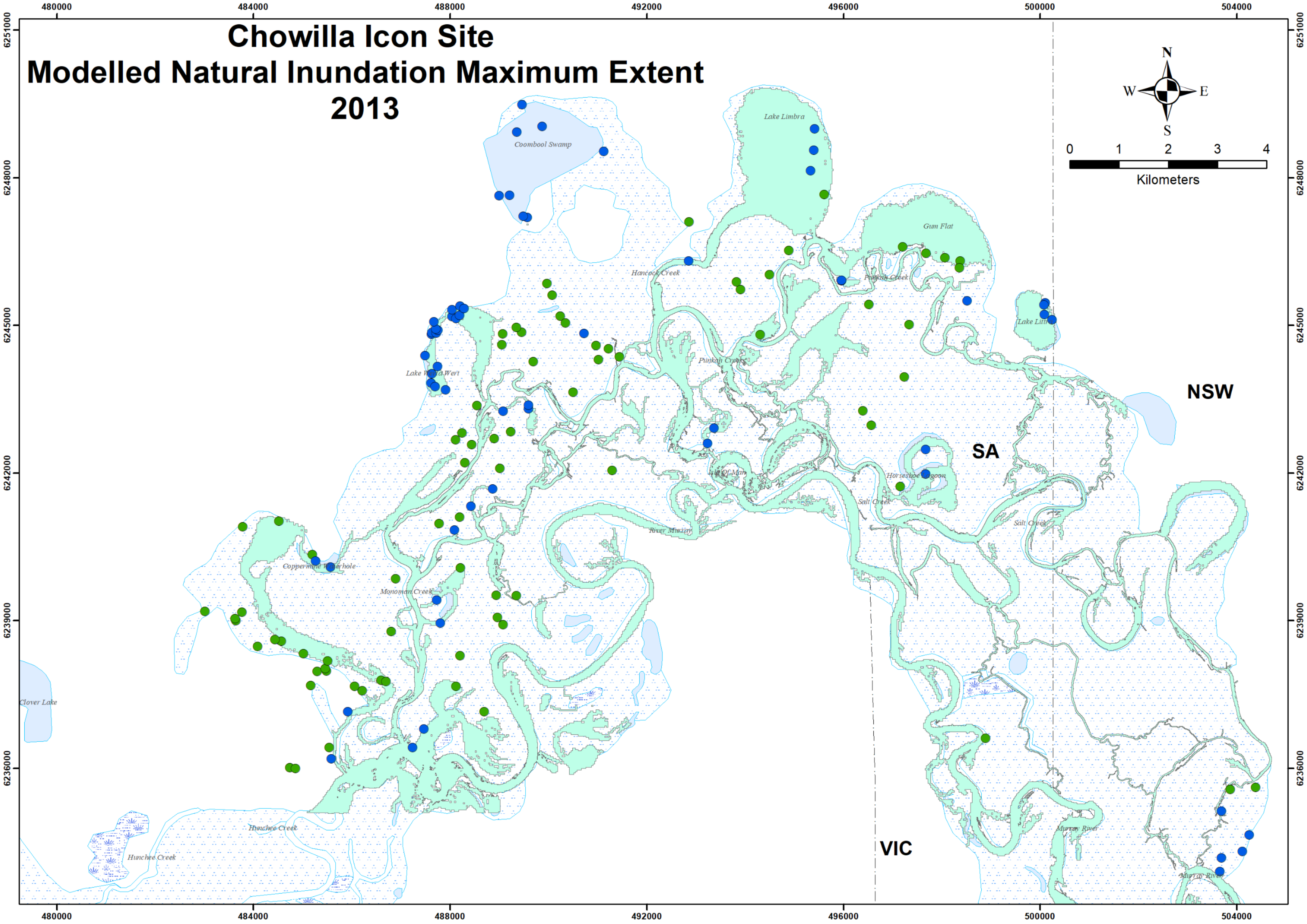
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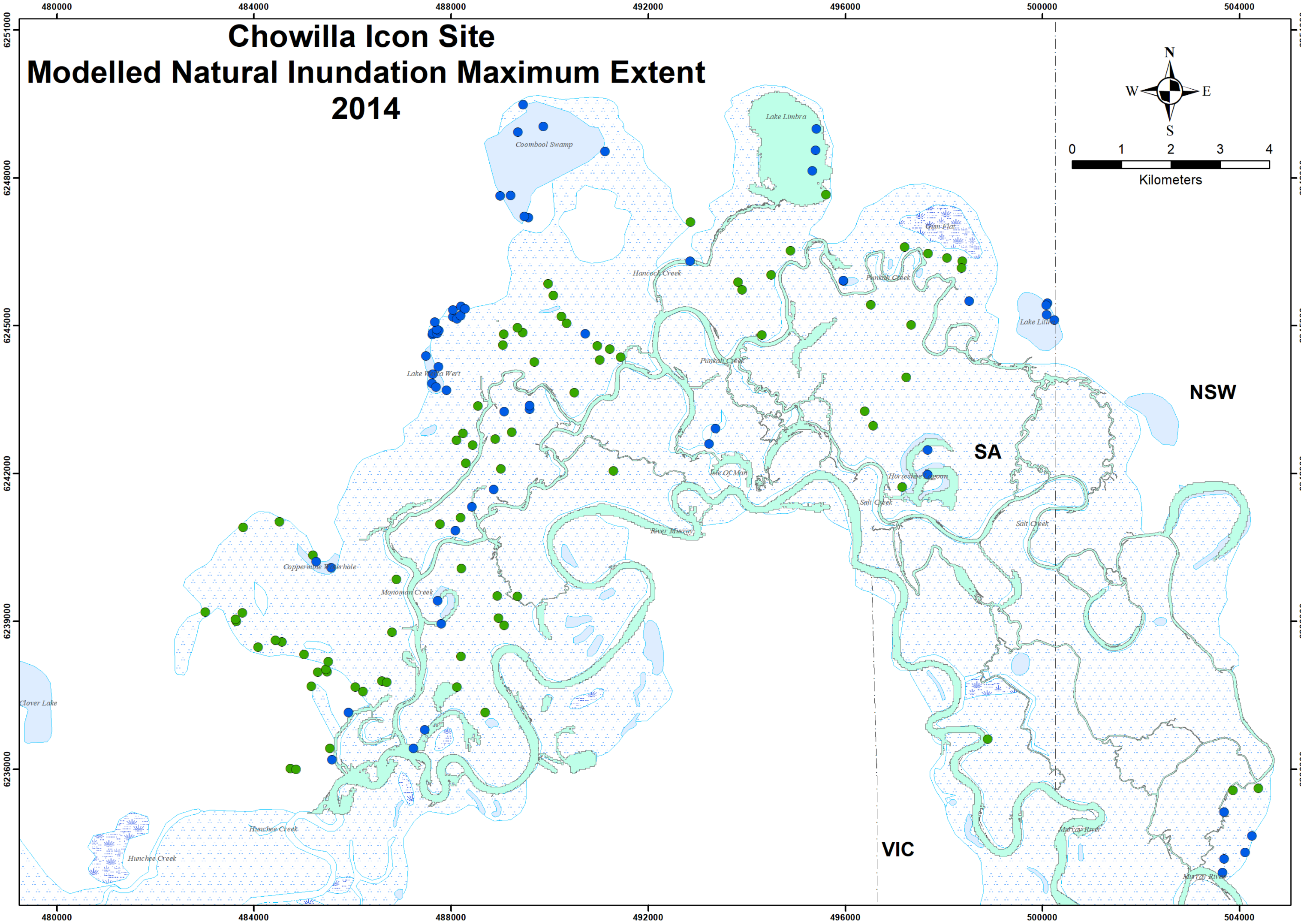

Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
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Lake Littra
Lake Woolpolool Weir
Isle Of Man
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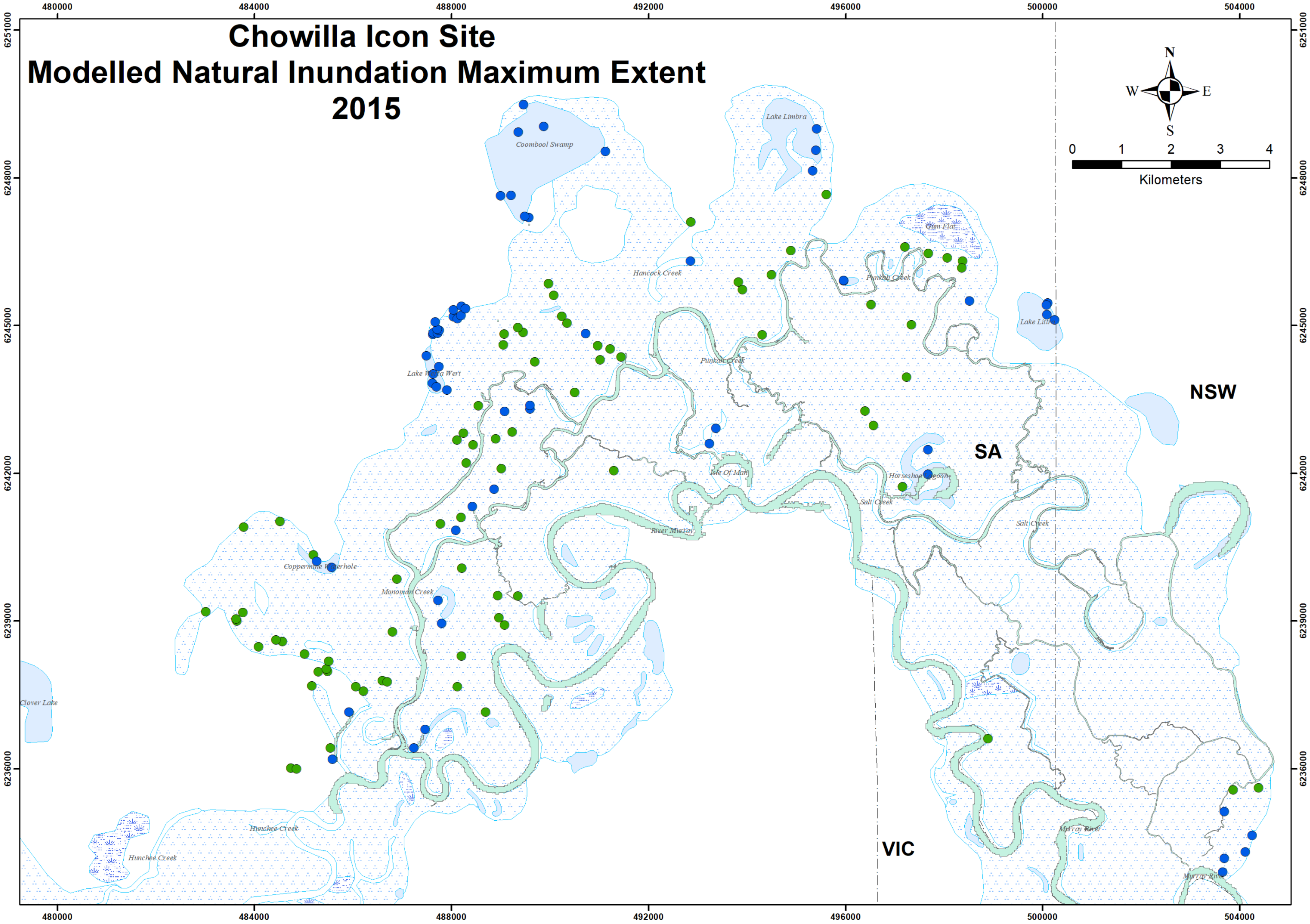
Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
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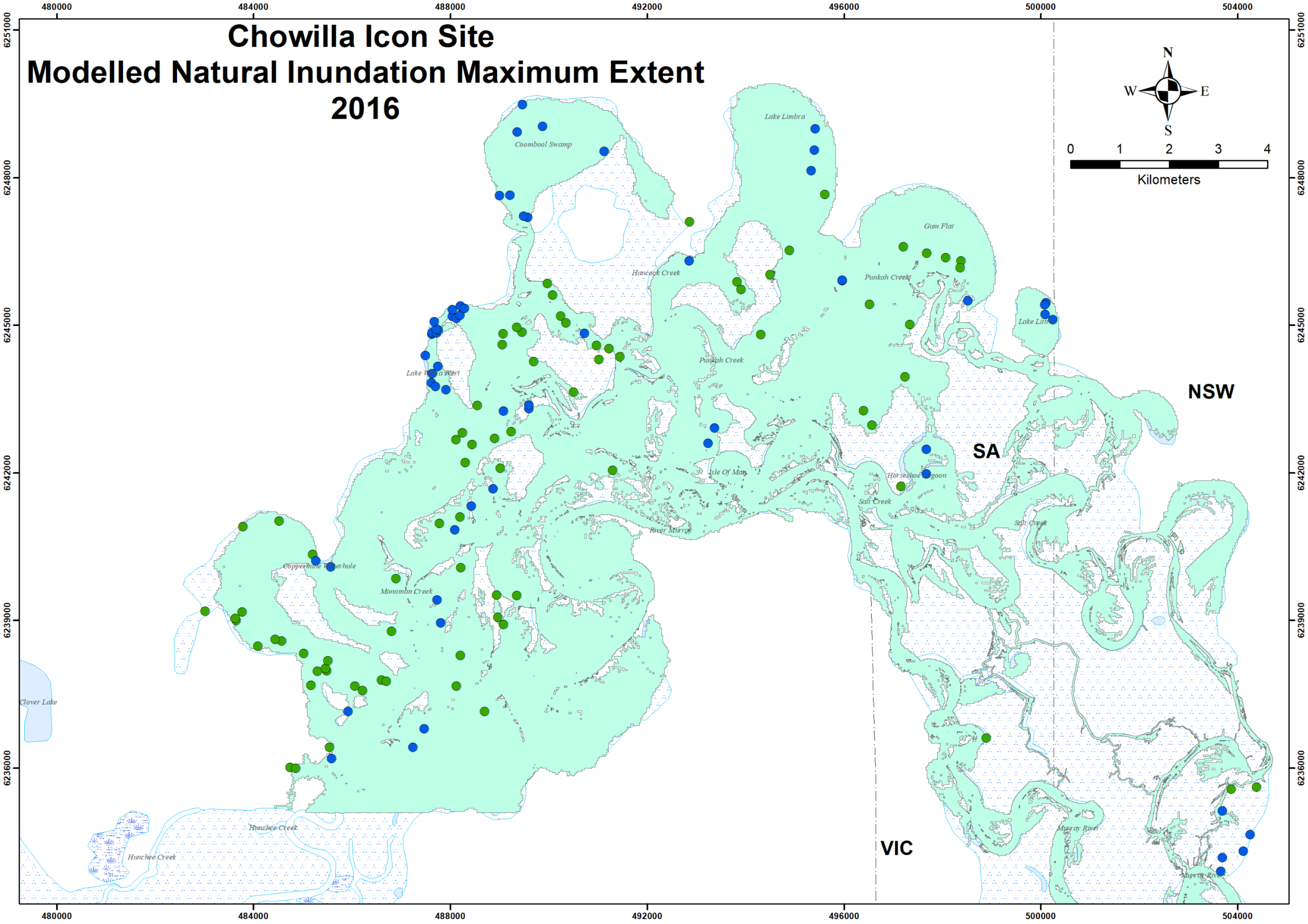
Chowilla Icon Site
Modelled Natural Inundation Maximum Extent
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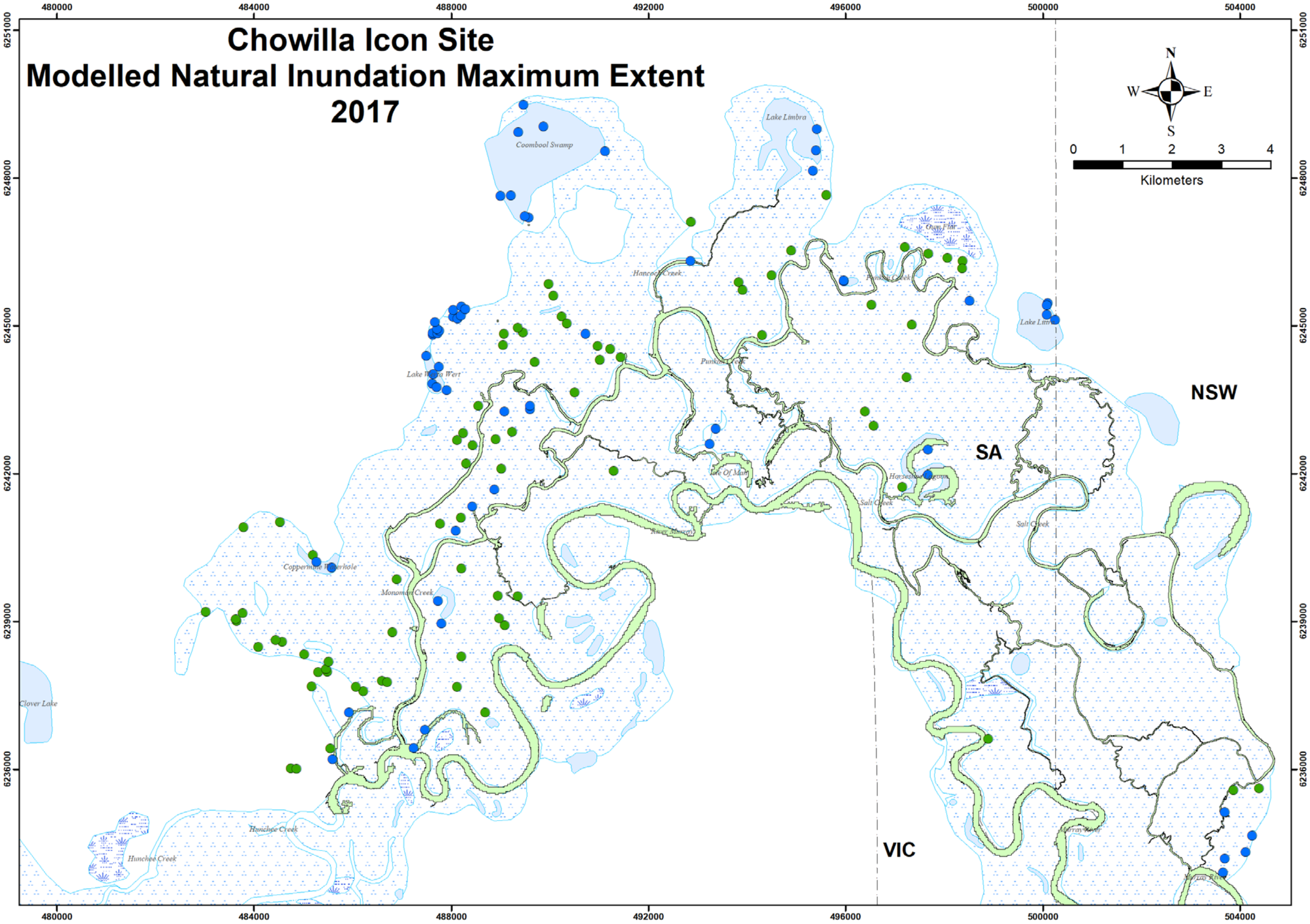
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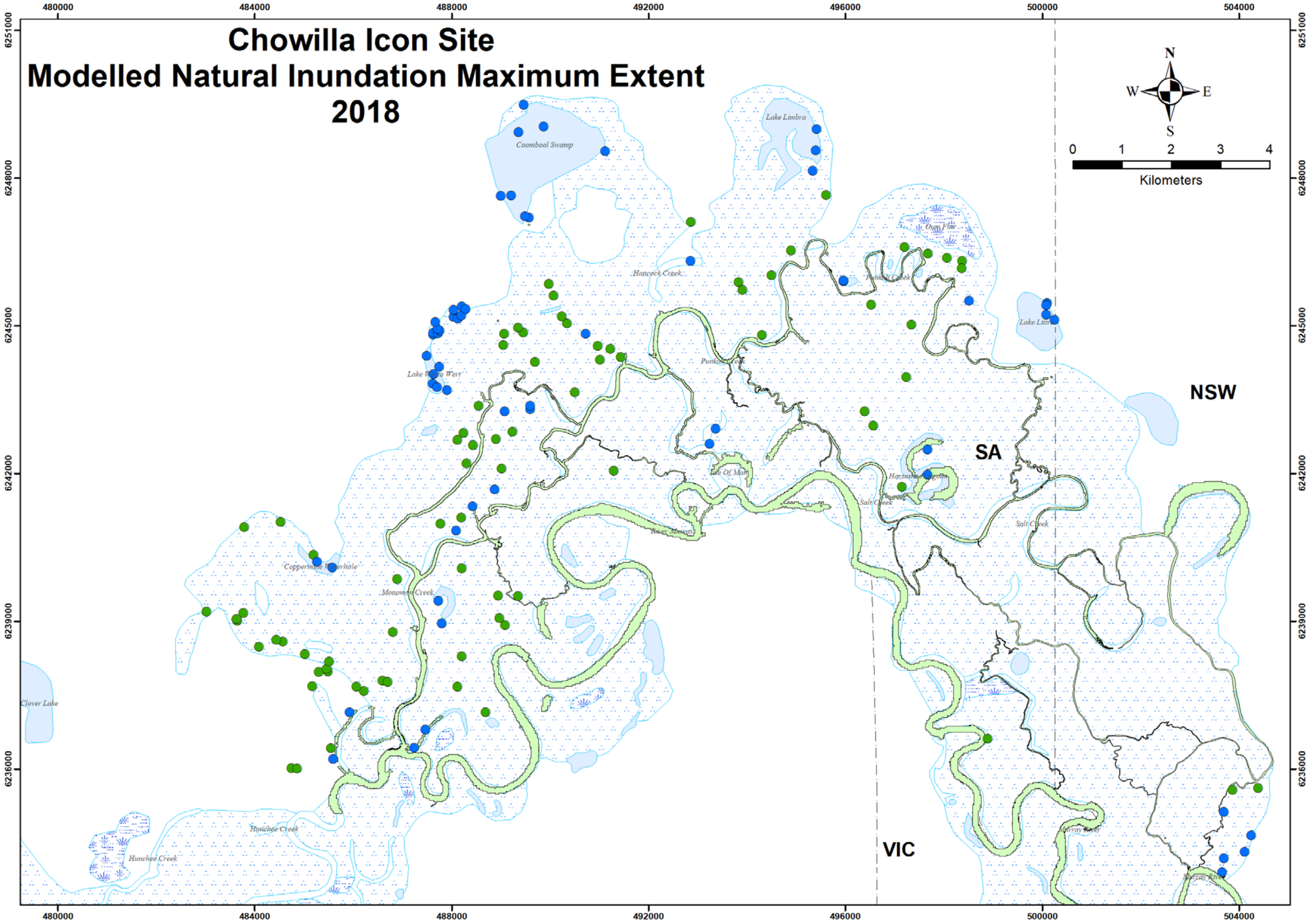
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Pipeclay Creek
Coppermine Waterhole
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Isle Of Man
Horseshoe Lagoon
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River Murray
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