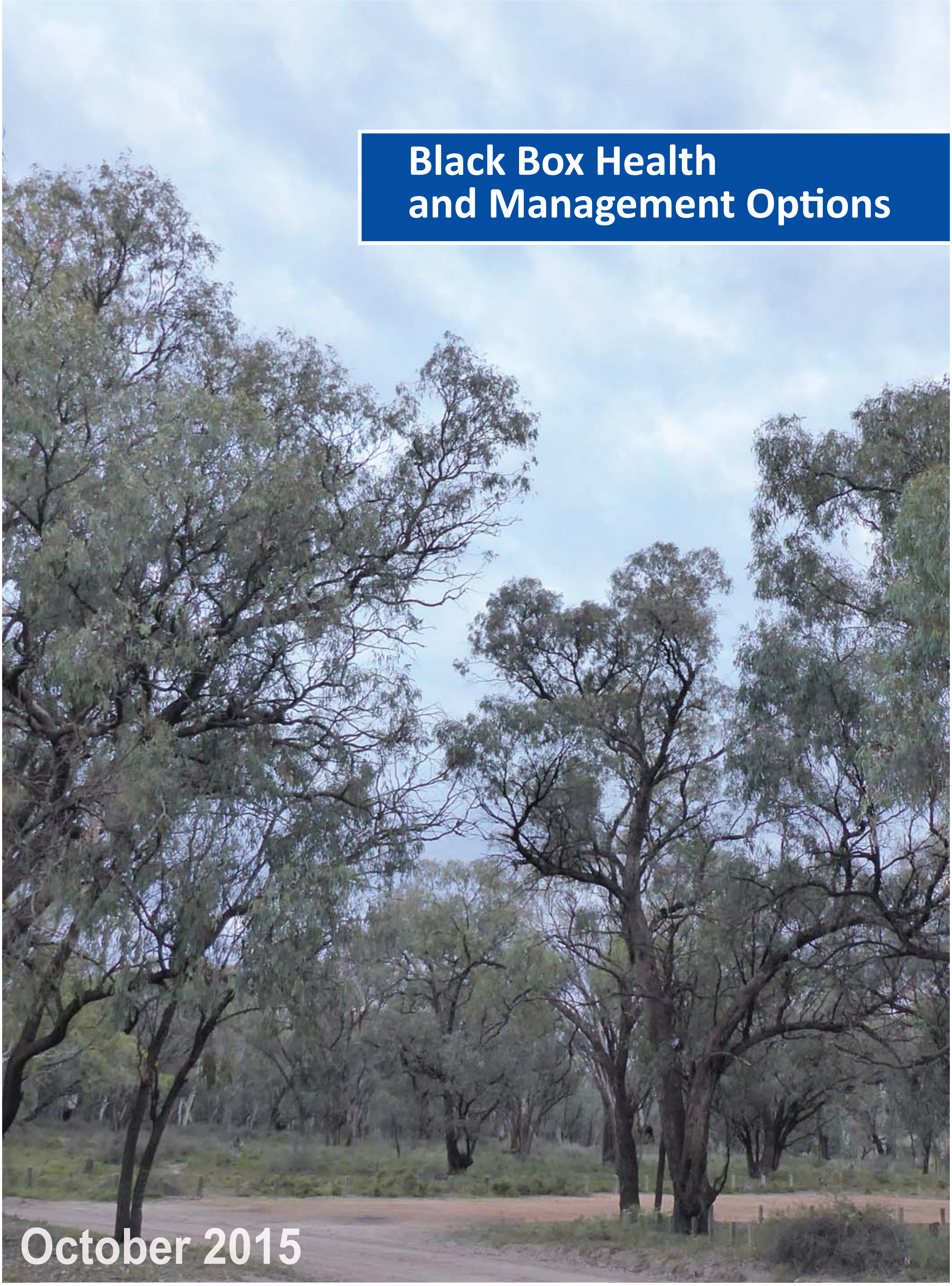
Black Box Health and Management Options



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Australian WATER Environments

Black Box Health and Management Options

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Executive Summary

The Lower River Murray floodplain supports extensive woodlands of River Red Gum and Black Box trees, with River Red Gum found on the river banks and in low-lying areas, and Black Box on the higher parts of the floodplain (Smith & Smith 2014). Unlike River Red Gums, Black Box cannot cope with anoxia during prolonged flooding (Heinrich 1990). Black Box are therefore typically located in more elevated, periodically-flooded positions on the floodplain on heavy clay soils, and along dry-lake margins (Jensen, 1983; Margules & Partners et al., 1990). There has been a serious overall decline in vegetation health along the Lower River Murray floodplain since the 1980s, and in 1988 the condition of Black Box (44% unhealthy or dead) was worse than the condition of River Red Gum (29% unhealthy or dead). It was concluded that the poor condition of the Black Box trees, coupled with poor regeneration, meant that the long-term future of this species along the Murray, particularly below the Darling Junction, was already tenuous in the late 1980s (Margules & Partners et al., 1990; Smith & Smith, 2014). The decline in vegetation health is usually linked to reductions in flood frequency (MDBC, 2003, 2005).

The Murray Darling Basin Authority's Environmental Watering Strategy in relation to Black Box aims to maintain the current extent of forests and woodlands, prevent a decline in the condition of these communities across the Basin, and improve recruitment, with the long term goal of diversifying the age range of trees (MDBA 2014). Another key aim of the strategy is to make the best use of environmental water by delivering it at the right time and at the right location to achieve the environmental outcomes described above (MDBA 2014). This study concludes with a Black Box Floodplain Response Model that improves our understanding of the response of Black Box to historic changes in their environment, and which leads to an improved ability to predict outcomes from management actions.

At present, the indicator usually used as the cause of decline and the predictor of improvement in Black Box health is inundation frequency.

Environmental watering by surface inundation has been employed to maintain and or improve the condition of floodplain vegetation. Managed surface inundations have been biased toward River Red Gum communities, because they occupy the lowest terraces of the floodplain where gravity flooding is easier and the inundation extent can be more easily contained using natural topographic control. Black Box communities are typically found at higher elevations on the floodplain, and this increases the cost and complexity of environmental water delivery.

Anecdotal evidence suggests that, for Black Box, the health benefits from inundation are variable. In some cases, watering has produced little short-term or long-term improvement. Black Box health response to environmental watering has not been systematically documented, and there has been little analysis of the processes which drive this change.

Soil salinity is the key indicator of Black Box health. The review also concludes that groundwater salinity is a primary driver of unsaturated zone salinity, which in turn controls vegetation health. A soil salinity of 39,000mg/L and a groundwater salinity of 22,000mg/L are proposed as separating healthy Black Box from unhealthy. Variations in the subsurface materials (e.g. clay vs. sand) have the potential to affect health patterns at the local scale.

It is considered likely that floodplain groundwater salinities are increasing after locking of the River Murray occurred. Locking has increased the permanent height of the groundwater table so that in now resides within the Coonambidgal Clay. The rate of evaporative loss from the floodplain will have increased due to two separate processes – a shallower depth to water will increase the rate of evaporative loss, and the water table being permanently in the Coonambidgal Clays will have significantly increased the rate because of the significantly larger extent of capillary rise. Soil and groundwater salinity will therefore increase, leading to vegetation health decline.

Groundwater salinity and flood frequency appear to jointly contribute to the health outcomes for Black Box trees. Where groundwater salinity is well below the threshold value, Black Box tend to be very healthy irrespective of the flood frequency. Inundation frequency becomes more important as groundwater salinity increases toward and past the threshold value.

The recharge rates through the higher terraces where Black Box occur is around 1mm/d. This low infiltration rate limits the amount of water that is available to Black Box once watering ceases. Under these conditions, perhaps only 10% of the water applied. Therefore, surface inundation alone may not be enough to achieve the long term outcomes outlined in the Murray Darling Basin Authority's Environmental Watering Strategy.

Groundwater pumping at Bookpurnong has been successful in drawing River water into the aquifer and reducing the salinity of the overlying unsaturated zone. The volume of the low salinity lens at Bookpurnong is equivalent to around 22% of the pumped volume (AWE 2015, 2015c), which is higher than preliminary estimates for surface inundation. The calculated conversion efficiency from both surface and groundwater sources will vary through space.

Temporal change in groundwater salinity is proposed as a primary cause of Black Box health decline, along with reductions in flood frequency. If a slow but persistent rise in groundwater salinity is occurring as a result of Locking, and this trend is not addressed, then the prognosis for Black Box communities along the River is poor. Groundwater manipulation strategies need to be considered, as well as surface water manipulation strategies, to achieve the MDBA Environmental Watering Strategy outcomes for Black Box.

The findings from this project indicate that long-term slow increases in groundwater salinity are a key factor in long term Black Box health decline, along with changes in flood frequency. Management strategies for Black Box need to address and reverse this long history of gradual change. The scale of management strategies need to extend beyond targeted floodplain inundation and annual projects inundating individual wetlands if the associated long term ecological outcomes under the Basin-wide Environmental Watering Strategy are to be realised. Management strategies will need to consider interventions and outcomes over both short and long timeframes, and extend in scale from individual wetlands to the landscape scale.

This report identifies a range of new groundwater management strategies to complement the current strategies that target surface inundation of individual wetlands or wetland groups. The new strategies focus on management options that aim to directly influence groundwater and soil salinity. These include groundwater pumping, water injection into the aquifers (managed aquifer recharge), and passive infiltration galleries or wells to drain surface water into the aquifers. The groundwater management strategies range from proven technologies to feasible concepts. These groundwater management strategies could be complemented by changes to River Murray system operations, for example seasonal lowering of weir pools.

This new perspective of groundwater management opens up not only new watering techniques, but also provides the opportunity to develop and refine tools to better understand and quantify the drivers of Black Box health and their responses to watering, by considering indicators relating to groundwater processes as well as indicators relating to surface water processes. To that end, a new GIS-based tool is proposed that collates existing GIS data on the predictors of health (which have been identified in this report), and combines the GIS indicator data with expert knowledge of watering outcomes. At first, this will be used to evaluate the benefits of historic actions, and then lead to a predictive tool for assessing management strategy outcomes. This will support the development and assessment of proposals for the effective and efficient use of environmental water and funding, and will become increasingly useful as the management strategies diversify. Key data gaps and monitoring strategies have been identified.

1 Introduction

1.1 Background

Floodplains of the Lower River Murray play an important role in the ecological health of the River system, and their declining condition has been well documented. This recognition has highlighted the need for dynamic floodplain management strategies to maintain and improve the health of the River Murray corridor.

The Murray Darling Basin Authority's Basin-wide Environmental Watering Strategy aims to achieve the best environmental outcomes from the increased amount of water made available through the Basin Plan (MDBA 2014). The Environmental Watering Strategy documents the outcomes expected from environmental water delivery. In the case of Black Box trees, the expected outcomes include maintaining the current extent of forests and woodlands, preventing a decline in the condition of these communities across the Basin and improving recruitment, with the long term goal of diversifying the age range of trees. Another key aim of the strategy is to make the best use of environmental water by delivering it at the right time and at the right location to achieve the environmental outcomes described above (MDBA 2014).

Environmental watering by surface inundation has been employed along the Lower River Murray as a management tool to maintain and or improve the condition of floodplain vegetation. Surface watering aims to achieve this by increasing soil moisture availability, reducing soil and groundwater salinity, triggering seed germination and supporting recruitment.

To date, vegetation health improvements from environmental watering have been variable. In some cases, watering has produced little short-term or long-term improvement. In cases where environmental watering has produced successful ecological outcomes, there has been little analysis of the mechanisms which drive this change. The conclusions regarding improvements in health are largely correlative (i.e. water was applied and vegetation health improved) rather than causative (i.e. A caused B which caused C). Whilst it is generally accepted that surface watering is important for seed germination, the long term effectiveness of surface watering in providing benefits to mature trees by increasing soil moisture and reducing soil and groundwater salinity has been largely unquantified. Additionally, the response of groundwater salinity to surface watering, and the influence of groundwater on unsaturated zone salinity is rarely considered.

1.2 Aims and Outputs

The aim of this project is to evaluate the influence that groundwater salinity exerts on environmental watering outcomes, through literature review, collation of empirical data, and collection of additional field data. From this review, the study aims to identify indicators that can be used to predict ecological outcomes for Black Box vegetation from watering at new or existing sites.

The key delivery outputs are:

- An evaluation of the influence of groundwater and groundwater salinity on vegetation health;
- An evaluation of the influence of environmental watering on groundwater and groundwater salinity; and

- Identification of indicators that can be used to predict ecological outcomes (specifically tree health improvement) from environmental watering, with particular reference to Black Box vegetation.

The findings of the literature review lead to a better definition of the Floodplain Response Model, and this and the field data collection has caused the authors to reconsider the common assumption regarding the cause of declines in health. We conclude with a new specific variant on the Floodplain Response Model (the Black Box Floodplain Response Model) that seeks to better inform the selection of management options for maintaining and improving Black Box health outcomes.

Recommendations are outlined that support improvements in management strategies, through targeted data collection, improved conceptualisation of key processes, and through field trials of groundwater manipulation strategies.

1.3 Conceptual Model of Floodplain Response to Water Management

A conceptual model describing the relationship between water management (e.g. surface water inundation or groundwater manipulation) and floodplain response (i.e. soil and groundwater salinity and tree health responses) is presented in Figure 1.1 (the Floodplain Response Model). The soil salinity in the unsaturated zone is represented by dots: blue for “fresh” and red for “saline”. The groundwater salinity is represented by solid colour: blue for “fresh” and red for “saline”.

The Floodplain Response Model illustrates the key relationships between water management (i.e. groundwater and surface water management), soil salinity and groundwater responses and tree health response. In summary, the Lower River Murray Floodplain is generally a saline environment, both in the groundwater and in the unsaturated zone. Surface water manipulation strategies have the potential to introduce low salinity water into the unsaturated zone and perhaps influence the salinity of the saturated zone (i.e. the groundwater). Groundwater manipulation has the potential to introduce low salinity water into the aquifer, and from there perhaps influence the salinity of the overlying unsaturated zone.

An improved understanding of the relationships between water management and soil salinity, groundwater salinity and vegetation health response is critical to achieving management goals and ecological objectives.

The Floodplain Response Model underpins the report structure. In Figure 1.1 the letters in the key processes (yellow arrows) reflect key data or knowledge gaps in the Floodplain Response Model. The key questions for each of the labelled arrows are detailed below. The questions are addressed in later Chapters.

- Part A: How much water do plants use?
- Part B: What are the saturated and unsaturated zone salinity thresholds for River Red Gum and Black Box trees?
- Part C: Can low salinity lenses be created using groundwater management strategies?
- Part D: How effective are low salinity lenses in reducing the salinity of the overlying unsaturated zone?

- Part E: How effective is surface watering in increasing the availability of low salinity soil moisture in the unsaturated zone?
- Part F: How effective is surface watering in emplacing low salinity lenses?

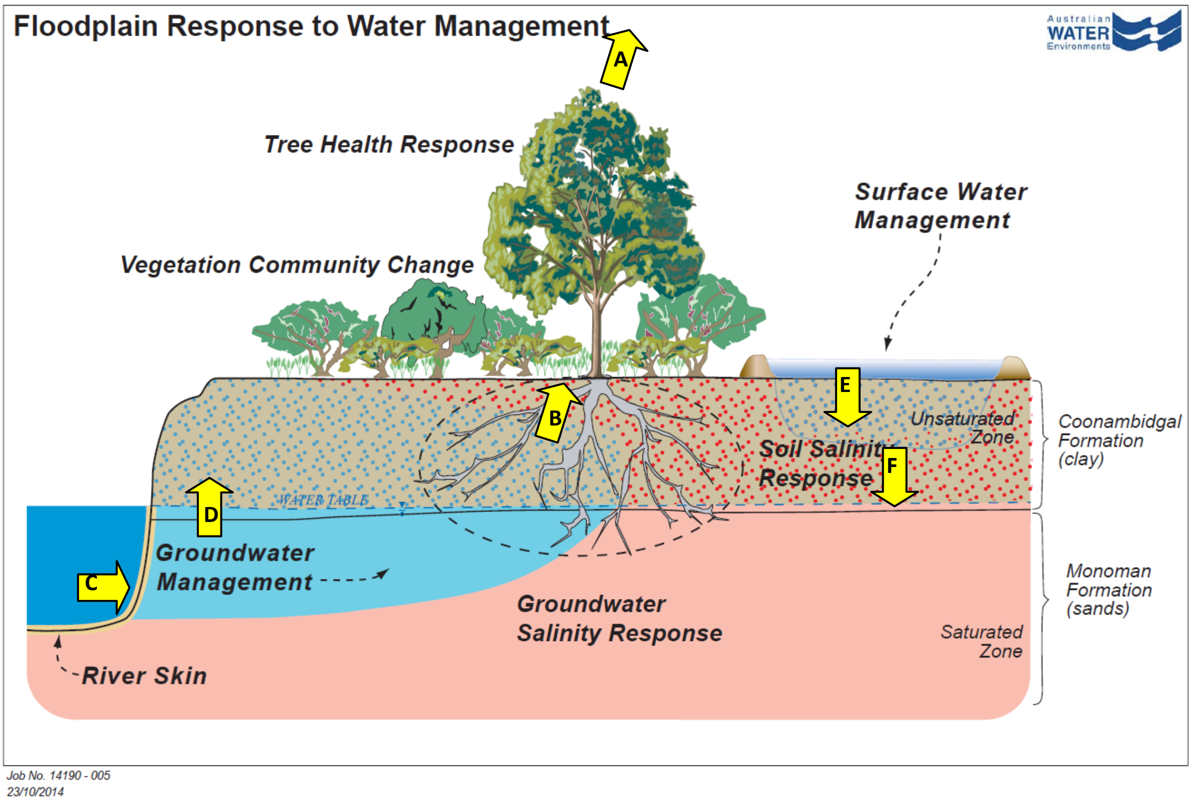


FIGURE 1.1: FLOODPLAIN RESPONSE MODEL

1.4 Report Structure

A flow chart of the report structure is provided in Figure 1.2.

Chapter 2 summarises the documented decline in Black Box health and is presented with a review of water needs, water sources and salinity thresholds for River Red Gum and Black Box trees. A review of factors which may be contributing to this decline is also presented and includes factors that are currently considered (e.g. flood frequency) as well as factors that are not commonly considered (e.g. groundwater salinity).

Chapter 3 introduces the water management strategies that have been applied in the Murray Darling Basin to improve floodplain vegetation health. This section also introduces the floodplain site characteristics that influence the outcomes of floodplain management and may be used as indicators for management level review to target the delivery of environmental water. Chapter 3 provides a review of the current state of knowledge for each indicator and details the importance of each indicator in assessing or predicting the influences of key process on outcomes of floodplain management.

Chapter 4 documents outcomes from the implementation of surface water and groundwater management actions, providing examples of where groundwater and soil salinity responses have been quantified.

The site indicators are applied to five floodplain sites within the Mallee CMA region in Chapter 5, where variable responses to environmental watering have been observed. The aim of this section is to test the relationship between groundwater salinity, soil salinity and vegetation health using new monitoring data collected at each of the floodplain sites. This section then applies the key process indicators at each site, to evaluate the success, or otherwise, of previous environmental watering and to identify sites where the application of groundwater manipulation strategies may provide beneficial outcomes.

In the Conclusions (Chapter 6), the general Floodplain Response Model is extended to derive a specific Black Box Floodplain Response Model.

Recommendations are provided in Chapter 7.

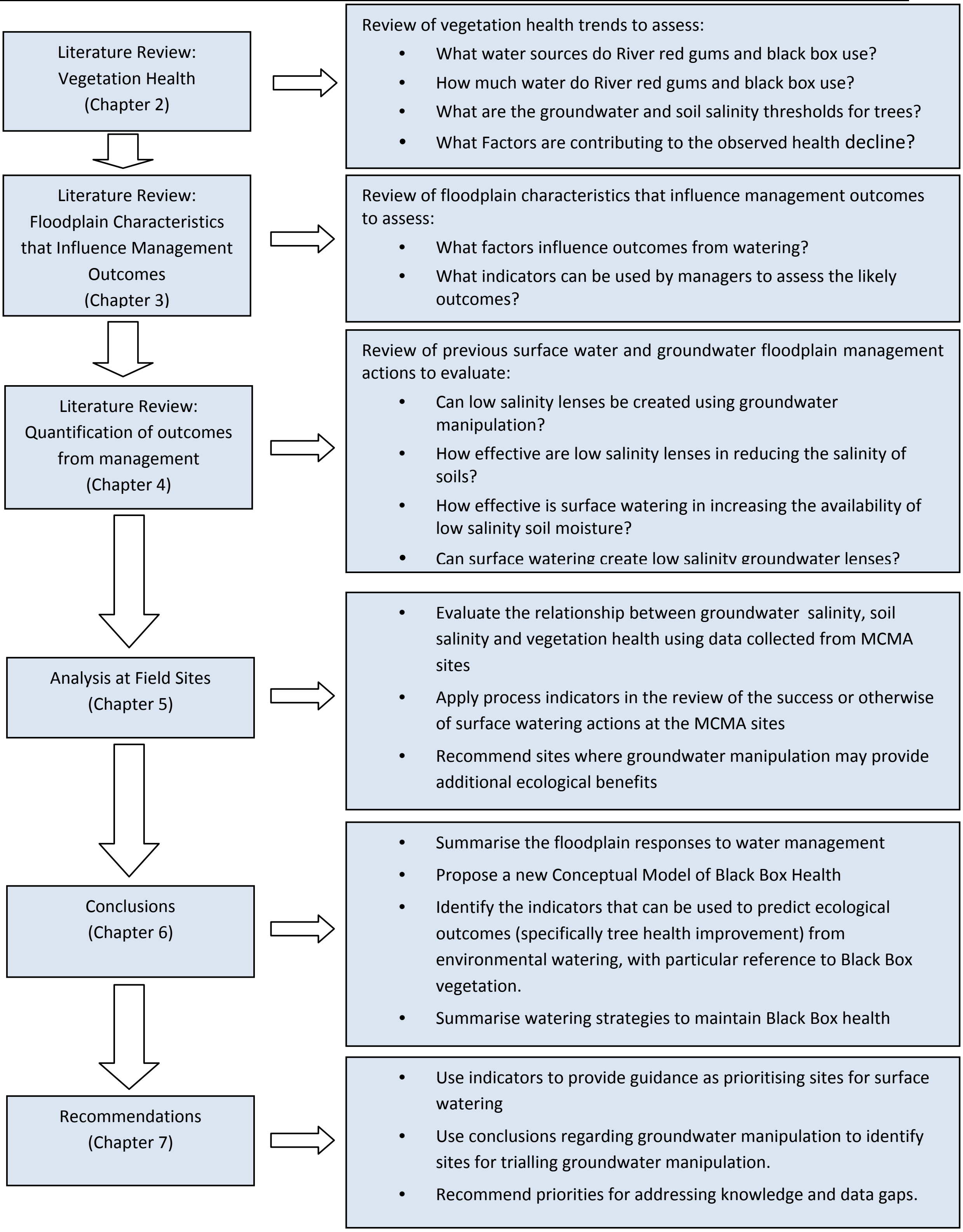


FIGURE 1.2: REPORT STRUCTURE

2 Literature Review: Health Trends, Water Needs and Salinity Thresholds

Summary:

Black Box health is poor, and declining, in the Lower River Murray floodplains.

- Although Black Box trees can survive at relatively high groundwater salinities, vegetation vigour can begin to decrease at moderate groundwater salinities, especially where the water table is shallow. Periodic access to low salinity groundwater or surface water is essential.
- The primary water source for Black Box trees is soil moisture from the unsaturated zone. The soil moisture in the unsaturated zone can be sourced from surface water infiltration, rainfall, or groundwater.
- The influence of soil salinity on Black Box health, and associated tolerance thresholds is not well established in current literature. The upper limit of groundwater salinity underlying healthy Black Box may not be a good metric for a management threshold. The 75th percentile for soil and groundwater salinity provides a better metric as an indicator for salinity conditions that support healthy trees.
- Flood frequency and duration are commonly cited as the cause of Black Box health decline. While correlations exist between flood frequency and health trends, causality is not demonstrated.

The correlations and/or causality between temporal trends in groundwater salinity and trends in Black Box health have not previously been considered.

2.1 Black Box Distribution and Associations

The floodplain of Lower River Murray supports extensive woodlands of River Red Gum and Black Box trees (Myrtaceae: *Eucalyptus camaldulensis*, *E. largiflorens*), with a shrub understorey of tangled lignum (Polygonaceae: *Muehlenbeckia florulenta*) (Margules & Partners *et al.,* 1990). These two eucalypt species dominate the vegetation of the River Murray floodplain, with River Red Gum found on the River banks and in low-lying areas, and Black Box on the higher parts of the floodplain (Smith & Smith, 2014).

The distribution of Black Box trees on the floodplain is strongly linked to elevation. Black Box trees are typically located on heavy clay soils, in more elevated, periodically-flooded positions on the floodplain, and along dry-lake margins (Jensen, 1983; Margules & Partners *et al.,* 1990). Black Box trees occur at floodplain elevations typically with flood frequencies of 1 in 5-10 years. Unlike River Red Gums, Black Box cannot cope with anoxia during prolonged flooding (Heinrich, 1990). Above the elevation where flooding occurs, Mallee species dominate.

The distribution of Black Box seedlings and a narrow belt of mature trees indicate the outer limits of larger floods and the extreme edge of the floodplain (Cunningham *et al.,* 1981; Jensen, 1983; Slavich *et al.,* 1999). They may also be found on the slopes of minor sandy rises, where favourable seed bed conditions have occurred after a flood and seedlings have survived to maturity (O'Malley & Sheldon, 1990). It usually forms open woodland stands, where canopy cover is less than 30% (Roberts & Marston, 2000). Along the Murray Valley, the reaches with highest numbers of Black Box compared to River Red Gum are the Wallpolla, Chowilla, Murtho and Ral Ral reaches (MDBC, 2005).

Height of Black Box trees varies, and erectness and vigour are dependent on water availability. Heights on the Chowilla floodplain have been measured in the range 3-21m, with the tallest trees associated with frequently flooded sites (Roberts & Marston, 2000). The diameter or height of Black Box trees is not a good indicator of age (George, 2004) because growth rate is linked to water availability. For example, a cohort of regenerants from 1956 at Coppermine Waterhole on the Chowilla floodplain have a height < 4 m and DBH <20 cm (Jensen pers. obs., 2006).

For Black Box communities, there is a major division between the communities of the higher parts of the Black Box zone (characterised by the perennial saltbushes, *Atriplex rhagodioides*, *A. nummularia* and *A. vesicaria*) and those of the lower parts (characterised by Lignum *Muehlenbeckia florulenta*, also including the uncommon *E. largiflorens-Melaleuca* communities, which grow on higher ground) (Smith & Smith, 2014). The lower subgroup also includes the *Dodonaea-Callitris* community of the rises, while the higher subgroup includes the samphire *Tecticornia* spp. community of the most saline sites.

There is also a division between the South Australian Black Box communities (e.g. the *E. largiflorens-Muehlenbeckia-Atriple*x and *E. largiflorens-Atriplex rhagodioides* communities) and their counterparts across the border in New South Wales and Victoria (the *E. largiflorens-Muehlenbeckia-Chenopodium* and *E. largiflorens-Atriplex nummularia* communities). The reason for this spatial division in understory communities is unclear (Smith & Smith, 2014).

Black Box communities on the higher elevations of the Lower River Murray floodplain are generally found on cracking grey clays with low transmissivity. Regional groundwater salinity is typically high (55,000 µS/cm or ~35,750mg/L), and the watertable is often less than 4 m below the soil surface, thus very close to the root zone of mature Black Box trees (Sharley & Huggan, 1995). Temporary low-salinity groundwater lenses can develop at the base of the unsaturated zone and over-lying the highly saline regional groundwater, providing an alternative water source between flood events.

2.2 Black Box and River Red Gum Health Trends

There has been a serious overall decline in vegetation health along the Lower River Murray floodplain since the 1980s (MDBC, 2003, 2005). A survey of tree health in 1987-88 found that poor tree health was already evident along the River at that time, with a geographical pattern of worsening condition in a downstream direction (Margules & Partners *et al.,* 1990; Smith & Smith, 2014). Tree health was poorest in the lower reaches below the Darling Junction, and the condition of Black Box trees (44% unhealthy or dead) was worse than the condition of River Red Gum trees (29% unhealthy or dead).

In the 1987-88 survey, eucalypt regeneration was also poorest below the Darling Junction, with regenerants present in 77% of survey plots upstream of the Darling but only 35% of plots downstream. Black Box regeneration was sparser overall, compared to River Red Gum regeneration (regenerants present in 69% of River Red Gum plots but only 29% of Black Box plots). It was concluded that the poor condition of the Black Box trees, coupled with their poor regeneration, meant that the long-term future of this species along the Murray, particularly below the Darling Junction, was already tenuous in the late 1980s (Smith & Smith, 2014).

Black Box are more drought-tolerant than River Red Gums, but have been showing signs of extreme water stress since the early 2000s, although they are reputed to endure 10 years without flooding (George, 2004; George *et al.,* 2005; MDBC, 2003).

2.3 Water Requirements

2.3.1 Sources of Soil Moisture

The primary water source for Black Box trees is soil moisture from the unsaturated zone. Low salinity soil moisture in the unsaturated zone can be sourced from:

- Vertical downward recharge by inundation of the floodplain by overbank flows.
- Vertical downward recharge by infiltration of rainfall.
- Lateral recharge from surface water bodies (River or lakes) where losing stream conditions exist or through bank recharge during floods.
- Capillary rise from groundwater. The soil texture will influence the height of the capillary fringe and will be higher in clays than in sands.

The first three water sources generally add fresh water; however the salinity of the groundwater is variable. Therefore, the relative contribution of groundwater to the water balance of the trees will be controlled by the salinity tolerances of the trees, and perhaps also by soil texture.

Groundwater extracted from the capillary fringe can be an important water source for both River Red Gum and Black Box species¸ but lack of oxygen prevents vegetation water use from below the water table (Holland *et al.,* 2006; Mensforth *et al.,* 1994). However, this needs to be tempered with anecdotal visual observations of tree roots below the water table.

It has been demonstrated that Black Box are opportunistic in water use, and can switch between water sources, providing that they have developed suitable coverage in their root systems (Roberts & Marston, 2000; Holland *et al.,* 2006). Black Box trees can subsist on soil water during prolonged dry periods (Slavich *et al.,* 1999), but are stressed by saline groundwater (>40,000 µS/cm or ~26,000mg/L) within 2 to 4m of the surface (Sharley & Huggan, 1995).

Research on River Red Gums on the Yanga floodplain of the Lowbidgee in New South Wales found that the primary water source is moisture in the top 1m of the soil profile, with the tap root system operating as a back-up (Doody, pers comm., 2014), and it is likely that Black Box has a similar primary reliance on access to soil moisture in the unsaturated zone.

Mensforth et al (1994) investigated the water sources used by River Red Gum trees in summer and winter. The study focused on trees located between 0.5m and 40m from the edge of a River where underlying groundwater salinities ranged between 30,000 µS/cm (~19,500mg/L) and 50,000 µS/cm (~32,500mg/L). The study concluded that River Red Gum trees located more than 15m from the edge of the River did not use water from the River. Instead, trees used groundwater in summer and a combination of groundwater and rain derived surface soil water (0.05 - 0.15m) in winter (Mensforth et al. 1994).

Similarly Holland et al. (2006) investigated the water sources used by Black Box trees during summer at three floodplain sites where groundwater salinities exceeded 40,000µS/cm (~26,000mg/L). The study concluded that Black Box trees used low salinity soil water deep in the soil profile. Holland et al. (2006) used isotopic techniques and water potential measurements to infer the source of recharge for low salinity, deep soil water. This analysis suggested that low salinity deep soil water was recharged vertically by direct infiltration of rainfall and flood waters, where trees were growing in small depressions or where soils were sandier at the break of slope. The study also concluded that bank recharge was also an important source of low salinity water for trees growing within 50m of surface water bodies.

Doody et al. (2009) assessed the response of Black Box, River Red Gum and cooba trees to groundwater pumping from The Living Murray Production Bore on the Bookpurnong floodplain. Tree water use and water stress were assessed using sap flow, pre-dawn water potentials and isotopic analysis, before and after groundwater freshening had occurred, due to pumping. Within The Living Murray Transect it was found that prior to pumping, mature trees typically used soil water from 0.5 to 3m in the profile with some additional water use from groundwater and surface water sources. Following pumping, it was found that mature trees typically used soil water from deeper in the profile (2.5 to 5m) which coincided with a significant decline in groundwater salinity (Doody et al. 2009). It was concluded that the open mixed forest lining the River Murray, that had access to low salinity groundwater, used five times more groundwater and maintained greater canopy vigour in comparison to monitoring sites located inland. Black Box trees demonstrated reduced plant water stress, but no increase in transpiration, where groundwater salinity declined and the water table was lowered (marginally) as a result of pumping. At another site where SIS pumping had lowered the water table but no groundwater freshening occurred, Black Box trees did not show any change in plant water stress (Doody et al. 2009).

A recent study demonstrated the extreme variability of isotope values in samples taken at nine sites within a 3m*3m grid (Telfer, 2014), highlighting that any analysis and conclusions based on single sites where isotopic results are extrapolated more than a few metres need to be viewed with caution.

Additional information regarding the soil moisture needs for germination, recruitment and regeneration is presented in Appendix A.

2.3.2 Flood Frequency and Duration

The marked decline in general biodiversity and condition of floodplain species has usually been attributed to the reduced frequency and duration of floodplain inundation, particularly the smaller, more frequent floods (Walker & Thoms, 1993; Walker *et al*., 1994, MDBC, 2003, 2005; Walker, 2006). River regulation along the Lower River Murray has eliminated small floods (up to 1 in 7 year frequency; 25-40,000 ML/d) and reduced the frequency and duration of medium floods (up to 1 in 20 year; 40-60,000 ML/d) (Walker & Thoms, 1993; Maheshwari *et al.,* 1995; Roberts, 2004; Walker, 2006). The primary cause of the decline in vegetation health is usually attributed to removal of smaller higher frequency floods, reducing the primary source of water for these communities, but salinisation and grazing are also locally significant factors (MDBC, 2003, 2005; Walker & Thoms, 1993; Walker, 2006).

The extremities of the floodplain (e.g. Rotten Lake on the Chowilla Floodplain) have not been flooded since 1956. The Black Box communities at the highest elevations on the floodplain have not been flooded since the mid-1970s. The last effective inundation of Black Box communities at intermediate elevations occurred in 1993, with a flood peak of 110,000 ML/d. A minor flow in 1996 peaked at 62,000 ML/d in December with over-bank flows lasting for four weeks, providing limited benefits to lower elevations of the floodplain. The Millennium drought resulted in 14 years (from 1996) without any effective over-bank flooding in the Lower River Murray Valley. Large numbers of River Red Gum and Black Box trees became visibly stressed from 2000 onwards. Surveys of vegetation health were conducted in 2002 and again in 2004. Along 700 km of the Murray Valley, from Gunbower to Mannum, stressed, dying or dead River Red Gum and Black Box trees increased dramatically in just 2 years, from 52% in 2002 to 76% in 2004 (MDBC, 2005). On the severely affected Chowilla floodplain, stressed trees rose from 54% in 2002 to 89% in 2004, with River Red Gums more affected than Black Box trees. Sampling of Black Box showed 50-88% of individual trees were stressed, dying or dead in 2004 (MDBC, 2005). Flooding has occurred in 2010 and 2012.

On the Chowilla floodplain, natural flood frequencies of 1 in 2 years have been halved (Sharley & Huggan, 1995). Floods are approximately one-third of natural volumes, occur less than half as often, and last for about one-quarter as long (Close, 1990; Jensen, 1983; Thoms *et al.,* 2000). Dry phases, once-rare, are now a common occurrence, with man-induced drought occurring 1 in 2 years compared to the natural frequency of 1 in 20 years.

A recent assessment of tree condition in the mid-Murray Valley suggested a general trend of declining condition with distance downstream from Hume Dam, correlated with an increasing decline of flood frequency due to regulation (Maheshwari et al. 2005), and lower average rainfall (Cunningham *et al.,* 2007). The study suggested that current watering regimes in the mid-Murray (including both rainfall and flooding) are insufficient to maintain River Red Gum communities in good condition. This concurs with a similar finding for River Red Gum and Black Box communities at Banrock Station in the South Australian Riverland, that the current flow regime was inadequate to provide the necessary water for the survival and maintenance of these communities (George, *et al.* 2005).

Prior to regulation, peak flows in the Lower River Murray occurred in late spring and early summer (Oct-Dec). Hydrological data for Morgan (320 km from the Murray mouth) shows that peak discharge flows now occur about one month later than under natural conditions (Maheshwari *et al.,* 1995; Roberts, 2004) and is much more variable (Jensen, 2008).

The shift in seasonality of flow peaks is compounded by the loss of small floods due to flow regulation, resulting in much drier conditions on the floodplain, sufficient to trigger shifts in species distributions toward those that are less flood tolerant and more salinity tolerant, and decline in health of the endemic species (Margules and Partners *et al.,* 1990; Walker & Thoms, 1993; Roberts, 2004).

This study seeks to examine the traditional emphasis on flood frequency as the primary contributor to changes in tree health, by examining more closely the influence of groundwater.

2.3.3 Rainfall

While rainfall is an important supplementary factor which should not be overlooked, a recent study compared the effects of rainfall and flooding on soil moisture to determine their relative importance for recharge of soil moisture. This study found that flooding produced at least an order of magnitude more organic material than any rain-induced response (Baldwin *et al.,* 2013). Thus flooding is relatively much more important in the long term for generating carbon sources which persist into the following dry phase, although rain-induced pulses can assist in maintaining tree health through dry phases. Additional information regarding the role of rainfall in germination, recruitment and regeneration is presented in Appendix A.

2.3.4 Soil Moisture Needs

Limited information is available on the specific quantities of water needed to maintain Black Box and River Red Gum communities. However, the timing, frequency and duration of floods can be used to infer the natural watering regime.

Sufficient soil moisture needs to be sustained in the unsaturated zone to support growing seedlings and saplings, and to maintain mature trees during periods between floods when soil moisture is their primary source of water. The quantities required for application during environmental watering can be calculated as for irrigation of horticultural crops, taking into account soil types and antecedent conditions. For example, it is recommended that sufficient water be applied to penetrate up to 1.5m below the surface where Black Box seedlings and mature trees are growing on low permeability clays (Atkinson, pers. comm., 2014). Application rates need to be tailored to the method of application and the absorption capacity of the site being watered, to avoid surface ponding and run-off (Forward, pers. comm., 2014). For example, application rates of 25mm/d are typical for sprinkler irrigation at Bookpurnong and rates exceeding ~100mm/d result in run-off (Forward, pers. comm. 2015).

Doody et al. (2015) used plant available soil water post flooding and average rainfall to estimate the time that the soil moisture needs of River Red Gum trees would be maintained following a flood event. From this investigation at Yanga, guidelines for frequency of inundation for River Red Gums were suggested (Doody, pers. comm., 2014). For degraded River Red Gums, inundation 1 in 2 years is needed for recovery. It was suggested that a cycle of 8 years with 1 in 2 year flooding frequency is needed to recover lost transpiration from an extended period without inundation. In healthy River Red Gums, it was suggested that 1 in 5 year is sufficient to maintain health, but the frequency should never extend to > 1 in 7 year. Leaf area index should not fall below 0.5 for extended periods and annual evapotranspiration should be > 550 mm (Doody, pers. comm.. 2015). There was a lag of 2 months before vegetative responses to watering could be detected.

Readings of soil moisture for a site with germinated seedlings on the Chowilla floodplain June 2005 -- June 2006 peaked at 38% in July 2005 (360 seedlings) and declined through spring to a low of 1.9% in summer, with just 6 seedlings surviving to June 2006 (Jensen, 2008a). These seedlings continued to survive in a dormant state and put on a spurt of growth following a subsequent rain event in 2007.

River Red Gums and Black Box seedlings both require soil moisture (of a suitable water quality) to be sustained between 10% and 25% moisture volume (Jensen, 2008a). Seedlings need to be sustained with sufficient soil moisture until they develop a sinker root to deeper water sources, taking about 2 years (George, 2004). To maintain River Red Gum and Black Box seedlings, the aim should be to maintain 10-25% soil moisture volume in the top 25 cm of the soil profile through the dry summer months following germination (Jensen *et al.,* 2008a).

2.4 Soil Salinity Thresholds

Whilst a number of studies have evaluated the groundwater salinity tolerances of River Red Gum and Black Box trees (e.g. Overton and Jolly, 2004, Sharley and Huggan, 1995), the influence of soil salinity on vegetation health and tolerance thresholds are not well established. A summary of the reported soil salinity thresholds for River Red Gum and Black Box trees are presented in Table 2.1.

A study on the South Australian floodplain examined the relationship between soil texture, groundwater salinity and soil salinity at over 200 sites in 2002 (McEwan *et al.,* 2003). AWE has cross referenced this data with the spatial vegetation survey data collected at the same sites by the (then) Department of Environment & Heritage (2001-2003), analysing the dataset for relationships between soil and groundwater salinity, depth to groundwater, and vegetation type and health (AWE, 2012). The results of this analysis are presented in Figure 2.1. The left hand side of Figure 2.1 indicates that average soil salinities for both River Red Gums and Black Box are consistently larger for unhealthy trees; similar conclusions can be reached for groundwater salinities. This data suggests that 75% of healthy Black Box trees occur where average soil salinity is less than 39,000 mg/L and that 75% of unhealthy Black Box trees occur where average soil salinity exceeds 32,500 mg/L.

TABLE 2.1: SOIL SALINITY THRESHOLDS FOR HEALTHY BLACK BOX AND RIVER RED GUMS

Species	Upper limit (100th Percentile) (mg/L)			75th Percentile (mg/L)	Median (mg/L)
Source	MDBC (2003)	Hollingsworth et al (1990)	AWE (2012) using McEwen et al (2003)		
Black Box	-	-	57,000	39,000	19,500
River Red Gum	>39,000	65,000	62,000	16,250	13,000

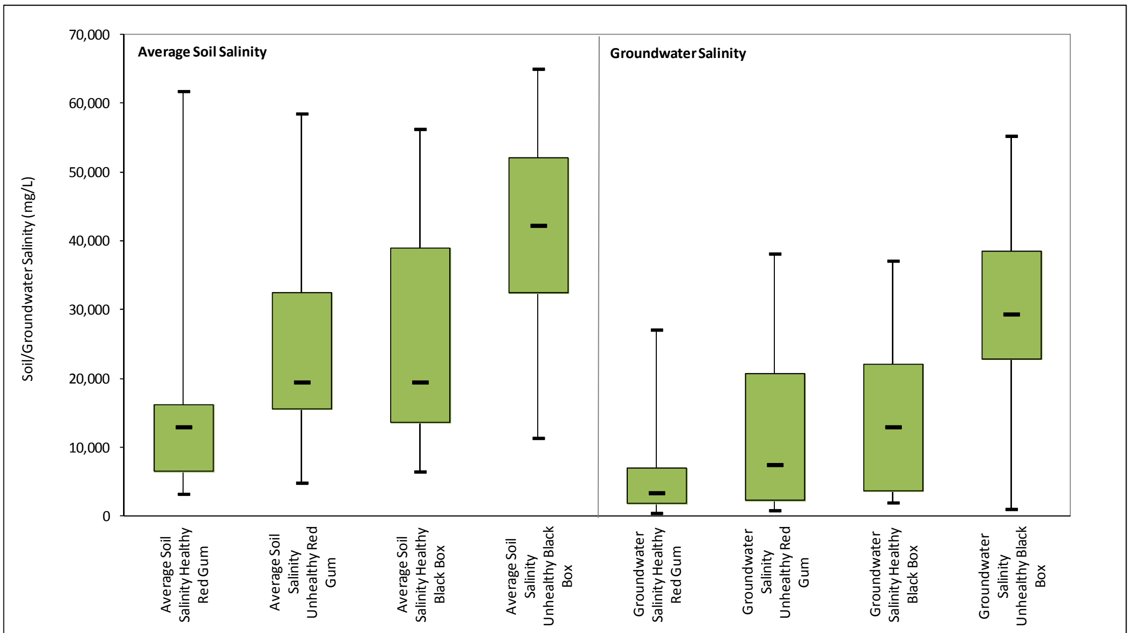


FIGURE 2.1: BOX AND WHISKER PLOT OF AVERAGE SOIL SALINITY AND GROUNDWATER SALINITY IN RELATION TO VEGETATION HEALTH (AWE 2012)

MDBC (2003) showed that River Red Gum trees can show growth reductions when root-zone soil salinities range from 2,000 to 5,000 µS/cm in an extract from a saturated soil paste (ECe), and survival is likely to be affected at soil ECe > 15,000 µS/cm (MDBC, 2003). For comparison to data presented in Figure 2.1, the growth reduction range can be approximated as 5,200 to 13,000 mg/L, and the value affecting survival is > 39,000 mg/L, assuming moisture content of 20% and clayey soils.

Hollingsworth et al. (1990) found no relationship between soil salinity and health, but suggested a soil salinity threshold of close to ECe 25,000 µS/cm (~65,000 mg/L), as there was a total absence of River Red Gum trees where soil salinities exceeded this value (MDBC 2003). Black Box trees can tolerate up to double the salinity of groundwater, compared to River Red Gum trees, so it is likely that they will tolerate higher soil salinities, although no specific figures were given for Black Box in the MDBA study.

Tucker (2003) identified a threshold surface soil salinity (EC1:5) of 3,120 µS/cm associated with stress in River Red Gums.

The skewed soil salinity distribution for healthy Black Box and healthy River Red Gum suggests that upper limits may not be a good metric for management purposes, and the 75th or 50th (median) percentiles may provide better targets for management purposes.

2.5 Groundwater Salinity Thresholds

While native species are highly salt-tolerant, it is essential that sufficient, appropriate salinity water is available to sustain growth and life cycle processes. The AWE (2012) analysis (Figure 2.1) demonstrates that unhealthy River Red Gum and Black Box trees are associated with consistently high groundwater salinities. A summary of the reported groundwater salinity thresholds for River Red Gum and Black Box trees are presented in Table 2.2.

River Red Gum trees can tolerate semi-saline groundwater conditions and have an upper tolerance limit of ~30,000µS/cm (19,500mg/L) (Overton & Jolly, 2004). Prolonged exposure to groundwater of this salinity will have significant impacts on growth, especially when coupled with other stresses such as drought (MDBC 2003; Overton & Jolly, 2004). AWE (2012) indicates that the upper tolerance of River Red Gum is as high as 27,000 mg/L, however the 75th percentile groundwater salinity for healthy River Red Gum is much lower at 7,000 mg/L and the median salinity is 3,500 mg/L. Periodic access to low salinity groundwater or surface water is essential for River Red Gums, with a suggested frequency of 1 in 2 years for healthy growth based on the natural flood frequency associated with tree distribution on the floodplain (Roberts & Marston, 2000).

Black Box trees show an upper tolerance limit of ~55,000µS/cm (~35,750mg/L) (Sharley & Huggan, 1995; Overton & Jolly, 2004, AWE 2012). Black Box displays a greater salt tolerance than River Red Gums, but has a lower tolerance for flood inundation. Data presented above in Figure 2.1 suggests that 75% of healthy Black Box trees occur where the groundwater salinity is less than 22,000mg/L.

Although Black Box trees can survive at relatively high salinities, vegetation vigour can begin to decrease at moderate groundwater salinities, especially where the water table is shallow, within 2 to 4 m of the surface. Again, periodic access to low salinity groundwater or surface water is essential, with a suggested frequency of 1 in 5-10 years for healthy growth, based on the natural flood frequency associated with tree distribution on the floodplain (Roberts & Marston, 2011).

Johns *et al* (2009) suggests that ideal conditions for healthy Black Box include inundation for 2-4 months every 2-5 years (with a depth to regional groundwater >3.65 m and groundwater salinity < 32,000 µS/cm (Overton *et al.,* 2009)).

The skewed distribution of the groundwater salinity beneath healthy Black Box and healthy River Red Gum suggests that upper limits may not be a good metric for management purposes, and that the 75th percentiles for healthy trees may provide better thresholds for management purposes.

TABLE 2.2: GROUNDWATER SALINITY THRESHOLDS FOR HEALTHY BLACK BOX AND RIVER RED GUMS

Species	**Upper Limit (100th Percentile)**		**75th Percentile**	**Median**
Source	Sharley and Huggan (1994) and Overton Jolly (2004)	AWE (2012) after McEwen at al (2002)		
Black Box	35,750	35,000	22,000	13,000
River Red Gum	19,500	27,000	7,000	3,500

3 Literature Review: Controls on the Response to Water Management Strategies

Summary:

The ecological response of Black Box to management actions is largely determined by the amount of low salinity water that is made available, and the length of time it remains available. Low salinity water can be sourced from surface water or groundwater manipulation.

Floodplain characteristics that control the Black Box health responses to water management include:

- Unsaturated zone salinity and moisture availability
- Pre-watering vegetation condition
- Groundwater salinity
- Depth to groundwater and evapotranspiration rates
- Regional hydrogeological setting
- Floodplain geomorphology
- River Skin

These characteristics can be used as indicators for management level review of floodplain sites to target the delivery of environmental water, assess the likely outcomes of delivery, and identify complementary actions such as groundwater manipulation.

3.1 Water Management Strategies

Since 2004 numerous watering events have occurred to make use of additional water made available through the various environmental water allocations and the Basin Plan. Types of water manipulation for ecological benefit include:

- Inundation of ephemeral wetlands to increase soil moisture availability, reduce soil salinity and potentially freshen groundwater via vertical infiltration through the wetland bed or via lateral recharge through the bank.
- Inundation of low lying floodplain areas to mimic overbank flows from large floods with the aim of increasing soil moisture availability, reducing soil salinity and potentially reducing groundwater salinity via vertical infiltration of water through floodplain soils.
- Irrigation of floodplains using dripper or sprinkler irrigation to increase soil moisture, reduce soil salinity and potentially reduce groundwater salinity via vertical infiltration of water through floodplain soils.
- Pumping groundwater to generate or enhance freshwater lenses with the aim of providing a freshwater source for trees and potentially reducing soil salinities through interaction with the watertable. There is only one example of groundwater pumping being employed

specifically for ecological benefit. However, groundwater pumping from Salt Interception Schemes also appear to provide secondary ecological benefits.

- Injection of water into the floodplain aquifer to provide a freshwater source for mature trees and potentially reduce the salinity of the unsaturated zone through interaction with the water table. Although the principle of injecting surface water into an aquifer is well established (e.g. Managed Aquifer Recharge and Aquifer Storage and Recovery schemes), there is only one example where this has been trialled as a floodplain management intervention.

3.2 Floodplain Characteristics that Influence Responses to Water Management

The ecological response to management actions is largely determined by the amount of low salinity water that is made available to vegetation and the length of time it remains available. This section provides a literature review of site characteristics that influence outcomes from floodplain management. It is suggested that these characteristics be used as indicators for management level review of floodplain sites to target the delivery of environmental water, assess the likely outcomes of the delivery and identify sites where complementary actions, such as groundwater manipulation may provide benefits. Some of the indicators are directly measurable (e.g. groundwater salinity) however other indicators are used to assess the influence of a key process on management outcomes (e.g. floodplain geomorphology to indicate soil permeability).

3.2.1 Unsaturated Zone Salinity and Moisture Availability

The primary water sources accessed by Black Box trees are soil moisture stores in the unsaturated zone and freshwater lenses overlying saline regional groundwater. The soil water store is controlled by a combination of recharge from rainfall, groundwater and laterally from surface water bodies and discharge from evaporation, deep drainage and lateral flow (Roberts et al. 2009). The magnitude of recharge and discharge is in turn controlled by factors such as topography, soil type, depth to groundwater, proximity to surface water and hydraulic connectivity (Roberts et al. 2009). The amount of water available to floodplain vegetation is also dependent upon the soil type and the salinity of soil water i.e. a clayey soil will retain more water than a sandy soil however the matric potential required to extract water from the clayey soil is also greater. Once the soil water salinity exceeds the osmotic potential of the plant roots then the vegetation can no longer access the soil water.

As discussed in Section 2, soil salinity and moisture availability affect floodplain vegetation condition. However, only limited information is available regarding the soil moisture needs and salinity thresholds of Black Box. It is hypothesised that soil salinity is a key site indicator for long term success of floodplain management interventions. Further, it is suggested that groundwater salinity influences the salinity of the unsaturated zone and therefore management interventions which include groundwater manipulation may also invoke changes in the unsaturated zone providing long term, ecological outcomes.

It is proposed that the unsaturated zone salinity and moisture availability be used as site indicators for floodplain management. It is suggested that soil salinities be considered in relation to the salinity thresholds for River Red Gum and Black Box trees (Section 2) and the quantification of soil salinity responses to management actions (presented in Section 4).

3.2.2 Pre-Watering Vegetation Condition

The pre-watering condition of floodplain vegetation is also likely to affect the ecological response/outcomes of floodplain management. The responses of stressed vegetation to management interventions are much less predictable than that of healthy trees. In addition, there is also likely to be a point beyond which extremely stressed trees will not recover in response to watering or groundwater manipulation. It is also commonly accepted that the best outcomes from environmental rehabilitation are achieved by maintaining healthy systems rather than repairing damaged systems (Rutherford *et al.,* 2000). Therefore the existing condition of floodplain vegetation and its likelihood to respond to management interventions should be considered when identifying sites where surface water or groundwater manipulation as a management tool could be used.

3.2.3 Groundwater Salinity

Groundwater salinity significantly influences the health and distribution of floodplain vegetation and upper tolerance limits have been determined for both River Red Gum and Black Box trees (see Section 2). The role of groundwater as a contributing factor in the assessment of health trends is generally not considered in the literature, although some studies have assessed groundwater as one of the water sources used by River Red Gum and Black Box trees (e.g. Mensforth et al 1994, Holland et al 2006). Changes in groundwater salinity over time have not been considered as a contributing factor in health declines, although this study presents a hypothesis that this is a possibility.

Discussions with Louise Chapman (MCMA) suggest that environmental watering has produced the most successful ecological outcomes at sites upstream of Colignan; that ecological responses to watering have been variable on floodplains between Lock 10 and the South Australian border; and that ecological responses to watering have been limited particularly for Black Box trees on floodplains in the vicinity of Mildura and Red Cliffs. These observations broadly correlate with the pattern of floodplain groundwater salinity, which is low upstream of Mallee Cliffs, moderate downstream of lock 10 to lock 6, and high between Mallee Cliffs and Lock 10. The salinity distribution is illustrated in a map of available Airborne Electromagnetic (AEM) data between the South Australian-Victoria border and Euston, which is presented with Black Box distribution in Appendix B. In this map red areas represent high conductivity (high groundwater salinity) and blue areas represent low conductivity (low groundwater salinity).

It is proposed the groundwater salinity be used as site indicators for floodplain management. It is suggested that groundwater salinities be considered in relation to the salinity thresholds for River Red Gum and Black Box trees and the quantification of groundwater salinity responses to management actions (presented in Section 4).

3.2.4 Depth to Groundwater

The depth to groundwater will influence evaporation rates, and perhaps transpiration rates, from the floodplain soils. Both processes extract fresh water from the soil and leave the salt behind. Evaporation rates are inversely related to depth to water – shallower depths to water result in higher evaporation rates and higher rates of salt accumulation (for a given soil type). Higher salt accumulation rates will result in higher soil salinities and higher groundwater salinities, leading to reduced vegetation health.

The depth to groundwater in the floodplain has been reduced by three landscape modifications: building locks and weirs; irrigating on or adjacent the floodplain; and perhaps the effects of mallee clearance causing increased rates of recharge to groundwater. These all lead to increases in groundwater level. Building Locks and weirs (i.e. locking) has had the most effect on the floodplain water levels. The groundwater level in the floodplain has been permanently raised by 1 to 3 metres everywhere between Mallee Cliffs (upstream of Lock 11) and the mouth of the River Murray, and also upstream of the Euston and Torrumbarry weirs.

Irrigation and land clearing may have also contributed to raised water tables on the floodplain. These land practices have increased the amount of water recharging the regional aquifer and hence the groundwater flux towards the floodplain and River.

Evaporation rates from soils are influenced by capillary rise, which is very small (centimetres) in sands and can be over ten metres in clays. Locking has permanently raised the groundwater table into the silty clays of the Coonambidgal Clays across most of the floodplain. The pre-locking groundwater level would have probably resided mostly in the Monoman Sands, rising less frequently during high flows and floods into the Coonambidgal Clays. So, not only has the water level increased (i.e. depth to water decreased), but the effect of the increase has magnified the increase in the rate of salt accumulation because the water table now resides in clays rather than sands.

The floodplain downstream of Mallee Cliffs usually has high salinity groundwater (Appendix B). Analysis of the patterns of regional groundwater head indicate that they occur in throughflow or gaining floodplains (see Section 3.2.5), and that the pre-European salinity distribution would have been similar (except adjacent irrigation districts). However, the permanent decrease in depth to groundwater will have exacerbated the pre-European salinity regime by accumulating salt at a faster rate now than occurred previously. Therefore the current groundwater salinities are the sum of the pre-European salinity plus the post-Locking increase caused by increased rates of salt accumulation.

It is logical to expect that an increase in groundwater and soil salinity will have a major influence on Black Box health trends, especially if the salinity increases above the soil and/or groundwater salinity thresholds for healthy Black Box.

3.2.5 Regional Hydrogeological Setting

The regional hydrogeological setting of a floodplain provides an indication of the likely groundwater salinity (and potentially soil salinity) where monitoring data is limited. Within the Mallee region characterisation of the floodplain setting may consider the occurrence of losing or gaining stream conditions, the floodplain type, floodplain width and the presence or absence of an aquitard which separates floodplain aquifer from the regional aquifer.

A key predictor of floodplain salt risk is the Floodplain and River Classification Matrix (Figure 3.1) (AWE 2011).

The Floodplain and River Classification Matrix categorises river reaches and floodplains as:

- Gaining or losing river reaches; and
- Gaining, losing or throughflow floodplain systems.

Gaining floodplain conditions occur where the regional groundwater discharges into the floodplain alluvium (e.g. downstream of Lock 11) whereas losing floodplains occur along river reaches where groundwater flow is from the floodplain sediments to the regional groundwater system. Throughflow floodplains are found in reaches where the regional groundwater flows beneath or through the floodplain. In throughflow reaches, the floodplain alluvium is potentially gaining water from the up-gradient side, but is losing water to the regional groundwater system on the down-gradient side (AWE 2011). Gaining floodplains are more likely to be associated with high groundwater salinity, and therefore high unsaturated zone salinity, due to the discharge of highly saline regional groundwater to the floodplain. Groundwater salinities measured on gaining floodplains tend to be higher than the regional groundwater inputs to the floodplain which is likely to be due to reflux or evaporative concentration. The risk of salinisation declines for through flow and losing floodplains.

A gaining stream is a reach of river where groundwater discharges from the alluvial sediments of the floodplain into the river. Conversely losing stream conditions occur where the river is losing water to the floodplain alluvial sediments. Low salinity lenses are likely to occur adjacent losing stream reaches of river, providing a lower salinity water source for floodplain vegetation. Low salinity lenses are associated with good vegetation health and may also be associated with low soil salinity. In terms of groundwater manipulation, it is hypothesised that it may be easier to enhance an existing freshwater lens than to generate a new lens, however this has not yet been tested. The lateral extent of low salinity water from the river is likely to be limited adjacent gaining stream reaches (i.e. only accessible to River Red Gum trees lining the river). Floodplains located adjacent gaining stream reaches are more likely to be associated with higher groundwater salinity, potentially higher unsaturated zone salinity, and poor vegetation health. NanoTEM data may provide a good indicator of the likely success of watering for near-river River Red Gum trees.

The width of the floodplain may also influence groundwater and unsaturated zone salinity and therefore the condition of floodplain vegetation. Not all salt entering the floodplain discharges directly to the river. Regional groundwater inputs can be diminished while in transit through the floodplain, as the result of evaporation through the soil, transpiration by vegetation where salinity is low (i.e. along losing reaches of river) and via evaporation from open water. These processes reduce the discharge flux to the river, as water is lost to the atmosphere, but the salt remains in the floodplain. Wide floodplains tend to have a high evaporative capacity and may also be flooded less frequently, leading to an increased risk of salt accumulation. The evaporative capacity of narrow floodplains is comparatively less so that a greater proportion of the regional groundwater flux (and salt) may discharge to the river rather than being stored in the floodplain.

On some floodplains in the Mallee region, the Blanchetown Clay aquitard separates the regional Parilla Sands aquifer from the floodplain aquifer (Monoman Formation) limiting the hydraulic connection between these systems. Where the Blanchetown Clay is absent there is greater connection between the regional and floodplain aquifers. The salinity of the Monoman Formation is influenced by the connection between the aquifer and surface water bodies, inputs from the regional system and evapotranspiration. Groundwater salinities in the Monoman Formation tend to be more variable than those measured in the Parilla Sands. Groundwater salinities in the Monoman Formation may be less where the Blanchetown Clay is present and limits the interaction with saline groundwater from the Parilla Sands aquifer.

It is suggested that the regional hydrogeological setting be used as a site indicator to assess the regional groundwater inputs to the floodplain, the relative groundwater salinities where monitoring data is limited and to assess the likely occurrence of freshwater lenses.

3.2.6 Floodplain Geomorphology

The groundwater and soil salinity response to environmental watering will largely be determined by the amount of water that can infiltrate floodplain soils and recharge the floodplain aquifer. Examples where this recharge flux has been quantified are limited however, it will largely be controlled by the vertical conductivity of floodplain soils. In the case of the River Murray floodplain, the vertical conductivity of the Coonambidgal Clay will determine the magnitude of the recharge flux. Again, measured examples of Coonambidgal Clay vertical conductivity are limited, however a number of studies suggest that floodplain geomorphology may be used to infer the likely permeability of floodplain materials and therefore the magnitude of the groundwater and unsaturated zone response (i.e. freshening) to inundation.

In a study on the Chowilla floodplain, Akeroyd et al. (1998) concluded that soil type was a critical factor in the extent of leaching in the floodplain soil profile. Relatively high rates of leaching were observed at sites with sandy soil profiles compared to those with a high clay content that showed very little leaching. Fuller and Telfer (2007) suggest vertical hydraulic conductivity values ranging between 10^{-5} and 10^{-2} m/d for the Coonambidgal Clay based on studies by Barnett et al (2003), SKM and Fuller and Telfer (2007). Additionally, a vertical hydraulic conductivity of $7.5*10^{-4}$ was calculated using monitoring data from an inundation event on an old floodplain terrace near Colignan (AWE 2014).

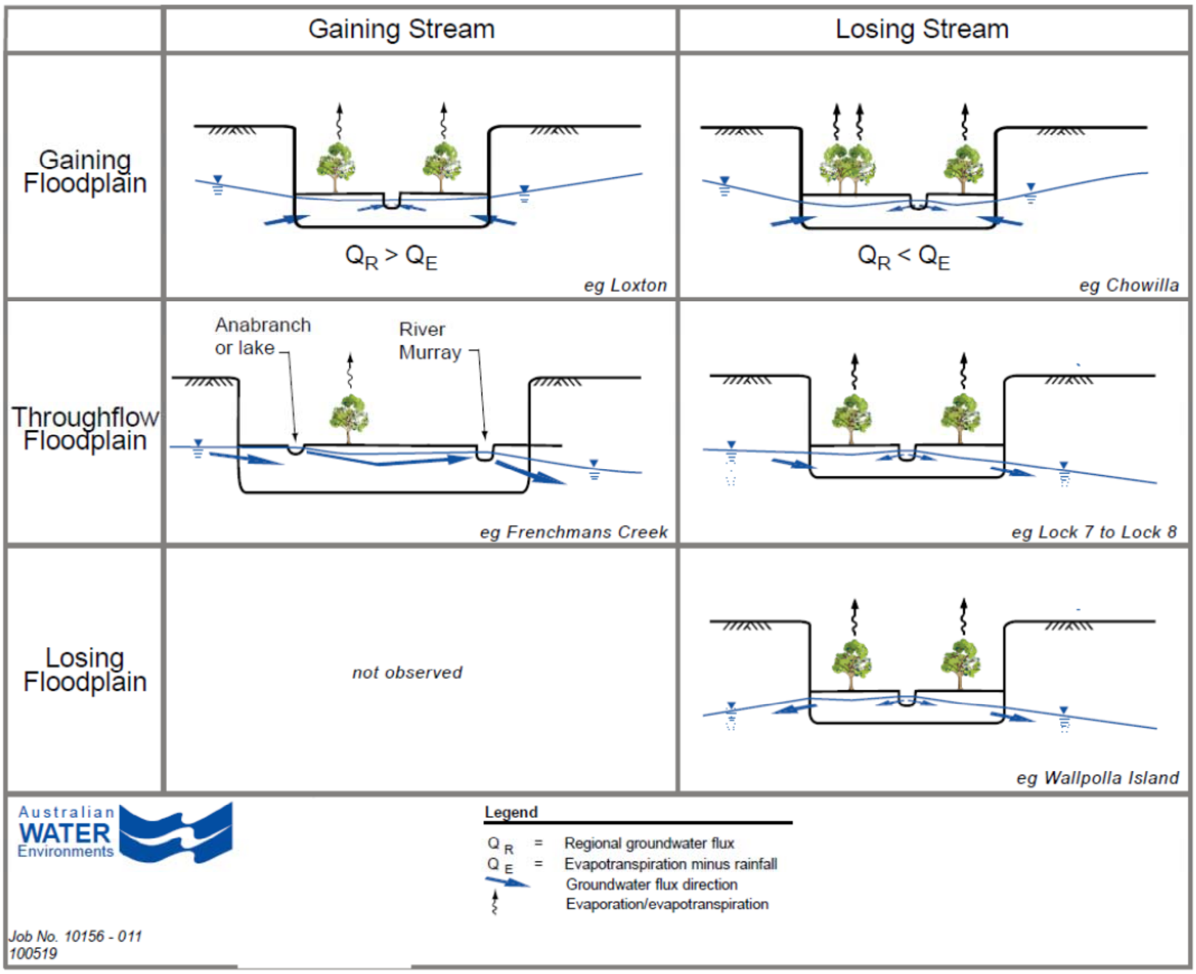


FIGURE 3.1: FLOODPLAIN AND RIVER CLASSIFICATION MATRIX (AWE 2011)

Clarke et al. (2008) suggest that floodplain soils of the Murray Basin are closely related to Quaternary geology. This study separates the floodplain into four geomorphic categories; alluvial terrace, oldest meander belt, intermediate meander belt and youngest meander belt. Work undertaken in the Lindsay-Wallpolla area included the mapping of soil types using morphological characteristics. The analysis and soil sampling undertaken by Clarke et al. (2008) on the Lindsay-Wallpolla floodplain, predicts that:

- With the exception of the youngest floodplain terraces, floodplain sediments are sealed by dispersive clays that restrict recharge when the floodplain is inundated.
- On the floodplain, active channels have a sandy base, however once they become inactive they become clay lined which also limits recharge.
- Where sand dunes are present on floodplain terraces, localised areas of high infiltration may occur and may lead to the formation of perched water tables.
- The width of floodplain vegetation bands can also provide an indication of the magnitude of recharge through floodplain soils or through the River bank.
- Zones of healthy vegetation are widest on the youngest floodplain units where scroll bars are commonly sandier than the older floodplain terraces. These sandier deposits are likely to allow greater rates of infiltration, lateral recharge from the River and a greater extent of flushing of salts from the soil profile.
- Zones of healthy vegetation are much narrower adjacent abandoned or inset channels (such as Wallpolla Creek) where infiltration and lateral recharge may be limited by the clay seal at the base of the channel.

Hughes (2005) in mapping soils at Pike and Murtho, assigned relative permeabilities to soil types under a morphological classification similar to the Clarke et al. (2008) approach. The morphological work consistently suggests that the high terrace floodplains (oldest sediments) have the lowest vertical conductivities, with permeability increasing as the terraces get lower in elevation and the age of the terraces gets younger.

The role of soil texture (i.e. clay vs. silt vs. sand) is not generally considered in assessing the causes of health trends, although personal observations (A Telfer) indicate that soil texture appears to exert some influence on health. For example, the presence of a sand layer (e.g. Woorinen Formation) over the floodplain Coonambidgal Formation clays can facilitate the infiltration of more rainfall into the subsurface than rainfall falling directly onto the Coonambidgal Clays. This increased store of water will lead to a better tree health outcome in a fresh-water constrained floodplain.

The above studies suggest that floodplain geomorphology can be used to indicate the likely magnitude of recharge from inundation in the absence of measured data. Young floodplain terraces are more likely to consist of sandy deposits and allow greater rates of vertical infiltration, flushing of salts and lateral exchange with surface water bodies. Conversely, clayey deposits found on the oldest floodplain terraces are likely to limit infiltration, leaching of salts and exchange with surface water bodies which may in turn limit the response of floodplain vegetation to watering. Black Box trees tend to be found on higher elevation terraces and at greater distances from the River than River Red Gum trees. These higher terraces are likely to represent old floodplain terraces with low permeability sediments. This may limit the amount of vertical infiltration from floodwaters and explain the limited response of Black Box trees to flooding in these locations.

3.2.7 River Skin

The River skin is the interface between the River (or anabranch) and the floodplain aquifer. Similar to the vertical hydraulic conductivity of floodplain soils controlling the amount of vertical infiltration, the hydraulic properties of the River skin are likely to influence the extent of lateral recharge from surface water bodies. Where the River skin is tight, the connection between the River and floodplain aquifer is limited and this makes it more difficult for changes in River stage to emplace/replenish groundwater lenses via bank recharge. Conversely, where the River skin is leaky, there is likely to be greater potential for exchange between the floodplain aquifer and the River and conditions favour development of freshwater lenses. There are a limited number of studies where the hydraulic properties of the River bank have been quantified. However it has been observed by several workers (e.g. Holland, Telfer, etc) that the width of riparian vegetation communities may indicate the likely exchange between the floodplain aquifer and River, with wide bands of riparian vegetation associated with a leaky River skin.

It has been suggested that River skin conductance may be related to River morphology (AWE 2004). River skin conductance may be higher at bends in the River where flow velocities are higher and scouring of the River/floodplain aquifer interface may also be higher. Conversely the River may be tight along wide relatively straight reaches of River.

A number of studies have evaluated the role of River skin conductance in controlling the magnitude of bank recharge as a result of flood events, managed or natural. Fewer studies have examined the role of River skin conductance on the magnitude of bank recharge where groundwater pumping has been used to create or enhance and effect.

Lamontagne et al. (2005) used a combination of water level monitoring and environmental tracers to investigate groundwater-surface water interactions during two small floods on the Hattah-Kulkyne floodplain (losing stream reach). Surface water - groundwater interactions between two monitoring sites were contrasted with one site located on a sandy point bar and the second adjacent a clay lined bank. Environmental tracers suggested that groundwater beneath the floodplain originated from bank recharge in the riparian zone and represented combination of diffuse rainfall recharge and localised floodwater recharge on the remainder of the floodplain (Lamontagne et al 2005). The study also concluded that the response of the floodplain aquifer to changes in River stage was a function of the type of stream bank. Results indicated that the connection between the aquifer and River was greatest at the sandy point bar monitoring site compared to the clay lined bank (Lamontagne et al 2005).

Holland et al (2009) concluded that the hydraulic properties of the bank and floodplain aquifer controlled the magnitude of the groundwater response (freshening) to an environmental watering trial at Monoman Island Horseshoe on the Chowilla floodplain.

A qualitative assessment of River skin properties at Bookpurnong was undertaken as part of The Living Murray Pilot Project (AWE 2004). In this case it was observed that the hydraulic conductivity of the River (or anabranch) skin was likely to control the spatial extent to which low salinity River water can be drawn into the floodplain aquifer by pumping. A combination of aquifer testing, groundwater and surface water monitoring were applied to provide a qualitative assessment of this observation. Results from the study confirmed that pumping was more likely to enhance bank recharge at locations where the River skin was leaky compared to locations where the River skin was tight. Pumping was also less efficient in lowering floodplain water levels where the River skin was leaky compared to where the River skin is tight. It is suggested that pumping may induce drawdown on the other side of the River where the River skin is tight, although this was not measured by the study.

When considering groundwater manipulation as a management tool, floodplains located adjacent sections of River (or anabranch) with ‘leaky’ hydraulic properties may require less effort to emplace or enhance a freshwater lens, although this may be difficult to predict. Indicators of the leakiness of the River skin may include the following factors:

- NanoTEM data indicating losing stream conditions;
- AEM data to indicate the thickness and extent of a freshwater lens;
- The historic and current width of the riparian vegetation community;
- The hydrograph response of floodplain bores to flooding; and
- The strength of the regional groundwater gradient towards the floodplain.

4 Literature Review: Quantified Responses to Floodplain Management

Summary:

- On the higher terraces, where Black Box usually occur, infiltration rates from floodplain inundation appear to be of the order of 1mm per day. This may be expected to provide sufficient water for a year. Infiltration rates may be higher on the lower terraces, but these are dominated by Red Gum and do not usually contain Black Box.
- Recharge of the floodplain aquifer by vertical infiltration from floodplain inundation is controlled by the vertical hydraulic conductivity of the Coonambidgal Clay. This parameter is poorly quantified.
- Groundwater pumping can be used to create low salinity lenses. The salinity of the unsaturated zone over the low salinity lens appears to decline in response to the creation of the low salinity lens.
- Injection of low salinity water into the aquifer to create a low salinity lens is technically quite feasible, but has not yet been successfully implemented.
- The long-term vegetation health benefits of environmental watering are variable. The causes of variability have not previously been examined in any detail.

The following section provides a summary of studies and data sets that quantify the salinity responses of groundwater and the unsaturated zone to surface water and groundwater management actions. Vegetation responses to floodplain management are detailed in Appendix A.

4.1 Groundwater Salinity Responses to Environmental Watering

Floodplain inundation through both natural events and engineered floods can recharge the groundwater system via two mechanisms:

- Through the vertical infiltration of floodwaters when overbank flows occur; and
- Via bank recharge under losing stream conditions.

Empirical evidence of the success of these recharge pathways is detailed in the following sections.

4.1.1 Groundwater Responses to Watering via Vertical Infiltration

The recharge flux via vertical infiltration to the floodplain aquifer is largely controlled by the vertical conductivity of floodplain soils, namely the Coonambidgal Clay. However, the hydraulic conductivity of the Coonambidgal Clay, and its spatial variability, is a key area of uncertainty with little measured data available.

Quantification of the vertical recharge flux to the floodplain aquifer due to inundation has been limited and the majority of studies within the Murray Darling Basin have focused on the Chowilla floodplain. A study by Jolly et al. (1994) at Chowilla suggested that diffuse recharge was likely to be negligible due to the occurrence of clayey, sodic soils (Coonambidgal Clay). They postulated that localised recharge may be significant where clays are absent, displacing groundwater to surface water bodies over time. However, the Coonambidgal Clays are present almost everywhere along the River Murray floodplain, and the hypothesis of preferential recharge through holes in the Coonambidgal Clay has yet to be supported by empirical data.

Gehrig (2005) documents monitoring data collected as part of a series of watering projects on the Chowilla floodplain implemented under The Living Murray Works and Measures Program between August 2004 and January 2005. The inundated sites include Pipeclay Weir Billabong, Werta Wert Wetland, Lake Littra, Pilby Creek and Twin Creeks. Overall the report concluded that:

- Groundwater levels at each site rose in response to watering events;
- This rise in groundwater levels ranged between 0.1m and 0.45m
- Groundwater levels remained elevated for 2 to 3 months following a watering event before declining;
- The magnitude of the groundwater response (salinity and level) was greatest closest to the inundated area and diminished with distance from the water body; and
- The magnitude of the groundwater response was highly site dependent (Gehrig 2005).

Groundwater salinity data was only measured (or reported) for the sites at Werta Wert Wetland and Twin Creeks. Monitoring data collected at the Werta Wert Wetland indicates that the groundwater response to watering was limited, with groundwater salinities declining from 40,000 µS/cm to 37,000 µS/cm (24,050 to 26,000mg/L), remaining above the upper groundwater salinity tolerance for River Red Gum trees (SKM 2009). Groundwater levels increased by 0.5m near the edge of the wetland to 0.1m at a distance of 300m in response to the inundation event. The groundwater response to watering events at Werta Wert was observed to last for 5 months. It was noted that groundwater salinity responses to watering were difficult to determine as the screened intervals of the bores were below the watertable and therefore may not have picked up the development of a freshwater lens at the top of the water column.

Monitoring data from Twin Creeks also suggests that groundwater freshening in response to watering was limited. With the exception of one site that was located within the creek, groundwater salinities remained between 30,000 mg/L and 40,000 mg/L following the inundation event. Groundwater salinities measured at the piezometer in the creek ranged between 20,000 mg/L and 30,000 mg/L and increased by approximately 10,000mg/L in the three months following the inundation event.

A significant amount of monitoring data has been collected on the floodplain at Bookpurnong as part of SIS monitoring and The Living Murray Program (AWE 2015, AWE 2005, Holland et al. 2009, Holland et al. 2013). At this location the Site A Transects were partially inundated by both managed and natural flood events. In all transects groundwater salinity increases with distance from the River. Monitoring data suggests that the groundwater response to managed flooding was limited with no significant groundwater freshening occurring in response to events. Instead, some sites along A Transects recorded an initial, small spike in groundwater salinity corresponding to the timing of artificial watering events. Following the natural floods of 2010 and 2011, bores A2 and A10 show a significant decline in groundwater salinity even though bores located closer to the River did not. These bores are located on a low lying section of floodplain and also adjacent a break in slope in terms of floodplain elevation. AWE (2015) considers that this may represent a change in the age of floodplain terrace, and hence the vertical hydraulic properties of the Coonambidgal Clay, creating a localised zone of preferential recharge. The variable groundwater response to natural and managed flooding may be due to a number of factors including the strength of losing stream conditions during the flood, the vertical hydraulic conductivity of floodplain sediments and the hydraulic properties of the River bank and floodplain aquifer.

4.1.2 Groundwater Responses to Flooding via Bank Recharge

Holland et al. (2009) monitored the vegetation response to managed flooding at Monoman Island Horseshoe on the Chowilla floodplain. This study quantified the extent of lateral recharge (groundwater response) and compared this to the vegetation response. Holland et al. (2009) concluded that the vegetation response to flooding was controlled by floodplain hydraulic conductivities, which in turn controlled the extent and degree of groundwater freshening via bank recharge. In one instance of groundwater freshening, salinities declined from 19,000EC to 1,000EC, 40m away from the inundated area and this response lasted for the duration of the monitoring period (2 months). The lateral extent of freshening may have been greater as the monitoring network only extended 40m back from the inundated area. The duration of the freshening may have also lasted longer as the site was only monitored for 9 weeks following the watering event. A salt and water balance was developed using monitoring data, and it suggested that water stored via bank recharge would be discharged through evapotranspiration within 3 years, indicating that regular flooding would be required to maintain vegetation conditions during low flow periods (Holland et al. 2009).

Cartwright et al (2010) demonstrated, using isotopic and chemical data, that the very extensive low salinity lens around Robinvale was emplaced through the bank of the River Murray during high flow events, and that there was little evidence of infiltration through the floodplain soils from overbank flows.

The importance of bank recharge therefore varies, depending on the strength of gaining or losing stream conditions and the hydraulic properties of the River bank and aquifer.

4.2 Groundwater Salinity Responses to Groundwater Manipulation

Empirical data is presented below that demonstrates the groundwater response to manipulation via both pumping and injection.

4.2.1 Groundwater Pumping

The Bookpurnong Living Murray Pilot Project (AWE 2005) is the best example to date, of the application of groundwater engineering to deliver ecological benefits in the Murray Darling Basin.

Groundwater salinity responses to pumping from The Living Murray Production Bore (LMPB) at Bookpurnong are best demonstrated in data obtained from Transect B3. The Living LMPB is located along this transect approximately 175m away from the River. The LMPB began operating in late 2006 pumping from the Monoman Formation aquifer with an operating flow rate of 3 to 5 L/s.

Salinity monitoring data from Transect B3 was gridded to illustrate the migration of the freshwater lens due to pumping and via bank recharge. The results from Berens et al. (2009a) are presented in

Figure 4.1 (note that data presented below 7mAHD for site B9 has been interpolated using data recorded from the adjacent bores as B9 is only 6m deep).

The LMPB was operational between August 2006 and November 2006 and between May 2007 and the flood in 2010/11. Salt Interception Scheme wells located across the floodplain had been operating since July 2005 (but were switched off between November 2006 and May 2007) and produced a groundwater gradient away from the River of 0.3 m over 190 m between B7 and B25 (Berens et al., 2009).

The influence of pumping from the Bookpurnong SIS can be observed in the January and July 2006 transects which pre-date operation of the LMPB (Figure 4.1). In these transects the blue zone represents the freshwater lens, groundwater with a salinity of less than 5,000 µS/cm (3,250mg/L). The July 2006 salinity profile indicates that SIS operation had increased the vertical extent of freshwater lens at B7 by approximately one metre (Berens et al., 2009).

The impact of pumping from the LMPB on migration of the freshwater lens can be observed in transects from December 2006 to December 2008. Data from December 2006 shows significant enhancement of the freshwater lens due to pumping from the LMPB. Data from April 2007 suggests no significant change in the extent of the freshwater lens, which is expected, as both the LMPB and SIS were not operating during this time. Data from February and December 2008, shows significant migration of the freshwater lens due to pumping. Pumped groundwater salinities from the LMPB declined from 55,000 µS/cm in mid-2006 to approximately 30,000 µS/cm in 2010, representing a mix of both the freshwater lens and highly saline groundwater from the floodplain (AWE, 2011).

Water level, groundwater salinity and soil chloride data sourced from Holland et al. (2013) are shown in Figure 4.2 for the four Site B piezometer Transects (B1 to B4) on Clark's floodplain. For each transect, the data for the bores are plotted on graphs, and the AWE interpretation of a "breakthrough curve" is added in the same colour. This additional interpretation of groundwater and soil responses and breakthrough curves (dashed lines) have been added following re-analysis of this data as part of a status report of groundwater and salinity responses to water manipulation at Bookpurnong (AWE 2015). The breakthrough curves are plotted over sampled data points, which are assumed to represent pumped groundwater samples from each bore. It is also assumed that the loggers used to collect continuous salinity data were kept at a constant elevation over the monitoring period. An approximation of the migration of the freshwater lens has also been made using the EM data presented in Figure 4.1 and salinity data from Holland et al. (2013). The Living Murray Production Bore (LMPB) is located in Transect B3, with production bores 32F, 34F and 36F from the Bookpurnong SIS located in close proximity to other Site B transects. On the water level graphs, the blue bar represents time when the LMPB was operational and the red bar represents time that the Bookpurnong SIS was operational. It should also be noted that no monitoring data is available between December 2008 and December 2010 during the rising limb of the flood.

Available water level data suggests losing stream conditions adjacent all the Site B transects prior to the 2010 flood with the strongest hydraulic gradient from the River to the floodplain aquifer observed at Transect B3 (LMPB).

Transect B3 is likely to show the greatest response to pumping as the LMPB is located at this site. Bore B7 is located closest to the River, recording consistently low groundwater salinities and soil chloride over the monitoring period. The next bore along the transect is B8 and data from this site suggests a significant decline in groundwater salinity from approximately 50,000 µS/cm in 2006, prior to LMPB operation, to less than 1,000 µS/cm after 6 months of pumping from the LMPB. The pattern of the groundwater salinity data matches the breakthrough response type curves. A similar groundwater salinity response can be observed in data from B9, however, this is delayed as this bore is located further back from the River. Low groundwater salinity is maintained at these sites following the 2010 and 2011 floods. Site B25 is located on the highland side of the LMPB, with variable groundwater salinities recorded at this site prior to 2009. Some continuous salinity data has also been measured along the transect using loggers. This data indicates significant fluctuations in groundwater salinity at B8, consistent with oscillation of the halocline when the LMPB was pulsed on and off during 2008.

A similar groundwater response can be observed along Transect B4, although the spatial extent of the freshwater lens is not as great as that at Transect B3. Groundwater salinity data from B11 indicates a breakthrough curve response. However, the salinity decline at B11 is delayed beginning in approximately September 2007 and stabilising after September 2008, even though this site is located at the same distance from the River as B8. This response is due to Transect B4 being located at a greater distance from both the LMPB and Bookpurnong SIS bores.

Transect B2 was partially inundated by artificial watering during September 2006 with flood runners naturally drying within 3 or 4 months. Freshening of groundwater salinity at B5 coincides with this watering event. Low salinities persisted at B5 until December 2008 (and possibly longer as this is the last monitoring point before the natural flood), long after the freshwater in flood runners had dried. Groundwater gradients away from the River are enhanced by SIS pumping and this may help to maintain freshwater lenses emplaced via bank recharge during watering events. The groundwater freshening response again matches the break through type curve observed at other transects.

Monitoring data indicates that the groundwater salinity response (freshening) and extent of the freshwater lens was much greater at the Site B Transects compared to Site A. The groundwater salinity data from the B transects, particularly B3, provides a template for the pattern of groundwater salinity response that can be expected in observation bores affected by pumping, namely, a breakthrough curve that occurs rapidly close to the River and more slowly with increasing distance from the River.

Analysis of pumping data and the migration of the freshwater lens at Bookpurnong indicates that pumping a megalitre of groundwater creates a low salinity lens that contains only 0.2 mega litres of low salinity water (AWE 2015c). That is, the conversion efficiency from pumping to lens creation is only around 20%. When factored across the size of the lens, and accounting for the changes in area over time, this means the pumping efficiency may exceed 20%. This quantification is based on empirical data from the Bookpurnong Living Murray Trial (AWE 2005, Berens et al 2009, Holland et al 2013) and subsequent reanalysis of that data as well as data collected at a later date (AWE 2015). The leading edge of the lens migrates slowly through the aquifer, and the lens maintains a wedge shape (Figure 4.1). An accessible porosity of 0.15 was assumed. The volume of the wedge of low salinity water was calculated by dividing the area between lines B2 and B4 (Figure 4.2) into four segments, and calculating the average width and length between the River and the December 05 and the December 08 contours respectively. Lens depth data was derived from the monitoring of the lenses (Berens et al 2009). The increase in volume of the low salinity lens was calculated as the difference between the December 08 wedge volume and the December 05 wedge volume. The Living Murray Bore pumping rate averaged 4L/s during that period, and it is assumed that the Bookpurnong SIS bores had lowered the regional gradient such that The Living Murray bore did not have to intercept any flux to the River (AWE 2015c). The calculated increase in volume of the low salinity lens between December 05 and December 08 is 29 ML. However, Doody et al (2009) calculated a net discharge over the low salinity lens of 208mm/a close to the River, and around 50mm further inland by 2009. This equates to a net discharge volume from the lens of around 20ML over the three years. The volume pumped from The Living Murray bore in that period was 220 ML. Therefore, the conversion efficiency for The Living Murray bore at Bookpurnong is around 22% (AWE 2015c). It is anticipated that the conversion efficiency will vary along the River (AWE 2004), however there are no documented systematic trends in River skin permeability, or any currently available predictive methodologies.

While the data at Bookpurnong suggests only 22% of pumping is converted to a low salinity lens, this is a higher conversion efficiency than we anticipate from surface watering on the higher floodplain terraces. For example, assuming reasonable parameter ranges[1], the conversion efficiency from surface inundation on the higher terraces may only be 10%.

Pumping from Salt Interception Scheme (SIS) borefields may also provide secondary ecological benefits as a result of groundwater manipulation although published data sets that demonstrate this are limited to The Living Murray at Bookpurnong site.

Alaghmand et al (2014) developed a numerical model of surface water and groundwater flow and solute transport for the Bookpurnong floodplain. The model was calibrated using field monitoring data of groundwater heads and salinity, with model results suggesting it was capable of reproducing the dynamics of both flow and solute between the River and aquifer. The calibrated model was then used to assess the relative impacts of River stage manipulation and SIS pumping on groundwater-surface water interactions, particularly freshening of the floodplain aquifer.

Modelling results suggested that SIS pumping was able to reduce the saline groundwater flux to the floodplain and the absence of a SIS would have resulted in the continuous discharge of saline groundwater to the River having implications for water quality and vegetation health. Results from scenarios that assessed the impact of River stage (weir pool) manipulation suggested that raising the River stage created a gradient that allowed bank recharge and the response was proportional to the height and duration of the River level rise. This pattern was reversed when the River stage was lowered. It was observed that the impact of River manipulation was commonly observed within 100m of the River but that longer duration manipulations may extend this influence further back into the floodplain.

Alaghmand et al (2014) concluded that of all the drivers examined by the study, groundwater extraction had the greatest influence on solute mass mobilisation in the unsaturated zone. The study also concludes that bank storage is one of the main drivers of semi-arid floodplain groundwater-surface water interactions. Induced River manipulation reduced salinity in the floodplain aquifer by lowering the gradient between the regional aquifer and floodplain and freshening groundwater in the near River zone.

[1] Floodplain vertical hydraulic conductivity of 0.001, average inundation depth of 1 metre, 100 days of inundation, therefore 0.1m of infiltration or 10% of a “static” inundation volume.

On the Mallee Cliffs floodplain, the application of sequential down-hole Electromagnetic (EM) logging by Williams (2010) demonstrates that the SIS has induced the formation of a freshwater lens in the floodplain aquifer. The deepest piezometers adjacent to the River were EM logged at three monthly intervals. The development of a freshwater lens is shown by a progressive reduction in formation conductivity, from approximately 8,000 µS/cm to 2,000 µS/cm in a shallow zone, while EM conductivity in other zones has remained steady (Williams 2010).

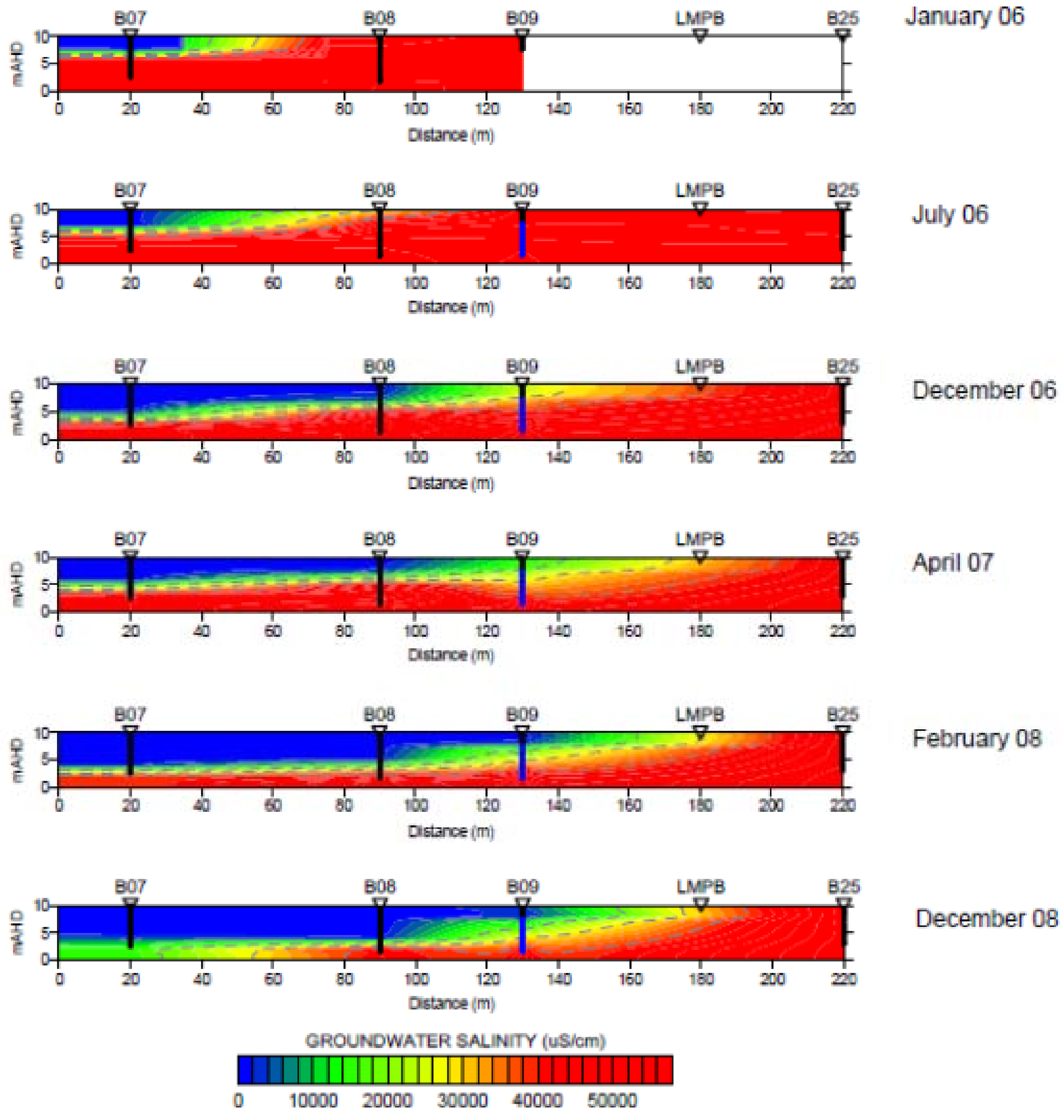
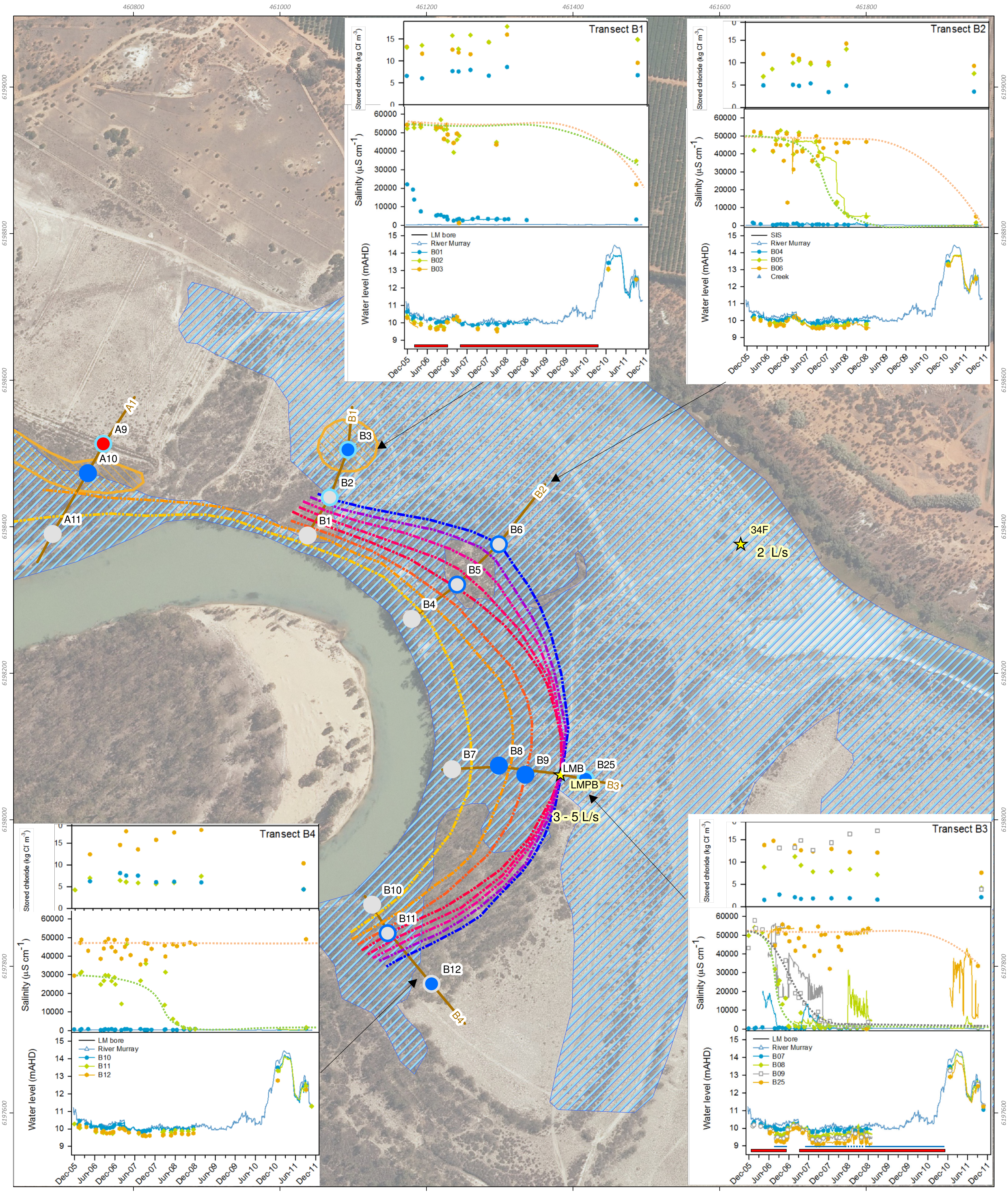


Figure 18. Transect 3 sonde profile data indicating freshwater lens development resulting from Living Murray pumping.

FIGURE 4.1: GROUNDWATER MONITORING FROM THE LIVING MURRAY PILOT PROJECT AT BOOKPURNONG (TRANSECT B3) (AFTER BERENS ET AL 2009)



LEGEND

Soil Salinity Response
- Decline
- Increase
- No Change

Groundwater Salinity Response
- Decline
- Partial Decline
- No Change
- SIS Bores

Approximate Extent of Freshwater Lens

Date_
- Dec 2005
- Dec 2006
- Dec 2007
- Dec 2008
- Dec 2009
- Dec 2010
- Dec 2011
- Dec 2012

- Monitoring Transect
- Approx. Inundation at 94ML/d (from Holland)
- Preferential Recharge Zone ?

Note: The colour at the centre of the monitoring site matches the colour of monitoring data presented in the graphs.

0 50 100 150
Meters

Data Source:
Aerial photography supplied by Dept of Environment & Heritage (DEH); Survey Locations supplied by Australian Water Environments (AWE).Data/Charts from Holland et al 2013 with annotation by AWE

Interpretation of Freshwater Lenses and Geophysics in Bookpurnong

Bookpurnong Floodplain Groundwater and Soil Salinity B Transects

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Figure 4.2

4.2.2 Injection

Injection of low salinity water into the floodplain aquifer is another option for floodplain management. Although the principle of injecting surface water into an aquifer is well established (e.g. Managed Aquifer Recharge and Aquifer Storage and Recovery schemes), there is only one example where this has been trialled as a floodplain management intervention. Two additional studies in the Murray Darling Basin have assessed the use of injection to deeper aquifers as a method for disposal of saline groundwater.

An injection trial was conducted at Bookpurnong as part of The Living Murray Pilot Project. During this trial 4.9ML of River Murray water was injected into the Monoman Formation aquifer over an 8 week period (Berens et al. 2009b). The injection trial stopped after this time due to the well and aquifer clogging with biological and particulate matter that caused surface leakage. Overall, the study concluded that only very localised and short duration groundwater freshening occurred as the result of injection and this freshening produced no observable benefits to floodplain trees within the zone of influence (Berens et al. 2009b). This may also be due to the short operating time of the trial. The trial report also suggests that overcoming the technical difficulties associated with injection would be costly considering the poor ecological results and life span of operations (Berens et al. 2009b). As the trial suggests, significant capital costs are associated with the injection option and it would likely require the injection of filtered water to be successful.

An injection trial was conducted at Gum Flat on the Chowilla floodplain to assess the feasibility of injecting groundwater from the Monoman Formation into the Murray Group (Rammers et al. 2005). Results from the trial suggested that the permeability of the Murray Group sediments was not high enough for injection to be a feasible disposable option. Limited chemical analysis also suggested that injection water from the Monoman Formation would require filtration due to high levels of iron bacteria and particulate matter (Rammers et al. 2005).

Another study assessed the potential for deep injection of groundwater from the Monoman Formation to the Renmark Group. The Renmark Group predominantly consists of sandy sediments at the base, with an increasing proportion of silts and clays in the upper sequence however, bore logs are few. The feasibility of deep injection as a disposal option was investigated at the Stockyard Plain Basin (AWE 2005b) but concluded that neither the Olney Formation nor the Warina Formation (sandy units) were viable targets for injection. In the case of the Olney Formation this was due to the low porosity and high clay content of the unit at this location. In the case of the Warina Formation, the unit was too thin or absent for it to be the target of long term disposal (AWE 2005b).

A follow-up study assessed the clogging risks associated with deep injection and made the following recommendations for managing these risks:

- Pre-treatment of the intercepted water to reduce particulate matter to an acceptable minimum;
- Minimising the aeration of Monoman Formation water during storage;
- The well be re-developed (i.e. cleaned out) before a 20% reduction in the injection rate is observed;
- Ongoing monitoring of injection rates and pressures and oxygen and turbidity levels of injection water during the injection trial; and
- Monitoring of key water quality indicators (EC, pH etc.) for injection water and at observation wells within the area of influence of the trial (Pavelic et al. 2007).

Although the injection of surface water to create a low salinity lens in the floodplain aquifer has not been successfully demonstrated in the Murray Darling Basin, Managed Aquifer Recharge by injection of surface water, stormwater or treated effluent into groundwater is a common practice across South Australia and the world. There are many successful Managed Aquifer Recharge schemes in South Australia, although most of them target the Tertiary limestone aquifers.

Injection using filtered water should be a feasible option for emplacing low salinity water into the floodplain aquifer. Successful implementation of an injection trial would provide confidence that the methodology could be employed to manage Black Box health decline.

4.3 Unsaturated Zone Response to Floodplain Management

The response of the unsaturated zone to floodplain management is not well understood in terms of mechanisms of salt storage and mobilisation between the floodplain surface, unsaturated zone and saturated zone. The unsaturated zone is thought to accumulate salt during the low flow periods however, storage and release mechanisms within the floodplain are incompletely conceptualised and sparsely quantified (AWE 2011). To our knowledge, rates of salt accumulation in the unsaturated zone have not been measured. Additionally the current thinking around the mechanisms and rates of salt accumulation are based on models which are not supported by measured data.

The following sections examine the response of the unsaturated zone to:

- Environmental watering (or flooding); and
- Groundwater manipulation.

4.3.1 Unsaturated Zone Response to Environmental Watering

Soils may be considered saline once the concentration of salt present in the soil water is high enough to inhibit plant growth. Salinity tolerance varies according to plant species and age, with seedlings having a lower salt tolerance than mature plants (Rengasamy et al. 2010). Flooding (managed or natural) may improve floodplain vegetation health by increasing soil moisture availability and reducing salinity in the root zone by washing salt from the surface or leaching salt from the upper profile. However, overall there is very little data available concerning leaching of salts from floodplains due to flooding (natural or managed). This study hypothesises that a number of factors are likely influence the magnitude of the reduction in soil salinity, including flood frequency, duration and soil type (Wallace and Rengasamy 2011).

The direction of salt movement in the soil profile is dependent on the driving process. A study by Crosbie et al. (2007 & 2009) analysed soil salt dynamics beneath Lake Littra on the Chowilla floodplain. This study concluded that the Lake behaved as a groundwater discharge feature when empty (i.e. salt moved upwards through the profile due to evaporation) and as a recharge feature when flooded. In this case, the salt movement from leaching when the Lake was flooded did not reach the water table, and instead the salt moved upwards in the soil profile again when the Lake was dry.

A review of monitoring data collected as part of environmental watering trials on the Chowilla floodplain (SKM 2009) concluded that the response of the unsaturated zone to environmental watering was limited. SKM presented two examples of unsaturated zone sampling undertaken as part of watering events at the Gum Flat and Werta Wert Wetlands.

Soil sampling undertaken at Werta Wert found that there was good correlation between soil texture and soil salinity. Soil samples taken from sandy profiles displayed lower soil chloride values than those with clayey profiles. The majority of soil samples were taken prior to the watering event with soil chloride concentrations ranging between less than 10,000mg/L up to 40,000mg/L at depths of up to 2m. Soil moisture content varied with depth and with soil texture but generally gravimetric water content increased with depth. Soil salinity was only monitored pre and post watering at 2 sites. These sites were located on the edge of the wetland and were not likely to have been inundated as part of the watering event. These sites were characterised by clayey soil profiles and did not show any significant change in soil chloride pre and post watering (SKM 2009).

Soil sampling was undertaken at four sites around the Gum Flat wetland before and after a watering event. Results from this analysis indicated that watering flushed chloride from the upper 0.5 to 1m of the soil profile. This response was observed across the site even where the soil profile was clayey. It was also noted that a rainfall event which occurred three weeks before the second sampling event may have contributed to the observed decline in chloride in the upper profile (SKM 2009).

Floodplain management trials for Black Box tree health at Markaranka found that bank recharge was observed up to 100m from the River mainstream during weir pool raising events (Gehrig, pers. comm., 2014). With respect to soil salinity levels, soil profiles freshened to 4m deep at a distance of 10m from ponded environmental water in a creek at Markaranka, while at 30m from the creek, freshening occurred to 1.5 m depth (Doody, pers comm., 2014). Drip irrigation freshened soils to 1m depth. The initial research finding from the Markaranka trials is that 60mm/month (delivered by irrigation) is required to flush salt to below 2m, away from root zones, but this will be site (soil) dependent.

Reanalysis of soil chloride profiles, presented in Holland et al. (2013), suggest that the soil salinity responses to flooding, both managed and natural, are quite variable across the floodplain (Figure 4.4) (AWE 2015). However, data indicates that the soil salinity response to the natural flood was greater than that observed following environmental watering. Soil chloride trends, particularly at the base of the profile, appear to correlate with groundwater salinity trends, i.e. where groundwater salinity has declined during 2007/08, soil salinity shows the same declining trend in 11 of the 12 sampling sites. There also appears to be a trend indicating some freshening from the surface (AWE 2015).

Wallace and Rengasamy (2011) provide an assessment of the distribution and magnitude of sodic and salinised soils on the Pike floodplain. Of particular interest is the comparison of soil salinity prior to and following the flood events of 2010 and 2011.

The ability of floodplain inundation to reduce soil salinity was assessed using a simple comparison between soil EC data collected by Gehrig and Nicol (2010) prior to flooding with that collected in the same transects following flooding by Wallace and Rengasamy (2011). Although soils were sampled within the same transects, it was not possible to collect samples at the exact same locations as those in 2010. However, as datasets concerning soil salinity response to flooding are few, this study provides a useful dataset despite the sampling limitations.

Comparison of pre and post flooding soil EC are presented in Figure 4.3. Results suggest that floodplain inundation may have lead to substantial leaching of salt from the upper soil profile (top 20cm) at the majority of sites sampled (Wallace and Rengasamy 2011). The availability of soil moisture is a function of both salt content and soil moisture. In either case, flooding will increase soil moisture availability to some degree which is beneficial to floodplain vegetation (Wallace and Rengasamy 2011, SKM 2009). Multiple floods may be required to sufficiently reduce root zone salinity on floodplains where soil salinity is high (Nicol et al. 2010). Overall, Wallace and Rengasamy (2011), recommend that further research is required to assess the ability of floodplain inundation and rainfall to leach salt from the soil profile.

Bramley et al. (2003) investigated whether floodwater preferentially infiltrates through channels created by Black Box roots, flushing salt from the root zone and allowing increased water uptake. In this study a series of sites on the Chowilla floodplain were artificially flooded by pumping water from a nearby creek and impounding it on the floodplain.

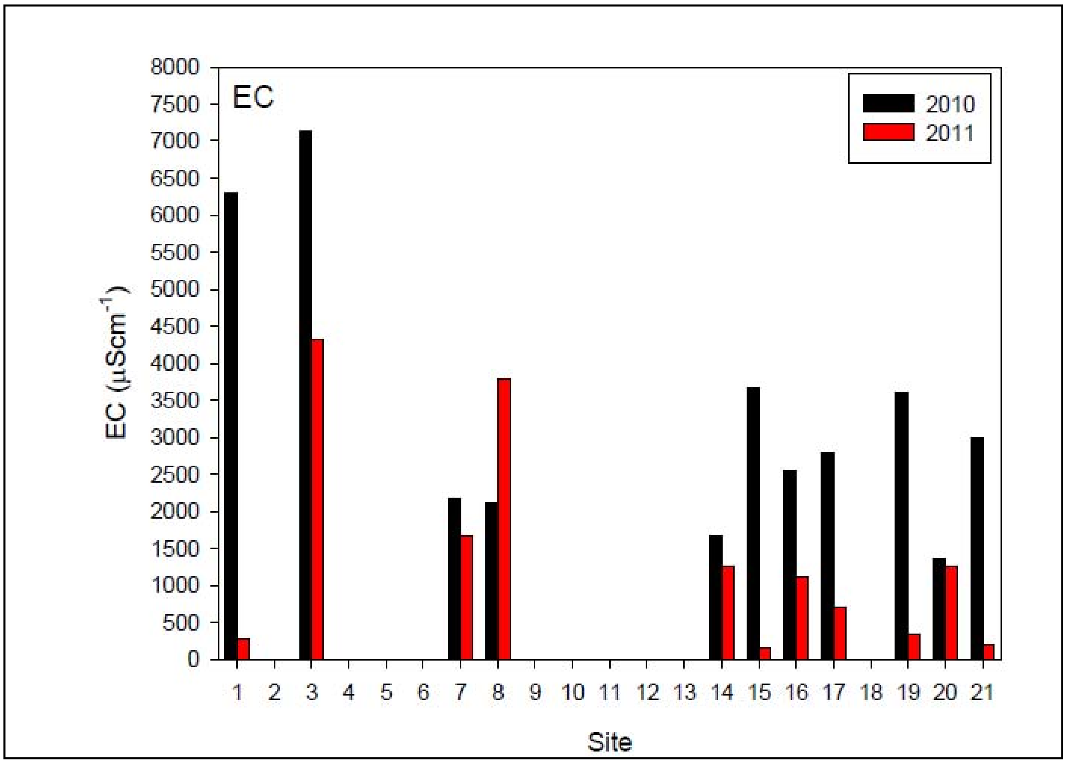

FIGURE 4.3: COMPARISON OF SOIL EC IN THE TOP 20CM OF THE SOIL PROFILE BETWEEN 2010 AND 2011 (AFTER WALLACE AND RENGASAMY 2012)

Analysis of tree response to flooding suggested that the trees experienced less water stress a week after the event as indicated by an increase in water potential. However, this response was not evident one month after flooding (Bramley et al. 2003). Infiltration rates around Black Box trees were compared to infiltration rates beneath bare ground within artificially flooded impoundments. Bramley et al. (2003) concluded that floodwater infiltrated 2 to 17 times faster at sites around trees compared to the adjacent bare ground (non-grazed). Analysis of dye tracer results suggested that the mechanism of infiltration beneath bare ground is different to that beneath trees. Distribution of the dye tracers suggested diffuse flow through the soil profile beneath bare ground.

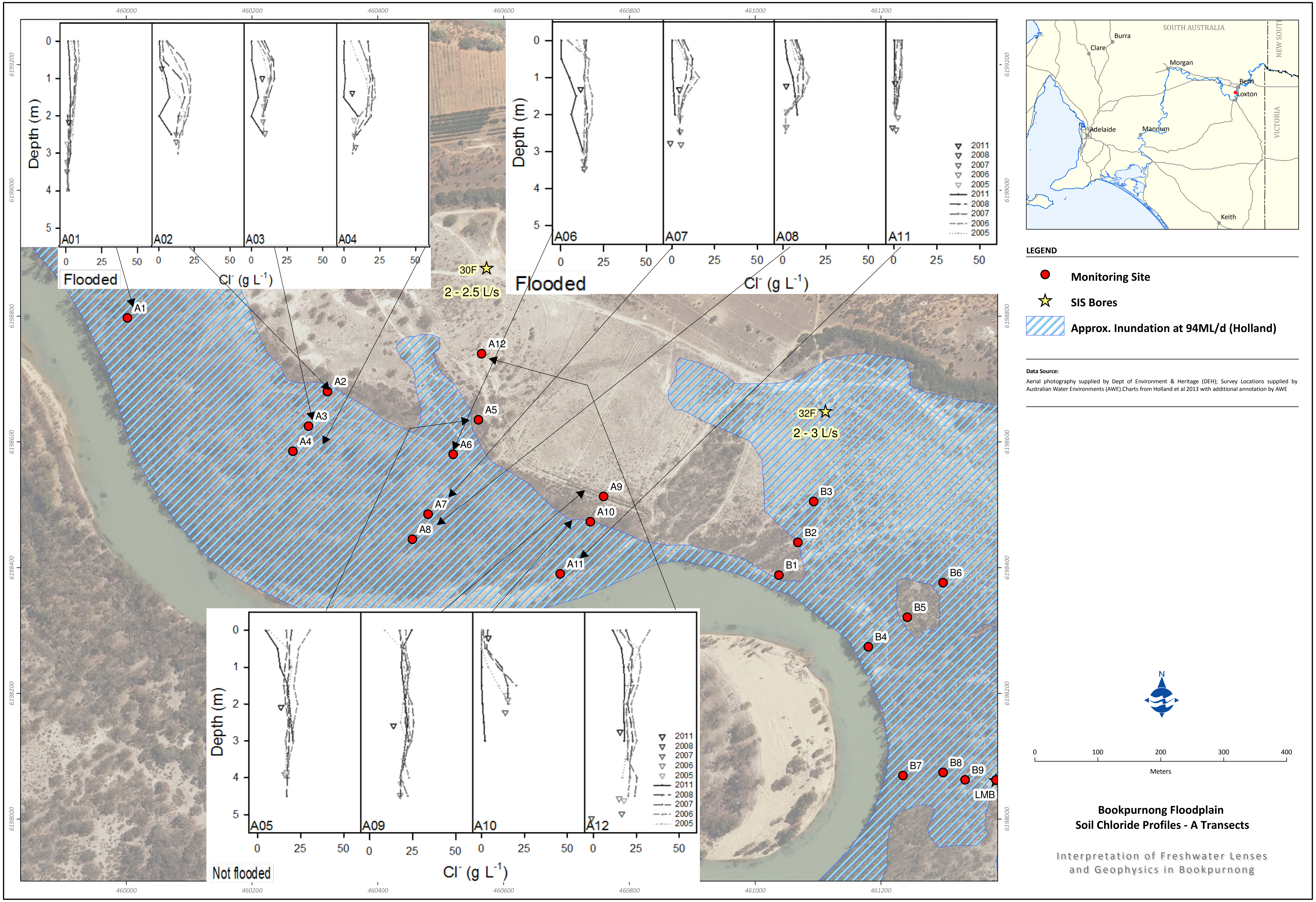

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Figure 4.3

Conversely, high concentrations of dye were found deeper in the soil profile beneath flooded trees, suggesting rapid movement of the tracer through root channels. Bramley et al. (2003) also concluded that flooding leached salts from the soil profile in the direct vicinity of tree roots but comparatively small amounts of salt were leached from the soil in other locations.

4.3.2 Response to Groundwater Manipulation

It is considered likely that change in groundwater salinity (i.e. the development of a freshwater lens) will create a response in the overlying unsaturated zone. This is supported by evidence from Overton and Jolly (2004) who concluded that the soil salinity was well correlated with the underlying groundwater salinity. Whilst a number of analytical and numerical models are available, very little monitoring data is available to asses this hypothesis. The limited studies available which assess the influence of groundwater salinity on the unsaturated zone are detailed below.

Visual inspection of soil salinity profiles and groundwater salinity presented in McEwan et al (2003) suggests that there is a moderate to good correlation between soil salinity at the base of the soil profile and groundwater salinity (AWE 2012). The relationship between average soil salinity and groundwater salinity is presented in Figure 4.5. The average difference between groundwater and soil salinity for the 199 samples was calculated to be 15,721mg/L.

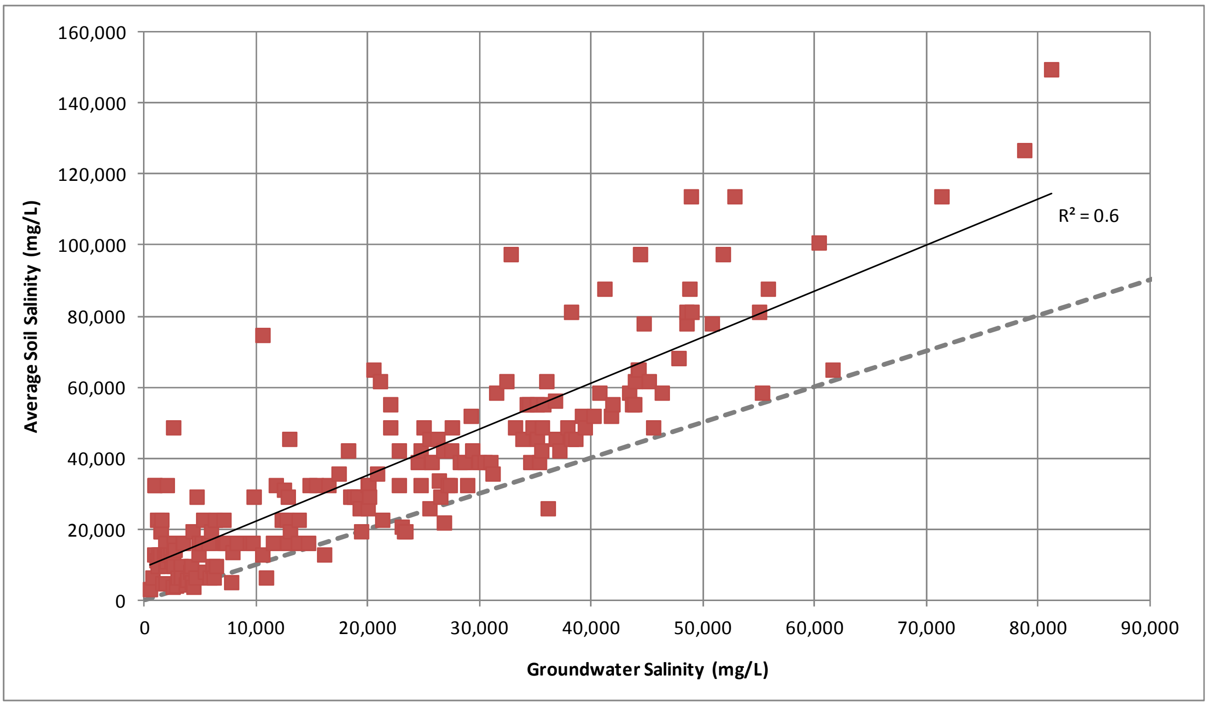


FIGURE 4.5: GROUNDWATER SALINITY VS. AVERAGE SOIL SALINITY (AWE 2012 FROM DATA PRESENTED IN MCEWAN ET AL. 2003)

Soil salinities at the top of the soil profile tended to be higher than groundwater and soil salinity at the base of the profile. At the top of the soil profile, salinity will be more influenced by recharge and discharge processes. It was also observed that the largest difference between groundwater and soil salinity occurred where groundwater salinity was low (AWE 2012). Similarly it can also be observed that the strength of the correlation between soil and groundwater salinity declines where groundwater salinity exceeds about 39,000mg/L. It is interesting to note that this corresponds to the upper limit of healthy Black Box, and it can be speculated that plant moderated soil salt reflux processes break down once trees become unhealthy, leading to increased rates of retention of salts within the unsaturated zone and hence hastening health decline. The data suggests that there is no obvious relationship between depth to water and salinity of groundwater and soil, however this comparison is undertaken at a snapshot in time.

The influence of changes in groundwater salinity on the unsaturated zone is a key knowledge gap in demonstrating the benefits of groundwater manipulation for floodplain vegetation. Studies conducted on the Bookpurnong floodplain provide the best example of the influence of groundwater manipulation on soil salinity.

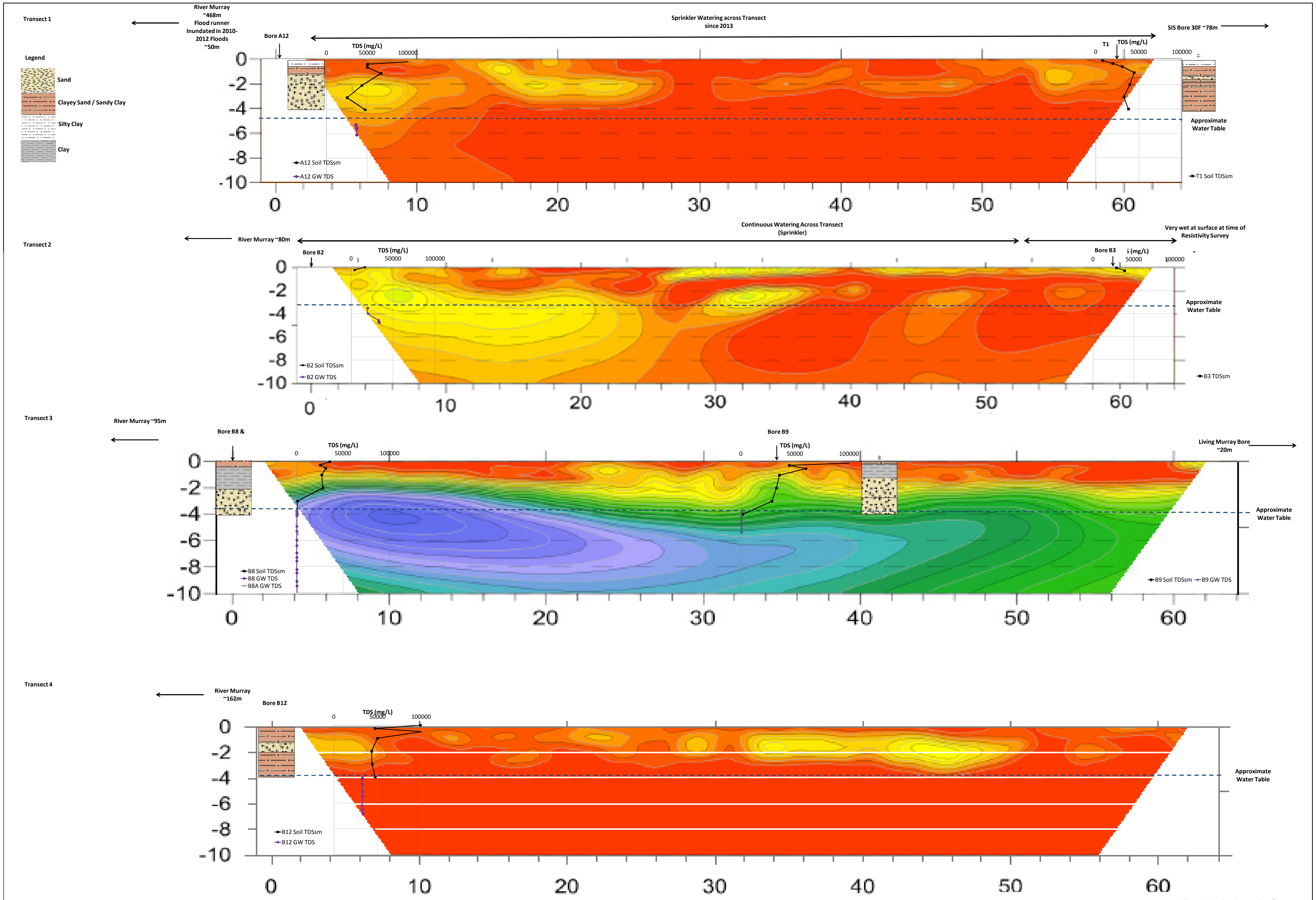
AWE (2015) presented a review of previous work at this site and analysed a series of soil salinity datasets and studies in the context of evaluating the ecological benefits of SIS pumping. This includes the use of geophysical techniques (resistivity survey), unsaturated zone sampling and vertical groundwater salinity profiling, across a series of transects where a variety of management interventions have been applied.

Preliminary results from this field work are presented (Figure 4.6) and suggest that there is a good correlation between the resistivity survey and changes in soil and groundwater salinity. Available soil and groundwater salinity profiles, along with texture data from the soil cores, are presented on the resistivity transects and were collected at the same time as the geophysical survey. In the resistivity transects red and orange indicate high conductivity materials with blue and green representing lower conductivity materials. The following summarises the likely influences on each transect:

- Resistivity Transect 1 – site watered using sprinkler irrigation, start of transect located approximately 50m from the edge of a flood runner inundated by natural flood in 2010 and 2012 and the end of the transect may be within the influence of SIS pumping.
- Resistivity Transect 2 – the start of the transect is located approximately 80m from the edge of the River Murray and the site has also been watered using sprinkler irrigation. At the time of the resistivity survey it was noted that the surface was very wet near bore B3.
- Resistivity Transect 3 – the start of the transect begins approximately 95m from the River Murray, ending approximately 20m from The Living Murray Bore. This site has not been watered.
- Resistivity Transect 4 – the control transect and was unlikely to have been inundated during the natural floods in 2010 and 2012, the site has not been watered and is also likely to be outside the influence of pumping from the SIS.

Transect 3 illustrates the influence of groundwater manipulation on the salinity of the unsaturated zone. At this site soil cores were taken within the extent of the freshwater lens created by pumping from The Living Murray Production Bore (LMPB). Significantly lower soil salinities were measured at this site compared to the other transects and vertical profiles show a consistent decline in soil salinity with depth. The average soil salinity at 4m for Transect 3 is 1,065 mg/L compared to 36,175mg/L for the remaining floodplain sites.

For Transect 3 soil salinities at the base of the profile correlate well with the low salinity groundwater measured in the adjacent monitoring bores. This is in contrast to soil profiles from the other 3 transects where soil salinity is significantly higher and varies with depth.



Long Term Monitoring at Bookpurnong

Comparison of Soil Salinity, Groundwater Salinity and Resistivity Profiles

Figure 4.6

Groundwater salinity averages 480 mg/L beneath Transect 3 compared to 25,300 mg/L beneath Transect 2 which is located at a comparable distance from the River.

Although not directly comparable, data presented in Holland et al. (2013) suggests that soil chloride at bore site B9 was approximately 18,000mg/L in 2005 before the LMPB was operational. Data collected at the time of the resistivity survey suggests soil salinities of 1,689 mg/L at the base of the soil profile for bore B9 (AWE 2015).

Vertical changes in groundwater and soil salinity also correlate well to changes in conductivity shown in the resistivity profile. The influence of lower salinity groundwater on the unsaturated zone can also be observed in soil samples taken from above the water table. This is also supported by results from the resistivity survey which suggests a lower conductivity signal extends 1.5m to 2m above the water table along Transect 3.

Overall, the analysis of groundwater salinity, soil salinity and resistivity data indicates the greatest amount of freshening has occurred along Transect 3 where the LMPB is located. Whilst localised changes in conductivity can be observed in the geophysical profiles of the remaining three transects (yellow); data from the soil cores and groundwater monitoring data indicates that salinities along the transects remain high (i.e. above the tolerance of River Red Gum trees).

Ongoing vegetation monitoring is being undertaken at these sites, however results are not yet available.

5 Summary of Field Program

Summary:

The relationships between groundwater salinity, soil salinity and vegetation health that were derived from literature review have been confirmed from analysis of the field site data:

- 75% of healthy Black Box occur where the groundwater salinity is less than 17,000 mg/L;
- 75% of unhealthy Black Box occur where the groundwater salinity is greater than 21,000 mg/L

A field program was implemented to collect additional monitoring data across floodplain sites that have shown a range of ecological responses to environmental watering in the Mallee CMA region. The primary aim of the field program was to collect data that will allow correlation of ecological responses and soil salinity with groundwater salinity. The site indicators described in Section 3.2 are applied to five floodplain sites within the Mallee CMA region where variable responses to environmental watering have been observed.

The aim of this section is to test the relationship between groundwater salinity, soil salinity and vegetation health using new monitoring data collected at each of the floodplain sites. This section then applies the key process indicators at each site, to evaluate the success, or otherwise, of previous environmental watering and to identify sites where the application of groundwater manipulation strategies may provide beneficial outcomes.

Five floodplain sites within the Mallee CMA region have been chosen to be the focus of field data collection. The following factors were considered in the site selection process:

- Data availability for the key site indicators;
- History of environmental watering;
- Sites that represent a range of vegetation responses; and
- Variation in key indicators between sites.

The following floodplain sites were selected in consultation with Mallee CMA staff, who implement the Mallee Environmental Watering Program:

- Lake Wallawalla is an elliptical lake and lunette system covering an area of approximately 815 hectares on the Lindsay-Wallpolla floodplain. Lake Wallawalla and some of the adjacent floodplain were last inundated during the high flows experienced in the River Murray in 2010 and 2011. The floodplain to the west of Lake Wallawalla was chosen as a focus site as Black Box trees have been showing signs of stress at this location and there have been limited improvements in vegetation health due to natural and managed flood events with increasing distance from the perimeter of the Lake.

- On the Chaffey Bend floodplain, observed trends in vegetation health correlate well with changes in groundwater and soil salinity. The best condition Black Box trees occur on a section of floodplain that requires very high flows to flood (higher than the maximum flood assessed by the Floodplain Inundation Model (FIM)). However, these healthy trees occur within the known extent of the freshwater lens beneath the wastewater lagoon, where a low salinity water source is available and corresponding soil salinities are below the 75th percentile ranges identified in this study and in data from McEwan et al. (2003).
- Kings Billabong is a pumped storage for irrigation supply to the Mildura Irrigation District. Water levels in the storage are held higher than River level. Black Box vegetation is significantly healthier at this location compared to Psyche Lagoon. The Kings Billabong floodplain is located just downstream of the Psyche Bend floodplain and in a similar hydrogeological setting.
- Psyche Lagoon (approximately 22 ha) is located to the south of Kings Billabong and was used as a drainage disposal basin until the end of 1996. The lagoon and surrounding vegetation has been severely affected by salinisation (Ecological Associates 2007). The Woorlong Wetlands (Basin 12) are also located on the Psyche Bend floodplain to the south west of the Lagoon and are also used for the disposal of drainage water.
- Hattah Lakes is one of The Living Murray Icon sites and consists of a series of freshwater lakes connected by a series of floodplain channels that are fed by the River Murray during high flows (McCarthy et al. 2008).

The field program inputs, methodology and outputs are detailed in Appendix C. Site compilations of the available datasets on key site indicators for each of the five floodplains are also provided in that Appendix. The results of the field program are summarised below.

5.1 Analysis of Groundwater Salinity, Soil Salinity and Vegetation Condition at the Field Sites

The following section presents outcomes from the field program in terms of the relationships between groundwater salinity, soil salinity and vegetation health across the five floodplain sites. Figure 5.1 presents the relationship between soil salinity at a depth of 4m and tree health across the five floodplain sites. Soil salinity and tree health have an inverse relationship, with vegetation health increasing with declining soil salinity.

The majority of healthy Black Box trees (Score ‘4’ and ‘5’) occur where soil salinities are below 30,000mg/L; conversely, the majority of unhealthy Black Box trees (Score 0 to 3) were found where soil salinity exceeded 30,000mg/L. The grouping of health scores is consistent with the approach adopted by DEH (2003) in broad scale health mapping of Black Box and River Red Gum trees along the Lower River Murray.

Soil salinity data presented in Figure 5.2 indicates that:

- 75% of healthy Black Box trees occur where soil salinity is less than 26,000mg/L at 4m; and
- 75% of unhealthy Black Box trees occur where soil salinities exceed at 32,000mg/L at a depth of 4m.

This is consistent with previous analysis of data from McEwan et al. (2003) which suggested that 75% of unhealthy Black Box trees were found on floodplains where soil salinity exceeded 32,500mg/L (AWE 2012). However, the previous study also found that healthy Black Box trees occurred at higher soil salinities than those measured in this study.

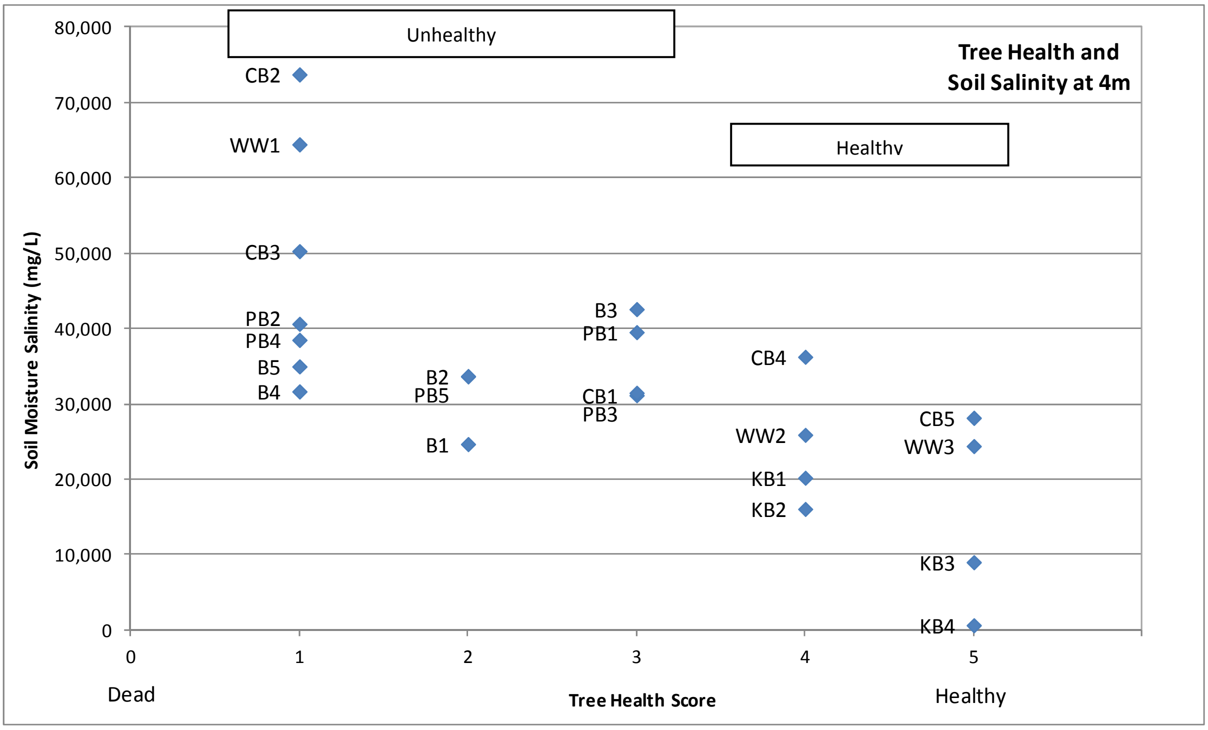


FIGURE 5.1: RELATIONSHIP BETWEEN TREE HEALTH AND SOIL SALINITY AT 4M DEPTH

Groundwater salinity data presented in Figure 5.2 indicates that:

- 75% of healthy Black Box trees are found where groundwater salinity is less than 17,000mg/L; and
- 75% of unhealthy Black Box trees are found where groundwater salinities exceed 21,000mg/L

This compares well to previous analysis of data presented in McEwan et al. (2003) which suggested that 75% of healthy Black Box trees were found on floodplains where groundwater salinity was less than 22,000mg/L and 75% of unhealthy Black Box trees were found where groundwater salinity exceeded this value (AWE 2012).

Figure 5.3 presents the relationship between groundwater salinity and average soil salinity with data from McEwan et al. (2003). The data from 2015 only uses sites where groundwater salinity was available directly adjacent the soil sampling site. Data presented in Figure 5.3 indicates that there is a good to moderate correlation between groundwater salinity and soil salinity with linear regression producing a correlation coefficient of 0.6. This is consistent with data from McEwan et al. (2003) which also produced a correlation coefficient of 0.6 for a greater sample size (AWE 2012). The data suggests that soil salinities are typically higher than groundwater salinities, but that the relationship is proportional i.e. if groundwater salinity increases so does soil salinity. This is consistent with data presented in McEwan et al. (2003) which also indicated that soil salinities were generally higher than groundwater salinity, but that the relationship was proportional (AWE 2012).

A number of other correlations were also assessed by this analysis including relationships between tree health and soil moisture, depth to water, floodplain elevation, flooding frequency and soil salinity and texture. However, this analysis suggested that there were no observable correlations between these factors in the dataset collected.

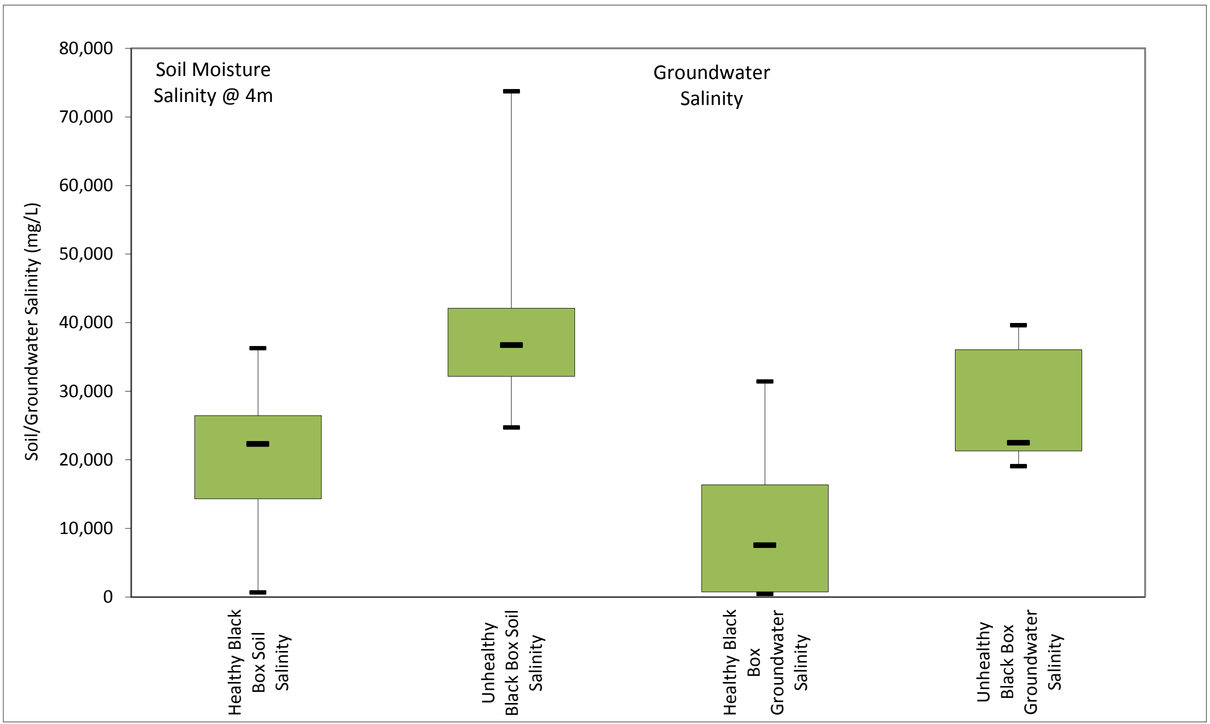


FIGURE 5.2: BOX AND WHISKER PLOT SHOWING RELATIONSHIP BETWEEN GROUNDWATER SALINITY, SOIL SALINITY AND VEGETATION CONDITION

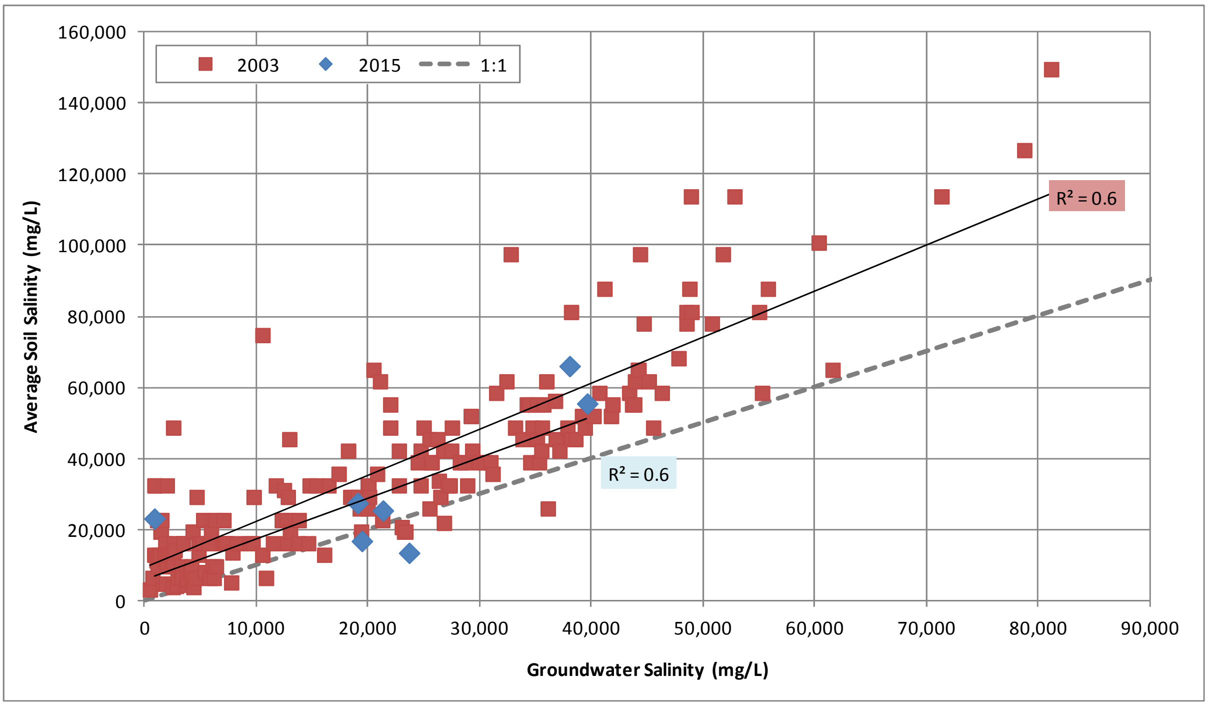


FIGURE 5.3: GROUNDWATER SALINITY AND AVERAGE SOIL SALINITY

6 Conclusions

The key delivery outputs from the project are:

1. An evaluation of the influence of groundwater and groundwater salinity on vegetation health
2. An evaluation of the influence of environmental watering on groundwater and groundwater salinity
3. Identification of indicators that can be used to predict ecological outcomes (specifically tree health improvement) from environmental watering, with particular reference to Black Box vegetation.

Section 6.1 summarises the conclusions regarding floodplain responses to water management, with reference to the Floodplain Response Model represented in Figure 6.1.

- The first of the key delivery outputs are discussed in Parts B, C and D of Section 6.1 below,
- The second key delivery output is discussed in Parts E and F in Section 6.1.

Section 6.2 then takes the conclusions drawn regarding the general Floodplain Response Model and formulates a more specific detailed assessment in relation to Black Box health (i.e. the Black Box Floodplain Response Model).

- The third key delivery output, which is the identification of indicators that can be used to predict ecological outcomes are discussed in the context of the Black Box Floodplain Response Model.

Watering strategies to maintain Black Box health are discussed in Section 6.4.

6.1 Floodplain Responses to Water Management

The following discussion refers to the annotations presented in the Floodplain Response Model (Figure 6.1), and summarises the findings of this report.

Part A: How much water do plants use?

Transpiration rates have been reported in the range of 11 to 365mm/yr for Black Box and 303 to 1,882mm/yr for River Red Gum trees (Holland et al 2011).

Part B: What are suitable saturated and unsaturated zone salinity thresholds for maintenance of health in mature trees?

Floodplain vegetation accesses appropriate salinity water from the unsaturated zone. The field program undertaken as part of this project identified quite conclusively that soil salinity and tree health have an inverse relationship (Figure 5.1), with vegetation health increasing with declining soil salinity. At the individual floodplain sites surveyed there is good correlation between changes in Black Box condition and patterns in soil (and groundwater) salinity. The best condition Black Box trees are found on the Chaffey Bend and Kings Billabong floodplains within the known extent of low salinity lenses. Conversely Black Box trees in poor condition occur on floodplains that tend to flood infrequently and have high soil and groundwater salinities.

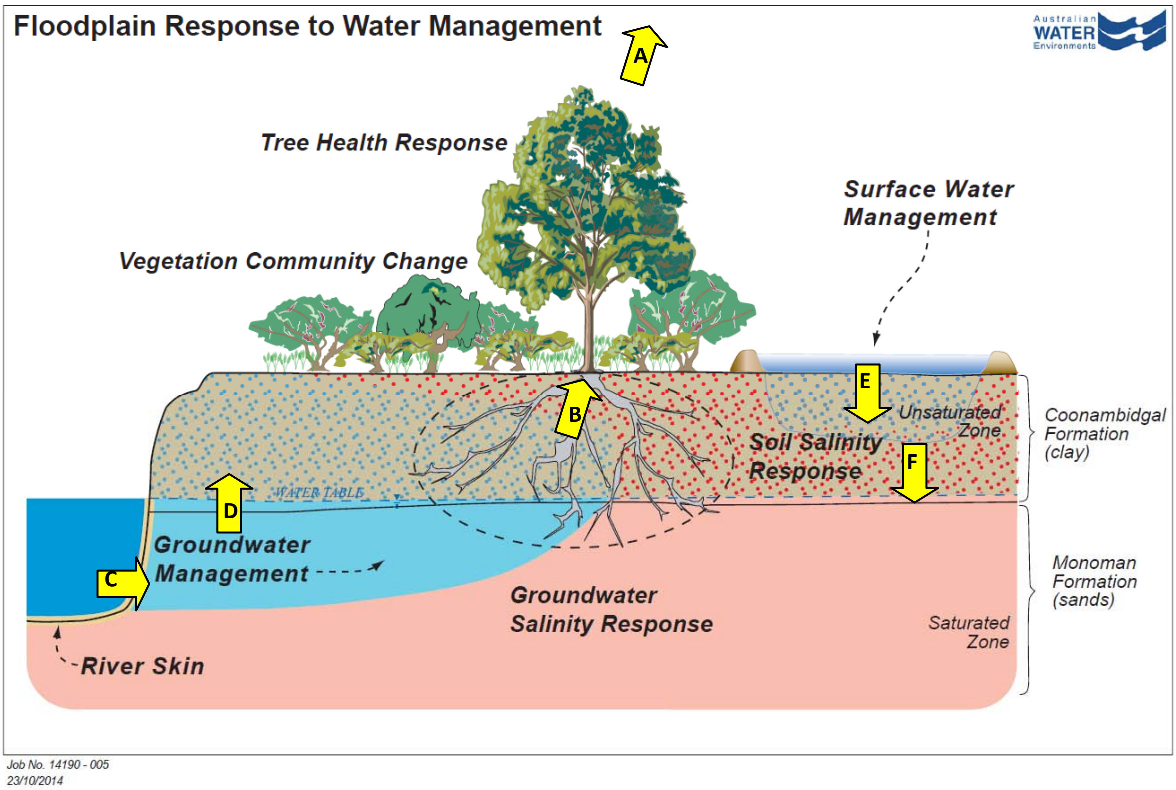


FIGURE 6.1: FLOODPLAIN RESPONSE MODEL

The salinity range for healthy Black Box is wide, but the distribution is skewed, both for saturated and unsaturated zone salinities (Figure 2.1). From review of the AWE (2012) study, supplemented by the field data from this study, we have observed that the 75th percentile unsaturated zone salinity for healthy Black Box and the 25th percentile for unhealthy Black Box are similar at around 39,000mg/L. That is, around 75% of healthy trees occur where the unsaturated zone salinity doesn't exceed 39,000 mg/L, and around 75% of unhealthy trees occur where the unsaturated zone exceeds a slightly lower value. We conclude that the 75th percentile unsaturated zone soil salinity value for healthy Black Box (i.e. 39,000 mg/L) could be adopted as the threshold value that separates healthy Black Box from unhealthy Black Box. This value is better than the maximum observed range, because the salinity distributions are skewed and the upper limits are disproportionately high compared to the median and 25th percentile values.

For River Red Gum, the 75th percentile unsaturated zone soil salinity value is 15,000 mg/L.

The same pattern holds true in the saturated zone. That is, the salinity of the 75th percentile for healthy trees and the 25th percentile for unhealthy trees are reasonably coincident. The saturated zone 75th percentile healthy Black Box value is 22,000 mg/L and the River Red Gum value is 7,000 mg/L.

It is recommended that these values be adopted as indicators when evaluating the likely outcomes from watering strategies. That is, the probability of a successful outcome from watering is equivocal if the groundwater and soil salinity thresholds are exceeded.

Part C: Can Low Salinity Lenses be created with Groundwater Management Strategies

Low salinity lenses form naturally where losing stream conditions occur. The naturally developed low salinity lens at Robinvale was emplaced through the bank during floods, with little recharge from overbank flows (Cartwright et al, 2010).

Groundwater pumping can emplace low salinity groundwater lenses actively through bank recharge (Part C), by creating losing stream conditions. The trial at Bookpurnong (AWE, 2005, Berens et al 2009, AWE 2015c) is the only site where the rates of formation have been measured. At Bookpurnong, only 22% of the pumped groundwater has been converted into the low salinity lens (AWE 2015c). The conversion factor for surface inundation has been estimated using a simple logic at around 10%, based on a “static” water column over the higher terraces. The conversion factor is expected to be variable. The cost effectiveness of different operating strategies has not been fully assessed.

The formation of the low salinity lens is controlled by the groundwater gradients between the regional system and the River, and the hydraulic properties of the aquifer and River skin. The hydraulic resistance of the River skin has not been directly quantified (to our knowledge) and the dynamics of freshwater lenses are not well understood. The hydraulic conductivity appears to vary over at least an order of magnitude, based on groundwater model results. Therefore, the efficiency of creating low salinity lenses by pumping will vary from site to site. Additional site trials are required before the efficiency of creating low salinity lenses by pumping can be adequately characterised.

Groundwater injection to create a low salinity lens was unsuccessfully trialled at Bookpurnong (Berens et al 2009b) using unfiltered River Murray water, injected into a lower permeability zone in the Monoman Formation. However, Managed Aquifer Recharge by injection of surface water, stormwater or treated effluent into groundwater is a common practice across South Australia and the world, and injection using filtered water should be a feasible option for emplacing low salinity water into the aquifer.

Part D: How effective are Low Salinity Lenses in reducing the salinity of the overlying unsaturated zone?

Investigations have demonstrated a strong correlation between soil salinity and groundwater salinity (e.g. McEwan et al. 2003, Jolly et al 2004, and AWE 2012). Linear regression of soil salinity and groundwater salinity produced a correlation coefficient of 0.6, indicating a moderate relationship, for both the AWE (2012) analysis and the investigations conducted for this study. Jolly et al (2004) note that groundwater salinity was the only parameter that correlated with soil salinity.

Results from The Living Murray Transect at Bookpurnong (AWE, 2015 in press) show that groundwater pumping has generated a low salinity lens which has then led to a reduction in the unsaturated zone salinity above the low salinity lens (Figure 6.1 Part D). The change in salinity has taken several years to occur and longer term monitoring at the site is recommended, to confirm the results.

Low salinity groundwater lenses float on top of more saline groundwater. This means the water is available to the unsaturated zone immediately the lens is formed, and it cuts off the supply of higher salinity water to the unsaturated zone.

The unsaturated zone salinity rarely exceeds the groundwater salinity by more than 20,000 mg/L in the DEH (2003) data presented in AWE (2012). This finding, and the measured reduction in unsaturated zone salinity over the low salinity lens at Bookpurnong (AWE 2015), points to the interchange of water between the saturated and unsaturated zone. If there were no interchange process, there is no reason why the soil salinity would not continue to increase. The process(es) facilitating the interchange have not been formulated or quantified as yet and this is a key knowledge gap. It is proposed that that fluctuations of the capillary fringe may assist with leaching salt from the unsaturated zone, and that osmotic gradients may also be involved.

However, even given the limited understanding of the interchange process, the empirical data from the Bookpurnong trial and from the DEH (2003) data indicates that the low salinity lenses are effective, over a period of years, in reducing the salinity of the unsaturated zone.

Groundwater management is therefore likely to be an important, if not critical, element in creating sustained benefits from water management on floodplains.

Part E: How effective is surface watering in increasing the availability of low salinity soil moisture in the unsaturated zone?

Rainfall, and natural or managed overbank flooding, can reduce the salinity of the unsaturated zone and increase soil moisture availability (Figure 6.1 Part E). Infiltration rates in the lower terrace at Bookpurnong have been measured at 10mm/d (AWE 2007). However, the rate of infiltration appears to be an order of magnitude lower for the higher elevation floodplain soils which support Black Box communities (e.g. 1 mm/d).

The lack of infiltration through the higher terraces is also supported by the analysis of the formation of the low salinity lens at Robinvale (Cartwright et al, 2010), which concluded that lenses were emplaced through the bank of the River rather, than by downward infiltration through the floodplain. Measurements of soil salinity in the Bookpurnong floodplain (Holland et al, 2013) also illustrate very little infiltration into the higher terraces.

It appears likely that the lowest (youngest) terrace of the floodplain may be more permeable than the higher terraces. However, the lower terraces usually support River Red Gum communities.

Therefore, surface watering of the higher terraces may provide relatively small volumes of low salinity water for Black Box to utilise. Additionally, while flooding may emplace fresh water into the uppermost portion of the unsaturated zone, this water will be subject to high rates of evaporative as well as transpirative losses because it is close to the surface. Conversely, emplacing appropriate salinity groundwater beneath the Black Box will provide orders of magnitude more water, and the low salinity groundwater will be subjected to lower loss rates through evaporation because of its increased depth below the surface. Transpirative losses may be similar in both instances, but if appropriate salinity groundwater is present then the transpiration can continue for much longer if fed by a groundwater source.

Part F: How effective is surface watering in emplacing low salinity lenses?

The probability that floodplain inundation will recharge the floodplain aquifer beneath the higher elevation floodplain soils (i.e. replenish freshwater lenses via vertical infiltration) (Figure 6.1 Part E) appears to be small. As discussed in Part E above, the rate of recharge is controlled by the vertical hydraulic conductivity of floodplain soils, for which there is little empirical data. Groundwater recharge from flood inundation at Bookpurnong seems to be limited to the interface between the youngest and the intermediate terraces (AWE 2015 in press).

For example, at Bookpurnong, groundwater pumping has been successful in delivering 19 ML of water to trees (calculated from ET rates), with a further 29 ML in storage in the saturated and unsaturated zone, over an area of 5 hectares over three years. This equates to consumptive use of around 1ML/ha, with 6 years supply held in storage in the aquifer. By contrast, 100 days of inundation over soils with an infiltration rate of 1mm/d will store 1 ML/ha in the unsaturated zone. This is around one year of water supply for Black Box.

6.1.1 Key Conclusions regarding the Floodplain Response Model

The literature review and the field program show that:

- Black Box and River Red Gum health is strongly correlated with unsaturated zone salinity
- Unsaturated zone salinity is strongly correlated with groundwater salinity
- Natural floods or environmental watering may generate groundwater recharge on the lowest (youngest) terraces, but recharge rates appear low (1mm/d) under the higher terraces. Reductions in flood frequency will reduce the volume of water recharged into the unsaturated zone
- Changes in soil salinity seem to be more successfully achieved through emplacement of freshwater lenses than through surface inundation.

It can therefore be concluded that:

- Groundwater and soil salinity is a primary control on Black Box health, along with inundation frequency.
- The existing groundwater salinity will influence the effect that changes in flood frequency will have on vegetation health. The effects of reduced flooding frequency will have less impact on health where groundwater salinity is well within tolerances for Black Box. However, as groundwater salinity approaches the upper limit of Black Box tolerances, the effects of reduced flood frequency will become a critical factor.
- The timing and magnitude of rainfall will be critically important when groundwater salinities approach the upper limit of tree salinity tolerances.
- Surface inundation of sandy surface soils will have a beneficial impact on vegetation health outcomes if water can be introduced into them, but inundation of clay floodplain soils is less effective due to very slow infiltration rates.

We have identified a new environmental influence that can affect Black Box health, that we haven’t seen considered previously, which is that long-term slow increases in groundwater salinity caused by locking have the potential to be a key factor in long term Black Box health decline. Any long-term slow increases in groundwater salinity will drive an increasing dependence on flooding and rainfall as the source of appropriate salinity water.

6.2 Extending the Floodplain Response Model to consider Black Box in particular

The learnings from the review of key processes within the general Floodplain Response Model, coupled with the analysis of data at Black Box sites collected in this study, are synthesised (in the highlighted box on the next page) below into a specific, more detailed Floodplain Response Model (i.e. the Black Box Floodplain Response Model). Most of the Black Box Floodplain Response Model is supported by data presented herein, some parts are supported by data that has not been reviewed as part of this study, and a small proportion of it needs additional quantification.

The Black Box Floodplain Response Model is not presented with the expectation that it is entirely correct, but with the expectation that articulating a new paradigm will lead to critical enquiry. Further testing of the Model will lead to its improvement, which in turn will lead to better management strategies for Black Box and better outcomes for an ecosystem under stress.

The key areas of uncertainty in the Black Box Floodplain Response Model are:

1. Vertical hydraulic conductivity of the Coonambidgal Formation, particularly for the higher terraces. This parameter controls recharge rate through the floodplain soils, as well as the effectiveness of flooding or environmental watering in delivering low salinity water for vegetative use.
2. Identification and quantification of the salt reflux mechanisms from the unsaturated zone to the saturated zone. These processes can be inferred from examination of data, but have not been conceptualised as yet. The identification of a reflux mechanism shifts the focus from the unsaturated zone to saturated zone as the primary control on tree health, however saturated zone salinity has not previously been considered in this light.
3. Quantification of likely rates of groundwater salinity rise post-locking. Quantifying this process is an important adjunct to quantifying the salt reflux mechanisms. Points 2 and 3 combined provide a more holistic view of the fate and cycling of salt in the floodplain, which is demonstrably a key control on Black Box health.

Section 7 recommends strategies which have resulted from consideration of the implications of this Conceptual Model.

In relation to uncertainty in regeneration and recruitment, which is not the subject of the Black Box Floodplain Response Model, the extended length of time to maturity in River Red Gum (10-20 years) and Black Box (20-30 years) trees means that successful recruitment from initial numbers of regenerating seedlings will only be demonstrated over these very long periods. For shorter monitoring periods, a baseline needs to be established for phenological cycles in healthy mature trees across several regional sites, to establish critical seasonal peaks for flowering and seed fall. The effect of watering can then be monitored by comparison of crop volumes in the seed production cycle, i.e. are there higher numbers of new leaves, buds, flowers, mature fruit at watered sites.

Black Box Floodplain Response Model

Black Box are located on the higher terraces of the floodplain, which are of relatively low hydraulic conductivity compared to lower terraces. On these higher terraces, the low hydraulic conductivity means that floodplain inundation contributes to changes in moisture content and salinity in the unsaturated zone, but inundation is not a significant contributor of water to the groundwater system.

In contrast, the lower terraces adjacent the River have a higher hydraulic conductivity. Bank recharge from the River, and/or infiltration through the lower terraces, facilitates the development of low salinity lenses which are utilised by River Red Gum communities. River Red Gum dominates on the lower terraces because it has a higher tolerance for flooding.

Locking has caused groundwater levels to increase under the floodplain from Mallee Cliffs to the Barrages, and upstream of the locks at Robinvale and further upstream. In these areas, the permanent water table is now usually located within the Coonambidgal Clays – the silty clay at the top of the floodplain alluvial sequence. The height of capillary rise is much greater in clays than in sands. Locking has increased the rate of evaporative discharge from the floodplain because the greater height of capillary rise brings more water closer to the surface. Transpirative losses would have initially remained the same after locking.

The increased evaporative water losses lead to an increase in the rate of salt accumulation in the floodplain soils. Reflux mechanisms transfer salt from the unsaturated zone to the groundwater, limiting the differential between soil and groundwater salinity.

The post-locking increased rate of evaporative salt concentration in the soils, and the reflux of salt back into the groundwater system, drives groundwater salinity higher. The salinity impact in the aquifer is most marked in gaining floodplains, less so in throughflow floodplains, and at a minimum in losing floodplains.

Locking has caused a gradual increase in groundwater salinity. Black Box are not dependent on low salinity lenses, unlike River Red Gum, because they have a higher salinity tolerance. The higher terraces preclude significant quantities of recharge. Flooding and rainfall will provide intermittent supplies of low salinity water, however Black Box is primarily dependent on groundwater. Where groundwater salinity is low, Black Box will survive and flourish with intermittent rainfall or inundation. As groundwater salinity increases, floodplain surface inundation and rainfall play an increasingly important role in sustaining Black Box health.

Sand deposits on the floodplain (e.g. Woorinen Sand) can provide "reservoirs" that facilitate infiltration and store rainfall or floodwaters, particularly where the sands overly the Coonambidgal Clay. The sand facilitates relatively high recharge rates, and this is then retained over the clay, making more low salinity water available for vegetative use and reducing reliance on groundwater.

The post-locking increase in groundwater salinity is a major cause of long-term decline in Black Box health. The trend in groundwater salinity is paralleled by reductions in flooding frequency, which are easy to identify, and hence have been attributed as the major cause of Black Box health decline. The change in groundwater salinity is an equal, if not greater, contributor to health declines. However, it has not previously been postulated, and hence evidence has not been gathered.

While environmental watering can deliver relatively small quantities of water through floodplain inundation, arresting and reversing the change in groundwater salinity is the larger challenge. Strategies that reduce groundwater salinity will deliver long-term health benefits for Black Box.

Regeneration is intimately tied to surface watering and the salinity regime in the top 100mm of soil, however successful recruitment is probably correlated with access to groundwater of an appropriate salinity in the 2 to 4 metres below the surface.

6.3 Black Box Health Indicators

The following factors need to be considered when assessing the likelihood of positive Black Box health outcomes from floodplain management.

The first two indicators discussed below (unsaturated zone salinity and pre-watering vegetation condition) are direct indicators of response. The remaining indicators (saturated zone salinity, depth to water, unsaturated zone materials and flood frequency and rainfall) are indirect indicators of response. They are presented in an indicative order of importance.

6.3.1 Unsaturated zone salinity

The previous analysis indicates that average soil salinity is **the** key parameter influencing Black Box vegetation health. The results of investigations for this report also suggest that the salinity at 4m depth may be a very useful indicator, although this will need to be modified where the water table is shallower than 4m. Threshold salinity values have been derived based on the 75th percentile for healthy vegetation, therefore watering strategies are more likely to be effective where the soil and groundwater salinities are below the threshold values.

Unfortunately, while soil salinity is the key indicator of Black Box health, there is little data and no systematic ongoing program to collect new data. This data gap needs to be rectified.

However, there are some surrogate indicators that may prove useful. These include the excellent AEM data sets, which provide data on the electrical properties of various depth slices beneath the floodplain. These unsaturated zone AEM coverages have not been correlated with field data as yet (although the correlation between the groundwater and AEM layers has been demonstrated). The correlation in the unsaturated zone is potentially more complicated than for the saturated zone, because the correlation has to consider moisture content variations as well as salinity variations. However, given the almost universal coverage of the AEM data, investing in studies which demonstrate the correlation is highly recommended.

6.3.2 Pre-watering vegetation condition

The pre-watering condition of floodplain vegetation is also likely to affect the ecological response to floodplain management. The responses of stressed vegetation to management interventions are much less predictable than the responses of healthy trees. In addition, there is also likely to be a point beyond which extremely stressed trees will not recover in response to watering or groundwater manipulation. It is also commonly accepted that the best outcomes from environmental rehabilitation are achieved by maintaining healthy systems rather than repairing damaged systems (Rutherford *et al.,* 2000). Therefore, the existing condition of floodplain vegetation, and its likelihood to respond to management interventions, should be considered in identifying sites that potentially could employ groundwater manipulation as a management tool.

6.3.3 Saturated zone salinity (e.g. at the water-table)

The saturated zone salinity is correlated with the unsaturated zone salinity. Direct measurement data sets of groundwater salinity from groundwater monitoring networks are widespread, though sparse. Bore completions do not always sample the salinity at the water table, which is the key parameter. The large scale patterns in groundwater salinity can be correlated with the Gaining/Losing Floodplain matrix (Figure 3.1) which classifies the regional hydrogeological setting.

The AEM data has been correlated with groundwater salinity data. Variation in soil properties has been demonstrated to have little impact on the AEM signal, which is dominated by the groundwater salinity.

6.3.4 Depth to Water and/or Evapotranspiration (ET) Rates

The depth to water can be inferred from the subtraction of regional groundwater network elevation data from surface elevation data. The accuracy will be moderate to low, influenced by the precision of measurement for both data sets, and also influenced by the paucity of groundwater elevation data.

The measurement of site scale depth to water could be undertaken in parallel with collecting soil salinity and soil moisture content data, if that were to occur.

The depth to water data is important because it provides information on the rates of evapotranspiration from the water table, and hence informs the longevity of supply from soil moisture of low salinity lenses. Depth to water is particularly important when considering the integrated hypothesis, because the combination of reduced depth to water caused by locking and the consequent positioning of the water table within the Coonambidgal Clay will have caused an increase in evaporation rate from the soils. This in turn will have perturbed the salt balance in the floodplain and driven soil and groundwater salinities higher. Therefore, the equilibrium salinity of the soil and groundwater will be significantly influenced by the depth to water.

Direct or remote sensed ET or Potential ET data could provide a more accurate measure of the actual losses, and if based on remote sensing would provide a spatially continuous data set. Pixel scale would need to be considered in interpretation of the data.

6.3.5 Unsaturated Zone Materials

The presence of sand (e.g. the windblown Woorinen Formation) over the Coonambidgal Clay provides a reservoir that can hold water. The sand layer provides the following benefits:

- It facilitates rapid infiltration of surface water or rainfall, thereby increasing the volume of water that can be stored from an inundation or rainfall event;
- Sands support much less capillary rise than clays because the pore spaces are larger and surface tension cannot pull the water as high; and
- The sand extends the duration for which water can infiltrate into the soils.

The surficial geology has been mapped as part of some of the AEM studies and dunes on the floodplain can also be identified from air photos.

6.3.6 Flood Frequency and Rainfall

Flood frequency data has been used extensively in analysis of floodplain vegetation condition, and River stage is monitored at many stations along the River. Flood inundation extent has been estimated with the RIM-FIM model (Overton et al, 2006), which is a useful estimate of the inundation extents.

Flood frequency is likely to have an effect on Black Box health, although this may be limited to the emplacement of relatively small volumes of water into the unsaturated zone where the surficial materials are clays. Inundation will probably have a greater effect where the clays are blanketed by sands, creating a reservoir that can retain additional water. We suggest that reduced flood frequency is not the sole cause of declines in Black Box health, and that the interaction between groundwater and the resulting salinity of available moisture in the soil zone is the primary cause.

Flooding and rainfall, and the resultant availability of appropriate salinity water in the root zone, is the major control of regeneration. The 2010 to 2012 flood and rainfall events sparked a major Black Box and River Red Gum regeneration event, indicating that the provision and maintenance of adequate soil moisture is critical in the regeneration process. The challenge will be to retain the regeneration to maturity (20 to 30 years). It is possible that in the early years of growth, young trees need to be sustained by surface watering. At sites where recent Black Box regeneration has occurred due to natural or managed flooding, management interventions should target the unsaturated zone to maintain sufficient soil moisture for seedlings until they have developed sinker roots. Maintenance of mature tree health will support crop development of buds and survival of fruit to maturity, thereby potentially increasing seed volumes.

6.4 Watering Strategies to Maintain Black Box Health

Surface watering strategies to maintain or improve the health of mature Black Box trees should aim to emplace a large volume of appropriate low salinity soil water or groundwater. This may be achieved via:

- Lateral recharge from surface water bodies;
- Infiltration through the soil profile as a result of inundation or irrigation;
- Groundwater pumping or injection; or
- A combination of the above processes.

Data from the monitoring of vegetation communities during watering events indicates that floodplain River Red Gum and Black Box trees benefit from surface watering, however there is insufficient long-term monitoring to provide evidence that watering creates lasting benefits in the Lower River Murray region and the specific processes controlling this response are not well understood. The Black Box Floodplain Response Model suggests that surface watering may be effective in the maintenance of health, if conducted frequently enough. It appears likely that sustained vegetation health improvement (including Black Box) from surface watering is significantly influenced by the underlying groundwater salinity. Surface watering is unlikely to halt a long-term increase in groundwater salinity because infiltration of surface water to the water-table is thought to rarely occur. Also, lateral infiltration from bank recharge will be limited to sites where the Black Box adjoins a surface water body, although both vertical and lateral infiltration will be facilitated where sandy surface soils overly the Coonambidgal Formation.

Based on data from The Living Murray trials at Bookpurnong, it seems probable that floodplain management interventions that involve the manipulation of groundwater provide an opportunity to deliver ecological benefits for mature Black Box communities. However, there are only limited examples where the role of groundwater in providing a source of low salinity water has been examined. Groundwater pumping to create low salinity lenses from adjacent water bodies, and direct injection of appropriate salinity water, could both be employed to create low salinity lenses in target areas. However, implementation of these strategies will be constrained by cost, and the availability of suitable infrastructure and suitable low salinity water sources.

In summary, it can be concluded that both groundwater manipulation and surface watering strategies can be beneficial for Black Box health. However, data on effectiveness of watering is not readily available, so it is difficult to draw empirically based conclusions regarding the specific benefits of watering one site compared to another. A Black Box Floodplain Response Model has been developed, and it is recommended that this be adopted as the framework for assessing the likely benefits from watering. The key site criteria governing benefits from watering are soil salinity, groundwater salinity and extant vegetation health. Environmental watering should aim to achieve soil and groundwater salinities below the threshold value for healthy Black Box in the shallow root zone (within 4m of the soil surface). Both groundwater and surface water manipulation can be used to achieve this aim. The relative cost-effectiveness of surface watering versus groundwater watering strategies will need to be evaluated.

7 Recommendations

The following chapter outlines recommendations that support improvements in management strategies, through targeted data collection, improved conceptualisation of key processes, and through field trials of groundwater manipulation strategies. Each of the following recommendations is independent of the others, with the first three aiming to improve lines of evidence to test the Black Box Floodplain Response Model, and the last recommending options for field trials for new groundwater manipulation strategies.

7.1 Develop and Trial an Environmental Watering Decision Support System

The indicators that are considered useful in predicting Black Box response to watering are outlined in Section 6.3. Most of these indicators already exist in GIS layers.

It is recommended that a project be undertaken to collate the existing data sets and, in the first instance, compare the indicators to the Mallee CMA GIS datasets which illustrate watering locations and frequencies. If the watering sites can be scored in terms of the response of Black Box to the watering, using an appropriate scoring regime, then the watering outcomes can be correlated with the indicators to identify if there are any broad or specific correlations that support or challenge the Conceptual Model. This work could also include targeted site visits to confirm vegetation health trends and their relationship with existing groundwater salinity (AEM) and depth to water datasets.

Once evaluated against a response dataset, the indicators can be employed as a tool to assist site managers and the Commonwealth Environmental Water Office in the development and prioritisation of environmental watering actions targeting Black Box outcomes, both within and across jurisdictions. The immediate priority will be to develop the GIS-based tool for surface watering activities. Once groundwater manipulation trials (see Section 7.4 below) have been evaluated, the tool's application could be extended to support the identification of groundwater manipulation site selection.

7.2 Address Key Data Gaps at Existing Watering Sites

Soil and groundwater salinity data have been identified as key predictors of Black Box health. This data is not routinely collected at watering sites. Sampling soil and groundwater salinity and moisture content before and after watering, within the watering extent, will build a database that can be used to refine the Black Box Floodplain Response Model. In the interests of cost effectiveness and efficiency, it is suggested that soil salinity data be collected where possible, whilst also utilising groundwater data from existing groundwater monitoring infrastructure. Some new groundwater monitoring bores should be installed at key sites and soil sampling should be undertaken immediately adjacent to groundwater monitoring bores at watering sites, to build the data set correlating soil and groundwater salinity.

Three key areas of uncertainty in the Black Box Floodplain Response Model have been identified in Section 6.2. One of these is the quantification of recharge rates in the floodplain. A cheap and easy strategy for rectifying this data gap is to measure the rate of decline in surface water levels in inundated areas. The rate of decline will be controlled by the sum of evaporation and seepage rates, and will be influenced by the hypsographic curve (that is, the relationship between water volume in the wetland and the depth of water). The evaporation rate from open water can be easily calculated, with reasonable precision. LIDAR data can be used to calculate the hypsographic curve, or in the absence of detailed data a typical wetland curve can be used. Given these inputs, the rate of seepage can be calculated. Where the floodplain soils are permeable, evaporation rates are small compared to infiltration rates. Tighter soils will result in infiltration rates that are similar to evaporation rates. Given the soil infiltration rates will vary across at least two orders of magnitude, small errors in quantifying the hypsographic curve or the evaporation rate will have little effect on identifying the correct order of magnitude for infiltration. That is, the method is simple and robust, and will provide very useful information.

From this data, the vertical hydraulic conductivity of the floodplain soils can be directly derived. This addresses a key data gap, because there is almost no empirical data across the floodplain. This data set directly informs the quantification of the efficacy of surface watering – how much water is stored in the unsaturated zone from a watering event, and how long will the benefits of inundation last, given a particular transpiration rate.

The volume and timing of water delivery into wetlands should be measured and recorded, particularly when pumping is employed to implement the watering strategy. Where water bodies are filled once, then refilled in the same season, the refill volume required to bring the water level back to the original water level is exactly the volume lost to seepage and evaporation. This data can then also be used to calculate seepage rates. But this approach is only useful when a “fill and refill” watering strategy is employed.

7.3 Progress Understanding of Conceptualisation Uncertainty in the Black Box Floodplain Response Model

Of the three areas of uncertainty in the Model, two relate to the conceptualisation of processes:

1. Quantification of likely rates of groundwater salinity rise post-locking.
2. Identification and quantification of the salt reflux mechanisms from the unsaturated zone to the saturated zone

The rates of rise of groundwater salinity post-locking can be quantified using salt and water balance models. The focus should be on assessing the likely magnitude and rate of rise of salinity increases under a number of scenarios. The scenarios should include Gaining and Throughflow Floodplain situations (see Figure 3.1), and a range of potential evaporation and transpiration rates. Using a salt and water balance model will be appropriate if it is assumed that reflux mechanisms cycle salt back into the groundwater from the unsaturated zone. The salt and water balance modelling is considered a priority. The work should include an assessment of the magnitude of capillary rise in typical floodplain materials, both pre- and post-locking.

The identification and quantification of salt reflux mechanisms is perhaps more challenging, and may require lateral thinking and literature review. AWE has identified previously (AWE 2011) that the work of Weisbrod and Dragila (2006) provides one conceptualisation. Those studies identified that, in fissured chalk, evaporation from the fissures leaves salt crystallised on the wall of the fissures. When the sites are inundated,, the salt is dissolved from the walls of the fissures and travels downward through the fissures, deeper into the unsaturated zone. The fissures provide a direct recharge mechanism downward through the soil profile. Whether this process occurs in Australia’s sodic floodplain soils is not immediately clear, but it serves to illustrate that there are alternate floodplain salt cycling mechanisms that can be considered. This conceptualisation uncertainty may perhaps be most efficiently addressed through collaboration between soil and groundwater scientists who are familiar with the floodplains of the Lower River Murray

A third area where a modest investment will yield significant advances is the correlation of AEM resistivity data for the unsaturated zone with soil salinity data and soil moisture content data. The AEM data is widely available along the River Murray floodplains, and the data is presented in “slices” at around 2m depth increments. This means that there are one or two slices within the unsaturated zone. The slices convey the distribution of the subsurface bulk resistivity, and this data set (which combines the effect of the materials, the soil moisture content and the soil moisture salinity into one electrical conductivity reading) needs to be compared to measured soil salinity and moisture content data to identify if the electrical conductivity can be correlated with the soil moisture salinity. Our observations of the Coonambidgal Clays in this study and at Bookpurnong are that the soil moisture content below about 0.5 m depth is relatively constant at around 20%. This relatively constant soil moisture content removes some of the variability that might complicate the correlation between AEM conductivity and soil moisture salinity. If reliable correlations can be obtained, the AEM data then becomes a very powerful data set in the Environmental Watering Decision Support Suite discussed in Section 7.1 above.

7.4 Groundwater Manipulation Strategies

Groundwater manipulation may provide a mechanism for Black Box health improvement and a number of trial strategies and trial locations are outlined below..

7.4.1 Pumping

Chaffey Bend

The Chaffey Bend floodplain is ideally suited for a trial of one or more groundwater management strategies. It is recommended that groundwater pumping is implemented to trial the manipulation of the low salinity lenses under the wastewater lagoon and under the River. The aim will be to remove the saline groundwater from the aquifer and pull the existing lenses toward the centre of the floodplain from the two edges, and hence modify the unsaturated zone salinity and improve conditions for improved tree health.

The requirements for this trial are likely to be at least one production bore completed in the Monoman Formation, and some additional observation bores to monitor the migration of the lenses. Soil sampling would be undertaken to measure before and after soil salinity regimes. Vegetation health mapping would assess the response of the vegetation to the trial.

A trial plan will need to be prepared and the site-works costed.

Psyche Bend

The Psyche Bend Floodplain is also a good target area for groundwater manipulation. Here the primary strategy will be to halt the migration of the saline plume emanating from the Psyche Bend Disposal Basin, and hence prevent the progressive deterioration and death of the floodplain vegetation to the east, which is the direction the lens is heading. It is possible that the recent surface water manipulations in the Psyche Bend lagoon are exacerbating the rate of migration of the high salinity drainage disposal plume, without mitigating the risk posed by the plume.

The requirements for this trial are likely to be at least one production bore completed in the Monoman Formation, and some additional observation bores to monitor the migration of the lenses. Soil sampling would be undertaken to measure before and after soil salinity regimes. Vegetation health mapping would assess the response of the vegetation to the trial.

A trial plan will need to be prepared and the site-works costed.

7.4.2 Injection

Although the injection of surface water to create a low salinity lens in the floodplain aquifer has not been successfully demonstrated in the Murray Darling Basin, the principle of injecting surface water into an aquifer is well established (e.g. Managed Aquifer Recharge and Aquifer Storage and Recovery schemes). Injection is a potentially feasible option for floodplain management, but success would be site dependent. Any trial would need to manage issues identified in previous trials (4.2.2) such as having access to a filtered water source.

Chaffey Bend

It is recommended that a trial be implemented to inject low salinity water into the aquifer at Chaffey Bend. The injection water will need to have a low turbidity, to prevent clogging of the aquifer at the injection bore. The Bookpurnong trial failed within days because unfiltered River water was used. The most cost-effective injection trial strategy would be to use filtered mains water in the first instance. This puts the optimum location for the trial in the vicinity of towns. The Chaffey Bend Environmental Water Management Plan (AWE 2014b) recommended that an injection trial take place near the Caravan Park on Chaffey Bend, where "town water" is already located on the floodplain. This will have the advantage of being located close to the Mallee CMA office to keep monitoring costs low.

The requirements for this trial are likely to be at least one injection bore completed in the Monoman Formation, and some additional observation bores to monitor the migration of the lenses. Soil sampling would be undertaken to measure before and after soil salinity regimes, and also vegetation health mapping to assess the response of the vegetation to the trial.

A trial plan will need to be prepared and the site-works costed.

Injection elsewhere on the floodplain

Injection can be trialled anywhere on the floodplain, however if filtered water is not available, then a sand filtration or equivalent system will need to be employed. Ideally, the injection site would be located near existing power networks to reduce the cost of implementation. Otherwise, diesel generators will be required, with their attendant refuelling and maintenance costs.

7.4.3 Infiltration galleries

An alternative strategy for emplacing low salinity groundwater is to consider using infiltration galleries. For example, large diameter bores or trenches could be installed through the Coonambidgal Formation and into the Monoman Formation. These would be filled with sand, or gravel in the case of the trenches. The bores could also be filled or they could be left open if a suitable casing and screen was installed. The infiltration galleries would be constructed within the inundated area, to facilitate direct recharge of the groundwater from the surface water.

This approach is similar to that employed by the NSW Office of Water at the Mallee Cliffs disposal Basin, where the Blanchetown Clay has been removed and the Disposal Bay floor is in the underlying

Parilla Sand. The Disposal Bay clogs over a period of time, and requires excavation every few years to remove the fines that build up over the sands as the water infiltrates.

Similar to the injection scenario, clogging is the greatest risk to successful implementation of the infiltration galleries. However, intermittent use means long dry phases occur, and the fines may be dispersed by wind and/or floodwaters during natural inundations. The attractiveness of this option is that there are no additional operating energy costs, and that potentially large infiltration volumes may be able to be emplaced into the aquifer.

The logistics and cost of creating an appropriate infiltration gallery will need to be assessed and evaluated. A trial infiltration gallery could be implemented anywhere.

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Appendix A: Additional Background Information for Black Box Trees

Regeneration and Recruitment

Germination of seedlings is termed 'regeneration'. Recruitment'' is defined as survival to reproductive age, i.e. 10-20 years for River Red Gum trees and 20-30 years for Black Box trees, dependent on water availability.

Conditions for Germination

Successful regeneration occurs when seeds fall onto moist soil, or fall onto water and float to the edge within 10 days (Jensen, 2008). Their survival then depends on continue availability of low salinity water through subsequent hot and dry periods until they have established sufficient roots to access deeper soil moisture sources.

Black Box regeneration is episodic, often following major flood events or wet winters (Roberts & Marston, 2011). A flood recession during spring or summer can provide favourable soil moisture conditions for seed germination. Large scale regeneration historically followed large flood events in consecutive years. The regeneration of Black Box in the Lower River Murray following the 2011 flood peak is the first widespread germination in the region since 1956 (Jensen, pers obs., 2013).

The recent flood peak of 93,000 ML/d at the SA border in February 2011 was high enough to inundate Black Box woodlands of the lower floodplain in the Lower River Murray, but did not reach the communities on the higher floodplain. Seedlings which germinated following the 2011 flood are surviving well to date. Significant summer rainfall events in 2012 and in 2014 supplemented soil moisture reserves through the hot summer periods since the Black Box seedlings germinated, and several sites have received environmental water to sustain the seedlings (Jensen, 2014).

Recruitment

Conditions for successful recruitment of the key species occur much less often under the reduced flood regime, as water does not reach large sections of the floodplain, or does not persist long enough for seedlings to establish or water is not available to support growing saplings to maturity (Jensen *et al.,* 2003; Roberts, 2004). The resilience of these stands and their ability to survive drought conditions are thought to have been compromised by water diversions, declining rainfall and drought (Jensen & Walker, 2012).

Black Box recruitment is associated with River flows >80,000 ML/d and annual rainfall >300 mm (George, 2004). A flood recession occurring during spring or later is likely to provide soil moisture conditions that promote seed germination and early growth (Roberts & Marston, 2011). Subsequent flooding to recharge soil moisture in the same year or the year following germination is likely to aid seedling establishment. Soil moisture recharge following germination may also be achieved naturally through high rainfall events or via floodplain irrigation.

Black Box recruitment is generally successful as a narrow band of trees along the high-water line of the flood of origin (Cunningham *et al.,* 1981). Healthy surviving trees from the 1870 and 1956 floods are known, for example Rotten Lake and Overland Corner (1870) and Burra Creek at Morgan and Calperum boundary fence and Coppermine Waterhole at Chowilla (1956) (Foweraker, pers comm., 1981).

No significant regeneration of Black Box has survived to maturity on the Lower River Murray floodplain from the floods of the 1970s or 1990s, apart from a few isolated patches of 20-50 trees (Jensen, pers obs., 2013). Black Box regeneration reported on the Chowilla Floodplain (Seekamp, pers comm., 1998) has not survived (Jensen, per obs, 2008). Healthy Black Box regeneration and healthy mature woodland occurs in the flushed zones upstream of weirs at Banrock Station, in Paringa Paddock at Renmark and near Merbein, where relatively fresh groundwater lenses occur.

Monitoring of vegetation structure in the Mallee CMA region in the mid-Murray Valley indicates no significant Black Box recruitment except in flushed zones upstream of weirs (Henderson, pers comm., 2015). It is likely that the last significant recruitment in the mid-Murray was associated with the 1955-56 floods, although the data has not been specifically checked against the dates of key flood events in the 1970s and 1990s.

Role of Rainfall in Successful Regeneration and Recruitment

The chance of rainfall in the Lower Murray Valley is highest in winter and spring, with 58% of average annual rainfall due to the influence of weather systems driven by the westerly wind systems (Jensen, 2008; Figure A.1 Part a, b).

There is also a 20% chance of rainfall in summer, due to regional summer thunderstorms generated by heating of the semi-arid landscape. The delay in potential over-bank flows into summer means that there is less chance of coincidence of floods with spring rains, although occasional summer thunderstorms may be useful. Where these rainfall events occur during summer following a flood recession, this has the potential to temporarily reduce moisture stress for seedlings at a critical time, as occurred in 2012 and 2014.

The significance of rainfall for recruitment and tree health was highlighted for the Chowilla floodplain in an assessment of the decline of Black Box, with sudden death of mature trees in the 1980s occurring in the fourth year of rainfall drought in the absence of flood events (Jensen *et al.,* 1998). A strong correlation has been found between above average rainfall (>300mm) and high flow events in successful germination and recruitment events for River Red Gum and Black Box in the Riverland (George, 2004).

Vegetation Responses to Watering

For healthy trees, the appearance of new leaves, flowers or new buds is not necessarily due to a watering event. Healthy River Red Gum and Black Box trees put on a crop of new leaves at a fixed time, usually in summer, while shedding old leaves and bark (Jensen *et al.,* 2007). Their cycles are geared to the highest chance of soil moisture from flooding, and crops are set by conditions in the previous year. In some locations, some Black Box trees are on winter cycles rather than summer cycles, geared to the highest chance of soil moisture from rainfall (Jensen, 2008).

In order to monitor vegetation responses to watering, as opposed to natural growth cycles, it is essential to identify local seasonal phenological cycles as a baseline of tree growth cycles. The natural phenological timing needs to be established, to avoid the attribution of naturally-occurring cycles of new growth as being due to the effect of watering. The effect of watering can be measured by monitoring phenological crops in comparable groups of watered and non-watered trees.

The low volumes of seed rain after watering suggest a lag time to allow seed crops to set and mature in response to increased soil moisture (Jensen, 2008; Figure A.1). Crops are determined by conditions that affect bud development up to a year before flowering (Paton *et al.,* 2004). Low seed volume may reflect sub-optimal climatic conditions for seed development in the previous season, and an enhanced seed response may appear in the following season, provided that watering coincided with the reproductive cycles of the trees. Thus, a succession of flooding or rainfall events over several years may be required to maximize seed production and recruitment. Single, short-lived watering events clearly are not sufficient to sustain germinants through dry periods, and recent field trials showed that single watering events were not sufficient to sustain improved health in stressed mature Black Box trees (Gehrig 2014). Soil moisture availability is critical for plant recruitment in other semi-arid zones (Cooper *et al.,* 1999). Groundwater manipulation may provide an additional methodology for long term maintenance of soil moisture for mature tree health and facilitation of seed production.

The key to survival of seedlings is maintenance of soil moisture through the first summer period after germination. Artificial watering offers some flexibility in timing but limited duration and volumes. Volumes of water available under regulation are much less than under natural floods, and there are constraints on delivery of water to higher elevations on the floodplain. The effectiveness of 'environmental flows' for recruitment of eucalypts could be increased by linking the timing of late spring-early summer watering with local rainfall, to promote seedling survival to sapling stage and also retention of bud crops in autumn, hence increased seed production in the following summer (Jensen *et al.,* 2008a).

For floodplain woodlands, the priority issue is lack of recruitment at a population scale. Therefore, it is recommended that environmental watering should be tailored to different age classes, to benefit multiple growth stages, including seedlings and immature trees, as well as maintaining survival of mature trees (George *et al.,* 2005). Provision of additional soil moisture is recommended to improve seedling establishment during the first or second year following germination, particularly if the summer is very hot (Roberts & Marston 2011). Black Box seedlings are not very tolerant of saturated conditions and additional soil moisture may be provided through high rainfall events, short, shallow inundation events, or floodplain irrigation. Groundwater manipulation may also be a tool to lower to induce lateral recharge from the River to create low salinity lenses at the base of the unsaturated zone.

Watering at Bookpurnong Floodplain in 2013 by the Nature Foundation SA Water For Nature Initiative targeted areas showing signs of desiccation in River Red Gum and Black Box seedlings during a warm dry summer (Jensen, pers obs, 2013). Minimal death of seedlings has been observed in watered areas to date (Jensen, pers obs., 2015).

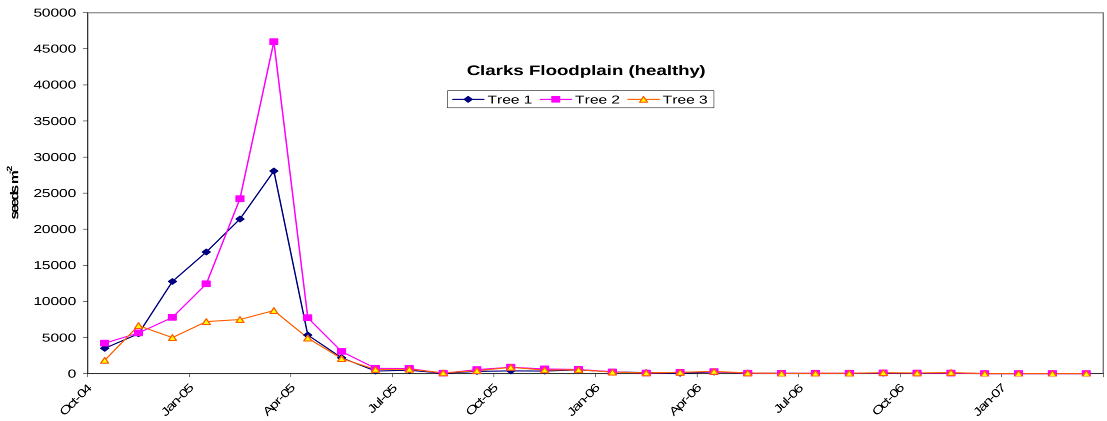
Watering trials for Black Box at Markaranka in the SA Riverland indicated that mature trees were using water from irrigation up to 1.5 m depth (Gehrig, 2014). Isotopic analysis indicated that the di-morphic nature of the root system allowed Black Box trees to switch between water sources. Analysis of tree condition found that watering via drip irrigation had the potential to significantly improve vegetation condition but the benefits were temporary and unlikely to persist without follow-up watering in the subsequent year (Gehrig, 2014). Watering rates > 20 mm per week were required to shift tree health from poor condition to good condition. Note that these trials applied water via a vineyard irrigation system, and were constrained to application of water in a weekly regime. There were also several interruptions to supply during the trials, resulting in reduced volumes being applied.

In the Markaranka trials, it was noted that large summer rainfall events had a very beneficial effect on tree health, and the response to > 100mm rainfall was greater than to weekly application of 20mm of water by irrigation (Gehrig, Doody, Wegener, pers comm., 2014).

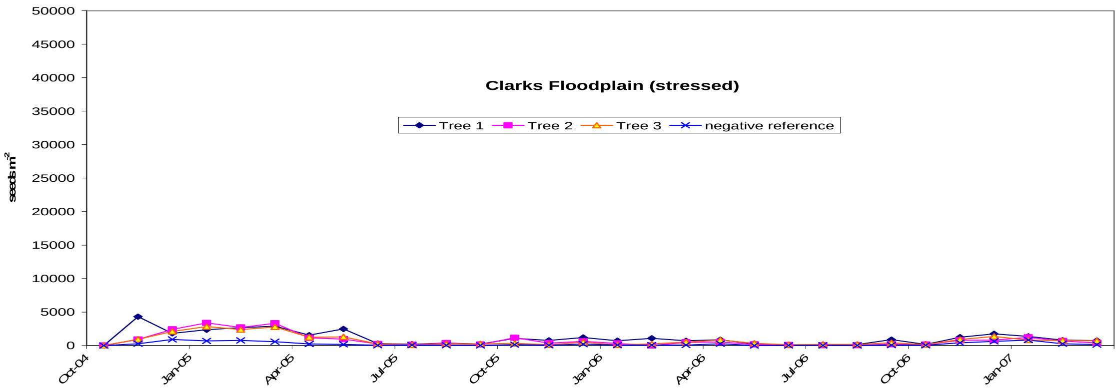
Stressed vegetation produces much reduced volumes of seed, up to an order of magnitude) and responds to watering in a much more variable pattern, compared to healthy vegetation (Figure A.1 Jensen *et al.,* 2008b). As with all environmental rehabilitation work, the best outcomes are achieved by maintaining healthy ecosystems, compared to time and resources needed to repair systems in decline (Rutherford *et al.,* 2000).

In stressed trees, response to watering is much less predictable, as trees may use all remaining physiological resources to start a new production cycle, so the responses are less easy to quantify (Figure A.1). The appearance of epicormic growth (direct from the main branches, instead of from the tips) is a sign of a stressed trees responding to available moisture, and can be attributed to a watering event. If the tree does not suffer further water stress for the next annual cycle, the epicormic growth will normalise, with growth from the tips in the following season. Eucalypts have the capacity to re-grow a full canopy and continue healthy seed production if there is sufficient water available to support the tree through the recovery period (Jensen, pers obs., 2014). One of the most productive River Red Gums monitored for seed production from 2004-2007 on the Chowilla floodplain had grown a complete new canopy after losing its main trunk and original canopy to an earlier lightning strike (Jensen, 2008).

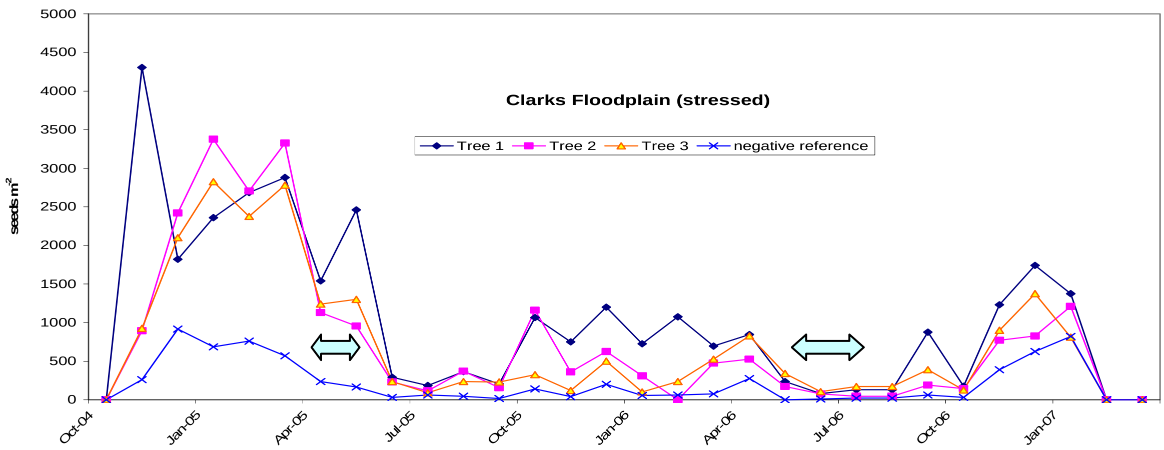
If a tree is extremely stressed, it may be approaching a condition called the 'stage of exhaustion' where there is permanent irreparable damage, and watering cannot save the tree (Lichtentaler, 1996). This effect was observed in early watering trials by The Living Murray Program at Chowilla, where highly stressed River Red Gums commenced epicormic growth but then died while standing in water, having exhausted their physiological resources in a final effort at a reproductive cycle (Jensen, pers obs., 2005). It was subsequently concluded that trees with deep cracking in their bark were in the 'stage of exhaustion' and would not recover with watering (Wallace, pers comm., 2006).



Part A: Monthly seed rain measured at healthy individual trees at Clarks Floodplain from Oct 2004 to March 2007, showing no significant seed rain in summer 2006



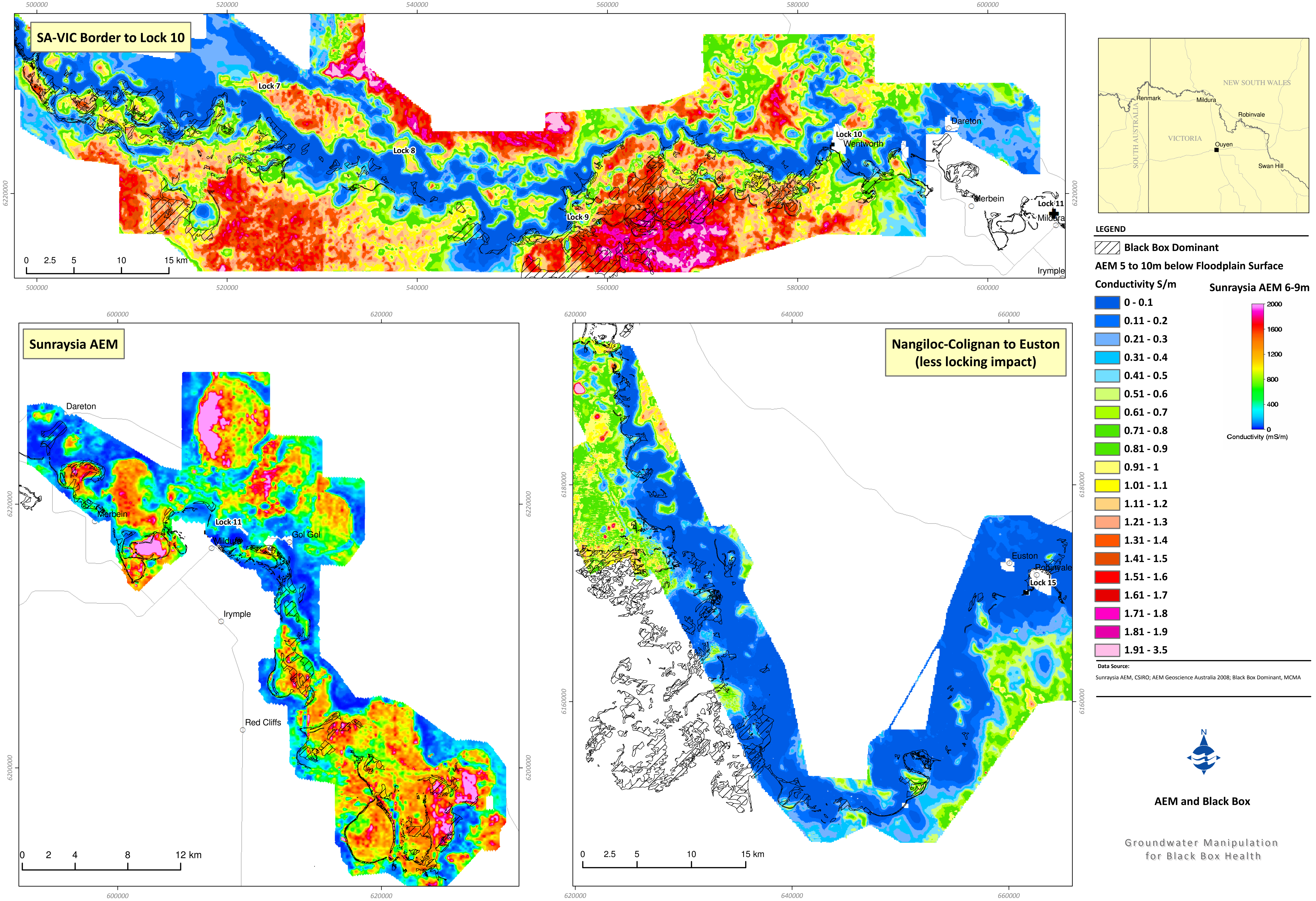
Part B: Monthly seed rain measured at stressed individual trees at Clarks Floodplain from Oct 2004 to March 2007, showing significantly reduced seed rain compared to healthy trees (Part A)



Part C: Monthly seed rain measured at stressed individual trees at Clarks Floodplain from Oct 2004 to March 2007, drawn at a larger scale to show highly variable and extended seed rain pattern compared to healthy trees (Part A)

Figure A.1: Seed Rain Measurements for Healthy and Stressed Trees at Bookpurnong (Jensen 2008)

Appendix B: AEM and Black Box Distribution



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Appendix B

Appendix C: Field Program

1 Field Program

A field program has been designed to collect additional monitoring data across floodplain sites that have shown a range of ecological responses to environmental watering in the Mallee CMA region. The primary aim of the field program is to collect data that will allow correlation of ecological responses and soil salinity with groundwater salinity. In this section the site indicators described in Section 3 are applied to five floodplain sites within the Mallee CMA region (Chapter 5) where variable responses to environmental watering have been observed. The aim of this section is to test the relationship between groundwater salinity, soil salinity and vegetation health using new monitoring data collected at each of the floodplain sites. This section then applies the key process indicators at each site, to evaluate the success, or otherwise, of previous environmental watering and to identify sites where the application of groundwater manipulation strategies may provide beneficial outcomes.

The methodology employed is described in the first Section of this Appendix, and followed by site compilations of the available datasets on key site indicators for each of the five floodplains. A summary of outcomes from the field program in terms of the relationships between groundwater salinity, soil salinity and vegetation health is detailed in Chapter 5.

2 Methodology

2.1 Site Selection

Five floodplain sites within the Mallee CMA region have been chosen to be the focus of field data collection. The floodplain sites were selected in consultation with Mallee CMA staff, who implement the Mallee Environmental Watering Program. The following factors have been considered in the site selection process:

- Data availability for the key site indicators;
- History of environmental watering;
- Sites that represent a range of vegetation responses; and
- Variation in key indicators between sites.

The following floodplain sites have been selected:

- Lake Wallawalla on the Lindsay-Wallpolla floodplain;
- Chaffey Bend floodplain at Mildura;
- Kings Billabong Floodplain;
- Psyche Bend Floodplain; and
- Lake Bitterang on the Hattah Kulkyne floodplain.

Table C.2 summaries the key indicators and data availability for each site and provides a brief rationale for the selection.

2.2 Soil Sampling

Push tube sampling was undertaken at each of the five selected floodplain sites for analysis of correlations between groundwater salinity, unsaturated zone salinity and responses to environmental watering. Push tube sampling was chosen as the preferred sampling technique as it minimises moisture loss during the drilling process and also allows the collection of an intact soil core. This method also has a relatively low impact on the surrounding floodplain.

Soil sampling was undertaken between 22nd and 24th June 2015 to collect soil cores at 23 sites using a 4WD Rockmaster push tube drill rig. Soil samples were collected at the following depths until the maximum sampling depth (4m):

- Surface
- 0.25m
- 0.5m
- 1m
- 2m
- 3m
- 4m

In total 161 samples were collected from the 23 sites with samples sent for laboratory analysis of gravimetric water content and soil $EC_{1:5}$. The remaining soil core was placed in a tray and retained for logging.

Soil salinity results are commonly reported as an $EC_{1:5}$ soil to water ratio (µS/cm). However, these salinities are influenced by the soil moisture content and also represent a diluted salinity. Therefore soil salinities reported here have been converted from $EC_{1:5}$ to a Soil Moisture Salinity (mg/L) using the following equations:

- Convert soil moisture EC to soil moisture salinity (Total Dissolved Salts ($TDS_{1:5}$)) by multiplying by conversion factor of 0.65
  - **$TDS_{1:5}$ (mg/L) = $EC_{1:5}$ (µS/cm) x 0.65** **Equation 1**
- Calculate the salinity of the soil moisture (TDS_{SM}), incorporating the soil moisture content
  - **TDS_{SM} (mg/L) = [$TDS_{1:5}$ (mg/L) / MC (%)] x [5 + MC (%) / 100] x 100** **Equation 2**

2.3 Tree Health Assessment

A broad scale tree health assessment was also undertaken at the time of push tube sampling and groundwater monitoring. This assessment focused on mature trees and primarily uses canopy cover to attribute a health score. The assessment is based on the methodology developed and applied by DEH (2002) and tree health criteria are presented in Table C.1 below. This assessment was selected as it is a quick method that can be used to correlate general trends in vegetation health with measured groundwater and soil salinity. This method has also been widely applied in large scale vegetation mapping studies throughout the Lower River Murray region (DEH 2002, AWE 2008).

TABLE C.1: TREE HEALTH ASSESSMENT CRITERIA

Rating	Description
5	Tree with >75% of the original canopy present. May include some dead branchlets and leaves <5% epicormic growth
4	Tree with 50-75% of the original canopy present. Some dead branchlets (<50% canopy). <10% epicormic growth
3	Tree with 25-50% of the original canopy present. Some small dead branches. Some epicormic growth (<50% of remaining canopy)
2	Tree with 10-25% of the original canopy present. Some main branches dead (<50% of remaining canopy)
1	Tree with < 10% original canopy
1e	Most main branches of tree dead. All epicormic growth.
0	Dead tree

TABLE C.2: SUMMARY OF SITE INDICATORS FOR SELECTED SITES

Site	Groundwater Salinity	Vegetation Condition and Response to Watering	Floodplain Geomorphology (Unsaturated Zone Permeability)	Regional Setting Gaining/Losing/ Throughflow Floodplain	Unsaturated Zone Salinity	Regional Setting Monoman Underlain by Blanchetown Clay	Data Availability (Prior to Field Program)	Rationale for Site Selection
Lake Wallawalla	Highly Saline	Generally poor to very poor Black Box Health Limited Response to watering	Alluvial terrace	Wide throughflow floodplain adjacent losing stream reach of River	?	Absent	• Groundwater Monitoring Data • NanoTEM • AEM • Floodplain geomorphology classification • History of environmental watering	Test soil salinity data at an unwatered site to see if there is a significant difference in soil salinity correlated with changes in vegetation health. Possible future water source for manipulation trials from lake Wallawalla. Test soil salinity data at a site that was last inundated during the 2010-2011 floods and where freshwater lenses are not known to occur.
Chaffey Bend	Fresh and Saline	Black Box condition varies depending on location on the floodplain and ranges from good to poor. Potential freshwater lens beneath wastewater lagoon. Black Box showed limited response to environmental watering	Mostly located on youngest floodplain meander belt	Gaining floodplain Gaining or Losing Stream Conditions Vary	?	Absent	• Groundwater Monitoring Data • NanoTEM • AEM • Floodplain geomorphology classification • History of environmental watering	Groundwater salinity is known to be variable at this site and influenced by the River and wastewater lagoon. Compare soil and groundwater salinities near the River where vegetation is in good condition near the River and wastewater lagoon to that collected at the lower terraces in the middle of the floodplain where vegetation condition is poor and showed limited response to watering.
Kings Billabong	Fresh and Saline	Black Box trees generally in good condition between the Billabong and the River. Although this site has not been watered in a traditional sense, permanently holding water in the Billabong provides a long term example of the effect of lateral recharge of freshwater to the floodplain aquifer.	Located on a combination of old floodplain meander belt away from the River and the youngest floodplain meander belt close to the River	Gaining Floodplain Losing Stream	?	Absent	• Groundwater Monitoring Data • AEM • NanoTEM • Floodplain geomorphology classification	Compare vegetation condition and soil/groundwater salinities within the extent of a freshwater lens near River and near the Billabong. Compare with results from sampling upstream at Psyche Bend.
Psyche Bend	Highly Saline	Black Box health generally poor. Response to watering has been limited although some seed germination has been noted.	Mostly located on intermediate floodplain meander belt	Throughflow Floodplain / Gaining Floodplain Gaining Stream	?	Absent	• Groundwater Monitoring Data • AEM • NanoTEM • Monitoring data from 2014 watering event • Floodplain geomorphology classification • History of environmental watering	Compare vegetation condition and soil/groundwater salinities at a throughflow/gaining floodplain adjacent gaining stream conditions that has recently been watered and will be watered again this year. Compare with results from sampling downstream at Kings Billabong.
Lake Bitterang	Fresh and Saline	Vegetation condition is variable. Watering on the wider Hattah floodplain has produced improved ecological outcomes in comparison to sites downstream.	?	Located a significant distance from the main River channel	?	Present	• Vegetation condition monitoring • Seed monitoring trial (in progress) • Groundwater monitoring data on the wider floodplain	Compare soil salinity responses at recently watered site at Lake Bitterang to sites that have not and at a floodplain location where positive ecological outcomes have been achieved as a result of previous watering events.

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3 Lake Wallawalla

3.1 Regional Setting

Lake Wallawalla is located on a wide section of the Lindsay-Wallpolla floodplain. Lake Wallawalla is fed by the Lindsay River when flows at Lock 8 exceed 50,000ML/d (approximately) (MDBC 2006). Previous management plans for the site note that the key threat to Lake Wallawalla is the changed water regime, namely the reduced frequency, timing and duration of inundation events.

The main geological units encountered on the Lake Wallawalla floodplain, in order of increasing depth are the Woorinen Formation, Coonambidgal Clay, Monoman Formation, Parilla Sands and Lower Parilla Clay. At Lake Wallawalla, the Blanchetown Clay is absent in the floodplain and does not separate the Monoman and Parilla Sand aquifers.

3.2 Current Vegetation Condition

The Groundwater Dependent Ecosystem (GDE) Atlas developed by the CSIRO and SKM (2012) classifies the Lake Wallawalla floodplain as having a high potential for vegetation groundwater interaction. Four distinct vegetation zones have been described for the Lake Wallawalla floodplain (MDBC 2006), namely:

- Lakebed herbland;
- Riverine grassy forest;
- Black-Box chenopod woodlands;and
- Alluvial plains shrubland.

A survey conducted at the site at the start of the Millennium drought suggested that the Riverine grassy forest which is dominated by a River Red Gum community was relatively healthy and showing signs of recruitment (SKM 2003, MDBC 2006). However, the same survey found that the Black Box communities were showing signs of stress and that the frequency and duration of inundation at the site may not have been adequate to maintain the health of the community (MDBC 2006). It was particularly noted that the Black Box community to the west of the Lake was showing signs of stress and there were no signs of recruitment. This area was also associated with extensive cover of pigface spp. and other halophytic shrubs suggesting that surface soil was saline at this location (MDBC 2006, SKM 2003).

3.3 History of Watering and Vegetation Response

Lake Wallawalla received its first environmental water allocation in 2009-2010 to prevent irreversible losses of the River Red Gum and Black Box communities located on the surrounding floodplain (Figure C.1). Prior to this watering event, it is estimated that the Lake had been dry for nine years. A second watering event took place in 2010-2011. In early 2011, large sections of the Lindsay Island floodplain, including Lake Wallawalla, were inundated as a result of high flows in the River Murray and an extreme rainfall event in the region. Following these natural and managed flood events it was noted that River Red Gum and Black Box communities were showing signs of improved condition through increased foliage cover (DSE 2012).

FIGURE C.1: INUNDATION OF LAKE WALLWALLA MARCH 2011 (PHOTO BY MALLEE CMA SOURCED FROM DSE 2012)

3.4 Floodplain Geomorphology and Vertical Permeability

Surface materials to the west of Lake Wallawalla are classified as predominantly silty clays with secondary fine to medium sands. The Lake bed itself is classified as a clay deposit with secondary gypsum rich sands, silts and clay (Geoscience Australia 2008). The presence of gypsum indicates evaporative concentration processes. Natural wetting and drying cycles have lead to the shrinking and swelling of clays which line the lake and have resulted in the formation of deep cracks (MDBC 2006). These cracks may act as preferential pathways for recharge when the Lake is flooded.

The floodplain to the west of Lake Wallawalla has been classified as an alluvial terrace (Geoscience Australia 2008). Clarke et al. (2008) describe the alluvial terrace as consisting of clay and fine sandy alluvium of the Rufus Formation. The terrace is covered in places by sand dunes of the Woorinen Formation. Clarke et al. (2008) found there was no observable relationship between geomorphic units and salinity, however soil samples from the alluvial terrace tended to be more saline than those from floodplain units and the uplands. The report also predicts that infiltration through the soil profile on the alluvial terrace will be limited due to dispersive clays which seal the floodplain sediments (Clarke et al. 2008). This suggests that flushing of the soil profile due to inundation of the floodplain is likely to be limited to the west of Lake Wallawalla.

3.5 River Skin - Lake Bed

The influence of the River skin on the outcomes of floodplain management is not expected to be significant at this site. Airborne Electromagnetic (AEM) data indicates that low salinity lenses occur along the River Murray adjacent the Lindsay Island floodplain, however these are not located within the influence of Lake Wallawalla. AEM data does not indicate the presence of freshwater lenses along the Lindsay River adjacent Lake Wallawalla, even though it is a permanently flowing feature (Geoscience Australia 2008). Limited groundwater monitoring data is available from around the Lake however the available data suggests that groundwater levels responded to flood events during the early 1990s. This suggests some connection between the Lake and the floodplain aquifer. This is also consistent with AEM and groundwater salinity data which suggests lower salinity groundwater beneath and fringing the Lake.

3.6 Groundwater Salinity, Soil Salinity and Vegetation Health

Groundwater, soil salinity and vegetation health data collected at Lake Wallawalla are presented with AEM data in Figure C.2.

Healthy stands of Black Box trees were observed around the western fringe of Lake Wallawalla with tree health scores of ‘4’ and ‘5’ recorded. Black Box seedlings were also observed at sampling site WW3 and River Red Gum seedlings were noted on the banks of the lake and on the lake bed itself. However, despite the good health of fringing Black Box trees, vegetation condition declines rapidly with distance from the Lake. Adjacent sites WW2 and WW3, trees with a health score of ‘1’ and ‘2’ were recorded within 200 to 400m of the Lake. Similarly, Black Box vegetation is in very poor condition 1.7km west of the Lake a site WW1, with a health score of 1 recorded for this location.

Patterns in vegetation health correlate well with changes in groundwater salinity. Groundwater monitoring data indicates groundwater salinities of less than 20,000mg/L surrounding Lake Wallawalla and adjacent Lindsay River, where healthy mature trees and seedlings were observed. Groundwater salinity then increases with distance from the Lake. A groundwater salinity of 38,000mg/L was measured at site WW1 for the Monoman Formation and 45,305mg/L for the Parilla Sands aquifer. This is well above the 32,000mg/L limit identified in AWE (2012) below which 75% of healthy Black Box trees occur. These trends in groundwater salinity are also supported by AEM data presented in Figure C.2 which suggests increasing groundwater salinity with distance from the Lake.

Soil salinities also correlate closely with changes in groundwater salinity and vegetation health. Average soil salinity at sites WW2 and WW3 was 18,659mg/L. Conversely soil salinity at site WW1 was more than three times that recorded near the Lake, with an average of 66,044mg/L. This fits within the data ranges identified in AWE (2012) which suggested that 75% of healthy Black Box trees occur where average soil salinity is less than 19,500mg/L (30,000µS/cm) and that 75% of unhealthy Black Box trees occurred where soil salinities exceeded 32,500mg/L (50,000 µS/cm). Additionally the soil salinity recorded at site WW1 is at the extreme high end of values recorded and analysed by McEwan et al (2003) and AWE (2012).

3.7 Summary

The condition of Black Box trees fringing the western edge of Lake Wallawalla is good, but deteriorates rapidly with distance from the Lake. Where Black Box vegetation is healthy, groundwater and soil salinities are below the 75th percentile ranges identified by this study and in AWE (2012). Conversely away from the Lake at site WW1, groundwater and soil salinities far exceed these ranges and Black Box condition is very poor. These high values are consistent with the site being located on a wide throughflow floodplain with a high capacity for evapoconcentration of regional groundwater inputs. Access to low salinity water at WW1 is likely to be limited to rainfall, as the site is located outside the influence of the Lindsay River and Lake Wallawalla. This site is also likely to be flooded less frequently than those adjacent the Lake.

Lower groundwater and soil salinities are consistent with Lake Wallawalla being a more frequently flooded feature compared to the outer floodplain. Anecdotal evidence suggests that the best responses to flooding were observed in vegetation communities fringing the Lake. This is likely to be influenced by the better starting condition of vegetation and correspond to areas where groundwater and soil salinities are low compared to the outer floodplain. Soil profiles at this location are also comparatively sandier and likely to facilitate higher rates of recharge from rainfall or flooding close to the lake edge.

4 Chaffey Bend

The Chaffey Bend floodplain is located downstream of Lock 11 at Mildura between River kilometres 878 and 884. The floodplain has high environmental and recreational value within the Mallee region and is unique in its hydrogeological setting with pumping from the Mildura Merbein Salt Interception Scheme (MMSIS), the operation of a wastewater lagoon, Lock 11 and the flow regime of the River Murray all influencing the behaviour of groundwater.

The Mildura Wastewater Treatment Plant (WWTP) and associated farm is located on 150 hectares of land adjacent the Chaffey Bend floodplain (Lower Murray Water 2011). This includes a wastewater lagoon of approximately 30 hectares, which is used for wet weather storage. The lagoon has a total capacity of 507 ML but volume varies from 34 ML (in March) up to 480 ML (July to October). The plant receives approximately 1,150ML of waste per year and discharges treated water via flood irrigation to a tree plantation (59.7 hectares) and pasture plantation (56 hectares). Drainage water is collected and returned to the lagoon. The interaction of the freshwater lagoon and the floodplain aquifer is likely to influence groundwater salinities, soil salinities and spatial patterns of vegetation health on the floodplain. At the time of the development of the Environmental Watering Management Plan (EWMP) for Chaffey Bend in 2014, the wastewater lagoon was partially empty and aerial imagery suggests it had been drying out since 2012.

A portion of the MMSIS borefield is also located along the back of the Chaffey Bend floodplain adjacent the wastewater lagoon. The original SIS borefield was commissioned between 1979 and 1981 with seven wellpoint bores located on the Chaffey Bend floodplain which targeted salt interception from the shallow floodplain aquifer (Monoman Formation). The MMSIS has since been refurbished and now only two pumping bores are located on the western side of the Chaffey Bend floodplain. Salt interception now targets both the floodplain and regional aquifers. Since the borefield was refurbished, the SIS has only operated intermittently (AWE 2013).

4.1 Regional Setting

The main geological units encountered on the Chaffey Bend floodplain, in order of increasing depth are; the Coonambidgal Clay, Monoman Formation, Parilla Sands and Lower Parilla Clay. At this location, the Blanchetown Clay is absent in the floodplain and does not separate the Monoman and Parilla Sand aquifers.

The Chaffey Bend floodplain is located adjacent to the Mildura Irrigation District and is a gaining floodplain. Groundwater contours indicate the presence of a groundwater mound beneath the adjacent irrigation district where elevated groundwater levels have created a radial flow pattern away from the mound and towards the River. Groundwater levels at the peak of the mound are in excess of 38mAHD which is approximately 7m above the Lock 11 downstream pool level (30.8mAHD) indicating strong regional gradient towards the floodplain (AWE 2013).

Groundwater heads suggest gaining stream conditions adjacent the Chaffey Bend floodplain. Results from NanoTEM surveys indicate high to medium resistivities along this reach of River. Therefore it is likely that groundwater discharging to the River is of comparatively low salinity (freshwater lenses). The 2012 NanoTEM survey was conducted in February of that year following a flood which is likely to have recharged the floodplain aquifer with fresh water.

Gaining floodplains and gaining stream reaches of River have the highest salinisation risk. This is likely to influence soil and groundwater salinity on the Chaffey Bend floodplain and hence floodplain vegetation condition.

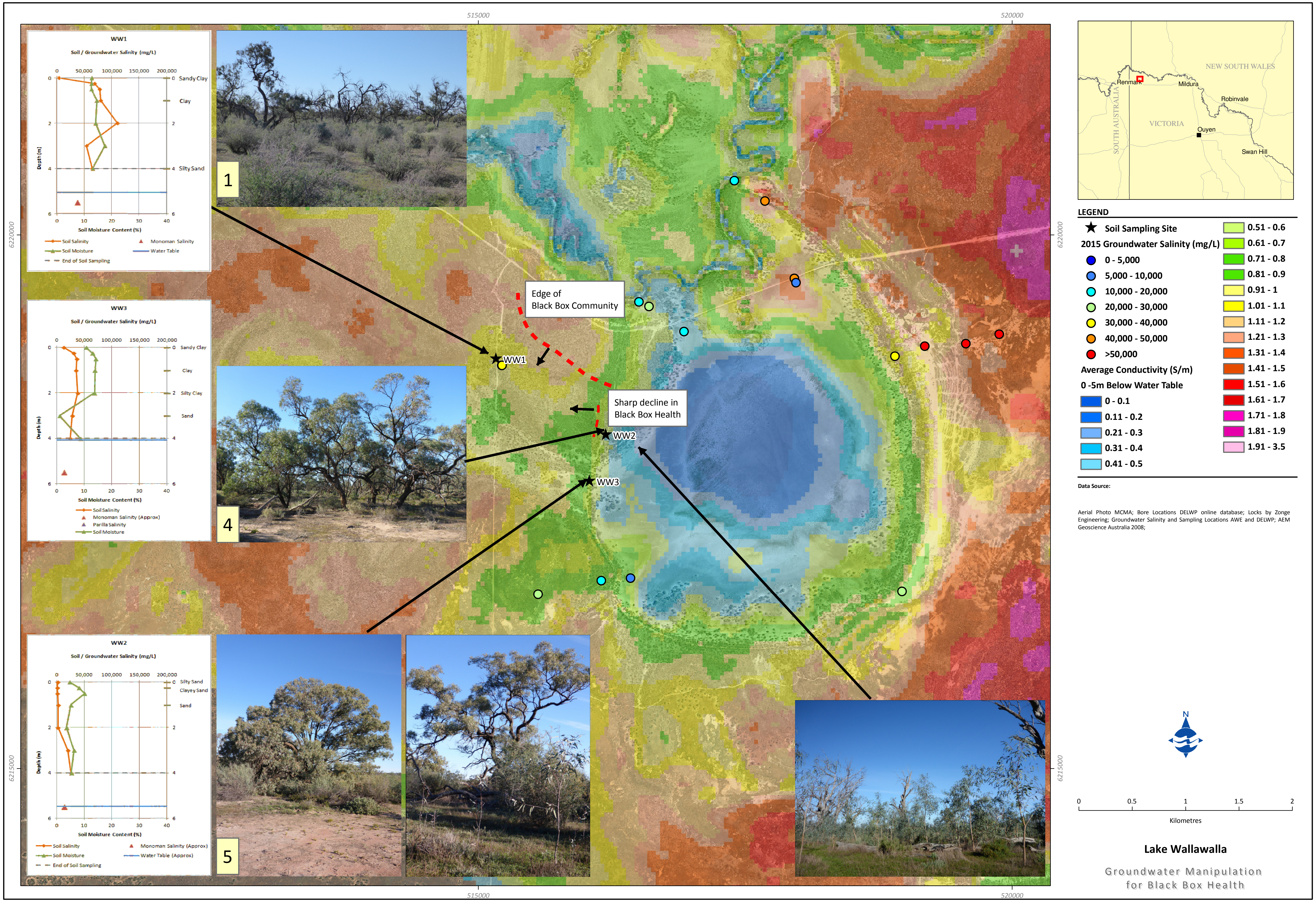

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Figure C.2

4.2 Current Vegetation Condition

The Chaffey Bend floodplain is located within the Murray Scroll Belt bioregion. The Ecological Vegetation Classes found on the floodplain are shown in Figure C.3. River Red Gum trees line the River Murray and flood runners, with Black Box and lignum becoming more dominant with distance from the River. The Groundwater Dependent Ecosystem (GDE) Atlas developed by the CSIRO and SKM (2012) classifies the Chaffey Bend floodplain as having a high potential for vegetation groundwater interaction.

The following observations detail the spatial patterns of vegetation health on the Chaffey Bend floodplain:

River Red Gums lining the River Murray are healthy;

The health of Black Box on the floodplain between the River and the lagoon is poor and vegetation condition is continuing to decline;

Black Box trees fringing the wastewater lagoon are in good condition;

Tree health on low-lying sections of the floodplain has improved due to recent flood and high rainfall events. Sections of the Chaffey Bend floodplain were inundated due to high River flows during 2010 and 2012. These natural flood events may have reduced soil salinity and increased soil moisture availability for use by mature trees and also seed germination.

4.3 History of Watering and Vegetation Response

Environmental water was first delivered to the Chaffey Bend floodplain in 2005 as part of an emergency watering program to maintain the condition of River Red Gum trees. A second watering event occurred at the site in June 2006 as detailed in Table C.2 below (Kelly 2006). During these events, water was pumped directly from the River into low lying flood runners on the western section of the floodplain, as shown in Figure C.4. At the time of the 2006 watering event, it was noted the Chaffey Bend floodplain was the most stressed site of the 16 floodplains that were watered as part of the emergency response program (Kelly 2006).

The Floodplain Inundation Model (FIM) suggests that the Chaffey Bend floodplain requires high flows for natural inundation to occur. The western section of floodplain sits at the lowest elevation and is likely to flood when River Murray flows exceed 55,000ML/d (AWE 2009). Low lying sections of the floodplain were inundated by the natural flooding that occurred between 2010 and 2012.

Anecdotal reports suggest that floodplain vegetation did show some response to the watering events however this was limited by the extent of inundation. Additionally the higher elevation parts of the flood runners (i.e. Black Box trees) showed no discernible response to the watering events (Kelly 2006). Anecdotal evidence at the time suggested that magnitude of the ecological response to flooding at Chaffey Bend was less than that observed on other floodplain sites.

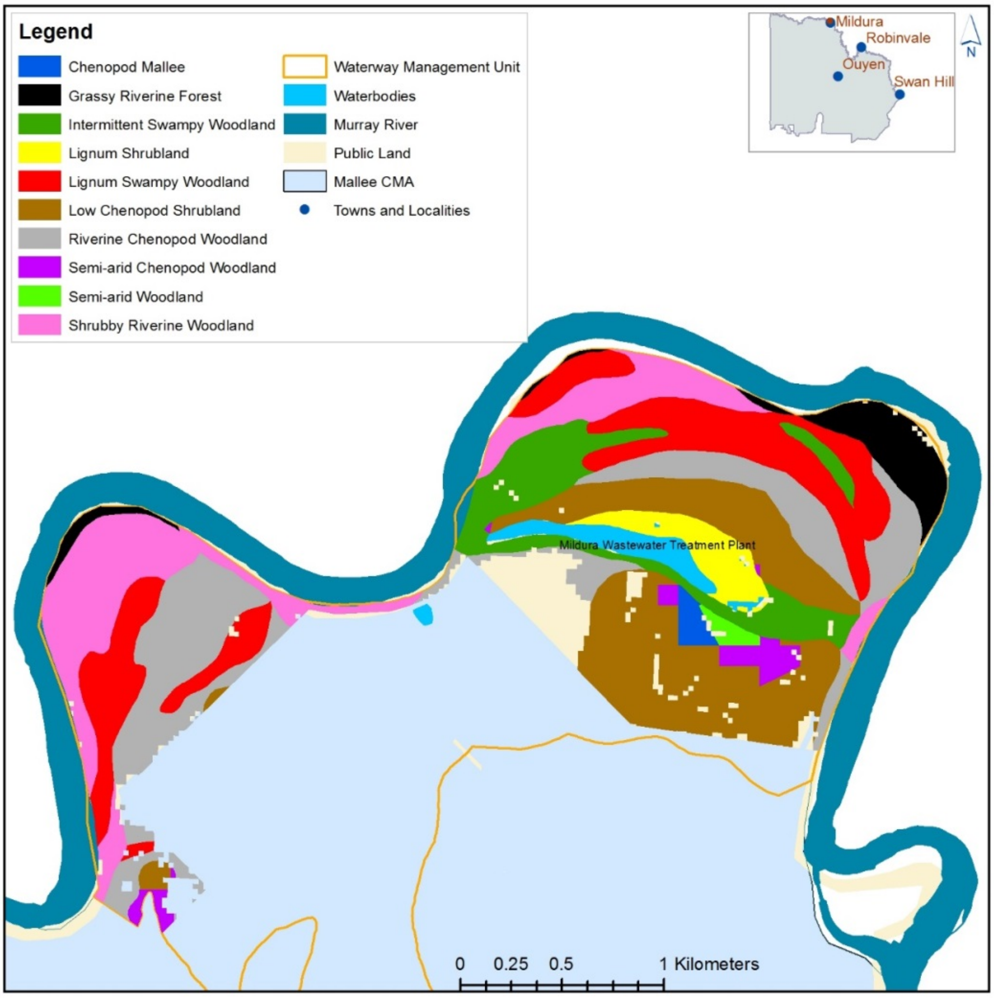

FIGURE C.3: ECOLOGICAL VEGETATION CLASSES FOR THE CHAFFEY BEND FLOODPLAIN (SOURCE AWE 2014B)

TABLE C.2: SUMMARY OF ENVIRONMENTAL WATER DELIVERY TO THE CHAFFEY BEND FLOODPLAIN

Year	Volume (ML)	Area (ha)	Distance of Runner (km)
2005	151	13	2
2006 (June)	61	14	3

FIGURE C.4: INUNDATION AT CHAFFEY BEND FLOODPLAIN JULY 2006 (PHOTO BY CLAIRE MASON MCMA IN KELLY 2006)

4.4 Floodplain Geomorphology and Vertical Permeability

The Chaffey Bend floodplain is classified as occurring on the youngest floodplain meander belt (CRCLEME in AWE 2008). Young floodplain sediments are typically sandier than those found on the intermediate and old terraces, suggesting a greater capacity for vertical infiltration through the soil profile. Sampling sites located adjacent the wastewater lagoon are located on the alluvial terrace which is likely to be less permeable

4.5 River Skin

A review of groundwater monitoring data in the Mildura area suggests that groundwater levels respond to changes in River flow up to 1km from the River (AWE 2009). This is also true for available hydrograph data on the Chaffey Bend floodplain which suggests that groundwater levels respond to flooding in the River Murray in both the Monoman Formation and Parilla Sands. However, corresponding salinity data is not available to confirm the occurrence of groundwater freshening as a result of lateral recharge during floods. Strong regional groundwater gradients towards the Chaffey Bend floodplain my also limit exchange between the floodplain aquifer and the River.

4.6 Groundwater Salinity, Soil Salinity and Vegetation Condition

Groundwater depth and salinity beneath the Chaffey Bend floodplain is influenced by regional groundwater fluxes, River Murray flow regime, the operation of Lock 11, SIS pumping and operation of the wastewater lagoon. Groundwater depths and salinities vary both spatially, with depth and with time.

As discussed previously, Chaffey Bend is a gaining floodplain with regional groundwater fluxes driven towards the floodplain by the groundwater mound beneath the Mildura Irrigation District.

Groundwater salinity, soil salinity, AEM and vegetation health data is presented in Figure C.5for the Chaffey Bend floodplain. A narrow band of both healthy River Red Gum and Black Box trees was observed fringing the River Murray adjacent site CB1. Vegetation health then declines rapidly with distance from the River. Black Box trees at the centre of the Chaffey Bend floodplain are in very poor condition, with mature trees consisting of dead branches with epicormic growth at sampling sites CB2 and CB3 (health score ‘1e’). Black Box vegetation condition is good surrounding the wastewater lagoon at the back of the floodplain with tree health scores of ‘4’ and ‘5’ recorded at sites CB4 and CB5.

Changes in vegetation condition on the Chaffey Bend floodplain correspond well to changes in conductivity indicated by AEM data. Figure C.5 illustrates that the declines in vegetation condition begin at the outer extent of the freshwater lens from the River Murray. Similarly, the change from the good condition Black Box to poor condition Black Box coincides with the outer extent of the freshwater lens from the wastewater lagoon.

These trends are confirmed by groundwater monitoring data. Groundwater salinities measured within the freshwater lens of the wastewater lagoon average 860mg/L for the Monoman Formation. Groundwater salinity at site CB1 near the River is higher at 19,435mg/L but still within the 75th percentile threshold for Black Box trees. Groundwater salinity at CB1 may be lower than that measured at bore 7280 as this bore is screened within the Parilla Sands aquifer and the freshwater lens is most likely to be observed in the Monoman Formation. A vertical salinity profile for bore R47 is also presented in Figure C.5. This bore is fully screened across the floodplain aquifer at the western tip of the waste water lagoon. The salinity profile for bore R47 indicates that the freshwater lens extends to a depth of 23m at this location. A steep halocline can then be observed where groundwater salinity increases from 469 mg/L to 52,455 mg/L over a depth interval of 5m. Groundwater salinity at the centre of the floodplain averages 21,352mg/L around site CB2 and CB3.

Soil salinities at the three sites where Black Box trees are healthy (CB1, CB4 and CB5), range between 28,000mg/L and 36,000mg/L at a depth of 4m. At sites CB2 and CB3 where Black Box trees are in poor condition, soil salinities in the top 2m of the soil profile are comparable to those observed within the freshwater lens, however salinities increase significantly below a depth of 2m, ranging between ~50,000mg/L and 73,000mg/L. This is significantly higher than the 32,500mg/L (50,000 µS/cm) soil salinity identified by AWE (2012) from the data presented in McEwan et al (2003), above which 75% of unhealthy Black Box trees occurred.

4.7 Summary

A narrow band of healthy vegetation can be observed lining the River Murray. Groundwater and soil salinities at this location (CB1) are at the higher end of values expected to be associated with healthy vegetation. This section of floodplain is low-lying and likely to be inundated at lower flows than the remainder of the floodplain. At this site flooding frequency and access to River water may maintain this narrow band of vegetation.

The condition of Black Box trees on the floodplain between the River and the lagoon is poor. Soil salinities at the sampling locations within this zone are above the range expected to be associated with good vegetation health (AWE 2012). Additionally, groundwater salinity at these locations is at the higher range of values expected to be associated with healthy vegetation. Access to a low salinity water source at the centre of the floodplain is likely to be limited to rainfall and flooding, although commence to flood data suggests that the flooding threshold for this section of the floodplain is high and infrequent.

As no water level monitoring is available for the inundation event at Chaffey Bend, the magnitude of recharge that occurred during flooding cannot be determined. However, the Chaffey Bend floodplain is predominantly located on the youngest floodplain terrace and this is supported by soil cores which tended to be dominated by sandy sediments. The exception is site CB5 which is located on the alluvial terrace where the soil profile is dominated by clay. This data suggests that inundation of Chaffey Bend would have a greater potential for vertical infiltration of floodwaters, compared to the other sites assessed by this study. However, anecdotal evidence suggests the response of Black Box trees to flooding was limited.

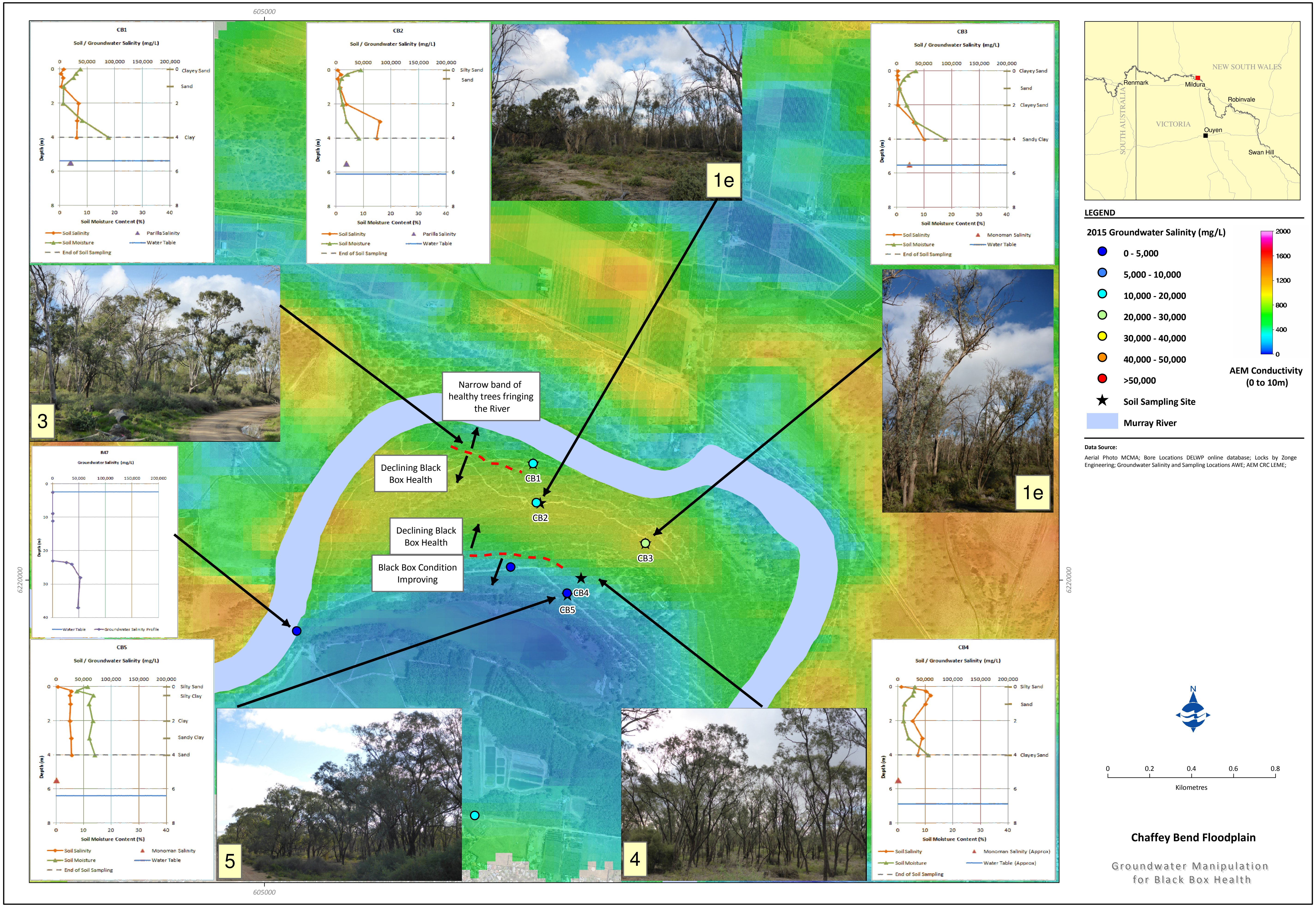

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Figure C.5

It is hypothesised that inundation of the Chaffey Bend floodplain did not induce significant recharge of low salinity water in the deeper soil profile or to water table. It is also hypothesised that the flooding frequency has not been great enough to sustain Black Box trees at the centre of the floodplain where groundwater and soil salinities are close to or exceed the expected values that are associated with healthy trees. The outcomes of floodplain management may have also been limited by the poor starting condition of Black Box vegetation on the floodplain. Similarly Black Box trees on the highest sections of the floodplain were likely to be outside the influence of flooding.

Groundwater manipulation may provide an opportunity to manage or improve the condition of Black Box trees on the Chaffey Bend floodplain. It is hypothesised that groundwater pumping may extend the freshwater lens from the wastewater lagoon or from the River. This would provide a low salinity water source to Black Box trees located on the centre and outer floodplain which may in turn influence the salinity of the unsaturated zone as has been observed at Bookpurnong.

5 Kings Billabong

5.1 Regional Setting

The major geological units encountered on the Kings Billabong floodplain, in order of increasing depth are the Woorinen Formation, Coonambidgal Clay, Monoman Formation (or Channel Sands), Parilla Sands and Lower Parilla Clay. At this location, the Blanchetown Clay is absent in the floodplain and does not separate the Monoman and Parilla Sand aquifers.

The Kings Billabong floodplain is located adjacent the Red Cliffs Irrigation District and can be considered a gaining floodplain. Groundwater contours indicate the presence of a groundwater mound beneath the irrigation district where elevated groundwater levels have created a radial flow pattern away from the mound and towards the River. Groundwater levels at the peak of the mound are in excess of 38mAHD which is approximately 3.6m above the Lock 11 upstream pool level (34.4mAHD) indicating regional gradient towards the Psyche Bend floodplain (AWE 2015b).

Data from the 2004 and 2006 NanoTEM surveys indicate losing stream conditions adjacent the Kings Billabong floodplain. Water stored in the Billabong is held above River level but unlike Psyche Lagoon upstream, which is also held above River level, no gaining stream signals were observed in the NanoTEM survey.

5.2 Current Vegetation Condition

The Kings Billabong floodplain supports healthy stands of River Red Gum forest and Black Box woodland (higher terraces). Ecological Associates (2007) report that where these communities lie close to the Billabong they benefit from the fresh shallow source of water.

The Groundwater Dependent Ecosystem (GDE) Atlas developed by the CSIRO and SKM (2012) classifies the Kings Billabong floodplain as having a high potential for vegetation groundwater interaction. Black Box woodlands occupy the higher terraces of the Kings Billabong floodplain. Previous studies have noted that Black Box trees in close proximity to the Billabong are in good condition, benefiting from the freshwater lens created by the Billabong. However, trees located outside the extent of the freshwater lens are vulnerable to drought and saline groundwater (Lloyd Environmental 2006).

5.3 History of Watering and Vegetation Response

Environmental watering has not occurred at Kings Billabong to date. However, water held permanently in the Billabong above the adjacent groundwater level provides a fresh water source for fringing vegetation via lateral recharge.

Historically, under natural conditions the Kings Billabong behaved as an intermittent or ephemeral wetland with the water regime controlled by flow in the River Murray and evaporation (EA 2007). The Billabong is now used as a balancing water storage basin for irrigators and permanently contains water. Water is pumped into the Billabong at its upstream end and a levee has been constructed across the northern tip to maintain water at full supply level (37mAHD) (EA 2007). Prior to the construction of the levee the Billabong was connected to the River at its downstream end by Butlers Creek. The water level in Butlers Creek is controlled by the upstream pool level of Lock 11 which is held at approximately 34.4mAHD.

If the water level in Kings Billabong is above 37.25mAHD water spills into the floodplain inundating River Red Gum and Black Box woodlands on the eastern fringe of the Billabong. Flood runners to the east of the Billabong begin to flow into the floodplain when River Murray flows exceed 37,900ML/d and this again inundates River Red Gum and Black Box communities on this section of floodplain.

A regulator structure was installed at Kings Billabong in 2012-2013 to allow water levels in the wetland to be varied, in particular lowering the water levels during the irrigation off-season to mimic a more natural wetting and drying cycle for the Billabong.

5.4 Floodplain Geomorphology and Vertical Permeability

The Kings Billabong floodplain is located on the oldest floodplain meander belt (CRCLEME in AWE 2008) and sediments are associated with low permeability materials (clays) that are likely to limit recharge to the groundwater system when the floodplain is inundated. A narrow band of young floodplain (sandier) sediments, which potentially allow greater recharge to the floodplain aquifer, have been identified adjacent the River. Young floodplain sediments at Kings Billabong are coincident with the River Red Gum communities which line the River.

5.5 River Skin

Instream and land based vibro-coring was undertaken at Kings Billabong as part of salt interception investigations in the Sunraysia region to ground truth AEM and NanoTEM data. Results from the in-stream survey around Kings Billabong from River km 898 to River km 906 highlight the accuracy of the NanoTEM survey in determining gaining and losing stream conditions. In-stream pore water salinity at River km 899.5 adjacent Kings Billabong is (<1,000 mg/L (~1,500 µS/cm)) from the surface to a depth of approximately 8 m. This trend supports the NanoTEM signal which shows an area of low conductivity suggesting losing stream conditions. Bore logs for site RC09 (River km 899.5) indicate fine grained silt from the surface of the River bed to 1m and 2m. This is underlain by fine to medium sands of the Monoman Formation Aquifer. Bore logs for sites RC10, RC11 and RC13 appear to be in direct connection with either the Monoman Formation of the Parilla Sands Aquifer.

5.6 Groundwater Salinity, Soil Salinity and Vegetation Condition

Monitoring data for the Kings Billabong floodplain is presented in Figure C.6. Of the five sites surveyed, Black Box condition was best on the Kings Billabong floodplain with tree health scores of 4 and 5 recorded across the site. A Black Box community is the dominant type of vegetation present at sites KB1, KB2 and KB3. At site KB4 adjacent the River Murray, River Red Gum trees were dominant, however stands of Black Box trees were also present and in good condition.

AEM data for Kings Billabong indicates comparatively low groundwater salinities across the floodplain and the presence of a freshwater lens beneath the Billabong and adjacent the River Murray. Groundwater monitoring data is not available adjacent the soil sampling sites, as the bore locations on the Kings Billabong floodplain were not accessible by the push tube rig. However, monitoring data to the south of the soil sampling sites indicates groundwater salinities of approximately 416 mg/L within the freshwater lens adjacent the River Murray, well within the salinity threshold of Black Box. Groundwater salinities in the centre of the floodplain are only available for the Parilla Sands aquifer, with recorded values ranging between 22,685mg/L and 31,395mg/L. Groundwater salinity may be lower at the top of the Monoman Formation. This is supported by field data where groundwater salinity was measured in the drill hole at KB2 and was approximately 10,800mg/L at water table.

Average soil salinities recorded on the Kings Billabong floodplain range between 12,148 mg/L at KB4 up to 43,362mg/L at KB1, with soil salinity increasing with distance from the River. The two sites located within the extent of the freshwater lens recorded the lowest soil salinities and best vegetation health. Although soil salinities outside the freshwater lens are higher than the 75th percentile ranges identified by this study, Black Box vegetation at these sites is still considered healthy. Similarly groundwater salinity is also higher than the 75th percentile ranges at sites KB1 and KB2. This data is only available for the Parilla Sands aquifer and it is considered likely that groundwater salinity in the Monoman Formation would be lower due to the influence of leakage from Kings Billabong. This is supported by field data where groundwater salinity was measured in the drill hole at KB2 and was approximately 10,800mg/L at water table.

5.7 Summary

Although the Kings Billabong floodplain is located just downstream of the Psyche Bend floodplain and in a similar hydrogeological setting, Black Box vegetation is significantly better at this location. This is likely to be influenced by a number of factors including:

- The permanent holding of water above River level and groundwater levels in the floodplain aquifer has created a freshwater lens;
- The freshwater lens is likely to provide fringing vegetation with a permanent source of low salinity water and also be associated with low soil salinities;
- Permanently holding water is likely to protect the floodplain from the strong regional groundwater gradients towards the gaining floodplain;
- Permanently holding water is likely to limit the amount of evapoconcentration of saline groundwater and soil salinity on the floodplain, as has been observed upstream at Psyche Bend;
- The Kings Billabong floodplain has a lower ‘commence to flood’ threshold than the other floodplain sites assessed in this study;
- Losing stream conditions adjacent the floodplain have facilitated the formation of a freshwater lens adjacent the River which corresponds to areas of good vegetation conditions and low soil salinity.

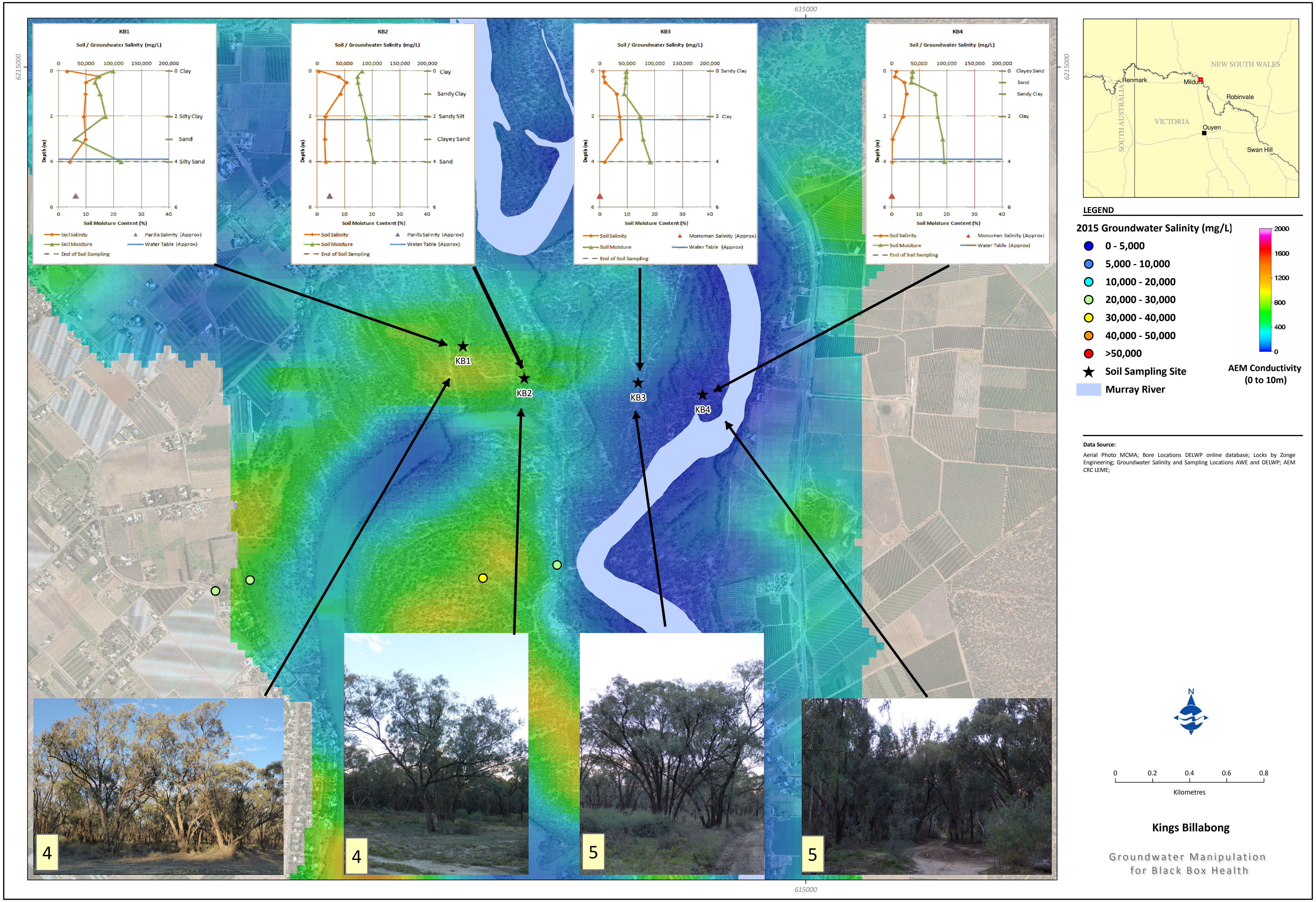

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Figure C.6

6 Psyche Lagoon

6.1 Regional Setting

The major geological units encountered on the Psyche Bend floodplain, in order of increasing depth are the Woorinen Formation, Coonambidgal Clay, Monoman Formation (or Channel Sands), Parilla Sands and Lower Parilla Clay. At this location, the Blanchetown Clay is absent in the floodplain and does not separate the Monoman and Parilla Sand aquifers.

The Psyche Bend floodplain is located adjacent the Red Cliffs Irrigation District and can be considered a throughflow floodplain. Groundwater contours indicate the presence of a groundwater mound beneath the irrigation district where elevated groundwater levels have created a radial flow pattern away from the mound and towards the River. Groundwater levels at the peak of the mound are in excess of 38mAHD which is approximately 3.6m above the Lock 11 upstream pool level (34.4mAHD) indicating regional gradient towards the Psyche Bend floodplain (AWE 2015b). As a throughflow floodplain, Psyche Bend gains regional groundwater flux driven by the mound beneath the Red Cliffs Irrigation District, but loses some of this flux to the regional groundwater system beneath the River.

Data from the 2004 and 2006 NanoTEM surveys indicate gaining stream conditions adjacent the northern and southern tip of Psyche Lagoon where the River loops towards the irrigation district, corresponding to River kilometres 904 and upstream of 906. However, the NanoTEM signal between these points suggests losing stream conditions. Gaining stream conditions upstream of River kilometre 906 correspond to a structurally controlled thinning of the Parilla Sands aquifer. This thinning of the aquifer is thought to generate higher water table elevations on the upstream floodplain which lead to gaining stream conditions (AWE 2004b).

In summary, Psyche Bend Lagoon is located on a throughflow floodplain adjacent both losing and gaining stream reaches of River. However, the section of floodplain which is the focus of sampling is located adjacent the gaining stream section of River. This places the Psyche Bend floodplain at a moderate to high risk of salinisation in the Floodplain-River Classification Matrix which is likely to influence the observed trends in soil and groundwater salinity, and hence floodplain vegetation condition.

6.2 Current Vegetation Condition

The Groundwater Dependent Ecosystem (GDE) Atlas developed by the CSIRO and SKM (2012) classifies the Psyche Bend floodplain as having a high potential for vegetation groundwater interaction. Healthy floodplain vegetation is limited to a narrow band fringing the River. Vegetation condition then deteriorates with distance from the River and is stressed adjacent the Lagoon.

6.3 History of Watering and Vegetation Response

Psyche Lagoon was used as an irrigation drainage disposal basin until 1996 when the Drainage Diversion Scheme was implemented. This scheme diverted irrigation drainage water away from the Lagoon and also implemented operational protocols that allowed flushing flows through the Lagoon and Woorlong Wetlands when River Murray flows exceeded 35,000ML/d (Aquaterra 2010). Two flushing events have occurred since the Drainage Diversion Scheme was implemented; the first between December 2010 and April 2011 and the second between March and May 2012 (CDM Smith 2015). The primary aim of these flushing events was to export salt that had accumulated in the floodplain as a result of the disposal of drainage water at the site and also groundwater discharge. Low lying sections of the floodplain were also likely to have been inundated at these times as a result of natural flood events in the River Murray. It was noted that these flushing/flooding events triggered a response in the surrounding Black Box community as demonstrated by the increase in seedling numbers and epicormic growth on mature trees (Mallee CMA 2014 reported in CDM Smith 2015). An extreme rainfall event also occurred in February 2011 and this is also likely to have contributed to the positive vegetation response observed to result from the 2010-2011 flushing/flooding event.

More recently, the Psyche Bend Lagoon has been the target of environmental watering activities with the first inundation event beginning in April 2014 and a second planned for 2015. The aim of these environmental watering events has been to refresh lagoon waters, to improve the health of surrounding Black Box trees and to improve water quality, providing an opportunity for relocation of the threatened Murray Hardyhead fish (CDM Smith 2015).

A review of monitoring data from the inundation of Psyche Lagoon in 2014 concluded that between 932 and 2,628 tonnes of salt was exported from the site as a result of the watering event (CDM Smith 2015). However, despite this, the calculated salt store in the Lagoon was higher following the inundation event compared to that calculated for the site prior to watering. The analysis concluded that most of the salt was exported from a layer of lower salinity water at the top of the water column and that a layer of highly saline water persisted at the base of the Lagoon following the inundation event.

Vegetation responses to the watering event were not the focus of the monitoring review by CDM Smith (2015). It is considered that the mechanism by which watering may improve Black Box condition at this site is via the lateral recharge of lower salinity water from the Lagoon to the floodplain aquifer, as a result of surface water being held on the floodplain at an elevation above the surrounding water table.

6.4 Groundwater Depth and Salinity

The review of the 2014 environmental watering event, notes that the monitoring program was not designed to identify the extent of lateral recharge from the Lagoon (CDM Smith 2015). However, a review of groundwater level monitoring data presented in the report can infer a connection between the Lagoon and the floodplain aquifer. Data presented in CDM Smith (2015) suggests that:

- Depth to water ranged between 2 m and 5 m below natural surface;
- Comparison between groundwater heads in the Monoman Formation and Parilla Sands suggests an upward groundwater flux;
- Groundwater monitoring started part way through filling of the Lagoon, however data indicates that groundwater levels in bores adjacent the lagoon (monitoring the Monoman Formation) rose in response to filling; his response was greater to the east of the Lagoon (down the hydraulic gradient) than to the west;
- Monitoring data from bore 7987, located approximately 125m east of the Lagoon, shows the groundwater elevation increased by nearly 1m compared to 0.2m in bore 7981 located approximately 30m to the west;
- Water levels on the floodplain adjacent Psyche Bend Lagoon were below the maximum inundation height suggesting that watering created a hydraulic gradient that would allow lateral recharge of the floodplain aquifer;
- Groundwater levels across the floodplain declined at the time water was released from the Lagoon. However, this also coincides with a significant drop in the adjacent River due to works at the Mildura Weir and is likely to have contributed to this decline, particularly for bores located close to the River; and
- The groundwater salinity data presented for bores does not show any significant freshening in response to the watering event. This may in part be due to the screened interval of the bores which did not provide monitoring data for the top of the watertable where groundwater freshening is most likely to be observed.

AEM survey data collected in 2008 provides an indication of spatial salinity patterns on the Psyche Bend floodplain (AWE 2008). The shallow AEM depth slice suggests the occurrence of lower salinity groundwater adjacent the River between kilometres 905 and 906 which is consistent with the losing stream signal shown in the 2004 and 2006 NanoTEM surveys. AEM data also suggests lower salinity groundwater at the floodplain-highland interface which may reflect the influence of lower salinity irrigation drainage water. The deeper AEM slice (0 to 20m) indicates uniformly high groundwater salinity beneath the Psyche Bend floodplain.

Data collected as part of the 2014 MCMA annual monitoring round indicates highly saline groundwater with an average of 37,050 mg/L (or 55,000µS/cm - above the tolerance for Black Box trees). As indicated by AEM data, groundwater salinities measured in the Monoman Formation are more variable, ranging between 22,000 and 58,000 µS/cm. Groundwater salinities in the Monoman Formation are lowest adjacent the River and the Woorlong Wetlands. However, no monitoring data is available for the floodplain segment where AEM data suggests the occurrence of a freshwater lens and the NanoTEM survey indicates losing stream conditions.

6.5 Floodplain Geomorphology and Vertical Permeability

Geomorphology data presented in the Sunraysia AEM Atlas suggests that the floodplain located to the west of the Lagoon is the oldest floodplain meander belt (AWE 2008). The majority of the floodplain to the east of the Lagoon is identified as intermediate floodplain meander belt. A thin section of young floodplain sediments is identified directly adjacent the River and this corresponds to the lowest elevation parts of the floodplain (AWE 2008). The unsaturated zone sampling sites located to the east of the Lagoon target the intermediate age floodplain sediments on low lying sections of the floodplain. The one sampling site to the west of the Lagoon targets old floodplain sediments at a higher floodplain elevation.

6.6 River Skin

Instream and land based vibro-coring was undertaken to ground truth AEM and NanoTEM data at Psyche Bend as part of salt interception investigations in the Sunraysia region. As discussed above, the majority of this reach is dominated by losing stream conditions except for a 2 km stretch at Psyche Bend (River km 903 to River km 905). In-stream coring at River km 904 revealed pore water salinity in excess of 30,000 mg/L (~46,000 µS/cm) from the River bed, and to a depth of 10m, which correlates with the NanoTEM signal. Bore logs for this site also indicate that the River is in direct contact with the Monoman Formation at this location. Immediately upstream of this at River km 905.5 low pore water salinity is found from the surface of the River bed to a depth of 7m. At this point the salinity increases with depth up to approximately 10,000 mg/L (~15,400 µS/cm) at 11m. This is consistent with losing stream conditions into the regional saline groundwater. A similar pattern occurs downstream of Psyche Bend at River km 902.7. Bore logs from this sampling location suggest a layer of silt occurs 1 to 2m below the River bed and are underlain by fine to medium sands of the Monoman Formation aquifer (AWE 2009)).

6.7 Groundwater Salinity, Soil Salinity and Vegetation Condition

Monitoring data for the Psyche Bend floodplain is presented in Figure C.7. Vegetation condition to the west of the lagoon appears better (tree health score '3') compared to the eastern section of the floodplain. The eastern section of floodplain is dominated by dead trees with an understorey of Samphire (*Tecticornia* spp. and/or *Sarcocornia* spp.) up to approximately 150m from the edge of the lagoon. At sampling site PB2, Black Box trees in poor condition are dominant (health score '1'). Black Box condition is generally poor on the eastern side of the floodplain with health scores of '1' and '2' recorded at sites PB4 and PB5. Black Box health then improves closer to the River at sampling site PB3 (health score '3').

AEM data correlates well with the broad scale patterns in vegetation health observed on the Psyche Bend floodplain. AEM data for the Psyche Bend floodplain indicates uniformly high groundwater salinity to the east of the Lagoon which is consistent with poor vegetation health observed at the site. Groundwater monitoring data from bores located on the eastern section confirms this with groundwater salinity exceeding 35,000mg/L in monitoring bores on this section of the floodplain. These groundwater salinities are well above the ~23,000mg/L groundwater salinity limit identified by AWE (2012) from data presented in McEwan et al (2003) and are consistent with the poor vegetation health observed on this section of the floodplain.

AEM data indicates lower salinity groundwater to the west of the Lagoon at the floodplain-highland interface. Groundwater monitoring data from bores 7977 and 7979 which are located within this low conductivity zone and screened in the Monoman Formation, indicate groundwater salinities of 1,735 and 5,941mg/L in this area. This is likely to reflect the influence of lower salinity irrigation drainage water. Groundwater salinity for the Monoman Formation adjacent sampling site PB1 is 25,740 mg/L. Lower salinity groundwater measured on the western side of the Lagoon is consistent with the better condition of Black Box trees compared to that on the eastern side.

Soil salinities measured on the Psyche Bend floodplain were consistently high with averages for each site ranging between 28,743mg/L at PB3 up to 81,544mg/L at PB2 on the eastern side of the Lagoon. The range of soil salinities measured at the 4m depth was less, ranging from 31,480mg/L to 40,362 mg/L, with the lowest soil salinity recorded at PB3 and the highest at PB2. Analysis of soil salinity thresholds presented in Section suggests that 75% of healthy Black Box trees in regions assessed by the study were found where soil salinities were less than 39,000mg/L (AWE 2012). The majority of soil salinities recorded at Psyche Bend are above this value which is consistent with the poor condition of Black Box trees at this site.

6.8 Summary

The poor condition of vegetation on the northern section of the Psyche Bend floodplain and the limited response to floodplain management is likely to have been influenced by a number of factors, including:

- Groundwater and soil salinities on the Psyche Bend floodplain exceeded the 75th percentile limits for healthy vegetation identified in this analysis and from AWE 2012, using data presented in McEwan et al. (2003).
- These high salinities occur despite the floodplain having a lower commence to flood threshold than the other sites assessed by this study and that the Lagoon was recently filled to flush salts from the floodplain.
- Soil cores collected during the sampling program suggest the upper profile is dominated by clay adjacent the Lagoon which is thought to be the oldest floodplain meander belt. This may limit the vertical infiltration of floodwaters or rainfall. Increasing sand content was observed where sampling sites are located on the intermediate floodplain terrace.
- The response to the flushing event was limited and although groundwater levels rose adjacent the Lagoon no significant freshening was measured in the groundwater system.
- The salinity of water in the Lagoon increased following flooding.
- Groundwater monitoring data also indicates strong regional gradients towards the (gaining) floodplain and the occurrence of gaining stream conditions adjacent the sampling sites.
- Vertical gradients also suggest upward flux of groundwater from the Parilla Sands to the Monoman Formation.
- These regional gradients towards the floodplain and River, combined with high groundwater and soil salinities, may limit the ability of flooding to produce lasting benefits to floodplain vegetation.
- The starting condition of Black Box trees on the Psyche Bend floodplain is also poor which may also limit the response of trees to floodplain management.

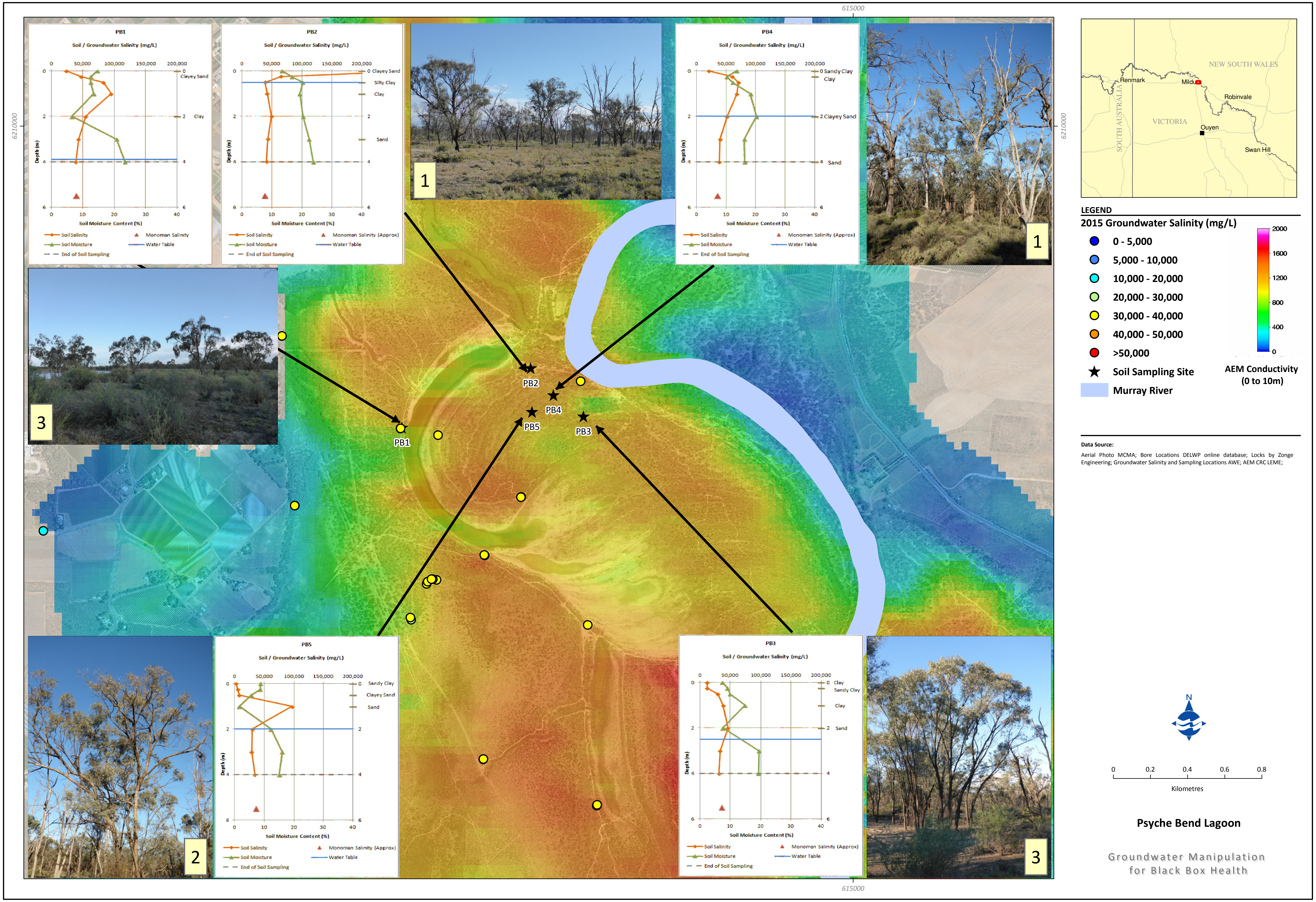

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Figure C.7

Groundwater manipulation may provide an opportunity to improve floodplain vegetation health on the Psyche Bend floodplain. Groundwater pumping may:

- Reduce the regional groundwater gradients towards the floodplain;
- Reduce salt accumulation on the floodplain and move excess salt form the aquifer in the long term;
- Increase the extent of lateral recharge from the lagoon if low salinity water is available in the Lagoon;
- Aid the management of water salinity in the Lagoon itself by reducing saline groundwater inputs (depending on the location); and
- Extend the extent of freshwater lenses adjacent the main River channel, particularly where losing stream conditions already occur.

7 Hattah – Lake Bitterang

The Hattah Lake Icon site is a wetland-floodplain complex that consists of 17 perennial and intermittent lakes and is defined by the boundary of the 100 year flood level (MCMA 2014a). Chalka Creek provides the main connection between the lakes and the River Murray with a series of floodplain channels connecting the lakes. The retention level for most of the lakes is 42.5mAHD and when this is exceeded, flood waters begin to inundate the surrounding floodplain. River Red Gum forest and woodland communities occupy areas of the floodplain up to an elevation of 43.5mAHD and Black Box communities occupy the floodplain at elevations up to 45mAHD.

Significant works have been undertaken at Hattah Lakes to install permanent pumps which can deliver up to 1,000ML/d of water to the system. Retention structures have also been constructed to hold water on the floodplain to an elevation of 45mAHD. These new structures can control flow through the lakes and connecting channels on the floodplain (Moxham et al 2014).

River regulation and water use has influenced the flooding frequency of the Hattah floodplain. Modelling suggests that under natural conditions the lakes in the Hattah complex would have flooded 6 times in the period between 1998 and 2007 however this only occurred once when flow in the River Murray exceeded 36,700 ML/d (McCarthy et al 2008). As a result of reduced flooding frequency, the pumping of environmental water onto the floodplain has become a necessary form of management intervention. Environmental watering was first employed at Hattah in April 2005 as an emergency measure to maintain River Red Gum communities. However, this did not include Lakes Bitterang, Yelwell or Kondardin around which soil samples are being collected as part of this study.

The reduction in flooding frequency, magnitude and duration of high flows has significantly affected the flow regime of the wetland system and the condition of floodplain vegetation.

7.1 Regional Setting

The Hattah Lakes complex is located on a wide through-flow floodplain where regional groundwater flow is from east to west. It is also located adjacent a losing stream reach of River, however the section of floodplain which is the focus of this study is located at significant distance from the River and not influenced by this interaction.

7.2 Current Vegetation Condition

The Groundwater Dependent Ecosystem (GDE) Atlas developed by the CSIRO and SKM (2012) classifies the floodplain surrounding Lake Bitterang has a high potential for vegetation groundwater interaction.

Vegetation condition monitoring has been occurring for a number of years on the Hattah Lakes floodplain as part of The Living Murray program. Black Box trees were first included in condition monitoring at Hattah in 2008 with health surveys undertaken at 9 sites for both ecological vegetation classes across the floodplain. At Hattah Lakes Black Box trees occur within two ecological vegetation classes namely; Riverine Chenopod Woodland and Black Box Swampy Woodland (McCarthy et al 2008). Condition monitoring at Hattah in 2008 (6 transects totalling 1.5 ha) concluded that 95% of the Black Box trees surveyed were in a poor condition, however no Black Box trees were recorded as dead within the transects surveyed. The poor condition of Black Box trees was largely attributed to the ongoing drought conditions and long period since overbank flooding had occurred. Analysis of foliage vigour data collected in 2009 indicated an increase (improvement) in tree condition at each of the 18 sites. However, use of photopoints suggested that there was little change and that the increase in vigour may be attributed to the variability between different assessors (Kattel et al 2009). Condition monitoring undertaken in 2010-2011 concluded that there was a marked increase in good condition

Black Box on the Hattah floodplain as a whole and a corresponding decrease in trees in the poor category. Additionally, dead trees were present in small number from 2009-2010 and increased slightly in 2010-2011 (Henderson 2011). An example of photopoint data collected as part of condition monitoring at Hattah is shown in Figure C.8. These photos were taken at Site 5, located between Lake Bitterang and Lake Mournpall, and soil samples will be collected at this site.

Plate 3.5 BB Condition Site 5 (M. Tucker, April 2008).

Plate 3.6 BB Condition Site 5 (M. Tucker, March 2009).

Plate 3.7 BB Condition Site 5 (D. Wood, April 2010).

Plate 3.8 BB Condition Site 5 (D. Wood, January 2011).

FIGURE C.8: PHOTOPOINTS FOR BLACK BOX MONITORING BETWEEN LAKE BITTERANG AND LAKE MOURNPALL (WALTERS ET AL. 2011)

7.3 History of Watering and Vegetation Reponses

Black Box communities on the Hattah floodplain vary in condition with the majority of sites categorised as having poor to average health (Moxham et al. 2014). Environmental watering has been used to fill specific lakes at Hattah and natural flooding inundated a small area of floodplain around Hattah Lake in 2011. The remainder of the floodplain, including that surrounding Lake Bitterang, had not experienced any flooding since 1993 (MCMA 2014b). Monitoring of environmental watering events has shown improvements in the condition of Black Box trees, however the regeneration response has not been as vigorous when compared to River Red Gum trees (Moxham et al. 2014). A large environmental watering event occurred in late 2014 to inundate the higher elevation sections of the Hattah floodplain (up to 45mAHD) (including Lake Bitterang).

A monitoring project is currently underway to investigate the influence of environmental watering on aerial seed bank production by floodplain Black Box trees (Moxham et al. 2014). This study aims to compare Black Box condition and seed fall at a watered and unwatered site adjacent Lake Bitterang. The results from this study are not yet available but the sites selected for unsaturated zone sampling coincide with the seed fall and vegetation monitoring site.

7.4 Groundwater Salinity, Soil Salinity and Vegetation Condition

Monitoring data collected for the Hattah Lakes floodplain is presented in Figure C.9. Broad scale vegetation monitoring at the soil sampling sites suggests that Black Box trees are generally in poor condition with tree health scores of 1 to 2 recorded for most sites. Black Box condition was very poor adjacent sampling site B5. Black Box condition was best in a small depression close to site B4 which appeared to have been recently inundated. At this location both mature Black Box trees and seedlings were observed to be in good condition (photo shown in Figure C.9).

Groundwater salinity data is limited adjacent the soil sampling sites at Hattah and there is no AEM data available to infer spatial trends in groundwater salinity. Groundwater salinity, soil salinity and vegetation health is only directly comparable adjacent site B4. Groundwater salinity measured at this location was 21,321mg/L. This is close to the 23,000mg/L groundwater salinity identified from McEwan et al. (2003), above which 75% of unhealthy Black Box trees were found.

Soil salinities measured on the Hattah Lakes floodplain tended to be lower than those recorded at the four other floodplain sites. This is consistent with the site being a throughflow floodplain with regional groundwater flow from east to west. Depth to groundwater is also greater at this site compared to the other floodplains investigated by this study. The lowest average soil salinity of 9,749mg/L was recorded at site B1, with the highest average soil salinity of 34,980mg/L recorded at site B5. Soil salinities measured at a depth of 4m were higher, ranging between 9,173 mg/L at site B6 up to 42,582mg/L at site B3.

A large environmental watering event occurred on the Hattah Lakes floodplain in late 2014 and aimed to inundate parts of the floodplain below an elevation of 45mAHD. This suggests that sites B2, B3 and B5 would have been inundated during the watering event and that sites B1, B4 and B6 would not have been inundated. There is no clear distinction between the soil salinities measured at sites that were inundated compared to sites that were not. In fact average salinities and soil salinity at 4m tended to be higher at the sites that were likely to be inundated. This does not necessarily indicate that inundation has not impacted soil salinity as measurements were only taken following inundation and sampling was limited to 4m where the water table is at approximately 9m.

7.5 Summary

The groundwater monitoring network on the Hattah floodplain is sparse in the focus area, making it difficult to correlate groundwater salinity trends with changes in vegetation condition. Groundwater salinity measured adjacent sampling site B4 is at the upper range of salinity values that are expected to be associated with healthy Black Box trees, based on the results of this study and from data presented in McEwan et al. (2003).

Soil salinities measured on the Hattah floodplain tended to be lower than those measured at the other floodplain sites, particularly near the surface. However, soil salinities measured at a depth of 4m were at or just above the thresholds identified in Chapter 2. Commence to flow data for Hattah suggests that the sections of floodplain that were the target of sampling have a significantly high flood threshold (i.e. flows required to inundate the sampling sites exceed the maximum flood height assessed by the FIM model). Given the greater depth to groundwater and generally lower groundwater and soil salinities observed at this site it is hypothesised that a lack of available low salinity water (e.g. reduced flooding frequency) is a major factor contributing to the decline in Black Box condition at this site.

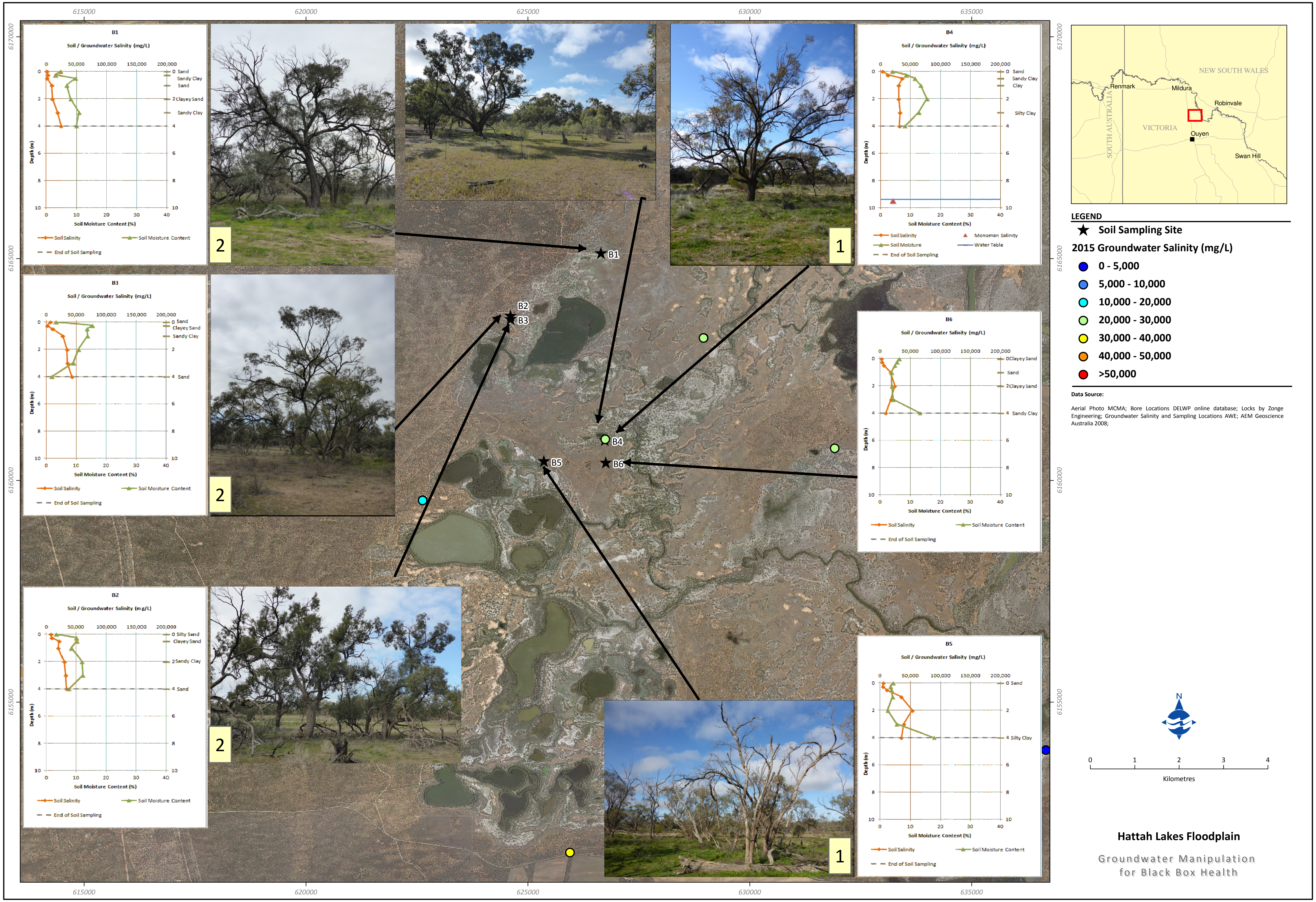

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Figure C.9