SUSTAINING IRRIGATION AND SOIL CONDITION UNDER CHANGING CLIMATE AND LAND USE IN THE LOWER MURRAY RECLAIMED IRRIGATION AREA (LMRIA)

THE SOUTH AUSTRALIAN RIVER MURRAY SUSTAINABILITY PROGRAM IS FUNDED BY THE AUSTRALIAN GOVERNMENT AND DELIVERED BY THE GOVERNMENT OF SOUTH AUSTRALIA

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EXECUTIVE SUMMARY

The University of Adelaide has conducted a South Australian River Murray South Australian River Murray Sustainability (SARMS) Industry-led Research project titled "*Sustaining irrigation and soil condition under changing climate and land use in Lower Murray irrigation areas*".

The LMRIA is located on the historic floodplain of the lower River Murray in South Australia. This area is commonly known as the "Lower Murray Swamps", reflecting its nature before it was reclaimed for agriculture in the early 1900s. Historically the land use in the area has predominantly been pasture for dairy production. The severe "millennium" drought from 2007-2010 had severe impacts on infrastructure, environment (soils, waters) and the farming community. The predominant land use in the region is still dairy production although this has declined markedly from pre-drought levels with a switch to more beef production and retired areas.

The aim of this study was to develop strategies to improve irrigation efficiencies, reduce drainage volumes and water quality impacts, maintain groundwater levels and soil moisture, and remediate salinised land under changing climate and land-use patterns in the LMRIA. A combination of field trials, soil-water modelling, assessment of irrigation data, and review of previous studies were used to achieve this aim.

Key findings of the project include:

- Pre-drought and following a major rehabilitation program from 2004-2008, irrigation efficiencies of 0.7–1.0 ML/ha/watering were achieved in the LMRIA on laser levelled bays with good channel infrastructure. Post-drought, due to the soil cracking and slumping, irrigation efficiencies declined to greater than 3 ML/ha in many areas. Recent irrigation efficiency data suggest that pre-drought irrigation efficiencies are now being achieved (≤1 ML/ha) following On-Farm Irrigation Efficiency Program (OFEIP) upgrades coordinated by the SAMDB NRM Board. At Long Flat the OFEIP upgraded irrigation bays watered at about twice the efficiency of non-laser levelled bays. Similarly at Mobilong, laser levelling greatly improved irrigation efficiency and reduced watering times. Coordinating irrigations across adjacent bays within a few days can produce additional gains by building on the effects of lateral losses of water.
- Soil-water process modelling (HYDRUS 1D and 2D) proved successful at representing the complex interactions between river level, groundwater level and irrigation. HYDRUS modelling, based on measured soil properties, indicates 3-7 irrigations per year, could be sufficient to keep land from salinizing and soil from cracking. This compares well to the number of Environmental Land Management Allocation (ELMA) irrigations achievable on improved (OFEIP upgraded) infrastructure (e.g. about 0.7-1 ML/ha or less efficiency can be achieved which would enable up to about 5-7 ELMA irrigations per annum). More irrigations are needed to sustain full commercial production.
- Land that is currently salinized and sodic in back swamp areas can be remediated. Our research trial showed that with 4 irrigations and active drainage the soil salinity was reduced to about a third of its initial value with sodicity also reduced. In contrast, in the soil that was not irrigated, salinity increased over the 2 month trial period.
- Modelling suggests minimum amounts (≥ 3 per year) of irrigation and river level stabilization (>0 m AHD) could have greatly lessened the severity of soil cracking and acidification during the Millenium Drought.
- Alternative irrigation strategies are possible during drought using a travelling irrigator. These techniques could also be useful for irrigating ELMA only or back swamp areas where water is difficult to apply via flood irrigation.
- Climate change is predicted to significantly increase (approximately 15% more) the number of irrigations required by 2030 or 2050 and drought frequency is likely to increase.
- The outcomes of the project enable development of strategies to improve irrigation efficiencies and techniques, reduce drainage volumes and water quality impacts, maintain groundwater levels and soil moisture during drought, and remediate salinised land under changing climate and land-use patterns.

Key messages arising from the research include:

- The top soils (0-70 cm) in the LMRIA are some of the best agricultural soils in Australia (high organic matter and nutrient content, low bulk density, and high hydraulic conductivity enabling good irrigation and drainage).
- The sub-soils (>70 cm) in the LMRIA are some of the "nastiest" in Australia as they contain acid sulfate soil materials that can severely acidify if exposed during drought.
- Regular irrigation and drainage is needed in the LMRIA to maintain soil condition and prevent impacts from rising saline regional groundwater inputs.
- The LMRIA sub-soils have not yet recovered from the 2007 to 2010 extreme "Millenium" drought period with acid drainage persisting into 2017.
- Irrigation efficiency has been restored post-drought in about 50% of the LMRIA with the infrastructure upgrade programs.
- Limited (≥ 3 per year) irrigation and river level stabilization (>0 m AHD) during the extreme 2007-2010 "Millennium" drought period could have greatly lessened the severity of soil cracking and acidification.
- It is important to retain ELMA and ensure its use in the LMRIA, particularly during drought conditions and on non-commercially irrigated properties.
- Irrigation and drainage can restore salinized and sodic soils.
- Alternative irrigation strategies are possible during drought to protect soils and infrastructure and should be supported by the government.
- It is critical the Murray-Darling Basin Plan is successfully implemented to provide water security to the LMRIA to enable the region to be sustained into the future.

Research translation activities in the project included:

- Production of a comprehensive manual to assist farmers and environmental managers to better manage the area in the future
- Field days and meetings with farmers
- Meetings with key stakeholders, managers and politicians to highlight the importance of the region and impacts that have occurred
- Attendance at scientific conferences to present the outcomes of the research
- Publication of the findings in peer-reviewed international journals

Recommended policy and operational responses for future protection of the LMRIA are:

Murray-Darling Basin - The sustainability of the LMRIA is directly dependent on the water level in (and flows to) the Lower River Murray (below Lock 1) in South Australia. It is considered critical that the Basin Plan is fully implemented to deliver improved water security to the LMRIA region during drought. By doing so, severe impacts on the soils and irrigation infrastructure could be minimized.

South Australia - There are policy and operational management revisions required surrounding the use of ELMA to protect the LMRIA in future droughts. The recent discussion paper "Environmental Land Management Allocations (ELMA) and the Water Allocation Plan for the River Murray Prescribed Watercourse" (Appendix 2) outlines these. In relation to maintaining soil condition to prevent severe cracking and acidification it is considered critical that ELMA is retained and applied at its highest level during drought conditions. The application of ELMA should be mandatory under these conditions and support given to irrigators where required (e.g. fuel subsidies, access to portable pumps and travelling irrigators) under extreme drought conditions. During drought, older deeper-rooting pasture types and Lucerne proved useful for some irrigators. Restricting salt drain pumping operations, to keep saline water table high which minimized deep soil cracking (although likely increased top soil salinity), was also used successfully by some irrigators.

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1 REVIEW AND COLLATE EXISTING INFORMATION

1.1 BACKGROUND

Activity 1 – *Existing information on the condition of soil, water, vegetation and irrigation practices in the LMRIA was collated and reviewed. The review includes historical studies in the LMRIA dating back to the early 1900s and also results of the more recent post-drought studies.*

1.2 LMRIA AREA OVERVIEW

This section gives a brief background to the LMRIA region, further specific details are provided in subsequent chapters. There is approximately 5,200 ha of land, comprising over 20 separate areas, on the former floodplain of the lower River Murray in South Australia. This area is now known collectively as the Lower Murray Reclaimed Irrigation Area (LMRIA) or the "Lower Murray Swamps". The predominant land use in the region is still dairy production although this has declined markedly from historical levels with a switch to more beef production and retired areas. The severe "millennium" drought from 2007-2010 had severe impacts on infrastructure, environment (soils, waters) and the farming community.

There is approximately 5,200 ha of land, comprising over 20 separate areas, on the former floodplain of the lower River Murray in South Australia (Figure 1-1). This area is now known collectively as the Lower Murray Reclaimed Irrigation Area (LMRIA) or the "Lower Murray Swamps". Historically, this floodplain region contained patches of reed growth and standing water that changed according to river levels and local climatic conditions. The swamp areas began to be reclaimed in the late 1800s and between 1900-1930 development intensified with the construction of levee banks near the river edge, pumping out of standing water, and development of a drainage system to maintain the water-table at a sufficiently low level to grow pasture (Taylor and Poole, 1931).

Since completion of barrages to prevent seawater ingress at the mouth of the river in 1940, the reclaimed areas have been 1.0–1.5 m below the river level, enabling gravity fed flood irrigation consistently from the River Murray. Dairy farming has been the predominant land use with smaller areas used for beef cattle, fodder production, horticulture and lifestyle farming. To enable sufficient soil quality for agricultural production, the rising saline water tables in the LMRIA are maintained below the pasture root zone via a drainage network and pumps. Large volumes of drainage water containing pollutants such as nutrients and pathogens have historically been returned to the river that has impacted water quality (Murray and Philcox, 1995; Mosley and Fleming, 2010). A major LMRIA rehabilitation project was undertaken by the irrigators and State and Federal governments from 2003–2007 to improve irrigation efficiency and reduce drainage volumes returned to the river.

The LMRIA has faced severe challenges over the past 7 years (2008-2015) from the effects of the severe "millennium" drought. River and groundwater levels fell to their lowest in over 100 years between 2007 and 2010 (Mosley et al., 2014a). Coupled with restricted irrigation water allocations, there was very little irrigation water applied. This led to severe soil cracking to depths up to 4m, salinisation and acidification (Fitzpatrick et al., 2009; 2017c; Mosley et al., 2014) and severe socio-economic impacts. The result of this was that many irrigators ceased or down-scaled their operations in the LMRIA, with a pronounced loss of dairy farming activities (Philcox and Scown, 2012). Five years after the drought ended (in terms of river levels), the LMRIA soils, waters and irrigation infrastructure is still impacted. There is an increased risk of negative drought effects becoming more prevalent in the future given climate change projections for this region.

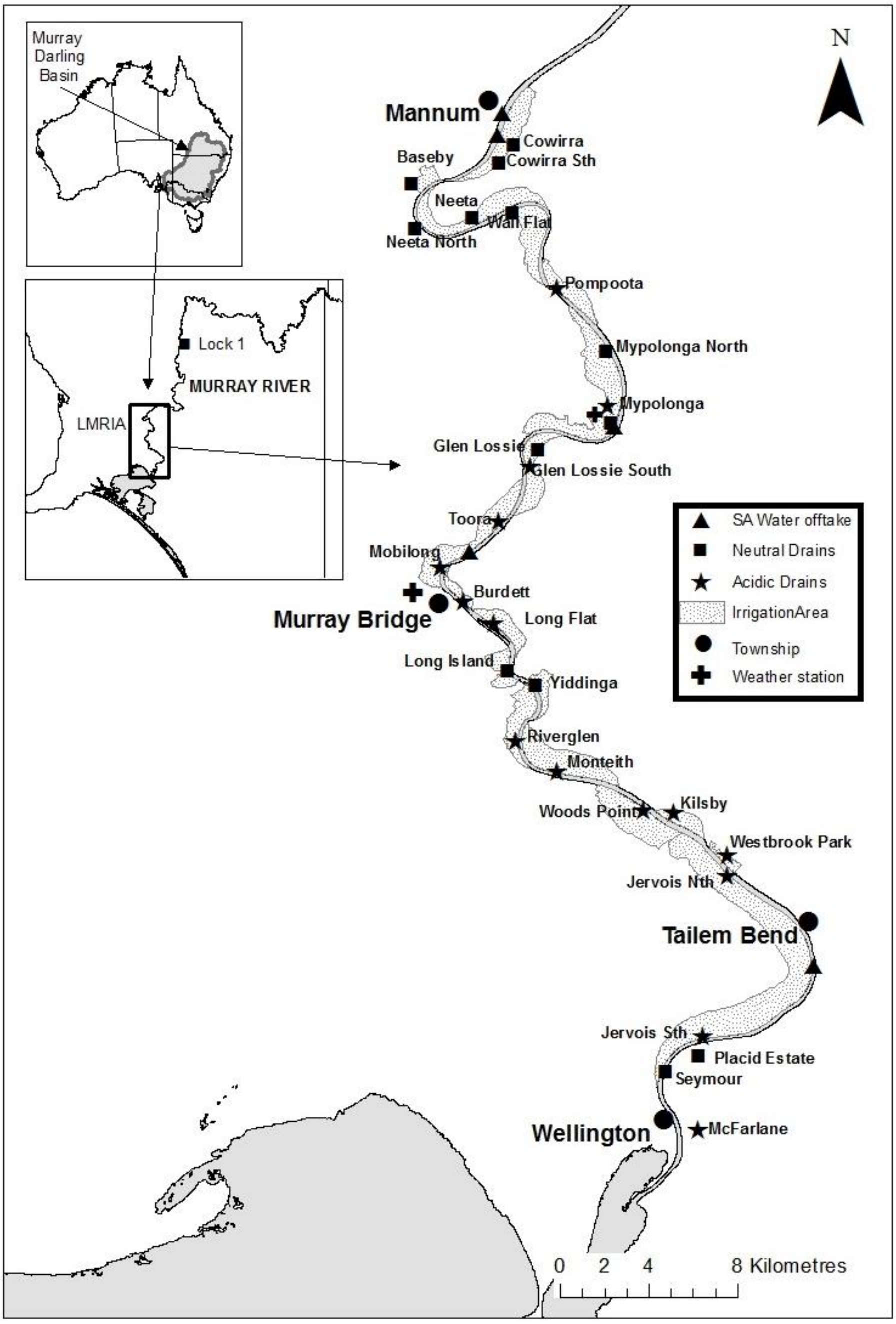


Figure 1-1 Locality map showing the general LMRIA location in the Lower River Murray region of South Australia. The individual irrigation areas/swamps comprising the LMRIA are shown (and as listed in Table 1.1)

1.2.1 LMRIA individual areas and land use

The main areas/swamps comprising the LMRIA region are shown on Figure 1-1 and listed in Table 1-1, along with their area. Historically the land in the LMRIA was almost exclusively utilised for dairy production. In 1990, the LMRIA was estimated to provide about 40% of Adelaide's fresh milk supply (Philcox and Douglas, 1990). From 2003–2008 approximately 4,200 ha of land was rehabilitated under the LMRIA rehabilitation project with approximately 1,000 ha of land retired from farming and not rehabilitated (EPA, 2009). This includes the SA Water owned land at Mobilong and Toora. Post-drought (from 2011), the total area of 'productive' farms remaining in the LMRIA was estimated to be 3,192 ha (Philcox and Scown, 2012). Dairy production has reduced from approximately 5,000 ha historically to 1,866 ha, a reduction of approximately 63%. There has been a decided switch to beef production during and post- the drought, with this landuse covering an estimated 735 ha of the LMRIA (Philcox and Scown, 2012).

Table 1-1 List of key irrigation areas/"swamps" in the LMRIA with their area. Some additional smaller retired areas exist that contribute to the total LMRIA area (5200 ha).

Irrigation area/swamp	Area (ha)
Cowirra	259
Baseby	67
Neeta	303
Wall Flat	243
Pompoota	160
Mypolonga	557
Glen Lossie	150
Toora	143
Mobilong	207
Burdett	42
Long Flat	129
Long Island	72
Yiddinga	65
River Glen	163
Westbrook Park	40
Kilsby	42
Monteith	386
Woods Pt	262
Jervois	1490
McFarlanes	113
Total	**4893**

1.3 SOILS AND GEOLOGY

This section outlines the regional geology and soils within the LMRIA. The LMRIA soils are heavy clays of an alluvial origin with a more loamy organic-rich upper (0-50 cm) layer. The surface soils are in general very fertile with high levels of nutrients and organic matter. On average most of the soils are classed as “moderately saline” although higher salinities and development of soil sodicity has been observed at some poorly drained and irrigated areas.

During reclamation of the LMRIA in the early 1900s, highly acidic (pH<4) soils were observed. The surface soil pH has in general improved over time to be typically in the range of pH 6–7. However falling river and groundwater levels, and lack of irrigation, in the millennium drought from 2007–2010 resulted in oxidation of acid sulfate soils 1–4 m below ground level. These soils are still acidic and the low pH and availability of organic matter is preventing sulfate reduction (natural microbially-driven remediation process that generates alkalinity during pyrite reformation).

1.3.1 Regional geology and topography

The contemporary Murray River valley was incised during a period of low sea level at approximately 600 000 years BP when coastal barriers of Pliocene and Early Pleistocene age were breached, allowing drainage of the ancient Lake Bungunnia (Bone 2009). The Murray River valley has subsequently been infilled with fluvial sediments. According to Bone (2009), the valley fill can be divided into the following two sequences: (i) Late Pleistocene upper terrace deposits of the Mannum Formation comprising limestone fine grained calcarenite and (ii) heavy clays (Figure 1-2).

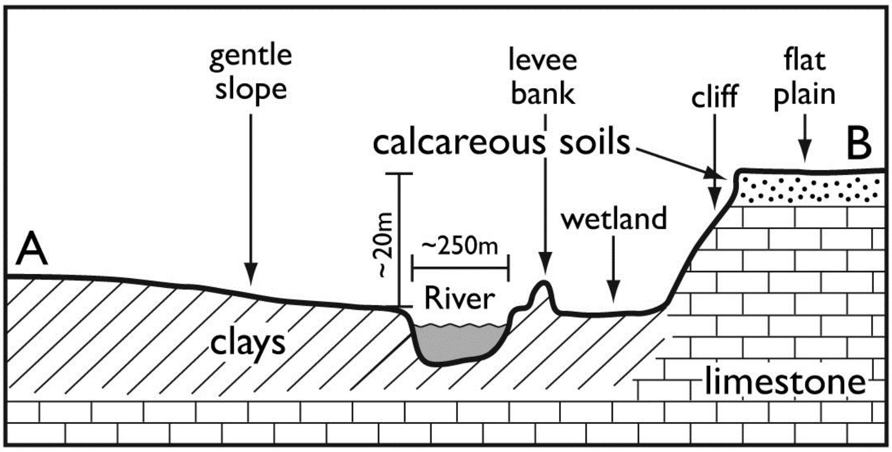
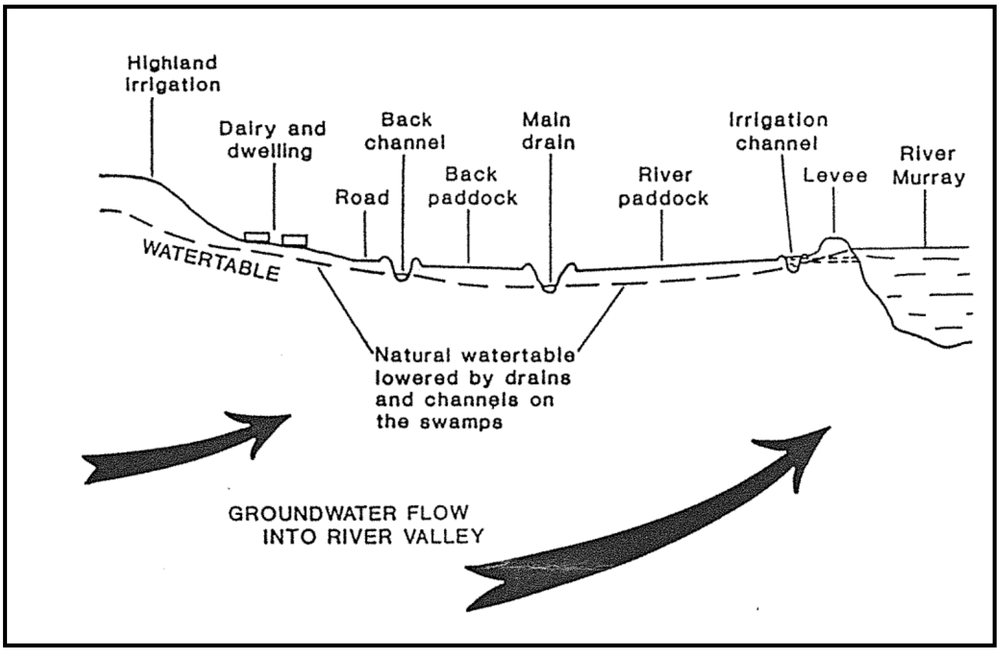


Figure 1-2: Stratigraphical section of the Lower Murray-Darling Basin in the LMRIA showing distribution of heavy clays, wetlands and limestone cliffs (modified from Bone, 2009)

The LMRIA geological formation consists of layers of clays, silt, sands and limestone, up to 150 m thick overlying a basement rock (Barnett, 2003). The upper sediments of the Plain Zone in which the LMRIA is located were deposited during a period of rapid sea level rise which followed an ice age 20,000 years ago. In the upper (15-40 m) LMRIA formation, the finer mostly alluvial clays, silts and sands of the younger Coonambidgal Formation (10–20 m thick) are underlaid by the medium to coarse grain sands of the Monoman Formation (5–20 m thick).The Coonamnidgal formation is where the reclaimed and modified LMRIA agricultural soils are located as discussed further below.

The typical present topography of the Irrigation Areas is characterized by a constructed levee bank on the river’s edge, a gradual slope extending from the levee bank to a large drainage channel (termed the “salt drain”, as it intercepts the regional saline water table), and rising again towards the highland region (Figure 1-3). Some irrigation areas have a back swamp and channel area. Lateral/side drains run alongside each irrigation bay and divert drainage water to the salt drain. The bottom of the salt drain is the lowest topographic and hydrologic point in the local and entire regional South Australian Murray-Darling Basin catchment. This creates a rising pressure for the saline groundwater (Barnett et al. 2003, see Figure 1-2). More groundwater would historically (pre-1900s) have discharged to the river before the construction of the levee banks and drainage infrastructure, and permanent raising of the river level below Lock 1. A portion of the deeper regional groundwater still does enter the river. The River also loses water to the swamp/floodplain (Figure 1-3).



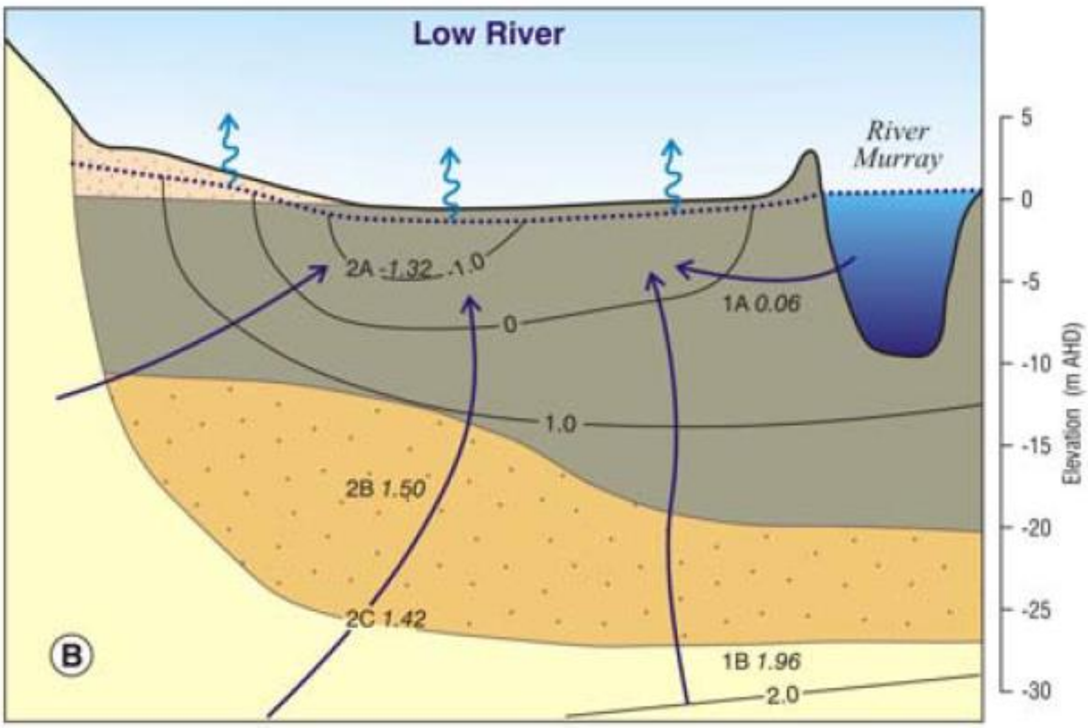


Figure 1-3 Longitudinal cross section of a typical LMRIA topography and hydrology (top) (from Philcox and Murray, 1990) and (bottom) from Barnett et al. 2003.

1.3.2 General soil description and classification

Taylor and Poole (1931) first described the LMRIA soils as predominantly "Type 2" (heavy clay soils) with a layer of heavy black clay (50-70 % clay) overlying a brown heavy clay, which in turn rests on an indefinitely deep uniform layer of grey clay. It was suggested by Taylor and Poole that this LMRIA soil type be named "Mobilong clay". This classification persisted until at least the

1950s (Russell and Harvey, 1959). Fitzpatrick et al. (2017c) classified the soils in accordance with Soil Taxonomy (Soil Survey Staff 2014) as mostly Vertisols (Typic Sulfaquert or Sulfic Sulfaquert) because "they have within 100 cm of the surface a layer 25 cm thick with slickensides and wedge-shaped soil aggregates that have their long axis tilted 20 to 40 degrees from horizontal; >30% clay to 50 cm and cracks that open and close periodically". The major clay mineral in the soils is smectite. The upper 0–50 cm layer of the LMRIA soils is loamy with high organic matter (5-15% total carbon) content (Fitzpatrick et al, 2017c). Further acid sulfate soil classifications are discussed below. The general soil type is relatively uniform across the various irrigation areas although various localised differences exist (Taylor and Poole, 1931; Fitzpatrick et al., 2008a,b,c; 2017c; Philcox and Scown, 2012). The soil chemical characteristics are discussed in more detail below.

1.3.3 Salinity and sodicity

The surface soils of the LMRIA following reclamation in the early 1900s were quite saline (Taylor and Poole, 1931). The current soils of the LMRIA have a range of salinities, typically from 1.2–2.86 dS/m (Table 2-1) and hence can be classed as "moderately saline soils" (Tables 1-2 and 1-3). These soils comprise "flocculated clays" (i.e. fluffy or loosely aggregated clay particles) and surface layers with salt efflorescences.

Taylor and Poole (1931) found that in all cases where the accumulation of salt in the soil had become serious, a high water-table was present. This is still the case today as a consequence of poor drainage and/or high groundwater inputs. The rising groundwater in the LMRIA is very saline (10 to 30 dS/m) and hence, without sufficient irrigation/rainfall and drainage, can result in a rapid increase in the salt content of the surface soil. To prevent salt impacts on soil and pasture, drainage systems in the LMRIA must function effectively to keep the water table and enable salt leaching below the root zone (i.e. maintained at least 0.5–1.0 m below ground level).

Droughts, due to the lack of irrigation and rainfall flushing of salts from the upper soil profile, can also increase salinity. The recent drought results in some high soil salinities in comparison to typical levels in the LMRIA (Philcox and Scown, 2012). Post-drought, salinity has reduced significantly throughout the soil profile in the LMRIA, likely due to increased irrigation and improved drainage (Philcox and Scown, 2012).

Soils with a high proportion of sodium (Na) compared to other cations (Ca, Mg) on the soil exchange complex and solution are termed "sodic". Sodic soils are characterized by low permeability and thus restricted water flow because the clay and organic fractions of these soils are dispersed. Saline soils can transform to "sodic soils" over time due to leaching with river or rain water (i.e. low levels of salinity). Applying calcium-based amendments such as gypsum (highly soluble salt) and lime can be beneficial to reduce sodicity. However, this option is seldom economically viable in the LMRIA due to the large amounts required (over 10X the amount usually needed on other soil types due to the high cation exchange capacity of the soil)[1]. Poor plant growth and germination is common on both saline and sodic soils.

An exchangeable sodium percentage (ESP) of >15 is commonly used to ascribe sodicity and many of the LMRIA soils fit into this category (ESP 5-50, Fitzpatrick et al, 2017c). However across the LMRIA there has been corresponding reduction in exchangeable sodium in the soils post drought due to irrigation and drainage (Philcox and Scown, 2012).

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[1] See http://www.dairysa.com.au/f.ashx/ProjectPublications/DairySA-factsheet-gypsum-for-the-lower-murray.pdf

Table 1-2: Summary of published soil quality data for the LMRIA.

Study	Location	EC (ds/m)	C (%)	N (%)	P (%)	pH
Taylor & Poole, 1931[1]	Multiple	nd[2]	2.1–16.8	0.3 –1.4	nd	3.9–6.7
Russell & Harvey, 1959[1]	Multiple	nd	nd	0.3 –1	nd	4.4–6.9
Philcox & Douglas, 1990	Multiple	2.4[3]	nd	nd	0.15	nd
Philcox, 2005	1995 2005	2.0 0.77	3.9 6.4	nd[4]	0.07 0.17	6.7 6.9
CSIRO, 2008	Mobilong, Toora	nd	nd	- nd	nd	5.2 – 7.1
Fitzpatrick et al, 2008a,b,c	Multiple			- nd	- nd	2.2–8.8
Fitzpatrick et al, 2017b,c	Long Flat, Toora, Jervois	0.08–2.86	1.2–11.1	0.1–1.1	nd	4.0–8.6
Philcox & Scown, 2012[5]	Multiple	1–2	4.0	nd[4]	0.08	6.7
Grealish et al. 2011; 2014;	Multiple			- nd	- nd	2.5–8.9

[1] Values are taken from Russell and Harvey, 1959 who reanalysed many Taylor and Poole (1931) samples using more modern analytical methods. However, their reanalysed results are very comparable to the original results of Taylor and Poole (1931). The use of different methods in 1931 compared to 1959 suggests that the apparent increase in pH over time may be an artifact of the different analysis methods.

[2]Taylor and Poole measured Total Soluble Salts and Cl via an electrical conductivity method but direct conversion of these results back to EC was not possible.

[3] Philcox and Murray 1:5 EC, average of 0-40cm layer

[4] Ammonia and nitrate-N were determined but not total N

[5] Average values are displayed for surface (0-100 cm) layers

Nd = Not determined/measured.

Table 1-3: Salinity hazard for soils as defined by the electrical conductance of a saturation extract (ECse) and 1:5 soil:water extract (i.e. soil is extracted with distilled water)[1]

Salinity hazard	**EC_{se} dS/m**	**Effects on plant yield**	**1:5 Soil/Water Extract (dS/m)**				
			Loamy sand	**Loam**	**Sandy clay loam**	**Light clay**	**Heavy clay**
Non-saline	**<2**	Negligible effect	<0.15	<0.17	<0.25	<0.30	<0.4
Slightly saline	**2-4**	Very sensitive plants effected	0.16-0.30	0.18-0.35	0.26-0.45	0.31-0.60	0.41-0.80
Moderately saline	**4-8**	Many plants effected	0.31-0.60	0.36-0.75	0.46-0.90	0.61-1.15	0.81-1.60
Very saline	**8-16**	Salt tolerant plants uneffected	0.61-1.20	0.76-1.45	0.91-1.75	1.16-2.30	1.60-3.20
Highly saline	**>16**	Salt tolerant plants effected	>1.20	>1.45	>1.75	>2.30	>3.20

[1]EC 1:5 - the electrical conductance of a 1:5 soil:water extract (i.e. soil is extracted with distilled water), normally expressed in units of Siemens (S) or deciSiemens (dS) per meter at 25°C. While the EC1:5 method is quick and simple it does not take into account the effects of soil texture. It is therefore inappropriate to compare the EC1:5 readings from two soil types with different textures. It is possible to approximately relate the conductivity of a 1:5 soil-water extract (EC1:5) to that of the saturation extract (ECse) and predict likely effects on plant growth. The above criteria are used for assessing soil salinity hazard and yield reductions for plants of varying salt tolerance, ECse is saturated paste electrical conductivity (after Richards, 1954) and EC1:5 is the corresponding calculated electrical conductivity of a 1:5 soil:water extract for various soil textures.

1.3.4 Nutrients and organic matter

The surface soils of the LMRIA following reclamation in the early 1900s were high in nitrogen and organic matter (Taylor and Poole, 1931). These characteristics are largely present today (Table 1-2). Decades of irrigation, drainage and agricultural amendment (fertilisation, dairy farming) have improved the suitability of the LMRIA soils over time for agriculture (Taylor and Poole, 1931; Russell and Harvey 1959) and in general they now possess high fertility (Philcox and Douglas, 1990). Total Nitrogen and Carbon are particularly high in the surface soil (0-50 cm) layer (Fitzpatrick et al., 2013), reflecting the agricultural inputs.

Post-drought, Philcox and Scown (2012) found soil nutrients (phosphorous, potassium, nitrogen and sulphur) have remained unchanged with a marginal reducing trend in nitrogen, potassium and sulphur, the more mobile/soluble nutrients. This may be due to increased irrigation and improved drainage and drainage management in the area following the end of the drought. Organic carbon has shown a beneficial increase, although variable, throughout the soil profile.

1.3.5 pH AND ACID SULFATE SOILS

Many of the surface soils in the LMRIA following reclamation in the early 1900s were very acidic (as low as pH 3.9, Table 1-2, Taylor and Poole, 1931). This may be due to sulfide oxidation during reclamation/drainage as discussed below. By 1958, the majority of these soils had increased somewhat in pH but many were still pH 4 to 5 (Russel and Harvey, 1959).

During the drought (2008-2010) several workers (Fitzpatrick et al. (2008 a,b,c; 2009; Grealish et al 2011; 2014) identified the occurrence of strongly saline and acidic (pH <4) acid sulfate soils (ASS) with sulfuric materials in the LMRIA.

Post-drought, Philcox and Scown (2012) found pH has remained largely unchanged throughout the upper (100 cm) soil profile and is more typically in the range of 6 to 7 in surface layers (Table 2-1). However, Fitzpatrick et al. (2017c) identified the occurrence of strongly saline and acidic (pH <4) acid sulfate soils (ASS) with sulfuric materials up to depths exceeding 4 metres at several sites sampled post-drought (2011-2012) in the LMRIA.

Acid sulfate soils are those soils in which sulfuric acid may be produced, is being produced, or has been produced in amounts that have a lasting effect on main soil characteristics (Pons 1973). Acid sulfate soils form naturally in wetland environments when sulfate in the water is converted by bacteria to sulfide minerals, predominantly iron pyrite (FeS_2). Exposure of the soils to air (via drainage or other disturbance) results in the oxidation of pyrite and generation of sulfuric acid. If insufficient neutralising materials (typically carbonates) are present, the soil may develop a pH of 4 or less. The low soil pH results in the release of metals and metalloids due to dissolution of soil surface layers and minerals. The acid together with toxic elements can be leached from the soils in drainage or runoff can kill aquatic organisms and plants, contaminate waterways, and corrode concrete and steel (Dent, 1986; Fitzpatrick et al., 2009).

The development of subsoil (1-4 m below ground level) horizons with sulfuric material in the LMRIA is a direct consequence of falling water tables during the drought and deep soil cracking, which resulted in the oxidation of hypersulfidic material (pyrite-rich) (Fitzpatrick et al., 2008 a,b,c; 2009; 2017c; Grealish et al. 2011, 2014; Mosley et al., 2014a)(see Figure 1-4). The acidic soils have persisted for several years post-drought (Mosley et al., 2014b), as has the acid drainage in the region (see discussion below). CSIRO (2008) surveyed acid sulfate soil characteristics at Mobilong and Toora during the drought period but as sampling was only undertaken to the top 1 m of the soil profile the major acidification zone was not sampled.

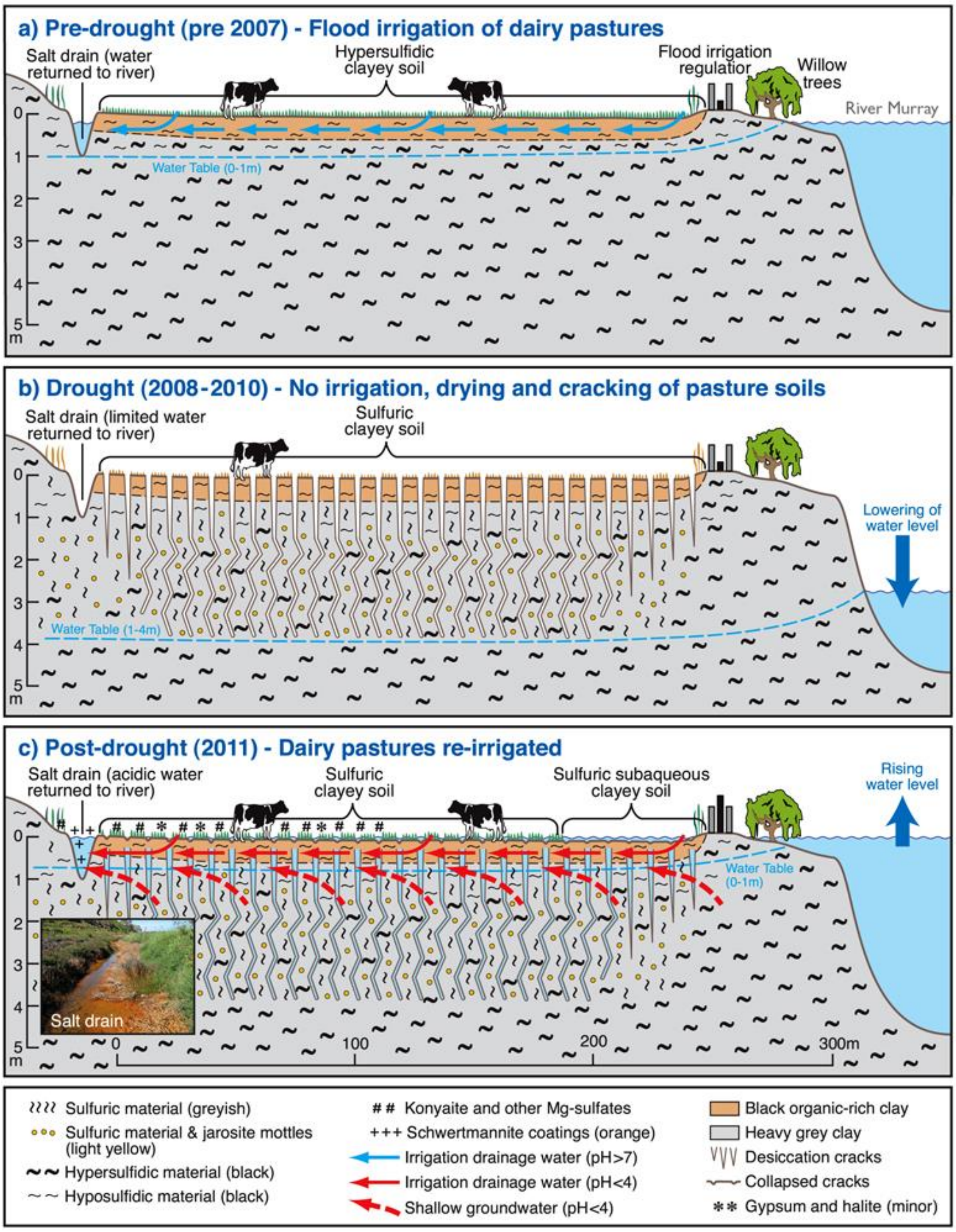


Figure 1-4 Generalised soil-landscape conceptual model during post-drought reflooding and irrigation (2011) in the LMRIA illustrating the spatial heterogeneity of: (i) ASS materials, (ii) water flows (i.e. surface water levels, groundwater table levels and river flow) and (iii) reddish-yellow (orange) iron-rich precipitate (comprising schwertmannite) and salt efflorescences (Fitzpatrick et al. 2012; 2017c).

1.4 WATER, IRRIGATION AND CLIMATE

This section presents information on the surface water (River Murray), groundwater, and drainage water in the LMRIA. The River Murray level is now less variable than pre-river regulation and is usually, with the exception of during extreme drought, elevated enough to enable gravity fed flood irrigation of the LMRIA. The LMRIA has a rising saline groundwater table and requires drainage channels and pumps to prevent the land becoming waterlogged and salinised. The drainage water is returned to the river and can contain high levels of salt, organic matter, nutrients and bacteria.

Pre-drought and following a major rehabilitation program, irrigation efficiencies of 0.7–1.0 ML/ha/watering (85-90% efficiency) were achieved in the LMRIA on laser levelled bays with good channel infrastructure. Post-drought, due to the soil cracking and slumping, irrigation efficiencies declined to great than 3 ML/ha in many areas. Recent irrigation efficiency data suggest that pre-drought irrigation efficiencies are close to being achieved. The On Farm Infrastructure program (laser levelling and channel upgrades) administered by the SAMDB NRM Board is greatly assisting in this regard with over 500 ha of the LMRIA receiving re-laser levelling and channel upgrades.

1.4.1 The River Murray

The LMRIA is located in the last freshwater reach on the River Murray system. Prior to river regulation the Lower Murray system was likely influenced, at least in terms of water level, by both upstream catchment inflows and tidal circulation. During the 1920s to 1940's a series of large infrastructure projects were initiated along the River Murray. This included the construction of locks and barrages, and levee banks along the river channel. Since Murray Mouth barrage construction the Lower Murray (below Lock 1) river level is still influenced by upstream flows but also regulation of the barrages. Typically there is now a much more stable operating in a typical range of 0.4-0.8 m AHD. Before these changes were initiated the hydrological regime in the area was much more variable, with the river level rising and falling with seasonal fluctuations that would have regularly flooded the historical floodplains of the LMRIA. Wind conditions and seiching from Lake Alexandrina can also cause lower river water levels to rise/fall in the river depending on direction.

Figure 1-5 shows the river level at Murray Bridge 2002 to 2012 and a longer term (1921 to 2013) dataset of Lower Murray River levels measured upstream (but same pool) of the LMRIA at Lock 1 (see Figure 1-1). A large reduction in water levels (to <-1 m AHD) occurred during the extreme drought period from 2007–2010 with water levels recovering to "normal" pool levels (approx. 0.75 m AHD) in late 2010.

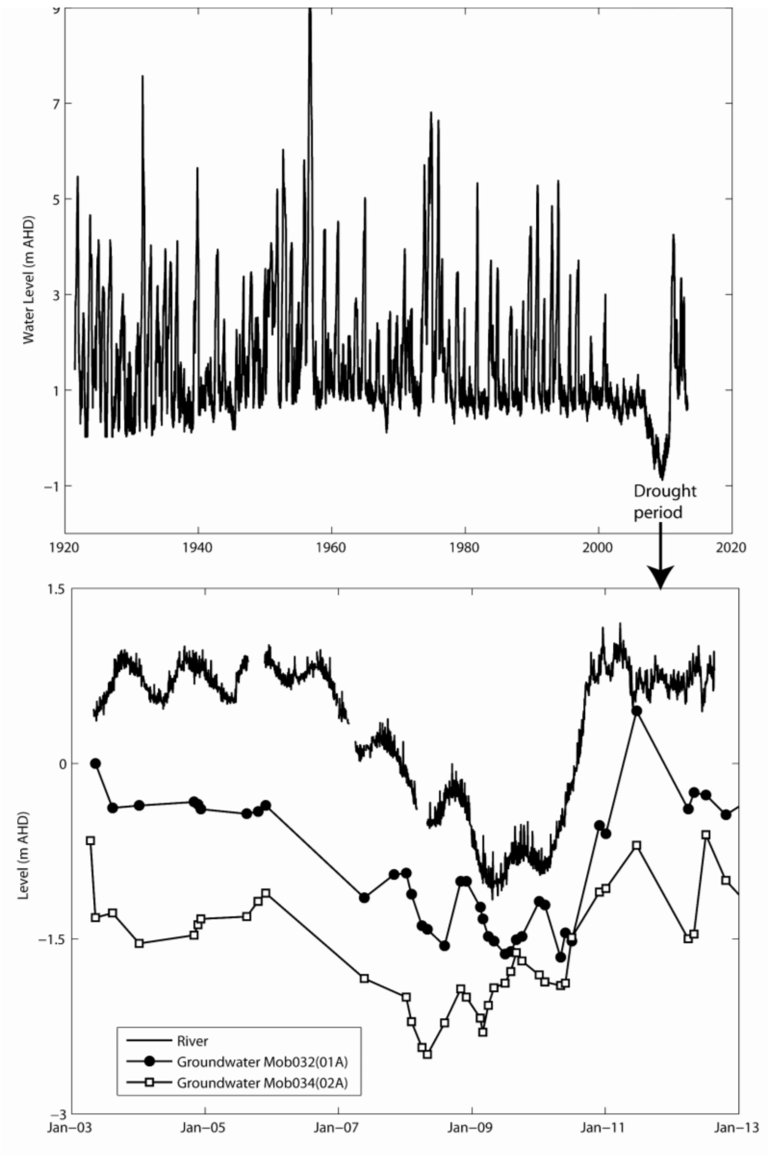


Figure 1-5: Groundwater and surface water levels, 2002 – 2012 at Murray Bridge. (Source: Mosley *et al.*, 2014a).

1.4.2 Groundwater

The main regional aquifer on the Plains Zone where the LMRIA is located is the Murray Group Limestone which is the regional watertable aquifer that wholly encloses the river valley and is in hydraulic connection with it (Barnett et al., 2003). The aquifer is about 25 – 30 m thick and contains groundwater with salinities up to about 20,000 mg/L near the river. Below this aquifer is the Remark Group aquifer (interbedded sands and lignite clays) which are around 10–30 m thick. It is confined from the Murray Group Limestone aquifer by the Ettrick Formation, a grey–green fossiliferous marl. Regional groundwater flows through pore spaces in the limestone beds towards the River Murray Valley, and alluvial floodplains which are the point of discharge (Barnett 1989).

Above the Murray Group limestone, the sediments of the Monoman Formation form a permeable aquifer (connected to the lower limestone aquifer) which is semi-confined by the upper Coonambidgal Formation. The regional groundwater flows beneath the floodplain in the alluvial sediments of the Monoman and Coonambidgal Formations to its discharge point, which was originally the River Murray (Barnett et al., 2003). However, the infrastructure changes also altered the hydrological regime of the area, with the swamps becoming the new discharge point for the highly saline (10,000 to 15,000 µS/cm) regional groundwater (see Figure 1-3 bottom). Near the river/levee bank, there is shallow groundwater flow from the river into the Coonamnidgal formation.

The regional groundwater discharge point would have been the River Murray, owing to it being the lowest point in the landscape. Once the locks and barrages were built, however, the river level was maintained at a relatively constant level, eliminating large seasonal fluctuations. This, along with the construction of the levee banks which contained and raised the level of the river in the main channel, benefited the development of agriculture on the reclaimed swamps as it ensured water security and enabled low cost gravity fed irrigation. This had the negative effect however of shifting the saline regional groundwater discharge point to the floodplain.

Figure 1-5 shows the level from a shallow (5 m) piezometer at Mobilong (Bore Mob01A/032) irrigation area in the LMRIA from 2002 to 2012. Due to the connectivity to the river, the groundwater level follows river levels and seasonal patterns. The falling river level and lack of irrigation during the drought resulted in a large decline in groundwater levels (Mosley et al. 2014a) and severe groundwater acidification and metal release (Mosley et al. 2014b). Apart from the recent EPA groundwater monitoring there is very little data available, apart from SA Water data for piezometers at Mobilong and Toora (see Sims, 2014).

1.4.3 Irrigation

Figure 1-6 illustrates a cross section of a typical rehabilitated irrigation paddock/bay and drainage layout. During irrigation events, a sluice gate or siphon is opened to allow water to be gravity fed into an inlet channel, and then through an outlet onto the paddock/irrigation bay. A large drain at the end of the irrigation bay, the "salt" or main drain, returns regional saline groundwater, excess surface irrigation runoff and sub-surface irrigation drainage (and occasionally stormwater runoff) to the river via large electric pumps. Lateral or "side" drains are present alongside each irrigation bay that flow into the salt drain. A "toe" drain is often present to intercept surface irrigation runoff for recycling on farm. Typically the drainage pump is operated as required to maintain the saline groundwater table about 1 m below the surface of the paddock.

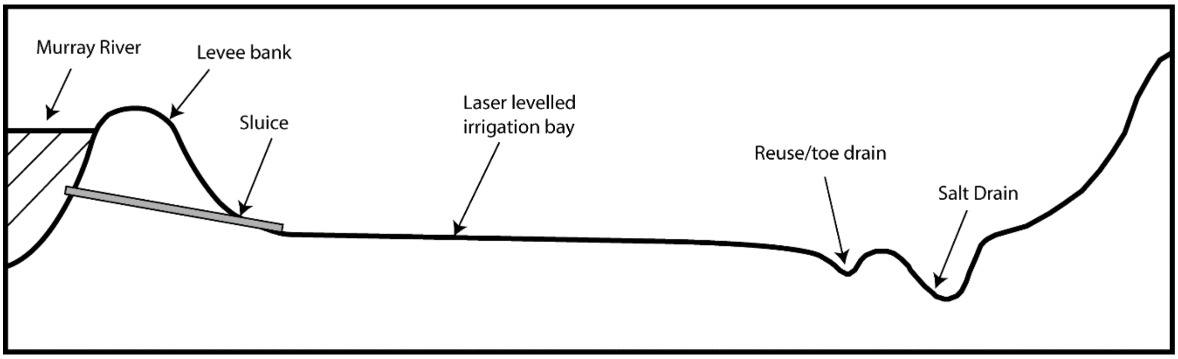


Figure 1-6: Schematic cross-section of a typical irrigated area in the LMRIA (not to scale)

Prior to the 1940s when the barrages near the Murray Mouth were constructed and river levels permanently raised, irrigation in the LMRIA was dependent on river heights being sufficiently high (Taylor and Poole, 1931). The southern areas of the LMRIA, being at lower elevation, required lower river heights for irrigation than the northern areas. Post barrage construction, the topography of the swamps, when combined with the consistently elevated hydraulic head and large flow rates, make flood irrigation a cheap and simple method of irrigating pastures in the LMRIA (Philcox and Douglas, 1990).

In 1990, flood irrigations were undertaken typically 14-21 times per year (Philcox and Douglas, 1990), although the frequency of irrigation has reduced towards the lower end of this scale on most commercially-irrigated properties now (Philcox and Scown, 2012). Towards the end of the inter-irrigation period the pasture may obtain up to 40% of its water from the water table.

Historically the water use per irrigation was approximately 1.8 ML/ha (water depth of 180 mm per irrigation). Post the 2003–2007 LMRIA rehabilitation (improved inlet structures, flow metering, elimination of water leaks, laser levelling of paddocks, and construction of re-use systems to recycle excess surface irrigation runoff) substantial reductions in water use were observed (Mosley and Fleming, 2009). The average water use per watering of 0.6 ML/ha for the fully rehabilitated farm was one third of the average water use per watering (1.8 ML/ha) for non-rehabilitated farms. Partially rehabilitated farms had an average application rate of 1 ML/ha per watering. A large improvement in efficiency of water use was achieved by upgraded water delivery infrastructure and laser levelling of paddocks.

Following the severe 2007-2010 drought, the irrigation water efficiencies in the LMRIA were severely reduced. During the drought river and groundwater levels fell to their lowest in over 100 years from 2007–2010. Coupled with restricted irrigation water allocations, there was very little irrigation water applied. This led to severe soil cracking to depths greater than 2 m. Remaining irrigators have observed large water losses during irrigation due to flow through the cracks and increased lateral movement to adjacent irrigation bays. Irrigation has now become much more "patchy" across the region with less commercial irrigation and dairy land use. Philcox and Scown (2012) surveyed farms across the LMRIA region and estimated total post-drought area and volume of irrigation. Philcox and Scown (2012) found only 7 of 21 (33%) dairy farms surveyed have water use near to pre-drought levels (1-2 ML/ha/irrigation). The rest were extremely variable with amounts from 4-5 up to 7.4 ML/ha/irrigation.

In terms of irrigation water allocations held in the LMRIA, Philcox and Scown (2012) found 3 of the 21 dairies (14.2%) they surveyed post-drought had sold over 90% of their water allocation. The 21 dairy enterprises visited comprised 1,696 ha of reclaimed area representing approximately 16 GL of allocated water (not including ELMA). The 12 beef/hay enterprises visited comprised 735 ha of reclaimed area representing approx. 3.7 GL of allocated water. There was approx. 144 ha of irrigated highland and 2,517 ha of dryland associated with these reclaimed areas. A perceived 34 ha of reclaimed land was said to be acid affected by interviewed landholders. In total the 33 visited enterprises comprised 2,431ha of reclaimed area and 19.6 GL of allocated water. Associated with these enterprises was 488 ha of irrigated highland and 15,864 ha of dryland. It was estimated that there were a further 4 dairy enterprises comprising approximately 170 ha and 9 beef/hay enterprises and 1 horse property comprising approx. 591 ha that were not visited. This gives a total area of 25 dairy enterprises of approx. 1,866 ha and 21 beef/hay enterprises and 1 horse property comprising 1,326 ha. This gives a total 'productive' farmed area of approx. 47 enterprises comprising 3,192 ha in total.

1.1 NON-COMMERCIALLY IRRIGATED (ELMA-ONLY) LAND

Philcox and Scown (2012) estimated that there were 24 landholders in the LMRIA who would be Environmental Land Management Allocation (ELMA) only water holders and not deriving significant income from their LMRIA land holding. The ELMA only areas include the substantial land holdings of SA Water at Toora and Mobilong which were purchased to remove pathogen risks from grazing cattle near major source drinking water supplies.

The Regional Development Australia (RDA 2013) report stated "*The abandonment of formerly irrigated land is not favoured by the vast majority of landholders. In reality, it is rarely a choice and generally occurs because the landholder has insufficient funds to manage the property appropriately or to a lesser degree, insufficient knowledge on how to manage the property. This is not an appropriate land use under any circumstance. It has potential to reduce the value of surrounding land and the broader region through reduced visual amenity, environmental impacts and impacts on adjacent productive land*".

1.4.4 Drainage water

Beginning from the 1900s, to prevent the land from becoming water logged and salinized and unsuitable for agriculture, a series of drainage channels and pumps were installed in the LMRIA to intercept the rising saline regional groundwater. Figure 3-2 illustrates a typical drainage layout. A large drain at the end of each irrigation bay, the "salt" or main drain, returns saline groundwater, excess surface irrigation runoff and sub-surface drainage (and occasionally stormwater runoff) to the river via large electric pumps. Lateral or "side" drains are present alongside each irrigation bay that flow into the salt drain. A "toe" drain is often present to intercept surface irrigation runoff for recycling on farm. Typically the drainage pump is operated as required to maintain the saline groundwater table about 1 m below the surface of the paddock.

This drainage water returned to the River Murray has historically contained high levels of nutrients and bacteria that impacted river water quality (EPA, 2009; Mosley and Fleming, 2010). Between 2003–2008 the Commonwealth and South Australian state governments funded ($22 million) and facilitated a major rehabilitation and restructuring program in the Lower Murray Reclaimed Irrigation Area (LMRIA) in partnership with irrigators to reduce irrigation water use and pollutant loads returned to the River Murray. Unfortunately the lack of irrigation and soil cracking and slumping during the drought resulted in large-scale loss of the infrastructure improvements that were made during rehabilitation.

Post-drought and acid sulfate soil exposure and oxidation, rising water tables resulted in mobilisation of acidity and metals to the drainage channels and back to the River Murray (Figure 1-7). This issue has persisted to present across the LMRIA (Mosley et al., 2004a and b). Recent research by a PhD student at the University of Adelaide has found the low soil pH, low availability of organic matter, and presence of nitrate is preventing sulfate reduction (natural microbially-driven remediation process that generates alkalinity during pyrite reformation)(Yuan et al. 2015 a and b).

Figure 1-7 Photograph of the acidic **Burdett** drain (looking west towards the River Murray showing pump station in distance) near Long Flat showing surface precipitates of iron-rich reddish-yellow (orange) coloured mineral, schwertmannite sampled on 2nd September, 2011

1.4.5 Climate and climate change

The climate in the LMRIA region is semi-arid with low annual rainfall and and high evaporation, evaporation exceeds rainfall in every month of the year. At Murray Bridge in the middle of the LMRIA region, the annual average rainfall from 1885 to 2015 was 349.6 mm with a mean maximum and minimum temperature of 22.9 and 9.9 °C (Bureau of Meteorology data).Tailem Bend at the southern end of the LMRIA has higher annual rainfall (374.1 mm) and Mannum at the northern end slightly lower (295 mm). The winter months (May-Sept.) have higher rainfall and irrigation is not usually undertaken in this period. In contrast the estimated annual average evaporation is 1624 (Murray Bridge), 1580 (Wellington/Tailem Bend), and 1711 (Mannum) mm per year (Tonkins, 2006). The low rainfall means stormwater contributions from the adjacent highland agricultural and urban areas to the LMRIA typically form a low proportion of the total water balance (Tonkins, 2006).

Climate change predictions suggest that the South Australian Murray-Darling Basin Projected will experience warming and reduced rainfall (Suppiah et al., 2006). Specifically by 2030, the annual temperature is predicted to increase between 0.5 and 1.3°C; summer warms by 0.5 to 1.5°C, autumn warms by 0.5 to 1.3°C, winter warms by 0.4 to 1.3°C and spring warms by 0.5 to 1.4°C. By 2070, the annual temperature is predicted to increase between 1.0 and 4.0°C; summer warms by 1.1 to 4.7°C, autumn warms by 1.0 to 3.9°C, winter warms by 0.8 to 3.8°C and spring warms by 1.0 to 4.4°C. The annual rainfall shows changes of -8 to 0% by 2030 and -25 to +1% by 2070. Spring shows a strong decrease, while other seasons show moderate decreases. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes. River Murray flows will also decrease (Connor et al., 2008).

1.5 VEGETATION

Summary

The vegetation in the LMRIA has been substantially modified from the original swamp/wetland vegetation types, and now consists mostly of agricultural pasture, with salt-tolerant species on the backswamp areas, river red gums on the river and channel margins, and remnant stands of the reed *Phragmites* sp.

1.5.1 Original vegetation

In their original condition the Lower Murray "swamps" appear to have shown a strip of higher land along the immediate river frontage, with the remainder divided between patches of reed growth and standing water (Taylor and Poole, 1931). The annual reed growth and lagoonal nature likely increased or decreased according to river levels and local climatic conditions. A dominant reed species, still to the present in many areas, was *Phragmites australis*. *Eucalyptus camaldulensis* (River Red Gum) stands likely existed, as per presently, along the river channel frontage and margins of semi-permanent swamp areas.

There is evidence of burning of vegetation and soil organic matter having been undertaken prior or during reclamation of the swamps. Taylor and Poole (1931) observed burnt layers that were mostly 7-15 cm thick (some over 30 cm) with their position in the soil profile varying from 15-110 cm from the surface (frequently to depth of water table).

The above is generally consistent with the first image/painting of the LMRIA in 1846 (Figure 1-8) showing dense reed beds, a higher zone along the river frontage and a small fire burning.

Figure 1-8: “The River Murray near Lake Alexandrina”, 1846 State Library of South Australia B15276/25. Note this vista appears to be overlooking what would become Jervois irrigation area from the cliffs at Tailem Bend.

1.5.2 Remnant native vegetation

There are several sites in the LMRIA which contain remnant native vegetation although this forms a relatively small percentage of the total LMRIA area. Native vegetation has also been re-established in the LMRIA (from Dairy SA, 2010):

- Samphire areas (10 years old) at Monteith, Jervois, Long Flat, Wall Flat and Pompoota: These areas have been successfully planted with mixed salt-tolerant species including Salt River Paperbark (*Melaleuca halmatuorum*).

- Two sites that have vegetation planted as shelter belts on the edge of paddocks at Woods Point and Ponde: These areas have also been successful and provide shade and shelter to livestock grazing the area, particularly in summer.

- Entire paddocks have been planted out on Mobilong, Cowirra and Pompoota

- Paiwalla wetland was created when 64ha of former dairy farm returned to wetland with native plant regeneration and revegetation including a managed wetting and drying cycle.[2]

Dairy SA (2012) concluded that "*The growing of native vegetation on selected suitable areas in the LMRIA can be a viable option given that the aim to maintain the river pool level during drought at or above 0.45m AHD is achieved. Once the river pool level drops below this level, the water table under the LMRIA drains out to the river. This then allows and encourages the vegetation to excessively extract soil water further drying the soil and possibly contributing to slumping and structural collapse. This could be ameliorated by pollarding trees during drought to control their growth and reduce the weight contributing to slumping from tree biomass and by ensuring the application of ELMA entitlements to reduce soil drying.*"

1.5.3 Agricultural pasture and crops

The dominant vegetation type across the LMRIA is now agricultural pasture, a mix of old permanent (typically kikuyu/paspalum) and "improved" pasture types (clover/rye grass)(Philcox and Scown, 2012). The drought and lower water use on some farms has led to a trend to pastures becoming more dominated by older species such as paspalum, kikuyu, Prairie grass, couch, strawberry clover and Ladino white clover (Philcox and Scown, 2012).

There has been some experimentation with other crops during and post the drought such as lucerne, chicory and cereals. One small area (Tobelong) has established a viable horticultural operation. The report by Dairy SA (2010) noted that *Sulla* appears to have great potential as an alternative crop for the LMRIA area, especially where water supplies are limited. It produced high quantities of feed of excellent feed quality, equal or surpassing lucerne as a stock feed. As it also has anti-bloat and anti-helminthic qualities it can be an excellent feed for finishing off livestock for market or adding condition to cows prior to mating or adding live weight to younger stock – beef or dairy. Additional sites of Sulla have been established to assess its potential over a range of soil conditions and sown as a component of a pasture mix rather than 'stand-alone'.

[2] See www.paiwalla.org.au

2 IMPROVING IRRIGATION EFFICIENCY

2.1 BACKGROUND

Sub-activity 2.1 - *Improve irrigation efficiency and reduce drainage volumes via coordinated irrigation –*

Coordinated irrigation has the potential to increase irrigation efficiency across an irrigation area by reducing the lateral drainage losses from individual irrigations. To test this, normal and coordinated irrigations were undertaken in collaboration with landholders at Long Flat during two irrigation seasons (2014–2015, 2015–2016).

Sub-activity 2.2 – Improve irrigation efficiency and drainage volumes via laser levelling of drought-affected soils

Laser levelling occurred across the LMRIA in 2015 funded under the On-Farm Irrigation Efficiency Program (OFIEP). This provided an ideal opportunity to study the benefits of laser levelling where a legacy of deep sub-soil cracking during the drought still persists. Previous pre-drought research has shown large efficiency benefits but these gains may be less due to the subsoil (unaffected by lasering) still containing cracks.

Sub-activity 2.3 – Alternative watering strategies for ELMA-only irrigators using a travelling irrigator

The large channel losses and difficulty getting water down the end of an unlasered irrigation bay are compounded on Environmental Land Management Allocation (ELMA)-only properties due to the sporadic watering regime and often poor or absent water delivery infrastructure. ELMA-only irrigators are difficult to engage through efficiency programs as they do not have irrigation water (class 3a) to return to receive funding for infrastructure upgrades. However, the watering regime on ELMA properties is likely influential to efficiency of commercial irrigation on adjacent bays. Furthermore ELMA application is considered critical for protection from drought impacts on soil and infrastructure. We trialled whether a well-designed travelling irrigator could potentially be used to reduce delivery and drainage losses on ELMA properties, provide an irrigation method that would work during drought, and to improve land and vegetation condition.

2.2 METHODS

Two irrigation trials were undertaken.

1. Sub-activity 2.1 – Coordinated irrigation – As previously described we have established a field trial site at Long Flat irrigation area, consisting of a series of piezometers (1.75 m below ground level), extending across approximately 7 irrigation bays (Figure 2-1). One piezometer was installed in the middle of each bay and one towards the side. Soil moisture monitoring tubes were installed at 4 locations. Soil samples were also collected for determination of soil physical and chemical characteristics.

   Continuous (15 min interval) water pressure/level loggers (HOBOTM) were installed in each piezometer at the Long Flat trial site. A graph of water levels from these piezometers is shown in Figure 2. Three irrigation events were conducted and monitored, two prior to any laser-levelling and one after laser levelling of 3 bays (corresponding to Lat 7-11 area on Figure 2-1). The irrigation on the recently laser levelled bays (irrigation event 3, early December) raised the groundwater level only slightly compared to the previous non-laser levelled irrigation (irrigation events 1 and 2) where the water table rises to the surface. This indicates much greater irrigation efficiency after laser levelling and it is likely that flow down cracks has been reduced.

Figure 2-1 Map of Long Flat irrigation area showing location of piezometers and soil moisture tubes extending laterally across seven irrigation bays. The inset shows the installation in progress.

2. Sub-activity 2.2 Travelling irrigator – a travelling irrigator (Trailco T300-2 with a ¾" spray nozzle, see photo below) was leased for the trial and two irrigations conducted (1/3/2016 and 17/3/2016) at Mobilong irrigation area (Figure 2-2). A diesel pump was hired separately to pump water out of the supply channel and into the irrigator. The pump produced approximately 80psi of pressure via a 4" suction and layflat delivery hose. The layflat delivery hose that was used was 200 m long which only enabled irrigation of approximately half the bay. The irrigator travel speed setting was set at 1-1.5 (lower range of speed and could be speeded up if desired but this would lower water application rate). Water application rate was measured by placing rainwater gauges in the middle and edge of the irrigation bays. Groundwater levels were monitored continuously using level loggers.

3. Subactivity 2.3 - Laser levelling – Laser levelling of an irrigation bay occurred on the 31st of January 2016 at Mobilong irrigation area (Figure 2-2). Water use was measured by a meter in the irrigation siphon. Groundwater levels were monitored continuously using level loggers.

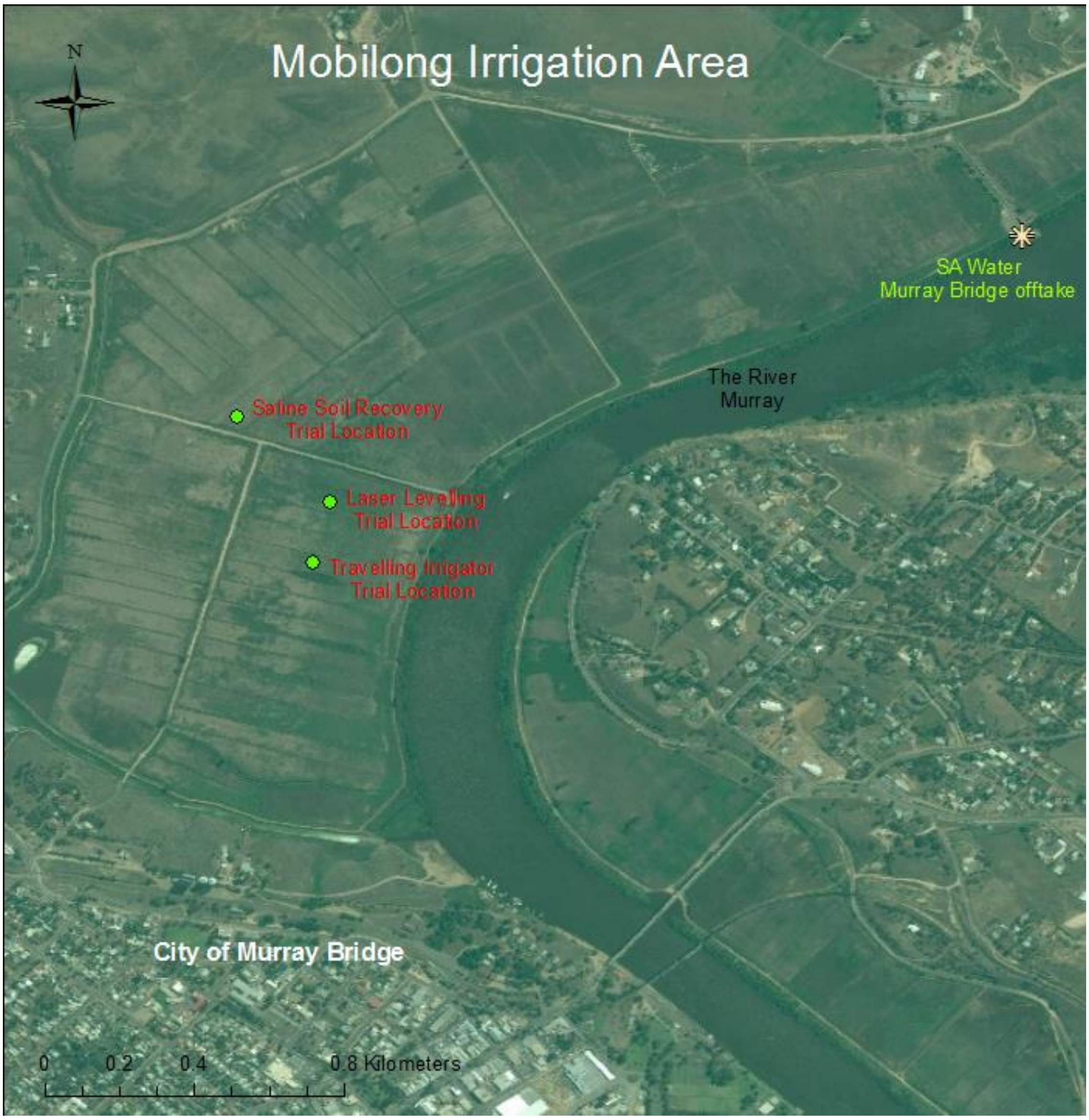
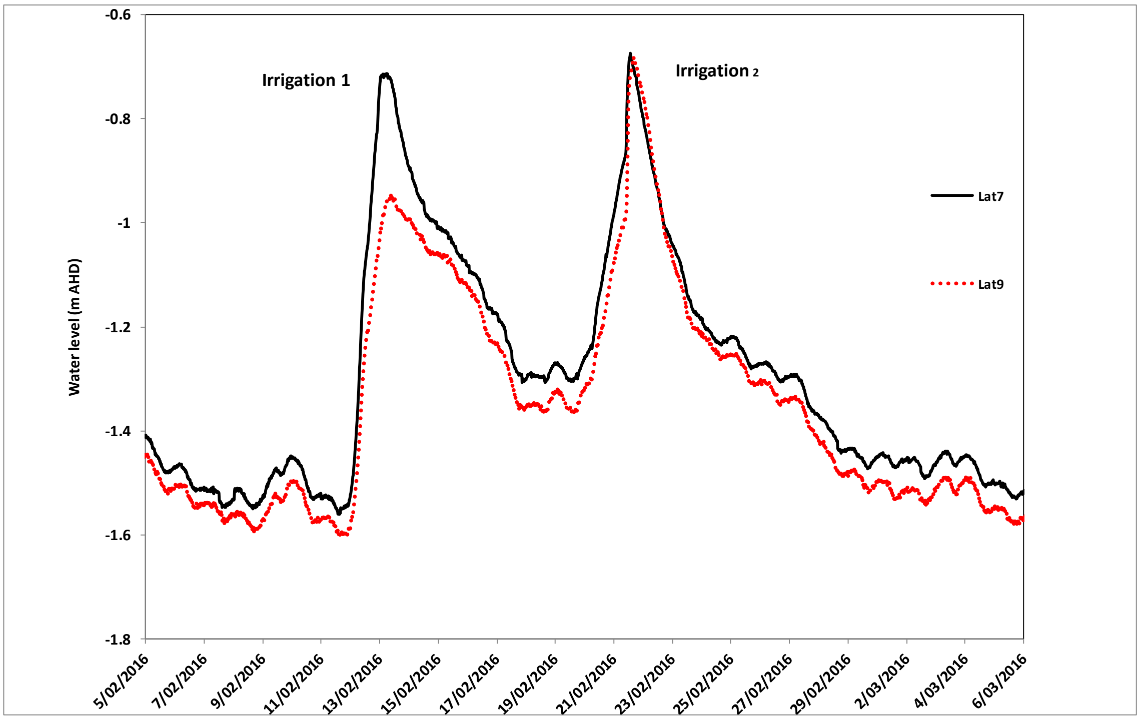


Figure 2-2 Map of the study area at Mobilong showing the location of the three trial areas, 1) Saline soil recovery trial, 2) Travelling irrigator trial, and 3) Laser Levelling trial

2.3 RESULTS – COORDINATED IRRIGATION

An example from results from the coordination of irrigation are shown in Figure 2-3. The first irrigation has a broad shape and the drainage takes several days. Before the drainage is complete the second irrigation was triggered. The 2nd irrigation uses much less water (narrower shape). This is because the soil profile has residual water from the first irrigation. The results highlight that sequential irrigation is beneficial if conducted within about 5-7 days of irrigation on adjacent paddocks that have been affected by lateral movement from the first irrigation.



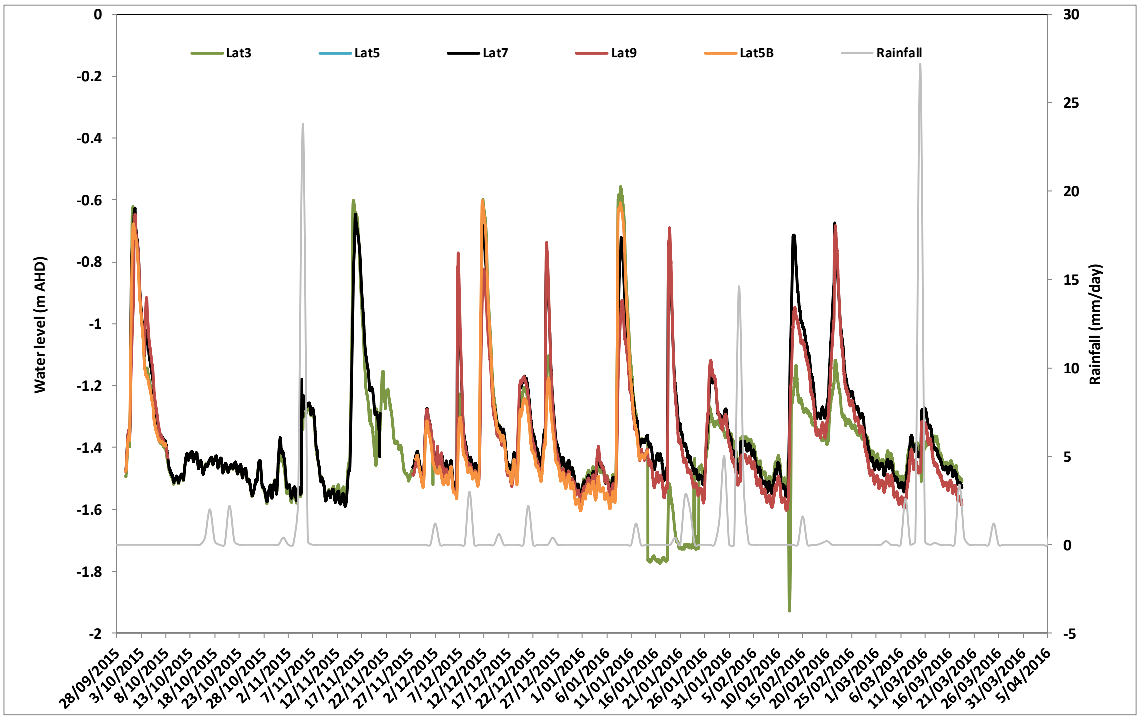


Figure 2-3 Groundwater response over two coordinated irrigations (top) and full timeseries from selected piezometers (bottom)

Two-dimensional modelling and assessment of the lateral water flows across Long Flat irrigation area would be beneficial to better understand the processes and management implications but this was outside the scope of the study.

2.4 RESULTS - TRAVELLING IRRIGATOR TRIAL

A travelling irrigator was successfully trialled at Mobilong for two irrigations (Figure 2-4). On average approximately 50 mm of water depth was applied over a period of about 12 hours (Table 2-1). This equates to 0.5 ML/ha watering, which is better than average efficiencies from laser-levelled flood irrigation systems (Mosley and Fleming 2009). The irrigation depth was measured in the centre and edge of the irrigation bay using a rain gauge. The water application was quite even across the irrigation bay. There would have been additional channel losses in the trial but by sourcing water direct from the river these could be avoided.

Table 2-1 Results from the two travelling irrigator trials in terms of irrigation duration and depth in centre and side of irrigation bay.

Parameter	Irrigation 1 (1/3/2016)	Irrigation 2 (17/3/2016)
Start time	9:15 am	10:40 am
End time	9:30 pm	10:30 pm
Approximate duration of irrigation	12 hours^	12 hours^
Irrigation Depth Centre Bay (near piezometers)	50, 35* mm	63, 40 mm
Irrigation Depth Side of Bay	50, 30* mm	49, 48 mm
Approximate irrigator speed	13 m/hour (200mm/minute)	15 m/hour

^ This was for irrigation of an approximately 200 m length of irrigation bay

*Irrigator was at the end of the travel so spent less time at the piezometer location

Figure 2-4(top) travelling irrigator in operation, and (bottom left) photograph showing full irrigation bay width was watered and (bottom inset) 4" diesel pump used to provide water to irrigator (via layflat hose)

The groundwater level response during irrigation for a flood irrigation event (November 2015) previous to the travelling irrigator trial were compared to the irrigation response during the two travelling irrigator trials. A markedly different profile is seen (Figure 2-5). In the flood irrigation (non-laser levelled) the groundwater rise is slow, and the drainage takes > 10days. In order to flood irrigate at present, the siphon? at Mobilong is operating for approximately 3 days (see duration of rise in water table below) as a large amount of water lost down cracks and sideways, and irrigations are still only able to get about half way down the bay. This problem has only been apparent since the drought, pre-drought irrigation was easier (Rob Hutchinson pers. comm.).

In contrast the travelling irrigator resulted in a rapid rise in groundwater levels within a few hours following by drainage over the following 4 days. The peak of the groundwater rise corresponds (dependent on the specific yield) to the amount of water draining to the water table following the irrigation. The subsequent decrease in the water table is a combination of drainage to depth, lateral drainage and evapotranspiration. The latter is discernible from the diurnal pattern seen in the water table heights. For the travelling irrigator these combined processes result in return of the water table to the initial condition in approximately 4 days. The area under the curve up to this point will correspond to the amount of water draining from the soil above following the irrigation. In contrast the flood irrigated soil takes greater than 10 days to return to the starting water table height. This indicates that a much greater volume of water is lost to drainage from flood irrigation and corresponds to the area under the curve.

Given the longer time the flood irrigated soil has an elevated water table for increases the probability of salt concentrating in the topsoil and at the soil surface due to evapotranspiration of the water. This effect can be discerned from the diurnal pattern of water table fluctuation as evapotranspiration causes the drainage and hence water table rise to cease or drop.

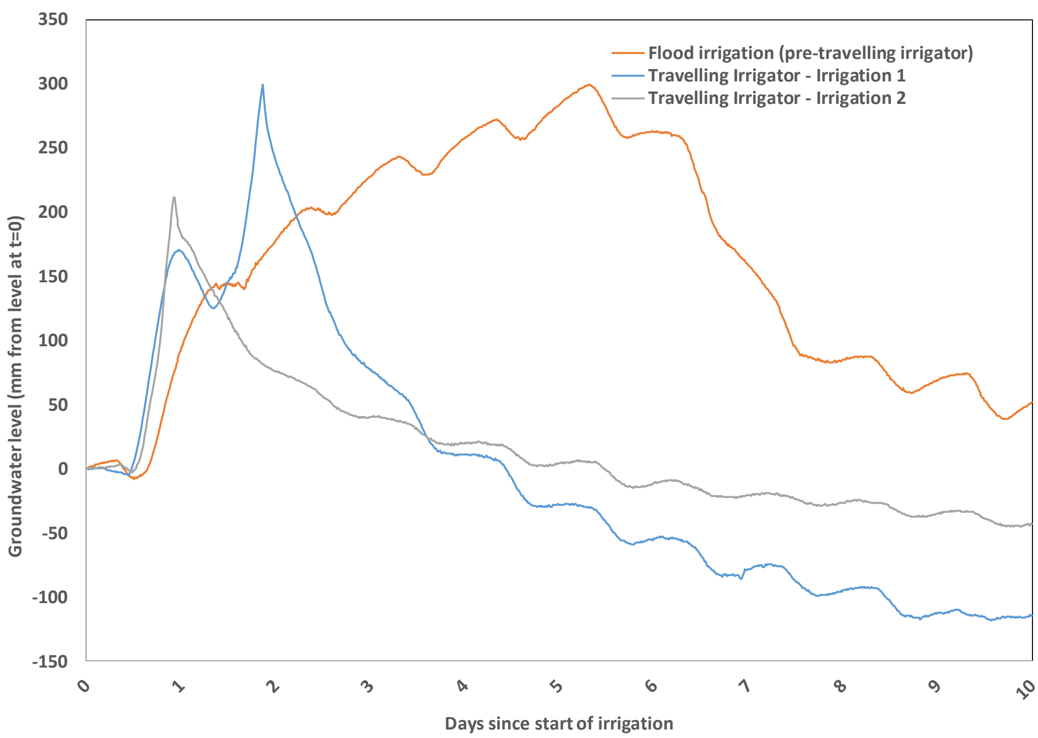


Figure 2-5 Groundwater level response for irrigation on a non-laser levelled bay at Mobilong pre- and post- use of a travelling irrigator. The groundwater levels were normalized to the same starting point for comparison.

2.5 RESULTS – LASER LEVELLING TRIALS

2.5.1 Long Flat Laser Levelling Trial

Laser levelling of 3 irrigation bays was successfully undertaken at Long Flat (part of On Farm Irrigation Efficiency Program infrastructure upgrades) and a cover crop established (Figure 2-6).

Figure 2-6 Laser levelled irrigation bay at Long Flat irrigation area

Figure 2-7 shows a graph of irrigation water efficiency from Long Flat irrigation area trial site. OFEIP infrastructure upgrades (principally laser levelling) has halved water use per irrigation in 2015/16 to an average of approximately 0.7 ML/ha/watering compared to the unlasered paddock average of 1.5 ML/ha/watering. This is now comparable to the pre-drought average efficiencies on laser levelling infrastructure in the LMRIA (Mosley and Fleming 2009). The unlasered paddock efficiency in 2015/16 still showed a large efficiency improvement from the immediately post-drought irrigation efficiency (Figure 2-7), likely due to soil cracks closing over time.

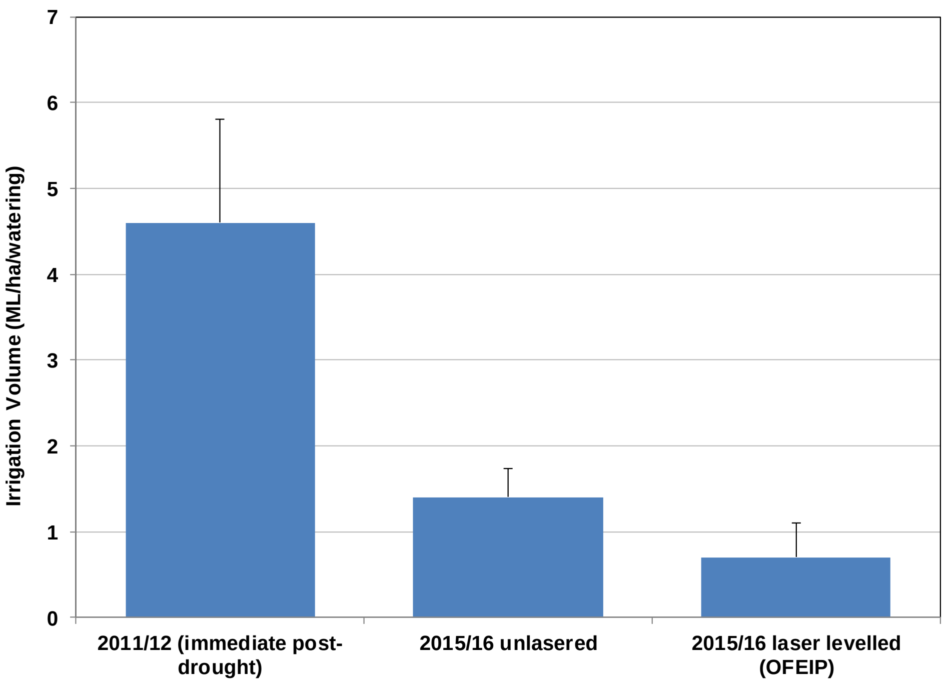


Figure 2-7 Water use per irrigation immediately post-drought (2011/12) and after laser levelling (2015/16) of some bays

Further evidence of water efficiency and groundwater response dyanmics following laser levelling is shown in Figure 2-8. The plot shows groundwater levels from a couple of piezometers at Long Flat (Lat 11 is in a laser levelled bay sowed with Millet, Lat 5B is the unlasered historical trial site bay). The results show that laser levelled irrigations produce a much “sharper and narrower” irrigation and drainage curve, whereas non-laser levelled have a much broader curve, (i.e. it takes much more water to irrigate, and much longer to irrigate and drain on non-lasered bay, the area under the curve corresponds to water use). The non-laser levelled curve reaches the soil surface with ponding occurring. Lateral losses to non-irrigated paddocks occur in each of the two separate irrigations, the losses are much greater (broader curve) with non-lasered paddocks due presumably to the extra water applied to lose sideways and influence of old cracks and ponding. The results confirm that laser levelling produces marked improvement in groundwater flow processes, and that lateral losses of water can be significant in these areas. This highlights as discussed above the potential benefits of sequential/coordinated irrigation on bays that have received water from lateral losses.

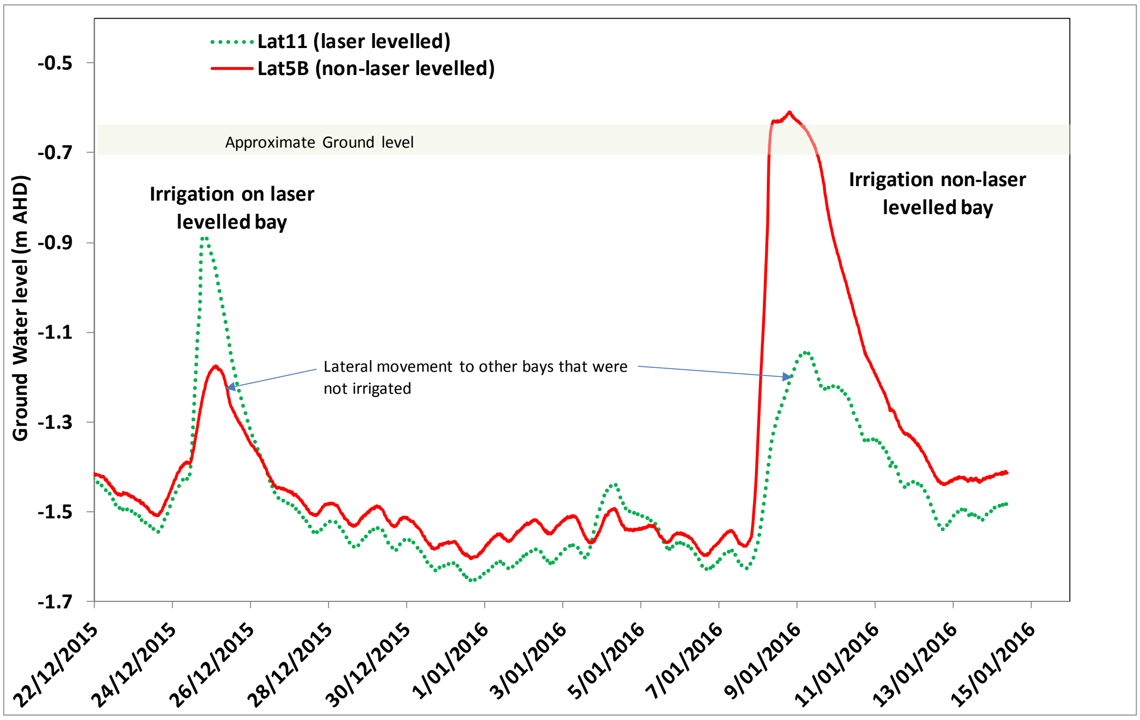


Figure 2-8 Groundwater response on a non-laser levelled bay compared to a laser levelling bay at the Long Flat trial site

2.5.2 Mobilong Laser Levelling Trial

Laser levelling of an irrigation bay was successful at Mobilong and a cover crop established (Figure 2-9).

Figure 2-9(top left) Irrigation bay at Mobilong being laser levelled, and (top inset) after laser levelling, and (bottom) laser levelled paddock with new crop sown and monitoring piezometer in foreground.

The groundwater level response during irrigation for a flood irrigation event (November 2015) previous to the laser levelling trial were compared to the irrigation response after laser levelling. A markedly different profile is seen as shown in Figure 2-10. In the flood irrigation pre-laser levelling, the groundwater rise is slow, rises to a greater maximum height, and the drainage takes >10 days. In contrast after laser levelling the rate of initial groundwater level rise is similar to the non-laser levelled but a lower magnitude peak is reached much quicker, following by drainage over the following 4 days. This split peak is likely due to unauthorised shutting off of the siphon part way through the irrigation (Rob Hutchinson pers. comm.). Pre-lasered irrigations were not successfully completed (water couldn't get all the way down the bay) but post-lasering water reached the end of the bay.

As described above the area under the irrigation-drainage curves above zero correspond to the estimated irrigation water lost to drainage, which is much greater for the non-laser levelled flood irrigation compared to the laser levelled irrigation. The average water use from 2011-2015 (pre-laser levelling) was 3.65 ML/ha, the laser levelled bay achieved approximately half this at 1.7 ML/ha (but this included an estimated about 1ML of channel losses so efficiency is likely about 1 ML/ha in reality). Further gains in irrigation efficiency would be expected with subsequent irrigations once pasture is established (less resistance than cover crops), and delivery channel and bay outlet upgrades are completed. The current siphon (poly pipe) at Mobilong is only 300 mm diameter which is smaller and hence delivers slower flow rates than most other siphons (typically 450 mm diameter) used for flood irrigation in the LMRIA. Higher flow rates are important for efficiency as they enable more rapid passage of the irrigation front down the bay with less drainage losses.

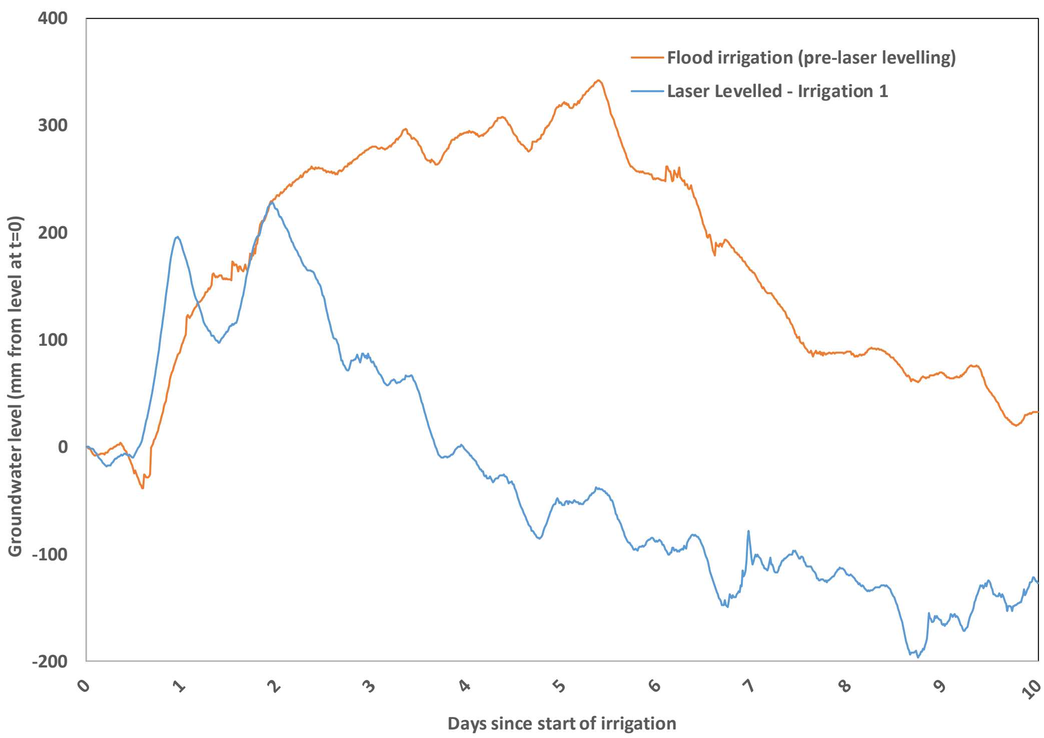


Figure 2-10 Groundwater level response for irrigation on a non-laser levelled bay at Mobilong pre- and post- use of a travelling irrigator. The groundwater levels were normalized to the same starting point for comparison.

3 REDUCE AND PREVENT LAND SALINISATION

3.1 BACKGROUND

Sub-activity 3.1 – Reduce soil salinity

A large area of land in the LMRIA is still salinised from the drought. By improving drainage and using irrigation we assessed how salt moves out of the landscape. We used this information in models to develop strategies to prevent land salinization reaching critical levels (i.e. where salt levels damage pasture or sodic soils develop).

Sub-activity 3.2 – Remediation of severe salinization

In some locations where sodic and dispersed clay soils are present we trialled recovery of these soils using conventional and novel techniques.

3.2 METHODS

An approximately 200m x 50 m trial plot area was established in a salinised area in the middle of Mobilong irrigation area (see Figure 2-2). The samphire vegetation in this area was scraped off the soil cultivated to a depth of about 30 cm with a rotary hoe.

Various 2m by 2m treatment plots were established in a randomized block design (3 blocks)(see Figures 3-1 and 3-2). Each treatment plot had the soil cultivated and a 15 cm high polyethylene barrier installed around it extending approximately 5 cm into the soil. A shallow (0.5 m deep) surface drain was created around two of the sides of each treatment plot. The drains were graded to a central discharge point but there was only minor seepage and no bulk drain flow observed during the experiment.

The six treatments within each block were control (not irrigated, drainage only), irrigation only, gypsum application (1.5 kg/m^2 = 15 tonne/ha rate), limestone application (1.5 kg/m^2 = 15 tonne/ha rate), seawater (50 mm irrigation depth, single application), and acid water (50 mm irrigation depth, single application, pH 3 drainage water) and drainage. The aim of the gypsum (CaSO4), limestone ($CaCO_3$), seawater and acid treatments was to supply calcium to the soil exchange sites to remove soil sodicity. The acid treatment aimed to dissolve calcium carbonate already present in the soil to release Ca to the exchange sites.

Each treatment plot, with the exception of the control/drainage only treatment, received four "irrigations" with a 50 mm depth of water each irrigation (i.e. 400 L per 4 m^2 or 0.5 ML/ha). This irrigation depth is comparable to very efficient water application flood irrigation rates for this region (Mosley and Fleming, 2009). The first irrigation in seawater and acid treatment was with seawater and acid drainage water respectively, all other irrigations were with River Murray water. Irrigation was applied evenly across the treatment plot at a rate that did not result in significant ponding. The "irrigations" were scheduled approximately every 3 weeks; on 17/11/2015, 7/12/2015, 28/12/2015, and 18/1/2016.

Soil samples were collected and analysed from the 10 cm layer at each treatment plot at time zero (16/11/2015), on 10/12/15 after the first 2 irrigations, and on 22/1/2016 after the final 2 irrigations. A composite sample was collected from each 2 m x 2m treatment plot at each sampling time by mixing five 0-10 cm samples.

Samples were analysed for salinity (EC 1:5 soil:water ratio), pH (1:5 soil:water ratio), exchangeable cations (Ca, Mg, Na, K), and total cation exchange capacity (CEC) as per the methods outlined below.

pH and electrical conductivity were determined on a 1:5 soil/water extract using the methods of Rayment and Lyons (2011, method 4A1 and 3A1 respectively). 5 g air dried soil was shaken with 25 ml water for one hour. Left to settle for 20 minutes. Electrical conductivity was first determined and pH in water was then determined. The electrical conductivity was determined using a Metrohm 815 Robotic Processor and standardised conductivity cell. The cell was calibrated using a KCl reference solution chosen to have conductivity near that of the unknown solution and adjusted to a standard temperature of 25°C. A 0.01M KCl solution has a conductivity of 1.413dS/m at 25°C. A 0.1M KCl solution has a conductivity of 12.9dS/m at 25°C. A 1.0M KCl solution has a conductivity of 111.8dS/m at 25°C. The EC of the unknown sample solution was then measured and recorded in dS/m. The pH was measured using a Metrohm 815 Robotic Processor and Metrohm 854 glass electrode calibrated at pH 4.0, 7.0 and 10.0 using commercial pH buffers. The electrode was placed in the sample and measured while stirring. The value was recorded to two decimal places when a stable reading was obtained.

Exchangeable cations and cation exchange capacity (CEC) were determined using NH_4Cl solution at pH 8.5 (Rayment and Lyons 2011, method 15D2). Samples were pre-treated for soluble salts prior to extraction. Exchangeable cations (Ca, Mg, Na and K) were analysed by Flame Atomic Absorption Spectrometry. Cation exchange capacity ammonium and chloride were analysed using a Flow Injection Analyser. The Exchangeable Sodium Percentage (ESP) was calculated from the exchangeable Na value divided by the CEC value times 100.

The saturated hydraulic conductivity (K_s) at the soil surface was measured using a CSIRO disc permeameter. In this method a constant head of water is applied to the soil and K_s determined when steady state flow is reached.

An additional saline soil area that was rehabilitated by the farmer (improved drainage, irrigation application, limestone and gypsum treatment) was sampled at Burdett irrigation prior to rehabilitation and will be resampled after winter.

Figure 3-1 (left) Saline soil recovery treatment plots with one treatment receiving irrigation, and (middle) salinized area where saline soil recovery trial was conducted with (right) Prof. Rob Fitzpatrick sampling the undisturbed soil profile.

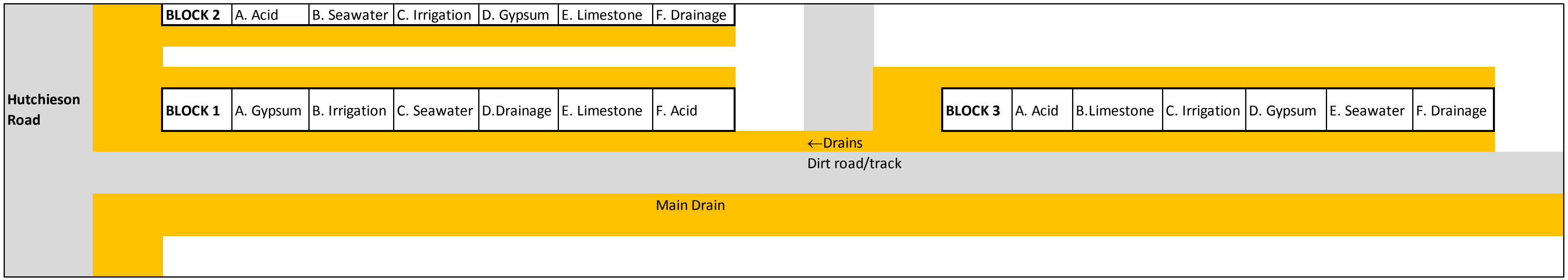


Figure 3-2 (top) design of saline soil recovery trial showing randomized block design (three blocks and six treatments).

3.3 Results and discussion

The properties of the undisturbed (prior to establishment or saline soil recovery treatment plots and rotary hoeing) profile at the Mobilong trial site is shown in Figure 3-3. A very high salinity (>20 dS/m) was present in the soil surface (0-5 cm) layer. The pH was approximately neutral at the soil surface but declined significantly to reach pH < 5 at 80-100 cm depth. The exchangeable cations were dominated by sodium and the ESP is very high (>40%) at 0-10 cm depth.

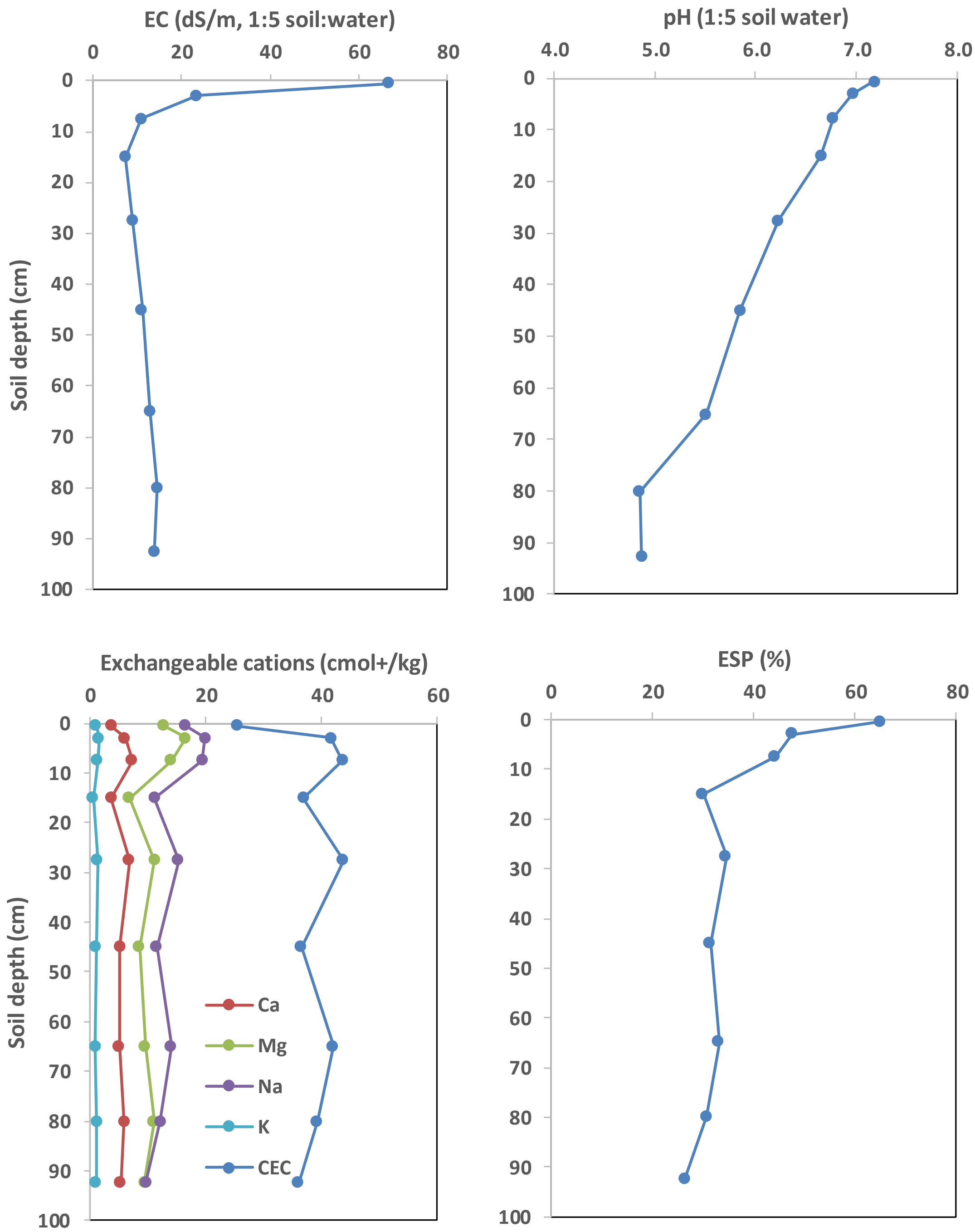


Figure 3-3 Electrical conductivity (EC, 1:5), pH (1:5), exchangeable cations and exchangeable sodium percentage (ESP) in the undisturbed soil profile at the location of the saline soil recovery trial.

The soil properties at the end of the trial are shown in Figure 3-4 and Table 3-1. Irrigation significantly reduced the EC of the soil, The decrease in EC was greatest in the irrigation only treatment followed by the gypsum and limestone treatments. The irrigation only treatment EC was about a quarter of the control EC at the end of the trial. The seawater and acid (also saline) treatments reduced the EC compared to the control but were 2-3 dS/cm higher than the irrigation, gypsum and limestone treatment at the end of the trial. pH was relatively unaffected by the treatments, even the acid treatment (following by 3 neutral River Murray irrigations) did not reduce the final pH.

The gypsum, irrigation only, and limestone treatments were effective in terms of increasing exchangeable Ca with an approximately doubling compared to the control (Table 3-1). Correspondingly exchangeable Na was reduced in these treatments. Seawater and drainage increased the exchangeable Ca only slightly compared to the control. The total CEC did not vary significantly among the different treatments, averaging approximately 40 cmol+/kg.

All treatments have large saturated hydraulic conductivity (Ks) values at the soil surface (i.e. ~10^{-4} m/s) and they are all within an order of magnitude of one another (0.7 to 2.0 x 10^{-4} m/s) (Table 3-1). A comparison shows the largest mean Ks for the Murray River irrigation water treatment and the smallest mean Ks for the Control (drainage only) treatment. We also measured K_s at 50cm on one of the plots and found it to be approximately 1 order of magnitude smaller than any of the surface Ks values, suggesting any amelioration treatments to remove salt need to take into account the potential hydraulic bottleneck with depth. Having said this, Ks values in the order of 10^{-5} m/s in this layer are still quite large for heavy clay soils so may enable sufficient leaching. If leaching of salt was an issue, mole drainage at the bottleneck depth could help alleviate this (i.e. moles are installed around 45cm depth and extending to the side and/or main drain).

Despite the large improvements in some treatments (irrigation only, limestone and gypsum application plus irrigation), all the soils at the end of the trial were still classed as saline and sodic. Only 4 irrigations (simulating ELMA application) were undertaken in the trial whereas over a full commercial irrigation season of 14+ irrigations the salinity dilution effect would be much higher

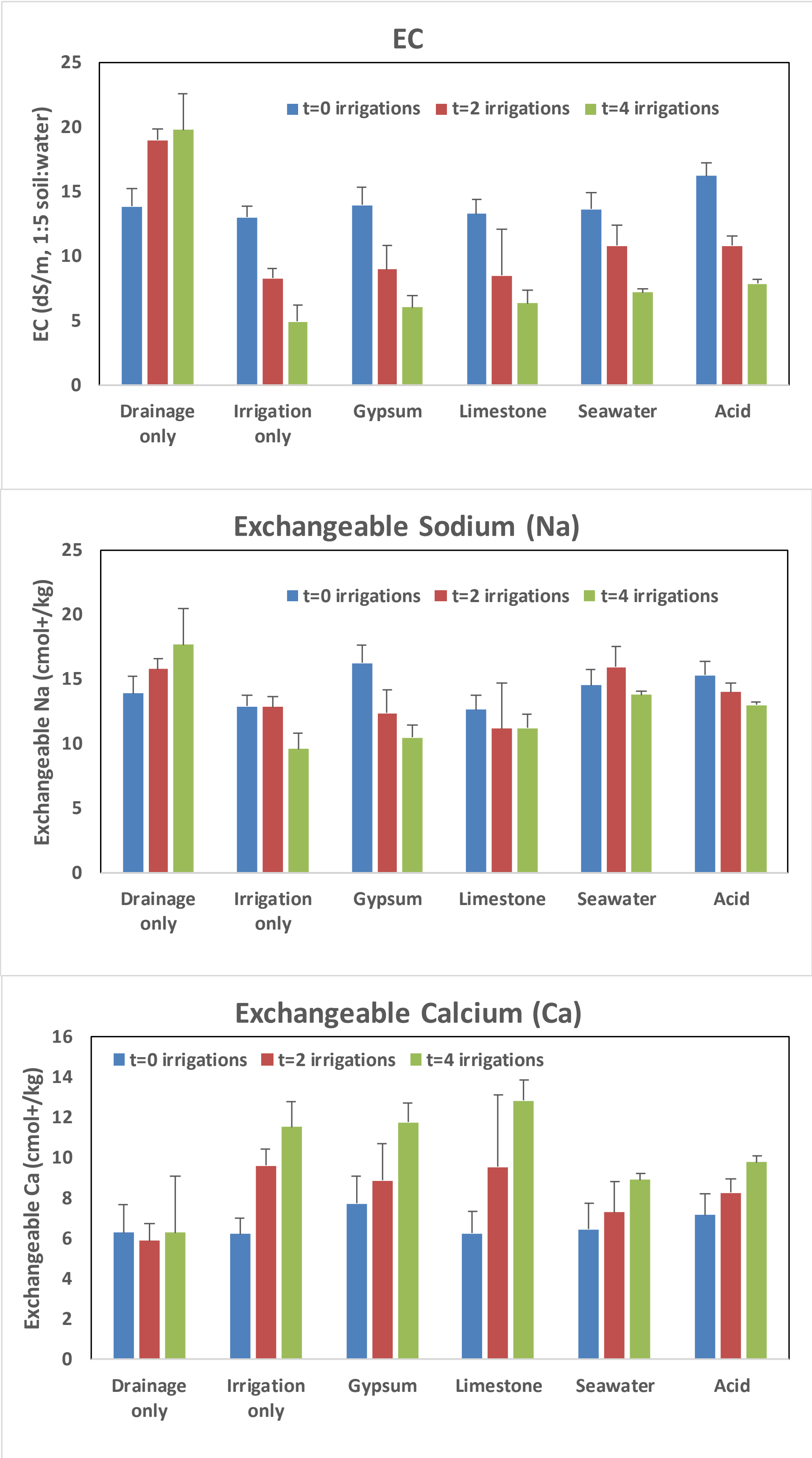


Figure 3-4 Electrical conductivity (EC, 1:5), exchangeable sodium and calcium at t= 0, 2 and 4 irrigations in the saline soil recovery trial. Note: the drainage only treatment did not receive any irrigations but samples were taken at the same time as the other treatments.

Table 3-1 Mean and standard deviation in electrical conductivity (EC, 1:5 soil water solution), pH, exchangeable cations (Ca, Mg, Na, K), exchangeable sodium percentage and saturated hydraulic conductivity from the treatment types

Treatment		E.C. dS/m	pH	Ca cmol+/kg	Mg cmol+/kg	Na cmol+/kg	K cmol+/kg	Σ Exch. cations	CEC	ESP %	Ks m/s
Drainage only	Mean	**19.8**	**6.5**	**6.2**	**13.7**	**17.7**	**1.5**	**39.1**	**40.0**	**44.2**	**7.0E-05**
(control)	SD	2.8	0.2	1.1	0.9	3.6	0.0	3.3	1.2	8.8	9.6E-05
Irrigation only	Mean	**4.9**	**6.9**	**11.5**	**15.0**	**9.6**	**1.2**	**37.3**	**42.6**	**22.3**	**2.0E-04**
	SD	1.3	0.1	0.8	1.3	1.9	0.2	4.1	1.9	3.6	1.2E-04
Gypsum	Mean	**6.0**	**6.9**	**11.7**	**14.9**	**10.5**	**1.3**	**38.3**	**41.1**	**25.6**	**1.1E-04**
	SD	0.9	0.1	1.3	1.1	1.9	0.1	0.7	1.2	5.2	9.3E-05
Limestone	Mean	**6.4**	**7.4**	**12.8**	**15.8**	**11.2**	**1.4**	**41.2**	**41.7**	**26.8**	**1.4E-04**
	SD	1.0	0.2	1.2	1.2	0.7	0.1	0.9	0.5	1.5	7.8E-05
Seawater	Mean	**7.2**	**6.9**	**8.9**	**15.1**	**13.7**	**1.7**	**39.4**	**42.4**	**32.4**	**1.1E-04**
	SD	0.3	0.1	0.7	0.7	0.9	0.1	0.4	0.8	2.1	7.0E-05
Acid	Mean	**7.9**	**6.9**	**9.7**	**16.5**	**12.9**	**1.4**	**40.5**	**41.6**	**31.2**	**1.5E-04**
	SD	0.3	0.0	1.4	1.7	0.3	0.1	2.9	1.9	2.1	9.3E-05

4 HYDROLOGICAL AND SALT MODELLING

4.1 BACKGROUND

Activity 4 *- Numerical (Hydrus 2D/3D) and analytical hydrological and salt transport models were developed using the measured groundwater levels, soil moisture, and soil salinity collected during the field trials. The models were used used to test various irrigation, drought and climate scenarios with the aim to optimise strategies (maintain soil moisture, prevent soil cracking, maintain groundwater levels, manage salinisation) to protect the LMRIA into the future.*

4.2 HYDROGEOLOGY

The general hydrogeology of the LMRIA is described by Barnett et al. (2003) (Figure 4-1) on the basis of drilling data and subsequent monitoring of bores at Mobilong, Toora and Mypolonga regions. Their results indicated that the general regional groundwater water flow is towards the centre of the swamp area and salt discharge is about 5 tonnes/day. There is some shallow groundwater flow out from the river to the swamp.

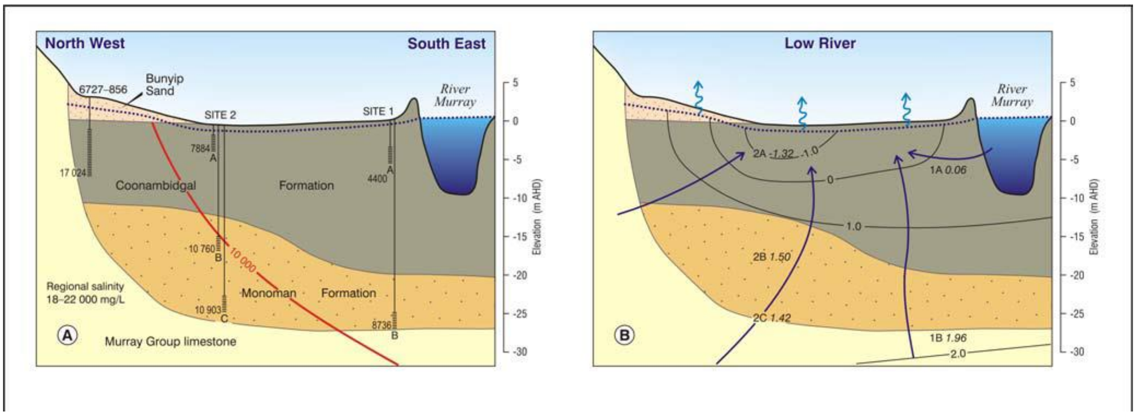


Figure 4-1. Mobilong hydrogeology section (Barnett et al., 2003 Figure 9).

4.3 HYDRUS2D MODEL BRIEF DESCRIPTION

The HYDRUS2D model (Simunek et al., 2012) is a model for solving water and solutes in a variably saturated layered porous media using a finite element spatial structure. It solves the Richard's equation for water flow and the advection dispersion equation for solute transport in a rigid porous media. Details of the model are given in Simunek et al. (2012). HYDRUS2D provides a flexible modelling platform it maintains its precision by adjusting the Courant number (Cr):

$$Cr = v\frac{\Delta t}{\Delta x} \qquad (1)$$

v is the velocity (m/s)

Δt is the time step (s)

Δx is the space step (m)

to be less than 1 by adjusting Δt. This means that there is a trade off between the size of the space steps and the time step range that can be used for the velocity range that will occur for a particular problem.

When solutes are modelled another criterion the Peclet number (*Pe*):

$$Pe = \frac{q\Delta x}{D} \qquad (2)$$

q is the pore water velocity (v/θ) (m/s)

θ is the volumetric water content (m^3/m^3)

D is the dispersion coefficient (m^2/s)

is introduced and for stability *Cr.Pe* must be less than 2. This usually results in the requirement that Δx is reduced which results in Δt having to be reduced. This can lead to models where it becomes difficult if not impossible to get results for solutes.

Thus in using such models careful selection of the domain (spatial extent of the model) and the boundary conditions are vital to develop computationally tractable models. This is part of the 'art' of modelling.

4.4 LMRIA HYDRUS2D Model Structure

The problem for the Mobilong swamp and the relevant bores are showed in Figure 4-2. The domain was cut in two at the second drain to reduce the total domain size and to see if this would give two domains which could fit together.

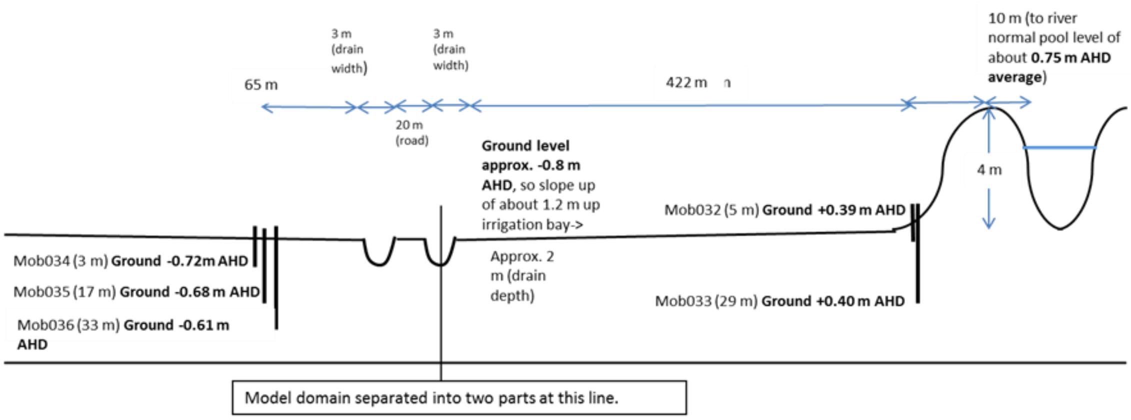


Figure 4-2. Schematic diagram for Mobilong swamp (not to scale).

4.5 Upslope Domain, Gridding, Soil Layers and Boundary conditions.

The domain, grid, observation nodes, boundary fluxes and layers are shown in Figure 4-3 for the up slope area. The thickness of the soil layers is 4m, 11m and 19.34 m respectively for layers 1, 2 and 3 with the total domain depth approximately 34.4 m. The variable flux on the upper boundary was determined from the bore results for Mob 34.

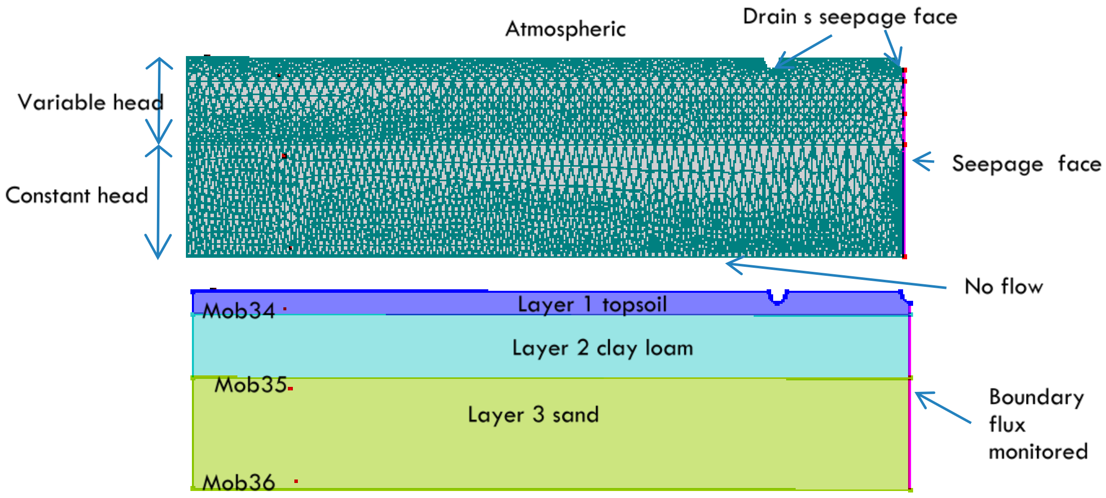


Figure 4-3. *Domain, griding and boundary conditions for HYDRUS 2D upslope model in upper panel. The lower panel shows the layers, observation nodes (corresponding to the bores Mob 34, Mob 35 and Mob 36) and the boundary flux monitoring on the lower face. The domains have been stretched in the depth direction to make them easier to view.*

The atmospheric flux was taken from the simulations used for the LMRIA project (Mosley et al., 2014b) and the data is shown in Figure 4-4. The model will adjust the evaporation flux to be the lesser of the PET or the flux that can be transport through the soil surface. The maximum potential that the soil surface can decrease to was set at -100 m.

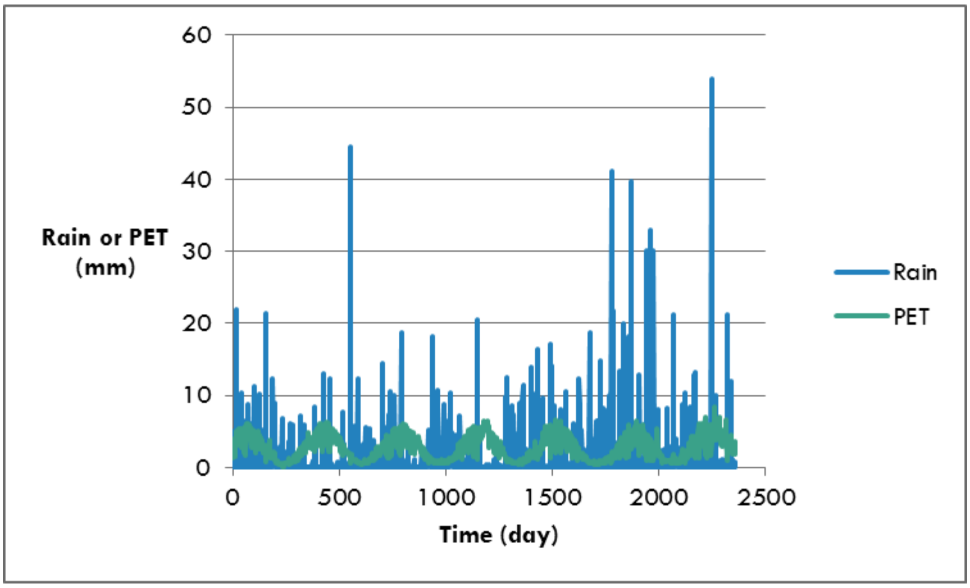


Figure 4-4. *Atmospheric boundary conditions (rain and potential evaporation (PET)).*

The boundary condition on the drains was set as a seepage face with water passing through this when there is a positive potential (head) on the surface and reverting to an atmospheric flux when the potential was less than zero. A seepage face was applied on the lower boundary to simulate flow into the downslope area and towards the river.

The initial conditions were taken as a pressure head equivalent to the depth and in equilibrium with the soil within the domain. This results in an almost linear increase in pressure from zero at the surface to a head equivalent to the depth within the soil. The effect of this initial condition is lost within the first 20 days.

The soil parameters were chosen on the basis of existing data and information in the bore logs. The soil moisture characteristics of the soil were measured on cores taken from the site. Two cores were taken and triplicate samples from each of three layers were used in determining the soil moisture characteristics. More details are given in Cook et al. (2017). The average moisture characteristics for each layer from the six samples was obtained by fitting the data to the van Genuchten equation using the RETC program (van Genuchten et al. 2004) and are presented in Table 4-1. These give the parameters for the top two layers in the model and the third layer was estimated for a sand from the HYDRUS library. The top layer corresponds to the 0-0.1m depth layer in Cook et al. (2017). The values for the 0.1-1.0 m in Cook et al. (2017) were also tried in the simulations but did not give results which were as good as using the 0-0.1 m layer. This is possibly because this layer controls the evaporative flux from the soil surface.

The comparison with the values used in the second report (Mosley et al. 2015) are also shown.

Table 4-1. *Soil hydraulic parameters for HYDRUS2D simulations. The properties are: the residual water content, θ_r (m^3/m^3); the saturated water content, θ_s (m^3/m^3); a parameter that determines the shape of the van Genuchten function, n; a parameter that determines the shape of the van Genuchten function, α (1/m); the saturated hydraulic conductivity, Ks (m/day); and a parameter that determines the shape of the Mualem function, l. The values used in an earlier report (old) and the values used here (new) are shown for comparison.*

Layer	Soil		θ_r		θ_s	n	α (1/m)	Ks (m/day)	l
1	topsoil	Old	0		0.662	1.143	3.22	6.0	0.5
		new	0.365		0.731	1.442	12.125	1.0	0.5
2	clay loam	Old	0.095		0.41	1.31	1.9	0.0005	
		new	0		0.689	1.0386	3.884	0.00204	0.5
3	sand		0.045		0.43	2.68	14.5	1	0.5

The saturated hydraulic conductivity (Ks) was taken initial taken from the values measured for the drainage only plot and these are the values indicated as old in Table 4-1. The new values were obtained by fixing the soil moisture characteristic properties and using the inverse function in to fit the borehole water level data. The fitted value for Ks value for the topsoil is similar to the and within the range of measured values (Table 3-1).

4.6 Downslope Domain, Gridding, Soil Layers and Boundary conditions.

The length of the domain for the downslope area is almost 4 times larger than the upslope area. This again has consequences when gridding the domain as there is now a larger area which means than the size of the grids needs to small enough to give the features required but not so large than computation time is excessive and the computation unstable. The domain, grids, soil layer, and boundary conditions are shown in Figure 4-5.

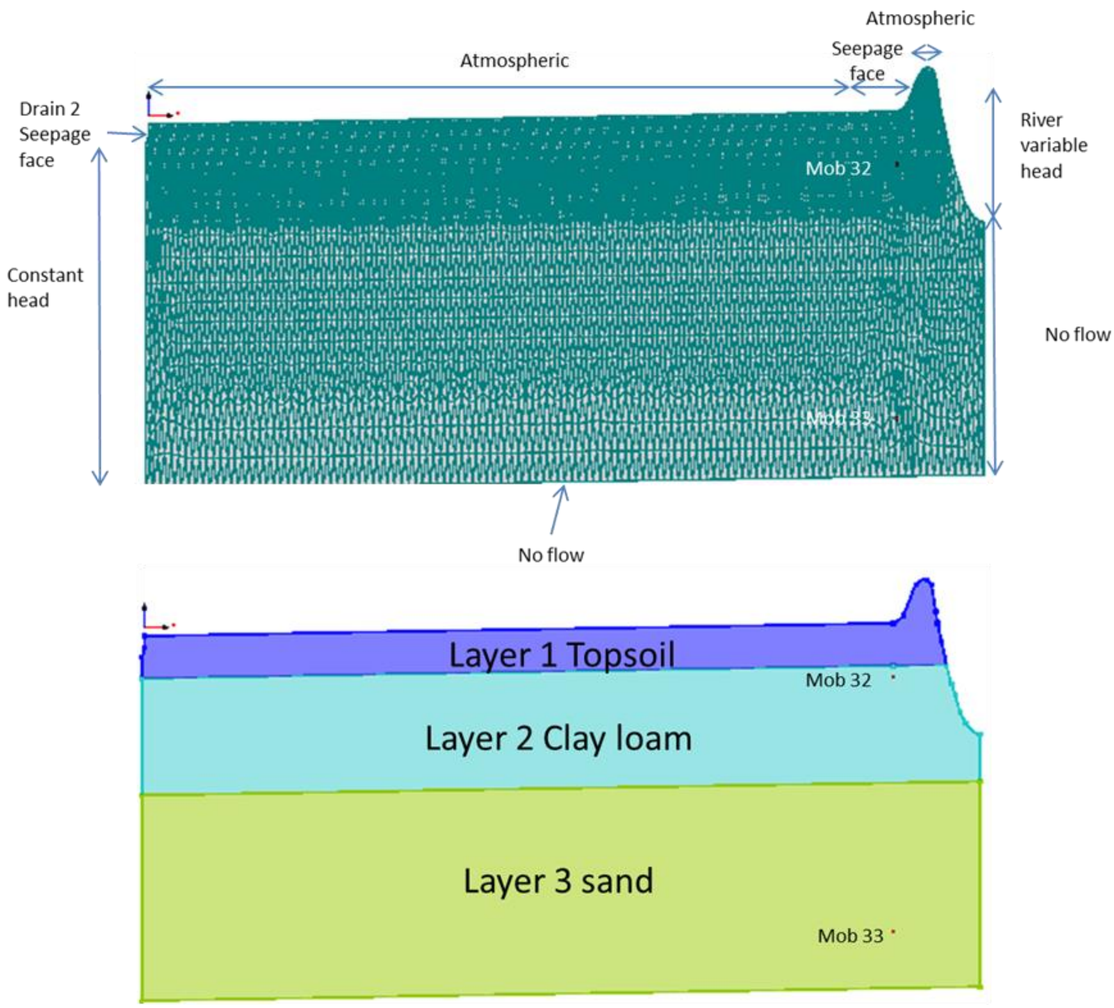


Figure 4-5. Domain, gridding and boundary conditions for HYDRUS 2D downslope model in upper panel. The lower panel shows the layers, observation nodes (corresponding to the bores Mob 32 and Mob 33). The size of the domain is approximately 471 m in length and 36 m in depth. The domains have been stretched in the depth direction to make them easier to view.

The river variable head data was adapted from the data used in the LMRIA modelling to reflect the river depth as indicated by Barnett et al. (2003) and the relative elevation difference and is shown in Figure 4-6. A seepage face is introduced on the bund wall away from the river. This reverts to an atmospheric condition when potential is negative. The top of the bund has an atmospheric boundary condition as does the rest of the upper surface of the domain.

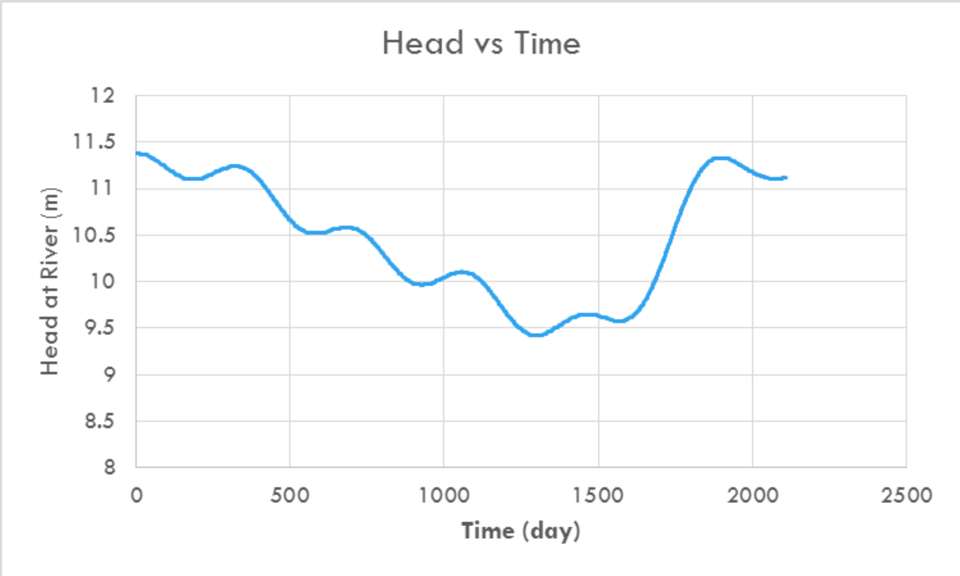


Figure 4-6. Head at the bottom of the variable head boundary condition (river) on the upslope domain.

The constant head condition used on the boundary with the upslope area was based on pressures monitored at the bottom of this boundary the interface between layers 3 and 2, the interface between layers 2 and 1 and the bottom of the drain 2 (Figure 4-7).

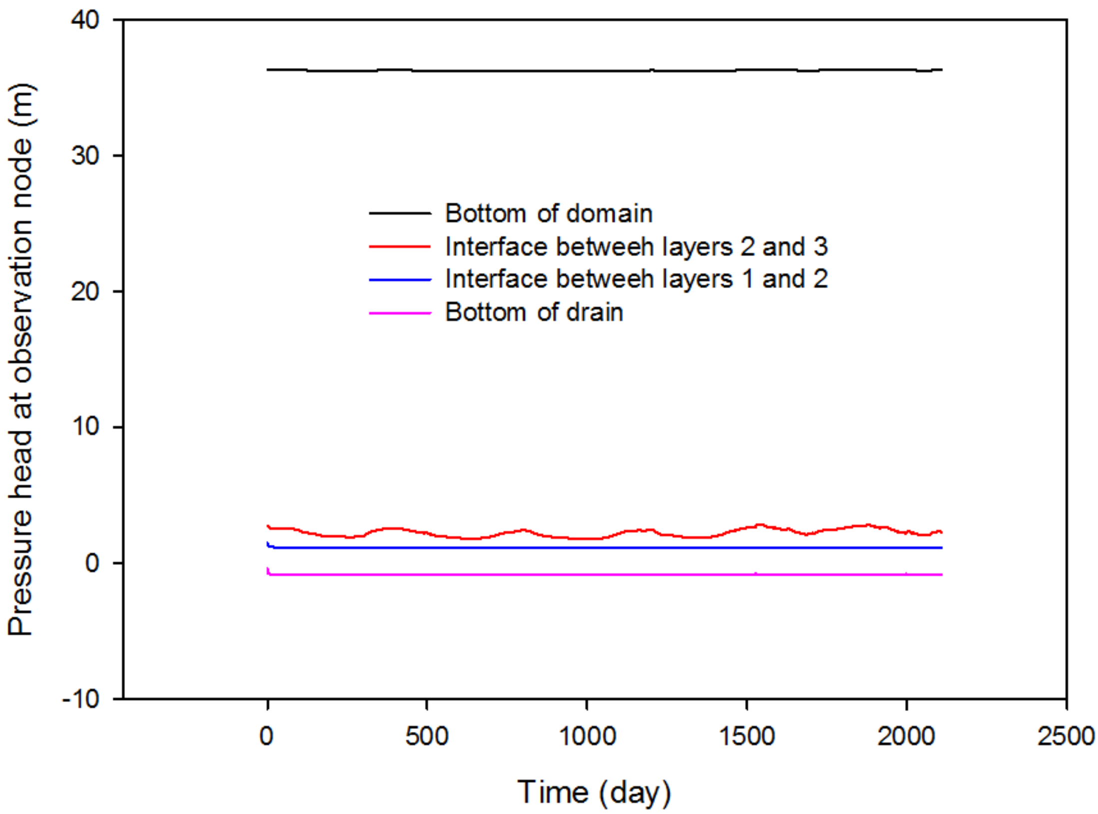


Figure 4-7. *Pressure potential head from observation points on the boundary between the upslope and downslope areas. The maximum variation in head was 0.735 m at the bottom of the drain 2.*

Flowing particles were introduced at various points in the domain, so that the water flow could be tracked and to give guidance as to whether solutes could be simulated using a one dimensional approach (HYDRUS1D). The pink lines in figure 4-8 show that the water in layer 3 is mainly horizontal from left to right and in the clay layer mainly vertical (Figure 4-8). The flow in layer 1 is a mixture.

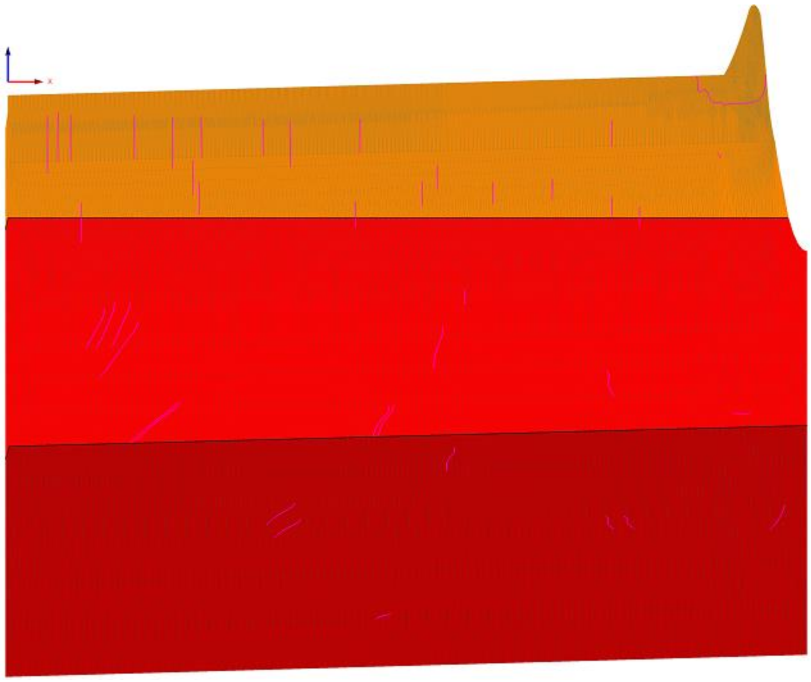


Figure 4-8. Flowing particle tracks (pink lines) for water flow in the domain during the simulation.

A no flow condition is imposed on the bottom boundary and the side below the river. These are considered reasonable as there should be a lack of flow at the river due to pressure from the other side and no flow is considered to come up through the bottom due to the sand layer being pressurised (Barnett et al., 2003).

4.7 Results Upslope Area

The pressure heads at the observation nodes corresponding to the bores are compared to measured values and shown to given a good fit (Figure 4-9). The heads are plotted as rswl which is the head compared to AHD (Australian Height Datum). The simulated deeper bores (Mob 35 and 36) show almost no change during the time period, whereas the measurements show a small variation due to probably lower water input to the sand aquifer during the drought. The use of the simple variable head condition has been sufficient to provide a good match with the MOB 34 bore data (Figure 4-9).

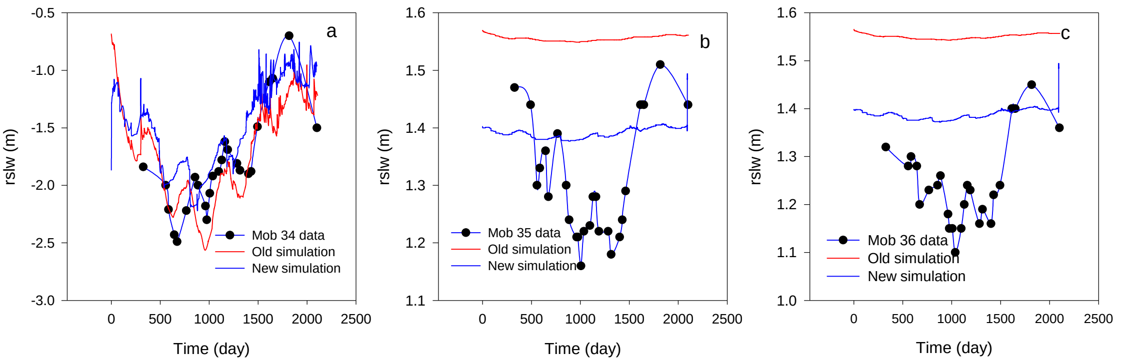


Figure 4-9. Comparison of water table heads (rswl = AHD – swl, swl is depth below soil surface) with time for the period from 23/10/2005 to 9/4/2012 for a) borehole 34, borehole 35 and c) borehole 36

The upslope area was simulated to get the pressure on the boundary with the downslope area and to consider the flux across this boundary. This can be obtained from the cumulative seepage face flux and is approximately 1.3×10^{-3} m^3/m^2/day. The reason this is approximate is that it is not possible to separate out the flux from the drains and also the fact that these drain faces will evaporate water when the potential on the face is negative. Thus this cumulative flux is greater than the flux to the upslope area. It still represents a transfer of approximately 1.2 mm/day for each meter of face in a horizontal (inter the page in the domain diagram).

The water content especially near the surface during the driest period (approximately 1200 days into the simulation) is of interest with regard to the extent of drying and depth. Figure 4-10 shows that the drying almost extended down towards layer 2.

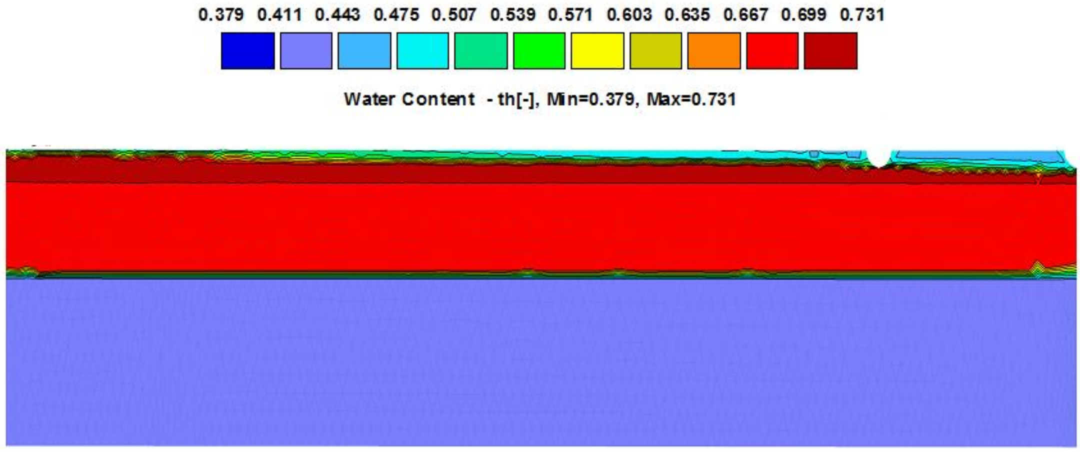


Figure 4-10. *Water content of upslope domain on day 1182. This shows that the drying front has extended all the way through layer 1.*

A cross-section graph through layer 1 shows that the drying front extended to about 2.5 m (Figure 4-11) at a point 96 m from the left hand face of the domain. This is generally consistent with the depth of acid sulfate soil oxidation in the drought.

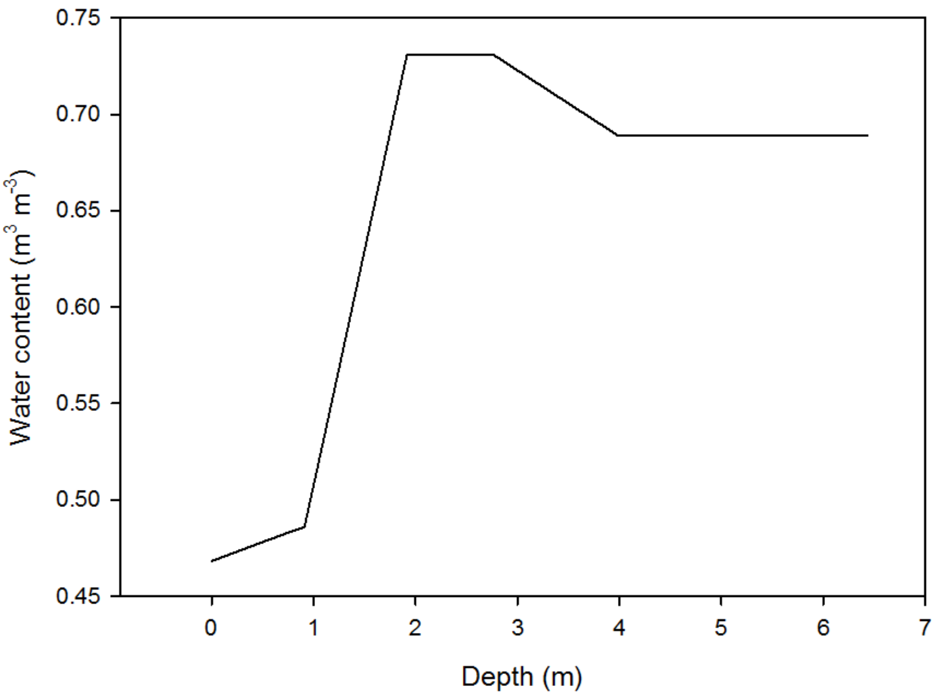


Figure 4-11. Water content versus depth on day 1181 for a point 96 m from the left hand face of the domain.

The potential evaporation during the simulation period was the largest surface flux component with a total of 5882 mm, while the total rainfall was 2088 mm. Due to surface drying reducing the ability of the soil to evaporate water the actual evaporation was 1309 mm (Figure 4-12). Surface runoff was a very minor component of the water balance with less than 1 mm occurring. The simulated infiltration was 2042 mm which is about 48 mm less than the potential the difference is due to rounding errors, rainfall directly into the drain and surface runoff. The other fluxes into and out of the domain are from the constant and variable heads on the upstream boundary (left hand side of the domain) and the seepage faces (drains and downstream boundary). The transfer from the upslope to the downslope area was simulated using a free drainage boundary condition on the right hand face of the domain with a slope of -0.0016 calculated as 0.04 mm day^{-1} The change in the soil water storage from the start to end of the simulation was small and equivalent to 6 mm of water depth.

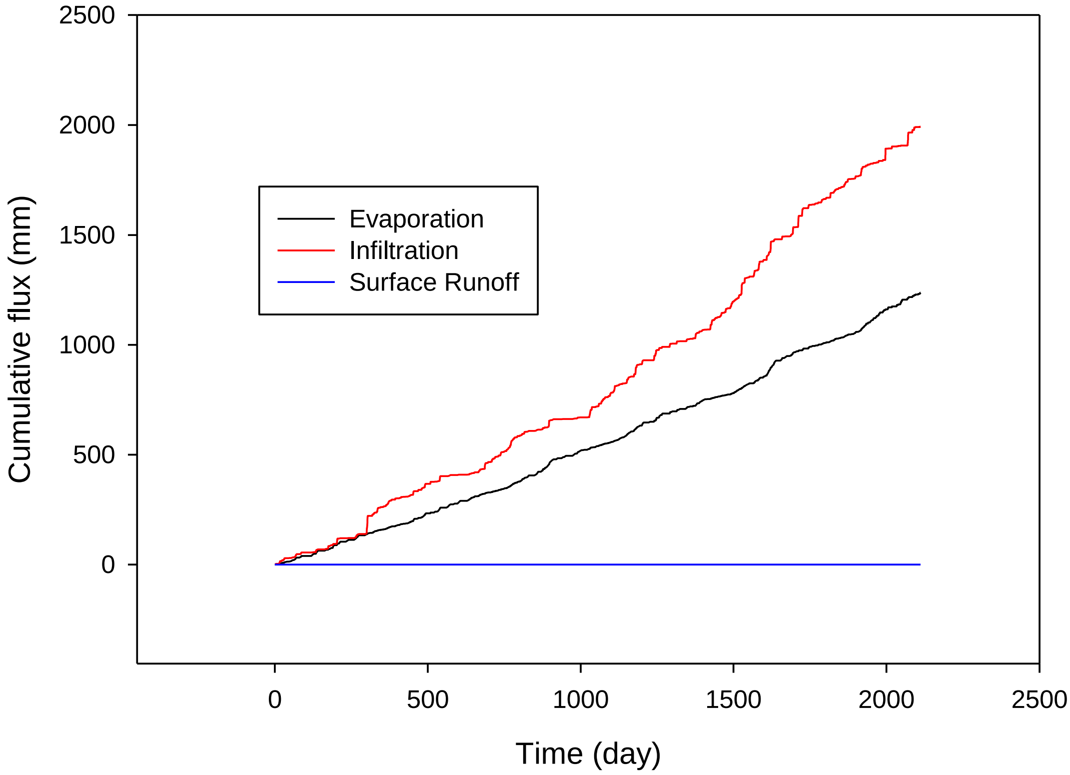


Figure 4-12. *Cumulative surface fluxes for upslope area during simulation.*

Flowing particles were introduced at various points in the domain, so that the water flow could be tracked and to give guidance as to whether solutes could be simulated using a one dimensional approach (HYDRUS1D). The pink lines in figure 4-13 show that the water in layer 3 is mainly horizontal from left to right and in the clay layer mainly vertical (Figure 4-13). The flow in layer 1 is a mixture with strong horizontal flow deeper in the soil and vertical nearer to the soil surface. The influence of the drain and transport to this can be clearly seen in these particle tracks.

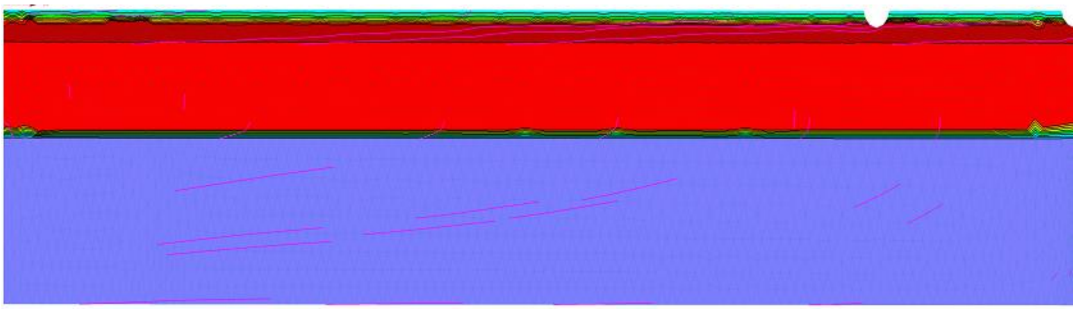


Figure 4-13. Flowing particle tracks (pink lines) for water flow in the domain during the simulation.

From the above flow information, a HYDRUS2D model, equivalent to one dimensional (1D) flow (0.5 m wide), with was developed using the top two layers and salinity introduced as a sodium equivalent as no chemical composition data was presented in Barnett et al. (2003). The reason for including the only the top two layers is that the flow in the sand is essentially horizontal, so the salinity at the base of the clay layer can be considered to be constant. Based on the salinities found by Barnett et al. (2003) we chose this constant value to be 10 kg/m^3 and the initial concentrations were chosen as a linear increase from 10 to 7.8 kg/m^3 in layer 2 (clay loam) and 7.8 to 4.4 kg/m^3 layer 1 (topsoil). Grid spacing, inclusion of transpiration via plants, irrigation and climate change scenarios were simulated with this 1D. These simulations would have been difficult if at all possible with the large 2D domains.

4.8 Results Downslope Area

The downslope area is much larger and getting a grid within the domain proved to be more time consuming and difficult than for the upslope area. The best fit that could be obtained to the bores is shown in Figure 4-14. The rise in the head measured in the bores is now simulated quite well with the new soil data. There the discrepancy in the timing of water table rise is now similar and better than those in the preliminary report (Cook et al. 2015). The results for borehole 33 which is at 26.5 m depth are underestimated.

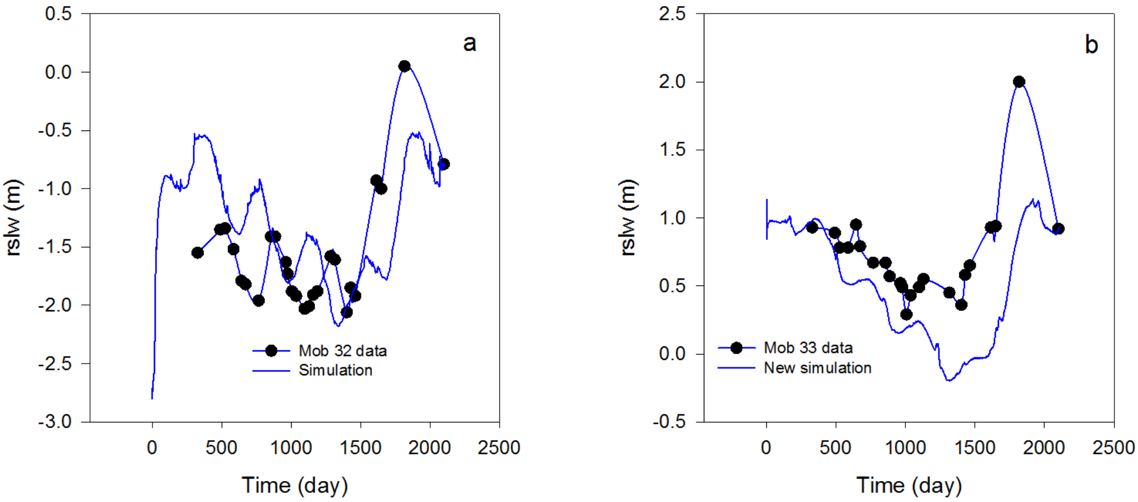


Figure 4-14. Comparison of rswl versus time for simulation and measured bores for downslope area; a) borehole 32 and b) borehole 33.

Due to the pressure heads from both the river and upslope area the pattern of the water content distribution in the domain on day 1181. This now shows a saturated wedge occurring in layer 1 at both ends of the domain due to inflow from upslope and the river (Figure 4-15).

The flow pattern in the down slope domain was investigated by using flowing particles. This showed that the flow in the layer 3 was essentially horizontal until hear the right hand face and then becomes essentially vertical. This suggests that salt from this deeper layer could move into the river via layer 2 due the pressure head gradient. This warrants further investigation. There is transport of water particles from the river through layer 1 initially horizontally of up to 40 m and then vertically to the surface. Flow in layers 1 and 2 away from either face is essentially vertical.

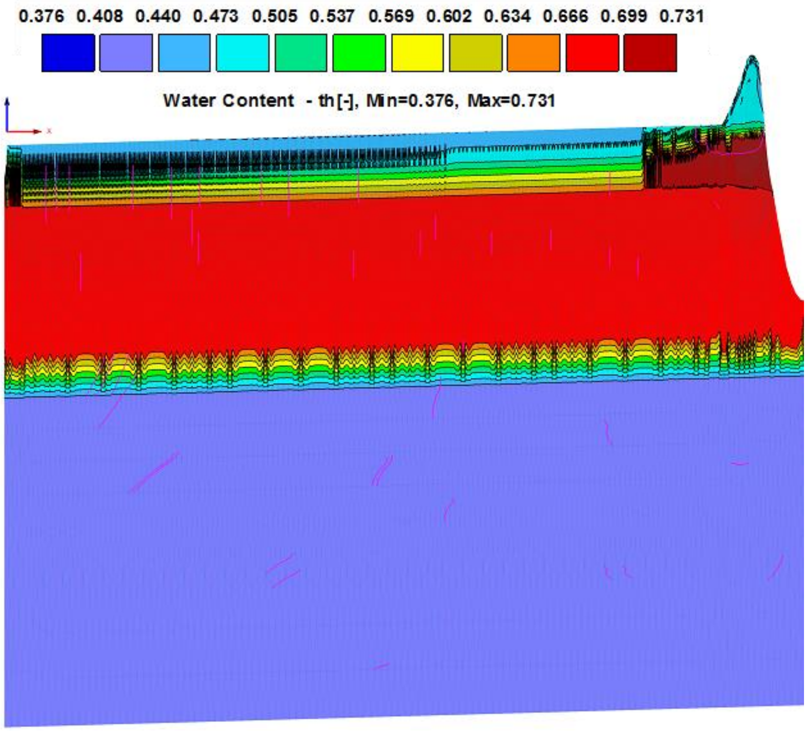


Figure 4-15. *Water content in the domain at day 1180. The effect of flow from the upslope and river are seen in the saturated wedge in layer 1 at both ends of the domain, but particularly at the river end*

4.9 ONE DIMENSIONAL MODELLING GRIDDING

The effect of the grid spacing on the transport of water and salt was investigated with the 1D model. Three different grid spacings were used a coarse, fine and very fine grid. The depth of the domain was taken as only the two top layers as the two dimensional simulations showed that because of the low hydraulic properties of the second layer the third layer could be ignored.

Observation nodes were placed at the surface, 0.3, 0.5, 1, 4, 10 and 14.5 m depth. The salt concentration was set as for the 2D simulations with a concentration of 10 kg m^{-3} set constant at 14.5 m and initial conditions of 10 to 7.8 kg m^{-3} linearly increasing within layer 2 (top at 4 m) and a linear increase with depth from 4.4 kg m-^{3} at the surface to 7.8 to kg m-^{3} at the layer ½ boundary. The number of nodes increased from 146 for the coarse grid to 246 for the fine grid and 406 for the very fine grid. The object is to get a grid has enough precision to give consistent results but is not computationally difficult because of the number of nodes at which the equations must be solved. The salt concentration is the most sensitive to the grid precision as both stability criteria for the Courant and Peclet numbers are required. Salt concentration at 0, 0.3, 0.5 and 1 m shows that the coarse grid gave only slightly different results from the coarse grid (Figure 4-16). As the accurate is okay with the coarse grid this will be used for the rest of the one dimensional simulations.

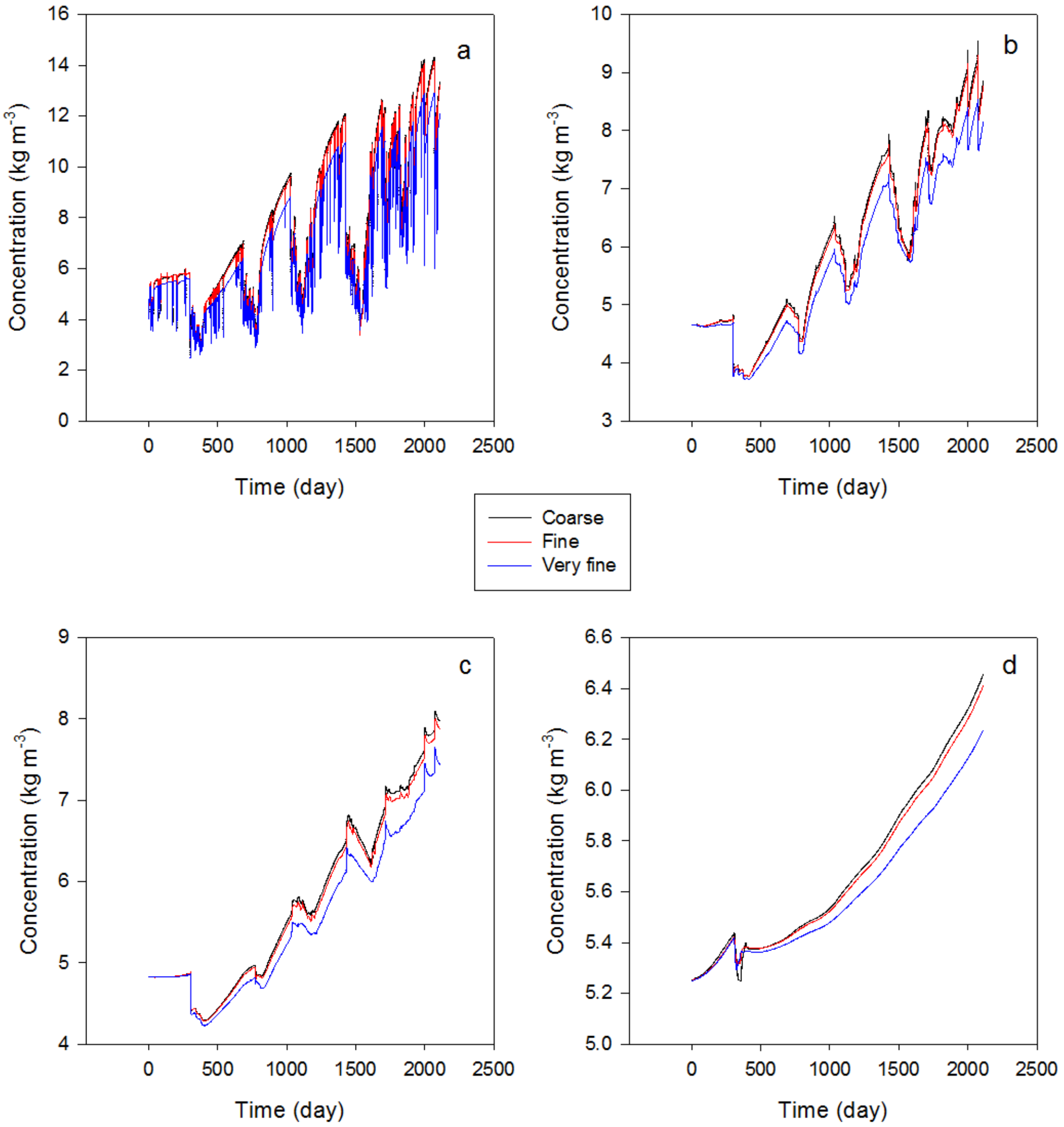


Figure 4-16. Comparison of salt concentration at a: soil surface, b: 0.3 m depth, c: 0.5 m depth and d: 1 m depth for three different grid spacing. The time period of the simulation is from 1/7/2006 to 10/4/2012.

4.10 Effect of pasture on water content and salt concentrations

The 2D simulations were done with only evaporation as the surface boundary condition but mostly the soils in the Mobilong will have vegetation, most grass growing on them. Simulations using the very fine grid spacing were simulated with both a pasture growing (transpiration and evaporation) and no vegetation (evaporation only). The introduction of transpiration required partitioning of the potential evapotranspiration (PET) into transpiration and evaporation. Assuming a leaf area index of 3 this results in 75% of PET for transpiration and 25% for evaporation. With no pasture evaporation is taken as 100% of PET. The results for salt again are used as the indicator of the effect and it can be seen that the introduction of pasture results in higher concentrations at all depths (Figure 4-17). This is because with an assumed rooting depth of 0.5 m (linear decreasing root length density from 1 to 0 over this depth) more water is extracted from the soil. This rooting depth is considered an average as older (paspalum type) pastures may have a greater rooting depth to 1 m whereas newer (rye grass/clover) pastures may have a shallower depth of around 0.3 m)(Philcox and Douglas 1990). The simulations show that with no plants the cumulative evaporation in the approximately 6 years would be 2539 mm, while the combined evaporation (616 mm) and transpiration (1923 mm) is 2324 mm, 215 mm more. Since the plant does not take up the salt this remains in the soil hence the greater salt concentrations. We see the largest difference at the 0.3 m this is due in part to the assumed decrease in the root length density and water extraction with depth.

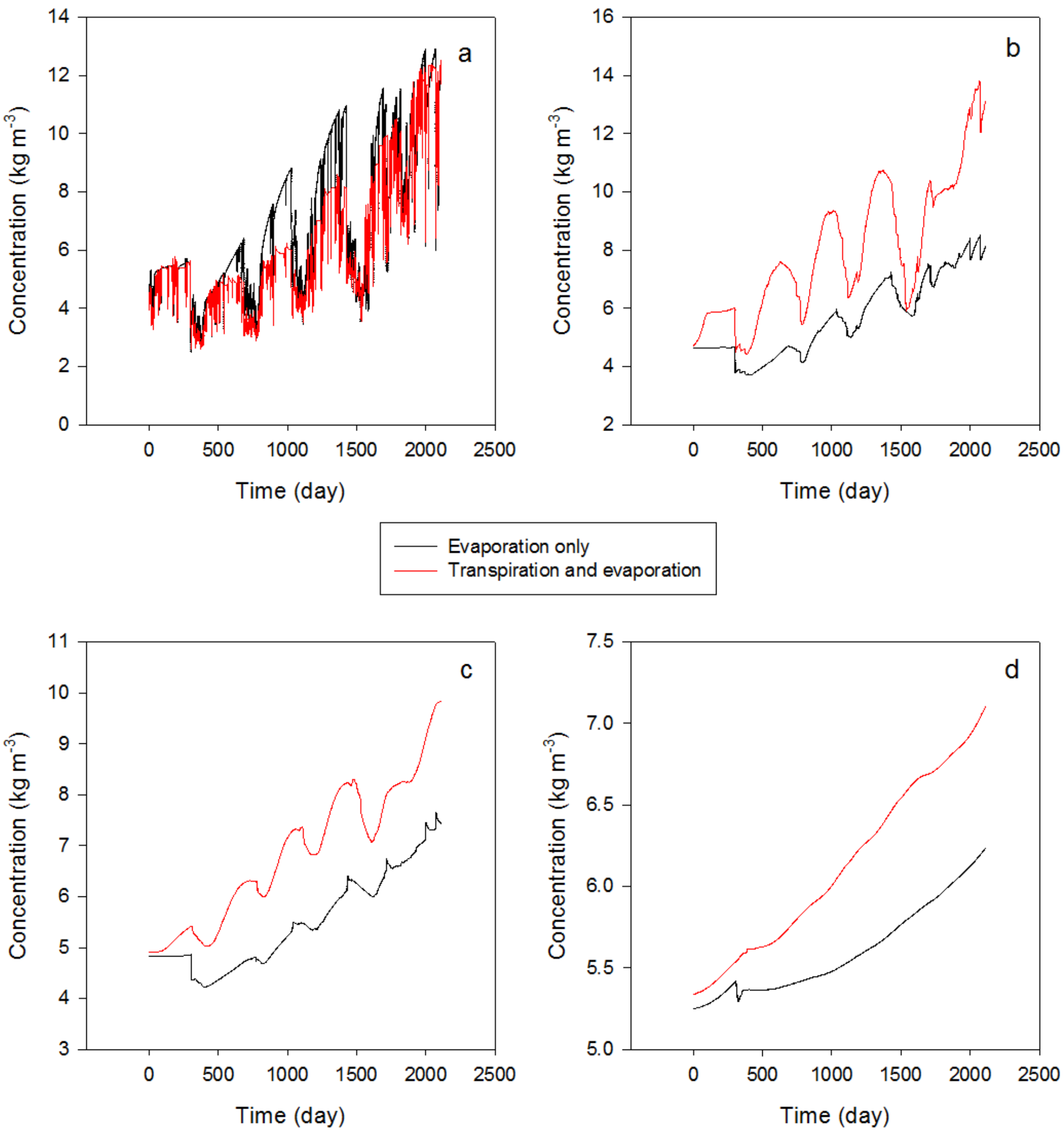


Figure 4-17. Simulations of the salt concentration with (transpiration plus evaporation) and without pasture (evaporation only) at a: soil surface, b: 0.3 m depth, c: 0.5 m depth and d: 1 m depth for three different grid spacing. The time period of the simulation is from 1/7/2006 to 10/4/2012.

For the rest of the simulations pasture will be used in the simulations.

4.11 Irrigation scenarios

The period used for the simulations above is during the 'millennium drought' so simulations were carried out to consider the irrigations that may have been required if water had been available during this period. The control is the simulation with the very fine grid and pasture. Four irrigation scenarios were chosen based on recommendations by Philcox and Murray (1990):

1. T1 Irrigation when the cumulative deficit (Σrainfall – PET) reached -100 mm,
2. T2 When the soil matric potential at 0.3 m depth reached -20 kPa
3. T3 When the soil matric potential at 0.3 m depth reached -30 kPa
4. T4 When the soil matric potential at 0.3 m depth reached -40 kPa

Scenario T3 was not considered by Philcox and Murray (1990) but we have added this intermediate scenario. All irrigations applied 100 mm of water.

The number of irrigations applied by the triggered irrigation model was 37, 24, 21 and 20 respectively for scenarios 1 to 4 respectively. The timing of the irrigations is shown in figure 4-18. These simulations were carried out using only the top 1 m (only layer 1) of soil and applying a ditch drainage bottom boundary condition with a drain spacing of 100m. This is similar to the actual conditions at the Mobilong site.

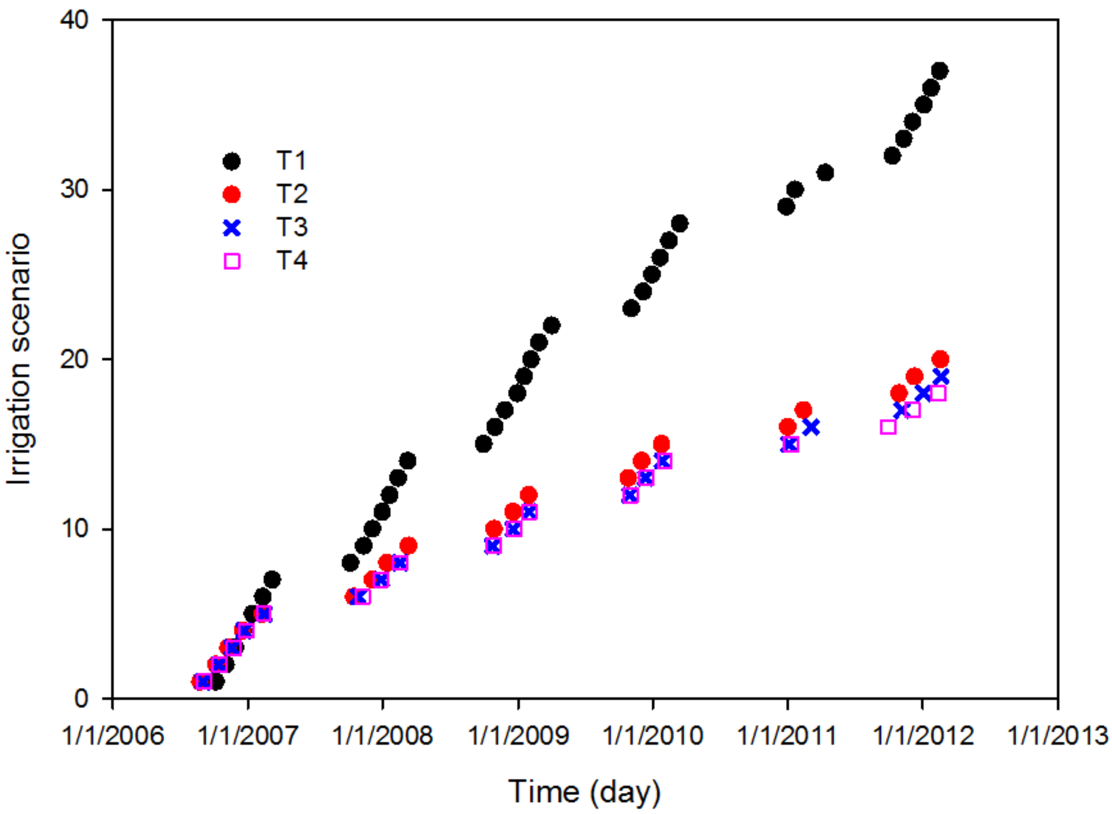


Figure 4-18. Timing of irrigations for each of the irrigation scenarios.

Scenario T1 applies the most water with 37 irrigations giving a total of 37 ML ha^{-1} of water use in this period, scenarios T2, T3 and T4 would apply 20, 19 and 18 irrigations and similarly water use would be 20, 19 and 18 ML ha^{-1}. On average this is approximately 3 – 6 irrigations per year. The least number of annual irrigations were in the 2010-11 year with 2 irrigations by scenarios T2-4 and 3 for scenario T1. The most irrigations were predicted in the year 2006-7 with 5 irrigations for scenarios T2-4 and 7 for scenario T1. The T1 scenario cannot be successfully run in HYDRUS without altering the boundary conditions in a way that does not allow comparison with the other irrigation scenarios. This is because scenario T1 in the simulation this scenario applies too much water and this suppresses the transpiration due to aeration problems and leads to numerical instabilities in the solution. Thus the T1 scenario is likely to result in excessive irrigation if applied at this site.

All scenarios result in similar results for the salt concentrations and water contents at the soil surface due to the strong atmospheric forcing of the evaporative flux (Figure 4-19a). As the depth increase there is a divergence in salt concentration between the irrigation scenarios compared to no irrigation and a small difference in the irrigation scenarios (Figure 4-19). This is due to the irrigation allowing flushing of the salt to the drains.

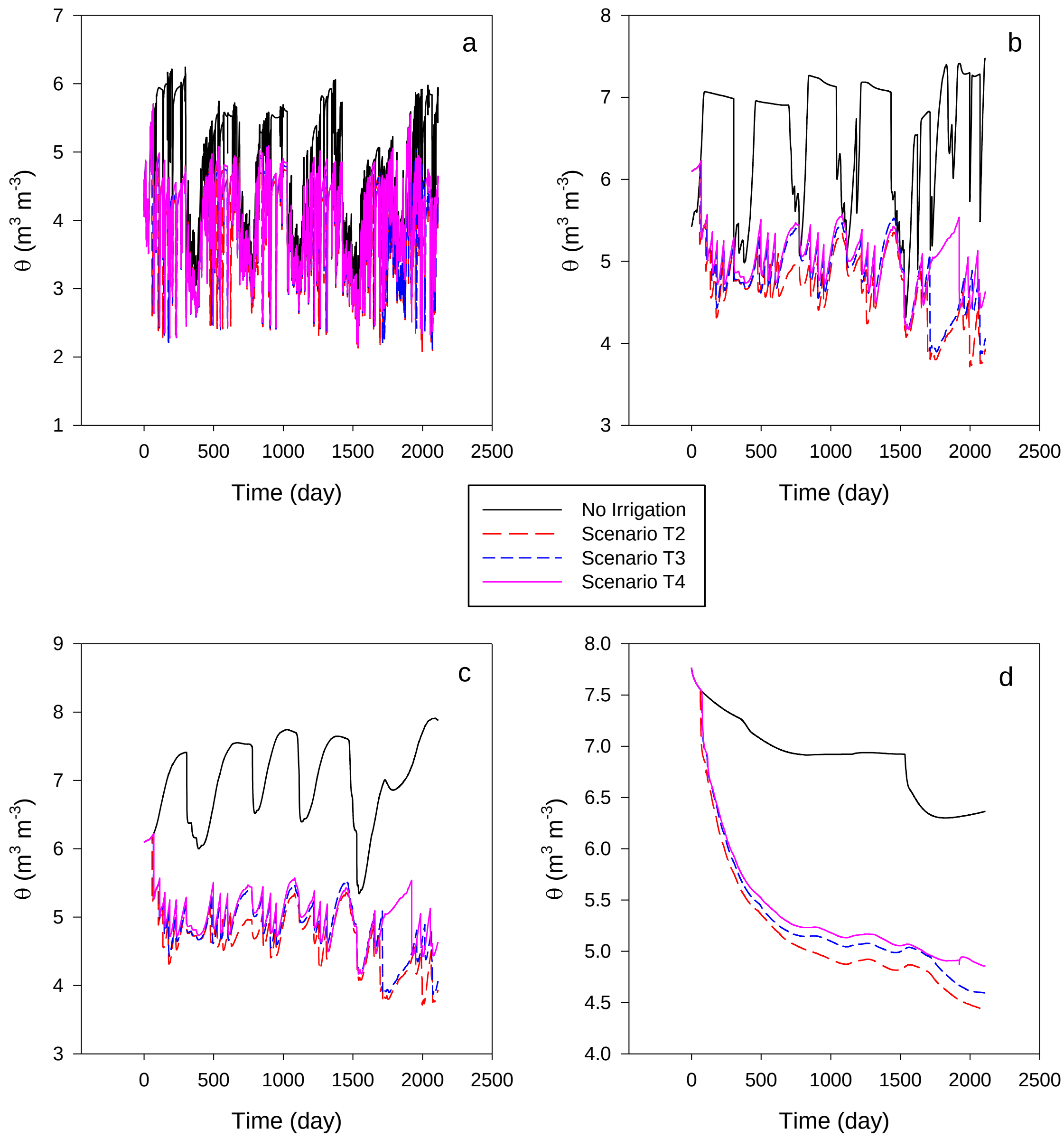


Figure 4-19. Salt concentrations (C) with time for non-irrigated and irrigation scenarios at depths of a: 0 m, b: 0.3 m, c: 0.5 m and d: 1 m.

This increase in salt concentration will affect plants and could result in the formation of saline scalds and seeps when if no irrigation is applied.

The earlier modelling to compare grid spacing and pasture allows us to estimate the upward flux of salt to be about 62 tonnes of salt would have entered into the upper layers of the soil over the period of the simulation. Given the time period this is equivalent to about 10.3 tonnes per year and will need to drained if the soil is not to be salinized with time.

The water content in the non-irrigated simulations also shows that the water content at the surface will still decrease to low values even with irrigation which may result in surface cracking.

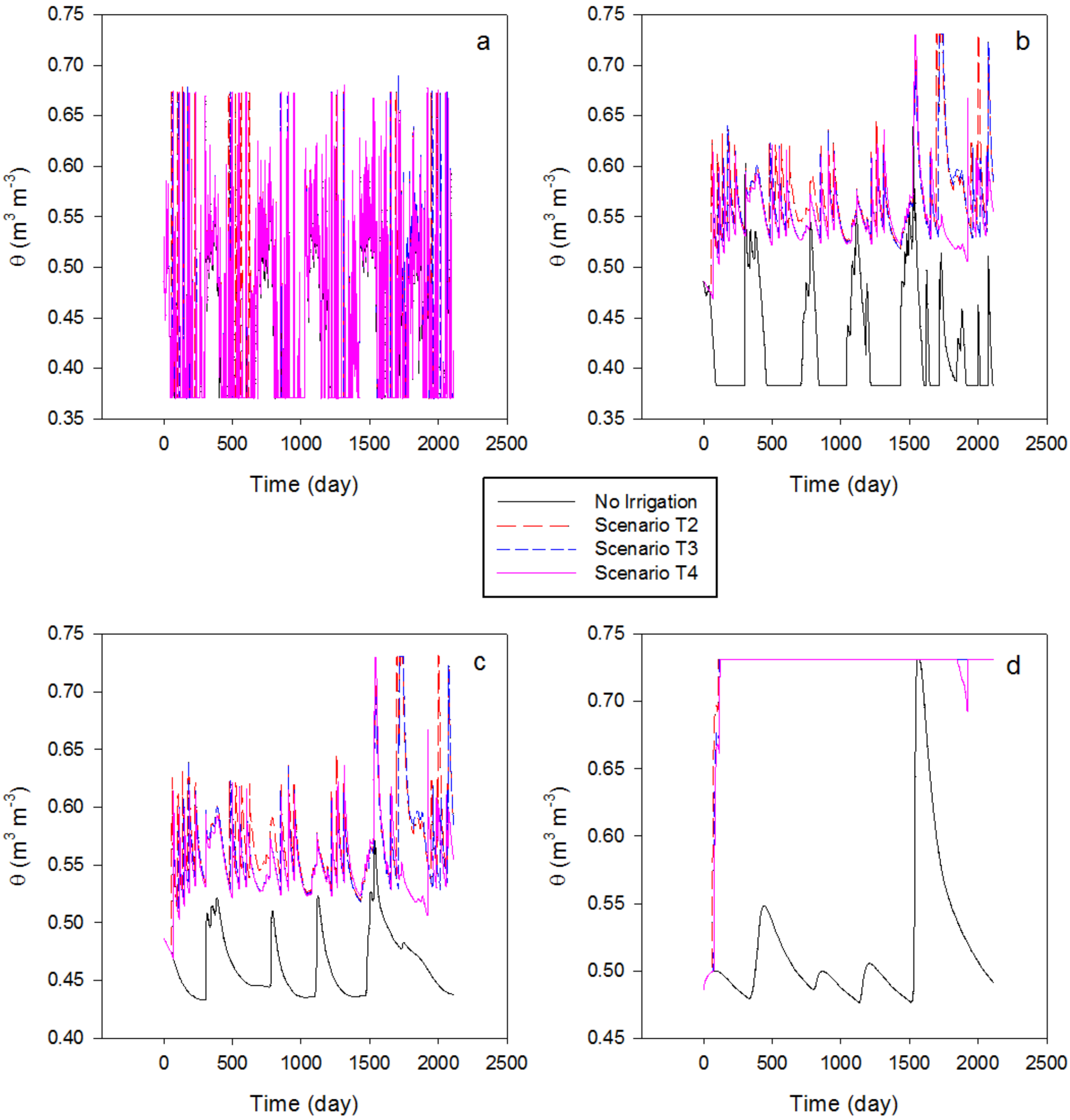


Figure 4-20. Water content (θ) with time for non-irrigated and irrigation scenarios at depths of a: 0 m, b: 0.3 m, c: 0.5 m and d: 1 m.

The water content at greater depths though is much greater for the irrigation scenarios which will mean that this cracking will not propagate down the soil profile (figure 4-20). It can also be seen that for the irrigation scenarios, scenario T2 results in the highest water content at depth and a similar result would be expected for scenario T1. At 0.5 and 1 m depth the water content is still well above water contents where shrinkage problems may occur. During times like the millennium drought fewer irrigations could be used annually to prevent severe drying to depth. Simulations which look at such targeted irrigation strategies should be attempted. The strategies for these would need to be developed by consulting water managers and other stake holders.

4.12 Climate change simulations

The effect of climate change on South Australia may result in (Gibbs et al., 2013):

- increased temperatures
- reduced rainfall
- increased rainfall variability
- increased evaporation
- significantly increased frequency and severity of drought

- changes in the frequency of extreme weather events, including flooding.

Here we wanted to estimate the effect on the water balance of the soil to changes in rainfall and evaporation amounts. Mobilong (longitude-35.05, latitude 139.33) was chosen and the climate for 2030 and 2050 generated along with the baseline climate data using the Long Paddock site (https://www.longpaddock.qld.gov.au/climateprojections/access.html). The baseline period was 1960-2010 as is recommended. The CSIRO Mk3.5 model was used and three climate projections AIF1, A1B and A2 emission scenarios (The State Government of Queensland, 2015) were chosen with medium climate change increases. The CO_2 assumed in these projections are shown in Table 4-2.

- The A1F1 scenario is the most recommended scenario with very rapid economic growth, population peak around 2050 followed by a decline and rapid introduction of new and more efficient technologies. It is fossil fuel intensive.
- A1B is similar to A1F1 but the energy usage is balance across all sectors and results in lower CO_2 concentrations.
- A2 is a preferred alternative to A1F1 and has a continuously increasing population and regionally orientated economic growth with more fragmented and slower technology change.

Table 4-2. Median of projected carbon dioxide (CO_2) concentrations at 2030 and 2050 for the three emission projectionss used.

Projection	**Median projected CO2 concentration (ppm)**	
	2030	**2050**
A1F1	449	555
A1B	447	522
A2	444	522

These percentage changes in the rainfall and potential evaporation (PET) for the climate projections are given in Table 4-3. These changes result in reduction in rainfall and evaporation (ET) for the projections compared to the baseline time period (1960-2010). The soil water balance is likely to be severely affected by the projected climate change. Rainfall is estimated to decrease by 10 - 12% by 2030 and further decrease by 2050 by 19 – 24% compared to the baseline. This is compounded by the increase in potential evaporation of 3 – 4% by 2030 and 6 – 8% by 2050.

Table 4-3. Reduction in rainfall and potential evaporation (PET) for the projections compared to the baseline time period (1960-2010).

Site	**Projection**	**2030**		**2050**	
		Rain (%)	**PET (%)**	**Rain (%)**	**PET (%)**
Mobilong	A1F1	-11.61	3.88	-24.36	8.33
	A1B	-12.05	4.02	-20.58	6.98
	A2	-10.53	3.49	-19.35	6.53

Simulations were carried out for all three climate change projections compared to the baseline simulations and the following information taken from these simulations:

- Minimum and maximum water content at the same depths 0, 0.3, 0.5 and 1 m
- Total transpiration and evaporation.

Initially we also calculated the time the soil would be below a minimum water content where shrinkage occurred. Given the new soil data a water content less than 0.25 or 0.3 cannot be simulated. Such water contents are less that the permanent wilting point (-154 m of water), so will only occur near the surface under very dry conditions. The cracks formed can propagate downward due to the soil on the edges of the cracks being directly open to the atmosphere. At this site, we would not expect excessive deep cracking.

The minimum and maximum water contents recorded at four depths were similar for the baseline, all climate change projections and for both 2030 and 2050 (Table 4-4).

Table 4. Percentage of days where the water content (q) is less than 0.25 or 0.3 and maximum or minimum water content at depths of 0, 0.3, 0.5 and 1 m depth for the baseline and three climate change projectionss at 2030 and 2050.

Projection	Depth (m)	Baseline		2030		2050	
		θ_{min}	θ_{max}	θ_{min}	θ_{max}	θ_{min}	θ_{max}
Baseline	0	0.38	0.62				
A1F1				0.38	0.62	0.38	0.62
A1B				0.38	0.62	0.38	0.62
A2				0.38	0.62	0.38	0.62
Baseline	0.3	0.38	0.56				
A1F1				0.38	0.61	0.38	0.60
A1B				0.38	0.61	0.38	0.60
A2				0.38	0.61	0.38	0.60
Baseline	0.5	0.48	0.50				
A1F1				0.38	0.54	0.38	0.51
A1B				0.38	0.54	0.38	0.51
A2				0.38	0.54	0.38	0.51
Baseline	1	0.69	0.69				
A1F1				0.69	0.69	0.69	0.69
A1B				0.69	0.69	0.69	0.69
A2				0.69	0.69	0.69	0.69

The cumulative evaporation, transpiration and infiltration indicate a decrease in evaporation compared to the baseline of 3 – 3.5% in 2030 and a decrease of 9 – 7% by 2050 (Table 4-5) which is similar to the PET decrease (Table 4-3). However, the transpiration decreases by a much larger proportion with 9 -12% and 22 – 24% decrease in 2030 and 2050. This is similar to the infiltration decline of 11 – 12 % in 2030 and 20 – 23% in 2050. This decrease in transpiration will cause a similar decline in plant production which will have an effect on the productivity of this region.

Table 4-5. Comparison of cumulative evaporation (E), transpiration (T) and infiltration (I) for the climate change projections with the baseline. The values in brackets are the percentage change from the baseline.

Projection	2030			2050		
	E (mm)	T (mm)	I (mm)	E (mm)	T (mm)	I (mm)
Baseline	2546	5682	6400			
A1F1	2459 (-3.4)	5031 (-11)	5656 (-12)	2306 (-9)	4371 (-24)	4840 (-23)
A1B	2453 (-3.5)	5000 (-12)	5632 (-12)	2306 (-9)	4371 (-24)	4840 (-23)
A2	2469 (-3.0)	5170 (-9)	5696 (-11)	2498 (-7)	4432 (-22)	5120 (-20)

The final series of simulations was for irrigation over the same period of time. The irrigation scenarios 2 and 4 were used and the total number of irrigations is shown in Table 4-6. The simulations were only done for the A1F1 climate change scenario, as the computational time is very large.

Table 4-6. Number of irrigations required for irrigation scenarios T2 and T4 for A1F1 climate change projections at 2030 and 2050. The numbers in brackets are the percentage increase in the number of irrigations.

Projection	Number of Irrigations	
	Irrigation scenario T2	Irrigation scenario T4
Baseline	472	529
A1F1 2030	507 (6.7)	573 (7.1)
A1F1 2050	551 (14.4)	619 (15.0)

The irrigations simulations show that if the predicted 2030 climate had occurred from 1960 to 2010 then about an extra 30 - 40 irrigations would have been required. This increase to 80-90 irrigations for the 2050 climate change scenario. Given that water is likely to be in shorter supply as climate change progresses it is unlikely that this irrigation demand would be met. It may seem strange but the modelling suggests that the number of irrigations would increase when irrigation scenario T4 is used compared to scenario T2. This is because the soil can dry out further and time that the soil is wetter than the aeration limit is greater allowing more transpiration. This was confirmed by comparing the cumulative transpiration flux.

4.13 Long Flat, Gridding, Soil Layers and Boundary conditions.

The domain, grid (this cannot be seen as it is too fine), observation nodes, boundary fluxes and layers for the Long Flat site are shown in Figure 4.21 for the up slope area. The thickness of the soil layers is 1m and 5.5 m respectively for layers 1 and 2 at the river end. The thickness of layer 2 tapers off towards the drain. The variable flux on the upper boundary was determined from the bore results for Mob 34.

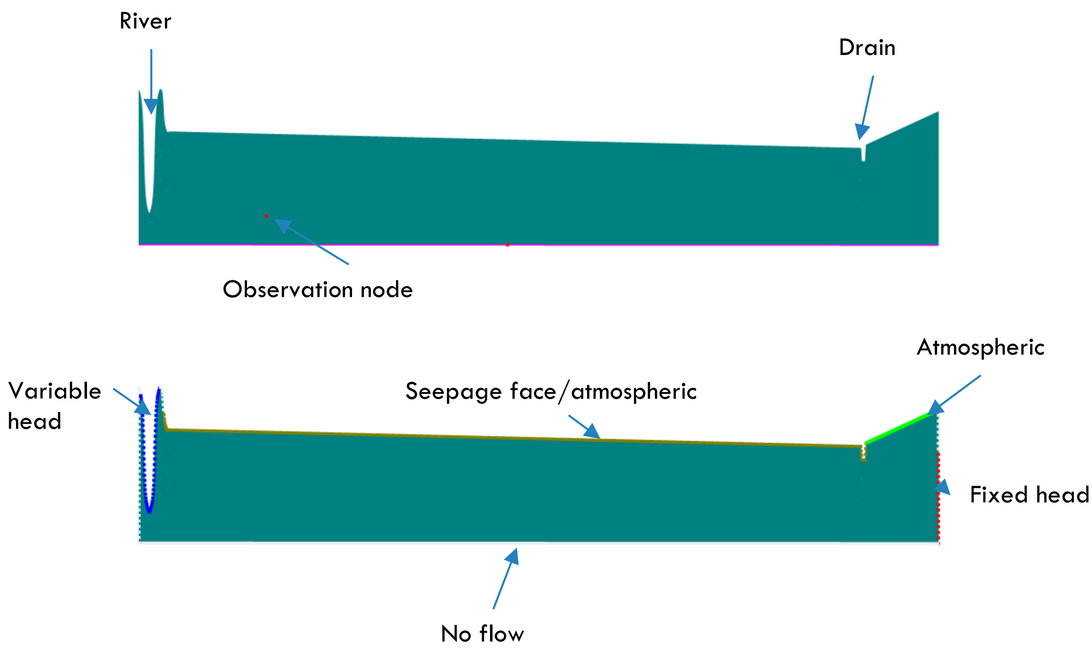


Figure 4-21 Domain, griding and boundary conditions for HYDRUS 2D Long Flat model are shown above. A seepage face that converts to atmospheric boundary conditions is used for the surface due to the influence of the river level causeing some flow when it is high and the evapotranspiration is low.

The atmospheric flux was taken from the simulations used for the LMRIA project (Mosley et al., 2014b) and the data is shown earlier in 4-4. The model will adjust the evaporation flux to be the lesser of the PET or the flux that can be transport through the soil surface. The maximum potential that the soil surface can decrease to was set at -1000 m.

The boundary condition on the drain was set as a seepage face with water passing through this when there is a positive potential (head) on the surface and reverting to an atmospheric flux when the potential was less than zero. A variable head was used for the river and a fixed head for the flow from the upslope area.

The initial conditions were taken as a pressure head equivalent to the depth and in equilibrium with the soil within the domain. This results in an almost linear increase in pressure from zero at the surface to a head equivalent to the depth within the soil. The effect of this initial condition is lost within the first 20 days.

The soil parameters were initially chosen on the basis of bulk density and particle size information and fitted to the van Genuchten (1980) moisture characteristic function using the pedotransfer function in HYDRUS2D. New soil data has recently become available as a result of measurements made and these were used to define new moisture characteristics. Previous bore saturated hydraulic conductivity was known for layer one and this was used but the unsaturated hydraulic conductivity was modified on the basis of the new soil data and fitting to the bore hole data. These parameters for the two layers are given in Table 4-7. This shows that the new properties have a higher saturated water content and that layer 1 now has to be fitted with the modified van Genuchten function.

Table 4-7. *Soil hydraulic parameters for HYDRUS2D simulations. The properties are: the residual water content,* θ_r *(m^3/m^3); the saturated water content,* θ_s *(m^3/m^3); a parameter that determines the shape of the van Genuchten function, n; a parameter that determines the shape of the van Genuchten function,* α *(1/m); the saturated hydraulic conductivity, Ks (m/day); and a parameter that determines the shape of the Mualem function, l. The other parameters are for the modified van Genuchten function which allows for the flow to occur faster nearer saturation.*

Soil property	Old Soil Properties		New Soil Properties	
	Layer 1	Layer2	Layer 1	Layer2
θ_r	0.1	0.1	0.388	0.302
θ_s	0.587	0.590	0.651	0.674
n	3.947	2.117	1.421	1.074
α (1/m)	1.537	1.709	0.685	38.1
Ks (m/day)	1.3	0.45	1.3	0.4
l	0.5	0.5	0.5	0.5
θ_m	0.587	0.595	0.655	0.655
θ_k	0.587	0.57	0.6	0.63
Kk (m/day)	1.3	0.1	0.1	0.075

4.14 RESULTS LONG FLAT 2D SIMULATIONS

The pressure heads at the observation node corresponding to the bore are compared to measured value and shown to given a good fit with both soil data sets (figure 4-22). The new soil data set is able to simulate the low values better than the old soil data set while still being able to give the same peak values.

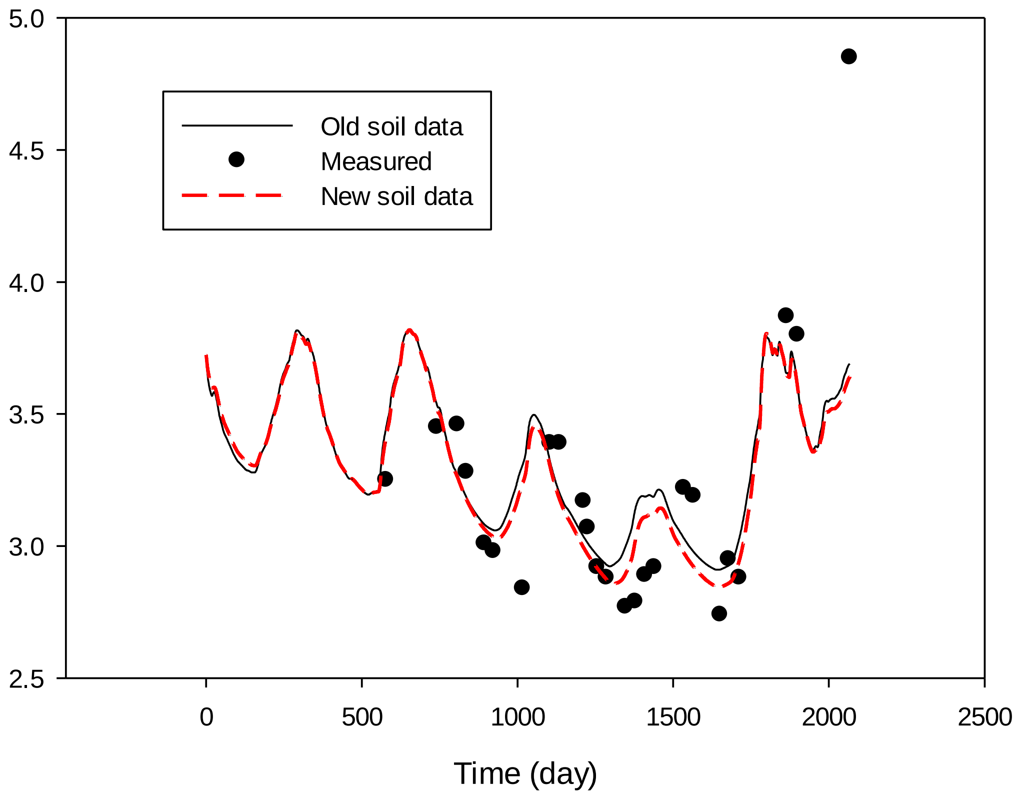


Figure 4-22 Comparison of water table head (rswl = AHD – swl, swl is depth below soil surface) with time for the period from 23/10/2005 to 9/4/2012.

The water content especially near the surface during the driest period (approximately 1200 days into the simulation) is of interest with regard to the extent of drying and depth (Figure 4-23). It also shows that the driest area is about two thirds of the length of the bay. Figure 4-23 shows that the drying almost extended down towards layer 2.

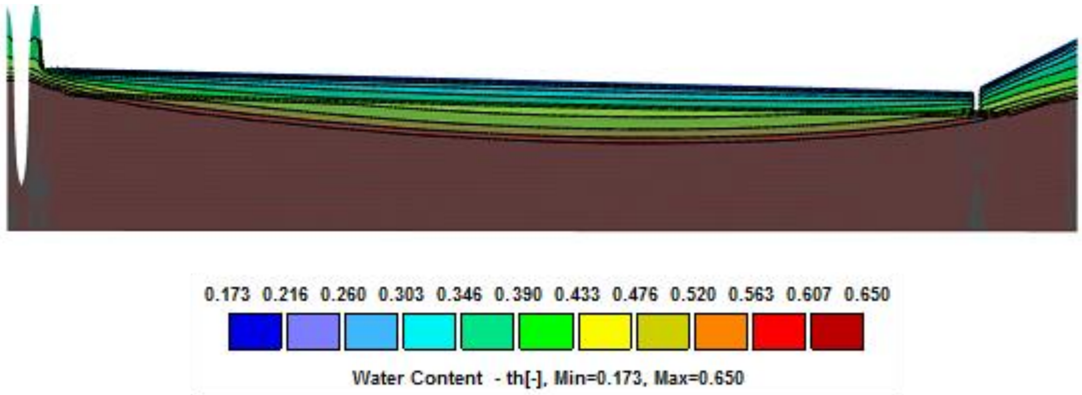


Figure 4-23 Water content the domain on day 1182. This shows that the drying front has extended all the way through layer 1.

A cross-section graph through layer 1 shows that the drying front extended to about 3 m (Figure 4-24) at a point 262 m from the left hand face of the domain. It also shows the change in soil properties and water content (θ) that occurs at a depth of 1 m.

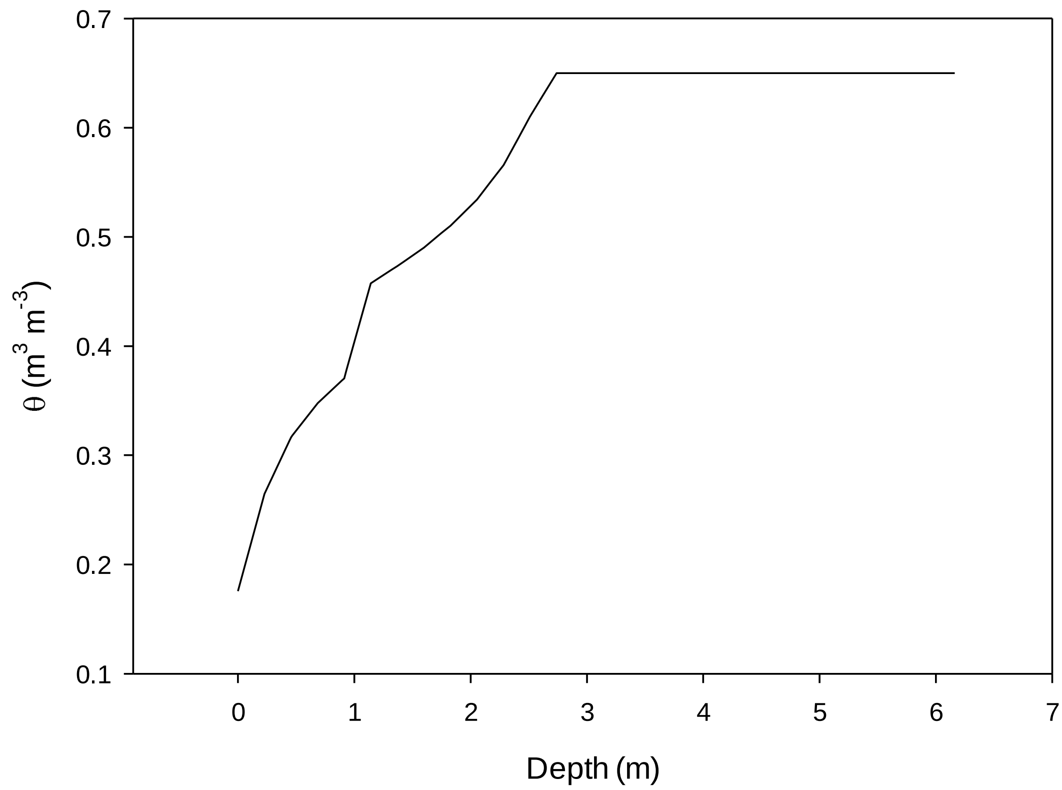


Figure 4-24. Water content (θ) versus depth on day 1182 for a point 262 m from the left hand face of the domain.

The evaporation during the simulation period was the largest surface flux component with a total of 6100 mm, while the infiltration was 2190 mm and the surface runoff 1.6 mm (Figure 4-25). This deficit of evaporation compared to infiltration was offset to a large extent by the water flow in from the upslope regions (variable and constant head of left hand side of domain) result in a change in total volume of water in the domain only changing by 2.33%. This would be equivalent to a change, on average, of 102 mm in the total depth of water in the soil profile.

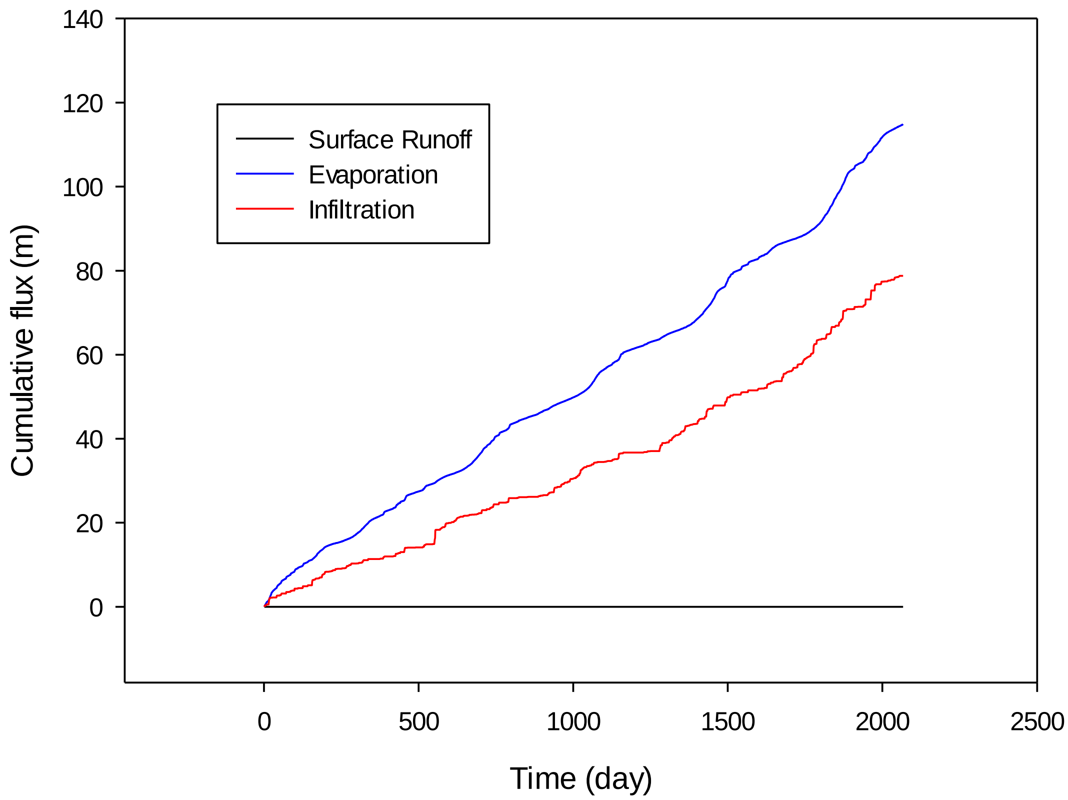


Figure 4-25 Cumulative surface fluxes for Long Flat area during simulation.

4.15 Effect of pasture on water content

The 2D simulations were done with only evaporation as the surface boundary condition but mostly the soils in the Long Flat area will have vegetation, most grass growing on them. Simulations using the very fine grid spacing were simulated with both a pasture growing (transpiration and evaporation) and no vegetation (evaporation only). The introduction of transpiration required partitioning of the potential evapotranspiration (PET) into transpiration and evaporation. Assuming a leaf area index of 3 this results in 75% of PET for transpiration and 25% for evaporation. With no pasture evaporation is taken as 100% of PET. No salt was simulated because as yet a stable solution with HYDRUS is still to be found. Thus only water flow was simulated.

The simulations show that with no plants the cumulative evaporation in the approximately 6 years would be 2179 mm, while the combined evaporation (436 mm) and transpiration (4184 mm) is 4620 mm, 2144 mm more. The evaporation + transpiration is still less than the potential evaporation plus transpiration of 5882 mm by 1262 mm over the same time period. The simulation assumed a rooting depth of 1 m with a linear decrease with depth, representing older type pastures. Other rooting depths will also be simulated. The lower boundary condition for these simulations was taken from an observation node inserted in the 2D simulations at the midpoint of domain (Figure 4-26).

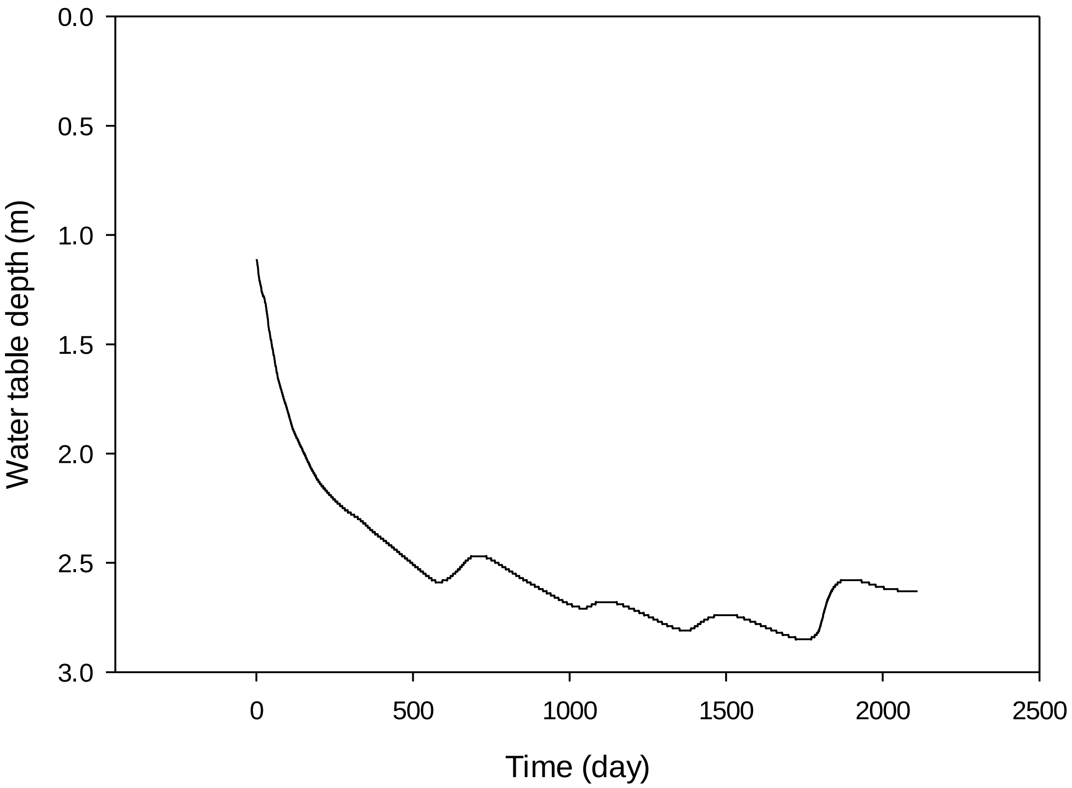


Figure 4-26 Water table depth with time used in the one dimensional simulations of water flow with and without pasture.

For the rest of the simulations pasture will be used in the simulations.

4.16 IRRIGATION SCENARIOS

The period used for the simulations above is during the 'millennium drought' so simulations were carried out to consider the irrigations that may have been required if water had been available during this period. The control is the simulation with the very fine grid and pasture. Four irrigation scenarios were chosen based on recommendations by Philcox and Murray:

1. Irrigation when the cumulative deficit (Σrainfall – PET) reached -100 mm,
2. When the soil matric potential at 0.3 m depth reached -20 kPa
3. When the soil matric potential at 0.3 m depth reached -30 kPa
4. When the soil matric potential at 0.3 m depth reached -40 kPa

These scenarios are near completion with results available shortly.

4.17 DROUGHT PROTECTION BY RIVER LEVEL STABILISATION AND IRRIGATION

The Millennium Drought resulted in severe groundwater level declines under the LMRIA floodplains that resulted in extreme soil and water acidification (Mosley et al. 2014a,b). The groundwater level decline was a result of both falling river levels (hydraulically connected to the groundwater) and lack of application of irrigation water. The river levels fell to below -1 m AHD in the drought from an average pre-drought level of about +0.75 m AHD. The Basin Plan states that water levels should not fall below 0 m AHD in the future as additional water has been recovered to provide environmental flows that was not available in the Millennium Drought. Building on our earlier modelling of management scenarios (Mosley et al. 2014a) and new information obtained in this SARMS project outlined above, we refined the 2D model for Long Flat irrigation area and ran drought protection scenarios. This involved comparing a Millennium Drought simulation to a protection simulation involving river level stabilization at 0 m AHD and minimum irrigation (3 irrigations on 1st December, 1st January and 1st February each year between 2007 to 2010). Figure 4-27 shows the results from these simulations. The influence of minimum irrigation water application (3 per year, 100 mm irrigation depth per irrigation) is profound. The groundwater level during the drought period is 0.5 to 1 m higher with irrigation. This would have greatly lessened the zone of soil acidification as the acid sulfate soils would not have oxidized (i.e. they would have remained saturated in this zone). These results highlight both the importance of maintaining and applying ELMA (and commercial irrigation where possible) allocations during drought. Just maintaining the river level appears to have only a minor direct benefit, but the indirect benefits are likely much larger due to a higher river level making irrigation much easier (i.e. either via gravity fed flood irrigation if possible or pumping if not possible to gravity feed).

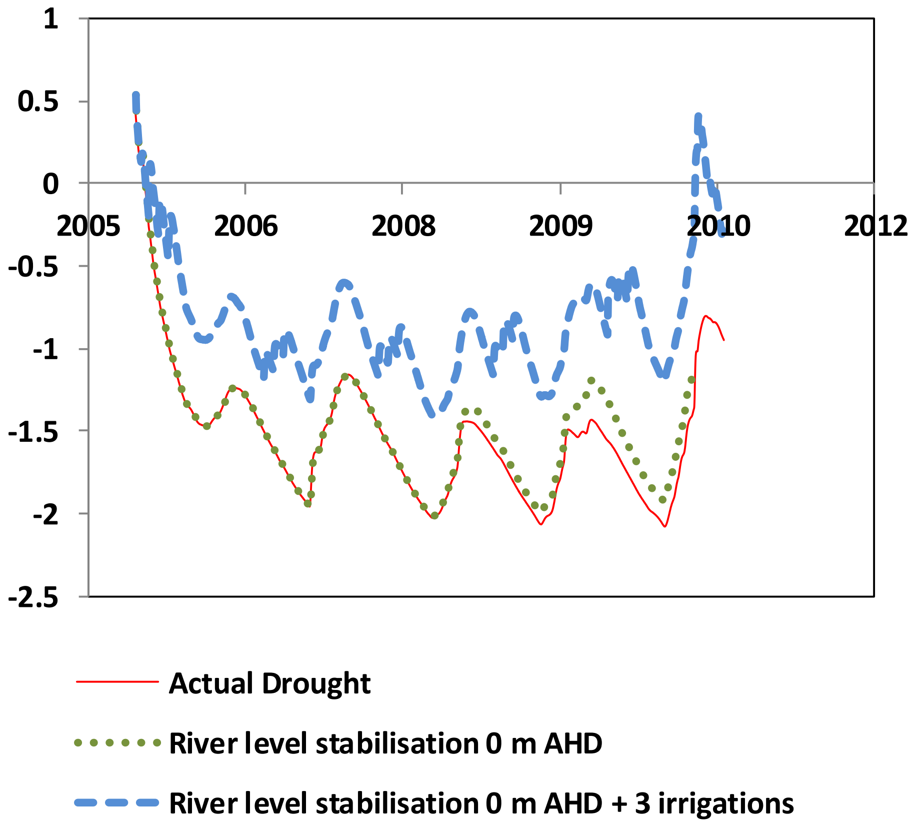


Figure 4-27 Modelled groundwater levels at Long Flat irrigation area from the refined 2D model (see Mosley et al. 2014a for further details). Three model simulations were performed; one actual drought simulation, one with river level stabilization at 0 m AHD during drought period, and one with river level stabilization plus 3 irrigations per year during drought (1st December, 1st January, 1st February each year).

5 RESEARCH TRANSLATION AND KEY MESSAGES FOR FUTURE MANAGEMENT

5.1 BACKGROUND

Activity 5 *- Using the results from the field trials, modelling, and the soil, water and vegetation indicators (identified in Activity 1), we developed and published for LMRIA irrigators and management agencies (e.g. PIRSA, DEWNR, EPA, SAMBD NRMB, MDBA, Dairy SA, private service providers/consultants/advisors) a practical manual titled: "Strategies and indicators for managing irrigation, drainage, soil, and vegetation in the LMRIA" and communicated the project results via various methods.*

5.2 RESEARCH TRANSLATION ACTIVITIES

Key research translation activities that occurred during the project included:

- **Production of a practical manual** to assist farmers and environmental managers to better manage the area in the future (see Fitzpatrick et al. 2017a)
- **Field days and meetings with farmers**
- **Meetings with key stakeholders, managers and politicians** to highlight the importance of the region and impacts that have occurred
- **Media releases and articles**
- **Attendance at scientific conferences** to present the outcomes of the research
- **Publication of the findings in peer-reviewed international journals (see Appendix 1)**

5.3 POLICY AND OPERATIONAL RESPONSES FOR FUTURE PROTECTION OF THE LMRIA

Murray-Darling Basin

The sustainability of the LMRIA is directly dependent on the water level in (and flows to) the Lower River Murray (below Lock 1) in South Australia. It is considered critical that the Basin Plan is fully implemented to deliver improved water security to the LMRIA region during drought. By doing so, severe impacts on the soils and irrigation infrastructure will be minimized.

South Australia

There are policy and operational management revisions required surrounding water allocation to protect the LMRIA in future droughts. The recent discussion paper involving “Environmental Land Management Allocations” (ELMA) and the Water Allocation Plan for the River Murray Prescribed Watercourse” (Appendix 2) outlines these issues and policies. There is a clear rationale for providing ELMA due to the uniqueness of the rising saline groundwater tables in the LMRIA that is not present in other regions. ELMA enables the minimum number (approx. 2-3) irrigations to prevent salinization and cracking as supported by our model. ELMA is insufficient to maintain full pasture or crop production but some cross-benefits obviously occur to irrigators following its application. In relation to maintaining soil condition to prevent severe cracking and acidification it is considered critical that ELMA is retained and applied at its highest level during drought conditions. The application of ELMA should be mandatory under these conditions and support given to irrigators where required (e.g. fuel subsidies, access to portable pumps and travelling irrigators) under extreme drought conditions. During drought, older deeper-rooting pasture types and Lucerne proved useful for some irrigators to maintain some production. Restricting salt drain pumping operations, to keep saline water table high which minimized deep soil cracking (although likely increased top soil salinity), was also used successfully by some irrigators.

5.4 KEY MESSAGE FOR FUTURE MANAGEMENT

Key messages arising from the research include:

- The top soils (0-70 cm) in the LMRIA are some of the best agricultural soils in Australia (high organic matter and nutrient content, low bulk density, and high hydraulic conductivity enabling good irrigation and drainage).
- The sub-soils (>70 cm) in the LMRIA are some of the "nastiest" in Australia as they contain acid sulfate soil materials that can severely acidify if exposed to air during drought.
- Regular irrigation and drainage is needed in the LMRIA to maintain soil condition and prevent impacts from rising saline regional groundwater inputs.
- The LMRIA sub-soils have not yet recovered from the 2007 to 2010 extreme "Millennium" drought period as they have remained strongly acidic with sulfuric material (pH < 4) persisting for over 10 years (i.e. some of these soil changes are irreversible).
- Many drains in the LMRIA have continued to be acidic with the formation of abundant iron precipitates (schwertmannite mineral) since 2007.
- Irrigation efficiency has been restored post-drought in about 50% of the LMRIA with the infrastructure upgrade programs.
- Limited (^{3} 3 per year) irrigation and river level stabilization (>0 m AHD) during the extreme 2007-2010 "Millennium" drought period could have greatly lessened the severity of soil cracking and acidification.
- It is important to retain ELMA and ensure its use in the LMRIA, particularly during drought conditions and on non-commercially irrigated properties.
- Irrigation and drainage can restore salinized and sodic soils.
- Alternative irrigation strategies are possible during drought to protect soils and infrastructure and should be supported by the government.
- It is critical the Murray-Darling Basin Plan is successfully implemented to provide water security to the LMRIA to enable the region to be sustained into the future.

5.5 WHAT DO WE STILL NEED TO KNOW?

As with any part of scientific work, there are unavoidable gaps. Some are thought-provoking, while others are critical. The project team made decisions about where work was to be done. Our initial decisions were made around what we knew already of the LMIRA and its different zones, with attention focussed on numerous sites where we already had existing information. Different project components used subsets of this large group of sites, and, while we attempted to stay consistent, there were gaps. As the project developed, we became interested in some areas that were not an initial focus, e.g. areas in drains and abandoned paddocks with *Phragmites australis*. While we have a greatly improved understanding of soil and water processes and management needs in the LMRIA we believe more work should be undertaken:

- to train "advisor(s)/facilitator(s)" in the field across the LMRIA to easily observe soil-water indicators and processes as outlined in the Manual: "Identifying and managing acid sulfate, salt-affected and waterlogged soils in the Lower Murray Reclaimed Irrigation Area"
- by conducting a series of "facilitated discussion groups across the LMRIA" to train irrigators to use the outcomes of our study and apply the manual to their farm

- to understand soil recovery in drains and abandoned paddocks planted with *Phragmites australis*
- to further test and develop the recommendations and modelling during real drought scenarios
- to conduct two-dimensional modelling and assessment of the lateral water flows to better understand the processes and management implications
- to better assess irrigation infrastructure operating constraints better versus river level variation

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Report - summary overview (2.5 MB)

Appendix B1 - Descriptions for assessed wetlands from Pomanda Bay to Sunnyside - Paiwalla managed wetland(10 MB)

Appendix B2 - Descriptions for assessed wetlands from Sunnyside - Paiwalla Swamp to Teal Flat Hut wetland (10 MB)

Appendix B3 - Descriptions for assessed wetlands from Teal Flat Hut wetland to Devon Downs Swamp (7.3 MB)

Appendix B4 - Descriptions for assessed wetlands from Greenways Landing wetland to Yarramundi Creek (6 MB)

Appendix B5 - Descriptions for assessed wetlands from Yarramundi North (Morgan's Lagoon) wetland to Morgan Conservation Park wetland (6.2 MB)

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APPENDIX 1 – ABSTRACTS FROM PEER REVIEWED JOURNAL PUBLICATIONS ARISING FROM THIS PROJECT

Mosley, LM., Cook F.J., and Fitzpatrick R.W. (2017) Remediation of soil salinity and sodicity in Lower Murray irrigation areas; comparison and modelling of different treatments. Submitted to *Soil Research*.

Abstract: Rising saline groundwater tables and drought in the Lower Murray Reclaimed Irrigation Area (LMRIA) has created soil salinity and sodicity conditions, which has resulted in a decline in agricultural production. A two month field experiment was conducted at Mobilong irrigation area using a randomized block design with trial plots (4 m^2) in each of the three blocks containing the following six treatments: (i) control (not irrigated), (ii) irrigation (River Murray water) only, (iii) gypsum application (1.5 kg/m^2) and irrigation, (iv) limestone application (1.5 kg/m^2) and irrigation, (v) seawater (source of dissolved Ca^{2+}) application (100 mm depth) and irrigation, and (vi) acid (pH 3) drainage (to dissolve $CaCO_3$ in soil to release Ca^{2+}) application (100 mm irrigation water depth) and irrigation. Soil electrical conductivity (EC), pH, exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), exchangeable sodium percentage (ESP), and saturated hydraulic conductivity were measured. The decrease in EC was greatest in the irrigation only treatment followed by the gypsum and limestone treatments. At the end of the trial the EC in the irrigation only treatment was about one quarter of the control where the EC increased. The seawater and acid drainage treatments reduced the soil EC compared to the control but the EC was 2-3 dS/m higher than the irrigation, gypsum and limestone treatment at the end of the trial. The gypsum, irrigation only, and limestone treatments approximately doubled the exchangeable Ca compared to the control and exchangeable Na was reduced. Unsaturated water and solute transport model (HYDRUS-UNSATCHEM) simulations were able to represent the general trends in the field results. The results suggest that just River Murray water irrigation and drainage could be effective to manage soil salinity and sodicity in the LMRIA but further research is required to establish the threshold electrolyte concentration to prevent soil dispersion.

Mosley, LM, Biswas T, Cook F., Marschner P, Palmer D, Shand P, Yuan C, and Fitzpatrick RW (2017) Prolonged recovery of acid sulfate soils with sulfuric materials following severe drought: causes and implications. Submitted to *Geoderma* special issue on acid sulfate soils.

Abstract: Pyrite in acid sulfate soils can oxidise during drought resulting in severe soil and water acidification (pH < 4). The frequency and severity of drought and flooding is increasing in many regions of the world due to climate change but there has been limited research on the ability of acid sulfate soils to recover from these events. We studied the recovery of heavy clay soils in the Lower Murray River (South Australia) irrigated agricultural areas over a 5 year period (2011–2015). The heavy clay acid sulfate soils in this region dried, cracked and acidified due to river and groundwater levels falling by nearly 200 cm during the 2007–2010 severe "millennium" drought followed by reflooding events between 2011 and 2015. Approximately 300 cm deep soil cores were collected from three locations along a transect in 2011, 2012, 2013, and 2015. The soil properties measured were pH, reduced inorganic sulfur (RIS, pyrite), titratable actual acidity (TAA), retained acidity, and acid neutralising capacity. Soil pH showed very little change over the post-drought period with a very acidic (pH 3.5 – 4.5) layer at approximately 100 – 225 cm depth in all three soil profiles. In this acidic layer there also was substantial amounts of TAA (up to 200 mol H^+ $tonne^{-1}$ dry weight) and retained acidity (up to 70 mol H^+ $tonne^{-1}$ dry weight) in the form of the Fe oxyhydroxy sulfate mineral jarosite. There was limited reformation of RIS. To assess why the sulfuric material in the acid sulfate soils has not recovered post-drought we conducted (i) laboratory incubation experiments with and without organic matter amendment, and (ii) modelling of the flushing of acidity from the soil due to irrigation, rainfall and drainage. Based on the field and laboratory results the causes of slow recovery appear to be: (i) lack of available organic carbon and too low a pH to enable microbial reduction reactions that generate alkalinity, ii) slow flushing of acidity due to the low hydraulic conductivity in the heavy clay layers with the main zone of below the drain depth, and (iii) slow dissolution of the sparingly soluble jarosite mineral, which is likely buffering the sub-surface soil layers at approximately pH 4. The implications are that acid sulfate soils with sulfuric materials have long recovery times following droughts and impacts are likely to increase in the future.

Fitzpatrick R.W., Shand P., and Mosley L.M. (2017). Acid sulfate soil evolution models and pedogenic pathways during drying and wetting conditions - A case study from the lower River Murray, South Australia. Submitted to *Geoderma* special issue on acid sulfate soils.

Abstract: A previously successfully farmed irrigation area for well over 100 years (1880's to 2007) dried and cracked due to extreme drought conditions during the Millennium drought (2007 to 2010) to form deeply (>3m) acidic Sulfuric clay soils (pH<4) that became re-flooded with freshwater in 2010. The objective of this study was to better understand and predict the progressive pedogenic and geochemical change-processes over time in deep clayey Acid Sulfate Soils with hypersulfidic (pH >4) and sulfuric (pH <4) materials, during drought events and subsequent reflooding to enable land and water managers to prepare for the future (e.g. design optimal wetting and drying cycles to protect irrigated land, agricultural water supplies and adjacent aquatic ecosystems). There is a high risk of drought effects becoming more prevalent in the future given severe climate change projections for the Lower Murray River region and other major irrigation areas in the world with hypersulfidic materials such as in the Mekong Delta and Brunei. Soil cores were collected repeatedly from three Sulfuric clay soils (Sulfic Sulfaquerts and Typic Sulfaquerts) in 2011, 2012, 2013, and 2015 along a representative transect in the Middle Zone of The Murray Reclaimed Irrigation Area (LMRIA). Similarly, in 2011 and 2012 three Sulfuric clay soils (Sulfic Sulfaquerts and Typic Sulfaquerts) were collected repeatedly along a transect in the Northern Zone and three Sulfuric organic soils (Sulfic Endoaquepts and Typic Endoaquepts) from the Southern Zone in the LMRIA. Sampling was followed by detailed laboratory analyses [soil incubation pH testing, reduced inorganic sulfur (RIS, pyrite), titratable actual acidity (TAA), retained acidity, acid neutralizing capacity (ANC), X-ray diffraction analyses, scanning electron microscopy]. Two predictive soil-regolith hydro-toposequence models were constructed to describe and compare the major changes in acid sulfate soil subtypes, soil properties, key intrinsic features and external drivers occurring over time during the following major periods of drying and wetting/reflooding cycles in irrigated pastures and natural wetlands:

- Before 1880s (approximately 5,500 BC to 1880s period) when region cycled between wetting and flushing, and partial drying conditions in response to seasonal and climatic cycles causing the build-up of hypersulfidic material to be kept in check by oxidation and removal during scouring floods.
- During the 1880s to 2007 period when: (i) the river and natural wetland systems were first used for navigation and irrigation during the 1880s and (ii) During the 1930s to 1993 period when the river and wetland systems were first managed using barrages and locks. This resulted in the increased formation and build-up of pyrite (i.e. hypersulfidic material).
- During the 2007 to 2010 period (4 years) when complete (or unprecedented) drying took place due to the Millennium drought causing oxidation of pyrite to form sulfuric acid and jarosites in Sulfuric clay soils.
- During the 2011 period when complete rewetting took place causing mobilization of sulfuric acid, soluble sulfates, ferrous iron, nutrients and metals with likely transport into the River Murray.
- During the 1993 to 2006 period when partial drying cycles and substantial rewetting cycles occurred in several natural wetlands because of the installation of control structures (e.g. levee banks and water flow regulators).

Our findings highlight that maintaining water tables on agricultural soils via irrigation and drainage can promote the formation of deep (>3.5 m) sulfuric material with extensive retained acidity (jarosites), which can persist for decades or longer. During droughts, reduced rainfall and limited irrigation water availability may result in falling water tables, which can lead to major agricultural and environmental impacts arising from exposure and oxidation of acid sulfate soils.

Fitzpatrick R.W., Mosley L.M., Raven M.D., and Shand P. (2017). Schwertmannite formation and properties in acid throughflow from re-flooded Acid Sulfate Soil environments following river level decline during drought. Submitted to *Geoderma* special issue on acid sulfate soils.

Abstract: This paper describes the occurrences, mineralogical assemblages and environmental relevance of acidic (pH <4) iron-rich precipitates containing dominantly schwertmannite from a diverse range of physical settings: (i) suspended flocculated precipitates in ponded water, (ii) dry and moist coatings or pastes on soil and vegetation surfaces and (iii) cemented crusts and aggregates in Phragmites roots and stems across the Lower Murray Reclaimed Irrigation Area (LMRIA) in Australia. Schwertmannite formed in acid drain environments following exposure and oxidation of acid sulfate soils when deep (>3.5m) clayey hypersulfidic material (pH >4) dried, cracked and acidified to form to deep (~0.5 - >3.5 m) sulfuric materials (pH<4) due to river and groundwater levels falling by nearly 2m during the latter part of the Millennium drought (2007 to 2010) followed by reflooding events between 2011 and 2015. All samples displayed X-ray diffraction (XRD) patterns typical for schwertmannite. In some samples, additional weak reflections indicating presence of small amounts of jarosite, natrojarosite, gypsum, hexahydrite, konyaite and halite indicates deposition under variable pH conditions and sulfate concentrations due to different flow or evaporation stages. SEM images indicate that some morphological and compositional features of schwertmannite are dominated by: (i) framboid-like spheroidal clusters that have been preserved after crystallization and likely formed by microbial oxidation of $Fe2+$ by acidophilic bacteria and (ii) biogenic schwertmannite because it comprises a mixture of large (2 μm) smooth regular spheres interspersed in 0.3-3 μm fibrous spheres with filamentous morphology with a high degree of porosity. Speciation calculations (PHREEQC) using the dissolved metal and major ion concentrations in the drain waters supported the XRD results as the saturation index (SI) exceeded zero for schwertmannite in many drains. The schwertmannite-rich precipitates contained high concentrations of metals (Al> Cu> As> Zn> Pb>Co) and nutrients (e.g. P) due to co-precipitation/scavenging of these elements during the formation of schwertmannite. There is also spatial variability in concentrations of metal(loids) in schwertmannite-rich precipitates between drains. A conceptual model explains and summarizes the morphological properties, mineralogy, geochemistry and environmental processes influencing the formation and relative stabilities of schwertmannite-rich precipitates from six diverse physical settings. The environmental relevance, which has significant implications for rehabilitation options is shown in three perspectives: (i) the conditions for schwertmannite formation has persisted in irrigation drains for over 7 years, (ii) the ability for schwertmannite-rich precipitates to reveal acid sulfate conditions and therefore act as a mineralogical indicator in irrigation systems and (iii) the pollution potential of metals and metalloids scavenged by schwertmannite-rich precipitates.

Cook F.J., Mosley L.M., Grant C.D., Cutting M., and Fitzpatrick (2017 in prep.). Soil Moisture Parameter Variablility Effect on Triggered Irrigation.

Variation in the soil moisture characteristics of the soil from triplicate measurements at three depths on two soil cores showed that for triggered irrigation the number of simulations in a 50-year period could vary from 105 to 161. This variation is in part due to the soil properties and how this effects the timing of the irrigation in relation to rainfall events which is indicated by the significant relationship between cumulative runoff and the number of irrigations for core 3. The numbers of irrigations are also very dependent on the lower boundary condition. In this soil a layer starting at 1 m depth has a high clay content and lower saturated hydraulic conductivity, this combined with the low soil water storage means that much of the time the transpiration is limited by poor aeration and the number of irrigations is restricted due to this. When a free drainage boundary condition is allowed at 1 m depth the number of irrigations increase more than 5-fold. These simulations suggest that about 2-3 irrigations per year would be required to meet the triggered irrigation used here and to provide leaching. By contrast using the climate data 13 irrigations per year are estimated and for free drainage 14 irrigations per annum. A simulation with ditch drains spaced 40 m apart was carried out and showed only a modest increase in the number of irrigations simulated. The results here are concert with the ELMA allocations for this irrigation district.

APPENDIX 2 – ENVIRONMENTAL LAND MANAGEMENT ALLOCATION (ELMA) DISCUSSION PAPER

Government of South Australia
South Australian Murray-Darling Basin
Natural Resources Management Board

DISCUSSION PAPER

Environmental Land Management Allocations (ELMA) and the Water Allocation Plan for the River Murray Prescribed Watercourse

1. Purpose

This paper presents the policy behind the development of ELMA and relates it to the review of the River Murray Water Allocation Plan (WAP). This paper is intended to provide a broad background to the history behind ELMA and its relevance to the WAP.

2. Key Messages

- Appropriate scheduling of ELMA is essential in managing the risks associated with historically high saline groundwater levels, acid sulphate soils and protection of private and public infrastructure; including the integrity of the Murray River Levee Bank
- The application of ELMA is essential to maintaining the productive capacity of the Lower Murray Reclaimed Irrigation Areas (LMRIA), and when applied properly can assist production,
- Drought has demonstrated the risks associated with not applying ELMA as intended including cracking of soils, slumping of levee banks and the generation of acid soil conditions.

3. Context

The Water Allocation Plan (WAP) for the River Murray Prescribed Watercourse sets out the rules for the determination of consumptive pools, water entitlements, water allocations, site use, works approvals and permits and transfer of water. A prescribed water resource is one that is managed through a licensing system, informed by a water allocation plan.

This paper discusses the status and proposed policy position(s) for existing Class 8 entitlements known as Environmental Land Management Allocations (ELMA). This discussion paper is to be considered in conjunction with other relevant discussion papers prepared for the River Murray WAP. ELMA is only applicable within the area described as Lower Murray Reclaimed Irrigation Area (see figure 1), hereafter referred to as the LMIRA.

The total area of productive farms remaining in the LMRIA is estimated to be 3,192 hectares. Historically there was approximately 5,200ha of productive irrigated farm land (EPA, 2009) which was almost exclusively utilised for dairy production. Approximately 4,200ha of this land was rehabilitated under the LMRIA rehabilitation project in 2008 with approximately 1,000ha of land retired from farming and not rehabilitated (EPA, 2009). Dairy production has reduced from approximately 5,000ha to 1,866ha – a reduction of approximately 63% (Philcox 2012) due to impacts of drought together with changes in the dairy industry.

4. Introduction

The 2009 water allocation plan for the River Murray watercourse provides (and limits) 22.2GL (representing 22 200 000 unit shares) for Environmental Land Management Allocation, and categorises it as its own water access entitlement class (or consumptive pool). ELMA is only available to those that own land within the LMRIA.

The Murray-Darling Basin Agreement requires that the Government of South Australia ensure that at least 22.2GL of the states diversion is reserved for ELMA purposes and is not transferred (to another purpose). The WAP can only allocate to ELMA, it cannot force the application of ELMA into the land.

ELMA is provided to landholders to minimise the historical effects of high saline groundwater levels on irrigated pasture or on land that has been retired from irrigation within LMRIA. More recently, it has become evident that the application of ELMA assists with minimising the production of acid sulphate soils, which in turn generate acid water upon hydration. Production of acid water finds its way back into the river through subsurface drains and poses a water quality risk to SA Water off takes at Mannum, Murray Bridge and Tailem Bend. Land within the LMRIA is typically lower than the river level and as such is a natural discharge point for saline regional groundwater (figure a).

There has been extensive cracking of swamp soils through reduced application of water due to low River levels (landowners are unable to siphon or pump the water) and low irrigation allocations. Experience shows that with repeated rewetting of these soils, combined with some rotary cultivation, these soils can again be suitable for flood irrigation and pasture productions (Philcox 2010, EPA 2013).

Whilst the application of ELMA on land (more specifically land that is not regularly irrigated) is unable to be enforced (as there are some areas without appropriate infrastructure), the lessons learnt from drought should provide landholders with the understanding that correct use of ELMA has a range of benefits whilst acting as an insurance policy against risks including cracking of soils and generation of acid sulphate soils. The EPA Guidelines for the Lower Murray Reclaimed Irrigation Area provide a good basis when determining appropriate land management practices – and should be considered by all LMRIA landholders when undertaking land and irrigation management actions.

Many of the issues around ELMA have been realised during and following the drought. Drought conditions lowered the local groundwater table to the point where the soils lost their hydration and began cracking (figure b). Farms that watered during the drought to some degree, sometimes with as little as one irrigation per season, appeared to have recovered faster post drought. This highlights the importance of the application of some water during dry conditions, even if it is limited to ELMA (Philcox 2012). Exposure of cracked soils to air also generated acid sulphate soils (figure c). Once these soils were rewetted, high levels of acid were formed causing significant impacts to the water, land and its productive capacity (figure c).

ELMA provides maximum benefit when it is taken in full, annually. Consequently it is not eligible for private carryover.

Figure a

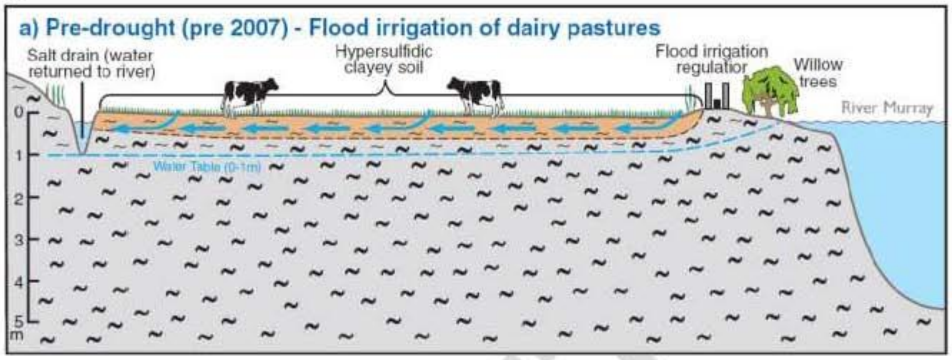


Figure b

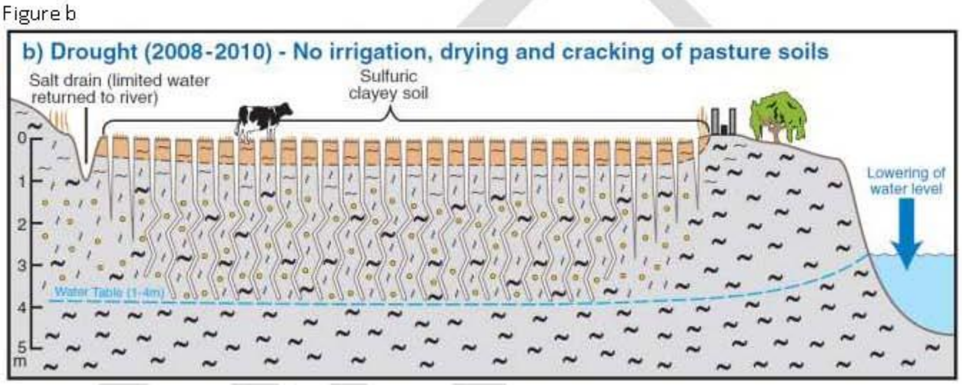
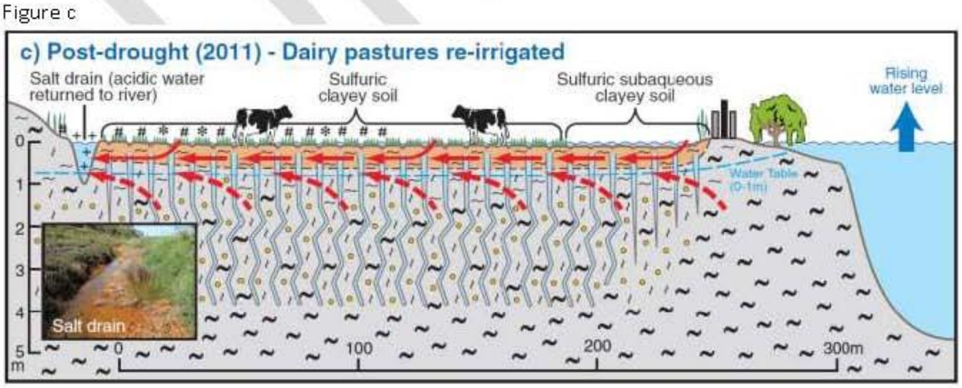


Figure c



5. Current Policy Position

The key policies from the current water allocation plan for the River Murray that deal with ELMA include:

Policy 33 *Water allocations obtained on account of class 8 entitlements for environmental land management purposes shall only be applied to land within an Irrigation Area listed in Table 1*

Policy 34 *Water allocations obtained on account of class 8 entitlements used on land upon which pasture is irrigated shall not be used at a rate greater than the relevant rate applicable to the Irrigation Area (as set out in Table 1).*

Policy 35 *Where pasture is not irrigated on the land upon which water allocations obtained on account of class 8 entitlements are to be used, the rate of application shall reflect a rate that is appropriate for managing the effects of rising saline groundwater on the particular land.*

Table 1

Irrigation Area	Rate (ML/Ha)	Irrigation Area	Rate (ML/Ha)
Cowirra	6.49	Mobilong	4.68
Neeta North	6.14	Burdett	4.56
Baseby	6.44	Long Flat	4.46
Neeta	6.23	Long Island	4.22
Wall Flat	6.06	Swanport	4.15
Pompoota	5.86	Yiddinga	4.13
Mypolonga	5.50	River Glen	3.98
Burbridge	5.37	Monteith	3.87
Paiwalla	5.15	Kilsby	3.61
Glen Lossie	5.10	Woods Point	3.58
Toora	4.87	Westbrook	3.46
Jervois	2.96	Seymour	2.33
Finniss	1.38		

Policy 45 *Water allocations obtained on account of a class 8 entitlement will revert to the Minister upon sale of land*

Policy 7 *The Minister will determine the volume of water available for allocation under each entitlement class pursuant to Section 146(4) of the Natural Resources Management Act 2004. The Minister will determine the volume of water available for allocation under each entitlement class pursuant to Section 146(4) of the Natural Resources Management Act 2004.*

For the purpose of developing an amended water allocation plan for the River Murray, it is considered appropriate that the intent of the above policies remain and continue to be administered.

6. Current ELMA Administration

The following points outline the key characteristics of ELMA:

- ELMA entitlements are granted by the Department responsible for water licensing administration on behalf of the Minister for Sustainability, Environment and Conservation. The granting of allocations is guided by the policies within the River Murray water allocation plan.
- ELMA is considered as the first water taken through the meter.
- Upon sale of a property, it is the responsibility of the ELMA entitlement holder to surrender the ELMA entitlement back to the Minister, whereby it can be allocated to the new landowner upon application.
- ELMA allocations do not attract a water based levy

7. Policy Considerations

Many of the issues experienced with the management of ELMA stem from an operational perspective rather than a policy perspective. It is acknowledged that access to River water can be dependent on a number of factors including River height and access to infrastructure or delivery systems. Land rehabilitation, drought and economic markets have all contributed to changing the LMRIA landscape – and adaptive management needs to complement these changes. The following areas are those that the water allocation plan is able to influence.

1. Annual ELMA Allocation

Between 2003 and 2012, ELMA ranged between 18% and 100% of entitlement. From experience we now know that application of ELMA water is essential in helping maintain land management aspects of the LMRIA. As a separate water access entitlement class, ELMA are able to be independently managed in a dry condition scenario. Whilst it is difficult to detail a precise approach for ELMA in all water allocation scenarios (where irrigation allocations are less than 100%), it is proposed that the amended water allocation plan outline a high level objective regarding the importance of ELMA in all water allocation scenarios – to the effect of:

'When determining annual allocations for individual consumptive pools, consideration be given to maintaining ELMA at the highest level possible in order to protect environmental land assets (private and public) of the LMRIA.'

2. Application of ELMA

The primary purpose of ELMA is to protect soils against high saline groundwater levels and minimise the risk of acid sulphate soil production, along with long term integrity of the Murray River Levee Bank within the LMRIA. Application of ELMA, having regard to the EPA Guidelines for Lower Murray Reclaimed Irrigation Areas, is essential to the long term management of the area.

A secondary benefit of ELMA is to support production in both irrigated and non irrigated environments. Most benefit is obtained by using ELMA to extend the wetter months. So application of ELMA in Autumn and Spring provides the greatest benefit.

3. River Level

The landscape of the LMRIA has changed considerably over the last 10 years, due to the effects of drought. Today, much of the laser levelling has been compromised due to cracking or slumping and the return of normal river levels has introduced the impacts of acid sulphate soils. As such, landholders are facing additional management issues to those 10 years ago. It is acknowledged that ELMA alone is not adequate to manage all of the land management issues currently experienced. The role of river levels is critical as a complementary tool to long term management the LMRIA.

Below lock 1, river level is primarily driven by the amount of water being delivered to South Australia. The WAP can only set policy for water that is delivered to the state. Local factors (eg wind direction) also play a part in river levels. During the drought, it became clear that there was a minimum level below which access to water became problematic. As such, an objective of the 2012 Basin Plan is to manage water levels in the Lower Lakes to help prevent acidification and river bank collapse. This is to be achieved by maintaining levels above 0.4 metres AHD for 95% of the time, as far as practicable; and above 0.0 metres AHD at all times.

Whilst the WAP is unable to guarantee a minimum river height, it is appropriate for the plan to articulate the reasons why a minimum river height is critical to the LMRIA. This will be expressed in the WAP as an overarching objective – consistent with the Basin Plan.

8. Proposed policy positions

In addition to the general principals of the water allocation plan, the following policies are proposed for the management of Environmental Land Management Allocations:

1. ELMA to be retained as a consumptive pool comprising 22.2GL.
2. ELMA shall only be applied to the land described as the Lower Murray Reclaimed Irrigation Area having regard to the EPA Guidelines for the Lower Murray Reclaimed Irrigation Area.
3. ELMA are not to exceed the relevant rate applicable to the irrigation area (as per table 1).
4. ELMA may be granted by the Minister upon application and remain subject to policies relating to application rate and location.
5. ELMA entitlements expire upon sale of land.
6. ELMA are not eligible for private carry over.
7. The Minister may consider the objectives of the WAP with respect to ELMA in determining the volume of water available from the ELMA consumptive pool pursuant to s146(4) of the *NRM Act*

9. Objectives to be included in the WAP

Objectives for the management of ELMA to be included in the WAP include:

1. Maintain ELMA at the highest level possible in order to protect environmental land assets (private and public) of the LMRIA.
2. Assist where possible to maintain water levels in the Lower Lakes above 0.4 meters AHD to complement land management practices within the LMRIA.

Next Steps

- This discussion paper will be used to develop an engagement paper for endorsement by the South Australian Murray-Darling Basin Natural Resources Management (SAMDBNRM) Board for use in community consultation.

Figure 1
The Lower Murray Reclaimed Irrigation Areas