Prepared for **Department of Water**

Yarra Yarra Regional Drainage Program

Evaluation of Xantippe, Jibberding and Mongers 16 drains

January 2017

Summary

The Yarra Yarra Regional Drainage Program is a regional network of arterial deep drains constructed for the purpose of providing landholders with access to a discharge point for deep drainage they may construct on their own land. The arterial drainage network comprises approximately 99 km of arterial deep drains constructed by the Yarra Yarra Catchment Management Group (YYCMG) over the period December 2006–July 2009 with funding from the Commonwealth and State Governments. The YYCMG has been monitoring the catchment to evaluate the performance of deep drains and to identify potential downstream impacts.

The purpose of this study was to present results of an analysis of groundwater monitoring data collected by the YYCMG and evaluate the performance of arterial deep drains in the Xantippe, Jibberding and Mongers 16 sub-catchments of the Yarra Yarra Regional Drainage System. The sub-catchments were selected based on an initial review of the quality and completeness of the watertable monitoring record.

The measured watertable response at the Xantippe, Jibberding and Mongers 16 drains show that single deep drains are unable to lower and control groundwater levels to a sufficient depth and at a sufficient distance from the drain to reliably return adjacent agricultural land to cropping. However, the increased drainage density due to additional spur drains connected to Jibberding drain did have a local effect on the watertable at one transect. Anecdotal evidence suggests that construction of the arterial drain in parallel to existing deep drainage at one transect in Xantippe also increased the drainage density to improve crop productivity between the two drains. These observations suggest that properly designed and constructed parallel drains (connected to arterial drains for the disposal of drainage discharge) may be viable in some locations.

While an initial watertable response is observed at all transects excluding the Jibberding Wasley Road transect these initial responses were confounded by antecedent conditions (including rainfall events and groundwater recession) in the pre-drain period.

Long-term declines in watertable of up to 0.5 m were observed across bores at all three drains. However, since similar declines were observed both close to the drains and at distances of several hundred metres from the drain (where the initial watertable response to drain was very small), these long-term groundwater declines are more likely due to climate than the deep drains. Within all sub-catchments the groundwater levels measured at all bore transects generally followed trends in AMRR.

Watertable responses at some bore transects have been influenced by the location of the arterial drain in relation to other constructed drains, drainage features (e.g. playas), as well as adjacent existing treatments (e.g. alley farming). For example, anecdotal evidence of improved productivity observed near the Xantippe Campbell Road transect was in an area between the arterial drain and an existing deep drain that runs north along Dalwallinu-Kalannie Road. Similarly, groundwater levels at the Jibberding Woolf Road transect appeared to be locally controlled in an area bounded by deep drains on three sides: the arterial drain and two adjacent private spur drains, resulting in a high drainage density in the vicinity of the groundwater transect. For the Xantippe Angel transect existing alley farming treatment adjacent to the transect, and location of a playa east of the transect, likely influenced the watertable response to the deep drain construction.

An objective of the Yarra Yarra Regional Drainage Program was the rehabilitation of the drainage corridors along the valley floors, with revegetation to stabilise the central waterway and provide wildlife corridors linking isolated patches of remnant vegetation. Observations during the

site visits in June 2016 found the drainage corridor rehabilitation to be generally successful with plantings of broom bush and saltbush well established.

Given the general understanding of watertable response to deep drain construction, no further monitoring of the drains in the Yarra Yarra Regional Drainage Program is recommended

Acknowledgements

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1. Introduction

Widespread clearing of native vegetation for agriculture has caused rising groundwater and increasing salinisation across large areas of the Western Australian Wheatbelt. Deep drains have been identified as a potential method of lowering and controlling groundwater and arresting salinisation. However, the performance of deep drains in the Wheatbelt is not clearly understood or universally accepted.

The Yarra Yarra Regional Drainage Program is one of the most extensive systems of deep drains in Western Australia and has been monitored by the Yarra Yarra Catchment Management Group (YYCMG) over a long period.

GHD was engaged by the Department of Water, with the support of the Department of Agriculture and Food WA (DAFWA), Shire of Dumbleyung and Wheatbelt Catchment Alliance to collate and review the data collected by YYCMG and determine their suitability for further analysis and then to use those suitable data to evaluate the performance of deep drains of the Yarra Yarra Regional Drainage Program.

Yarra Yarra catchment

The Yarra Yarra catchment is one of four sub-regions of the Northern Agricultural Region of southwestern Western Australia. The greater Yarra Yarra catchment covers an area of approximately 41,800 km^2, extending from Carnamah in the west, to Mt Magnet in the northeast and Kalannie in the south (Figure 1).

Natural drainage within the Yarra Yarra catchment is internal, with irregular surface flow directed to a chain of several thousand ephemeral salt lakes and samphire covered claypans approximately 300 km long and 2,500 km^2 in area near the catchment's western edge. The lake system drains from the south, toward the north, then to the southwest, culminating in the Yarra Yarra Lakes.

The agricultural portion of the catchment, west of the clearing line, is an area of approximately 10,600 km^2 and is characterised by relatively small catchments, broad valleys with little or no defined channel, draining toward low-lying areas along the major lake system. Prior to clearing for agriculture, these valleys supported tree-based woodland systems and probably produced infrequent surface water flow to the lake systems.

The Yarra Yarra Regional Drainage Program

The Yarra Yarra Regional Drainage Program is a regional network of arterial deep drains constructed for the purpose of providing landholders with access to a discharge point for deep drainage they may construct on their own land.

The arterial drainage network comprises approximately 99 km of arterial deep drains constructed by the YYCMG over the period December 2006–July 2009 with funding from the Commonwealth and State Governments. The arterial drains were constructed in eight sub-catchments, each discharging to a salt lake, wetland or playa within the Yarra Yarra lake chain:

- Burakin
- Xantippe
- Jibberding
- Mongers 16
- Bowgada

- Merkanooka and
- Canna-Gutha.

Deep drainage was also constructed in the Mongers 55 sub-catchment during early 2006 as a precursor to the Yarra Yarra Regional Drainage Program.

In addition to the arterial deep drains constructed by the YYCMG, 99 km of privately funded drains have been constructed and connected to the arterial drainage network (YYCMG 2010).

The Yarra Yarra Regional Drainage Program has been the subject of a range of monitoring activities by the YYCMG to evaluate the performance of deep drains and to identify potential downstream impacts.

The YYCMG monitoring program included groundwater levels, drainage discharges, surface water and groundwater quality, vegetation health (Fordyce, 2012; Fordyce, 2015) and aquatic ecosystem monitoring (Wetland Research & Management, 2008). DAFWA has also monitored groundwater levels in the Mongers 55 and Canna-Gutha catchments (Stuart Street *et al.,* in publication) and the Department of Water used part of the Mongers 55 drain for batter trials (Cox and Tetlow, 2009).

Drain design and construction

Pre-construction site investigations included preliminary surveys for drain alignment, and geotechnical investigation comprising observation pits excavated at approximately 2 km intervals along the drain alignment. The observation pits were used by YYCMG to assess the soil profile, measure rate of inflow (to estimate drawdown), identify the presence of hardpans and assess the ease of excavation (YYCMG 2007). No observation pit data was available for inclusion in the evaluation of the watertable response to deep drains. Following construction, the arterial drains were surveyed to confirm the final elevation and position of the drain.

The basic design of the drain incorporates a central deep drain, with the spoil used to form continuous 1.5 m high levee banks on both sides of the channel to prevent surface water inflow and silt accumulation in the drain (Plate 1). Drains were constructed just upslope of the lowest alignment along the valley floor to maintain floodway capacity in the valley for significant events. The levee banks are set back 1.5 metre either side of the channel with shallow surface water channels formed on the outer edge of the levee banks to convey surface water out of the catchment. The arterial drains were generally 2.5 m depth, with 1.25 m width bottom and 1(V):0.5(H) batter slopes, forming a channel with cross-section of approximately 5.6 m^2.

Plate 1: Construction of arterial drain showing central channel, levee banks and surface channel (YYCMG 2010)

Selection of drains for detailed evaluation

Monitoring of watertable responses in groundwater transect bores commenced in 2007 for the majority of sub-catchments (2006 in Mongers 55 sub-catchment) and continued until 2013 for some drainage sites. Although the YYCMG groundwater dataset is extensive, the monitoring bores were not surveyed when first installed, limiting the value of some data. The Department of Water has subsequently surveyed (position and level) those YYCMG bores considered suitable for further analysis. Using aerial photography and site inspections, bores were selected for survey based on their proximity and orientation to the drainage system and isolation from other hydrologic features (Cox, *pers. comm.*).

As part of this study GHD collated and evaluated the monitoring data collected in the Yarra Yarra Regional Drainage System by the YYCMG. The purpose of the evaluation was to identify sites that had data of suitable quality and completeness to evaluate watertable response to the construction of deep drains. The key criteria used in the evaluation included:

- Bore transect spacing - a closely spaced network of shallow piezometers and observation bores to describe the drawdown of watertable and changes in hydraulic gradients.
- Bore transect alignment – the monitoring bore transect is perpendicular to the drain away from other drainage features that may affect assessment of watertable response.
- Completeness of the pre- and post-drainage watertable monitoring dataset – the monitoring bore transect has a number of monitoring events pre- and post-drain construction, with few gaps in the monitoring record.

Additional monitoring data collected by the YYCMG including drain discharge data and drain water quality data are available for some sub-catchments. Available drain pH water quality data are reported here, however other drain water quality data and discharge data (where available) are not included in this evaluation which focusses on watertable response to deep drainage. Vegetation transect monitoring has been completed for all sub-catchments, with a summary of the results reported in YYCMG (2010) and referred to in this report.

Based on the evaluation of the YYCMG groundwater monitoring dataset the Xantippe, Jibberding, Mongers 55, Mongers 16 and Canna-Gutha drains were considered suitable for further detailed assessment and reporting. Since the Mongers 55 and Canna-Gutha drains have already been the subject of detailed evaluation and reporting (Stuart Street *et al.,* in publication), they were excluded from further analysis in this study.

This report presents an evaluation of the performance of three deep drains in the Xantippe, Jibberding and Mongers 16 sub-catchments of the Yarra Yarra Regional Drainage System. The locations of the groundwater monitoring transects within the Xantippe, Jibberding and Mongers 16 sub-catchments are shown in Figure 2.

These catchments have relatively complete pre- and post-drain groundwater datasets and the monitoring bores have been surveyed by the Department of Water. Of the Mongers 16 transects, only MU8A-MU11A was identified as suitable for further analysis. Other transects within the Mongers 16 sub-catchment were identified as unsuitable or had significant gaps in the monitoring record and were of limited value.

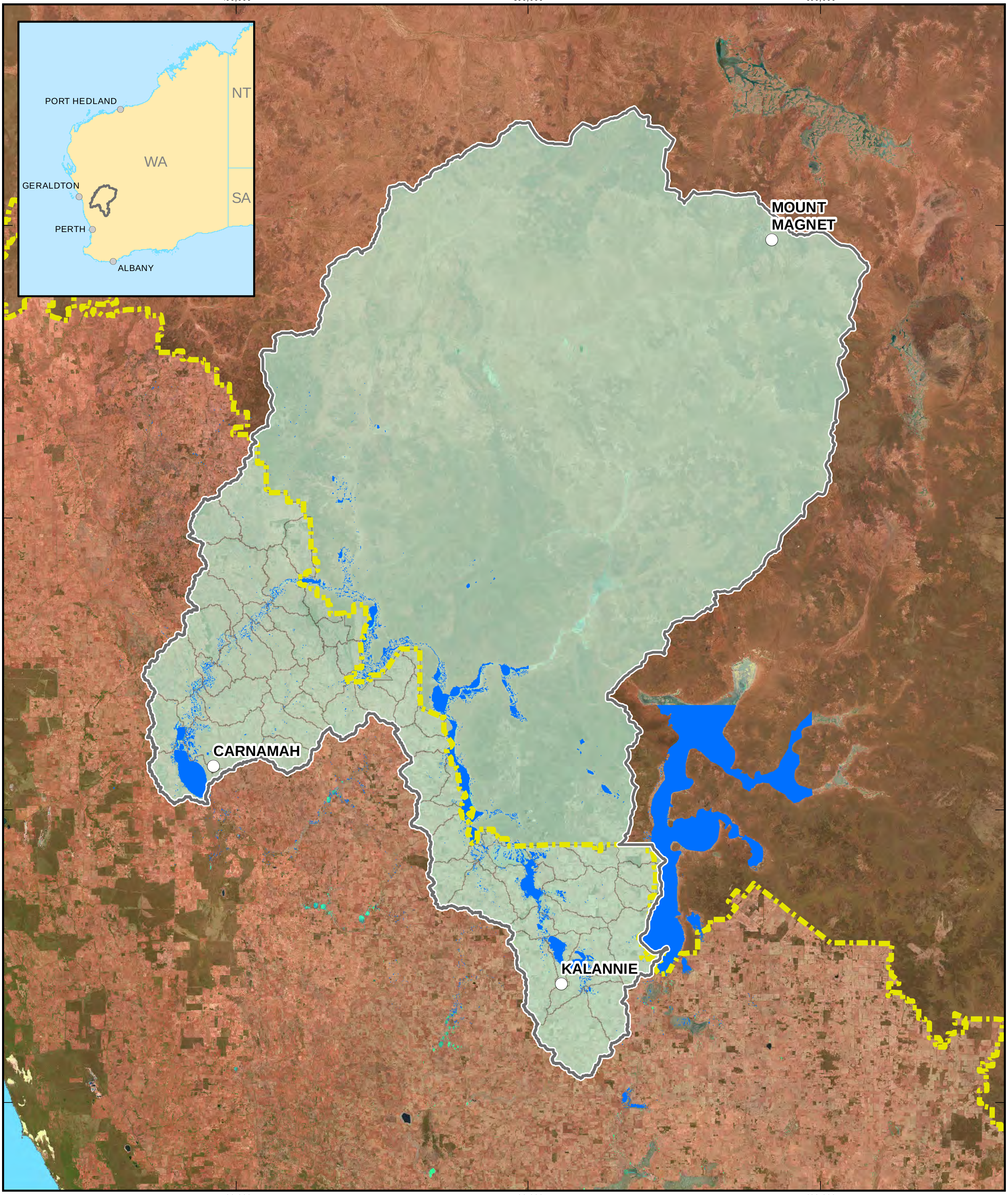
Scope and limitations

This report has been prepared by GHD for Department of Water and may only be used and relied on by Department of Water for the purpose of presenting results of an analysis of groundwater monitoring data collected by the YYCMG and evaluating the performance of arterial deep drains in the Xantippe, Jibberding and Mongers 16 sub-catchments of the Yarra Yarra Regional Drainage System

GHD otherwise disclaims responsibility to any person other than Department of Water arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The opinions, conclusions and any recommendations in this report are based on information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

GHD has prepared this report on the basis of information provided by Department of Water and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.



LEGEND

- Major Town
- Yarra Yarra Subcatchment
- Clearing Line
- Perrenial and non-perrenial lakes

Paper Size A4

0 10 20 30 40 50

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

Department of Water
Yarra Yarra Regional Drainage Program;
Evaluation of Xantippe,
Jibberding and Mongers 16 drains

Job Number	61-33069
Revision	0
Date	08 Sep 2016

Catchment Location and Study Area

Figure 1

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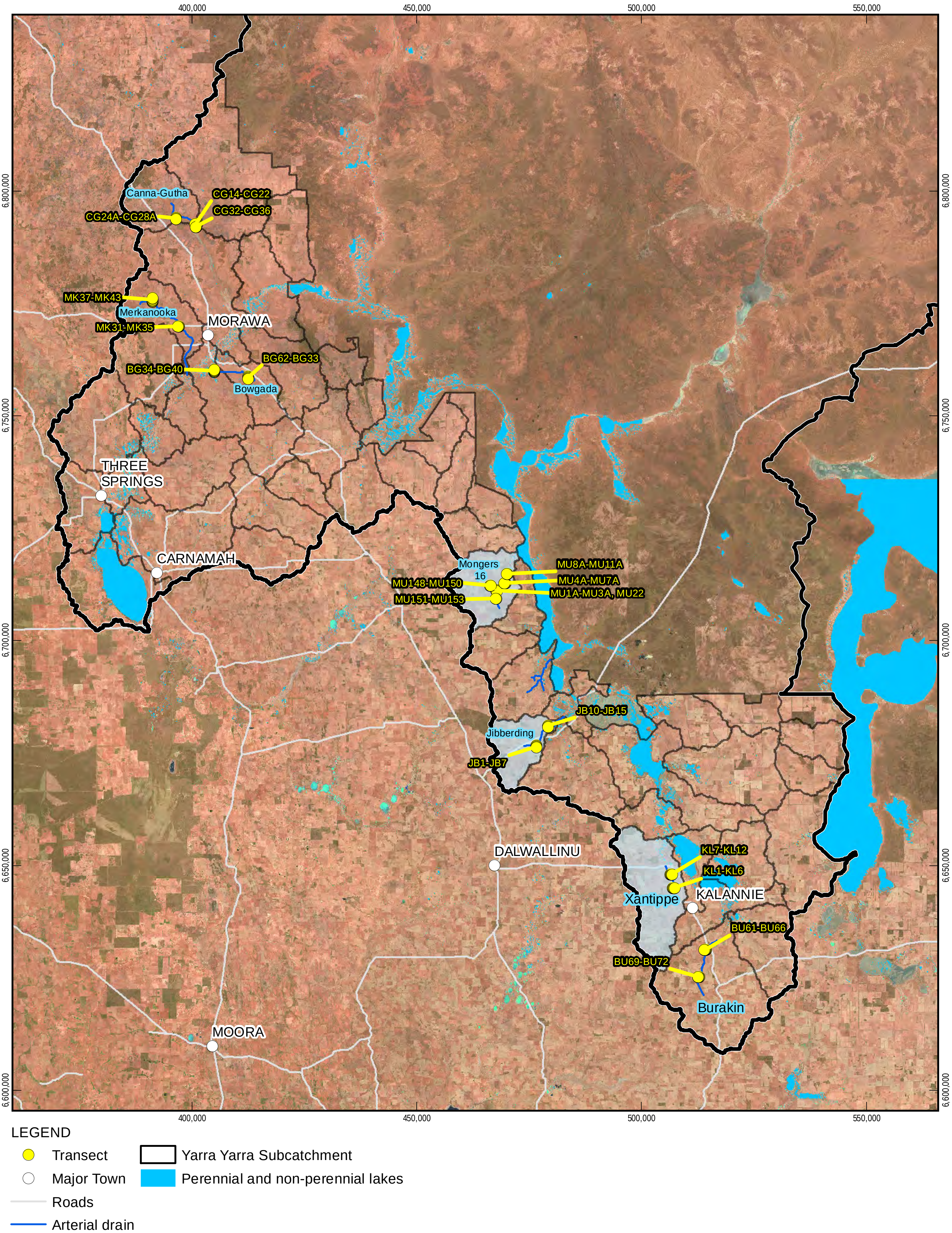
999 Hay Street Perth WA 6004 Australia T 61 8 6222 8222 F 61 8 6222 8555 E permail@ghd.com.au W www.ghd.com.au

Data source: Geoscience Australia: Landsat Imagery, GeoData Topo 250k Series III; Yarra Yarra Catchment Group: Major Lakes; Shire of Dumbleyung: Yarra Yarra Subcatchment; GHD: Clearing Line - 20060926. Created by:mmikkonen



Paper Size A4

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Yarra Yarra Regional Drainage Program
Drainage Site

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Figure 2

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999 Hay Street Perth WA 6004 Australia T 61 8 6222 8222 F 61 8 6222 8555 E permail@ghd.com.au W www.ghd.com.au

Data source: Geoscience Australia: Landsat Imagery, GeoData Topo 250k Series III; Yarra Yarra Catchment Group: Major Lakes; Shire of Dumbleyung: Yarra Yarra Subcatchment. Created by:mmikkonen

2. Methodology

2.1 Groundwater monitoring

Groundwater monitoring data

Groundwater monitoring bore transects (Figure 2) were installed prior to drain construction in order to monitor pre-drain watertable levels. Bore transects comprised 4-10 groundwater bores spaced at distance from the arterial drain.

Groundwater levels in the monitoring bores were manually dipped, with more frequent measurements during and immediately after drain construction. Groundwater levels were initially reported as depth below ground level. Following survey of the groundwater transects by Department of Water (Cox, pers. comm.) the groundwater levels were converted to metres above local height datum (m LHD).

Table 1 summarises the available watertable level monitoring data for the bore transects that were selected for detailed evaluation, and identifies significant gaps in the monitoring dataset.

Table 1 Summary watertable monitoring record

Catchment	Transect	Monitoring period	Pre-drain record Frequency (period)	Post-drain record Frequency (period)	Significant gaps in record
Xantippe	KL1-KL6	Sep 2007-Oct 2013	~ Monthly (7 months)	Bi-weekly/ weekly (2 months) Fortnightly (12 months) Monthly (Jun 2009-Oct 2013)	Apr 2010-Feb 2012 Sep 2012-Jul 2013
	KL8-KL12	Sep 2007-Oct 2013	~ Monthly (7 months)	Bi-weekly/ weekly (2 months) Fortnightly (12 months) Monthly (Jun 2009-Oct 2013)	Apr 2010-Feb 2012 Sep 2012-Jul 2013
Jibberding	JB1-JB8	Nov 2007-Aug 2013	Weekly/ fortnightly/ monthly (2 months)	Weekly/ fortnightly (3 months) Monthly (Jul 2008-Aug 2013)	Apr 2010-Jun 2011 Oct 2012-May 2013
	JB10-JB15	Oct 2007-Aug 2013	Weekly/ fortnightly (2 months)	Weekly/ fortnightly (4 months) Monthly (Jul 2008-Aug 2013)	Apr 2010-Jun 2011 Oct 2012-May 2013
Mongers 16	MU4-MU7	Jul 2007-Jun 2011	~ Monthly (7 months)	Bi-weekly/fortnightly (1 month) Monthly (Jul 2007-Jun 2011)	Jul 2009-Nov 2009 May 2010-Jun 2011
	MU8-MU11	Jul 2007-Aug 2013	~ Monthly (6 months)	Bi-weekly/fortnightly (2 months) Monthly (Jul 2007-Aug 2013)	Jul 2009-Nov 2009 May 2010-Jun 2011 Jun 2011-Jan 2012 Oct 2012-Jul 2013

Measurement error

Groundwater level measurements collected for the YYCMG were measured manually, with associated instrument and field measurement error. The measurement error used in this report for groundwater level data are ±0.05 m.

Water level QA/QC

The following data points were identified as being outside the observed range of water levels and have been removed from the data.

Jibberding – Woolf Road transect (JB1-JB7)

- All bores: data point 2/05/2013 removed as the 1 m scale of decline is outside of the previously observed record and assumed to be monitoring error.
- Bore JB7: data point 21/07/2011 removed as it is approximately 0.85 m lower than previous record and is outside of the range of adjacent bores on this date.

Jibberding - Wasley Road transect (JB10-JB15)

- Bore JB10: data point 14/03/08 removed as it is approximately 1 m lower than the previous record 5 days earlier.
- Bore JB15: data point 19/03/12 removed as it is 0.8 m higher than previous record and is outside of the range of adjacent bores on this date.
- All bores: data point 2/05/2013 removed as the 1 m scale of decline is outside of the previously observed record and assumed to be monitoring error.

Xantippe – Campbell Road transect (KL1-KL6)

- Bore KL6: data point 27/09/12 removed as it is approximately 1 m higher than the previous record and outside of the range of adjacent bores.

Xantippe – Angel transect (KL8-KL12)

- Bore KL12: data point 14/02/10 removed as it is outside of the range of adjacent bores on this date.

Comparison bores

A critical constraint for the analysis of the YYCMG data is the lack of suitable comparison bores. Comparison bores are typically located sufficiently far from the drain so that groundwater levels are not affected by the drain but sufficiently close to the drain to be representative of the aquifer system - experiencing similar seasonal and annual fluctuations due to climatic conditions. High quality data from suitable comparison bores allow the relative impacts of climate and drainage to be separately identified.

Groundwater response

A review of initial and longer term watertable response to drain construction was undertaken using the available groundwater level dataset for each site.

The watertable response measured within a bore (as vertical movement up and down) is related to a number of factors including aquifer transmissivity, climatic influences (response to rainfall events, evapotranspiration) as well as external influencing treatments (such as constructed drainage).

Typical watertable responses to constructed drainage include steepening of the groundwater hydrograph immediately following drain construction (initial response) followed by a step decline in pre-drain watertable levels that is maintained during the post-drain period (long term response).

The review of initial watertable response compared the groundwater level immediately before and after construction of the drain.

For the majority of drainage locations included in this review the initial response is complicated by drain construction occurring during the onset of winter rainfall, and associated difficulties with separating out the watertable recession response from rainfall from potential watertable response to drainage. The variability in temporal data collection during the pre- and post-drain period further complicates the review of initial drain response.

Initial watertable response to drain construction was reviewed by comparing the groundwater level immediately before and after construction of the drain. When drain construction occurred during a rainfall event, or during groundwater recession from a previous rainfall event, these alternate sources of influence on initial groundwater response are noted. Plots are presented showing the pre-drain monitoring record, and up to three months post-drain data.

Longer-term watertable response was assessed by comparing baseflow pre-drain watertable level with the groundwater table response over the monitoring period, and considering watertable responses to rainfall periods.

In addition, plots are presented displaying the pre-drain watertable profile with post-construction dates that are selected to represent the lowest observed post-drain watertable, mid- to late-winter watertables of typical growing seasons (presented for two subsequent post-drain years) and the watertable at the end of the monitoring period. These post construction dates were selected because, to be effective, the drains need to control groundwater levels during the period when most of the growing season rainfall has been received and the risk of damage to crops and pasture from a shallow watertable is greatest (Stuart Street *et al.* in publication).

2.2 Rainfall trends (AMRR)

Analysis of the impact of deep drains on groundwater levels needs to account for changes due to climate. Calculation of the Accumulative Monthly Residual Rainfall (AMRR) is a useful method for analysing and displaying the impact of rainfall on groundwater levels (Ferdowsian *et al.* 2001). AMRR reflects the monthly rainfall trends within a given period, and presents the progressive accumulation of rainfall for each month after subtracting the average monthly rainfall for the period of analysis.

For the Wheatbelt region the typical AMRR pattern during the normal summer-winter rainfall season is an observed decline from around October and rise again from about April, with large increases in AMRR outside this seasonal trend typically in response to significant unseasonal rainfall events (Cox 2010).

The rainfall stations and available rainfall records used in the AMRR assessment for each sub-catchment are summarised in Table 2. Rainfall data for each of the sub-catchments were taken from the nearest site with appropriate long-term records. Three different rainfall records were reviewed for the Jibberding sub-catchment (Table 2). Due to the limited rainfall record available for the Lee Farm, which is located closest to the study area, and significant gaps in the Sunnydale BoM Station, the Dalwallinu North Bureau of Meteorology (BoM) Station is presented as this is the nearest station with a continuous long-term rainfall record.

The AMRR was calculated for the longest continuous record of monthly data for each rainfall station and presented for the period immediately preceding drain construction to the end of the groundwater monitoring period (where data are available).

Plots of monthly rainfall totals and AMRR for each location, as well as comparison of the AMRR trends for the three Jibberding stations, are displayed in Appendix A.

Table 2 Rainfall station data

Sub-catchment	Nearest rainfall station	Continuous rainfall record used for AMRR assessment	Rainfall record presented in AMRR plots
Xantippe	Xantippe (BoM Station 10141)	1 January 1955 – 31 December 2013	1 January 2007 - 31 December 2013
Jibberding	Lee Farm	1 January 2007 – 31 December 2009	1 January 2007 – 31 December 2009
	Sunnydale (BoM Station 8021)	1 January 1959 – 31 December 2012 (Missing 2007, four months in 2009)	1 January 2008 – 31 December 2012
	Dalwallinu North (BoM Station 8014)	1 January 1999 – 31 December 2013	1 January 2007 - 31 December 2013
Mongers 16	Latham (BoM Station 8072)	1 January 1987 – 31 December 2013	1 January 2007 - 31 December 2013

2.3 Site observations

Each of the monitoring sites were inspected over the period of the 14, 15 and 16 June 2016. During the site visits observations of the adjacent crop productivity and adjacent vegetation health were observed on-site and discussions with the landholders were held where possible.

Additional site observations include a summary of available YYCMG vegetation transect and water quality (as pH measurements) monitoring data.

The YYCMG established a minimum of two vegetation transects for each sub-catchment discharge site in order to monitor the impact of drainage discharge on the vegetation species and vegetation community structure. Vegetation transects were established prior to drain construction and monitored annually for a period post-drain construction. A summary of the vegetation transect monitoring is provided.

In situ drain pH water quality measurements are reported for the sub-catchments where data are available.

3. Xantippe

3.1 Sub-catchment overview

YYCMG (2007) identified approximately 7% of farming land within the Kalannie Zone was affected by salinity, mostly located within the Xantippe sub-catchment (Kalannie sub-catchment 34). Existing deep drainage occurs within the sub-catchment, commencing near the intersection of the Rabbit Proof Fence Road and Pithara East Road. The drainage was constructed in the 1960’s to formalise the existing creek line and prevent flooding of the Dalwallinu-Kalannie Road (S. Hathaway pers. comm.). The drain was initially approximately 2.5 m deep near the Dalwallinu-Kalannie Road, however over time this has reduced to approximately 2 m deep (S. Hathaway pers. comm.).

The Xantippe arterial drain was constructed as part of the Yarra Yarra Regional Drainage Program between March and June 2008. The total length of arterial drain was 6.7 km, which included modification to an existing privately funded drainage line established in 1988 to address salinity issues within the upper part of the Xantippe sub-catchment (YYCMG 2007).

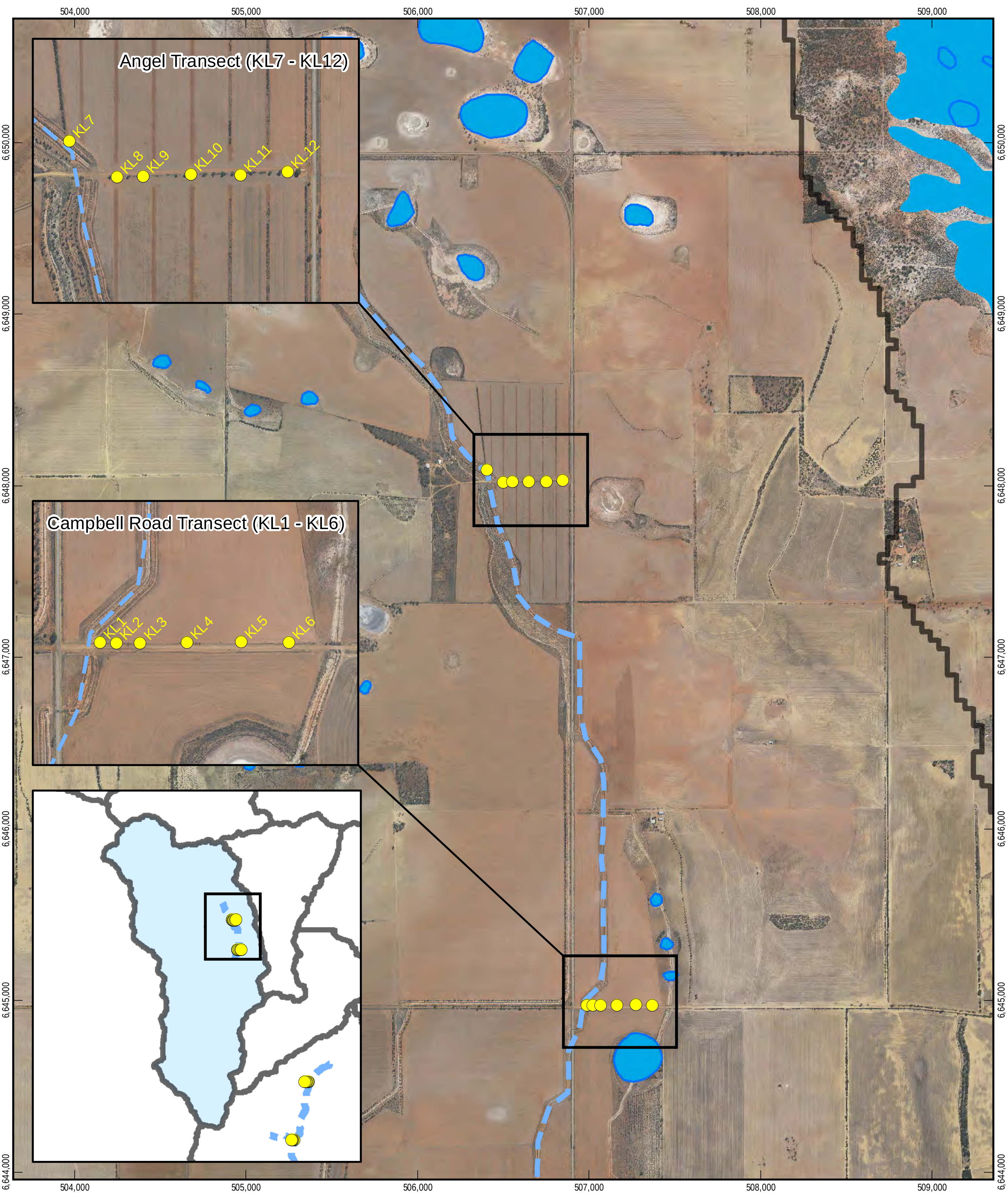
Soil landscape mapping (DAFWA) shows variable soils of the valley floor in the Xantippe sub-catchment. Within the vicinity of the arterial drain and bore transects the soil landscape is primarily mapped as *Calcareous loamy earth and red sandy earth* (Map unit: 258BCL). Downstream sections of the valley floor are also mapped as *Red sandy earth and alkaline grey shallow sandy duplex* (Map unit: 258BrWI) and *Red sandy earth, salt lake soil and grey deep sandy duplex* (Map unit: 258Wa_2).

The YYCMG established two groundwater monitoring bore transects in the Xantippe sub-catchment (Figure 3):

- Campbell Road transect (KL1-KL6), and
- Angel transect (KL8-KL12).

Aerial photographs of the transects pre- and post-arterial drain construction are displayed in Figure 4 (Campbell Road transect) and Figure 5 (Angel transect).

YYCMG (2007) notes that the groundwater prior to excavation of the arterial drainage was neutral pH, compared to the more acidic water in the Burakin catchment located to the south.



LEGEND

- Transect
- Arterial drain
- Perennial and non-perennial lakes
- Yarra Yarra Subcatchment
- Xantippe Subcatchment

Paper Size A4

0 500 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Xantippe Sub-Catchment

Figure 3

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Data source: Geoscience Australia: Landsat Imagery, GeoData Topo 250k Series III; Yarra Yarra Catchment Group: Major Lakes; Shire of Dumbleyung: Yarra Yarra Subcatchment. Created by:mmikkonen

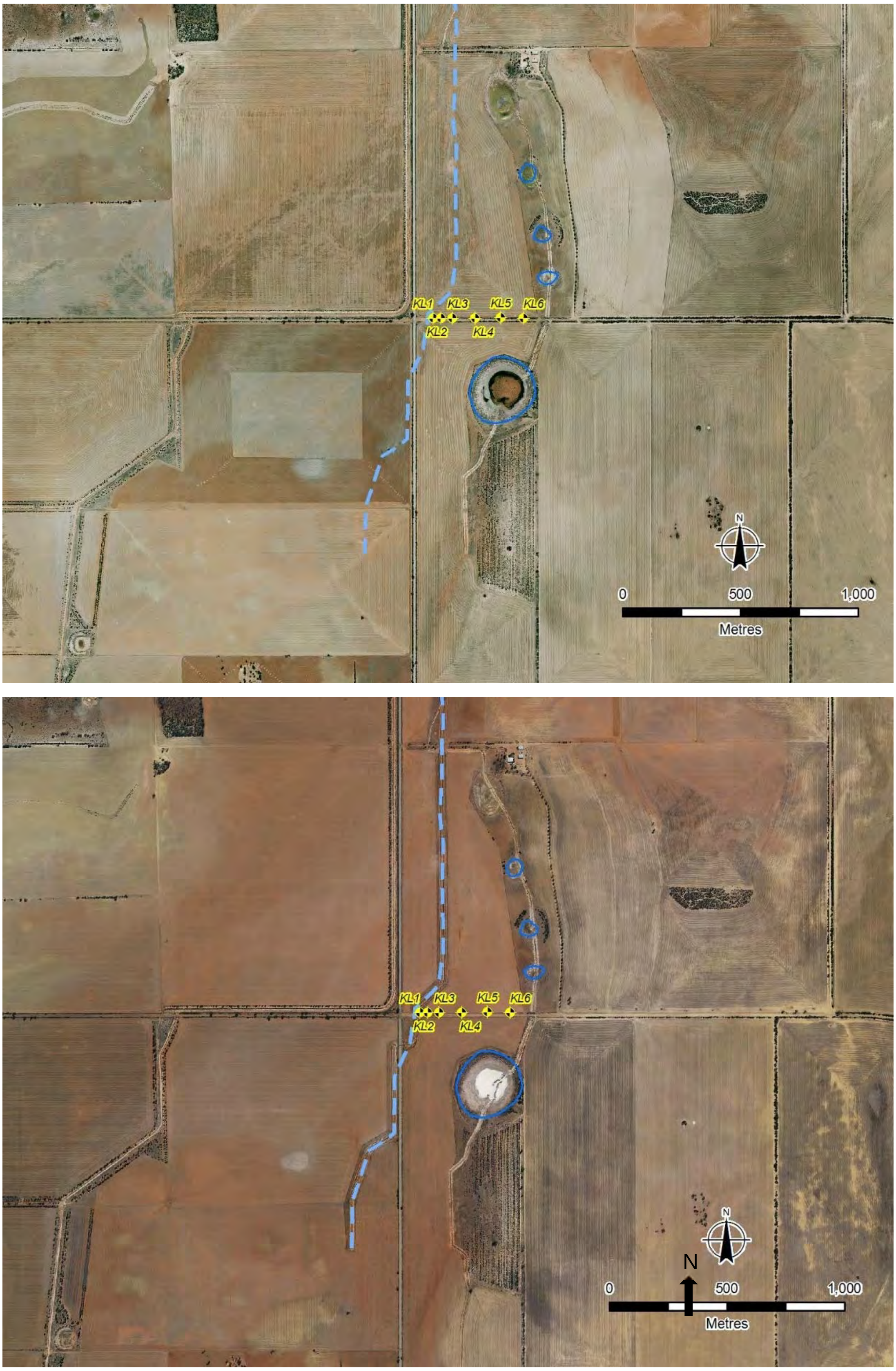


Figure 4 Campbell Road transect (KL1-KL6) pre-drain (top; January 2006) and post-drain (bottom; March 2011)

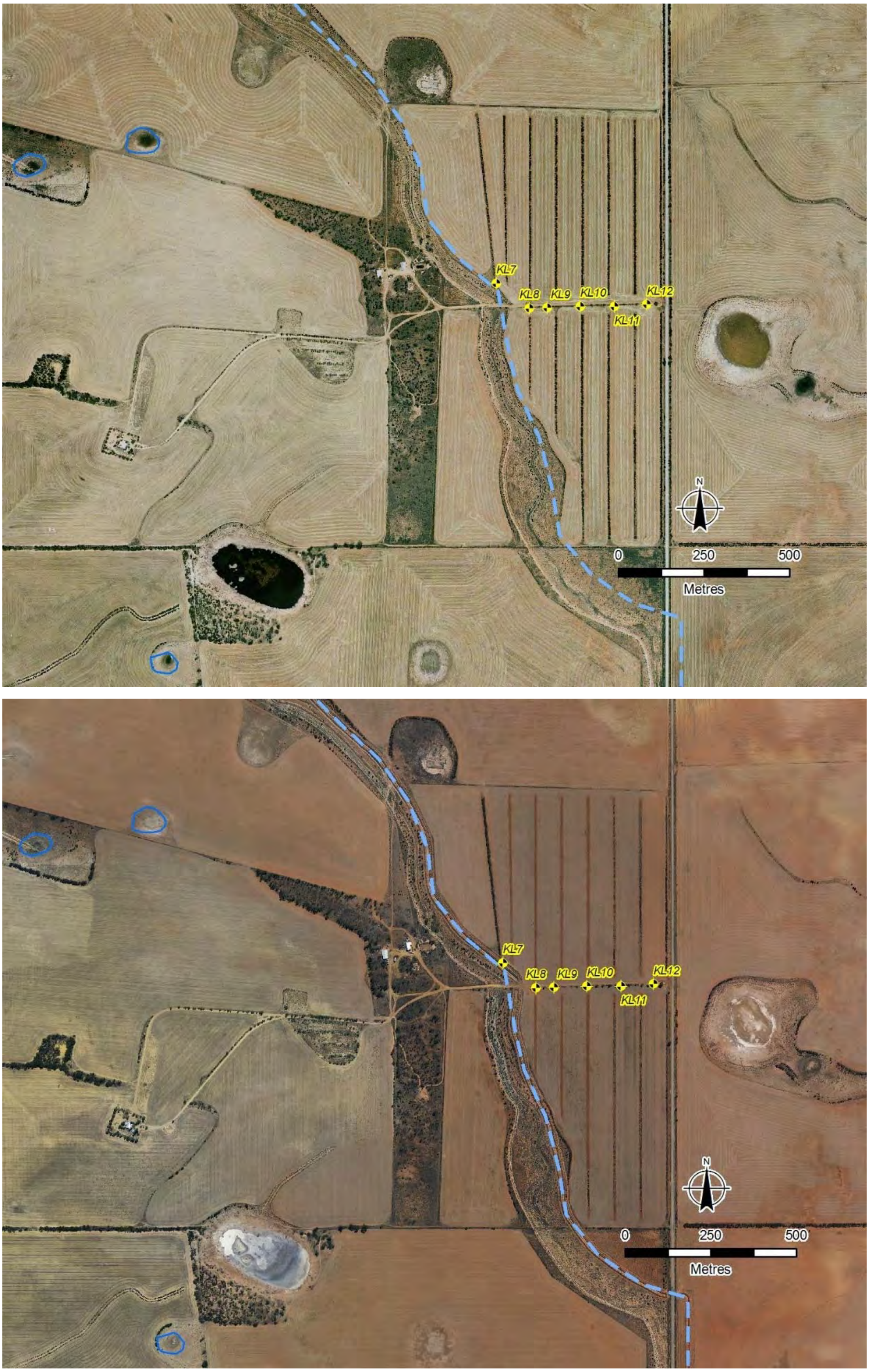


Figure 5 Angel transect (KL8-KL12) pre-drain (top; January 2006) and post-drain (bottom; March 2011)

3.2 Campbell Road transect (KL1-KL6)

The Campbell Road transect (KL1-KL6) is located toward the upper end the Xantippe deep drain alignment, and comprises six bores installed along a transect perpendicular to the drain (Figure 3, Table 3). Water levels in all bores were manually measured between 29 September 2007 and 15 October 2013. The arterial drain was excavated past the transect on or about the 20 April 2008.

Existing drainage in the vicinity of the Campbell Road transect includes the existing deep drain that runs north along the western side of the Dalwallinu-Kalannie Road, approximately 130 m west of the start of the monitoring bore transect.

There is also a length of shallow drain connecting the chain of lakes to the east of the Dalwallinu-Kalannie Road (100 m east of the transect) (Figure 4). These drains connect along the Dalwallinu-Kalannie Road approximately 1.5 km north of Campbell Road.

The proximity of these existing drains may potentially influence the watertable response at this site, and were considered in review of the available groundwater data.

Table 3 Campbell Road transect bore location details

Bore ID	Distance from drain (m)	Easting	Northing	Survey elevation (m LHD)	Initial groundwater level (m LHD)
KL1	17	506988	6644975	9.80	7.89
KL2	50	507021	6644974	9.93	7.80
KL3	98	507069	6644974	9.88	7.97
KL4	193	507164	6644975	10.25	8.38
KL5	303	507274	6644977	10.44	8.82
KL6	382	507370	6644975	10.00	7.85

Initial watertable response

Changes in groundwater level before and immediately after construction of the 2.5 m deep drain are summarised in Figure 6.

Pre-drain the groundwater levels in bores within 100 m of the drain peak in late March (Figure 6), which coincides with 35 mm rainfall at Xantippe BoM station (23 March 2008). Drain construction past the transect occurred on or about the 20 April 2008, following some minor rain events and a further 14 mm of rainfall on 18 April 2008. The watertable recession following the 35 mm rainfall event, and the subsequent rainfall events prior to drain construction, are likely to have influenced the initial watertable response.

In bores closest to the drain (KL1-KL3, 17-98 m from the drain) there appears to be an immediate watertable response to drain construction. Bores located at greater distances from the drain (KL4-KL6, 193-382 m from the drain) show a slight upward trend in watertable during the construction period in response to rainfall.

The initial observed decline in watertable in bores closest to the drain is temporary, with the watertable in all bores returning to levels above the pre-drain level by the 29 April 2008, coinciding with 30 mm of rainfall recorded at Xantippe BoM station.

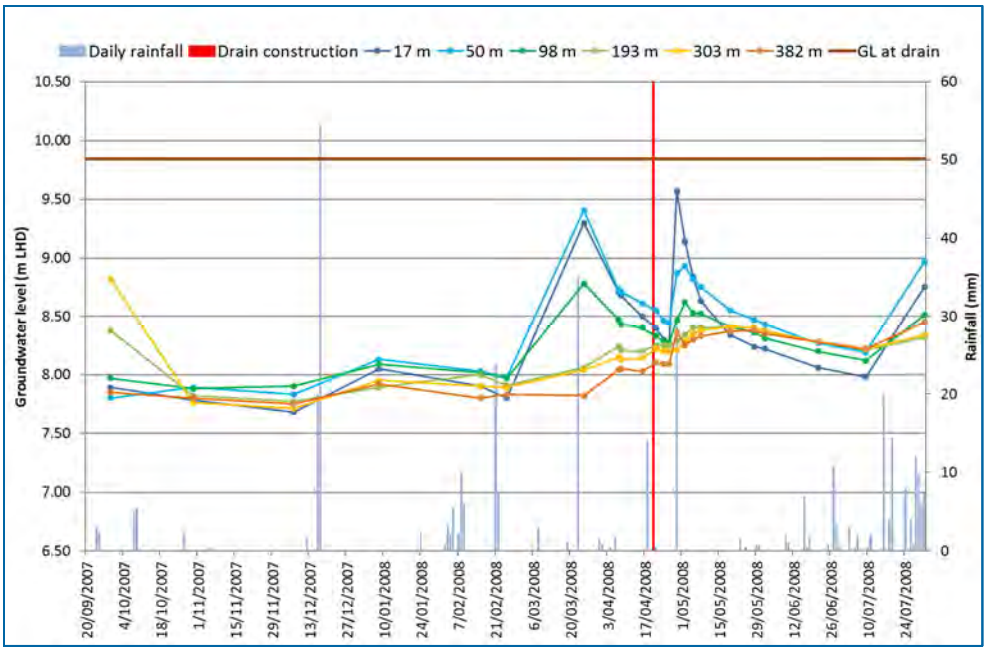


Figure 6 Campbell Road transect initial groundwater response

Longer term watertable response

Figure 7 displays the extent of the monitoring data for the Xantippe Campbell Road transect, with pre-drain watertable levels and selected post-drain watertable profiles displayed in Figure 8. Peak groundwater level in response to rainfall periods is generally highest in bore KL2 (50 m from drain). In bores at distance from the drain (193 m and beyond) the watertable response to rainfall recharge is delayed.

Before construction of the drain, the watertable in proximity to the drain (KL1, 17 m) was measured between 1.13 m (7 April 2008) and 2.13 m (7 December 2007) below ground level, and at distance from the drain (KL6, 382 m) the watertable is observed between 1.95 m (7 April 2008) and 2.25 m (7 December 2007) below ground level.

Other than the watertable response in bores in close proximity to the drain following 35 mm rainfall recorded at the Xantippe BoM station, the depth to the watertable within the pre-drain monitoring period generally exceeds the watertable benchmark of 1.5 m below ground level required for agricultural production of barley and wheat (Nulsen 1981).

Similarly, during the post-drain monitoring period there are short periods when the watertable in the immediate vicinity of the drain responds to rainfall events in proximity to the drain. However, in general the watertable remained greater than 1.5 m below ground level. From December 2008 the watertable was predominantly greater than 2 m below ground level across the monitoring bore transect. Watertable levels at the end of the monitoring record in October 2013 were within 0.2 to 0.5 m of pre-drain groundwater levels.

As noted in Table 1 there are large gaps in monitoring record between April 2010 and February 2012, and September 2012 and July 2013, and therefore likely groundwater peaks in response to significant rainfall events during these periods were not recorded (Figure 7).

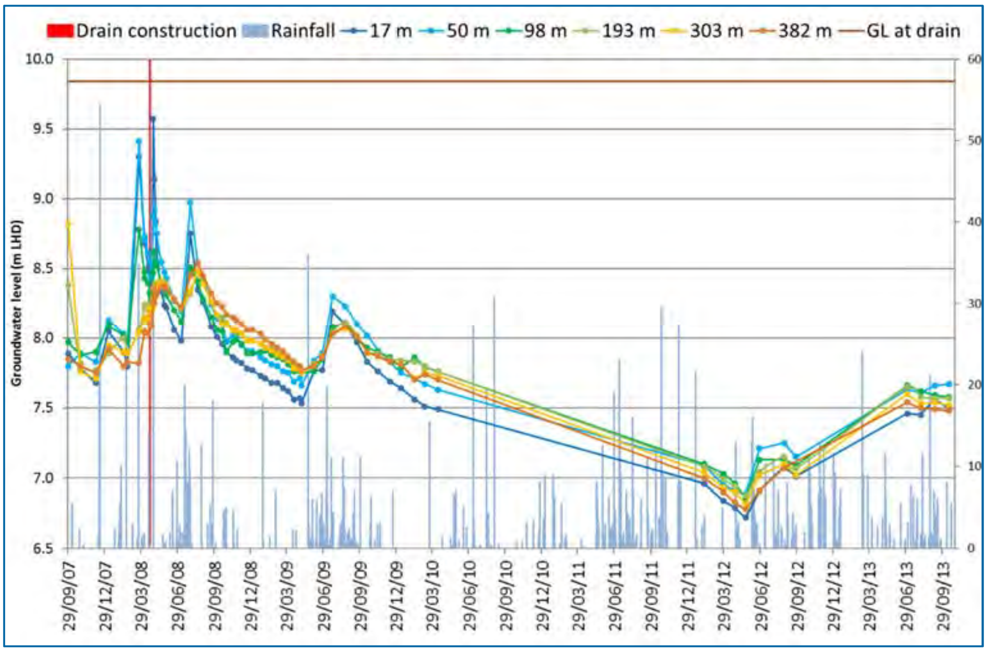


Figure 7 Campbell Road transect all groundwater data

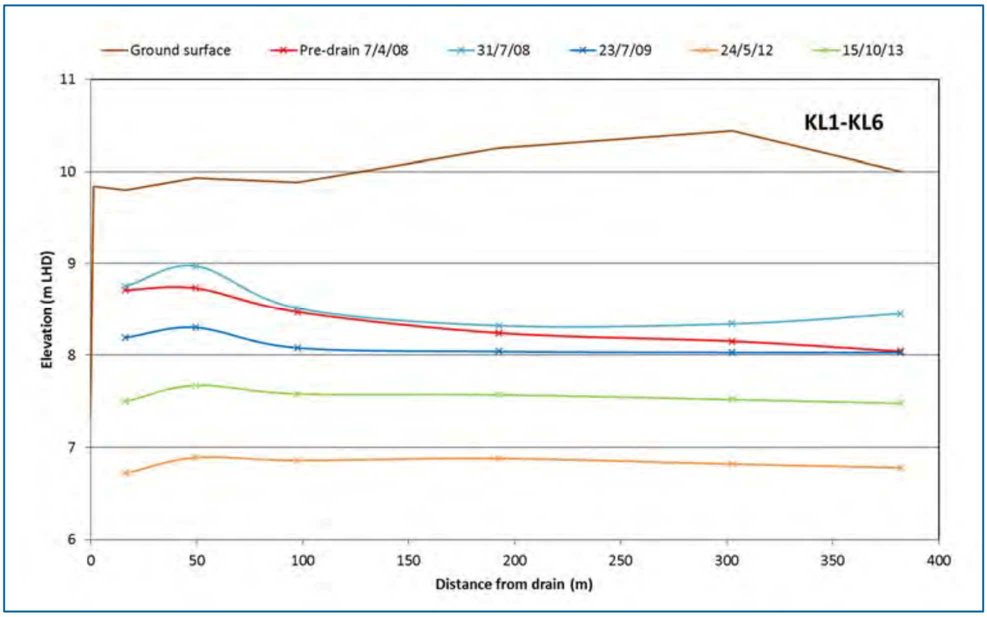


Figure 8 Campbell Road watertable profiles

Rainfall trends (AMRR)

Comparison of the Campbell Road (KL1-KL6) watertable response and AMRR at Xantippe (Figure 9) shows that watertable levels across the transect broadly reflect AMRR trends. Watertable increases above pre-drain levels (before April 2008) tended to coincide with observed upward trend in AMRR. Similarly, declines in watertable below the observed pre-drain watertable generally coincide with a downward trend in AMRR.

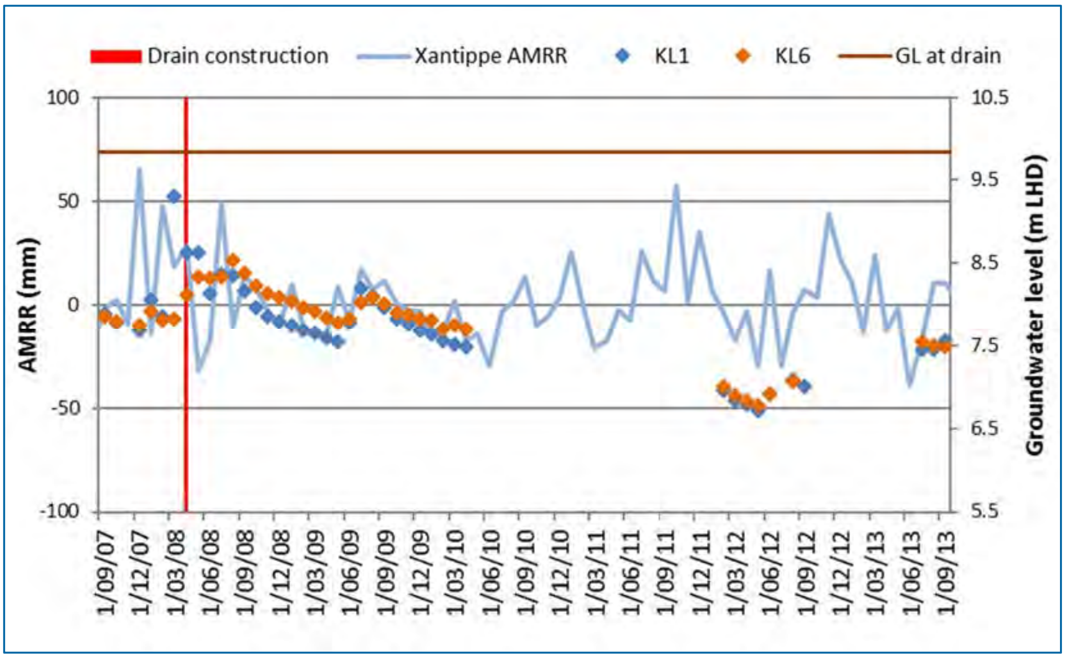


Figure 9 Campbell Road transect AMRR comparison

3.3 Angel transect (KL8-KL12)

The Angel transect (KL8-KL12) is located two thirds of the way down the Xantippe deep drain alignment, and comprises five bores installed along a transect perpendicular to the drain (Figure 3, Table 4). Water levels in all bores were manually measured between 29 September 2007 and 15 October 2013. The arterial drain was excavated past the transect on or about the 31 March 2008.

Pre-existing drainage within the vicinity of the transect consisted of a shallow drain that passed through the western portion of the vegetated drainage corridor (Figure 5), which is the downstream extension of the drain that extends upstream to Pithara East Road. Alley farming is observed to be present within the paddocks adjacent to the transect prior to drain excavation, and a small playa is also located 200 m east of the end of the transect (Figure 5). The review of watertable response at this site was undertaken with consideration of the potential influence of the presence of alley farming and the playa to the east of the transect.

Table 4 Angel transect bore location details

Bore ID	Distance from drain (m)	Easting	Northing	Survey elevation (m LHD)	Initial groundwater level (m LHD)
KL8	57	506500	6648023	9.54	7.58
KL9	110	506553	6648025	9.60	7.51
KL10	207	506650	6648028	9.83	7.52
KL11	307	506750	6648027	10.07	7.34
KL12	402	506845	6648034	10.00	7.40

Initial watertable response

Changes in groundwater level before and immediately after construction of the 2.5 m deep drain are summarised in Figure 10.

Drain construction past the transect occurred on or about the 31 March 2008, following a significant rainfall event (35 mm, 23 March 2008). The observed initial response is therefore influenced by the antecedent rainfall conditions, and likely occurs during a groundwater recession period.

There appears to be an immediate watertable response to drain construction in the bores closest to the drain (KL8-KL10, 57-207 m from drain). Bore KL11 (307 m from drain) shows an upward trend at drain construction followed by a slow decline, and bore KL12 (402 m from drain) shows a slow decline.

Following the initial responses the watertable level is observed to return to pre-drain levels on 29 April 2008, coinciding with 30 mm of rainfall recorded at Xantippe BoM station.

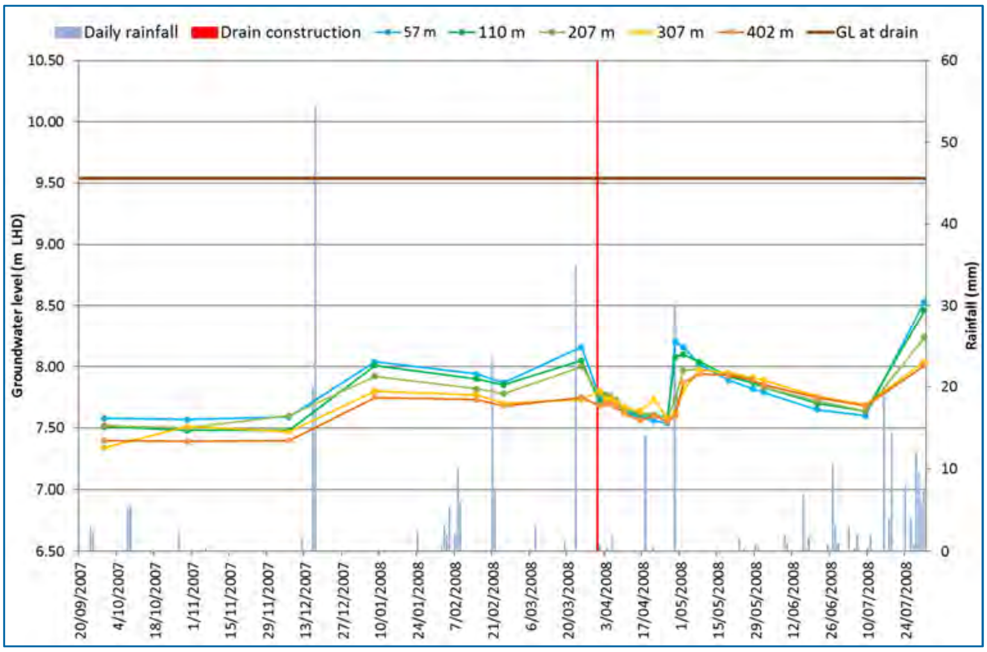


Figure 10 Angel transect initial groundwater response

Longer term watertable response

Figure 11 displays the extent of the monitoring data for the Xantippe Angel transect, with pre-drain watertable levels and selected post-drain watertable profiles displayed in Figure 12.

The watertable in the Angel transect follows similar trends to the Campbell Road transect, with peak groundwater levels in response to rainfall periods generally highest in bore KL8 (57 m from drain), and groundwater responses to rainfall in bores at distance from the drain more subdued.

Also similar to the Campbell Road transect, with the exception of watertable response to significant rainfall events the watertable in pre- and post-drain periods is typically greater than 1.5 m below ground level, exceeding the watertable benchmark of 1.5 m below ground level required for agricultural production of barley and wheat (Nulsen 1981).

Figure 12 displays profiles of the pre-drain watertable level with selected post construction dates, identifying that the hydraulic gradient within the transect generally slopes away from the drain.

Watertable levels at the end of the monitoring record in October 2013 is within 0.3 m of pre-drain baseflow groundwater levels. As noted in Table 1 there are large gaps in monitoring record between April 2010 and February 2012, and September 2012 and July 2013, and therefore likely groundwater peaks in response to significant rainfall events during these periods are not displayed in Figure 11.

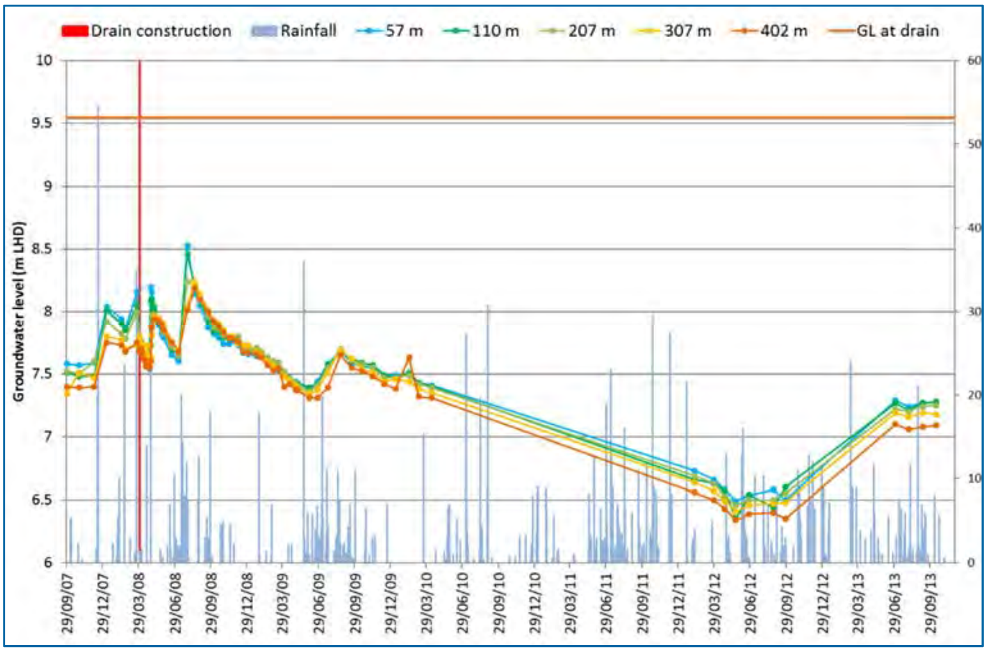


Figure 11 Angel transect all groundwater data

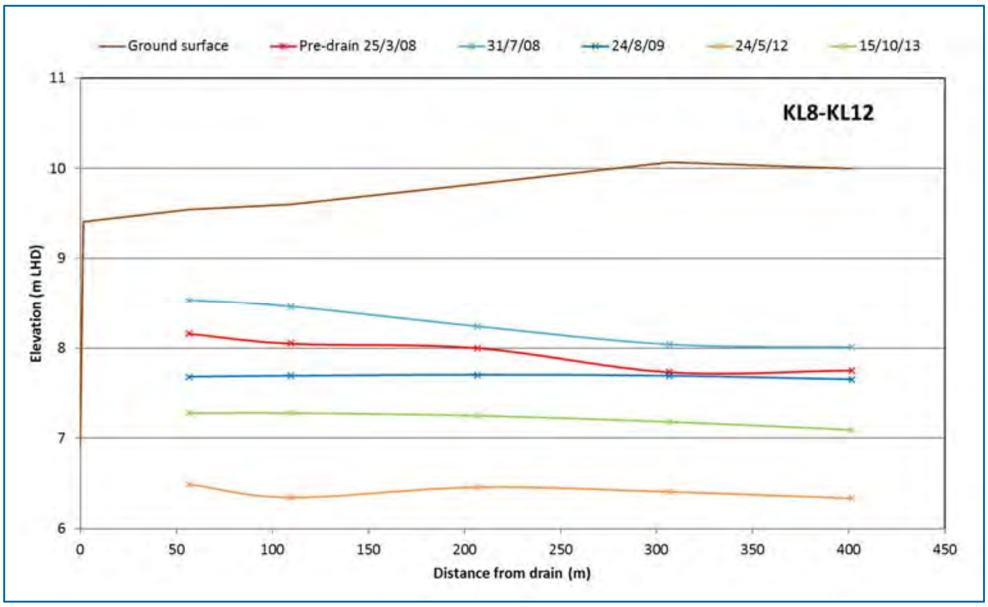


Figure 12 Angel transect watertable profile

Rainfall trends (AMRR)

As with the Campbell Road transect a comparison of the watertable response at the Angel transect (KL8-KL12) to AMRR at Xantippe (Figure 13) identifies that observed watertable across the transect broadly reflects AMRR trends during both the pre-and post-drain monitoring period.

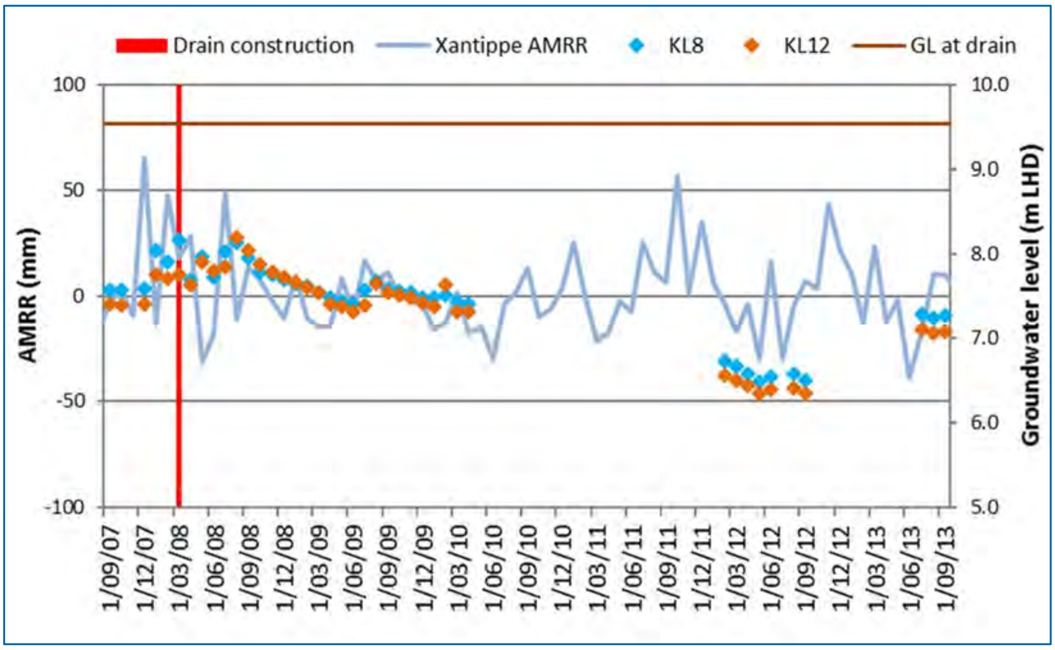


Figure 13 Angel transect AMRR comparison

3.4 Site observations

Crop productivity

Discussions with the landholder and leaseholder of the property adjacent to the Campbell Road transect during the site visit suggested improvement in surface condition and crop productivity in the paddocks immediately north-east and south-west of the intersection of the Dalwallinu-Kalannie Road and Campbell Road. The paddocks were previously reported as having visible salt crusts, with Fordyce (2015) noting that the paddock to the north-east of the intersection previously had been patchily cropped, with numerous bare areas and waterlogged patches that supported sparse Nypa grass, samphire and bluebush. After drain construction the landholder and leaseholder both observed improvements in crop condition within both paddocks, which are now cropped to barley and have no visible salt scalds or observed patchiness (Plate 2).

Review of the pre- and post-drain aerial photography (Figure 5) does not identify any change in cropping areas in the vicinity of the Angel transect.

Plate 2: View north-west from Campbell Road drain crossing looking across Hathaway front paddock towards Dalwallinu-Kalannie Road. Paddock planted to barley.

Adjacent vegetation health and vigour

In June 2016, the broombush plantation adjacent to the Campbell Road transect (KL1-KL6) appeared to be well established (Plate 3), and volunteer shrubs had established on the drain banks (Plate 2). Similarly, the vegetation within the wide drainage corridor adjacent to the Angel transect (KL10-KL15) appeared to be in good condition and showing no signs of stress associated with salinity (Plate 4).

Plate 3: View north-east from Campbell Road drain crossing showing established broombush plantation within drainage corridor.

Plate 4: View south-west from Angel transect showing drain bank and vegetation within the drainage corridor.

Downstream vegetation transects

Two vegetation transects were established in the Xantippe sub-catchment, with monitoring of the transects in 2008 and 2009. YYCMG (2010) report there were no changes to the vegetation transects that can be attributed to discharge from the arterial drainage scheme.

Water quality

In-situ pH measurements from the existing drain on the Dalwallinu-Kalannie Road on 11 April 2008 recorded a pH of 3.5. Following drain construction pH observations from reference lakes in the sub-catchment recorded pH ranging between 3.0 to 8.4.

In-situ analysis of arterial drain water quality within the Xantippe sub-catchment in 2012 identified a pH of 3.7 (Fordyce 2012).

3.5 Discussion

Initial watertable responses to drain construction were observed in bores closest to the drain in both the Campbell Road transect (KL1-KL3, 17-98m from drain) and the Angel transect (KL8-KL10, 57-207 m from drain). However drain construction at both locations occurred following rainfall events and the observed initial response occurred during groundwater recession periods. These factors combined likely influence the observed initial response at each site.

The watertable at both transect locations was observed to return to above the pre-drain levels in response to significant rainfall events between 2 weeks (Campbell Road) and 4 weeks (Angel transect) after drain construction.

The watertable at the monitoring bore transects generally follows trends in AMRR, with the reduced watertable level at the end of the monitoring period likely attributed to an extended period of downward trending AMRR and reduction in significant rainfall events in the preceding period. Review of the available monitoring bore transect data has not identified a long term watertable response that may be attributed to the construction of the arterial drainage at either site within the Xantippe sub-catchment.

The observed cropping improvements in the paddocks to the west of the arterial drain at the Campbell Road transect may be attributed to the existing deep drainage that runs north along the Dalwallinu-Kalannie Road. The close spacing of the arterial drain to the existing drain (120 m near the start of the transect) is likely to mean they act as parallel drains to control groundwater levels between the drains (Cox and Tetlow, 2014; Cox and Tetlow in prep.). This potential watertable control between the two drains is not recorded by the monitoring bore transect, which is located to the east of the arterial drain. The observed cropping improvements reported for the Campbell Road transect are therefore confounded by the presence of the existing drainage, and are not able to be attributed in isolation to the construction of the arterial drain. Further the location of the watertable monitoring bore transect does not enable further assessment of the data to examine the impact of drainage density on watertable levels.

Within the Angel transect the alley farming treatment within the paddock adjacent to the transect is likely to have influenced the long-term local watertable response at the site.

The observed trend of hydraulic gradient sloping away from the drain may be in response to this additional treatment at the site, and may also be confounded by the presence of a playa 200 m east of the transect.

4. Jibberding

4.1 Sub-catchment overview

YYCMG (2007) identified approximately 11% of farming land was affected by salinity within the Jibberding Zone, predominantly occurring within sub-catchments 19 and 21. Extensive privately funded farmer drains occur throughout the Jibberding Zone, with drainage constructed within sub-catchment 21 in a joint project between farmers and the State Salinity Council in 2002. Construction of the arterial drain within the Jibberding 19 sub-catchment occurred between December 2007 and April 2008 to a total length of 11.5 km.

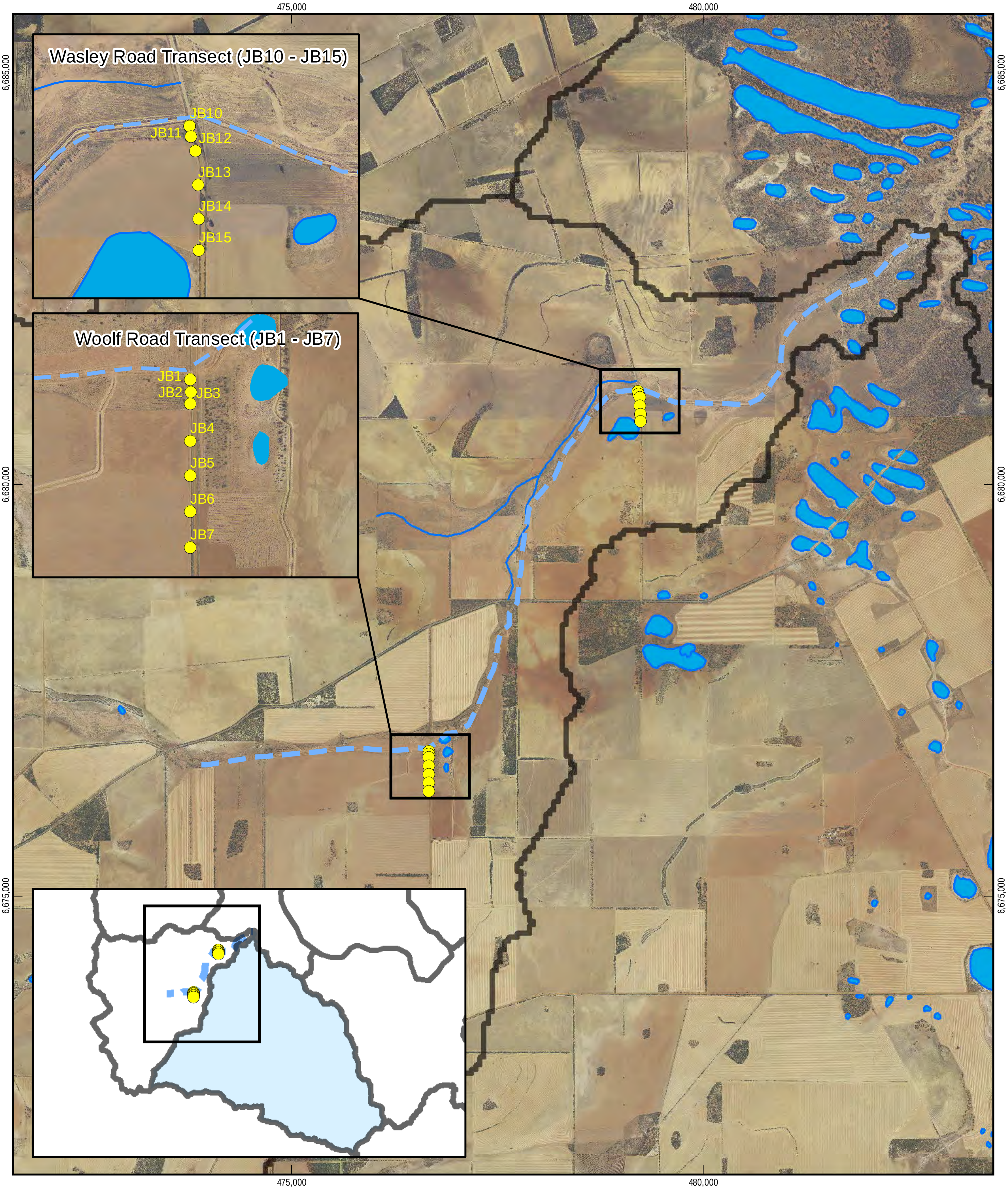
Soil landscape mapping (DAFWA) describes the soils of the valley floor as *Red-brown hardpan shallow loam, red deep sandy duplex and red shallow sandy duplex* (Map unit: 271Gn_4).

Water quality in groundwater monitoring bores prior to excavation of the arterial drainage was reported as having salinity ranging from 5 to 98 mS/cm and pH ranging from 3.3 to 7.4 (YYCMG 2007).

The YYCMG established two groundwater monitoring bore transects in the Jibberding 19 sub-catchment (Figure 14):

- Woolf Road transect (JB1-JB7)
- Wasley Road transect (JB10-JB15).

Aerial photographs of the transects pre- and post-arterial drain construction are displayed in Figure 15 (Woolf Road transect) and Figure 16 (Wasley Road transect).



LEGEND

- Transect
- Arterial drain
- Watercourse
- Perennial and non-perennial lakes
- Yarra Yarra Subcatchment
- Jibberding Subcatchment

Paper Size A4

0 500 1,000 2,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

SLIP ENABLER

Department of Water
Yarra Yarra Regional Drainage Program;
Evaluation of Xantippe,
Jibberding and Mongers 16 drains

Job Number	61-33069
Revision	0
Date	08 Sep 2016

Jibberding Subcatchment

Figure 14

999 Hay Street Perth WA 6004 Australia T 61 8 6222 8222 F 61 8 6222 8555 E permail@ghd.com.au W www.ghd.com.au

Data source: Geoscience Australia: Landsat Imagery, GeoData Topo 250k Series III; Yarra Yarra Catchment Group: Major Lakes; Shire of Dumbleyung: Yarra Yarra Subcatchment. Created by:mmikkonen

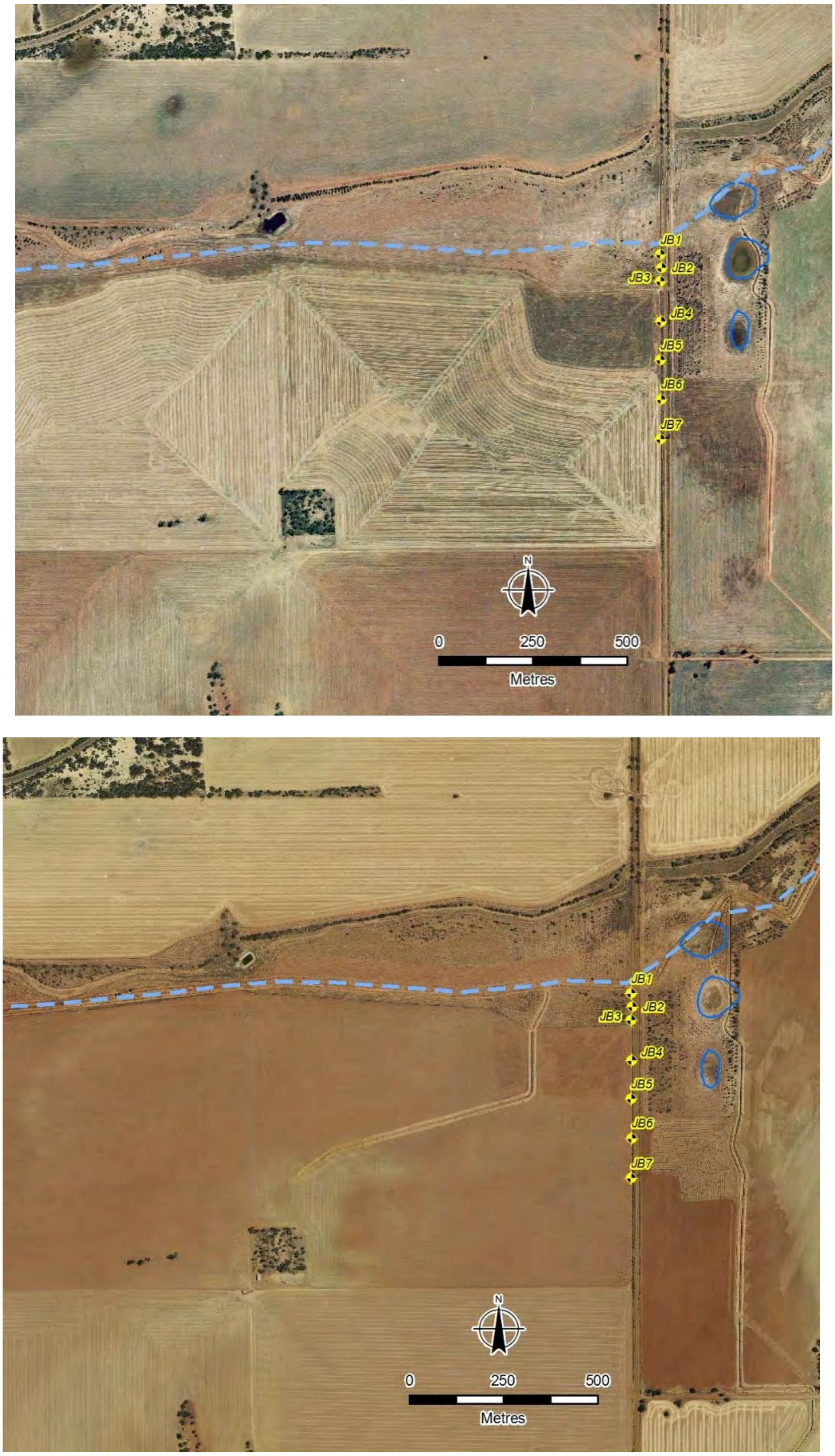
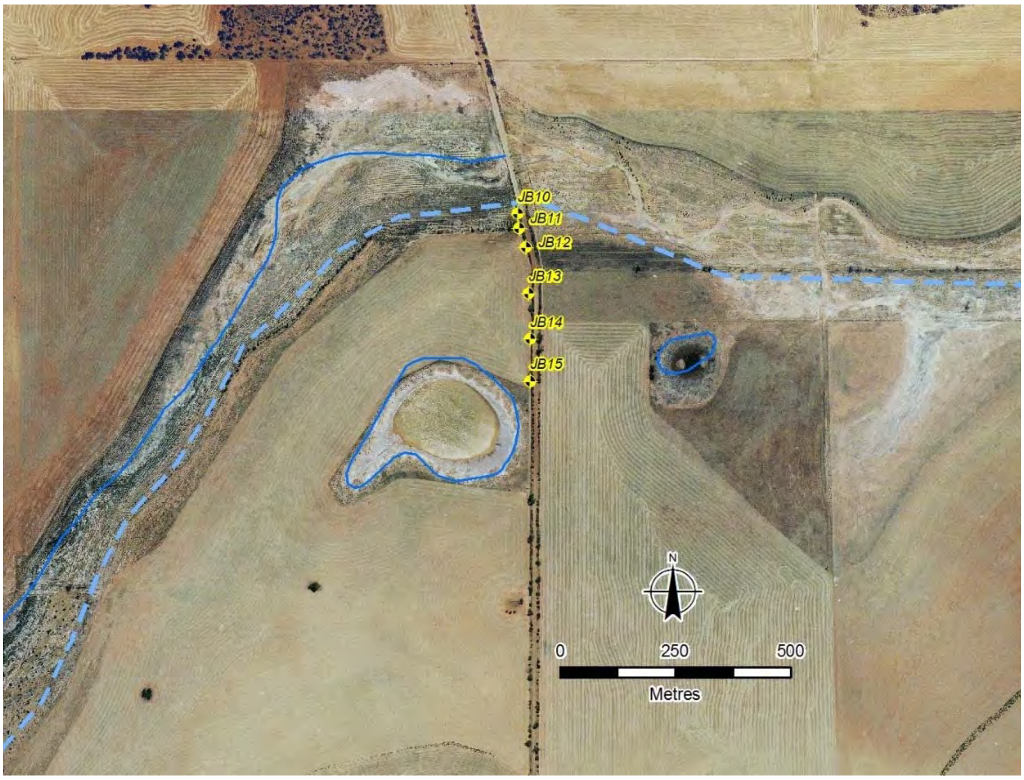


Figure 15 Woolf Road transect (JB1-JB7) pre-drain (top; January 2006) and post-drain (bottom; August/December 2010)



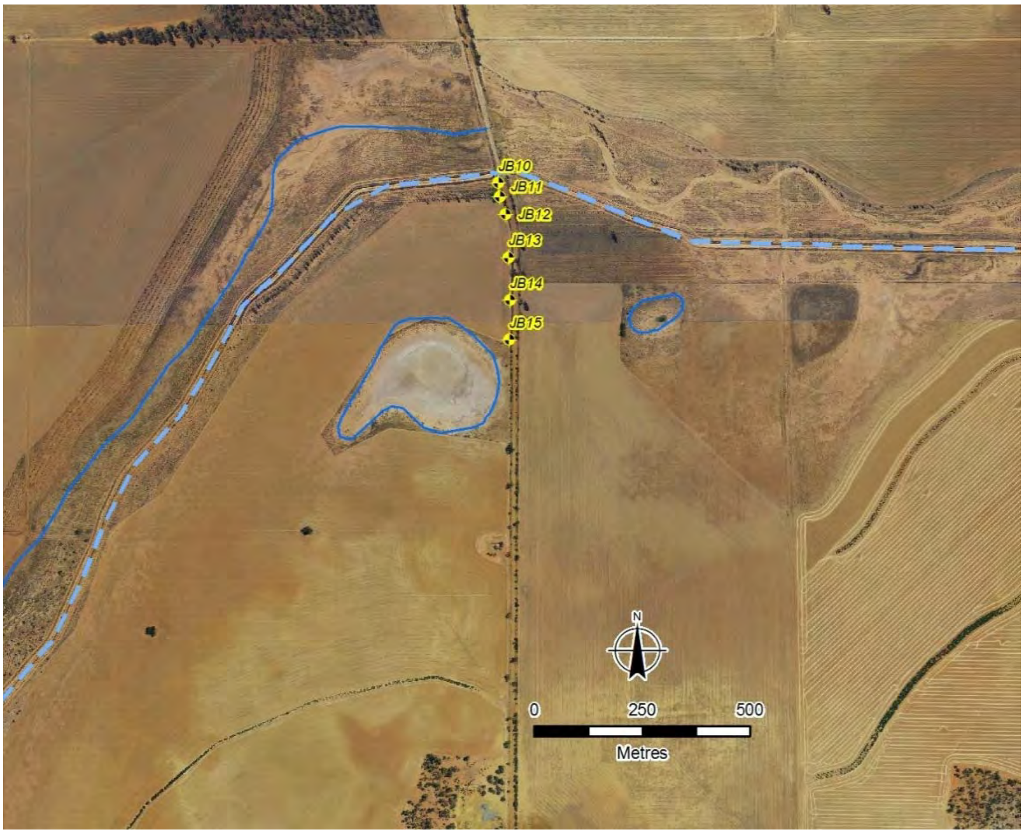


Figure 16 Wasley Road transect (JB10-JB15) pre-drain (top; January 2006) and post-drain (bottom; August/December 2010)

4.2 Woolf Road transect (JB1-JB7)

The Woolf Road transect (JB1-JB7) is located toward the upper end the Jibberding deep drain and comprises seven bores installed along a transect perpendicular to the drain (Figure 14, Table 5). Water levels in all bores were manually measured between 1 November 2007 and 16 August 2013. The arterial drain passes through a wide vegetated valley floor, and was excavated past the transect on or about the 29 February 2008. Aerial photos of the site pre-drain (2006) and post drain (2010) are shown in Figure 15.

At the Woolf Road transect (JB1-JB7) the landholder has constructed private spur drains, with an initial private drainconstructed prior to the Yarra Yarra arterial drain with no outlet and reliance on evaporation located to the east of the monitoring bore transect (Figure 15). An additional spur drain was constructed at the same time as the arterial drain construction to the west of the monitoring bore transect. The resulting drain configuration results in deep drainage constructed on three sides of the of the monitoring bore transect location.

The farmer has since constructed an additional spur drain connecting to the arterial drain on the northern side, completed following the end of the Yarra Yarra monitoring period.

Additional land treatments in proximity to the arterial drain location include privately funded revegetation of the valley floor with saltbush vegetation and tree belts within proximity to the transect location. The proximity of the spur drainage and vegetation treatments to the monitoring bore transect may potentially influence the watertable response at this site, and were considered in review of the available groundwater data.

Table 5 Woolf Road transect bore location details

Bore ID	Distance from drain (m)	Easting	Northing	Survey elevation (m LHD)	Initial groundwater level (m LHD)
JB1	36	476670	6676766	8.76	7.32
JB2	72	476672	6676730	8.88	7.31
JB3	106	476670	6676696	8.94	7.48
JB4	214	476671	6676588	9.14	7.63
JB5	316	476670	6676486	9.48	7.88
JB6	420	476671	6676382	9.65	7.95
JB7	490	476670	6676276	10.00	8.04

Initial watertable response

Changes in groundwater level before and immediately after drain construction are presented in Figure 17. Drain construction occurred on or around the 29 February 2008, following 35.5 mm of rainfall on the 21 February and 7 mm on the 22 February 2008 (Lee Farm, Jibberding rainfall data). Rainfall totals of 23.8 mm and 3 mm were reported for the 21 and 22 February respectively at Dalwallinu North (Figure 17). Earlier rainfall at the beginning of February (totalling 35.5 mm) also contributed to the observed groundwater rise in all bores immediately prior to drain construction (Figure 17).

An immediate watertable response to drain construction is observed in bores 36 m to 106 m from the drain, however the initial watertable response is influenced by both antecedent rainfall conditions and likely occurs during a groundwater recession period. The observed initial response should therefore be viewed with consideration of the antecedent conditions.

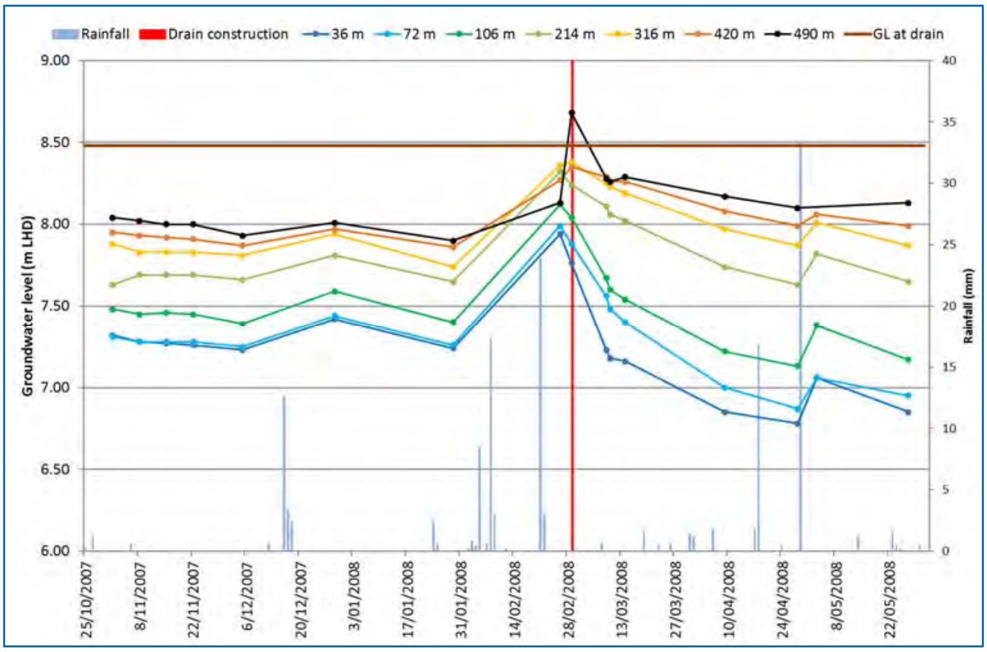


Figure 17 Woolf Road transect initial response

Longer term watertable response

Figure 18 displays the extent of the monitoring data for the Jibberding Woolf Road transect, with pre-drain watertable levels and selected post-drain watertable profiles displayed in Figure 19.

Following construction of the arterial drain and additional private spur drain there appears to be an observed step decline in watertable level in the bores located within approximately 100 m of the arterial drain. During the post drain monitoring period the watertable within the bores located within approximately 100 m of the arterial drain observe a more subdued response to rainfall events than bores greater than 200 m from the arterial drain, which have a response of similar magnitude as observed during the pre-drain monitoring period.

The persistent increased watertable slope towards the arterial drain along the bore transect after the construction of the arterial and additional private spur drain (Figure 19) indicates the drainage density in proximity to the transect (drainage on three sides) has an influence on the watertable, extending over several hundred metres.

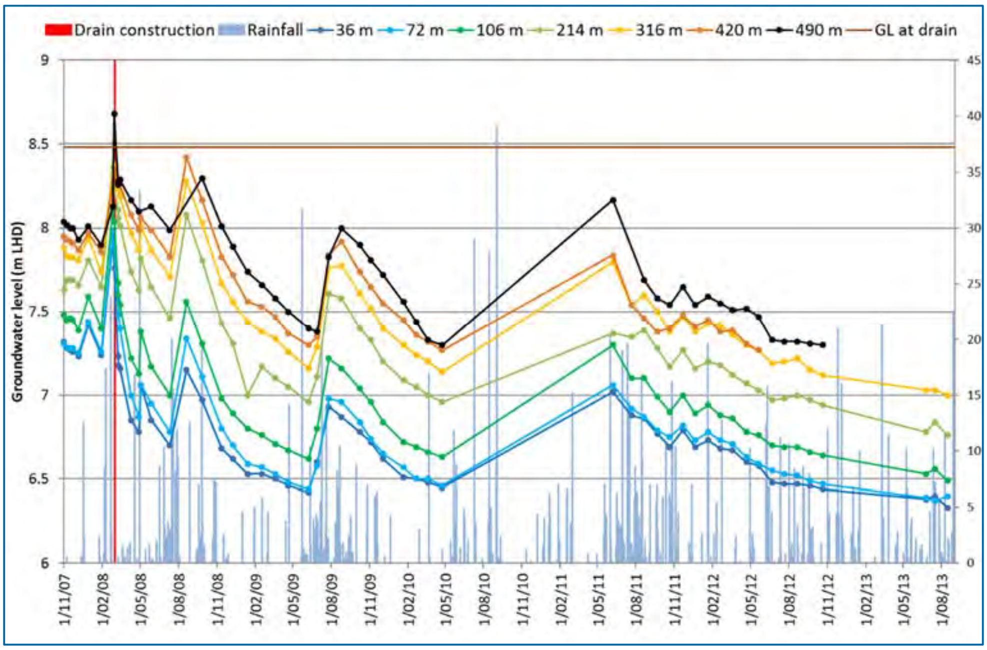


Figure 18 Woolf Road transect all groundwater data

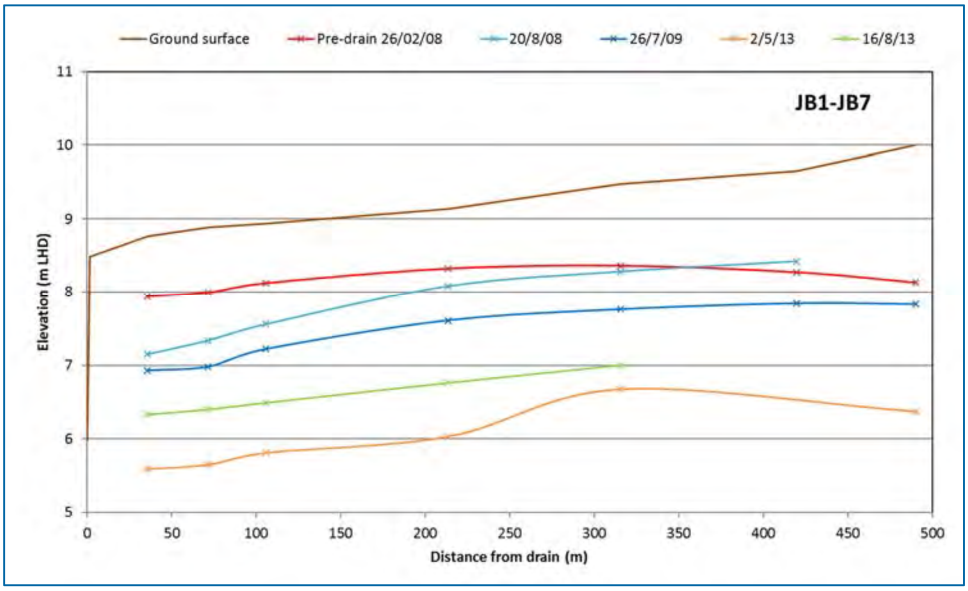


Figure 19 Woolf Road transect watertable profiles

Rainfall trends (AMRR)

Comparison of the watertable response of bores JB1 and JB7 to AMRR trend for the Dalwallinu North BoM station shows that the drain construction (29 February 2008) occurred during an upward trend in AMRR indicating a period of predominantly above-average rainfall (Figure 20). Subsequent watertable peaks across all bores also coincide with upward trend in AMRR (August 2009), however later periods of above average rainfall (September 2011 onwards) do not produce similar peaks in watertable response, particularly in bore JB1.

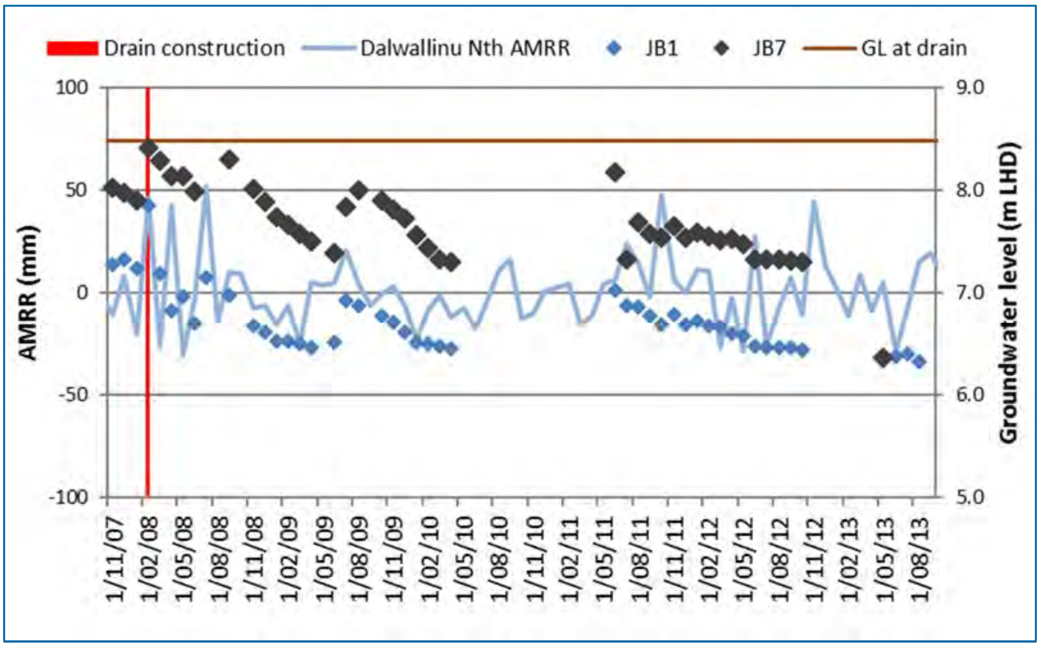


Figure 20 Woolf Road transect AMRR comparison

4.3 Wasley Road transect (JB10-JB15)

The Wasley Road transect (JB10-JB15) is located toward the lower end the Jibberding drain and comprises six bores installed along a transect perpendicular to the drain (Figure 16, Table 6). Water levels in all bores were manually measured between 10 October 2007 and 16 August 2013. The arterial drain was excavated past the transect on or about the 3 January 2008.

A playa is located in proximity to the southern end of the monitoring bore transect. The review of watertable response at this site was undertaken with consideration of the potential influence of the playa.

Aerial photos of the site pre-drain (2006) and post drain (2010) are shown in Figure 16.

Table 6 Wasley Road transect bore location details

Bore ID	Distance from drain (m)	Easting	Northing	Survey elevation (m LHD)	Initial groundwater level (m LHD)
JB10	24	479212	6681134	8.78	7.47
JB11	55	479216	6681103	8.84	7.43
JB12	98	479230	6681062	9.02	7.45
JB13	198	479237	6680962	9.43	7.44
JB14	297	479240	6680863	9.69	7.45
JB15	388	479239	6680772	10.00	7.33

Initial watertable response

Changes in groundwater level before and immediately after drain construction are presented in Figure 21.

Prior to construction of the drain past the Wasley Road transect the watertable was flat with no gradient between the bore closest to the drain (JB10, 24 m) and the bore constructed nearly 300 m from the drain alignment (JB14, 297 m) (Figure 21).

As the drain was excavated past the Wasley Road bore transect the measured decline was small in bore JB12 (in the order of 0.10 m) with the response in the remaining bores uncertain (within the range of measurement error).

Rainfall amounts of 10.5 mm in late January, 35.5 mm in early February and 42.5 mm in late February 2008 were reported at the local farmer rain gauge in Jibberding (Lee Farm), with above average rain also reported for the Dalwallinu North BoM station in February. This unseasonal rainfall caused water levels in the valley floor to rise above monitored pre-drain levels across the bore transect in March 2008, with the largest observed increases in the bores located 98 m (JB12) and 198 m (JB13) from the drain.

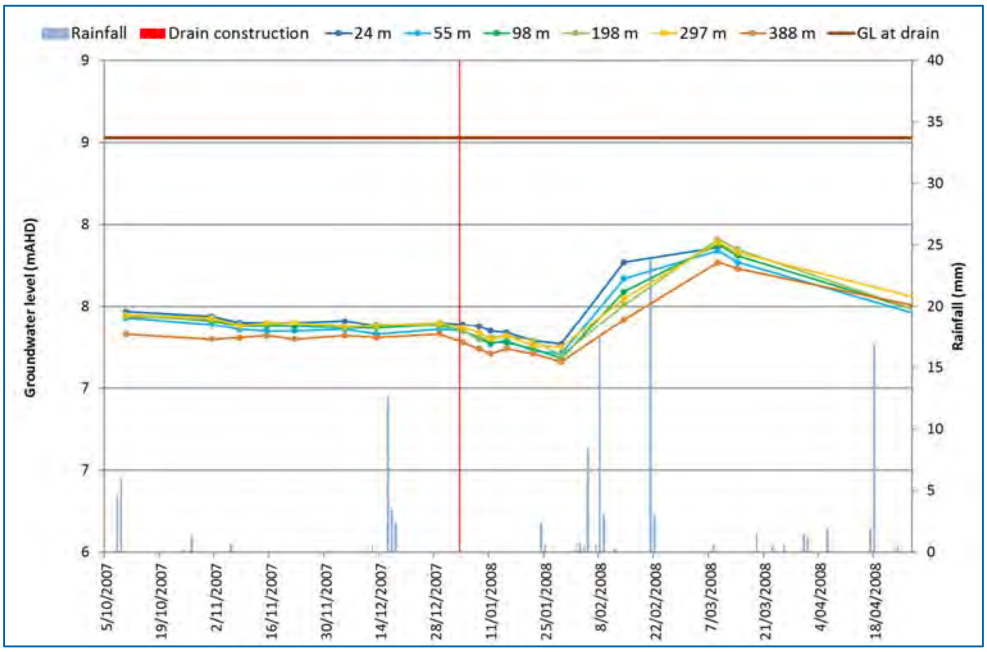


Figure 21 Wasley Road transect initial groundwater response

Longer term watertable response

Figure 22 displays the extent of the monitoring data for the Jibberding Wasley Road transect, with pre-drain watertable levels and selected post-drain watertable profiles displayed in Figure 23. Following the initial subtle watertable response to drain excavation the groundwater levels in all bores were observed to exceed the pre-drain levels with peaks recorded in March 2008, May 2008, August 2008 and August 2009.

During both peak and baseflow groundwater periods the hydraulic gradient across the transect is generally flat (Figure 23). Between June and December 2011 there is an extended period of reversal of the hydraulic gradient away from the drain (Figure 22). During this period the observed rainfall record at both the Sunnydale and Dalwallinu North BoM stations returned to average winter rainfall, with above average rainfall observed for the September to December period.

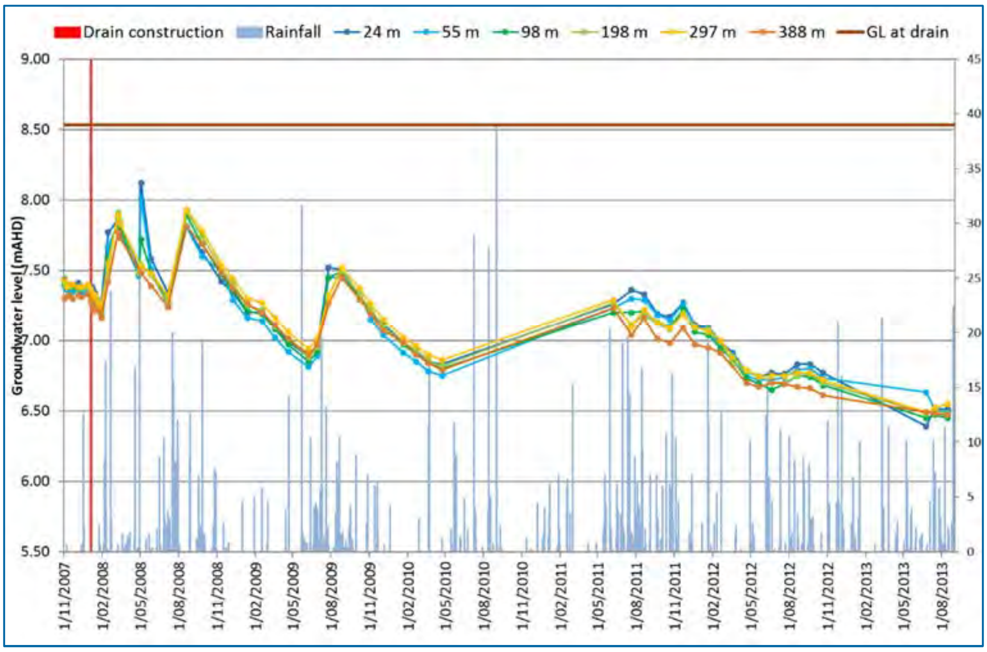


Figure 22 Wasley Road transect all groundwater data

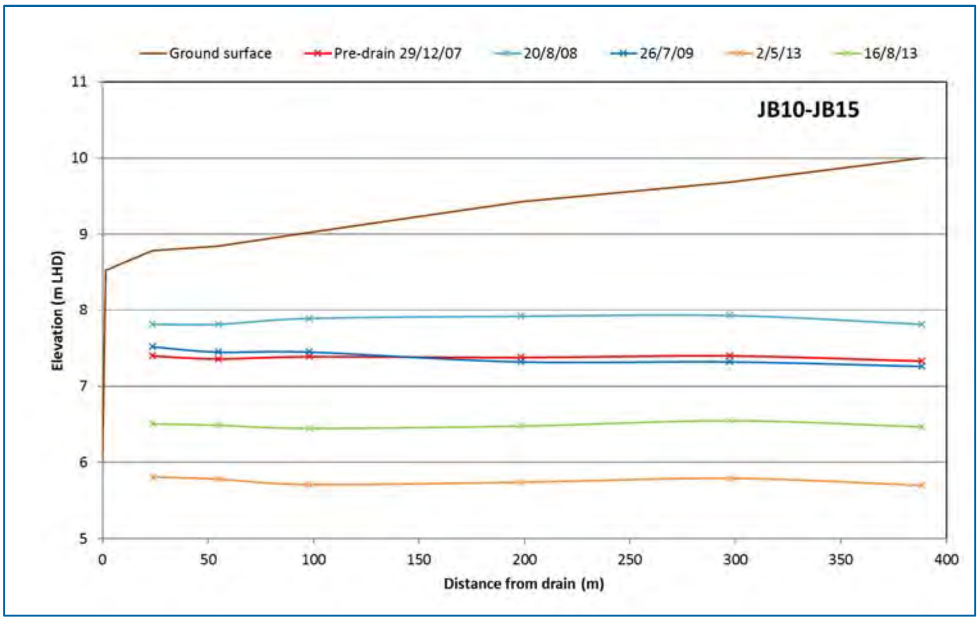


Figure 23 Wasley Road transect watertable profiles

Rainfall trends (AMRR)

Comparison of the watertable response of bores JB10 and JB15 to AMRR trends at Dalwallinu North BoM station reveals that drain construction (3 January 2008) occurred at the end of an extended period of predominantly below average rainfall, resulting in a flat watertable gradient across the transect preceding excavation. Subsequent watertable peaks across all bores (August 2008, August 2009) are observed to coincide with upward trend in AMRR. However, similar to the Woolf Road transect, later periods of above average rainfall (September 2011 onwards, Figure 24) do not produce similar peaks in watertable in any bores along the transect.

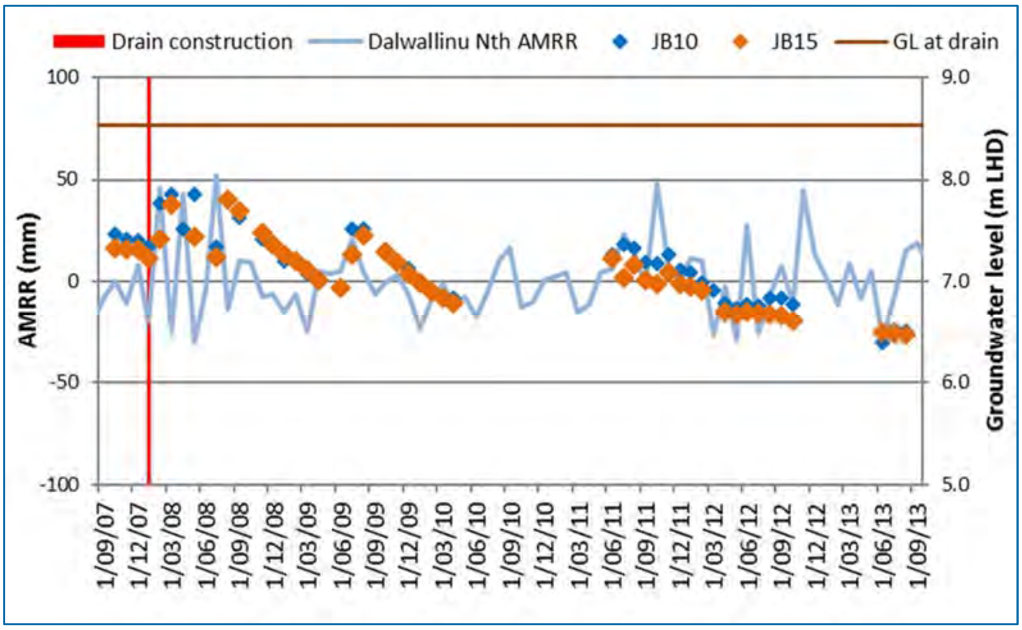


Figure 24 Wasley Road transect AMRR comparison

4.4 Site observations

Crop productivity

Crop productivity improvements were reported by the landholder at the Woolf Road transect who observed that isolated areas of paddocks impacted by salinity had been reclaimed through construction of privately funded spur drains. The landholder had constructed a spur drain to a southern paddock (west of the bore transect) at the same time as construction of the arterial drain to connect a 20 ha area that was previously unable to be cropped, with the area now cropped as wheat (Plate 5). Additional private spur drains constructed by the landholder included a previously constructed drain to the south of the arterial drain (located east of the bore transect), and a more recently constructed spur drain to the north.

Plate 5: View south-west from Woolf Road transect towards corner of southern spur drain. Area further in distance now planted to wheat

A review of the pre- and post-drain aerial photography identified no changes to the crop productivity are observed within the vicinity of the Wasley Road (Figure 16).

Adjacent vegetation health and vigour

Immediately adjacent to the arterial drain at the Woolf Road transect the valley floor vegetation includes both privately established saltbush vegetation and trees (trees planted in 1990s) as well as volunteer shrub establishment along the drain banks (Plate 6).

During the site visit in June 2016 rye grass and cape weed were observed to be growing in the valley floor area of the Woolf Road transect suggesting that the area is less saline than previously. The landholder intends to clear some of the privately planted oil mallee, York gum and saltbush for the purpose of preparing the soils for barley cropping following ripping and application of gypsum.

Plate 6: View west-south-west from Woolf Road transect looking upstream towards southern spur drain, showing adjacent vegetation.

Eight vegetation monitoring transects were established by the YYCMG in the Jibberding sub-catchment and vegetation surveys completed in 2007 to 2009. An additional transect was monitored in 2009 only. While YYCMG reported no changes to the vegetation transects that can be attributed to discharge from the arterial drainage scheme (YYCMG, 2010), there have been observed impacts at the immediate outfall area of the Jibberding drain (Fordyce, 2012).

Fordyce (2012) reports that the Jibberding drain appears to be having a detrimental impact on wetland vegetation with almost all samphire in the immediate outfall area desiccated or dead, with similar impacts on the riparian samphire of the creekline observed over several hundred metres.

Water quality

In-situ pH measurements from the Jibberding creekline in April and September 2007 reported pH measurements of 3.3 and 2.81 respectively (YYCMG 2010). Two months after completion of the arterial drain in the Jibberding 19 sub-catchment in-situ analysis of drain water quality was undertaken at locations along the drain alignment. The pH declined marginally further downstream along the drainage alignment from 4.77 at the Woolf Road bore transect (JB1-JB7), 4.06 at the Wasley Road bore transect (JB10-JB15) and 3.51 at the outlet of the drain to the Mongers Lake system. An in-situ drain measurement taken in 2012 had a pH of 3.4 (Fordyce 2012).

Based on these data, the Jibberding drain has not had any measurable impact on downstream water quality.

4.5 Discussion

Following construction of the Jibberding arterial drain an immediate watertable response was observed in bores closest to the drain at the Woolf Road transect. The response in bores at distance from the drain (214 m and beyond) was delayed and subdued by comparison.

Following construction of the arterial drain and additional private spur drain at the Woolf Road transect there is an observed step decline in watertable response of up to 0.5 m in monitoring bores, with the largest decrease observed in bores located closest to the arterial drain.

The increase in the drainage density around the monitoring bore transect, resulting in deep drainage on three sides of the transect, has also increased the watertable slope towards the arterial drain along the transect and there appears to have been a reduction in the watertable response to rainfall events in bores within approximately 100 m of the drain (JB1-JB3, 36-106m from drain).

Following arterial and spur drain construction at the Woolf Road site, the watertable levels in the bore closest to the arterial drain were maintained deeper than 1.6 m below ground level (and below observed pre-drain levels), even following significant rain periods. A similar response was observed in bores JB2 (72 m) and JB3 (106 m) with watertable levels maintained below pre-drain levels. Beyond this distance the watertable in the bores is observed within the range of pre-drain levels.

It has been reported that the construction of parallel drains can significantly improve performance of deep drains by isolating the area between the drains from the surrounding regional aquifer (Cox and Tetlow, 2015; Cox and Tetlow, in prep.). Based on the observed watertable response at the Woolf Road site the increased drainage density around the monitoring bore transect appears to have resulted in watertable control within the area between the three drains.

In contrast, the construction of the Jibberding arterial drain as a single deep drain had no significant impact on the adjacent watertable at the Wasley Road transect.

5. Mongers 16

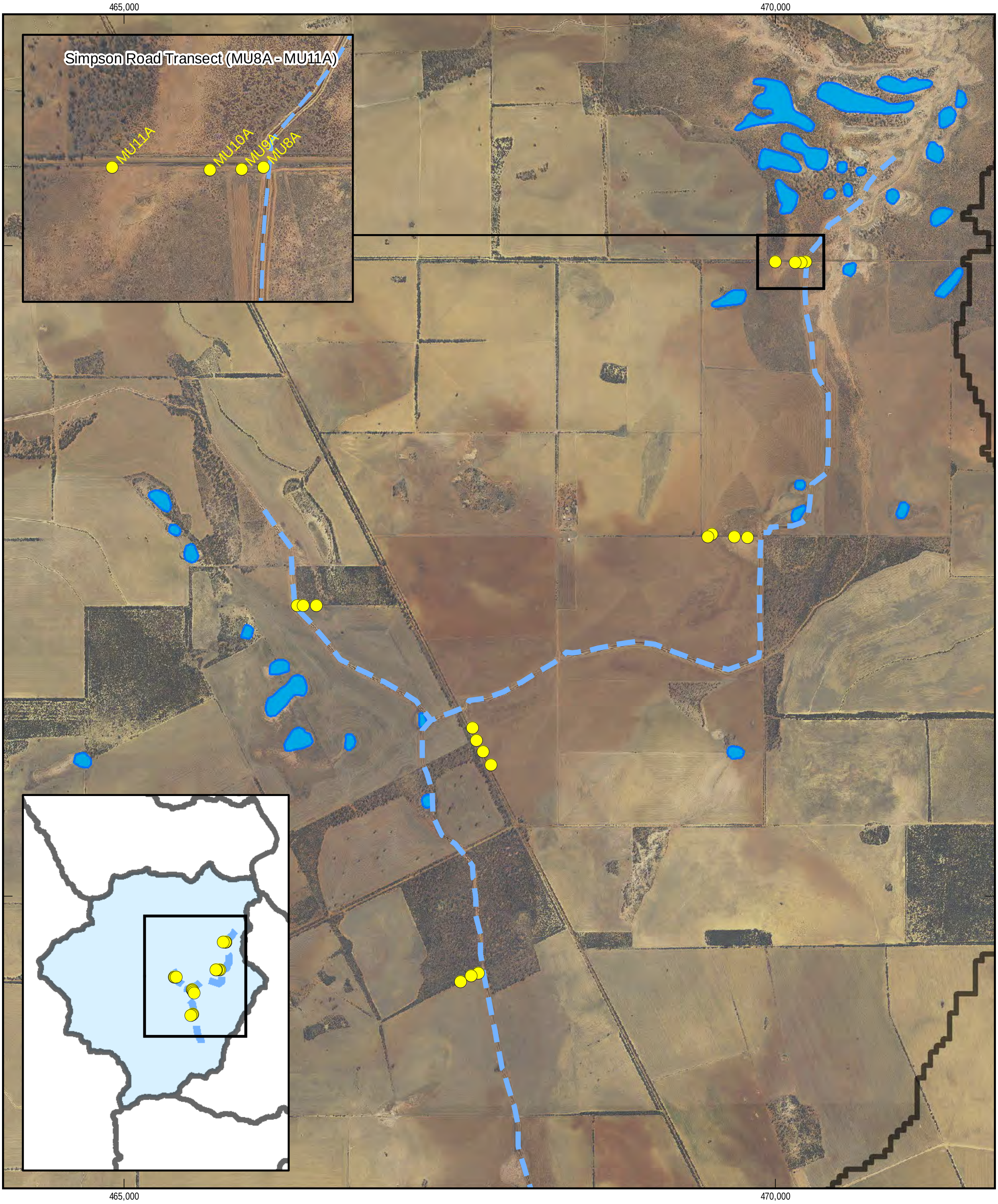
5.1 Sub-catchment overview

Construction of the Mongers 16 arterial drain occurred between March and July 2008 to a total length of 14 km. Several privately funded farmer drains have also been constructed within the sub-catchment.

Soil landscape mapping (DAFWA) describes the soils of the valley floor as *Red-brown hardpan shallow loam, red deep sandy duplex and red shallow sandy duplex* (Map unit: 271Gn_4).

Water quality in groundwater monitoring bores prior to excavation of the arterial drainage was reported as having salinity ranging from 16.5 to 45 mS/cm and pH ranging from 6.3 to 6.9 (YYCMG 2007).

The YYCMG established five groundwater monitoring bore transects in the Mongers 16 sub-catchment, one of which (Simpson Road transect, MU8-MU11) is included within this assessment (Figure 25).



LEGEND

- Transect
- Arterial drain
- Watercourse
- Perennial and non-perennial lakes
- Yarra Yarra Subcatchment
- Mongers 16 Sub-Catchment

Paper Size A4

0 500 1,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

SLIP ENABLER

Department of Water
Yarra Yarra Regional Drainage Program;
Evaluation of Xantippe,
Jibberding and Mongers 16 drains

Mongers 16

Job Number	61-33069
Revision	0
Date	08 Sep 2016

Figure 25

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Data source: Geoscience Australia: Landsat Imagery, GeoData Topo 250k Series III; Yarra Yarra Catchment Group: Major Lakes; Shire of Dumbleyung: Yarra Yarra Subcatchment. Created by:mmikkonen

5.2 Simpson Road transect (MU8A-MU11A)

The Simpson Road transect (MU8A-MU11A) is at the downstream end of the Mongers 16 deep drain and comprises four bores installed along a transect perpendicular to the drain (Figure 25, Table 7). Water levels in all bores were manually observed between 20 July 2007 and 16 August 2013. The arterial drain is understood to have been excavated past the transect on or about the 1 May 2008.

Before the construction of the drain, drainage within the sub-catchment comprised deepening of the natural drainage channel south of the Simpson Road (Figure 26, pre-drain 2004). Arterial drain construction further deepened the existing drain, before heading north and reconnecting with the natural channel approximately 1 km downstream of the Simpson Road transect.

Table 7 Simpson Road transect bore location details

Bore ID	Distance from drain (m)	Easting	Northing	Survey elevation (m LHD)	Initial groundwater level (m LHD)
MU8A	17	470234	6714875	9.88	8.69
MU9A	50	470201	6714872	9.89	8.66
MU10A	99	470152	6714871	9.67	8.66
MU11A	232	470002	6714875	10.00	8.75

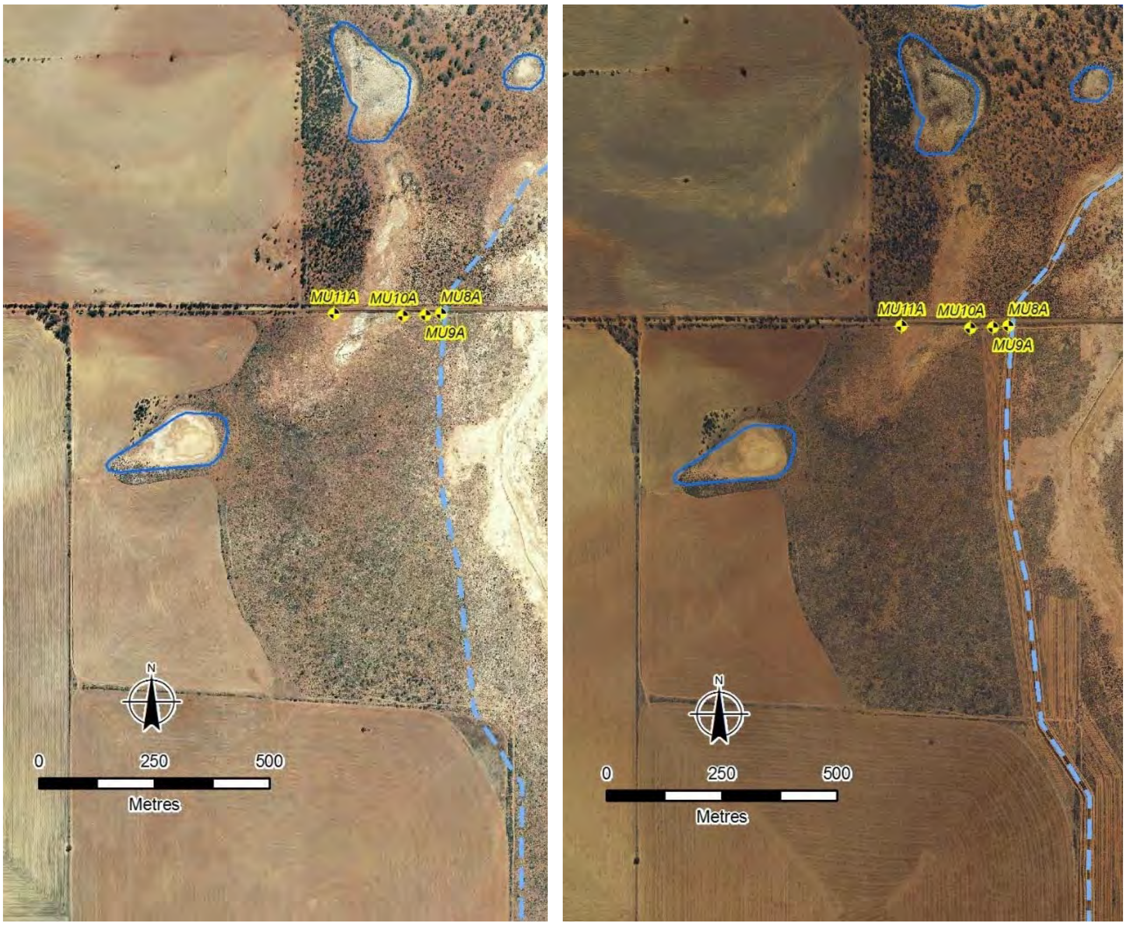

Figure 26 Simpson Road transect (MU8A-MU11A) pre-drain (left; December 2004) and post-drain (right; July 2010).

Initial watertable response

Changes in groundwater level before and immediately after construction of the 2.5 m deep drain are presented in Figure 27.

During the pre-drain period the groundwater levels in bores peak on the selected pre-drain watertable date (9 April 2008, Figure 27), following a 34.4 mm rainfall event on 21 February 2008, and minor events (< 2 mm) in the subsequent period. Two additional rainfall events of approximately 15 mm each occur in the fortnight preceding drain construction. The observed initial watertable response to drain construction should therefore consider antecedent conditions.

Bores located within 100 m of the drain showed an immediate response to the construction of the deep drain, with a more subdued response observed in the bore furthest from the drain (MU11A). Following this initial decline the watertable recovered to within the range of observed pre-drain levels until the next rainfall event on the 6 August 2008. Groundwater levels in all bores were observed to rise following the onset of winter rainfall in July 2008. The groundwater response to the winter rainfall is highest in bores located 50 m and beyond the drain, with an early but minor response in bore MU8A (17 m from drain).

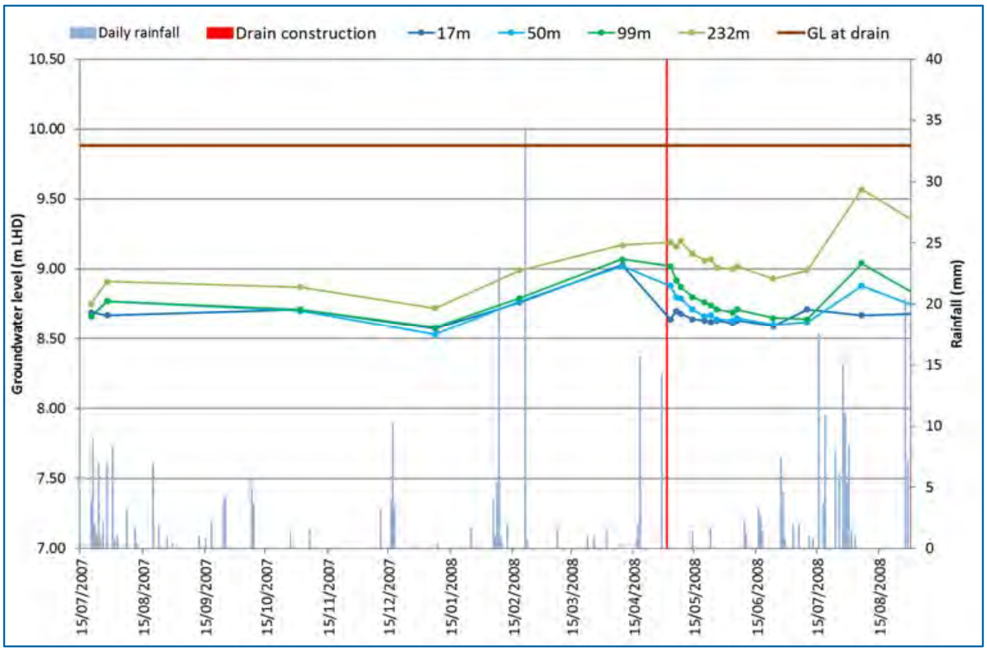

Figure 27 Simpson Road transect initial groundwater response

Longer term watertable response

Figure 28 displays the extent of the monitoring data for the Mongers 16 Simpson Road transect. After the initial watertable response to drain excavation and following 88 mm of rain in the preceding month, in August 2008 groundwater levels in all bores increased to above the pre-drain levels.

Figure 29 presents profiles of the pre-drain watertable level with selected post construction dates. The groundwater level is generally highest in bore MU11A (232 m from drain), with this bore also having highest observed groundwater peaks in response to rain events. There are periods where the watertable is higher in the bore closest to the drain (MU8A, 17 m) than bores 50 m and 99 m away, indicating a reversal of the watertable gradient and potential for the drain to be losing water to the aquifer (Jan/Feb/Mar 2009, Jan 2010). Bore MU8A is higher than all bores, including bore MU11A (232 m from the drain) in June 2011.

During the limited pre-drain monitoring period the depth to watertable in proximity to the drain (MU8A, 17 m) ranged from 1.31 m to 0.85 m below ground level. Following drain construction the lowest recorded watertable level was observed at the end of the monitoring period (6 August 2013) when the groundwater was 1.56 m below ground level, representing a maximum decrease in groundwater level of approximately 0.25 m. At the furthest bore from the drain (MU11A, 232 m) the fluctuations are greater but the maximum pre- to post-drainage decline was of a similar magnitude.

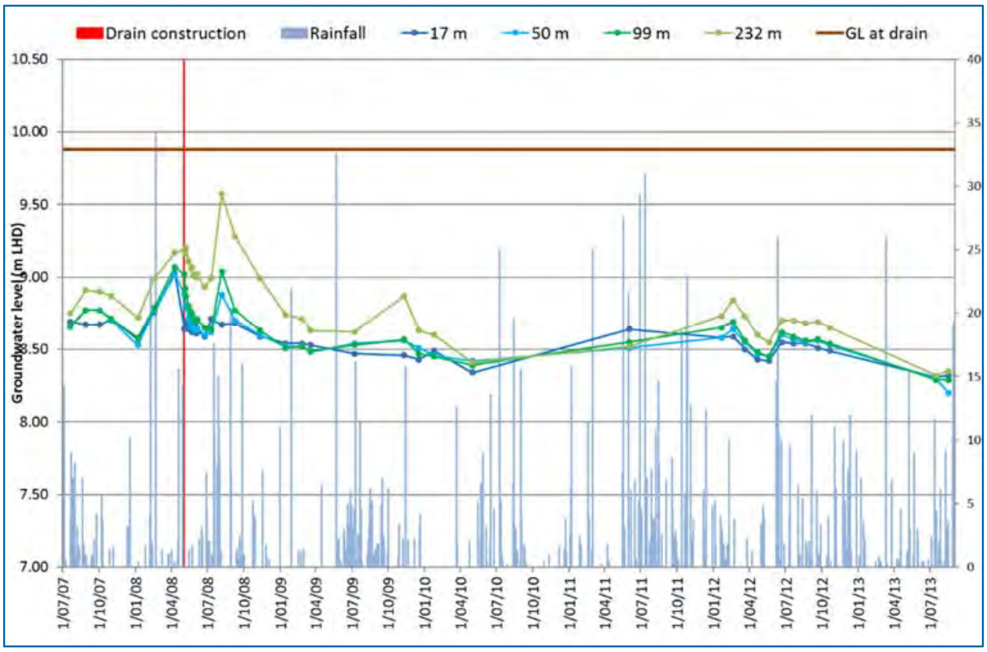

Figure 28 Simpson Road transect all groundwater data

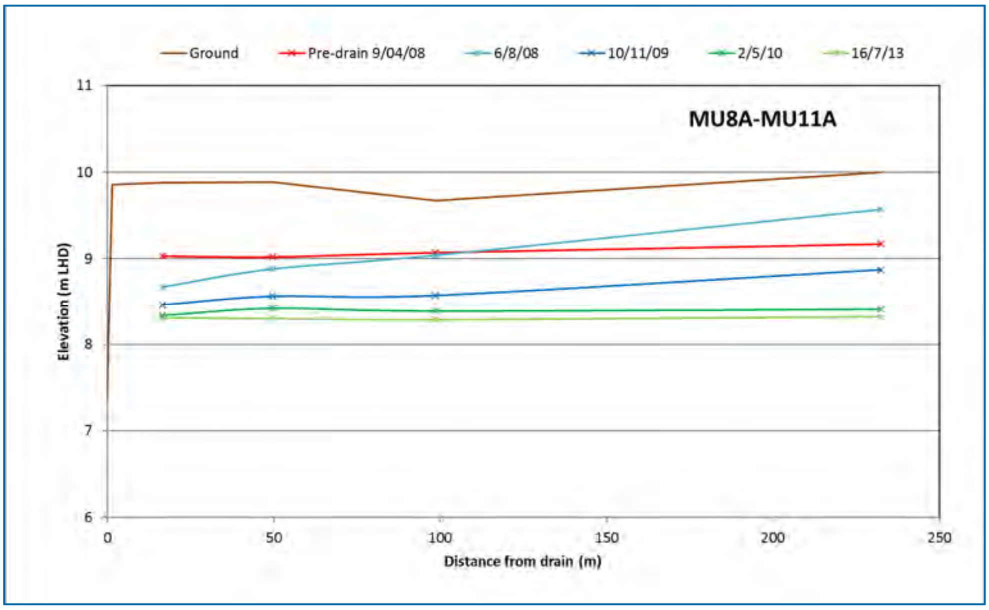

Figure 29 Simpson Road transect watertable profiles

Rainfall trends (AMRR)

Comparison of the watertable response of the bores in the Simpson Road transect to AMRR trends (Figure 30) indicates that the bore furthest away from the drain appears to be more responsive to the trends in AMRR than the bores closest to the drain. The observed watertable response broadly reflects AMRR trends, however later periods of above average rainfall do not appear to produce similar peaks in watertable response in bore MU11A.

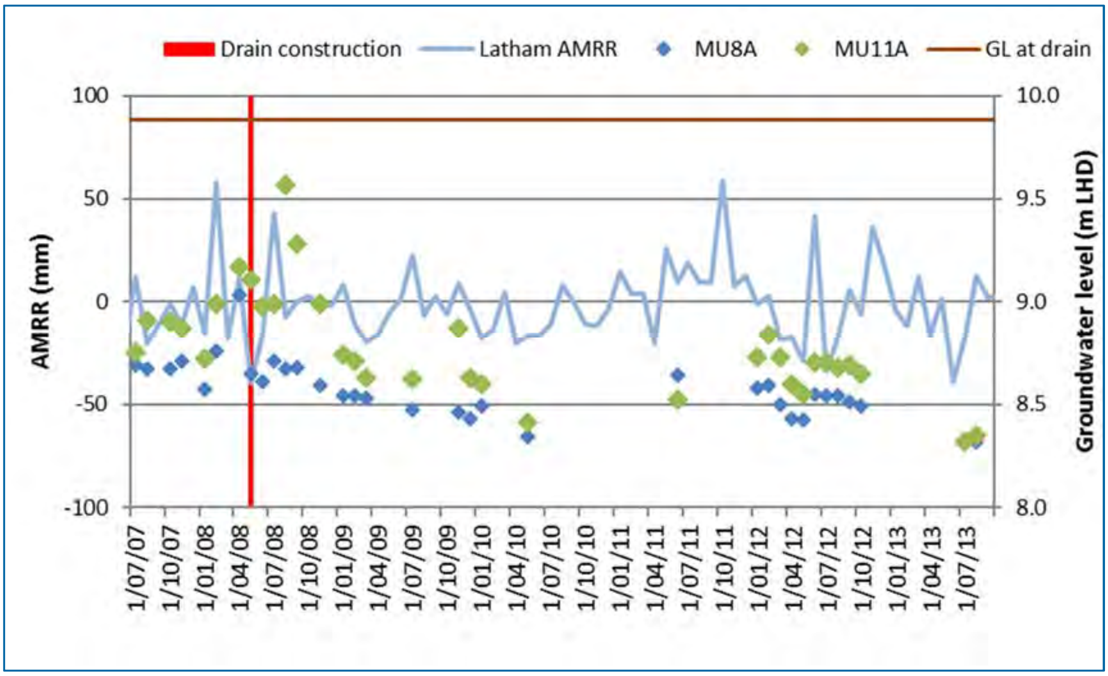

Figure 30 Simpson Road transect AMRR comparison

5.3 Site observations

Crop productivity

The Simpson Road transect (MU8A-MU11A) is located within an area of remnant vegetation. Review of the pre-drain (December 2004) and post-drain (July 2010) aerial photography (Figure 26) does not identify any changes to cropping practices in the vicinity of the study transect (MU8A-MU11A) or within the farmland located between the study transect and the transect located further south (MU4A-MU6A).

Adjacent vegetation health and vigour

At the time of the site visit in June 2016, the remnant vegetation within the immediate vicinity of the Simpson Road transect and extending downstream to the location of the monitoring flume appeared to be in good condition. Volunteer shrubs have established along the drain banks.

Vegetation transects

Four vegetation monitoring transects were established in the Jibberding sub-catchment, with vegetation surveys completed in 2008 and 2009. An additional two transects were monitored only in 2009. The vegetation monitoring identified no changes that could be attributed to the arterial drainage scheme (YYCMG, 2010).

Water quality

Shortly after completion of the arterial drain in the Mongers 16 sub-catchment in-situ pH measurement of the drain water quality at the Simpson Road crossing recorded a pH of 4.9 (3/05/2008),which is lower than pH observed in the bores prior to drain construction (pH ranging from 6.3-6.9). Subsequent in-situ pH measurements in the drain at the same location recorded pH 6.7 (27/10/2008) and pH 7.7 (17/09/2009), and at the outlet of the drain to Mongers Lake the in-situ pH in the drain was recorded as 6.5 (9/04/2008).

An in-situ drain measurement taken in 2012 had a pH of 7.6 (Fordyce 2012). It is likely the low pH measurement ni May 2008 was an anomaly and that the construction of the Mongers 16 drain has had no significant impact on downstream water quality.

5.4 Discussion

While an immediate watertable response is observed for the bores closest to the arterial drain the timing of the bore construction following a watertable response to rainfall events and the impact of antecedent conditions on the initial response should be considered.

Following arterial drain construction the watertable in bores over 50 m from the arterial drain is observed to respond to rainfall periods, suggesting the drain was unable to control groundwater levels.

There was a decline of approximately 0.25 m over the monitoring period but this could be attributed to climate. The uncertain initial watertable response to arterial drain construction at MU11A (232 m from the drain) suggests that bore MU11A was not significantly influenced by the drain. However, it recorded very similar long-term decline in groundwater levels as other bores, suggesting that the falling watertable in all bores was largely due to climate rather than the drain.

The construction of the arterial drain in isolation of any other private spur drains appears to be unable to significantly lower and control the watertable within the vicinity of the Simpson Road transect to the critical depth required for reliable crop growth.

6. Conclusions and recommendations

The effect of the arterial drain construction on watertable levels within monitoring bore transects in the Xantippe, Jibberding and Mongers 16 sub-catchments has been difficult to demonstrate due to the presence of a number of additional influencing factors that have been identified as confounding the watertable response at the locations.

The additional influencing factors include the presence of existing deep drainage, playa and vegetation treatments within proximity to the arterial drain and bore transects at some locations, as well as the influence of climate on both initial responses (e.g. antecedent conditions) and long term watertable responses (e.g. AMRR).

The observed watertable response at the Xantippe, Jibberding and Mongers 16 monitoring bore transects show that single deep drains are unable to lower and control groundwater levels to a sufficient depth and at a sufficient distance from the drain to reliably return adjacent agricultural land to cropping. However, anecdotal evidence from the Xantippe Campbell Road transect (KL1-KL6) on cropping improvements between the arterial drain and an existing deep drain, and the apparent watertable control observed at the Jibberding Woolf Road transect (JB1-JB7) as a result of increased drain density in proximity to the transect, indicate that increasing drain density through either parallel drainage or construction of spur drains may achieve sufficient watertable control to improve agricultural land productivity.

Watertable response

While an initial watertable response is observed at all transects excluding the Jibberding Wasley Road transect (JB10-JB15) these initial responses were confounded by antecedent conditions in the pre-drain period. It is likely that the timing of significant rainfall events preceding drain construction resulted in the groundwater table already being in a recession phase at the time of drain construction at other four transects.

Long-term declines in watertable of up to 0.5 m were observed across bores at all three drains. However, since similar declines were observed both close to the drains and at distances of several hundred metres from the drain (where the initial watertable response to drain was very small), indicating that these long-term groundwater declines are more likely due to climate than the presence of the deep drains. Groundwater levels measured at all bore transects generally followed trends in AMRR.

Because watertable levels in all transects appear to respond to both AMRR and individual larger rainfall events, the absence of large individual rainfall events in 2012 and 2013, towards the end of the monitoring period, may have contributed to the low watertables observed at the end of the monitoring period across all sub-catchments.

Large gaps in groundwater measurements following larger individual rainfall events meant that the available groundwater data do not capture likely periods of high watertable for the individual transects. For example, two large individual rainfall events were recorded occurred at the Latham BoM station at the end of June (29.4 mm, 29 June 2011) and early July (31 mm (11 July 2011). However, no groundwater measurements were taken at the Mongers 16 drain between early June 2011 and January 2012.

The impact of other influencing factors

Watertable responses at some bore transects have been influenced by the location of the arterial drain in relation to other constructed drains, drainage features (e.g. playas), as well as adjacent existing treatments (e.g. alley farming).

For example, improved productivity was observed near the Xantippe Campbell Road transect (KL1-KL6) by both the landholder and the leaseholder within the area between the arterial drain and the existing deep drain that runs north along Dalwallinu-Kalannie Road. The close spacing of these drains may be producing a parallel drain response that is controlling the watertable between the drains. However this is not observed in data from the monitoring bore transect, which is located east of the arterial drain and not in the area between the parallel drains.

Groundwater levels at the Jibberding Woolf Road transect (JB1-JB7) appeared to be controlled following construction of the deep arterial drain, however the monitoring bore transect lies between private parallel spur drains resulting in drainage on three sides of the transect, and a high drainage density. Parallel deep drains have been found to be more effective that single deep drains (Cox and Tetlow, 2015; Cox and Tetlow in prep.).

In the case of the Xantippe Angel transect (KL8-KL12), existing alley farming treatment within the paddock adjacent to the transect and location of a playa east of the transect likely influencing the watertable response to the deep drain construction at this location.

Within all sub-catchments the groundwater levels measured at all bore transects generally followed trends in AMRR.

The role of arterial drains

Although it was anticipated that the construction of deep drains would lower groundwater in valley floors the groundwater monitoring data do not identify any clear long-term watertable response adjacent to the arterial drains.

A secondary objective of the Yarra Yarra Regional Drainage Program was to provide an arterial drainage network for discharge from privately constructed deep drains. By providing a discharge point for private deep drainage and conveying drainage discharge water to appropriate disposal sites, the Yarra Yarra Regional Drainage System offers the potential for properly designed and constructed deep drains to be installed by adjacent landowners for the purposes of controlling groundwater and arresting salinisation. However there has been only limited connection of privately constructed drains to the Yarra Yarra arterial drains. This report does not evaluate the performance of those privately constructed drains.

Other benefits

A further objective of the Yarra Yarra Regional Drainage Program was the rehabilitation of the drainage corridors along the valley floors, with revegetation to stabilise the central waterway and fencing to exclude stock. The intention of the rehabilitated valley floors was to provide wildlife corridors linking isolated patches of remnant vegetation within a highly cleared landscape and enhance local biodiversity. Observations during the site visits in June 2016 found the drainage corridor rehabilitation to be generally successful with plantings of broom bush and saltbush well established.

No further monitoring recommended

Monitoring of the watertable response of the Yarra Yarra Regional Drainage Scheme was undertaken immediately prior to construction, and for a period post-drain construction, with additional monitoring completed over subsequent years. Given the general understanding of watertable response to deep drain construction, no further monitoring of these drains is recommended for the purpose of drain assessment.

7. References

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Appendices

Appendix A – Rainfall trends and AMRR

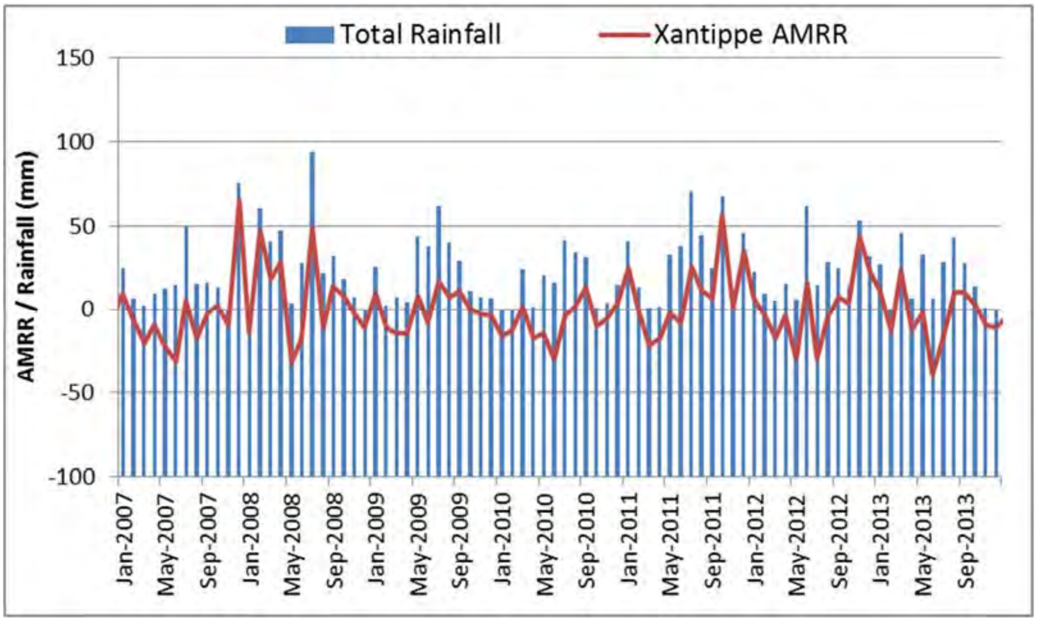
A.1 Xantippe

A.2 Jibberding

A.3 Mongers 16

A.1 Xantippe

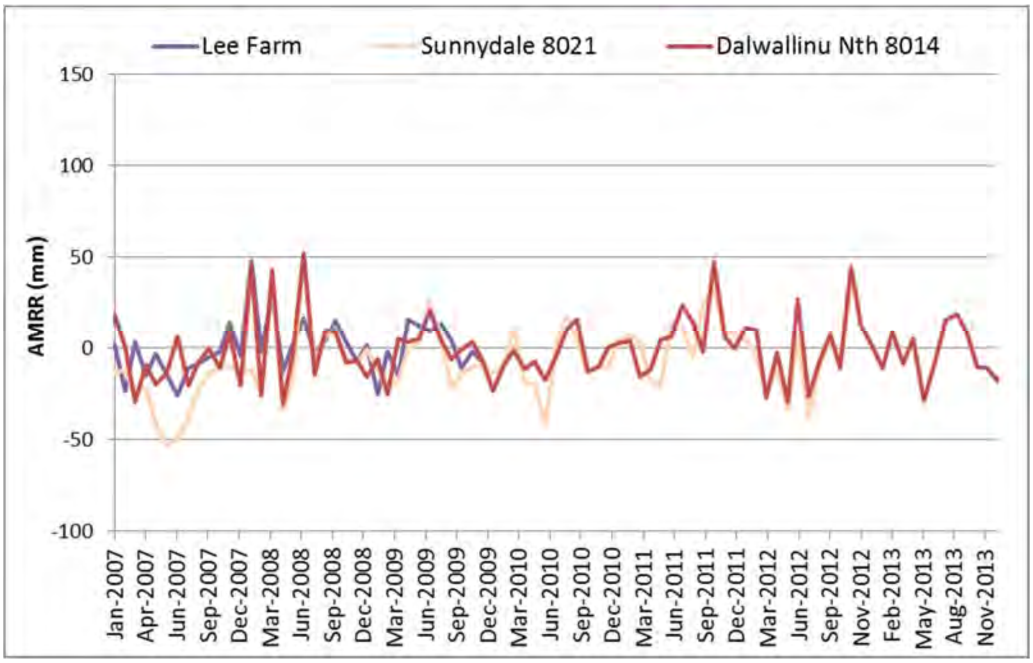
The monthly rainfall totals and AMRR trend for the nearest rainfall station at Xantippe (BoM Station 10141) is displayed in below figure.



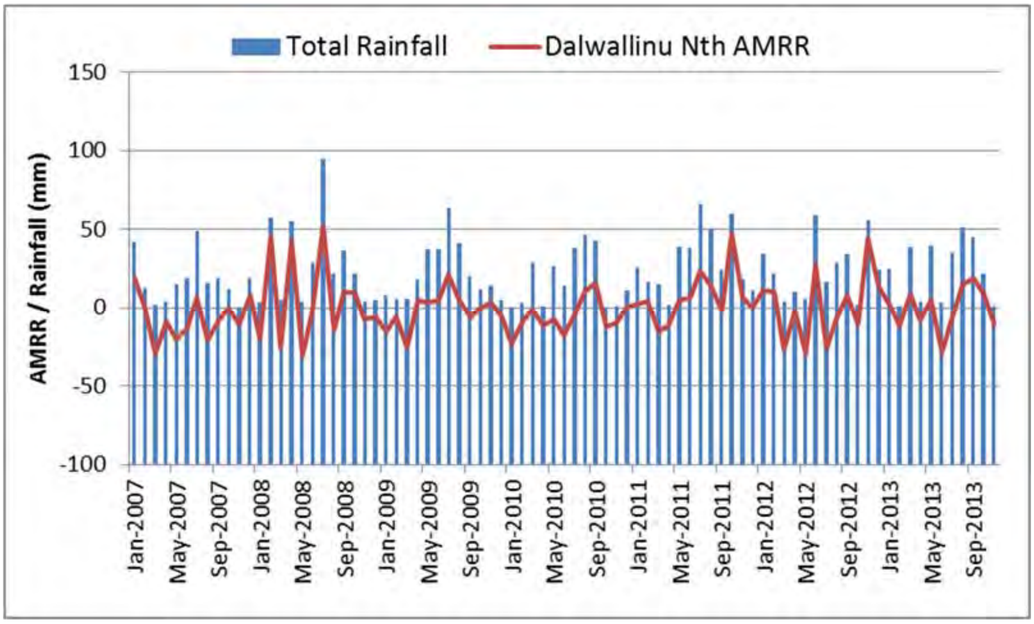
Xantippe AMRR plot

A.2 Jibberding

The AMRR plots for the three nearest rainfall stations to the Jibberding transects are displayed in below figure, identifying similar AMRR responses between stations. Due to the short record available for the Lee Farm rainfall data and missing months of data at Sunnydale (BoM Station 8021) the AMRR trend at Dalwallinu North (BoM Station 8014) is used for this assessment.



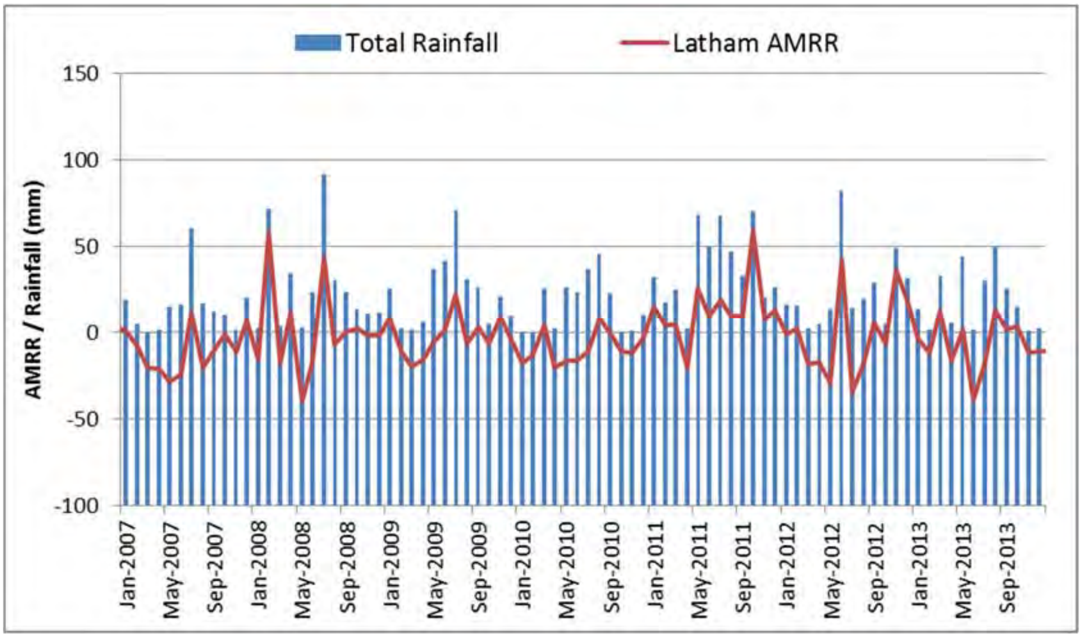
Jibberding combined rainfall station AMRR plot



Dalwallinu North AMRR plot

A.3 Mongers 16

The monthly rainfall totals and AMRR trend for the nearest rainfall station at Latham (BoM Station 8072) is displayed in below figure.



Latham AMRR plot

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