MANAGING SALINITY IN THE MALLEE

Role of Policy, Practice, New Science and Climate Change

Proceedings from the Mallee Catchment Management Authority's Regional Salinity Forum
19th November 2019, Mildura (Victoria)

mallee catchment management authority

VICTORIA State Government

ACKNOWLEDGEMENTS

The Forum and proceedings were funded by the Mallee Catchment Management Authority, with the Victorian Government.

Facilitation of the Forum and editing of proceedings by RMCG

Layout and graphic design by Jody Soh

Photos provided by Mallee Catchment Management Authority unless stated otherwise

March 2019

Mallee Catchment Management Authority
PO Box 5017 Mildura 3502
T: 03 5051 4377
E: info@malleecma.com.au
www.malleecma.vic.gov.au

CONTENTS

FOREWARD

The following introduction is based on the opening speech delivered by James Kellerman, General Manager of Operations and Community, who formally opened the Forum on behalf of Jenny Collins, CEO, Mallee Catchment Management Authority. A Welcome to Country was provided by Robbie Knight, an elder of the First People of the Millewa-Mallee Aboriginal Corporation.

THE MALLEE IS RECOGNISED NATIONALLY AND INTERNATIONALLY for the diversity and uniqueness of its natural and cultural landscapes. It has been occupied for thousands of generations by Aboriginal people, with human activity dating as far back as 23,400 years ago. The region was named the Mallee from the aboriginal word 'mali' meaning water, which refers to the fresh drinking water contained in the roots of the Mallee tree. The enduring connection to land and water by the Traditional Owners of the region highlight the significance and value of this landscape.

Saline groundwater is found naturally under large areas of the region, however with land clearing and irrigation this groundwater has risen through the soil profile causing salinisation in low points in the landscape. This ultimately led to land salinisation and increased salinity in the Murray River, becoming particularly severe in the mid 1960s and again in the 1980s.

During the late 1980s and early 1990s the community were involved in developing a range of Salinity Management Plans to address the salinity threat. These plans included salinity impact zoning, charging arrangements, processes to manage new irrigation development along with a range of other mechanisms to mitigate the threat. Collectively these plans established the Salinity Management Framework, which has successfully enabled sustainable irrigation development in the Victorian Mallee while ensuring an improvement in water quality of the Murray River.

While the SMF has reduced the salinity risk it hasn't removed the threat. Irrigation will continue to mobilise salt in the landscape and any water quality impacts on the Murray River will need to be accounted for at a regional level. In addition, future climate projections for the region predicting warmer temperatures over longer periods of time and less rainfall, means an adaptive management approach is essential for future salinity management. The SMF is central to this approach, backed by up to date science and sound government policy.

Taking the opportunity to consider recent salinity knowledge and current government policy, the Mallee Catchment Management Authority held its Regional Salinity Forum in Mildura on the 19th November 2019, bringing together representatives from government, scientific community, irrigation industry and water authorities.

FOREWARD CONTINUED...

The purpose of the Forum was to:

- Showcase specific projects that highlight new understanding of salinity and/or achievements in salinity management, building upon knowledge shared at the 2012 Regional Salinity Forum;
- Maintain the profile and significance of salinity in the Victorian Mallee region;
- Consider the future of salinity management in the Mallee with reference to the regional, state and national policy context.

Key government representatives, scientists, consultants and industry representative were invited to present at the Forum, which covered the following themes:

- Setting the scene
- Strategy, policy and planning
- Irrigation development
- What's changed in practice and on the ground

The following proceedings document Forum presentations and includes technical papers, provided by those scientists and consultants invited to present on specific projects or salinity issues. Summaries of other presentations given on the day, including the keynote address by Professor Lowe are also included. Titles of technical papers are highlighted in **blue** and presentation summaries are listed in **green**.

KEYNOTE ADDRESS PROFESSOR IAN LOWE

Photo supplied by Prof. Ian Lowe

Professor Ian Lowe was invited to deliver the keynote address for the Forum. Professor Lowe has been a leader in the area of policy decisions influencing use of science and technology, especially in the fields of energy and environment for 30 years. He was made an Officer of the Order of Australia in 2001 for services to science and technology, received the Prime Minister's Environment Award for Outstanding Individual Achievement and the International Academy of Sciences Konrad Lorenz Gold Medal, for contribution to sustainable futures.

Professor Lowe provided a thought-provoking keynote address, titled ***Science, Salinity and Sustainability***. The following are the main points from his address:

- **State of the Environment** reports from 1996 – 2016 have continually emphasised critical environmental problems for Australia, namely: loss of unique biodiversity, pressures on the coastal zone, state of most inland rivers, degradation of rural land and greenhouse gas emissions. These problems are associated with both the individual and cumulative pressures of climate change, land-use change, habitat fragmentation and degradation, and demands on natural resources.

- **Climate change** has occurred due to global warming caused by a dramatic rise in carbon dioxide concentrations in the atmosphere, as illustrated through key graphs presented by Ian. Climate change impacts include changing temperatures, weather patterns, water availability and increased risk of drought; all of which will have a significant effect on agriculture production, particularly in the Murray-Darling Basin.

- **Adaptation to climate change** will be essential for all parts of society. For example, water conservation, public health, social resilience, emergency management and agriculture are all areas that will require adaptive responses to climate change.

- **Water extraction** has had a significant impact in terms of species and ecosystem services loss in our watercourses, wetlands and groundwater systems. Climate change is likely to accelerate these impacts, so there is an even stronger imperative to reconcile human needs with environmental flows to ensure resilience of our water systems. Effective and efficient use of this extracted water is still required in the Murray-Darling Basin, even though there have been improvements in recent times (e.g furrow to drip irrigation).

- **Mallee CMA region** has led the way with some of these improvements, including water delivery through pipes rather than open channels, furrow to drip irrigation, economic policies to support water trading, increases in average farm size, better salinity management and improved economic and environmental outcome.

- **Sustainability** is about living within our means with environmental, social and economic outcomes being balanced. However, our focus on the economy as the central pillar has meant that we are currently not living sustainably.

- **A systems approach** is required if we are to adapt to the impacts of climate change. This means acknowledging the connections across systems (i.e. environment, society, economy), being able to monitor changes over time and implement action plans. This adaptive management approach, learning by doing, will be essential for a sustainable future. Actions and activities in the Mallee CMA, provide an excellent example of adaptive management and showcases how real change can happen when there is focused effort to address a problem.

Professor Lowe's presentation can be found in the **Appendix**

STRATEGY, POLICY AND PLANNING

The purpose of this theme was to set the strategic context for the Forum. An overview of the current status of salinity in the Victorian Mallee and how our understanding of the issue has changed since the last Regional Salinity Forum, held in 2012, was presented to establish historical background.

Presentations on the current policy setting for land and water management from a national (MDBA), state (Department of Environment, Land, Water and Planning) and regional (Mallee Catchment Management Authority) perspective were provided to highlight the current and future role of policy in supporting salinity management in the region.

Recent work on refinement of existing numerical groundwater models was also presented to highlight current understanding of salinity processes and how this will influence salinity management planning, particularly formal accountability of salinity impacts with the Murray Darling Basin Salinity Register.

Original presentations can be found in the **Appendix**

- **Setting the Scene - Status of Salinity in the Region**
  Tim Cummins, *Tim Cummins & Associates*
- **Basin Salinity Management (BSM2030)**
  Dr Asitha Katupitiya, *Murray-Darling Basin Authority*
- **Water for Victoria (Action 4.8)**
  Jenn Learmonth, *Department of Environment, Land, Water and Planning (Victoria)*
- **Mallee Irrigation Region Land and Water Management Plan**
  Don Arnold, *Mallee Catchment Management Authority (Victoria)*

PAPER **Mallee Model Refinement for Salinity Accountability**
Greg Hoxley, *Jacobs*

SETTING THE SCENE - STATUS OF SALINITY IN THE REGION

Tim Cummins, *Tim Cummins & Associates*

Tim's presentation established the historical context of salinity management in the Victorian Mallee. He noted significant improvements in institutional knowledge and maturity have been made in recent years since the last Mallee Salinity Workshop in 2012, compared to any other time period.

From 1986 – 2012 there was a 'bedding down' of solid processes with adaptive management. Since 2012, key improvements with respect to salinity management have included:

- Maturity of institutional processes (i.e. Basin Salinity Management 2030 Strategy (BSM2030) and Water for Victoria);
- Changing land uses and irrigation practices, particularly mapping of irrigation development and crop types, best practice for irrigation development and the role of water trading;
- Better understanding of salinity processes through groundwater modelling, improved estimates of rootzone drainage, monitoring groundwater trends, focus on salt accumulation in the floodplains and using climate change projections to prepare for risks.

(For further information about the history on irrigation and salinity management in the region see: Cummins, T. and Thompson, C. (2018). A Short History of Irrigation in the Victorian Mallee. Mallee Catchment Management Authority.)

BASIN SALINITY MANAGEMENT (BSM2030)

Dr Asitha Katupitiya, *Murray-Darling Basin Authority*

Asitha provided an overview of the current salinity management strategy for the Murray-Darling Basin, BSM2030, including the precursors to its development, main elements of the strategy and how it is intended to be implemented.

BSM2030 is the third phase in adaptive Basin salinity management, following on from the Salinity and Drainage Strategy (1988 to 2000) and the Basin Salinity Management Strategy (2001 – 2015). Leading to BSM2030 development in 2015, a general review of salinity management in the Basin was undertaken, focusing on cost saving opportunities, documenting all technical details including salinity modelling and identifying future salinity management requirements.

The main approach to BSM2030 has been to retain the effective parts from BSMS including the cap on salinity through existing Basin Salinity Target and accountability framework.

Other focus areas included in the strategy are:

- Streamlined mature processes in relation to the salinity accountability framework (i.e. fit for purpose auditing, reporting and reviews)
- Environmental water included in the accountability framework
- Flow management decisions considered in salinity management
- Exploration of opportunities for efficient and innovative Salt Inception Schemes (SIS) operation
- Investment in knowledge priorities to reduce uncertainty about future salinity risks.

Implementation of this strategy will include the following activities:

- Amend Schedule B to enable the Commonwealth Government, and the partner governments collectively, to hold salinity credits and debits (given salinity impacts associated with environmental water management will be accountable actions under the Schedule)
- Continue periodic reviews of register entries and associated models, though application of a risk- based
- Trial risk-based approach of SIS
- Invest in key knowledge priorities
- Prepare Basin Salinity Management procedures
- Undertake monitoring, reporting and auditing
- Coordinate implementation with Basin states (through Basin Salinity Management Advisory Panel)

WATER FOR VICTORIA (ACTION 4.8)

Jenn Learmonth, *Department of Environment, Land, Water and Planning (Victoria)*

Jenn presented an overview of those actions in DELWP's Water for Victoria, that relate to salinity management in the Mallee.

Water for Victoria was launched in 2016 as Victorian Government's strategic plan for water resources. Action 4.6 of the plan addresses impacts from water logging, salinity and water quality issues associated with agricultural activities and remains compliant with the Murray-Darling Basin Agreement, while Action 4.8 specifically focuses on improving salinity management in the Mallee.

In addressing Action 4.6, DELWP has completed or is currently implementing the following activities:

- Establishing and implementing priorities for the Victorian Irrigation Drainage Program
- Remaining compliant with Schedule B of the Murray Darling Basin Agreement
- Progressing the required reviews of accountable actions, including the Mallee Model Refinement
- Contributing to the implementation of BSM2030, including responsive trials of SIS
- Accounting for environmental water and its impact on salinity in the Basin
- Understanding implications of a drying climate and water moving to different parts of the catchment based on allocation and price.

For Action 4.8, DELWP have been progressing a number of projects in partnership with the Mallee Catchment Management Authority and Lower Murray Water, including:

- A review of salinity charges
- Reviewing policies of the High Impact Zones in the Mallee
- Improving contemporary knowledge of salinity
- Ensuring a level playing field with other Basin states in salinity management

MALLEE IRRIGATION REGION LAND AND WATER MANAGEMENT PLAN

Don Arnold, *Mallee Catchment Management Authority (Victoria)*

Don presented an overview of the recently drafted Land and Water Management Plan (LWMP) for the Mallee Irrigation Region. This included the history of Salinity Management Plans developed during the 1980s – 1990s, with involvement from the community, and how these plans came to establish the Salinity Management Framework.

The Salinity Management Framework focused on:

- Increased irrigation efficiency
- Improved irrigation drainage disposal
- Implementation of Salinity Impact Zones
- Beneficiary pays principle (i.e. salinity offset charges)
- Management of new irrigation development through a standardised assessment process

The 'new' LWMP applies to irrigation area of impact for the Victorian Mallee, pump districts, private diverters and Murrayville and will build on the momentum of previous plans. It identifies priority actions to meet, as outlined in the Mallee Regional Catchment Strategy and other State and Commonwealth Government objectives, policies and regulations (e.g. Water for Victoria, Water Act, Catchment and Land Protection Act, BSM2030).

In particular, it will:

- Strive for continuous improvement in the adoption of irrigation best management practices
- Refine the salinity management framework, where required
- Renew efforts to rehabilitate the environmental impacts of irrigation and river operations
- Help meet Victoria's obligations under the BSM2030
- Support Aboriginal partnerships
- Encourage the irrigation community to be forward looking and resilient

PAPER

MALLEE MODEL REFINEMENT FOR SALINITY ACCOUNTABILITY

Greg Hoxley, *Jacobs*

1. INTRODUCTION

1.1 Victorian Mallee salinity accountability and management policy framework

Over the past 20 years, Victoria has successfully managed to keep the impact of salinity from irrigation development in the Mallee region within the State's bounds of the allocated salinity impact allowance (salinity credits).

Three important features of the policy framework employed in the Mallee are (Cummins and Thompson, 2018):

- Zoning of irrigation areas (12 salinity impact zones - SIZ) that direct irrigation to areas with the lowest salinity impact;
- Application of salinity offset charges commensurate with the impact associated with irrigating in each zone; and
- Enablement of trade in water that also allows for an associated redistribution of salinity impacts (through AUL trade) to make the most efficient use of a finite salinity impact allowance (salinity credits).

The Salinity Impact Zoning Approach is a critical component of the broader policy framework. It is the approved method for estimating the salinity impact of new irrigation development in the Mallee.

The SIZ, salinity impact coefficients and estimates and offset charges were based on a region-wide hydrogeological assessment using an analytical model to estimate potential salinity impacts of new irrigation.

1.2 Role of the Mallee Catchment Management Authority in salinity

The Mallee CMA manages salinity credits and debits in the Victorian Mallee (DSE, 2011). The role includes:

- Allocating credits to offset the salinity impact of regional actions and activities in accordance with agreed Government priorities to maximise regional benefits;
- Updating regional registers each year using new data and agreed assumptions;
- Annual reporting on BSM2030 implementation at a regional level;
- Undertaking 5-year reviews of regional accountable actions, in accordance with the BSMS;
- Initial assessment of potential new accountable actions;
- Promoting activities that minimise the impact of salinity;
- Providing regional input to BSM2030 Reports; and
- Representation on the Victorian Salt Disposal Working Group and the Victorian Salt Disposal Advisory Group.

1.3 Nyah to SA Border Salinity Management Plan

The 'Nyah to the SA Border Salinity Management Plan' (N2B SMP) is a Schedule B accountable action under the Murray Darling Basin Salinity Management Strategy (BSMS). The plan was approved in 1993. The action recognises the impact on Murray River salinity of post-1988 water trade into Victorian private diversion areas between Nyah and the SA border. Impacts result from salt mobilisation through increased groundwater flow into the river.

The Salinity Impact Zoning Approach is used to estimate the increase in salt loads into the Murray River resulting from the use of irrigation water traded into private diversion areas. The approach uses an analytical spreadsheet model that differentiates impacts from developments occurring in five High Impact Zones (HIZ) and seven Low Impact Zones (LIZ). The method was peer reviewed by the then Murray-Darling Basin Commission in 2003-04 and is approved for use to estimate the salinity impact of irrigation developments in the Victorian Mallee.

The approach divides the Mallee region into Salinity Impact Zones (SIZ), each with its own salinity impact coefficient (a map showing the impact calculation zones is presented in Figure 1). The impact coefficients provide an estimate of the salinity impact at Morgan of 1,000 ML of new irrigation development in the N2B SMP area. Impact estimates are used for annual reporting required by the Murray Darling BSMS and for charging salinity levies to irrigators in private diversion areas.

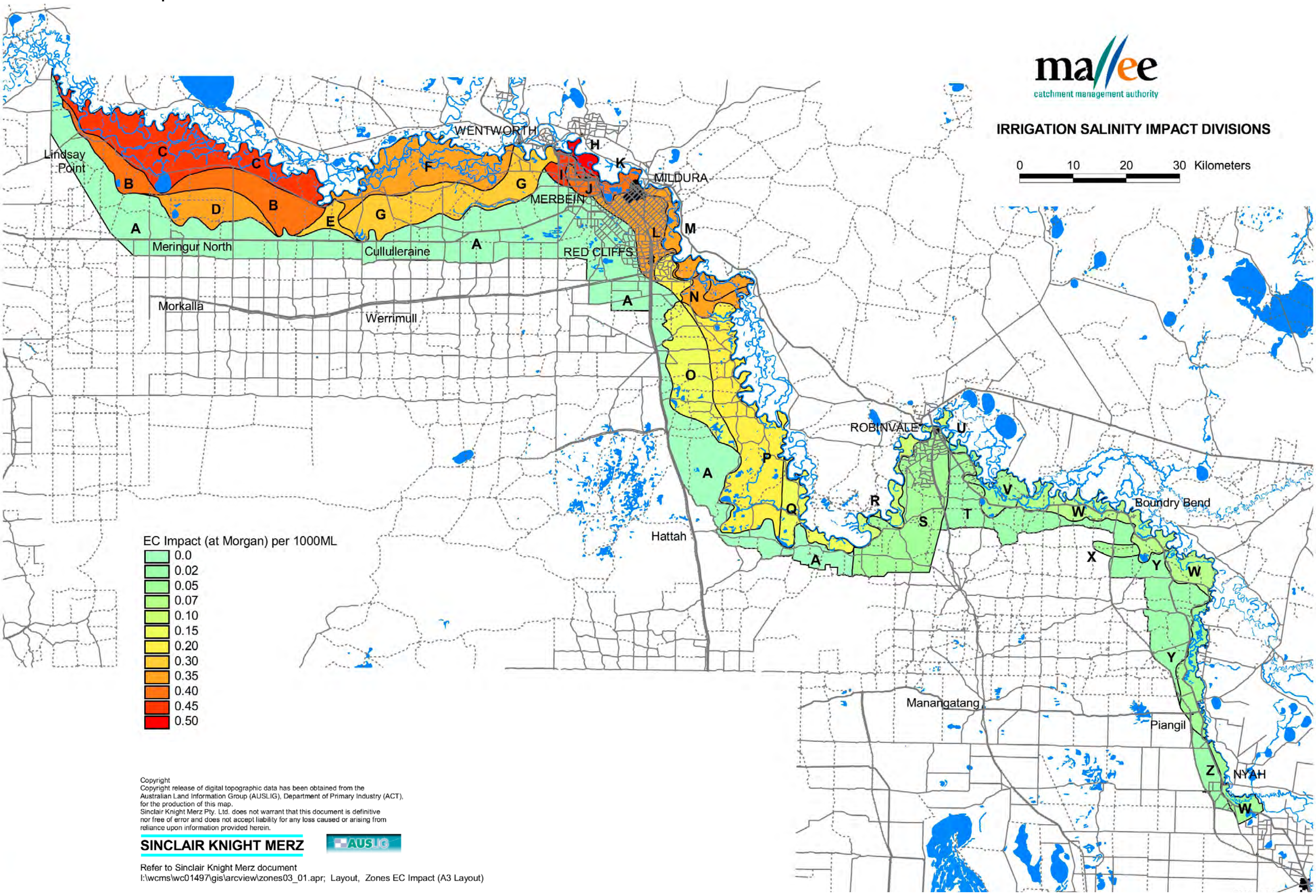


Figure 1: Illustration of High and Low Impact Zones (HIZ and LIZ) with impact co-efficients

The 2008 five-year review of the N2B SMP accountable action advised that the accredited Salinity Impact Zoning Approach was acceptable if more detailed modelling was undertaken to verify salt load estimates. In response, six numerical models covering the private diversion areas from Nyah to the SA border were developed. Although the Salinity Impact Zoning Approach was approved for use and the concepts and approach was supported by the water trade model suite, the model suite itself was not accredited.

The models currently being refined are the existing water trade numerical model suite and the EM2 model.

RPS Aquaterra developed the EM2 models for a range of purposes. EM2.3 and EM2.3.1 have been independently peer reviewed and judged fit for assessing the salinity impacts of new SISs and RISIs of irrigation activities in the Sunraysia region within NSW and Victoria. The Mallee Catchment Management Authority (MCMA) has used the models as part of salinity credit claims associated with reduced salinity impacts resulting from improved irrigation practices from 1988 to 2007.

2. PURPOSE OF THE MODEL REFINEMENT PROJECT

The model refinement project has combined and updated several existing numerical groundwater models to help improve the confidence with which they can estimate potential salinity impacts of near river irrigation in the Victorian Mallee. Subject to acceptance of the refinement process, these models may be used in the future as input to update the formal determination of salinity impact on the Murray Darling Basin Salinity Register. The current register entries are based on an analytical approach.

It is recognised that the analytical approach is relatively simplistic and include numerous (simplifying) assumptions. This salinity impact zone approach is the Murray Darling Basin Authority accredited method for assessing salinity impacts from irrigation in the Victorian Mallee. Numerical groundwater modelling projects undertaken through 2005 to 2008 provided more complex and spatially variable assessments of the groundwater flow to the Murray River and they have consistently suggested that the existing salinity impact zone approach provides conservative estimates of the salt impacts on the River.

The work undertaken on this project follows on from a series of projects aimed at verifying an approach to assessing salinity impacts on the River Murray (for example, see the projects described in the Mallee Salinity workshop, Mallee CMA, 2013). The numerical groundwater modelling is being undertaken to help verify and, re-calculate the Salinity Impact Zone coefficients that are used to quantify the N2B SMP salinity debit on the MDBA Salinity Register. The current project develops models that can be used to obtain more reliable salinity coefficients to be incorporated in the Salinity Impact Zoning Approach and provides a basis for revising salinity register entries.

3. MODEL REFINEMENT PROJECT APPROACH

3.1 Review of model conceptualisation

The existing conceptualisations included in the documentation of the EM2 and Numerical Water Trade Models were reviewed against the requirements of the project. The conceptualisation focussed on the shallow hydrogeological system that influences the development of mounds beneath irrigated land and the aquifers that interact with the Murray River and its anabranches. The conceptualisation included:

- The historic development of irrigation within each model domain and its influence on groundwater levels.
- Important recharge and discharge processes.
- The role of riverbed seepage, flood inundation and evapotranspiration.

In addition, two significant areas were subject to more detailed review:

- Recharge; and,
- Groundwater Salinity Mapping.

Groundwater Recharge was subject to extensive review and assessment through the course of the refinement process. Differences between root zone drainage and recharge to groundwater were the topic of ongoing discussions amongst project participants. This discussion revolved around the observations that have been made about root zone drainage rates and how these compared with groundwater recharge. A key aspect of this that is important when considering the results from the refined models is that groundwater recharge can never be more than root zone drainage and is often much less. This is because of the range of soil water processes that can occur between root zone drainage becoming recharge. Figure 2 gives a diagrammatic representation of the different processes acting in the sub-surface that can affect recharge. Recent work (DEDTJR 2018) has confirmed that the typical regional average for root zone drainage in the Victorian Mallee is 10% of applied water. Accordingly, groundwater recharge must be less than 10% of applied water.

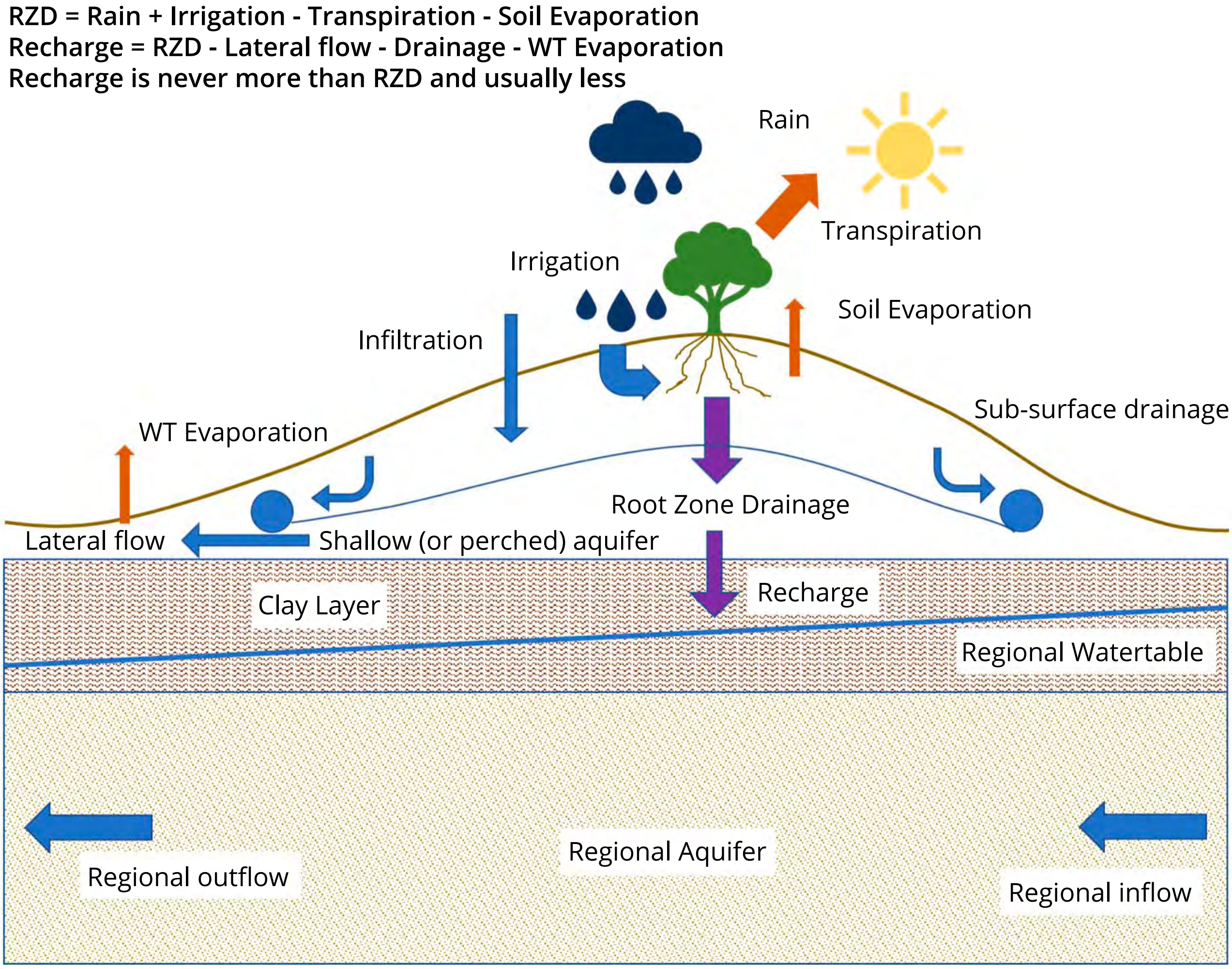


Figure 2: Diagrammatic representation of water movement sources and pathways showing sub-surface interactions

Three existing models were used for the project:

- Yelta to South Australia Water Trade Model,
- Eastern Mallee EM2.3, and
- Nangiloc-Colignan Water Trade Model

A further three existing Numerical Water Trade models were merged to create a single new groundwater model called the Nyah to Wemen Model. The existing models that have been merged are:

- Robinvale to Wemen Water Trade Model,
- Robinvale to Piambie Water Trade Model and,
- Piambie to Nyah Water Trade Model.

The locations of the refined models are shown in Figure 3.

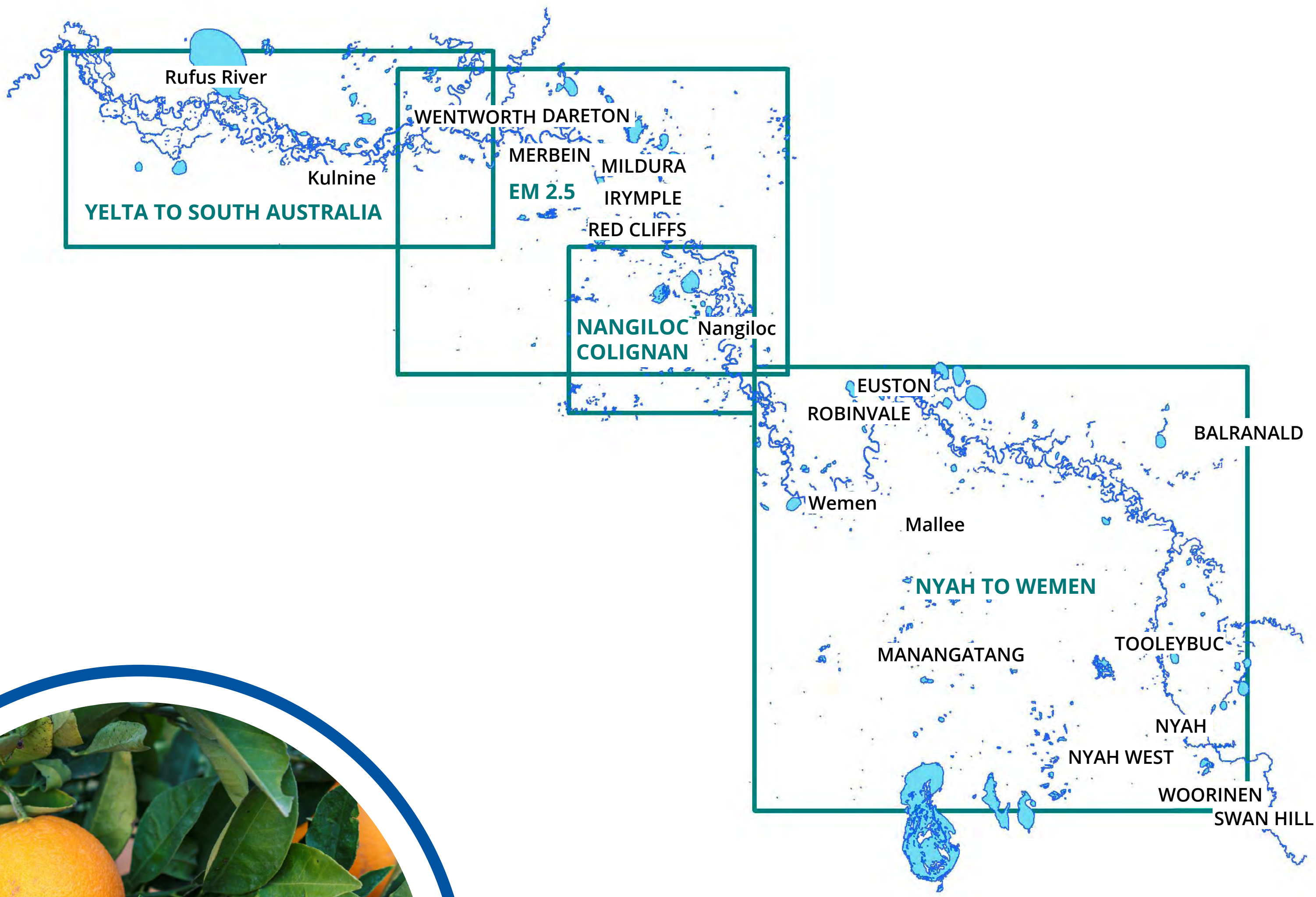


Figure 3: Locations and extent of the refined models

Specific design features of the refined groundwater models are:

- The EM2 model extent and recharge rates were preserved.
- The recharge time series for both calibration and predictive scenarios in EM2 was revised to include monthly variability in recharge. This has included a monthly time series for root zone drainage beneath irrigated land and beneath dry land. The root zone drainage estimates consider the annual recharge rates included in the existing EM2.3 model as well as the irrigation assessment, extended for the full calibration period.
- The river boundary condition used in both calibration and predictive scenarios in EM2 was included as monthly time series that is based on gauged data and accounts for the presence of weirs and weir pool levels.
- Where model domains abut or overlap the head dependent boundary conditions assigned to the neighbouring models are consistent (both in terms of the assigned head and the direction of flow across the boundary).
- The Nangiloc-Colignan drains are included explicitly in the (Nangiloc-Colignan) model. Drain invert elevations are included in the model using the MODFLOW DRN Package.
- The three existing Numerical Water Trade Models used for the study which have been combined for the Nyah to Wemen model have been extended beyond the existing model areas to include recent and potential future irrigation developments and to fully cover the area of interest including the full extent of the Robinvale and Nyah irrigation districts.
- The existing Numerical Water Trade Models used for the study and the new Nyah to Wemen Model have been extended into New South Wales. The intention of this approach is to provide an explicit representation of possible groundwater fluxes beneath the river. It is noted that the representation of the groundwater system in those parts of the models in New South Wales have not been calibrated and include a simple extrapolation of the model layer structure from Victoria beneath the river.

3.2 Refinements in each model

The following table (Table 1) provides a summary of the refinements and upgrades for each model.

Table 1: Refinements and upgrades applied to each model

Refinement / Upgrade	Nyah to Wemen	Nangiloc Colignan	EM 2.5	Yelta to South Australia
Extended calibration period 1975 to 2017	Previous calibration 1975 to 2001 (Robinvale Wemen), 2004 (Piambie – Nyah) and 2012 (Robinvale – Piambie)	Previous calibration 1975 to 2012		Previous calibration 1975 to 2007
Extended domain into NSW	5 km fringe	Activation of existing domain in NSW	N/A	Activation of existing domain in NSW
Extended model domain in Victoria	Minor extensions in all directions	Substantial extension to the west	N/A	N/A
Improved recharge estimates under irrigation	Based on reach-scale mass balance estimates	Based on reach-scale mass balance estimates		Based on reach-scale mass balance estimates
Improved dryland recharge estimates	Previously used a percentage of rainfall. Now based on published MOLR	Previously used a percentage of rainfall. Now based on published MOLR		Previously used a percentage of rainfall. Now based on published MOLR
Improved representation of flooding inundation	Inundation recharge added	Inundation recharge refined	Inundation recharge added	Inundation recharge refined
Refined model grid	N/A	N/A	N/A	Previously 500 to 1000 m grid cells refined to 200 m squares.
Increased temporal refinement	N/A	N/A	Previously annual stress periods now monthly	N/A
Addition of shallow drains	N/A	Drains now included	N/A	N/A
Increased number of calibration bores	New calibration bores added	New calibration bores added	N/A	New calibration bores added
Implementation of PEST Pilot Point calibration	Pilot points for hydraulic parameters and recharge factors	Pilot points for hydraulic parameters and recharge factors	N/A	N/A
Uncertainty Analysis	Linear Uncertainty Analysis	Linear Uncertainty Analysis	Linear Uncertainty Analysis	Linear Uncertainty Analysis

3.3 Calibration

Calibration was undertaken in transient mode over the period July 1975 to June 2017. All models have been calibrated by matching model predicted heads to those measured in a network of monitoring wells within each model domain. The calibrated models have also been assessed for consistency with available information and conceptualisation of the groundwater exchange fluxes with the river.

One of the key parameters that was adjusted during the calibration process was the recharge to the regional watertable, under irrigated land. The starting point for recharge rates was the percentage of recharge that had been used successfully in the models prior to refinement. With the refinement process, the models required some adjustment to recharge rates to reach the best calibration. The adjustment varies across the models.

Figures 4 to 7 present the final, calibrated recharge rates over time for the models. An important part of the refinement process was to use irrigation delivery estimates over time, which accounts for some of the variability evidenced in these figures. For example, the increase in recharge rate over time on the Yelta to South Australia Model and the Wemen Reach of the Nyah to Wemen Model is in large part a result of increasing rates of irrigation application according to the records that are available.

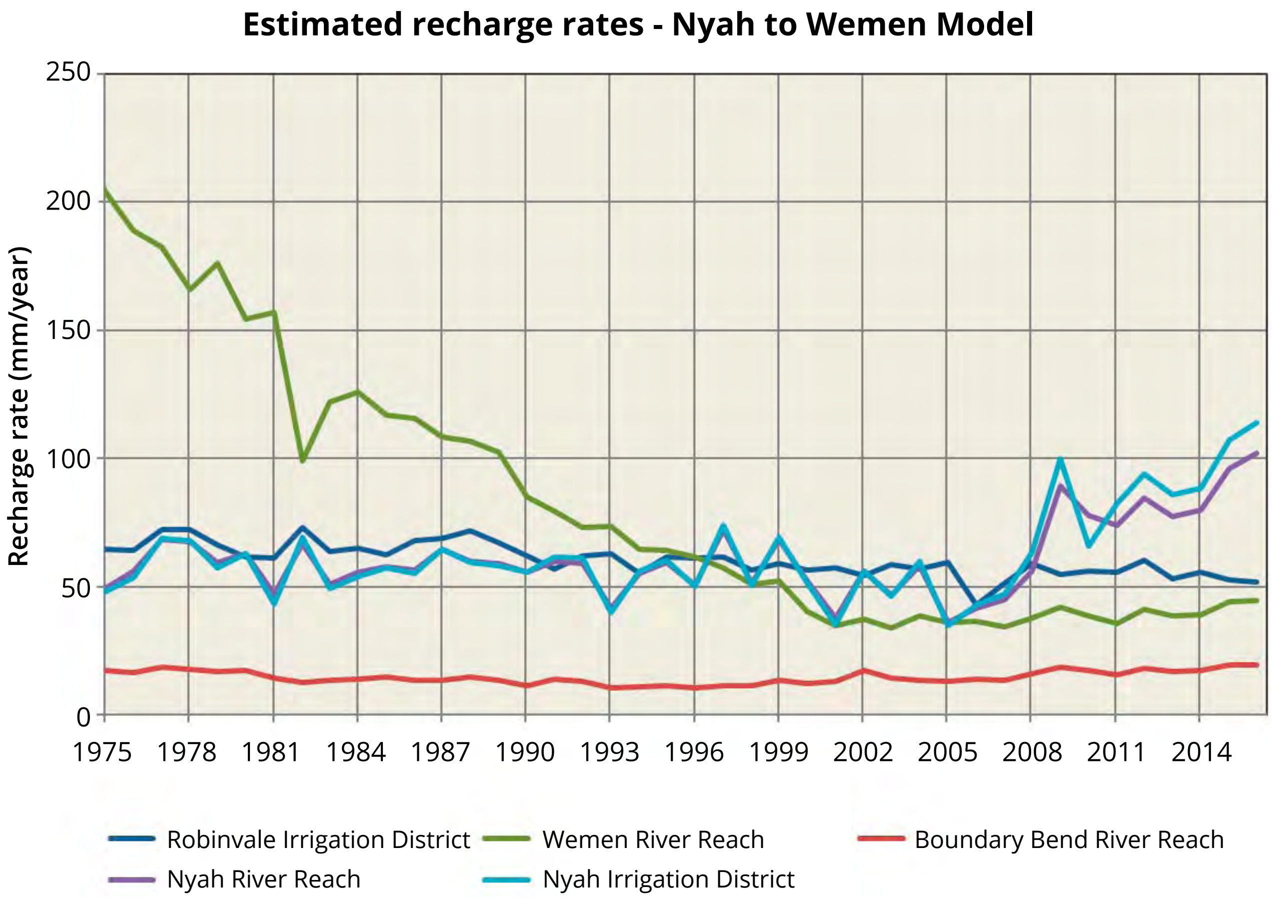


Figure 4: Estimated irrigation recharge rates for the river reaches and irrigation districts included in the Nyah to Wemen Model. Note that the area of irrigation varies in these areas so the total recharge volume that is applied to the model also varies.

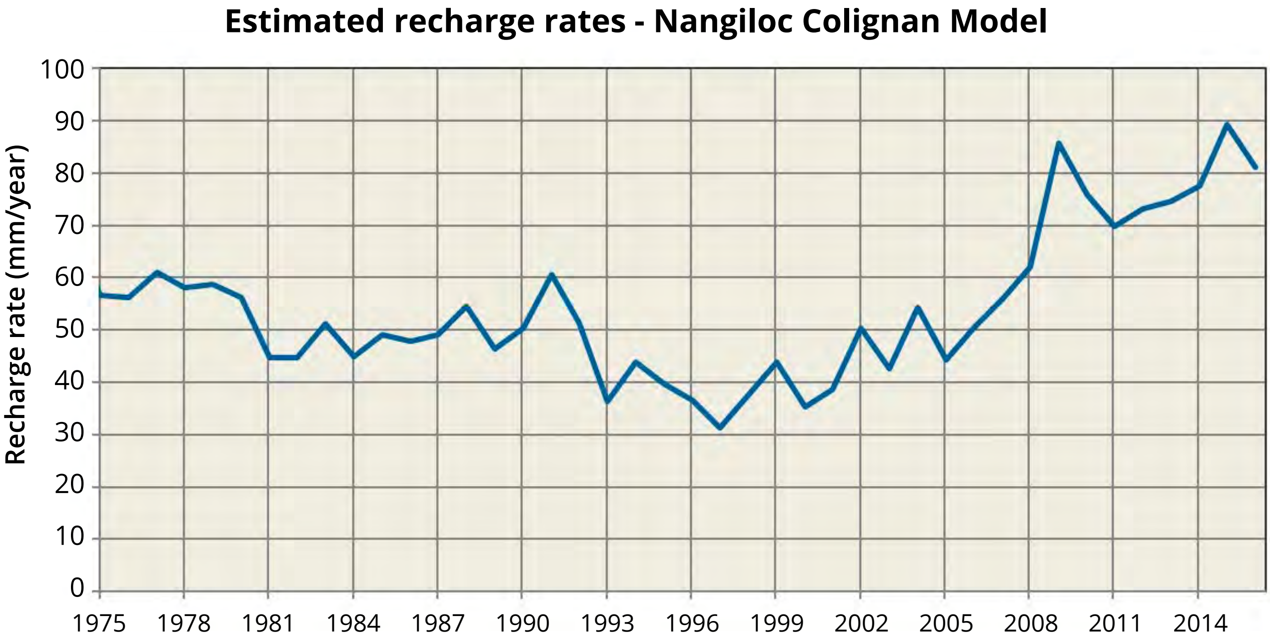


Figure 5: Estimated irrigation recharge for the Colignan River Reach used at the start of calibration of the Nangiloc-Colignan Model.

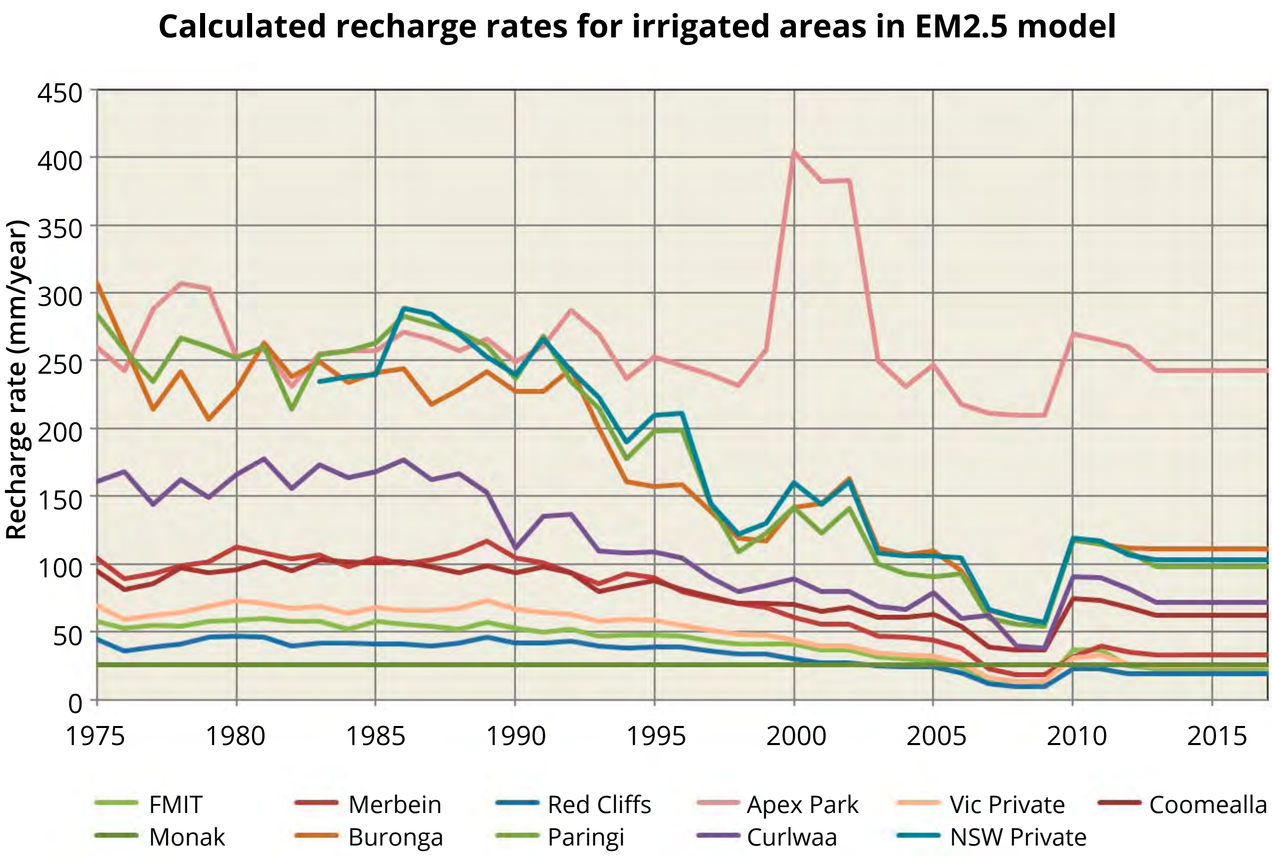


Figure 6: Calculated annual recharge fluxes for EM 2.5 (Data is compiled by Jacobs from EM 2.3 information in RPS and AWE reports). Note that recharge prior to 2015 is unaltered from the EM 2.3 model.

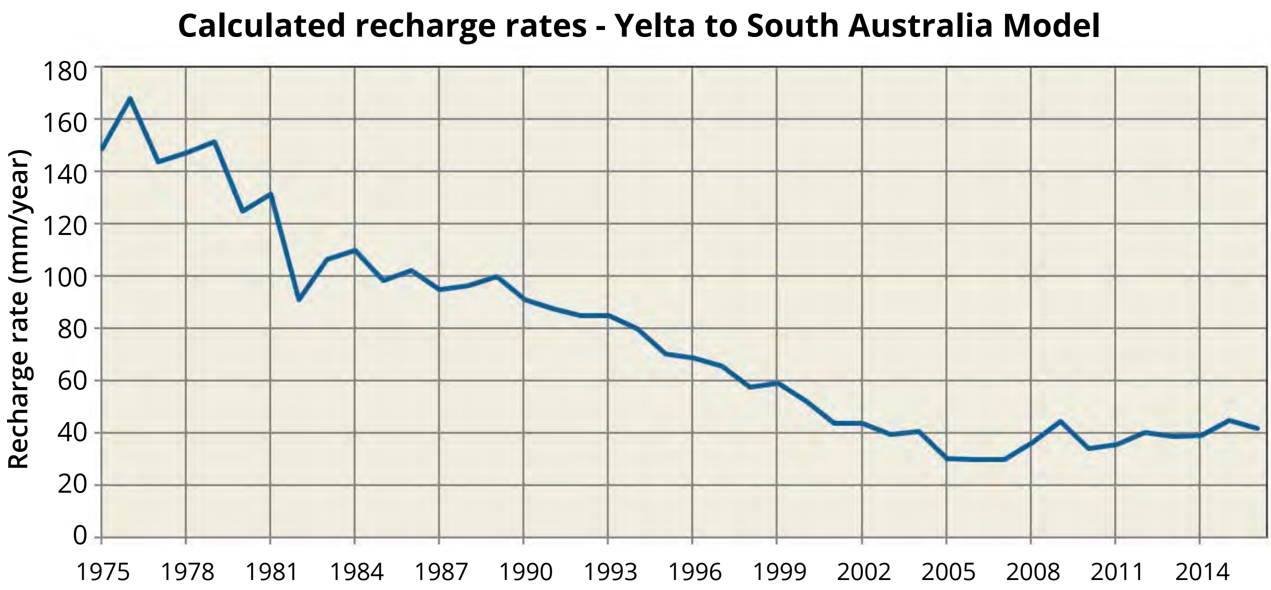


Figure 7: Calculated irrigation recharge rates for the Lock 10 to South Australia River Reach used for the start of calibration.

Near river groundwater salinity is also a key parameter that has a strong influence on the calculated salt load to the river. To help improve estimates of this parameter, the available data have been reviewed and used to define a series of river reaches within which constant groundwater salt concentrations are adopted for the purposes of converting groundwater discharge fluxes to river salt load.

For the calculation of salt loads from groundwater fluxes, salinity values have been used that represent a mixture of the near river salinity and the groundwater salinity beneath the area of irrigation. This is in line with the original credit claim methodology.

For the calculation of salt load, the following salinities have been used:

- Fresh zone = 7,000 mg/L
- Brackish zone = 15,000 mg/L
- Saline Zone = 35,000 mg/L

Unaccounted salt loads from the BIGMOD model have been analysed to provide an indication of the upper limit of salt loads that could be targeted by the models.

3.4 Sensitivity Analysis

A sensitivity analysis has been undertaken that presents the sensitivity of the final calibration to changes in model parameters. This sensitivity is expressed in terms of the change in calibration statistic plotted against an incremental change in parameter value.

3.5 Predictive Scenarios

The principal objective of the numerical modelling is to verify and, if necessary, re-estimate a set of Salinity Hazard Zone coefficients for the N2B SMP. The predictive scenarios have been run with monthly stress periods and include monthly variability in river stage, recharge and evapotranspiration parameters where temporal variability in evapotranspiration is significant.

Predictive scenarios involved the following for each model area:

Null Case (Scenario 0): irrigation development area and recharge rates growing from 1975 as per historic conditions up to 1988 and then held at 1988 conditions until 2100. This run sets the underlying impact of baseline conditions on groundwater discharge to the Murray River.

Base Case (Scenario 1): irrigation development area and recharge rates growing from 1975 as per historic conditions up to 2017, then held at the area of development in 2017 constant to 2100 using the average recharge rates of the five years 2012-2017.

Development Zone Scenarios: for each irrigation impact division the base case (described above) was expanded so that all land available for irrigation in individual development zones were fully irrigated from 1989 to 2100, using the average recharge (2012-2017) for the river reach that was calculated from calibration.

For all model runs, a repeating cycle of benchmark conditions for river level and flood re-charge was used to define river levels and flooding in the future. The cycle was adjusted so that the end of the defined MDBA "benchmark period" (May 2000) coincides with all future salinity reporting dates. The sequence used is described in Table 2.

Table 2: River stage and flooding sequence included in predictive scenarios

Start Year	End Year	River conditions used for scenarios
1975	1988	All scenarios: Historic river and flood conditions for all scenarios
1988	2017	All scenarios: Historic river and flood conditions
2017	2030	1987 to 2000 (last 23 years of the benchmark)
2030	2050	1981 to 2000 (Last 20 years of the benchmark)
2050	2100	Two cycles of benchmark conditions (1975-2000)

3.6 Uncertainty Analysis – Predictive Uncertainty

During the technical modelling workshop that was part of the method development, it was recognised and agreed that modelling to date has not adequately acknowledged or explored the predictive uncertainty of the numerical models to be used for the project. It was also recognised that implementation of a rigorous stochastic modelling approach as required to fully quantify predictive uncertainty may not be achievable within the allocated time frame. Nevertheless, it is appropriate and judicious to address predictive uncertainty in a way that will help frame the problem and provide insights into the relative significance of the numerical modelling and groundwater salinity estimations (used to convert modelled groundwater flows from the models into river salt loads) in the overall predictive uncertainty.

A linear uncertainty analysis was conducted for all models. The parameters in the calibrated models that give rise to the most uncertainty in flux to the river are presented in Table 3. While the uncertainty analysis considered all the uncertain model parameters, only the principal sources of model uncertainty are included in Table 3. It should be noted that the predictive uncertainty generally arises when a parameter has a strong influence on the predicted groundwater and salt fluxes to the River but is not clearly identifiable in calibration (i.e., the calibration data set does not contain enough information to constrain a parameter). In this regard Table 3 does not necessarily indicate those parameters of most significance in estimating river salt loads. It simply identifies those parameters that provide the most significant contributions to predictive uncertainty.

Table 3: Summary of parameters that are the principal contributors to predictive uncertainty

Model Area	Parameter	Contribution to uncertainty
Yelta to South Australia	River conductance	The final groundwater flux is highly dependent on the river conductance. Perfect knowledge of conductance would reduce groundwater flux variance by approximately 65%.
EM2	River conductance	The final groundwater flux is highly dependent on the river conductance. Perfect knowledge of conductance would reduce groundwater flux variance by approximately 50%.
Nanglioc-Colignan	River conductance Closely followed by storage	The final groundwater flux is highly dependent on the river conductance. Perfect knowledge of conductance would reduce groundwater flux variance by approximately 80%.
Nyah to Wemen	River conductance Followed closely by storage	The final groundwater flux is dependent on river conductance used in the model. River conductance provides approximately 60% of the variance. Approximately 50% of the variance can be removed if storage is known.

4. SALT LOAD FINDINGS

Estimated salt loads to the River Murray were calculated based on the difference in modelled groundwater fluxes in Scenario 1 and Scenario 0 and the near river salinity assumptions. The results are summarised below in Tables 4 to 7.

Negative impacts included in Tables 4 to 7 are a result of reducing trends in modelled irrigation recharge rates in Scenario 1 for the period following 1988. Such declines in recharge rates are not included in Scenario 0 (the definition of the scenario is to hold irrigation constant at 1988 rates) and hence the irrigation derived recharge rates are higher in Scenario 0 than for Scenario 1 for a period after 1988. Positive salt load impacts are predicted after 2015 or 2030 as the increased recharge footprint becomes the dominant change in recharge. Unlike all other models, the Nangiloc-Colignan model does not include negative salinity impacts. The reason for this behaviour is that there is a strong decline in modelled irrigation recharge rates after 1988 and hence Scenario 1 recharge fluxes are greater than those in Scenario 0 on average for all reporting times. Negative salinity impacts are predicted for all reporting years for EM 2.5. This outcome reflects the strongly reducing rates of irrigation recharge post 1988 together with extremely limited growth in the irrigation footprint in the pumped districts and in private irrigation areas.

About the estimated EC impacts in the following tables: To arrive at an estimated EC impact at Morgan, a fixed ratio of tonnes per day discharged to the Murray River to EC at Morgan has been used. This approach is referred to as the "*ready reckoner*" method. It is not an accurate method of estimating salt loads, as the only accurate approach is to run MSM-Bigmod for the salt load series in question. As using MSM-Bigmod is a time-consuming activity, to provide the reader with an approximation of the likely EC effect, the ready reckoner approach has been used. This is an approximation and is likely to be different when finally calculated accurately.

Table 4: Salt loads estimated for the Yelta to South Australia Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact at Morgan (to be confirmed)
2000	79.32	76.63	-2.69	-0.44
2015	57.24	54.65	-2.59	-0.42
2030	84.33	83.59	-0.64	-0.10
2050	100.64	100.66	0.02	0.00
2100	107.40	107.58	0.18	0.03

Table 5: Salt loads estimated for the EM2 Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact (to be confirmed)
2000	244.40	243.60	-0.80	-0.13
2015	261.93	250.23	-11.70	-1.90
2030	295.66	272.45	-23.21	-3.76
2050	348.87	319.09	-29.78	-4.83
2100	336.06	303.61	-32.45	-5.26

Table 6: Salt loads estimated for the Nangiloc-Colignan Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact (to be confirmed)
2000	165.71	166.06	0.32	0.05
2015	140.88	142.69	1.81	0.29
2030	148.94	155.58	6.64	1.08
2050	175.98	184.43	8.45	1.37
2100	170.47	178.94	8.47	1.37

Table 7: Salt loads estimated for the Nyah to Wemen Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact (to be confirmed)
2000	150.1	149.5	-0.6	-0.10
2015	109.5	109.4	-0.1	-0.02
2030	130.8	146.7	15.9	2.58
2050	175.2	208.4	33.2	5.38
2100	192.7	235.9	43.2	7.00

Excluding the EM2 area (for which there is a reducing salt load because of the irrigation district changes rather than private diversion areas) the total salt load increase at 2100 of private diversion areas, at 2017 levels of growth, is 51.85 tonnes per day. This is estimated to be an approximate increase of 8.4 EC at Morgan.

The results present the likely impact of irrigation development on the Murray River. To estimate the appropriate salinity impact for use on the Salinity Register, the salt load sequences must be submitted to the MDBA for BIGMOD model runs. Consideration will then need to be given to the uncertainty analysis and allowance made for the uncertainty that is reported.

5. DISCUSSION OF FINDINGS

5.1 Overview

The estimated salt loads presented in the final report and in this document are lower than the salt load impacts that are provided by the currently accredited N2B SMP method (the analytical approach). This is not unexpected. As discussed in the earlier sections of the report, there was an expectation that the salt loads from the refined models would be less than those embedded in the register entry. There are several reasons for this which are discussed below.

5.2 The effect of variable river levels and floods

The refined groundwater models have demonstrated the variable nature of groundwater flow into the river and especially the variability that is controlled by river level fluctuation. The analytical method used a long run average river level to define flow gradients. No allowance was made in the analytical approach for flood periods or times when the river level was elevated. This will have the effect of overstating the groundwater flow to the river in the analytical model, thereby overstating the salt load. Because of the differences in methodology between the two approaches it is very difficult to estimate the effect of this, but it may be in the order of 10% of the salt load, based on the amount of time that river levels are elevated.

An additional process that is represented in the numerical models that is not included in the analytical model is the effect of flood recharge on groundwater levels across the floodplain. River floods that extend across the floodplain occur periodically and provide short periods of intense groundwater recharge. Given that groundwater levels rise during these flood periods, there is a corresponding decrease in the long-term effective flow to the river from irrigated areas outside the floodplain.

Variable river levels and extensive flood areas both reduce the impact of groundwater discharge from irrigation compared to the method used in the analytical approach. This reduces the salt load impact of irrigation from the groundwater models when compared with the analytical approach. Using the results from the calibration of the model we have split the different sources of water that recharge the aquifer. Figure 8 shows the relative contribution of the different sources of recharge into the model and puts flood recharge and river flows (into the aquifer) in perspective with irrigation and dryland recharge. Inspection of this figure demonstrates that there are differences between the end of the model and the whole calibration period and that irrigation contribution to recharge varies across the region. For example, irrigation recharge is a significant part of the last five years of the calibration period for the Nangiloc-Colignan model area. Over half of groundwater recharge comes from irrigation in the period 2012 to 2017. Conversely, in the Yelta to SA Border model area, river interaction dominates recharge. The combination of flood recharge and flow out of the river to the aquifer is the dominating recharge feature in this model.

Accordingly, it would be expected that (across the whole model) irrigation recharge will have a modest effect on groundwater response. Clearing within the irrigated area, the effect will be still important, but when considered across the whole model it is a modest component. In the Nyah to Wemen model the importance of river flows and floods can also be seen. In this model area the significant growth in irrigation area, resulting in a significant growth in irrigation recharge, can clearly be seen. The average for the 2012 to 2017 period shows that irrigation recharge is double the contribution to recharge over this period compared to the long-term average.

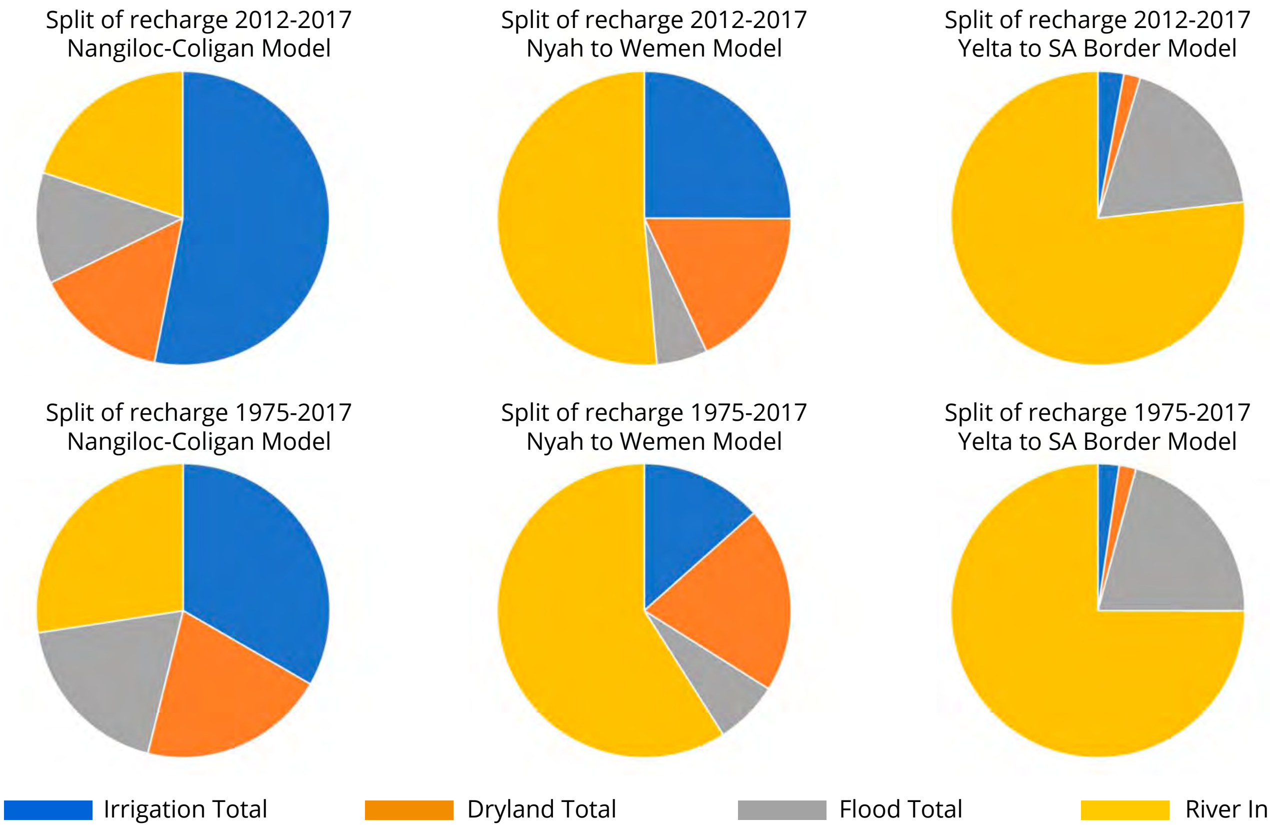


Figure 8: Relative contribution of different sources of recharge to the three water trade models

5.3 Evapotranspiration, especially on the floodplain

Groundwater models include the potential for groundwater to discharge by evaporation and transpiration when groundwater levels are sufficiently close to the surface. Thus, there are areas in the groundwater models where evapotranspiration is predicted. Some areas are within the irrigation areas (such as in Nangiloc-Colignan, for example), but most of the areas are in the floodplain. Evapotranspiration from groundwater reduces the amount of discharge that enters the river. Thus, the groundwater models have less groundwater discharge to the river than the analytical approach, which does not allow for evapotranspiration.

This effect is especially pronounced in the Yelta to South Australia Model where there are large areas of floodplain with relatively shallow groundwater and evapotranspiration can account for a large volume of water. Thus, when comparing the salt load impacts in the Yelta to South Australia Model with the analytical model, there is a large difference. There is a significant influence of floodplain evapotranspiration in the Yelta to South Australia Model results.

Evaporation and salt accumulation on the floodplain are not without environmental and salinity impact. There is potential for soil productivity decline, damage to vegetation, including native vegetation and the potential for salt accumulated at the soil surface to be washed off in flood events. Whilst these effects are salinity impacts, they may not all result in increased salinity in the Murray River, so would not contribute to EC impacts at Morgan. Thus, they are not accountable on the salinity register.

Evaporation from shallow groundwater, (including perched groundwater), has the effect of reducing root zone drainage so that the recharge to groundwater is thus less than root zone drainage. In the Nangiloc-Colignan area, where there are areas of saline discharge from groundwater, this has the effect of providing an alternative discharge outlet for root zone drainage, which reduces the overall rate of nett recharge to the regional groundwater system. This effect was not included in the analytical approach.

5.4 Effect of sub-surface drains

Sub-surface drains control the watertable elevation and provide an alternative discharge route for root zone drainage, before it becomes groundwater recharge. Irrigated areas with extensive sub-surface drainage will have less overall recharge than undrained areas, provided that the sub-surface drainage intercepts water.

There are several areas within the models where sub-surface drainage is either not installed, or do not discharge any drainage water. Other areas, where sub-surface drainage intercepts recharge before it reaches the regional watertable. The analytical models used to derive the salinity Hazard Zone Coefficients do not account for the effects of drains while the groundwater model does. The Nangiloc-Colignan model area is believed to have to be significantly influenced by sub-surface drainage. Drains in Nangiloc-Colignan discharge large volumes of water. In other areas, drains do not discharge as much (or at all). This contributes to the difference in river salt loads predicted for the Nangiloc-Colignan area by the numerical model and by the analytical method.

5.5 Controlling influence of clay layers and perched aquifers

Perched aquifers tend to reduce the rate of groundwater recharge to less than the rate of root zone drainage. Perched aquifers only develop where the infiltration rate is higher than the ability of a subsurface clay layer to pass water. A local watertable “perched” over the clay then develops. It follows that wherever sub-surface clay layers force the development of a perched watertable, the recharge to the regional aquifer system will be less than root zone drainage.

The groundwater models account tor the effects of perched watertables without explicitly modelling them by way of the calibration. As the calibration adjusts groundwater recharge rates to optimise the match to observed groundwater level response. Where clay layers reduce the rate of recharge the models will tend to also have a reduced recharge rate (even when the clay layers are not modelled explicitly). This process is not accounted for in the analytical method, which assumes the full root zone drainage reaches the watertable.

In some areas, perched groundwater may discharge locally and causes salinity impacts to land. This discharge will generally not reach the river and so will not increase EC at Morgan. In this way, salinity effects can occur locally that are not accounted for on the salinity register. In other areas the perched water is controlled and intercepted by drains, and in some locations the perched watertables may be increasing in elevation and extent and may cause shallow water logging problems in future. The effect of clay layers reducing the recharge rate, thus slowing the rate of rise of groundwater, is not allowed for in the analytical model and is another reason why the groundwater models will predict less river impact than the analytical approach.

5.6 Improving irrigation techniques and management

Over time irrigation practices have changed and generally improved in the N2B SMP area. In part, this is a direct result of the irrigator education efforts that were included in the SMP. The groundwater models allow for regional improvements in practice through the inclusion of irrigation delivery data into the recharge calculations. As the average application rate (per ha) changes over time, the groundwater models embed these changes. This is done on a river reach basis, not for individual properties. The analytical model was developed in the 1990's and has a constant irrigation application rate over the forecast period. Thus, it does not include any areas where improvements have been made. The effect of this is that the groundwater models can respond to the changes in application rate while the analytical approach does not.

5.7 Adopted groundwater salinity

The refined models are used to determine groundwater flow rates and volume into the river. Groundwater salinity values are then used to convert flow into salt load. This calculation occurs after the models have been run. There is a difference in the groundwater salinity values that have been used in the groundwater models compared with the analytical model.

The current register entry incorporates groundwater salinity values that are based on the salinity beneath the irrigation development areas, not the near river salinity. Best practice for groundwater models in the Mallee is to use near river salinity values, such as derived from AEM or Nano-TEM surveys.

Because much of the river length through the N2B SMP area has very fresh groundwater immediately adjacent to the river, use of groundwater salinity values from next to the river results in very low salt load estimates. These estimates are unrealistically low for future forecasts. As well, they may not be sufficiently precautionary for the purposes of the register.

On the other hand, use of groundwater salinity values from beneath the irrigated land tends to predict salt loads that are unrealistically high when compared with the available record of salt loads reaching the river. A compromise value has been adopted for this work, which uses near river values, lower than the inland salinity values, but higher than the immediate river bank values.

There is thus an inherent reduction in the predicted salinity discharge values when compared with the analytical approach, which has generally higher groundwater salinity used in the calculation. Despite this, the adoption of values that are higher than the current day river bank salinity is considered a suitably conservative approach that will not under-estimate the actual salt load reaching the river. In this way the adopted salinity value is conservative and appropriately allows for salinity accountability from irrigation.

6. CONCLUSIONS

The following conclusions have been reached:

- Refinement of the numerical models has allowed an improved representation of the groundwater response to irrigation to be developed
- The required model refinements were all able to be implemented successfully and all models were calibrated to acceptable norms
- Irrigation development, which has resulted in significant expansion of irrigated area in the Mallee is calculated to increase the overall amount of salt displaced to the Murray River from regional groundwater
- Inclusion of month river levels has highlighted the role of river level in controlling groundwater discharge and as a result the models have identified that groundwater discharge is an intermittent occurrence
- The models are sensitive to recharge and groundwater flow parameters. Changes in recharge lead to changes in river salt load
- The rate of salt load discharge is lower than had been calculated by the analytical method by roughly how much?. This can be explained by differences in the representation of groundwater processes in the two approaches. The key differences are the role of river levels and the effect of evapotranspiration (especially in the near river area)

7. REFERENCES

Cummins, T. and Thompson, C. (2018) A short history of irrigation development in the Victorian Mallee, Mallee Catchment Management Authority

DEDJTR (2018) Satellite based estimates of Mallee Crop Water Use and Root Zone Drainage

DSE (2011) Manual for Victoria's Salinity Accountability in the Murray-Darling Basin, ISBN 978-1-74287-005-2 (online)

Mallee CMA (2013) Mallee Salinity Workshop Report, http://www.malleecma.vic.gov.au/resources/salinity accessed May 2019

IRRIGATION DEVELOPMENT

This section of the Forum highlighted changes to irrigation development over recent years, from a regional perspective through to the orchard level and how such changes have had an impact on water and salinity management.

In particular, changes to the total irrigation area, crop type and irrigation methods across the Victorian Mallee was presented, along with a comparative assessment of irrigation practices in the region against international frameworks and the practical experience in adopting best management irrigation and drainage practices.

Original presentations can be found in the **Appendix**

PAPER **Mapping Irrigation Development and River Salinity Impact Zones in the Victorian Mallee, 1997 to 2018**
Sue Argus, *SunRISE Mapping and Research, Mildura, Victoria*

PAPER **Achieving and Maintaining Irrigation Best Practices for the Mallee**
Associate Professor John Hornbuckle and Dr Carlos Ballester-Lurbe, *Centre for Regional and Rural Futures, Deakin University, Griffith, NSW*

- **Irrigator's Perspective – Changing Practices and Technology Over Time**

  Troy Richman, *Almas Almonds General Manager, Robinvale, Victoria*

PAPER

MAPPING IRRIGATION DEVELOPMENT AND RIVER SALINITY IMPACT ZONES IN THE VICTORIAN MALLEE, 1997 TO 2018

Sue Argus, *SunRISE Mapping and Research, Mildura, Victoria*

ABSTRACT

Information on irrigation status and development is used by the Mallee Catchment Management Authority (Mallee CMA) to better understand the dynamics of irrigation and its impact on salinity and water quality.

The information is produced by SunRISE Mapping and Research (SunRISE) from analysis of its mapping and databases that have track irrigated areas across the Mallee since 1997. The mapping is based on high resolution aerial imagery. Crop and culture details are validated as irrigators access mapping products for development, planning, export registrations, irrigation system designs and quality assurance programs.

Information outputs from the mapping have been documented in a series of reports prepared for the Mallee CMA. The 2018 Mallee Horticulture Crop Report produced in November 2018 quantifies changes from 1997 to 2018 with respect to irrigation expansion, crop types, irrigation methods, property numbers and size and area irrigated in each river salinity impact zone.

From 1997 to 2018, the irrigable area in the Mallee catchment increased by 40,825 hectares, with 42,715 hectares of expansion and 1,890 hectares retired from irrigation.

While wine grape plantings were the dominant crop type in 1997, almond trees were dominant by 2018. Wine grape plantings decreased by 1,915 hectares whereas almond plantings increased by 22,740 hectares.

The trend to efficient water application systems was evident from 1997 to 2018. Furrow irrigation decreased by 12,970 hectares and drip irrigation increased by 43,140 hectares.

The estimated number of irrigation properties was 1,925 in 2018, a decline of 523 properties since 1997. While property numbers declined, the average irrigated area per property increased from 16 hectares to 42 hectares.

Irrigation expansion from 1997 to 2018 predominantly occurred in the lowest salinity impact zone, L1. The area irrigated in L1 was 24,950 hectares greater in 2018 than in 1997 while the area irrigated in the high salinity impact zone decreased by 3,470 hectares.

1. INTRODUCTION

SunRISE commenced mapping irrigated horticulture in 1997 with the aim of addressing the need for accurate information on irrigated horticulture. Better information was needed for improved industry planning and resource management in a region where irrigation has an impact on economic, social and environmental outcomes.

The advent of Geographic Information System (GIS) technologies provided an ideal tool to map and integrate details on irrigated horticulture. SunRISE applied GIS to mapping irrigated horticulture and in collaboration with irrigators, service providers, industry bodies and stakeholder agencies, has maintained the information system consistently for twenty-one years.

Analysis of the crop mapping has produced a series of reports for the Mallee CMA including the 2018 Mallee Horticulture Crop Report completed in November 2018. The report quantifies changes from 1997 to 2018 with respect to irrigation expansion, crop types, irrigation methods, property numbers and size, and area irrigated in each river salinity impact zone. Information from the report is used by the Mallee CMA to better understand the dynamics of irrigation and its impact on salinity and water quality.

Results in this paper are from analysis undertaken for the 2018 Mallee Horticulture Crop Report. The geographic extent of the study covers irrigation areas within the Victorian Mallee catchment, along the Murray River and in the Murrayville Groundwater Management Area (GMA). River salinity impact zones do not extend to the Murrayville GMA hence the information on salinity impact zones does not include Murrayville GMA areas.

2. METHOD/DATA

SunRISE crop mapping is captured to the individual patch or variety level using a map base of high-resolution, scale accurate, aerial imagery. Details for each crop patch such as type, variety, rootstock, year planted and irrigation method are collected from irrigators, field surveys and aerial imagery interpretation. Some details are discernible from the imagery while others, such as variety, require input from irrigators.

Details are also collected in collaboration with local agencies and industry bodies to support specific programs, such as planting statistics for industry planning and management, and spatial information for infrastructure development, biosecurity, economic assessments and environmental monitoring.

SunRISE maintains the crop mapping and databases on an on-going basis. In particular, the 'shop-front' provision of mapping to irrigators facilitates an exchange of information. Mapping is sought by irrigators for planning and development, irrigation design, property sales, soil surveys, spray records, export registration, Freshcare certification, organic certification and environmental management. The privacy of individual property details is maintained and only aggregated information is published.

When irrigators provide more detailed information than was previously recorded from interpretation of imagery or field survey, earlier databases are backfilled where relevant and the time-series databases are continually improved.

3. RESULTS

3.1 Change in irrigation area from 1997 to 2018

From 1997 to 2018, the irrigable area in the Mallee catchment increased by 40,825 hectares. This was a 101% increase from 40,325 hectares in 1997 to 81,150 hectares in 2018 (Figure 1). The net increase of 40,825 hectares was the balance of 42,715 hectares expansion and 1,890 hectares retired from irrigation.

Expansion from 1997 to 2018 was predominantly permanent plantings. Permanent plantings almost doubled in area with a 98% increase of 27,495 hectares, whereas the increase in seasonal crops was 2,160 hectares, a 19% increase.

The millennium drought, global financial crisis and end to Managed Investment Schemes brought permanent plantings to a halt around 2009 after twelve years of continued development. Little further development occurred for six years, with the area of permanent plantings in 2012 and 2015 less than in 2009 by 1%. Renewed activity was evident from 2015 to 2018 and permanent plantings increased by 4,345 hectares (8%).

From 1997 to 2006, the net area of seasonal cropping increased by 3%. By 2009, drought, low water allocations and high water prices impacted on seasonal cropping and areas dropped by 43% compared with the area irrigated in 2006. Seasonal cropping areas were back to 2006 levels by 2012 and continued to increase through to 2018.

The proportion of the irrigable area that was vacant[1], not irrigated, increased from 3% in 1997 to 20% by 2009. Recovery from the millennium drought was slow with vacant areas at 17% in 2012 and 2015, and declining to 15% by 2018.

	1997	2003	2006	2009	2012	2015	2018	Change 1997-2018
Permanent - irrigated	27,975	36,075	42,165	51,460	50,890	51,125	55,470	+27,495
Seasonal - irrigated	11,160	12,310	11,470	6,550	11,230	12,445	13,320	+2,160
Vacant - permanent	425	920	1,890	6,380	7,710	7,610	6,475	+6,050
Vacant - seasonal	765	2,045	3,925	7,865	5,450	5,065	5,885	+5,120
Total (ha)	40,325	51,350	59,450	72,255	75,280	76,245	81,150	+40,825
% Permanent	69%	70%	71%	71%	68%	67%	68%	
% Seasonal	28%	24%	19%	9%	15%	16%	16%	
% Vacant	3%	6%	10%	20%	17%	17%	15%	

Figure 1: Change in the Mallee catchment irrigation area from 1997 to 2018

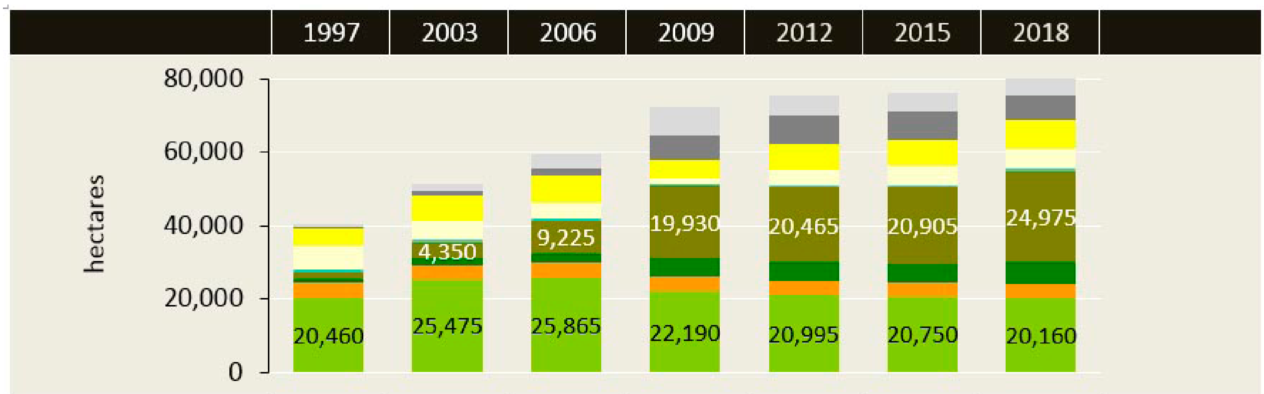
[1] Vacant areas are irrigable but were not irrigated in the season recorded. They may have been in redevelopment, dried-off temporarily or indefinitely.

3.2 Change in crop types from 1997 to 2018

From 1997 to 2018, the area of almond plantings in the Mallee catchment increased by 22,740 hectares (1,303%). By 2009, almonds had replaced wine grape plantings as the dominant crop type (Figure 2).

Apart from almonds, the main crops being planted were table grapes, olives and potatoes, increasing by 4,810 hectares, 3,655 hectares and 1,705 hectares respectively.

Crop types with net removal were dried grapes, wine grapes and field crops, decreasing by 3,195 hectares, 1,915 hectares and 965 hectares respectively.



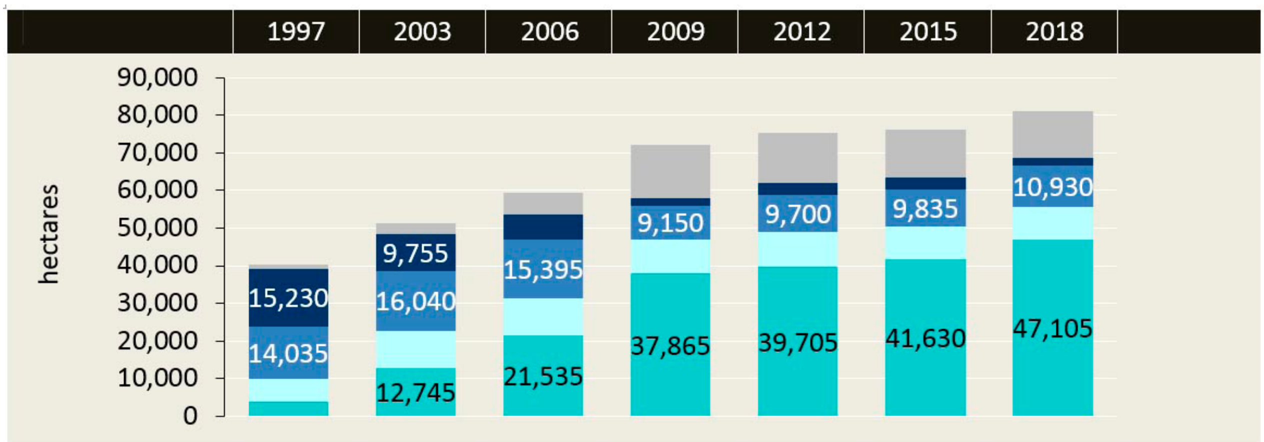
	Crop type	1997	2003	2006	2009	2012	2015	2018	Change 1997-2018
Permanent	Grape Dried	6,340	4,925	4,210	3,015	3,035	3,045	3,145	-3,195
	Grape Table	4,155	5,805	5,805	5,650	6,430	7,280	8,965	+4,810
	Grape Wine	9,965	14,745	15,850	13,525	11,530	10,425	8,050	-1,915
	Citrus	3,995	3,830	4,005	3,720	3,830	3,760	4,135	+140
	Fruit Olive	160	745	1,285	4,075	3,805	3,670	3,815	+3,655
	Fruit Other	795	945	1,030	970	1,305	1,530	1,800	+1,005
	Nut Almond	1,745	4,145	9,010	19,695	20,190	20,610	24,485	+22,740
	Nut Other	185	205	215	235	275	295	490	+305
	Miscellaneous	635	730	755	575	490	510	585	-50
Seasonal	Field Crop	6,650	5,160	4,280	1,270	4,480	5,300	5,685	-965
	Veg. Carrot	1,575	2,600	2,540	2,490	2,410	2,395	1,565	-10
	Veg. Potato	1,705	2,745	2,830	1,805	2,695	2,725	3,410	+1,705
	Veg. Other	1,230	1,805	1,820	985	1,645	2,025	2,660	+1,430
	Vacant P	425	920	1,890	6,380	7,710	7,610	6,475	+6,050
	Vacant S	765	2,045	3,925	7,865	5,450	5,065	5,885	+5,120
Total (ha)		40,325	51,350	59,450	72,255	75,280	76,245	81,150	+40,825
Dominant		wine grape	wine grape	wine grape	almond	almond	almond	almond	

Figure 2: Change in crop types in the Mallee catchment from 1997 to 2018

3.3 Change in irrigation methods from 1997 to 2018

The dominant irrigation method in the Mallee catchment changed from furrow irrigation in 1997 to overhead sprinklers, including centre pivots, by 2003 and to drip irrigation by 2006. Drip irrigation remained dominant from 2006 to 2018.

The use of pressurised systems (drip, low level and overhead irrigation) increased from 61% of the irrigated area in 1997 to 97% by 2018. Gravity systems (furrow and flood) decreased from 39% of the irrigated area in 1997 to 3% by 2018.



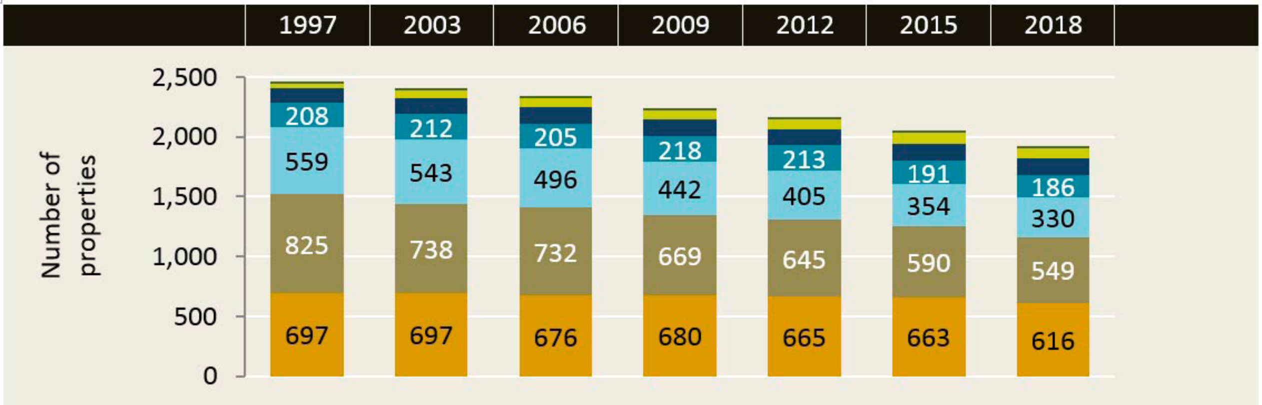
Irrigation method	1997	2003	2006	2009	2012	2015	2018	Change 1997-2018
Drip	3,965	12,745	21,535	37,865	39,705	41,630	47,105	+43,140
Lowlevel	5,905	9,845	9,920	9,060	9,350	8,860	8,495	+2,590
Overhead, pivot	14,035	16,040	15,395	9,150	9,700	9,835	10,930	-3,105
Furrow, flood	15,230	9,755	6,785	1,935	3,365	3,245	2,260	-12,970
Vacant	1,190	2,965	5,815	14,245	13,160	12,675	12,360	+11,170
Total (ha)	40,325	51,350	59,450	72,255	75,280	76,245	81,150	+40,825
Dominant	furrow	overhead	drip	drip	drip	drip	drip	

Figure 3: Change in irrigation methods in the Mallee catchment from 1997 to 2018

3.4 Change in irrigation properties from 1997 to 2018

In 2018, there were approximately 1,925 irrigation properties in the Mallee catchment with an average irrigable area of 42 hectares.

Across the Mallee catchment from 1997 to 2018, the number of properties decreased by 523, while property size (irrigable area) increased from 16 hectares to 42 hectares. Properties with an irrigable area less than 20 hectares decreased by 586, while the number over 20 hectares increased by 63.



Property size (irrigable area)	1997	2003	2006	2009	2012	2015	2018	Change 1997-2018
1 to 5 ha	697	697	676	680	665	663	616	-81
5 to 10 ha	825	738	732	669	645	590	549	-276
10 to 20 ha	559	543	496	442	405	354	330	-229
20 to 40 ha	208	212	205	218	213	191	186	-22
40 to 100 ha	113	131	137	141	135	146	142	+29
100 to 500 ha	42	66	75	73	86	87	78	+36
> 500 ha	4	11	15	19	17	19	24	+20
Total properties	2,448	2,398	2,336	2,242	2,166	2,050	1,925	-523
Average size (ha)	16	21	25	32	35	37	42	

Figure 4: Change in irrigation properties in the Mallee catchment from 1997 to 2018

3.5 Irrigable area in each River Salinity Impact Zone in 2018

River salinity impact zones are mapped zones in north-west Victoria that correlate to tonnes of salt displaced to the Murray River from new irrigation. The salinity impact zones in Figure 5 are 'Salinity Offset Charging Zones'; comprising four low impact zones (L1, L2, L3 and L4) and one high impact zone (HIZ).

The zones do not apply to the Murrayville GMA. Areas are for irrigation along the Murray River within the Mallee catchment, the Murray-Mallee.

In 2018, the irrigable area in the Murray-Mallee of 78,775 hectares was 51% (40,470 ha) in L1, 20% (15,500 ha) in L2, 3% (2,480 ha) in L3, 12% (9,730 ha) in L4 and 13% (10,595 ha) in the high impact zone, HIZ.

3.6 Change in irrigation areas in each River Salinity Impact Zone from 1997 to 2018

Salinity impact zones of 'irrigated' and 'vacant/not irrigated' areas respectively are shown in Figures 6 and 7.

In 2018, the area irrigated in HIZ was 3,470 hectares less than in 1997, a 32% decrease from 10,840 to 7,370 hectares (Figure 6). Areas irrigated in LIZ (i.e. L1, L2, L3 and L4) increased by 31,335 hectares; a 113% increase from 27,710 to 59,045 hectares.

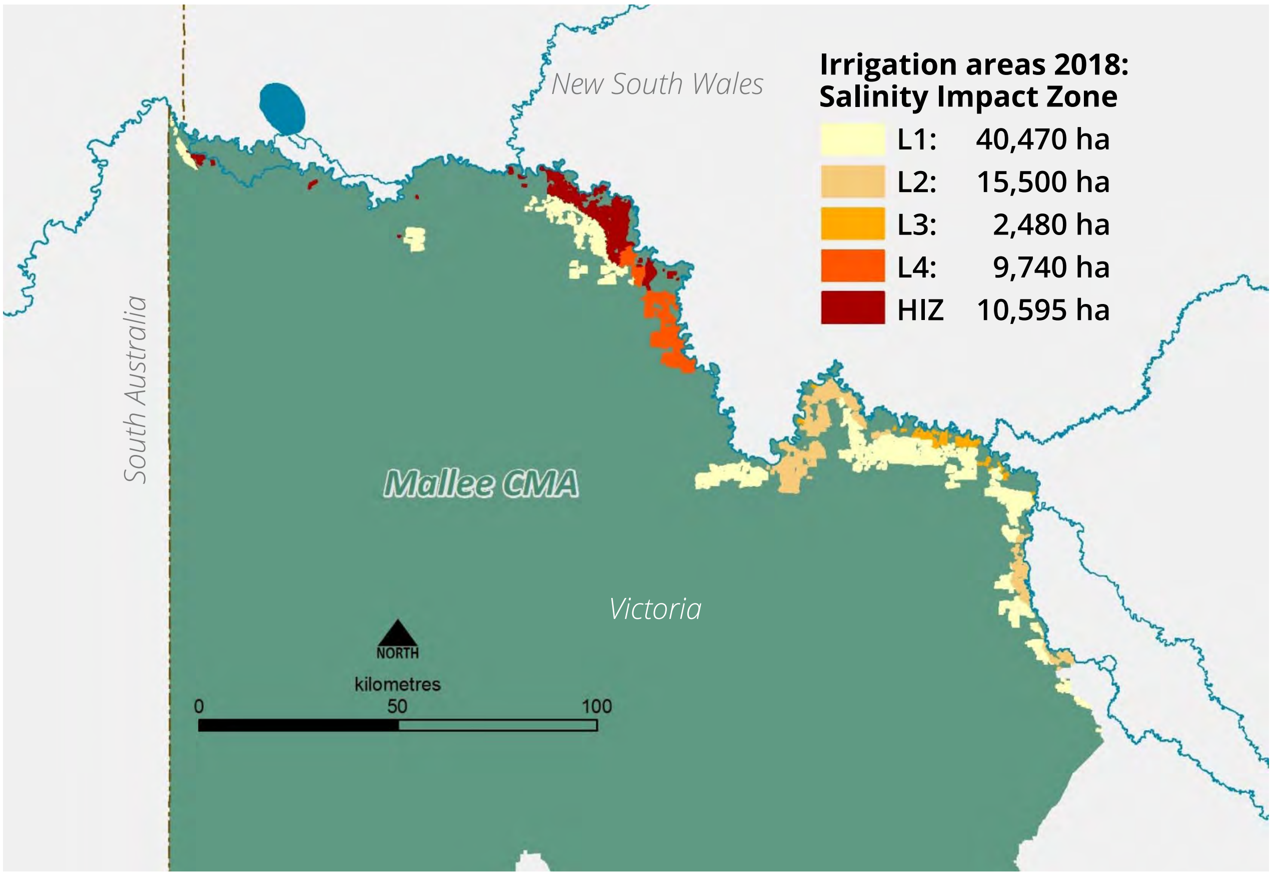
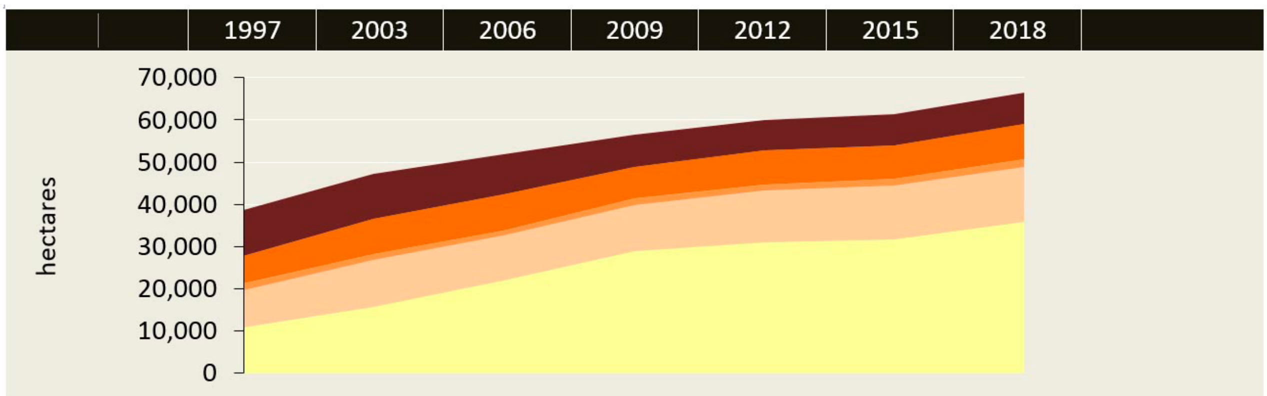


Figure 5: Map of the river salinity impact zones of irrigable areas in 2018

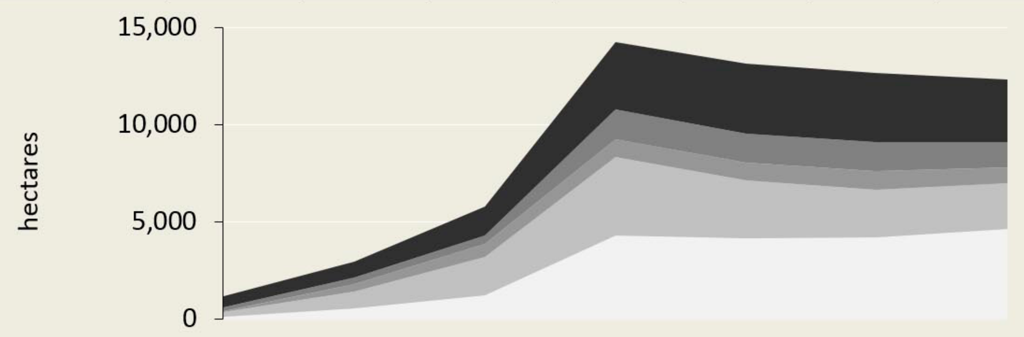


Salinity impact zone	1997	2003	2006	2009	2012	2015	2018	Change 1997-2018
L1 irrigated	10,875	15,785	22,050	29,025	31,100	31,700	35,825	+24,950
L2 irrigated	8,735	11,135	10,490	10,885	12,090	12,845	13,150	+4,415
L3 irrigated	1,655	1,370	1,340	1,455	1,605	1,505	1,665	+10
L4 irrigated	6,445	8,390	8,545	7,600	7,945	8,000	8,405	+1,960
HIZ irrigated	10,840	10,465	9,555	7,550	7,335	7,250	7,370	-3,470
Total (ha)	38,550	47,145	51,980	56,515	60,075	61,300	66,415	+27,865

Figure 6: Change in the area irrigated in each salinity impact zone from 1997 to 2018

Areas that were vacant, not irrigated, in the represented years from 1997 to 2018 are shown in Figure 7. Areas in high impact zones were predominantly permanent plantings dried-off due to the millennium drought. They peaked at 3,610 hectares in 2012. Areas began to come back into production in 2015 and by 2018 the area not irrigated in HIZ was down to 3,225 hectares. Areas not irrigated in LIZ (i.e. L1, L2, L3 and L4) increased by 8,540 hectares; a 1,435% increase from 595 ha in 1997 to 9,135 ha in 2018.

	1997	2003	2006	2009	2012	2015	2018	



Salinity impact zone	1997	2003	2006	2009	2012	2015	2018	Change (ha) 1997-2018
L1 vacant	145	565	1,220	4,325	4,175	4,200	4,645	+4,500
L2 vacant	225	850	1,995	4,015	2,965	2,450	2,350	+2,125
L3 vacant	55	390	640	920	915	970	815	+760
L4 vacant	170	330	465	1,525	1,495	1,485	1,325	+1,155
HIZ vacant	595	830	1,495	3,460	3,610	3,570	3,225	+2,630
Total (ha)	1,190	2,965	5,815	14,245	13,160	12,675	12,360	+11,170

Figure 7: Change in the area not irrigated in each salinity impact zone from 1997 to 2018

3.7 River Salinity Impact Zones of expansion and retired areas from 1997 to 2018

From 1997 to 2018, the irrigable area in the Mallee catchment, excluding the Murrayville GMA, increased by 39,035 hectares. The net increase of 39,035 hectares was the balance of 40,925 hectares expansion and 1,890 hectares retired from irrigation (Figure 8).

99% of irrigation expansion from 1997 to 2018 was in low salinity impact zones, 73% in the lowest salinity impact zone, L1. There was 1,300 hectares (69%) retired from irrigation, in the high salinity impact zone.

Salinity impact zone	1997 (ha)	1997 to 2018				2018 (ha)	Change 1997-2018 (ha)
		Retired		Expansion			
		ha	%	ha	%		
L1	11,020	-210	11%	+29,660	73%	40,470	+29,450
L2	8,960	-175	9%	+6,715	16%	15,500	+6,540
L3	1,710	-165	9%	+935	2%	2,480	+770
L4	6,615	-40	2%	+3,155	8%	9,730	+3,115
HIZ	11,435	-1,300	69%	+460	1%	10,595	-840
Total	39,740	-1,890	100%	+40,925	100%	78,775	+39,035

Figure 8: Salinity impact zones of expansion and retired areas from 1997 to 2018

4. CONCLUSION

Mapping of irrigated horticulture in a spatial information system, based on high resolution aerial imagery, enables data on irrigated horticulture to be integrated at the individual crop patch level and analysed across specific areas of interest, such as districts and catchments.

Consistent maintenance of the mapping system in collaboration with irrigators, service providers, industry bodies and stakeholder agencies ensures accurate tracking of a constantly changing industry.

Tracking changes and trends in irrigated horticulture assists better understanding of the dynamics of irrigation which, in turn, enables better modelling and analysis of its impact on salinity and water quality.

5. REFERENCES

SunRISE Mapping and Research (2018). 2018 Mallee Horticulture Crop Report. Mallee Catchment Management Authority https://mk0malleecmacomvmcpd.kinstacdn.com/wp-content/uploads/2019/07/2018-Mallee-Horticulture-Crop-Report-Final.pdf

PAPER

ACHIEVING AND MAINTAINING IRRIGATION BEST PRACTICES FOR THE MALLEE

Associate Professor John Hornbuckle and Dr Carlos Ballester-Lurbe,
Centre for Regional and Rural Futures, Deakin University, Griffith, NSW

ABSTRACT

Irrigated agriculture in the Victorian Mallee has seen a significant increase in area in the last 25 years with more than 80 000 ha now irrigated in the region. Best management practices in irrigation are a critical component of achieving sustainable irrigation systems that minimise the impact of irrigation on the environment and are a key component of the Mallee Land and Water Management Plan to meet salinity target objectives within the plan while allowing irrigation development to continue. As irrigation continues to expand and existing irrigation systems and infrastructure are upgraded, there is a need to assess irrigation guidelines and associated outcomes of guidelines to ensure that offsite environmental issues are avoided or minimised, particularly in regards to salinity.

A recent review of Irrigation Best Practice in the Mallee found that The Victorian Mallee Irrigation Development Guidelines are a comprehensive set of guidelines that have achieved best practice irrigation development, which is of a world standard. They clearly set out processes, responsibilities and expected outcomes for new irrigation development. However, it was found that there is scope for improvement (indeed best management practices involve continually seeking improvement) in the implementation of the guidelines and, specifically, in compliance after irrigation developments have been assessed and approved.

Three broad areas were identified in the review for improving/strengthening irrigation best management practices within the Victorian Mallee to meet Land and Water Management Plan objectives. These were:

1. Strengthening ongoing monitoring and evaluation to ensure compliance.
2. Harnessing new technologies in data gathering and reporting.
3. Benchmarking practices with a focus on parameters that capture on-ground outcomes of best practice.

This paper presents the review findings on potential options for strengthening outcomes from irrigation practices in the Victorian Mallee.

1. BACKGROUND

Irrigated agriculture in the Victorian Mallee has seen a significant increase in area in the last 25 years with more than 80 000 ha now irrigated in the region, a large part of them associated with private irrigation diverters from the river (Cummins and Thompson, 2018). The Nyah to South Australia Border Salinity Management Plan has enabled this expansion to occur while aiming to minimise and mitigate the salinity impacts that were present in earlier irrigation developments in the Mallee. A key part of mitigating impacts of salinity associated with irrigation development has been the adoption and uptake of Best Management Practices (BMP's) in irrigation design and management to ensure that new irrigation development achieves high efficiencies and reduces the risk of potential for offsite environmental impacts from inefficient irrigation practices. As irrigation continues to expand and, indeed, existing irrigation systems and infrastructure are upgraded, there is a need to assess irrigation guidelines and associated outcomes of guidelines to ensure that offsite environmental issues are avoided or minimised, particularly in regards to salinity.

The aim of this review was to provide external insights into the contemporary understanding of best management practices as applied to irrigation within the Victorian Mallee and to identify potential areas for improvement.

2. APPROACH TO REVIEW AND FINDINGS

The approach taken due to the limited timeframe, was to use existing documentation on irrigation changes and irrigation best management practices and performance on ground. This documentation was collated by a range of agencies (i.e. SunRISE Research & Mapping, Mallee CMA, Agriculture Victoria part of Victorian Department of Jobs, Precincts and Regions) and a range of stakeholder discussions with irrigators, irrigation designers, water providers and agency staff to capture knowledge on irrigation practices occurring within the Victorian Mallee. This was done through tours of irrigation enterprises within the Mallee Irrigation Districts as well as a range of phone-based discussions with the identified stakeholders. More details about the approach taken and findings from the review can be found in Hornbuckle, J. and Ballester-Lurbe, C. (An Assessment of Irrigation Best Practices for the Victorian Mallee, Final report 2019 – Centre for Regional and Rural Futures, Deakin University Project 4502-4533).

3. IDENTIFIED AREAS FOR IMPROVEMENT

The review found that the Victorian Mallee Irrigation Development Guidelines presents a comprehensive set of guidelines that have led to best practice irrigation development in the region, which is of a world standard. The document clearly sets out processes, responsibilities and expected outcomes for new irrigation development. Its purpose and intent is clear and the underlying drivers behind the recommended best practices are sound and robust.

In contrasting this to other national and international approaches to irrigation development, the Victorian Mallee Irrigation Development Guidelines is clearly a leader in this field. Identification of risks of irrigation development on the environment and associated practices to mitigate or minimise these risks have been developed into the guidelines and approval process. A range of regulatory government and industry agencies have proactively worked well to develop a robust methodology to ensure new irrigation development is of a world class standard and minimises the risk to surrounding environmental and eco-systems within the scope of the Victorian Mallee irrigation operations.

However, the review found there was scope for improvement in the implementation of the guidelines and, specifically, in compliance after irrigation developments have been assessed and approved. It appeared evident that once irrigation development had taken place there is not a clear monitoring and evaluation process that occurs to ensure that best practice irrigation management is occurring on a wide scale. For instance, the use of irrigation monitoring and scheduling technology (i.e. soil moisture probes) can be mandated through the development process and yet, there is no compliance reporting which is routinely undertaken or any assessment of this data, i.e. testing effectiveness of irrigation scheduling or through benchmarking performance. Likewise for mandated test wells to monitor groundwater levels. This information does not appear to be routinely collated and assessed for investigating regional trends or potential issues that could arise. Collation and analysis of this data appears to only occur if there is a specific problem that is identified or an off-site impact occurs. This is a gap that has the potential to lead to poor environmental outcomes and it is reactive rather than proactive in nature, which often leads to poor environmental outcomes.

Currently, the guidelines appear to be delivering irrigation systems that are capable of offering very high efficiency and productivity with minimal environmental risks but on-going compliance to ensure these efficiencies and risk minimisation to the environment is met was found to be not as strongly supported. In order to address these potential gaps, it was recommended that three broad areas could be improved within the guidelines and appropriate management structures to strengthen an already strong approach in the Victorian Mallee. These areas were: 1) Ongoing monitoring and evaluation for compliance, 2) Harnessing new technology in data capture and reporting, and 3) Benchmarking practices.

3.1 Ongoing monitoring and evaluation for compliance

Ongoing monitoring and evaluation of performance is critical to ensure that the long-term goals of avoiding or minimising on-site and off-site impacts on the environment of irrigation developments are met. While the development guideline process ensures that infrastructure and conditions are put in place to monitor and manage irrigation systems and to track or measure threatening processes such as groundwater level rise, the reporting and analysis of this data is not as clearly articulated.

At present, monitoring and evaluation of irrigation and threatening process appears to fall to the irrigator and only if there is a third party issue did this data appear to be utilised or evaluated. This is a potential weakness of current processes and largely reduces the effectiveness of such monitoring and infrastructure that has been mandated in the development process. This evaluation process of monitored data also has the potential to be used at a much larger regional scale analysis to capture trends or potential issues arising from irrigation practices. When analysed or evaluated as a collective of information, it has the potential to inform both at a regional level as well as at a farm level of key threatening processes (i.e. un-seasonal heavily rainfall impacts on watertables) and guide proactive management responses. Examples of ongoing monitoring and evaluation could include, for instance, assessing soil moisture regionally to ensure that irrigation scheduling is effective and matching soil water holding capacities. This could feedback into future irrigation design and also effectiveness of irrigation management, utilising testwell/groundwater data regionally to assess/understand irrigation management impacts and climatic impacts on groundwater levels.

It was indicated that on-farm data that was collected on groundwater levels as mandated in Irrigation Development Plans seemed to rarely be used or analysed and hence, there was a disincentive to keep collecting it from an irrigator perspective. It was also indicated, however, that if this data was analysed regionally and used to feedback to growers trends occurring on a regional level, then the information would be much more valuable.

It was also found that efforts should be given to ensuring monitoring after irrigation development occurs, particularly in relation to irrigation system performance reviews or system checks. The Schache (2012) dataset highlights the fact that even high tech irrigation systems such as drip irrigation, have the potential to operate well below acceptable levels of efficiency. Ideally, an independent system check on a 5-year basis would ensure that many of these system issues are picked up and that compliance is being adhered too.

3.2 Harnessing new technology in data capture and reporting

In continually improving best management practices, a focus on reviewing technology change should be continually investigated to streamline processes and improve outcomes. Over the past few years, the cost and availability of sensing networks for agriculture has dramatically reduced. Additionally, many of these technologies are now capable of using 'Internet of Things' (IoT) approaches where sensing data is automatically stored directly on the web in real-time. These technologies offer the potential for ongoing real-time data collection and collation and streamline this process while reducing costs. These approaches should be considered in the context of providing key data back to a central point for compliance reporting functions and analyses of the data for regional trend identification and benchmarking. Such regional data would have real power, particularly when combined with other regionally collated data such as that collected by SunRISE for the Mallee Horticulture Crop Report. As an example, data on crop performance and variability could be linked with irrigation deficits and groundwater levels, irrigation applications and efficiencies in a regional and spatial sense. This would allow the effectiveness of irrigation scheduling to be assessed. It would also have benefits at the regional management level for tailoring incentives and at the farm/irrigator level for benchmarking performance or identifying best practice.

3.3 Benchmarking practices

Developing best practice through benchmarking is an important activity for sharing and transferring knowledge. It is well known that poor management of irrigation systems may result in excessive water resource utilisation and nutrient use as well as degrading of the environment. Benchmarking the performance of irrigation systems allows design and management practices to be adjusted or modified to achieve desired outcomes. In assessing the Victorian Mallee irrigation practices, there would appear to be a useful role for expanding benchmarking of irrigation system performance and management to support the objectives of the irrigation develop guidelines. For instance, yearly benchmarking the area of irrigated land converted to drip irrigation over surface irrigation may not actually be a good indicator of environmental performance if these new irrigation systems are not operating at the desired efficiencies and performance level after they have been installed. Therefore, collating and analysing data on, for instance, application efficiency, deep drainage events, or root zone salinity across farms and different irrigation systems and management approaches may give a much better indication on the environmental performance of the irrigation enterprise. Documents such as the SunRISE Mallee Horticulture Crop Report could be potentially expanded to include some of this regional scale information.

Figure 1 shows examples of this form of spatial benchmarking data from California on application efficiencies between 2001 and 2010. Data presented in this figure clearly show the impacts of best management practice change over time on a measurable parameter (application efficiency), which directly reduces the environmental risk by improving the distribution of water across the fields.

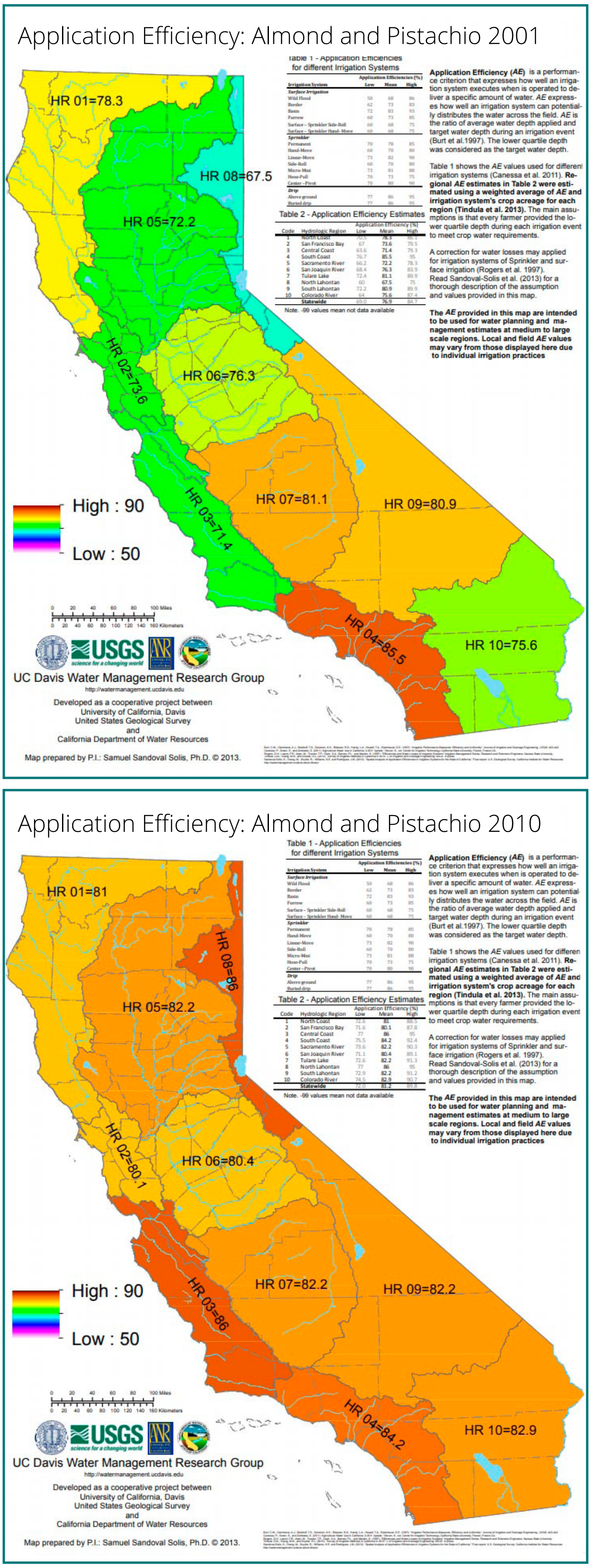


Figure 1: Application efficiency for Almond and Pistachio orchards in California 2001-2010 http://watermanagement.ucdavis.edu/research/application-efficiency/maps/

Regular irrigation system checks and benchmarking of this data would be extremely valuable in strengthening best management practice. This data is critical in understanding system issues and it is useful for individual irrigators to see how their management compares with other enterprises as well. More regular collection and reporting of this data would be extremely valuable for improving the performance of irrigation systems and ensuring these are capable of meeting high operational efficiencies and, hence, minimising impacts off site.

Satellite derived data on crop water use is also now readily available and can be a powerful tool for system checking. Linking this to the annual use limits (AUL) that relies on the international standard (Allen et al., 1998), actual water use and benchmarking such data would provide the Victorian Mallee with valuable compliance information on a platform that can be used to target incentives, educate to change practice or regulate to ensure best management practice is occurring. Approaches which have been developed (Whitfield et al., 2018) in the “Satellite based estimates of Mallee Crop Water Use and Root Zone Drainage” project funded through the Mallee Catchment Management Authority could be looked at to provide some of this information.

The three recommendations outlined above for strengthening best management practice within the Victorian Mallee are focused on filling gaps that in the reviewers’ opinion will be critical in ensuring impacts on the environment continue to be minimised from irrigation practices. Earlier years of the irrigation development guidelines have largely focused on new developments and infrastructure, which has been their strength. Moving forward with the Murray Darling Basin Plan, there will be reduced water supplies for irrigation across the basin and an increased wider community focus on social licence of irrigation. The need to ensure that irrigation systems are not only well design but are continually well managed and can be demonstrably shown to be meeting best management practice will be critical in ensuring the sustainability of irrigators into the future.

4. SUMMARY

The review of Irrigation Best Practice in the Mallee found that the Victorian Mallee Irrigation Development Guidelines have clearly led to the achievement of a world class best practice irrigation development within the Victorian Mallee. The document clearly sets out processes, responsibilities and expected outcomes for new irrigation development. Its purpose and intent is clear and the underlying drivers behind the recommended best practices are sound and robust.

However, the review evidenced that there is scope for improvement in implementation of the guidelines and, specifically, in compliance after irrigation developments have been assessed and approved. This is based in the fact that once irrigation development has taken place there is no clear monitoring and evaluation process to ensure that best practice irrigation management and compliance are occurring on a wide scale.

Moving forward, this aspect could be seen as a potential gap or weakness in the irrigation development guidelines. Based on this, we recommend improvement in three broad areas. First, we consider that ongoing monitoring of the irrigation performance after irrigation development occurs and evaluation of the effectiveness of the irrigation management would be useful to inform key threatening processes at farm and regional level. Second, we recommend the adoption of new technologies available, which enable sensing data to be automatically stored directly on the web in real-time ready for reporting and analysing for regional trend identification and benchmarking. Finally, we recommend benchmarking practices with a focus on parameters that capture on-ground outcomes of best practice such as, application efficiency, deep drainage events, or root zone salinity.

5. REFERENCES

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56 http://www.fao.org/3/X0490E/X0490E00.htm

Cummins, T. and Thompson, C. (2018) A short history of irrigation development in the Victorian Malllee, Mallee Catchment Management Authority

Irrigated Horticultural Crop Report (SunRISE) 2018 - http://www.malleecma.vic.gov.au/2018-irrigatedhorticulture-crop-report

Schache, M. (2012) Analysis of System Checks Reports. Department of Primary Industries, Victoria http://www.hin.com.au/__data/assets/pdf_file/0010/7201/Analysis-of-the-results-of-the-2009-2011-systems-checks.pdf

Victorian Mallee Irrigation Development Guidelines 2017 – http://www.malleecma.vic.gov.au/aboutus/programs/water/victorian-mallee-irrigation-development-guidelines

Victorian Mallee Irrigation Region Land and Water Management Plan (2011) http://www.malleecma.vic.gov.au/resources/corporate-documents/lwmp.pdf

Whitfield, D., McAllister, A. and Abuzar, M. (2018) Satellite based estimates of Mallee Crop Water Use and Root Zone Drainage, Final Report for Mallee CMA, Project CMI Number 106029

IRRIGATOR'S PERSPECTIVE – CHANGING PRACTICES AND TECHNOLOGY OVER TIME

Troy Richman, *Almas Almonds General Manager, Robinvale, Victoria*

Troy, as manager of Almas Almonds, provided practical insights into applying best practice irrigation and drainage management for an almond orchard in the Mallee. He highlighted key irrigation activities for the sustainable management of the orchard and surrounding environment, which includes:

- Planning nutrition and water requirements seasonally
- Providing staff with the tools and equipment to manage and record activities
- Maintaining irrigation and fertigation assets
- Monitoring and managing the effects of water and nutrient application
- Continual monitoring and improving in the application of irrigation activities

In addition, he outlined the importance of upgrading and improving irrigation systems to suit soil types and topography for water application efficiency and manage drainage issues. Troy illustrated the value of monitoring equipment such as test wells, bores, drainage pits and soil samplers for sustainable management of the orchard and surrounding environment.

WHAT'S CHANGED IN PRACTICE AND ON THE GROUND?

This section focused on presenting recent trends in drainage and groundwater in the Victorian Mallee and how changing irrigation development and practices, as well as environmental factors, have influenced these trends over time.

Original presentations can be found in the **Appendix**

INTRODUCTION

Dr John Cooke, *Deputy Chairperson - Mallee CMA Board (Victoria)*

Dr Cooke provided a brief background on the ‘how’ and ‘why’ the Mallee CMA has supported research into ‘Satellite-based soil water balance modelling to improve estimates of crop water use and root zone drainage’. Until now the errors in estimation of both the water applied to crops and the evapotranspiration of that applied water may be an order of magnitude greater than the volume of root zone drainage. It follows that it has not been previously possible to provide an accurate estimation of the amount of root zone drainage at a farm or regional scale.

The *Victorian Mallee Irrigation Development Guidelines* (Hornbuckle and Ballester-Lurbe, this proceedings) provided the basis for a logical and scientific framework to reassess the relationship between water applied and rootzone drainage.

These *Guidelines*, mandated the use of pipes for the delivery of irrigation water between the river and the farm and within the farm. This has largely eliminated losses of water from the delivery infrastructure. A soil capability assessment was mandated prior to each new development. All water extracted was accurately measured and accountable.

The consistence and high level of compliance with the *Guidelines*, across the 41,000 ha of new irrigation since 1997 (Argus, this proceedings) has provided the opportunity to develop a scientific basis for monitoring and modelling of crop water requirements and soil water balances. Data was able to be drawn from 40 sites (crops) over five consecutive years. There is a unique relationship between the measurement of extracted water and the site being assessed at each site.

The research by Whitfield, McAllister and Abuzar (this proceedings) will provide spatio-temporal analyses of irrigation water requirement and root zone drainage that has not been previously available. Catchment managers, modelers (Hoxley, this proceedings) and advisors will now have access to information systems, modern innovative data and analytical processes used in this project.

PAPER

SATELLITE-BASED SOIL WATER BALANCE MODELLING TO IMPROVE ESTIMATES OF MALLEE CROP WATER USE AND ROOT ZONE DRAINAGE

Des Whitfield, Andy McAllister and M. Abuzar, *Agriculture Victoria Research, Department of Jobs, Precincts and Regions, Tatura, Victoria*

ABSTRACT

This project was undertaken to provide a scientific basis for the Mallee CMA's ongoing monitoring and modelling of crop water requirements and soil water balances, which underpins their capacity to:

- Improve region-scale estimates of deep drainage beneath irrigated areas of the Victorian Mallee, and
- Provide evidence to support crop water requirement against annual use limits/maximum application rates.

To achieve this, a three-year work program was delivered which focussed on:

- Refining and testing a satellite-based soil water balance methodology to improve estimates of crop water requirement, their relationship to irrigation supply and the modelling of root zone drainage (RZD) in the almond industry,
- Extending the developed methodology for almonds over a longer time series to gain an improved understanding of the seasonal climatic and crop status variability and its impacts on RZD,
- Evaluating model sensitivity to key variables, and
- Extending the methodology to table grapes and citrus to test its effectiveness to provide region wide and crop comprehensive assessments.

Satellite-based model estimates of Mallee RZD and irrigation water requirements accounted for varying seasonal conditions and showed a strong dependence on vegetation status (Normalised Difference Vegetation Index) of individual crops.

Results showed that the satellite-based RZD approach was highly suited to district and regional hydrological assessments in major Mallee perennial crops and almonds in particular.

The project has made major advances in improving the understanding of factors that link Mallee RZD and irrigation inputs, and towards estimates of RZD and their dependence on climate, crop type, and vegetation status.

The methods developed and applied in this project support an affordable objective means of monitoring and evaluating Mallee irrigation water balances applicable to new and existing crops and crop management options on both green- and brown-field sites using FAO56 principles. These have been adapted for Mallee applications by using the robust "tall-crop" ETo option that improves the ability of the FAO56 approach to cater for the crops and advective weather conditions experienced in the Mallee.

1. INTRODUCTION

This project was undertaken to provide a scientific basis for the Mallee CMA's ongoing monitoring and modelling of crop water requirements and soil water balances, which underpins their capacity to:

- Improve region-scale estimates of deep drainage beneath irrigated areas of the Victorian Mallee, and
- Provide evidence to support crop water requirement against annual use limits/maximum application rates.

Depth of irrigation RZD in the Victorian Mallee is a critical input to the salinity modelling that underpins compliance with Schedule B of the Murray-Darling Basin Agreement. RZD estimates drive the models used to estimate the salinity impact of new irrigation developments and those which verify the benefits of improved irrigation practices associated with Reduced Irrigation Salinity Impact (RISI) salt credit claims. Numerous studies have attempted to quantify RZD in the Mallee at point, farm and regional scales. However, these values are subject to extreme variability depending on season, crop, and irrigation inputs, and the method used in field estimates of RZD. The variability in estimates continues to exacerbate uncertainty in the values of RZD used as input to groundwater models.

Newman et al (2009) reviewed studies of root zone drainage conducted by the Murray-Darling Basin Authority, and emphasised the critical importance of accurate RZD estimates for Schedule B compliance. Newman et al also acknowledged the role that remote sensing of evapotranspiration might play in enabling more accurate definition of water balances, crop water use and RZD.

Point-scale estimates of RZD have been shown to depend on the many site-specific variables that impact on the point/field-scale soil water balance, including the contribution of rainfall and irrigation to RZD. Site-specific factors, such as crop type and vegetation cover, weather (evaporative demand + rainfall) and irrigation, are collectively highly variable in time and space, and play a major role in the determination of point-field scale soil water balance outcomes (e.g., Allen et al 1998; Jensen and Allen 2016), including field-scale RZD. Soil type and soil management may also impact on the partitioning of excess water between RZD and surface runoff.

Impacts of Mallee irrigation development on river salinity are calculated according to zone-dependent 'Hoxley' coefficients which describe EC impact at Morgan per GL of applied water (Mallee CMA 2011). However, the strategic targeting of salinity management options is inherently compromised by the cost and impracticality of undertaking, collating and reconciling the many point-source measurements that are needed to support an extensive comprehensive real-time monitoring system of district and region-scale RZD (Newman et al 2009).

Biophysical models that systematically incorporate key inputs of irrigation water supply, and major site-specific crop and weather variables impacting on the soil water balance, potentially provide a pragmatic alternative to the routine monitoring of Mallee irrigation RZD at field-district scales.

Mallee CMA estimates of regional RZD currently rely on the Annual Use Limit (AUL - Mallee CMA, 2013) proportionality relationship as follows:

RZD = 10% AUL, (1)

This project extended the development of methods based on the use of satellite data to gauge irrigation supply/demand relationships in Mallee crops, and implications for regional RZD. Project activities consequently aimed to develop, test, demonstrate and refine the existing Agriculture Victoria Research satellite-based approach to address the major limitations of the RZD proportionality relationship when applied at field, district and regional scales in the Victorian Mallee.

2. METHODOLOGY

Agriculture Victoria Research (AVR) used new satellite data and methods to study water use by tree and vine crops grown in the Riverland, Sunraysia and Goulburn-Murray irrigation districts (DPI 2010). Results showed that evapotranspiration (ET) was strongly dependent on both weather (ETr – tall crop reference crop evapotranspiration) and crop vegetation status (measured as Normalised Difference Vegetation Index; NDVI). Relationships between ET/ETr and NDVI were subsequently developed to describe Irrigation Water Requirement (IWR) of orchards in Goulburn-Murray Irrigation District, and Mallee almond, citrus and table grape crops (Whitfield et al 2011, 2014; Whitfield and Abuzar 2014). Estimates of IWR in almond and table grape crops grown in the Robinvale district were compared against Victorian Water Register measures of irrigation supply to gauge the extent to which irrigation matched IWR (Whitfield and Abuzar 2014).

This project extended the development of methods based on the use of satellite data to gauge irrigation supply/demand relationships in Mallee crops, and implications for regional RZD. Project activities consequently aimed to develop, test, demonstrate and refine the existing AVR satellite-based approach to address the major limitations of the RZD proportionality relationship when applied at field, district and regional scales in the Victorian Mallee. The satellite-based modelling approach centred on a dynamic daily evaluation of the root zone soil water balance, where the "tall-crop" ET reference (ETr; ASCE-EWRI 2016) was used to overcome limitations on the application of "short-crop" ET reference (FAO56) on tall crops grown in warm, advective climates (Allen and Pereira 2009).

The model was underpinned by four major data innovations as follows:

1. SILO (Scientific Information for Land Owners) open-access weather data support both retrospective and near-real-time analyses of crop water requirement and RZD. SILO data are constructed from observational records sourced from the Bureau of Meteorology: SILO infills gaps and missing values in the raw data with interpolated values to produce daily data that are both spatially and temporally complete.

2. WUL (Water Use Licences) - scale actual water supply data (source: Victorian Water Register) to estimate WUL-scale irrigation water use

3. Contemporary field-scale land use maps (SunRISE Mapping and Research, Mildura) provided field-scale location + crop information

4. Satellite data, in conjunction with land-use maps, above, are used to identify a) active area of crops and b) vegetation and water use status of crops associated with water use licences.

Daily estimates of field-scale root-zone soil water balance were aggregated by the model to provide WUL-scale estimates of regional RZD, which are readily aggregated to district and regional scales. Resultant spatially-explicit estimates of irrigation RZD are consequently readily incorporated into GIS applications that may be used to explore relationships between RZD and local-scale management and/or contextual options (e.g., district, crop age, soil type).

The satellite-based model thereby explicitly aimed to account for the major field-scale variables that determine rates of water use (ET) by irrigated crops (viz. crop type, height, area and vegetation cover), actual (WUL-scale) water use, and actual weather conditions experienced by Mallee crops. Satellite data allow water-balance estimates to be undertaken at near-field scale in near-real time for monitoring purposes, and, consequently, for model estimates to account for actual crops, actual crop area, and actual stages of crop development. The ability to account in near-real time for regional field-scale differences in crop type(s) and stage(s) of crop development facilitates model appraisals of unusual seasonal conditions and/or rapid changes in regional crop inventory (crop types, area and distribution).

3. RESULTS

This project effectively combined modern computing power with innovative data sources to "deconstruct" the RZD proportionality relationship, by model and data processes that exposed effects of season and field-scale crop variability on crop water use and RZD to scientific scrutiny. The model/data approach accounted for spatial variation in irrigation water supply, and field-scale spatial variation within crop types, including stage of development, and crop water use capability (Kc), and their relationship to near-real-time daily changes in evaporative demand and rainfall. Satellite and on-ground data sources were used to quantify field-scale spatial variation in crop water use characteristics.

Spatial and seasonal implications of the RZD proportionality relationship were thereby opened to scrutiny. The project systematically combined the widely-adopted, FAO56/ASCE-EWRI water use/soil water balance model with unique data sources in a computer model where key water balance inputs of WUL-scale irrigation water supply, and major site-specific crop and climatic variables (ETref, rainfall), were combined with extensive field-scale crop data, appropriate to the routine monitoring of crop water requirement and Mallee irrigation RZD at field-district scales.

3.1 Crop demand and water supply hydrographs

The results of these analysis are demonstrated in the crop demand and water supply hydrographs presented in Figure 1. Figure 1a shows the basic supply-demand hydrographs for farm/WUL 24 in the first year of the project. It shows that very early in the season, water supply to the orchard (the black line) exceeds crop water demands (the red line). From then on, the cumulative water demand exceeds the cumulative water supply. Importantly, however, it is the differences between the rates of change in the slopes of the two curves that reveals the volumes of rootzone drainage; the cumulative differences reveal the net irrigation deficit, but they do not reveal the rootzone drainage.

The volumes of rootzone drainage are explored in Figure 1b. It shows major trends in the differences between the rates of change in supply and demand throughout the course of the season. It shows that supply consistently exceeded demand prior to day-of-season 100. Between day-of-season 100 and day-of-season 250, there is a regular negative trend in the differentials (the smoothed blue line) and a relatively steady match between supply and demand after that.

Importantly, however, Figure 1b also shows results of mathematical analyses used to identify events within those trends where the differentials show supply exceeding demand; the intermittent dashed red lines show that positive values of the supply-demand differential were frequent prior to day-of-season 70, a few positives were seen during the protracted period after day-of-season 70, and demand was seen to exceed supply more frequently after day-of-season 250.

Figure 1c shows the resultant frequency distribution and magnitude of the events in which irrigation supply exceeded demand and irrigation therefore contributed to RZD: suggesting that irrigation contributions to RZD were characterised by a relatively large number of small events (less than 1.5 mm).

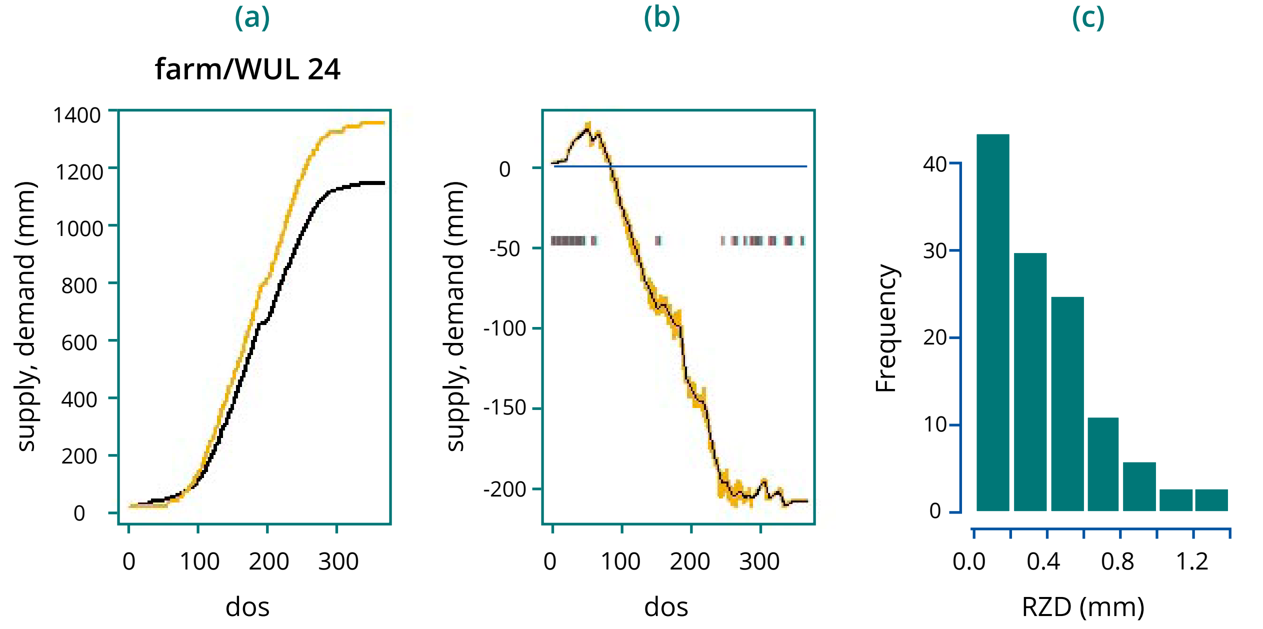


Figure 1: **Over-irrigation contributions to RZD on farm/WUL 24:**

(a) basic supply (black) and demand hydrographs (yellow) – with supply information sourced from the Victorian Water Register and demand sourced from satellite-based soil water balance methods,
(b) difference (yellow) and smoothed difference (black) calculated from the supply/demand hydrographs in (a), and
(c) magnitude and frequency of RZD events derived from (b)

The findings of this analysis showed that, early and late in the season almond irrigators in the Victorian Mallee were frequently applying very small volumes in excess of their crops' irrigation requirements. And those instances of over-irrigation were equated to irrigation-induced RZD as illustrated in Figure 2.

3.2 RZD estimates for almonds across a range of seasons

These analyses have been undertaken for almond water use licences across the Mallee for irrigation seasons 2010/11 – 2015/16 (Note: period of available water supply data from the Victorian Water Register).

Estimates of RZD were based on the assumption that in-field irrigation losses associated with drip irrigation systems contributed overwhelmingly to RZD, and that WUL-scale system losses, associated with pipe leaks and/or surface evaporation losses and leaks from storage dams were small in relation to the magnitude of in-field losses.

Under those conditions, over-supply estimates in the satellite-based soil water balance were attributed to RZD. As shown in Figure 2 (a to d), irrigation application efficiencies varied between 60 per cent (in the very wet 2010/11 season) and something approaching 95 per cent

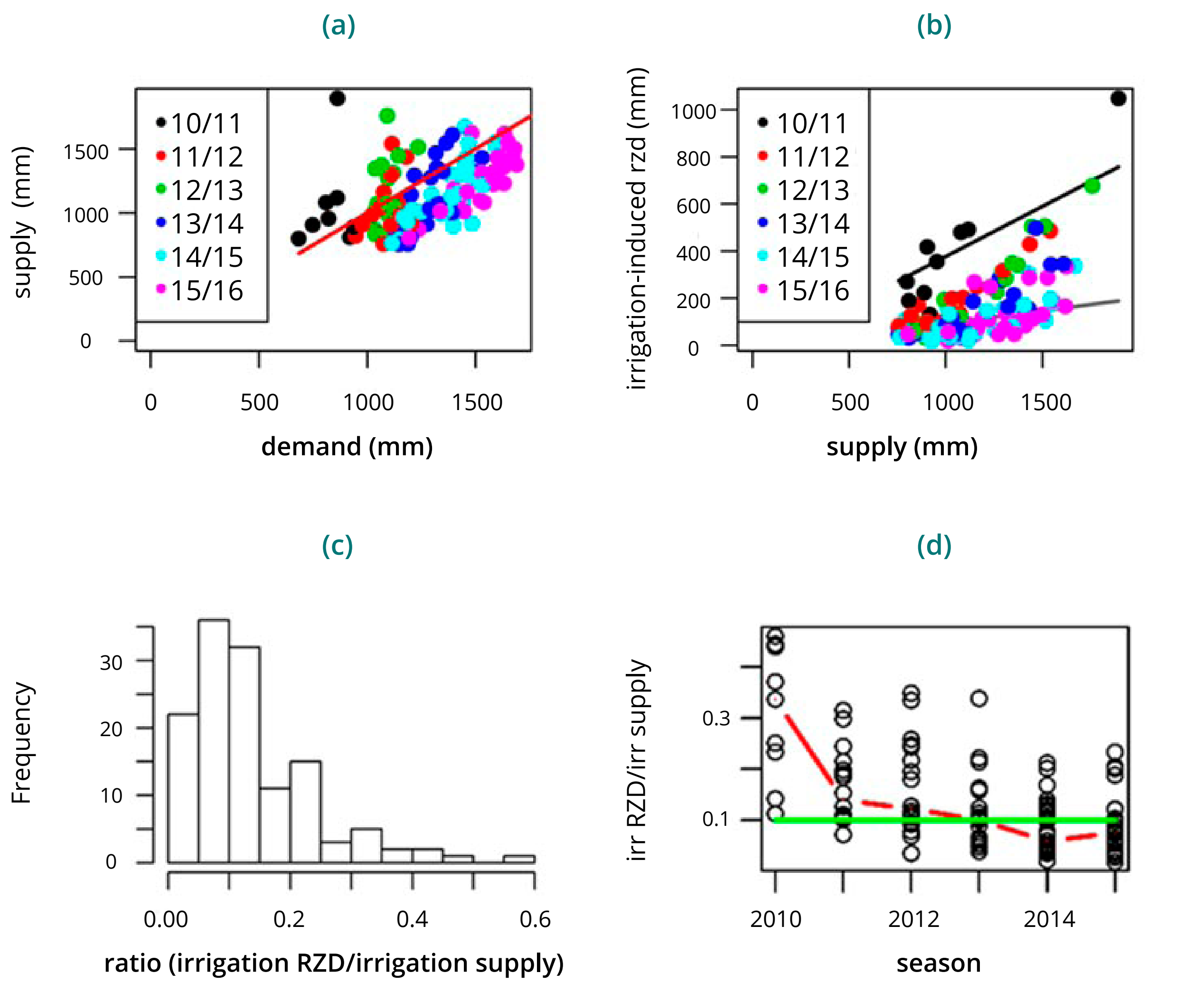


Figure 2:
(a) Relationship between irrigation supply to almond farms/WULs relative to satellite-based estimates of irrigation demand (assuming an application efficiency of 100 per cent);
(b) Relationship between satellite-based estimates of irrigation-induced RZD relative to the irrigation supply to farms (upper and lower lines represent the ratio of irrigation-induced RZD to irrigation supply of 0.4 and 0.1 – which correspond to application efficiencies of 60 per cent and 90 per cent respectively);
(c) Frequency distribution of the ratio of irrigation-induced RZD relative to irrigation supply
(d) Seasonal changes in the ratio of irrigation RZD to irrigation supply: the red line depicts changes in the seasonal median ratio with time, and the green line represents the median value of the ratio over the entire range of data: the ratio of irrigation RZD to irrigation supply = 0.103. This represents an application efficiency of 90 per cent.

in the 2014/15 season. The median value of the ratio of irrigation RZD to irrigation supply over the entire range of data was 0.103. This represents an irrigation application efficiency of 90 per cent.

This model has also been applied across citrus and table grape mono-culture water use licenses in the Mallee.

The model results for citrus were consistent with the high values of application efficiency associated with drip irrigation systems and well-managed sprinkler irrigation. Under the seasonal and water use conditions of this study, irrigation supply rarely exceeded model estimates of irrigation demand.

The results for table grapes suggested that evaporative cooling potentially led to increased levels of irrigation over-supply, and decreased application efficiency values. However, because it is common practice to place plastic canopy covers over table grapes once the fruit starts to ripen, in order to protect the fruit from water damage, and to delay ripening, NDVI could not be used to measure irrigation demands once the covers had been installed.

4. CONCLUSION

Project findings effectively quantified the importance of the large seasonal and spatial sources of variation associated with Mallee RZD and water use estimates based on AUL values implied by the RZD proportionately relationship.

Major seasonal variations in both evaporative demand and rainfall contributed to temporal sources of variation in Irrigation Water Requirement of crops, whilst crop type and crop vegetation characteristics made major contributions to field/WUL-scale spatial variation in IWR, and, also, RZD estimates. The ability of irrigators to match irrigation water supply to IWR contributes an additional, management-controlled contribution to spatial variation in Mallee irrigation RZD.

The importance of these temporal and spatial sources of variability in Irrigation Water Requirements, and the ability of irrigators to match water supply to crop water demand are widely recognised in major publications that serve as global guidelines for high quality field-scale irrigation management for a diverse range of crops over a diverse range of seasonal conditions.

Catchment managers and advisors have not previously had access to the information systems and modern innovative data and analytical systems used in this project to support spatio-temporal analyses of Irrigation Water Requirement and RZD afforded by approaches used in this project. This combination of frequent readily-available SILO weather data, the increasing availability of high quality satellite data, and daily water use data made available by through the Victorian Water Register make the project methods applicable at operational field -regional appraisal and planning scales.

Further studies are required to investigate the potential value of field-scale vs WUL-scale water supply data, and improvements in the basic model that are needed in order to adapt its use from standard, open-air field-scale irrigation operations free of potential crop-specific nuances that compromise the interpretation of data in crops like table grape (multiple irrigation sources with multiple source-dependent irrigation AE values).

The data/modelling approach used in this project confers the ability for near-real time spatially-targeted analyses of irrigation development and water use. This provides catchment managers with the evidence-based tools required to quantify and respond to both positive and negative spatio-temporal trends in regional catchment management scenarios in a timely spatially-appropriate manner that is required to meet the challenge of rapid ongoing irrigation development in the Mallee region.

The key recommendation from this project was to ensure the continued application of the methods to support regional and industry water management goals and to undertake the development and application of in-field measurement methods in major target crops that will improve the confidence in field against regional water balance estimates.

5. REFERENCES

Allen, RG, and Pereira, LS. (2009) Estimating crop coefficients from fraction of ground cover and canopy height. Irrig. Sci. 28: 17-24.

ASCE-EWRI (2016) “Evaporation, Evapotranspiration, and Irrigation Water Requirements”. Jensen, ME, and Allen, RG., eds.

DPI (2010) DPI SEBAL-METRIC: Measurement, Monitoring and Reporting Systems for improved management of Farm and Regional Water Resources in Australia. Final Report Project 100719. Department of Primary Industries, Future Farming Systems Research Division, Tatura, Victoria, Australia.

MALLEE CMA (2013) Final Report: Augmentation of the Mallee Regional Policy for Setting Annual Use Limits on Water-Use Licences

Newman, B., Currie, D., Evans, R. and Adams, T. (2009) Irrigated Agriculture in the Mallee: Estimating Root Zone Drainage. Canberra

Whitfield, DM, O’Connell, MG, McAllister, A, McClymont, L., Abuzar, M. and Sheffield, K. 2011. SEBAL-METRIC Estimates of Crop Water Requirement In Horticultural Crops Grown In SE Australia. Acta Hort. (ISHS) 922: 141-148.

Whitfield, DM, and Abuzar, M. (2014) Satellite-based Irrigation Water Management. Final Report Project CMI103729. Department of Primary Industries, Future Farming Systems Research Division, Tatura, Victoria, Australia.

Whitfield, DM, Abuzar, M, and McAllister, A. (2014) Satellite-based assessments of irrigation water use by table grapes grown in the Robinvale District of SE Australia. Proc. 7th International Table Grape Symposium, Victoria, Australia, November 2014; pp. 106–108.

PAPER

TRENDS IN GROUNDWATER ACROSS THE VICTORIAN MALLEE

Andrew Telfer and Alison Charles, *Water Technology*

ABSTRACT

The Mallee Catchment Management Authority (CMA) monitors a network of over 500 bores across the region, as well as drain flow data within both the pumped irrigation districts and private diverter reaches. This data has been analysed to compare groundwater and drainage trends across the region. Monitoring data indicates that groundwater heads in the pumped districts are generally declining. Conversely, in the private diverter reaches, groundwater heads are more responsive to changes in river level and show increasing or constant (variable) trends. Even though significant advances have been made in reducing groundwater gradients towards the River from the irrigation districts, there remain significant in-river salinity and ecological risks as groundwater levels are still above River level at a number of locations, driving groundwater and salt towards the floodplain and River Murray. Additionally, the rapid return of groundwater mounds in some areas during recent 'wet' periods (i.e. 2011/2012) illustrates the responsiveness of the groundwater systems and the need to continue to lower groundwater mounds to cope with future variable climate and river flows.

1. INTRODUCTION

In 2018, the total irrigable area in the Mallee Catchment was 81,150 hectares, more than double the irrigable area in 1997 (SunRISE 2018). The expansion of irrigation has primarily occurred in private diverter river reaches (39,940 hectares of expansion) and retirement of irrigation has primarily occurred in the pumped districts (1,890 hectares) (SunRISE 2018). Irrigation development and consequent drainage has been proactively managed within the Mallee Catchment through Salinity Management Plans (SMPs). Three separate SMPs were developed by communities and endorsed by Government during the early 1990s as part of the salinity management framework for the Victorian Mallee. These SMPs were the Sunraysia SMP, Nangiloc Colignan SMP and Nyah to the SA Border SMP.

Mallee CMA monitors a network of over 500 bores within the Sunraysia irrigation districts and across the region. Mallee CMA also monitor drain outflows within both the pumped irrigation districts and private diverter river reaches. This data has been analysed to review groundwater trends at both a district and regional scale. The following paper compares the groundwater responses and drain flow trends within the Red Cliffs river reach (pumped district) and the Nangiloc Colignan reach (private diversion) of the Mallee Catchment. This paper presents an updated subset of monitoring data originally analysed as part of a targeted review of groundwater and drain flow trends for Mallee CMA undertaken in 2015 (AWE 2015).

2. RED CLIFFS PUMPED IRRIGATION DISTRICT

Irrigation within the Red Cliffs Pumped District primarily occurs on the highland where the Woorinen formation overlies the Blanchetown Clay and Parilla Sands aquifer. The floodplain adjacent most of the district is relatively wide except near the Red Cliffs Pump Station where the cliff directly abuts the River. The Blanchetown Clay is absent on the floodplain adjacent the Red Cliffs Pumped District. The absence of the Blanchetown Clay allows connection between the Monoman Formation and the Parilla Sands Aquifer in the floodplain increasing the potential for saline groundwater discharge to the River.

Drain flow data for Drain 1 and trends in irrigated area and method (data from SunRISE 2018) are shown in Figure 1. Drain Number 1 (Figure 1) is the only monitored catchment at Red Cliffs with a data record that extends back before the Sunraysia SMP was implemented. Monitoring data for this site indicates that drain flows have declined significantly since the start of the monitoring record by an average of 87% when comparing annual volumes measured in the 1980s to those measured since 2010.

Drain flows were lowest at the end of the drought between 2007 and 2009. The highest annual drain flow recorded at the site since 2001, occurred in 2011. This is likely to reflect the high rainfall event that occurred in February 2011, as the drainage catchment for station 414703 collects stormwater runoff from Red Cliffs and the irrigation volume for the district and irrigated area in the catchment was lower than in previous years. Over this time there has also been a decline in the irrigable area within the pumped district and a significant increase in the adoption of more efficient irrigation methods.

Drip irrigation has been the dominant irrigation method since 2009 compared to furrow irrigation which was the dominant irrigation method in 1997 and now represents only 1% of irrigation in the district (SunRISE 2018).

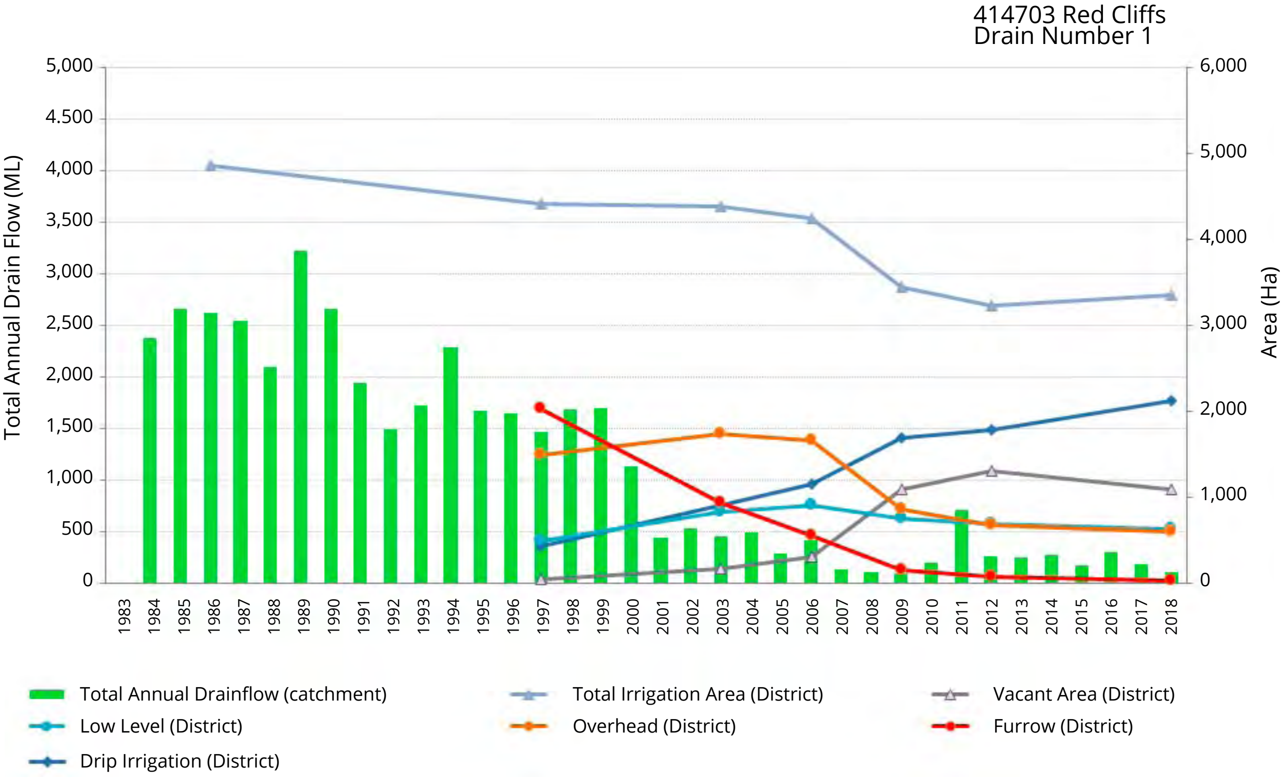


Figure 1: Drain Flows and Changes in Irrigation Area and Methods

Temporal changes in groundwater levels are illustrated in the representative bore hydrographs presented for the district in Figure 2. The River Murray adjacent Red Cliffs is within the influence of the Lock 11 upstream pool which is held at approximately 34.5mAHD. Hydrograph data show that groundwater levels are consistently higher than the adjacent river level indicating groundwater flow towards the River. This is supported by NanoTEM surveys from 2004 and 2006 which indicate saline groundwater discharge to the River Murray adjacent the Red Cliffs irrigation District (gaining stream conditions) from Mallee Cliffs to Psyche Bend (Telfer et al 2007). Hydrograph data indicates elevated but relatively steady groundwater levels during the 1980s. During the early 1990s groundwater levels begin to decline and this trend continues over the available record. Observation bores located between the monitored drainage catchments and River show a small response to the period of high rainfall and high River flow in 2010-2012. In general groundwater levels have continued to decline following 2012, however the rate of decline has slowed.

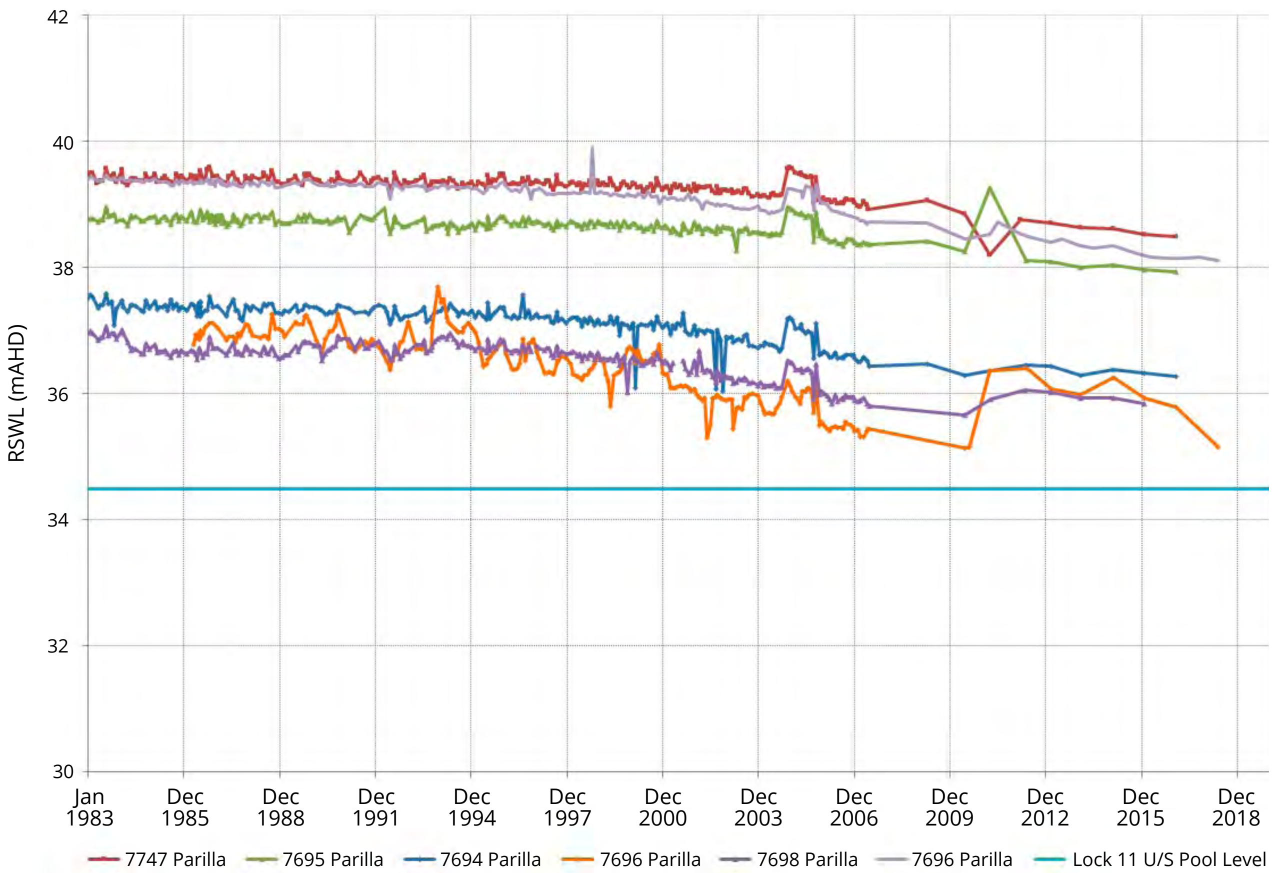


Figure 2: Groundwater trends within the Red Cliffs Pumped District

3. NANGILOC COLIGNAN IRRIGATION AREA

The Nangiloc Colignan Irrigation region is located between Karadoc and Colignan. Irrigation commenced in the region in the early 1920s with a rapid increase in irrigation development during the 1960s triggered by the arrival of electricity (SunRISE 2010). During this time drainage disposal was ad hoc, leading to productivity losses and environmental degradation as a result of rising water tables and salinisation of the landscape (SunRISE 2010). Tile drainage was then installed to dispose of drainage water to the River. On-farm sub surface tile drains are the primary form of drainage collection in the Colignan region (SunRISE 21 2010).

Irrigation in the Nangiloc-Colignan region occurs on a wide section of floodplain over the Woorinen Sands. The Blanchetown Clay is present on the floodplain within the Nangiloc-

Colignan region. The Blanchetown Clay acts as an aquitard separating the shallow floodplain aquifer (Monoman Formation) from the regional aquifer (Parilla Sand). The hydrogeological setting of the Nangiloc Colignan region significantly differs to that of the highland pumped districts covered by the Sunraysia SMP and this influences drain flow and groundwater trends.

Drainage data from the Kulkyne Outfall is presented in Figure 3 with changes in irrigation methods and area (data from SunRISE 2018). Monitoring data from this catchment indicates declining drainage volumes from the late 1990s to the end of the drought, followed by an increase in drain flow post 2010 to 2015, before declining again. In the more recent monitoring record, the highest drain flows were recorded in 2011, followed by 2015. Monitoring data also indicates that drain flow (in ML/ha) recorded at the Kulkyne and Hewetts Road outfalls during the late 1990s were much higher in the Nangiloc Colignan region in comparison to the pumped districts during the same time period. This may in part be attributed to the drainage systems being installed during the mid-late 1990s in this region as part of the coordinated community drainage scheme facilitated by Nangiloc Colignan SMP. These high drain flows may reflect the drainage of residual water held within the perched system when the drains were first installed.

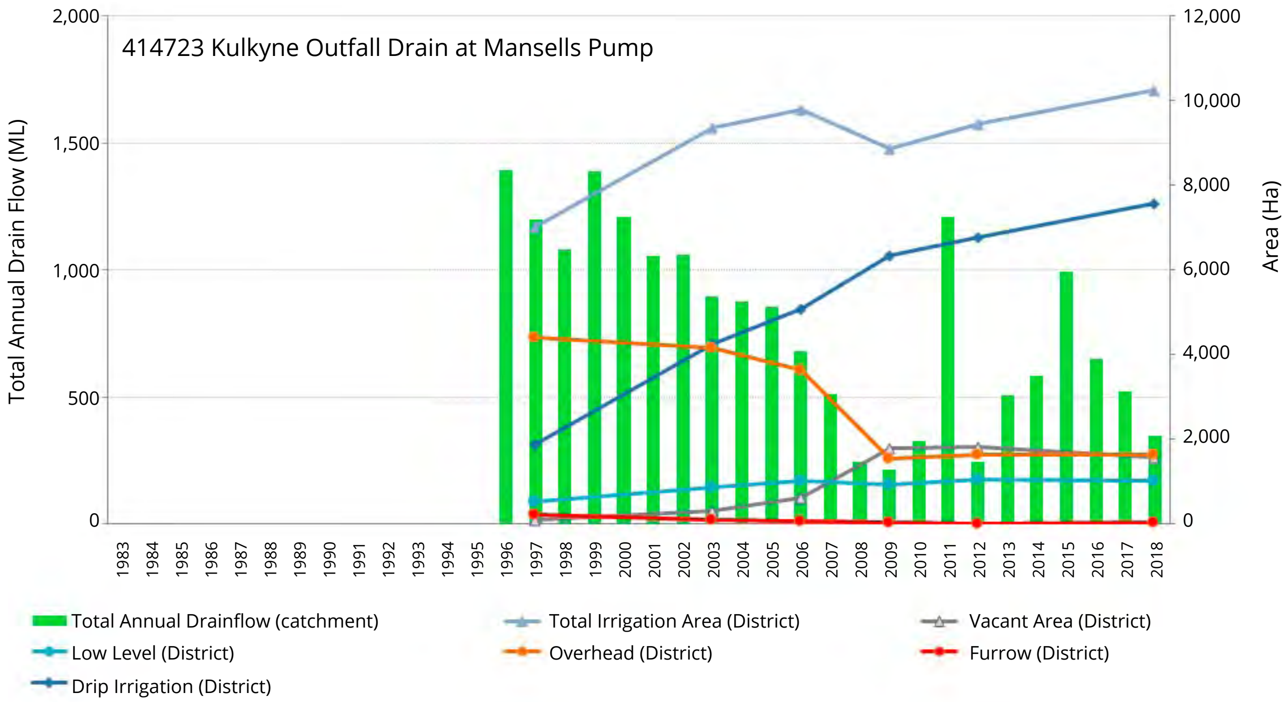


Figure 3: Drain Flows and Changes in Irrigation Area and Methods

Temporal changes in groundwater levels are illustrated in the representative bore hydrographs presented for the Nangiloc Colignan reach in Figure 4. Unlike the pumped irrigation districts of Merbein, Mildura, Red Cliffs and Robinvale where irrigation primarily occurs on the highland, within the Nangiloc Colignan region irrigation occurs on the floodplain.

Groundwater contours and hydrograph data show groundwater gradients towards the river under low flow conditions. However, groundwater levels in Nangiloc Colignan reach are responsive to changes in River level and are influenced by flood events. During floods, the River adds water into the groundwater system, causing the perched and regional groundwater heads to rise. These increased heads will cause increases in drain flows. Additionally, there is only a comparatively small head gradient between the perched groundwater system and the Channel Sands aquifer. This limits the rate of deep drainage loss to the regional system and increases the rate of drainage compared to other locations. The combined effect of floods and low vertical hydraulic gradients explains a significant amount of the difference in groundwater and drainage trends observed in the Nangiloc Colignan region compared to the highland pumped districts.

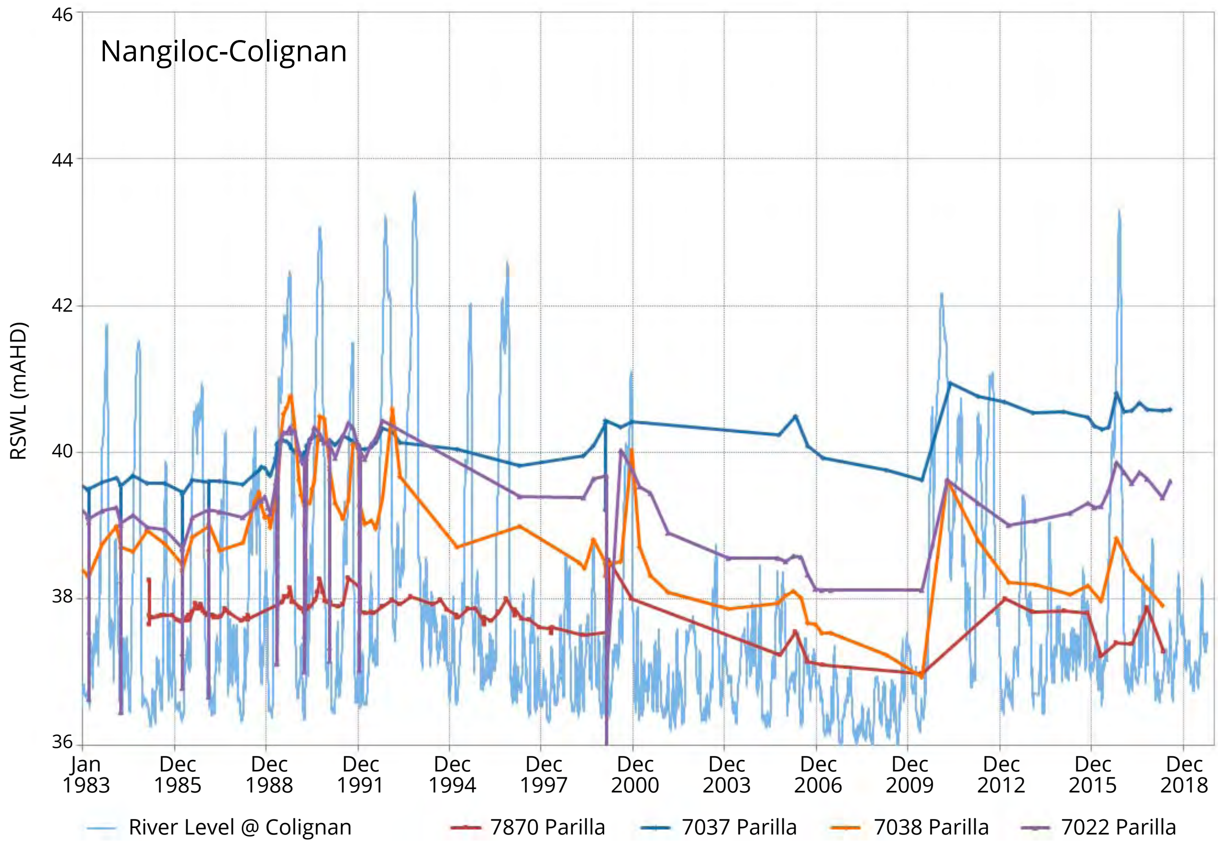


Figure 4: Groundwater trends within the Nangiloc Colignan Reach

4. CONCLUSIONS

Salinity Management Plans have been effective tools for managing salinity risks in the Mallee region, contributing to the reduction in groundwater heads and drain flows in most irrigation areas and guiding the expansion of irrigation to low salinity impact zones. However, even though significant advances have been made, in-river salinity risks remain as the groundwater levels are above River level at a number of locations, driving groundwater and salt towards the floodplain and River Murray. Additionally, the declining trends in groundwater heads and drain flow have been enhanced by the extended period of below average rainfall and low river flows experienced by the region between 2001 and 2009.

Increases in drain flow and groundwater levels observed during the wet sequence (2011/2012) highlight the need for ongoing management to limit the salinity impacts of irrigation, particularly in areas where irrigation occurs on the floodplain as these locations are more responsive to rainfall and groundwater recharge from high River flows and floods.

5. REFERENCES

Australian Water Environments (2015) Targeted Investigation of Groundwater and Irrigation Drainage Water Monitoring in the Mallee Irrigation Region, prepared for Mallee Catchment Management Authority, AWE Ref: 15042

SunRISE Mapping and Research (2018) Mallee Horticultural Crop Report, prepared for Mallee Catchment Management Authority.

SunRISE Mapping and Research (2010) Mallee Irrigation Drainage, Volume 2, Nangiloc Colignan Region, prepared for Mallee Catchment Management Authority.

Telfer, AL, Hatch, MA, Woods, JA and Shintodewi, PA (2007) Atlas of Instream NanoTEM 2006 - Wentworth to Torrumbarry - Lindsay - Mullaroo, Australian Water Environments Report 45755b, prepared for the Murray Darling Basin Commission, Mallee Catchment Management Authority, Goulburn Murray Water and the North Central Catchment Management Authority.

Darling Basin Commission, Mallee Catchment Management Authority, Goulburn Murray Water and the North Central Catchment Management Authority

PAPER

IRRIGATION DRAINAGE MONITORING IN THE MALLEE REGION – CURRENT DRAINAGE FLOW RATES ACROSS IRRIGATED DISTRICTS

Dr Joanna Stephens[1] (Senior Environmental Scientist) and Charles Thompson[2] (Senior Fellow)
[1] *GHD Pty Ltd (on secondment to Mallee Catchment Management Authority)*
[2] *RMCG, Bendigo, Victoria*

1. INTRODUCTION

1.1 Background

Irrigation drainage water is monitored across drainage catchments within Mildura (including districts of Red Cliffs, Merbein, Mildura), Karadoc-Colignan (including Nangiloc) and Robinvale. These irrigation drains collect excess water that drains through the root zone of crops to subsurface drains in managed drainage schemes that outfall to various locations including the Murray River, floodplain and inland basins. Gauging stations are installed on 19 drainage sites to monitor parameters including flow (ML/day) and salinity (electrical conductivity) with data uploaded to the State Water Monitoring Information System (WMIS). Mallee CMA has used data from these monitoring sites to support salinity accountable actions, assess the long-term trends in irrigation flow rates, and salinity and to assess the success of Salinity Management Plans (SMPs) and actions to reduce drain flows and salt loads. Previous assessment of drainage data from these sites have demonstrated a drastic decline in drain flows, especially since the early 1990s with the adoption of more efficient irrigation methods. Recent drought conditions (i.e., the millennium drought), has also seen drainage volumes decline as irrigators have adopted irrigation scheduling and application techniques that more accurately reflect crop water requirements and reduce root zone drainage.

An assessment of drainage volumes and salinity (Telfer et al., 2015), showed that irrigation drainage volumes had declined by greater than 70% over a 20 year period (1994 – 2014) and that some drains were completely dry most of the time. Some of the analysis completed by Telfer et al. (2015) has been repeated as part of this current assessment to assess ongoing drainage trends based on data available for monitored drainage sites from 2012 to 2019.

1.2 Scope of the assessment

This assessment considers drainage monitoring data available from ten sites within the drainage catchments monitored within the Mallee CMA region. The sites selected for assessment and the characteristics and location of the catchment for each drainage site are provided in Table 1; these sites have the most up-to-date and complete historical data sets to inform the objectives of this particular assessment.

1.3 Objectives

The objectives of this assessment were to review drainage flows (ML/day) from selected drainage sites across irrigated districts within the Victorian Mallee to assess:

1. Trends in discharges from irrigation drainage sites over time, with particular focus on the last ten years to assess if drainage volumes are still declining in the years after the millennium drought
2. Identify possible causes for observed trends in drainage volumes across irrigated districts (i.e., land use, rainfall trends, stormwater inflows to irrigation drains, etc.)
3. Consider additional work that may be required to provide a more complete picture of irrigation drainage trends across the region and accurately predict future trends in irrigation drainage.

1.4 Limitations of the assessment

This paper assesses drainage flow data from gauged monitoring sites for 2012-2019. Longer term trends have not been assessed in detail, but have been considered over the available, long-term record, where relevant to provide context for this current assessment. Available information on crop types, crop area, and irrigation methods for 2012-2019 has been referenced to provide commentary on observed trends in irrigation drainage. However, some data was only available for the entire irrigation district, with the catchments monitored only accounting for a proportion of the total irrigated area in each district. Data from monitoring sites has not been scaled to estimate drainage across the whole of each irrigation district on the basis that the difference between the characteristics expansion and re-development within compared with outside monitored drainage catchments has not been assessed.

2. METHODS FOR ASSESSMENT

2.1 Selection of drainage sites for analysis

Data was obtained from WMIS for the same sites assessed by Telfer et al. (2015) and inspected to determine if data for 2015 – 2019 was suitable for analysis. Thirteen sites were assessed by Telfer et al. (2015); ten of these thirteen sites are assessed herein (as listed in Table 1). The three sites not re-assessed were:

- Merbein North-west drain (414706) – reported as dry most of the time (no recent data) by ALS (2019)
- Red Cliffs Drain No. 10 @upstream outfall to south-east basin (414712) – used to deliver environmental water during part of the period of interest
- Red Cliffs Drain No. 8, @ Stewarts Road (414714) – very low flows or dry in recent years

All available data from WMIS was downloaded in excel format with values reported in ML/day (average flow per day). Graphs of ML/day over time for sites showed a distinct, seasonal pattern to flows, which were highest over the irrigation season (i.e., November – March) and lowest over the winter months. This observation is consistent with analysis by Telfer et al. (2015), which noted a strong correlation between drain flow and irrigation volumes. On this basis, November – March data for each site was used for further assessment for 2012-2019. The years of 2012 – 2019 was selected to assess drainage flow trends following the very wet years after the millennium drought (2010-2011).

Drainage flow data (ML/day) data graphed over time was visually assessed for large peaks in flow and compared against rainfall data from the nearest Bureau of Meteorology site. Single data points that could be attributed directly to large rainfall events were excluded from the data set. For sites in Nangiloc-Colignan, extreme peaks in flow in November 2015 – February 2016 were directly related to flooding in the Murray River (as discussed further in sections below) and excluded from the data set.

2.2 Data analysis – assessment of change in ML/day over time

Data for each site for 2012 – 2019 (November – March) was assessed using a Spearman's Rank Order (S.R.O) Test for Correlation; this statistical test assesses the correlation between two variables – ML/day and time (years). The results for the statistical analysis for each site is shown in Table 1 and graphs representing the relationship between drain flow and time are provided in section 3.

3. RESULTS AND DISCUSSION

3.1 Statistical trends in drainage volumes across all catchments assessed

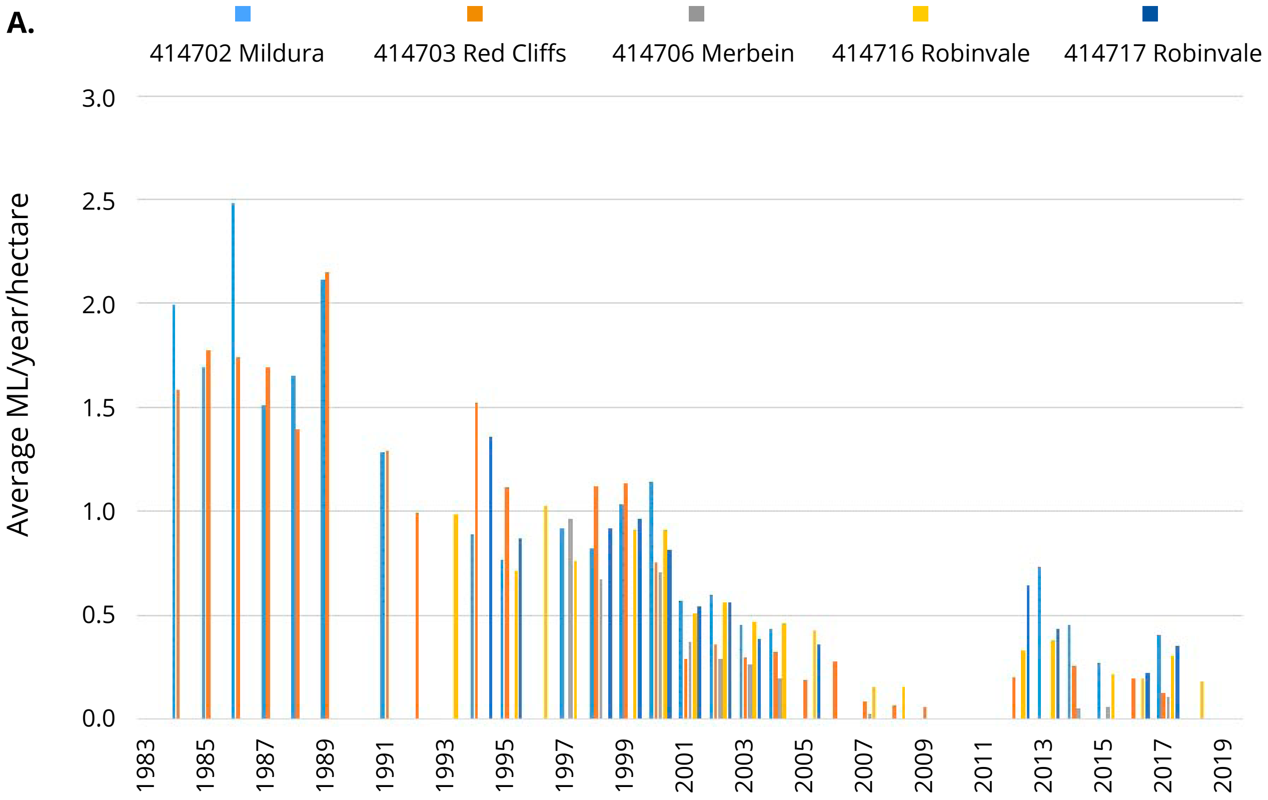
The results from S.R.O tests for each of the drainage sites assessed are summarized in Table 1. The S.R.O tests all indicate either a significant increasing or decreasing trend (as noted by the **), the rs values indicate the slope of the relationship, with positive values indicating an increasing trend, and negative values a decreasing trend over time.

Table 1: Site summary and correlation between drain flow and year (ML/day) & time (2012 –19)

Site code / Irrigation district	Area (ha)	1997[1] ML/ha/yr	2018[1] ML/ha/yr	S.R.O Correlation (2012 - 2019)
414702 FMIT North East Drain @ Bruces Bend	695	0.92	0.0023	r_s = -0.512**↓
414703 Red Cliffs Drain No. 1 @ Blounts Rd	1500	1.12[1]	0.124[2]	r_s = -0.503**↓
414705 Red Cliffs Drain No. 10 @ upstream outfall (south east basin)	1245	-[3]	0.160	r_s = -0.298**↓
414716 Robinvale No. 4 System Outfall @ Pethard Rd	990	0.76	0.181	r_s = -0.165**↓
414717 Robinvale No. 6 System Outfall @ Malaya Rd	1370	0.91[1]	0.352[2]	r_s = -0.327**↓
414721 Nangiloc-Colignan Drain @ Hewetts Rd	220	2.95	0.673	r_s = 0.356**↑
414722 Nangiloc-Colignan at Doerings Basin	285	0.90	0.684	r_s = 0.360**↑
414723 Kulkyne Outfall Drain at Mansells Pump	550	0.58	0.635	r_s = 0.176**↑
414724 Nangiloc Colignan Drain at Nangiloc	1045	0.19	0.261	r_s = -0.098**↓
414728 Browns Group Drainage Area	1025	-[3]	0.207	r_s = -0.215**↓

[1] 1998 data used; [2] 2017 data used; [3] not available (no site record for 1997-1998, data collection commenced c.2006)

A.



B.

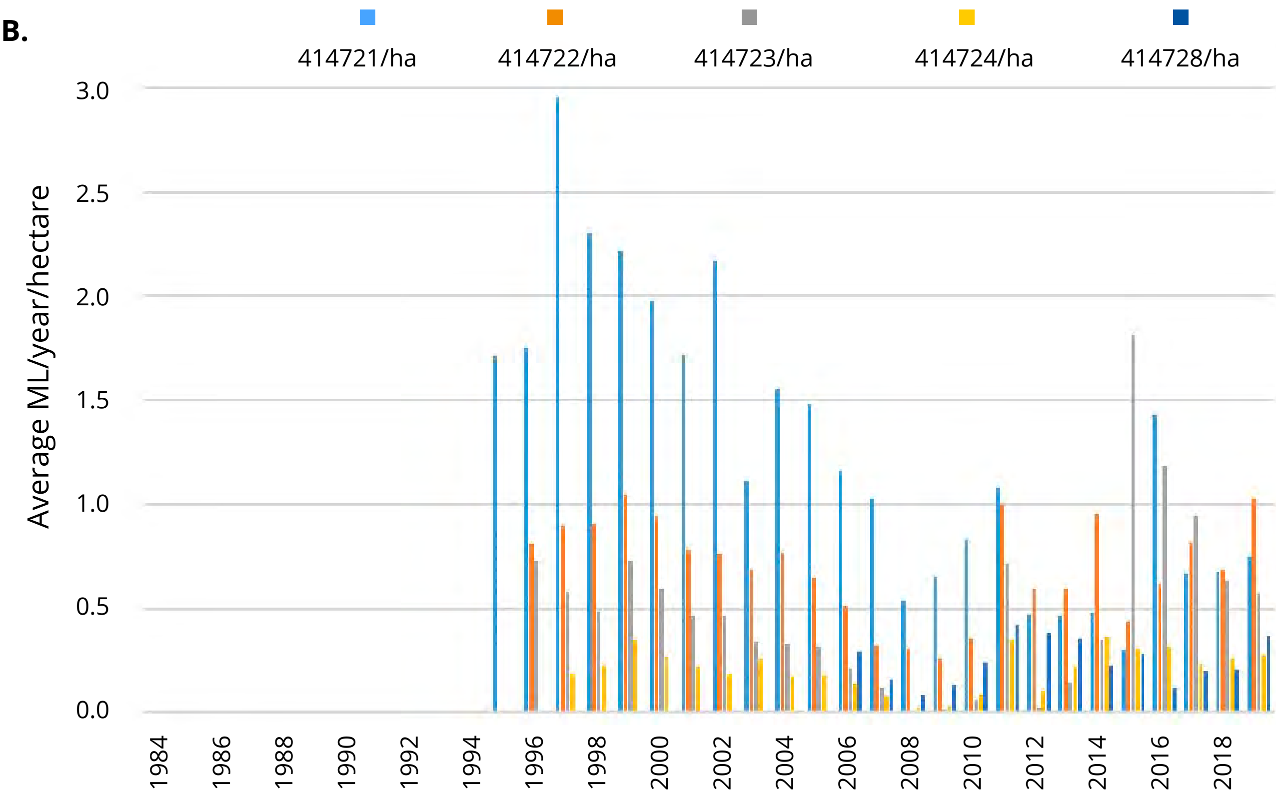


Figure 1: Drain flow (average ML/year/hectare of drainage catchment)
A. between 1984 and 2019 in Mildura irrigation district and Robinvale. Most drains dry during the peak of millennium drought (2008 – 2009), peak during 2010 – 2011 due to rainfall.
B. 1996 – 2019 in Nangiloc-Colignan drainage catchments

A previous assessment of trends in irrigation drainage over time, examined monitoring data for drainage sites for a period of greater than 20 years (between 1994 – 2014, or, as far back as monitoring data for sites allowed) (Telfer et al., 2015). This review concluded that there had been dramatic decreases in drain flow since the implementation of the Salinity Management Plans (SMPs) implemented in the early 1990s. A visual representation of the dramatic decrease in drainage volumes over time is shown for a selection of five drainage sites in Figure 1. The purpose of this current assessment is not to repeat the work of Telfer et al. (2015) or other similar investigations by examining the long-term trends in drainage flows. However, Figure 1 illustrates that drain flows since 2000 have been very low (typically below 1.5 ML/day on average) and as such there is not the scope for the continuation of the dramatic decreases in drainage flow seen in previous decades. Caution should be used when interpreting the results from the statistical analysis in Table 1 as some trends are only slight and given the low volumes of drainage water, these results may be influenced by factors other than drainage from irrigation. A further discussion on the results for each drainage catchment are provided in sections below.

3.2 Mildura Irrigation District - FMIT North East Drain @ Bruces Bend (414702)

Statistical analysis indicates drainage flows are still decreasing (Figure 2). Based on available reports and data for the Mildura irrigation district, the following is of particular note:

- In 2018, the irrigable area (available as potential/actual irrigation land) of 5,830 ha comprised of 68% of permanent plantings, 7% of irrigated seasonal crops, and 25% of unirrigated land.
- Crop reports for the Mallee region were prepared in 2009, 2012, 2015 and 2018. Furrow irrigation decreased from approximately 505 ha (8.5% of the 2018 irrigated area) in 2009 to 195 ha in 2018 (3% of the total irrigated area). A continued change in irrigation practices from furrow and overhead sprays towards drip and low level sprays may be contributing to the ongoing decrease in drain flows in this catchment.
- Significant areas of the Mildura irrigation district have been converted to residential land; from 2009 to 2015 approximately 5.3% of irrigation land was retired for residential development (Sunrise 21, 2016a). Across the enitre Mildura irrigated district (including areas outside the monitored drainage network), the decrease in irrigated area from 2009 to 2018 was approximately 4.2% (Sunrise 21, 2018).
- Stormwater outflows to irrigation drainage networks will likely increase with expansion of urban development within the Mildura irrigation district. A recent report (Jacobs, 2017) postulates that increases in stormwater contributions will not significantly change data from drainage monitoring because intentional cross-connections without a MOU occur more in the parts of the catchment that are not gauged (Jacobs, 2017).

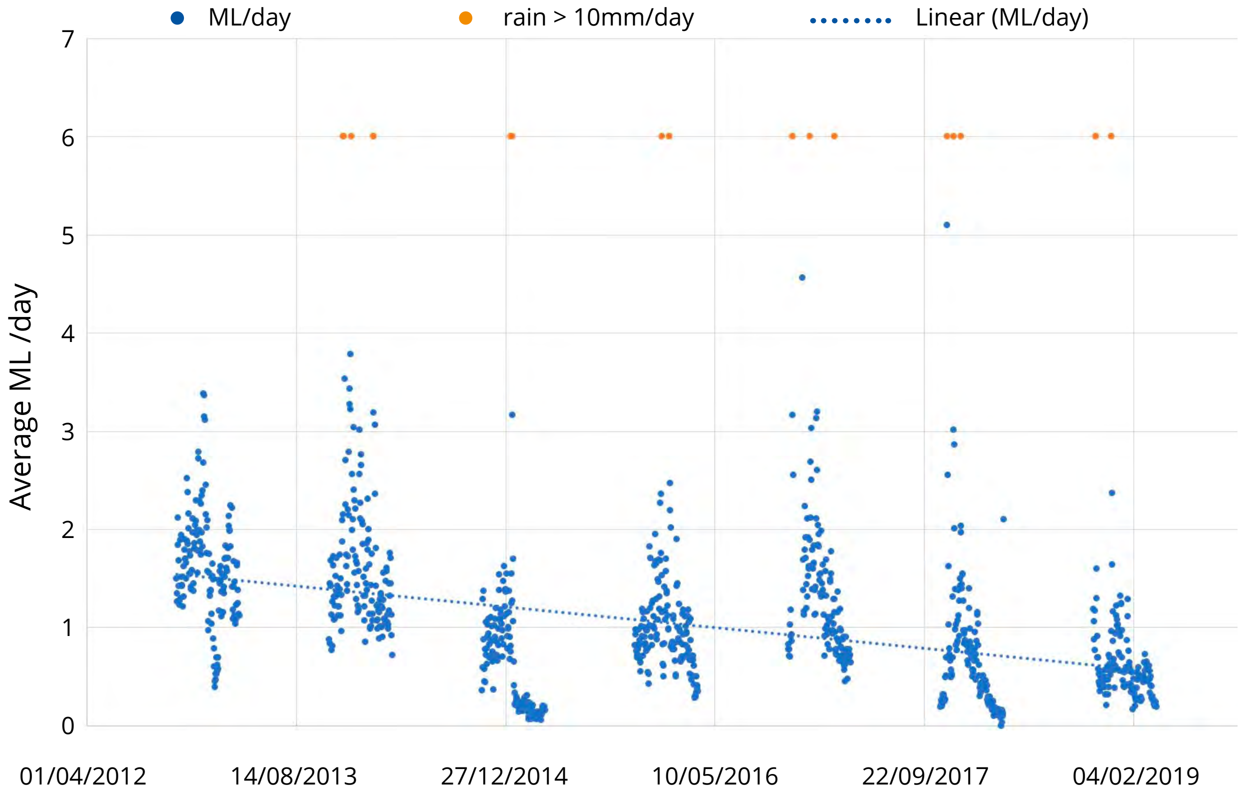


Figure 2: Drain flow (ML/day) 414702 – Mildura irrigation district, 2012 – 2019. S.R.O Correlation indicated a significant negative correlation between ML/day and time, with over 50% of the variance in the data for ML/day, explained by time. Values > 3 ML/day within three days following rainfall > 10 mm removed from data set.

3.3 Red Cliffs (Drain No. 10 to south-east basin, 414705 & Drain No.1 Drain at Blounts Rd, 414703)

Data from two of the four drainage sites had data suitable for assessment for 2012-2019. Drain No. 10 (414705) covers the area south of the township of Red Cliffs. Drain No. 1 the southern part of the Red Cliffs irrigation district (414703). Statistical analysis indicates that drainage flows decreased at both locations (2012-2019; Figure 3). Based on available data and reports, the following observations are made about irrigation drainage in the Red Cliffs district:

- In 2018, at least 410 ha (14%) of permanent crops were planted or redeveloped within the previous three years, with redevelopment dominated by table grapes (230 ha) (Sunrise 21, 2018). Vacant irrigation land decreased slightly between 2012 (1,265 ha) and 2018 (1,085 ha) (Sunrise 21, 2018). Additional years of data is required to assess the impact of returning vacant, dried off land to production on drain flows.
- 135 ha was retired from irrigation (for development for commercial/residential) within the Red Cliffs drainage catchment between 1997 – 2018, a decrease of approximately 3%, most of which appears to have occurred since 2009 (approximately 2%).
- Drains in Red Cliffs receive stormwater as well as irrigation drainage (Telfer, et al. 2015). Two MOU exist for cross-connection of urban stormwater to the irrigation drainage network located in the catchment of gauge 414712 (data not assessed here, see section 2.1) (Jacobs 2017).
- Drip irrigation (2,115 ha) and low level sprays (620 ha) were the dominant irrigation method from 2009 to 2018. Drip irrigation increased by 23% from 2009 to 2018. Overhead sprays and furrow irrigation were less than 14% of the total irrigated area in 2018 (620 ha).

- Available data suggest that irrigation drainage volumes are continuing to decline, despite irrigated area remaining relatively static between 2009 and 2018. The observed decline in drain flows is likely due to continued conversion to more efficient methods of irrigation over this period. The impact of intentional, ungauged cross-connections with stormwater in the two drainage catchments assessed here are not known.

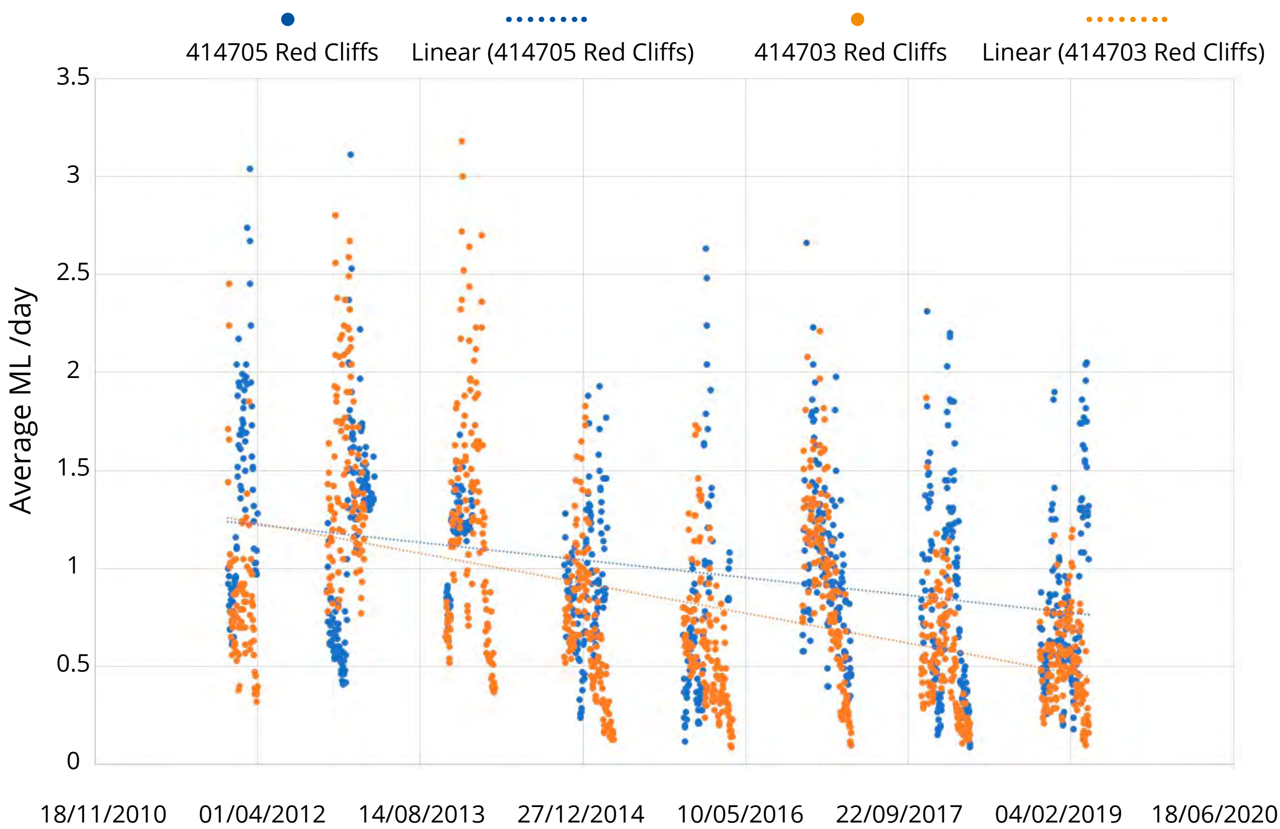


Figure 3: Drain flow (ML/day) 414705 – Red Cliffs Drain No. 10 and 414703 Drain No.1, 2012 – 2019. S.R.O Correlation indicated a negative correlation between ML/day and time, with 16% and 33% of the variance in the data for ML/day, explained by time (414716 and 414717 respectively). Values > 3 ML/day within three days following rainfall > 10 mm removed from data set.

3.4 Robinvale district drains

Statistical analysis indicates a continued downward trend in irrigation drainage volumes (2012-2019, Figure 4), however, the continued downward trend is slight, especially for 414716 (Table 1, rs = 0.165). Based on available data and reports, the following observations are made about irrigation drainage in the Robinvale irrigation district:

- 414716 drains the north-west irrigation district of Robinvale covering approximately 25% of the total irrigable area. 414717 drains the west irrigation district and covers approximately 35% of the total irrigation area (Sunrise 21, 2016b).
- Vacant irrigation land peaked in Robinvale in 2009 at 305 ha (12.6% of the total irrigated area) and remained stable through 2012 (300 ha) (Sunrise 21, 2018). In 2018, 75 ha remained unirrigated, potentially indicative of the 13% of crops redeveloped (predominantly table grapes) or planted in three years to 2018 (Sunrise 21, 2018). Total irrigable area remained relatively stable over this period (no significant retirement).
- From 2009 to 2018, furrow irrigation declined from 4.3% of the total irrigable area to 0% in 2018 and overhead sprays declined from approximately 6.4% of the total irrigable area to less than 1%. These declines were offset by increases in drip irrigation (from 7.8% in 2009 to 35.3% in 2018).

- Table grapes are the dominant crop type in the Robinvale irrigation district (86% in 2018). Seasonal adjustments have been made to Available Use Limits (AULs) since 2013-2014 (> 25% additional water in some years) to allow for use of overhead sprays to provide cooling in the grapevine canopy during very hot and dry periods (Telfer et al., 2015; LMW pers comm). Further assessment is required to determine if additional water use for table grapes has contributed to higher and/or more variable drain flows.

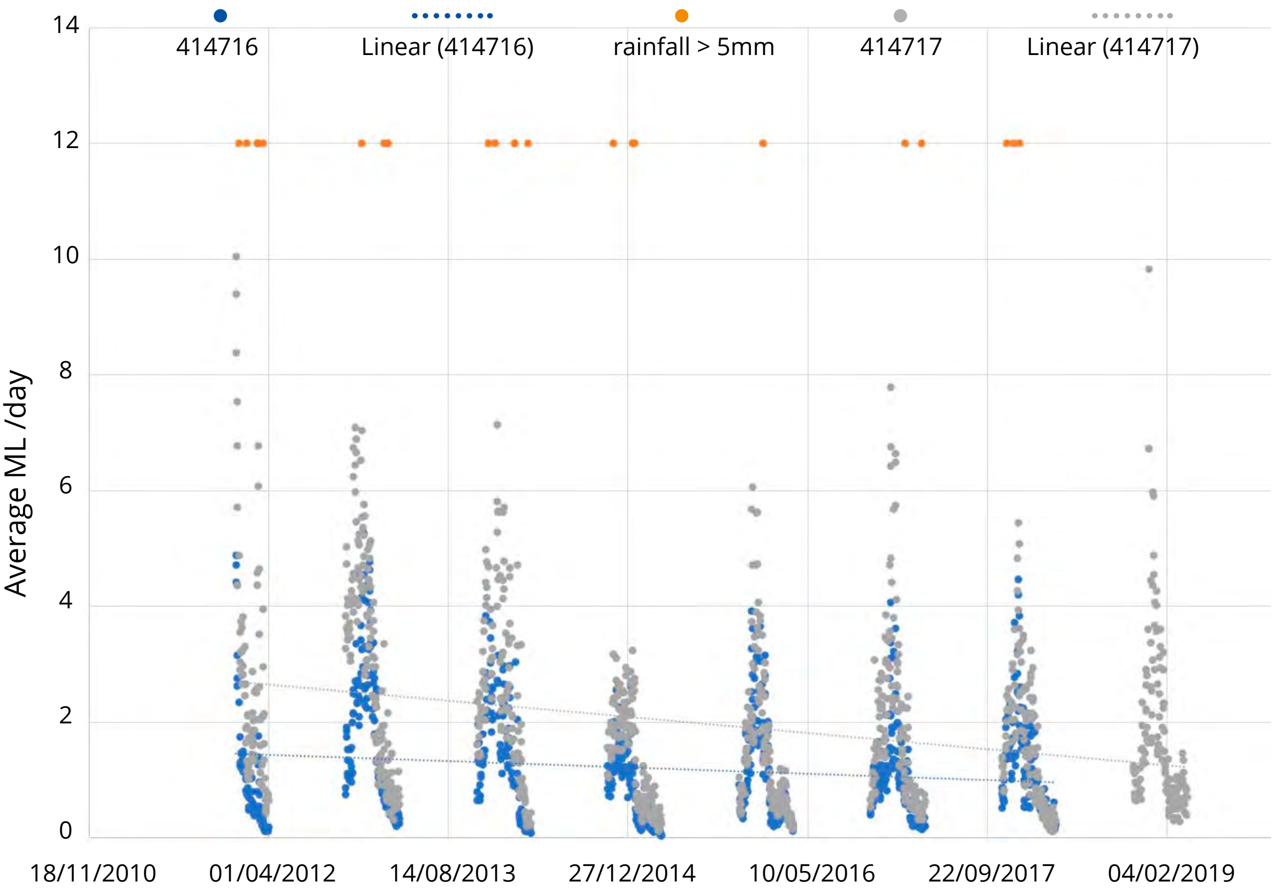


Figure 4: Drain flow (ML/day) 414716 – Robinvale No. 4 system outfall and 414717 No. 6 system outfall, 2012 – 2019. S.R.O Correlation indicated a significant negative correlation between ML/day and time, with 30% and 50% of the variance in the data for ML/day, explained by time (414705 and 414703 respectively). Values > 3 ML/day within three days following rainfall > 10 mm removed from data set.

3.5 Nangiloc-Colignan Drains

Statistical analysis (Table 1) indicates that flow rates for irrigation drains in Nangiloc-Colignan district have shown an increasing trend (414721, 414722) remained almost stable (414723, very slight decreasing trend reported) or shown a decreasing trend (414724, 414728). Average daily drain flow (ML/day) is illustrated in Figure 5; the following observations are made about irrigation drainage in the Nangiloc-Colignan district:

- The six drainage sites covered approximately 39% of the total irrigated area in 2015 (Sunrise 21, 2016c), most new irrigation development from 1997 to 2018 has been outside of these monitored catchments (Sunrise 21, 2018).
- Dominant plantings in 2018 were citrus (26% of total irrigated area at 3,125 ha), wine grapes (23% at 2,765 ha) and dried grapes (9%, at 1,035 ha). From 2009 to 2018 wine grapes declined by 1,270 ha and were replaced by other crops (predominantly citrus, 390 ha and almonds 580 ha) (Sunrise 21, 2018).

- The vacant (unirrigated) area peaked in 2015 at 1,805 ha and is decreasing (1,575 ha in 2018). 15% of permanent plantings were replanted or redeveloped from 2015 to 2018.
- The proportion of crops irrigated by dripper increased slightly from 2009 to 2018 (from 60% to 64%), all other types of irrigation remained relatively stable (based on percentage and area).
- Irrigation in Nangiloc-Colignan occurs within the Murray Trench, where in the other districts discussed above irrigation is on the highlands. Irrigation within the Trench in this district significantly impacts drain flow and groundwater trends (Telfer et al 2015). In particular, groundwater levels on the Channel Sands aquifer respond to changes in river levels and are therefore influenced by flood events - rises in river levels cause perched and groundwater heads to rise, resulting in higher drain flows. This effect was observed in drainage data corresponding to river flooding events in 2015-2016, especially for 414723 and 414728. Data was corrected to remove data points associated with river flooding, however, the data for each site was still highly variable across the period monitored (Figure 5).
- Telfer et al. (2015) noted that average drain flows declined for Doerings Basin Outfall (414722) by 25% between 2010 – 2014 to 0.62 ML/ha/year, but then increased in 2013-2014 to levels similar the mid-2000's. Based on data available to 2018, drain flows for Doerings Basin Outfall (414722) appear to be increasing, supported by statistical analysis. Drain flows for Browns Group Drainage Area (414728) appears to be increasing since 2016 (Figure 5), however, statistical analysis indicates a slight decreasing trend, likely due to the high variability in drain flow for this site over the period assessed (2012-2019).
- A more detailed assessment on changes of crop type and irrigation types within the monitored catchment is required to determine factors responsible for the apparent increase in drain flows for some sites. Ongoing data collected during drought (current) and future wet periods will provide further data to assess if climatic conditions are a significant driving factor for drain flows compared with the impact of redevelopment or existing irrigation areas.

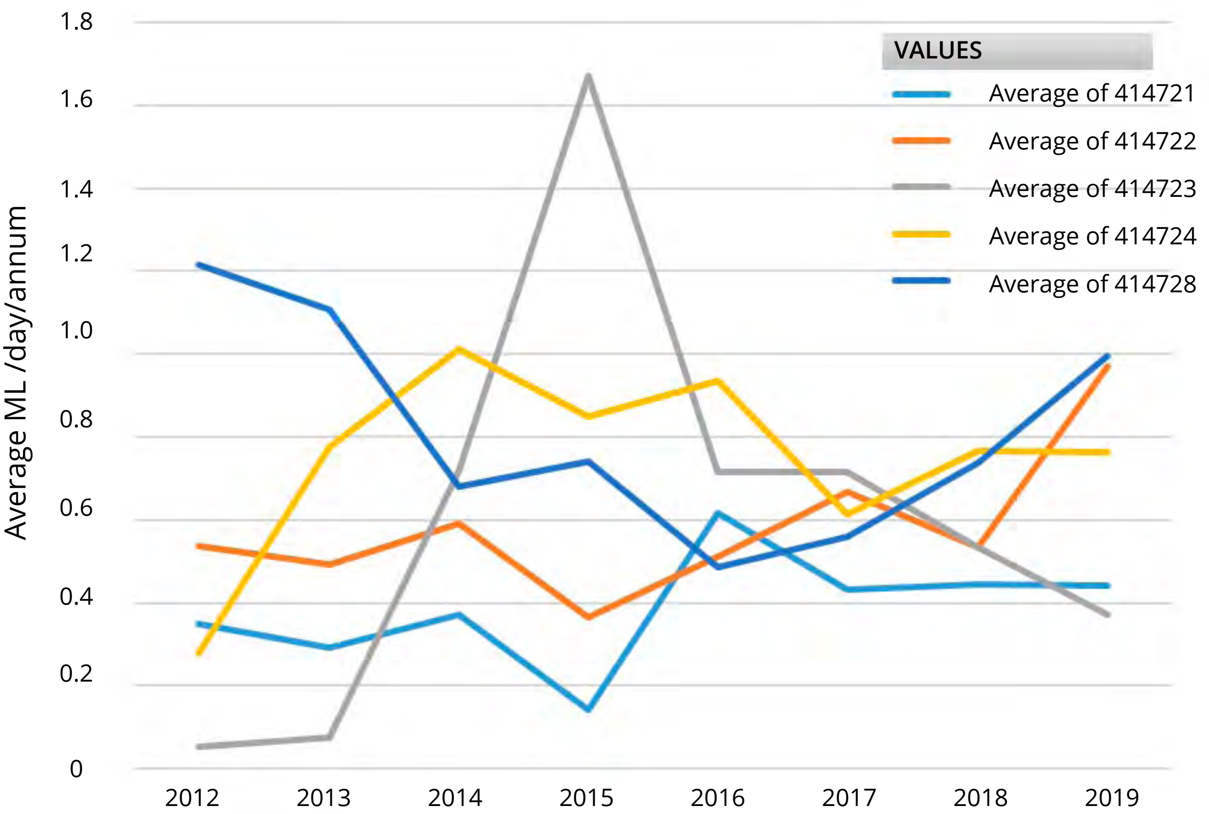


Figure 5: Average annual drain flow (ML/day) for irrigation drains in Nangiloc Colignan, 2012-2019

4. CONCLUSIONS AND FUTURE WORK

Overall, available data for monitored drainage sites indicates that irrigation drainage rates are generally declining. However, this ongoing decline is slight in most instances and the very low drain flows seen in all catchments mean that data trends may be significantly influenced by factors not related to irrigation practices (such as, but not limited to, urban expansion, rainfall, hydrogeology, river levels and flooding).

Monitoring of existing drainage sites should continue, along with collection of data on crop types and irrigation practices within the specific these catchment areas. It is also considered that the need for additional monitoring sites should be assessed, especially where urban development and irrigation expansion and redevelopment is occurring predominantly outside of monitored areas. It is noted that where urban expansion is contributing significant stormwater volumes to drainage outfalls, the chemistry of the drainage water is likely change over time on the basis that stormwater directly discharging to drains will likely be lower in salinity than irrigation drainage water that percolates through soil and potentially interacts with perched groundwater. Further assessment should be completed on trends in drainage water salinity, as recommended in previous reports (Jacobs, 2017). Significant areas of irrigation expansion have occurred in private diverter areas, where irrigators are responsible for the installation, monitoring and maintenance of their own irrigation drainage water. At present, there is insufficient data to assess the effectiveness of on-farm drainage systems in managing drainage and this warrants further assessment.

5. REFERENCES

ALS (2019) Mallee Catchment Management Authority Monitoring Site Condition Assessment

Jacobs (2017) Urban and peri-urban salinity impacts on irrigation drainage, June 2017

Sunrise 21 (2016a) 2015 Irrigation Drainage Reports, Executive Summary, September 2016

Sunrise 21 (2016b) 2015 Irrigation Drainage Report, Robinvale, September 2016

Sunrise 21 (2016c) 2015 Irrigation Drainage Report, Karadoc - Colignan, September 2016

Sunrise 21 (2018) 2018 Mallee Horticulture Crop Report, Report for the Mallee Catchment Authority, November 2018

Telfer et al. (2015) Mallee Irrigation Region Monitoring Review: Targeting Investigation of Groundwater and Irrigation Drainage Water Monitoring in the Mallee Irrigation Region, May 2015

PAPER

FORMATION OF PERCHED AQUIFERS BENEATH IRRIGATED ALMONDS – IMPLICATIONS FOR ROOT ZONE DRAINAGE

Peter Cook[1], Dougal Currie[2], Nicholas White[1], Sangita Dandekhya[1] and Eddie Banks[1]

[1] *National Centre for Groundwater Research and Training, College of Science and Engineering, Flinders University, Adelaide*

[2] *CDM Smith, Adelaide*

ABSTRACT

Increased rates of groundwater recharge beneath irrigated almonds has the potential to increase flows of saline groundwater to the Murray River and its floodplain. However, the presence of clay layers within the soil profile can impede the downward movement of root zone drainage, leading to creation of perched water tables and waterlogging in low lying areas. This project investigated this process on an almond orchard between Robinvale and Boundary Bend. While perched water tables occur at this site, preliminary data suggests that the volume of water intercepted by the clay layers is relatively small. Work is ongoing to quantify the rate of root zone drainage and groundwater recharge, to determine implications for on-farm and regional water and salt management.

1. INTRODUCTION

There are more than more than 66,000 ha of irrigation south of the Murray River between Nyah and the South Australian border, and groundwater mounding from increased rates of groundwater recharge beneath irrigation developments has the potential to increase flows of saline groundwater to the river and floodplain. Traditionally, much of the irrigation was for citrus and wine and table grapes, however the area has seen a rapid expansion in irrigated almonds since 1997. Most of the almond development has occurred in the Nyah to Wemen irrigation region which has seen an expansion of irrigated almonds from 900 ha in 1997 to 21,450 ha in 2018.

Irrigation of almonds typically occurs between August and April and involves application of 1200 – 1500 mm of water each year. It is estimated that root zone drainage (RZD) represents about 10 % of the water applied to the crops; however, it is possible that recharge rates are lower than the RZD. This may be the case if clay layers within the profile interrupt vertical infiltration, leading to the development of perched aquifers. Sub-surface clay units (e.g. the Blanchetown Clay) are widespread in the Mallee and may cause perched water tables to form, with potentially important implications for productivity of irrigation developments and for rates of recharge to underlying aquifers and salt loads to the Murray River. This project therefore aims to quantify the volume of water that is intercepted by clay layers, and its significance for the regional groundwater balance.

The project was set up in 2019 and is planned to extend over several growing seasons. This paper presents a summary of the initial project findings.

2. FIELD SITE DESCRIPTION

The field site is located on an Almas Almonds orchard, between Robinvale and Boundary Bend. The site was planted in 2007, and drainage systems have been installed in response to waterlogging that reduced yields and caused the death of almond trees in some areas. The drainage system uses tile drains to intercept water that collects on shallow clay layers. The water that is intercepted drains under gravity to drainage pits, which are pumped out to low lying areas on the property that have not been planted to almonds. The site has been well instrumented with eight shallow test wells (1 – 2 m deep) and seven piezometers (to 20 m deep), and there are several State observation bores in the vicinity. A map of the site is provided as Figure 1.

3. METHODS

Field trips to the site have taken place in late April – early May, mid-July and early September 2019. The irrigation season typically extends from August till April, and so the current sampling period only includes the end of the 2018-2019 irrigation season and beginning of the 2019-2020 season. Further work is planned over the 2019-20 growing season and beyond.

In-Situ LevelTroll® pressure transducers and data loggers were installed in eight test wells and all seven piezometers, as well as in all active drainage pits. Pressure transducers and loggers were also installed in four state observation bores adjacent to the site (6962, 6966, 26002 & 26688) and manual water levels were recorded from a fifth state observation bore (26265). Water levels were logged at 15-minute intervals. All drainage pits, state observation bores, test wells and piezometers were surveyed using a Trimble RTX unit.

Figure 1: Locations of test wells, piezometers and drainage pits

Groundwater samples were collected after first purging three well volumes from piezometers and observation bores. pH and electrical conductivity (EC) were measured in the field. Samples were subsequently analysed for stable isotopes (2H and 18O) and ion chemistry.

Drainage pits are concrete lined pits approximately 1 m in diameter. Most are equipped with solar pumps that are activated during daylight when the water level reaches a 'trigger level' usually between 1 and 2 m below the land surface (between 2 and 3 m below the top of the concrete casing). Pumping ceases when the water level drops below the pump intake and at night. Water levels in most of these drainage pits show daily fluctuations of between 1 and 3 m (Figure 2), although pits that receive large volumes of drainage are pumped more than once daily.

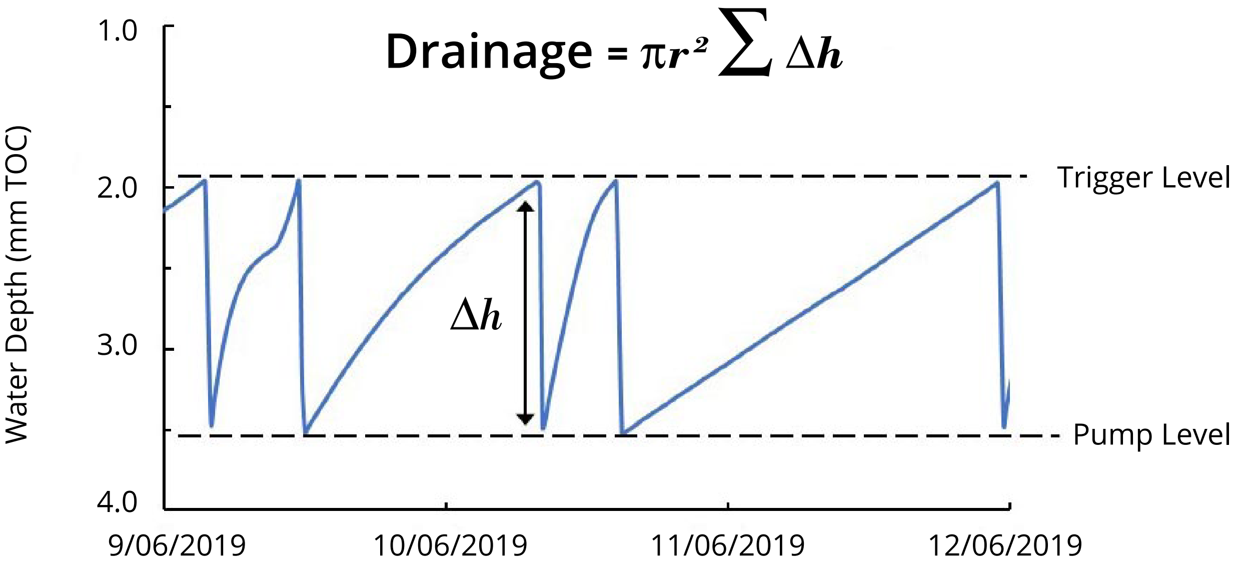


Figure 2: **Illustration of the method for estimating perched aquifer drainage from drainage pit water levels. (Data is from drainage pit DP2)**

Pumps installed in drainage pits discharge water to low lying areas on the property. Weir boxes have been installed on two outflow pipes that collect water from most of the drainage pit pumps (Figure 3). In-Situ LevelTroll® pressure transducers were installed within the boxes logging at 10-minute intervals and an In-Situ BaroTroll® was installed nearby. In September additional pressure transducers were installed to log EC at 10-minute intervals. At the same time one of the original loggers in each weir box was replaced with a more accurate Global Water WL400 pressure-compensated pressure transducer attached to a Campbell Scientific CR800 data logger. Manual measures were taken of flow rates from the two outflow pipes for calibration purposes. Manual flow rate measurements are continuing to be taken by an Almas Almonds employee at regular intervals to increase accuracy of the calibration. However, calibration of the weir boxes is not yet complete, and so discharged volumes are not reported in this paper.

Electrical resistivity tomography (ERT) surveys were carried out along a single north-south transect on each fieldtrip. The surveys used both Dipole – Dipole and Wenner – Schlumberger arrays. Two separate spacings were used: a 5m electrode spacing along a 475-m transect and a 2.5 m electrode spacing along a shorter 237.5m transect. The 2.5m electrode spacing measurements covered the mid-section of the 5m spacing transect. In this paper, only data from the Wenner – Schlumberger array with the 5 m electrode spacing is presented.

Figure 3: Weir boxes installed to collect outflow from drainage pits

Electromagnetic conductivity surveys were carried out using a CMD Explorer[2] to examine the representativeness of the resistivity transect, and to investigate lateral continuity of the subsurface clay layers. Four closely spaced north-south transects were completed in July, with a further nine transects, designed to cover the area of the almond crop, completed in September. In this study, the instrument was used in 'high depth' mode and was operated while walking and carried at hip height (approximately 0.8 m above the ground surface). Larger coil spacings result in greater depths of penetration, with approximate penetration depths of 2.2, 4.2 and 6.7 m. Results from the four July transects were similar, and so only one is included in this paper.

4. RESULTS

4.1 Electrical Resistivity Tomography (ERT) and Electromagnetic Induction

The resistivity pseudo-section obtained along the 500 m north-south transect in July 2019 is shown in Figure 4. High resistivity values were measured near the surface in the central part of the transect (between 200 and 300 m), which coincides with a sand ridge. Low resistivity values (approximately 1 ohm metre) are found at 5 – 15 m depth, and these indicate the presence of clay layers. In places, these clay layers contain water with high salinity, and this would contribute to the low resistivity values. This unit appears to be continuous along the survey transect. Higher resistivity values below 25 m depth reflect the Parilla Sands Aquifer.

The electromagnetic induction survey (Figure 5) recorded lowest apparent electrical conductivity on the dunes, and highest readings in the swales between the dunes. A small increase in electrical conductivity with increasing coil spacings is observed on the sandhills and is consistent with an increase in electrical conductivity with depth.

[2] The GF instruments™ CMD-Explorer is a frequency-domain electromagnetic induction device and measured the bulk electrical conductivity of the earth. The instrument can simultaneously measure with transmitter – receiver inter-coil spacings of 1.48, 2.82 and 4.49 m.

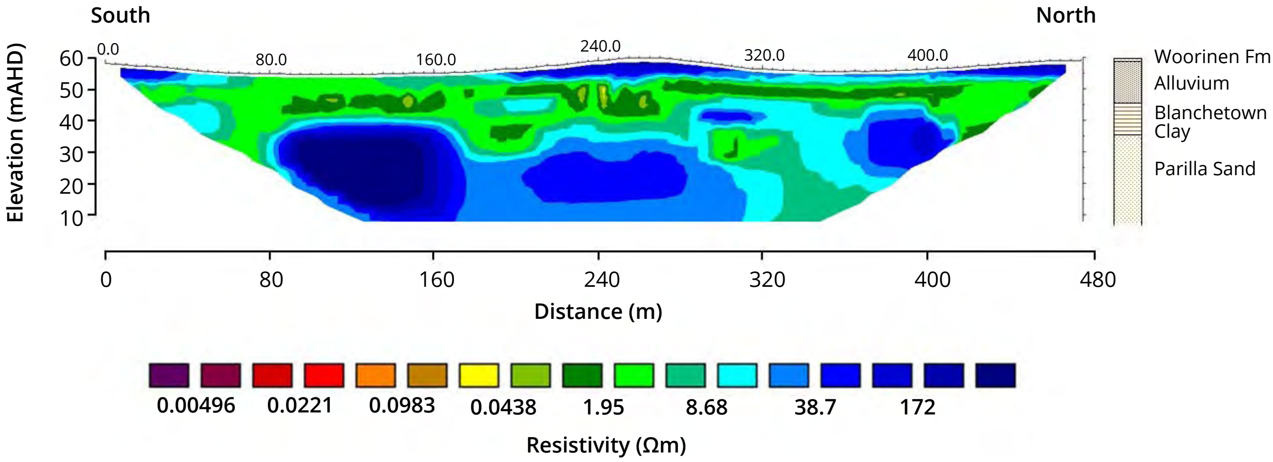


Figure 4: Results of resistivity survey

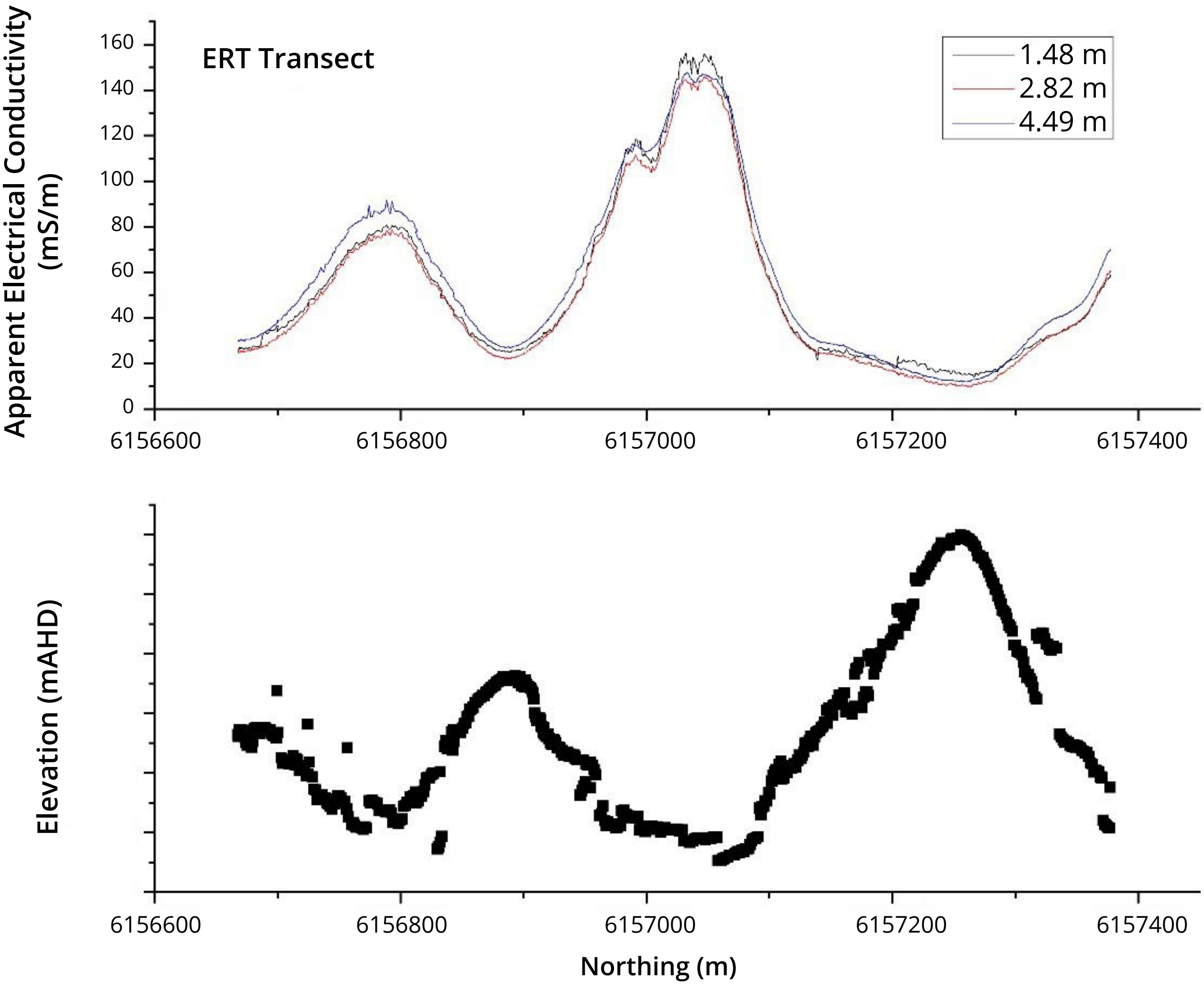


Figure 5: Results of electromagnetic induction survey carried out adjacent to the resistivity survey at three different coil spacings.

4.2 Hydraulic Head

A comparison between depth of screened intervals of piezometers and observation bores and hydraulic head shows significant lateral and vertical head gradients at the site (Figure 6). Shallow piezometer P2S is screened at approximately 51 - 52 m AHD and has a hydraulic head of approximately 52 m AHD. State observation bores, which are screened below 30 m depth and below the Blanchetown Clay, have hydraulic heads between 48.5 and 51 m AHD. Piezometers screened between 30 and 50 m (P1d, P2d, P3d and P4) have hydraulic heads between 48.5 and 50.5 m AHD – lower than heads in the shallowest piezometers, but significantly different from those in the State observation bores. Hydraulic heads in drainage pits vary over time as they fill and are emptied by pumping, but mostly range between 50 and 53 m AHD, similar to the level in P2S and significantly higher than levels in deeper piezometers. The State observation bores show a trend of decreasing head towards the river (to the north), but this is not apparent in shallower piezometers. These results show that clay layers at several depths (both within the alluvium and within the Blanchetown Clay) impede the vertical flow of groundwater to the regional water table.

Results: Hydraulic Head

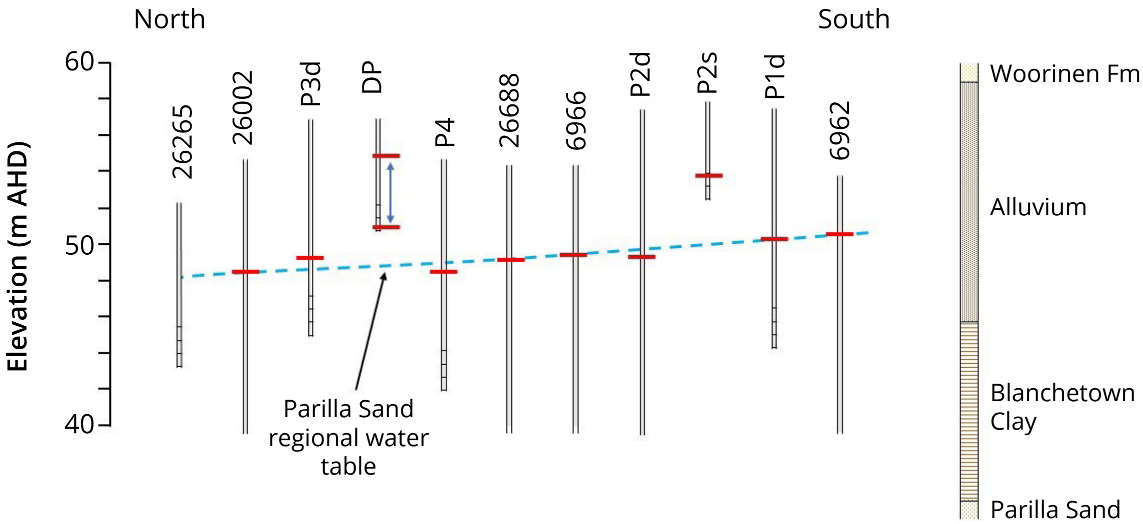


Figure 6: Hydraulic head data for piezometers and State observation bores.
Red lines denote approximate heads in individual piezometers in July – September 2019, and the blue line represents the regional water table in bores and piezometers screened within the Parilla Sand Aquifer. Note that screened intervals for 26002, 26688, 6966, P2d and 6962 are not shown, as they are below 35 m AHD. The stratigraphic section is approximate only and does not consider possible variation in depths of geological units within the study area.

Hydraulic head data in piezometers for the period from 30 April – 5 September are shown in Figure 7. Piezometers P1s and P3s were dry for the period of measurement, and so these are not shown. Significant rain events were recorded on 10 May (8.8 mm) and 8 July (15.8 mm), and these induced water level rises of between 0.05 and 0.15 m and 0.03 and 0.2 m, respectively. Of note is the large difference in head between P2S and P2D.

Electrical conductivity of drainage pits in July 2019 ranged between 400 and 4400 µS/cm. The lowest value was measured in DP1 and the highest value in DP9 – all other values were between 1300 and 1800 µS/cm. In April 2019, based on analysis of ion chemistry, EC is estimated to range between 240 and 610 µS/cm, with the highest value again observed in DP9. Based on ion chemistry, the EC of the water draining through the southern discharge pipe in April 2019 was 280 µS/cm. Results for the northern discharge pipe and for more recent sampling are not yet available.

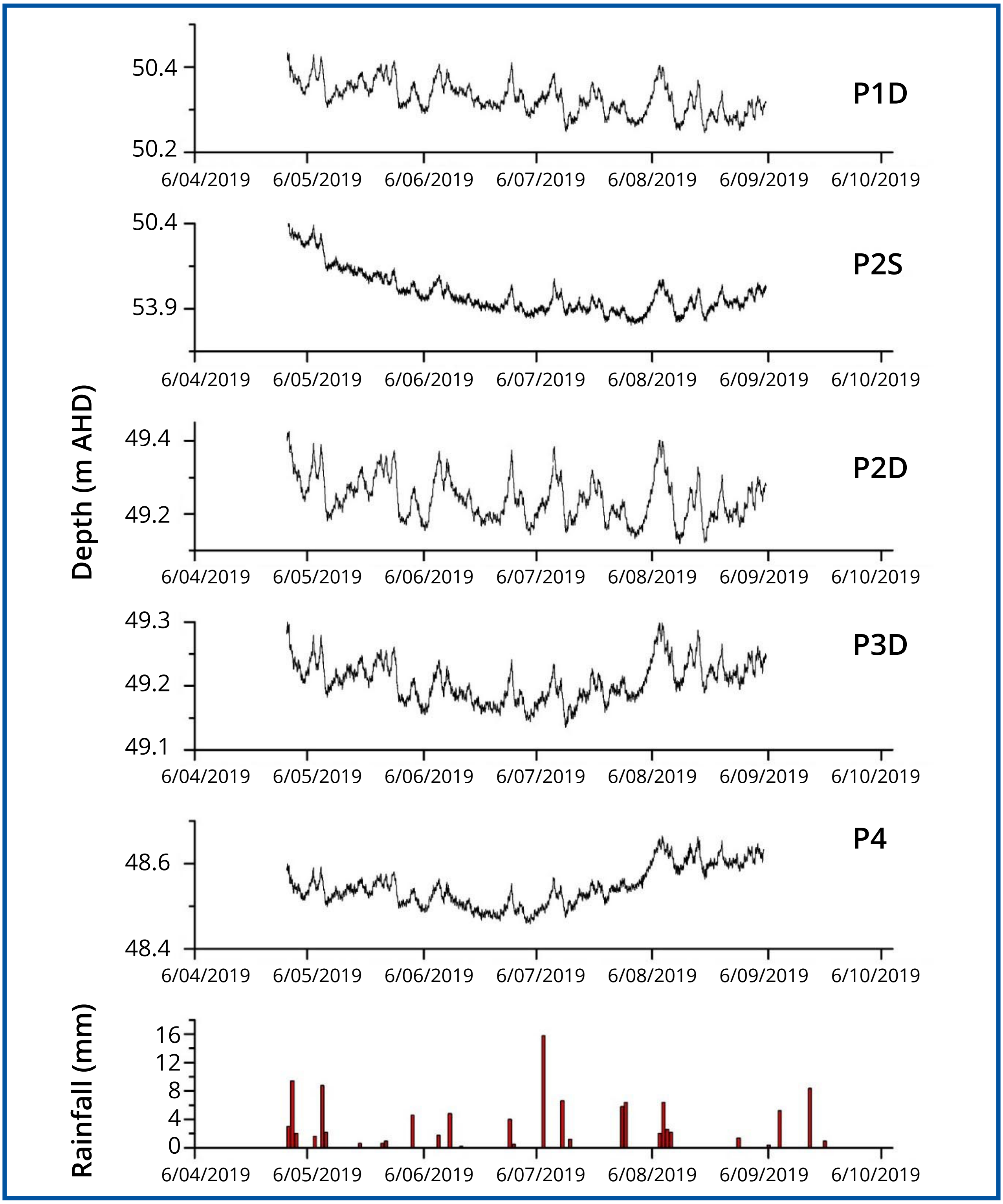


Figure 7: Water levels measured in piezometers on the Almas site

4.3 Drainage Volumes

Most of the drainage pits show water level fluctuations of 1-2 m on approximately daily intervals. This is due to filling of the pits by drainage during the night, and then pumping of the water in the pits to discharge points when the solar pumps activate each morning.

In drainage pit DP4 (Figure 8), the triggers for turning the pump on and off were closer than for some of the other drainage pits (1.5 m difference). The result is that DP4 often fills and

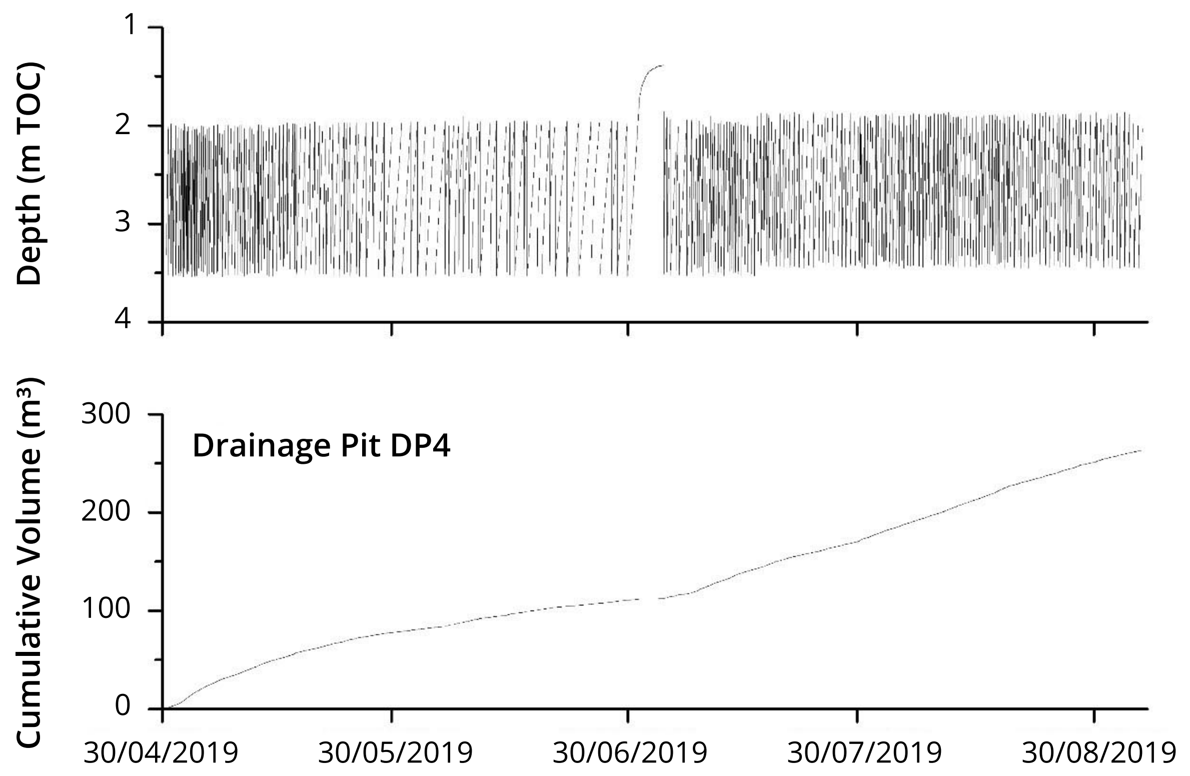


Figure 8: Water level depths (below top of cement casing) and cumulative volumes pumped from drainage pit DP4 between 30/4/2019 and 5/9/2019

empties several times per day during the irrigation season. This was the case until late May. Pumping occurred approximately once per day through June, then more frequently again from early July. The high water level recorded in late June is probably due to pump failure. The slope of the cumulative pumped volume curve is greatest in early May and July – August, and relatively flat in late May – early July when rainfall was low and there was no irrigation. The total pumped volume over the period of measurement is 264 m^3, over approx. 2.5 months. Drainage pit DP4 also has the largest cumulative volume of all drainage pits.

Drainage Pit	Cumulative Volume (m^3)
DP1	6.8
DP2	118.1
DP3	48.5
DP4	263.5
DP5	94.0
DP6	9.2
DP7	156.4
DP8	151.9
DP9	35.6
TOTAL	884.0

Some drainage pits do not show regular water level fluctuations during the irrigation season, indicating that they do not collect large volumes of irrigation drainage. However, in some cases, increases in water levels are apparent following large rainfall events. The cumulative volume pumped from each drainage pit is given in Table 1, and monthly variations in the drainage rate are depicted in Figure 9.

Table 1: Total drainage pumped from drainage pits over 126-day period between 30 April and 4 September 2019

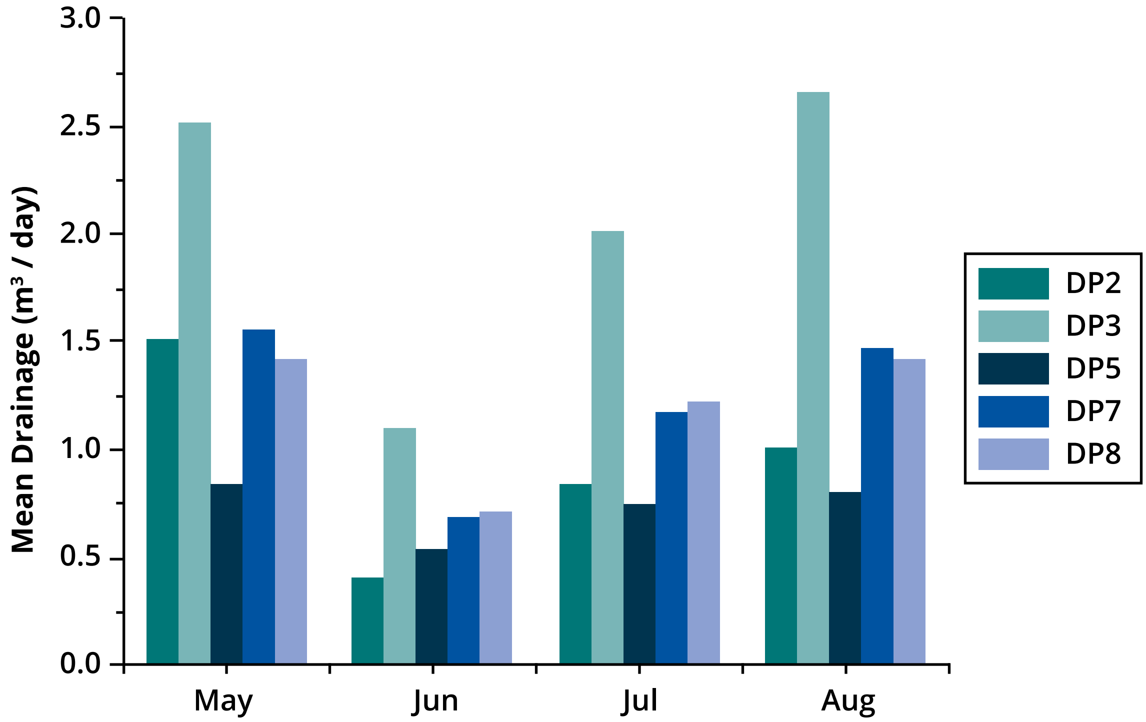


Figure 9: Monthly inflows for the five drainage pits with the greatest total inflow volumes

5. DISCUSSION

The total volume pumped from the nine drainage pits over the 126-day period between 30 April and 4 September 2019 was 884 m^3, an average of 7.0 m^3/day. This data includes both irrigated and non-irrigated periods, although we have not yet captured a full irrigation season. Nevertheless, our preliminary data suggests that drainage during the irrigation season is between two and three times greater than during the non-irrigated period.

Dividing by the area of irrigated land of approximately 283 ha, gives a mean flow rate of 0.002 mm/day, or approximately 1 mm/y. Although there are clearly issues with extrapolating the short period of data to annual values, the available data suggests that the volume of water draining from the shallow clay layers is very small – less than 1% of the annual irrigation volume. Differences between volumes collected in the different drainage pits also suggests large spatial variations in drainage volumes, although the areas of land draining to the different drainage pits are not the same. Ongoing work will partition drainage across the site and capture a full irrigation season. Understanding spatial variations in drainage volumes will be particularly important for farm productivity.

6. ACKNOWLEDGEMENTS

The authors of this paper are particularly indebted to staff of Almas Almonds who have facilitated and assisted with data collection. We are also grateful for the advice and input of Karuppan Sakadevan throughout the project. The work is funded by the Mallee Catchment Management Authority.

FUTURE CHALLENGES

The theme for this section was to consider future challenges with respect to salinity management in the region. In particular, the accumulation of salt in the floodplains and its impact on the landscape and risks associated with climate change and how it will affect the region.

Original presentations can be found in the **Appendix**

PAPER **Salt Movement in South Australian Murray Floodplains**
Dr Juliette Woods, *Department for Environment and Water (South Australia)*

- **Climate Projections for the Mallee Region**
  Geoff Steendam, *Department of Environment, Land, Water and Planning (Victoria)*

- **Panel Session**

PAPER

SALT MOVEMENT IN SOUTH AUSTRALIAN MURRAY FLOODPLAINS

Dr Juliette Woods, *Department for Environment and Water (South Australia)*

ABSTRACT

Floodplain salinity impacts vegetation health and river water quality. Conditions change depending on irrigation, salt interception schemes, river level, climate, and environmental watering. What tools do we have to monitor and conceptualise water and salt movement in this complex environment? Recent work in South Australia has explored this. Hydrogeochemistry revealed that recharge to the floodplain aquifer occurs via lateral flow from the river and from vertical inundation, with the dominant process differing depending on the floodplain. Analytical equations can describe the growth and reduction of lower-salinity lenses, as confirmed through laboratory experiments. Models have explored processes at both small scales and floodplain scales, informing environmental watering and estimating salt load impacts to the river. Inundation rates, evapotranspiration (ET), and solute transport remain as key areas that require further work.

1. INTRODUCTION

The lower River Murray flows through an extensive region where groundwater salinity is high (Figure 1). Changes to river operation and land use have shifted the balance between regional groundwater, floodplain groundwater, and the river (Woods, 2015a). More salt and less freshwater have been passing into the floodplain aquifers. The salt can accumulate in the floodplain groundwater and soils, potentially degrading conditions for vegetation, or it can move into the river, increasing its in-stream salinity.

Management of floodplains and the river depend on understanding how water and salt move within this landscape. In recent years, the South Australian Department for Environment and Water (DEW) has conducted, or collaborated on, many projects relating to salinity within River Murray floodplains. While it is not possible to do justice to the full span of works in a short paper, the aim is to summarise key findings and point the reader towards resources, papers and reports. The focus is on the following tools and approaches which may be useful for saline floodplain management in regions inside and outside SA: (1) hydrogeochemistry to identify sources of groundwater recharge, (2) physical and mathematical modelling of lower-salinity groundwater lenses, and (3) numerical modelling of floodplain soils and groundwater. These tools need to be underpinned by good quality data.

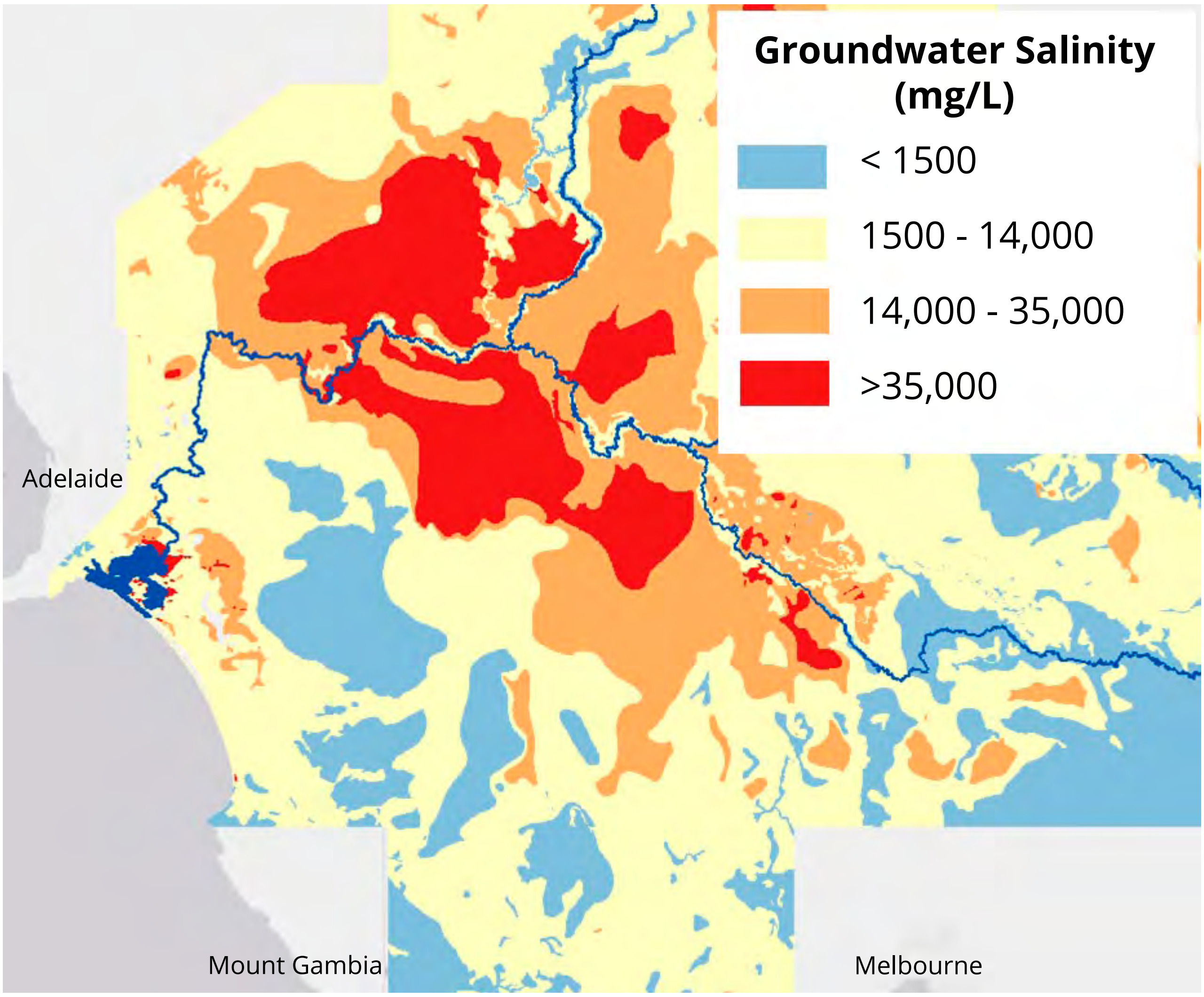


Figure 1: Groundwater salinity of unconfined aquifers adjacent to the lower River Murray

2. HYDROGEOCHEMISTRY TO IDENTIFY SOURCES OF GROUNDWATER RECHARGE

One of the aims of environmental watering is to freshen the soil water and groundwater, as this provides a usable water source for river red gum, black box, and other floodplain vegetation. To optimise environmental watering, it is therefore useful to understand how floodplain aquifers are recharged.

Prior work on recharge mechanisms had occurred for sites between Nyah and Colignan in Victoria, where there is a kilometres-wide lens of lower-salinity groundwater adjacent to the river. In this region, recharge occurs laterally via the riverbank at high river levels, and the lens shrinks during droughts (Cartwright et al., 2010).

However, lenses of lower-salinity groundwater are smaller downstream of Colignan, and it was not clear if the same mechanisms applied to recharge those areas. Hence studies were conducted in SA, at Pike Floodplain and Katarapko Floodplain (Cartwright et al., 2019). Results from Pike Floodplain differed greatly from those of Nyah-Colignan, as there was little evidence of lateral recharge directly via the riverbank. Instead, the “youngest” water was found below the floodplain clays, at the top of the floodplain sand aquifer, indicating that recharge occurs at localised sites of enhanced vertical flow, perhaps every few years, and may indicate episodic recharge during floods (Figure 2). At Katarapko Floodplain, there was evidence for both lateral and vertical recharge.

The results demonstrate that the recharge mechanisms differ by floodplain. This may inform how each floodplain is managed, particularly the spatial distribution of environmental watering. Also, in areas where lateral recharge creates lower-salinity buffer zones near the river, management can support and protect these buffer zones.

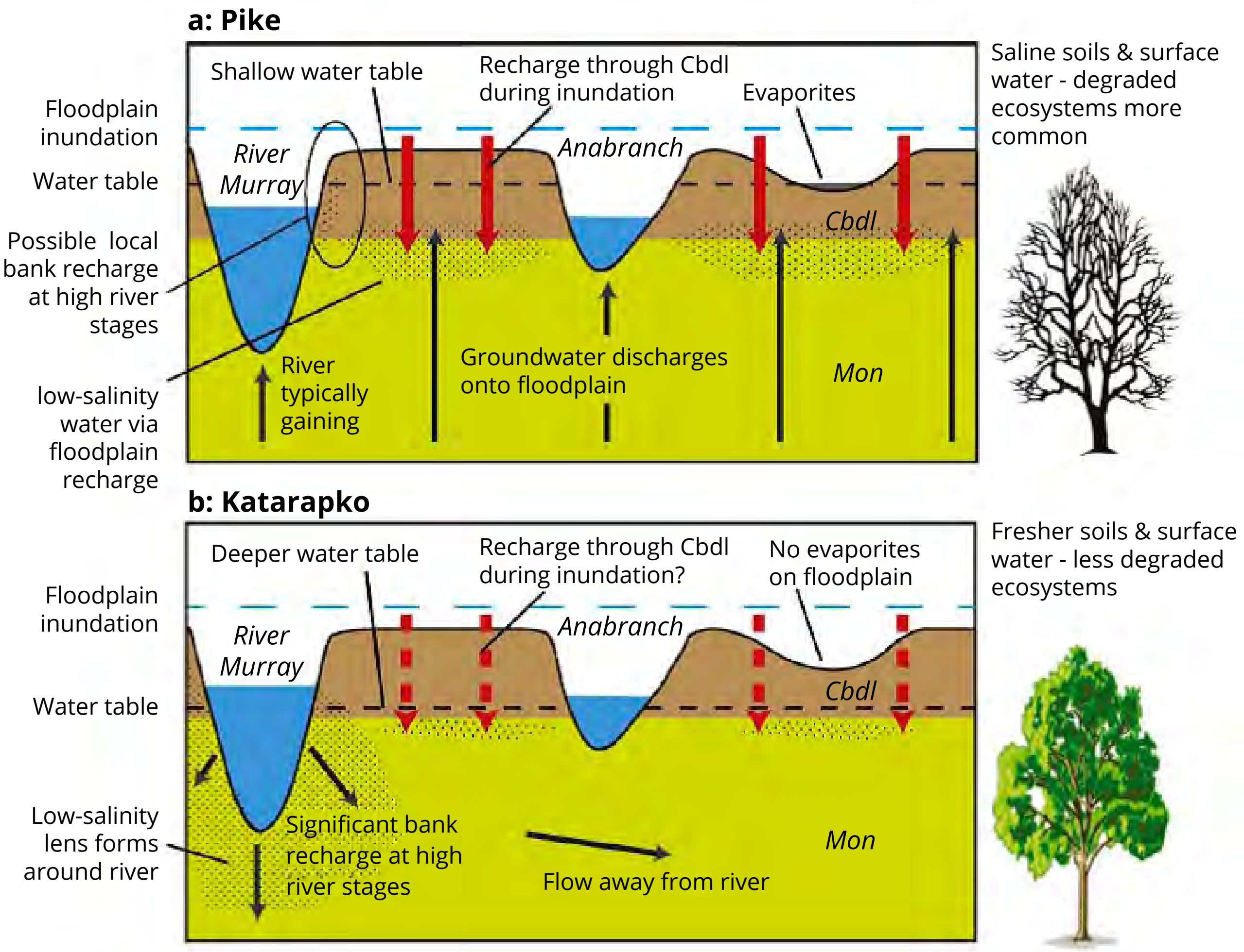


Figure 2: Comparison of Pike and Katarapko Floodplains (from Cartwright et al., 2019)

3. PHYSICAL AND MATHEMATICAL MODELLING OF LOWER-SALINITY LENSES

A series of studies conducted at Flinders University investigated the physics of lenses of lower-salinity groundwater near rivers. Laattoe et al. (2017) mapped locations of known terrestrial freshwater lenses worldwide, and presented a typology based on topography, geology, groundwater-surface water interaction and recharge mechanisms.

Research then focused specifically on conditions similar to the lower River Murray. The physics can be compared to the situation of seawater intrusion of coastal aquifers; using similar methods, analytical equations were developed for lower-salinity lenses under stable (steady-state) conditions which are fed by lateral recharge through riverbanks. The equations aim to predict the conditions under which lower-salinity lenses may occur (Werner & Laattoe, 2015). A key finding is counterintuitive: lower-salinity lenses may form, due to buoyancy effects, where the river is otherwise gaining. The equations were verified against sand-tank experiments (Figure 3) which were used to mimic the lenses in the laboratory (Werner et al., 2016). These equations have not yet been tested against field data. A final paper modified the equations to include dispersivity (mixing of fresher and more saline waters caused by flow through the pores in sediments), and compared the results with cross-sectional numerical models (Werner, 2017).

Cross-sectional numerical models were also used to investigate the physics of the lenses under transient conditions, both generically and for the Katarapko Floodplain. The aim was to explore how changes to river management could affect the lenses. Preliminary results identified key properties, such as riverbed hydraulic conductivity, and the depth of the riverbed when compared to the thickness of the floodplain aquifer. There was a wider mixing zone in these simulations, when compared to the steady-state models. This work is yet to be published.

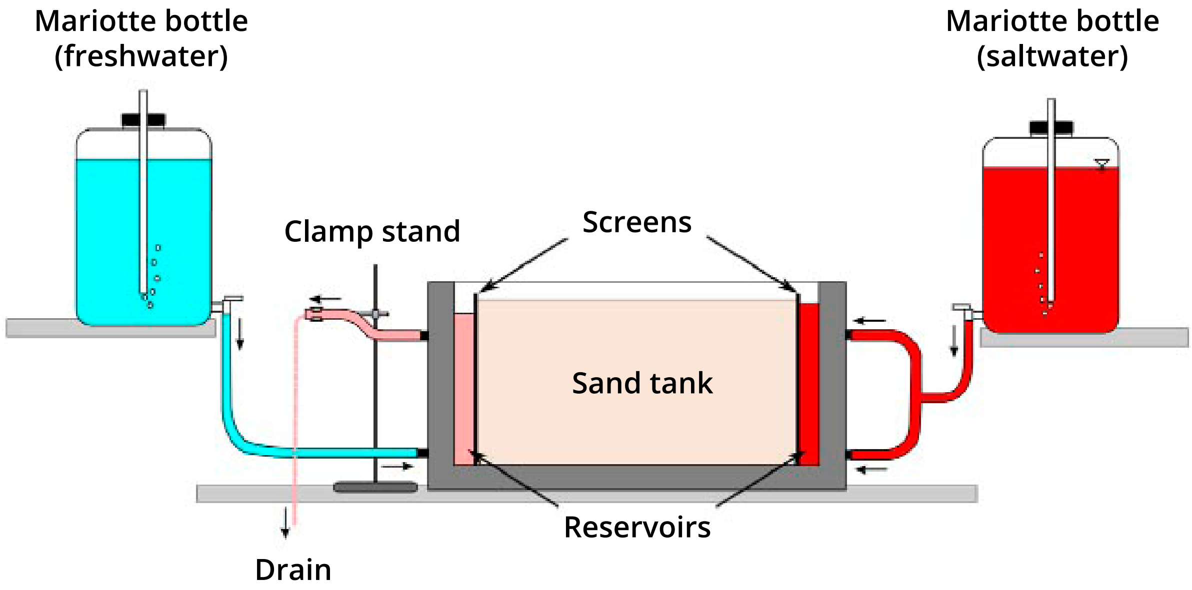


Figure 3: Example sand tank experiment for lower-salinity groundwater lenses (from Werner et al., 2016)

4. NUMERICAL MODELS OF FLOODPLAINS

Groundwater models of the lower River Murray have been developed to meet two main management goals: (i) to estimate the salt load moving from aquifers via the floodplain into the river, and (ii) to estimate the impact of different management actions on vegetation health.

A key question is: how complex does the representation of a floodplain need to be in a numerical model, given its goals? DEW has explored this using models which have grown increasingly more complex as we have sought to answer more challenging management questions.

For rough estimates of salt movement into the river due to highland irrigation, a semi-analytical approach may be sufficient. This has been demonstrated using the SIMPACT and SIMRAT codes (Miles & Kirk, 2005; Fuller et al., 2005; Woods et al., 2016), which describe the influence of the floodplain on salt movement to the river with a single multiplicative factor, “floodplain attenuation”, which is based on expert knowledge only. These models are designed to produce conservative estimates which over-estimate the salt loads; when their results are compared to regional MODFLOW models, their salt loads are considerably higher (Woods et al., 2017).

To assess the salt load impacts of long-term, largely continuous management actions, such as irrigation or salt interception schemes, South Australia has developed a series of numerical groundwater models. These simulate the floodplain groundwater fairly simply, assuming constant river levels and ET, and not simulating salt transport (e.g. Yan et al., 2012). This approach is usually sufficient for averaged conditions, provided there is adequate data on how the groundwater system responds due to near-river stresses (e.g. potentiometric head data responding to salt interception scheme pumping).

More complexity is needed for groundwater models which assess the impacts of environmental watering on groundwater salt loads to river (Purczel et al., 2016). Environmental watering involves multiple, discontinuous actions over many years. A model simulating an idealised section of floodplain showed that fine spatial discretisation was needed, with stress periods that are monthly or shorter (Woods, 2015b). All processes critical to environmental watering need to be simulated, as they interact and are interdependent: evaporation, transpiration, changing river levels, and flood inundation (Woods, 2015b; Riches et al., in prep.). The models also need to be carefully calibrated to transient floodplain conditions; regional models calibrated only to long-term conditions fail to match observations when detailed floodplain processes are added but no recalibration is done (Riches et al., in prep.). While there are no shortcuts, a well-calibrated, detailed floodplain model is capable of simulating the salt load impact to the river of environmental watering (Li et al., 2019).

The most challenging aim for a floodplain model is to estimate the impacts of management on floodplain health. The critical factor is soil water availability, which is influenced by soil and groundwater conditions. Both flow and solute transport need to be simulated. Prior work simulating the unsaturated (soil) zone in River Murray floodplains includes the use of the detailed WAVES model (Dawes et al., 1998), and the simpler rapid analysis model, WINDS (Slavich et al., 1999; Overton & Jolly, 2004, 2008; Overton & Doody, 2010), while Holland et al. (2005) developed a semi-analytical groundwater model to identify the risk of long-term salinisation. However, these are limited in how they simulate the interactions between the unsaturated zone and groundwater.

For the SA Riverland Floodplain Integrated Infrastructure Program (SARFIIP), a generalised floodplain unsaturated zone was simulated using LEACHM to determine the possible impacts from inundation and groundwater manipulation (Li, in prep.). The results informed the development of a detailed groundwater model of the Pike Floodplain, which simulates the fraction of time when groundwater level and salinity were optimal, marginal or poor for river red gum and black box trees (Figure 4) (Denny et al., in prep.).

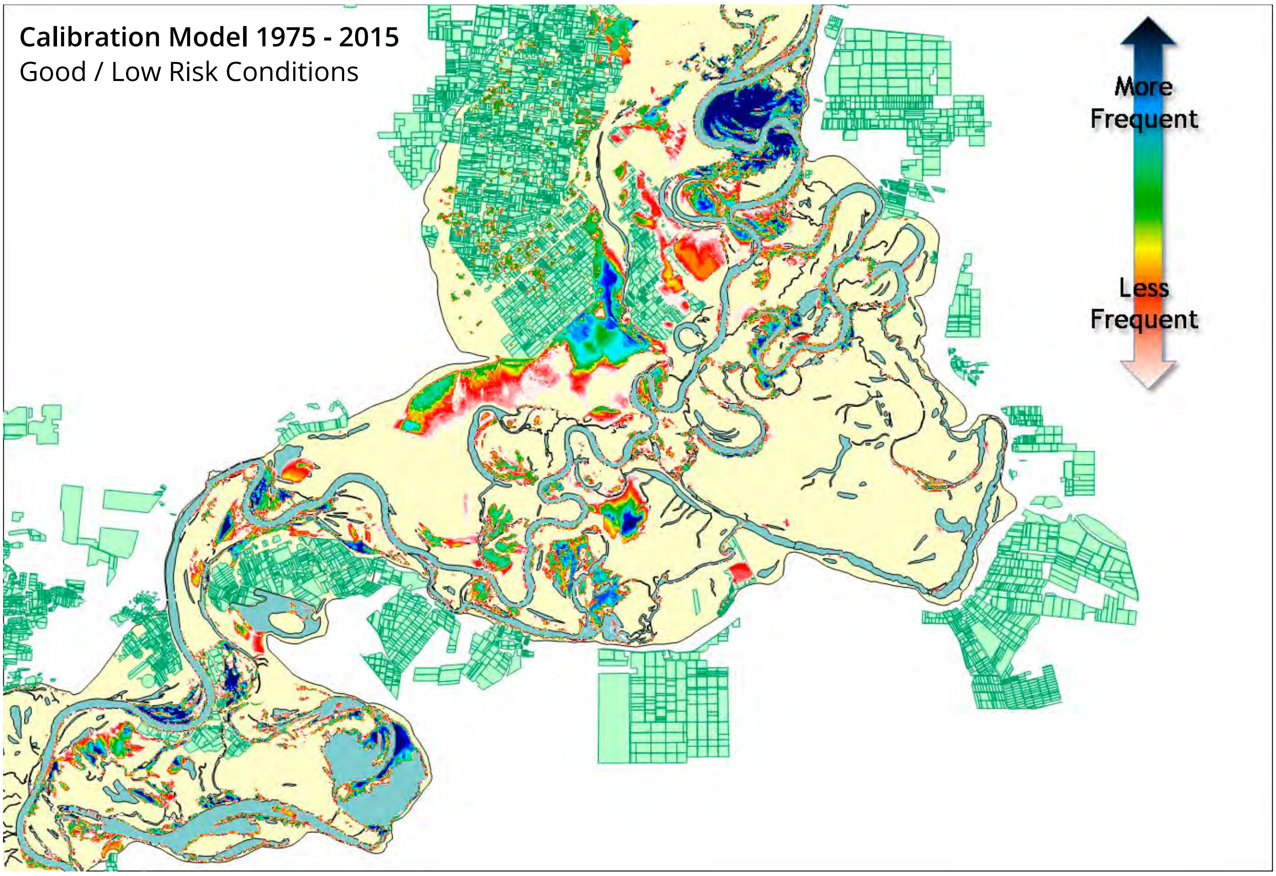


Figure 4: Sample output from the Pike Floodplain model, showing the frequency of good groundwater conditions for tree health

5. LIMITATIONS OF CURRENT MODELLING

5.1 Interactions between groundwater and the unsaturated zone

Groundwater and unsaturated zone processes cannot be easily separated in the floodplain, as water and salt movement depend on complex, interlinked processes at the intersection of hydrology, hydrogeology, soil science, ecology, and micro-meteorology (Figure 5). When the unsaturated zone and groundwater domains are modelled separately, key interactions between drainage, water table and ET are missed. One approach is to employ a modified ET function in a groundwater model (Doble et al., 2006; Bauer et al., 2006; Ajami et al., 2010). Others have used fully-integrated unsaturated-saturated models (Jolly et al., 1998; Alaghmand et al., 2014, 2015), but these models are too computationally intensive to be useful for regional-scale floodplain management on the required management time scales of 25 to 100 years.

5.2 ET, inundation and solute transport

Additionally, three key processes have proved difficult to simulate (Woods, 2015b): ET, inundation recharge, and solute transport. Understanding ET is essential for estimating salt movement to the river via groundwater and inundation-driven “salt washoff”, as well as vegetation health. Standard groundwater modelling packages for simulating ET do not take into account the relationship between salinity and ET, and they allow evapoconcentration to occur beyond physically-possible limits. Improved simulation of evapoconcentration has therefore required modifications to simulation codes (Bauer et al., 2006; Zhang et al., 2014); these techniques are yet to be trialled for the River Murray floodplains.

Inundation recharge is also difficult to characterise. Data is rarely collected during floods, due to the inaccessibility of sites and the potential for damage to equipment. Some floodplain clays are cracked when dry but swell when wet, so in areas without good vegetation cover, drainage may be swift initially, then cease. Areas with established root systems may have different dynamics.

Solute transport is difficult to simulate because it is dependent on ET and inundation. It also depends on the riverbed hydraulic conductivity, which is often extremely heterogeneous (Holland et al., 2009). There is also a paucity of salinity data. Aerial electro-magnetic surveys have provided snapshots of inferred salinity across large areas, but there is very little data on how salinity changes over time.

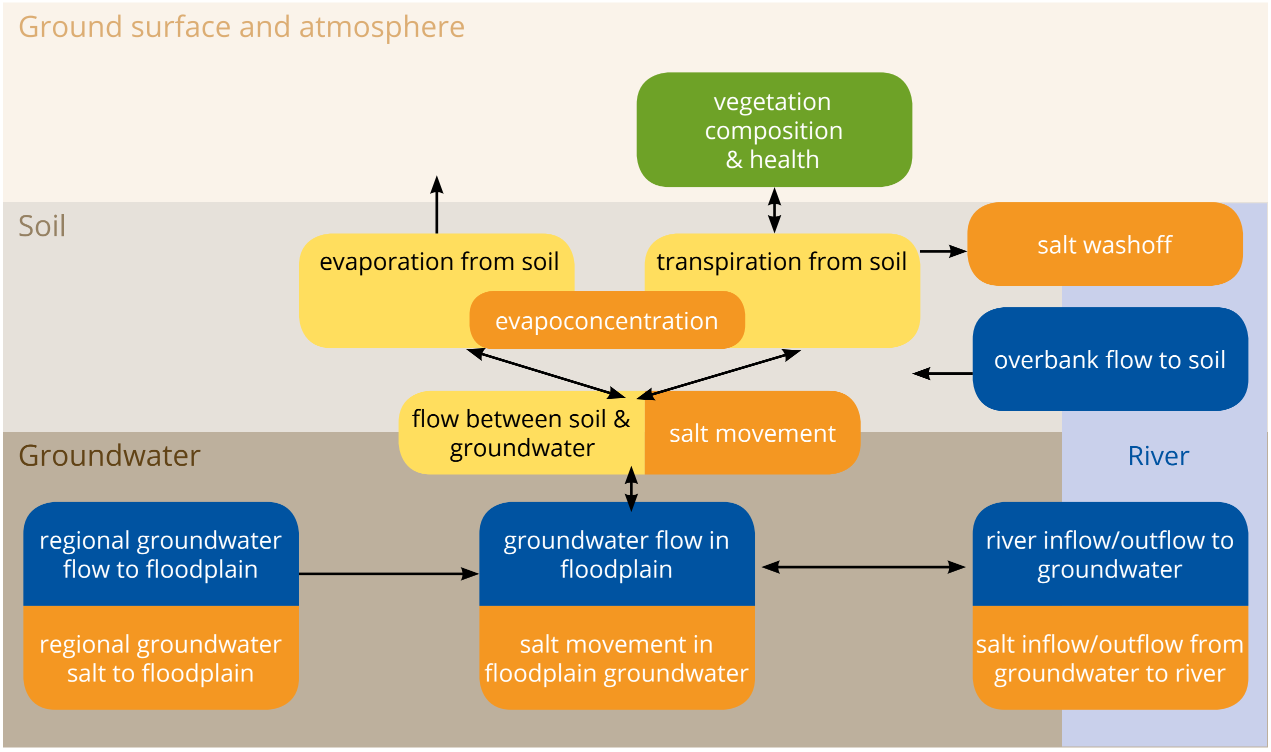


Figure 5: Key processes for water and salt movement in the floodplain (blue relates to flux of groundwater and surface water, orange to salt flux, yellow to soil water, and green to vegetation).

5.3 Lack of verification

Many models are at a stage where they are based on the best science and data available, but some key assumptions have not been tested against field data. Data needs to be collected to resolve the appropriate parameter ranges for inundation recharge, evaporation, transpiration, riverbed conductivity, and solute dispersivity.

The model outputs also need to be compared with observations. For the lower-salinity lens models, site data is available but is yet to be used to verify the modelled results. For the environmental watering models, there is limited scope to thoroughly test them until after environmental watering begins. Targeted monitoring is required to collect data suitable for verifying the accuracy of models (i.e. model post-audits).

6. RECOMMENDATIONS

For management purposes, a modelling approach is needed that can evaluate options and estimate outcomes for river salinity and floodplain tree health on regional and multi-decadal scales. It must include all key processes while having achievable data requirements and run times. Currently, no model fully meets these requirements. To develop a model suitable for floodplain management will require significant improvements in understanding ecological and physical processes relating to salt movement, including reliable data on ET and inundation recharge. It will also require a computationally efficient simulation of the interaction between the unsaturated zone and groundwater. These improvements will need to be demonstrated and verified in a pilot model before the methodology can be adopted. A program to investigate and partially resolve these issues has been developed as a collaboration between DEW, the Murray-Darling Basin Authority, CSIRO, Flinders University, the University of Adelaide, and ecological consultancy Flora, Flows, and Floodplains; the project team has applied for Australian Research Council funding, which is yet to be determined.

For lower-salinity groundwater lenses, there is scope to test and improve cross-sectional models, by trialling them at well-monitored sites such as those at Bookpurnong, SA, and Mallee Cliffs, NSW.

7. ACKNOWLEDGEMENTS

The lower-salinity groundwater lens research was supported by the Australian Research Council under the Linkage Projects funding scheme (project number LP140100317), and by DEW's SA Riverland Floodplain Integrated Infrastructure Program (SARFIIP). The floodplain modelling of Woods (2015a,b) was funded by the Goyder Institute for Water Research. SA's regional-scale SA MDB groundwater models are funded by DEW and the MDBA. The Chowilla Groundwater Model was funded under The Living Murray program. The detailed models of the Pike and Katarapko Floodplains are funded by SARFIIP.

The sections on limitations and recommendations are informed by numerous conversations with: DEW colleagues (Virginia Riches, Carl Purczel, Kittiya Bushaway and Chris Li), Flinders University colleagues (Dr Tariq Laattoe, Professor Adrian Werner, Professor Okke Batelaan and Associate Professor Huade Guan), Dr Todd Wallace of the University of Adelaide, Dr Tanya Doody and Dr Rebecca Doble of CSIRO, Dr Sue Gehrig of Flora Flows and Floodplains, Stuart Richardson and Dougal Currie of CDM Smith, and Dr Chenming Zhang of the University of Queensland. Many others have contributed over the years: an incomplete list is given in Woods (2015a,b).

8. REFERENCES

Ajami H, Meixner T, Maddock T, Hogan JF & Guerin DP (2011), Impact of land-surface elevation and riparian evapotranspiration seasonality on groundwater budget in MODFLOW models. Hydrogeology Journal 19: 1181-1188.

Alaghmand S, Beecham S, Jolly ID, Holland KL, Woods JA & Hassanli A (2014), Modelling the impacts of river stage manipulation on a complex river-floodplain system in a semi-arid region. Environmental Modelling & Software 59: 109-126.

Alaghmand S, Beecham S, Woods JA, Holland K, Jolly I, Hassanli A & Nouri H (2015), Injection of fresh river water into a saline floodplain aquifer as a salt interception measure in a semi-arid environment. Ecological Engineering 75: 308-322.

Bauer P, Held RJ, Zimmermann S, Linn F & Kinzelbach W (2006), Coupled flow and salinity transport modelling in semi-arid environments: The Shashe River Valley, Botswana. Journal of Hydrology 316 (1-4): 163-183.

Cartwright, I., Weaver, T.R., Simmons, C.T., Fifield, L.K., Lawrence, C.R., Chisari, R., Varley, S., 2010. Physical hydrogeology and environmental isotopes to constrain the age, origins, and stability of a low-salinity groundwater lens formed by periodic river recharge: Murray Basin, Australia. Journal of Hydrology 380: 203–221. https://doi.org/10.1016/j.jhydrol.2009.11.001.

Cartwright, I., Werner, A.D., Woods, J.A., 2019. Using geochemistry to discern the patterns and timescales of groundwater recharge and mixing on floodplains in semi-arid regions. Journal of Hydrology 570: 612-622. https://doi.org/10.1016/j.jhydrol.2019.01.023.

Dawes WR, Slavich PG, Hatton TJ & Walker GR (1998), Modelling water and salt movement on the Chowilla Floodplain, in Zhang, L & Dawes, WR, WAVES - An Integrated Energy and Water Balance Model. Canberra: CSIRO Land and Water; Report 31/98, doi:10.4225/08/585973a56d288.

Denny M, Thompson D, Purczel C & Riches, V (in prep), Pike Floodplain ecological response to groundwater management: comparison of management scenarios, Department for Environment and Water, Adelaide, South Australia.

Doble R, Simmons C, Jolly I, Walker G (2006), Spatial relationships between vegetation cover and irrigation-induced groundwater discharge on a semi-arid floodplain, Australia. Journal of Hydrology 329: 75-97.

Fuller D, Watkins N, Miles M and Hoxley G (2005) SIMRAT V2.0.1 Data Report and Atlas Prepared for the Murray Darling Basin Commission, May 2005.

Holland K, Jolly I, Overton I, Miles M, Vears L & Walker G (2005), The Floodplain Risk Methodology (FRM): A suite of tools to rapidly assess at the regional scale the impacts of groundwater inflows and benefits of improved inundation on the floodplains of the lower River Murray. CSIRO Land & Water 2005-12, doi:10.4225/08/5866a1cc0fd30.

Holland K, Charles, A, Jolly I, Overton I, Gehrig S, and Simmons C (2009). Effectiveness of environmental watering of a semi-arid saline wetland for managing riparian vegetation health. Hydrological Processes, 23 (no. 24): 3474-3484. doi: 10.1002/hyp.7451.

Jolly ID, Narayan KA, Armstrong D & Walker G (1998), The impact of flooding on modelling salt transport processes to streams. Environmental Modelling & Software 13: 87-104.

Laattoe, T., Werner, A.D., Woods, J.A., Cartwright, I., 2017. Terrestrial freshwater lenses: unexplored subterranean oases. Journal of Hydrology 553: 501–507. https://doi.org/10.1016/j.jhydrol.2017.08.014

Li C, Karbasi M & Herbert T (2019). Post-audit of the Chowilla groundwater model for predicting the salinity impacts of regulator operation, DEW Technical note 2019/XX, Government of South Australia, Department for Environment and Water, Adelaide.

Miles MW & Kirk JA (2005), Applications of the SIMRAT model for salinity management in the Lower Murray–Darling, extended abstract from MODSIM 2005 conference. https://www.mssanz.org.au/modsim05/papers/miles.pdf

Overton IC & Jolly ID (2004), Integrated studies of floodplain vegetation health, saline groundwater and flooding on the Chowilla Floodplain South Australia. CSIRO Land and Water: 2004-05, doi:10.4225/08/586be85545d98

Overton I & Jolly I (2008), Vegetation Health Predictions from Management Options on the Murtho, Pike, Gurra Gurra and Bookpurnong Floodplains, River Murray. doi:10.13140/2.1.4526.4006

Overton I & Doody T (2010), Ecosystem response modelling in the Chowilla Floodplain, Lindsay and Wallpolla Islands icon site. In: Saintilan N & Overton I Eds. Ecosystem Response Modelling in the Murray-Darling Basin. CSIRO Publishing: 2010-16

Purczel, C., Riches, V., Li, C., Woods, J., Wood, C. and Costar, A., 2016, South Australian Riverland Floodplain Integrated Infrastructure Project –Pike Floodplain Numerical Groundwater Model, DEWNR Technical report 2016/30, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

Riches, V., Li, C., Coff, B., Bushaway, K., Osei-Bonsu, K. and Woods, J. (in prep.) Cumulative salinity impact estimation project, Department for Environment and Water, Adelaide, South Australia.

Riches, V., Woods, J.A. and Bushaway, K. (in prep.), Impact of modelled floodplain processes on key model outputs, Department for Environment and Water, Adelaide, South Australia.

Slavich PG, Walker GR & Jolly ID (1999), A flood history weighted index of average root-zone salinity for assessing flood impacts on health of vegetation on a saline floodplain. Agricultural Water Management 39: 135-151

Werner, A. D., and T. Laattoe (2016), Terrestrial freshwater lenses in stable riverine settings: Occurrence and controlling factors, Water Resour. Res.,52, 3654–3662 https://doi.org/10.1002/2015WR018346

Werner, A. D., A. Kawachi, and T. Laattoe (2016), Plausibility of freshwater lenses adjacent to gaining rivers: Validation by laboratory experimentation, Water Resour. Res., 52 https://doi.org/10.1002/2016WR019400

Werner, A.D., 2017. Correction factor to account for dispersion in sharp-interface models of terrestrial freshwater lenses and active seawater intrusion, Adv. Water Res., 102, 45-52. http://dx.doi.org/10.1016/j.advwatres.2017.02.001

Woods J. (Ed.) (2015) Modelling salt dynamics on the River Murray floodplain in South Australia: Conceptual model, data review and salinity risk approaches. Goyder Institute for Water Research Technical Report Series No. 15/9, Adelaide, South Australia. ISSN: 1839-2725. http://www.goyderinstitute.org/_r450/media/system/attrib/file/132/15_9_E.1.11%20Litrev_final%20%28SMALL%29.pdf

Woods J. (Ed.) (2015) Modelling salt dynamics on the River Murray floodplain in South Australia: Modelling approaches. Goyder Institute for Water Research Technical Report Series No. 15/10, Adelaide, South Australia. ISSN: 1839-2725. http://www.goyderinstitute.org/_r142/media/system/attrib/file/133/15_10_E.1.11_Modelling_RAC-v2.pdf

Woods, J., Peat., V. and Middlemis, H. (2016). Stage 1 Review of SIMRAT V2.0.1. Prepared for the Murray-Darling Basin Authority.
https://www.mdba.gov.au/sites/default/files/pubs/SIMRAT-stage1-review.pdf

Woods, J., Kirk, J., Bushaway, K., and Vears, L., 2017. Addendum to the 5-year reviews at Waikerie to Morgan, Woolpunda and Pike-Murtho. DEWNR Technical report 2017/18, Government of South Australia, Department of Environment, Water and Natural Resources, Adelaide. https://data.environment.sa.gov.au/Content/Publications/DEWNR-TR-2017-18_5yearsreview.pdf

Environment, Water and Natural Resources, Adelaide. https://data.environment.sa.gov.au/Content/Publications/DEWNR-TR-2017-18_5yearsreview.pdf

CLIMATE PROJECTIONS FOR THE MALLEE REGION

Geoff Steendam, *Department of Environment, Land, Water and Planning (Victoria)*

Geoff provided an overview of climate projections for the Mallee region, with specific reference to:

- Relevant information sources for observed trends and climate projections
- Observed changes and future projections with respect to changes in climate and water resources
- Guidance on how climate change projections can be applied to water resource planning

Important information sources for observed trends and climate projections include:

- South East Australia Climate Initiative (www.seaci.org)
- Victorian Climate Initiative; Victorian Water and Climate Initiative (www.water.vic.gov.au/climate-change)
- Victorian Climate Projections (www.climatechange.vic.gov.au)
- Climate Change in Australia (www.climatechangeinaustralia.gov.au)

The physical risks posed by climate change will impact different parts of the water cycle and the landscape and are likely to include:

- Temperature increases
- More heat waves
- More droughts
- Lower than average rainfall
- More bushfires
- More intense rainfall
- More flash floods
- Rise in sea level and storm surges

Observations for Victoria have included:

- Temperatures have increased by over 1°C from 1970 to 2018, with the warming trend expected to continue
- Winter rainfall has been in decline and will continue, particularly under a high greenhouse gas emissions scenario
- Substantial decline in streamflow over the last 20 years
- Reduction in streamflow response after a rainfall event in particular river basins

Future climate projections for the Mallee region include:

- Maximum temperatures are expected to show a median increase of 1.3°C by the 2030s (2020–2039), compared to 1986–2005, under a high emissions scenario and by mid-century, the increase is likely to be greater, with a median of 2.2°C.
- More extreme heat events are expected, with the 1-in-20-year hottest summer day likely to increase by a median value of 2.3°C in the 2050s under high emissions, compared to 1986–2005. While for medium emissions scenario, the median increase is 1.7°C.
- Mildura is likely to experience a tripling of days over 40°C by 2050s
- A warmer climate is expected to bring more extreme rainfall events, but variability in high rainfall events is naturally large so there is a wide range of possibilities

Finally, a summary on how climate projections from Global Climate Models are being used to help form guidelines to assist the water resource sector in Victoria with planning for various climate change scenarios was provided (see Guidelines for Assessing the Climate Change on Water Supplies in Victoria, 2016, DELWP)

PANEL SESSION

The panel session featured a facilitated discussion led by Dr Anne-Maree Boland (RMCG) with the following presenters:

- Tim Cummins (Cummins and Associates)
- Dr Asitha Katupitiya (MDBA)
- Jenn Learmonth (DELWP – Basin Salinity Management, Water and Catchments)
- Don Arnold (Mallee CMA)
- Greg Hoxley (Jacobs)
- Geoff Steendam (DELWP – Water Resource Strategy Division, Water and Catchments)
- Ray Evans (Salient Solutions)

OPENING QUESTION:

What have we learnt from the past that can help how we respond to challenges in the future?

QUESTION:

What have been the most important changes over the years as to how we manage salinity in the Mallee? What have been the one or two big 'changes' that have had a big impact?

Summary of Tim Cummins' and Ray Evans' responses:

- Water trade has allowed massive expansion of horticulture in the region that potentially could have had a negative impact on salinity, but we were ahead of the game having implemented mechanisms that avoided or minimised any such impacts.

- On farm cultural practices in terms of production systems, irrigation systems and irrigation management has been the other significant change. Water trading has also encouraged and influenced practice improvements.

- Water reforms of the 1990s that focused on 'uncoupling' of water licences from the land, introduction of cap and trade on water, as well as a pollution trading system on salt within a regulated market. The market-based approach has fundamentally driven water efficiencies. This is world's best practice – we shouldn't throw it away, without a lot of consideration.

QUESTION:

What are the risks for the future and how should we address those? (Climate change is a key one).

Summary of Geoff Steendam's response:

- For government agencies, it's about understanding the risks so we can make informed decisions. Making sure decision makers have all the information at hand, so they can make wise decisions armed with the best science and knowledge we have.

QUESTION:

What is the next big challenge or scientific information we need to explain to the policy makers?

Summary of Greg Hoxley's response:

- We're reaching a point with our understanding of the detail in the natural system, where we can make really small-scale management decisions. For example, having sensors and the degree of detailed information you can get on individual blocks and the timing in which you can access this information. We've probably past this threshold in the last five years.
- Temptation will be to manage at that really detailed level. However, sometimes our process understanding and models can keep up with that level of information and sometimes they can't. So, if we are going to make decisions at this level, really need to think about the policy basis and fairness of it. This is where the salinity program (SMF) is a good example, as it was so well based and entrenched within the community, in which the changes had to be made. We need to be so careful that we don't, unwittingly, set up 'oppositional structures' around trying to make micro-decisions about how the landscape is managed.
- Biggest challenge for policy makers is how to work out what you want the landscape to look like, so that when you are managing it, you can actually achieve it. We have to manage adaptively, which we've seen that happen over the last 30 years. Are we really going to decide, for example, what we want one little valve area or block to 'look like' or do we set objectives for some part of a wetland or do we have more broader ones? Don't have the answer to these questions, but this will be quite challenging, particularly if you are the landholder or custodian of a particular feature and these decisions affect you. How do you get fairness into the system? One of the key principles of the SMF has been a sense of fairness; sharing both the benefits and dis-benefits. This will have to now be done at the micro-level.

QUESTION:

What are the biggest challenges and what do government policy makers need more of to help in the decision making (particularly for the Mallee)?

Summary of Jenn Learmonth's response:

- Acknowledgement that Mallee CMA has led or commissioned a lot of recent work to improve our understanding of salinity in the landscape. Previously we'd assumed that all of the salinity was heading to the Murray River, so that was our highest priority and we managed for the worst case in order to get the best outcomes.
- However, recent information confirms that risk was real, but because we've looked at the River so closely, we didn't look at the low-lying areas in the landscape or the floodplains in the same way. So, this recent work suggests we need to look at the broader impacts of salinity in the landscape around the high irrigation areas. Given we've managed the impacts to the River really well and will continue to do so, how are we going to manage these other impacts?
- There's a delineation in the finer detailed information and the broader information that applies at a landscape scale. At a policy level, we're interested in what can be generalised, what are the 'outcomes' from what we understand and know at the smaller scale (e.g farm level).
- Original Nyah to Boarder plan was based on best available knowledge and on generalisations, and we used that to implement actions and we've further refined the plan and we are getting to finer levels of detail for our regional plan and regional strategy. What we need more of, is to work at that landscape level.

QUESTION:

From MDBA's point of view, what do you want to see more (regarding information) in the development of policy, as it relates to the Mallee?

Summary of Asitha Katupitiya's response:

- The strategy is aimed at protecting the shared water resources and BSM2030 is about protecting everyone's and the Basin's interest. In terms of the Mallee, we know there is a lot of development in this area and a lot more water being used in this area. This is in the low impact zones, while it means low impact on the River but it doesn't mean low impact on the landscape.
- We know it can take 50 – 100 years for what you did today to impact on the River. We need to understand how developments and water use changes that are happening in the landscape will impact in the long term on the shared water resources. What can be controlled at this point in time so future impacts are managed?

QUESTION:

What are the big policy challenges or the things that will stop Mallee CMA 'moving forward' in the future?

Summary of Don Arnold's response:

- The people in this region who've made policy decisions in the past about managing salinity and the impact on the River, have had an outstanding success in this area. Our challenges moving forward will be more to do with the impacts made in the landscape rather than perhaps the River.
- Our other challenge is that generally the community think salinity has been addressed. While the risk has been reduced the threat still remains, as there is very saline groundwater underlying most of the Mallee. This risk is perhaps not to the River so much but rather to the landscape. We need to be working closely and reminding the community about the threat that still remains.
- In terms of irrigation, the risk is related to the significant amount of development in the region. The amount of water available downstream is nearly all consumed – the development is nearly all permanent crops and they have high water demands each year. For the irrigation industry, this will be a real challenge as to how we support that level of development, particularly when we learn about potential changes in water yield in the catchment (due to climate change) and how that will play out over time.

APPENDIX

The following images are the original slides which were presented at the Mallee Regional Salinity Forum on 19th November 2019

Professor Ian Lowe's Keynote Presentation: Science, Salinity and Sustainability

Strategy, Policy and Planning

- Basin Salinity Management 2030 by Dr Asitha Katupitiya
- Water for Victoria by Jenn Learmonth
- Mallee Irrigation Region Land and Water Management Plan by Don Arnold
- Mallee Model Refinement by Greg Hoxley

Irrigation Development

- Mapping Irrigation Development and River Salinity Impact Zones in the Victorian Mallee by Sue Argus
- Achieving and Maintaining Irrigation Best Practices for the Mallee by Associate Professor John Hornbuckle and Dr Carlos Ballester-Lurbe
- Irrigator's Perspective – Changing Practices and Technology Over Time by Troy Richman

What's Changed in Practice and on the Ground?

- Introduction by Dr John Cooke
- Satellite-Based Soil Water Balance Modelling to Improve Estimates of Mallee Crop Water Use and Root Zone Drainage by Andy McAllister, Des Whitfield and Mohummad Abuzar
- Trends in Groundwater Across the Victorian Mallee by Andrew Telfer and Alison Charles
- Irrigation Drainage Trends by Dr Joanna Stephens and Charles Thompson
- Formation of Perched Aquifers Beneath Irrigated Almonds – Implications for Root Zone Drainage by Peter Cook, Sangita Dandekhya, Nick White and Dougal Currie

Future Challenges

- Salt Movement in South Australian Murray Floodplains by Dr Juliette Woods
- Climate Projections for the Mallee Region by Geoff Steendam

Science, salinity and sustainability

IAN LOWE

1

Salinity: topic of this forum

Science: systematic, organised knowledge

Sustainability: ability to be sustained !

2

The fundamental premise

- The future is not somewhere we are going, but something we are creating
- Many possible futures
- We should be trying to shape a sustainable future , i.e. one that can be *sustained* for the foreseeable future

3

4

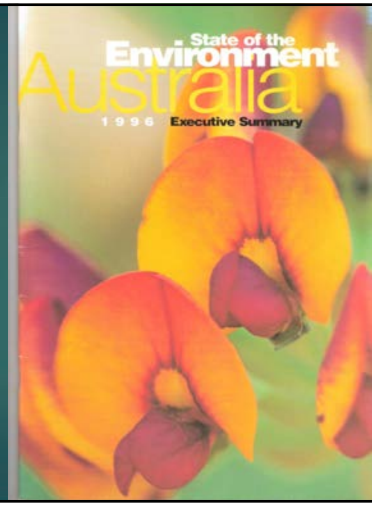
You can't choose which way the wind will blow, but you can set the sail.

4

CoAG 1992

- National Strategy for Ecologically Sustainable Development
  - "a path of economic progress that does not impair the welfare of future generations"
  - "equity within and between generations"
  - "recognition of the global dimension"
  - "protection of biological diversity and the maintenance of ecological processes and systems"

5



6

The conclusion

- "Australia has some very serious environmental problems. If we are to achieve our goal of ecological sustainability, these problems need to be dealt with immediately.
- "The problems are the cumulative consequences of population growth and distribution, lifestyles, technologies and demands on natural resources"

7

The five big problems

- Loss of our unique biodiversity
- Pressures on the coastal zone
- State of most inland rivers
- Degradation of rural land
- Greenhouse gas emissions

8

2016 SoE Report

- There are areas where the condition of the environment is poor and/or deteriorating. These include the more populated coastal areas and some of the growth areas within urban environments, where human pressure is greatest…and the extensive land – use zone

9

The driving forces

- The main pressures facing the Australian environment today are the same as in 2011: climate change, land – use change, habitat fragmentation and degradation, and invasive species…interactions between these and other pressures are resulting in cumulative impacts.

10

Changing pressures

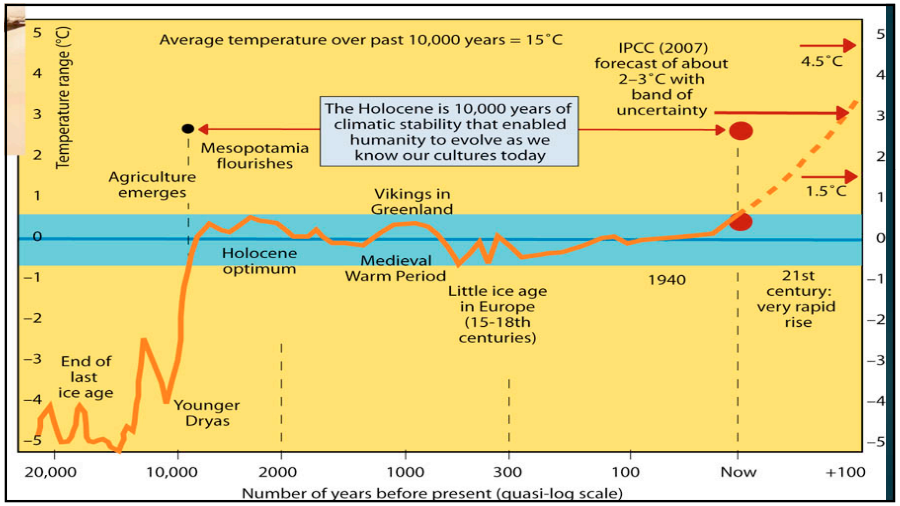
- “some individual pressures on the environment have decreased since 2011, such as those associated with air quality, poor agricultural practices, commercial fishing, and oil and gas exploration and production in Australia’s marine environment.
- “other pressures have increased — for example, those associated with coal mining and the coal-seam gas industry, habitat fragmentation and degradation, invasive species, litter…

11

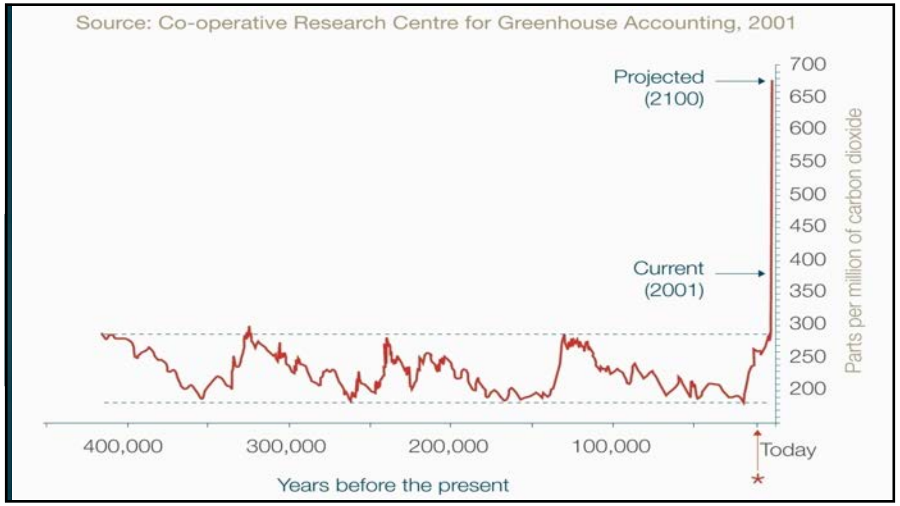
Climate change

- “Climate change is an increasingly important and pervasive pressure on all aspects of the Australian environment. It is altering the structure and function of natural ecosystems, and affecting heritage, economic activity and human wellbeing… the impacts of climate change are increasing, and some of these impacts may be irreversible.”

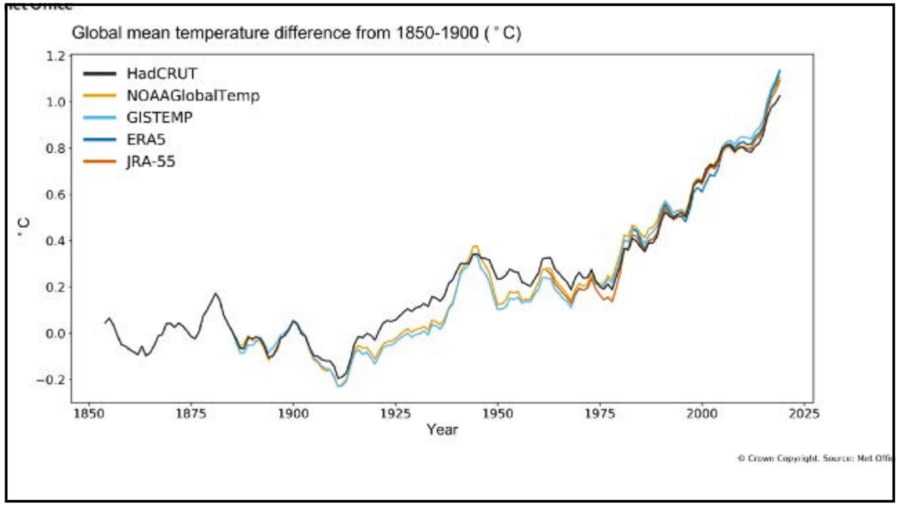
12


Average temperature over past 10,000 years = 15°C
Temperature range (°C)
IPCC (2007) forecast of about 2–3°C with band of uncertainty
4.5°C
1.5°C
The Holocene is 10,000 years of climatic stability that enabled humanity to evolve as we know our cultures today
Mesopotamia flourishes
Agriculture emerges
Vikings in Greenland
Holocene optimum
Medieval Warm Period
Little ice age in Europe (15-18th centuries)
1940
21st century: very rapid rise
End of last ice age
Younger Dryas
20,000
10,000
2000
1000
300
100
Now
+100
Number of years before present (quasi-log scale)

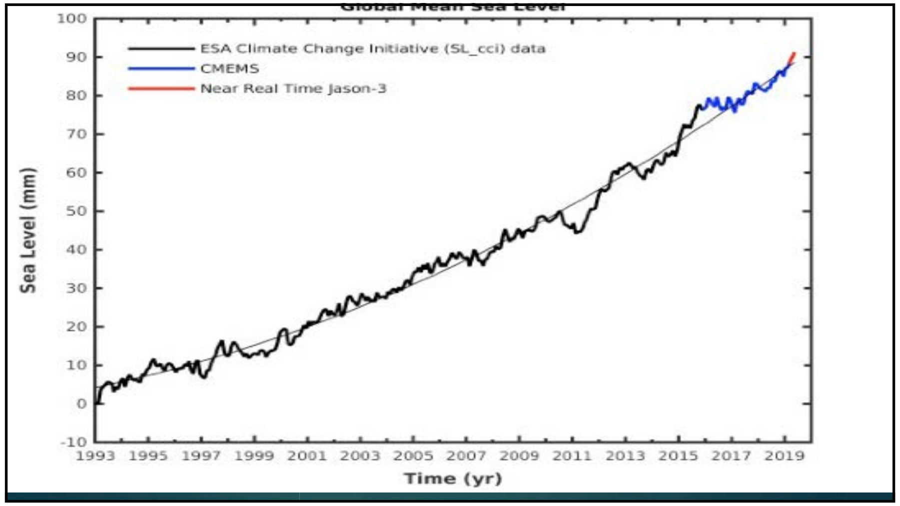
13


Source: Co-operative Research Centre for Greenhouse Accounting, 2001
Projected (2100)
Current (2001)
Parts per million of carbon dioxide
400,000
300,000
200,000
100,000
Today
Years before the present

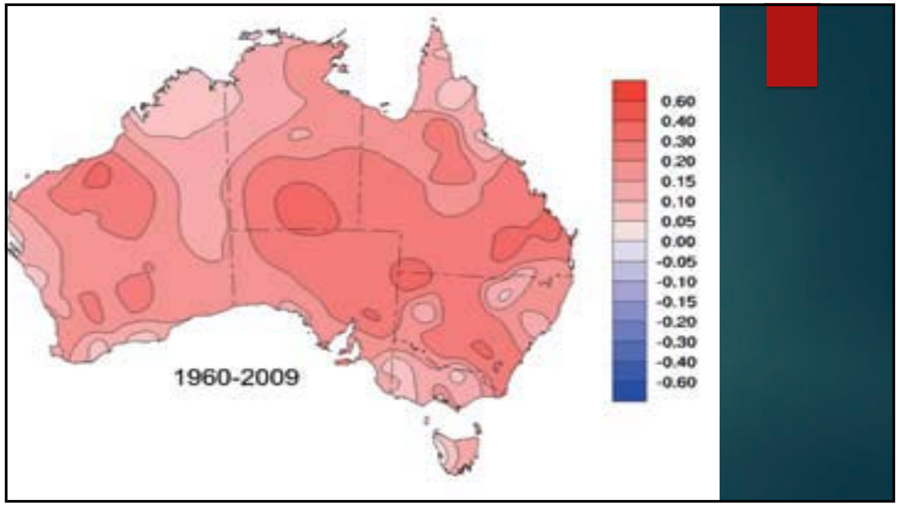
14


Global mean temperature difference from 1850-1900 (°C)
HadCRUT
NOAAGlobalTemp
GISTEMP
ERA5
JRA-55
°C
Year
© Crown Copyright. Source: Met Office

15

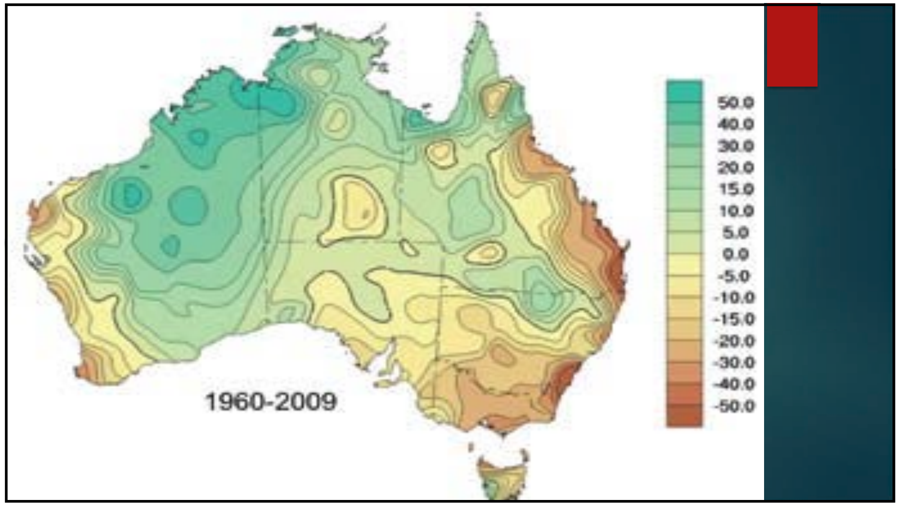

ESA Climate Change Initiative (SL_cci) data
CMEMS
Near Real Time Jason-3
Sea Level (mm)
Time (yr)

16



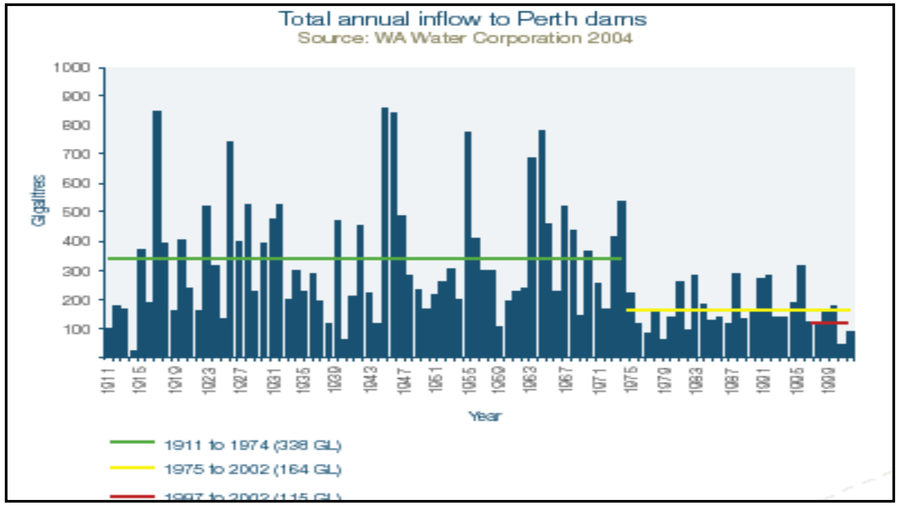
1960-2009
0.60
0.40
0.30
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.30
-0.40
-0.60

17



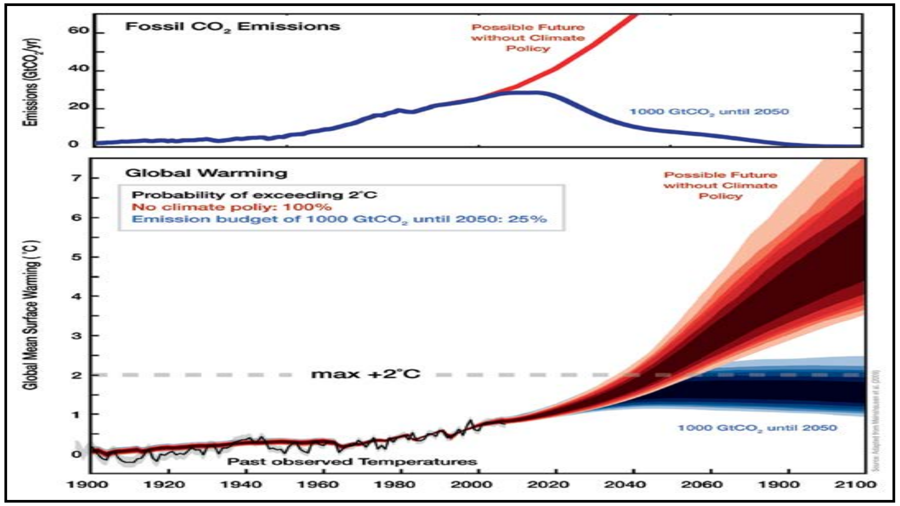
1960-2009
50.0
40.0
30.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-30.0
-40.0
-50.0

18



Total annual inflow to Perth dams
Source: WA Water Corporation 2004
Gigalitres
Year
1911 to 1974 (338 GL)
1975 to 2002 (164 GL)

19



Fossil CO₂ Emissions
Emissions (GtCO₂/yr)
Possible Future without Climate Policy
1000 GtCO₂ until 2050
Global Warming
Probability of exceeding 2°C
No climate poliy: 100%
Emission budget of 1000 GtCO₂ until 2050: 25%
Global Mean Surface Warming (°C)
Possible Future without Climate Policy
max +2°C
1000 GtCO₂ until 2050
Past observed Temperatures

20

21

Ian Lowe 11 February 2020

To have a **better than even** chance of keeping global average temperature rise below 2°C, the world would need to be emitting **less than half** the 2000 amount of CO_2 by 2050.

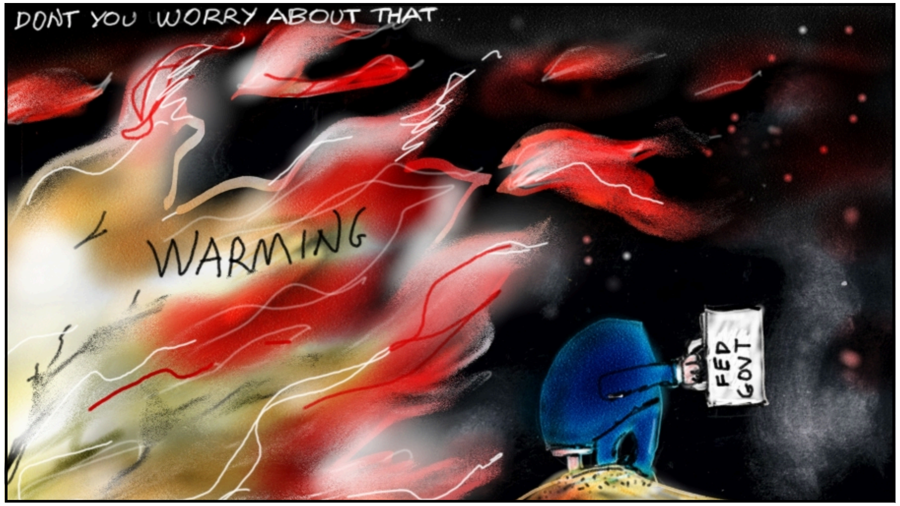
So global emissions need to peak by 2020 and then decline rapidly.

21

Paris 2015 agreement

- Goal: keep average temp. Increase below 2 degrees
- "efforts to limit rise to 1.5 degrees"
- "economy – wide emission reduction targets" for OECD
- Australia agreed to cut 2005 levels 26-28 % by 2030
- N.B. This would be > 50 % per head, ~ 65 % / GDP
- Finkel: "no way Australia can reduce carbon levels to what was promised in the Paris agreement"

22



23

Water quality

- **"Since 2011, there have been noticeable local improvements in water quality in the Murray – Darling Basin.** In more populated regions, inland water quality is in moderate to very poor condition. **In most regions, the condition of Australia's groundwater is poor."**

24

S.R. Morton et al, The Big Ecological Questions Inhibiting Effective Environmental Management in Australia, Austral. Ecology 34, 1-9 (2009)

- "Increasingly, managers and policy-makers will be called on to use the present state of scientific knowledge to supply reasonable inferences for action based on imperfect knowledge."
- "enough information already available to develop effective policy and management to address several significant ecological issues."
- "participatory research, co-production of knowledge and adaptive management are central"

25

Areas of continuing research

- Alteration of natural habitats
- Invasive species
- Altered fire regimes
- Water extraction

26

Water extraction and use

- Loss of species & ecosystem services from watercourses, wetlands & groundwater-dependent ecosystems
- Likely climate change accelerating impacts
- Over-exploitation [and pollution?] of groundwater
- Reconciling human demands with environmental flows to ensure resilience of rivers, wetlands and estuaries
- Need for more effective use of extracted water

27

Predicted impacts of climate change

28

- Significantly hotter, especially inland
- Long-term drying trend, increased risk of drought
- More severe storm events, flooding
- Greater risk severe heatwaves

28

ABARE projections

29

- Australian production of wheat, beef and dairy products could decline by 9-10% by 2030 and 13-19 % by 2050
- Agricultural exports projected to decline 11 - 63 % by 2030 & 15 - 79 % by 2050
- Murray – Darling Basin "one of the most adversely affected regions"
- Adaptation measures "particularly important"

Ian Lowe

29

Adaptation

30

- Agriculture needs to plan for hotter, drier, less predictable weather
- Water conservation ***crucial***
- Public health: heat, disease
- Social resilience
- Emergency management

Ian Lowe

30

Mark Howden et al, 2007

31

- "many potential adaptation options"
- "implementation of these options is likely to have substantial benefits under moderate climate change for some cropping systems"
- "there are limits to their effectiveness under more severe climate changes"

Proceedings US National Academy of Sciences, Dec. 2007

Ian Lowe

31

Murray - Darling system

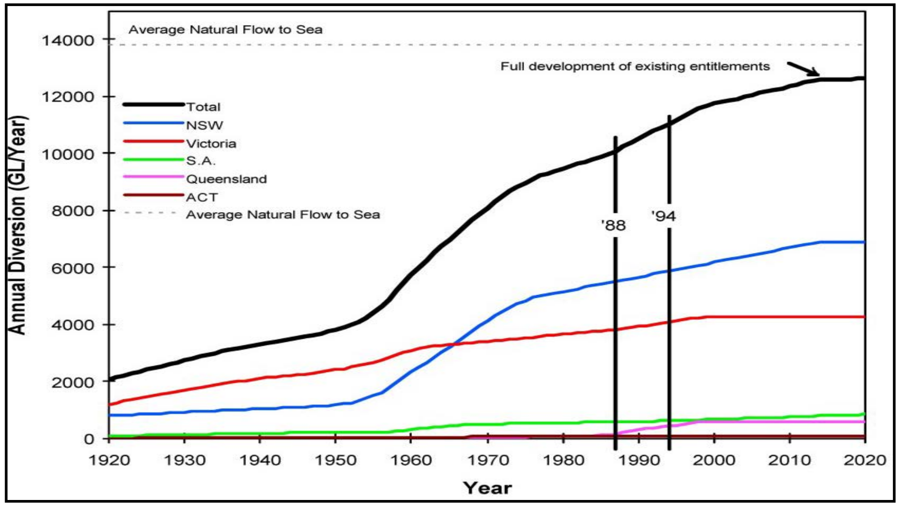
32

"vegetation change, increases in farm dams, increased groundwater use and climate change could reduce the flow in the river Murray by 2000 GL/year by 2025"

\- Dr Richard Davis, LWA

Ian Lowe

32



33

Product value, $ / Megalitre, 2006

34

Pasture	200-300?
Rice	230
Cotton	750
Grapes	1600
Fruit	2400
Vegetables	2000-20,000

Ian Lowe

34

Sensible allocation ?

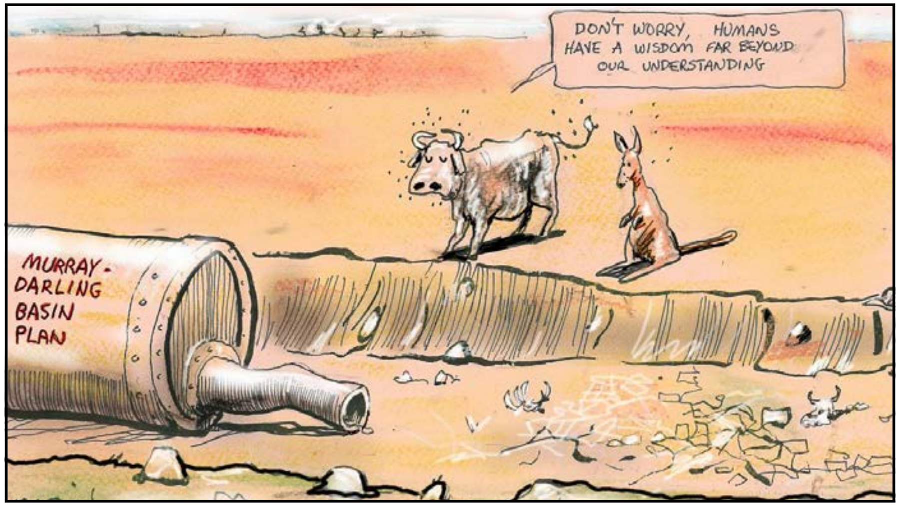
35

Land irrigated for dairy pasture was greater than the sum of fruit and tree nuts, grapes, rice, sheep, vegetables, hay, legumes and oil seeds combined…

[>50% all irrigation water]

Ian Lowe

35



36

Efficient use ?

37

Ian Lowe

- Twenty years ago, most irrigation water still flowed in open channels
- Most of the water that reached fields was not delivered efficiently to crops
- This still happens further north....
- More water evaporated than was used by crops
- Dramatic improvements in recent time

37

Recent changes in Mallee CMA

- Piping of extracted water
- From furrow to drip irrigation
- Changes in product range
- Water trading
- Increasing average farm size
- Much better management of salinity
- Improved economic and environmental outcomes

38

A systems approach

- Making reasonable inferences from existing knowledge
- Recognising connectivity
- Implementing action plans
- Monitoring changes over time
- Adaptive management based on responses

39

Vision for a Sustainable Region

Sustainability

Sustainability is about living within our means. It is about managing our consumption of resources and balancing environmental, economic and social outcomes. It means improving our quality of life, but making that improvement without leaving a burden on the future generations.

Looking after our Environment

Environmental Sustainability is about reducing our impact on the environment by protecting our air, water and land, our native flora and fauna. It means reducing the load on our natural resources, such as water and fuels for energy, and decreasing our production of waste.

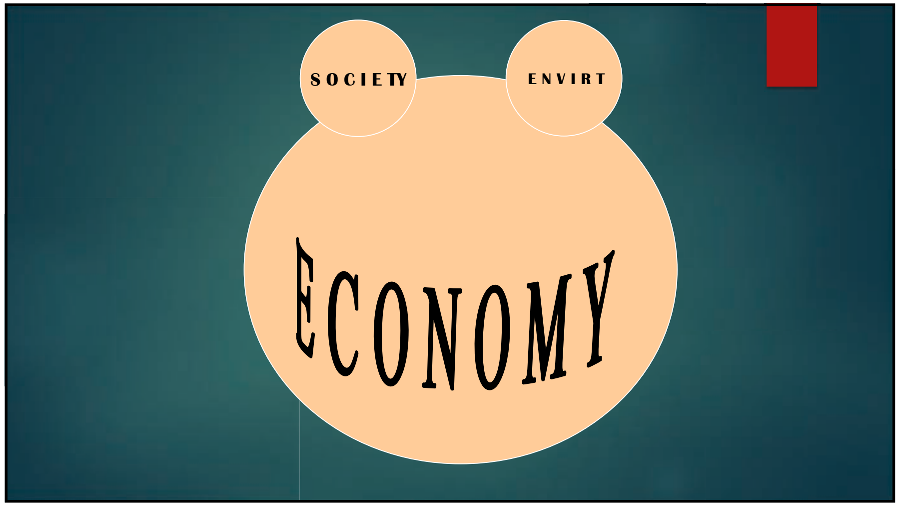
A Better Place to Live

Liveability is about making here a better place to live. It means being able to walk to your corner shop, local school, park or bus stop, as well as providing us with a choice of housing that meets our needs.

Supporting our Economy

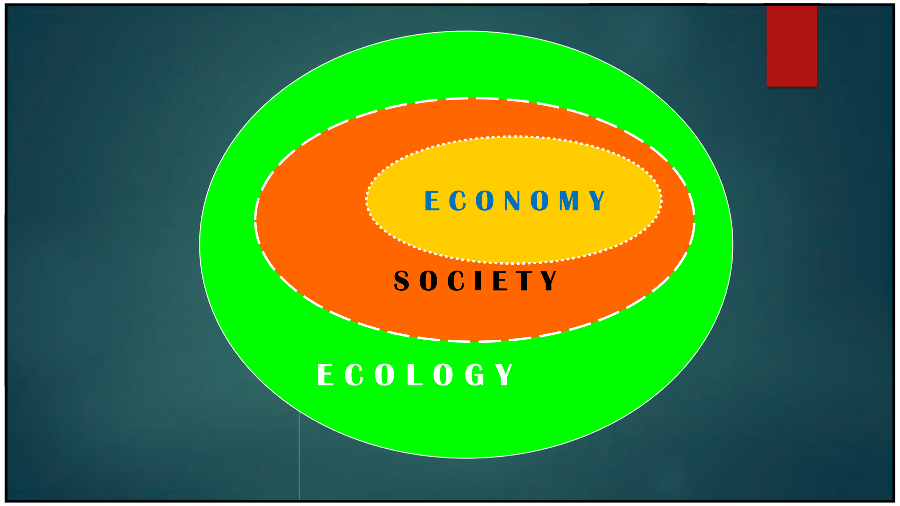
Competitiveness is about ensuring our long term economic prosperity. It means providing quality infrastructure and services to service our jobs and the economy, and supporting urban centres

40



41

42



43

Conclusion

- Despite CoAG 1992, no overall vision or national policy
- Environmental decline continues
- Accelerating climate change a threat
- Recent actions in Mallee CMA show that concerted action can make a real difference
- Learning by doing, adaptive management for sustainable futures

44

45

Basin Salinity Management 2030

(BSM2030)

Dr Asitha Katupitiya – MDBA
Mallee regional salinity forum

19 November 2019

Australian Government

MURRAY–DARLING BASIN AUTHORITY

1

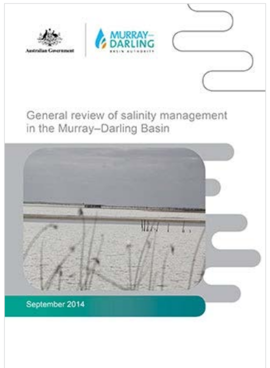
Outline

- ➢ What's changed since 2012
  - ➢ General review of salinity management - 2014
  - ➢ Basin Salinity Management 2030 (BSM2030) – 2015

2

First step…2014 salinity review

- ➢ General review of salinity management in the Basin
  - ➢ Looked at current status of play
  - ➢ Opportunities for cost savings?
  - ➢ Documented all technical details, including salinity modelling
  - ➢ Future salinity management requirements
  - ➢ Reference base for pitching a salinity strategy for next 15 years

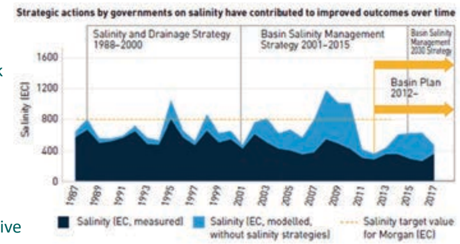


3

The third phase - 2016 to 2030 Basin Salinity Management 2030

General Approach

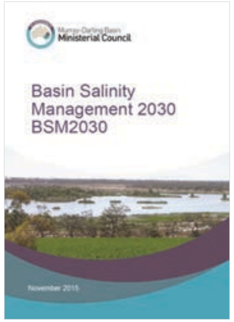
- ➢ Keep good bits from the BSMS
- ➢ Maintain the salinity accountability framework
  - • Risk-based approach
  - • Streamline mature processes
- ➢ Bring in contemporary issues
  - • E-water
  - • Flow management
- ➢ Explore opportunities for efficient and innovative SIS operation and learn capability for the future
- ➢ Invest in knowledge priorities to reduce key uncertainty and prepare for next phase
- ➢ New strategy agreed by Ministers in November 2015



4

BSM2030 - implementation

- Amend Schedule B
- Accountability framework - manage Salinity Registers
- Review register entries and models (including the MDBA river model) used for salinity impact assessments as per the review plan
- Trial responsive management of SIS
- BSM2030 reporting and audit and salinity forum
- Coordination BSM2030 implementation with states (through Basin Salinity Management Advisory Panel)
- Prepare Basin Salinity Management procedures
- Invest in key knowledge priorities



5

Thank you.

Office locations
Adelaide
Albury-Wodonga
Canberra
Goondiwindi
Toowoomba

mdba.gov.au 1800 630 114
engagement@mdba.gov.au

6

Regional Salinity Forum – Mallee

Water for Victoria

Jenn Learmonth
Acting Senior Manager,
Sustainable Irrigation
19 November 2019

Environment, Land, Water and Planning

1

Salinity Management in Victoria

DELWP launched Water for Victoria in 2016

Priorities for the future include:

- **continuing to manage salinity impacts to the Murray River and tributaries**
- **remining compliant with the Murray-Darling Basin Agreement**
- **continue to progress the required reviews of accountable actions**
- **continue the implementation of BSM2030**
- **ensuring all irrigation development is accounted for**
- **accounting for environmental water and climate change**
- **Mallee salinity management**

2

Mallee Irrigation Region
Land & Water Management Plan

Regional Salinity Forum 19 Nov 2019

Don Arnold
Manager Salinity & Irrigation

1

The Initial Victorian Mallee Salinity Response

The Regional Approach - Community salinity management plans

Salinity Management Plans in irrigation area established:

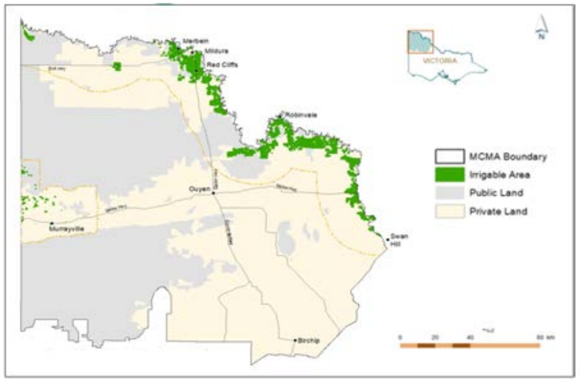
- Original Salinity Framework, focused on
  - Increased irrigation efficiency
  - Improved irrigation drainage disposal
  - Salinity Impact Zones
  - A beneficiary pays principle
  - Management of new irrigation development

2

What Informs Todays Salinity Management

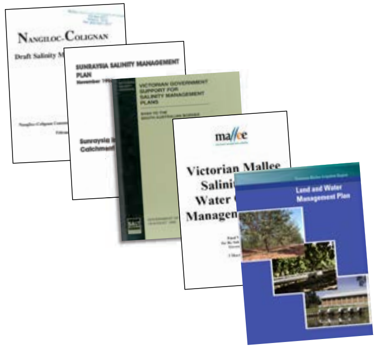
3

Area of the LWMP



4

2019 LWMP: Seeks to



- Maintains moment of past plans
- Meets BSM2030 obligations
- Seeks continuous improvement
- Refine Salinity Mgt Framework
- Renew rehabilitation effort
- Supports Aboriginal partnerships
- Encourages resilient & forward looking irrigation communities.

mallee

5

Mallee Model Refinement

Mallee Salinity Workshop Presentation

19 November 2019

JACOBS

www.jacobs.com | worldwide

1

Agenda

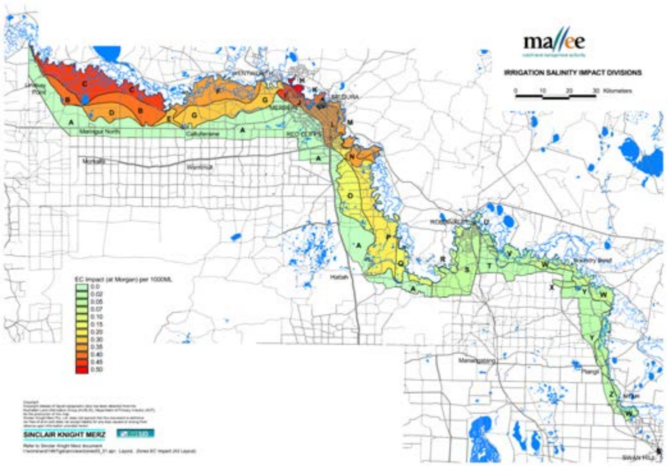
1. Project Purpose
2. Overview of Approach
3. Findings

2

Project Purpose

- upgrade and refine a number of existing groundwater models;
- develop a groundwater model that merges existing models in the region of the Murray River in the Victorian Mallee between the town of Nyah in the east and Hattah Lakes (Wemen);
- contribute to delivering on Victorian government commitment to improve salinity management in the Victorian Mallee irrigation region by "…*updating the contemporary knowledge of the Victorian Mallee salinity impacts…consistent with the Basin Salinity Management Strategy (BSM) 2030*" as documented in the Victorian Water for Victoria Water Plan (DELWP 2016);
- Gain accreditation of the models for use for the purpose of Salinity Impact estimation for the BSM2030 salinity registers.

3

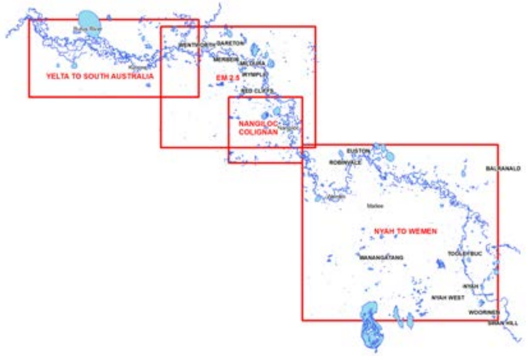


4

Objective

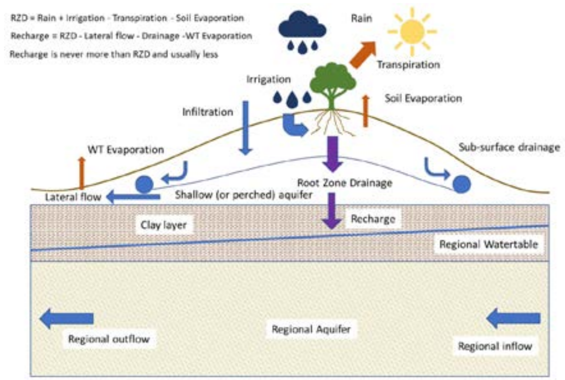
- to improve the confidence with which numerical models can predict salinity impacts that may arise from irrigation developments in the Victorian Mallee
- This is a "model review" activity under the BSM2030
  - It is not an "accountable action review"

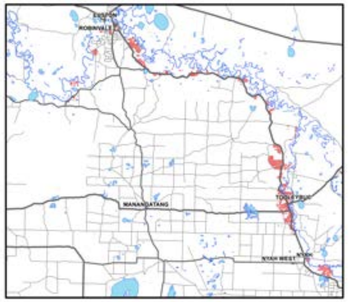
Model Areas

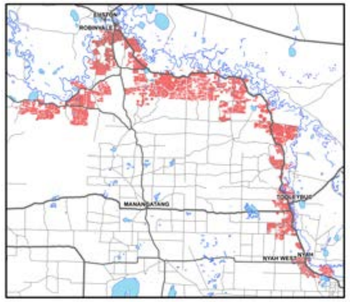


Overview

- Models were refined and re-calibrated to groundwater observations from 1975 to 2017
- Predictive models have been run from 2017 to 2100 with a range of irrigation scenarios
- Formal uncertainty analysis was performed
- The models have been accredited



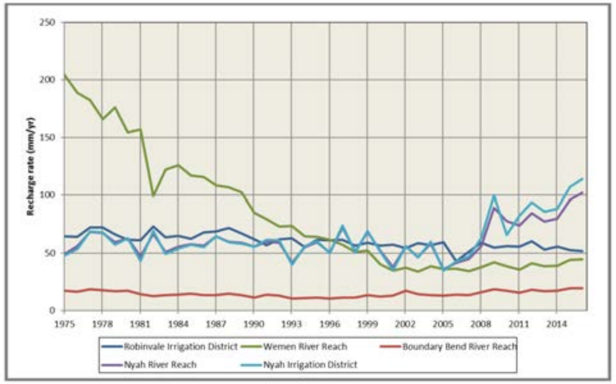




9

9

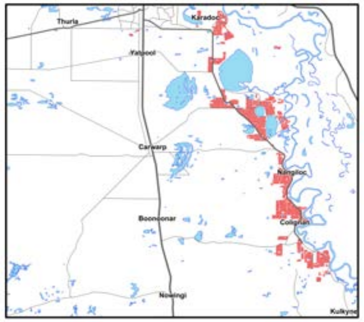
Calibrated Recharge – Nyah to Wemen

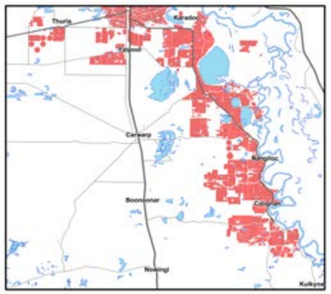


10

JACOBS

10

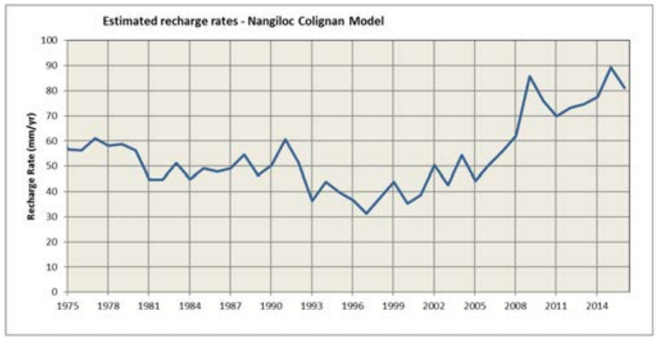




11

11

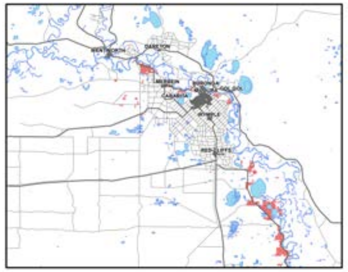
Calibrated Recharge – Nangiloc – Colignan

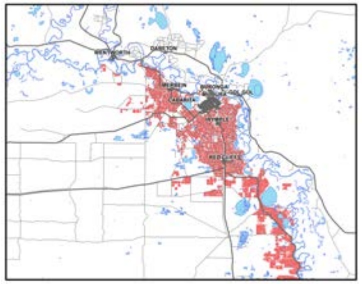


12

JACOBS

12

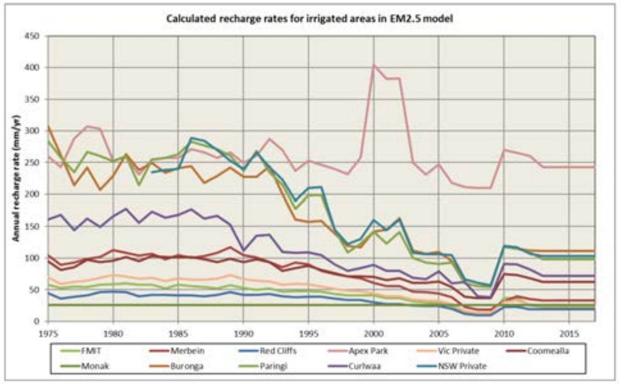




13

13

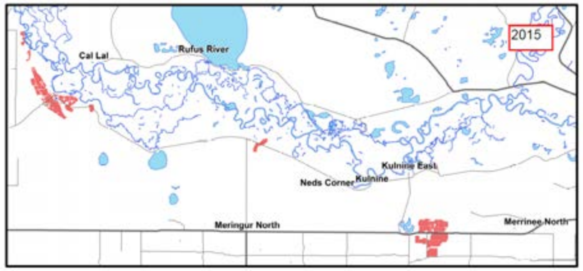
Calibrated Recharge – EM2



14

JACOBS

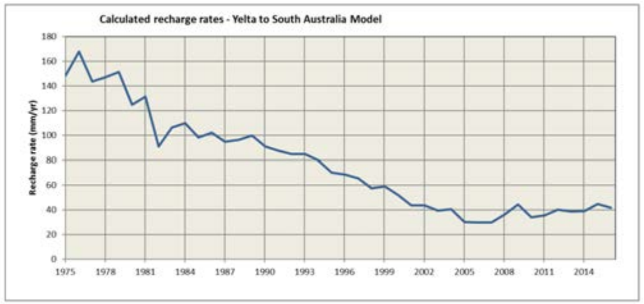
14



15

15

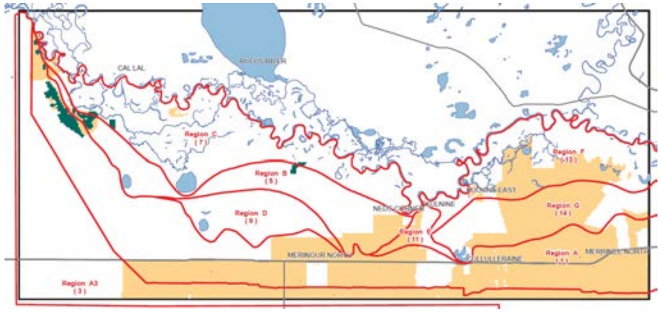
Calibrated Recharge – Yelta



16

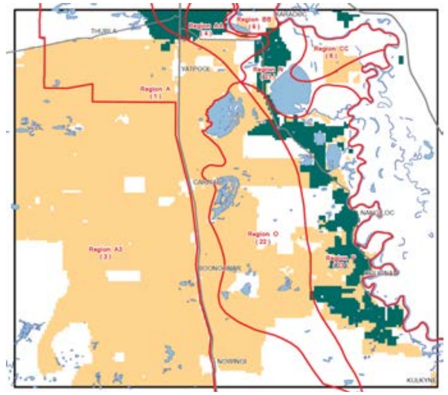
JACOBS

16



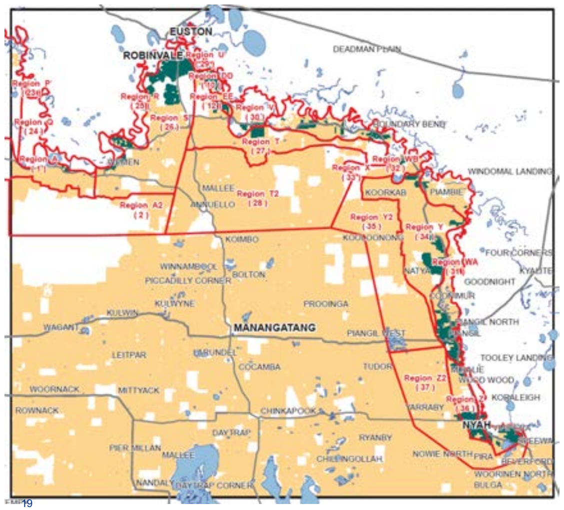
17

17



18

18



19

19

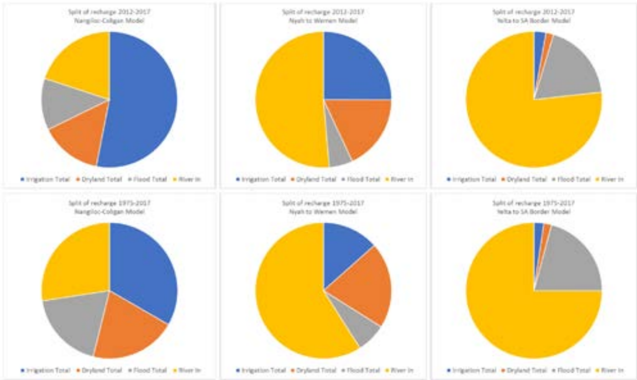
Model findings

- River flooding and the effect of high river levels is very important part of controlling the discharge to the river, this makes the river operations (and flood pattern) important for salt export timing;
- ET on the floodplain is a significant part of the overall discharge process
- Many areas show small groundwater response to extensive irrigation over many years (Yelta, Boundary Bend)
- Subsurface drains are an important control
- Clay layers and perched aquifers are locally very significant for river impact
- Irrigation management practices and trends influence the timing of effects
- Overall the salt load impact is less than the analytical approach
- Nangiloc – Colignan area has seen a significant reduction in the expected salt discharge to the river
  - Was an expected result
  - Due to effect of drains and ET across the irrigation area.

20

20

Where’s the Recharge From?



Predictive Uncertainty

Model area	Parameter	Contribution to uncertainty
Yelta to South Australia	River conductance	The final groundwater flux is highly dependent on the river conductance. Perfect knowledge of conductance would reduce groundwater flux variance by approximately 65%.
EM2	River Conductance	The final groundwater flux is highly dependent on the river conductance. Perfect knowledge of conductance would reduce groundwater flux variance by approximately 50%.
Nanglioc-Colignan	River conductance Closely followed by storage	The final groundwater flux is highly dependent on the river conductance. Perfect knowledge of conductance would reduce groundwater flux variance by approximately 80%.
Nyah to Wemen	River conductance Followed closely by storage.	The final groundwater flux is dependent on river conductance used in the model. River conductance provides approximately 60% of the variance Approximately 50% of the variance can be removed if storage is known.

Table 8: Salt loads estimated for the Nyah to Wemen Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact (to be confirmed)
2000	150.1	149.5	-0.6	-0.10
2015	109.5	109.4	-0.1	-0.02
2030	130.8	146.7	15.9	2.58
2050	175.2	208.4	33.2	5.38
2100	192.7	235.9	43.2	7.00

Table 7: Salt loads estimated for the Nangiloc – Colignan Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact (to be confirmed)
2000	165.71	166.06	0.32	0.05
2015	140.88	142.69	1.81	0.29
2030	148.94	155.58	6.64	1.08
2050	175.98	184.43	8.45	1.37
2100	170.47	178.94	8.47	1.37

Table 6: Salt loads estimated for the EM2 Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact (to be confirmed)
2000	244.40	243.60	-0.80	-0.13
2015	261.93	250.23	-11.70	-1.90
2030	295.66	272.45	-23.21	-3.76
2050	348.87	319.09	-29.78	-4.83
2100	336.06	303.61	-32.45	-5.26

JACOBS

Table 5: Salt loads estimated for the Yelta to South Australia Model

Year	Average Salt Load Scenario 0 [t/d]	Average Salt Load Scenario 1 [t/d]	Increased Salt Load [t/d]	Estimated EC Impact at Morgan (to be confirmed)
2000	79.32	76.63	-2.69	-0.44
2015	57.24	54.65	-2.59	-0.42
2030	84.33	83.59	-0.64	-0.10
2050	100.64	100.66	0.02	0.00
2100	107.40	107.58	0.18	0.03

JACOBS

JACOBS

www.jacobs.com | worldwide

Disclaimer

Important

The material in this presentation has been prepared by Jacobs®.

Copyright and other intellectual property rights in this presentation vest exclusively with Jacobs. Apart from any use permitted under applicable copyright legislation, no part of this work may in any form or by any means (electronic, graphic, mechanical, photocopying, recording or otherwise) be reproduced, copied, stored in a retrieval system or transmitted without prior written permission.

Jacobs is a trademark of Jacobs Engineering Group Inc.

JACOBS

Mapping Irrigation Development and River Salinity Impact Zones in the Victorian Mallee 1997 to 2018

Sue Argus
SunRISE Mapping and Research
Mildura

Mallee CMA Regional Salinity Forum
19 November 2019

11/2/20 1

1

SunRISE Mapping

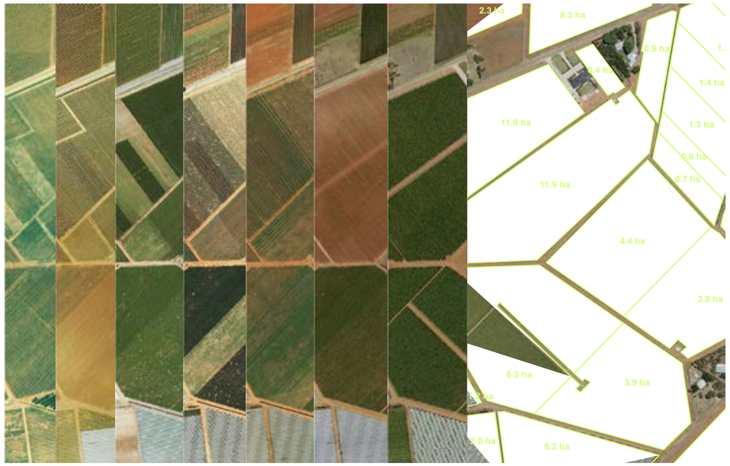
Mapping and information used by:

- The Mallee CMA to better understand the dynamics of irrigation and its impact on water quality and salinity
- Other land & water management agencies
- Irrigators - planning & management
- Industry bodies - planning & management

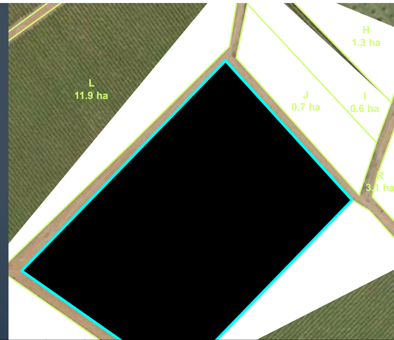
2

2

1997 2000 2003 2006 2009 2012 2015 2018



3

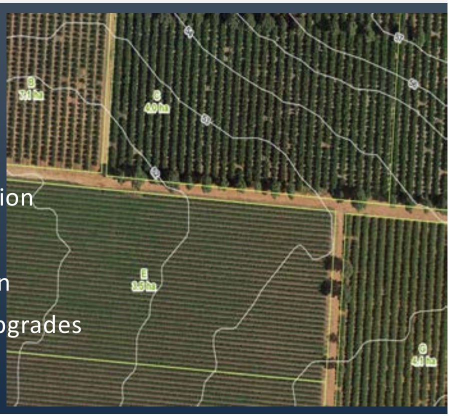


Property	Patch	Hectares	Row	Plant	Trees	Type	Category	Variety	Rootstock	Year	Irrigation
SMITH B	A	1.0	7.32	6.71	68	FruitTree	Avocado	Avocado		2010	Lowlevel
SMITH B	J	0.7	7.32	6.71	84	FruitTree	Avocado	Avocado		2016	Lowlevel
SMITH B	L	11.9	3.35	2.44		Grapevine	GrapeWine	Shiraz	OwnRoots	2000	Lowlevel
SMITH B	H	1.3	7.32	6.71	123	FruitTree	Avocado	Avocado		2012	Lowlevel
SMITH B	C	0.8	7.32	6.71	85	FruitTree	Avocado	Avocado		2016	Lowlevel
SMITH B	F	1.4	7.32	6.71	147	FruitTree	Avocado	Avocado		2016	Lowlevel
SMITH B	D	1.5	3.35	2.44		Grapevine	GrapeWine	Gordo	OwnRoots	2000	Lowlevel
SMITH B	B	0.6	7.32	6.71	80	FruitTree	Avocado	Hass		1991	Lowlevel
SMITH B	O1	4.4	3.35	2.44		Grapevine	GrapeTable	Flame Seedless	Ramsey	2015	Drip
SMITH B	P	7.1	3.35	2.44		Grapevine	GrapeTable	Midnight Beauty	Paulsen1103	2015	Drip
SMITH B	O2	3.9	3.35	2.44		Grapevine	GrapeTable	Crimson Seedless	Ruggeri140	2015	Drip

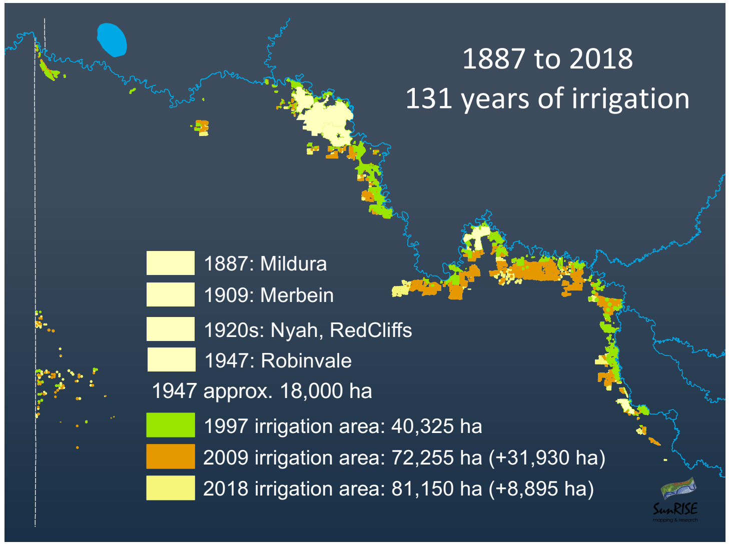
4

Farm maps

- New development
- Redevelopment
- Export registration
- Freshcare certification
- Spray diary records
- Organic certification
- Irrigation system upgrades

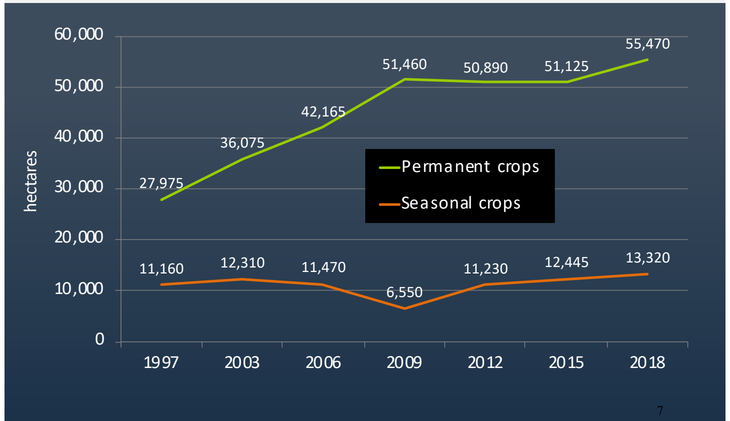


5



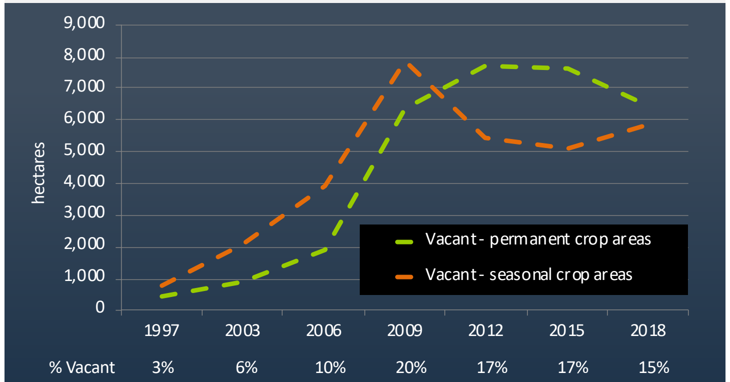
6

Profile of permanent and seasonal crops



7

Profile of vacant/not irrigated areas



8

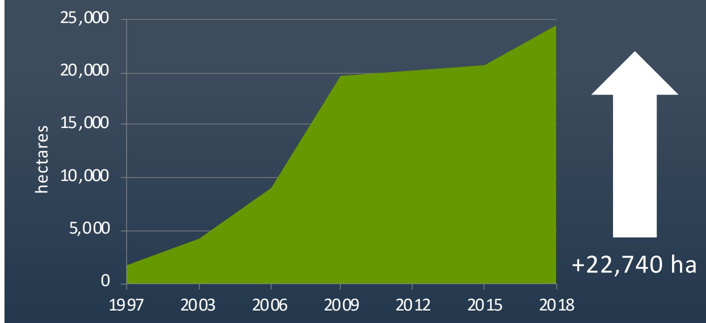
Crop types in 2018

	Crop type	2018	% of 2018
Permanent	Grape Dried	3,145	4%
	Grape Table	8,965	11%
	Grape Wine	8,050	10%
	Citrus	4,135	5%
	Fruit Olive	3,815	5%
	Fruit Other	1,800	2%
	Nut Almond	24,485	30%
	Nut Other	490	1%
	Miscellaneous	585	1%
Seasonal	Field Crop	5,685	7%
	Veg. Carrot	1,565	2%
	Veg. Potato	3,410	4%
	Veg. Other	2,660	3%
	Vacant P	6,475	8%
	Vacant S	5,885	7%
Total (ha)		81,150	100%

9

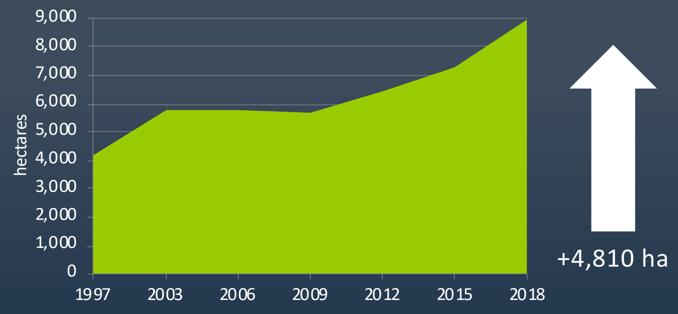
9

Almonds 1997 to 2018



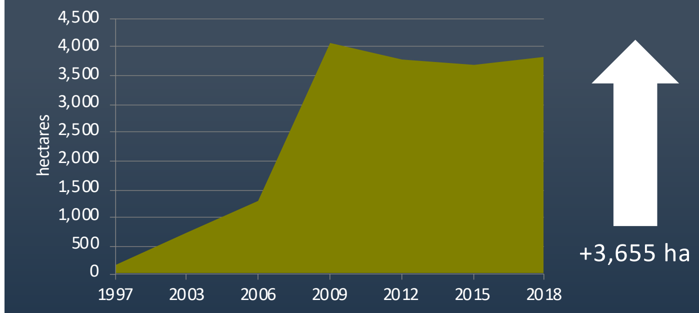
10

Table grapes 1997 to 2018

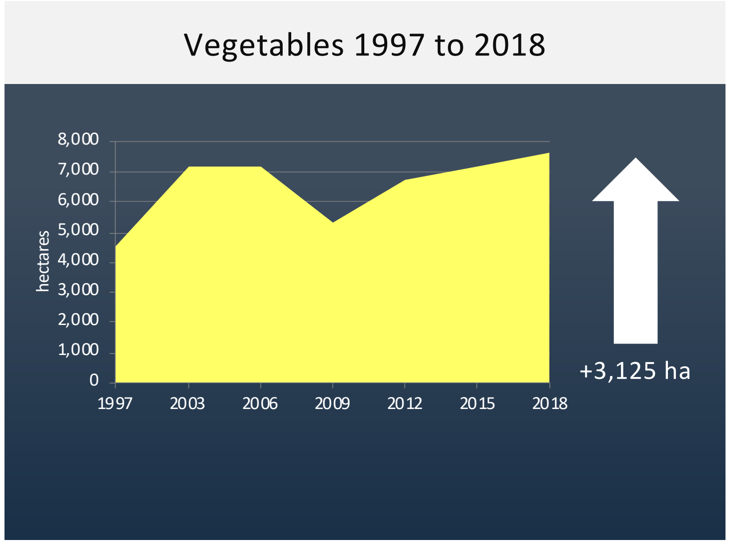


11

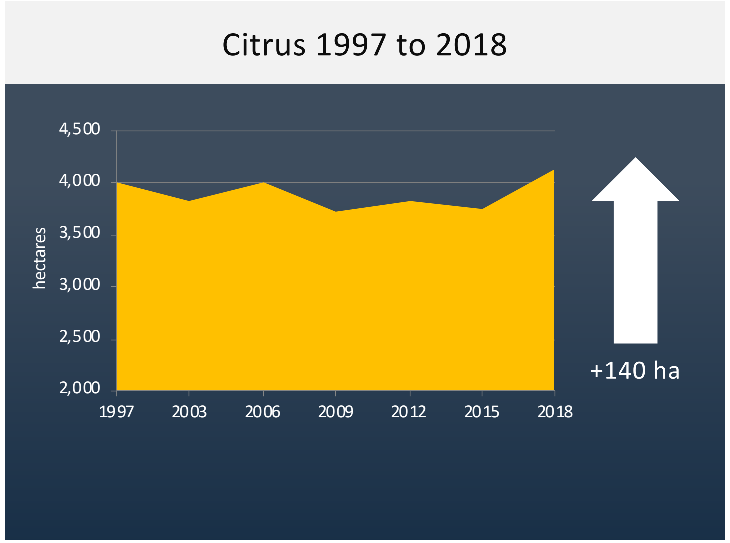
Olives 1997 to 2018



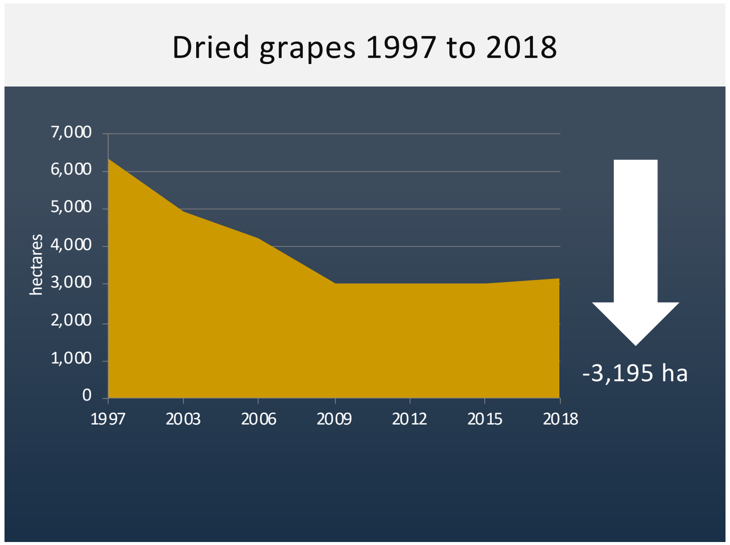
12


Vegetables 1997 to 2018
hectares
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1997
2003
2006
2009
2012
2015
2018
+3,125 ha

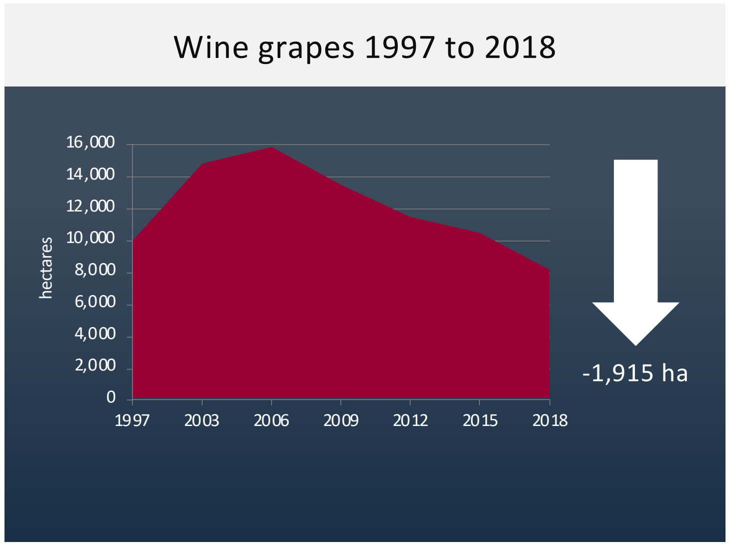
13


Citrus 1997 to 2018
hectares
4,500
4,000
3,500
3,000
2,500
2,000
1997
2003
2006
2009
2012
2015
2018
+140 ha

14

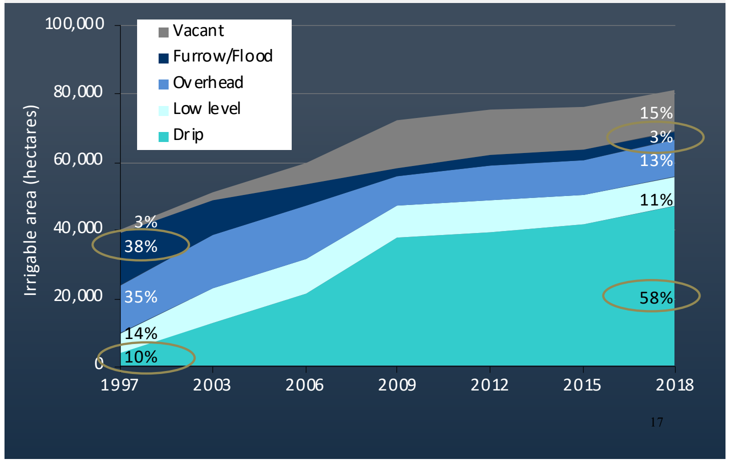

Dried grapes 1997 to 2018
hectares
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1997
2003
2006
2009
2012
2015
2018
-3,195 ha

15


Wine grapes 1997 to 2018
hectares
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1997
2003
2006
2009
2012
2015
2018
-1,915 ha

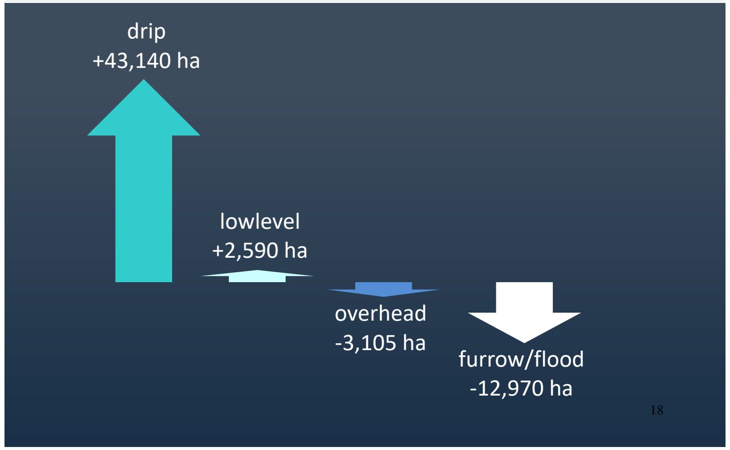
16

Irrigation methods 1997 to 2018



17

Change in irrigation methods 1997 to 2018



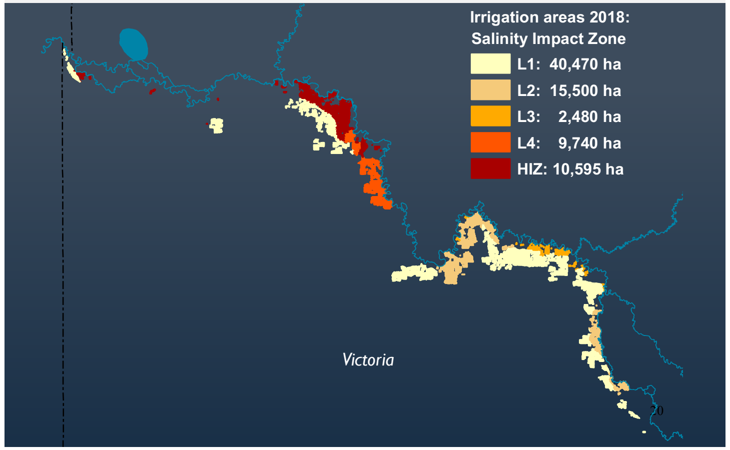
18

Irrigation properties 1997 to 2018

	1997	2018	Change
Number of properties:	2,448	1,925	-523 (-21%)
Average size (irrigable area):	16 ha	42 ha	
Properties > 40 ha (irrigable):	159	244	+85 (+53%)
Properties < 40 ha (irrigable):	2,289	1,681	-608 (-27%)

19

Irrigation area & salinity impact zones in 2018



20

Change in salinity impact zones 1997 to 2018

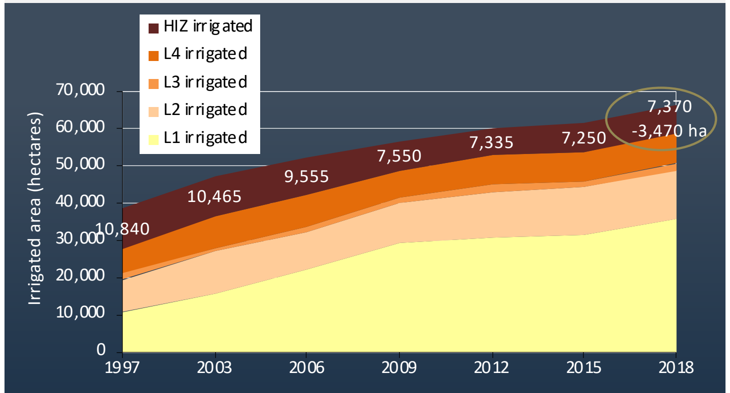
Salinity zone	1997 (ha)	Retired ha	Retired %	Expansion ha	Expansion %	2018 (ha)	Change 1997-2018
L1	11,020	-210	11%	+29,660	73%	40,470	+29,450
L2	8,960	-175	9%	+6,715	16%	15,500	+6,540
L3	1,710	-165	9%	+935	2%	2,480	+770
L4	6,615	-40	2%	+3,155	8%	9,730	+3,115
HIZ	11,435	-1,300	69%	+460	1%	10,595	-840
Total*	39,740	-1,890	100%	+40,925	100%	78,775	+39,035

* Total irrigable area

21

21

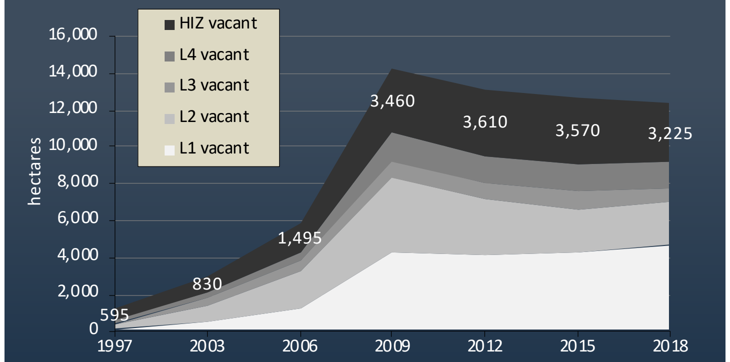
Salinity impact zones – irrigated areas



22

22

Salinity impact zones – vacant areas



23

23

Achieving and Maintaining Irrigation Best Practices for the Mallee

John Hornbuckle & Carlos Ballester-Lurbe

1

TALK OUTLINE

- Background \ Review objectives \ Approach taken
- Benchmarking Irrigation Practices against international frameworks
- Review of technical aspects of VMIDG
- Strengthening Irrigation BMP’s
- Summary

2

BACKGROUND

- Review current <u>documentation and processes</u> in place within the Victorian Mallee CMA irrigation regions, aimed at improving irrigation best practice and identifying any potential gaps that may be leading to non-optimal outcomes.
- Review was desktop based ~ 5 week duration.

3

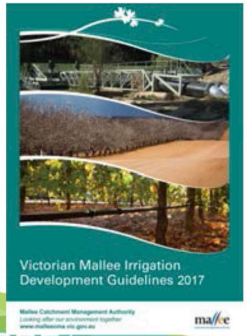
Review Objectives

- Briefly review contemporary irrigation management practices in the Mallee.
- Perform a desktop benchmarking of contemporary practices for irrigation in the Victorian Mallee against national and international best management practices for irrigation (in the form of a gap analysis).
- Recommend options that could be considered to fill any gap and reach (or maintain) best management practices.

4

Review approach

Existing Documentation



Stakeholder discussions

5

Benchmarking Irrigation Practices against international frameworks

- Two frameworks used to assess Vic Mallee Irrigation Processes and practices

  – Food and Agricultural Organisations (FAO) Sustainability Assessment of Food and Agricultural Systems (SAFA)

  – International Commission on Irrigation and Drainage (ICID) guidelines for benchmarking performance in irrigation and drainage systems

6

Assessment against SAFA indicators for sustainable agricultural systems

- Internationally, SAFA (Sustainability Assessment of Food and Agricultural Systems) provides a framework for assessing the sustainability of food and agricultural systems using a series of themes and key indicators.
- A 'Dark green score' indicates that the sustainability indicator or practice is being considered and applied within the operation while a 'Red score' indicates that the application of the indicator is not being considered within the operation. A 'Limitations' score indicates that elements of the indicator are being considered but these are not being applied

7

Vic Mallee comparison against SAFA Framework

Water

Indicator Name	Mallee Rating
Water Conservation Target	Green
Water Conservation Practices	Green
Ground and Surface Water Withdrawals	Green
Clean Water Target	Green
Water Pollution Prevention Practices	Green
Concentration of Water Pollutants	Green
Wastewater Quality	Green

Land

Indicator Name	Mallee Rating
Soil Improvement Practices	Green
Soil Physical Structure	Green
Soil Chemical Quality	Green
Soil Biological Quality	Limitations
Soil Organic Matter	Limitations
Land Conservation and Rehabilitation Plan	Green
Land Conservation and Rehabilitation Practices	Green
Net Loss/Gain of Productive Land	Green

- Favourable score across all but two indicators
- Soil Biological and Soil organic matter only two areas that are not specifically addressed/measured in development guidelines, however are addressed on a secondary basis through water holding capacity/infiltration

8

Assessment against ICID guidelines for benchmarking performance in irrigation and drainage systems

Environmental performance	Water quality: Salinity (mmhos/cm)	Electrical conductivity of periodically collected irrigation water samples Total daily measured water inflow to the irrigation system Electrical conductivity of periodically collected drainage water samples Total daily measured drainage water outflow from the irrigation system	✓
	Water quality: Biological (mg/litre)	Biological load of periodically collected irrigation water samples Total daily measured water inflow to the irrigation system Biological load of periodically collected drainage water samples Total daily measured drainage water outflow from the irrigation system	✓
	Water quality: Chemical (mg/litre)	Chemical load of periodically collected irrigation water samples Total daily measured water inflow to the irrigation system Chemical load of periodically collected drainage water samples Total daily measured drainage water outflow from the irrigation system	✓
	Average depth to watertable (m)	Periodic depth measurement to watertable	✓
	Change in watertable depth over time (m)	Periodic depth measurement to watertable over 5 year period	
	Salt balance (tonnes)	Periodic measurement of salt content of irrigation water Periodic measurement of salt content of drainage water	✓

Assessment against frameworks

- Victorian Mallee Irrigation Development Guidelines incorporate all the key framework indicators of maintaining environmental and sustainable best practice in irrigated agricultural systems when contrasted against international sustainability indicators.

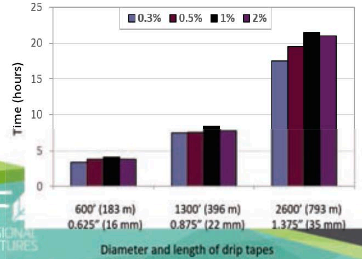
- Biological soil and water aspects are not as well covered in best management practices as salinity; however, this is a function of the major issue of salinity management within the Victorian Mallee irrigation areas and is the major threatening process from an irrigation development/management perspective on surrounding environments and ecosystems within the Mallee environment

Review of Technical Aspects of the VMIDG – Soil Survey

- 75x75m grid sampling + RAW still seen as critical for good irrigation design
- Seen as a major cost by some however <5% of development costs
- Options for use of electromagnetic surveys may offer useful information in terms of salinity management and potentially remote technologies in future may have the ability to replace traditional soil survey approaches currently used but it would need further R&D

Review of Technical Aspects of the VMIDG – Irrigation Design

- Individual designs beyond scope
- Matching irrigation valves/sets to soil water holding capacity is key
- Certified Designers
- One issue identified was unequal drainage from drip lines. Problematic with larger diameter lines and undulating fields.



Unequal drainage discharge from the last emitter on a drip tape, expressed as equivalent hours of operation across four different slopes (0.3, 0.5, 1 and 2%), with typical tape diameters and lengths. Adapted from Burt and Styles (2007).

Review of Technical Aspects of the VMIDG – Management and Monitoring of Irrigation

- Warrant's further consideration in its implementation and on-going use.
- Difficult from the guidelines to gain a clear understanding when a plan for monitoring groundwater levels and quality was triggered within the Irrigation and Drainage Plan (IDP).
- Not clear how this data was utilised and how assessment of it was communicated back to the irrigator or wider community.
- This same process for mandated soil moisture monitoring/ irrigation scheduling is also a weakness in the current implementation of the development guidelines

13

Review of Technical Aspects of the VMIDG – Annual Use Limits

- Technically sound and relies on the international Standard "FAO 56 Crop evapotranspiration – guidelines for computing crop water requirements"
- AUL approach might become less important as the price of irrigation water increases and possibly alternative approaches could be used.
- AUL is based on a yearly or annual time step, which is not conductive to drainage management under current and future conditions . Future approaches might consider shorter time steps as drainage events under present day irrigation management are usually of short durations.

14

Review of Technical Aspects of the VMIDG – Drainage Management

- Future aspects of drainage are likely to be associated with high sporadic rainfall events or point source hotspot drainage, i.e. unequal drainage in emitters when pulsing, and this will likely challenge existing knowledge on drainage management.
- Additionally, problems of highly efficient irrigation systems and high costs of irrigation water could also lead to rootzone salinity issues, for some irrigators. A robust monitoring and educational plan should be considered to cover this aspect.

15

STRENGTHENING IRRIGATION BMP'S

Three broad areas were identified in the review for improving/strengthening irrigation best management practices. These areas were:

- Strengthening ongoing monitoring and evaluation to ensure compliance.
- Harnessing new technologies in data gathering and reporting.
- Benchmarking practices with a focus on parameters that capture on-ground outcomes of best practice.

16

ONGOING MONITORING AND EVALUATION FOR COMPLIANCE

- At present, monitoring and evaluation of irrigation and threatening process appears to fall to the irrigator and only if there is a third party issue does this data appear to be utilised or evaluated.
- Potential weakness of current process and largely reduces the effectiveness of such monitoring and infrastructure that has been mandated in the development process.
- i.e. GW levels collected by irrigator but not used regionally or benchmarked
- Irrigation system performance – not mandated to be routinely monitored after development

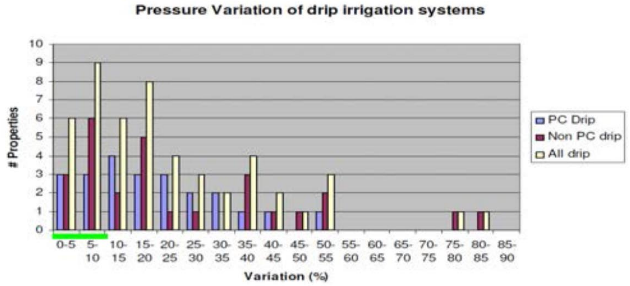
CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

17

ONGOING MONITORING AND EVALUATION FOR COMPLIANCE



Pressure variations of drip systems (including pressure compensated drip) as field measured across Mallee irrigation systems after Schache (2012). Green line is industry standard of 10%.

CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

18

HARNESSING NEW TECHNOLOGY IN DATA CAPTURE AND REPORTING

- Technologies are now capable of using ‘Internet of Things’ (IoT) approaches where sensing data is automatically stored directly on the web in real-time.
- These technologies and approaches should be considered in the context of providing key data back to a central point/agency for compliance reporting functions and analyses of the data for regional trend identification and benchmarking.
- Such regional data would have real power, particularly when combined with other regionally collated data such as that collected by SunRISE for the Mallee Horticulture Crop Report.

CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

19

BENCHMARKING PRACTICES

- Benchmarking is an important activity for sharing and transferring knowledge
- Useful role for expanding benchmarking of irrigation system performance and management to support the objectives of the irrigation develop guidelines
- Current routinely collected data may not capture performance well.
- i.e. Yearly benchmarking the area of irrigated land converted to drip irrigation over surface irrigation may not actually be a good indicator of environmental performance if these new irrigation systems are not operating at the desired efficiencies and performance level after they have been installed

CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

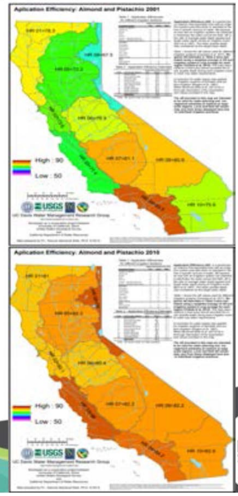
Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

20

BENCHMARKING PRACTICES

- Collating and analysing data on application efficiency, deep drainage events, or rootzone salinity across farms and different irrigation systems give a much better indication on the environmental performance of the irrigation enterprise.
- Documents such as the SunRISE Mallee Horticulture Crop Report could potentially be expanded to include some of this regional scale information.



CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

21

Summary

- The Victorian Mallee Irrigation Development Guidelines are a comprehensive set of guidelines which have achieved best practice irrigation development that is of a world standard.
- Document clearly sets out processes, responsibilities and expected outcomes for new irrigation development.
- Its purpose and intent is clear and the underlying drivers behind the recommended best practices are sound and robust.

CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

22

Summary

- However, there is scope for improvement (indeed best management practices involve continually seeking improvement).
- Particularly, in implementation of the guidelines and, specifically, in compliance after irrigation developments have been assessed and approved.
- Once irrigation development has taken place there is not a clear monitoring and evaluation process that occurs to ensure that best practice irrigation management is occurring on a wide scale and compliance is occurring.

CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

23

Thank you

j.hornbuckle@Deakin.edu.au

@CeRRF_Griffith

CeRRF CENTRE FOR REGIONAL + RURAL FUTURES

Deakin University CRICOS Provider Code: 00113B

DEAKIN Worldly

24

REGIONAL MALLEE SALINITY FORUM 19TH NOVEMBER

PRESENTER-TROY RICHMAN- ALMAS ALMONDS GENERAL MANAGER

1

ALMAS ALMONDS IS A FAMILY OWNED BUSINESS BASED IN ROBINVALE WITH FOUR ALMOND FARMS TOTALLING 1139 HECTARES

2

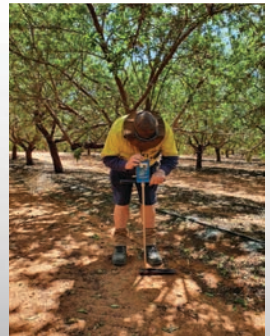
KEY IRRIGATION ACTIVITIES

- PLANNING NUTRITION AND WATER REQUIREMENTS SEASONALLY
- PROVIDE STAFF WITH THE TOOLS AND EQUIPMENT TO MANAGE AND RECORD ACTIVITIES
- MAINTAIN IRRIGATION AND FERTIGATION ASSETS
- MONITOR AND MANAGE THE AFFECTS OF WATER AND NUTRIENT APPLICATION
- MANAGE SUSTAINABILITY OF THE ORCHARD AND THE ENVIRONMENT AROUND THEM
- CONTINUAL IMPROVEMENT IN THE APPLICATION AND MONITORING OF ACTIVITIES

3

SCHEDULING TOOLS

LEAF PRESSURE BOMB



SOIL AUGER

4

SOIL MOISTURE TENSION- GYPSUM BLOCK

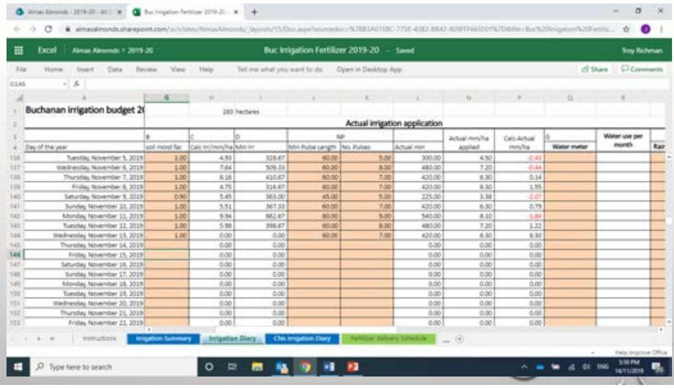
- Data logs 24hrs
- Phone based access
- Remote access to agronomy assessment
- Live feed to management for assessment

5

SOIL MOISTURE CONTENT- CAPACITANCE PROBE

6

IRRIGATION SCHEDULING AND RECORDING



Buc Irrigation Fertilizer 2019-20

Buchanan irrigation budget 20 — 283 hectares

Actual irrigation application

	Day of the year	B soil moist fac	C Calc irr/mm/ha	D Min irr	NP Min Pulse Length	No. Pulses	Actual min	Actual mm/ha applied	Calc Actual mm/ha	G Water meter	Water use per month	Rain
136	Tuesday, November 5, 2019	1.00	4.93	328.67	60.00	5.00	300.00	4.50	-0.43			
137	Wednesday, November 6, 2019	1.00	7.64	509.33	60.00	8.00	480.00	7.20	-0.44			
138	Thursday, November 7, 2019	1.00	6.16	410.67	60.00	7.00	420.00	6.30	0.14			
139	Friday, November 8, 2019	1.00	4.75	316.67	60.00	7.00	420.00	6.30	1.55			
140	Saturday, November 9, 2019	0.90	5.45	363.00	45.00	5.00	225.00	3.38	-2.07			
141	Sunday, November 10, 2019	1.00	5.51	367.33	60.00	7.00	420.00	6.30	0.79			
142	Monday, November 11, 2019	1.00	9.94	662.67	60.00	9.00	540.00	8.10	-1.84			
143	Tuesday, November 12, 2019	1.00	5.98	398.67	60.00	8.00	480.00	7.20	1.22			
144	Wednesday, November 13, 2019	1.00	0.00	0.00	60.00	7.00	420.00	6.30	6.30			
145	Thursday, November 14, 2019		0.00	0.00			0.00	0.00	0.00			
146	Friday, November 15, 2019		0.00	0.00			0.00	0.00	0.00			
147	Saturday, November 16, 2019		0.00	0.00			0.00	0.00	0.00			
148	Sunday, November 17, 2019		0.00	0.00			0.00	0.00	0.00			
149	Monday, November 18, 2019		0.00	0.00			0.00	0.00	0.00			
150	Tuesday, November 19, 2019		0.00	0.00			0.00	0.00	0.00			
151	Wednesday, November 20, 2019		0.00	0.00			0.00	0.00	0.00			
152	Thursday, November 21, 2019		0.00	0.00			0.00	0.00	0.00			
153	Friday, November 22, 2019		0.00	0.00			0.00	0.00	0.00			

Instructions | Irrigation Summary | Irrigation Diary | Chn Irrigation Diary | Fertilizer delivery Schedule

7

IRRIGATION IMPROVEMENTS

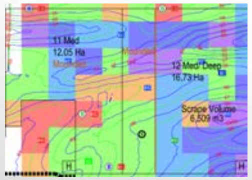
- INCREASED MAIN FILTRATION SYSTEM TO GET ADEQUATE PRESSURE
- REDUCED IRRIGATION VALVE SIZE TO 40% OF THE BLOCKS WITH NEW SUBMAINS TO COVER SOIL AND CONTOUR CHANGES
- REMOVED FLUSHING MANIFOLDS AND REPLACED WITH INDIVIDUAL TAPS
- REPLACED THE DRIPPER LINE FROM 2.3LHR @700MM TO 1.6LHR @480MM.
- INSTALLED TEST WELLS, BORES, SOIL SAMPLERS (SOIL BASED NUTRIENT TRAPS)

8

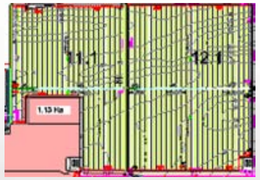
IRRIGATION UPGRADES

9

BUCHANAN BLOCK 11 &12 UPGRADE EXAMPLE



6 DIFFERENT UNIT SOIL TYPES WITHIN ONE VALVE OF 41 ACRES



ORIGINAL DESIGN TWO IRRIGATION VALVES WITH FLUSHING MANIFOLDS

NEW DESIGN 4 VALVES AND INDIVIDUAL FLUSHING TAPS

10

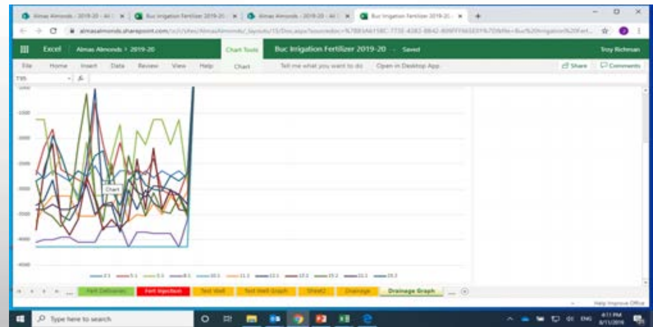
BORE AND DRAINAGE MONITORING

PIEZO MONITORING

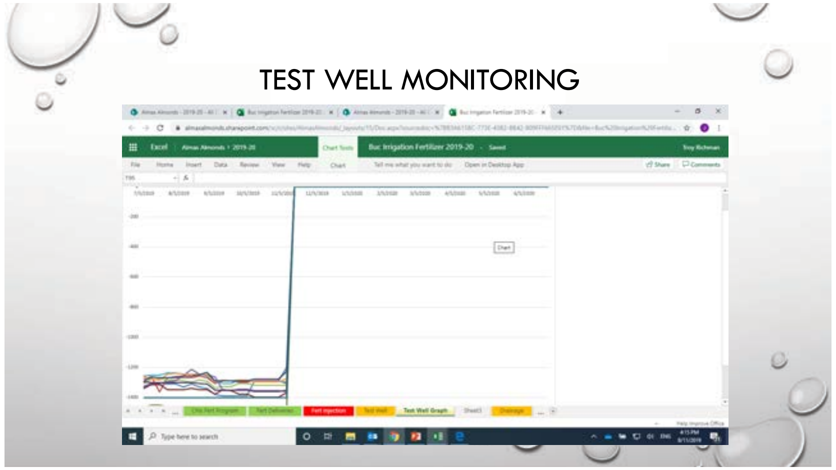
DRAINAGE-E PAN EC MONITORING

11

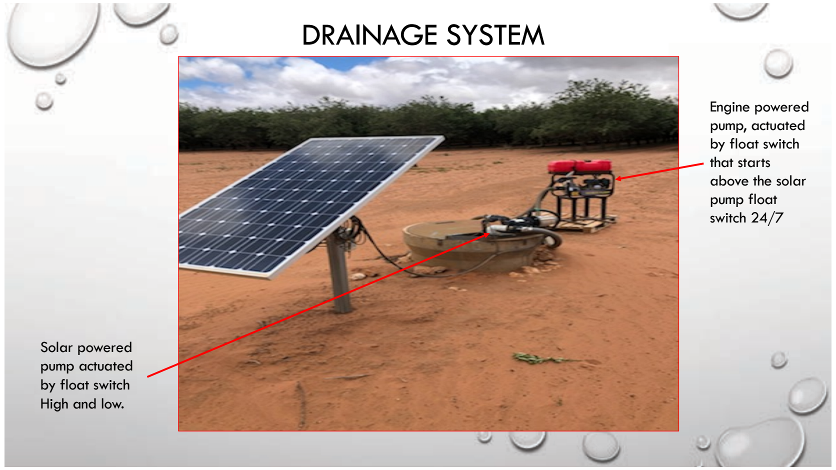
DRAINAGE MONITORING



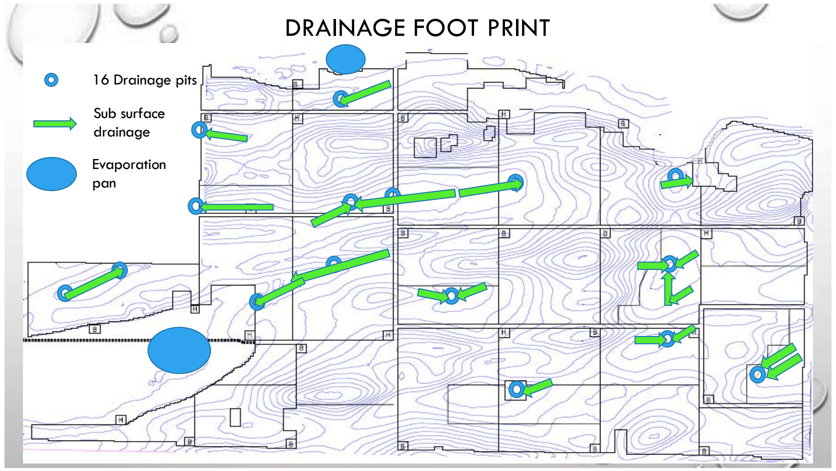
12


TEST WELL MONITORING

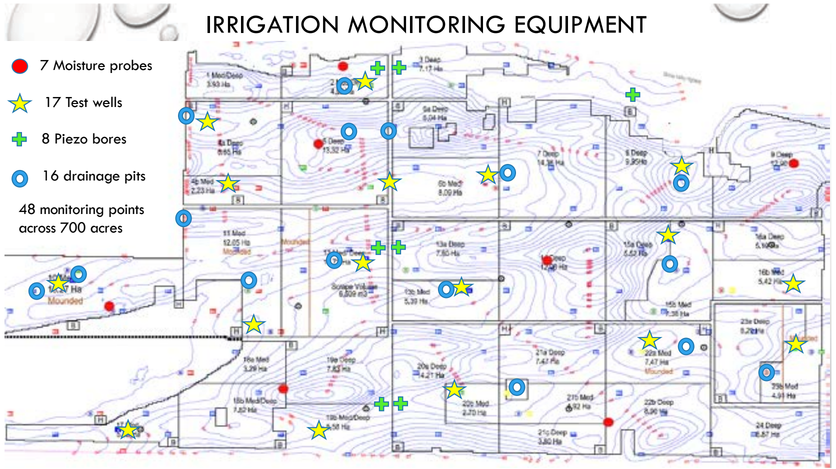
13


DRAINAGE SYSTEM
Engine powered pump, actuated by float switch that starts above the solar pump float switch 24/7
Solar powered pump actuated by float switch High and low.

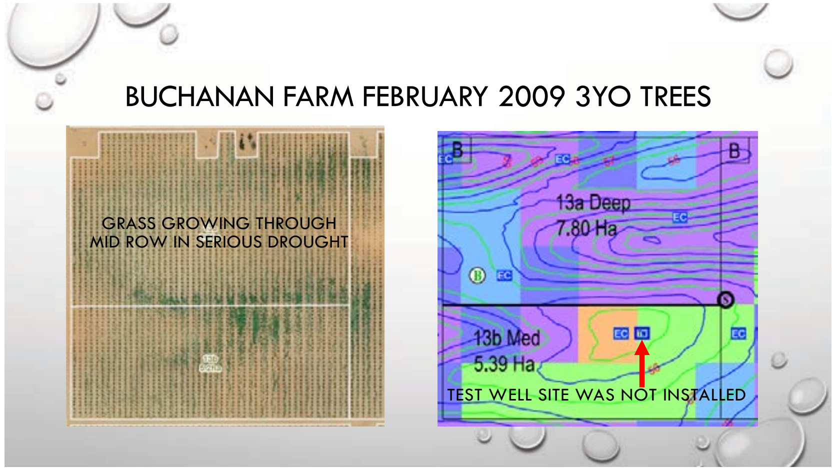
14


DRAINAGE FOOT PRINT
16 Drainage pits
Sub surface drainage
Evaporation pan

15


IRRIGATION MONITORING EQUIPMENT
7 Moisture probes
17 Test wells
8 Piezo bores
16 drainage pits
48 monitoring points across 700 acres

16


BUCHANAN FARM FEBRUARY 2009 3YO TREES
GRASS GROWING THROUGH
MID ROW IN SERIOUS DROUGHT
13a Deep
7.80 Ha
13b Med
5.39 Ha
TEST WELL SITE WAS NOT INSTALLED

17

Mallee Catchment Management Authority

The “how” and “why” of the
research into Crop Water use and Root Zone Drainage,
by Whitfield, McAllister and Abuzar
came about.

John Cooke

1

Inherent difficulties in measuring RZD

Simmer I, (1998) published an overview of Groundwater Recharge. The Review concluded that:

- *the combination of reliable data, remote sensing, GIS Technology, and geostatistical techniques promise for a better understanding and quantification of recharge over extended areas*

In the later Review (Newman et al. 2009) it was clear that RZD could still not be reliably estimated by difference based on Water Balance Models alone.

- In short, the error in estimating evapotranspiration (or water applied) was greater than the magnitude of Root Zone Drainage. This was the key limitation to using the Water Balance Model approach at that time.

2

The opportunity to address the key limitation to using the Water Balance Model approaches

- Until now the error in estimating evapotranspiration (or water applied) was greater than the magnitude of Root Zone Drainage.

3

A logical approach

The Mallee CMA developed a logical framework to undertake a new approach to the assessment of RZD.

- The Mallee CMA, through the *New Irrigation Development Guidelines,* had created an opportunity to objectively measure rootzone drainage (RZD), in situ
- The Mallee CMA saw an opportunity to assess whether irrigation development, consistent with the NID Guidelines, provided a foundation on which to assess if the errors in estimating evapotranspiration (or water applied) could be reduced, and
- Locally, there was a clear need for improved accuracy of RZD for input into modelling and for water use policy.

4

Building on the 4 available opportunities

1. Water losses between the river offtake and the farm are minimal
2. State-of-the-art irrigation infrastructure is used on the farm
3. The layout of irrigation had used a layered approach on which crop selection and water management were based on a soil capability
4. Ancillary information was available by 2012 that covered crop mapping, metered extracted water, silo evapotranspiration etc.

5

The core of the logical framework

- There was a Logical Framework developed for the project
- There was a unique relationship between the meter and the plot at 40 sites x 5 years
- There was an experienced Research Team with local knowledge available
- The research was to be peer reviewed

6

The importance of findings to date

1. The earlier assumption that the error in estimating evapotranspiration (or water applied) was greater than the magnitude of Root Zone Drainage *need no longer apply* as:
   i. Losses in the delivery between the river and the farm have been largely eliminated
   ii. Losses in the delivery within the farm *could be substantially minimised* because crops could be watered on demand

7

Building on the New Irrigation Guidelines

1. The Mallee CMA project appears to be one of the few and perhaps the only project that had access to 40 sites (crops) over 5 years where there is a *unique relationship* between demand and supply of irrigation water
2. The ancillary information available to the project helped explain the differences between supply and demand
3. The research findings have implications for irrigation management wider than the estimation of RZD providing the *unique relationship* is observed

8

Satellite-based soil water balance modelling to improve estimates of Mallee Crop Water Use and Root Zone Drainage.

Andy McAllister, Des Whitfield & Mohammad Abuzar

1

Introduction

RZD: depends on the frequency and magnitude of events where Water Supply (WS) > Evapotranspiration (ET)

"Errors in estimating evapotranspiration are an order of magnitude greater than the RZD estimate" this leads to a low confidence in RZD estimates arising from water balance approaches.

Newman et al (2009) suggested that:

1. improving collection of district scale data and analysis techniques to a common and best standard *may present the highest value area for investment;*
2. there *is no single approach that can usefully up-scale point estimates to the district scale in the context of irrigated horticulture in the Mallee region*; and
3. *Use of remote sensing of evapotranspiration should be pursued*

2

What's changed since 2009

- Large increase in almond plantations

Data available

1. Regular mapping of crop type and area, stage of crop, and irrigation method
2. measured water extraction on a daily timestep;
3. Scientific Information for Land Owners (SILO) open-access weather data
4. Normalised Difference Vegetation Index (NDVI) satellite data that can be linked to crop water use estimates ; and
5. Satellite based relationships linking ET to NDVI for major Mallee crops

Question:

What's the model for integrating and analysing this to provide information on supply/demand relationships and inform RZD?

3

The project

Aim: to provide a scientific basis for the Mallee CMA's ongoing monitoring and modelling of crop water requirements and soil water balances, which underpins their capacity to:

- Improve region-scale estimates of deep drainage beneath irrigated areas of the Victorian Mallee, and
- Provide evidence to support crop water requirement against annual use limits/maximum application rates.

4

Satellite-based soil water balance approach

Method

According to the soil water balance equation, water contributions to the root zone (rainfall, RF, and irrigation, Irr) either increase the quantity of soil-stored water (ΔSW), or are dissipated by evapotranspiration (ETc) and runoff (RO) and root zone drainage (RZD):

$$\Delta SW = Irr + RF - ETc - (RZD + RO)$$

ETc or _crop water requirement_ (CWR)* is a key component of methodology:

$$ETc = Kcr\ ETr$$

ETr = Reference evapotranspiration for 'tall' crop e.g. almond

Kcr = Crop coefficient for 'tall' crops

- 1970 → NDVI provides a reliable estimate of foliage cover
- 1997 → reliable estimates of field-scale ET available from satellites
- 2011 → science developed to replace Kcr with NDVI

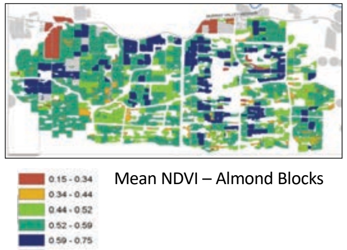
* **Whitfield, D.M.**, **O'Connell, M.G.**, **McAllister, A.**, **McClymont, L.**, **Abuzar, M.** and **Sheffield, K.** 2011. SEBAL-METRIC Estimates Of Crop Water Requirement in Horticultural Crops grown in SE Australia. **Acta Hort.** (ISHS) 922:141-148.

Satellite-based estimation of Mallee crop water use and root zone drainage

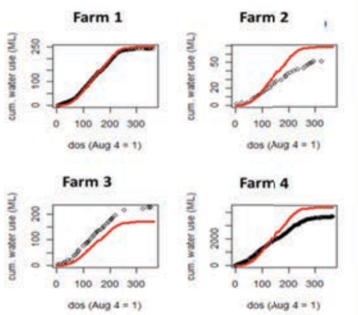
Method

Investigation of spatial and historical variation in Almond water supply vs demand using data from 2010/11 to 2015/16 across the Mallee CMA

Method applied to all fields within Water Use Licenses in the Mallee region.



Mean NDVI – Almond Blocks



Satellite-based water use estimates (red) in relation to VWR crop water supply (black)

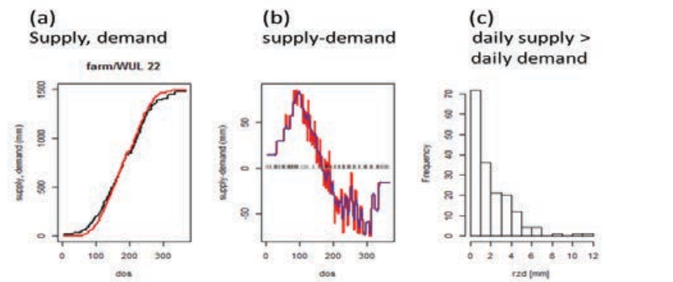
Satellite-based estimation of Mallee crop water use and root zone drainage

Methods

RZD

RZD types:
1. Irrigation-induced RZD
2. Rain-induced RZD

Calculations:
1. Identify instances; supply > demand
2. RZD = (supply – demand)



$$RZD = \sum (\text{daily supply} - \text{daily demand});\ \text{daily supply} > \text{daily demand}$$

Satellite-based estimation of Mallee crop water use and root zone drainage

Results

- Improved region-scale estimates of RZD beneath irrigated areas of the Victorian Mallee.
- Provided evidence to support crop water requirement against AULs / MARs for almonds
- Model applied to investigate historical seasonal variation using data from 2010/11 to 2015/16.
- Model applied to other key crops within the Mallee specifically Table Grapes and Citrus.
- Almond industry water use is generally within Annual Use Limits
- Results indicate 10% RZD in line with previous estimates however this method is applied to water supply rather than AUL and therefore reflects between and within season variability in supply.

The project has provided a methodology that accounts for spatial and temporal variability in demand and supply driven by climate, crop type and vegetation status.

Satellite-based estimation of Mallee crop water use and root zone drainage: Next Phase

Objective

The overall objective of the proposed project is to improve the confidence in salinity impact estimates of irrigation developments in the Mallee Region. The specific objectives are:

1. Assess real time soil water balance and crop water requirements using field based monitoring and satellite based NDVI data; and
2. Provide real time evidence to support crop water requirement against irrigation water supply.

Context

- *The project developed and applied methods that support an affordable objective means of monitoring and evaluating Mallee irrigation water balances applicable to new and existing crops and crop management options on both green- and brown-field sites*
- *As part of this study it was recommended that further work focus on improving confidence in the methods developed through the undertaking of field based soil water and crop status assessments that can be integrated with the satellite approaches*

VICTORIA State Government | Jobs, Precincts and Regions

AGRICULTURE VICTORIA

9

Mallee CMA Salinity Forum

November 19, 2019

Andrew Telfer and Alison Charles
Water Technology

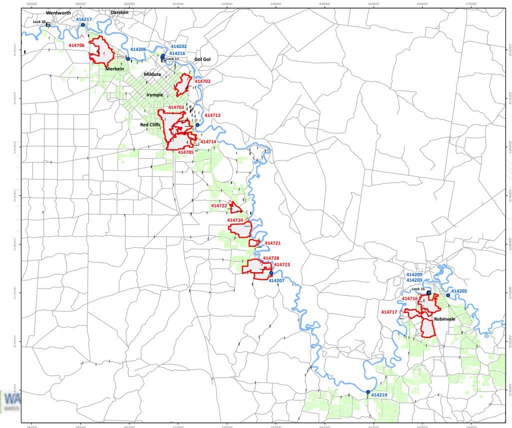
1

Background

- Australian Water Environments (2015) prepared a report on an assessment of the correlation between irrigation and groundwater trends in the Mallee CMA area
- We are presenting an update of that report, extending some of the data to current day.

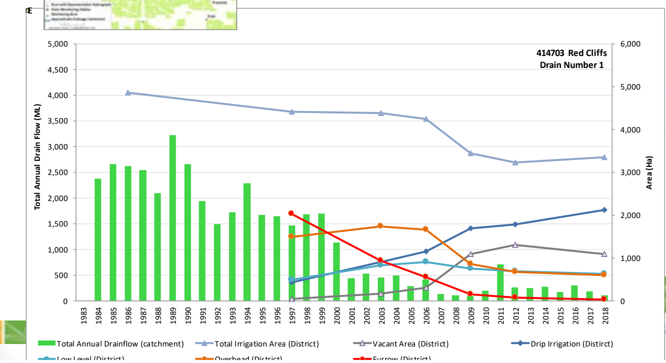
2

Location Plan – Selected Catchments for Water Balance



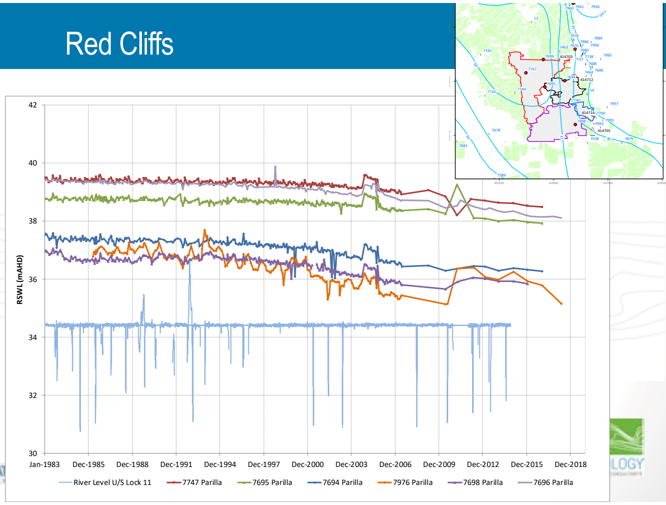
3

Red Cliffs



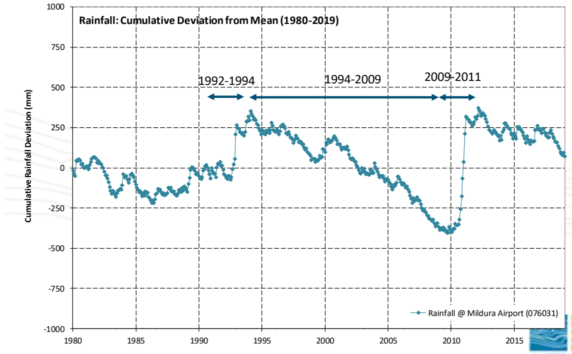
4

Red Cliffs



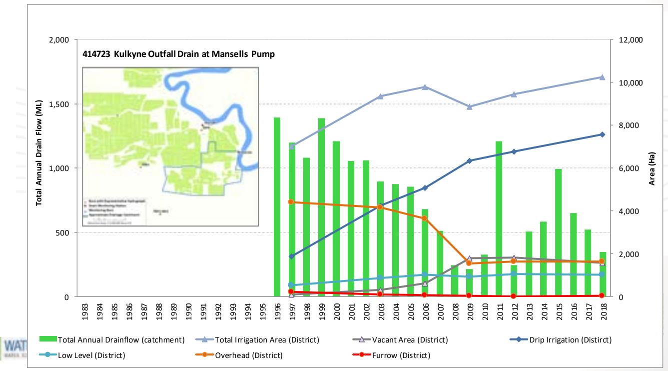
5

Rainfall Trend



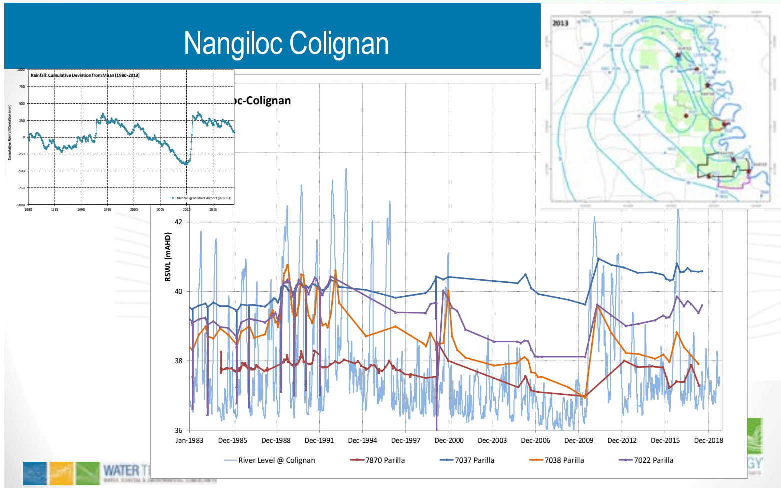
6

Nangiloc Colignan

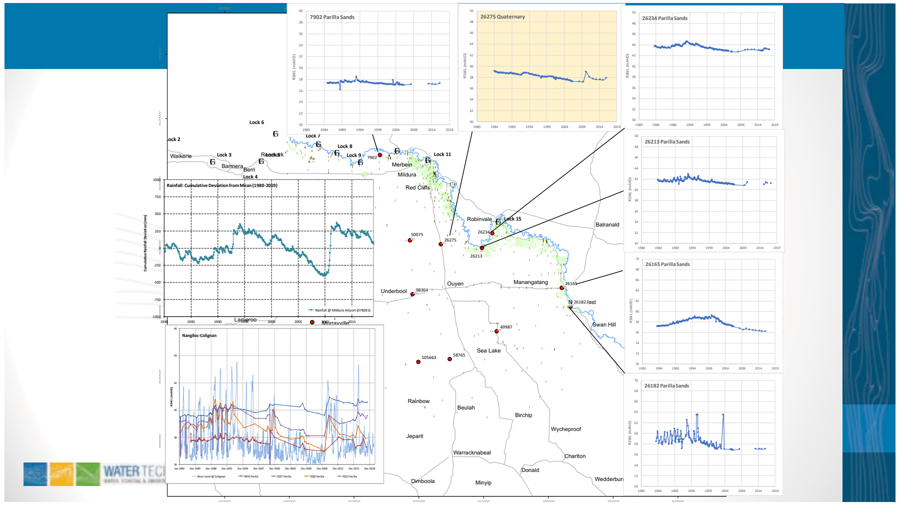


7

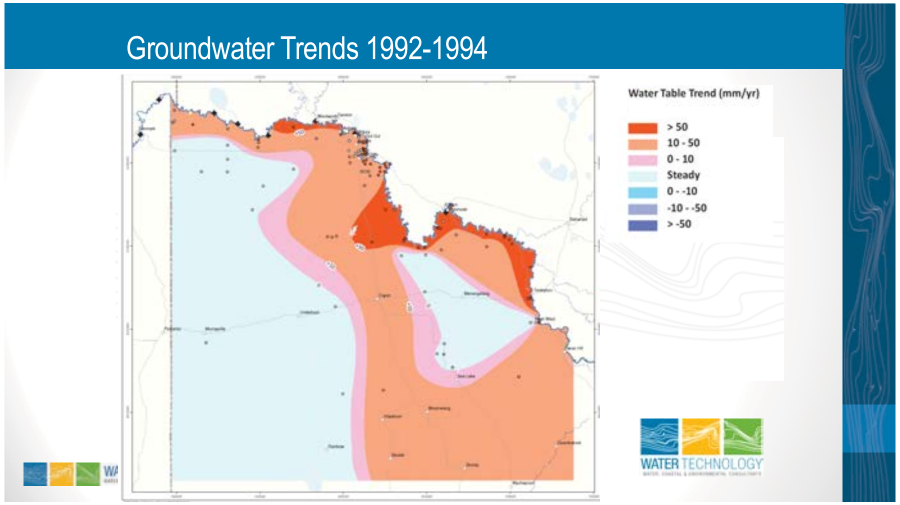
Nangiloc Colignan



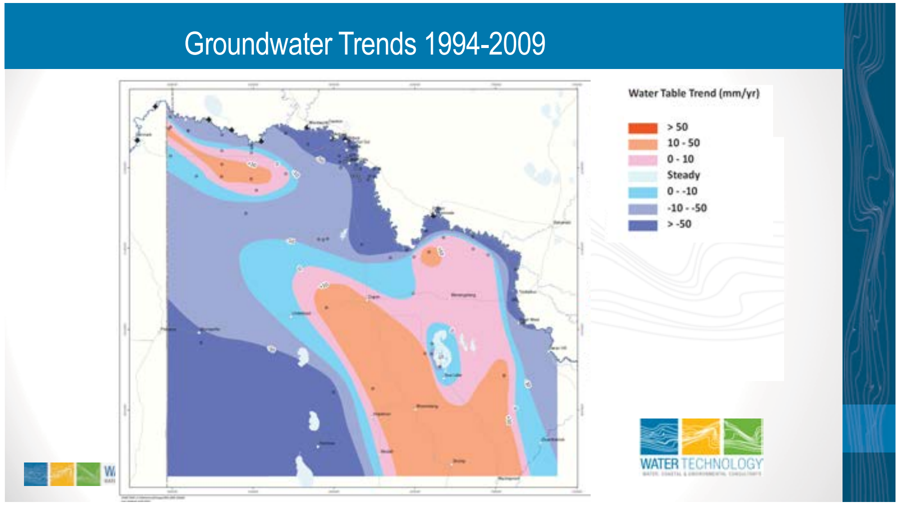
8



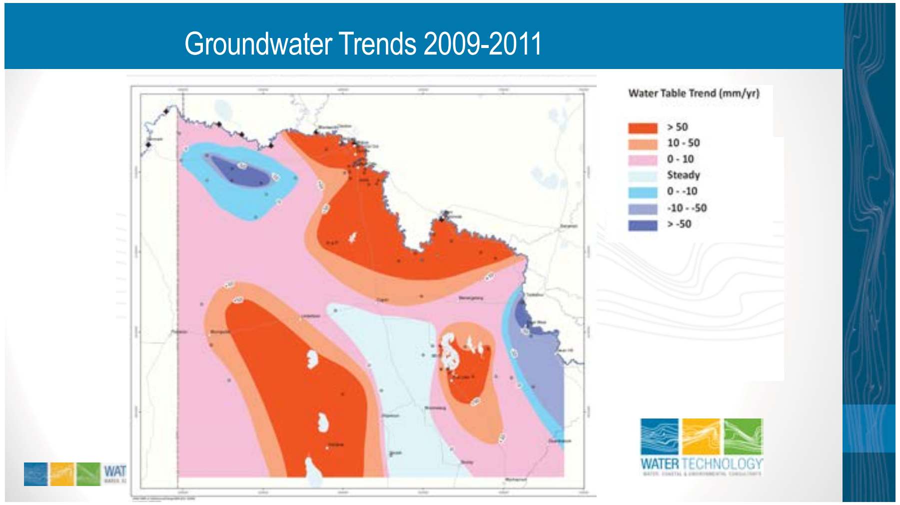
9


Groundwater Trends 1992-1994
Water Table Trend (mm/yr)
> 50
10 - 50
0 - 10
Steady
0 - -10
-10 - -50
> -50
WATER TECHNOLOGY

10


Groundwater Trends 1994-2009
Water Table Trend (mm/yr)
> 50
10 - 50
0 - 10
Steady
0 - -10
-10 - -50
> -50
WATER TECHNOLOGY

11


Groundwater Trends 2009-2011
Water Table Trend (mm/yr)
> 50
10 - 50
0 - 10
Steady
0 - -10
-10 - -50
> -50
WATER TECHNOLOGY

12

Conclusions

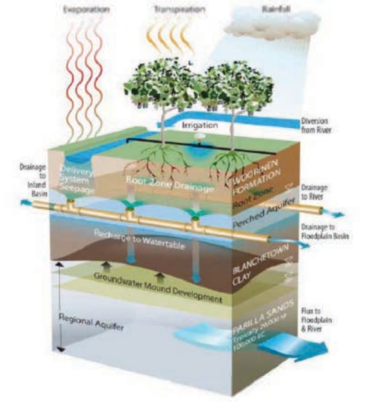
- Salinity Management Plans (from the 90's) have been successful in managing and minimising the impacts of irrigation
- Irrigation area doubled since 97, growth mostly in LIZ private diverter areas, retirement mostly in pumped districts.
- Groundwater heads declining in pumped districts, increasing or constant (variable) in private diversion
- Major rainfall events influence drain flows, but rainfall and drainflow only weakly correlated because irrigation inputs are much larger than rainfall.
- Wet-dry-wet sequence reflected in regional groundwater trends in most districts, however some patterns need more analysis.

WATER TECHNOLOGY

Irrigation drainage trends

Drainage flow rates across irrigated districts in the Mallee region

1

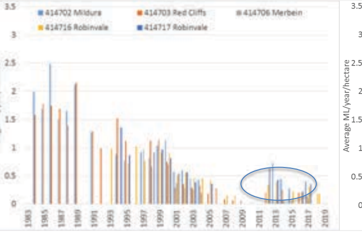


2

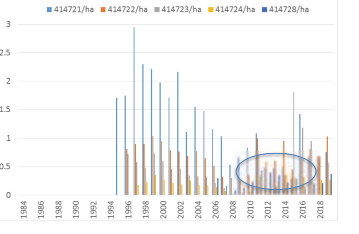
Irrigation drainage monitoring

- Red Cliffs, Merbein, Mildura, Karadoc-Colignan (including Nangiloc), Tol Tol, Boundary Bend and Robinvale (including Bumbang)
- Gauging stations - monitor flow (ML/day) and salinity (electrical conductivity) data uploaded WMIS
- Long-term monitoring data - dramatic decline in drain flows with the adoption of more efficient irrigation methods
- Some drainage sites are dry most of the time

3



Mildura, Red Cliffs, Merbein, Robinvale



Nangiloc Colignan

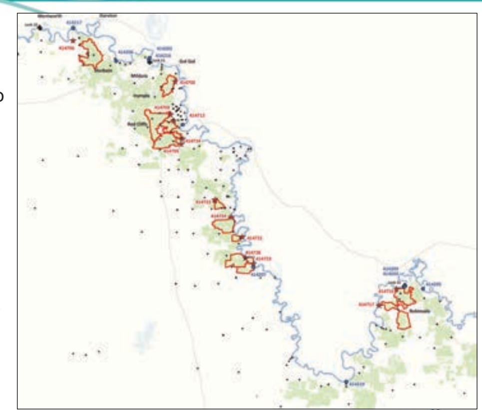
Drain flows (ML/year/hectare)

4

Assessment objectives:

Review drainage flows from ten drainage sites to assess:

1. Trends in irrigation drainage vs time (2012 – 2019) – still declining?
2. Assess possible causes for observed trends
3. Consider further work that may be required



5

Table 1 Site summary and correlation between drain flow and year (ML/day) & time (2012 –19)

Site code/irrigation district	Area (ha)	1997[1] ML/ha/yr	2018[2] ML/ha/yr	S.R.O Correlation (2012-2019)
414702, FMIT North East Drain @ Bruces Bend	695	0.92	0.0023	r_s = -0.512** ↓
414703, Red Cliffs Drain No. 1 @Blounts Rd	1500	1.12[1]	0.124[2]	r_s = -0.503** ↓
414705, Red Cliffs Drain No. 10 @ upstream outfall (south east basin)	1245	-[3]	0.160	r_s = -0.298** ↓
414716, Robinvale No. 4 System Outfall @ Pethard Rd	990	0.76	0.181	r_s = -0.165** ↓
414717, Robinvale No. 6 System Outfall @ Malaya Rd	1370	0.91[1]	0.352[2]	r_s = -0.327** ↓
414721, Nangiloc-Colignan Drain @ Hewetts Rd	220	2.95	0.673	r_s = 0.356** ↑
414722, Nangiloc-Colignan at Doerings Basin	285	0.90	0.684	r_s = 0.360** ↑
414723, Kulkyne Outfall Drain at Mansells Pump	550	0.58	0.635	r_s = 0.176** ↑
414724, Nangiloc Colignan Drain at Nangiloc	1045	0.19	0.261	r_s = -0.098** ↓
414728, Browns Group Drainage Area	1025	-[3]	0.207	r_s = -0.215** ↓

[1]1998 data used; [2]2017 data used, [3]not available (no site record for 1997 – 1998, data collection commenced c.2006)

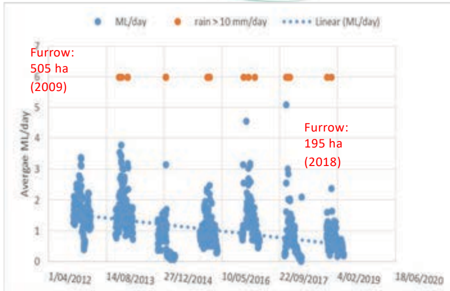
6

Estimates of rootzone drainage (RZD) rates

Crop type (mature)	Irrigation system (note only minor areas of furrow irrigated vines remain)	Typical average application rate ML/ha/y	Estimated % RZD	Indicative RZD (recharge rate) ML/ha/y	Estimated volume collected by tile drains from perched system &/or discharged via natural drainage from perched w/table ML/ha/y	Estimated deep drainage from perched water table to regional aquifer ML/ha/y
Targets				1.0 (2006 LWMP)	1.8 (from 2.3 Sunraysia SMP) 1.3 (from 1.8 Nangiloc-Colignan SMP)	
Dried vine fruit & wine grapes	Furrow Sprinkler Drip	9 9 8	30% 17.5% 12.5%	2.7 1.4 0.9	1.7 to 2.2 based on historic drain flows from pumped districts 0.9 to 1.2 0.4 to 07	0.5 to 1.0 0.2 to 0.5 0.2 to 0.5
Table grapes	Sprinkler Drip	10 9	17.5% 12.5%	1.8 1.1	1.3 to 1.6 0.6 to 0.9	0.2 to 0.5 0.2 to 0.5
Citrus and other tree crops	Sprinkler Drip	13 12	17.5% 12.5%	2.3 1.5	1.7 to 2.1 1.0 to 1.3	0.2 to 0.5 0.2 to 0.5
Almonds/ nut crops	Sprinkler Drip	15 14	17.5% 10-15%	2.6 1.4 -2.1	2.1 to 2.4 0.9 to 1.9	0.2 to 0.5 0.2 to 0.5
Vegetables	Sprinkler Drip	8 7	17.5% 12.5%	1.4 0.9	0.9 to 1.2 0.4 to 0.7	0.2 to 0.5 0.2 to 0.5

7

Mildura (FMIT North east drain, 414702)

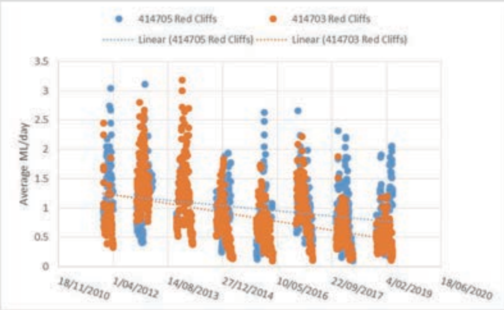


Retirement of irrigation land 5.3% between 2009 -2018

Increase in stormwater contributions urban development

8

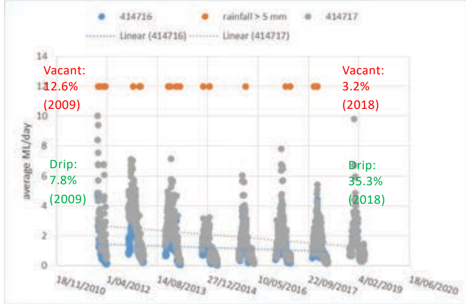
Red Cliffs (Drain No.10 - 414703; Drain No 1 - 41405)



14% area redeveloped 2015 -2018 mostly table grapes
Increase in drip 23% 2009 – 2018
Irrigated area static – decline likely from switch to drip (less drainage)

mallee

Robinvale No. 4 (414716) and No. 6 (414717) system outfalls

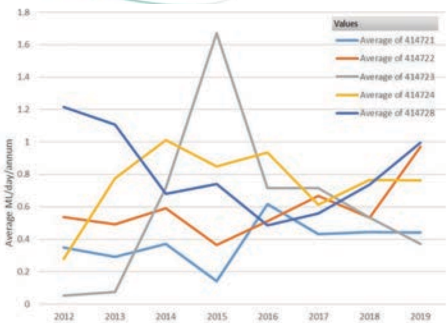


Downward trend in irrigation drainage slight
Table grapes 86% in 2018 seasonal adjustments made to Available Use Limits (AULs) since 2013-2014

mallee

Nangiloc-Colignan

- 39% irrigated area monitored (2015) New irrigation development 1997 – 2018 outside monitored area
- 2018: citrus (26%), wine grapes (23%:) and dried grapes (9%)
- Irrigation on lowland rises in river levels cause groundwater heads to rise = higher drain flows
- Data highly variable



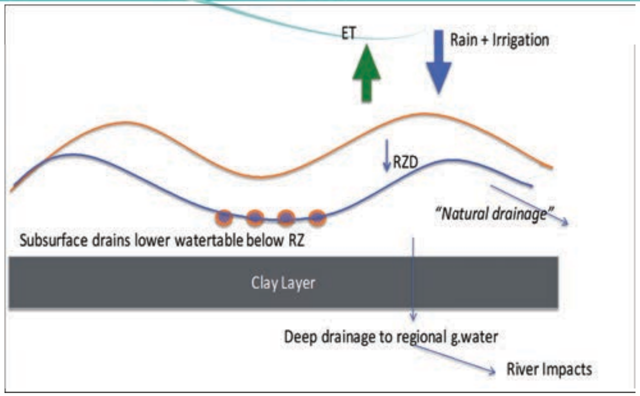
mallee

Conclusions and next steps

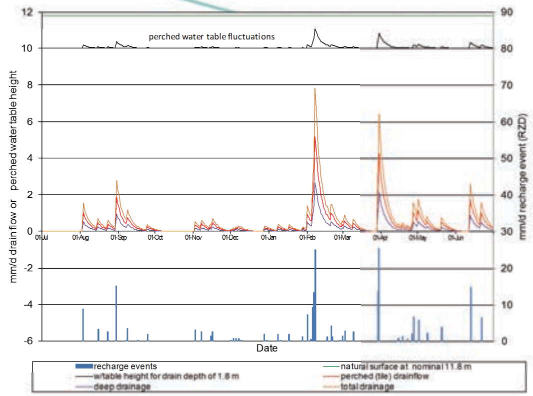
Possible next steps:

- Continue monitoring existing drainage sites and consider if new sites are required
- Collect data on crop types and irrigation practices within the drainage catchments vs outside the catchments (rather than assuming they are comparable)
- Assessment of chemistry of drain flows where stormwater inflows are expected to be increasing
- Consider how data on irrigation drainage in private diverter areas can be assessed (drainage managed on farm in these areas)

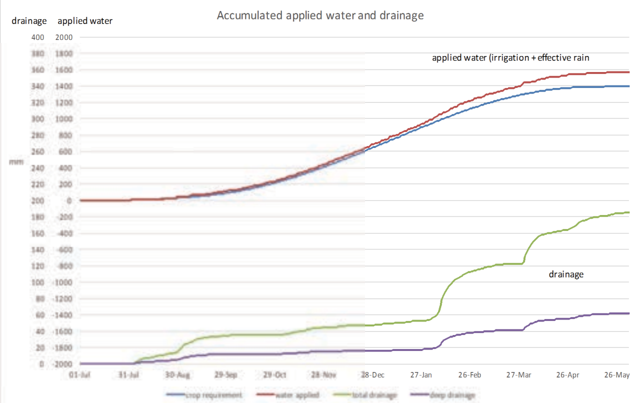
mallee


ET
Rain + Irrigation
RZD
"Natural drainage"
Subsurface drains lower watertable below RZ
Clay Layer
Deep drainage to regional g.water
River Impacts

13

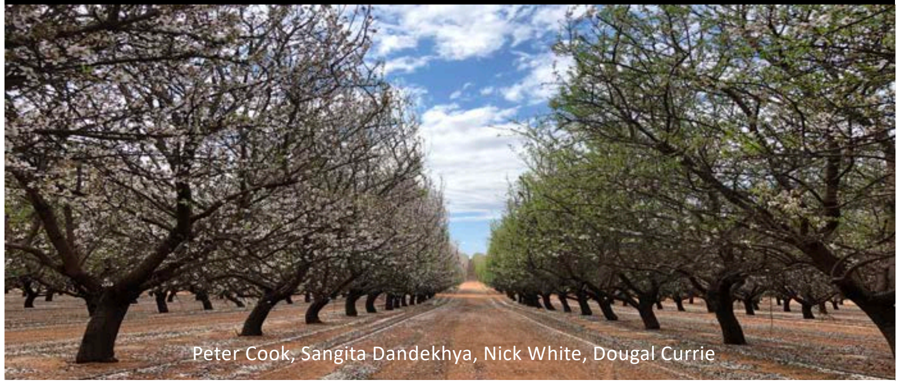

perched water table fluctuations
mm/d drain flow or perched water table height
mm/d recharge event (RZD)
Date
recharge events
w/table height for drain depth of 1.8 m
deep drainage
natural surface at nominal 11.8 m
perched (tile) drainflow
total drainage

14


Accumulated applied water and drainage
drainage
applied water
applied water (irrigation + effective rain
drainage
mm
crop requirement
water applied
total drainage
deep drainage

15

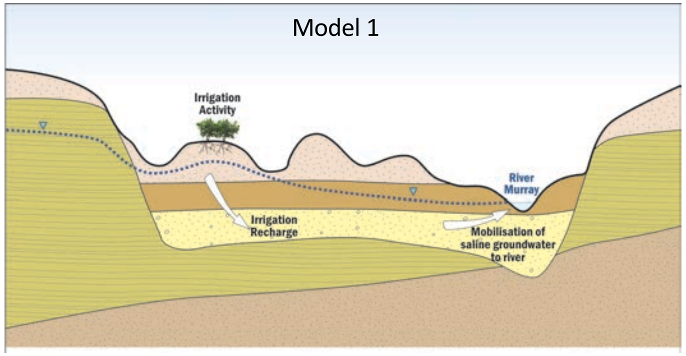
Formation of Perched Aquifers Beneath Irrigated Almonds – Implications for Root Zone Drainage



Peter Cook, Sangita Dandekhya, Nick White, Dougal Currie

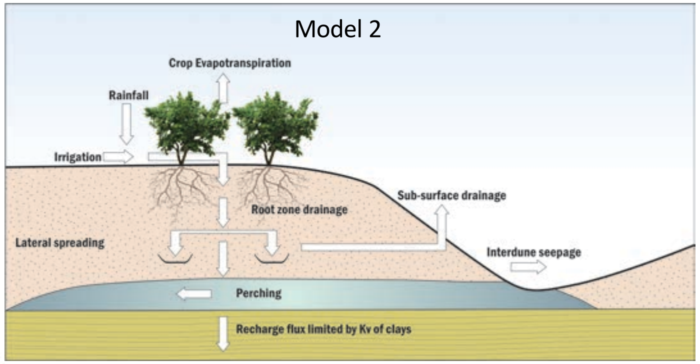
1

Irrigation Recharge and River Salinisation



2

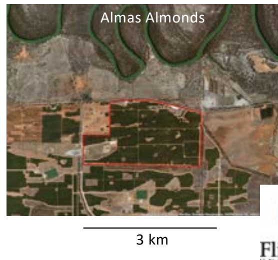
Irrigation Recharge and River Salinisation



3

Project Aims

- Is a clay layer present?
- Is water perching on top of the clay?
- How much water is being intercepted by the clay layer?



4

Question 1: Is a clay layer present?

Resistivity

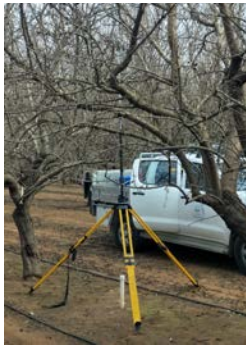
Electromagnetic Induction

CDM Smith listen. think. deliver.

Flinders University

5

Question 2: Is water perching on top of the clay?



CDM Smith listen. think. deliver.

Flinders University

6

Question 3: How much water is being intercepted by the clay layer?

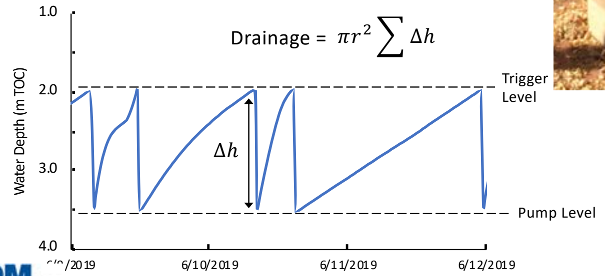
CDM Smith listen. think. deliver.

Flinders University

7

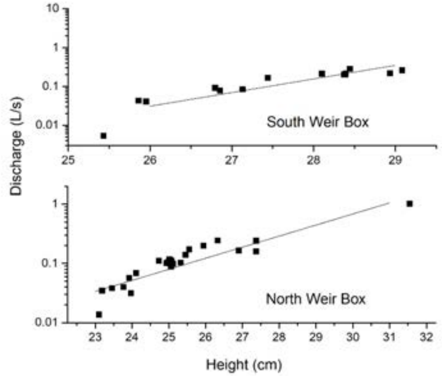
8

Drainage Pits



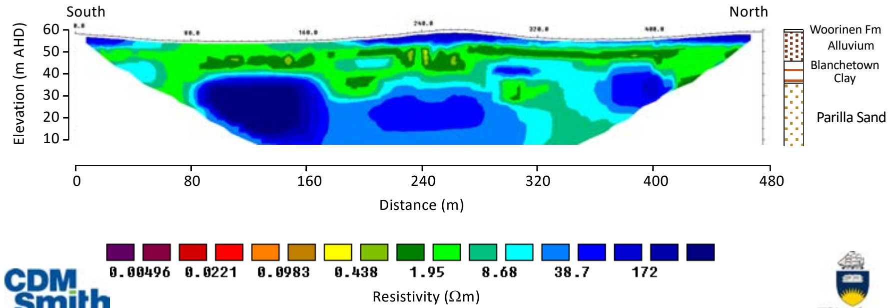
9

Weir Boxes



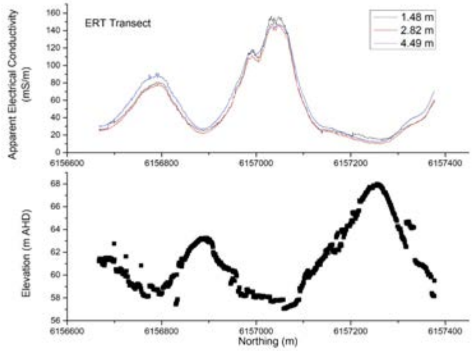
10

Results: Resistivity



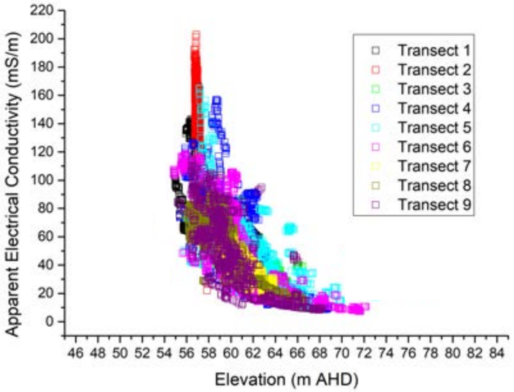
11

Results: Electromagnetic Induction



12

Results: Electromagnetic Induction

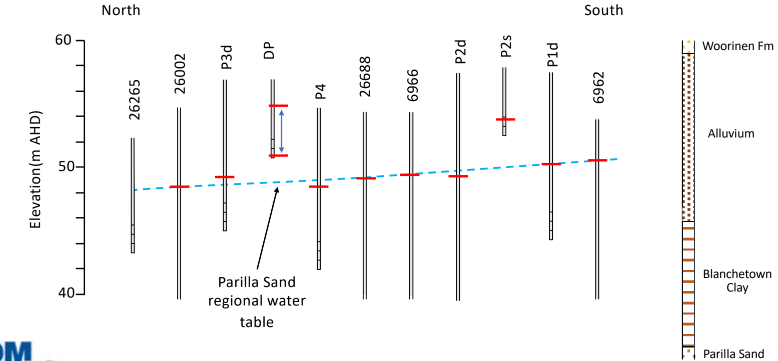


13

Electromagnetic Induction

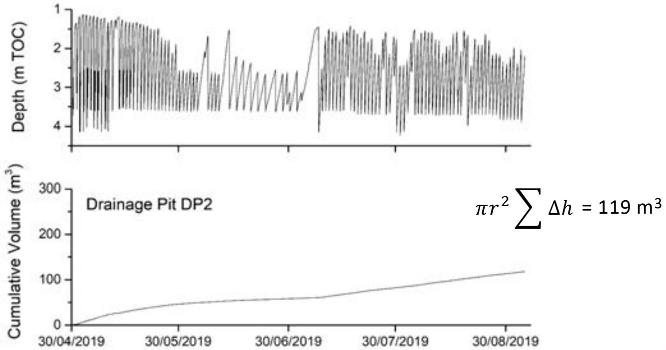
14

Results: Hydraulic Head



15

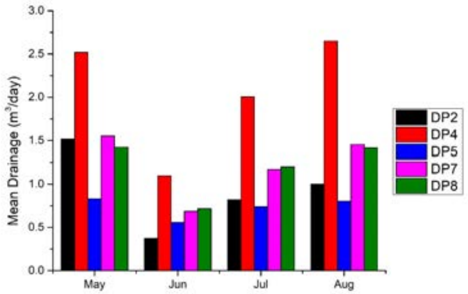
Results: Drainage Pits



$$\pi r^2 \sum \Delta h = 119 \text{ m}^3$$

16

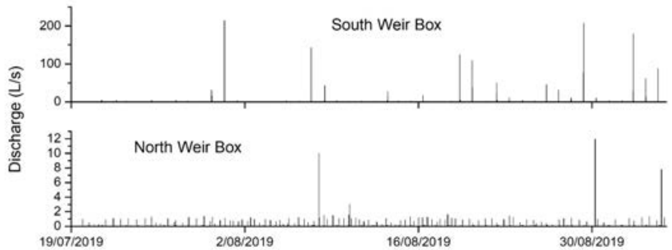
Results: Drainage Pits



Overall Total = 884 m³
= 7 m³/day
Equivalent to 1 mm/year

No Irrigation

Results: Weir Box Flows



Equivalent to 6 mm/year

Preliminary Conclusions and Further Questions

- Clay layers are continuous across the site and have the potential to intercept root zone drainage
- Water levels above the clay layers are somewhat disconnected from the Parilla Sands regional aquifer
- The total drainage from above the clay layers is very small

Where is the water going?

1. It is draining laterally on top of the clay
2. It is leaking through the clay
3. The almonds are using it

Other Activities

- Salt balance of site to improve water balance, and predict future salinity increases
- Measurement of nitrate concentrations – potential tracer and could potentially improve nutrient applications

CDM Smith listen. think. deliver. Flinders University

21

Acknowledgements

CDM Smith listen. think. deliver. National Centre for Groundwater Research and Training Flinders University

22

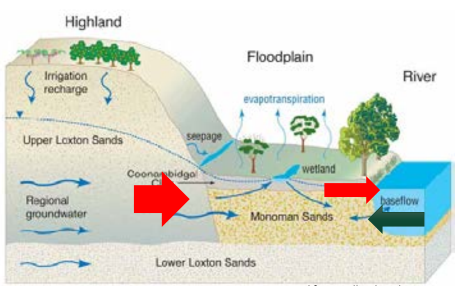
Salt movement in *SA* River Murray Floodplains

Juliette Woods
SA Department for Environment and Water

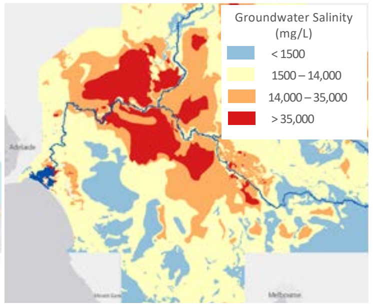
1

3

Floodplains: Less freshwater, more salt



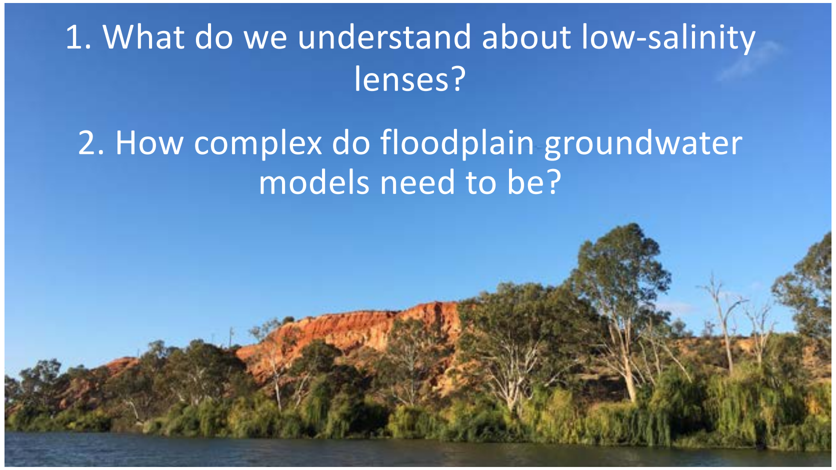
Annotated from Holland et al. 2005



4

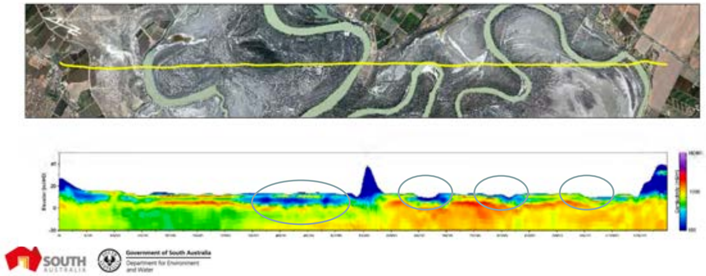
Salt movement affects river salinity and floodplain trees


5

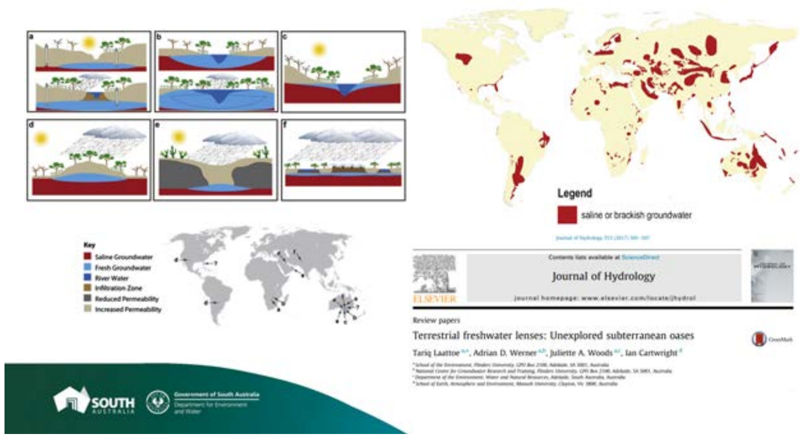


7

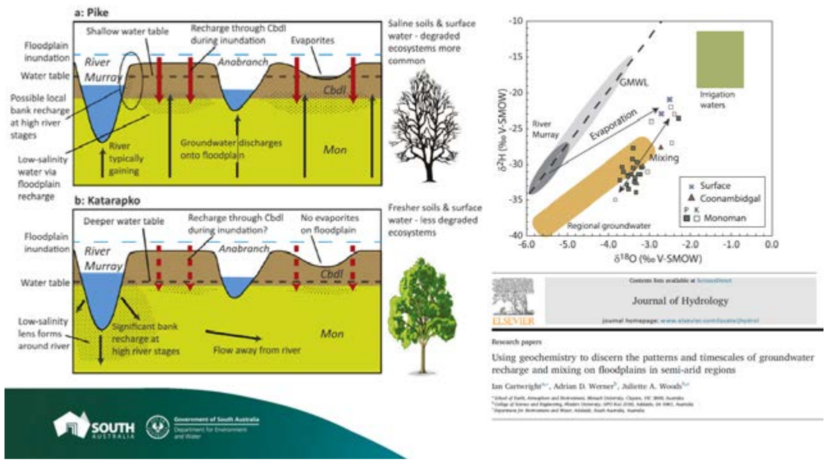
Lower-salinity lenses



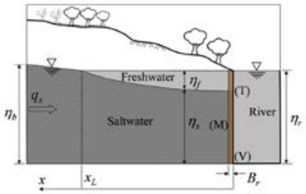
8



10



11



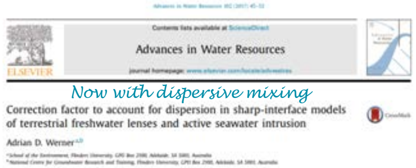
Analytical solution for:

- Flow to the river (q_s)
- Lens length (x_L)
- Lens thickness near the river (η_{fr})
- Lens shape (η_f)

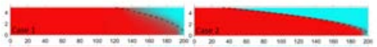
Assumes steady-state

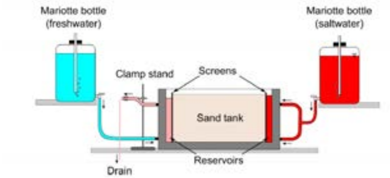
Sharp interface, no dispersion

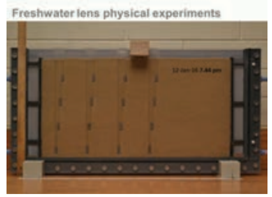
Key finding: lenses may occur even when river is gaining

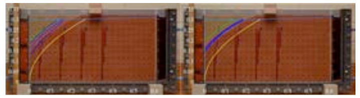


Now with dispersive mixing

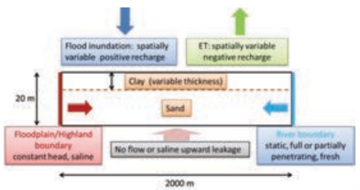


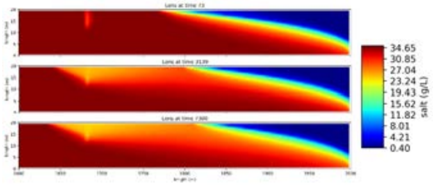






Experiments versus numerical modeling



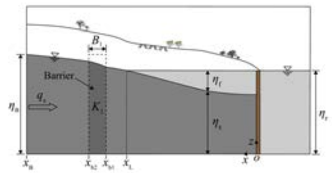


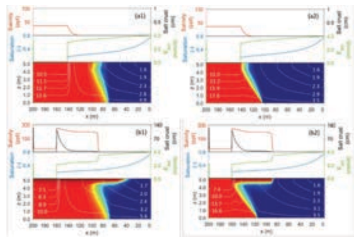
Well screened 6-9 m depth, injecting 0.03 m^3/d

Ongoing work

Vertical low-hydraulic-conductivity barriers

- Huiqiang Wu, Adrian Werner





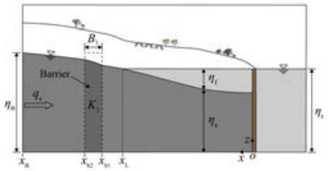
Evaporation and salt accumulation effects on riparian freshwater lenses

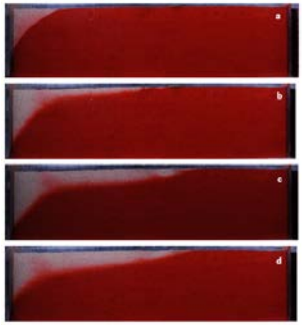
- Ilja America, Chenming Zhang

Ongoing work

Effects of river partial penetration, and flooding

- Amir Jazayeri, Adrian Werner

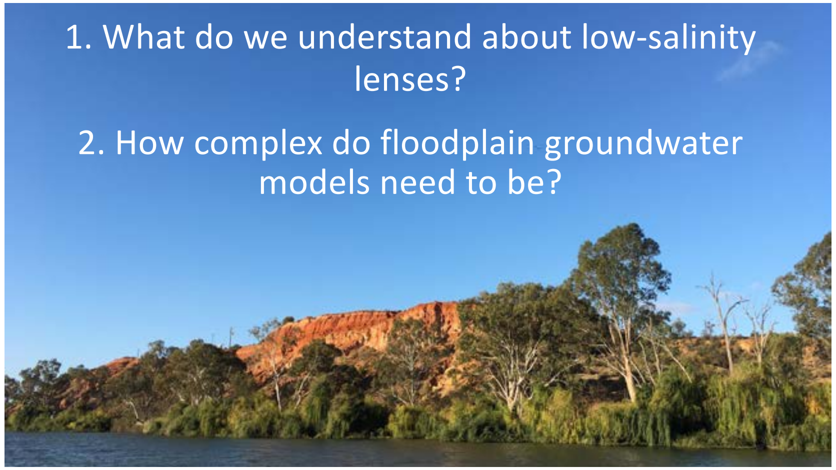




16

1. What do we understand about low-salinity lenses?

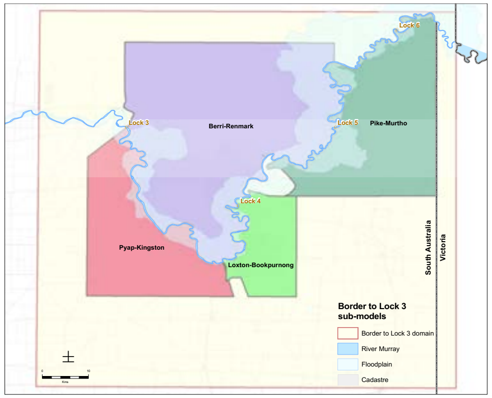
2. How complex do floodplain groundwater models need to be?



17

Salt load to river from long-term continuous actions

- SIMRAT: “floodplain attenuation factor”
- Salinity Register groundwater models: pool level river, constant ET

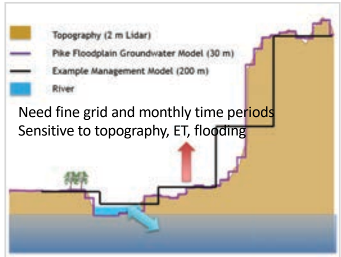


e.g. Yan W, Li C & Woods J (2012), *Waikerie to Morgan Numerical Groundwater Model 2012*. DFW Report 2012/18.

18

For environmental watering

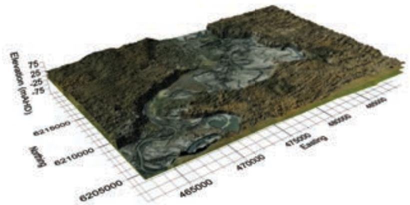
Can’t use a model not calibrated to dynamic conditions. Riches, V., Woods, J.A. and Bushaway, K. (in prep.), *Impact of modelled floodplain processes on key model outputs*, Department for Environment and Water, Adelaide, South Australia.



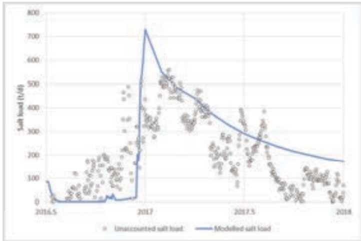
Woods J. (Ed.) (2015) *Modelling salt dynamics on the River Murray floodplain in South Australia: Modelling approaches.* Goyder Institute for Water Research Technical Report Series No. 15/10.
Riches, V., Woods, J.A. and Bushaway, K. (in prep.), *Impact of modelled floodplain processes on key model outputs*, Department for Environment and Water, Adelaide, South Australia.

19

For environmental watering



Purczel, C., Riches, V., Li, C., Woods, J., Wood, C. and Costar, A., 2016, South Australian Riverland Floodplain Integrated Infrastructure Project –Pike Floodplain Numerical Groundwater Model, DEWNR Technical report 2016/30, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide



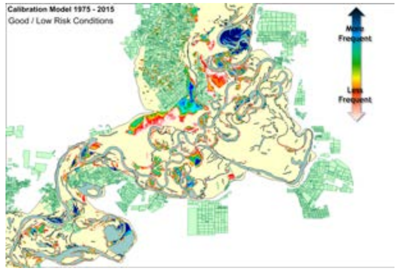
It does work!

Li C, Karbasi M & Herbert T (2019). *Post-audit of the Chowilla groundwater model for predicting the salinity impacts of regulator operation*, DEW Technical note 2019/XX, Government of South Australia, Department for Environment and Water, Adelaide.

20

For ecological management

- Fine detail
- Solute transport



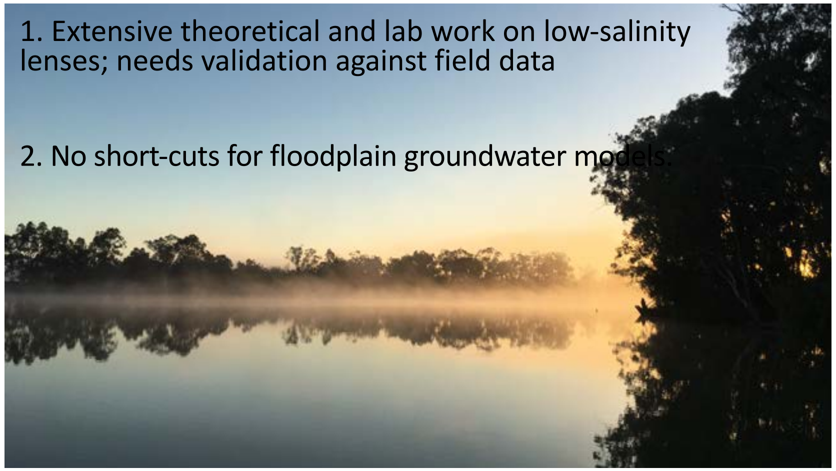
Denny M, Thompson D, Purczel C & Riches, V (in prep), Pike Floodplain ecological response to groundwater management: comparison of management scenarios, Department for Environment and Water, Adelaide, South Australia.

21

Limitations & further work

- Processes:
  - Inundation recharge
  - Evaporation, transpiration
    - Impact of salinity
  - Solute transport
- Need for data and validation
  - Low-salinity lens modelling
  - Post-audits of floodplain models
- ARC Linkage proposal to investigate

22



1. Extensive theoretical and lab work on low-salinity lenses; needs validation against field data

2. No short-cuts for floodplain groundwater models.

23


SOUTH
AUSTRALIA
Government
of South Australia
Department for
Environment and Water

24

Climate - observed trends and future projections

Geoff Steendam
Hydrology and Climate Science Team

Victorian Water and Climate Initiative

VICTORIA State Government | Environment, Land, Water and Planning

1

Overview

1. Information sources
2. Changes in climate & water resources
   - Observed changes
   - Future projections
3. Guidance and application – water resources

2

2

Overview

1. **Information sources**
2. Changes in climate & water resources
   - Observed changes
   - Future projections
3. Guidance and application – water resources

3

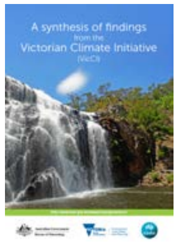
3

Some information sources for observed trends and climate projection

South East Australia Climate Initiative (SEACI) (2006 – 2012)

www.seaci.org

Victorian Climate Initiative (VicCI) (2013-2017)
Victorian Water and Climate Initiative (VicWaCI) (2017-2020)



www.water.vic.gov.au/climate-change

Victorian Climate Projections 2019

www.climate-change.vic.gov.au

Climate Change in Australia

www.climatechangeinaustralia.gov.au

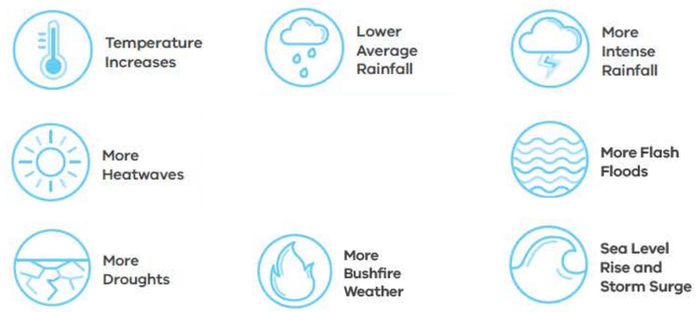
4

4

1. Information sources
2. **Changes in climate & water resources**
   - Observed changes
   - Future projections
3. Guidance and application – water resources

5

Physical risks posed by climate change for the water sector

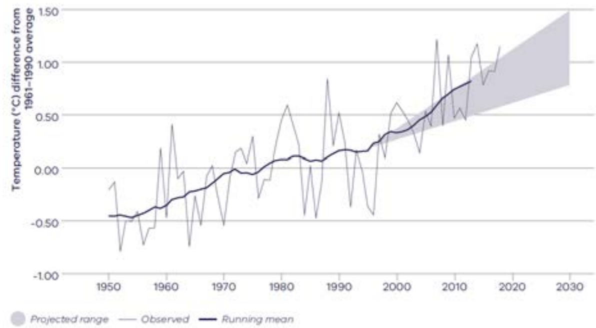


6

1. Information sources
2. **Changes in climate & water resources**
   - **Observed changes**
   - Future projections
3. Guidance and application – water resources

7

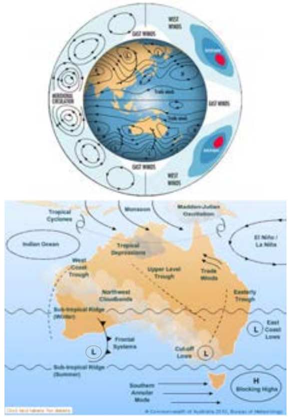
Observed temperature in Victoria is increasing

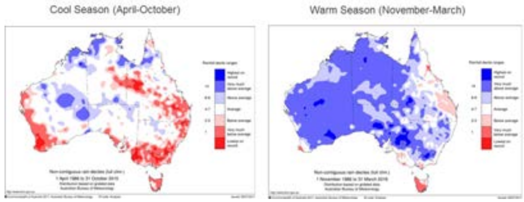


CSIRO, 2019

8

Southward shift in weather systems

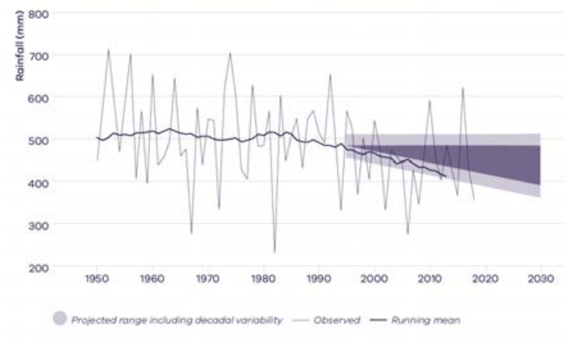




9

9

Observed winter rainfall in Victoria has been declining

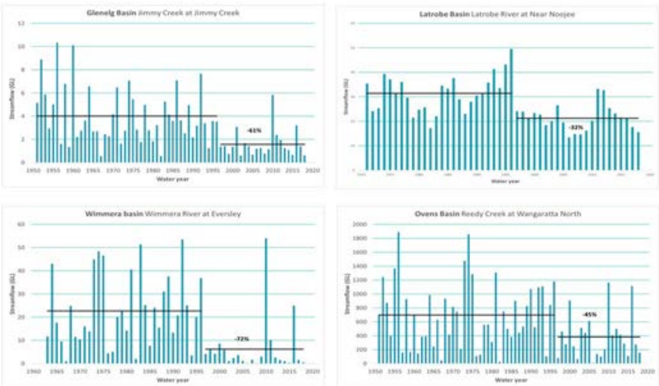


CSIRO, 2019

10

10

Declines in streamflow past ~20years

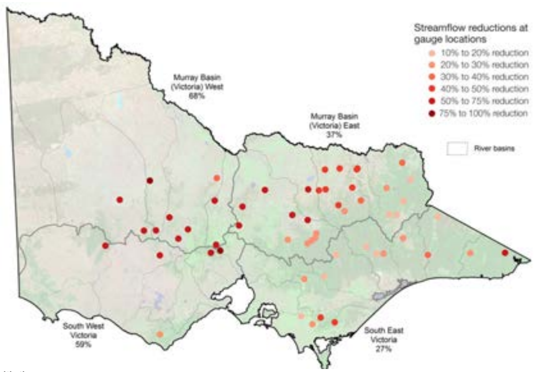


Source: DELWP

11

11

Declines in streamflow past ~20years

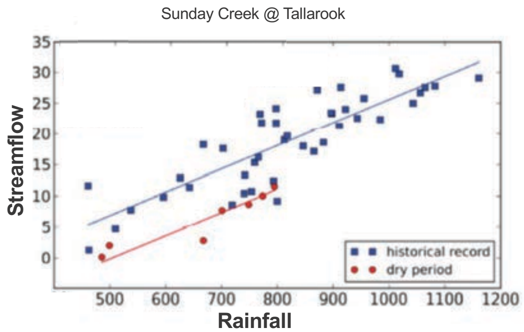


Source: Victorian Climate Initiative

12

12

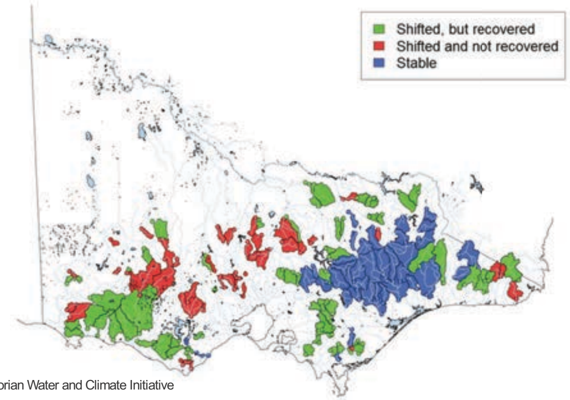
Reduction in streamflow response to rainfall



Source: Victorian Water and Climate Initiative

13

Reduction in streamflow response to rainfall



Source: Victorian Water and Climate Initiative

14

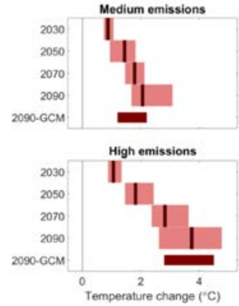
Overview

1. Information sources
2. **Changes in climate & water resources**
   - Observed changes
   - **Future projections**
3. Guidance and application – water resources

15

Temperature – average annual

Variable	Season	1986–2005 average Mildura[1]	Emissions scenario	Projected changes		
				2020–2039	2040–2059	2080–2099
Maximum temperature (°C)	Annual	23.9°C	RCP4.5	1.1 (0.8 to 1.4)	1.7 (1.0 to 2.0)	2.4 (2.0 to 3.8)
			RCP8.5	1.3 (0.9 to 1.6)	2.2 (1.6 to 2.8)	4.3 (2.6 to 5.5)
	Summer	31.5°C	RCP4.5	1.0 (0.5 to 1.7)	1.5 (1.2 to 2.2)	2.1 (1.8 to 3.5)
			RCP8.5	1.0 (0.6 to 1.8)	2.1 (1.6 to 2.9)	3.9 (2.3 to 5.4)
	Autumn	23.9°C	RCP4.5	1.1 (0.2 to 1.4)	1.7 (0.7 to 2.2)	2.1 (1.8 to 3.6)
			RCP8.5	1.2 (0.9 to 1.7)	2.0 (1.6 to 2.6)	4.3 (2.6 to 5.3)
	Winter	16.2°C	RCP4.5	0.9 (0.7 to 1.1)	1.3 (0.5 to 1.7)	1.9 (1.7 to 3.6)
			RCP8.5	1.1 (0.7 to 1.3)	1.9 (1.5 to 2.0)	4.1 (2.5 to 5.0)
	Spring	24.1°C	RCP4.5	1.4 (1.0 to 1.8)	2.4 (1.3 to 2.7)	2.9 (2.6 to 4.5)
			RCP8.5	1.8 (1.1 to 2.2)	2.9 (1.6 to 3.7)	5.1 (2.8 to 6.6)

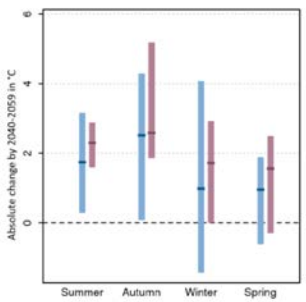


Source: Victorian Climate Projections – Mallee climate projections

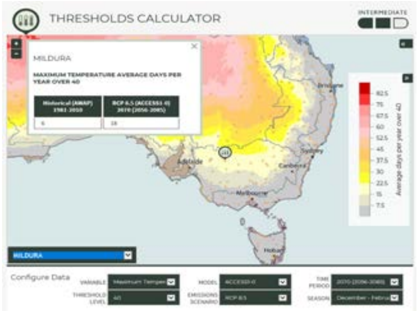
16

Temperature extremes

1 in 20 year hottest day



Days over 40'C



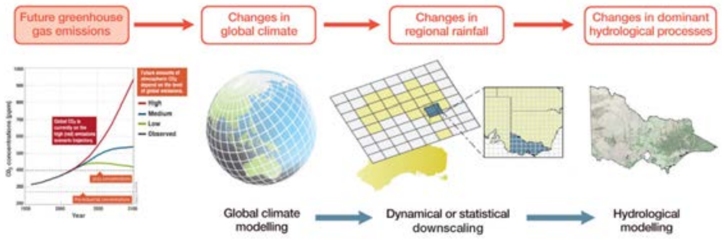
Source: Victorian Climate Projections – Mallee climate projections

[Source: www.climatechangeinaustralia.gov.au](http://www.climatechangeinaustralia.gov.au)

17

17

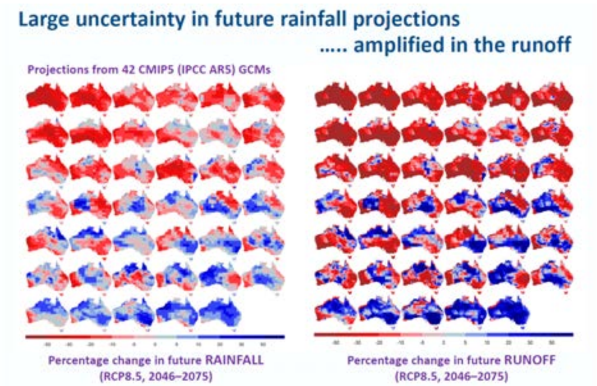
Projections uncertainty



18

18

Projections uncertainty – Global Climate Models

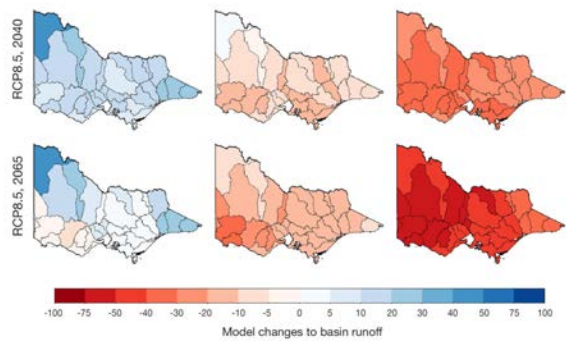


Credit: CSIRO

19

19

GCM based climate projections – empirical scaling approach

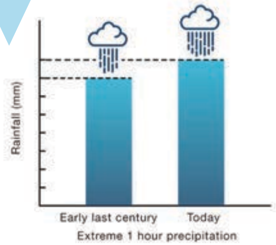


Source: Victorian Climate Initiative

20

20

Extreme rainfall



Duration
Events lasting less than 1 hour will increase in intensity the most.

Season
Storms in summer are expected to become more intense.

Rare events
More intense and more frequent.

Location
Rate on increase will depend on the season and place

Source: Victorian Water and Climate Initiative (factsheet)

21

21

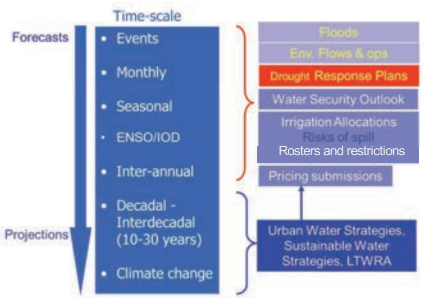
Overview

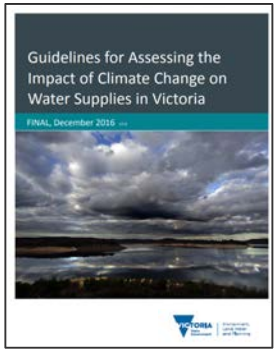
1. Information sources
2. Changes in climate & water resources
   - Observed changes
   - Future projections
3. **Guidance and application – water resources**

22

22

Application – water resources





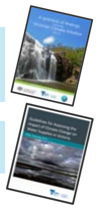
23

23

Application – water resources

development of
Victorian Water and Climate Initiative Synthesis Report

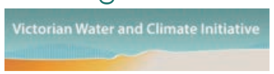
reviewing & updating
DELWP guidelines



- Next suite of IPCC Global Climate Models
- Local downscaling efforts with the new IPCC projections
- MDBA climate program
- National Earth Systems & Climate Change Hub
- BOM Hydroclimate Projections
- Etc…

October 2019

October 2020



24

24

Further Information

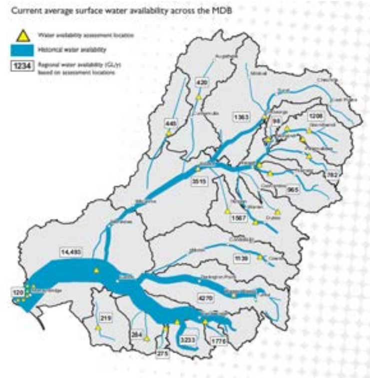
- Newsletter
- Website
- Annual Science Seminar
- Factsheets
- Working Group
- Guidelines

www.water.vic.gov.au/climate-change/climate-and-water-resources-research

Or google "Victorian Water and Climate Initiative"

25

Complex natural systems and water allocation framework



26

26

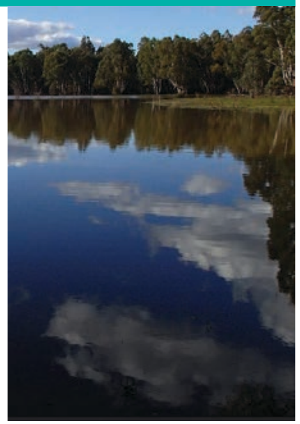
Hydrology and Climate Science Team

DELWP

Water and Catchments

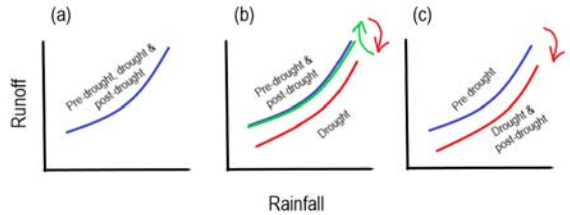
Water Resource Strategy Division

Hydrology and Climate Science Team



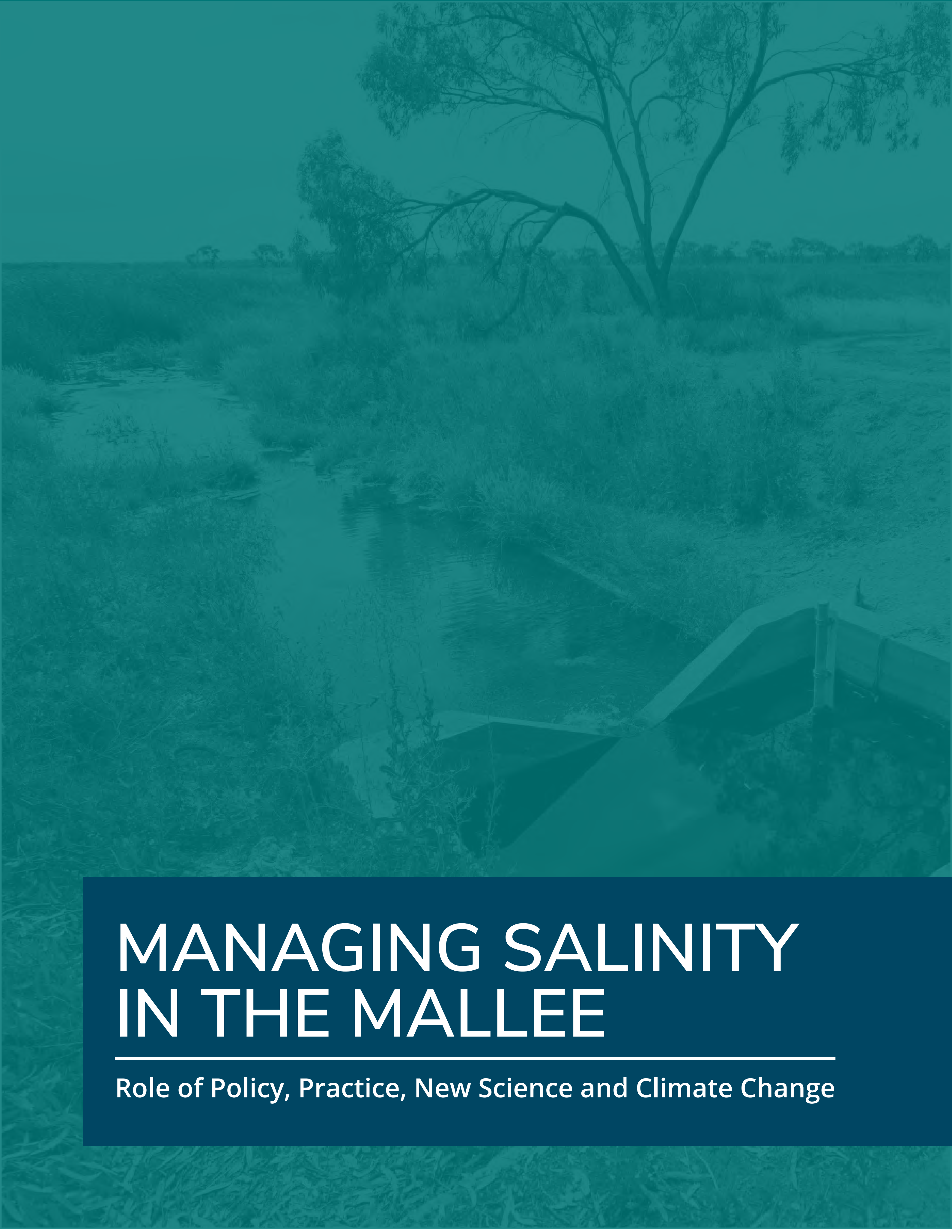
27

Reduction in streamflow response to rainfall



28

28



MANAGING SALINITY IN THE MALLEE

Role of Policy, Practice, New Science and Climate Change

mallee catchment management authority

VICTORIA State Government