Australian Government
Cotton Research and Development Corporation

FINAL REPORT 2018

For Public Release

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: DAN 1802

Project Title: Innovative approaches to water security for Australian cotton irrigators

Project Commencement Date: 1/7/2017 **Project Completion Date:** 30/6/18

CRDC Research Program: 2 Industry

Part 2 – Contact Details

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Signature of Research Provider Representative: ______________________

Date Submitted: ______________

Part 3 – Final Report

(The points below are to be used as a guideline when completing your final report.)

Background

1. Outline the background to the project.

It is paradoxical that Australia is the driest country on earth but the world's wettest continent, in terms of rainfall per person (Quiggin 2006). Therefore the water security problem for irrigated agriculture is not the inadequacy of the rainfall but that water may not be available where it is demanded. This mismatch between availability and demand is the single most important limiting factor for the productivity of irrigated cotton production in Australia. The issue of water availability and water productivity can be resolved in two ways – by identifying new sources of water or improving the distribution of existing water supplies.

This project explores existing and new, innovative approaches to improving water security. These approaches are evaluated in terms of their potential to increase water security for the Australian cotton industry. Recommendations are made identifying options for increasing the water security of the Australian cotton industry which warrant further investigation.

Objectives

2. List the project objectives and the extent to which these have been achieved, with reference to the Milestones and Performance indicators.

MS No.	Milestone Description (what are the key steps in answering the question)	Performance Indicator (one Output per Milestone)	Expected science/industry outcome (one S/I Outcome per Milestone)	Start Date *(dd/mm/yy)*	Finish Date *(dd/mm/yy)*
	1. Research question What are the innovative approaches to water security for Australian cotton irrigators				
1.1	Establish Project Management Committee and hold inception meeting	Project management Committee established	Industry engaged	31/07/2017	15/08/2017
1.2	Survey method questions developed and endorsed by the Project Management Committee	Documented survey method and questions	Scientifically credible survey method	31/07/2017	25/08/2017
1.3	Key growers advisors and irrigation industry participants identified and interviewed	Record of interviews	Industry engaged Industry better informed of innovative approaches to water security	28/08/2017	30/03/2018
1.4	Literature review and benefit cost study completed	Literature review	Industry and growers informed of innovative approaches to water security	2/10/2017	27/04/2018
1.5	Case studies on innovative approaches completed	Case studies documented	Industry and growers informed of innovative approaches to water security	16/10/2017	31/05/2018
1.6	Innovative approaches assessed and documented in the project Final Report	Final report	Industry and growers informed of innovative approaches to water security	6/11/2017	29/06/2018

Milestone 1.1 Establish Project Management Committee and hold inception meeting
Milestone 1.2 Survey method questions developed and endorsed by the Project Management Committee

A project management committee (PMC) comprising relevant industry experts was established and convened on 14 September 2017 as the first priority of the projects implementation plan. The members were David Duncan (Sustainable Soil Management Warren) Jim Purcell (Aquatech Consulting), Janelle Montgomery (Cottoninfo) and David Mitchell (NSW DPI).

The PMC endorsed survey questions designed to determine current innovative approaches to water security within the cotton industry, and to canvass expert and industry thoughts and ideas for future innovations. PMC members provided suggestions regarding appropriate industry contacts for survey participation.

Milestone 1.3 Key growers, advisors and irrigation industry participants identified and interviewed

Interviewees endorsed by the PMC are listed in the Interview Report, as are the questions utilised during the interviews (Attachment 1). The Interview Report summarises responses to each interview question, whilst a full transcript of each interview is provided as an appendix to the report.

Semi-structured interviews with industry representatives commenced mid-November 2017 and continued until the end of May 2018. The semi-structured interviews took longer than anticipated mainly due to the interview process coinciding with winter cereal harvest and cotton harvest. A total of 48 individuals from across the Australian cotton industry were identified and contacted. Overall, 25 industry participants made themselves available and were interviewed.

Milestone 1.4 Literature review completed

A literature review (Attachment 2) was completed in mid-June 2018. Part of this review identified and subsequently modified a framework to assess water security based around five key principles;

1. Supply Augmentation
2. Practice
3. Compliance
4. Markets
5. Policy

Innovations identified through both the interview responses and literature review were categorised under one of these principles.

In the project proposal, it was intended to identify a number of innovative approaches and undertake a benefit cost analysis (BCA) of promising approaches. The literature review and industry survey identified a number of approaches that appear promising and most of these have been detailed in the case studies undertaken as part of this project (Attachment 3). Of these, only the managed aquifer recharge (MAR) approach was deemed suitable for a BCA as all other options were either highly experimental (and clearly not presently cost effective) or were not suitable for such analysis.

A highly detailed BCA was completed on MAR for the Namoi in 2014 (Arshard *et al.* 2014). This study found that for the Namoi, MAR using basin infiltration was more profitable than surface storage, but this result was highly dependent on the selection of a range of parameters including high infiltration rate, low loss rates, evaporation rates and pumping costs. As MAR has a high energy requirement due to additional pumping it was decided to assess the overall environmental impact of this method. To that end a Lifecycle Assessment (LCA) was undertaken to measure the change in the greenhouse gas emissions profile of cotton production when MAR is used as a primary water source.

Arshad M, Guillaume J, Ross A (2014) Water 2014, 6(9), 2748-2769

Milestone 1.5 Case studies on innovative approaches completed

Four case studies have been prepared and provide greater detail regarding some of the approaches to water security identified during the literature review and interview process (Attachment 3).

The four opportunities covered in the case studies are:

- Supply Augmentation
- Antitranspirants
- Managed Aquifer Recharge
- Nature Based Solutions

Of these four case studies, Supply Augmentation is, naturally, classified into the Supply Augmentation principle, while the Antitranspirants, Managed Aquifer Recharge and Nature Based Solutions case studies are detailed examinations of the Practice principle.

Supply augmentation was a prominent theme in the industry survey and most of the responses were centred around building new dams, or increasing capacity of existing, storages. Additionally another prominent suggestion was the transboundary relocation of water, namely diverting freshwater supplies from high rainfall coastal catchments into the Murray-Darling Basin. Other more innovative approaches to supply augmentation were identified through the literature review and were considered to have greater potential, in terms of social acceptance, than those identified in the industry survey to provide enduring water security and therefore were further explored in the case study.

Concepts that were explored through the other three case studies, Antitranspirants, Managed Aquifer Recharge and Nature Based Solutions, were not identified in the industry survey but were identified in the literature review. The project team considered these three opportunities, which can be categorised within the Practice principle, warranted further detail and presentation as case studies. Case studies were not developed for opportunities identified under the Compliance, Markets and Policy principles as these were quite general in nature and were considered unsuitable for a case study.

Milestone 1.6 Innovative approaches assessed and documented in the project

This final report includes three attachments: the Interview Report; the literature review; and the four case studies. Each of these attachments document innovative approaches that may enhance water security for the Australian cotton industry.

The interview report is a collation of potential approaches elicited during discussion with industry participants and experts. As such, it does not assess the potential for the cited approaches to actually enhance water security for the Australian cotton industry. It does, however, provide an indication of the areas of interest for the industry in improving water security. Each option identified by interviewees is further examined in the Literature Review undertaken as part of this project.

The Literature Review collates and summarises information on innovative approaches to water security sourced within grey literature and peer reviewed scientific journal papers, and includes available information on those options identified by interviewees. The Review includes an initial assessment of the potential for each of the identified innovative approaches to increase water security for the Australian cotton industry.

The four case studies expand on this initial assessment for four areas considered by the authors to have the greatest potential to increase water security for the Australian cotton industry. The case studies provide recommendations regarding the requirement for either further investigation (potential R&D investment) or the development of education/extension campaigns.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

Industry member interviews

The survey methodology employed in this component of the project was based on a successful collaborative project between NSW DPI, Irrigation Australia Ltd. and Local Land Services. This project, "Review of current vegetable irrigation technologies (HIA Project #: VG14048 July 2015)", provided Australian vegetable industries with recommendations for further R&D to improve water productivity through the adoption of innovative irrigation technology and best management practices.

Interviews are the most commonly used data collection method in qualitative research and the semi-structured format is the most frequently used interview technique (DiCicco-Bloom & Crabtree 2006). Semi-structured interviews have proved to be both versatile and flexible and their structure can be varied depending on the study purpose and research questions (Kelly 2010).

Kallio *et al*. (2016) provides a framework to develop semi-structured interviews:

1. identifying the prerequisites for using semi-structured interviews;
2. retrieving and using previous knowledge;
3. formulating the preliminary semi-structured interview guide;
4. pilot testing the guide; and
5. presenting the complete semi-structured interview guide

The methodology used in the current study is consistent with this framework.

The following references were utilised in determining the interview questions and approach:

DiCicco-Bloom B. & Crabtree B.F. (2006) The qualitative research interview. Medical Education 40(4), 314–321. doi:10.1111/ j.1365-2929.2006.02418.x

Kallio H, Pietila A, Johnson M, Kangasniemi N(2016) Systematic methodological review: developing a framework for a qualitative semi-structured interview guide ***JAN*** (72) 12 pp2954-2965

Kelly S.E. (2010) Qualitative interviewing techniques and styles. In The SAGE Handbook of Qualitative Methods in Health Research (Bourgeault I., Dingwall R. & De Vries R., eds), SAGE, London, pp. 307–327.

The interviews

The interviewers were NSW DPI project staff: Dr David Mitchell (Tech Special Hydrology), David Cordina (Policy and Planning Officer Inland) and Sarah Dadd (Research and Development Officer). The interviewers arranged initial contact and the subsequent interview date and time. Interviews were conducted between November 2017 and June 2018.

The interviewee's were asked the following questions:

1. Would you consider access to water to be the key limitation to growth in the Australian Cotton industry?

1a. Are there any other things that may prevent growth of the industry?
- Water policy
- Industry reputation
- Competition against other industries
- Technology
- Access to labour market

2. For the industry to grow, do you think the cotton industry needs:
   - access to more water,
   - Greater reliability of water supply,
   - to use the available water more efficiently, or
   - a combination of above? our opinion what is the key limitation to growth of the Australian Cotton Industry?
3. Can you describe some of the technology/methods you are using to improve on farm water management?
4. Have you ever thought of, or come across, any ideas about improving water security? (If So) What do you think the barriers are to this being adopted?
5. Do you have any other suggestions?
6. What comments or questions do you have for me? Is there anything you would like me to explain? Is there anything you would like to tell me that you've thought about during this interview?
7. We may give you a call in a few weeks follow up some of these ideas? Would that be ok?

Interview Responses

Responses from the interviews were assessed and discussed by the project team to identify if any new concepts had been uncovered. This took place between March and May 2018 whilst the interviews were still in progress. The responses were compared to the findings of the literature review. Firstly the responses were classified into the five principles and then matched to the individual concepts identified in the literature review.

Literature review

The literature review was conducted using NSW DPI Library Services Google Custom search tool. This tool provides direct access to journal articles available through the NSW DPI library's online subscriptions or open access. This tool has access to over 4,000 online full text journals via NSW DPI Library Services subscriptions. Additional searches were conducted through the Google Scholar platform.

The range of search terms used included, but were not limited to: water security, irrigation water security, innovative irrigation water security, irrigation water scarcity, irrigation water availability, water availability, irrigation supply augmentation, managed aquifer recharge, anti transpirants, irrigation water markets, NSW water policy, Queensland water policy, Australian water policy.

Case studies

The case studies were selected during a number of discussions within the project team based on a range of factors. These included what concepts and opportunities the project team felt required additional information and detail that was above and beyond the scope of literature review. The four topics identified for the case studies were then researched using the same search platform as used for the literature review.

Results

4. Detail and discuss the results for each objective including the statistical analysis of results.

Industry Survey

Semi-structured interviews commenced in mid-November 2017 and continued until the end of May 2018. Towards the end of April 2018, after one of the project team discussions, it was identified that no new concepts or ideas were being identified. It was decided that no further interviews would be undertaken after the scheduled 25 had been completed as it was unlikely that additional interviews would elicit any new ideas and project resources needed to be allocated to different tasks.

A full report collating and summarising interview responses is provided as Attachment 1 to this report. As part of the analysis of interview responses, they were classified into the five key principles of water security identified in the literature review. A summary of responses aligned with the key principles is provided below:

1. **Supply augmentation**

Overall, 14 interview respondents discussed issues associated with supply augmentation, with the majority of the responses suggesting increasing the current size or number of off- and on-farm storages. Respondents also discussed: supply augmentation via translocating water from outside the catchment; improvement to river and dam operations to improve conveyance efficiency of delivered water; and more efficient management of flood waters.

2. **Practice**

15 respondents discussed issues associated with improving irrigation practice. The majority of the responses discussed ways to improve the management of losses within an irrigation system, and specifically the losses incurred when storing water in on-farm reservoirs.

3. **Compliance**

There were eight respondents who suggested options that were classified under the compliance principle. The responses fell into three broad groups:

- education of the public on how the cotton industry undertakes, and is improving, the transparency of compliance to show that the industry is a responsible corporate citizen,
- technology, such as metering and telemetering of water take, to improve industry's image and increase social licence, and
- applying punitive measures such as debiting illegal take from future allocations.

4. **Markets**

Six responses were classified into the market principle and these covered three areas:

- improving the use and utility of temporary water markets by improving market function through development of a central clearing house for water trades;
- education of growers in the use of water trades as an operation tool, and
- development of broader and more sophisticated trading products that covered a range of irrigation entitlements such as supplementary or environmental flows allowances.

5. **Policy**

This principle attracted the greatest response and the strongest opinions from respondents. Over 70% of interviewees (18 responses) provided an opinion or concept that could be classified into the policy principle. The overarching opinion presented in this area was that the constant shifting of water policy undermines irrigation investor confidence. One response identified sovereign risk as a major issue in regard to the fact that a government could default on its policy obligations.

The other major response area within the Policy principle centred on the appropriate management of environmental water, including the need for a transparent approach to the development of environmental watering plans, rules and goals. One response suggested that environmental water could be managed by using existing on farm infrastructure. This on farm infrastructure would be employed for the storage and delivery of environmental water to targeted sites. Another response suggested that the number of water entitlement shares be reduced thereby increasing reliability.

The interview results were compared to the results from the literature review to identify if any concepts that had been uncovered in the industry survey were absent in the literature review. This was done iteratively as the literature review and the industry survey were refined simultaneously throughout the duration of the project. Most concepts identified in the industry survey were captured by the literature review and those that were not were then included in the review.

Literature Review
The literature review undertaken for this project identified a wide range of approaches with potential to improve water security in the Australian cotton industry.

It also identified and subsequently modified a framework to assess water security based around five key principles:

1. Supply Augmentation
2. Practice
3. Compliance
4. Markets
5. Policy

The Literature Review is provided in full as Attachment 2 to this report. Some findings are summarised following.

1. **Supply augmentation**

The review identified that whilst the most apparent method to improve water security is by the provisioning of additional supply, it can be the most expensive with the construction of new storages, enhancement of existing storages and novel extraction methods being very costly. Many approaches to supply augmentation are also often in conflict with State and Commonwealth government policies, such as building new dams and further exploiting finite water resources.

2. **Practice**

There has been significant investment into research and development focused on improved on- and off-farm water management and use efficiency practices over the last 30 years. As a result, agricultural water productivity improvements have occurred across all sectors. However, this is still the most likely area in which the greatest improvement in agricultural water security could be made.

3. **Compliance**

In both NSW and Queensland a range of new compliance requirements are being implemented during 2018-19. Compliance is central to improving water security as these laws and regulations protect water users' rights and minimise the unlawful take or use of water. Across the board compliance with water regulations will ensure equitable sharing of water resources for all users.

4. **Markets**

Water markets in the Murray Darling Basin have been operating for over 30 years, but are not necessarily well understood. Improved provision of information for effective market operations as well as education on the fundamentals of water trade will allow more efficient resource allocation via the market and hence improved water security.

5. **Policy**

Water management policy is highly contested and has seen considerable change, mainly since the early 1990s. Water management is often embedded within a larger, systemic natural resource reform agenda and as such has many stakeholders and competing interests. There has been a near continuous revision of policy over the past 25 years and many cotton growers are pleading for stability and certainty in this area (as evidenced by interview responses gathered as a result of this project, Attachment 1).

Stability and certainty of policy can be improved and if undertaken will create a stable investment environment. Additional areas of improvement within water policy are centred around better provisioning of information and data on which water policy is informed and developed. This information and data includes environmental needs and groundwater architecture, enhanced accounting of conveyance losses as environmental water, and better communication between environmental and consumptive users.

Case study development

Four case studies have been drafted and are provided as Attachment 3. The four case studies provide further analysis of the potential for each selected option to provide enhanced water security for the Australian cotton industry.

The four areas that are covered in the case studies include:

- Supply Augmentation

In recent decades, exponentially growing water demand, decreasing reliability of water resources, and recurring extreme droughts in many regions have compelled scientists and policy makers to rethink the future of water availability and its management. Two areas of research for the augmentation of water supplies are the capture of atmospheric water for consumptive use and the use of low-quality water.

- Antitranspirants

Antitranspirants are chemical compounds that reduce the rate of transpiration from plants by limiting the amount of water that can be transpired. Antitranspirants can be categorized into three classes, namely; film-forming, stomatal regulating or reflective compounds (Abdullah *et al*. 2015). Research has been undertaken into the effects and efficacy of antitranspirants (Shinohara and Leskovar 2014). However, the research results are highly variable, and many researchers concluded that using antitranspirants were not economically and practically feasible (Evans and Sadler, 2008).

- Managed Aquifer Recharge

Managed aquifer recharge (MAR) refers to the intentional recharge of water to aquifers for subsequent use or environmental benefit (CSIRO). It has been estimated that up to 8,000 GL of water is evaporated from large dams each year in Australia. Managed aquifer recharge (MAR) is potentially a method to limit these losses, where the savings can be used for additional cotton production. However, a range of barriers need to be overcome to allow this practice to be implemented by the cotton industry in Australia.

- Nature Based Solutions

Nature-based solutions (NBS) are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN). Nature-based solutions for water refer to solutions that are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water (WWAP/UN-Water, 2018).

Outcomes

5. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

Industry survey

The expected outcome of the industry survey was to identify innovative options to enhance water security. These approaches were required to be relevant and of high potential from the point of view of the Australian cotton industry. A wide range of responses were gathered by the industry survey and all the responses were consistent with innovations identified through the literature review. This suggests that the cotton industry is relatively abreast of the latest developments in water security and largely consider water security as an important issue underpinning their irrigation business.

Literature review

A comprehensive review of literature was undertaken in order to determine innovative approaches of most relevance and potential for the Australian cotton industry.

A number of innovations were identified through the literature review (and industry survey) that could potentially provide additional water security for the Australian cotton industry. These were categorised under one of the five key principles and include:

<u>Practice</u>

- Reducing losses
    - Evaporation mitigation

It is estimated that around 8,000 GL of water is evaporated from Australian reservoirs each year. A number of approaches have been identified that could reduce this loss including a range of chemical and physical barriers such as polymers, low-cost covers and floating solar arrays for evaporation mitigation.

It should be noted that CRDC and NSW DPI have previously invested in developing and assessing polymer options for evaporation mitigation. However due to the commercial-in-confidence nature of the research very little if any of this information is available in the public domain.

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    - Antitranspirants

Antitranspirants are chemical compounds that reduce the rate of transpiration from plants by limiting the amount of water that can be transpired. These compounds may provide an option within the suite of current management tools to reduce water use in cotton at specified plant growth stages. For example, water loss in cotton seedlings was reduced by approximately 40% (Christiansen and Ashworth 1978), reducing early stage water demand and leaving more water available for irrigation in later stages of plant growth. An opportunity exists to explore these compounds through further R&D that investigates their cost, effectiveness and associated potential side effects.

- Irrigation delivery systems upgrades

Assessment of the Trangie Nevertire Irrigation Scheme (TNIS) identified network water losses and showed that if these losses could be mitigated, then a total of over 29,000 ML in water savings would be generated (Vanguard 2016). There were three broad categories identified to address these water losses, namely;

  - Scheme rationalisation which consisted of removal of redundant, inefficient or underutilised channels. In total, 97 km of open channels were removed.
  - On farm modernisation which involved mainly changing from less efficient flood irrigation to more efficient sprinkler irrigation (lateral move or centre pivot irrigation), through making changes to tailwater reuse systems and improving the efficiency of on-farm water storages.
  - Scheme modernisation which involved lining supply channels (143 km of channels were upgraded with rubber lining), improving water control, metering and improved accounting for water.

- On farm Irrigation Modernisation

Significant volumes of water lost in on-farm irrigation systems each year can be recovered. For example, the Sustaining the Basin: Irrigated Farm Modernisation (STBIFM) program (delivered by the NSW Department of Primary Industries) funded 112 projects (section 4.2.4) that resulted in the combined recovery of approximately 34.2GL in water previously lost from the system.

- System harmonisation

Water abstractions for irrigation and environmental watering have so far been managed separately, with the two water demands being under separate and divergent control. There has been an ongoing desire to harmonise both water demands to produce sustainable use of land and water resources. This concept entails considering irrigation systems as an integral part of the catchment landscape as well as the regional economic and governance system.

- Nature Based Solutions

Nature-based solutions (NBS) is a new umbrella term describing a range of environmental management and research techniques that promote natural processes as a means for providing solutions to emerging environmental issues. It is recommended that further research into NBS be undertaken to identify what, if any, appropriate options for the Australian cotton industry can be adopted as a means of improving water security. These options would assist in keeping more moisture in the landscape to be available for plant growth, and in turn provide essential return flows and help build resilience to climate change. Additionally adoption of a NBS approach within the cotton industry could be promoted globally to demonstrate the cotton industry's contribution to good water stewardship and improve the industry's reputational risk profile.

- Storage of excess water

Managed aquifer recharge (MAR) refers to the intentional recharge of water to aquifers for subsequent use or environmental benefit. It has been estimated that up to 8,000 GL of water is evaporated from large dams each year in Australia. Managed aquifer recharge (MAR) is potentially a method to limit these losses, and the savings can be used for additional irrigated agriculture production. An opportunity exists to explore the exploitation of MAR through further R&D that investigates how this technique could be incorporated into irrigation scheme and or farm operation.

Christiansen M, Ashworth N (1978) Prevention of chilling injury to seedling cotton with anti-transpirants ***Crop Science*** (18) 907

Vanguard (2016) Trangie Nevertire Co-operative Ltd (TNCL) Final Project Report under Round One of the Private Irrigation Infrastructure Operators Program in NSW Trangie Nevertire irrigation Scheme http://www.tnis.net.au/LiteratureRetrieve.aspx?ID=216813

Compliance

- Development of "social license to operate" strategy

The long term viability and success of any business requires a 'social licence to operate'. This is particularly the case in irrigated agriculture which is highly visible, has high exposure to global markets and, as part of the water sector, has a wide range of stakeholders keen to influence practice.

An industry or any business part of that industry can be deemed 'legitimate' and granted social licence when its operations and the organisational values and processes underpinning them meet stakeholder expectations and satisfy societal norms (Dare *et al*. 2014). If the public deem the cotton industry is a responsible manager of natural resources such as water, and the cotton industry can demonstrate water stewardship, this then may reduce social and political pressure to divert water away from consumptive use. Therefore, demonstrating water stewardship by ensuring water compliance within the cotton industry can assist in securing long term access to water resources.

It is recommended that the Australian cotton industry invests in the development of a program that advocates the benefits of water compliance and encourages industry to adopt and promote compliant practices as a way of demonstrating their water stewardship. This could be undertaken by a social research approach such as community-based social marketing.

Dare M, Schirmer J, Vanclay F (2014) Community engagement and social licence to operate Impact Assessment and Project Appraisal (32)3:188-197

Markets

- The provision of information for effective market operations specifically the availability of water for trading

Improved market information on water trades and prices will allow improvements in allocative efficiency in market transactions as well as reducing transaction costs and uncertainty. Additionally, more transparent market information may help identify compliance issues and opportunities for more efficient water management (such as those caused by metering inaccuracies).

Improved knowledge and understanding of specific water trading products and markets (Aither 2017) and how water trades can be better used as an operation tool will allow cotton growers to make more informed decisions and better fulfil seasonal cotton water requirements. For example if a cotton producer wants to grow 100 ha of cotton this will require approximately 800 ML of water. However if the grower only has an allocation of 500 ML, they will require an additional 300 ML. This additional supply can be sourced by using a variety of water trading products, but is a task made difficult with limited understanding of the use of water products and market to obtain this water.

It is recommended that education of growers is undertaken regarding specific water trading products and how they can better use water trades as an operation tool.

Aither (2017) Water markets in New South Wales Improving understanding of market fundamentals, development, and current status
https://www.industry.nsw.gov.au/__data/assets/pdf_file/0006/155859/Water-markets-in-nsw-aither-report-for-dpi-water.pdf

Policy

- Accounting and valuing conveyance losses as environmental water

It has been shown that if conveyance losses are considered environmental watering of wetlands then this will increases the system efficiency proportionally by the percentage of wetland water consumption (Jia *et al.* 2013). This concept entails considering irrigation systems as an integral part of the catchment landscape as well as the regional economic and governance system.

It is recommended that further research be undertaken in this area as it may provide a mechanism to improve water security because irrigation would be seen as mutually beneficial to both environmental and productive use of water.

Case studies documented

The purpose of the case studies was to detail a number of novel concepts and techniques to inform the industry about innovative approaches to water security. Four case studies have been prepared that document selected approaches to water security uncovered through industry surveys and the literature review. The four areas of innovation covered by the case studies include:

- Supply Augmentation

  A range of technology is available to harvest water from the atmosphere, including highly specialised and experimental material through to age old techniques. Water yields from these approaches are very low with existing technologies and whilst these approaches may be useful in meeting deficits in critical human need, they would not be fit for purpose in supplying commercially irrigated cotton. However, this is an area that may experience rapid technological progress and development and as such, requires a "watching brief" on these developments. If this technology develops to achieve water yields that could supply commercially irrigated cotton then additional investment in R&D would be recommended.
- Antitranspirants

  An opportunity exists to explore antitranspirants through further R&D that investigates the cost, effectiveness, and associated potential side effects. Much of the existing R&D was conducted several years ago. Considering advances in science and technology since, revisiting its potential may be warranted.
- Managed Aquifer Recharge

  Managed aquifer recharge has been shown to increase cotton production in the Murrumbidgee catchment and will provide global environmental benefits and improve the environmental profile of Australian cotton production. The use of MAR also provides water savings as water losses through evaporation and seepage from surface-based storage systems are reduced. It is recommended that education and awareness of growers regarding the potential use of MAR to both increase cotton production and reduce environmental effect is undertaken.
- Nature Based Solutions

  Adoption of a NBS approach within the cotton industry could be promoted globally to demonstrate the cotton industry's contribution to good water stewardship and improve the industry's reputational risk profile. A recommendation is that the cotton industry invests in the development of a program that advocates for the benefits of NBS as a way of demonstrating water stewardship.

A major outcome of this project has been a number of recommendations to undertake R&D as well as capacity building in a range of areas. Acting on some or all of these recommendations should help to improve water security for the Australian cotton industry.

The further outcome of the project will include publication of the literature review and the case studies. Concepts of improved water security identified in the study provides a shortlist of potential investments as well as a structured method to assess new ideas that may not have been identified or developed by this project.

6. **Please describe any:-**
   a) **technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);**
   None
   b) **other information developed from research (eg discoveries in methodology, equipment design, etc.); and**
   None
   c) **required changes to the Intellectual Property register.**
   None

Conclusion

7. **Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?**

The industry survey respondents (as a representative sample of the cotton industry) have a good understanding of the importance of water security to the cotton industry. They also appear to have a good understanding of a range of issues and concepts that contribute to water security. This is evidenced by the consistency of industry survey responses between respondents and with the findings of the literature review. Through this research, a variety of water concepts have been recommended for further development that industry should support.

Improving water security can be viewed in terms of five key principles: supply, practice, compliance, markets and policy. Using this framework, new water security concepts can be categorised and an evidence based decision can be reached providing value for money, clarity and efficiency in the investment process.

Innovations to improve water security
This project identified a range of innovations that can be implemented to improve water security. Categorised under the five key principles, the following recommendations are provided:

Supply Augmentation
A range of technologies is emerging that could produce additional water supply for consumptive use, and if these developments achieve water yields that could supply commercially irrigated cotton then additional investment in R&D is recommended.

Practice
A range of techniques and methods are available to improve understanding and management of losses from off and on farm irrigation systems. In particular, this includes better management of channel seepage and evaporation mitigation via a range of technologies including novel polymer compounds, infrastructure upgrades, low cost covers and floating solar arrays. Other practices include the management and storage of excess water via managed aquifer recharge as well as reducing the transpiration of cotton without compromising yield by chemicals or genetic methods. Additionally, improved practice could be the aligning of current on and off farm activities with the concept of nature based solutions (NBS). This alignment would identify which current practices are aligned to NBS, what more could be done, and then NBS could be promoted as a way of demonstrating water stewardship.

It is recommended that an investment review be undertaken on these identified practices.

Compliance
A recommendation is that the cotton industry invests in the development of a program that advocates the benefits of water compliance to the industry as a way of demonstrating water stewardship. This could be undertaken by a social research approach such as community based social marketing.

Markets
It is recommended that education and awareness campaign is undertaken to inform growers regarding specific water trading products and how they can use water trades as an operation tool. This understanding will allow growers to make more informed decisions and to better fulfil seasonal cotton water requirements.

Policy
Water management policy is highly contested as there are many competing stakeholders. There are a number of concepts that would improve water management policy and include the better understanding of:

- environmental water requirements
- the groundwater architecture (aquifer geometry and subsequent modelling)
- enhanced accounting of conveyance losses as environmental water, and
- better communication between environmental and consumptive users.

It is recommended that further research be undertaken in this area as it may provide a mechanism to improve water security as irrigation is seen as mutually beneficial to both environmental and productive use of water.

Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:
(a) to further develop or to exploit the project technology.
(b) for the future presentation and dissemination of the project outcomes.
(c) for future research.

Further extension and education opportunities for this project will include:

- presentation of these finding to the CRDC board
- publication of the four case studies and the literature review
- development of popular press article/s for publications such as Spotlight or Australian Cotton grower
- publication of information via the NSW DPI STBIFM community of practice
- dissemination of project information via Cottoninfo
- assist the irrigation delivery systems managers to identify funding sources to provide upgrades and harmonisation including novel methods to store excess water.
- development of "social license to operate" strategy
- the provision of information for effective market operations specifically the availability of water for trading
- accounting and valuing conveyance losses as environmental water
- better communication between environmental and consumptive users

The area of water security is extensive ranging across international policies to improve transnational collaboration to enhance not only water security but social and political security through to local management techniques to improve access to irrigation water. As such this project has made initial steps towards the modification of an existing water security framework, gathering industry based evidence and then testing the robustness of the framework by categorising that evidence.

However there is a need to further develop and explore the framework and its utility in identifying and categorising opportunities to enhance water security for the Australian cotton industry. One of those opportunities is the use of the framework to explore the cross linkages between the identified water security concepts. As stated above this project categorised water security concepts however what is required beyond this is that all identified concepts need to consider how they address the five principles and provide evidence that the five principles are considered in the implementation of the concepts. This exploration of the cross linkages allow identification and potentially avoidance of perverse outcomes.

Other specific areas of research include:

- Develop and explore additional innovative policy options for water security including policy options include the flexible sharing between consumptive and environmental uses
- Develop and explore novel water market trading instruments
- Explore social licence development and approaches
- Continued development of framework for categorising water security and expand the scope beyond irrigated cotton industry to determine how if any concepts identified can also benefit other industries within the Australian irrigation sector
- Evaporation mitigation through a range of approaches including covers or novel materials,
- Technologies and methods to reduce transpiration of cotton without sacrificing yield

9. A. List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)

David Mitchell David Cordina Sarah Dadd 2018 Innovative approaches to water security in the Australian Cotton Industry Irrigation Australia Conference Sydney

A journal paper based on the modification of an existing water security framework, gathering industry based evidence and then testing the robustness of the framework by categorising that evidence is being drafted .

B. Have you developed any online resources and what is the website address?

No

Part 4 – Final Report Executive Summary

Improving water security can be viewed in terms of five key principles: supply, practice, compliance, markets and policy. Using this framework, new water security concepts can be categorised and an evidence based decision on investment or implementation can be reached providing value for money, clarity and efficiency in the investment process.

Innovations to improve water security

This project identified a range of innovations that can be implemented to improve water security. Categorised under the five key principles, the following recommendations are provided:

Supply Augmentation

Whilst the most obvious method to improve water security is by the provisioning of additional supply it can be the most expensive, with the construction of new dams, enhancement of existing dams and novel water extraction methods being very costly. A range of technologies is emerging that could produce additional water supply for consumptive use, and if these developments achieve water yields that could supply commercially irrigated cotton then additional investment in R&D is recommended. Two areas of research for the augmentation of water supplies are the capture of atmospheric water for consumptive use and the use of low-quality water. These two areas are investigated further through a case study developed as part of this project.

Practice

There has been significant investment into research and development focused on improved on and off-farm water management and use efficiency practices over the last 30 years. As a result, agricultural water productivity improvements have occurred across all sectors. However, this is still the most likely area in which the greatest improvement in agricultural water security could be made. A range of techniques and methods are available to improve understanding and management of losses from off and on farm irrigation systems. In particular, this includes better management of channel seepage and evaporation mitigation via a range of technologies including novel polymer compounds, infrastructure upgrades, low cost covers and floating solar arrays. Other practices include the management and storage of excess water via managed aquifer recharge as well as reducing the transpiration of cotton by chemicals or genetic methods without compromising yield. Additionally, improved practice could be the aligning of current on and off farm activities with the concept of nature based solutions (NBS). This alignment would identify which current practices are aligned to NBS, what more could be done, and then NBS could be promoted as a way of demonstrating water stewardship. It is recommended that an investment review be undertaken on these identified practices.

Compliance

In both NSW and Queensland a range of new compliance requirements are being implemented during 2018-19. Compliance is central to improving water security as these laws and regulations protect water users' rights, and minimise the unlawful take or use of water. If compliance is not enforced then any water sharing plan will fail. A recommendation is that the cotton industry invests in the development of a program that advocates the benefits of water compliance to the industry as a way of demonstrating water stewardship. This could be undertaken by a social research approach such as community based social marketing.

Markets

Water markets in the Murray Darling Basin have been operating for over 30 years but are not necessarily well understood by irrigators. Improved provision of information for effective market operations as well as education on the fundamentals of water trade will allow more efficient resource allocation via the market and hence improve water security. It is recommended that an education and awareness campaign is undertaken to inform growers regarding specific water trading products and how they can use water trades as an operation tool. This understanding will allow growers to make more informed decisions and to better fulfil seasonal cotton water requirements.

Policy

The water management policy space is a highly contested and has seen much change mainly since the early 1990. Water management is often embedded within a larger, systemic natural resource reform agenda and as such has many stakeholders and competing interests. With this near continuous revision of policy many cotton growers are pleading for stability and certainty in this area. Improvement in the stability and certainty of policy will create a stable investment environment which in turn will provide for water security. There a number of concepts that would improve water management policy and include the better understanding of:

- environmental water requirements

- the groundwater architecture (aquifer geometry and subsequent modelling)
- enhanced accounting of conveyance losses as environmental water, and
- better communication between environmental and consumptive users.

Attachment 1 Lit review
Attachment 2 Case studies
Attachment 3 Record of interviews
Attachment 4 David Mitchell David Cordina Sarah Dadd 2018 Innovative approaches to water security in the Australian Cotton Industry Irrigation Australia Conference Sydney

Review of innovative approaches to water security for the Australian cotton industry

Executive Summary

A review of literature undertaken as part of the DPI Agriculture/CRDC partnership project "Innovative approaches to water security for the Australian cotton industry" identified a range of innovations that can be implemented to improve water security. Improving water security can be viewed in terms of five key principles: supply, practice, compliance, markets and policy. Using this framework, new water security concepts can be categorised and an evidence based decision on investment or implementation can be reached providing value for money, clarity and efficiency in the investment process.

Categorised under the five key principles, the following recommendations are provided:

Supply Augmentation
Whilst the most obvious method to improve water security is by the provisioning of additional supply it can be the most expensive, with the construction of new dams, enhancement of existing dams and novel water extraction methods being very costly. A range of technologies is emerging that could produce additional water supply for consumptive use, and if these developments achieve water yields that could supply commercially irrigated cotton then additional investment in R&D is recommended. Two areas of research for the augmentation of water supplies are the capture of atmospheric water for consumptive use and the use of low-quality water. These two areas are investigated further through a case study developed as part of this project.

Practice
There has been significant investment into research and development focused on improved on and off-farm water management and use efficiency practices over the last 30 years. As a result, agricultural water productivity improvements have occurred across all sectors. However, this is still the most likely area in which the greatest improvement in agricultural water security could be made.

A range of techniques and methods are available to improve understanding and management of losses from off and on farm irrigation systems. In particular, this includes better management of channel seepage and evaporation mitigation via a range of technologies including infrastructure upgrades, novel polymer compounds, low cost covers and floating solar arrays. Other practices include the management and storage of additional water via managed aquifer recharge as well as reducing the transpiration of cotton without compromising yield by chemicals or genetic methods.

Additionally, improved practice could be the aligning of current on and off farm activities with the concept of nature based solutions (NBS). NBS is a new umbrella term that describes a range of environmental management and research techniques that promote natural processes as a means for providing solutions to emerging environmental issues. This alignment would identify which current practices are aligned to NBS, what more could be done, and then NBS could be promoted as a way of demonstrating water stewardship. It is recommended that an investment review be undertaken on these identified practices.

Compliance
A range of new compliance requirements are being implemented in both NSW and Queensland during 2018-19. Compliance is central to improving water security as these laws and regulations protect water users' rights, and minimise the unlawful take or use of water. If compliance is not enforced then any water sharing plan will fail. A recommendation is that the cotton industry invests in the development of a program that advocates the benefits of water compliance to the industry as a way of demonstrating water stewardship. This could be undertaken by a social research approach such as community based social marketing.

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Policy
The water management policy space is highly contested and has seen much change, and particularly since the early 1990s. Water management is often embedded within a larger, systemic natural resource reform agenda and as such has many different stakeholders, often with competing interests.

With this near continuous revision of policy many cotton growers are pleading for stability and certainty in this area, which growers believe will create a stable investment environment which in turn will provide for water security. There a number of concepts that would improve water management policy including the better understanding of:

- environmental water requirements
- the groundwater architecture (aquifer geometry and subsequent modelling)
- enhanced accounting of conveyance losses as environmental water, and
- better communication between environmental and consumptive users.

Contents

Review of Innovative approaches to water security for the Australian cotton irrigators

1 Purpose

This document is a review of the scientific literature and presents the current understanding of irrigation water security for the Australian cotton industry. The purpose is to develop a clear framework to categorizing concepts of water security and present a range of innovative ideas that warrant further cotton specific research or that could be developed and extended to improve water security in the Australian cotton industry.

2 Definitions

There are many definitions of water security in the literature and for convenience a definition has been selected for this project. Water security is defined here as "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies" (Grey and Sadoff 2007).

3 Water management in Australia

It has been advanced that water management develops along a series of step changes and paradigm shifts (Kampragou *et al.* 2010) (Figure 1). By following this approach improvements to water security can be assessed through the lens of a management continuum.

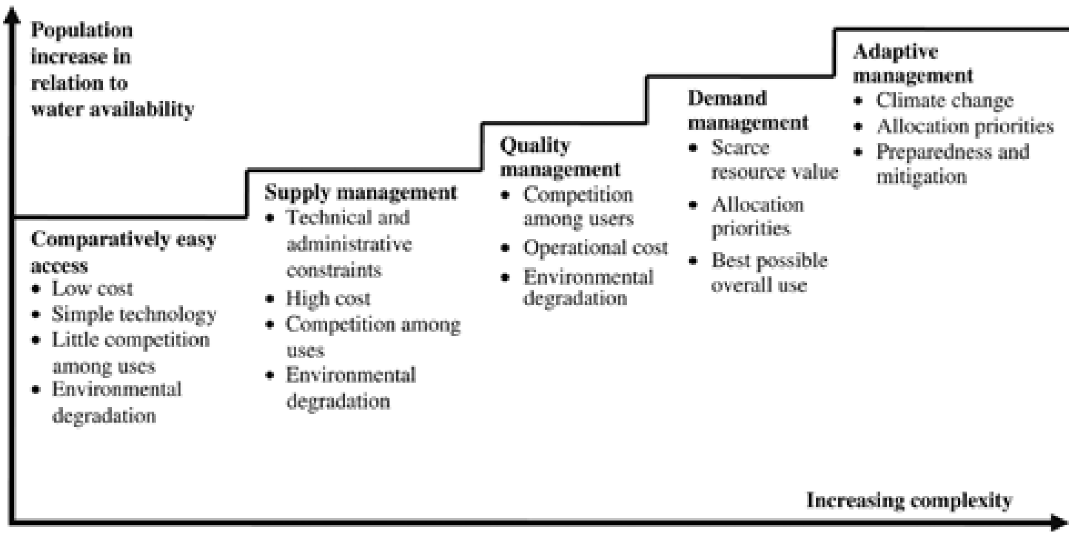

Fig 1 Paradigm shifts in water management (after Kampragou *et al.* 2010)

Water management in the Murray Darling Basin (MDB) is currently changing from demand management to adaptive management, particularly with the implementation of the MDB Plan (MDBP). This change has brought about additional concern over the security of water for irrigators particularly within the Australian cotton industry.

Irrigation development in the MDB commenced in the late 1880's, which symbolised the "easy access" phase of water management within the MDB. This phase came to an end when the River Murray Waters Agreement commenced in 1915.

The "supply" phase began with a period of public dam and weir construction. The construction of major dams commenced in 1908 and peaked in the 1960-70's, with the last major MDB dam completed in 1992 (Larsen *et al.* 2014).

"Quality" management was initiated with the implementation of the Salinity and Drainage Strategy (S&DS) in 1988 to combat river salinity, waterlogging and land salinisation in the Murray Valley. This strategy is continued in the Basin Salinity Management Strategy 2030 (BSMS).

In 1995, the MDB Ministerial Council introduced the MDB Cap on Surface Water Diversions (the Cap). The Cap introduced long-term limits on how much water could be taken from rivers in 24 designated river valleys and can be argued as the beginning of the "demand" management phase.

In 2012 the MDBP was enacted, and was specifically designed to be dynamic. The MDBP will be refined and updated with the knowledge gained from ongoing monitoring and evaluation (MDBA 2012). It heralds the commencement of the "adaptive" management phase.

4 Development of a framework to assess options to increase water security

Water security covers a vast range of activities, policies and technologies and there are a multitude of water security concepts present. It is necessary to classify these options to determine their relative merit in terms of utility in improving water security. To assess the utility of innovative approaches to water security, it is convenient to classify these approaches into supply-side augmentation solutions and demand-side efficiency solutions. These approaches consider how agricultural water is currently being used, and for what purposes. This is necessary as the purpose of use dictates both the scope and the extent of these solutions. In particular, the focus of this research is on new technologies and approaches that can be implemented to modify water use and supply, and allow farmers to better prepare and manage for water scarcity.

Simplistically, water security can be resolved by increasing water availability. This can be achieved by a combination of three main elements: identifying new sources of water (supply management), reducing current losses from existing water supplies, and improving water planning to maximise water use or efficiency (demand management).

However, water is a commodity that cuts across physical, economic, cultural and social boundaries. Therefore it follows that water management and security requires a more comprehensive approach and the development of a framework to assess concepts and management systems to enhance water security is required.

Loch (2018) proposed that improved water security can be achieved by implementing actions under five principles of water management (Loch's "5 P's"):

1. Project (supply augmentation)
2. Preachment (education, make people aware of the scarcity and value of water, encouraging behaviour change)
3. Police (compliance)
4. Price (effective markets)
5. Property rights

Whilst this framework is useful, it is proposed that it be modified to better reflect the requirements of the Australian irrigation industry, and that the five water management principles are renamed:

1. Supply Augmentation (such as new dams, reuse of low quality water and novel water sources)
2. Practice (for example, improved management of irrigation systems (on and off farm,) novel materials to reduce evaporation, antitranspirants and improving end-use efficiency of water)
3. Compliance (particularly improving property rights to water through enforcing catchment protection and ecosystems conservation and metering)
4. Markets (specifically improved water market education and intelligence)
5. Policy (including more flexible responses between environmental and consumptive users)

We have used this framework to categorise options to enhance water security for the Australian cotton industry. A suite of options that cover all five of these principles are required to ensure enduring water security in the Australian cotton industry.

4.1 Supply Augmentation

4.1.1 Supply-side water management

Supply-side water management works increase the amount of available water by:

- determining new sources of water;
- increasing the capacity of existing storages;
- diverting water to increase supply at a particular asset; or
- using technology to create clean, potable water from a previously unusable source.

(Delfau 2017)

Water supply augmentation can be achieved through supply-side water management upgrades to public assets or other government initiatives. These may include:

- building new or upgrading existing dams;
- desalination or reuse and recycling of low quality water; and
- collection of atmospheric water.

However, many of these techniques are often expensive, socially and environmentally challenging, and therefore difficult to implement (Montilla-López *et al.* 2016; Randall, 1981).

Further, this provides little incentive for users to improve their efficiency of use of the available water.

In terms of the MDBP, the volume of water extracted for irrigation cannot exceed the Long Term Annual Average Extraction Limits (LTAAEL), which are implemented via the Sustainable Diversion Limits (SDL). Supply-side management options must comply with this policy, therefore any new supply volume must fall within the current SDL's for a particular valley unless the new supply is derived from sources outside of the water licensing framework.

4.1.1.1 New sources of water

Obvious options for "new" water arise as a result of the construction of new, or the upgrade of existing, dams and storages. The potential for storage solutions within the MDB is discussed below.

However, the most significant sources of "new" water will be through improvements in current productivity per unit of water and a reduction in water losses within irrigation systems.

Building new or upgrading existing storages

Development of new dams within the MDB ceased in 1992 (Larsen *et al.* 2014) and no new dams have been built since. There are 310 storages in Australia with a total capacity of 80,958 GL (AWA 2014) of which 22,256 GL of that storage is within the MDB. However the 2014 "Agricultural Competiveness White Paper" identified 27 potential new dam sites in Australia that may help develop new food growing regions (Australian Government 2014).

In 2017, a $520 million capital component of the National Water Infrastructure Development Fund and the $2 billion National Water Infrastructure Loan Facility was provided by the Australian government to fast track water infrastructure construction in partnership with the state and territory governments. However, no new dams were commissioned as part of the Water Infrastructure Projects fund (Dept. Infrastructure Regional Development and Cities 2017).

WaterNSW recently completed an Options Study that detailed the existing NSW rural bulk water supply systems and developed a strategic level assessment of infrastructure solutions to mitigate or improve long-term "level of service" (LOS) issues in the NSW regulated valleys (WaterNSW 2018). The study reviewed the range of existing infrastructure and developed a LOS framework which is designed to provide transparency to customers in relation to their on-going water security. This in turn supports the long-term water infrastructure plans of WaterNSW (WaterNSW 2018). The LOS concept presents a customer's water supply as a series of delivery parameters that can be negotiated and adjusted in the broader context of customers' willingness to pay (WaterNSW 2018).

The options study suggested a number of supply augmentation projects including new infrastructure:

- In the Border rivers a new 100 GL Dam on the Mole River costing $331 million
- In the Gwydir Valley a new 350 GL Dam on the Horton River costing $937 million

- In the Namoi Valley a new 360 GL Blue Hole Dam costing $235 million and a new 22.5 GL Dungowan Dam and supply augmentation pipeline costing $484 million
- In the Lachlan Valley the raising of the wall of Wyangala Dam by about 10m costing $650 million
- In the Murrumbidgee Valley a new dam (Mingay Dam near Gundagai) up to 1000 GL costing $1,174 million

Additional to infrastructure, it was recommended that the full supply level for Burrendong Dam be changed by improving flood mitigation zone management (a no cost option). It should be noted that the Options Study is not a Capital Investment Plan for WaterNSW, but a baseline to guide future decision making and as a benchmark for future investments. As such this study should be taken as a starting point for discussion by stakeholders within the irrigation sector to improve water security for this sector.

Translocating water
Other novel sources of water include inter/intra-basin water transfers across long distances. Examples of "physical" transportation include the movement of surface freshwater or groundwater via large pipelines or across the sea in extremely large bags (Edmonds undated, Qadira *et al.* 2007). Additionally from time to time the concept of diverting coastal rivers inland to provide water to the MDB has been suggested. The Clarence River Interdepartmental Committee on Water Resources was constituted in 1968 (Ghassemi *et al.* 2006). In 1975 the committee reported that the scheme to divert water from the Clarence River to the MDB was not feasible, but suggested the concept be reviewed in 10 years. In 1980 the plan was revisited and in 1982 Rankine and Hill presented a preliminary investigation into the concept (Rankine & Hill 1982). The proposal identified fourteen basic schemes that could divert water inland from a number of northern NSW coastal catchments (Ghassemi *et al.* 2006). However a benefit cost analysis showed that none of the schemes were cost effective (Ghassemi *et al.* 2006).

Another transportation scheme suggests that 250ML plastic bags are filled with Burdekin River water and that these bags are towed by tug boat out through the Barrier Reef and released into the East Australian Current (EAC). Each bag is directed by an unmanned power pod that provides up to 250 km correction to the EAC path if necessary. The progress of the water bags is monitored by beacons on the power pods until the bags have arrived offshore of Tathra. Tathra has a nearby natural water storage reservoir, the Wallagoot Lake and is in close proximity (80 km) to the headwaters of both the Murrumbidgee and Snowy River systems and within 160 km of Lake Jindabyne in the Snowy Mountains Hydroelectric Scheme. The Murrumbidgee and Snowy River headwaters lie on the Dividing Range about 1000 m above sea level. This option proposed that water discharged at Tathra be pumped over a relatively short pipeline into the headwaters of the Murrumbidgee or Snowy Rivers and pumped into a reservoir of the Snowy Mountains Scheme via another short pipeline (Edmonds undated).

Desalination or reuse and recycling of low quality water
Non-conventional water resources include marginal or low quality water (CSG co-produced water, low quality (saline sodic) groundwater), wastewater reuse and desalination (Murphy

2018, Qadira *et al.* 2007). There are however, a number of constraints limiting the productive use of these water sources.

Low quality water: Coal Seam Gas (CSG) co-produced water

Coal Seam Gas co-produced water for irrigated agriculture will be constrained by:

- modest volumes of water available from this source, particularly in NSW;
- short-term supply of water (CSG projects generally have a production life of less than 20 years, and volumes of water in NSW are likely to peak at just three years)
- the need for a distribution system; and
- variable and seasonal irrigation demand (Murphy 2018).

In south-western Queensland, stretching between Oakey and Injune (Darling Downs), there are around 300 active CSG wells producing between 4.3 - 190 GL/y of water. This water will be available for reuse for beneficial activities including: ongoing operational uses, communities, farming and the environment. Annual production of produced water will increase until 2022, after which production will level off at around 160-190 GL/year (mean), before generally decreasing after 2031. Cumulative water production up to 2060 is predicted to be between 4500-5100 GL (QDNRM 2016).

The volume of produced water in NSW is much less than that predicted for Queensland. For instance the Camden Gas project in the Sydney Basin produces a maximum of 30 ML of water per year from all gas wells. It is predicted that the Narrabri Gas Project, in north west NSW and relevant for cotton production, will yield a maximum of approximately 1,500 ML per year which in turn could produce 190 ha of cotton at 7.8 ML/ha per year (Murphy 2018). Additionally produced water is produced year round and, during winter months, is not required for irrigation, hence additional storages for this period also be required.

Further, CSG produced water tends to be highly saline-sodic and is unsuitable for re-use in irrigation without comprehensive treatment. The feasibility of establishing infrastructure to treat a modest yield of produced water would depend on the quality parameters of the produced water, and in many instances would likely be cost prohibitive.

Low quality water: Groundwater

Groundwater can provide a valuable source of water for irrigation. However, the variable quality of this water requires appropriate management to avoid adverse impacts from its use in irrigation.

All groundwater contains salts, predominantly sodium chloride (NaCl), and if used to irrigate in its raw form, can result in:

- impaired plant growth due to salinity impacts on crops
- specific ion toxicity to plants (particularly sodium and chloride)
- damage to soil structure and permeability because of the high sodium and low calcium magnesium concentrations
- possible impacts on shallow aquifers

The use of marginal-quality groundwater resources therefore requires appropriate soil-, crop- and irrigation-management strategies to ameliorate considerable risks, in terms of the potential development of salinity, sodicity, ion-specific toxicity, and nutrient imbalances in soils (Sharma and Minhas 2005). Some of these strategies include the application of more (fresh) water than the plants require in order to flush accumulated salts away from the plant root zones.

Alternatively, the concentration of salts in marginal-quality groundwater can be reduced using a number of approaches. These include:

- removal of salts (desalination)
- dilution with low salinity water (shandying).
- Improving the balance of salts (decrease SAR, water softening)

Low quality water: Desalination

Desalination is a process that removes salts and minerals from low quality water. Water can be desalinated by a number of methods including:

- Distillation (Vacuum, Flash, multiple-effect, vapour-compression). This method essentially boils the water leaving the impurities behind.
- Freeze-thaw. This method uses freezing to remove fresh water from salt water as fresh water melts first due to a higher melting point and is recovered.
- Solar evaporation. Similar to distillation but uses heat from the sun to evaporate water
- Membranes and Reverse osmosis. This technique uses a temperature or pressure difference across a membrane to evaporate or filter water from a salty brine solution.
- Electrodialysis reversal utilises electric potential to move the salts through pairs of charged membranes, which trap salts in alternating channels.

A range of factors contribute to the cost of producing and conveying desalinated water and these include: desalination plant capacity, power use efficiency associated with whichever desalination process is utilised, the energy source utilised, proximity of the plant to source water and end users, and the project financing model (AWA 2018). An estimate of costs is highly variable and ranges between $1000-$4000 per ML. This cost should be compared to the current cost of permanent entitlement regulated river water of around $50 per ML.

Currently in Australia the only example of using desalinated water for agricultural production was the Sundrop Farms in South Australia (New Scientist 2016). This farm produces high value fresh vegetables for human consumption.

Low quality water: Conjunctive use of ground and surface water

The most common and cost effective approach where surface water is readily available is shandying. The aim of this practice is to dilute low quality water with higher quality water to mitigate the impact of the low quality water on crop performance. Usually this takes the form of diluting higher salinity groundwater with lower salinity surface water. Another method is alternating surface and groundwater applications. This practice of conjunctive use is widely used within the mid Murray Valley particularly for rice production.

Low quality water: Improving the balance of salts

As discussed above the concentration of salts within most groundwater can inhibit plant growth and degrade soil structure. One option to address this and increase the productive use of groundwater is to rebalance the ratio of cations present in order that the effect (particularly of sodium) on soil structure is diminished. This would require expert advice, close monitoring and careful management. Treating vast quantities of water required for broadacre cotton irrigation would therefore be costly and require considerable effort.

4.1.2 Extracting water from the atmosphere

Atmospheric water is a resource equivalent to about 10% of all fresh water in lakes on Earth. At any point in time, there is an estimated 142,000,000 GL's of water in the atmosphere present as vapour. There is obvious attraction in considering opportunities to harvest this water for agricultural purposes and as such, a number of approaches for extracting water from air have been conceptualised.

4.1.2.1 Metal-organic frameworks

Devices using porous metal-organic frameworks (MOFs) in ambient air with low relative humidity (down to 20%) have been developed that capture water from the atmosphere at ambient conditions using low-grade heat from natural sunlight below one sun (1 kW per square meter). At night, these crystals (MOFs) soak up water vapour from the atmosphere, and use heat from the sun to release it as liquid water during the day.

Assessment of the current yield from MOFs shows that continuously harvesting water in a cyclic manner for a 24-hour period with low-grade heat at 1 kW m^{-2} can yield approximately 0.9 L m^{-2} day^{-1} of water with a MOF layer with of 1 mm thickness (Kim *et al*. 2017). This innovation is highly experimental and has only been demonstrated on a minute scale to date. In its current state, MOF technology does not appear to be practical or cost effective means of enhancing water security for the Australian cotton industry at the paddock scale. However this in an area of technology that could quickly develop into paddock scale solutions.

4.1.2.2 Solar cyclone

A solar cyclone is an experimental device that is composed of a greenhouse for collecting and storing solar energy as heat, with a central chimney that channels an updraft of surface air heated in the greenhouse. An expansion cyclone separator for condensing and removing atmospheric water is placed at the base of the chimney. The separator consists of a strongly rotating vortex in which the central temperature is well below the dew point for the greenhouse air. Typical yields are calculated as 4.4 g water available for removal, per kg of air passing through the Solar Cyclone. Based on a rough analysis and extrapolation, a solar cyclone tower 500 m high with a diameter of 42 m could produce about 2 GL per year in an arid region (Kashiwa *et al.* 2008) plus approximately 3MW of power. Obviously the construction of such a device would require a high level of engineering construction and financial skills and as such would likely be cost prohibitive.

4.1.2.3 Fog collection and dew harvesting

Dew harvesting takes advantage of water vapour in the atmosphere to harvest water occurring as condensation. People have practiced dew harvesting for thousands of years in areas where rainfall and groundwater resources are scarce (Khalil *et al*. 2016). In situations where there is any humidity at all in the air, and there is a surface that is cool enough to provoke condensation, dew will condense on that surface until the humidity is too low. Desert vegetation has evolved to allow collection of its own humidity from the air. Technology based on the characteristics that allow desert plants to collect humidity in desert regions has advanced significantly around the world.

A review of dew harvesting potential was undertaken in 2015, this documented a large conical dew harvesting prototype that provided 50% of the water requirements for maize (Gabin 2015 cited in Tomaszkiewicz *et al.* 2015). However, the review concluded that whilst yields were low, the highest being 39 mm per year, future research needs to improve the understanding and performance of dew harvesting in the context of adaptation to climate change (Tomaszkiewicz *et al.* 2015).

Current dew water collectors are divided into two types: radiative (or passive) and active dew water condensers. According to the radiative energy available for condensation, the upper limit of dew yield is 0.8 L m^{-2} day^{-1} L/day/m^2 (Monteith and Unsworth 1990). The reported volume of dew from a 1 m^2 radiative condenser is between 0.3 and 0.6 L/day of dew water in arid and semi-arid regions (Khalil *et al.* 2016).

Active condensers work in a manner similar to that of a dehumidifier to extract water from the air (Khalil *et al*. 2016). Although they are more effective than the radiative condensers in terms of water yield per day, they require a source of energy which makes their operating costs much higher than those of radiative condensers which do not require an energy source other than natural sunlight (Khalil *et al.* 2016). The water yield of active condensers varies depending on the design and purpose and yields fall within the range of 15–50 L/day for a small portable drinking water unit to up to 56 ML per year (Belleza 2010) for the largest of units currently in operation.

4.1.3 Discussion

This section has presented a number of technologies that could provide novel water augmentation. The main constraint in this area is providing cost effective water yields that could supply commercially irrigated cotton. Upgrading storages or translocating water across catchments boundaries has in the past solved the supply side problem. However both these broad options are not cost effective and physically impractical. A range of technology is available to harvest water from the atmosphere, including highly specialised and experimental material through to age old techniques. Augmentation of supply by capture of atmospheric water, whilst still in some cases in it's infancy (MOF) and in other cases limited by yield (dew and fog harvesting), provides an area that could benefit from future research and development. As such it is recommended that the capture of atmospheric water for consumptive use and the use of low-quality water be explored for future potential research and development.

4.2 Demand-side water management

4.2.1 Practice improvement

Managing the demand for irrigation under situations of water scarcity includes a range of agronomic, economic, and technical practices and management decisions. These practices reduce the volume of irrigation water applied by the adoption of practices leading to water conservation and savings in irrigation. This reduces the demand for agricultural water, and an increase in yields and income per unit of water used (Pereira *et al.,* 2002).

Demand-side water management reduces the amount of water that is being used for irrigation and can be implemented by:

- physical ways such as reducing losses in on and off farm irrigation systems, improved accounting for water and improved physiological plant water use traits in crop breeding
- economic approaches focussing on financial incentives for reducing water use, or disincentives for overuse
- improvement in practices by education to change user behaviour
- maintaining a stable policy context to allow investment decisions in water efficient irrigation infrastructure. (Pereira *et al.* 2002)

4.2.2 Water accounting

The foundation of water accounting is knowing what water goes where. There are a two primary aims in water accounting;

- to assist in meeting the information needs of users in making water related decisions,
- to instil public and investor confidence in the amount of water being traded or extracted for consumptive use and recovered and managed for environmental and other public benefit outcomes (BoM 2009).

The Australian Bureau of Meteorology has published a Water Accounting Conceptual Framework (WACF) that consists of eight "Statements of Water Accounting Concepts" (SWACs) (BoM 2009). The framework is used to provide information on the flows of water within a system to allow, where required, remedial action to be undertaken to reduce or stop losses within that system. Before any action can be undertaken to reduce losses they must be identified and quantified to allow for appropriate and cost effective measures to be applied.

Statements of Water Accounting Concepts
SWAC 1 - Definition of the Water Reporting Entity
SWAC 2 - Objective of General Purpose Water Accounting Reports
SWAC 3 - Qualitative Characteristics of General Purpose Water Accounting Reports
SWAC 4 - Definition of Elements of General Purpose Water Accounting Reports
SWAC 5 - Recognition of the Elements of General Purpose Water Accounting Reports
SWAC 6 - Quantification of Attributes of Elements of General Purpose Water Accounting Reports
SWAC 7 - Compliance Disclosures in General Purpose Water Accounting Reports
SWAC 8 - Assurance of General Purpose Water Accounting Reports

The framework allows for informed decision-making based on information about water resources management and can be applied on and off farm. An adaptive water accounting framework, that acknowledges and supports innovations such as remote sensing and integrated crop and hydrologic modelling (Giordano et al. 2017) will provide better water governance and practices that contribute to water security.

The Australian cotton industry has a long history of accounting for water at the field and farm scale (Tennakoon and Milroy 2003, Chaffey 2018). Accounting for water allows for assessment of the efficiency of the irrigation system. If the efficiency of irrigation performance is improved then available water can be used more productively which adds to water security.

To develop accurate water accounts data associated with water application to the field and subsequent crop water use is required. There is also a long history of acquiring and using these measurements to develop water use indices (Roth *et al.* 2014). There is an ongoing development process in acquiring the data sets and ongoing refinement of data collection, collation and analysis would benefit the accuracy and relevance of this process. This includes sensor networks as well as remote, proximal or crowd sourced water application, crop water use and yield data. A review of the range and scope of these sensing technologies has been undertaken (Sanders and Masri 2016). The conclusion is that collecting of data at the optimum temporal and spatial scales allows for improved agronomic and irrigation planning and risk avoidance.

For example, crop growth measurements such as NDVI and LAI and water use can be measured at high spatial (3 m) and temporal (daily) resolution using Cubesat technology (Houborg and McCabe 2018). Crop water stress can be determined by the use of proximal sensors such as infrared thermal cameras to measure leaf water potential. Crop water stress can then be used to determine irrigation demand (Sela *et al.* 2007). As this data is collected daily, irrigation requirements can be better tailored to crop water needs improving the efficiency of water use.

Crowdsourcing water use data is the collection of industry wide water use and yield data. There are a number of online sites that allow for the general public to enter stream levels (Lowry and Fienen 2010, Crowdwater). The relevance to the Australian cotton industry is the development of a process to collect and collate widely available water and crop data to better understand how the current irrigation water is being used and to identify areas that could be improved, leading to enhanced water productivity. Additionally assessment of crop productivity by comparison with global water footprint benchmarks allows for targeting underperforming areas and hence opportunities to increase crop productivity (Mekonnen *et al.* 2014).

4.2.3 Reducing losses

Losses within irrigation systems occur two ways: either by seepage in to the soil or evaporation. Irrigation water that is currently lost in the system through evaporation, seepage and deep drainage is not available for productive use. Recovering some of these losses through the adoption of appropriate agronomic management and water delivery and application systems (modernisation) can dramatically increase on-farm availability of water. Roth *et al.* 2013 found that an increase in the use of more efficient irrigation systems, such as irrigation scheduling tools and irrigation system modernisation has dramatically reduced in-field losses from deep drainage. This study also found that evaporation from on-farm water storages on cotton farms comprised the largest losses to the farm water balance. It is important that the Australian cotton industry continue to focus effort on "reducing the major losses related to evaporation from storages", improving application efficiency and uniformity, and the use of modernised irrigation equipment (Roth *et al.* 2013).

Significant volumes of water lost in on-farm irrigation systems each year can be recovered. For example, the Sustaining the Basin: Irrigated Farm Modernisation (STBIFM)[1] program (delivered by the NSW Department of Primary Industries) funded 112 projects that, combined, resulted in approximately 34.2GL in water savings (Verwey *et al.* 2018). This program also requires irrigators to undertake Irrigated Farm Water Use Assessments (IFWUEAs) that identify on-farm water losses. There were 147 IFWUEAs completed for STBIFM, from which a total of 238GL in water losses were identified and verified. These represent only a sub-sample of cotton farms in Australia, yet the potential total water losses and savings across the Australian cotton industry are evident.

4.2.3.1 Evaporative loss

It is estimated that around 23,000 GL of water evaporated from Australian reservoirs each year (University of Melbourne 2018). An extensive review of evaporation mitigation techniques was conducted in 2008 (Baillie 2008). The review concluded that the use of a range of evaporation mitigation techniques (EMT) products could potentially reduce evaporation losses by between 480 to 700 GL. This figure was based on the use of chemical barriers such as monolayers but the review also found that the performance of these products are highly variable and future research and development was needed if potential evaporation savings could be realised. The cotton industry has long invested in evaporation mitigation technology (Baillie 2008, Dagley 2012), and it has been identified that suspended and floating covers are the most effective evaporation reduction mechanisms (Yao et al. 2010). It should be noted that CRDC and NSW DPI have invested in using polymers to mitigate evaporation however due to the commercial in confidence nature of the research very little, if any of this information resides in the public domain.

4.2.3.2 Polymers

The principle of using polymers to reduce evaporation is based on the ability of these compounds to spread out across the surface to provide a thin (often only a single molecule thick) layer that is not visible and reduces evaporation by restricting the transfer of water into the air. The efficacy of these compounds was tested in a trial on a cotton farm at St George Queensland in 2011-12. The trial was conducted on two approximately eight hectare dams but no results have been published (CottonGrower 2012).

[1] STBIFM is in irrigation modernisation program funded by the Commonwealth under the Sustainable Rural Water Use and Infrastructure Program aimed at recovering water under the Murray-Darling Basin Plan (MDBP).

4.2.3.3 Low-cost covers for evaporation mitigation

The basic principle of floating covers is to reflect incoming solar radiation, by creating a physical barrier and preventing the movement of water vapour in both a horizontal and vertical direction. Floating covers are commonly classified under one of two categories: continuous floating or modular floating, where continuous floating covers are a single entity covering the water body while the modular cover provides is a number of smaller covers which are not joined.

Floating covers are more suitable for small scale water storage facilities and have not been widely implemented on large dams and reservoirs (Yao *et al.* 2010). Currently in Australia a number of products are available such as floating modules, floating bubble-wrap type sheets, suspended permeable (shade cloth) covers; and suspended impermeable covers. Suspended and floating covers have been rated as the most effective evaporation reduction mechanisms, as they significantly reduce incoming solar radiation, trap vaporised water and decrease wind speed over water (Burston 2002, Craig *et al.* 2005). Additionally Yao *et al.* (2010) report that floating modular covers can provide an evaporation efficiency of greater than 60%, along with a likely reduction of algae, reduced surface water temperatures and lower dissolved oxygen levels.

4.2.3.4 Floating solar panels to reduce evaporation

Floating solar arrays (FSA) are an array of solar panels on a structure that floats on a body of water, typically an artificial basin or a lake. FSA have become increasingly popular around the world as both sources of renewable energy and as an evaporation mitigation strategy (NQCC 2017). One of the largest FSA was installed at Queen Elizabeth II reservoir at Walton-on-Thames England in 2016 and consists of 23,000 solar panels (6.3 megawatts) and covers an area of 57500 m^2. Several FSA have been installed in Australia including Jamestown SA, and Lismore NSW and one has been proposed for Townsville (NQCC 2017).

Whilst no studies have been carried out to determine the efficacy of FSA in evaporation mitigation it can be assumed that this is comparable to floating covers

4.2.3.5 Reducing seepage and deep drainage

Seepage losses from on and off farm channels can represent a significant proportion of the total water consumed by an irrigation scheme. It has been found that seepage can consume between 1 and 14% of the total water supplied via channel for agricultural use (Brinkley *et al.* 2000). On farm estimates of seepage range from 1 and 2%, with one farm losing 4% of allocated water due to particular soil conditions (Khan *et al.* 2005). Typical capital costs to save 1 ML of water are between $500 /ML and $4000 /ML depending on losses per unit length and the seepage reduction method used (Khan *et al.* 2005).

A range of techniques can be used to identify seepage including directly using seepage meters such as an Idaho meter, measuring the loss along channel sections and sensing via electrical conductance (EM) to identify areas of lighter texture which are prone to seepage (Akbar 2000).

Once seepage has been identified and quantified, remediation is usually undertaken by compacting the areas in the channel that were identified as seepage zones or lining the seepage zones with clay (NSWDPI 2018).

Deep drainage occurs when too much water (over irrigation for example) enters the soil and this water drains through the soil to below the root zone. This water then becomes unavailable for plant water use as the plant roots cannot access it. Silburn *et al.* (2013) showed that Australian cotton soils are prone to deep drainage, with losses which have been measured as high as 2.5ML/y/ha on some sites.

Irrigation scheduling helps to reduce deep drainage by only applying the volume of water that the plants need at the correct rate. However, some deep drainage is desirable to avoid accumulation of salts around the plants' root zones.

Other approaches to limiting deep drainage include increasing the soil water holding capacity. A range of chemicals have been developed that increase the water holding capacity of the soil and limit deep drainage. These hydrophilic polymers can improve the water holding capacity of sandy soils (Banedjschafie and Durner 2015). The plant available water (PAW)[2] in a sandy soil was increased from 0.005 g/g to 0.06, 0.20, and 0.28 g/g, respectively when treated three times with polymers. However, in a sandy loam soil very high rates of similar compounds (4 times the recommended rates) were required to elicit a crop yield response under relatively mild water deficit conditions. This limits the value of these polymers for agricultural field use.

4.2.3.6 Reducing transpiration

Antitranspirants are chemical compounds that reduce the rate of transpiration from plants by limiting the amount of water that can be transpired. Antitranspirants can be categorised into three classes, namely; film-forming, stomatal regulating or reflective compounds (Abdullah *et al.* 2015).

The use of various antitranspirants to reduce water lost through plant physiological processes was highly researched in the 1960s and 1970s. However, results were very variable, and many researchers concluded they were economically and practically infeasible.

Daily transpiration could be reduced (e.g., 5% to 10%) after the application of antitranspirant materials (e.g., stomata closing type chemicals such as phenyl mercuric acetate or Atrazine, or reflecting materials such as finely powdered white clays like Kaolin), but efficacy was limited to about two weeks under rainless weather conditions [Gale and Hagan 1966; Davenport 1967; Agarwal and De 1979; Yadov and Singh 1981]. The purpose of film-type antitranspirants (i.e., various long-chain alcohols) was to block water loss, but they tended to block photosynthesis more than they blocked transpiration because CO_2 molecules are 1.6 times larger than water molecules. There has been limited research on the use of antitranspirants on cotton, one study reported that multiple weekly application of the product did not have any effect on plant height, fresh and dry weight, leaf number and flowering (Mukerejee 1974). Other studies on summer growing cucurbits showed that spraying with kaolin caused significant increases in early, total and marketable yield in both seasons (Ibrahim *et al.* 2010).

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[2] Plant available water (PAW) can be conceptualised as a bucket filled by irrigation and or rainfall. As plants use the stored soil water the bucket is emptied. The size of the bucket is dependent on the soil type, with clay soils holding more water than sandy soils (NSW DPI 2014).

Genetic improvements may play a major role in reducing water use in crops depending on genetic and environmental interactions, but are unlikely to create major shifts in water use efficiency (WUE) (Sinclair *et al*. 2004; Passioura 2006). However, a recent study has identified the Photosystem II Subunit S or PsbS gene. It has been hypothesised that Photosystem II Subunit S (PsbS) expression affects a chloroplast derived signal for stomatal opening in response to light, which can be used to improve water use efficiency.

A recent study has showed that transgenic tobacco plants with increased PsbS expression show less stomatal opening in response to light, resulting in a 25% reduction in water loss per CO_2 assimilated under field conditions (Głowacka *et al.* 2018). This study shows that by the use of genetic manipulation, increasing PsbS expression suppresses stomatal opening and has little effect on CO_2 uptake and so increases water use efficiency (Głowacka *et al.* 2018).

4.2.4 Irrigation delivery systems upgrades

Improvement in the way irrigation distribution networks are managed has been recognised as having significant potential to improve the efficiency of water use (Dinar *et al.* 2007). Opportunities exist through the implementation of channel management systems such as Total Channel Control™ (TCC), which has been shown to deliver many of the benefits of a piped distribution system, such as improved timing and ability to deliver and reduced losses, at a lower cost (Dinar *et al.* 2007).

The basis of the TCC technology is a new range of control gates with automation and control software that delivers smart control of multiple regulating sites, rather than individual control of stand-alone sites as is common across the rural water authorities within Australia (Luscombe 2004).

Total Channel Control is a proprietary channel management system and includes a range of automatic in-channel controllers such as remote-controlled overshot gates that are connected to canal structures such as checks and regulators, a SCADA communications network, and advanced channel control and modelling software all run from a host computing site (Dinar *et al.* 2007). According to the study the range of benefits from TCC includes:

- the ability for the irrigators to precisely control their irrigation water environment;
- irrigation water is available when required (close to on demand);
- water is supplied at rates that match crop needs; and
- there is an elimination of fluctuation in flows or long lead times to order.

A review of the initial roll out of this technology (Luscombe 2004) reports that:

- automatic regulation within the channel network allows water to be delivered more effectively and efficiently as compared to manual operation;
- customer service was improved to supply water on one hour notice compared to the previous 72 to 96 hours notice required;
- supply regardless of location can be maintained at a constant flow rate from start to end; and
- losses can be identified as there is accurate measurement of flow at each regulating structure and once losses are identified they then can be rectified.

All these outcomes allow irrigators to better use and manage water, as well as increasing the efficiency of water delivery.

In the Macquarie Valley NSW, the Trangie-Nevertire Irrigation Scheme (TNIS) undertook an assessment of the TNIS conveyance channel to identify where the network was losing water to seepage and other losses (Vanguard 2016). The assessment identified that if these losses could be mitigated then over 29,000 ML water savings would be generated (Vanguard 2016). There were three broad loss categories identified:

- scheme rationalisation which consisted of removal of redundant inefficient or underutilized channels. In total, 97 km of open channels have been rationalised.
- scheme modernisation which involved lining supply channels, improving water control, metering and accounting for water. In total, 143 km of open channels have been modernised.
- on-farm modernisation which involved mainly changing from flood to sprinkler irrigation (linear move or centre pivot irrigation) or changing tailwater reuse systems.

The cost of undertaking the identified management actions was $115 million and this generated 29,620ML of water savings. Economic modelling of the investment suggests that the $115 million investment created a $130 million improvement in overall outcomes (Vanguard 2016).

4.2.5 System harmonisation

Water abstractions for irrigation and environmental watering have so far been managed separately, with the two water demands being under separate and divergent control (Khan *et al.* 2008). There has been an ongoing desire to harmonise both water demands to produce sustainable use of land and water resources (Khan *et al.* 2008). ''System harmonisation'' seeks to identify on-farm practices for irrigators to become an integral part of an expanding environmental services industry and in so doing support a truly sustainable and diversified irrigation business environment (Khan *et al.* 2008). This concept entails considering irrigation systems as an integral part of the catchment landscape as well as the regional economic and governance system.

There is little actual detail on what the on- and off-farm practice changes may be under system harmonisation and a significant share of the benefits that it generates are social or non-tradable in nature. These benefits may arise from lower levels of agricultural pollution or higher levels of environmental security and amenity value, better access to common property resources and enriched biodiversity (Khan *et al.* 2008).

For example, conveyance losses from an irrigation scheme in China are considered as wetland watering. This fraction of the irrigation water loss then becomes efficient environmental use, which in turn increases the system efficiency proportionally by the percentage of wetland water consumption (Jia *et al.* 2013).

4.2.6 Nature Based Solutions

Nature-based solutions (NBS) is a new umbrella term describing a range of environmental management and research techniques that promote natural processes as a means for providing solutions to emerging environmental issues (Nesshöver et al. 2017). These techniques can include conservation tillage, improving on farm biodiversity to improve pest control and plant based management of dryland salinity. Nature based solutions (NBS) is defined by International Union for the Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN). Nature based solutions for water (WWAP/UN-Water 2018) refers to natural or semi-natural systems (green infrastructure) that provide options for water resource management. NBS approaches to water management can include the use of natural wetlands, soil moisture retention and groundwater recharge (WWAP/UN-Water 2018; Palmer et al. 2015) and can be implemented in synergy with grey infrastructure such as dams and weirs.

Nature based solutions can be divided into two classes; Soil-Vegetation or Landscape solutions. The landscape solutions in agriculture promote soil and water conservation and include measures that disconnect water and sediment fluxes (Keestra *et al.* 2018). These strategies, like grassed waterways, vegetation strips, contour planting, and even the use of soil and stone bunds, all have the objective of slowing down the surface runoff, retaining soil and nutrients on-farm and enhance infiltration.

Some nature based solutions may require compromises in part of the production system, but can offer improved benefits that exceed the initial compromise. For example, in 2003 a group of local Japanese farmers decided to flood the rice paddies in winter, this was a new practice as paddies are usually left dry in the winter. Winter flooding creates habitat for migratory birds, dispersing the roosts of geese and improving the wetland function. According to local farmers, crop yields dropped by about 20-30% following adoption of winter-flooded rice paddies. However, successful branding and ecolabelling of the product (as 'premium rice') almost doubled the retail price and a local sake brewery purchases winter-flooded rice at premium cost, selling it as limited edition sake (IUCN, 2018). With further R&D, yields under these systems could be improved without diminishing investment in NBS approaches.

Aligning current on and off farm activities with the concept of nature based solutions would enable the cotton industry to improve its sustainability outcomes. As such, if NBS is adopted by the Australian cotton industry, then this could potentially be promoted globally to demonstrate the cotton industry's contribution to good land and water stewardship, improve the industry's reputational risk profile and provide access to higher value premium markets.

4.2.7 Storage of excess water

Managed aquifer recharge (MAR) is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit (Dillon *et al*. 2009). Managed aquifer recharge has potential as a method to limit evaporative losses by allowing surface water to be "banked" in an evaporation free environment. On average, evaporation losses from surface water storages range between 1200 and 1800 mm/year (Wigginton 2011), this represents a loss of approximately 35 % to 50 % of the total on-farm storage capacity, compared to MAR which has an estimated loss factor or 15% (Arshad et al. 2014). Whilst

MAR provides an evaporation free environment, it is estimated that only 85% of recharged water can be recovered from the aquifer.

There has been significant research and development on the potential of MAR in Australia. Previous studies have developed guidelines to select suitable aquifers for MAR, as well as identifying individual aquifers for MAR (Dillon *et al.* 2009; GHD 2011; Parsons *et al.* 2012; Arshad *et al.* 2014). The National Water Commission has made significant investment to support the growth of MAR schemes in Australia, targeting knowledge gaps, providing educative resources and facilitating of development of MAR projects to areas that currently do not use this technique (Parsons *et al*. 2012).

Research has identified four operational aspects of MAR (Ward and Dillon 2011), namely:

1. source water harvesting or the water that is captured for reuse, this is typically out of season flows or storm or flood waters,
2. aquifer storage is the volume within the aquifer that can be allocated to storage,
3. recovery is the volume of water that can be recovered, usually not all water that is injected into the aquifer can be recovered, and
4. end use or the final consumptive use of the water, in this case to irrigate cotton.

Additionally, there are a number of reports and courses available to provide a framework for assessing MAR scheme viability from concept to operation (Dillon 2009, Parsons *et al*. 2012, Australian Water School MAR essentials course, NCGRT MAR course). CSIRO supports an online repository of up-to-date resources relating to MAR (https://research.csiro.au/mar).

A range of barriers need to be overcome before this practice can be implemented by the cotton industry in Australia. One major impediment to the utilisation of MAR in NSW and Queensland is that current legislation determines that upon recharge, source water (that is the water that is being recharged) is subject to the extraction and management rules of the groundwater source (aquifer) (Ward and Dillon 2011). Firstly, groundwater enters the "common pool" once it is in the aquifer, and can be accessed by anyone with a groundwater use licence. Secondly, the moment the recharged water enters the aquifer it becomes subject to the relevant water extraction limits and laws.

A highly detailed BCA was completed on MAR for the Namoi in 2014 (Arshard *et al.* 2014). This study found that for the Namoi, MAR using basin infiltration was more profitable than surface storage, but this result was highly dependent on the selection of a range of parameters including high infiltration rate, low loss rates, evaporation rates and pumping costs.

4.2.8 Discussion

This area of water security has benefitted from a significant level of activity in research and development. Firstly improved accounting for water by implementing a standard system would improve transparency and additionally provide public and investor confidence regarding water that is extracted and traded. Secondly a range of techniques and methods are available to improve understanding and management of losses from off and on farm irrigation systems. In particular, this includes better management of channel seepage and evaporation mitigation via a range of technologies including infrastructure upgrades, novel polymer compounds, low cost covers and floating solar arrays. Other practices include the management and storage of excess water via managed aquifer recharge as well as reducing the transpiration of cotton without compromising yield by chemicals or genetic methods.

4.3 Compliance

> *"103. No one shall draw water without an authorisation from Caesar, that is, no one shall draw water from the public supply without a licence, and no one shall draw more than has been granted. (De Aquis* Sextus Julius Frontinus 96 AD)"

In both NSW and Queensland, a range of new compliance requirements are being implemented during 2018-19 with the implementation of the MDBP. Compliance is central to improving water security as these laws and regulations protect water users' rights, and minimise the unlawful take or use of water. Across the board compliance with water regulations will ensure equitable sharing of water resources for all users.

Water extractions need to be managed to achieve long term economic, environmental and social outcomes, and to ensure equitable sharing of this resource between all water users. In Australia, compliance rests at the state level, therefore this section reviews compliance systems in NSW and Queensland separately. Since mid-2017 both NSW and Queensland have reviewed and instigated change in compliance. As such it is pertinent to review these changes and identify areas where they could improve water security.

4.3.1 Water compliance in NSW

In late 2017 an independent investigation into NSW water management and compliance (the Matthew's report) identified fundamental failures in the public administration of water management in NSW. Based on this investigation, the NSW government introduced four principles in December 2017 to ensure NSW has an equitable and transparent approach to the management of water. These principles are:

- introduce best practice for water management
- ensure transparency in how we share, allocate and manage water
- build a compliance and enforcement regime that ensures strong and certain regulation
- build capability to support implementation of water reforms

A number of compliance measures have been developed to support the management of water in NSW and include:

- establishing the Natural Resources Access Regulator (NRAR) to oversee an effective, efficient, transparent and accountable compliance and enforcement framework supported by fair and consistent procedures for the management of the State's natural resources
- clarifying the accountabilities of departments and agencies with water management responsibilities in NSW
- creating clear functional separation between those who provide and sell water to customers and those who oversee and regulate water as a public resource
- implementing a robust metering framework
- adopting innovative technologies to improve compliance effectiveness

- creating a public register of water information that could cover water entitlements, water licences and water work approvals.

These measures are all designed to strengthen the compliance regime for equitable sharing of water in the NSW. As pointed out above, compliance is central to improving water security as it protects water users' rights and as such allows fair access to water. The range of measures outlined above will underpin the future for water management and compliance and hence water security for NSW irrigators.

4.3.2 Water compliance in Queensland

In 2017, the Queensland Government commissioned an audit into water measurement and compliance. The audit undertook a strategic review of Queensland's current non-urban water measurement and compliance framework including the regulatory arrangements which support water measurement and compliance. The audit found three critical areas that need to be addressed as part of a program of reform for water measurement and compliance. These areas were:

- introduce robust measurement and compliance governance
- implement a new policy for water metering
- provide adequate resources to implement the above two actions

(Waldron *et al.* 2018)

Similarly to the measures described above in the NSW compliance section, these measures will underpin the future for water management and compliance and hence water security for Queensland irrigators.

4.3.3 Impacts on Social licence to operate

The long term viability and success of any business requires a 'social licence to operate'. This is particularly the case in irrigated agriculture which is highly visible, has high exposure to global markets and, as part of the water sector, has a wide range of stakeholders keen to influence practice (Dare *et al.*, 2014). An industry or any business part of that industry can be deemed 'legitimate' and granted a social licence when its operations and the organisational values and processes underpinning them meet stakeholder expectations and satisfy societal norms (Dare *et al.* 2014).

Media reports such as "Pumped" (ABC 4Corners) and "Best Laid Plans" (ABC Background Briefing) that suggest the cotton industry is not compliant with the relevant laws and policy are particularly damaging to the reputation of the industry. With diminished reputation comes public and political pressure for reduced or more constrained access to the water resources. To appropriately respond to these issues, it is important to regain stakeholder confidence in the compliance system as well as for industry to demonstrate its compliance with legislation, regulation and policy.

As part of that approach adopting or advocating for a system such as audited self-management (ASM) could provide a mechanism to provide this confidence. ASM is an established audit system in New Zealand designed to verify adherence to Good Management Practices (GMP) (Carruthers 2011). GMP are analogous to Australian BMP's. The system relies on regional councils engaging auditors who undertake compliance audits, using industry developed GMPs or catchment targets as a basis against which to audit. Audit outcomes would then be accepted as proof of regulatory compliance by the land owner or consent holder (Carruthers 2011). The transparency of these actions then demonstrates responsible water stewardship.

It is recommended that the Australian cotton industry invests in the development of a program that advocates the benefits of water compliance and encourages industry to adopt and promote compliant practices as a way of demonstrating their water stewardship. The cotton industry already undertakes a range of activities similar to those outlined above as part of myBMP. A social research approach such as community-based social marketing could be undertaken to better communicate these actions.

4.3.4 Discussion

A range of new compliance requirements are being implemented in both NSW and Queensland during 2018-19. Compliance is central to improving water security as these laws and regulations protect water users' rights, and minimise the unlawful take or use of water. If compliance is not enforced then any water sharing plan will fail. If the public deem the cotton industry is a responsible manager of natural resources such as water, and the cotton industry can demonstrate water stewardship, this then may reduce social and political pressure to divert water away from consumptive use. Therefore, demonstrating water stewardship by ensuring water compliance within the cotton industry can assist in securing long term access to water resources.

A recommendation is that the cotton industry invests in the development of a program that advocates the benefits of water compliance to the industry as a way of demonstrating water stewardship. This could be undertaken by a social research approach such as community based social marketing.

4.4 Markets

Water trade occurs in the MDB by buying and selling water allocation and entitlements, usually referred to as temporary or permanent water trades respectively. Temporary (water allocation) trade was first allowed in New South Wales and South Australia in 1983 and in Victoria in 1987. Permanent (water entitlement) trade within an irrigation district was permitted in South Australia in 1983, New South Wales and Queensland in 1989, and Victoria in 1991 (Grafton and Horne 2014).

Water trading as it relates to the cotton industry occurs in the northern MDB and the southern connected system of the MDB. However, over 90% of Australia's water market activity is concentrated in the southern MDB (NWC 2011). Water markets provide a mechanism to allocate resources efficiently, moving water to high value products. As such cotton growers can use the water market to ensure water supply in times of scarcity.

Additionally the water markets in the MDB have helped deliver improved environmental outcomes as well as assisting irrigators' adaptation to climate risks by providing a mechanism to sell and buy both permanent and temporary water. This mechanism at the same time increased gross value of farming and met social goals (Grafton *et al.* 2016). More importantly water markets have provided a key adaptation tool to irrigators to restructure and survive water scarcity (Grafton *et al.* 2016) by allowing water to be sold for environmental gain with this income then reinvested in more efficient irrigation infrastructure.

The water markets in the MDB are based on the concept of a 'cap and trade' system. The cap on water establishes the limit of total extraction of water, in this case the Sustainable Diversion Limits (SDL). Water inside the cap is often called the 'consumptive pool' (Aither 2017). The SDL ensures that sufficient water is reserved for use by the environment and allows the value of water to be calculated (Aither 2017). However, evidence suggests that the current MDB cap and trade scheme is not functioning optimally due to seven key flaws (Holley *et al.* 2018). These flaws include a lack of robust regulatory compliance; limited accuracy in water accounting; challenges in addressing universality of impact and source, (which relates to the fact that water is physically constrained with catchments and aquifers); queries over environmental benefits; lack of accounting for wider social impacts; and limited operation across Australia (Holley *et al.* 2018).

4.4.1 Barriers to water trade

Governments at all levels have worked together over a long period to put in place a legislative framework that promotes effective water markets (ACCC 2012). However, some states continue to impose restrictions on the operation of water markets which create inconsistencies in trading arrangements across the MDB and can have the effect of distorting market outcomes. Government restrictions of this nature can also hamper the ability of irrigators to utilise the water market in managing their businesses. In Victoria, a four per cent limit still applies to water trade out of certain districts. While there are some exemptions for the Australian Government purchasing water in certain districts, other market participants still face restrictions (ACCC 2012). In January 2013 the NSW Government imposed a 3% trade cap per valley per decade of surface water access entitlements in the NSW MDB for environmental purposes (ACCC 2012, Grafton and Horne 2014). These restrictions are inconsistent with the Basin water market and trading principles contained in the Water Act, efficiently functioning water markets and the objectives of the Water Trading Rules (WTR), which form part of the Murray Darling Basin Plan (ACCC 2012, Grafton and Horne 2014).

These barriers to trade distort the market by preventing trading of water to its highest value of use and by limiting the amount of water that can be traded out of certain districts. Therefore water access by high value commodities such as cotton is limited. This restriction of access directly impinges on the water security of the cotton industry.

4.4.2 Improvements in market operation

One of the key developments to enable water trading in the MDB has been the enforcement of compliance for surface water extractions. It is necessary for efficient market operation that compliance on water extractions be enforced. If compliance on water extractions is not enforced then then there is no true cap and water taken illegally will undermine the efficiency of the market.

Reliable, accessible and timely market information on water trades and prices allows improvements in allocative efficiency in market transactions as well as reducing transaction costs and uncertainty (Grafton and Horne 2014, Aither 2017). By having readily available information on water trades the market will, by its nature, allocate water to its highest value. Having reliable and timely market information improves this allocative mechanism and also reduces the cost of the buyer or seller obtaining reliable information on the true value of water. By providing reliable and timely market information these transactional costs are minimised.

In NSW over 100 GL of entitlement trade and several hundred GL of allocation trade occurred during peaks in the early to mid-2010's (Aither 2017). This trading has allowed irrigators to respond to climatic variability by either selling or buying water as their needs dictated. This water was traded to either other irrigators or bought by a range of environmental water holders. In other jurisdictions these mechanisms are referred to as "water banks" and have been shown to be useful tools for managing both cyclical and structural scarcity (Montilla-López *et al.* 2016).

Improved knowledge and understanding of specific water trading products and markets and how water trades can be better used as an operational tool, will allow cotton growers to make more informed decisions on whether to buy or sell water to meet seasonal cotton water requirements (Aither 2017). As part of this, recommendations to improvements in education on the fundamentals of water trade, such as trade related actions, trade rules, data provision in terms of quality and timeliness of price information is required (Aither 2017).

A number of flaws have been identified in the cap and trade system (Holley *et al.* 2018). A number of these flaws have been discussed in previous sections, including a lack of robust regulatory underpinning (Section 4.3.1-2) and limited accuracy in water accounting (section 4.2.2). Additional challenges remain, including addressing universality of impact and source. This concept relates to the fact that water is physically constrained within systems and as such trading is limited by the physical connection between systems. For example trading of water cannot occur between the Lachlan and the Gwydir. The outcome is a reduced number of market participants and in an ideal market, reducing the number of participants will inevitably reduce the overall efficiency of the trading system (Holley *et al.* 2018). No market tool has been identified that can overcome this universality of impact and source. As such this is an area that could be explored to develop novel policy instruments to overcome this and in turn enhance water security.

4.4.3 Emerging risks and markets

Property and water rights were separated as part of the water reforms (Section 4.4). This separation has enabled flexibility in water trading and the reconfiguring of water rights has in turn has improved resource allocation (Grafton and Horne 2014). The separation of property and water rights has enabled further unbundling of water access rights from delivery rights and has converted bulk water entitlements held by irrigation companies on behalf of their members or shareholders into individual water entitlement (Grafton and Horne 2014). However risks come with this separation and with familiarity regarding the use of these rights. One of the major risks identified is sovereign risk, or the possibility that the value of existing water rights can be degraded by changes in regulation and discretionary behaviour by state governments (Grafton and Horne 2014).

Trading in environmental water can improve water supply for irrigation. For example, in 2014, following the spring environmental watering period, the Victorian Environmental Water Holder (VEWH) undertook a demand-supply assessment across the VEWH's northern region entitlements (VEWH 2014). It was determined that up to 8,000 ML of Goulburn and Murray allocation could be sold on the water market (VEWH 2014) allowing this additional water to be used for irrigation.

Similarly, at times the Commonwealth Environmental Water Holder offers parcels of held environmental water for sale by tender, as it has previously for Gwydir and Peel Valleys. These water allocations are deemed surplus to meeting environmental objectives in a given season and provide opportunity for the cotton industry to enhance short term water security. This emerging market could play a greater role in water trading and as such plays a role in enhancing water security for the Australian cotton industry.

Innovative water trading using the Snowy Advance scheme led to Murray Irrigation entering into an agreement with Snowy Hydro Limited to make up to 200GL water available as an advance to Murray Irrigation for the 2016/17 irrigation season. This is a borrowing exercise and this water will be repaid in increments when allocations reach a target percentage with no roll-over fee or fixed repayment date (Murray Irrigation 2017). Whilst this emerging market is currently limited to the southern connected systems it has developed novel products that overcome the concept of universality of impact and source (Section 4.4.2).

4.4.4 Discussion

Whilst water markets in the MDB have been operating since the early 1980's a range of improvements could be made to these markets. These include the improved provisioning of water market information on water trades and prices. This information will allow improvements in the allocative efficiency of the market. By providing this information buyers and sellers will reduce their transaction costs and uncertainty, allowing increased market efficiency. Additionally, more transparent market information may help identify compliance issues and opportunities for more efficient water management.

Encouraging emerging markets such as trading between environmental and consumptive pools is also an area that should be encouraged and the development of market tools to facilitate these transactions is recommended. Development of novel market based products that can overcome the concept of universality of impact and source also should also be explored.

4.5 Policy

Policy that governs access and use of water resources can provide opportunities for improved water security for the Australian cotton industry. It establishes clear property rights to water for consumptive use, facilitated by markets that allow water trading from entitlement holders that have excess allocations to those who are in short supply.

4.5.1 Current state and federal water management laws and policy

Managing New South Wales and Queensland water resources relies on a range of legislation, initiatives and cooperative arrangements between the Commonwealth and State governments. Key legislation for the management of water in NSW and Queensland includes the Commonwealth Water Act 2007. Prior to the introduction of this act, the MDB was managed by the respective States and Territories (Lehane 2014).

Specific to NSW are the Water Act 1912 and the Water Management Act 2000. In NSW the Water Management Amendment Act was introduced in 2014 and this act modified some sections of the Water Management Act 2000 and added new sections. These changes relate to a range of aspects of water management including planning, licensing and compliance.

The NSW Department of Industry Crown Lands and Water is responsible for implementing the Water Act 1912 and the Water Management Act 2000 and for managing NSW surface and groundwater. The department also ensures equitable sharing of surface and groundwater resources and that water entitlements and allocations are secure and tradeable.

One of the key changes to policy has been the four key goals that have arisen from the recommendations made in the interim and final "Independent investigation into NSW water management and compliance" (Matthews) reports into water management and compliance in NSW. These include

- introduce best practice for water management
- ensure transparency in how water is shared allocated and managed
- build a compliance and enforcement regime that ensures strong and certain regulation
- build capability to support implementation of water reforms.

The key piece of legislation for the management of water in Queensland is the Water Act 2000. In Queensland the Department of Natural Resources, Mines and Energy is responsible for implementing the Water Act 2000 and for managing Queensland surface and groundwater resources.

4.5.2 What are the policy approaches that could enhance water security?

A range of innovative policy concepts were identified in the literature that could enhance water security. The central theme from the review is that improved policy relies on collaboration between the complete range of stakeholders and improved understanding of the systems that the policy is managing.

Water security cuts across a range of stakeholders and factors including biophysical, infrastructural, political, social, economic, spiritual and aesthetics (UN Water 2013). Foundational to water policy is the understanding of the construct and the parameters in which water sits. As discussed above water is constrained initially by physical barriers such as catchments and aquifers, as well as by social, political and environmental spheres. As such "Collaboration across sectors, communities and political borders", cooperation and multi-disciplinary and cross-sectoral approaches are required to effectively manage water resources and will help to reduce conflicts and promote sustainable development and growth (UN Water 2013; AWA 2017; Marks and Hooghe 2004; Daniell *et al.* 2014; Giordano *et al.* 2017).

AWA (2017) highlight an emerging opportunity towards future water security which includes increasing water R&D investment to develop more innovative solutions and "to fill knowledge gaps across the industry and community". This may include better ways that policy can accommodate variability in supply while giving water users confidence in making decisions for the future. Giordano *et al.* (2017) reiterated a notion by Molden *et al.* (2001, 2003, 2007) that improving water security by increasing water productivity in irrigation can be achieved through four main pathways, one of which included increasing water productivity by:

- providing flexibility in the delivery of water to better suit crop water needs (in particular at critical crop growth stages) by improving water management; and
- improving reliability of supply to allow irrigators to invest more strategically in other agricultural inputs.

Holmatov *et al.* (2017) also recommend improvements to water productivity as a means of improving water security. In 2007, the National Plan for Water Security was introduced to improve water efficiency and address over allocation of water in rural Australia. In response, the Water Act 2007 was passed in the Australian Parliament, under which a requirement was to develop and implement the Murray-Darling Basin Plan (MDBP). As part of the suite of measures funded under the MDBP, almost $6 billion was allocated to modernising irrigation infrastructure to improve water productivity, reduce losses and in turn, return water to the environment (Grafton 2007). Some of these opportunities are discussed in Section 4.2.4.

Management of floodplain harvesting, for example via the NSW Floodplain Harvesting Policy 2013, sets floodplain harvesting entitlements and provides for trading. Bringing floodplain harvesting into the water licensing framework offers additional security to water users (ABC 2013; NSW Irrigators' Council n.d.). It provides for more accurate measures of take, losses and usage, and therefore helps to better refine the long term average annual extraction limits (LTAAEL). The subsequent introduction of tradability facilitates efficient resource allocation, whereby floodplain harvesting entitlement or account water can be traded and utilised in concert with other water products to improve farm water security.

4.5.2.1 How can improved information help water policy?

Water policy will always be based on imperfect information and open to competing influence from the range of stakeholders. To develop robust water policy there needs to be an understanding of the water balance and its relative components. This could involve improved understanding of how water is sourced (uplands and recharge), how it is conveyed (streams, aquifers channels), and how it is used (consumptive, environmental or cultural). The next step is to determine the linkages between those components (supply, conveyance, use) to identify and determine the most efficient means of sharing water between them and stakeholders, namely consumptive, environmental and cultural users.

Much of the water allocation policy for NSW is based on modelling of both surface and groundwater separately. For instance current groundwater models in the Namoi which are used as part of the sustainable groundwater yield estimates are created using MODFLOW which does not model surface water inputs comprehensively. Meanwhile surface water estimates are undertaken by the IQQ Model (IQQM). However IQQM does not model groundwater contributions well and there is a disagreement regarding the amount of water at the boundary between surface and groundwater (Kelly *et al.* 2007). This separation of modelling will present inaccuracies in surface water assessments and hence setting of both water allocation and water policy (Kelly *et al.* 2007). The best available approach now is to use coupled surface and groundwater modelling and manage these systems as one (Young and McColl, 2009).

One of the foundational data sets required for accurate groundwater modelling is aquifer and aquitard architecture. The two agriculturally significant aquifers in the Namoi valley are the Gunnedah and Narrabri Formations. In setting water allocation, these two groundwater systems are treated separately (Smithson 2008). However recent studies in the Namoi Valley have failed to detect any evidence of a boundary between the Narrabri and Gunnedah formations revealing a rather gradual change in dominance of clays and silts over sands and gravels embedded in a clay-rich matrix. This result challenges the conceptualisation used to conduct groundwater modelling on the Liverpool Plains (Ackworth *et al.* 2014) which in turn reflects on how groundwater is understood and allocated. Improved understanding of aquifer geometry will enhance groundwater allocation and hence water security.

4.5.2.2 Improved understanding of the linkages between water balance components and stakeholders

Environmental flows can be defined as a flow that maintains river health in a particular state (Acreman and Dunbar 2004). However environmental water requirements are not only defined in terms of bulk volume targets, they involve a combination of volume, timing, quality and dynamic flows (Wheeler *et al.* 2013). There is scope to improve the understanding of environmental and consumptive needs to allow water to be used more efficiently between both systems. This concept was discussed in Section 4.2.5 and improvements in these allocative arrangements may provide efficiencies to both environmental and consumptive users.

Irrigators provisioning environmental water through conveyance losses
Improved understanding, accounting and valuing of conveyance losses is required. It has been shown that if conveyance losses are considered environmental watering of wetlands, then this will increase system efficiency proportionally by the volume of water being counted as wetland water consumption (Jia *et al.* 2013). In the case cited, seepage losses in irrigation delivery fed a local wetland. These losses where then counted as environmental watering and not as conveyance losses. This concept entails considering irrigation systems as an integral part of the catchment landscape as well as the regional economic and governance system.

Including on farm infrastructure as part of the storage mechanisms available for environmental watering could allow more flexible and targeted watering of environmental assets. Whilst no example of this could be found in the literature, this concept was suggested in the industry survey and as such is mentioned here. An example of this could be irrigators storing water in an on farm reservoir for release later in the season to provide water for a local wetland. In this case low volume of water is required and the irrigator is contracted to provide water to this wetland. This may be a more efficient method as water provided to the irrigator early on in the season avoids losses to both the irrigator and the environment.

4.5.3 Discussion

Water management policy is highly contested and has seen considerable change mainly since the early 1990s. Water management is often embedded within a larger, systemic natural resource reform agenda and as such has many stakeholders and competing interests. There has been a near continuous revision of policy over the past 25 years and many cotton growers are pleading for stability and certainty in this area. Whilst this process does not appear to be subsiding, as a range of new policies are being implemented currently for example flood plain harvesting, a number of other areas require improvement. Central to this is the provision of credible information to develop and implement policy. As part of that, additional investigations into the development of foundational data such as aquifer and aquitard geometry and architecture is recommended. Additionally investigations into the volume of water required for environmental purposes is also recommended.

Novel policy options that could be explored include the use of on farm infrastructure to be used as storage for local environmental watering and the better accounting and valuing of conveyance losses if they provide an environmental benefit.

5 Discussion

A comprehensive review of literature was undertaken in order to determine innovative approaches to water security that are of most relevance and have the most potential for the Australian cotton industry. The major finding was the identification and modification of a framework to categorise water security.

Water security covers a vast range of activities, policies and technologies and there are a multitude of water security concepts present. It is necessary to classify these options to determine their relative merit in terms of utility in improving water security. This can be achieved by viewing water security in terms of five key principles: supply, practice, compliance, markets and policy. Using this framework, new water security concepts can be categorised and an evidence based decision can be reached providing value for money, clarity and efficiency in the investment process.

The five principles can be grouped under the concept of either supply or demand management in which the first principle is self-evidently supply management. The latter four can be grouped under demand management. As it is shown in Kampragou *et al.* (2010) management of Australian water resources has followed a path from supply management through demand management and now is entering a phase of adaptive management.

Understanding the competing pressures on water resources requires a detailed knowledge of the future water balance under uncertain environmental change, which includes, but is not limited to, climate change and land-use. Making changes to the way water is managed and used in the future will allow sustainable and secure water resources. However, this change in management will need strong and robust evidence supported by appropriate research and innovation. The outcome of this research and innovation will be improved water security which in turn will enhance the use of water for agriculture and the environment.

Supply augmentation
A range of technology is available to harvest water from the atmosphere, including highly specialised and experimental material through to age old techniques. Water yields from these approaches are very low with existing technologies and whilst these approaches may be useful in meeting deficits in critical human need, they would not be fit for purpose in supplying commercially irrigated cotton.

However, this is an area that may experience rapid technological progress and development and as such, requires a "watching brief" of these developments. If this technology develops to achieve water yields that could supply commercially irrigated cotton then additional investment in R&D would be recommended. This area is explored in more detail in the corresponding case study developed as part of this project.

Practice
A range of techniques and methods are available to improve understanding and management of losses from off- and on- farm irrigation systems. In particular, this includes better management of channel seepage and evaporation mitigation via a range of technologies including novel polymer compounds, infrastructure upgrades, low cost covers and floating solar arrays.

Other practices include the management and storage of excess water via managed aquifer recharge as well as reducing the transpiration of cotton without compromising yield by chemicals or genetic methods.

Aligning current on and off farm activities with the concept of nature based solutions would enable the cotton industry to improve its sustainability outcomes. As such, if NBS is adopted by the Australian cotton industry, then this could potentially be promoted globally to demonstrate the cotton industry's contribution to good land and water stewardship, improve the industry's reputational risk profile and provide access to higher value premium markets.

Reducing losses
Estimates of evaporative and seepage losses from on- and off- farm irrigation systems exceed the total volume of irrigation water used for productive purposes in Australia. Therefore mitigation of losses is an area that can provide options for improving water security.

Significant volumes of water lost in on-farm irrigation systems each year can be recovered. For example, the Sustaining the Basin: Irrigated Farm Modernisation (STBIFM) program (delivered by the NSW Department of Primary Industries) funded 112 projects (section 4.2.4) that resulted in the combined recovery of approximately 34.2GL in water previously lost from the system (Verwey *et al.* 2018).

The cotton industry has long invested in evaporation mitigation technology (Baillie 2008, Dagley 2012), and it has been identified that suspended and floating covers are the most effective evaporation reduction mechanisms (Yao et al., 2010). Additional infrastructure potentially could be added to suspended and floating covers such as floating solar panels (NQCC 2017).

It should be noted that CRDC and NSW DPI have previously invested in developing and assessing options for evaporation mitigation, specifically polymer technology. However due to the commercial-in-confidence nature of the research very little if any of this information is available in the public domain.

Limiting deep drainage by increasing the soil water holding capacity using novel compounds such as hydrophilic polymers has been suggested. These compounds improve the water holding capacity of soils and increase the amount of water within the soil profile. However, very high rates of these compounds were required to elicit a crop yield response even under relatively mild water deficit conditions (Volkmar and Chang 1995).

The main use of water for plant growth is transpiration and there are several technologies that can be employed to reduce transpiration. Antitranspirants are chemical compounds that reduce the rate of transpiration from plants by limiting the amount of water that can be transpired. Antitranspirants may provide an option within the suite of current management tools to reduce water use in cotton at specified plant growth stages. An opportunity exists to explore antitranspirants through further R&D that investigates the cost, effectiveness, and associated potential side effects. Much of the existing R&D was conducted several years ago. Considering advances in science and technology since, revisiting its potential may be warranted. A case study has been prepared that explores antitranspirants in detail.

Reduction in transpiration also can occur via genetic modification through changing gene expression. A recent study has shown a 25% reduction in water loss per CO_2 assimilated under field conditions in transgenic tobbaco (Głowacka et al. 2018). This indicates that genetic modification has some potential for improved water use efficiency and hence water security. This should be considered cautiously as other studies have suggested that genetic improvements may play a major role, but are unlikely to create major shifts in water use efficiency (Sinclair et al., 2004; Passioura, 2006).

Irrigation delivery systems upgrades and harmonisation

A number of approaches have been identified and they include improvements to on and off farm conveyance and distribution networks. For example assessment of the Trangie Nevertire Irrigation Scheme (TNIS) identified network water losses and showed that if these losses could be mitigated, then a total of over 29,000 ML in water savings would be generated (Vanguard 2016). There were three broad categories identified to address these water losses, these included removal of some channels, modernisation of others and upgrading of on-farm infrastructure.

Nature-based solutions (NBS) is a new umbrella term describing a range of environmental management and research techniques that promote natural processes as a means for providing solutions to emerging environmental issues (Nesshöver et al. 2017). It is recommended that further research into NBS be undertaken to identify what, if any, appropriate options for the Australian cotton industry can be adopted as a means of improving water security. These options would assist in keeping more moisture in the landscape to be available for plant growth, and in turn provide essential return flows and help build resilience to climate change. Additionally adoption of a NBS approach within the cotton industry could be promoted globally to demonstrate the cotton industry's contribution to good water stewardship and improve the industry's reputational risk profile. A recommendation is that the cotton industry invests in the development of a program that advocates for the benefits of NBS as a way of demonstrating water stewardship. A case study has been prepared that explores NBS in detail.

Storage of excess water

Managed aquifer recharge (MAR) refers to the intentional recharge of water to aquifers for subsequent use or environmental benefit (CSIRO). It has been estimated that up to 8,000 GL of water is evaporated from large dams each year in Australia. Managed aquifer recharge (MAR) is potentially a method to limit these losses, where the savings can be used for additional cotton production. However the current legislative and policy environment does not allow MAR to be used as an innovative method of increasing water security for the Australian cotton industry. It is recommended that education is undertaken to increase the awareness of growers regarding the potential use of MAR to both increase cotton production and reduce environmental effect is undertaken. A case study has been prepared that explores MAR in detail.

Compliance

If the public deem the cotton industry is a responsible manager of natural resources such as water, and the cotton industry can demonstrate water stewardship, this then may reduce social and political pressure to divert water away from consumptive use. Therefore, demonstrating water stewardship by ensuring water compliance within the cotton industry can assist in securing long term access to water resources.

It is recommended that the Australian cotton industry invests in the development of a program that advocates the benefits of water compliance and encourages growers to adopt and promote compliant practices as a way of demonstrating their water stewardship. This could be undertaken by a social research approach such as community-based social marketing.

Markets

Water markets in the MDB have been operating since the early 1980's (NWC 2011). However a range of improvements could be made to these markets. Improved market information on water trades and prices will allow improvements in allocative efficiency in market transactions as well as reducing transaction costs and uncertainty. Additionally, more transparent market information may help identify compliance issues (such as those caused by metering inaccuracies) and opportunities for more efficient water management.

Improved knowledge and understanding of specific water trading products and markets and how water trades can be better used as an operation tool will allow cotton growers to make more informed decisions and better fulfil seasonal cotton water requirements (Aither 2017). For example if a cotton producer wants to grow 100 ha of cotton this will require approximately 800 ML of water. However if the grower only has an allocation of 500 ML, they will require an additional 300 ML. This additional supply can be sourced by using a variety of water trading products, but is a task made difficult with limited understanding of the use of water products and market to obtain this water.

It is recommended that education of growers is undertaken regarding specific water trading products and how they can better use water trades as an operation tool.

Policy

Water management policy is highly contested and has seen considerable change mainly since the early 1990s. Water management is often embedded within a larger, systemic natural resource reform agenda and as such has many stakeholders and competing interests. There has been a near continuous revision of policy over the past 25 years and many cotton growers are pleading for stability and certainty in this area.

Stability and certainty of policy can be improved, and if undertaken will create a stable investment environment. Additional areas of improvement within water policy are centred on better provisioning of information and data on which water policy is informed and developed. This information and data includes environmental needs and groundwater architecture, enhanced accounting of conveyance losses as environmental water, and better communication between environmental and consumptive users.

It has been shown that if conveyance losses are considered environmental watering of wetlands then this will increase the system efficiency proportionally by the percentage of wetland water consumption (Jia et al. 2013). This concept entails considering irrigation systems as an integral part of the catchment landscape as well as the regional economic and governance system.

It is recommended that further research be undertaken in this area as it may provide a mechanism to improve water security because irrigation would be seen as mutually beneficial to both environmental and productive use of water.

Conclusion

The area of water security is extensive, ranging across international policies to improve transnational collaboration to enhance not only water security but social and political security to local management techniques to improve access to irrigation water. As such this project has made initial steps towards the modification of an existing water security framework, gathering industry based evidence and then testing the robustness of the framework by categorising that evidence.

However there is a need to further develop and explore the framework and its utility in identifying and categorising opportunities to enhance water security for the Australian cotton industry. One of those opportunities is the use of the framework to explore the cross linkages between the identified water security concepts.

This project has categorised water security concepts. However what is required beyond this is that all identified concepts need to consider how they address the five principles and provide evidence that the five principles are considered in the implementation of the concepts. This exploration of the cross linkages allows identification and potentially avoidance of perverse outcomes.

The literature review and the companion industry survey was used to identified a range of innovations that, if implemented, may improve water security to the Australian cotton industry. A number of these innovations have been explored in four case studies developed as part of thisproject:

- Water from novel sources; atmospheric or low quality water
- Managed aquifer recharge
- Antitranspirants
- Nature Based Solutions

Other innovations identified by the literature review and industry survey include:

- Assisting irrigation delivery systems managers to identify funding sources to provide upgrades and harmonisation, including novel methods to store excess water.
- Developing a program that advocates the benefits of water compliance and encourages industry to adopt and promote compliant practices as a way of demonstrating their water stewardship
- Providing information for effective market operations, specifically the availability of water for trading
- Accounting and valuing conveyance losses as environmental water
- Better communication between environmental and consumptive users
- Developing and exploring additional innovative policy options for water security, including policy options that promote flexible sharing of water between consumptive and environmental uses
- Continuing development of a framework for categorising water security and expanding the scope beyond the irrigated cotton industry to determine how concepts identified can also benefit other industries within the Australian irrigation sector

6 References

ABC (2013) NSW floodplain harvesting policy 'a step in the right direction'. Article by Lisa Herbert and Sally Bryant, ABC Rural 2 May 2013.

Acreman M, Dunbar M (2004) Defining environmental river flow requirements? A review ***Hydrology and Earth System Sciences Discussions*** EGU 2004 8 (5) 861-876

Acworth R, Timms W, Kelly B, McGeeney D, Ralph T, Larkin Z Rau G (2015) Late Cenozoic paleovalley fill sequence from the Southern Liverpool Plains, New South Wales—implications for groundwater resource evaluation ***Australian Journal of Earth Sciences*** (62) 6 657-680, DOI: 10.1080/08120099.2015.1086815

Agarwal S, De R (1979) Effects of nitrogen rates, mulching and antitranspirants on water use and water use efficiency of barley ***Journal of Agricultural Science*** 92:263-268

Aither (2017) Water markets in New South Wales Improving understanding of market fundamentals, development, and current status https://www.industry.nsw.gov.au/__data/assets/pdf_file/0006/155859/Water-markets-in-nsw-aither-report-for-dpi-water.pdf

Akbar S (2000) Measurements of Losses from On-Farm Channels and Drains Cooperative Research Centre for Sustainable Rice Production https://ret.sunrice.com.au/Australian%20Rice%20Library/Akbar%20CRC1.PDF

Australian Government Agricultural Competiveness White Paper Securing Australia's water supplies http://agwhitepaper.agriculture.gov.au/SiteCollectionDocuments/Securing-Australia%E2%80%99s-water-supplies.pdf

AWA (2014) Large Dams fact sheet http://www.awa.asn.au/Documents/Dams_Fact_Sheet.pdf

AWA (2017) Emerging challenges and opportunities to secure our water future. Australian Water Association Discussion Paper, May 2017.

Baillie C (2008) Assessment of Evaporation Losses and Evaporation Mitigation Technologies for On Farm Water Storages across Australia Irrigation Matters Series No. 05/08 CRC Irrigation Futures

Banedjschafie S, Durner W (2015) Water retention properties of a sandy soil with superabsorbent polymers as affected by aging and water quality ***Journal of Plant Nutrition and Soil Science*** 178:798–806

Beddington J (2010) Food security: contributions from science to a new and greener revolution ***Philosophical Transactions Royal Society B*** (365):61–71

Best laid plans: The Murray-Darling Basin in crisis (2018) Background Briefing Radio National ABC http://www.abc.net.au/radionational/programs/backgroundbriefing/murray-darling-basin-crisis/9687538

BoM (2009) Water Accounting Conceptual Framework (WACF) http://www.bom.gov.au/water/standards/wasb/wacf.shtml

Brinkley A, Jackson P, Thompson A, Aseervatham E (2000) "Measurement, Remediation and Management of Seepage from Open Channels." Proceedings ANCID Conference, Australian National Committee on Irrigation and Drainage (ANCID)/Goulburn-Murray Water, Tatura, August

Burston I (2002) Conservation of water from open storages by minimising evaporation PhD Thesis RMIT https://researchbank.rmit.edu.au/view/rmit:11532

Carruthers G (2011) Auditing and critical review in Environmental Management Systems in agriculture: Is there value for similar approaches in New Zealand's proposals for audited self management?
https://www.massey.ac.nz/~flrc/workshops/11/Manuscripts/Carruthers_2011.pdf

Chaffey A (2017) Survey to benchmark water use efficiency in cotton
https://www.cottoninfo.com.au/blog/survey-benchmark-water-use-efficiency-cotton-6-october-2017

Coates D, Pert P, Barron J, Muthuri C, Nguyen-Khoa S, Boelee E, Jarvis D (2013) Water-related ecosystem services and food security. E. Boelee (ed.), Managing Water and Agroecosystems for Food Security. Comprehensive Assessment of Water Management in Agriculture Series No. 10. Wallingford, UK/Boston, USA, Centre for Agriculture and Bioscience pp29-41.

Craig I, Green A, Scobie M, Schmidt E, (2005) Controlling evaporation loss from water storages. Technical Report. University of Southern Queensland, National Centre for Engineering in Agriculture, Toowoomba, Australia

Crowdwater http://www.crowdwater.ch/en/welcome-to-crowdwater/

Dagley I (2012) Evolution of polymers mitigates evaporation in The Australian cotton water story – A decade of research and development Trindall J, Roth G, Williams S, Harris G, Wigginton D (Eds)

Daniell, K.A., Coombes, P.J. and White, I. (2014) Politics of innovation in multi-level water governance systems. ***Journal of Hydrology*** 519 (2014) 2415-2435

Dare M, Schirmer J, Vanclay F (2014) Community engagement and social licence to operate ***Impact Assessment and Project Appraisal*** (32)3:188-197 DOI: 10.1080/14615517.2014.927108

Davenport D, 1967 Effects of Chemical Antitranspirants on Transpiration and Growth of Grass ***Journal of Experimental Botany*** (18) 2:332–347

Delacámara G, Gómez C, Maestu J (2015) Water trading opportunities and challenges in Europe. In Routledge Handbook of Water Economics and Institutions; Burnett, K., Howitt, R.E., Roumasset, J.A., Wada, C.A., Eds. Routledge: Oxon, UK, 2015.pp. 281-295.

Delfau 2017 Understanding supply-side and demand-side to support water management in the Asia Pacific Kini Initiative https://kini.waterpartnership.org.au/posts/2720426-understanding-supply-side-and-demand-side-to-support-water-management-in-the-as

Dept Infrastructure Regional Development and Cities (2017) Water Infrastructure Projects The Department of Infrastructure, Regional Development and Cities https://infrastructure.gov.au/infrastructure/water-infrastructure/nwi-development-fund/water-infrastructure-projects.aspx

Dillon P, Pavelic P, Page D, Beringen H Ward J (2009) Managed aquifer recharge: An Introduction National Water Commission Waterlines Report Series No. 13, February 2009

Dinar A, Dayem A, Agwe J (2007)The Role of Technology and Institutions in the Cost Recovery of Irrigation and Drainage Projects Agriculture and Rural Development Discussion Paper 33 The International Bank for Reconstruction and Development/The World Bank

(undated) Murray River Drought Mitigation using Burdekin River water http://www.solartran.com.au/murray_river_drought_mitigation.htm

Furuta N (2016) Japan: Wetlands and rice paddy fields contribute to biodiversity conservation, flood control and the local economy pp41-44 in Nature-based Solutions to address global societal challenges Eds Cohen-Shacham E, Walters G, Janzen C, Maginnis S IUCN

Gale J, Hagan R (1966) Plant antitranspirants ***Annual Review of Plant Physiology*** (17) 269-282

Ghassemi F, White I (2006) Inter-Basin Water Transfer: Case Studies from Australia, United States Canada, China, and India Cambridge University Press

Giordano M, Turral H, Scheierling S, Tréguer D, McCornick P (2017) Beyond "More Crop per Drop": Evolving Thinking on Agricultural Water Productivity. International Water Management Institute (IWMI). IWMI Research Report 169.

Głowacka K, Kromdijk J, Kucera K, Xie J, Cavanagh A, Leonelli L, Leakey A, Ort D, Niyogi K, Long S (2018) Photosystem II Subunit S overexpression increases the efficiency of water use in a field-grown crop ***Nature Communications*** (9): 868

Grafton, R.Q. (2007) An economic evaluation of the National Plan for Water Security. In Dry Water – Policy Briefs. Eds. Grafton, R.Q., Bennet, J. and Hussey, K. Crawford School of Economics and Government. The Australian National University.

Grafton and Horne (2014) Water markets in the Murray-Darling Basin ***Agricultural Water Management*** (145) 61–71.

Grafton Q, Horne J, Wheeler S (2016) On the Marketisation of Water: Evidence from the Murray-Darling Basin, Australia ***Water Resources Management*** (30) 3 pp 913–926

Grey D, Sadoff C (2007) Sink or Swim? Water security for growth and development ***Water Policy*** (9) 545–571

Hall J, Grey D, Garrick D, Fung F, Brown C, Dadson S, Sadoff S (2014) Coping with the curse of freshwater variability: Institutions, infrastructure, and information for adaptation ***Science*** (346) No. 6208, pp 429-430

Holley C, Sinclair D (2018) Water Markets and Regulation: Implementation, Successes and Limitations. In: Holley C., Sinclair D. (eds) Reforming Water Law and Governance. Springer, Singapore

Holmatov B, Lautze J, Manthrithilake H, Makin I (2017) Water security for productive economies: Applying an assessment framework in southern Africa. ***Physics and Chemistry of the Earth*** 100 (2017) 258-269.

Houborg R, McCabe M (2018) Daily Retrieval of NDVI and LAI at 3 m Resolution via the Fusion of CubeSat, Landsat, and MODIS Data ***Remote Sensing*** 10(6):890 doi:10.3390/rs10060890

Ibrahim E, Selim E (2010) Effect of irrigation intervals and antitranspirant (kaolin) on summer squash (Cucurbita pepo L.) growth, yield, quality and economics ***Journal of Soil Sciences and Agricultural Engineering*** (1) 8:883-894

IUCN Nature-based Solutions https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

Jia Z, Wu X, Luo W, Xi W, Tang S W, Fang L (2013) The impact of improving irrigation efficiency on wetland distribution in an agricultural landscape in the upper reaches of the Yellow River in China ***Agricultural Water Management*** (121):54-61

Kampragou E, Lekkas D, Assimacopoulos D, (2010) Water Demand Management: Implementation Principles and Indicative Case Studies ***Water and Environmental Journal*** (25) 4 466-476

Kashiwa B, Kashiwa C (2008) The solar cyclone: A solar chimney for harvesting atmospheric water ***Energy*** (33) 2 331-339

Keestra S, Nunes J, Novara A, Finger D, Avelar D, Kalantari Z Cerdà A (2018) The superior effect of nature based solutions in land management for enhancing ecosystem services ***Science of The Total Environment*** (610–611) 997-1009

Kelly B, Merrick N, Dent B, Yates D (2007) Groundwater Knowledge and Gaps in the Namoi Catchment Management Area National Centre for Groundwater Management University of Technology, Sydney
https://archive.lls.nsw.gov.au/__data/assets/pdf_file/0003/496560/archive_groundwater-knowledge-gaps-namoi-catchment-management-area.pdf

Khan S, Akbar S, Rana T, Carmichael A (2005) Off-and-on farm savings of irrigation water. Murrumbidgee Valley water efficiency feasibility project January 2005 Water for a Healthy Country Flagship

Khan S, Malano H, Davidson B (2008) System harmonisation: a framework for applied regional irrigation business planning ***Irrigation and Drainage*** 57 **(**5) 493-506

Kim H, Yang S, Rao S, Narayanan S, Kapustin K, Furukawa H, Um A (2017) Water harvesting from air with metal-organic frameworks powered by natural sunlight ***Science*** 13 Apr 2017 DOI:10.1126/science.aam8743

Larsen J, Gibbes B, Quiggan J (2014) Dam hard: water storage is a historic headache for Australia The Conversation https://theconversation.com/dam-hard-water-storage-is-a-historic-headache-for-australia-33397

Lehane, S (2014) Australia's Water Security Part 1: Water Resources. Strategic Analysis Paper. FutreDirections International. September 2014.

Leonard E, Rainbow R, Trindall J, (Eds) (2017) Accelerating precision agriculture to decision agriculture: Enabling digital agriculture in Australia. Cotton Research and Development Corporation, Australia

Loch A (2018) Webinar: Good Water Governance to Enhance Future Security Tuesday, 3 April, 2018https://www.icewarm.com.au/australian-water-school/resources/webinar-good-water-governance-enhance-future-security/

Lowry C, Fienen M (2010) http://www.crowdhydrology.com/

Luscombe C (2004) Total Channel Control System Pilot On CG2 Channel, Tatura https://www.g-mwater.com.au/downloads/gmw/R_D/TCC_Pilot_System_Exec_Summary.pdf

Marks, G. and Hooghe, L. (2004) Contrasting visions of multi-level governance. In: Bache, I and Flinders, M. (Eds.) Multi-level Governance. Oxford University Press, Oxford.

MDBA (2012) A plan for the Murray–Darling Basin https://www.mdba.gov.au/basin-plan/plan-murray-darling-basin

Mekonnen A, Hoekstra Y (2014) Water footprint benchmarks for crop production: A first global assessment ***Ecological Indicators*** (46):214-223

Molden, D., Sakthivadivel, R. and Habib, Z. (2001) Basin-level use and productivity of water: Examples from South Asia. International Water Management Institute (IWMI). IWMI Research Report 49.

Molden, D., Murray-Rust, H., Sakthivadivel, R. and Makin, I. (2003) A water productivity framework for understanding and action. In: ***Water productivity in agriculture: Limits and opportunities for improvement***. Eds. Kijne, J.W., Barker, R. and Molden, D. International Water Management Institute (IWMI). Comprehensive Assessment of Water Management in Agriculture Series 1. Pp.1-18.

Molden, D. (ed.) (2007) Water for Food, Water for Life: Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, in association with International Water Management Institute (IWMI), Colombo.

Molden, D., Oweis, T.Y., Pasquale, S., Kijne, J.W., Hanjra, M.A., Bindraban, P.S., Bouman, B.A.M., Cook, S., Erenstein, O., Farahani, H., Hachum, A., Hoogeveen, J., Mahoo, H., Nangia, V., Peden, D., Sikka, A., Silva, P., Turral, H., Upadhyaya, A. and Zwart, S. (2007) Pathways for increasing agricultural water productivity. In: ***Water for food, water for life: A comprehensive assessment of water management in agriculture***. Ed. Molden, D. International Water Management Institute (IWMI). Pp.279-310.

Montilla-López, N. M., Gutiérrez-Martin, C. and Gómez-Limón, J.A. (2016) Water banks: what have we learnt from the international experience? ***Water*** (7) 652-678.

Mukherjee I (1974) Growth Promoting Effect of a Transpiration Suppressant on Cotton ***Physiologia Plantarum*** (32)3:287-288

Murphy S (2018) Using Coal Seam Gas produced water in irrigated agriculture in northern NSW 7 Primefact 1415 NSW DPI https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/797994/Primefact-1415-Using-Coal-Seam-Gas-produced-water-in-irrigated-agriculture-in-northern-NSW-October-2017.pdf

Murray Irrigation (2017) Snowy advance 2016/17 http://www.murrayirrigation.com.au/media/25347/2016%2007%2008%20FAQ%20-%20v6.pdf

New Scientist (2016) First farm to grow veg in a desert using only sun and seawater 14 October 2016 https://www.newscientist.com/article/2108296-first-farm-to-grow-veg-in-a-desert-using-only-sun-and-seawater/

NQCC A Case For a Floating Solar Farm on Townsville's Ross River Dam http://www.nqcc.org.au/floating-solar-viability-study

NSW DPI (2014) Determining readily available water to assist with irrigation management Primefact 1362

NSW DPI (2018) Checking leaky channels https://www.dpi.nsw.gov.au/agriculture/irrigation/irrigation/systems/leaks

NSW Irrigators' Council (n.d.) Flood Plain Harvesting Policy 081103. http://www.nswic.org.au/pdf/policy_documents/Flood%20Plain%20Policy.pdf

NWC (2011) Water markets in Australia National Water Commission Canberra ACT 2600 http://apo.org.au/system/files/27438/apo-nid27438-101806.pdf

Palmer M, Liu J, Matthews J, Mumba M, D'Ororico P (2015) Water Security: Gray or Green? ***Science*** (349) 6248 584-585.

Pereira L, Oweis T, Zairi A (2002) Irrigation management under water scarcity ***Agricultural Water Management*** **(**57) 3 175-206

Pumped: Who's benefitting from the billions spent on the Murray-Darling? (2017) Four Corners ABC TV http://www.abc.net.au/4corners/pumped/8727826

Qadir M, Sharma B, Bruggeman A, Choukr-Allah R, Karajeh K (2007) Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries ***Agricultural Water Management*** (87)2–22

Qasemi M, Johnson D, Sponsel V (2016) Plant Root Templated Irrigation ***Irrigation and Drainage*** (65) 1 38-48

QDRM 2016 Surat Underground Water Impact Report 2016 – Summary https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0008/345680/uwir-2016-summary.pdf

Randall A (1981) Property entitlements and pricing policies for a maturing water economy. ***Australian Journal of Agricultural Economics*** (25) 195-220

Rankine & Hill (1982) Possibilities for inland diversion of water from the Clarence Valley / [prepared by] Rankine & Hill Pty Ltd [for] Clarence Valley Inter-Departmental Committee on Water Resources.

Roth, G., Harris, G., Gillies, M., Montgomery, J and Wigginton, D. 2013 Water-use efficiency and productivity trends in Australian irrigated cotton: a review. ***Crop & Pasture Science*** (64) 1.33-1048.

Sanders K, Masri S (2016) The energy-water agriculture nexus: the past, present and future of holistic resource management via remote sensing technologies ***Journal of Cleaner Production*** (117) 73-88

Secretariat of the Convention of Biological Diversity (2013) Water and Biodiversity - Natural Solutions for Water Security. Montreal, 95 pages.

Sela E, Cohen Y, Alchanatis V, Saranga Y, Cohen S, Moller M, Meron M, Bosak A, Tsipris J, Orolov V (2007). Thermal imaging for estimating and mapping crop water stress in cotton In: J.V. Stafford (Ed.), Precision agriculture '07. Proceedings of the 6th European Conference on Precision Agriculture (pp. 365–372). Skiathos, Wageningen: Wageningen Academic Publishers.

Silburn, D.M. Foley, J.M. Biggs, A.J.W. Montgomery, J. Gunawardena, T.A. 2013, 'The Australian Cotton Industry and four decades of deep drainage research: a review', Crop and Pasture Science. CSIRO.

Smithson A (2009) Lower Namoi Groundwater Source: Groundwater Management Area 001 Groundwater Status Report 2008, NSW Department of Water and Energy, Sydney http://www.water.nsw.gov.au/__data/assets/pdf_file/0009/548712/avail_ground_lower_namoi_report_2008.pdf

Tennakoon S, Milroy S (2003) Crop and water use efficiency on irrigated farms in Australia ***Agricultural Water Management*** 61(3):179-194

Tomaszkiewicz M, Najm M, Beysen D, Alameddine I, El-Fadela M (2015) Dew as a sustainable non-conventional water resource: a critical review ***Environmental Reviews*** 2015, 23(4): 425-442, https://doi.org/10.1139/er-2015-0035

UN Water (2013) Water Security & the Global Water Agenda – Summary for Decision-Makers. October 2013. http://www.unwater.org/publications/un-water-analytical-brief-water-security-global-water-agenda-4-page-summary-decision-makers/

University of Melbourne (2018) Chemical Engineering Polymer Science Group Research https://chemical.eng.unimelb.edu.au/polymer-science/research/

Vanguard (2016) Trangie Nevertire Co-operative Ltd (TNCL) Final Project Report under Round One of the Private Irrigation Infrastructure Operators Program in NSW Trangie Nevertire irrigation Scheme http://www.tnis.net.au/LiteratureRetrieve.aspx?ID=216813

Vervoort, W (2014) Dams are not the smart way to secure water for agriculture. The Conversation, 21 October 2014.

Verwey, P., Strang, M., Norris, C. and Cordina, D (2018) Infrastructure upgrades in North West NSW help sustain the Murray Darling Basin. Presentation to the Irrigation Australia International Conference and Exhibition , 13-15 June 2018, Sydney. Presented by Peter Verwey, Sustaining The Basin: Irrigated Farm Modernisation, NSW Department of Primary Industries.

VEWH Water for the environment protects rivers and wetlands http://www.vewh.vic.gov.au/

Volkmar K, Chang C (1995) Influence of hydrophilic gel polymers on water relations and growth and yield of barley and canola ***Canadian Journal of Plant Science*** 75(3): 605-611,

Waldron T, Tan P, Johnson I (2017) Independent Audit of Queensland Non-urban Water Measurement and compliance https://dnrme.qld.gov.au/__data/assets/pdf_file/0010/1396756/independent-audit-water.pdf

WaterNSW (2018) 20 Year Infrastructure Options Study Rural Valleys Summary Report https://www.waternsw.com.au/__data/assets/pdf_file/0019/132616/20-Year-Infrastructure-Options-Study-June-2018.pdf

Wheeler S Garrick D Loch A Bjornlund H 2013 Evaluating water market products to acquire water for the environment in Australia ***Land Use Policy*** Vol 30 1 pp 427-436

WWAP (United Nations World Water Assessment Programme)/UN-Water (2018) The United Nations World Water Development Report 2018: Nature-based Solutions for Water. Paris, UNESCO.

Yadav S, Singh D (1981) The effect of irrigation and antitranspirants on plant water relations, radiation characteristics, leaf temperature, and the yield of barley ***Contributions to Tropical Agriculture and Veterinary Medicine*** 19(1): 41-48

Yao X, Zhang H, Lemckert H, Brook A, Schouten P (2010) Evaporation Reduction by Suspended and Floating Covers: Overview, Modelling and Efficiency Urban Water Security Research Alliance Technical Report No. 28 http://www.urbanwateralliance.org.au/publications/UWSRA-tr28.pdf

Young, M.D. and McColl, J.C. (2009) Double trouble: the importance of accounting for and defining water entitlements consistent with hydrological realities. ***The Australian Journal of Agricultural and Resource Economics*** 53: 19-35

Department of Primary Industries

Practice change
Antitranspirants

Antitranspirants

Water vapour exchange between leaves and the surrounding environment (transpiration) occurs through the plant stomata and cuticle. Antitranspirants are chemical compounds that limit the amount of water lost from plants by reducing the rate of transpiration.

Stomatal transpiration accounts for the major portion of total water loss from a plant (Kramer 1983). Less than 5% of the water absorbed by roots is used for crop growth and development; the remaining 95% is transpired (Abdullah *et al.* 2015). Therefore reducing transpiration presents an opportunity to reduce crop water requirements (Abdullah *et al.,* 2015). The control of stomatal opening could be used to minimise overall crop water use (Rajapakse *et al.* 1990).

Antitranspirant compounds can be categorized into three classes; film-forming, stomatal regulating or reflective compounds (Abdullah *et al.* 2015).

There is limited research on chemicals that control stomatal opening or reduce transpiration by other means. One reason may be that such treatments improve a plant's water use efficiency but do not necessarily increase crop yields (Whitmore, 2000). Further, it may be perceived as a resource and cost intensive treatment, given that several applications may be needed as the number and size of the plants' leaves increase (Whitmore, 2000). Nevertheless, if the goal is to improve water security in an irrigation system, reducing plant water use would reduce the demand for irrigation water or help to conserve soil moisture during drought for use at a critical stage in a crop's development.

Research has been undertaken into the effects and efficacy of antitranspirants (Shinohara and Leskovar, 2014). The research results to date are highly variable, and many researchers concluded that using antitranspirants was not economical or practically feasible (Evans and Sadler, 2008).

Film-forming antitranspirants

Film-forming materials create a wax, gel or plastic coating on the leaf surface which reduces water lost via transpiration. The consequence of reducing vapour loss can mean that the flux of carbon dioxide (CO_2) and oxygen (O_2) to the plant is impeded and hence may reduce plant growth. The film forming coatings must be permeable to allow the leaves' absorption of atmospheric carbon dioxide (needed for photosynthesis), whilst reducing water vapour transpired by the leaves. This can enhance the plant's water use efficiency. However, inhibiting transpiration may also result in an increase in leaf temperature. Additional coatings may also have to be reapplied fairly frequently, which will reduce or even nullify their cost effectiveness (Patil and De, 1976).

Current film-type antitranspirants are known to reduce photosynthesis more than they reduce transpiration as CO_2 molecules are 1.6 times larger than water molecules (Evans and Sadler, 2008). This is a key barrier to this treatment option and means that it is unlikely to be viable until alternative films can be developed that inhibit transpiration without inhibiting CO_2 exchange and plant growth.

Reflective antitranspirants

Reflective antitranspirants are compounds, such as kaolin clay or chitosan, that reflect radiation. These compounds decrease leaf temperature by increasing reflection from the leaf. This lowers transpiration from the plant and improves water use efficiency (Shinohara *et al.* 2014).

Reflective antitranspirants may cause similar issues as that of film-forming antitranspirants by reducing photosynthesis more than they reduce transpiration (Abou-Khaled *et al.* 1970). Further, the application of these compounds can be costly, time-consuming and labour intensive, and the coating is easy washed off the leaf surface, which means that the process has to be repeated each time it rains or overhead irrigated is used.

Physiological antitranspirants

These chemicals modify the growth and physiological responses of plants, and include ethanolamine, phenyl-mercuric acetate (PMA), abscisic acid and EXP-4464A (Hafez *et al*. 2016). Some of these compounds induce stomatal closure through metabolic processes in leaves to reduce water vapour loss (stomatal antitranspirants) (Degif *et al*. 2014, Shinohara *et al*. 2014). This reduction in water vapour reduced the stress applied on plants and in the case of cotton reduced the rate of bole abortion (Kawakami *et al.* 2010).

Related research in using antitranspirants

Numerous antitranspirants have been tested on a variety of plants under a range of conditions for their effect on desiccation, disease control, fruit production, transplant establishment and weed control (Chalker-Scott 2018). Research has been undertaken in the lab, greenhouse, nursery, and field using antitranspirants on a variety of plants including vegetable crops, ornamental plants, fruit and timber species. The results have shown that antitranspirants: :

- had minimal effect on bacterial and fungal diseases; but helped reduce insect pests
- had a highly variable effect on horticultural fruit splitting
- reduced marketable yield of fruit in some treatments
- increased water loss from fruit
- had no effect on heat or cold-induced desiccation
- reduced growth rate
- decreased, or had no effect on, transpiration;
- delayed leaf unfolding
- increased leaf drop
- had no effect on root regeneration
- increased leaf temperature through decreased evaporative cooling
- depressed chlorophyll content
- decreased transpiration on weeds and increased leaf temperature, and thereby increased weed mortality.

(Chalker-Scott 2018).

Overall there is little compelling evidence to show how the use of antitranspirants has improved the water use of cotton.

Use of antitranspirants in the cotton industry

The reported effects of antitranspirants on cotton have been limited. The cotton plant may lend itself to the use of physiological antitranspirants such as stomatal closure in the plant, if photosynthesis is not reduced to the same extent as transpiration (Whitmore 2000). Initial research found that antitranspirants applied to cotton improved water use efficiency and reduced leaf transpiration rates by up to 93% (Makus, 1997). However, it is important to note that this result has yet to be replicated in other studies.

Similarly a range of antitranspirants applied to cotton resulted in an increase in cotton lint yields of between 110-170% over an untreated control (Kumar *et al.* 2011). Other studies have shown antitranspirants reduced seedling water loss to approximately 40% which in turn maintained seedling water status allowing a measure of chilling protection through maintenance of seedling hydration (Christiansen and Ashworth 1978). A more recent study found that application of an antitranspirant reduced water stress in cotton and this in turn reduced the rate of bole abortion (Kawakami et al. 2010).

Currently, cotton growers exhibit little interest in applying antitranspirants to cotton, possibly due to concerns about the reliability and potential side-effects of these compounds and impacts on cotton yields.

Commercial antitranspirants on market

There are a range of commercially available antitranspirant products on the market such as 'Vapor Gard', Wilt-Pruf®, Wiltnot, WILT-GUARD and ENCASE™. All of these products use a film forming agent such as Pinolene®, a terpenic polymer that blocks transpiration. The labels claim this assists in the reduction of transpiration, improved response to cold desiccation, heat stress and drought stress. NSW DPI does not endorse these chemicals or provide any recommendation in the use of these products. Label safety and use directions must be followed.

Conclusion

There is little evidence supporting the benefits of the use of antitranspirants in cotton production. Antitranspirants may provide an option within the suite of current management tools to reduce water use in cotton at specific plant growth stages. Particularly in the reduction of stresses that the plant may encounter during the seedling stage and the boll set stage. An opportunity exists to explore antitranspirants through further R&D that investigates the cost, effectiveness, and associated potential side effects. Much of the existing R&D was conducted several years ago. Considering advances in science and technology since, revisiting its potential may be warranted.

References

Abdullah A, Aziz M, Siddique K, Flower K (2015) "Film antitranspirants increase yield in drought stressed wheat plants by maintaining high grain number" ***Agricultural Water Management*** 159: 11-18

Chalker-Scott L (2018) "The Myth of Antitranspirants" Horticultural Myths, from http://www.theinformedgardener.com.

Christiansen M, Ashworth E (1978) "Prevention of Chilling Injury to Seedling Cotton with Anti-Transpirants 1" ***Crop Science*** 18(5): 907-908

Degif A, Woltering E (2015). "Ethylene, 1-MCP and the antitranspirant effect of active compound-film forming blend" ***Journal of Horticulture*** 2(153): 256-261

Evans R, Sadler E (2008) "Methods and technologies to improve efficiency of water use" Water Resources Research 44

Hafez E, Gharib H (2016) Effect of exogenous application of ascorbic acid on physiological and biochemical characteristics of wheat under water stress ***International Journal of Plant Production*** 10(4): 579–596

Kawakami E, Oosterhuis D, Snider J (2010) Physiological Effects of 1-Methylcyclopropene on Well-Watered and Water-Stressed Cotton Plants ***Journal of Plant Growth Regulation*** 29 (3) pp 280–288

Kramer P (1983) Water Relations of Plants Academic Press, New York.

Kumar V, Patil R, Patel J (2011) Efficient Water Management Technology for Sustainable Cotton Production in Central India World Cotton Research Conference-5 Renaissance Convention Centre, Mumbai 7-11 November 2011

Makus D (1997) Effect of an anti-transpirant on cotton grown under conventional and conservation tillage systems Beltwide Cotton Conferences (USA)

Patil B, De R (1976) "Influence of antitranspirants on rapeseed (Brassica campestris) plants under water-stressed and nonstressed conditions" ***Plant Physiology*** 57(6): 941-943.

Rajapakse N, Kelly J Reed D (1990) "Use of antitranspirants under low-light environments to control transpiration of epipremnum-aureum leaves" ***Scientia Horticulturae*** 43(3-4): 307-312

Shinohara T, Leskovar D (2014) "Effects of ABA, antitranspirants, heat and drought stress on plant growth, physiology and water status of artichoke transplants." ***Scientia Horticulturae*** 165: 225-234.

Whitmore J (2000) Drought management on farmland Springer Science & Business Media

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CRDC COTTON RESEARCH AND DEVELOPMENT CORPORATION

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Practice change
Life Cycle Assessment Managed Aquifer Recharge

Managed Aquifer Recharge – why not now?

Managed aquifer recharge (MAR) refers to the intentional recharge of water to aquifers for subsequent use or environmental benefit (CSIRO undated). It is estimated that up to 8,000 gigalitres (GL) of water is evaporated from large dams each year in Australia (Ward and Dillon 2011). Managed aquifer recharge (MAR) is a method which has the potential to limit these losses, and the savings can then be used for additional cotton production. To allow this practice to be implemented by the cotton industry of Australia a range of barriers need to be overcome.

Whilst there are a number of current Australian MAR operations none of them occur in areas where cotton is produced. The longest running scheme is in the Burdekin Delta Queensland run by the Lower Burdekin Water Authority for the past 40 years.

However in other areas a number of barriers to widespread adoption remain. One major impediment to the utilisation of MAR in NSW and Queensland is that current legislation states that upon recharge, source water (that is the water that is being used to recharge the aquifer) is subject to the extraction and management rules of the water currently in the aquifer (Ward and Dillon 2011). Another barrier include the capital expenditure of the MAR infrastructure.

What this means is that water enters the "common pool" once it is underground, and can be accessed by anyone with a groundwater use licence and it is subject to the relevant water extraction limits and laws. Therefore the person who pumps the new water into an aquifer does not have ownership over that water and has no greater right to access it than any other licensed user, and can only access it within the limits of their own groundwater entitlement.

Enablers of MAR adoption

There has been significant research and development on the potential of MAR in Australia. Previous studies have developed guidelines to select suitable aquifers for MAR, as well as identifying individual aquifers for MAR (Dillon *et al.* 2009; GHD 2011; Parsons *et al.* 2012; Arshad *et al.* 2014). Of interest to the cotton industry is the aquifer identified in the Menindee Lakes area in NSW with potential storage of 200 Gl/yr (Parsons *et al.* 2012) and another in the Lower Namoi (Arshad *et al.* 2014). Note the latter study assumed 200ML of flood water could be stored as a worked example of a farm based case study.

The National Water Commission has made significant investment to support the growth of MAR schemes in Australia, targeting knowledge gaps, providing educative resources and facilitating the development of MAR projects in areas that currently do not use this technique (Parsons *et al.* 2012).

Additionally, there are a number of reports and courses available to provide a framework for assessing MAR scheme viability from concept to operation (Dillon 2009, Parsons *et al*. 2012, Australian Water School MAR essentials course, NCGRT MAR course). CSIRO supports an online repository of up-to-date resources relating to MAR (https://research.csiro.au/mar). Experience in the design and construction of these systems clearly demonstrates that the recharge method must be engineered to suit the characteristics of each aquifer as a whole.

Research has identified four operational aspects of MAR (Ward and Dillon 2011):

1. source water harvesting (the water that is captured for reuse, typically out of season flows or storm or flood waters);
2. aquifer storage (the volume within the aquifer that can be allocated to additional storage);
3. recovery (the volume of water that can be recovered, usually not all water that is injected into the aquifer can be recovered); and
4. end use (the final consumptive use of the water).

The implementation of MAR will require considerable planning and financial resourcing. However the four steps outlined above provide a framework that the cotton industry can employ to identify and implement MAR to enhance water security for this industry. For example if a cotton grower were to implement a MAR scheme they would need to understand the volume of water they could capture during flood times and how much of, and how quickly, this water could be injected into a suitable aquifer. Additionally to recover this water an estimate is required to determine the recovery volume as some of the water will not be able to be recovered, It is also important that any changes to the quality of the water are determined and how this may effect the usage of this water.

Life Cycle assessment of MAR for cotton production

By its nature MAR is energy intensive and assessments need to be made on the impact injection and extraction of water for irrigated cotton production has on the overall resource efficiency of a farming system and subsequent effects on water security. A technique to assess this is Life Cycle Assessment (LCA).

Life cycle assessment is a procedure to evaluate environmental impacts associated with all the stages of a product's life from raw material extraction through to materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. An LCA was undertaken to assess the environmental impacts of using water from MAR for cotton production in the Murrumbidgee region of NSW.

What was modelled in the Murrumbidgee LCA

The current LCA analysis modelled the environmental impacts associated with the production of an additional kilogram of cotton lint from a MAR scheme. Data for cotton production (e.g. yield, water requirement, herbicide and fertiliser inputs) were taken from NSW DPI southern cotton production gross margins.

In this case study, the aquifer was recharged with in-channel flood waters. It was assumed that the irrigation requirement for cotton was 10 megalitres (ML) per hectare (ha), and this yielded 5.5 tonnes per ha of raw cotton. It was also assumed that a five metre head was required to move water from the flooded river to the aquifer and a 40 metre head to remove water from the aquifer when required. All pumps were assumed to use diesel as an energy source. The model assumed that cottonseed oil and cottonseed meal were co-produced with cotton lint.

Of the total mass harvested from a cotton crop, the model assumed that 40% was recovered as lint while 35%, 15% and 10% of total biomass was recovered as cottonseed meal, cottonseed oil, and gin waste respectively. Co-production of meal and oil was dealt with by assuming that production of these co-products reduced global demand for these. In addition, the model incorporated market effects of production changes by assuming the additional cotton lint produced by using water from a managed aquifer reduced global demand for cotton lint from other cotton production systems.

Results of the LCA

The model suggested that increased cotton production in the Murrumbidgee catchment as a result of introducing MAR reduced the intensity of greenhouse gas emissions from cotton production by approximately 10 kg CO2-e per kg cotton lint. Cotton production using MAR reduced the amount of nutrients available for eutrophication as well as soil acidification and emissions of particulate matter (PM) to the atmosphere (by 0.03 kg phosphate PO4-e, 0.04 kg sulphate SO4-e and 0.01 kg PM2.3-e, respectively), per additional kg of lint produced.

The LCA did not consider the additional operational and capital cost of managed aquifer recharge. These costs include the development of infrastructure to manage injection and re-extraction of the water. The total annual cost (capital and operational) of MAR has been estimated to be between $120-240 /ML (Arshad *et al.* 2014). The additional cost to run a MAR scheme would require an additional 3-6 bales /ha of cotton to be produced (assuming $500 per bale) to cover this cost.

Water savings

On average, evaporation losses from surface water storages represent a loss of approximately 35 % to 50 % of the total on-farm storage capacity. The LCA model assumed that a water recovery rate of 85% is achieved from the aquifer (Arshad *et al.* 2014) or in other words a loss factor of 15%. Therefore, it will take just under 12 ML/ha to be stored via MAR (assuming 15% loss) to produce the same amount of cotton as 15ML/ha stored in surface water systems (assuming 35% loss) . This could provide an overall saving of 3.5 ML/ha of water, which could be used for additional irrigated cotton production.

Discussion

The LCA demonstrates that MAR in the Murrumbidgee catchment can increase cotton production whilst saving water by reducing seepage and evaporative losses from surface storage systems. Cotton production using water from MAR was shown to provide global environmental benefits and this would improve the environmental profile of Australian cotton production.

Enabling cotton production using MAR would allow the Australian cotton industry to promote the natural resource stewardship of its growers with messaging around water use efficiencies and reduced greenhouse gas emissions.

It should be noted that this is a preliminary analysis of impacts compared to average global impacts associated with the production of cotton lint, meal and oil. A more in-depth analysis could be undertaken and would consider using historic data to estimate the amount of additional water that would have been available over time had high flows been diverted to aquifers instead of surface storage subject to evaporation.

Future work would need to carefully consider the audience (e.g. policy makers), the research question and how to distinguish local impacts versus global impacts to ensure the final analysis meets the requirements of the Australian cotton industry.

References

Arshad M, Guillaume J, Ross A (2014) Assessing the Feasibility of Managed Aquifer Recharge for Irrigation under Uncertainty ***Water*** 2014, 6(9), 2748-2769; doi:10.3390/w6092748

CSIRO (Undated) Managed aquifer recharge https://research.csiro.au/mar/

Dillon P, Pavelic P, Page D, Beringen H, Ward J, (2009) Managed aquifer recharge. In An introduction Waterlines Report Series No. 13; National Water Commission: Canberra, Australia, 2009.

GHD (2011) Australian Groundwater Technologies. In Feasibility of Managed Aquifer Recharge for Agriculture; Waterlines Report 45; National Water Commission: Canberra, Australia, 2011.

Parsons S, Dillon P, Irvine E, Holland G and Kaufman C (2012). Progress In managed aquifer recharge in Australia, Waterlines report, National Water Commission, Canberra. Recharge in Australia. National Water Commission Waterlines Report Series No 73, March 2012, SKM & CSIRO, 107p. http://archive.nwc.gov.au/library/waterlines/73Ward and Dillon 2011

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Practice change
Nature Based Solutions

Nature-based solutions

Nature-based solutions (NBS) are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN). Put simply, NBS is a new umbrella term that describes a range of environmental management and research techniques that promote natural processes as a means for providing solutions to emerging environmental issues (Nesshöver *et al.* 2017). NBS techniques can include conservation tillage; improving on-farm biodiversity to improve pest control; and plant based management of dryland salinity.

Nature Based Solutions for water

NBS for water refer to solutions that are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water (WWAP/UN-Water, 2018). The solutions involve natural or semi-natural systems that provide options for water resource management including:

- the use of natural wetlands, to improve water quality by filtering sediments and nutrients and temporarily storing flood water for later consumptive use (Ghosh 1998)
- soil moisture retention, and
- groundwater recharge (WWAP/UN-Water, 2018; Palmer *et al.* 2015).

NBS can be used as a stand-alone management tool or in concert with infrastructure such as dams and weirs (referred to as grey infrastructure). .

WWAP/UN-Water (2018) states that "NBS are able to enhance water security by improving water availability and water quality while simultaneously reducing water-related risks and generating additional social, economic and environmental co-benefits". The NBS can improve water security across sectors through increased climate resilience and rebalanced water distribution (by retaining water in the landscape, for example in soils) (Secretariat of the Convention of Biological Diversity 2013; Molden 2007; Coates *et al*. 2013; Palmer *et al*. 2015).

It has been claimed that NBS could produce productivity gains of up to 20% in irrigated farming systems (WWAP/UN-Water 2018; Coates *et al.* 2013; Molden 2007) and these reports purport that "theoretical gains that could be achieved at a global scale exceed the projected increases in global demand for water" (WWAP/UN-Water 2018).

Examples of NBS solutions to enhance water security

NBS encourages water storage, such as within natural wetlands, improvements in soil moisture and more efficient recharge of groundwater, which could be more sustainable and cost-effective than traditional infrastructure such as dams. Several sources suggest NBS is a key component in meeting the future global challenges of water management (WWAP/UN-Water, 2018; Palmer *et al.*, 2015; Vervoort, 2014) and in the absence of an alternative approach, water security will continue to decline.

The projected global increase in food and fibre demand will require agriculture to meet these increases by simultaneously improving its resource use efficiency, whilst reducing its agriculture external footprint. Water is central to this need and a foundational solution is the 'sustainable ecological intensification' of food and fibre production, which enhances ecosystem services in agricultural landscapes (WWAP/UN-Water 2018). An example of this approach is the improved soil and vegetation management approach of 'Conservation Agriculture', which incorporates practices aimed at minimizing soil disturbance, maintaining soil cover and regularizing crop rotation (WWAP/UN-Water 2018). Agricultural systems that rehabilitate or conserve ecosystem services can be as productive as intensive, high-input systems, but with significantly reduced externalities (WWAP/UN-Water 2018).

Another well-known NBS is the System of Rice Intensification (SRI). This method uses a four-pronged approach:

1. Early, quick and healthy plant establishment
2. Reduced plant density
3. Improved soil conditions through enrichment with organic matter
4. Reduced and controlled water application

(SRI 2014)

System of Rice Intensification is described as a "flexible set of farming practices" that results in higher crop yields while simultaneously "reducing input requirements, especially seeds, agro-chemicals and water." SRI focuses on increasing productivity through improved functionality of soils (in terms of water content and ecology) rather than turning to new varieties of crops or chemical agents.

NBS also focuses on soil and water conservation including measures that disconnect water and sediment fluxes (Keestra *et al.*, 2018). These strategies, such as grassed waterways, vegetation strips, contour planting, and the use of soil and stone bunds, all slow down surface water runoff and enhance infiltration for later use.

Nature Based Solutions that improve soil water management strengthen water security, local livelihoods and resilience to climate change impacts. An example of this approach is from Rajasthan, India where one of the worst droughts in its history was experienced in 1986. Over the following years, water-harvesting structures were installed which improved water supply and the soils and forests were regenerated in the region. These activities led to a 30% increase in forest cover, groundwater levels rose by several metres and cropland productivity improved (UNWATER).

Conclusions

NBS is a relatively new term that covers a range of environmental management and research techniques that promote natural processes as a means for providing solutions to emerging environmental issues. A range of examples from around the world is presented, and it is clear that NBS described techniques that are very similar to a range of techniques already employed by not only the Australian cotton industry but within Australian agriculture more generally. These include the use of conservation tillage as well as improving on-farm biodiversity to improve pest control; and plant based management of dryland salinity. As such, there is an opportunity to identify current practices within the Australian cotton industry that conform to the definition of NBS. Additionally there is an opportunity to develop a program to promote these identified practices for wider adoption. This would allow the cotton industry to demonstrate its contribution to good water stewardship and improve the industry’s reputational risk profile.

Recommendation

We recommend that further research into NBS be undertaken to identify a suite of appropriate options for the Australian cotton industry that can be adopted as a means of improving water security. Adoption of appropriate NBS approaches within the cotton industry could be promoted globally to demonstrate the cotton industry’s contribution to good water stewardship and improve the industry’s reputational risk profile.

References

Coates D, Pert P, Barron J, Muthuri C, Nguyen-Khoa S, Boelee E, Jarvis D (2013) Water-related ecosystem services and food security. E. Boelee (ed.), Managing Water and Agroecosystems for Food Security. Comprehensive Assessment of Water Management in Agriculture Series No. 10. Wallingford, UK/Boston, USA, Centre for Agriculture and Bioscience pp29-41.

Cohen-Shacham E, Walters G, Janzen C, Maginnis S (eds.) (2016) Nature-based Solutions to address global societal challenges. Gland, Switzerland: IUCN.

Ghosh, Dhrubajyoti. "The Calcutta Wetlands: turning bad water into good" (PDF). www.dhrubajyoti.net. Changemakers (issue October 2008).

Hall J, Grey D, Garrick D, Fung F, Brown C, Dadson S, Sadoff S (2014) Coping with the curse of freshwater variability: Institutions, infrastructure, and information for adaptation Science (346) No. 6208, pp 429-430

IUCN Nature-based Solutions https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

Keestra S, Nunes J, Novara A, Finger D, Avelar D, Kalantari Z Cerdà A (2018) The superior effect of nature based solutions in land management for enhancing ecosystem services Science of The Total Environment (610–611):997-1009

Molden, D. (ed.) (2007) Water for Food, Water for Life: Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, in association with International Water Management Institute (IWMI), Colombo.

Nesshöver C, Assmuth T, Irvine K, Rusch G, Waylen K, Delbaere B, Haase D, Jones-Walters L, Keune H, Kovacs E, Krauze K, Külvik M, Rey F, van Dijk F, Vistad O, Wilkinson M, Wittmer H (2017) The science, policy and practice of nature-based solutions: An interdisciplinary perspective ***Science of The Total Environment*** Vol. 579 pp 1215-1227,

Palmer, M. A., Liu, J., Matthews, J. H., Mumba, M. and D'Ororico, P. (2015) Water Security: Gray or Green? Science, Vol. 349, No. 6248, pp. 584-585.

Secretariat of the Convention of Biological Diversity (2013) Water and Biodiversity - Natural Solutions for Water Security. Montreal, 95 pages

SRI-Rice. 2014. SCI - The System of Crop Intensification: Agroecological innovations for improving agricultural production, food security, and resilience to climate change. SRI International Network and Resources Center (SRI-Rice), Cornell University, Ithaca, New York, and the Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, Netherlands. (72p., 5.45MB pdf)

SWIM Project Sustainable Water Integrated Management in the Mediterranean http://www.waterandnature.org/projects/swim-sustainable-water-integrated-management-mediterranean

Vervoort, W (2014) Dams are not the smart way to secure water for agriculture. The Conversation, 21 October 2014.

WWAP (United Nations World Water Assessment Programme)/UN-Water (2018) The United Nations World Water Development Report 2018: Nature-based Solutions for Water. Paris, UNESCO.

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INT18/117836

Supply Augmentation
Water from novel sources; atmospheric or low quality water

Extracting water from the atmosphere

In recent decades exponentially growing water demand, decreasing reliability of water resources, and recurring extreme droughts in many regions have compelled scientists and policy makers to rethink the future of water availability and its management. One area of focus for research is the augmentation of water supplies by the capture of atmospheric water for consumptive use.

At any point in time the atmosphere contains around 142,000,000 gigalitres of water, which is present as vapour. There are current technologies, now being mass produced, which are available for extracting this water. These are marketed as being 'environmentally safe', 'ecologically friendly' and 'environmentally responsible' (Blackburn *et al*. 2013).

In addition to the new technology, there are recorded instances of ancient cultures harvesting fog or dew to supplement water supplies. Evidence of this practice has been found in the Middle East and South America, where low circular walls were built around plants and vines to collect moisture from condensation, or piles of stones arranged so that condensation could trickle down the inside walls where it was collected and then stored (Cho 2011).

Technologies for extracting water from the atmosphere

A feasible atmospheric water-harvesting system that would enhance water security for the Australian cotton industry should operate with a medium that can take up and release water with minimal associated energy requirements. It should also produce volumes of water which are adequate for irrigation purposes. A number of options are discussed below.

Metal-Organic Framework (MOF)

Using advanced material science, porous metal-organic frameworks (MOF) were developed to capture water from the atmosphere at ambient conditions (Kim *et al*. 2017). These MOFs are present as porous crystals that form continuous 3D networks which adsorb water, even under low-humidity conditions (Service 2017).

Devices using porous metal-organic frameworks in air with low relative humidity (down to 20%) have been developed that capture water from the atmosphere at ambient conditions using low-grade heat from natural sunlight (around 1 kW per square meter). At night these compounds adsorb water vapour from the atmosphere, and then use heat from the sun to release it as liquid water during the day.

Assessment of the current yield from MOFs shows that continuously harvesting water in a cyclic manner for a 24-hour period with low-grade heat at 1 kW m^{-2} can yield approximately 0.9 L m^{-2} day^{-1} of water with a MOF layer of 1 mm thickness (Kim *et al*. 2017). It would require around 1000 ha of MOF to produce

9 ML of water per day. Assuming 365 days of production this could yield just over 3000 ML per year and sustain an area of between 400-450 ha of cotton.

Fog collection and dew harvesting

Dew harvesting takes advantage of water vapour in the atmosphere to harvest water occurring as condensation. People have practiced dew harvesting for thousands of years in areas where rainfall and groundwater resources are scarce (Khalil *et al.* 2016). In situations where there is any humidity at all in the air, and there is a surface that is cool enough to provoke condensation, dew will condense on that surface until the humidity is too low. Desert vegetation has evolved to allow collection of water from the humidity in the air.

Current dew water collectors are divided into two types: radiative (passive) and active dew water condensers. According to the radiative energy available for condensation, the upper limit of dew yield is 0.8L m^{-2} day^{-1} (Monteith and Unsworth 1990). The reported volume or yield of dew from a 1 m^2 radiative condenser is between 0.3 and 0.6 L/day of dew water in arid and semi-arid regions (Khalil *et al.* 2016).

Active condensers work in a manner similar to that of a dehumidifier to extract water from the air (Khalil *et al.* 2016). Although they are more effective than the radiative condensers in terms of water yield per day, they require a source of energy which makes their operating costs much higher than those of radiative condensers which do not require an energy source other than natural sunlight (Khalil *et al.* 2016). The water yield of active condensers varies depending on the design and purpose and yields fall within the range of 15–50 L/day for a small portable drinking water unit to up to 56 ML per year (Belleza 2010) for the largest of units currently in operation.

There is a range of commercial technologies that capture both dew and fog. CloudFisher™ captures both sea and mountain fog using steel mesh (Figure 1). The fog harvesting technology consists of a single or double layer mesh net supported by two posts rising from the ground. The net allows for the fog to condense and then drain off into a collector. In the village of Chungungo, Chile where annual precipitation is less than 60 mm, 100 fog collectors produced 15,000 litres of water a year over the past ten years (https://www.aqualonis.com/cloudfisher).

A range of technology is available to harvest water from the atmosphere including highly specialised and experimental material through to age old techniques. Water yields from these approaches are very low and whilst they are useful in meeting deficits in critical human need would not be fit for purpose in supplying commercially irrigated cotton.

Figure 1 Fog collector (Images sourced from http://www.climatetechwiki.org/content/fog-harvesting)

Use of low quality water

In this case study low quality water relates to water that has high concentration of salts. In the agricultural context this usually relates to groundwater, but also potentially relates to a range of effluent water supplies such as town sewage treatment plants or industrial plants such as canneries and ethanol plants.

All groundwater contains salts, predominantly sodium chloride (NaCl), and if untreated and used to irrigate crops is likely to result in:

- impaired plant growth due to salinity impacts on crops
- specific ion toxicity in plants (particularly sodium and chloride)
- damage to soil structure and permeability because of the high sodium and low calcium magnesium concentrations
- possible impacts on shallow aquifers

To reduce the concentration of salts and other contaminants in low quality water a number of approaches can be employed. Some of these include:

- removal of salts (desalination)
- dilution with low salinity water (shandying)
- improving the balance of salts (decrease SAR, water softening)

Desalination of low quality water

Desalination is a process that uses either heat or membranes to remove salts and minerals from water. Desalination delivers high production efficiency, flexibility, and reliability in times of drought. A range of factors contribute to the cost of producing and conveying desalinated water and these include: desalination plant capacity; power use efficiency associated with whichever desalination process is utilised; the energy source utilised; proximity of the desalinisation plant to source water and end users; and the project financing model (AWA 2018).

Costs to produce desalinated water are highly variable, ranging from $1000-$4000 per ML. However, in most cases desalination is still not cost competitive compared with water from traditional sources (groundwater and surface water) (Zrolkowska and Reyes 2017), nor is it likely to be viable to apply water that costs $500 per ML or more to produce irrigated cotton.

Currently in Australia the only example of using desalinated water for agricultural production is Sundrop Farms in South Australia (New Scientist 2016). This farm produces high value fresh vegetables for human consumption.

Conjunctive use of ground and surface water

The aim of conjunctive use is to dilute low quality water with higher quality water to reduce the effect of the low quality water on crop performance. This process is usually referred to as shandying which is alternating surface and groundwater applications. This method provides a means of augmenting water supplies for irrigation, but access to either surface or groundwater is confined to the existing consumptive pool of water for irrigation. This practice of conjunctive use is widely used within the mid Murray Valley particularly for rice production.

Improving the balance of salts

As discussed above, the concentration of salts in most groundwater can inhibit plant growth and degrade soil structure. Too much sodium (and not enough calcium) within irrigation water will cause the clay particles in the soil to separate and go into solution (or disperse) when the soil is wet. Sodic irrigation water can reduce soil infiltration rate and permeability.

One option to address this and increase the productive use of groundwater is to rebalance the ratio of cations present in order that the effect (particularly of sodium) on soil structure is diminished. Gypsum is normally mechanically spread before irrigation and the amount of gypsum required is determined by soil tests as well as expert advice, close monitoring and careful management.

Conclusion

A range of technology is available to harvest water from the atmosphere, including highly specialised and experimental material through to age old techniques. Water yields from these approaches are very low with existing technologies and whilst these approaches may be useful in meeting deficits in critical human need, they would not be fit for purpose in supplying commercially irrigated cotton. However, this is an area that may experience rapid technological progress and development and as such, requires a "watching brief" of these developments. If this technology develops to achieve water yields that could supply commercially irrigated cotton then additional investment in R&D would be recommended.

Low quality water is an option to enhance water security within the cotton industry. However, desalination is an expensive treatment and obtaining reliable, cost effective supplies of an appropriate quality constrains the use of this water and makes it prohibitive for broadacre irrigation. Additionally in NSW low quality water (such as that produced from mining coal seam gas) is not available in large enough quantities to be considered viable.

Conjunctive surface and groundwater use is a widely applied technique particularly in southern irrigation systems. However caution should be use and it is important to assess the effect of this process on the soil and subsequent yield of cotton. If conjunctive use is employed then an increase in soil sodicity may occur. To overcome this gypsum can be used to rebalance the salts in the soil. It is recommended that expert advice, close monitoring and careful management be undertaken.

References

AWA (2018) Desalination Fact Sheet Australian Water Association PO Box 222, St Leonards NSW 1590 http://www.awa.asn.au/AWA_MBRR/Publications/Fact_Sheets/Desalination_Fact_Sheet.aspx

Belleza (2010) https://gulfnews.com/business/property/burj-khalifa-towering-challenge-for-builders-1.561802

Blackburn N, Armedion M (2014) Environmental assessment of air to water machines—triangulation to manage scope uncertainty **International Journal of Life Cycle Assessment** Vol 180 1149–1157 DOI 10.1007/s11367-013-0568

Cho R (2011) The fog collectors: Harvesting water from thin air Columbia University blog http://blogs.ei.columbia.edu/2011/03/07/the-fog-collectors-harvesting-water-from-thin-air/

Khalil B, Adamowski J, Shabbir A, Jang C, Rojas M, Reilly K, Ozga-Zielinski B (2016) A review: dew water collection from radiative passive collectors to recent developments of active collectors ***Sustainable Water Resources Management*** Vol 2, Issue 1, pp 71–86

Kim H, Yang S, Rao S, Narayanan S, Kapustin K, Furukawa H, Um A (2017) Water harvesting from air with metal-organic frameworks powered by natural sunlight ***Science*** 13 Apr 2017 DOI:10.1126/science.aam8743

Monteith J and Unsworth M (1990) Principles of Environmental Physics Academic Press 1990

NSWDPI (2018) Cotton gross margin budgets https://www.dpi.nsw.gov.au/agriculture/budgets/cotton

Rengasamy P, North S, Smith A (2010) Diagnosis and management of sodicity and salinity in soil and water in the Murray Irrigation region. The University of Adelaide, SA

Service R (2017) This new solar-powered device can pull water straight from the desert air ***Science*** http://www.sciencemag.org/news/2017/04/new-solar-powered-device-can-pull-water-straight-desert-air doi:10.1126/science.aal1051

Zhang S, Babovic V (2012) A real options approach to the design and architecture of water supply systems using innovative water technologies under uncertainty **Journal of Hydroinformatics** 14 (1) 13-29

Zrolkowska J, Reyes J (2017) Competition for Water Resources Experiences and Management Approaches in the US and Europe 2017, Pages 298-316

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Department of Primary Industries

Australian Government
Cotton Research and Development Corporation

Innovative approaches to water security

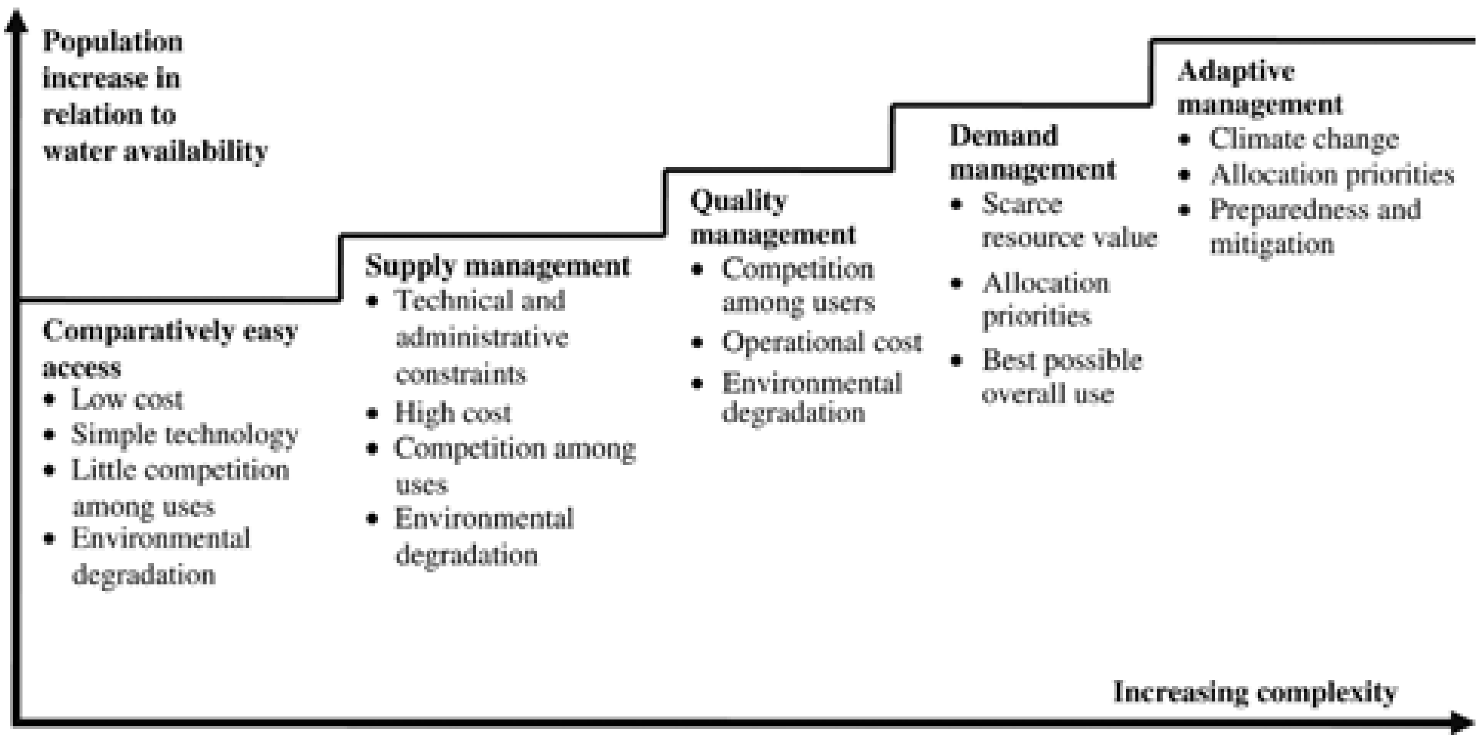
David Mitchell David Cordina Sarah Dadd
NSW DPI Agriculture

What is water security?

The availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies”

(Grey and Sadoff, 2007).

Development of water management paradigm



after Kampragou et al. 2010

How to measure or assess water security

Improving water security encompasses both maintaining and improving water availability for irrigation

The 5P's (Loch 2018)

- Project (supply augmentation)
- Preachment (education)
- Police (compliance)
- Price (effective markets)
- Property rights

Modified principles

- Supply
- Practice
- Compliance
- Markets
- Policy

Survey of cotton growers

Telephone survey

Semi structured interviews

20 growers and consultants across the Australian cotton industry

What we found

Stop changing policy!

Stop changing policy!

Stop changing policy!

Can we reduce losses?

Do we know where the water is going?

Can we reduce plant water use without compromising yield?

Supply Augmentation

- Non-conventional water resources (CSG, low quality groundwater, desalinisation)
- New or upgraded storages
- Water from air, fog harvesting
  - Current yields MOF can yield 2.8 L /kg/day
  - Fog/dew harvesting up to 39 mm/year

Practice

- Water accounting
- Physically reducing losses (480 to 700 GL)
- Reduction in plant demand
    - Transpiration reduction
- Improved storage and delivery
    - Managed aquifer recharge

Compliance

- Mathews report
    - Natural Resources Access Regulator
    - NSW Metering policy

Markets

Market can allocate resources efficiently

100 GL of entitlement trade

several hundred GL of allocation trade

during peaks in the early to mid-2010's.

Allowed responses to climatic variability

Return of water to the environment

Policy

- Over 130 years of policy development in MDB
- Irrigators want stability to invest and produce
- Range of novel approaches including
  - improving understanding of environmental needs
  - encourage novel responses such as selling and buying environmental water

Recommendations

Practice

- loss reduction
- improved accounting for water (benchmarking)
- transpiration reduction

  improved physiological plant water use traits

  Novel compounds
- Improved water delivery (System harmonisation)
- Improved water storage (MAR)

Recommendations

Markets

- Provision of information for effective market operations such as:
  availability of water for trading,
  presence of related party transfers
  quality and timeliness of price information
- Education on the fundamentals of water trade, such as trade related actions, trade rules,

Recommendations

Policy

- Long term stability in this space
- Improving understanding of environmental needs
- Accounting and valuing conveyance losses as environmental water
- Better communication between environmental and consumptive users

Conclusions

- Framework developed to define water security, allowing potential innovative approaches to water security to be identified, assessed and potentially developed.
- A range of concepts have been identified that can improve water security for the cotton industry