FINAL REPORT - PhD
TEMPLATE

CRDC ID: UNSW1801

Project Title: **Where does the water go?**

Confidential or for public release? For Public Release

Part 1 – Contact Details & Submission Checklist

Principal Researcher: Ehsan Zare

Organisation: UNSW Sydney

Ph: 0405016670

E-mail: Ehsan.zare@student.unsw.edu.au

Supervisor: **John Triantafilis**

Organisation: UNSW Sydney

Ph:

E-mail: j.triantafilis@unsw.edu.au

Researcher 2: (Name & position of additional researcher or supervisor).

Organisation:

Ph:

E-mail:

Submission checklist.

Please ensure all documentation has been completed and included with this final report:

☒ Final report template (this document)

☒ Final Technical Report (see Part 3) – CRDC will accept the Thesis as the Technical Report

☐ Final Schedule 2: IP register

☒ Final Financial report - SER

☒ PDF of all journal articles (for CRDC's records)

Signature of Research Provider Representative: ______________________

Part 2 - Monitoring & Evaluation

This data forms part of CRDC's M&E data collection. Please complete all fields and add additional rows into each table if required.

Achievement against milestones in the Full Research Proposal

Milestone	Achieved/ Partially Achieved/ Not Achieved	Explanation
1.1 ACRI" lower Namoi valley: Explore potential to monitor wetting phase of irrigation moisture status by creating EMCI using a DUALEM-421 along	*Achieved* Paper published.	Case study which shows how spatial distribution of a soil moisture can be monitored across an irrigated field and understand where water use inefficiencies may exist during a wetting cycle.
1.2 "ACRI" lower Namoi valley: Explore potential to monitor wetting-drying phase of irrigation moisture status by creating EMCI using a EM38 at various heights along single transects in field C1.	*Achieved* Paper published.	Case study which shows how spatial distribution of a soil moisture can be monitored across an irrigated field and understand where water use inefficiencies may exist during an entire wetting and drying cycle.
2 "Yungella": Explore potential to create a digital soil map (DSM) using six easy steps of DSM in a dryland cotton "field" to map permanent wilting point (PWP) and field capacity (FC) to determine available water content (AWC)	*Achieved* Paper published.	Case study which shows how spatial distribution PWP, FC and AWC can be mapped across a field and for potential application in understanding where water can be stored in a soil profile.
3 "Auscott": Develop electromagnetic conductivity images (EMCI) beneath a irrigation supply channel of a commercial cotton growing farm.	*Achieved* Paper published.	Case study which shows how spatial distribution of a soil property along a supply channel can be mapped in 2-d using EM inversion and for potential application in understanding where water use inefficiencies may exist and where improvements in design of the channel can be recommended.
4 "Warrianna": Explore potential to create a digital soil map (DSM) using EM and RGB data in a irrigated cotton "field" to map soil mineralogy (i.e. smectite, kaolin, illite, quartz).	*Partially* Samples prepared and part analysed using X-ray diffraction. However, interpretation has been impeded by COVID-19 with analytical centre operating not at capacity, slowing progress.	Case study which shows how spatial distribution of topsoil (0-0.3 m) mineralogy can be mapped across a field using EM data and for potential application in understanding water use inefficiencies in an irrigation field.
5 Additional research: *Comparing traditional and digital soil mapping at a district scale using residual maximum likelihood analysis*	*Achieved* Paper published.	Case study which shows how DSM of EM and gamma-ray data can be used to map the management zones in district scale.

Outcomes from project outputs *(Refer to examples document).*

Outcome	Description
1.1 Journal Paper	Zare, E., Li, N., Arshad, M., Nachimuthu, G., & Triantafilis, J. (2020). Time-lapse imaging of soil moisture in a flood irrigation field monitored using electromagnetic conductivity imaging: Wetting phase. Soil Science Society of America Journal. doi:10.1002/saj2.20192
1.2 Journal Paper	Zare, E., Arshad, M., Zhao, D., Nachimuthu, G., & Triantafilis, J. (2020). Two-dimensional time-lapse imaging of soil wetting and drying cycle using EM38 data across a flood irrigation cotton field. *Agricultural Water Management*, *241*. doi:10.1016/j.agwat.2020.106383
2 Journal Paper	Zare, E., Wang, J., Li, N., Arshad, M., & Triantafilis, J. (2021). Scope to map available water content using proximal sensed electromagnetic induction and gamma-ray spectroscopy data. *Agricultural Water Management*, 247, 106705.
3 Journal Paper	Zare, E., Li, N., Khongnawang, T., Farzamian, M., & Triantafilis, J. (2020). Identifying Potential Leakage Zones in an Irrigation Supply Channel by Mapping Soil Properties Using Electromagnetic Induction, Inversion Modelling and a Support Vector Machine. Soil Systems, 4(2), 25.
5 Journal Paper	Zare, E., Ahmed, M. F., Malik, R. S., Subasinghe, R., Huang, J., & Triantafilis, J. (2018). Comparing traditional and digital soil mapping at a district scale using residual maximum likelihood analysis. Soil Research, 56(5), 535-547.

Part 3 – Technical Report

This PhD project investigated the application of apparent soil electrical conductivity (EC_a) data, measured by electromagnetic (EM) induction instruments, used with inversion modelling to understand the dynamics in volumetric soil moisture content. Key outputs included

- Case study which shows how spatial distribution of a soil moisture can be monitored across an irrigated field. This study was conducted at ACRI using using a DUALEM-421 before and during an irrigation event, with time-lapse images of volumetric soil moisture content. The length and weight of the machine made it impractical for predicting volumetric soil moisture content. When combined with machine learning modelling, the results showed that the collection of EC_a and its inversion is a useful tool to create digital soil maps of estimates of soil moisture content and soil physical (e.g., clay, sand) and chemical (e.g., EC_e and CEC) properties.
- Case study which shows how spatial distribution permanent wilting point, field capacity and available water content can be mapped across a field. This study was conducted on a commercial dryland cotton field, combining DUALEM-421, gamma-ray spectrometry and modelling to develop maps and concluded it was possible to map availabe water content across a dryland cotton field in topsoil (0-0.3 m), subsurface (0.3-0.6 m) and subsoil (0.6-0.9 m) with good accuracy. This can potentially help the dryland farmers to make management decisions about planting time and row spacing.
- Case study which shows how spatial distribution of a soil property along a supply channel can be mapped in 2-d using EM inversion and for potential application in

understanding where water use inefficiencies may exist and where improvements in design of the channel can be recommended

3 "Auscott": Develop electromagnetic conductivity images (EMCI) beneath a irrigation supply channel of a commercial cotton growing farm.
Achieved
Paper published. Case study which shows how spatial distribution of a soil property along a supply channel can be mapped in 2-d using EM inversion and for potential application in understanding where water use inefficiencies may exist and where improvements in design of the channel can be recommended.
4 "Warrianna": Explore potential to create a digital soil map (DSM) using EM and RGB data in a irrigated cotton "field" to map soil mineralogy (i.e. smectite, kaolin, illite, quartz). Partially
Samples prepared and part analysed using X-ray diffraction. However, interpretation has been impeded by COVID-19 with analytical centre operating not at capacity, slowing progress. Case study which shows how spatial distribution of topsoil (0-0.3 m) mineralogy can be mapped across a field using EM data and for potential application in understanding water use inefficiencies in an irrigation field.
5 Additional research:
Comparing traditional and digital soil mapping at a district scale using residual maximum likelihood analysis Achieved
Paper published. Case study which shows how DSM of EM and gamma-ray data can be used to map the management zones in district scale.

Thesis Abstract:

Climate change forecasts and modelling for south-east Australia, where irrigated cotton growing occurs, suggest hotter conditions and reduced rainfall with less water for evapotranspiration. There are also ever increasing and competing demands for water from environment, mining and domestic applications. To improve soil-water management, knowledge on soil-water dynamics and soil properties which influence water holding capacity in cotton growing areas is required at the field, farm and district level. Given the heavy-clay nature of the soil (i.e., Vertosols), detailed characterization of soil moisture is a challenging task. Recently, apparent soil electrical conductivity (EC_a) data, measured by electromagnetic (EM) induction instruments, is increasingly being used with inversion modelling to understand the dynamics in volumetric soil moisture content (θ). This is because it is non-invasive, quick and inexpensive. In this thesis, electromagnetic conductivity images (EMCI), generated by inverting EC_a data (σ), has been used to map the spatial and temporal variations of θ along an irrigated cotton field located near Narrabri, New South Wales, Australia. Furthermore, EMCI was applied to create 2-dimensional maps of different soil properties in order to identify more permeable prior stream channels along a 4km section of a farm supply channel and to better understand how soil physical (e.g., clay, silt and sand) and chemical properties (e.g., EC_e and CEC) influence soil water holding capacity. In addition, the use of additional sources of digital data (i.e., gamma-ray spectrometry) was examined to understand spatial variation of available water content (AWC) at the field scale and landscape units across larger spatial scales, in concert with other digital data (i.e., EC_a and DEM). The results showed that the collection of EC_a and its inversion to produce estimates of σ is a useful tool to create digital soil maps (DSM) of θ and soil physical (e.g., clay, sand) and chemical (e.g., EC_e and CEC) properties using machine learning modelling (i.e., support vector machine) with good accuracy (Lin's Concordance > 0.8). Moreover, it was evident that DSM of AWC and soil profile classes can be created using EC_a in combination with gamma-ray spectrometry data. It was concluded that DSM techniques using easy and cheap to acquire digital data such as EC_a and gamma-ray spectrometry data can aid precision irrigation and agriculture by providing quantitative information and digital maps of soil properties for the farmers and decision makers.

Please contact your R&D manager if you would like to adopt a different approach.

Part 4 – Summary for public release

This summary will be published on Inside Cotton, CRDC's digital repository, along with the full final report (if suitable for public release). It is designed to provide a short overview of the project for all interested parties. Please complete all fields, ensuring that this exceeds no more than two pages.

Project title:	**Type Title here**	
Project details:	CRDC project ID:	UNSW1801
	CRDC goal:	*2. Improve cotton farming sustainability and value chain competitiveness*
	CRDC key focus area:	*3.1 Science and innovation capability, and new knowledge*
	Principal researcher:	*Ehsan Zare*
	Organisation:	UNSW Sydney
	Start date:	July 1, 2017
	End date:	December 31, 2020
Objectives	To improve soil-water management, knowledge on soil-water dynamics and soil properties which influence water holding capacity in cotton growing areas is required at the field, farm and district level. Given the heavy-clay nature of the soil (i.e., Vertosols), detailed characterization of soil moisture is a challenging task.	
Background	Apparent soil electrical conductivity (EC_a) data, measured by electromagnetic (EM) induction instruments, is increasingly being used with inversion modelling to understand the dynamics in volumetric soil moisture content (θ). This is because it is non-invasive, quick and inexpensive.	
Research activities	electromagnetic conductivity images (EMCI), generated by inverting EC_a data (σ), has been used to map the spatial and temporal variations of θ along an irrigated cotton field located near Narrabri, New South Wales, Australia. Furthermore, EMCI was applied to create 2-dimensional maps of different soil properties in order to identify more permeable prior stream channels along a 4km section of a farm supply channel and to better understand how soil physical (e.g., clay, silt and sand) and chemical properties (e.g., EC_e and CEC) influence soil water holding capacity. In addition, the use of additional sources of digital data (i.e., gamma-ray spectrometry) was examined to understand spatial variation of available water content (AWC) at the field scale and landscape units across larger spatial scales, in concert with other digital data (i.e., EC_a and DEM). Furthermore, EMCI was applied to create 2-dimensional maps of different soil properties in order to identify more permeable prior stream channels along a 4km section of a farm supply channel and to better understand how soil physical (e.g., clay, silt and sand) and chemical properties (e.g., EC_e and CEC) influence soil water holding capacity. In	

	addition, the use of additional sources of digital data (i.e., gamma-ray spectrometry) was examined to understand spatial variation of available water content (AWC) at the field scale and landscape units across larger spatial scales, in concert with other digital data (i.e., EC_a and DEM).
Outputs	The results showed that the collection of EC_a and its inversion to produce estimates of σ is a useful tool to create digital soil maps (DSM) of θ and soil physical (e.g., clay, sand) and chemical (e.g., EC_e and CEC) properties using machine learning modelling (i.e., support vector machine) with good accuracy. Moreover, it was evident that DSM of AWC and soil profile classes can be created using EC_a in combination with gamma-ray spectrometry data. It was concluded that DSM techniques using easy and cheap to acquire digital data such as EC_a and gamma-ray spectrometry data can aid precision irrigation and agriculture by providing quantitative information and digital maps of soil properties for the farmers and decision makers.
Impacts	The impact and implications to the cotton industry are that the objectives and aims have been met and that a DSM approach is feasible to make maps of individual soil physical and chemical properties. Specifically, at the field and district scale a DSM approach can be used with various EM data sets (e.g., EM38, EM34, DUALEM-421), and gamma-ray spectrometry data to predict and manage various soil physical (i.e., clay, silt and sand), chemical (i.e., CEC, EC_e) and hydrological properties (i.e., θ and available water content).
Key publications	1. Zare, E., Li, N., Arshad, M., Nachimuthu, G., & Triantafilis, J. (2020). Time-lapse imaging of soil moisture in a flood irrigation field monitored using electromagnetic conductivity imaging: Wetting phase. Soil Science Society of America Journal. 2. Zare, E., Arshad, M., Zhao, D., Nachimuthu, G., & Triantafilis, J. (2020). Two-dimensional time-lapse imaging of soil wetting and drying cycle using EM38 data across a flood irrigation cotton field. *Agricultural Water Management*, *241*. 3. Zare, E., Wang, J., Li, N., Arshad, M., & Triantafilis, J. (2021). Scope to map available water content using proximal sensed electromagnetic induction and gamma-ray spectroscopy data. *Agricultural Water Management*, 247, 106705. 4. Zare, E., Li, N., Khongnawang, T., Farzamian, M., & Triantafilis, J. (2020). Identifying Potential Leakage Zones in an Irrigation Supply Channel by Mapping Soil Properties Using Electromagnetic Induction, Inversion Modelling and a Support Vector Machine. Soil Systems, 4(2), 25.

	5. Zare, E., Ahmed, M. F., Malik, R. S., Subasinghe, R., Huang, J., & Triantafilis, J. (2018). Comparing traditional and digital soil mapping at a district scale using residual maximum likelihood analysis. Soil Research, 56(5), 535-547.