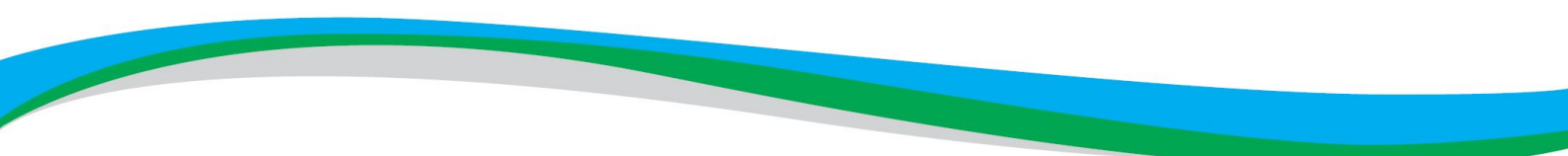


Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 5 - summary report

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Executive summary

The Northern Adelaide Corridor (NAC) has significant potential for economic development through the expansion of irrigated agriculture. This would build on the success of established horticulture activities on the Northern Adelaide Plains (NAP) around Virginia.

The Goyder Institute for Water Research instigated a stocktake of the water resources that could be made available for economic development in the region in the short-term and found approximately 26 GL per year of additional water may be available for use. Most of the potential water was recycled water (20 GL per year) due to a significant expansion of the recycled water network via the Northern Adelaide Irrigation Scheme (NAIS). At the time of writing, the NAIS delivery infrastructure was at an advanced stage of construction with the first water delivery planned for late 2019.

Recycled water is a significant irrigation source that could help expand irrigated agriculture and horticulture in the region, but its salt content should be managed to avoid soil salinisation and sub-optimal crop yields in areas north of the Gawler River. However, its use for irrigation has already been proven in the NAP and this experience provides invaluable guidance on management strategies that can be applied to sustainably develop irrigated agriculture in the NAC.

This Goyder Institute for Water Research project, *Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor* was established to address the following key knowledge gaps.

1. Current soil attributes which are needed to assist model predictions of the impacts of using recycled water and develop guidelines for the sustainable use of recycled water
2. The impact of water from different sources/of different quality on water-soil biochemical process interactions
3. The fate of nutrients from different sources on receiving waters and effects from variable irrigation water quality on the long-term sustainability of the land's ability to grow crops
4. The amount of water of different quality that can be supplied at different times of the year
5. The depth to shallow (often saline) groundwater which would be affected by increased recharge from expanded irrigation
6. The extent of resilient and vulnerable areas where further irrigation expansion could proceed subject to additional works and management practices being assured (such as interception and drainage of shallow, saline groundwater).

To address these knowledge gaps, the project was structured into five distinct tasks as outlined below.

Task 1: Baseline soil properties (*knowledge gap 1, outcomes reported in section 2.1*) (Oliver et al., 2019).

Task 2: Modelling nutrient and chemical fate, including salinity/sodicity risk, as the basis for identifying longevity of recycled water utilisation and mitigation strategies under current and future climate (*knowledge gaps 2 and 3, outcomes reported in section 2.4*) (Mallants et al., 2019).

Task 3: Source water options/water availability, quality and storage considerations (*knowledge gap 4, outcomes reported in section 2.2*) (Awad et al., 2019).

Task 4: Assessment of depth to groundwater (proof of concept) (*knowledge gap 5, outcomes reported in section 2.3*) (Hatch et al., 2019).

Task 5: Integration of project deliverables from Tasks 1–4 (*knowledge gap 6, this report*).

The acquired knowledge, coupled with the learning gained from the established horticultural industry, will guide the best use of water available to irrigate soil-based crops in the NAC. The HYDRUS-1D UNSATCHEM model was used to develop long-term modelling scenarios under the historical (1970–2017) and future climate (2018–2050). These scenarios were integral to our assessment of strategies to develop sustainable irrigation practices which minimise risk to the environment while maximising productivity. The modelling scenarios were informed by: (i) baseline soil properties; (ii) water resource quantity and quality; (iii) South Australian climate change projections; (iv) depth to shallow ground water; and (iv) knowledge gained through established irrigation practices on the NAP.

Baseline soil physical and chemical properties were established for the four most prevalent soil texture groups in the study area: (i) hard red-brown texture contrast (HrB); (ii) deep uniform to gradational (DuG); (iii) calcareous (Cal); and (iv) sand over clay (SoC) soils. Baseline soil analysis identified pH, salinity, sodicity and boron as the main soil constraints related to expanding irrigated agriculture. The long-term modelling scenarios undertaken in this project can be used to develop the associated risk management strategies to address these constraints, when combined with experience gained from the NAP's established horticultural industry.

We improved the understanding of water resource quality and quantity of the many water sources available to support irrigation but focused mainly on understanding what low salinity water resources were available and how they could best be used in conjunction with recycled water. Affordable fresh water resources, greenhouse roof runoff and urban stormwater were not considered primary irrigation sources for the region as they are seasonally dependent and of limited availability. However, roof runoff may be a key resource locally to irrigate greenhouse crops. Roof runoff and stormwater are low salinity irrigation sources that can be used with recycled water to mitigate long-term salinity issues. Conjunctive use may involve blending or cycling application. Desalination by reverse osmosis (RO) is used extensively by the hydroponic industry and but not used significantly in soil-based horticulture practices. However, with improved efficiency of RO desalination and less expensive technologies (e.g. capacitive deionisation), irrigating soil-based crops with desalinated water may be feasible, particularly where water quality targets for crops cannot be met by blending recycled water with other water resources.

Infrastructure is required to harvest, store (i.e. tanks/dams for above-ground storage or managed aquifer recharge (MAR)) and convey seasonally-available resources. Storage can also enhance recycled water use by storing water that isn't needed during the wet season to use in periods of high demand (dry season or drought). In the NAP, Tertiary aquifers are currently used to store water below ground (MAR) and have the capacity needed to store additional recycled water when it isn't needed for irrigation.

Groundwater resources and available surface water from the Gawler or Light rivers are expected to be of similar or higher salinity than recycled water and may require blending with low salinity resources or desalination for sustainable irrigation. Current knowledge of the hydraulic properties and water quality in the T1 aquifer to the north of the Northern Adelaide Plains Prescribed Wells Area (NAP PWA) is limited.

An Excel-based software tool, IW-QC2, was developed to facilitate decisions on the optimal water mix, treatment and storage requirements for covered cropping practices (greenhouse soil-based crops) based on crop specific parameters and climate conditions. This tool can be used to assess the volume of greenhouse roof runoff available for harvest (low salinity resource), the size of storage that may be required and how it can be used in combination with another available resource (groundwater, recycled water) to maintain water quality below the crop tolerance threshold.

It will be a challenge to balance irrigated area expansion with shallow water table management, but this will be critical to make sure irrigated agriculture in the NAC is sustainable. We identified the least likely areas to

have a shallow water table (lowest risk of watertable issues due to irrigation) using new depth to groundwater data generated by a combination of geophysical and drilling techniques. Geophysical techniques were also used to estimate particle size (clay, sand, gravel), relative hydraulic conductivity, and to delineate between soil groups. It is essential to consider irrigation impacts on watertable depth in areas considered to be at risk of water table issues. It may not be feasible to apply increased leaching fractions to manage salinity risks without draining the excess water in these high-risk areas.

Long-term modelling scenarios were conducted in four main NAP soil groups using: a range of water sources; open field crops (almond, viticulture, pistachio, pasture, carrot, onion and potato); greenhouse crops (tomato, cucumber, capsicum and eggplant); and management scenarios (including gypsum application and leaching fraction, LF). Data specific to the region, generated by other project components, was also included. Importantly we provide a critical understanding of the irrigation requirements of NAP crops under different climatic projections that will help optimise resources and the growth of irrigated agriculture.

The simulated field crop scenarios provided vital information on the irrigation-induced salinity and sodicity problems that may arise with long-term use of recycled water. HYDRUS modelling compared the degree of management required for salinity risks in the four main soil groups. Salinity risks need to be managed in calcareous and hard red-brown texture contrast soils (gypsum 8.6 t/ha, LF 0.2–0.5, conjunctive use of low salinity water). In comparison, salinity risks are lower in sand over clay and deep uniform to gradational soils (gypsum 4.3 t/ha, LF 0.2, optional conjunctive use of low salinity water). Irrigation and management practices are expected to be similar to established management practices in the NAP region, where salinity constraints have been adequately mitigated over the long-term. A new module of annual gypsum application was introduced and successfully tested in the HYDRUS-1D UNSATCHEM environment. Simulations for greenhouse crops (tomato, cucumber, capsicum and eggplant) grown in sandy clay loam and sandy loam soils revealed that gypsum application (1.7 t/ha) in combination with leaching (LF 0.15–0.20) may be adequate to mitigate salinity and sodicity hazards in the soil.

This project delivered five technical reports (this summary report and four additional technical reports), six published journal papers (and more in preparation), four theses, four conference presentations, one workshop, an Excel-based software tool for decision making and testing of a new module of annual gypsum amendment in the HYDRUS environment. Project databases include soil chemical and physical properties with depth, depth to shallow groundwater and water resource quantity and quality. This project data is available to integrate with existing South Australian data repositories. A knowledge adoption plan is currently being developed by Goyder Institute for Water Research and an integrated management framework for the NAP is being developed by PIRSA.

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1 Background

The Northern Adelaide Corridor (NAC) has significant potential for sustainable economic development if irrigated agriculture expands, building on the success of established horticulture on the Northern Adelaide Plains (NAP) around Virginia. The NAP region generated over one-fifth of South Australia's horticulture production, approximately 204 455 tonnes of fresh produce, valued at over \$313 million (around one-third of state total) in 2016–17; and a total of 5455 ha was used for horticultural production in 2017–18 (PIRSA, 2018).

From late 2019, the first stage (12 GL) of a 20 GL per year irrigation expansion will become available for irrigation across an area north of the current irrigated area at Virginia. The new Northern Adelaide Irrigation Scheme (NAIS) will provide 'Class A' recycled water from the Bolivar Wastewater Treatment Plant. Economic modelling of the first stage of NAIS estimates that at full production levels it can service about 3000 ha of new irrigated cropping, double the production from the region; deliver up to 3700 jobs; and increase gross regional product by \$500 million each year (PIRSA, 2018). A water resources stocktake (both quantity and quality (salinity)) (Goyder Institute for Water Research, 2016) reported that approximately 26 GL per year of additional water may be available for economic development in the short term with recycled water, delivered by NAIS, the main source.

This Goyder Institute for Water Research project, *Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor* was structured into five distinct tasks to address key knowledge gaps related to expansion of irrigated agriculture (Table 1).

Table 1: Summary of project tasks, the knowledge gaps addressed and where project outcomes are reported.

PROJECT TASK	KNOWLEDGE GAP(S) ADDRESSED	WHERE PROJECT OUTCOMES ARE REPORTED
Task 1: Baseline soil properties	1. Current soil attributes which are needed to assist model predictions of the impacts of using recycled water and develop guidelines for the sustainable use of recycled water	Section 2.1 Full details in Oliver et al. (2019)
Task 2: Modelling nutrient and chemical fate, including salinity/sodicity risk, as the basis for identifying longevity of recycled water use and mitigation strategies under current and future climates	2. The impact of water from different sources and different quality on water-soil biochemical process interactions 3. The fate of nutrients from different sources on receiving waters and effects of variable irrigation water quality on the long-term sustainability of the land's ability to grow crops	Section 2.4 Full details in Mallants et al. (2019)
Task 3: Source water options/water availability, quality and storage considerations	4. The amount of water of different quality that can be supplied at different times of the year	Section 2.2 Full details in Awad et al. (2019)
Task 4: Assessment of depth to groundwater (proof of concept)	5. The depth to shallow (often saline) groundwater which would be affected by increased recharge from expanded irrigation	Section 2.3 Full details in Hatch et al. (2019)
Task 5: Integration of project deliverables from Tasks 1–4	6. The extent of resilient and vulnerable areas where further irrigation expansion could proceed subject to additional works and management practices being assured (such as interception and drainage of shallow, saline groundwater).	This report

Importantly, recycled water has already been used successfully to irrigate in the NAP region and this experience provides confidence in its sustainability. Ryan and Kelly (2014) reported that the first ten years of Class A recycled water use via the Virginia Pipeline Scheme (VPS) delivered \$1 billion of benefit to the region by providing more than 100 GL of water for irrigation. New knowledge acquired in this project, coupled with the learning gained from the established horticulture industry, guides the best use of available water resources in the new NAC irrigation area. The general outcomes of this project will help the South Australian Government achieve a number of economic priorities, including generating new investment in horticulture infrastructure and production and creating jobs in the horticulture sector.

The area of this study was constrained to the primary study area of the *NAP water stocktake project* (Goyder Institute for Water Research, 2016), with the majority of effort focused on providing new information on the area north of the Gawler River where development of irrigated agriculture and horticulture is expected (Figure 1). We discuss the assessment of resilient and vulnerable areas, based on modelling long-term irrigation in the study area, in relation to soil groups which are dominant along the NAC and therefore these implications are broadly relevant to irrigation development across a larger area.

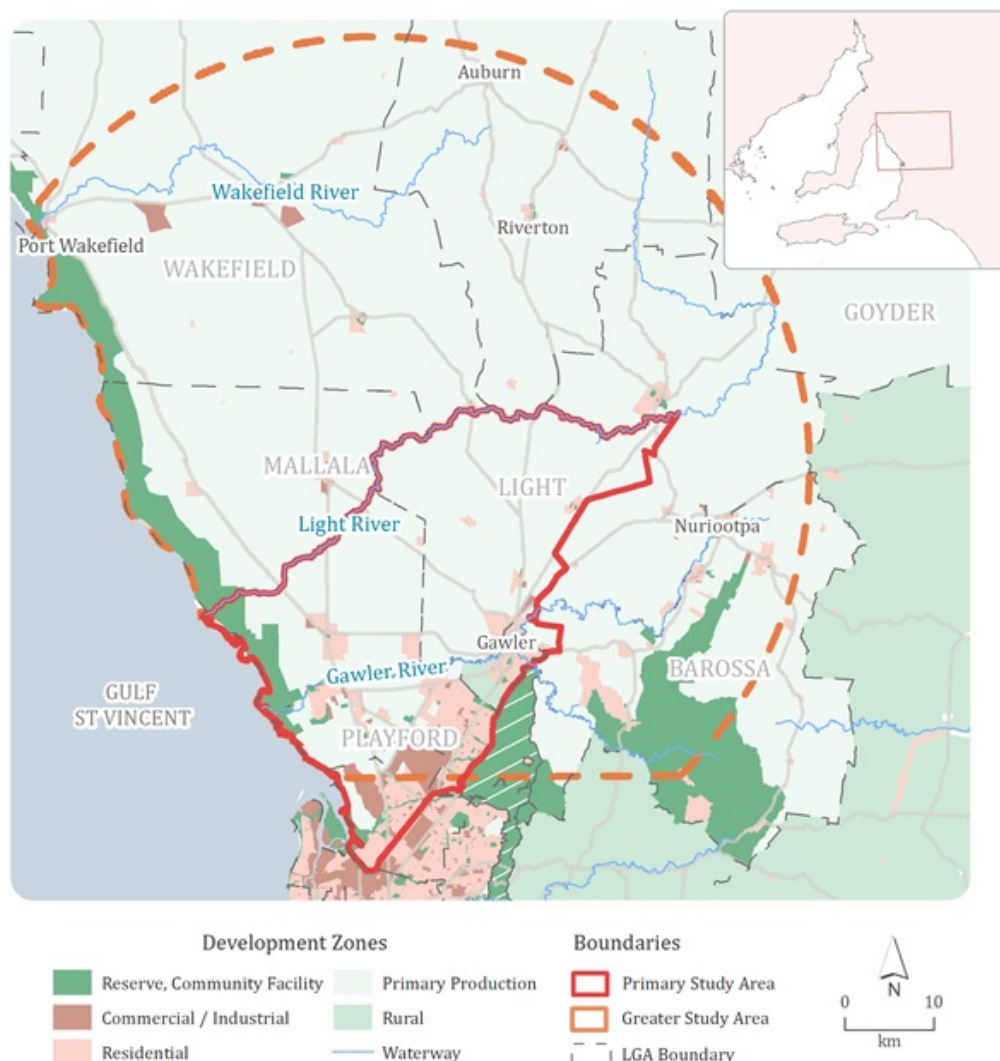


Figure 1. Study area (primary study area) within the larger Northern Adelaide Corridor (defined as the coastal plains region between northern Adelaide and Whyalla) (Goyder Institute for Water Research, 2016). Within the study area, this project focused on development potential to the north of the Gawler River.

2 Key outcomes

2.1 Task 1 – Baseline soil properties

The objective of this task (Task 1, Oliver et al., 2019) was to develop baseline physical and chemical soil properties that are required as input data for simulation of long-term irrigation scenarios using the HYDRUS-1D UNSATCHEM software (Task 2). For the purposes of soil collection, a focus area was defined extending north of Two Wells to the Light River and east towards Boundary Rd. Soil samples were collected from soil pits (NAP 1–7) or from hand-augered cores (NAP 8–20). Existing archived soils (CL014, CL015 and CL050) collected for soil classification in the region were also included in subsequent analyses. Soil sampling locations were chosen to represent the four major soil groups in the study area; hard red-brown texture contrast (HrB), deep uniform to gradational (DuG), calcareous (Cal) and sand over clay (SoC). These four soil groups represent approximately 87% of the soil collection focus area and approximately 70% of the larger study area.

The major soil properties considered as constraints to the expansion of irrigated agriculture in the region are pH, salinity, sodicity and boron, as outlined below. Strategies to manage these soil constraints can be developed from horticultural experience in the NAP region, where the same constraints have been identified (Ryan and Kelly, 2014; Stevens, 2004). HYDRUS modelling (section 2.4) also assessed the effectiveness of several management options in managing salinity and sodicity hazards, and the sensitivity of boron leaching to key parameters related to its transport in soil.

pH

Soil pH is one of the most important determinants of soil fertility. Generally, pH_w (1:5 water) were ≥ 7 irrespective of soil group or depth and generally increased with depth (Figure 2). Of the soils surveyed, 96% had $pH_w > 7$ in the surface soils (0–60 cm) and 77% had $pH_w > 8$ (maximum $pH_w = 10$, at 30–60 cm). This indicates that many of the soils are naturally slightly to highly alkaline and therefore the micronutrients required for crop growth (e.g. Fe, Mn, Cu, Zn) will be less available for plant uptake. In highly alkaline soils ($pH_w > 8$), aluminium toxicity can occur, and the concentration of plant-available boron can increase in soil solution. Naturally alkaline soils need to be managed so they can provide micronutrients to crops and/or to lower soil pH. A survey of NAP landholders reported that they used leaf tissue analysis to assess plant health and determine the need for management, such as micronutrient supplements (Awad et al., 2019).

Soil salinity (electrical conductivity)

Several crops being considered to expand irrigated agriculture in the NAC (including almonds, grapes, onions, potato, carrot, brassicas) are classified with a low or medium soil salinity rating (saturated paste electrical conductivity (EC_{se}) < 4.5 dS/m) (Table 2). This classification corresponds to an estimated 10% yield reduction. Results from the soil survey in the focus area suggest that baseline salinity levels in the surface soils would have an impact on crop growth, for crops with low or medium soil salinity tolerance. It is expected that crop yield would be impacted in 82% of the soils sampled at 0–10 cm deep and 73% of the soils sampled at 10–30 cm deep (Table 2 and Figure 3), without effective management. Seventeen per cent of the soils sampled in the 60–90 cm depth range would be considered too saline for shallow rooted crops.

Irrigation management could moderate the impact of soil salinity in the surface soils along with flushing soluble salts out of the root zone (provided a source of water is available) prior to planting and during the growing season. There is a risk of soluble salts moving back into the root zone with water rising through capillary action as the surface soil dries and so the impact of any impermeable sub-surface would need to be

considered. The irrigation and management practices required are expected to be like those used in the existing horticultural area. Ryan and Kelly (2014) reported no significant difference between the salinity of 0–20 cm soils in the NAP region after 14 years of irrigation to those without irrigation. We are confident that established management practices are adequate to mitigate salinity constraints over the long-term.

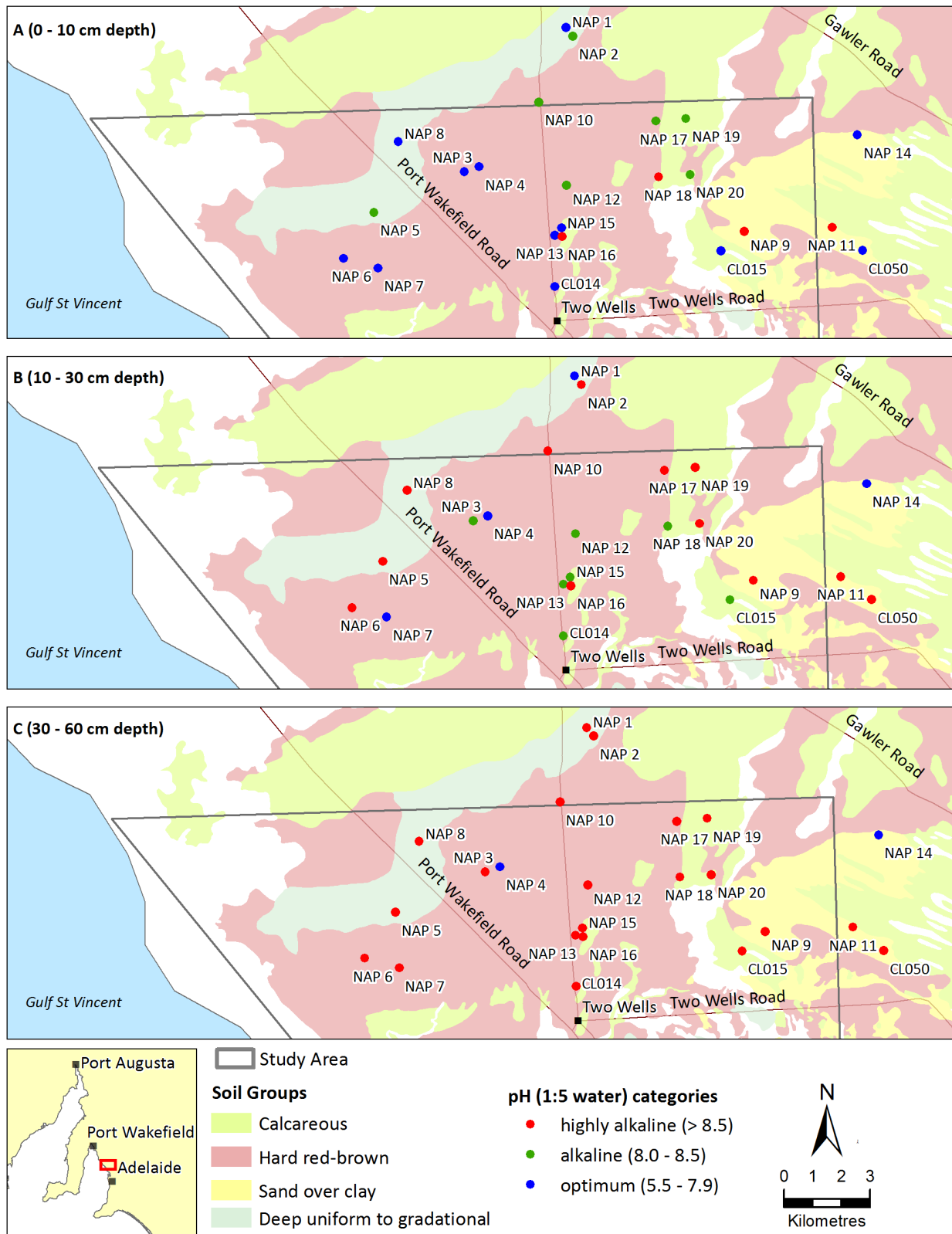


Figure 2. Spatial distribution of pH_w (1:5 water) in 0–10 cm, 10–30 cm and 30–60 cm depth across the soil survey focus area (Oliver et al., 2019).

Table 2: Number of soils sampled at 0–10 cm, 10–30 cm and 30–60 cm depth within crop salinity tolerance categories.

PLANT SENSITIVITY	NUMBER OF SOIL SAMPLES IN DEPTH INTERVAL			SOIL SALINITY RATING	EC _{se} [*] (dS/m)	SELECTED CROPS WITHIN THRESHOLD [†]
	0–10 cm	10–30 cm	30–60 cm			
Sensitive	5 (17%)	8 (27%)	2 (6%)	Very low	<0.95	Turnip
Moderately sensitive	12 (41%)	12 (40%)	14 (40%)	Low	0.95–1.9	Almond, grape, onion, potato , bean, cabbage, carrot, lettuce, pepper
Moderately tolerant	12 (41%)	10 (33%)	10 (29%)	Medium	1.9–4.5	Date, fig, olive, brassicas , cucumber, pea, spinach, squash, tomato, clover
Tolerant			8 (23%)	High	4.5–7.7	Wheat, zucchini
Very tolerant			1 (3%)	Very high	7.7–12.2	Barley, pistachio, ryegrass

*EC_{se}= saturated paste electrical conductivity, Shaw (1999); †bold text indicates crops examined in Task 2 modelling simulations

Sodicity (exchangeable sodium percentage)

Sodicity deteriorates the soil's physical structure because it causes or enhances swelling and dispersion of clay particles (Sumner, 1993). This leads to waterlogging, crusting and hard-setting which leads to poor water infiltration, decreased plant-available water, poor leaching and perched water tables. In Australia, sodic soils are defined as having an exchangeable sodium percentage (ESP) >6 in the top metre, with highly sodic soils having an ESP >14.

In the soils surveyed there was an increasing occurrence of sodic soils with depth, with 36% of 0–10 cm soils being sodic and 3% highly sodic; 49% of 10–30 cm soils sodic and 35% highly sodic; and 19% of 30–60 cm soils sodic and 72% highly sodic. However, the problems of clay dispersion and swelling only arise when the EC value is too low to maintain the soil clay in a flocculated condition at a given ESP.

A classification scheme to predict dispersive behaviour in A horizons of red-brown earths (Rengasamy et al., 1984) was applied to all the surveyed soils to indicate the proportion of the area where sodicity may be potentially problematic. While this predictive relationship was developed for red-brown earths it has been applied to all the soils in the focus area to give a general indication. Dispersive soils (dispersion class 1) are unstable, sodic soils that are the most challenging to manage, whereas potentially dispersive soils (dispersion class 2A and 2B) can be managed with strategies such as calcium amendment. At 0–10 cm depth, the majority (>90%) of soils were assessed as potentially dispersive. Deeper in the profile (10–30 cm, 30–60 cm and 60–90 cm) the ESP and salinity (EC) increased and approximately 30% of the soils were categorised as dispersive. A greater incidence of soil physical deterioration could occur if land use changes to horticulture, where mechanical stress on the soil is greater (due to working the soil to a greater extent or frequency) rather than remaining in cereal production or pasture. Soil sodicity can be managed with application of gypsum, which is a current practice for horticulture in the region (Awad et al., 2019).

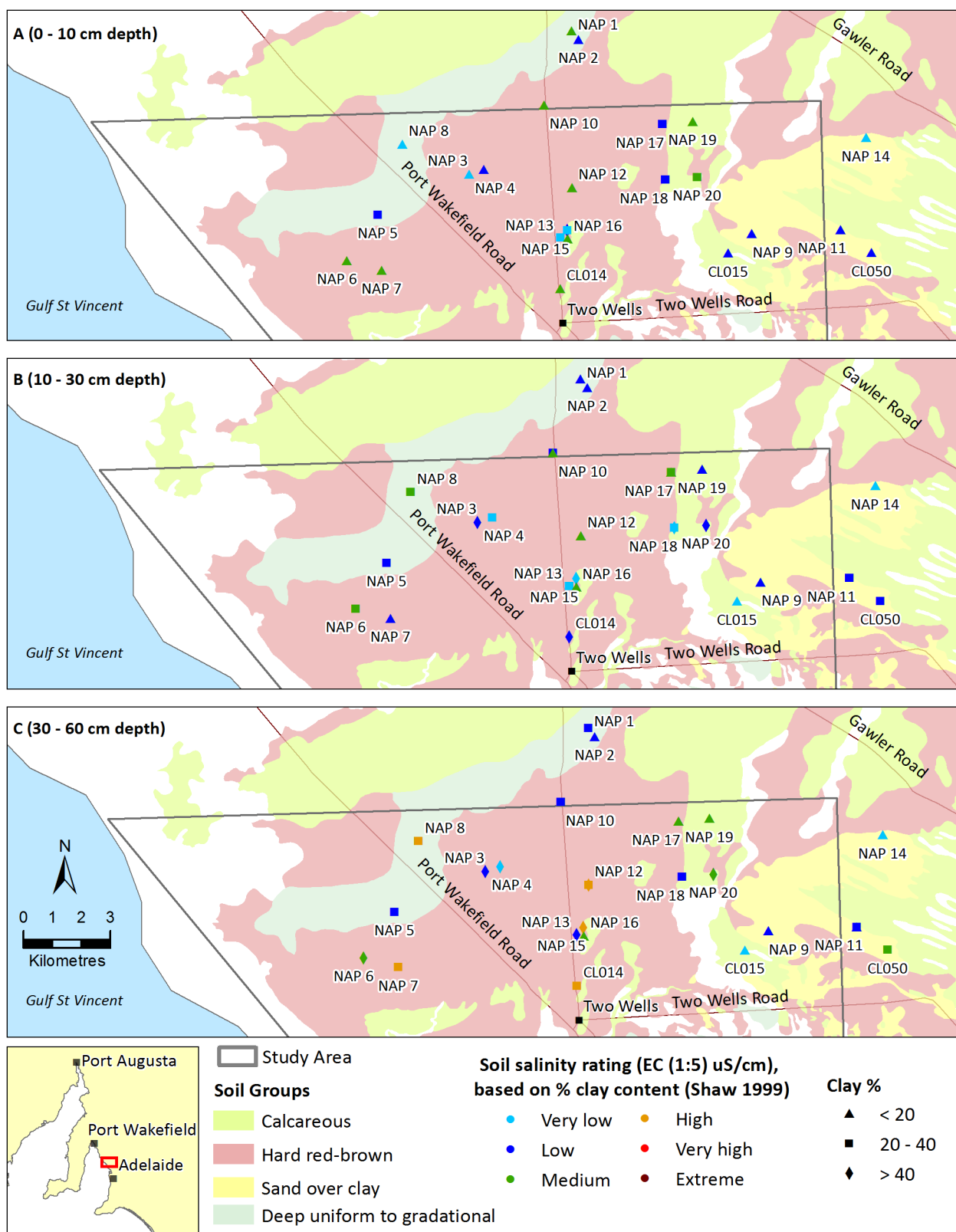


Figure 3. Spatial distribution of salinity in 0–10 cm, 10–30 cm and 30–60 cm depth across the soil survey focus area (Oliver et al., 2019).

Boron

Boron (B) is a micronutrient that is required by plants in small quantities (<500 g/ha) (Shorrocks, 1997) but it has a narrow concentration range between plant deficiency and toxicity. The maximum B concentration in irrigation water tolerated by very sensitive crops, without reducing yield, is 0.5 mg/L, while other crops can tolerate up to 15 mg/L B (EPHC-NRMMC-AHMC, 2006). Previous studies report that NAP soils are not considered to be at risk of B deficiency, but B toxicity may be a potential limiting factor for crop growth (Ryan and Kelly, 2014; Stevens, 2004).

In the focus area of this study, 72% of surface soils had B soil solution levels <0.5 mg/L, indicating low plant-available B and a low risk of B toxicity for most plants (Adriano, 2001) (Figure 4). However, 13% of soils had >1 mg/L and 8% had >2 mg/L B in soil solution, exceeding the B threshold for some of the crops that were being considered for production (e.g. broccoli, carrot, potato). This data suggests that B in some soils may already be at limiting concentrations or be toxic to crop growth before any irrigation commences.

Boron was sequentially extracted four times from a subset of soils to assess its release into soil solution in a scenario that represents multiple irrigation applications. The extraction solution had a high chloride content, typical of that found in recycled water. B continued to be mobilised into solution with successive extractions (representative of multiple irrigations) and 19–48% of the total soil B was easily extracted after four extractions. This mobilised B would potentially be available for plant uptake or leaching through the soil profile to groundwater. However, a potential problem previously reported in the NAP region is the release of sorbed B into solution in areas where sodicity may prevent B from being leached out of the system, as accumulation in soils will increase the B toxicity risk (Ryan and Kelly, 2004). Therefore, it is recommended to consider the baseline soil B and the potential for accumulation of B in the soil profile, when assessing the B toxicity risk of specific crops.

No relationship could be found between soil group and high B but there was a general trend of higher soil solution B at all depths occurring in two sub-groups of the main soil group; hard red-brown texture contrast soils (loam over red clay and loam over poorly structured red clay). However, the sample size for the soil sub-groups was small which made it difficult to determine whether this would be a definitive predictor of high B in soils.

Boron was measured at maximum water holding capacity, in surface soils only (0–10 cm, 10–30 cm and 30–60 cm) to better represent the soil solution and environment to which plant roots would be exposed. However, this soil solution B measurement may not be commercially available. Consequently, a comparison was made between the commercial measurement (hot 0.01M CaCl₂ extract) and the soil solution B measurement and we found there was a strong linear relationship between the two measurements.

2.2 Task 3 – Source water options/water availability, quality and storage considerations

Task 3 (Awad et al., 2019) involved developing new knowledge of established and potential water resource options to support sustainable expansion of irrigated horticultural and agricultural practices agriculture in the NAC. Through this work we now understand: (i) the quality and quantity of water resources in the region, (ii) the suitability (based on ANZECC and ARMCANZ (2000)) of available resources for particular soil-based crop production, (iii) water quality management options through desalination and blending, (iv) current irrigation and water quality management strategies used in the region (v) storage options to balance seasonal supply and demand, and (vi) representative water quality data to inputs into the HYDRUS modelling (Task 2).

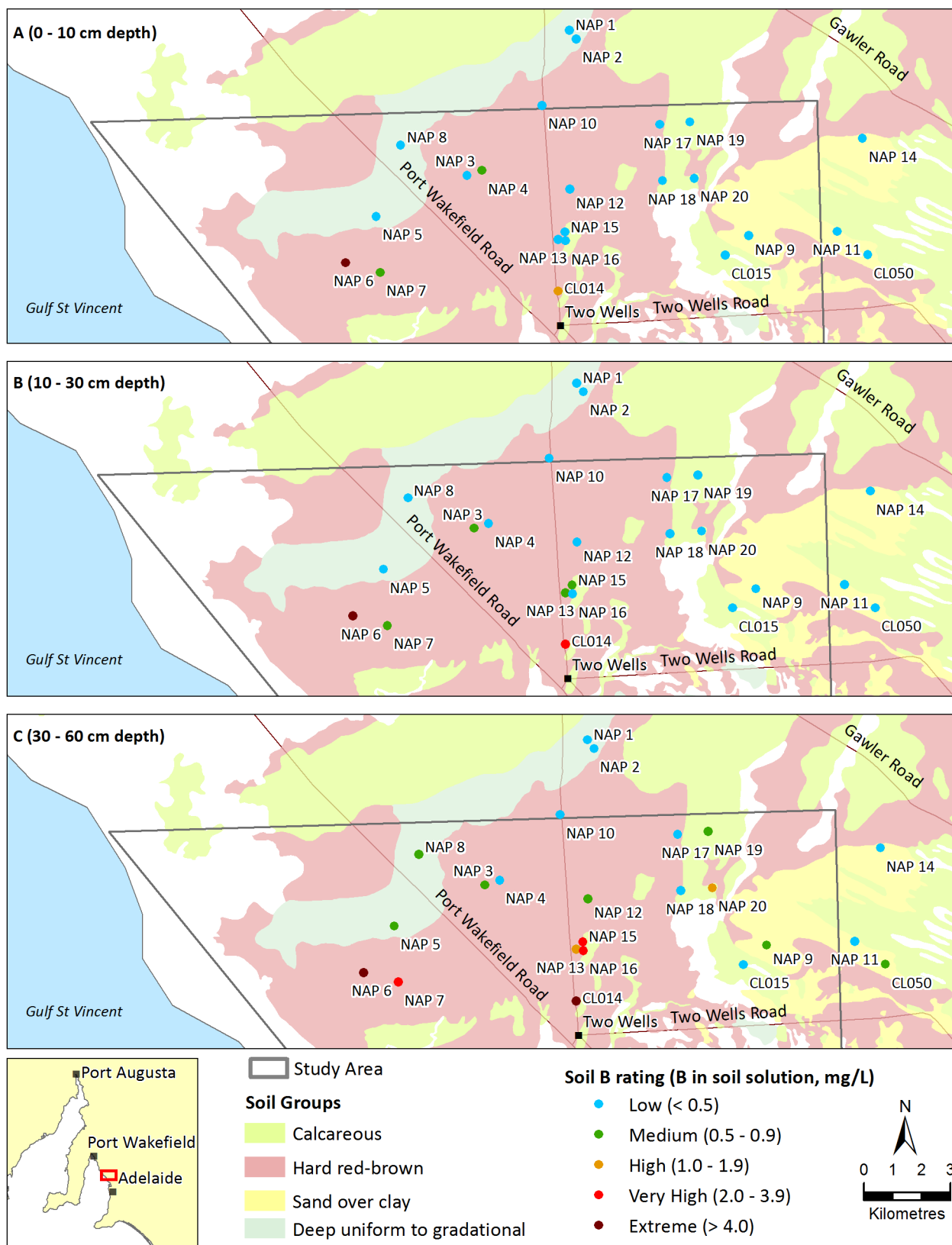


Figure 4. Spatial distribution of boron in in 0–10 cm, 10–30 cm and 30–60 cm depth across the soil survey focus area (Oliver et al., 2019).

Water resources

An overview of the quantity and salinity (total dissolved solids, TDS) of water resources in the study region is shown in Table 3. Recycled water, supplied through the VPS and NAIS, is a key resource for irrigation within the region. The VPS distributes approximately 17 GL per year, while it is intended that the NAIS will distribute approximately 20 GL per year (Stage1: 12 GL; Stage 2: 8 GL). The salinity of recycled water (mean >1000 mg/L TDS) is the primary concern for its use in irrigation. When recycled water is used for irrigation without any reverse osmosis (RO) pre-treatment, at least 4.2 t/ha and 5.1 t/ha of salt are added annually to horticultural lands used for open-field based crops and greenhouse crops, respectively. This could affect soil structure (e.g. by increased presence of sodium in clay soil) and lead to poor germination, slow crop growth and yield reduction. The major ions contributing to salinity, chloride and sodium, may also be present at concentrations that can cause foliar injury in more sensitive crops, but are at generally acceptable levels for moderately tolerant and tolerant crops.

Table 3: Summary of established and potential water resources to support expansion of irrigated horticulture and agriculture in the Northern Corridor (after Awad et al., 2019).

WATER RESOURCE [†]	ESTIMATED VOLUME IN STUDY AREA		COMMENT	TDS (mg/L)
	Current use (GL/yr)	Projected/further available (GL/yr)		
Recycled – VPS	17	2.5	projected further – winter only	~1050
Recycled – NAIS	0	20	Stage 1 = 12 GL/yr, Stage 2 = 8 GL/yr	<1165
Stormwater – greenhouse roof	unknown	5.7 [2]	based on current roof area (1680 ha) [additional with projected expansion/10 years]	~110
Stormwater –urban [#]	0	[2.25]	targeted for municipal uses	<500
Surface water – Gawler River	1.6	7.4	variable quality and quantity	~1060
Surface water – Light River	unknown	0.7	variable quality and quantity; desalination required	~4000
Groundwater – PWA T1 & T2	11.9	2.5		variable
Groundwater T1 – north of PWA	0	1.5	1–1.5 GL/yr 3000–7000 mg/L; <0.5 GL/yr >7000 mg/L; desalination required	>3000
Potable water (SA Water mains)	unknown	as available		<500 mg/L
~ Total	>30	>40	some desalination required	variable

[†] VPS=Virginia Pipeline Scheme; NAIS=Northern Adelaide Irrigation Scheme; PWA=Prescribed Wells Area; [] predicted volume based on 38% growth over 10 years; [#] further 5 GL could be potentially be supplied from Dry Creek catchment (outside of the study region)

Rainwater is currently harvested from greenhouse roofs but this could be substantially increased and used as a supplementary source of low salinity (fresh) water for irrigation purposes. A calculated water resource volume of approximately 5.7 GL could potentially be captured from the existing greenhouses within the region and a further 2 GL of water could potentially be captured from future commercial developments, based on an estimated 38% growth in greenhouse area per 10 years (PIRSA Spatial Information Services, 2017). However, we suggest that greenhouse roof runoff water quality is monitored for pH, paint-removal chemicals and *E. coli*. Some water quality issues could be managed by discarding the first flush post the dry season.

Water from the Gawler River is seasonally available for irrigation. Although surface water could be extracted between July and September (median total volume ~9 GL), the available volumes are highly variable based on climatic conditions. Therefore, water from Gawler River could be considered as a supporting resource for irrigation that is dependent on availability; sustainability of diversions for the river; water quality at the time of extraction; and proximity to the horticulture practice. No major differences were found in the salinity, chloride and sodium levels of Gawler River and recycled water. Suitable storage facilities (surface storage and/or subsurface storage) and associated infrastructures (e.g. distribution pipelines and pumping) would be required to use seasonal surface water resources.

Similar to the Gawler River, surface water might be extracted from Light River between July and October (~0.7 GL). The potential of this surface water as an irrigation supply is also highly dependent on the climate conditions and sustainability of river extractions. Water from the Light River might be considered as a supplementary horticultural irrigation resource that requires opportunistic extraction (when TDS low); potential desalination (unless used for salt tolerant crops); and storage. The TDS levels of the Light River were found to be unsuitable for horticultural use (TDS >4000 mg/L). Further, the SAR values were significantly higher in water collected from the Light River (17) compared to waters from the Gawler River (6). Desalination (e.g., ultrafiltration followed by RO) of Light River water and/or significant blending with low salinity water would be needed to achieve the quality of irrigation supply water needed for most horticulture practices.

Although the current use of groundwater from the T1 (3.4 GL/yr in 2014–15) and T2 (8.5 GL/yr in 2014–15) aquifers in the NAP PWA is significantly below the allocated extraction limit, it is considered that the aquifer is over-allocated and use of the entire allocation would have adverse impacts (Goyder Institute for Water Research, 2016). Groundwater resources of the T1 aquifer in the NAP PWA cannot be considered as a significant resource to support development (Goyder Institute for Water Research, 2016). Groundwater within the T2 aquifer in the NAP PWA may be available to support horticultural expansion, but this would only be possible beyond where current extraction of lower salinity water occurs (Goyder Institute for Water Research, 2016). As a result, groundwater availability from the T2 aquifer in the NAP PWA is limited (2–3 GL/yr) and salinity is expected to exceed 2000 mg/L TDS.

The T1 aquifer extends beyond the northern boundary of the NAP PWA and might be considered a potential groundwater resource for use in the project area. It was estimated that approximately 2 GL/year of groundwater may be available for irrigation within the boundary of the study area, which extends to the Light River in the north. Most of this potential groundwater resource is expected to have a salinity of 3000–7000 mg/L, with some more than 7000 mg/L. Currently there is no chemical water quality data available, aside from salinity measurements and those of some selected major ions. Therefore, the suitability and management of water quality would need to be assessed prior to this groundwater resource being developed used in that area.

Management options

A landholder survey was conducted to gain an understanding of the current horticultural practices within the region. Data were collected on the actual growing periods for various crop types, crop rotation cycles, irrigation systems and practices, soil properties, water treatment and water storage facilities.

Soil sodicity is considered a constraint to irrigated agriculture production in the region. Calcium (Ca) amendment, through gypsum or soluble Ca application, was a common strategy used in the region to manage soil sodicity. As a result, gypsum application was a key management strategy assessed within the HYDRUS modelling simulations (Task 2). Gypsum is primarily used on sodium (Na) affected soils, as a source of Ca to displace Na from the soil's colloidal exchange complex (Sanchez and Silvertooth, 1996) and subsequently overcome dispersion, improve soil drainage and enhance crop production (Shahid et al., 2018). In the NAP

region, the Mikhail method (Mikhail, 2017) is an option used to calculate the amount of gypsum application required to raise the available Ca to 68% and/or exchangeable Ca to 65%, as required for optimum soil friability and nutrient availability. Lime (calcium carbonate) is another form of Ca that can be used to improve sodic soils. However, as the soil pH levels were found to be alkaline, addition of Ca in the form of lime is not recommended (Kelly et al., 2001). Applying soluble Ca to the irrigation water is used to address Ca deficiency in broad-leaf crops.

Another common industry practice within the NAP region is to add organic matter (by adding compost, chicken manure or crop rotation with cover crops) to improve and maintain soil structure and nutrient supply as well as to prevent soil compaction and erosion (Jindo et al., 2016; Kelly et al., 2001).

IW-QC2 tool for covered crops

An Excel-based software tool termed 'Irrigation water quality and quantity for covered crops: IW-QC2' was developed for water resource managers and the horticulture industry to facilitate decision-making on water resource selection, desalination requirements, storage and consequential quality of water supply. Five sets of climate data are available within the tool to provide a robust evaluation of future water resource availability. The tool incorporates knowledge of industry practices obtained through a landholder survey. IW-QC2 was applied to examine the potential of harvested rainwater as a blending source to lower the salinity of other higher salinity water resources.

Harvesting greenhouse roof runoff and blending it with recycled water increases the volume of water available for irrigation, which in turn can increase the area of crops grown under irrigation. For example, blending recycled water with runoff from one hectare of roof area could increase the irrigation area by 56% or more (146%, 56%, 104% and 100% for greenhouses planted with eggplant, capsicum, tomato and cucumber, respectively) in comparison to using recycled water alone. This estimate assumes the storage of water in a dam and factors in evaporation losses. This blending of roof runoff and recycled water (and then proportionally reducing that volume of recycled water use) has the potential to concurrently reduce the salt load by 36% or more (59%, 36%, 51%, 50% for greenhouses planted with eggplant, capsicum, tomato and cucumber, respectively) compared with using recycled water as the sole water irrigation resource.

Blending greenhouse roof runoff with groundwater (with salinity levels >2000 mg/L) was only able to meet the target water quality (600 mg/L TDS) during a part of the growing period for greenhouses planted with tomato, eggplant or capsicum. Therefore, desalination (e.g., ultrafiltration followed by reverse osmosis) of the groundwater would be needed to reach the desired water quality. The desalination module of IW-QC2 was used to estimate the monthly concentrate (brine) volumes associated with desalination. It was estimated that soil-based greenhouse crops, using RO to treat brackish groundwater with salinity levels of 2000 mg/L to 14000 mg/L, would produce 0.5–3.5 ML/ha of brine per year.

Desalination and water quality considerations

Desalination is required for the hydroponic industry, regardless of the water resource. Expansion of the hydroponic industry appears to be dependent on the availability of recycled water and thus is likely to be considered in the NAC.

There is an apparent need for alternative, improved strategies to manage brine wastewater and disposal options. Hydroponic operations are expanding on a large scale in the region and there is a lack of knowledge of effective brine waste disposal from small-scale RO desalination operations. Currently in South Australia, small-scale RO systems are not regulated. Small RO systems include those where production of desalinated water does not exceed 200 kL/day and where a plant produces less than 2 ML/year of wastewater. Thus, it

might be expected that a localised increase in the number of smaller desalination operations following increased availability of recycled water has the potential to lead to significant environmental issues.

There could be economic benefits from effective brine disposal strategies, including reducing the operational and environmental impacts associated with evaporation ponds, the current conventional disposal method. Potential alternative strategies (Kim, 2011; Mansour et al., 2017; Morillo et al., 2014) might include: i) disposal through surface flow lines and pipework to well-mixed marine environments, ii) mixing of brine waste with urban stormwater using existing stormwater harvesting systems, iii) recovery of salts (e.g. magnesium hydroxide, gypsum) from the brine, and iv) local, decentralised-precinct and/or centralised deep well injection (to existing, sustainable, high saline aquifers).

Storage

Surface storage dams are commonly used by landholders within the NAP region to store excess winter waters (i.e. recycled water, harvested rainwater and Gawler River water) for reuse purposes when needed. Changes in the salinity and inorganic constituent levels are impacted by storage time, which is minimised as dam storage depth increases. Algal blooms are a common issue associated with using surface storage dams. Algal growth can be prevented by covering the dam to minimise the light available to algae/cyanobacteria and by reducing storage time.

Aquifer storage and recovery (ASR) could provide significant storage for water resources, particularly in the Tertiary aquifers. Storage can be inter-seasonal, which may be necessary to balance supply and demand for sources that are wet-season dependent (i.e. roof runoff). For sources that are continually available (i.e. recycled water) this storage can increase use of the resource. Longer term storage can also provide a buffer against climate variability. A single ASR well typically provides around 200 ML per year of storage, while larger storage is created with an ASR wellfield (e.g., NAIS ASR scheme of 4 GL/yr). A horticulture enterprise with a minimum of 60 ha of greenhouse roof area would be required to provide a minimum volume of 200 ML per year of harvested rainwater, which is a typical storage capacity provided by an ASR well in the Tertiary aquifers. Based on current practice, harvesting from a cluster of roofs may be required to capture volumes of this magnitude.

ASR has been successfully used to store water within the Tertiary aquifers of the Adelaide Plains, but there is limited hydrogeological information to the north of the NAP PWA with which to assess ASR feasibility. A preliminary assessment indicates the potential for ASR in the T1 aquifer north of the NAP PWA is limited to the western portion of the study area (west of Redbank Fault) (Awad et al., 2019). Additional ASR schemes could be considered in the T2 aquifer in the NAP PWA to support growth in horticulture. North of the NAP PWA, the ambient groundwater salinity is typically greater 3000 mg/L. Given the importance of recycled water salinity in horticultural use it will be necessary to consider how the salinity of recovered water may be impacted by mixing between the fresh injectant (i.e. roof runoff, stormwater) and the brackish groundwater. It will also be important to characterise aquifer hydraulic properties, along with heterogeneity in the aquifer and to construct the ASR well appropriately in zones with suitable permeability.

2.3 Task 4 – Assessment of depth to groundwater (proof of concept)

We developed and tested a rapid and cost-effective method to spatio-temporally map shallow groundwater depth under different pedological and groundwater salinity conditions (Task 4, Hatch et al., 2019). Increased irrigation in the region has the potential to increase recharge to the watertable, thereby exacerbating any existing shallow watertable problems and/or contributing to soil salinisation issues (The Goyder Institute for Water Research, 2016). The salinity of recycled water available for irrigation, coupled with locally high salinity

shallow groundwater and high soil salinity, means it is necessary that sufficient irrigation water is applied to ensure leaching of the salts through the root zone. The balance between increasing irrigation and managing the shallow watertable is difficult but critical in the sustainability of the NAP (The Goyder Institute for Water Research, 2016).

Estimation of the potentiometric surface of the shallow aquifer in an area like the NAC is traditionally done by measuring the depth to the watertable at available, often sparsely located, monitoring wells that are drilled to the appropriate depth. Using interpolation (and extrapolation) techniques the point measurements are used to create a watertable surface over the entire area, which can result in significant error due to sparse measurements and also subtle changes in the low-lying topography.

Geophysical techniques can identify groundwater depth and the presence of impermeable layers that may exacerbate shallow groundwater issues. The use of geophysical surveys to augment groundwater monitoring information in the region has the potential to greatly improve the spatial resolution of the interpolated shallow watertable surface over much of the area without the need to drill an extensive number of new and costly monitoring wells. In Task 4 we evaluated the ability of a suite of geophysical techniques to estimate the depth to the watertable in the NAC. This component of the task was intended to test new methods, and therefore the surface geophysics provided only provisional data on depth to the watertable. However, the shallow drilling, using a direct push core, provided an efficient means of augmenting the density of reliable water level data, and can also be combined with borehole geophysical techniques.

Surface-based geophysical techniques

Shallow groundwater is one risk factor that can impact on long-term soil salinity and crop productivity. The risk is greatest when the watertable is less than two metres below ground surface and capillary action can mobilise salt to the surface. The efficacy of five surface-based geophysical techniques to estimate the depth to the shallow (<10 m depth) watertable was evaluated. The surface-based geophysical techniques applied were transient or time-domain electromagnetics (TEM); electrical resistivity tomography (ERT); electromagnetic conductivity meters (CMD); ground penetrating radar (GPR); and seismic. Three field survey sites were selected to the west of the region, where a shallow watertable is most likely to occur. Two sites were in hard red-brown soils, while hard red-brown and deep uniform to gradational soils were present at the third site. Hand-augered bores were used to validate the surface geophysics.

Geophysical techniques that measure the ground conductivity (i.e. the electrically and electromagnetically-based techniques TEM, ERT, CMD) can determine the depth to groundwater when there is enough contrast between the conductivity of the groundwater and the background soils. The range of conductivities observed at the three survey sites, within predominantly hard red-brown texture contrast soils, was very small. This lack of contrast between relatively conductive soils and water that is of similar conductivity limited the application of geophysical techniques to identify depth to the watertable. Of the techniques trialled, TEM (NanoTEM®) was recommended for further assessment of groundwater depth in the NAC, based on performance across the survey sites. NanoTEM® also identified the boundary between deep uniform to gradational and hard red-brown texture contrast soils at the survey site where both soil groups were present. Therefore, this geophysical tool may have potential to delineate between soil groups.

A shallow seismic survey was tested as an alternative to the electrical techniques at one survey location without sufficient conductivity contrast. The seismic technique was able to identify the watertable; nevertheless, the methodology is: a) experimental, b) relatively slow, and c) costly. GPR failed to produce any subsurface detail due to high signal attenuation and was deemed not useful in this setting (Wilson, 2017). The suitability of the electrically- and electromagnetically-based techniques to identify the watertable within the other main soil groups has not been evaluated.

Drilling program and borehole geophysics

A major shallow (<10 m) drilling program was undertaken with 47 direct push cores drilled to six metres in depth (Figure 5). Soil samples were collected from drillholes at nominal 0.25 m to 0.5 m intervals and the soils were logged with depth. When the drillhole intersected groundwater within six metres of the surface, soil sampling and soil material description was extended to a depth of approximately eight metres.

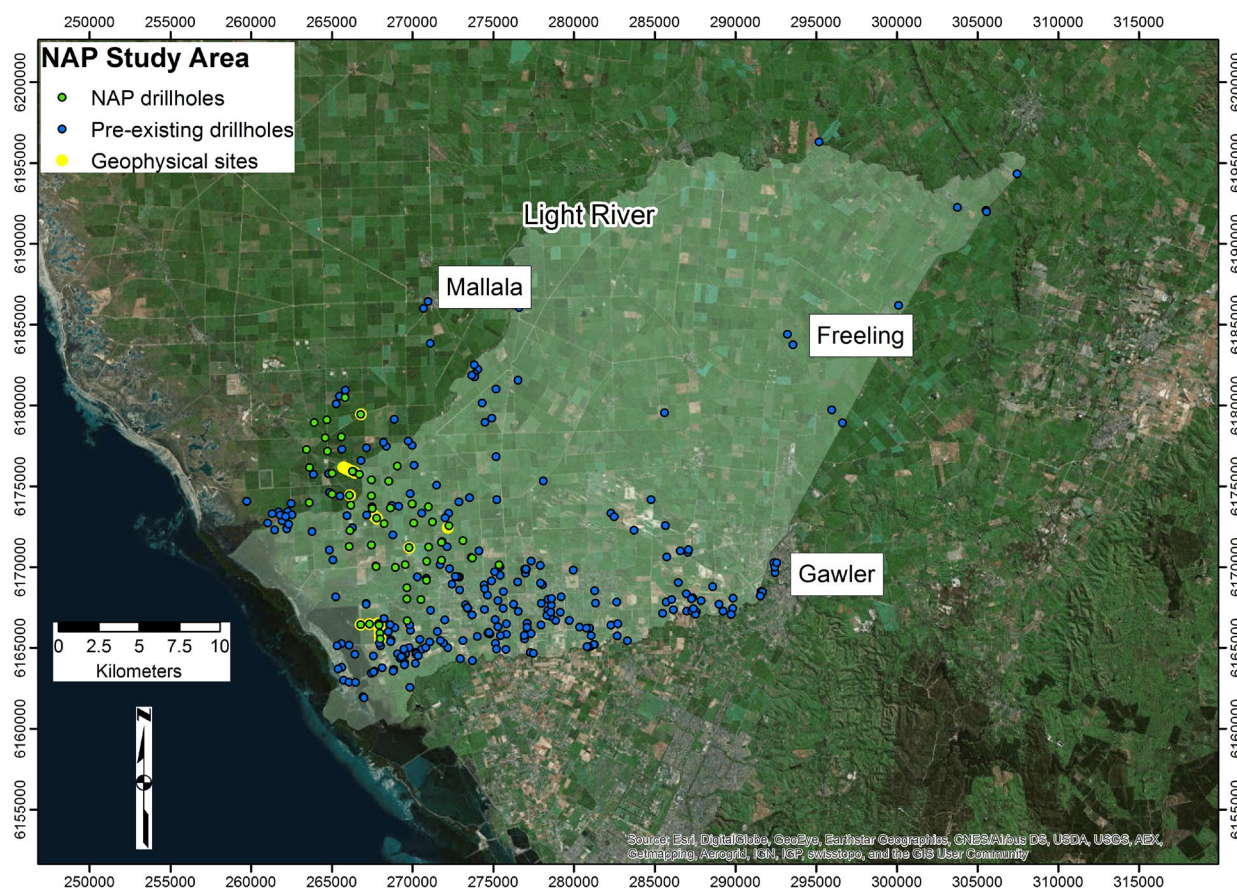


Figure 5. Study area, focused on the area to the north of Gawler River (translucent green area) indicating the locations of pre-project drillholes (<10 m depth) and drillholes drilled and tested for this project (NAP drillholes) (Hatch et al., 2019). Pre-existing holes are shown in green; holes drilled for this project are shown in blue.

Additionally, the holes were logged using a borehole nuclear magnetic resonance (NMR) tool, a relatively new development in groundwater hydrogeophysics that takes advantage of NMR response in the sediments to measure both water content and saturated zone water boundness (soil texture, used to estimate relative hydraulic conductivity) at a logged depth. The geophysical data sets are presented in comparison to soil logs and laboratory evaluated soil conductivities and soil moisture content (e.g. Figure 6).

Downhole NMR data provided rapid *in-situ* assessment of water content and estimates of relative permeability. NMR determines the degree to which water is 'bound' or immobile (i.e. in clays), or conversely, mobile (i.e. in pore spaces) and is used to interpret soil texture. This water 'boundness' was reported in three categories: i) clay (very small pore spaces), ii) capillary (silt to fine sand) and iii) mobile (sand to gravel). The *in-situ* results obtained using the NMR downhole tool were generally consistent with those obtained from samples collected and evaluated in the laboratory (Figure 6). It would be worthwhile continuing to evaluate these borehole tools (and perhaps other borehole logging tools) as the ability to collect this type of data in the field has the potential to significantly reduce logging, sampling and laboratory analysis time in the future.

Importantly, borehole NMR has the potential to identify the presence of heavy clays (e.g. Hindmarsh Clay) that could impede infiltration.

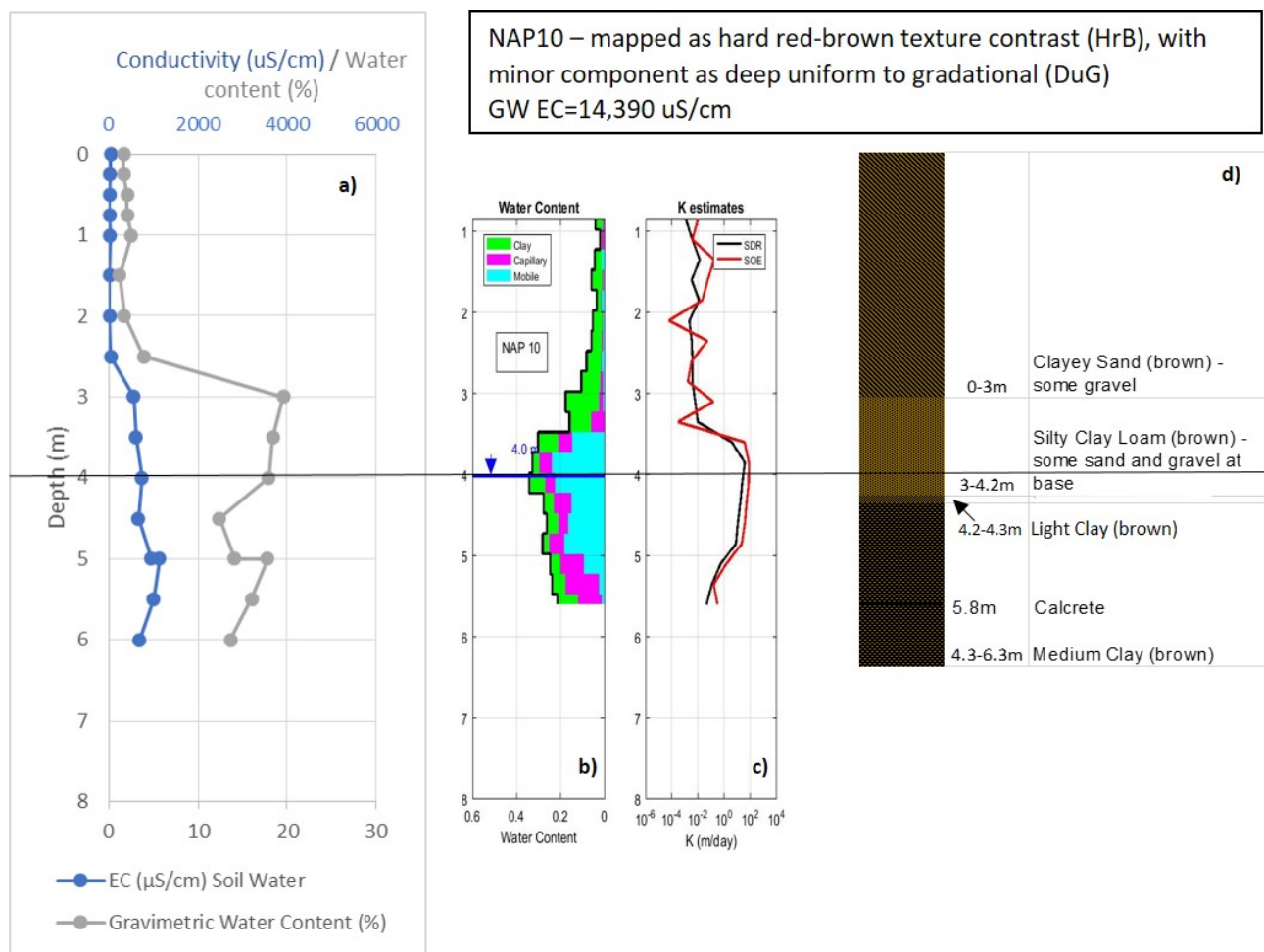


Figure 6. Example of integrated data from drilling program. a) conductivity and water content from soil samples; b) water content and relative hydraulic conductivity estimated by downhole NMR; and c) soil log (Hatch et al., 2019).

Depth of shallow groundwater

Greater spatial resolution of the interpolated shallow watertable surface was obtained in the vicinity of the major shallow drilling program. In general, within this focus area, the groundwater is mostly shallower to the west, and gets deeper away from the coast.

Groundwater in the shallow drillholes is generally brackish to saline ($>4,000$ mg/L TDS), and would pose a hazard to agriculture if it were to reach the surface. One of many risk factors for irrigation over this area is watertable rise in the shallow, brackish to saline groundwater. Figure 7 presents an overview of the shallow groundwater risk, where a depth to groundwater of less than two metres is considered at greatest risk of irrigation-induced soil salinisation as capillary action can mobilise salt to the surface (i.e. unlikely to be suitable for extensive irrigation), and a depth greater than five metres is most suitable, as irrigation is not expected to induce a significant watertable rise. For intermediate depths of 2–5 m, the effect of irrigation is less certain. Fresher shallow groundwater (<4000 mg/L) is evident to the south of the study area, directly to the north of the Gawler River, in a zone indicated as being suitable for irrigation, according to groundwater depth.

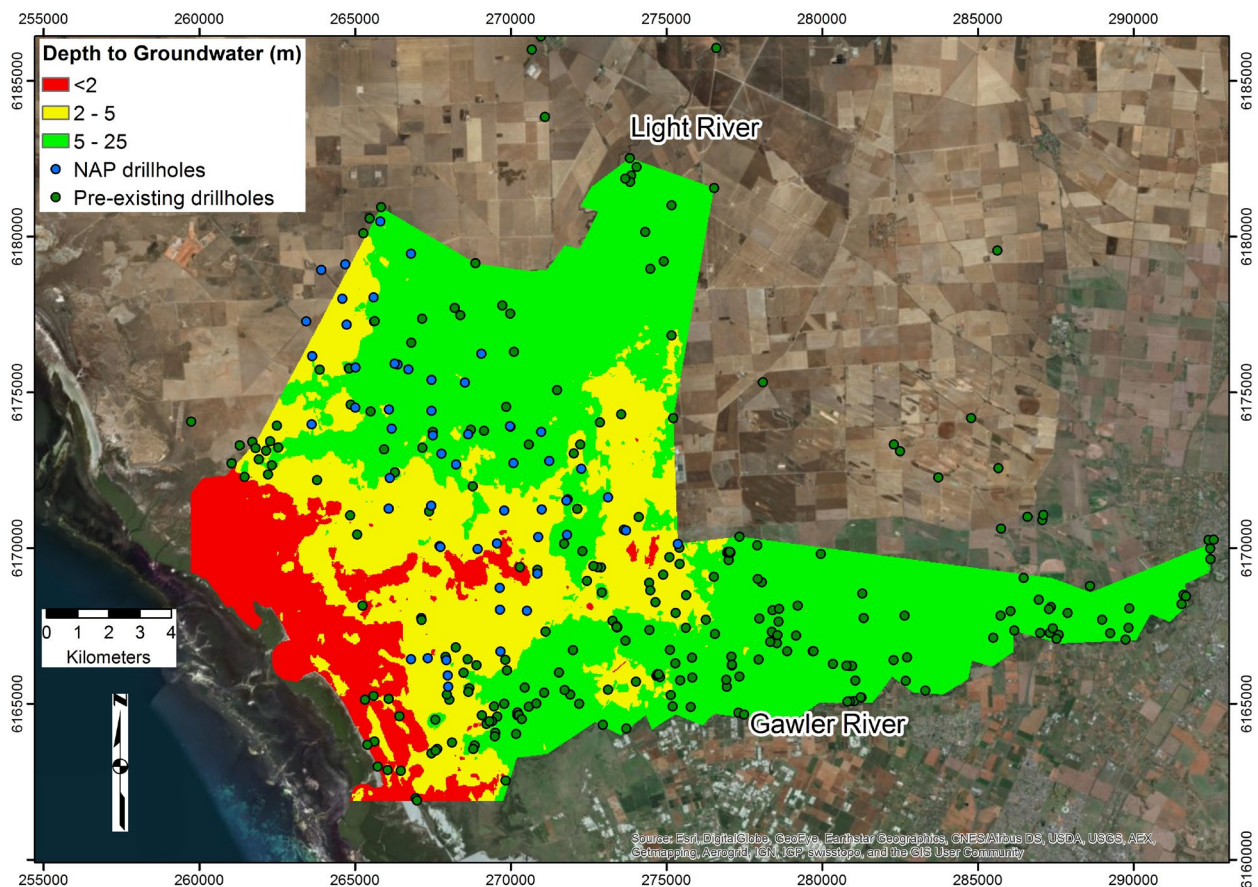


Figure 7. Depth to groundwater, using a simplified colour scale that highlights areas that are unlikely to be suitable for extensive irrigation (red), less likely to be suitable (yellow), and areas that are unlikely to be affected by irrigation (green) (Hatch et al., 2019). Pre-existing holes are shown in green; holes drilled for this project are shown in blue.

The depth to the shallowest groundwater in the focus area of the drilling program was highly variable and more depth estimates are required to fully characterise the extent of this water table.

2.4 Task 2 – Modelling nutrient and chemical fate, including salinity/sodicity risk, as the basis for identifying longevity of recycled water utilisation and mitigation strategies under current and future climate

The objectives of this task (Task 2, Mallants et al., 2019) were to further our understanding of coupled biogeochemical soil processes influenced by irrigation water quality as the basis for sustainable development of irrigated horticulture. The HYDRUS-1D UNSATCHEM software was used to simulate several irrigation scenarios to examine the long-term impacts of irrigation on soil and plant health and on environmental receptors. This task has delivered site specific parameters for quantitative evaluation of potential impacts of long-term irrigation. Typical parameters include soil hydraulic properties of the key soils at various depths and interpreted chemical parameters that control the complex interactions between major cations in soil solution (sodium, potassium, calcium, magnesium) and the soil solid phase (e.g. clay particles). In addition to these parameters, the project has also delivered a novel capability of the HYDRUS-1D simulator in the form of a gypsum amendment module that allows the annual addition and dissolution of solid gypsum in the soil. In addition, management options to mitigate risks associated with recycled water irrigation were assessed.

Numerous water-crop-soil and management option combinations were examined within the modelling scenarios (Table 4).

Table 4: Overview of HYDRUS modelling scenarios.

MODELLING SCENARIO THEME	EXPLANATION
Reference simulation (outdoor soil-based cropping)	Recycled water (reference): Bolivar treated wastewater after dissolved air flotation and filtration (DAFF water quality) Four soil types which cover 70% of NAP area (87% in focus area): hard red-brown (HrB), calcareous (Cal), sand over clay (SoC), deep uniform to gradational DuG) Seven crop types: almonds, vines, pistachios, pasture, potatoes, carrots, onions Estimation of irrigation requirements (IR) (20% leaching fraction)
Water quality alternatives	[explicitly simulated]: SA Water mains (SAW), blended water (DAFF:SAW – 1:1), greenhouse roof runoff [derived impacts]: Groundwater (T2; MAR), surface water, farm dams ~ DAFF & urban stormwater ~ SAW
Management options (outdoor soil-based cropping)	Gypsum application to manage soil sodicity: four levels (0, 1.7 t/ha, 4.3 t/ha, 8.6 t/ha) + 12.9 t/ha for HrB only. This range of application rates informed by the landholder survey (Awad et al., 2019). The survey reported gypsum application rates of 2.5–5 t/ha for almonds and 8–10 t/ha for greenhouse cucumber and capsicum. Gypsum application rates of 0.42–10 t/ha calculated from the soil analysis data using the Mikhail (2017) method. Alternative water application: monthly cycles (DAFF/SAW); half-year cycles (DAFF/SAW) Increased leaching fractions: 30%, 40%, 50%
Greenhouse cropping	Two soils (sandy clay loam, sandy loam) representing current greenhouse soils Cucumber, tomatoes, capsicums, eggplant Blended water (recycled water and greenhouse roof runoff) Estimation of irrigation requirements (IR) (input from Task 3 IW-QC2)
Management options (glass house cropping)	Gypsum application: four levels (0, 1.7 t/ha, 2.6 t/ha, 3.4 t/ha) Leaching fraction: 0, 15%, 20%, 30%
Management of solutes to streams	Optimising riparian zone widths to control lateral solute migration
Other toxicity	Boron toxicity/boron leaching potential
Climate extremes	Impact on crop production

In this task we developed an assessment method that can be applied NAC to examine the impact of other irrigation scenarios. It also documented model input parameters that may be used to extrapolate results to comparable scenarios.

The model was run initially with the historical climate data (1970–2017) before assessing the impact of each modelling scenario under the future climate projection (2018–2050). The climate data used is based on downscaled climate change projections for South Australia (Charles and Fu, 2014). The median decrease in annual rainfall by 2050 is 6.8% (relative to 1986–2005 baseline), the 10th percentile decrease is 8.8%, and the 95th percentile decrease is 3.5% (for the intermediate-emission Representative Concentration Pathway RCP4.5). The future climate data represents 0.7°C increase in the annual mean of the daily average temperature, 0.9°C increase in the annual mean of the daily maximum temperature and 2% increase in the number of dry days, for 2018–2050 when compared to 1985–2017.

Irrigation requirements under current and future climate

The annual irrigation requirement (IR) in four main soil groups was estimated using the FAO-56 dual coefficient approach under historical (1970–2017) and future (2018–2050) climate data (Table 5). The FAO-

56 (Allen, 2000) procedure is widely used to estimate crop evapotranspiration and is the composite of crop transpiration and soil evaporation.

An analysis of the predicted future climate data showed that the NAP region will be subjected to warming in the future, based on greater daily temperature indices and frequency of hot days relative to historic climate. There will be also a higher frequency of dry days (with rainfall less than 1 mm) and dry spells (three or more dry days) compared with historic data. The NAP region, based on global climate change predictions, will be subjected to milder winters based on smaller frequencies of frost and chill days. Appropriate management strategies, including increased irrigation or alternative irrigation techniques, are currently used in the region to mitigate climatic variability and it is anticipated these practices will continue to adapt to a future climate.

Irrigation requirements are expected to increase by 3–11% under the predicted future climate and the largest increases are for annual crops, which are predicted to require 6–11% more water annually. Regardless of the crop type, sand over clay soil had the largest irrigation requirement, which was 1–8% higher than in hard red-brown soil and 3–24% higher than in calcareous soil and deep uniform to gradational soil.

Table 5: Average irrigation requirements under current (1970–2017) and future climate (2018–2050) (after Mallants et al., 2019).

	ANNUAL IRRIGATION REQUIREMENT (MM)								ANNUAL AVERAGE ACROSS FOUR SOIL GROUPS (MM)	
	Current climate				Future climate				Current climate	Future climate
	Cal	HrB	SoC	DuG	Cal	HrB	SoC	DuG		
Grape	377	425	461	368	398	446	477	389	407	428
Pistachio	784	810	820	777	819	837	845	810	798	828
Almond	968	1004	1022	960	1038	1068	1083	1031	989	1056
Potato	548	592	619	532	604	646	674	591	573	629
Onion	641	663	686	631	705	723	750	696	655	718
Carrot (winter + summer)[#]	1005	1027	1040	999	1077	1091	1104	1073	1018	1085
Pasture (mixed)[‡]	1022	1061	1089	993	1103	1138	1165	1076	1041	1121

Cal = Calcareous, HrB = Hard red-brown, SoC = Sand over clay, DuG = Deep uniform to gradational; [#] IR estimated assuming a single crop as carrot is typically grown continuously in the NAP; [‡] perennial rye grass + annual legumes/clover

In the absence of management intervention (e.g. increased irrigation), the following crop specific consequences are anticipated as the result of a warmer and drier climate.

- Yield of potatoes will likely decrease and they'll be at higher risk of being invaded by pests with increased temperature and frequent hot days.
- Growth and yield in carrots will be stimulated due to the increased frequency of hot and dry days. However, extreme heat events may reduce the quality of carrots and mid-season drought stress can depress the yield in carrots.
- A warmer climate may reduce the duration of crop growth, yield, and seed production for onions, whereas low rainfall could reduce the risk of infection by pests (i.e. leaf blight).
- As the NAP region will be subjected to an increased number of hot days, a decline in pasture production is anticipated.

- The projected extremely hot weather, along with drought, can negatively impact vines, which may result in poor budburst, leaf loss, bunch damage, and consequently low yield and production or even crop loss.
- The current NAP climate hardly accommodates the chill requirements for almonds and pistachios and the projected climate shows there would be some years that this requirement cannot be met at all. It is expected that the yield and production of these fruits may be impacted by drought in the NAP region if not properly managed.

Recycled water irrigation

Based on the reference modelling scenarios without management interventions (Table 4), the predominant factors affecting the sustainability of recycled water irrigation are the interaction between the total salts in the soil and the irrigation water; the ratio of sodium to other cations (sodium adsorption ratio, SAR); and the hydraulic conductivity of the soil. Together these control the salinity, soil structure and leaching of soluble salts from the root zone. Salinity reduces plant growth through osmotic and toxicity effects, while a high SAR causes sodicity (soil dispersion/swelling) which increases soil resistance, reduces root growth, and reduces water movement through the soil (Rengasamy and Olsson, 1993). This reduces the opportunity for leaching of salts from the root zone and may cause oxygen depletion through waterlogging (Assouline and Narkis, 2013) and restricted drainage in the soil.

The initial long-term (2018–2050) modelling scenarios predicted the soil solution composition and soil exchange characteristics resulting from recycled water irrigation of seven crops in the four major soil groups. Simulated results confirmed the salinity and sodicity constraints predicted through baseline soil and water resource assessment. Changes in soil solution exchange characteristics enhance the risk of salinity and sodicity hazards in the soils. Soil pH was nearly identical for all soil depths across all soils and remained alkaline. This suggests that recycled water irrigation will not alter the need to manage the micronutrient availability from that identified for baseline soils.

The average simulated soil profile salinity (EC_{sw}) at year 2050 as a result of recycled water irrigation ranged from 2.9 dS/m at the soil surface to 4.0–9.5 dS/m at a depth of two metres across all soils and crops. The depth distribution of EC_{sw} varied between crops. Table 6 summarises the estimated yield reduction due to the increased salinity level in the soil after recycled water irrigation, for nine crop types in four soil groups. The productivity of salt tolerant species – rye, pistachio, and wine grapes – is not expected to be impacted. For almonds, clover and brassicas the reduction in yield is predicted to be less than 20% regardless of soil type. Potato yield is not reduced in sand over clay and deep uniform to gradational soils but may be significantly impacted in calcareous and hard red-brown soils (25–35%). Carrot and onion yield are consistently reduced across all four soil groups by 23–31%. Potential yields of salt sensitive crops, such as annual horticulture and almonds, was reduced by up to 35% (Table 6).

Table 6: Reduction in the potential yield (%) of different soil-based crops with profile average salinity build up in different soils in relation to recycled water use (after Mallants et al., 2019). Green highlights 0–10% yield reduction; orange highlights 11–20% yield reduction; red highlights >25% yield reduction.

SOIL	REDUCTION IN POTENTIAL YIELD (%)								
	ALMOND	GRAPE	PISTACHIO	CARROT	ONION	POTATO	BRASSICAS	PASTURE (CLOVER)	PASTURE (RYE)
Cal	18	1.7	0	27	31	35	11	19	0
HrB	11	0	0	23	28	25	8	14	0
SoC	15	0	0	28	29	1	11	16	0
DuG	18	0	0	27	31	8	11	20	0

*Cal = Calcareous, HrB = Hard red-brown, SoC = Sand over clay, DuG = Deep uniform to gradational

Recycled water irrigation also resulted in an increase in both SAR and ESP, which adversely affect structural stability and hydraulic movement in the soil and can severely impact sustainable crop production. Average initial (2018) profile SAR values (0.8–3.6) increased by 17% in calcareous soils and 16% in hard red-brown, sand over clay and deep uniform to gradational soils, at 2050. The average soil ESP also increased by 23%, 22%, 19% and 11% in calcareous, hard red-brown, sand over clay and deep uniform to gradational soils, respectively.

Threshold relationships between SAR and ESP for each soil were developed. These relationships revealed that an SAR of 4, 3.5, 6 and 3 for calcareous, hard red-brown, sand over clay and deep uniform to gradational soils, respectively, would develop a critical ESP (>6). This can lead to adverse impacts in the soil and affect normal crop growth.

Management options

Long-term use of recycled water for irrigation is likely to result in salinity and sodicity hazards in NAP soils. Therefore, sustainable use of recycled water for irrigation requires management solutions that can help reduce its harmful impacts on crops and soils as well as maintain the productive capacity of the soils. The effectiveness of several management options, deemed to be relevant to this region, was evaluated by simulating their long-term (2018–2050) benefit in managing salinity and sodicity hazards. The management options simulated were: i) the application of gypsum (four application rates: 0, 1.7, 4.3, and 8.6 t/ha); ii) conjunctive use of low salinity (<500 mg/L TDS) and recycled water resources (blending, alternate use in monthly or half yearly cycles); and iii) the leaching fraction (LF) applied (four LFs, 20%, 30%, 40%, 50%). SA Water mains quality water (SAW) was used to represent low salinity water in simulations.

Management options were assessed for the three soil groups most sensitive to sodicity: (i) calcareous, (ii) hard red-brown, and (iii) sand over clay soils, with annual horticulture (potato), wine grapes and perennial horticulture (almonds) as test crops, respectively. Management options for deep uniform to gradational soil can be inferred from those that are effective in sand over clay soils. Notably the increase in ESP was consistently lower in deep uniform to gradation soils than the three soil groups assessed.

Modelling simulations found that gypsum application is essential to control subsoil and irrigation-induced sodicity. The gypsum application rates simulated reflected the current practice on the NAP as reported by the landholder survey. One exception was for hard red-brown texture contrast soils, where the benefit of a higher application rate (12.9 t/ha) was simulated. For annual horticulture (potato) in sand over clay soils, gypsum application of 4.3 t/ha with a leaching fraction of 20% was found to be suitable to adequately reduce the salinity hazards associated with recycled water irrigation. This gypsum application rate reduced the ESP by 50%, whereas an increased application rate made only a minor improvement, which may not justify the additional cost that would be incurred. The pH values in the gypsum amended soils fall in the adequate pH range for crop nutrition (pH 6–9). Further reduction in SAR and ESP is expected with conjunctive use of low salinity water.

For perennial horticulture (grapes) in calcareous soils, additional management options were found necessary to reduce the salinity hazards associated with recycled water irrigation. In calcareous soils, a higher gypsum application rate of 8.6 t/ha, combined with an increased leaching fraction of 50% and conjunctive use of low salinity water was deemed necessary to mitigate salinity hazards. Despite this, ESP remained above the crop threshold at certain depths (30–60 cm and 90–120 cm), suggesting organic matter amendment should be considered to maintain good soil structure. Again, soil pH remained adequate for crop nutrition (pH 6–9).

Management options for hard red-brown soils were comparable to those for calcareous soils, as both pose a high sodicity risk under recycled water irrigation. For perennial horticulture (almond) in hard red-brown texture contrast soils, the same gypsum application rate of 8.6 t/ha with a leaching fraction of 0.5 and

conjunctive use of low salinity water was found to reduce the indicators of salinity hazards associated with recycled water irrigation, but not necessarily manage these risks to a level where productivity is maintained. High ESP was maintained which could reduce soil permeability and result in perched watertable conditions, suggesting that organic matter amendment is needed. The implication of increasing the leaching fraction on the overall amount of irrigation water required and on the shallow watertable must also be considered. Again, soil pH remained adequate for crop nutrition (pH 6–9).

The application of lower salinity water for irrigation, through blending (1:1) or cyclic use of recycled water and low salinity mains water, is likely to avoid the salinity risk associated with recycled water irrigation in calcareous and sand over clay soils. In these soil groups, the use of both lower salinity water and recycled water in combination with a lower gypsum application rate (1.7 t/ha) was at least as effective as gypsum alone (4.3 t/ha). Salinity and sodicity risks are evident for hard red-brown soils, regardless of irrigation water salinity.

In general, additional management strategies to maximise the use of recycled water and optimise crop production are recommended, included organic amendments (i.e. hard red-brown soils); development of salt tolerant cultivars; and adaptive management informed by ongoing soil and crop health monitoring (salinity, toxicity, micronutrient levels) and drainage conditions (moisture content, depth to shallow groundwater).

In addition to the impacts on soil and crops, we also studied the role of the riparian zone in protecting surface waters from migration of irrigation induced soluble salts under irrigation regimes by calibrating and validating HYDRUS-2D in the NAP region. We considered annual (potato, carrot) and perennial (almonds, grapes) horticulture. Owing to specific irrigation requirements, the likely average annual water flow from irrigation of almond and annual horticulture to a river is almost twice that under wine grapes. Buffer widths of 20, 60, and 40 m for irrigated wine grapes, almond, and annual horticulture, respectively, are needed to restrict the migration of salts to the nearby river.

Greenhouse cropping

The long-term (2018–2050) impact of irrigation on salt accumulation in soil under unheated greenhouse conditions was assessed for tomato, cucumber, capsicum and eggplant, which are commonly grown under these conditions in the region. Soil properties used in these simulations were determined on samples of sandy clay loam and sandy loam from existing NAP greenhouse operations. The irrigation resources applied were recycled water and greenhouse roof runoff, blended to meet the specific crop salinity criteria. The daily water requirements and water quality data were obtained from IW-QC2 (Task 3).

The landholder survey revealed that irrigation scheduling in greenhouses is informed by outdoor temperatures and that current irrigation practices are intended to leach salt from the soil profile. However, greenhouse cropping modelling scenarios (Table 4) indicated that outdoor temperature-based irrigation scheduling alone does not provide for sufficient water supply to adequately leach salt from the soil profile. The average soil solution salinity (EC_{sw}) at year 2050 increased as a result of irrigation and ranged from 6.5–9.3 dS/m, which exceeded the salinity threshold value for all crops. The increase in EC_{sw} was greatest for capsicum and eggplant due to their higher irrigation requirements. Irrigation also resulted in an increase in both SAR and ESP, which adversely affect structural stability and hydraulic movement in the soil. High final ESP values (>6) identify Ca amendment as a necessary management option.

For greenhouse cropping, gypsum application combined with leaching was adequate to mitigate the soil salt accumulation hazards associated with irrigation. It is important that both practices are applied, as increasing the LF alone is not effective, based on simulation results. For shallow rooted soil-based crops under unheated greenhouse conditions, gypsum application at a rate of 1.7 t/ha with 0.15 LF was determined to be adequate

to mitigate soil salinity and sodicity hazards, based on HYDRUS modelling. For deep rooted crops, additional leaching (0.2 LF) with a 1.7 t/ha or higher annual gypsum addition is required.

Boron transport

We modelled long-term B transport in soil, accounting for several processes including the rate of mineral dissolution, adsorption-desorption processes, and instantaneous or kinetically controlled B release from the solid phase. We ran several modelling scenarios that mainly served as a sensitivity analysis, given the uncertainty around key parameters such as the rate of B release from the solid phase.

Testing the sensitivity of B leaching towards several key sources of variability (and thus uncertainty) demonstrated that the leaching model is least sensitive to the natural soil variability (sorbed B concentration and sorption models) and most sensitive to the variation in B concentration in the irrigation water. Considering the mean B concentration in irrigation water, simulations showed that B in soil would increase by about a factor of four as a result of long-term irrigation. The B concentration time series showed a quasi-steady state condition is achieved across all depths, illustrating that there does not seem to be a long-term accumulation of B in the soil profile. Over time, an equilibrium is established between the B added and that leaving the soil profile by drainage.

Importantly, the higher the initial B concentration (i.e., prior to adding B containing irrigation water) in the pore water and on the solid phases, the smaller the effect on the long-term B concentrations. This means that soils with an already high B concentration will be at a lesser risk relative to soils with a much lower B concentration. With reference to the B tolerance/threshold classes for various crops, the following preliminary conclusions can be made:

- Moderately tolerant (2–4 mg/L B) to tolerant (4–6 mg/L B) class: crops such as lettuce, cabbage, and tomatoes are unlikely to be at risk owing to their high tolerance to B. Only a small number of sites (<9%) have been identified with such high B levels (in the 2–6 mg/L range) and further addition of B at current levels in irrigation water is not expected to increase B in soil significantly.
- Moderately sensitive (1–2 mg/L B) class: crops such as broccoli, capsicum, carrot, potato, and cucumber are unlikely to be at risk owing to their moderate sensitivity to B, a small number of sites have been identified with B levels >1–2 mg/L (<14%), and further addition of B at current levels in irrigation water is not expected to increase boron in soil substantially.
- Sensitive (0.5–1 mg/L B) to very sensitive (<0.5 mg/L B) class: crops such as lemon, grapefruit, avocado, orange, fig, grapes, walnut, and garlic could be at risk under certain conditions, i.e. where B levels are either already high (above the crop threshold) or where irrigation may increase B levels from below the crop threshold to above their threshold (about 72% of hard red brown soil samples have B levels below the 0.5 mg/L threshold).

3 Summary

3.1 Management options for expansion of irrigated agriculture and horticulture

The assessment of resilient and vulnerable areas based on modelling long-term irrigation in the study area, is discussed in relation to four main soil groups (Figure 8): (i) hard red-brown texture contrast soils with alkaline subsoil, (ii) deep uniform to gradational soils, (iii) calcareous soils, and (iv) sand over clay soils. These soil groups are dominant along the NAC and therefore the implications for long-term irrigation (Table 7) are broadly relevant to development across a larger area.

The increased soil salinity and sodicity can be mitigated by adopting a combination of management options: soil amendments with gypsum, increased leaching rates, and conjunctive use of low salinity irrigation water (continuously or as part of a cyclic approach). It is apparent that calcareous and hard red-brown texture contrast soils require the highest level of management to mitigate salinity and sodicity risks. Soil over clay and deep uniform to gradational soils require a lower level of management for salinity risks. In addition, deep uniform to gradational soils are least sensitive to the impacts of future climate projections.

A summary of project outputs that relate to broader management considerations follows:

- Expansion of irrigation in the NAC provides an opportunity to further demonstrate best-practice in managing available resources. Monitoring is an integral aspect of management and includes monitoring to establish the baseline condition and temporal monitoring to assess potential impacts and ensure risks to the environment are adequately managed. Monitoring is relevant to growers to determine baseline soil conditions and subsequently assess and manage soil and crop risks. However, monitoring is also required on a broader, regional scale to ensure risks to the environment are adequately managed. One aim of this project was to inform future monitoring and management programs, through further understanding the risks associated with long-term irrigation. Salinity was identified as the key hazard associated with recycled water irrigation, and subsequently management options are recommended to mitigate impacts on soil and crop health. A complementary regional monitoring program would consider the broader implications of salinity management to impacts to ensure all receiving environments (crop, soil, groundwater, surface water) are adequately protected against salinity risks. For example, a regional salt budget and management of brine from distributed water treatment (desalination) are applicable to regional scale management.
- Increasing the spatial resolution of the interpolated shallow watertable and understanding of the presence of impeding layers (heavy clays) will support the development of a monitoring program to assess and manage the risks of shallow groundwater.
- Further understanding of boron distribution and adsorption behaviour in the soils of this region is required to inform management of boron toxicity risks.
- Horticulture enterprise with a minimum of 60 ha of greenhouse roof area would be required to provide a minimum volume of 200 ML per year of harvested rainwater to operate a single ASR well. Based on current practice, harvesting from a cluster of roofs may be required to capture volumes of this magnitude.
- Aquifer hydraulic properties and groundwater quality of the T1 aquifer to the north of the NAP PWA area are required to fully assess the feasibility of ASR for storage of water during the wet season and to assess the suitability of groundwater for irrigation.

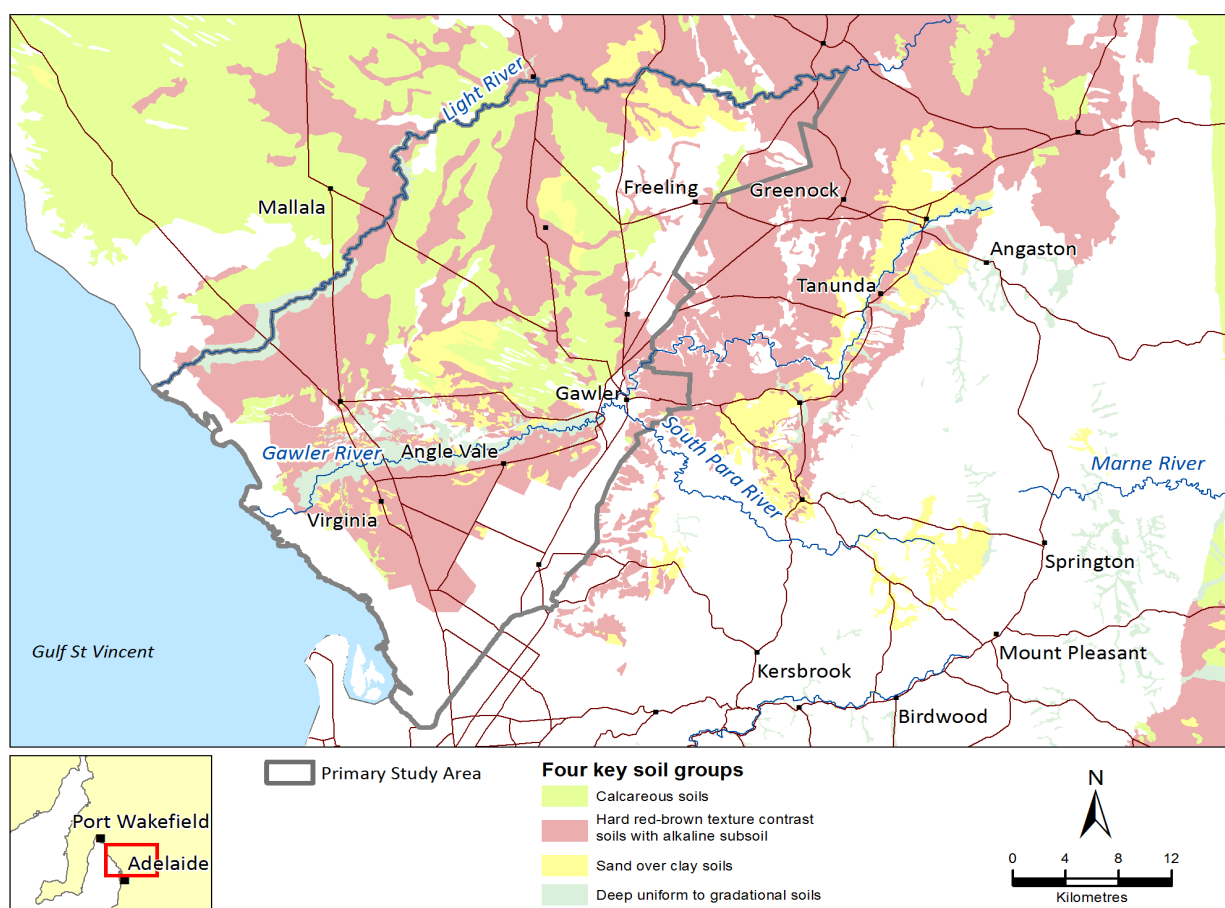


Figure 8. Distribution of four main soil groups in the Northern Adelaide Corridor.

Table 7: Summary of potential of four main soil groups for long-term irrigation in the Northern Adelaide Corridor.

SOIL GROUP*	IRRIGATION REQUIREMENTS CURRENT (FUTURE) CLIMATE †	IRRIGATION CONSTRAINTS	RECYCLED WATER CROP IMPACT	MANAGEMENT OPTIONS TO IMPROVE SUSTAINABILITY OF RECYCLED WATER IRRIGATION
Calc	377–1022 mm (398–1103 mm)	High salinity and sodicity risk	Potato, carrot, onion yield reduction ⁺	High level of management required: <ul style="list-style-type: none"> Gypsum application rate of 8.6 t/ha Leaching factor of at least 20–50% Conjunctive use lower salinity water Organic matter amendment *
HrB	425–1061 mm (446–1138 mm)	High salinity and sodicity risk	Avoid field crops Potato, carrot, onion yield reduction ⁺	High level of management required: <ul style="list-style-type: none"> Gypsum application rate of 8.6 t/ha Leaching factor of 20–50% Conjunctive use of lower salinity water Organic matter amendment *
SoC	461–1089 mm (477–1165 mm) Highest irrigation rate, most sensitive to increases under future climate	Salinity and sodicity risk	Carrot, onion yield reduction ⁺	Required: <ul style="list-style-type: none"> Gypsum application rate of 4.3 t/ha Leaching factor of 20% Beneficial: <ul style="list-style-type: none"> Conjunctive use of lower salinity water
DuG	368–993 mm (389–1076 mm) Least sensitive to increases under future climate	Salinity and sodicity risk	Carrot onion yield reduction ⁺	Required[#]: <ul style="list-style-type: none"> Gypsum application rate of 4.3 t/ha Leaching factor of 20% Beneficial[#]: <ul style="list-style-type: none"> Conjunctive use of lower salinity water

*Cal = Calcareous, HrB = Hard red-brown, SoC = Sand over clay, DuG = Deep uniform to gradational; † Irrigation requirements (IR) are mean values for historic (1970–2017) and future climate (2018–2050); ⁺ yield reduction based on profile salinity according and the yield-salinity relations defined by Maas and Hoffman (1977), on average yield reduction never exceeds 35% from optimal; ^{**}organic matter amendment not simulated; [#] management option not simulated for deep uniform to gradational soils, but can be inferred from those for sand over clay soils.

3.2 Project outputs

Project outputs, in the form of publications, workshops and models are summarised in

Table 8. Project databases include soil chemical and physical properties with depth, depth to shallow groundwater and water resource quantity and quality. Technical reports for specific project tasks provide full details of all datasets, which are available for integration within existing South Australian data repositories.

This project delivered data, tools and knowledge to support the expansion of sustainable irrigated agriculture and horticulture in the NAC, which has the potential to provide considerable economic growth in the region. An overall summary of project outputs in relation to i) development of new data and tools, and ii) knowledge to support sustainable expansion of irrigated agriculture and horticulture, is provided below.

In addition, horticultural production on the NAP provides evidence that recycled water irrigation in this region can be appropriately managed. Experience on the NAP also suggests the uptake of management strategies varies considerably amongst growers. As a result, it is acknowledged that ongoing knowledge adoption and capability building is essential to embed sustainable practices within the region over the long-term.

Table 8: Publications and models arising from sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor project.

TECHNICAL REPORTS
Task 1 Oliver, D.P., Fruzangohar, M., Johnston, C., Ouzman, J., Barry, K. (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide corridor: Task 1 - baseline soil properties, Goyder Institute for Water Research Technical Report Series No. 19/14, Adelaide, South Australia.
Task 2 Mallants D., Phogat V., Oliver, D., Ouzman, J., Beirgadhar, Y., Cox, J. (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 2 - modelling nutrient and chemical fate to support the long-term sustainability of the use of recycled water utilisation. Goyder Institute for Water Research Technical Report Series No. 19/15, Adelaide, South Australia.
Task 3 Awad, J., Vanderzalm, J., Pezzaniti, D., Olubukoa Esu, O.-O., van Leeuwen, J. (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 3 - source water options; water availability, quality and storage consideration. Goyder Institute for Water Research Technical Report Series No. 19/16, Adelaide, South Australia.
Task 4 Hatch, M., Batelaan, O., Banks, E., Flinchum, B., Hancock, M. (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 4 - assessment of depth to groundwater (proof of concept). Goyder Institute for Water Research Technical Report Series No. 19/17, Adelaide, South Australia.
Task 5 (this report) Vanderzalm, J., Cox, J., Oliver, D., Phogat, V., van Leeuwen, J., Awad, D., Pezzaniti, D., Hatch, Batelaan, O., Pitt, T. (2019). Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 5 - summary report. Goyder Institute for Water Research Technical Report Series No. 19/18, Adelaide, South Australia.
JOURNAL PAPERS
Phogat, V., Pitt, T., Cox, J., Šimůnek, J., and Skewes, M. (2018) Soil water and salinity under sprinkler irrigated almond exposed to a varied salinity stress at different growth stages. <i>Agricultural Water Management</i> , 201: 70–82.
Pitt, T., Stevens, R., and Cox, J. (2018) Assessing the salt sensitivity of mature almond trees by replacing the resident saline irrigation with fresh water at different growth stages. VII International Symposium on Almond and Pistachio; <i>Acta Horticulture</i> , 1219: 251–258.

Phogat, V., Cox, J. and Pitt, T. (2018) Modelling water and salinity risks to almonds under sustained deficit and saline water irrigation. VII International Symposium on Almond and Pistachio; *Acta Horticulture*, 1229: 169–176.

Phogat, V., Cox, J.W., Kookana, R.S. Šimůnek, J., Pitt, T. and Fleming, N. (2018) Optimizing the riparian zone width near a stream for controlling lateral migration of irrigation water and solutes. *Journal of Hydrology*, 570: 637–646 <https://doi.org/10.1016/j.jhydrol.2019.01.026>.

Bretreger, D., Yeo, I.-Y., Quijano, J., Awad, J., Hancock, G., and Willgoose, G. (2019) Monitoring irrigation water use over paddock scales using climate data and landsat observations. *Agricultural Water Management* 221: 175–191. <https://doi.org/10.1016/j.agwat.2019.05.002>

Phogat, V., Mallants, D., Cox, J.W. Šimůnek, J., Oliver, D.P., and Awad, J. (2020). Management of soil salinity associated with irrigation of protected crops. *Agricultural Water Management* 227. <https://doi.org/10.1016/j.agwat.2019.105845>

JOURNAL PAPERS IN PREPARATION

Flinchum, B., Hatch, M., Banks, E., and Batelaan, O. (2019) A combined geophysical approach to identify surface and groundwater connections in the Northern Adelaide Plains.

Hatch, M., Batelaan, O., Banks, E., Flinchum, B., and Hancock, M. (2019) Comparative analysis of four hydrogeophysical techniques for mapping shallow groundwater conditions in semi-arid conditions.

THESES

Kemp, W. (2018) Characterising and mapping shallow groundwater conditions in data poor areas of the Northern Adelaide Plains. Honours Thesis Flinders University.

Wilson, M. (2017) Comparison of different hydrogeophysical techniques to provide a rapid assessment of depth to watertable in the Northern Adelaide Plains. Masters of Science (Groundwater Hydrology) Thesis, Flinders University.

Sohrabi, S. (2019) Characterisation and mapping of soil profiles of the Northern Adelaide Plains. Masters of Science (Water Resources Management) Thesis, Flinders University (to be submitted).

Olubukoa Esu O.-O. (2018) Strategic management of water resources for fit-for-purpose use in greenhouse irrigation on the Northern Adelaide Plains in South Australia. Master's Thesis University College London.

CONFERENCE PAPERS

Bretreger, D., Quijano, J., and Awad, J. (2018) Monitoring irrigation volumes using climate data and remote sensing observations. The Hydrology and Water Resources Symposium (HWRS), Melbourne, Australia. Melbourne: Engineers Australia, 2018: 112-123.

Awad, J., Pezzaniti, D., Vanderzalm, J., Esu, O.-O., and van Leeuwen, J. (2019) Irrigation water resource management tools: 'IW-QC2' software tool. 23rd International Congress on Modelling and Simulation (MODSIM2019), Canberra, 1-6 December 2019.

CONFERENCE ABSTRACTS

Flinchum, B.A., Hatch, M., Banks, E., and Batelaan, O. (2018) Rapid assessment of groundwater levels in the Northern Adelaide Plains using seismic data Abstract for The Australian Geoscience Council Convention (AGCC), Adelaide, 14–18 October, 2018.

Hatch, M., Batelaan, O., Banks, E. and Flinchum, B. (2019) Evaluation of geophysical techniques to characterise depth to shallow groundwater in the agriculturally important Northern Adelaide Plains, South Australia. Geophysical Research Abstracts, vol. 21, EGU2019-3455-1. EGU General Assembly.

<https://meetingorganizer.copernicus.org/EGU2019/EGU2018-3455-1.pdf>.

WORKSHOP

Knowledge adoption workshop: Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor 19/3/2019. Attendees from horticultural industry, private sector, SA Water, SA Department for Environment and Water, SA EPA, PIRSA; 22 attendees + project team + Goyder staff.

MODEL

IW-QC2: Irrigation water quality and quantity for covered crop software tool.

<https://doi.org/10.25919/5d7ed23c09baa>

Development of new data and tools

Project outputs that relate to development of new data and tools:

- New soil and water resource data to support sustainable expansion of irrigation in the NAC.
- Delivery of an unprecedented set of new site-specific parameters to undertake quantitative evaluations of potential impacts of long-term irrigation induced impacts on soil and plant health.
- Development of a gypsum amendment module for HYDRUS-1D to simulate current horticultural practices in the region. This novel module allows the appropriate amount of an annual gypsum application to the soil profile.
- Improved capability to predict sodicity risk through new relationships between soil solution SAR and ESP for each soil, from which threshold SAR values can be derived that exceed threshold ESP values.
- Development of an Excel-based software tool, IW-QC2, tailored to current soil-based covered horticulture practices on the NAP, to support decision-making on water resource selection, desalination requirements, storage and consequential quality of water supply.
- Greater spatial resolution of the interpolated shallow water table surface obtained through a major shallow drilling program of 47 direct push cores.
- Evaluation of geophysical tools as a non-invasive, rapid approach to understand the depth to shallow groundwater. NanoTEM® was recommended for further assessment of groundwater depth in the NAC, based on performance across the survey sites. NanoTEM® also identified the boundary between deep uniform to gradational and hard red-brown texture contrast soils and therefore this tool has potential to delineate soils groups.
- An emerging technique in groundwater geophysics, downhole nuclear magnetic resonance (NMR), was tested and found to be provide rapid *in-situ* assessment of water content, particle size and relative hydraulic conductivity estimates. NMR may be useful to identify the presence of heavy clays (e.g. Hindmarsh Clay) that could impede infiltration.

Knowledge to support sustainable expansion of irrigated agriculture and horticulture

Project outputs that relate to knowledge acquired to support sustainable expansion of irrigated agriculture:

- Baseline assessment of soils in the target development area identified pH, salinity, sodicity and boron (B) as the key factors that pose risks to soil health and irrigated agriculture. Management strategies for these risks can be developed from the experience gained in the established horticultural industry on the NAP, coupled with the long-term modelling scenarios undertaken in this project.
- No relationship could be found between soil group and soil solution B, but there was a general trend of higher soil solution B in loam over red clay and loam over poorly structured red clay (within hard red-brown texture contrast soil group).
- It is recommended to consider the soil B and the potential for accumulation of B in the soil profile, in areas where solidity may limit leaching, when assessing the B toxicity risk of specific crops.
- Recycled water (20 GL/yr) is a significant irrigation resource but will need to be applied sustainably so as not to pose risks to soil and crop health.
- Seasonally-available roof runoff is a source of low salinity irrigation supply that could be used in conjunction with recycled water to reduce salinity risks, but may require investment in infrastructure for harvesting, storage and use.
- Groundwater resources are expected to be of similar or higher salinity than recycled water and may require blending with low salinity resources or desalination, however groundwater quality data in this region is limited.

- ASR in Tertiary aquifers provides the magnitude of storage capacity required for the winter supply of recycled water. Current knowledge of the T1 aquifer north of Gawler River did not reveal any major constraints to ASR.
- Regardless of the crop type, sand over clay soil had the largest irrigation requirement, followed by hard red-brown texture contrast, calcareous and deep uniform to gradational soils.
- Irrigation requirements are expected to increase by 3–11% under a future climate and the largest increases are for annual crops, which are predicted to require 6–11% more water annually.
- Irrigation simulations found that pH remained alkaline and therefore recycled water irrigation does not alter the need to manage the micronutrient availability from that identified for baseline soils in the region.
- Potential yield of salt sensitive crops, such as annual horticulture and almonds, was estimated to be reduced by 4–32% due to the increased soil salinity.
- Riparian zone widths of 20–60 m are needed to limit the migration of solutes from irrigated agriculture to nearby surface waters.
- Long-term salinity risks associated with recycled water irrigation might be mitigated with continued application of current management practices: such as calcium amendment with gypsum, supply of water to provide adequate leaching (leach factor, LF), and use of low salinity irrigation water (continuously or as part of a cyclic approach). While not explicitly included in the HYDRUS modelling scenarios, organic amendments as currently applied can reduce the sodicity impact.
- HYDRUS modelling compared the degree of management required for salinity risks in the four main soil groups. Management of salinity risks is required for calcareous and hard red-brown texture contrast soils (gypsum 8.6 t/ha, LF 0.2–0.5, conjunctive use of low salinity water). In comparison, salinity risks are lower in sand over clay and deep uniform to gradational soils (gypsum 4.3 t/ha, LF 0.2, optional conjunctive use of low salinity water). The irrigation and management practices required are expected to be like established management practices in the region, which have been reported to adequately mitigate salinity constraints over the long-term.
- Modelling found B leaching is least sensitive to the natural soil variability and most sensitive to the variation in B concentration in the irrigation water. The greatest B risk to crop productivity is for sensitive to very sensitive crops in soils that currently exceed 1 mg/L B (13% of soils), or where irrigation may increase B levels from below the crop threshold to above their threshold.
- Blending greenhouse roof runoff and recycled water has the potential to increase the volume of water available for irrigation and concurrently reduce the salt loads added to horticulture systems by at least 23% (for greenhouses planted with eggplant, capsicum, tomato and cucumber) compared with using recycled water as the sole water irrigation resource.
- For greenhouse crops (tomato, cucumber, capsicum, and eggplant) grown in sandy clay loam and sandy loam soils, gypsum application (1.7 t/ha) in combination with leaching (LF 0.15–0.20) was deemed adequate to mitigate salinity and sodicity hazards in the soil, based on HYDRUS modelling.

Glossary

ASR	Aquifer storage and recovery
Cal	Calcareous soil
CMD	Electromagnetic conductivity meter, used for frequency-domain electromagnetics
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Dissolved air flotation and filtration
DuG	Deep uniform to gradational
EC	Electrical conductivity
EC _{se}	Electrical conductivity of soil saturated paste extract
EC _{sw}	Electrical conductivity of soil pore water
ERT	Electrical resistivity tomography
ESP	Exchangeable sodium percentage
FAO-56	Dual coefficient approach to estimate crop evapotranspiration, which is the composite of crop transpiration and soil evaporation
HrB	Hard red-brown texture contrast
IR	Irrigation requirement
IW-QC2	Irrigation water quality and quantity for covered crops (Excel based software tool)
LF	Leaching fraction
MAR	Managed aquifer recharge
NAC	Northern Adelaide Corridor
NAP	Northern Adelaide Plains
NAP PWA	Northern Adelaide Plains Prescribed Wells Area
NAIS	Northern Adelaide Irrigation Scheme
PWA	Prescribed wells area
RO	Reverse osmosis
SAR	Sodium adsorption ratio
SARDI	South Australian Research and Development Institute
SoC	Sand over clay
TEM	Transient electromagnetics, also referred to as time-domain electromagnetics
UniSA	University of South Australia
VPS	Virginia Pipeline Scheme

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Appendix A Project ED-17-01 Outputs and Deliverables

Five project tasks were established in the *Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor* project, each to start in March 2017 and end in March 2019. The tasks outputs are documented within a series of five technical reports, which includes this Summary Report and four additional reports. Appendix 1 presents the objective, outputs and deliverables, for each of the five tasks, to provide an overview of the project.

Task 1 Baseline soil properties

Table 9: Task 1 objective, outputs and deliverables.

TASK 1	
TASK LEADER	Danni Oliver (CSIRO)
TASK OBJECTIVE	To establish baseline soil status and parameters as inputs to the environmental impact assessment modelling task (Task 2).
TASK OUTPUTS	Database with spatially explicit information on soil information; maps of the main soil properties identified as indicators of soil quality for irrigated agriculture based on the water sources identified in the NAP Water Stocktake; report on soil properties for impact assessment of long-term irrigation (Task 2).
SPECIFIC DELIVERABLES	Spatially explicit data for impact modelling – preliminary data Sept 2017; more detailed data April 2018.
TECHNICAL REPORT	Oliver DP, Fruzangohar M, Johnston C, Ouzman J and Barry K (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 1 - baseline soil properties. Goyder Institute for Water Research Technical Report Series No. 19/14. Adelaide, South Australia.

Oliver et al. (2019) describes the baseline soil physical and chemical properties developed within Task 1, and subsequently provided for use in Task 2 modelling. For the purposes of soil collection, and due to resource constraints, the Task 1 focus area was defined extending north of Two Wells to the Light River and east towards Boundary Road. The technical report discusses the major soil properties that are likely to be impacted by or will limit the sustainability and longevity of the expansion of irrigated agriculture in the region.

Soil samples were collected from soil pits (NAP 1-7) or from hand-augered cores (NAP 8-20). Also, existing soils (CL014, CL015 and CL050) collected for soil classification in the region were included in the analyses. Soils were dried and sieved then analysed using a combination of physico-chemical analyses and infra-red (IR) spectroscopy. The following soil properties were reported: pH, electrical conductivity (EC), total carbon, organic carbon, total nitrogen, ammonium, particle size, CaCO₃, exchangeable cations, cation exchange capacity, saturated hydraulic conductivity and water retention at a range of matric potentials.

The database with spatially explicit information on soil properties is available for inclusion in the South Australian Government Data Directory. It is feasible that the new data delivered by Task 1 can be integrated with existing soil datasets to improve the density of soil data in the focus area for this project. This data could subsequently be used within land suitability assessment for the NAC region. However, data compatibility will need to be assessed. For example, Task 1 reported soil solution boron, which cannot be integrated with boron concentrations determined on a hot 0.01M CaCl₂ extractable fraction.

Task 2 Modelling nutrient and chemical fate, including salinity/sodicity risk, as the basis for identifying longevity of recycled water utilisation and mitigation strategies under current and future climate

Table 10: Task 2 objective, outputs and deliverables.

TASK 2	
TASK LEADER	Dirk Mallants (CSIRO)
TASK OBJECTIVE	To further understanding of coupled biogeochemical soil processes influenced by irrigation water quality as the basis for sustainable development of irrigated horticulture.
TASK OUTPUTS	Model-based interdependencies between irrigation water quality-soil type-crop type climate-groundwater depth defining long-term safe operating conditions. Simple response surface-type models that could drive the development of a decision support system.
SPECIFIC DELIVERABLES	Simplified relationships defining safe operating conditions for a wide range of system parameters.
TECHNICAL REPORT	Mallants D, Phogat V, Oliver D, Ouzman J, Beirgadhar Y and Cox J (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 2 - modelling nutrient and chemical fate to support the long-term sustainability of the use of recycled water. Goyder Institute for Water Research Technical Report Series No. 19/15. Adelaide, South Australia.

Mallants et al. (2019) provide guidance on the potential impact of long-term irrigation, with a range of available water qualities, on the environment. Environmental receptors assessed include the four major soil groups, seven soil-based crop types and surface waters. Mallants et al. (2019) report modelling inputs and outputs in a suite of technical appendices. This approach provides sufficient knowledge: (i) of the approach used to assess long-term irrigation impacts, which may be repeated for other soil-water-crop combinations or (ii) to extrapolate the findings of reported simulations to comparable conditions. Task 2 documents the following:

- Root water uptake parameters from current literature (i) for use in HYDRUS modelling of selected crops and (ii) to support extrapolation of simulation results to other crops within broad crop categories of vegetative crops, root crops, fruit crops, grain crops and other vegetation.
- Assessment of variability in soil properties as given in Soil Spatial Data for SA across the project area. The analysis established property homogeneity in the study area for aluminium, depth to toxic layer (boron), and depth to water table. The other soil attributes, however, portrayed diverse characteristics with respect to deep drainage, dryland salinity and potential root zone depth for different crop types.
- Particle size distribution versus depth (to two metres) for major soil groups in project area. Data was derived from pedotransfer functions using existing data and applied within HYDRUS modelling. Data is presented for five soil groups; four of these were included in modelling.
- Hydraulic properties derived for major soil groups in project area. Data was derived with depth (to two metres) from pedotransfer functions using existing and acquired data (measured for soil samples collected in Task 1 at depths up to 90 cm) and applied within HYDRUS modelling. Data is presented for five soil groups; four of these were included in modelling.
- Chemical properties calculated from data acquired data and applied within HYDRUS modelling. Gapon selectivity or exchange coefficients, ionic strength and adsorbed and solution compositions were calculated from data provided by Task 1 for the four major soil groups included in modelling.
- Irrigation requirements for seven crops in four soil groups under historical and future climates, calculated using the FAO-56 dual coefficient approach.

- Ten climate indicators were considered when analysing the potential impact of future climate on crop production in the region.
- Long-term (2018–2050) impact of recycled water irrigation for seven crops and four major soil groups. EC_{sw} , SAR, ESP and reduction in crop yield are reported.
- Management options to mitigate risks associated with long-term (2018–2050) impact of recycled water irrigation for seven crops and four major soil groups. EC_{sw} , SAR, ESP and reduction in crop yield are reported. Management options simulated include application of gypsum (four application rates, 0–8.6 t/ha), conjunctive use of low salinity and recycled water resources (blending, alternate use) and leaching fraction (four ratios, 20–50%).
- Long-term (2018–2050) salt accumulation in soil under low-cost greenhouse conditions, for four crops and two soils (sandy clay loam and sandy loam) under irrigation with blended recycled water and greenhouse roof runoff. pH, EC_{sw} , SAR and ESP are reported.
- Management options to mitigate salt accumulation in soil under low-cost greenhouse conditions, for four crops and two soils under irrigation with blended recycled water and greenhouse roof runoff. pH, EC_{sw} , SAR and ESP are reported. The management options simulated included leaching fraction (four ratios, 0–30%) and application of gypsum (four application rates, 0–3.4 t/ha).
- Riparian zone requirements for protection of surface waters from migration of irrigation induced soluble salts, under irrigation regimes to be applied in the NAC.
- Development of a HYDRUS-1D module to represent Ca-amendment through application of gypsum. Development of this module was beyond the initial scope of Task 2 but considered necessary to incorporate findings of the land holder survey (Task 3) on management practices.

Task 3 Source water options/water availability, quality and storage considerations

Table 11: Task 3 objective, outputs and deliverables.

TASK 3	
TASK LEADER	John van Leeuwen (UniSA)
TASK OBJECTIVE	<p>To support sustainable expansion of horticultural and agricultural practices of the NAP and NAC. Each of the following objectives may also provide input to a future decision support system:</p> <ul style="list-style-type: none"> • Develop new knowledge of current water resource options and availability and their seasonal variations. • Develop a detailed understanding of current water resource qualities. • Assess strategies to mitigate risks posed by different water sources and qualities, including an evaluation of blending and treatment options. • Evaluate the potential for stormwater harvesting at a farm and enterprise scale. • Identify storage opportunities (surface and subsurface) in NAC. • Link water resource and quality scenarios to potential agriculture and horticulture opportunities as well as irrigation practices.
TASK OUTPUTS	<p>Documentation of existing water quality data, where accessible: recycled water, stormwater and groundwater.</p> <p>Documentation of the impacts of subsurface storage and mixing on source water qualities.</p> <p>Understanding of seasonal availability of water resources, based on existing data.</p> <p>Documentation of the simulation of harvestable stormwater quantity under varying climatic conditions.</p> <p>Development of a managed aquifer recharge (MAR) spatial opportunity map for NAC based on existing data.</p> <p>Documentation of potential water qualities through modification, surface blending and treatment options.</p>
SPECIFIC DELIVERABLES	<p>Database of water quality and blending options for current and potential water supply options, for key and selected representative NAP zones. Key zones to include representative horticultural and agricultural practices Task 3 report (2019) and/or refereed journal and conference papers detailing research outcomes.</p>
TECHNICAL REPORT	<p>Awad J, Vanderzalm J, Pezzaniti D, Olubukoa Esu O-O and van Leeuwen J (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 3 - source water options; water availability, quality and storage consideration. Goyder Institute for Water Research Technical Report Series No. 19/16. Adelaide, South Australia.</p>

Awad et al. (2019) provides an improved understanding of the qualities and quantities of established and potential water resources in the NAP and north to the Light River for horticultural practices. The water resource quality database includes recycled water (Bolivar wastewater post dissolved air flotation and filtration, point of use; farm dam, after subsurface storage via ASR), surface water (Gawler River, Light River, Gawler Water Reuse Scheme, urban stormwater, greenhouse roof runoff), and groundwater (T1 and T2 aquifers). The climatic influence on water resource availability and water quality is documented, along with opportunities for above ground and subsurface storage to balance the supply of water resources with demand. The suitability of available water resources for particular soil-based crop production is assessed based on ANZECC and ARMCANZ (2000). Consideration of supply options was based on fit-for-purpose water quality, tailored through blending of the available and potential (including through treatment processes) water resources.

In addition to water resource sample collection, Task 3 collected soil samples from two greenhouses (three locations and two depths) for generation of soil hydraulic and chemical properties for HYDRUS-1D simulation of covered cropping. This sampling was beyond the agreed scope of Task 3 but considered necessary to provide relevant input parameters for use within simulations.

A landholder survey was conducted to gain understanding of the current horticultural practices within the NAP. Data were collected on the growing periods for various crop types, crop rotation cycles, irrigation

systems and practices, soil properties, water treatment, water storage facilities and current practices to manage soil sodicity and water salinity. The implementation of the landholder survey was not explicitly listed in the original objectives of Task 3 but deemed necessary to gain first-hand landholder information, to better ensure modelling simulations were relevant to current practices.

An Excel-based software tool termed 'Irrigation water quality and quantity for covered crops: IW-QC2' was developed in Task 3 for application by water resource managers and the horticulture industry to facilitate decision-making on water resource selection, desalination requirements, storage and consequential quality of water supply. Five sets of climate data are available within this tool, to provide a robust evaluation of future water resource availability. Development of this tool within Task 3 was undertaken to facilitate application of acquired data and information, following project completion. Although the development of the model was not an explicit objective listed in the original proposal, it was deemed an appropriate tool to provide knowledge adoption.

Water quality data was sourced from established databases and study acquired data (measured and predicted) through Task 3. Water quality data and knowledge of current horticultural practices within the NAP were subsequently provided for use in Task 2 modelling.

Task 4 Assessment of depth to groundwater (proof of concept)

Table 12: Task 4 objective, outputs and deliverables.

TASK 4	
TASK LEADER	Okke Batelaan (Flinders University)
TASK OBJECTIVE	<p>To develop and test a rapid and cost-effective methodology for spatial-temporal mapping of shallow groundwater depth under different pedological and groundwater salinity conditions.</p> <p>Desktop analysis of available topographic, groundwater level and aquifer information.</p> <p>Literature review of hydrogeophysical methods and use of ancillary data/methods for mapping shallow groundwater depths.</p> <p>Joint identification with Task 1 and 2 of pedologically different test locations.</p> <p>Installation of additional shallow piezometers and installation of pressure transducers to capture seasonal trends.</p> <p>Two summer and two winter field programs applying different hydrogeophysical techniques (including electromagnetics, ground penetrating radar, frequency domain electromagnetics- CMD-explorer and EM34, transient electromagnetics-NanoTEM® system).</p> <p>Late winter/spring field survey of direct measurements of depth to groundwater at 50 locations using geoprobe push-tube corer.</p> <p>Comparison and validation of interpretation and interpolation methods for groundwater depth estimation.</p>
TASK OUTPUTS	<p>Paper 1. Comparison of different hydrogeophysical techniques to provide a rapid assessment of shallow water tables.</p> <p>Paper 2. Compare the two summer and winter field programs and how effective the methodology is in different soil moisture conditions.</p> <p>Paper 3. Upscaling from point measurements to regional scale depth to groundwater of shallow aquifers and effects of subdued topography. Data set of direct measurements of depth to groundwater (or confirmation of DTG> 5m) at 50 locations.</p>
SPECIFIC DELIVERABLES	<p>Output 1: December 2017</p> <p>Output 2: December 2018</p> <p>Output 3: March 2019</p>
TECHNICAL REPORT	Hatch M, Batelaan O, Banks E, Flinchum B and Hancock M (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 4 - assessment of depth to groundwater (proof of Cconcept). Goyder Institute for Water Research Technical Report Series No. 19/17. Adelaide, South Australia.

Hatch et al. (2019) reports on investigations undertaken to develop hydrogeophysical techniques for rapid assessment of shallow groundwater depth.

The efficacy of five surface-based geophysical techniques (transient electromagnetics (NanoTEM®), resistivity (ERT), conductivity (CMD), ground penetrating radar (GPR) and seismic to estimate the depth the shallow (<10 m depth) groundwater was evaluated. GPR data obtained through a Masters research study (Wilson, 2017) was deemed not to be useful in these conditions. Therefore, the scope of the study was expanded to consider the opportunity to evaluate the potential of seismic techniques.

Three field programs were undertaken to evaluate surface techniques, in June 2017, August 2017 and May to June 2018. To incorporate temporal variability in shallow groundwater, these programs represent winter (2017) and autumn following a dry summer (2018). Hand-augered bores were used to validate the surface geophysics.

Field surveys were located in region considered to be highest likelihood of shallow groundwater. The major soil group at each site was hard red-brown texture contrast. At one site, deep uniform to gradational soils were also evident, whereas another site was directly adjacent to wet saline soils.

A shallow drilling program (47 drill holes) was undertaken in May 2018 (post summer) in collaboration with South Australian Department for Environment and Water. A relatively new downhole geophysical technique (NRM tool) was compared to traditional laboratory techniques to measure water content and soil texture.

Existing and acquired data were synthesised to produce a revised map of depth to shallow groundwater in the project study area. Additional shallow piezometers and pressure transducers were not installed within this task, due to approvals required to install infrastructure and the limited time available to obtain seasonal data.

The three journal papers initially proposed as Task 4 outputs will be prepared from the content reported in Hatch et al. (2019). Task 4 also delivered three theses. The database with spatially explicit information on soil properties is available for inclusion in the South Australian Government Data Directory.

Task 5 Integration of project deliverables

Table 13: Task 5 objective, outputs and deliverables.

TASK 5	
TASK LEADER	Joanne Vanderzalm (task integration) with assistance from Jim Cox (project management), Tim Pitt, and Danni Oliver (PIRSA-SARDI and CSIRO)
TASK OBJECTIVE	To manage the project and integrate all tasks.
TASK OUTPUTS	Steering Committee meetings, workshops, guidelines, maps.
SPECIFIC DELIVERABLES	Subtask 5-1: Analysis of initial data from Task 1 and 3 will inform the field work and modelling (Subtask 5-2). Subtask 5-3: Prioritise scenarios for mapping: a limited set of water use scenarios will be selected for the production of risk maps. Subtask 5-4: Production of risk maps. Subtask 5-5: Final reporting.
TECHNICAL REPORT	This report. J Vanderzalm, J Cox, D Oliver, D Mallants, V Phogat, J van Leeuwen, Awad, D Pezzaniti, M Hatch, O Batelaan, and T Pitt (2019) Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 5 - summary Report. Goyder Institute for Water Research Technical Report Series No. 19/18. Adelaide, South Australia.

This summary report satisfies the task objective to integrate all tasks and deliver a final report with guidance for sustainable expansion of irrigated agriculture and horticulture in NAC. The assessment of resilient and vulnerable areas is presented in relation to four main soil groups in the region. Therefore, this integrated understanding of irrigation potential and management options for the use of recycled water on each soil groups was considered a more useful output than a series of individual risk maps.

A summary of the delivery of task outputs follows:

- Regular meetings were held with the project team. Whole of project meetings were held to initiate the project (February, 2016) and integrate outputs from individual tasks (April, 2019).
- Meetings between the project leader and individual task leaders and/or a sub-set of the project team were held on a regular basis, as required.
- Quarterly update reports were submitted to the Goyder office.
- A project variation request was approved in February 2019 to transfer project integration from SARDI to CSIRO.
- The Project Advisory Committee (PAC) was established in November 2018 and the inaugural PAC meeting was held on 27 November 2018. Establishment of the PAC was too late within the project timeframe for subsequent PAC meetings.
- Following feedback from the PAC, a knowledge adoption workshop was held on 19 March 2019. Attendees included members from the horticultural industry, private sector, SA Water, SA Department for Environment and Water, SA EPA, PIRSA; 22 attendees + project team + Goyder staff.



The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide, the University of South Australia, and the International Centre of Excellence in Water Resource Management.