Sustainable expansion of irrigated agriculture and horticulture in Northern Adelaide Corridor: Task 3 - source water options; water availability, quality and storage considerations.

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Goyder Institute for Water Research
Technical Report Series No. 19/16

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

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Citation

Awad, J., Vanderzalm, J., Pezzaniti, D., 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 considerations.* Goyder Institute for Water Research Technical Report Series No. 19/16.

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Abbreviations

Abbreviation	Meaning
ANZGFMWQ	Australian and New Zealand Guidelines for Fresh and Marine Water Quality
ASR	Aquifer storage and recovery
AWRP	Advanced water recycling plant
DAFF	Dissolved air flotation and filtration
EC_E	Salinity tolerance values
EC_i	Irrigation salinity
EC_{se}	Root zone salinity
EFPAs	Environmental and Food Production Areas
ESP	Exchangeable sodium percentage
ET_0	Reference evapotranspiration
FAO_{56}	Food and Agriculture Organization Paper 56
FDs	Farm dams
GCMs	Global circulation models
GWRS	Gawler Water Reuse Scheme
HRT	Hydraulic retention time
IR	Irrigation requirements
k_c	Crop coefficient
LF	Leaching fraction value
LTV	Long-term trigger value
MAR	Management aquifer and recovery
NAIS	Northern Adelaide Irrigation Scheme
NAP	Northern Adelaide Plain
NAP-PWA	Northern Adelaide Plains – prescribed wells area
Pc	Precipitation
RE	Recovery efficiency
RFU	Relative fluorescence unit
RO	Reverse Osmosis
SAR	Sodium absorption ratio
STV	Short-term trigger value
TDS	Total dissolved solids
VPS	Virginia pipeline scheme
WQs	Water qualities

Executive Summary

Expansion of horticulture along the Northern Adelaide Corridor, South Australia has the potential to achieve significant economic development. Sustainability and expansion of horticultural and agricultural practices in the Northern Adelaide Corridor (including the Northern Adelaide Plains, NAP) will be strongly influenced by the sustainability of water supply and the water qualities of the available and potential new water resources.

This report is a contribution to the Goyder Institute for Water Research project 'Project ED.17.01: Sustainable Expansion of Irrigated Agriculture and Horticulture in Northern Adelaide Plains'. The overall aims of the project are to 1) fill the gaps in scientific knowledge related to the impact of the application of water from different sources (and their blending) on long-term soil suitability for different types of crops, long-term impacts on soil quality and the quality of receiving waters, and the availability of water of different quality at different times of the year and 2) to integrate this knowledge in a set of guidelines to answer a number of key end-user defined questions.

The work conducted through Task 3, presented in this report, aimed to develop 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 to further develop knowledge of expanded supply options for irrigation and for water supply optimisation to meet horticulture production needs of the industries. Consideration of supply options were based on fit-for-purpose water quality, tailored through blending of the available and potential (including through treatment processes) water resources.

Data were acquired of water qualities of the various known water resources (reclaimed water, groundwater and surface water) of the NAP and Northern Corridor to the Light River (both established and acquired through this project). Reclaimed water and surface water qualities at point of use (e.g. at landholder storage dams) were investigated to determine potential blending options in terms of water quality and supply availability. Based on established data/information of the hydrogeology of the NAP, including north of Gawler River, available data of groundwater quality were summarised for the identification of risks associated with its use in horticulture and evaluation of potential strategies to manage these risks.

Water resources included stormwater obtained through harvesting from impervious surfaces of plastic and glass houses of intensive horticulture enterprises. The study area (34°21′48′′ to 34°40′24′′S and 138°25′51′′ to 138°54′37′′E) was divided into 42 segments (~24 km^2 each) based on the Australian gridded climate data. Investigation was conducted on the availability of fresh water that could potentially be harvested from impervious surfaces in these segmented areas. This was performed using continuous simulation models that incorporated historical and downscaled rainfall data from the SA Climate Ready Database.

A landholder survey was conducted to gain understanding of the current horticultural practices within the NAP. 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. Also, current practices applied to manage soil sodicity and water salinity were investigated.

Models were developed for determination of the quantities and qualities of irrigation water from blending of various water resources, e.g. harvested stormwater blended with reclaimed water, used for commonly grown greenhouse crops within the study region. This is based on historical and predicted climate data. From user selected climate models, we also report models developed to enable prediction of required water volumes for irrigation needs and desalination requirements (by reverse osmosis [RO]) based on trigger TDS and chloride concentrations.

In Task 3, aquifer storage and recovery (ASR) opportunities were also assessed for both tertiary aquifers (T1 and T2) in the study area based on existing hydrogeological information, including a recent review of water groundwater resources. Key criteria for the ASR suitability assessment were groundwater salinity and environmental value, proximity to existing groundwater users, depth to top of aquifer, thickness of aquifer and depth to groundwater.

Key findings include the following:

- Using Bolivar WWTP sourced reclaimed water (currently supplied post DAFF) for horticulture without any desalination treatment will add at least 4.2 t/ha/annum of salt to the horticulture enterprises based on volume (3.7 ML/ha/annum) supplied. This has the potential to effect soil structure and crop growth depending on crop salt tolerant levels.

- Water from Gawler River could be extracted seasonally, generally between Jul-Sep, at qualities similar to VPS reclaimed water. However, the water available is highly dependent on local climate conditions i.e. rainfall intensity, durations and patterns. For use of such water resources, suitable storage facilities (surface storage and/or subsurface storage) and associated infrastructures (e.g. distribution pipelines and pumping) would be required and sustainable diversion limits would need to be established and adhered to.

- A significant amount of stormwater from rooftop runoff (i.e. ~50% of total water volume that will be distributed by the NAIS scheme- Stage 1) of low TDS (< 150 mg/L) could be captured from existing plastic /glass greenhouses within the NAP. Blending harvested rainwater with reclaimed water could reduce salt loads added to horticulture systems by at least 23%, reduce the volume of reclaimed water required for irrigation by at least 36% and achieve a target salinity level of 600 mg/L during most of the crop cycle (i.e. for soil-based greenhouses planted with capsicum, cucumber, eggplant or tomato).

- Despite the limitation of urban stormwater supply north of the Gawler River, it has been estimated that another ~5 GL per annum of urban stormwater with low salinity level could be captured from Dry Creek (outside of the study area). However, infrastructure does not currently exist to support such water resources for irrigation purposes within the NAP and north of Gawler River.

- ASR has the potential to provide significant storage for water resources that are seasonally available (e.g. rooftop stormwater runoff) and to buffer seasonal water shortages (i.e. during summer seasons) to support irrigation and expansion of horticulture. However, the incentive for stormwater harvesting and storage in an aquifer for later extraction appears to be limited from a landholder perspective based on current governance and 'water use entitlement' of stormwater once it has been injected into the ground.

- The potential for ASR in the T1 aquifer in the NAP PWA is limited to the western portion of the study area (west of the Port Wakefield Rd) while additional ASR schemes could be considered in the T2 aquifer in the NAP PWA to support expansion of horticulture. Although a preliminary assessment indicates there is potential for ASR in the T1 aquifer in the north of NAP PWA, it is necessary to assess the local conditions for feasibility of a scheme.

Key outcomes include the following:

- Provision of input data [quantity and quality of reclaimed water (primarily Bolivar wastewater, post dissolved air flotation and filtration (DAFF) treatment, at the farm dam), surface water (Gawler River, Light River and GWRS), stormwater and groundwater (predominately T1 and T2 aquifers) sourced from established data bases, study acquired data (measured and predicted)] needed for Task 2 Hydrus modelling.

- Improved understanding of seasonal variation in water resource availability and quality for the horticulture industry of the NAP and north to the Light River.
- Suitability assessment (based on ANZECC and ARMCANZ (2000)) of water resources for particular soil-based crop productions.
- Data acquisition of stormwater harvesting potential from current and future predicted covered horticulture practices (38% over 10 years) in the NAP based upon rainfall and the climate prediction model (GFDL-ESM2M) previously developed through the Goyder institute.
- Based on historical and climate modelling, understanding of the potential of blending water sources for supply of irrigation waters for specific horticulture industries.
- Development of a managed aquifer recharge (MAR) spatial opportunity map for the Northern Corridor from available data bases on aquifers (water resource potential) and water quality (predominantly TDS).
- Development of a software tool (in Microsoft Excel) 'Irrigation water quality and quantity for covered crops: IW-QC2' designed for application by water resource managers and the horticulture industry to facilitate decision-making on water resource selection, desalination treatment requirement, storage and consequential supply water quality. For this software, the GFDL-ESM2M model was incorporated. However, application of alternative climate prediction data, e.g., from Charles and Fu (2014) could be readily integrated.
- Prediction of brine production from desalination process and, current practices for brine management in the NAP.

The intent of this report is the provision of enhanced knowledge and information to support the sustainability and growth of the horticulture industry of the NAP and Northern Corridor. Specifically, this to provide information on water resource options for key horticulture practices, for government agencies and horticulture industry (growers and associate organizations). It is not intended that this report promotes any specific use or uses of water resources for horticulture practices but details potential options that are known to be currently available or projected to be available.

Acknowledgments

This project was funded jointly by the Goyder Institute for Water Research, and its partner organisations, including: South Australian Research and Development Institute (SARDI), Commonwealth Scientific and Industrial Research Organisation (CSIRO), University of South Australia (UniSA), Flinders University (FU) and South Australian Department for Environment and Water (DEW). Data were provided by SA Water, DEW SA and Department of Primary Industries and Regions, South Australia (PIRSA).

The authors gratefully acknowledge the support provided by numerous individuals during the project, including Mr. Steve Barnett, Mr. Giorgio Okeley, Ms Donna-Lee Edwards and Mr Peter Kretschmer (DEW SA), Mr Tim Gubbin (SA EPA), Mr. Michael Edgecombe and Dr. Nirmala Dinesh (SA Water), Mr Bengy Paolo and Mrs Tamara Rohrlach (PIRSA), Dr Howard Hollow (Hortex Alliance, Virginia), Mr. Nick Giannes (Irribiz Virginia S.A), Mr. John Gransbury (HydroPlan, Adelaide) and staff from Virginia, SA commercial irrigation equipment and technical advisory companies (VISS Water and Star Drip irrigation Pty Ltd) for their support of this study. We sincerely thank Mr. Paul Pezzaniti (Complete Ag and Seed Supplies, Virginia, South Australia) for his support in our conducting a grower survey on current horticulture practices in the Northern Adelaide Plains region.

We express our gratitude to Dr Howard Hollow (Hortex Alliance, Virginia), Mr. Steven Gatti (DEW) and Professor Peter Teasdale (UniSA) for their thoughtful review comments.

1. Introduction

1.1. General introduction

Expansion of horticulture along the Northern Adelaide Corridor, South Australia has the potential to achieve significant economic development. Sustainability and expansion of horticultural and agricultural practices in the Northern Adelaide Corridor (including the Northern Adelaide Plains, NAP) will be strongly influenced by the sustainability of water supply and the water qualities of the available and potential new water resources.

The quality of irrigation water used in horticulture has significant effects on production yields. Salinity (total dissolved salts or TDS) of the irrigation water may lead to soil salinisation and thus reduction in crop yields (Wang et al., 2017). In dry regions of south-central and western Australia, where there is limited fresh surface water resources, farmers face pressures to explore alternative water resources for agricultural production (Mguidiche et al., 2015, Wang et al., 2017).

Reclaimed water from domestic and industrial effluent or stormwater can provide alternative water resources for irrigation. Depending on the treatment applied, reclaimed water may contain significant amounts of nutrients (nitrogen and phosphorous compounds), which contribute to the crop's nutrient requirements, saving on fertiliser costs for the farmer (Kelly et al., 2001). However, some studies have shown that use of reclaimed water for irrigation can alter the microbiological properties and physicochemical parameters of the soil including pH, organic matter content, nutrients, salinity and contaminants, which could affect the fertility and crop productivity (Jaramillo and Restrepo, 2017).

The use of desalinated water in agriculture, with added nutrient and micronutrients can increase productivity and the quality of agricultural produce. An assessment of the feasibility of desalination water for horticultural application in Australia by Barron et al. (2015) found that groundwater is the most feasible feed water for cost-effective desalination. The study (Barron et al. 2015) found that the likelihood of adopting desalinated water is principally determined by comparison to the prices of other water resources available. As desalination plants used for irrigation purposes are usually of relatively small scale, they tend to produce water at a high cost based on poor 'economies of scale'. In Australia, water prices are relatively low, despite the limited water resources in the country (Barron et al., 2015). Barron et al. (2015) estimated that Australian farmers are unlikely to be willing to pay more than AUD$1.2/kL for agricultural water Based on data from a study by Campos and Terrero (2013), it was concluded that using desalinated water for agriculture is most likely to be cost effective in a tightly controlled environments such as greenhouses, where agricultural practices involve effective water use and crop productivity is high.

In recent years, there has been significant expansion of greenhouse horticulture, globally (Yu et al., 2017). The agricultural sectors of many nations are exploiting greenhouse farming to increase crop production in order to close the gap between supply and demand, to reduce reliance on importation of off-season fresh vegetables and improve the quality of crop yields (Yu et al., 2017). In South Australia, an increase in the demand for high quality Australian crops led to $249M (2014-15 value) production of greenhouse grown tomatoes ($148M), capsicum ($64M) and cucumbers ($37M), respectively from NAP region (PIRSA, 2017). In the NAP, 220 commercial establishments have emerged in the 10 years, with 38% growth in greenhouse area (PIRSA Spatial Information Services, 2017).

1.2. Project background and original tasks

This report documents the findings from Task #3 of the Goyder Institute for Water Research project 'ED.17.01: Sustainable Expansion of Irrigated Agriculture and Horticulture in Northern Adelaide Plains' (http://www.goyderinstitute.org/projects/view-project/7). The overall aims of the project are to 1) identify and address the gaps in scientific knowledge related to the impact of the application of water from different sources (and their blending) on long-term soil suitability for different types of crops, long-term impacts on soil quality and receiving environments, and the availability of waters of different qualities at different times of the year and 2) to integrate this knowledge into a use a friendly framework for ready access and guidance for sustainable and optimised horticulture practices.

The project is structured into five separate tasks as follow:

Task 1: Development and optimisation of modelling domain and impact assessment of irrigation expansion on the receiving environment.

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

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

Task 4: Assessment of Depth to Groundwater and concentrates on a proof of concept for a rapid assessment of a hydro-geophysical method for estimating shallow groundwater depths and identifying possible localised management/infrastructure needs.

Task 5: Integration of the outcomes Tasks 1-4 to provide guidance for decision makers.

The work conducted in Task 3, presented in this report, builds on the body of knowledge developed by the Goyder Institute for Water Research – in Stage 1, with a particular focus on additional water resource options reported in the Northern Adelaide Plains - Water Stocktake Technical Report (GIWR, 2016). In the prescribed wells area (PWA) of the NAP, there are a range of water resources currently available (detailed in the NAP - Water Stocktake Technical Report (GIWR, 2016) as follows:

1) 17.0 GL/annum from Virginia pipeline scheme (VPS);
2) 11.9 GL/annum currently extracted from groundwater resources; and
3) 1.6 GL/annum from the Gawler water reuse scheme (GWRS).

This report (GIWR, 2016) details a further 26 GL/annum could be made available in the short term as follows:

1) 2.5 GL/annum winter water from the VPS;
2) 20 GL/annum through the upgrade of the St Kilda Dissolved Air Flotation and Filtration Scheme (DAFF);
3) 3GL/annum from water use efficiencies gains in the horticulture sector; and
4) Potentially between 2 to 4 GL/annum further extraction from the T2 aquifer of the NAP and 22 GL/annum from tertiary aquifer north of the NAP Prescribed Water Area.

However, some of these sources could be altered and/or improved through centralised or decentralised treatment technologies (particularly for reductions in TDS) that might enhance and better secure horticultural and agriculture production in the NAP region. Blending of water resources and innovative, efficient irrigation management strategies offer opportunities to further improve the sustainability of available resources for horticulture end-use.

This Task 3 study expands on the knowledge obtained in a previous Goyder Institute (GIWR, 2016) study by investigating the qualities of various water supply options in the NAP and, north of the Gawler River to the Light River, including established groundwater sources and surface waters and blending options, and potential stormwater harvesting. Stormwater and some surface waters (e.g., Gawler River) of the NAP are potential fresh water sources that can be used for horticulture but are season and climate dependent and importantly, vary in water quality. These sources may provide supply opportunities at the farm level through to large schemes such as the GWRS. There is also stormwater runoff from urban areas within catchments and impervious surfaces of farming enterprises, e.g. plastic and glass greenhouses. Capturing and storing stormwater at site and at enterprise/precinct scales from greenhouse roofs can be used to provide irrigation water supplies with qualities that are fit-for-purpose and enhance water supply and practice sustainability.

This task investigated and identified constraints associated with the use of the water resource options. The analysis assessed the water use options for horticulture and agriculture production based on potential impacts on the receiving environment and suggested how these constraints can be overcome. This task also developed the necessary input data for assessing water quantity and quality scenarios (actual and predicted with rainfall and climate modelling) needed for the Task 2 Hydrus modelling.

1.3. Aim and objectives

The aim of Task 3 was to develop an improved understanding of the qualities and quantities of established and potential water resource options in the study area for horticultural and agricultural practices. The application of the water options was assessed for typical horticulture production in the region. Consideration of supply options (spatially and temporally) were based on fit-for-purpose water quality, tailored through blending of the available and potential (including through treatment processes) water resources. This was conducted in the context of the sustainability and expansion of horticultural and agricultural practices of the NAP and the Northern Corridor.

This research study had the following specific objectives:

1) Investigations of water resources (quantity and quality) from source to point of use
2) Understanding of current irrigation systems and practices, and current horticultural industry management practices within the NAP
3) Assessment of strategies to manage the use of available water resources and their qualities
4) Identification of storage opportunities in Northern Adelaide Corridor

2. Methodology and approach

Data were acquired of water qualities of the various known water resources (reclaimed water, groundwater and surface water) of the NAP and Northern Corridor to the Light River (both established and acquired through this project). Reclaimed water and surface water qualities at point of use (e.g. at landholder storage dams) were investigated to determine potential blending options in terms of water quality and supply availability. Based on established data/information of the hydrogeology of the NAP, including north of Gawler River, available data of groundwater quality were summarised for the identification of risks associated with its use in horticulture and evaluation of potential strategies to manage these risks. Water resources included stormwater obtained through harvesting from impervious surfaces of plastic and glass houses of intensive horticulture enterprises. The study area was divided into 42 x segments (~24 km^2 each) based on the Australian gridded climate data. Investigation was conducted on the availability of fresh water that could potentially be harvested from impervious surfaces in these segmented areas.

A landholder survey was conducted to gain understanding of the current horticultural practices within the NAP. 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. Also, current practices applied to manage soil sodicity and water salinity were investigated.

Field and landholder survey data were needed for assessment of water quantity and quality (actual and predicted with rainfall and climate modelling) for Task 2 Hydrus modelling. These data have also been used as input data for the developed water resource tool 'IW-QC2'.

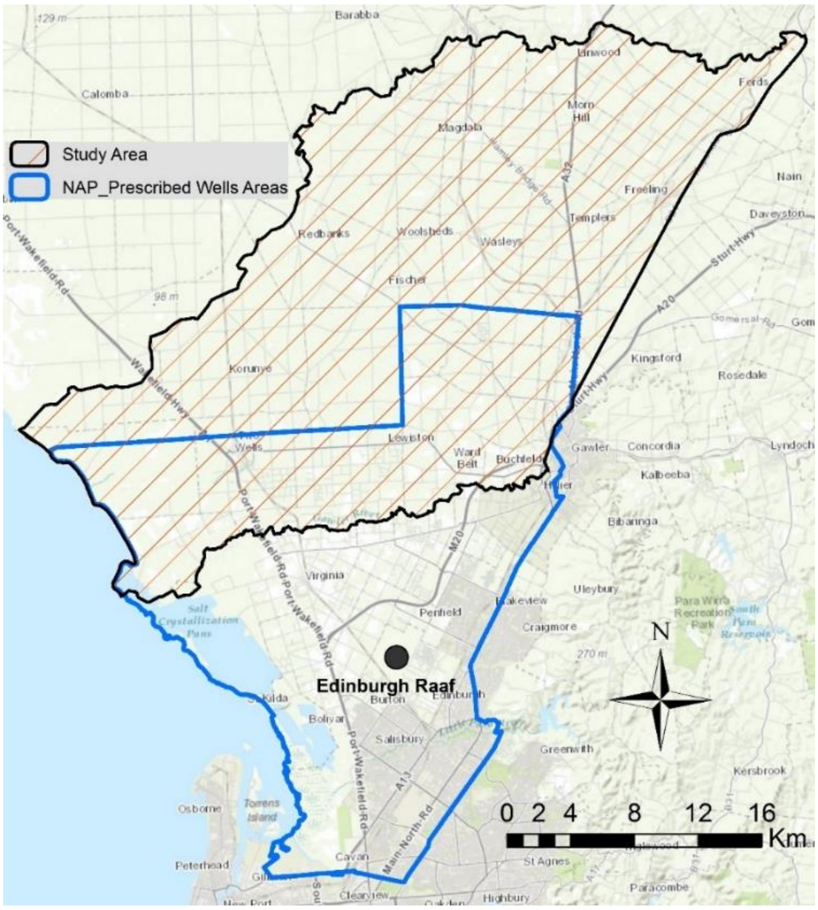

Figure 2–1. Location of Study area.

2.1. Study area

The area for this study (34°21′48′′ to 34°40′24′′S and 138°25′51′′ to 138°54′37′′E) is part of the greater 'Northern Corridor' region. The study area is located between the Gawler River to the south, Light River to the north, the coast to the west and Thiele Highway to east to Kapunda as shown in **Figure 2–1.** It has a catchment area of ~825 km^2. The area is a part of two local councils: The Light Regional Council and Adelaide Plains Council (**Figure A–3**). The northern boundary of the Northern Adelaide Plains – prescribed wells area (NAP-PWA) is located within the study area (see **Figure 2–1)**.

2.2. Precipitation and evapotranspiration data

2.2.1. Historical data

Gridded climate data was acquired from the Bureau of Meteorology (BoM) and through the Queensland Government's Scientific Information for Land Owners (SILO) service. These data are available in 0.05 x 0.05 degree grid scale over Australia, which is delivered on daily time steps and interpolated from gauging stations. Based on this grid system, the study region was segmented into 42 areas, each ~23.8 km^2, as shown in **Figure 2–2**. A daily time step (between Jan. 1889 to Jul. 2018) of precipitation (Pc), Pan A evaporation (Evap.PA) and reference evapotranspiration (ET_0) based on the Food and Agriculture Organization Paper 56 (FAO56) short crop, were downloaded for each grid from SILO (https://silo.longpaddock.qld.gov.au/gridded-data). Median annual Pc and Evap.PA values at each area were calculated and are shown in **Figure 2–3**. Median annual ET_0 values at each area were calculated and are shown in Appendix A, **Figure A–2** while the 10^{th} %ile and 90^{th} %ile annual Pc, Evap.PA and ET_0 values are presented in **Table A–1**, Appendix A. Median annual Pc values range from 367 mm to 477 mm while median annual Evap. PA values range from 1678 mm to 1850 mm and median annual ET_0 values range from 1275 mm to 1335 mm (**Table A–1**, Appendix A).

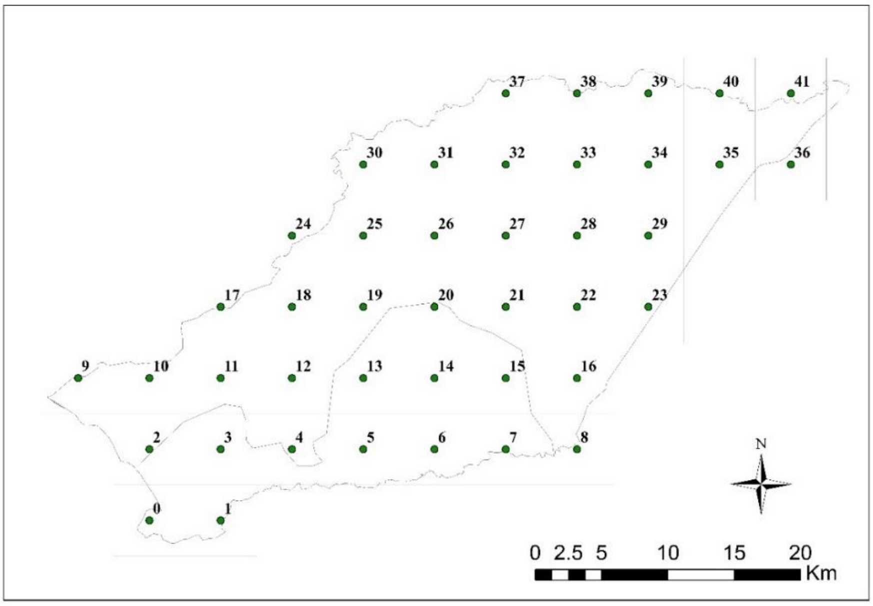

Figure 2–2. Location of small areas (~23.8 km^2 grid) within the region.

The NAP36 area was found to have the highest annual Pc values (10^{th} %ile: 342 mm; 50^{th} %ile: 477 mm; 90^{th} %ile: 634 mm) with the lowest annual ET_o values (10^{th} %ile: 1210 mm; 50^{th} %ile: 1275 mm; 90^{th} %ile: 1331 mm). Consequently, data from the NAP36 area was used to represent the study area's wetter and cooler scenario or 'best case' condition for these parameters. The lowest Pc values (10th %ile: 266 mm; 50th %ile: 364 mm; 90th %ile: 494 mm) with the highest annual ET_o values (10th %ile: 1268 mm; 50th %ile: 1331 mm; 90th %ile: 1384 mm) were for area NAP38, as shown in **Figure A–2**, Appendix A. Values of annual Pc (10th %ile: 293 mm; 50th %ile: 397 mm; 90th %ile: 529 mm) and ET_o (10th %ile: 1250 mm; 50th %ile: 1312 mm; 90th %ile: 1365 mm) for area NAP1 were found to present the median values within the region. Monthly climate data for NAP38, NAP1 and NAP36 are presented in Appendix A, **Figure A–4**.

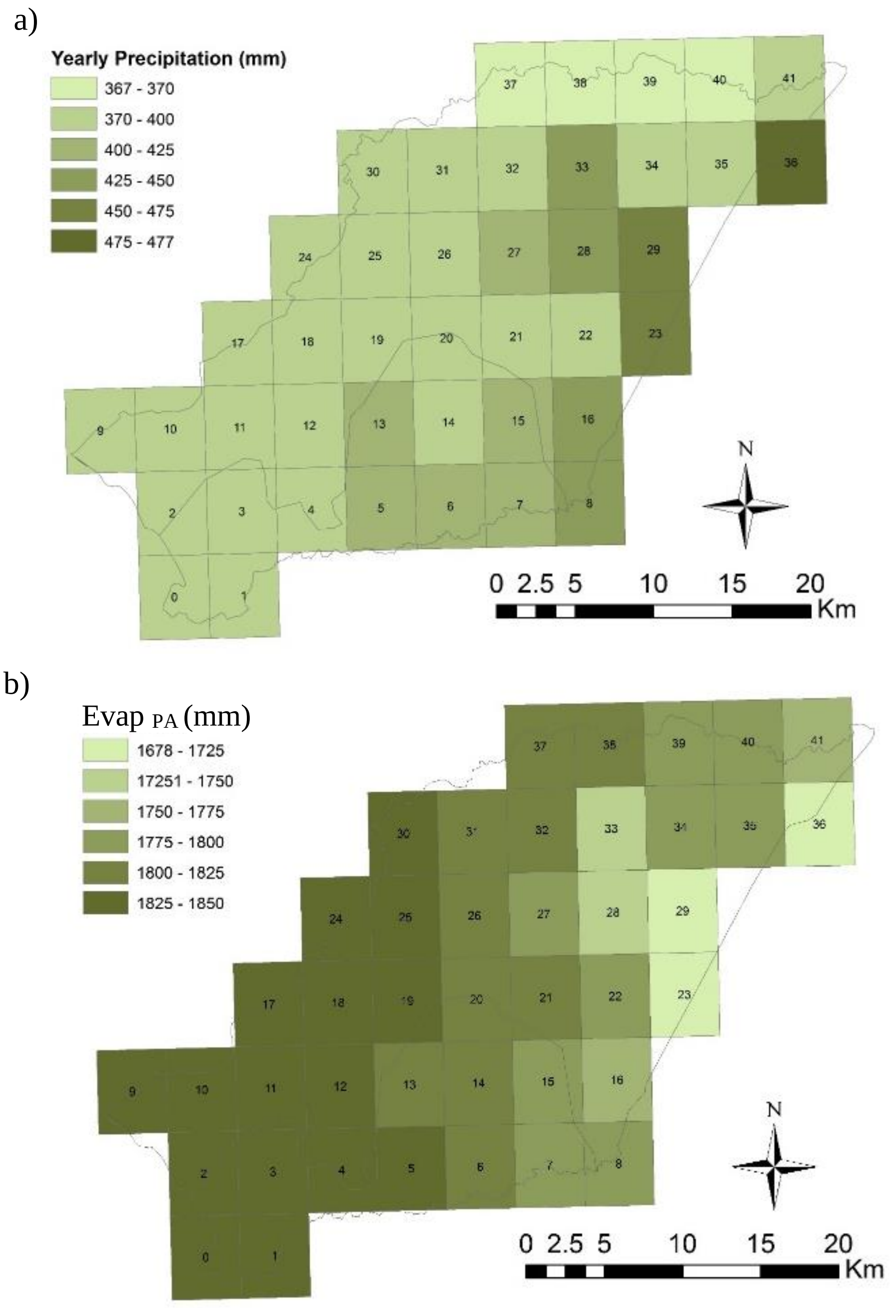

Figure 2–3. Median annual a) precipitation and b) evaporation for each grid.

2.2.2. Climate change model

For Task 3, climate change projections at the Edinburgh RAAF station (located within the NAP Primary Production Priority Area, **Figure 2–1**) were used. Charles and Fu (2014) downscaled global circulation models (GCMs) to six improved performing GCMs based on their ability to reproduce drivers of relevance to the

South Australian climate. For Task 3, the median daily values (calculated from the 100 ensembles of climate parameters) of GFDL-ESM2M model have been used. **Table 2–1** present the 10th %ile, 50th %ile and 90th %ile of annual Pc and ET_0 values calculated from GFDL-ESM2M model for the Edinburgh RAAF station. Using the percentage changes in the Pc and ET_0 values (future/historical) at the Edinburgh RAAF station, the estimated future climate data for the areas: NAP1, NAP36 and NP38 were estimated and are presented in **Table 2–1**. Monthly future climate data for these areas are presented in Appendix A, **Figure A–5**.

Table 2–1: 10th %ile, 50th %ile and 90th %ile of annual Pc and ET_0 values based on future climate data model

	10th %ile	Median (50th %ile)	90th %ile
Pc (mm)			
Edinburgh, historical	300	424	494
Edinburgh, future model	290 (-3% [a])	393 (-7%)	499 (~0%)
NAP1, future estimated	285	353	541
NAP36, future estimated	351	441	671
NAP38, future estimated	265	335	527
ET_0 (mm)			
Edinburgh, historical	1319	1343	1368
Edinburgh, future model	1358 (+3%)	1396 (+4%)	1432 (+5%)
NAP1, future estimated	1300	1371	1428
NAP36, future estimated	1300	1371	1428
NAP38, future estimated	1312	1384	1446

[a] Percentage change between the future and historical data (future value/historical value)

2.3. Horticulture practice survey

A survey was conducted (by personal interview with 'face-to-face' questionnaire) of horticulture farmers of the NAP between July and November 2018. The questionnaire comprised five categories, seeking 1) general information about the horticulture business, 2) crop types grown, 3) irrigation practices applied, 4) existing treatment and storage facilities, 5) issues and services affecting irrigation practices. Other questions addressed included current practices used to manage soil sodicity and water salinity issues. Participant information and the interview questionnaire are detailed in Appendix B. The survey (plan, participant information and confidentiality, data maintenance and the questionnaire) was approved by the University of South Australia Human Research Ethics Committee[1]. The number of survey interviews conducted was 14 participants that included 23 data sets of crop types (4 greenhouse soil-based crops and 6 open-field crop types). Further information including soil test data of 8 soil samples collected from various locations within the region; gypsum use, and compost analysis reports were also provided by a local agronomist (Paul Pezzaniti, personal communication, 2018).

2.4. Crops and water supplies

For major horticulture crops grown in the NAP, the planted areas of each crop type and the crop production value [$/m^2 = price ($/kg) x production rate (kg/m^2)] within the region were determined. Significant

[1] 'This survey was approved by the University of South Australia's Human Research Ethics Committee (Application ID: 201039) on July 12th, 2018.

horticulture practices (i.e., for crops with high proportion of the total irrigated horticulture area or with high production value) were selected for study. The proportions of the total irrigated horticulture area for each crop type are shown in **Figure A–6**, Appendix A, while the crops' production values are presented in **Table A–2**, Appendix A. For open field crops, potato production was found to have the highest percentage area (25.3%) followed by wine grape (12.4%) and almond (11.6%). For greenhouse crops, tomato was found to have the highest percentage area (3.7%) followed by capsicum (3.5%), and cucumber (2.4%), as shown in **Figure A–6**. For greenhouse crops, the crop production values were found to follow the same trend with the highest value for tomato (55 $/m^2) followed by capsicum (27 $/m^2) then cucumber (22 $/m^2), as shown in **Table A–2**, Appendix A. For open field horticulture, lettuce was found to have the highest value (3.4 $/m^2) followed by almonds (2.7 $/m^2) and then carrots (1.8 $/m^2).

Water requirements were estimated based on the methodology of Allen et al. (1998) and compared with actual irrigation practices within the region, determined from the survey. Growth period, planting month(s) and the number of cycles per annum for each crop type were determined for practices within the NAP region, through the survey. Equations used to estimate water requirements for each crops, based on the methodology of Allen et al. (1998), assumptions and monthly crop coefficients (k_c) applied are summarised in Appendix C.

2.5. Water resources and quality analyses

For nutrient [total nitrogen (TN), nitrite and nitrate (NOx), total kjeldahl nitrogen (TKN) and total phosphorus (TP)] analysis, water samples were collected in 60 mL plastic bottles contains sulphuric acid. For *Escherichia coli* (cfu/100 mL) analysis, water samples were collected in 125 mL sterile plastic bottles contains trace amount of sodium thiosulphate. For other water quality parameters (i.e., cations, anions, metals, pH, alkalinity, conductivity, dissolved oxygen and organics concentrations), water samples were collected in 600 mL PET sample bottles and stored at < 4 ^oC until analyses.

Nutrient, cations, anions, metals and bacteriological analysis were conducted by ALS Laboratory Group, a National Association of Testing Authorities (NATA) accredited laboratory. The following methods were applied, nitrogen compounds – APHA 4500 NH_3-H, N_{org}/NO_3, TP – APHA 4500 P –H, major cations (potassium, sodium, calcium, magnesium) - APHA 3120, major anions (chloride, sulphate) - APHA 4500 Cl/SO_4, metals (aluminium, arsenic, boron, iron, manganese) – ICP-MS, and *E. coli* – AS 4276:21-2005.

Phycocyanin and chlorophyll-a levels were measured in side using an EXO1 sonde with EXO Total Algae PC Smart Sensor (Xylem Analytics, Australia Ltd). Measurements of pH, conductivity and dissolved oxygen were made using a WTW inoLab Multi 9630 IDS. For determination of the concentration of dissolved organic matter (DOM) measured as UV absorbance, water samples were passed through 0.45 µm pre-rinsed sterile cellulose membrane filters prior to analyses. UV-Visible light absorbance was measured using a spectrophotometer (UV-120, MIOSTECH Instruments) for wavelengths from 200 nm to 700 nm, using a quartz cuvette of 1 cm path length.

2.6. Reclaimed waters

Data were acquired of the Bolivar DAFF WWTP's filtered water (post chlorination) collected between 2011 and 2017 by the SA Water0. This was done to determine the climate and seasonal impacts (climate condition, cycle and events (e.g. La Niña and El Niño)) on reclaimed water quality. Data were also acquired of the Bolivar WWTP's post activated sludge treatment before lagoon stabilisation treatment from the SA Water (Appendix

D). This was done to determine the effect of surface storage in stabilisation lagoons with a hydraulic retention time (HRT) of ~16 days on water quality (e.g., salinity levels).

In order to determine variation and changes in reclaimed water quality from source to point of use, water samples were collected seasonally from six landholder storage dams within the NAP. Locations of the study sites are shown in **Figure 2–4**. The key features of the study landholder storage (farm dams, FDs) are as follows: FD1: covered dam established in 2017 (Area: ~1900 m^2); FD2: uncovered-lined dam established ~7 years ago (Area: ~1000 m^2); FD3: uncovered-unlined dam established ~17 years ago (Area: ~2200 m^2); FD4: uncovered-unlined dam established ~17 years ago (Area: ~2600 m^2); FD5: uncovered-unlined dam (Area: ~1800 m^2); FD6: uncovered-unlined dam (Area: ~3100 m^2).

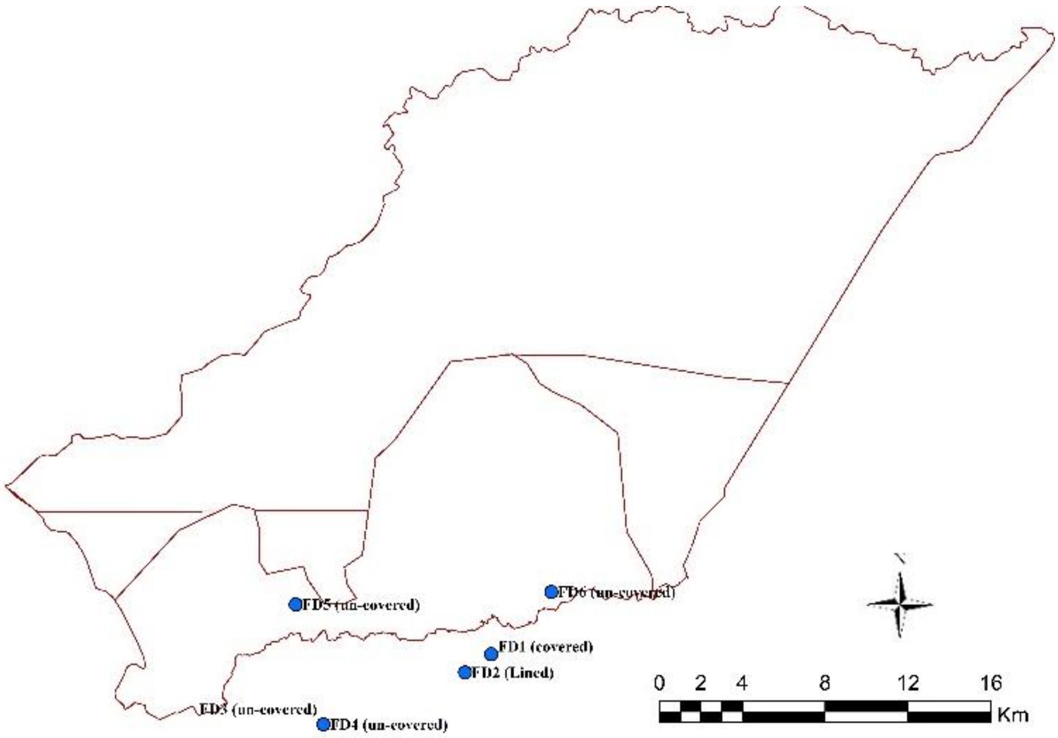

Figure 2–4. Location of study farm dams.

2.7. Surface waters

The Light River and Gawler River are two major surface waters in the region previously described in the Goyder Institute for Water Research, Phase 1 Stocktake Report (GIWR, 2016). Flow volume and water quality data (incl. TDS) for the Gawler River at Station A5050510, between 1972 and 2017 and the Light River at Station A5051003 between July 2010 and November 2016 were acquired from Water Data Services, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Government of South Australia[2]. Discharge volume and water quality data at the Gawler River Station A5050505 between 1996 and 2003 and Light River, Station A5050532 between 2002 and 2016, were sourced from WaterConnect database[3], Government of South Australia. A further dataset of water quality of the Gawler River at Virginia Park[4] was accessed from the EPA, South Australia. For this task, water samples were also collected at various points from both the Gawler River and Light River in 2017 to compare these with the different databases and to measure major

[2] http://amlr.waterdata.com.au/PDFViewer.aspx?page=UserGuide
[3] https://apps.waterconnect.sa.gov.au/SiteInfo/Data/Site_Data/a5050532/a5050532.htm
[4] https://www.epa.sa.gov.au/reports_water/c0021-ecosystem-2008

ions concentrations that can affect crop production. **Figure 2–5** shows the locations of flow gauge stations and sample collection sites along the Gawler and Light rivers.

Water samples were also collected from the Gawler Water Reuse Scheme (GWRS) 'Bunyip Water' at Wingate Basin (400 ML) and Hill Dam (700 ML) (**Figure A–7**). This scheme (operated since August 2016) was designed to capture waters from the Gawler River (1.2 GL licensed volume) and stored in above ground storage (Wingate Basin and Hill Dam) for reuse for intensive viticulture in western Barossa Valley (Light Regional Council, 2016a). The scheme is also connected to the VPS, for securing supply by an additional 500 ML of winter recycled water. Reclaimed water from VPS can be only stored in an enclosed, artificially lined 5 ML storage at the north-western of Wingate Basin (a lower level basin designed for pumping purposes) and in the Hill Dam.

2.8. Stormwater

2.8.1. Urban stormwater

The Department of Planning, Transport and Infrastructure (DPTI), SA detailed SA's protected food and agriculture production areas under the Environmental and Food Production Areas (EFPAs) Act (2016)[5]. This is to protect primary production land (general EFPAs, where the zoning does not allow for the division of land for residential purposes) and to preserve rural living areas (where the EFPA Act 2016 allows land to be divided for residential purposes). The region studied in this project is located within the EFPAs, as shown in **Figure E–5**. Landuse mapping (in 2016) was used to estimate the proportion of each area category (i.e., area identified as primary production land, animal husbandry zone and rural living areas) in the study region. Based on the stormwater management plans of the study area regional councils (Light and Adelaide Plains councils) for the key townships (Two Wells, Roseworthy and Freeling), current and projected stormwater runoff volumes are summarised in this report.

2.8.2. Rooftop stormwater runoff

Land use mapping of intensive horticulture categories, in 2016, was used to estimate the numbers and areas of greenhouses established in the NAP (**Figure E–7**). Historical gridded climate data and the climate change projections for the Edinburgh RAAF station were used to estimate the total volume of rainwater that could be harvested from the current and future development of greenhouse areas.

Samples were collected of harvested rainwaters (from the collection pipes and from storage dam) from poly- and glass-greenhouse roofs within the NAP at the start (May 2018) and end (Oct 2018) of the wet season to determine variation in the quality of water runoff.

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[5] Government of South Australia, DPTI, Planning, Development and Infrastructure Act 2016 Environment and Food Production Areas, issued date 04/04/17, SAPLANNINGPORTAL.SA.GOV.AU
https://www.saplanningportal.sa.gov.au/__data/assets/pdf_file/0011/282935/Factsheet_-_Environment_and_Food_Production_Areas.pdf

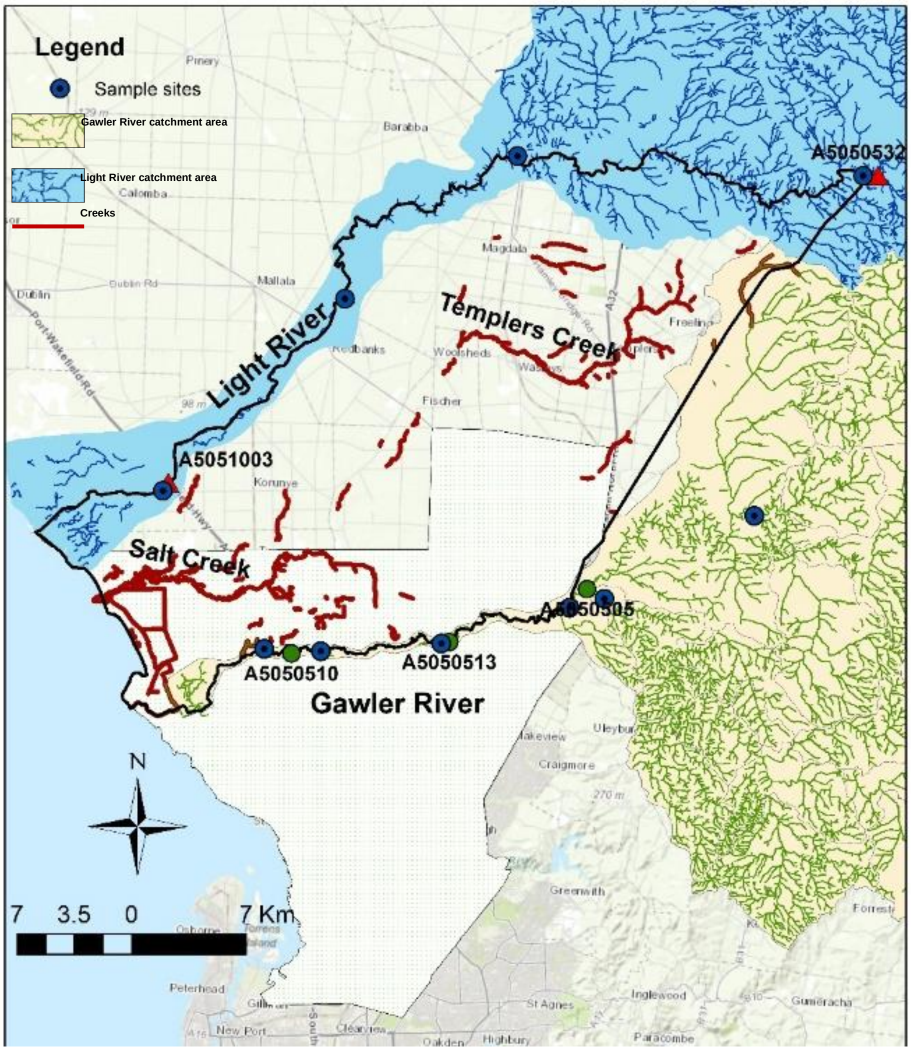

Figure 2–5. Surface waters within the study area, flow gauge stations and sample collection sites along the Gawler River and Light River.

2.9. Groundwater and managed aquifer recharge (MAR) suitability

The groundwater resource and managed aquifer recharge (MAR) suitability assessment was based on existing hydrogeological information, including a recent review of water groundwater resources (GIWR, 2016). This assessment, however, does not consider aquifer pressure constraints, as this requires numerical modelling which was outside of the scope of Task 3. Such modelling is hindered by the model domain of the current Adelaide Plains Groundwater Flow and Solute Transport model (AP2011) (RPS Aquaterra, 2011) and the limited groundwater observations north of Gawler River. Currently AP2011 extends to the Light River in the north but does not allow any buffer to reduce to impact of boundary conditions. Hydrogeological and hydrogeochemical investigations would be required along with flow and solute transport modelling to address the suitability of specific locations for an ASR bore field, and for overall optimisation of the bore field performance.

Groundwater salinity, well locations, depth to groundwater and other groundwater quality data (e.g. cations and anions) were obtained from WaterConnect (Government of South Australia, 2017). Salinity contours and piezometric surfaces were prepared by S. Barnett, DEW, using data from WaterConnect and are presented in **Figure F–6** (for T1 aquifer) and **Figure F–7** (for T2 aquifer). Data of the extent of the T1 aquifer, depth to top of aquifer and aquifer thickness were exported from the AP2011 (RPS Aquaterra, 2011).

Key criteria for the MAR suitability assessment were groundwater salinity and environmental value, proximity to existing groundwater users, depth to top of aquifer, thickness of aquifer and depth to groundwater. These criteria were reviewed by representatives of DEW and EPA for this study.

Results

The Results part of this report are comprised of 5 sections. I.e. **Section 3 to Section 7. Section 3** describes the seasonal impacts on Bolivar DAFF WWTP's reclaimed water quality and the differences and changes in the qualities from source (supply from St Kilda DAFF plant) to point of use (farm dam). Suitability assessment (based on the trigger values for each WQ parameter (ANZECC and ARMCANZ, 2000) of reclaimed water for irrigation purposes is also presented. **Section 4** details seasonal variation in surface water (i.e. Gawler River and Light River) quantity and quality. The quality and quantity of rainwater that could be harvested from the current and future development of greenhouse areas in NAP, based on historical climate data and the climate change projections (determined based on data for the Edinburgh RAAF station, SA), are also presented. **Section 5** provides known information (which was available to this project) on groundwater resources and qualities within the study area. This section also presents the findings of a MAR suitability assessment study. **Section 6** presents the findings from the landholder survey conducted in NAP. This includes information on some key current practices including growing periods for crop types, crop rotation cycle, the current irrigation systems and practices, water treatment and storage facilities and current practices used to manage soil sodicity and water salinity. **Section 7** details models and software tool (in Microsoft Excel) that were developed with user selected climate models to provide information on 1) the quantity and quality of irrigation water, 2) outcomes when blending different sources of water such as harvested stormwater with other sources (e.g., reclaimed water, Gawler River), and 3) to predict the quantity of irrigation water and desalination capacity requirements (by Reverse Osmosis-RO, as used in the NAP region) based on the trigger values for TDS and chloride concentrations.

3. Reclaimed water

3.1. Introduction

The Virginia pipeline scheme (VPS) distributes ~17.0 GL of reclaimed water sourced from the Dissolved Air Flotation and Filtration (DAFF) St Kilda plant, Bolivar to horticulture customers (~400) in the NAP region. Supply is at a maximum of 105 ML/d (GIWR, 2016). A further 2.5 GL of reclaimed water is available (at the time of this study) to landholders during winter months through the VPS, which would require storage in order to be used during other months of the year. The VPS is extended past the Gawler River to the intersection between Brownes Rd and Bailey Rd West, Two Wells which is a part of the study area (as shown in **Figure D–4**, Appendix D).

A new scheme, the Northern Adelaide Irrigation Scheme (NAIS) will distribute an additional 12 GL (in Stage 1) of managed-salinity reclaimed water (the reclaimed water salinity level will be capped to 1165 mg/L) and a further 8 GL will be provided in Stage 2. The total peak recycled water supply capacity for the NAIS scheme (12 GL per annum, Stage 1) post storage is 62 ML/d while the total peak treatment design capacity for the Stage 1 NAIS scheme is 52 ML/d with 50% of the flows, i.e. 26 ML/d coming from the existing DAFF plant and the remaining from the new advanced water recycling plant (AWRP). The approximate design blending ratio is 50: 50. However, depending on the demand profile and the operation of the AWRP and DAFF, there is flexibility to source water either from AWRP or DAFF alone (only in winter months) when the demand is low in the initial years (Nirmala Dinesh, personal communication, 2019).

The AWRP, constructed as part of NAIS scheme at the Bolivar WWTP site, includes pre-treatment with coagulation & flocculation prior to lamella clarification, followed by pressure media filtration, UV and chlorination. Feed water source to the AWRP will be post activated sludge treatment before lagoon stabilisation treatment from the main Bolivar WWTP. Pre-treatment is by coagulation and flocculation followed by lamella clarifier. The low-pressure media filtration is by anthracite and sand followed by UV irradiation (reduction equivalent dose (RED) UV dose: > 55 mJ/cm^2 at 54% UVT and chlorination (target dose rate: C_t > 10 mg.min/L). These treatment processes are for further reduction in suspended solids, and pathogens. The Stage 1 peak treatment design capacity of the AWRP is 26 ML/d with an ultimate design treatment capacity of up to 34 ML/d. The design of AWRP has flexibility to adopt a reverse osmosis process if required to meet the salinity limit.

As part of the NAIS scheme, surplus DAFF water is planned for injection and storage in a MAR scheme, during the winter. This MAR scheme is proposed to comprise of 25 bores spaced at 250 m apart at the Bolivar site, to provide a total storage capacity of 4.1 GL per annum. It is intended that 10 bores will be drilled initially, and any additional bores required will be evaluated by a post-performance review of the initial 10 bores. Injection and extraction rates are expected to average 11 L/s (up to 20L/s per well) and 15 L/s (up to 35 L/s per well) respectively, and the actual storage time is based on the customer demand profile, TDS level in the extracted water and recovery efficiency[6]. The NAIS scheme also includes two lined above-ground earth bank storages (200 ML each: 197.5 m x 109.5 m x 5 m depth) located at the corner of Hart and Porter Roads, ~5 Km north-west of Two Wells, SA. The NAIS water will be transferred from the Bolivar WWTPs to the earth bank storages and from these, will be distributed to the NAIS horticultural irrigation customers.

At the time of reporting, the AWRP and the rest of the NAIS infrastructure were in the design and/or construction stages. For the purposes of Task 3 objectives, an assumption was made that the applied treatment will be minimum to achieve the proposed water quality (salinity level capped to 1165 mg/L) and consequently, qualities of effluent water after the DAFF plant were used in this report to estimate the water qualities for both VPS and NAIS schemes (but capped to 1165 mg/L for the NAIS scheme only). Further, the NAIS scheme might source reclaimed water from either AWRP or DAFF alone when the demand is low in the initial years of NAIS operations, and the water quality from both DAFF and AWRP is expected to be similar except for salinity.

3.2. Qualities of source waters (seasonal variations)

With potential problems caused by low/lower than optimal water quality used for irrigation (e.g. limited crop growth and reduced product yield) there is a need to understand any seasonal variation in reclaimed water quality and the differences and changes in the qualities from source to point of use. Qualities of reclaimed water, post the DAFF plant, Bolivar (the source of the VPS) were obtained from SA Water and are summarised in **Table D–1** and **Table D–2**, Appendix D.

The concentrations of water salinity (measured as TDS mg/L) of the VPS scheme showed seasonal variation with the highest seasonal values [median value: 1188 mg/L; 95th %ile value: 1462 mg/L] occurring in the spring season (Sept-Nov 2012-2017) followed by the summer season (Dec-Feb 2012-2017; median: 1066

[6] The operational efficiency of the initially drilled bores will inform the final number of bores required for the NAIS scheme.

mg/L; 95th %ile: 1304 mg/L), winter season (Jun-Aug 2012-2017; median: 1031 mg/L; 95th %ile: 1230 mg/L) then autumn season (Mar-May 2012-2017; median: 906 mg/L; 95th %ile: 1180 mg/L). These variations are attributed to the salinity level in the influent wastewater to Bolivar wastewater treatment plant with the highest values occurring in the spring season (e.g. 2016-2017; median: 1420 mg/L) while the lowest values (e.g. 2016-2017; median: 1220 mg/L) occurring in the autumn season. The infiltration of groundwater into sewer systems leads to an increase in salinity levels in the wastewater during the wet seasons (including the winter season, in SA) following soil saturation compared with the dry season (summer months, SA). Furthermore, the sewer system can act as a drainage system when the groundwater level rises (Karpf and Krebs, 2004) and where intrusion into the sewer system can occur.

For the NAIS scheme, the TDS levels will be capped to 1165 mg/L and consequently the TDS values during the spring season are projected to be lower in reclaimed waters from the NAIS scheme (95th %ile: ~1165 mg/L) compared with the VPS scheme (95th ile: 1462 mg/L). In contrast and during other seasons, no such differences in the TDS values for waters of NAIS and VPS schemes can be expected. Trigger values (short-term trigger value (up to 20 years), STV and long-term trigger value (up to 100 years), LTV) for each water quality (WQ) parameter for irrigation water have been identified from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZGFMWQ), (ANZECC and ARMCANZ, 2000). The corresponding parameters for reclaimed water were compared with these values to assess the general level of crop tolerance to the irrigation using this reclaimed water source. Average root zone salinity (EC_{se}) levels in soils of different textures and composition (i.e. sand; loam; light clay; heavy clay) were calculated (see Equation **3-1**). This was done from the salinity level of the reclaimed water supplied for irrigation. **Figure 3–1** shows monthly calculated root zone salinity levels and threshold values of average root zone salinity for each crop investigated.

$$EC_{se} = \frac{EC_i}{2.2 \times LF} \qquad (\mathbf{3\text{-}1})$$

Where EC_{se} is average root zone salinity (dS/m); EC_i is irrigation salinity (dS/m); LF is average leaching fraction value [0.6 for sand, 0.33 for loam and light clay and 0.2 for heavy clay soils (ANZECC and ARMCANZ, 2000)].

For sandy soil of the VPS (salinity uncapped), the EC_{se} values exceeded the threshold values of onions and carrots during most of the year (**Figure 3–1**a). The calculated EC_{se} values exceeded the threshold values of grapes, almonds, lettuce and capsicum during the spring season (Sep-Nov) only. Consequently, we conclude that these crop types would be likely to be affected by the salinity of the reclaimed water. In contrast, the threshold values of tomato, cucumber, olives and potatoes are higher than the EC_{se} values, as shown in **Figure 3–1**a. For loam or light clay soils, the EC_{se} values were found to exceed the threshold values of all crops except olives, as shown in Figure 3–1b. For heavy clay soil the ECse exceeded the threshold values of all crop types considered in this study (**Figure 3–1**C).

For reclaimed water from the NAIS (salinity capped at 1165 mg/L), the calculated EC_{se} values for the spring season will be lower (than the VPS) and will not exceed the threshold values of all considered crops, except onions and carrots on sandy soil (**Figure 3–1**a). In contrast, the EC_{se} values of waters from the NAIS will follow the same trend as the VPS with values exceeding the threshold values of all the crop types except olives, on loam and light clay soils (Figure 3–1b). For heavy clay soils, these values will exceed the threshold values of all crop types considered in this study (**Figure 3–1**C).

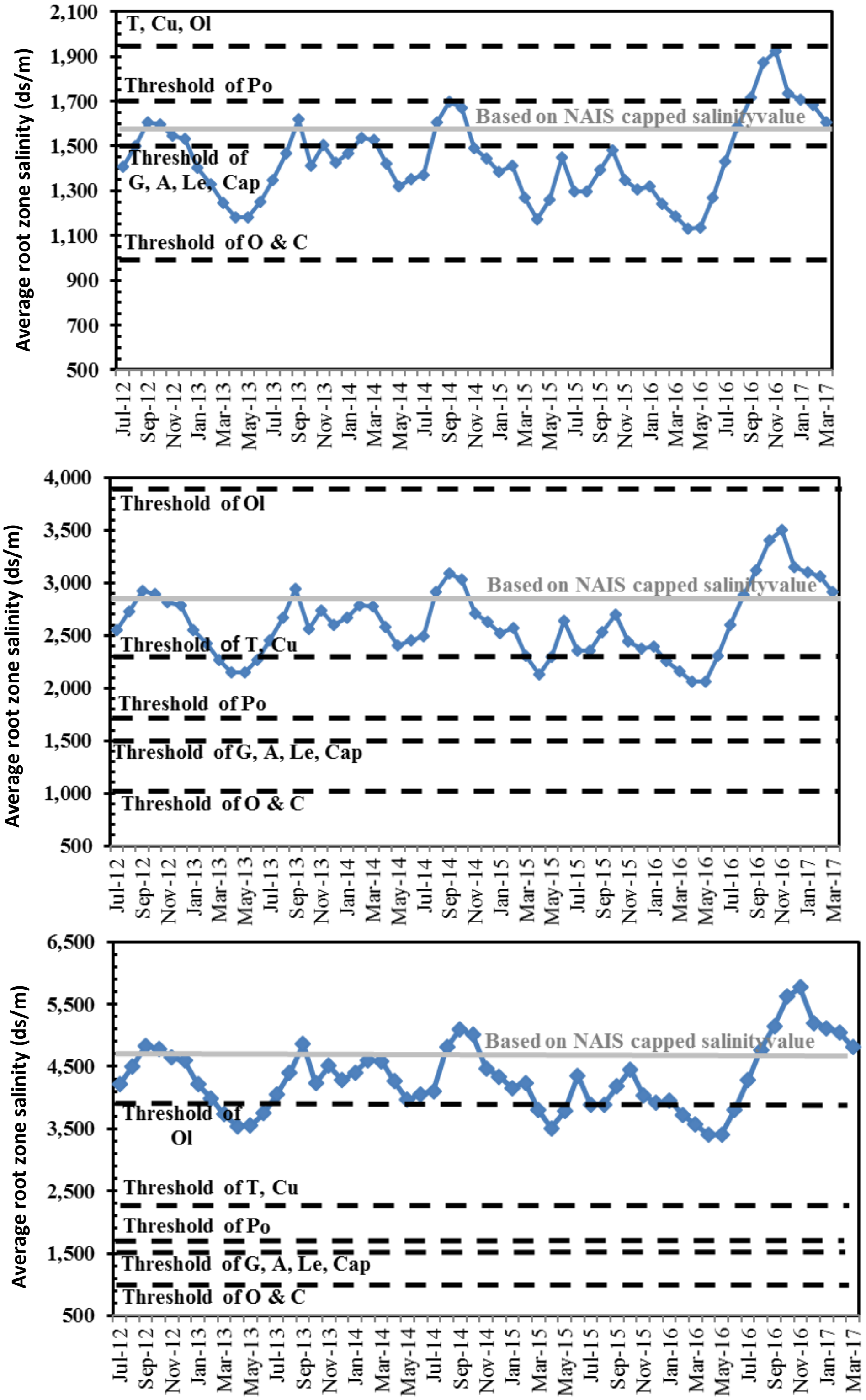

Figure 3–1. Average monthly EC_{se} values calculated from salinity levels in irrigation water (reclaimed water) in a) sand soil, b) loam or light clay soil, and c) heavy clay soil. Dash lines represents the EC_{se} threshold values for crops (A: Almonds; C: Carrots; Cap: Capsicum; Cu: Cucumber; G: Winegrape; Le: Lettuce; O: Onions; Ol: Olive; Po: Potatoes; T: Tomatoes). Solid line represents the EC_{se} values calculated based on capped salinity level from the NAIS scheme.

Sodium adsorption ratios (SAR) were calculated using Equation 3-2 (ANZECC and ARMCANZ, 2000), to predict the soil structure stability with irrigation using reclaimed water. For the VPS scheme, the highest seasonal SAR (median: 8.9; 95th %ile: 10.4) was found in waters that had been collected during the spring while the lowest seasonal SAR (median: 7.2; 95th %ile: 9.3) was found for water collected in the autumn. For NAIS, the monthly SARs were estimated from the product water from the DAFF plant where TDS value > 1165 mg/L were calculated as 1165 mg/L, and for months with TDS value ≤ 1165 mg/L, then the measured values were used. The SARs during the spring season are expected to be slightly lower (i.e., 8.3 and 10.3 for median and 95th %ile values respectively) while the SARs during the other seasons will be similar to those of the VPS.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \textbf{(3-2)}$$

Where SAR is the sodium adsorption ratio; Na^{+}, Ca^{2+} and Mg^{2+} are sodium, calcium and magnesium concentrations (mmol/L) respectively.

Based on the methodology described by ANZECC and ARMCANZ (2000), median values for EC_i and SAR were superimposed on **Figure D–1**, Appendix D to assess soil structure stability. The VPS water quality falls into the category 'dependent on soil properties and rainfall' and consequently further analyses are required to estimate the effect of the VPS water quality on the structures of the various soil types (this performed in Task 2, using the Hydrus Model).

Similar to TDS data, chloride and sodium levels in VPS waters also showed seasonal variation with the highest levels [chloride: 451 mg/L and 538 mg/L for median and 95th %ile; sodium: 318 mg/L and 409 mg/L] occurring in the spring season followed by the summer season (chloride: 406 mg/L and 490 mg/L; sodium: 286 mg/L and 349 mg/L), winter season (chloride: 391 mg/L and 460 mg/L; sodium: 277 mg/L and 326 mg/L) and autumn season (chloride: 343 mg/L and 441 mg/L; sodium: 246 mg/L and 307 mg/L). Both chloride and sodium levels were found to exceed the trigger values for prevention of foliar injury in sensitive and moderately sensitive crops[7] (**Table D–1**, Appendix D). Chloride and sodium values were found to not exceed the trigger values for prevention of foliar injury in moderately tolerant and tolerant crops. As the chloride values were found to be higher than 350 mg/L, there is a risk (median risk level based on ANZECC & ARMCANZ (2000)) of increasing the cadmium levels in crops[8] (subject to cadmium availability in the soil) and testing the cadmium concentration in the edible portions of crops is recommended. For the NAIS, the 95th %ile values of chloride and sodium are expected to be lower respectively 470 mg/L and 327 mg/L but will still exceed the trigger values for prevention of foliar injury in moderately tolerant and tolerant crops. Further, using the NAIS water for irrigation, crops are also still at a risk of increasing the uptake of cadmium from the soil.

Seasonal variation of other water quality parameters, i.e. nutrients, pesticides, anions, cations and heavy metals are summarised in **Table D–1** and **Table D–2**, Appendix D. Although the concentrations of each parameter can vary significantly between seasons, the concentrations do not exceed the corresponding trigger values identified from ANZGFMWQ (ANZECC and ARMCANZ, 2000) as shown in **Table D–3**, Appendix D. For example, boron concentrations (measured as soluble) were highest in waters collected during spring (median: 0.39 mg/L; 95th %ile: 0.53 mg/L) followed by winter (median: 0.38 mg/L; 95th %ile: 0.44 mg/L), summer (median: 0.30 mg/L; 95th %ile: 0.48 mg/L) and the lowest values were in waters collected during autumn (median: 0.25 mg/L; 95th %ile: 0.42 mg/L). Despite these variations in the concentrations, boron values were found to be less than the long-term trigger value (LTV = 0.5 mg/L).

[7] Sensitive crops: almonds, grapes; moderately sensitive crops: potato, tomato; moderately tolerant crops: cucumber
[8] Due to the increased mobility of cadmium in the soil-plant system conferred by chloride, particularly at the root surface, cadmium concentrations in crops are increased (ANZECC & ARMCANZ 2000. Australian and New Zealand guidelines for fresh and marine water quality. *Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra*, 1-103.

3.3. Climate and water quality

The urban areas of Adelaide, like most of the Australian continent, are highly influenced by Walker Circulation[9]. As such, extreme variation in climatic conditions can occur with varying strengths of El Niño and La Niña events. Under strong El Niño events, ongoing drought conditions prevail, and the groundwater level can drop, restricting water supplies and decreasing infiltration of groundwater into sewer systems. In contrast, under strong La Niña events with associated wet conditions, the groundwater level could rise leading to increased infiltration of groundwater into sewer systems. In order to examine the effect of El Niño and La Niña events on the quality of reclaimed water, the La Niña event between Apr 2010 and March 2012 and El Niño event between June 2014 and May 2016 were chosen for investigation, shown in **Figure D–2**, Appendix D. **Table D–4**, Appendix D summarises the qualities of effluent waters after the DAFF plant, Bolivar, SA (at the source of the VPS) during these events.

Waters collected during the La Niña event were found to have slightly higher TDS (Median: 1080 mg/L) and chloride (406 mg/L) concentrations compared to water collected during El Niño event (TDS: 1021 mg/L; chloride: 377 mg/L). However, no significant differences were found between waters collected during the La Niña and El Niño events for sodium concentration (266 mg/L for La Niña vs 274 mg/L for El Niño), boron concentration (0.28 mg/L for La Niña vs 0.28 mg/L for El Niño) and SAR levels (7.6 for La Niña vs 7.9 for El Niño) as shown in **Table D–4**. Median values for ECi and SARs were superimposed in **Figure D–1**, Appendix D and for both events, the water quality falls into the category 'dependent on soil properties and rainfall' and consequently further analyses are required to estimate the effects of the VPS water quality on structure of various soil types (through Task 2). For both events, chloride and sodium levels exceeded the trigger values for prevention of foliar injury in sensitive (chloride: <175 mg/L; sodium: <115 mg/L) and moderately sensitive (chloride: 175-350 mg/L; sodium: 115-230 mg/L) crops while the boron levels were found to be less than the trigger value (LTV = 0.5 mg/L). Furthermore, as the chloride values were found to be higher than 350 mg/L, there is a risk (median level based on ANZECC & ARMCANZ (2000)) of increasing the cadmium levels in crops by using the reclaimed water collected during either event.

In order to examine the effects of wet years (identified as a year with highest Pc value) on the qualities of reclaimed water, data collected during 2016 (NAP1: Pc = 606 mm) were compared to qualities of water collected during a year with a median Pc value (2013: 389 mm). **Where, STV:** short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved.

[9] An atmospheric circulation which can result in changes to the climate felt across the globe (BoM, http://www.bom.gov.au/climate/updates/articles/a020.shtml).

Table D–5, Appendix D summarises the quality of product water from the DAFF plant, Bolivar (VPS source) during both these years. Waters collected during the wet year were found to have significantly higher TDS (+13% for the median and +21% for 95th %ile), chloride (+16% and +15%, respectively), sodium (+22% and +32%, respectively), boron (+30% and +27%, respectively) and SAR (+17% and +15%, respectively) levels compared with water collected during year with median Pc. Using reclaimed water collected during the wet seasons/year for irrigation has potential to cause problems such as slow crop growth, crop yield reduction, reduced crop survival.

3.4. Water quality at the point of farm use (farm storage dams)

Water samples collected from six landholder storage dams were analysed and data of water quality parameters during different seasons are shown in **Table D–6**, Appendix D. In this study, the average WQs of the source water were used as baseline values to compare with corresponding parameters recorded for the six storage dam sites. For wet season data (samples were collected in early September 2017), no distinct differences were found between TDS values (TDS relative to source water: 0.99 for unlined-uncovered sites, 1.04 for lined-uncovered site, 1.01 for lined-covered site) of water samples collected from the source and from the dam. In contrast, during a dry season (samples collected early February 2018), TDS values were found to be higher in waters collected from the storage dams compared with the source water (TDS relative to source water: 1.17). For unlined-uncovered and covered-lined sites, the EC_{se} values (1370 mg/L and 1265 mg/L, respectively) exceeded the threshold values of all crop types investigated, except tomato, cucumber and olives when planted in sandy soil. For loam or light clay soil, the EC_{se} values were found to exceed the threshold values of all the crop types, except olives, while for heavy clay, these exceeded the threshold values of all the crop types considered.

Chloride showed the same trend, with concentrations considerably higher in waters of farm dams compared with the source water (chloride relative to source water during dry season: 1.39, 1.41 and 1.45; chloride relative to source water during wet season: 1.36, 1.09 and 1.28 for unlined-uncovered, lined-uncovered and lined-covered sites respectively). Chloride concentrations exceeded the trigger values for prevention of foliar injury in sensitive (< 175 mg/L) and moderately sensitive (175-350 mg/L) crops but less than that for moderately tolerate and tolerate crops. In contrast, no significant differences were found between SAR values of the water collected from the source and water collected at the dams (SAR relative to source water during dry season: 1.02, 1.09 and 1.09; SAR relative to source water during wet season: 1.0.3, 0.91 and 1.04 for unlined-uncovered, lined-uncovered and lined-covered sites, respectively). Similar to the water quality at the source and based on the SAR and salinity levels, the water quality falls into the category 'depend on the soil properties and rainfall' in **Figure D–1**, Appendix D.

The pH values were higher in waters collected from the storage dams compared with the source water. Highest pH relative to source water was from the unlined-uncovered sites (dry: 1.14; wet: 1.12) followed by lined-uncovered site (dry: 1.07; wet: 1.11) then lined-covered site (dry: 1.0; wet: 1.10). Despite these increases in the pH levels, the pH values (ranging from 7.1 to 8.1) do not exceed the trigger values (<6.5 and >8.5). Boron concentrations were also found to be higher in waters collected from the storage dams compared with the source water but with levels less than the trigger value (values range from 0.35 mg/L to 0.47 mg/L, i.e. < 0.5 mg/L).

Aluminium concentrations were found to be significantly higher in waters collected from the unlined dams compared to the lined ones (dry: 0.27 mg/L vs 0.04 mg/L; wet: 0.55 mg/L vs 0.05 mg/L). Iron concentrations followed the same trend with values higher in waters collected from the unlined compared to the lined dams (dry: 0.25 mg/L vs 0.05 mg/L; wet: 0.45 mg/L vs 0.06 mg/L). This could be attributed to the release of trivalent cations (e.g. Al^{3+}) from the clay soil to the waters stored in the dam.

Residual chlorine concentrations (measured as free and total chlorine) were found to be negligible in all samples and consequently the potential for regrowth/growth of microorganisms is high. *Escherichia coli* (cfu/100 mL) numbers were found to be much higher in the unlined dams compared to lined dams (dry: 165 vs 7; wet: 133 vs 15). A further risk associated with water storage in open-dams is the occurrence of cyanobacteria blooms (**Figure D–3**). Indication of the presence of algae and/or cyanobacteria were found to be higher in water samples collected in from unlined dams compared with lined dams (dry: 0.46 relative fluorescence unit (RFU) vs 0.07 RFU for *Chlorophyll a* and 0.36 RFU vs 0.02 RFU for BGA-PC; wet: 6.61 RFU vs 0.01 RFU for *Chlorophyll a* and 0.51 RFU vs 0.03 RFU for BGA-PC).

3.5. Storage (surface and subsurface) and water qualities

3.5.1. Surface storage

The salinity levels in landholder storage dams (surface storage) is influenced by storage time (hydraulic retention time, HRT), depth of the dam (d) and season conditions (Pc and total annual evaporation, $Evap._T$). In this study the monthly TDSout/TDSin ratios (using **Equation 3-3**) were calculated for three different depths: a) 3 m: minimum farm-dam depth within the region (survey data), b) 7 m: maximum farm-dam depth within the region (survey data) and c) 5 m: depth of the above ground earth bank storage for NAIS scheme (source SA Water). Monthly median, 90th %ile and 10th %ile salinity ratios for the areas NAP1, NAP36 and NAP38, based on historical climate data [a daily time step (between Jan. 1889 to Jul. 2018) acquired from the BoM and through the SILO service], are shown in **Figure D–5**, Appendix D.

$$TDS_{out}/TDS_{in} = \frac{d - Pc + Evap._{PA}}{d} \qquad \textbf{(3-3)}$$

Where TDS_{out} is the water discharge (from the dam) salinity level; TDS_{in} is influent (dam inflow) salinity level; d is the dam depth (in meters, m); Pc is the total precipitation value (in m) during the storage time (HRT); $Evap._{PA}$ is the total evaporation value (in m) during the HRT.

As shown in **Figure D–5**, Appendix D, the highest values of monthly median ranges of TDSout/TDSin ratios for January to December were found for a farm-dam with depth of 3 m (1.0-1.09 for NAP1, 1.0-1.07 for NAP36 and 1.0-1.09 for NAP38) followed by dam with depth of 5 m (1.0-1.05 for all areas) and farm-dam with a depth of 7 m (1.0-1.05 for all areas). The highest TDSout/TDSin ratio occurred during the summer (for a storage depth of 3 m: 1.07-1.09; for a storage depth of 5 m: 1.04-1.05; for a storage depth of 7 m: 1.03-1.04) followed by the spring season (3 m: 1.02-1.06; 5 m: 1.01-1.04; 7 m: 1.01-1.03) and the autumn season (3 m: 1.01-1.06; 5 m: 1.01-1.04; 7 m: 1.00-1.03). While the lowest ratios occurred during the winter season (~1.0 for all depths). These results are consistent with the findings from the survey (water samples collected at the point of use, as shown in Section 3.4) with values higher in waters collected during the dry season (median TDS relative to source water: 1.17) than waters collected during the wet season (median TDS relative to source water: 1.0).

Using the future climate model (as described in Section 2.2.2), monthly median, 90th %ile and 10th %ile salinity ratio for the areas: NAP1, NAP36 and NAP38 within the study region at the three depths, were calculated and are shown in **Figure D–6**, Appendix D. The median TDSout/TDSin values calculated from the historical climate data were similar to the corresponding median values calculated from the climate change model.

3.5.2. Subsurface storage (ASR)

Barry et al. (2010) reported the findings from field trial investigations on the feasibility of ASR of VPS reclaimed water. VPS reclaimed water was injected into a single well to a brackish confined limestone aquifer, with the aim of storing the water to recover at a later date for irrigation of horticultural crops. Four cycles of ASR were conducted between 1997 and 2010 injecting a total of 704 ML of recycled water and recovering 501 ML. Operating considerations including maintenance of injection rates via well redevelopment backwash and injection water quality (Pavelic et al., 2007), management of backwash water and recovery efficiency (R_E) were reported by Barry et al. (2010).

Qualities of injected and recovered waters from the ASR, over various cycles obtained by Barry et al. (2010) are summarised in **Table D–7**. Qualities (apart from nutrient levels) of injected VPS reclaimed water to the ASR storage trials are found to be similar to median values of current reclaimed water during the winter season (measured as median values between 2012 and 2017), as shown in **Table D–7**. Therefore, for Task 2 Hydrus modelling, recycled water after subsurface storage (ASR) was not differentiated from recycled water.

Recovery efficiency (R_E), is defined as the volume of water recovered from ASR at a quality that is suitable for its intended use (generally based on salinity) as a fraction of the volume injected. R_E improved from 60 to 80% between the first and second cycles was and maintained at 80% in the third cycle. However, the R_E for the fourth cycle reduced to 73% in context of a reduced TDS threshold requirement for recovered water of approximately 1300 mg/L for the fourth cycle compared with 1500 mg/L for the first three cycles. R_E can be optimised by creation of a buffer zone that separates inter-recovery period stored water from the surrounding ambient groundwater (Pyne, 2005). The buffer zone is created with a water of lower salinity than the groundwater (i.e. typically the injectant). In the fourth ASR cycle, TDS values of the recovered water collected were slightly higher compared to injected waters (ratio: 1.05 and 1.08 for median and 95th %ile values) due to mixing with the ambient groundwater. pH, chloride and sodium values showed the same trend with values of injected waters slightly higher compared to injected waters (ratios, pH: 1.04 and 1.03; chloride: 1.02 and 1.09; sodium: 1.00 and 1.02, respectively). Calcium concentrations were enriched above that expected from mixing due to dissolution of the calcium carbonate in the aquifer (Vanderzalm et al., 2006) (ratios: 1.60 and 1.66), but this only has a minor influence on SAR (median reduced from 8.3 to 7.3) due to the dominance of sodium.

In contrast, TP and TN concentrations of the recovered water collected were significantly lower compared to injected waters (i.e. output/input ratios were TP: 0.46 and 0.30; TN: 0.11 and 0.11) due to attenuation processes during storage (Vanderzalm et al., 2013). Arsenic release from aquifers can be an issue in aquifers containing pyrite, and the T2 aquifer in the vicinity of the Bolivar ASR trial contains traces of pyrite. However, as concentrations in the recovered water averaged 0.01 mg/L (significantly less than the long-term trigger value i.e. 0.1 mg/L for irrigation water (ANZECC and ARMCANZ, 2000)), arsenic mobilization was not considered a risk for use of the recovered water for irrigation (Vanderzalm et al., 2011). Barry et al. (2010) reported that trace organic chemical concentrations (Pharmaceuticals; atenolol, caffeine, DEET, iopromide, phenytoin and temazepam and herbicides; dicamba, MCPA, dalapon, diuron and simazine) were all not detected in any recovered water and found not to be an issue for irrigation use of the recovered water.

4. Surface water and stormwater

4.1. Surface waters

The study area is bordered by the two ephemeral rivers: the Gawler River and Light River. Other surface water within the study area are Salt Creek and Templers Creek. **Figure E–1** shows the location of various surface water catchments within the study area. Salt and Templers creeks (catchment area: 659.1 km^2) are un-prescribed surface waters flowing between Gawler and Light rivers rising in the hills (near Wasleys) and flowing towards Two Wells (DEWNR, 2016). No database or surface water monitoring data were available in 2016 for both the Salt and Templers creeks (Rouse et al., 2016, DEWNR, 2016) and no data was subsequently found. These creeks were not considered as potential sources for irrigation water in the Goyder Water Stocktake report (GIWR, 2016). These are ephemeral, generally low flow creeks but can act as significant drainage paths during flood events.

4.1.1. Gawler River

The Gawler River, a prescribed watercourse, extends for 30 km from the confluence of the North Para and South Para Rivers just downstream of the Gawler township, to the Gulf St Vincent at Port Gawler (GIWR, 2016, Tonkin consulting, 2018). Under the Western Mount Lofty Ranges Water Allocation Plan (AMLR NRM Board, 2013) extraction is limited to 10 GL per annum and is allowed only if the flows rates are between 500 L/s to 690 L/s. In this study, median, 10th %ile and 90th %ile monthly flow volumes were calculated for two locations: downstream (Station: A5050510, data available between 1972 and 2017) and upstream (Station: A5050505, between 1996 and 2003) and are presented in **Figure 4–1**.

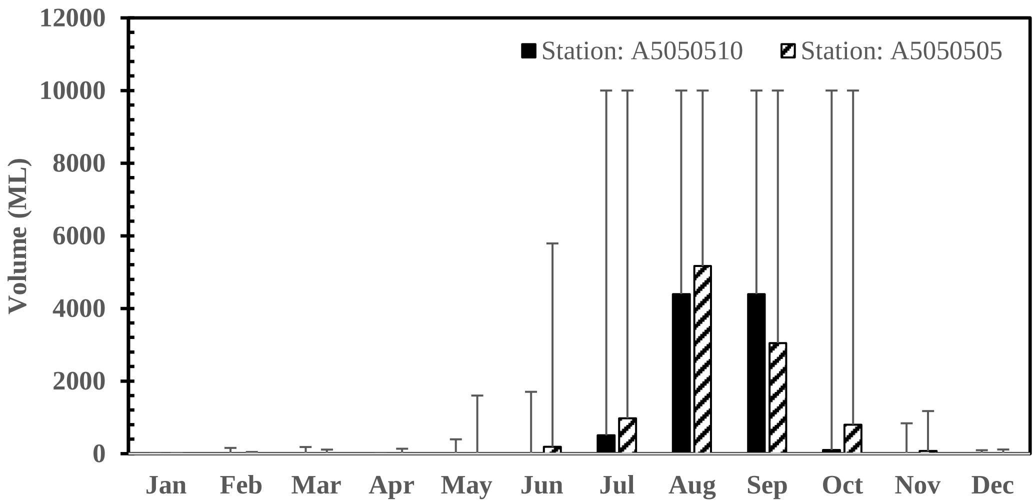

Figure 4–1. Monthly median flow volumes at Station: A5050510 and Station: A5050505, Gawler River. The top bars represent the 90th %ile values.

Based on these data sets, both locations showed the same trend in flows, with no/very low flow volumes during the dry seasons (Summer-Autumn: median values were ~0.0 ML) and also during the beginning of the wet seasons (June: 0.0 ML for Station: A5050505 and 193 ML for Station: A5050510) and the ending of the wet seasons (November: 0.0 ML vs 73 ML). During the remaining months of wet season (winter-spring), the flow volumes at both sites showed monthly variation with the highest values occurring in August (median value: 4397 ML for Station: A5050505 and 5169 ML for Station: A5050510), followed by September (4394 ML vs 3049 ML) then July (505 ML vs 977 ML). Furthermore, during these months (July-September), the streamflow was found to vary significantly between different years with the 10th %ile values of 0.0 ML at Station: A5050505 and ~100 ML at Station: A5050510 while the 90th %ile values were 10,000 ML for both sites, as shown in **Figure 4–1**. Although water could be extracted between Jul-Sep (median value of total volume: ~9 GL), the available volumes (10th %ile: ~ 0.0 GL; 90th %ile: 10 GL) are highly dependent on local climate conditions, i.e. rainfall volumes and patterns. The significant variance in flows from year to year is likely to increase with predicted climate change (W&G, 2009).

Water quality

Monthly salinity levels at Station A5050510, Gawler River are presented in **Figure E–2**, while **Table E–1** summarises the qualities of Gawler River water during various seasons. Although salt loads were found to be directly correlated with the river discharge as shown in **Figure E–3**, salt concentrations (measured as TDS, mg/L) were found to have an indirect relationship with river discharge [median TDS values were lower in waters collected between July and October (July: 1356 mg/L; August: 1076 mg/L; September: 1055 mg/L; October: 1244 mg/L) compared to other months (range of median values: 2421 mg/L to 3326 mg/L)] as shown in **Figure E–2**. Based on the water availability (**Figure 4–1**) and TDS values (**Figure E–2**), water extraction from the Gawler River is limited to the period between July and September. **Table E–2** summarises the water qualities of the Gawler River during this period.

Using Equation **3-1** and a median salinity level (1060 mg/L) of waters from Gawler River between Jul-Sep months, EC_{se} levels in various soil textures were calculated. These are 1.3 dS/m, 2.4 dS/m and 3.9 dS/m for sand, loam-light clay and heavy clay soils, respectively. For sandy soil, the EC_{se} value exceeded the threshold values of onions and carrots only. For loam and light clay soils, the EC_{se} value was found to exceed the threshold values of all considered crop types except olives, while for heavy clay these exceeded the threshold values of all crop types considered in this study. Median EC_i (1.72 dS/m) and SAR (6.2, **Table E–2**) values with soil stability are shown in **Figure D–1**, Appendix D. These are similar to data of the reclaimed water and the Gawler River water quality values are in the category of 'depend on the soil properties and rainfall'. Consequently, further analyses are required to estimate the effect of the Gawler River quality on the soil structure for various soil types (Task 2 Hydrus modelling).

Chloride (median: 519 mg/L; 75th %ile: 531 mg/L) and sodium (median: 252 mg/L; 75th %ile: 262 mg/L) values were found to exceed the trigger values for prevention of foliar injury in sensitive and moderately sensitive crops[10]. Chloride and sodium values were found to not exceed the trigger values for prevention of foliar injury in moderately tolerant and tolerant crops. As the chloride values were found to be higher than 350 mg/L, there is risk (median level risk based on ANZECC and ARMCANZ (2000)) of increasing cadmium levels in crops. WQ parameters (i.e. nutrients, anions and cations) are summarised in **Table E–2** and the concentrations for each WQ parameter do not exceed the corresponding trigger values identified from ANZGFMWQ (ANZECC and ARMCANZ, 2000).

4.1.2. Gawler Water Reuse Scheme (GWRS)

Water samples were collected from the Wingate Basin and Hill Dam, GWRS and qualities of waters are shown in **Table** E–3. Median WQs (**Table E–2**) of the Gawler River water were used as baseline values to compare with those of the GWRS. No major differences were found between TDS values (median TDS relative to source water: 0.98) of the water collected from the source and water collected at the point of use. The EC_{se} values

[10] Sensitive crops: almonds, grapes; moderately sensitive crops: potato, tomato; moderately tolerant crops: cucumber

(calculated from median TDS: 1.2 dS/m, 2.2 dS/m and 3.7 dS/m for sand, loam-light clay and heavy clay soils, respectively) did not exceed the threshold values for onions and carrots in sandy soil. For loam or light clay soil, the EC_{se} values were found to exceed the threshold values of all crops except olives while for heavy clay, these exceeded the threshold values of all crop types considered.

Chloride concentrations (median: 433 mg/L) exceeded the trigger values for prevention of foliar injury in sensitive (< 175 mg/L) and moderately sensitive (175-350 mg/L) crops but was less than that for moderately tolerate and tolerate crops. SAR values of the water collected from the GWRC (Sep 2017) were slightly higher compared to water collected (Sep 2017) from the source (ratio: 1.1). Similar to the water quality at the source and based on the SAR and salinity levels, the water quality falls in the category of 'dependent on soil properties and rainfall' as shown in **Figure D–1**, Appendix D. The pH values were found to be slightly higher in waters collected from the GWRS compared with the source water (pH relative to the source: 1.06). Despite slight increases in the pH levels, the median value (8.3) does not exceed the trigger values (<6.5, >8.5). Boron concentrations (median value: 0.31 mg/L) were also found to be higher in waters collected from the GWRS compared to the source water but levels are less than the trigger value (0.5 mg/L).

4.1.3. Light River

The Light River (catchment area: 1741 km^2) rises near the township of Waterloo, SA. It flows southward between parallel ridges of the northern Mount Lofty Ranges to the Gulf St Vincent (DEWNR, 2016). Median, 10th %ile and 90th %ile monthly flow volumes were calculated for two locations: downstream (Station: A5051003, data available between 2010 and 2017) and upstream (Station: A5050532, between 2002 and 2017) and are presented in **Figure 4–2**. Similar to the Gawler River, flow volumes are low during the dry seasons (summer-autumn: median values ~0.0 ML for Station: A5051003 and ~20 ML for Station: A5050532); at the beginning of the wet season (June: 0.0 ML for Station: A5051003 and 70 ML for Station: A5050532) and the end of the wet season (November: 0.0 ML and 24 ML, respectively). During the other winter-spring season months (July-October), water could be extracted (median value of total volume: ~0.7 GL at Station: A5050532), but the available volumes (10th %ile: ~ 0.0 GL; 90th %ile: 2.1 GL) are highly influenced by the climate conditions i.e. rainfall amounts and patterns.

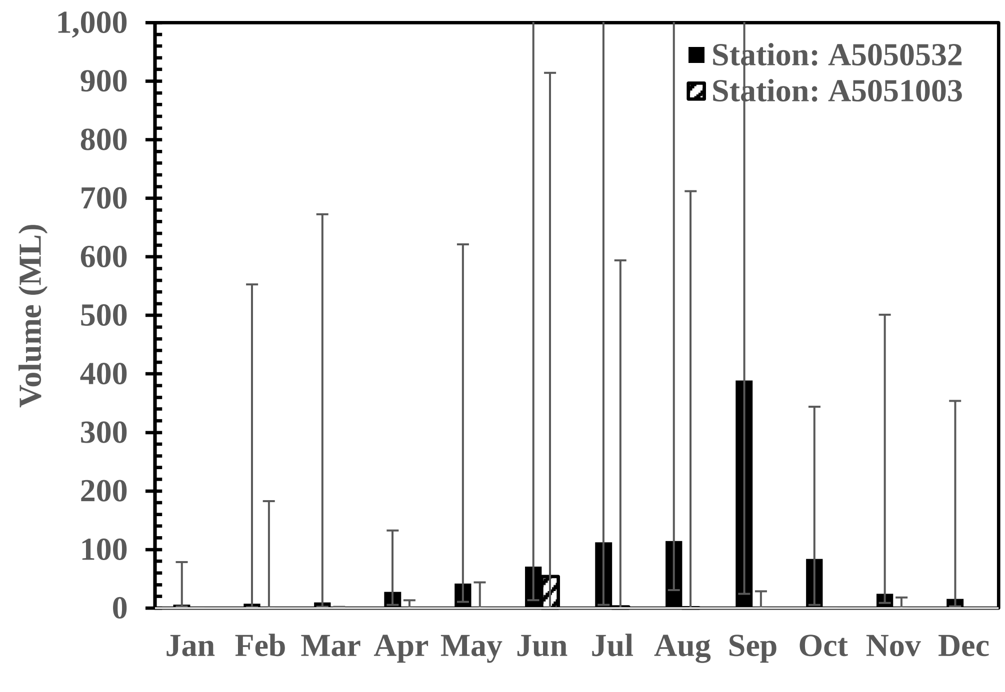

Figure 4–2. Median monthly flow volumes at Station: A5051003 and Station: A5050532, Light River. The top bars represent the 90th %ile values.

Water quality

Monthly salinity levels at Station A5050532, for the Light River are presented in Figure E–4, and Table E–2 summarises the qualities of samples collected from Light River at other points. TDS values are very high (TDS > 4000 mg/L) as shown in Figure E–4 and the calculated EC_{se} levels for various soil textures exceed the threshold values for all the crop types considered in this study. The SAR values were significantly higher for water samples collected from the Light River (median: 17.4) compared with waters from the Gawler River (median: 6.2). Despite the high SAR and salinity levels in Light River, the water quality falls into the first category of 'stable soil structure, as shown in **Figure D–1**, Appendix D.

Chloride (median: 3390 mg/L; 75th %ile: 3565 mg/L) and sodium (median: 1605 mg/L; 75th %ile: 1707 mg/L) values exceed the trigger values for prevention of foliar injury in all crops. Boron concentrations (median value: 0.9 mg/L) significantly exceed the trigger value (median: 0.5 mg/L). In contrast, pH levels (median: 8.2) do not exceed the trigger values (<6.5 and >8.5).

4.2. Urban stormwater

The study area of this project lies within the EFPAs with ~97.4% of the area identified as primary production land, 1.2 % of the area identified as animal husbandry zone and the remaining (1.4%) identified as rural living areas, as shown in **Figure E–5**. The capture of stormwater from these urban areas for the purpose of horticulture irrigation appears to be currently limited based upon the small percentage of urbanised area (1.4%) and lack of stormwater transfer networks. However, based on the stormwater management plan for Two Wells, the estimated total stormwater runoff volume is 1.0 GL annually from both current and projected (30 years urban growth area) urban catchments (total: 538 ha) (O'Broin et al., 2017). According to O'Broin et al. (2017), in order to capture and use at least 75% (0.76 GL, target post-development runoff for reuse) of the runoff, a large-scale MAR scheme would be required[11]. For the Roseworthy township, estimated total stormwater harvesting yield from current and future expansion areas (30 years urban growth area) is ~0.7-1.0 GL annually (Light Regional Council, 2014) while urban stormwater from the Freeling township is ~0.2 GL annually (Light Regional Council, 2016b). Stormwater infrastructure, treatment trains, reuse recommendations and proposed areas for expansions of these townships have been described by Light Regional Council (2014) Light Regional Council (2016b) and O'Broin et al. (2017).

Despite the current limitation of urban stormwater from urban areas within the study region, it has been estimated that ~5 GL per annum of urban stormwater may be available from Dry Creek catchment which is outside of the study area (GIWR, 2016). Infrastructure (e.g. pipelines and pumping) is not currently available to allow use of this water resource for irrigation purposes within the NAP and north of Gawler River but conceivably could be available in the future.

Water quality

The Managed Aquifer Recharge and Stormwater Use Options (MARSUO) project (supported by GIWR) monitored and summarised urban stormwater quality of the Parafield and neighbouring catchments of

[11] Current catchment areas (outside of the 30-year urban growth areas) are not sufficient to provide the runoff volume required to consider the MAR scheme as financially viable (runoff volume: 200 ML/year or more (O'Broin et al., 2017)) and this would need all of the 30-year urban growth area to have been developed

Salisbury (Page et al., 2013). The Parafield stormwater harvesting scheme operates within the Dry Creek catchment. In the present study, an assumption was made that treatment and storage requirement (i.e. detention basins, constructed wetlands and ASR) for the potential ~5 GL per annum of urban stormwater that could be extracted from Dry Creek would be similar to the Parafield stormwater harvesting scheme (i.e. being in same catchment). The qualities of waters of urban stormwater at Parafield (summarised in **Table E–4**, adapted from Page et al. (2013)) were used here to estimate the water qualities for such a further development.

Using **Equation 3-1** and median salinity level (235 mg/L) of the recovered waters, EC_{se} levels for various soil textures were calculated. These were found to be less than the threshold values of all considered crop types of this study. Median values for EC_i (0.4 dS/m) and SAR (1.6, **Table E–4**) were graphed (see **Figure D–1**, Appendix D) and the Parafield stormwater quality values are within the category 'stable soil structure'. Chloride (median: 35 mg/L; 95th %ile: 146 mg/L) and sodium (median: 42 mg/L; 95th %ile: 120 mg/L) values are less than the trigger values for prevention of foliar injury in sensitive, moderately sensitive, moderately tolerant and tolerant crops. Other WQ parameters (i.e., nutrients, anions and cations) are summarised on **Table E–4**. Concentrations of these WQ parameters are less than the corresponding trigger values of the ANZGFMWQ (ANZECC and ARMCANZ, 2000).

4.3. Rooftop stormwater runoff

Based on the 2016 land use mapping of intensive horticulture categories, ~1740 ha of greenhouses is established within the NAP and north to the Light River (**Figure E–7**). This includes 1588 ha of polyhouses (NAP-south of the Gawler River: 1321 ha; NAP-north of the Gawler River: 267 ha), 89 ha (NAP-south of the Gawler River: 15 ha; NAP-north of the Gawler River: 74 ha) of glasshouse-hydroponics and 61 (53 vs 8) ha of shade-houses (**Figure E–8**). Greenhouses are most frequently on parcels of land of between 2 and 8 ha (average surface area per greenhouse structure: 2000 m^2) and are concentrated north east of the Virginia township (**Figure E–7**).

Rainwater harvesting from greenhouse roofs can be used as a further source of fresh water for horticulture irrigation water supply. Based on the survey conducted, the amount of captured rainwater could meet all crop demands for up to 4 months for individual farmers. The growers use harvested rainwaters when it is available to meet the crop demands, and then use other sources (reclaimed water or groundwater) during the remaining periods of crop cycles. Based on the historical climate data, median annual volumes of rainwater (5% losses estimated) that can be captured from a hectare of greenhouse (polyhouses or glasshouses) are, 4.5 ML, 3.8 ML and 3.3 ML for NAP36, NAP1 and NAP38 areas, respectively. Based on climate change modelling (median values between 2020 to 2050), these are volumes are 4.2 ML, 3.4 ML and 3.2 ML for the corresponding areas. Consequently, ~5.7 GL (NAP-south of the Gawler River: ~4.6 GL; NAP-north of the Gawler River: ~1.1 GL) measured as median value (10th %ile: 2.7 GL; 90th %ile: 8.9 GL) of extra water can potentially be captured from the existing greenhouses within the NAP and north to the Light River. Monthly volumes of rainwater that can potentially be captured from greenhouses are shown in **Figure E–9**. Infrastructure (e.g. gutters, pipelines and storage tanks/dams) would be required to allow harvest and reuse of this water resource for irrigation purposes.

Water quality

Water samples were collected from harvested rainwater from poly- and glass-greenhouse roofs within the NAP and qualities of waters are shown in **Table** E–5**.** The salinity levels (at the beginning of the wet season: 74 mg/L; end of the wet season: 109 mg/L) were found to be low and the concentrations for other WQ parameters (i.e. ions, nutrients and metals) were found to be much less than the corresponding trigger values detailed by ANZGFMWQ (ANZECC and ARMCANZ, 2000). Although pH levels (median, at the beginning of the wet season: 7.4; end of the wet season: 8.2) were found to be higher than for reclaimed water, these were less than the 8.5 trigger value.

During the survey, it was noticed that most of the greenhouse roofs within the NAP region are whitened, with a white-paint (e.g. 5-Chlor-2-methyl-4-isothiazolin-3-on/2-methyl-2H-isothliazol-3-one, Q4 White, Hermadix), with chemicals (e.g. Whitefix, Royal Brinkman) or with chalk (CaO or $CaCO_3$) between November and April-May to reduce the solar radiation load and temperature control inside the greenhouses. Using chalk can led to increase in the pH level of the harvested rainwater especially during the first-flush. Therefore, it is recommended to monitor the pH level of harvested rainwater. Furthermore, removal of the white-paint (during the cold months to increase the light transmissivity and temperature in the greenhouse) needs a specific chemical agent (e.g. sodium hydroxide base, Removit, Hermadix). After applying the chemical agents, the first-few surface runoffs (first-flush) from the treated greenhouse roofs may be harmful to the plants and should be discarded. The first-flush volume varies as this depends on the timing and intensity of rainfall events and on the amount of the sprayed paint which is related to the targeted light penetration (light screening). E. coli were detected in water samples collected from the harvested rainwaters (beginning of the wet season: 1100 cfu/100 mL; end of the wet season: 195 cfu/100 mL). Consequently, management of pathogen risks will need to be considered as would apply to surface runoff impacted by grazing and urban stormwater. Options are prevention or treatment (e.g. discarding first flush and UV irradiation).

4.4. Mains water

Despite the price of mains water being high for the purposes of irrigation in South Australia ($2.362/kL-$3.652/kL)[12], it was evident during the survey conducted that some growers use mains water (when no other suitable source water is available and/or to supplement existing water supplies) for irrigation of greenhouses crops. **Figure E–10** shows the mains distribution system within the study area adapted from South Australian Government Water Main Data Collection (SA Water, 2018). Qualities of mains waters are with the Australian Drinking Water Guidelines (NHMRC, 2011) and as expected, are less than trigger values for each WQ parameter for irrigation water identified by ANZECC and ARMCANZ (2000).

[12] https://www.sawater.com.au/accounts-and-billing/current-water-and-sewerage-rates/residential-water-supply

5. Groundwater

Groundwater has historically been the major source of water supply for horticulture on the NAP (RPS Aquaterra, 2011). Groundwater use in this area is predominantly within the Northern Adelaide Plains Prescribed Wells Area (NAP PWA), which covers an area of approximately 800 km^2, centred 30 km north of Adelaide (Zulfic and Wohling, 2004). The northern boundary of the NAP PWA is located within the study area. However, to the north of the NAP PWA, there is limited groundwater use or hydrogeological information. Due to the lack of knowledge of the northern areas of the NAP, many predictions regarding the potential of aquifers for water supply or for water storage (managed aquifer recharge, MAR) are based on the hydrogeological understanding of the adjacent NAP PWA. Therefore, the discussion of groundwater as a resource for horticultural development in the current assessment is considered within two separate zones; (i) the NAP PWA and (ii) north of the NAP PWA. To the east of the NAP PWA, lie the fractured rocks of the Adelaide Hills, from which the Tertiary aquifer system is recharged (RPS Aquaterra, 2011).

5.1. Overview of hydrogeology

The sedimentary aquifer system of the Adelaide Plains comprises a complex arrangement of Tertiary and Quaternary aged units of the St Vincent Basin and a total thickness of up to several hundred meters. In the NAP, there are up to six Quaternary aquifers (Q1-Q6) and up to four confined Tertiary aquifers (T1-T4). The two shallowest Tertiary aquifer (T1 and T2) are the main sources of groundwater used for horticulture on the NAP (DEWNR, 2016, RPS Aquaterra, 2011, GIWR, 2016).

5.1.1 Quaternary aquifers

The Quaternary sediments are confined by six layers of low permeability sediments (Cb1-Cb6) and are typically considered as a single hydrostratigraphic unit called the Hindmarsh Clay, which acts as an aquitard (Bresciani et al., 2015). The shallowest aquifer is the perched aquifer, which forms when the infiltrating surface is hindered by low permeability sediments. The role of this shallow, perched aquifer within the Quaternary sediments in contributing to waterlogging and soil salinisation when irrigation is applied, is considered in Task 4.

5.1.2 Tertiary aquifers

The first Tertiary aquifer (T1) is comprised of Hallett Cove Sandstone, Dry Creek Sand, Carisbrooke Sand and limestone of the Upper and Lower Port Willunga Formation (Bresciani et al., 2015). The T1 aquifer is absent in the northeast portion of the NAP PWA (~ between Two Wells and Gawler) (GIWR, 2016) and is typically confined by Quaternary sediments, aside from where it outcrops, between the Hope Valley and Eden Burnside faults and to the east of the Para fault (south of this study area) (Bresciani et al., 2015).

The T1 aquifer extends well to the north of the NAP PWA, where it is believed to consist mainly of sand and contains salinity groundwater above 2000 mg/L TDS (GIWR, 2016). Previously the T1 aquifer was considered to extend from the coastline in the west to Hamley Bridge in the east and past Port Wakefield and Balaklava in the north (Figure F–2) (GIWR, 2016). However, the Adelaide Plains Numerical Groundwater Model 2011 (AP2011) (RPS Aquaterra, 2011) and inspection of available borehole logs in the study area revealed the absence of the T1 aquifer to the east of the Redbank Fault (**Figure F–4**).

The groundwater resource of the T1 aquifer is currently used in the NAP PWA; it is the only aquifer used in the southern part of the NAP PWA where it contains fresh groundwater (<1000 mg/L TDS), near Waterloo Corner (south of this study area).

The second Tertiary aquifer (T2) is comprised of sandy limestone of the Lower Port Willunga Formation (Bresciani et al., 2015). The T1 and T2 aquifers are separated by the Munno Para Clay, an aquitard for the T2 aquifer. The T2 aquifer does not extend beyond the PWA boundary due to the absence of Munno Para Clay. It is important to note that some literature reports that the T1 aquifer pinches out toward the north while the T2 aquifer extends further north. In this report the shallowest Tertiary aquifer that extends to the north, beyond the north-western boundary of the PWA (where the intervening Munno Para Clay confining layer is absent), is referred to as T1 (S. Barnett, pers. comm., 2018).

The T2 aquifer is also used as a groundwater resource in the NAP PWA; it is the main aquifer used in the northern part of the NAP PWA between Virginia and Gawler where it contains fresh groundwater (<1,000 mg/L TDS) and in some places the T1 aquifer is absent.

5.1.3. Fractured rock aquifers

Non-prescribed fractured rock aquifers are present in the eastern portion of the study area.

5.2. Groundwater use and water supply opportunities

The NAP PWA was implemented in 1976 due to increasing demands and concerns regarding the sustainability of the groundwater resource (RPS Aquaterra, 2011). This area was proclaimed in 1976, followed extensive groundwater extraction in the 1960s (Zulfic and Wohling, 2004) and for this area there is a water allocation plan for the sustainable use of groundwater resources (Government of South Australia, 2000). Groundwater use in the Kangaroo Flat region was prescribed in 2004 and is now encompassed in the NAP PWA (DEWNR, 2017).

Groundwater recharge occurs in the fractured rocks of the Adelaide Hills, and then feeds laterally into the Tertiary aquifer system towards the Gulf St Vincent (RPS Aquaterra, 2011). Water recharging the Tertiary aquifers is not considered susceptible to climate change as the deeper confined tertiary aquifer are recharged from lateral flow from connected aquifers rather than infiltration of contemporary rainfall (GIWR, 2016).

Comprehensive understanding of a groundwater system and its water balance is required in order to establish limits of sustainable groundwater extraction and use. The Adelaide Plains Numerical Groundwater Model 2011 (AP2011) (RPS Aquaterra, 2011) was developed to assist with management of the groundwater resources of the NAP. The model domain extends from the Eden Burnside Fault south of Adelaide to the Light River in the north and encompasses the NAP PWA.

As there is little information/understanding of the groundwater system north of the NAP PWA, it was not possible to define sustainable use targets. As noted previously, estimates of potential water supply were based on the hydrogeological understanding in the adjacent NAP PWA. Data is required to improve these estimates. In the NAP PWA, the hydraulic conductivity in the T1 aquifer is reported as 2.5-4 m/day, and 0.75 m/day in the T2 aquifer (RPS Aquaterra, 2011). It can only be assumed that the T1 aquifer north of the NAP PWA has a comparable hydraulic conductivity to that within the PWA.

The metered extraction from the Quaternary aquifers is approximately 540 ML/yr and is below the allocated volume of 3.2 GL/yr (GIWR, 2016). The groundwaters of Quaternary sediments do not constitute a resource that can be considered suitable for irrigation supply i.e. yields are too low and salinities are high.

The volume of groundwater currently extracted from the T1 (3.4 GL/yr in 2014-15,(DEWNR, 2016)) and T2 (8.5 GL/yr in 2014-15, (DEWNR, 2016)) aquifers in the PWA is considered to be at its limits (GIWR, 2016). While the current use of groundwater is well below the allocated extraction limit of 7.26 GL/yr for the T1 aquifer and 19.86 GL/yr for the T2 aquifer (27.12 GL/a in total, GIWR, 2016), it is considered that the aquifer is over-allocated and use of the entire allocation would have adverse impacts. Recommended limits of extraction are 3.5-3.8 GL/yr for the T1 aquifer and 15.9-16.8 GL/yr for the T2 aquifer (GIWR, 2016). This represents potential for some increase in extraction for current licensees from zones with lower salinity levels and extraction of an additional 2-3 GL/yr, predominantly from the zones beyond the major better water quality extraction zones (TDS > 2000 mg/L) from the T2 aquifer. Groundwater within the T1 aquifer in the NAP PWA cannot be considered as a significant available resource to support development. Groundwater within the T2 aquifers in the NAP PWA may be available to support expansion of horticulture. The deeper T3 and T4 aquifers are not considered to be a resource for irrigation supply due to high salinity groundwater (more saline than seawater) and the depth to access water (GIWR, 2016).

The T1 aquifer extends beyond the northern boundary of the NAP PWA and can be considered a potential groundwater resource for use in the study area of this project. Currently there is little use of water for irrigation in this area (GIWR, 2016). The area extending past Port Wakefield and Balaklava in the north was estimated to contain approximately 22 GL of water that could be extracted from T1 aquifer per year, however the salinity is generally unfavourable for irrigation use. Of this 22 GL approximately 4 GL/yr is between 2,000 and 3,000 mg/L (18%), 10 GL/yr is between 3,000 and 7,000 mg/L (45%) and 8 GL/yr is expected to be over 7,000 mg/L (37%)(GIWR, 2016).

Within the bounds of this assessment, which extends to the Light River in the north, it is estimated that less than 2 GL/yr of water may be available for irrigation; 1.0-1.5 GL/yr between 3,000 and 7,000 mg/L and <0.5 GL/yr above 7,000 mg/L. Based on the current knowledge of groundwater salinity, the groundwater resource from the T1 aquifer within this study area but to the north of the NAP PWA does not meet the irrigation and general primary industries use environmental value (SA EPA, 2015)(**Figure F–2**). Higher salinities, such as found in the study area, meet the livestock drinking water and aquaculture environmental values. Currently there is no chemistry data aside from salinity and selected major ions within this TDS category (**Table F–3** and **Table F–4**). Therefore, the suitability and management of water quality will need to be assessed prior to development of the groundwater resource. Areas with lower salinity groundwater (<3,000 mg/L) around Mallala and Balaklava fall out of the bounds of the current study area. However, it is possible that these zones could be redefined with greater amount of groundwater data.

Groundwater from the T1 aquifer to the north of the NAP PWA is available for use and can be considered as an available resource to support development; however, salinity levels may require management prior to use. Background groundwater quality will need to be assessed to ascertain if groundwater poses any other water quality concerns.

Fractured rock aquifers are currently used for localised irrigation and stock watering. The fractured rock aquifers do not constitute a significant groundwater resource to be considered for irrigation supply due to variable and low yields.

5.3. Managed aquifer recharge: aquifer storage and recovery (ASR)

MAR is defined as the intentional recharge of water to aquifer for subsequent recovery or environmental benefit (NRMMC-EPHC-NHMRC, 2009). Aquifer storage and recovery (ASR) is a MAR technique that uses a single well for injection and recovery; direct injection using ASR targets confined aquifers (NRMMC-EPHC-

NHMRC, 2009). Kretschmer (2017) reports 58 ASR schemes have been constructed in the Adelaide metropolitan area since 1989; of these approximately 10 schemes lie north of the Little Para River. There are currently 36 EPA licences for ASR and at least three schemes under investigation (**Figure F–10**).

In the NAP PWA, both the T1 and T2 aquifers are used to store urban stormwater and recycled water (treated wastewater) for subsequent non-potable use via ASR. The majority of current ASR schemes store stormwater or surface water with fewer operational recycled water schemes.

Notably, there is only one trial ASR scheme in the Tertiary aquifers in the current study area. This trial is the Ward Belt MAR scheme, otherwise known as Gawler Water Reuse Scheme (D.L. Edwards, pers. Comm. 2018). The proposed annual volume is 600 ML (a combination of Gawler River water and recycled water) (Light Regional Council, 2016a).

The Ward Belt MAR team recently received a DEW drainage and discharge permit to conduct a trial injecting 60 ML of groundwater extracted from a well nearby the proposed MAR well. This forms part of the necessary investigations (Stage 2 and Stage 3 investigations as per the MAR Guidelines, (NRMMC-EPHC-NHMRC, 2009)) prior to them applying for an EPA licence to discharge Bolivar reclaimed water to groundwater and/or applying for a drainage and discharge permit for the proposed scheme (D.L. Edwards, pers. comm., 2018).

On the southern boundary of this study area, the Food Forest MAR scheme is in final stages of EPA approval utilising Gawler River water and stormwater. The target aquifer is the Q4 (Carisbrooke) and the proposed annual injection volume is around 25 ML (D.L. Edwards, pers. comm., 2018). However the Q4 aquifer supports only small-scale or domestic-scale ASR (Hodgkin, 2004) and is not considered as a target for MAR in this assessment.

There is a proposed MAR scheme, south of Buckland Park, in the initial stage of investigations (Stage 1 as per the MAR Guidelines, (NRMMC-EPHC-NHMRC, 2009)); the proposed source water is roof runoff and Bolivar reclaimed water and the target aquifer is either the T1 or T2 aquifer (P. Okely, pers. comm., 2018).

A large-scale MAR facility is planned within the Northern Adelaide Irrigation Scheme (NAIS) project. A scheme capacity of ~4 GL/yr is planned in the vicinity of the Bolivar wastewater treatment plant (on SA Water land), comprising of approximately 25 ASR wells, spaced 250 m apart. The initial stage of MAR scheme development will consist of 10 ASR bores, equating to an approximate capacity of 1.6 GL/yr.

Given the widespread application of ASR in the T1 and T2 aquifer within the NAP PWA, these aquifers are considered for MAR within the study area of this project.

Fractured rock aquifers are used for ASR, but as with groundwater supply this is considered a localised storage options with less certainty of hydrogeological properties due to variable and low yields. Fractured rock aquifers are not considered as significant storages to support MAR in the study area.

5.4. Assessing the suitability of Tertiary aquifers for ASR

Given the lack of hydrogeological information for the area north of the NAP PWA, it was assumed the tertiary aquifer (T1) has similar properties to that in the NAP PWA. The discussion of MAR potential is also considered within two distinct zones; (i) the NAP PWA and (ii) north of the NAP PWA.

The MAR Guidelines (NRMMC-EPHC-NHMRC, 2009) provide a risk-based framework to assess the feasibility of a MAR scheme in relation to human health and environmental risks. The guidelines begin with a simplified assessment for small-scale projects with a low inherent risk (e.g. infiltration of domestic roof runoff into suitable water table aquifers for non-potable end use). All other projects are subject to four stages of project assessment and development. Stage 1 is entry-level assessment which is a desktop study using available data. Stage 2 involves investigations and risk assessment to assess and manage health and environmental risks associated with MAR projects. Typically, investigations are undertaken to provide necessary information to determine if the MAR scheme is technically feasible. Stage 2 of the MAR guidelines, in combination with a socioeconomic assessment could be considered as a scheme-scale feasibility assessment. Stage 3 is MAR scheme construction and commissioning, and Stage 4 is operation of the scheme.

The assessment of suitability of Tertiary aquifers for ASR in the study area of the current project aligns with Stage 1 of the MAR Guidelines as it draws on available data. The key attributes used to consider ASR feasibility in the T1 (**Figure F–11**) and T2 (**Figure F–12**) aquifers are the groundwater environmental value (based on TDS), the proximity to existing groundwater wells, the depth to the top of the aquifer and the thickness of the aquifer and the depth to water (**Table** F–2). This preliminary assessment provides guidance as to the most prospective locations to consider in more detail; however, the focus of the current assessment is predominantly on the hydraulic impact of ASR.

Given the lack of data to the north of the NAP PWA, further investigations (Stage 2) are required to determine aquifer physical and hydraulic properties in locations considered to offer promise for ASR. Furthermore, the Stage 1 entry-level assessment in the MAR Guidelines identifies all knowledge gaps where Stage 2 investigations are required to assess and manage human health and environmental risks. As noted above socioeconomic assessment is a key component of scheme-scale feasibility assessment; in particular where non-potable water sources such as recycled water or urban stormwater are used in ASR.

5.4.1. Within the NAP PWA

Within the NAP PWA, both T1 and T2 aquifers are present. While these aquifers can be screened for their suitability for ASR, calibrated groundwater models exist (AP2011) which allow more advanced assessment of hydraulic impacts.

Thickness and salinity are potential constraints for ASR in the T1 aquifer in the southern portion of the study area that lies in the NAP PWA. Thickness is a limitation aside from the western portion of the study area, adjacent to the coast. Salinity < 1500 mg/L TDS in the vicinity of Gawler River may be of drinking water environmental value and therefore injection of recycled water may be less favourable in this zone. The potential for ASR in the T1 aquifer in the NAP PWA is limited to the western portion of the study area (west of the Port Wakefield Rd). However, the potential for horticulture in this area is limited by the presence of shallow, saline groundwater. Based on this, the potential for horticulture development is hydroponics with desalination.

Salinity and proximity to existing groundwater users are the main constraints for ASR in the T2 aquifer within the NAP PWA. It is feasible that additional ASR schemes could be considered in the T2 aquifer to support growth in horticulture.

5.4.2. North of the NAP PWA

Based on salinity and potential environmental value of the aquifer, the majority of the T1 aquifer north of the NAP PWA study area is suitable for recycled water ASR (**Figure F–11**), subject to further assessments of risks associated with specific projects. Current knowledge indicates that ambient groundwater salinity exceeds 3,000 mg/L in most of this area. Given the importance of salinity for horticulture end-uses of recovered water, it will be necessary to consider the impact of mixing on the salinity of the stored and recovered water.

Consideration of proximity to groundwater users is most relevant in the vicinity of Two Wells where groundwater salinity is 2,000-3,000 mg/L. Aquifer thickness (**Figure F**–**13**) and depth to the top of the aquifer (**Figure F**–**15.**) do not appear to be constraints to development of ASR in the T1 aquifer north of the NAP PWA. However, it will be important to characterise heterogeneity in the aquifer and construct the ASR well appropriately, in zones with suitable permeability; low permeability limits injection and recovery rates while high permeability can result in decreased recovery efficiency. Given the limited use of groundwater north of the NAP PWA, the depth to groundwater may be less than the preferred level, which will reduce the Safe Operating Pressure (SOP) of the ASR scheme. It is necessary to define the local conditions to assess the feasibility of a scheme.

6. Survey of horticulturalists

To assist in evaluating water source options, an understanding of current irrigation and soil management practices in the NAP region was necessary. The existing horticultural region consists of a broad range of irrigation practices and has well-established use of recycled water since 1999. Over this period, the region has also experienced pressures from increased mains water prices and regulated use of limited groundwater resources. A survey could not only assist is identifying industry practices in the use and management of water sources for irrigation but also could help identify potential new opportunities to enhance the use of water sources. A survey was conducted to obtain information on growing periods for various crop types, crop rotation cycles, current irrigation systems and practices, water treatment and storage facilities and current practices used to manage soil sodicity and water salinity. **Table B–1, Table B–2** and **Table B–3** summarise the findings of the survey.

6.1. Management practices

In this survey, growers interviewed responded that soil samples are regularly collected between crop cycles (at depths of 0-15 cm) for soil analyses. Examples of soil analyses are given in **Table B–4**, Appendix B. Respondents detailed that these analyses are for determination of fertiliser requirements (e.g. N, P, K and S) and recommended calcium addition (mainly by addition of gypsum) for each specific crop type.

Based on this landholder survey, standard industry management practices within the NAP include addition of gypsum, compost and soluble calcium. According to one horticulture supply company, the method detailed by Mikhail (2017) is applied by some growers to determine the amount of Ca^{2+} (gypsum, see also **Figure B–2**) that is required for maintaining suitable soil properties.

As would be expected, a standard industry practice within the NAP region is compost addition (e.g. chicken manure). An example of the chemical properties of a compost that is used in the region is shown in **Figure** B–3. For open-field crop types (i.e. potato, carrots and onions), crop rotation with cover crops (e.g. oats) is commonly used to increase the soil organic matter (see **Table B–1**).

Leaf tissue analysis (~2 times during the crop cycle, **Table B–1**) is commonly performed by growers in the region. This is used to assess the need for supplementing crop nutrients and minerals. Applying liquid soluble calcium (i.e. used of 6% soluble calcium to reduce the % sodium by 5-10% in plant tissue) to the irrigated water is a common industry practice within the NAP region to control Ca deficiency with broad-leafed crops.

6.2. Irrigation practices

In situ sensor technology (e.g. soil moister sensors) is not commonly used by small enterprises within the NAP region (i.e. only one grower reported using soil moisture sensors) to schedule and calculate irrigation requirements. Growers schedule irrigation events based on their own experiences, the growth stage of various crops and on-air temperature. From information provided by growers, the following temperature threshold values and ranges were identified for scheduling of different irrigation frequencies: temperature < 20 °C, temperature between 20 °C to 25 °C, temperature between 25 °C to 30 °C, temperature between 30 °C to 35 °C and temperature > 35 °C with the following irrigation frequencies: once/week, every 4th day, 3 times/week, every second day and daily, respectively. Also, landholders apply irrigation distinctly for the leaching of salt from the soil profile. Examples of total irrigation volume used within the region are presented in **Table B–3**.

For open-field crops, total applied irrigation volumes for potatoes (560-660 mm) and carrots (1550 mm) were found to be higher than the corresponding crop water requirements based on the FAO56 method (potatoes: 409 mm using median Pc and ET_0 values, 246 mm using 10^{th} %ile Pc and ET_0 values and 504 mm using 90^{th} %ile Pc and ET_0 values; carrots: 1376 mm using median Pc and ET_0 values, 1290 mm using 10^{th} %ile Pc and ET_0 values and 1153 mm using 90^{th} %ile Pc and ET_0 values). While actual total applied irrigation volumes for almonds (870-940 mm) were found to be lower than the corresponding crop water requirements based on the FAO56 method (1282 mm using median Pc and ET_0 values, 1292 mm using 10^{th} %ile Pc and ET_0 values and 1176 mm using 90^{th} %ile Pc and ET_0 values).

Based on the survey findings, growers prefer to use water sources with high water quality (i.e. water with low salinity) during the leaf development & active growth of new shoots (e.g. between Aug-Sep for almonds) and for soil flushing (~every third irrigation events) if more than one water source is available. Furthermore, growers of the NAP harvest rainwater runoff from greenhouses and use it when needed and available. This could be to meet crop requirements for up to 4 months without additional sources (dependent on crop type and the available storage capacity). In this Task, volumes of rainwater that can be harvested from greenhouse roof and irrigation requirement for the common greenhouse crop types (i.e. tomato, cucumber, capsicum and eggplant) within the study region, based on historical and future climate data, were calculated. Median capture rainwater volumes between June to September were found to be sufficient for irrigation volume requirement during those months (example shown in **Figure G–1**).

In Section 7 of this report an 'Irrigation water quality and quantity for covered crop: 'IW-QC2' software tool' is described which was developed to provide information on the impacts of using different water sources of varying qualities on key greenhouse crop types. The modelling approach allows the running scenarios of different water sources and with treatment option (desalination). For example, using harvested rainwaters will lead to a decrease of the salt load added to horticulture land systems compared with some other water sources, i.e. brackish reclaimed water (examples shown in **Figure G–1:Figure G–2**). Harvested rainwater could also be used to flush the soil to clear of salt build-up from crop root zones. Horticulture practice in the NAP also includes the discard of roof runoff to adjacent land areas (including near roads) as shown in **Figure B–1**. This is due to the absence of a storage facility and perhaps a lack of understanding of the benefits of reuse of roof runoff.

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

7.1. Introduction

The advantage of greenhouse farming over field-grown crops is that with protected crops, the crop yields are proportional to the expenditure on seeds, planting and production, therefore providing a reliable return on investment. By comparison field-grown crops are exposed to natural, including extreme climate conditions. Greenhouse horticulture can also be a more water efficient than field cropping (Hadley, 2017). However, since the volume per area of crop production in a greenhouse is mostly higher than that produced in the open field, the annual water requirement per hectare in a greenhouse is greater than in open fields. One hectare of greenhouse can yield 10 times that of tomatoes grown in the same sized open field (Donnan, 2011). Therefore, a necessity for successful greenhouse production is the availability of sufficient water supply.

This section describes models that were developed to provide information on the quantity and quality of irrigation water, when blending different sources of water such as harvested stormwater with other sources (e.g. reclaimed water, Gawler River water). This was developed for the common greenhouse crop types (i.e. tomato, cucumber, capsicum and eggplant) within the study region, based on historical and future climate data. Predicted volumes of water that could be harvested from the greenhouse roofs can be used immediately when it is available (during the wet seasons) to minimise the storage requirements or could be used to blend with other water sources to achieve target WQs (for example, TDS) during a specific growth stage of crop plants (i.e., based on the 2018 survey findings, growers prefer to use a water source with less salinity level during the leaf development & active growth of new shoots). Consequently, two model scenarios were developed as follows: 1) using the harvested rainwater when it is available and 2) storing the harvested rainwater in a separate storage dam and reusing it when needed to achieve target WQs.

From these models, a software tool was designed for application by growers for decision-making of storage size and expected water quality of irrigation water. Outputs from this tool include: 1) volume of water that can be harvested according to greenhouse area, storage size and operating rules; 2) irrigation requirement according to theoretical demands and current practice; 3) time series daily data set of irrigation water quantity and quality (i.e., TDS, anions and cations). **Figure 7–1** outlines the modelling approach while a methodological description is presented in Appendix G - IW-QC2 software tool's methodological description.

7.2. Crop waters requirements

Annual irrigation water requirements for common current greenhouse crops and the annual salt loads associated with using reclaimed water as a sole source of irrigation (Scenario #1) and using blended waters (reclaimed water + harvested rainwater from the roof runoff) (Scenario #2 and Scenario #3) are demonstrated in **Table 7–1**. For Scenario #2, the harvested rainwater was used when it was available to minimise the storage capacity while for Scenario #3, the harvested rainwater was stored in a separate storage dam and then reused to achieve a target WQ for irrigation (i.e., TDS of irrigation water = 600 mg/L).

Using reclaimed water as a sole source of irrigation (Scenario #1) was found to add at least 5.1 t/ha/annum of salt to the horticulture system as shown in **Table 7–1**. For a storage capacity of 500 m^3, a minimum value of 2.3 ML/ha/annum (median value, Scenario #2) could be potentially harvested from the roof runoff and consequently this will reduce the volume of reclaimed water use required for irrigation by at least 36% (**Table**

7–1). Subsequently this will reduce the salt loading by at least 23%. Using harvested rainwater with the reclaimed water (Scenario #2) could enable increase in irrigation area[13] by at least 56% compared to using the same volume of reclaimed water without harvesting the rainwater (**Table 7–1**).

Table 7–1: 10th %ile, 50th %ile and 90th %ile of annual irrigation requirements and salt loads for the common greenhouse crops on the NAP (Eggplant, Capsicum, Tomato and Cucumber)

Crop types	Eggplant	Capsicum	Tomato	Cucumber
Scenario #1: Reclaimed water only [a]				
Reclaimed water (mm)	535 (464-609) [b]	802 (705-902)	521 (455-593)	521 (455-588)
Rainwater (mm)				
Salt load (t/yr)	5.5 (4.7-6.3)	8.3 (7.3-9.4)	5.1 (4.5-5.9)	5.4 (4.7-6.2)
Scenario #2: Reclaimed water & roof runoff (using harvested runoff when it is available)				
Reclaimed water (mm)	218 (68-377)	514 (309-687)	256 (132-366)	261 (92-414)
Irrigation volume (mm)	486 (425-553)	735 (652-822)	486 (428-553)	498 (438-566)
Salt load (t/yr)	2.9 (1.1-4.7)	6.4 (3.4-8.2)	3.0 (1.5-4.4)	3.4 (1.4-5.2)
Ratio (Scenario #2/ Scenario #1)				
Reclaimed water (%)	41 (15-62)	64 (44-76)	49 (29-62)	50 (20-70)
Salt load (%)	53 (23-75)	77 (52-87)	58 (33-75)	62 (30-84)
Potential irrigation area (%)	246	156	204	200
Scenario #3: Reclaimed water & roof runoff (using harvested runoff to achieve target TDS: 600 mg/L)				
Reclaimed water (mm)	280 (240-370)	521 (386-651)	314 (250-394)	284 (234-379)
Irrigation volume (mm)	490 (430-560)	721 (639-807)	482 (424-548)	483 (424-543)
Salt load (t/yr)	2.9 (2.6-4.3)	6.1 (3.8-7.9)	3.2 (2.5-4.5)	2.9 (2.5-5.0)
Ratio (Scenario #3/ Scenario #1)				
Reclaimed water (%)	52 (52-61)	65 (55-72)	60 (55-66)	55 (51-64)
Salt load (%)	53 (55-68)	73 (52-84)	63 (56-76)	54 (53-81)
Potential irrigation area (%)	191	154	166	183

[a] Input parameters for scenarios #1 and #2: Greenhouse area: 1 ha; storage volume: 500 m^3; Min. storage holding required: 100 m^3; storage area: 167 m^2; average roof runoff salinity: 100 mg/L; greenhouse ET adjustment: 0.6; Crop cycle(s): one cycle (Jan-Nov) for eggplant, one cycle (Jul-Apr) for capsicum, two cycles for cucumber (Aug-Dec and Feb-

[13] Potential irrigation area (%): percentage ratio between irrigation area of greenhouses by reclaimed water and harvested rainwater from the roof runoff to irrigation area of greenhouses by reclaimed water only.

May) and one cycle (Jan-Sep) for tomato; Climate data associated with NAP1 database; Greenhouse dimensions: 50 m x 7 m; No. of plant's lines: 5 for eggplant, 8 for capsicum and cucumber and 10 for tomato; dripper spacing: 0.15 m for all crops except cucumber (0.1 m); dripper flow rate: 1.5 L/h for all crop types except cucumber (1.7 L/h); surface mulches: No; Irrigation schedule: Once/week at T < 20°C, every 4th day at T 20-25°C, 3 times/week at T 25-30°C, every second day at T 30-35°C, and daily at T > 35°C. Input parameters for scenarios #1 only: Collection roof area: 0.0 ha. Input parameters for scenarios #2 only: Collection roof area: 1 ha; Model code # 1 i.e. using harvested rainwater when it is available. Input parameters for scenarios #3 only: Collection roof area: 1 ha; Model code # 2 i.e. using harvested rainwater to achieve target WQs; Target monthly TDS values: 600 mg/L. [b] 50th %ile (10th %ile - 90th %ile)

Results of Scenario #3 showed the ability of using harvested 'fresh' water to achieve the target TDS value of 600 mg/L when rainwater is blended with reclaimed water. This was achieved by using a storage capacity of ~600 m^3. Based on the median values, the target TDS value could be achieved during all of the growth periods for cucumber (cycle #1: Aug-Dec; cycle #2: Feb-May) and eggplant (Jan-Nov). For greenhouses planted with tomato and capsicum, the target TDS values could be achieved during most of the growth period (tomato: Jan-Sep except Mar; capsicum: Jul-Apr except Dec-Mar period). No such differences in the annual salt load added to the horticulture system was found by using harvested rainwater when it is available (Scenario #2) and those by storage and reuse harvested rainwater to achieve a target TDS of 600 mg/L (Scenario #3), as shown in **Table 7–1**. Using harvested rainwater with the reclaimed water (Scenario #3) to achieve a target TDS of 600 mg/L could also increase the irrigation area by at least 54% compared to using the same volume of reclaimed water without harvesting the rainwater (**Table 7–1**).

7.3. Effect of climate

In order to examine the effect of spatial locations on greenhouse production based on the potential volumes of rainwater that could be harvested, crop water requirements and WQ of irrigation waters and input parameters for Scenario #2 (see **Section: 7.2**) were used for capsicum production under climate conditions (predicted data) for the following NAP areas: NAP1, NAP36 and NAP38. As shown in **Figure 7–2**, the NAP36 area had the highest potential for rainwater harvesting from greenhouse roof runoff (Median: 2.5 ML/ha/annum) compared with NAP1 (2.3 ML/ha/annum) and NAP38 (2.3 ML/ha/annum), although these were similar. The irrigation volumes needed for greenhouses planted with capsicum were found to be similar (NAP36: 7.2 ML/ha/annum; NAP1: 7.4 ML/ha/annum; NAP38: 7.6 ML/ha/annum). The NAP36 area (had the highest potential for rainwater harvesting from greenhouse roof runoff) was calculated to have the least salt load (NAP36: 6.0 t/ha/annum) to the horticulture system compared with NAP1 (6.4 t/ha/annum) and NAP38 (6.6 t/ha/annum). Compared with historical climate data (based on Edinburgh RAAF weather station), the climate change projections model (median values of GFDL-ESM2M model, based on projection to 2100) was found to reduce the potential volume of rainwater that could be harvested per annum by ~12% and increase the amount of water that would be required from another source (i.e. reclaimed water) by ~26%. Consequently, the salt load added to the system could potentially increase by ~25% per annum.

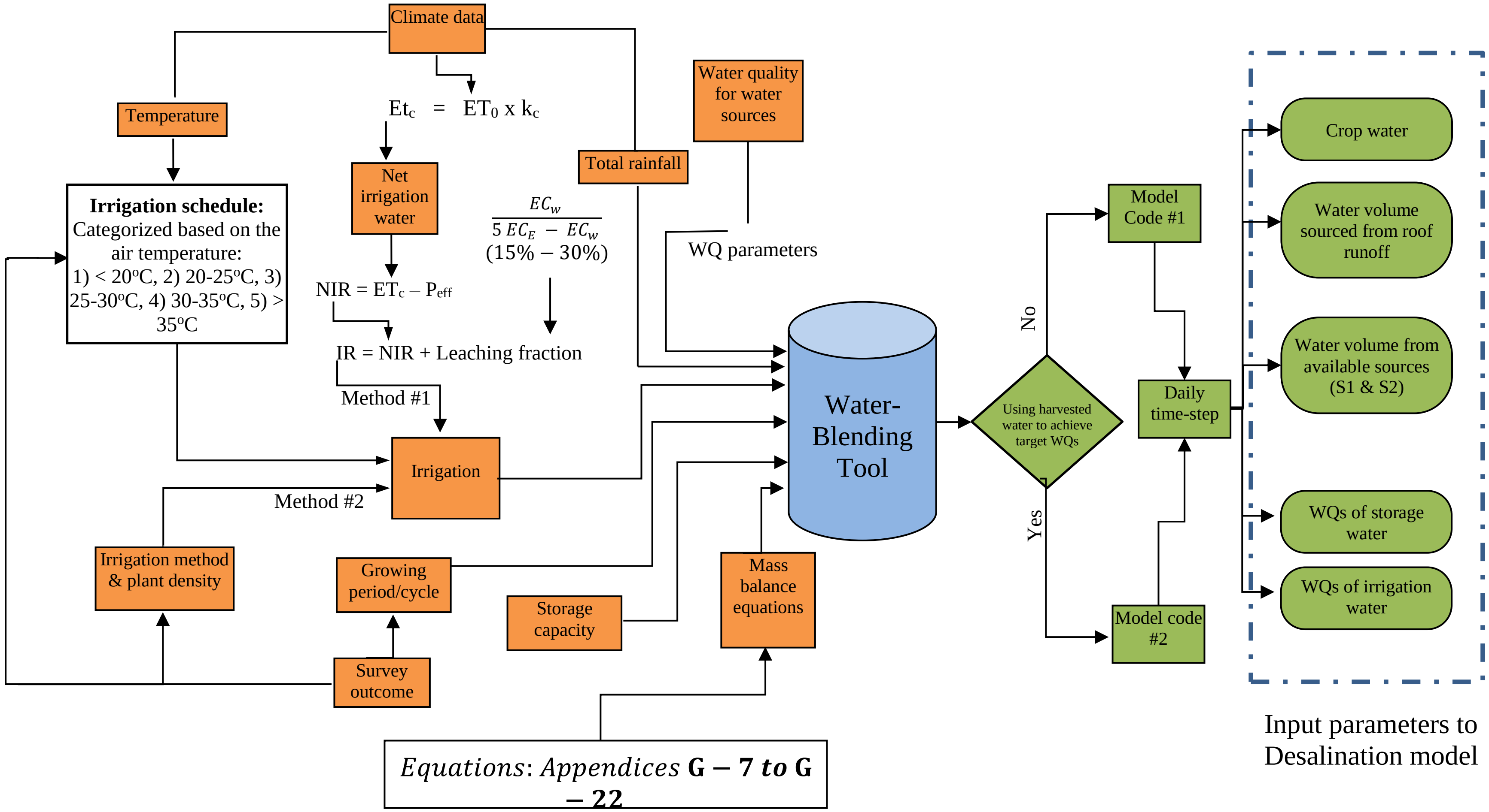

Figure 7–1. Modelling approach adopted for crop waters and water qualities of irrigation water.

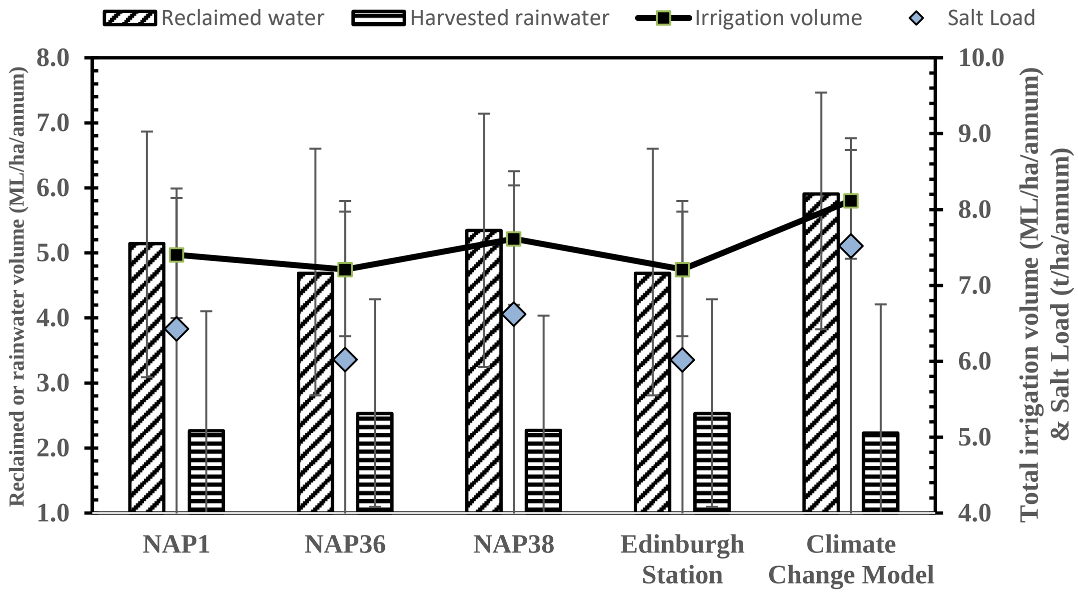

Figure 7–2. Annual median irrigation volume and salt load calculated by using various climate data set (described in Section 2.1). The top and bottom bars represent the 90th %ile and 10th %ile respectively.

7.4. Effect of storage volume

In order to examine the effect of storage capacity on the potential volume of rainwater that could be harvested and WQ of irrigation waters, input parameters for Scenario #2 (see **Section: 7.2**) were also used for greenhouse planted by capsicum under the following dam storage volumes: 0.0 (no rainwater harvesting), 50, 100, 150, 200, 300, 500 and 1000 m^3. As shown in **Figure 7–3b**, a power function was used to identify the relation between dam storage volume and potential volume of rainwater that could be harvested from the roof runoff. An exponential decay function (**Figure 7–3a**) was used to identify the relation between dam storage volume and annual irrigation volume from the other source water (i.e., reclaimed water).

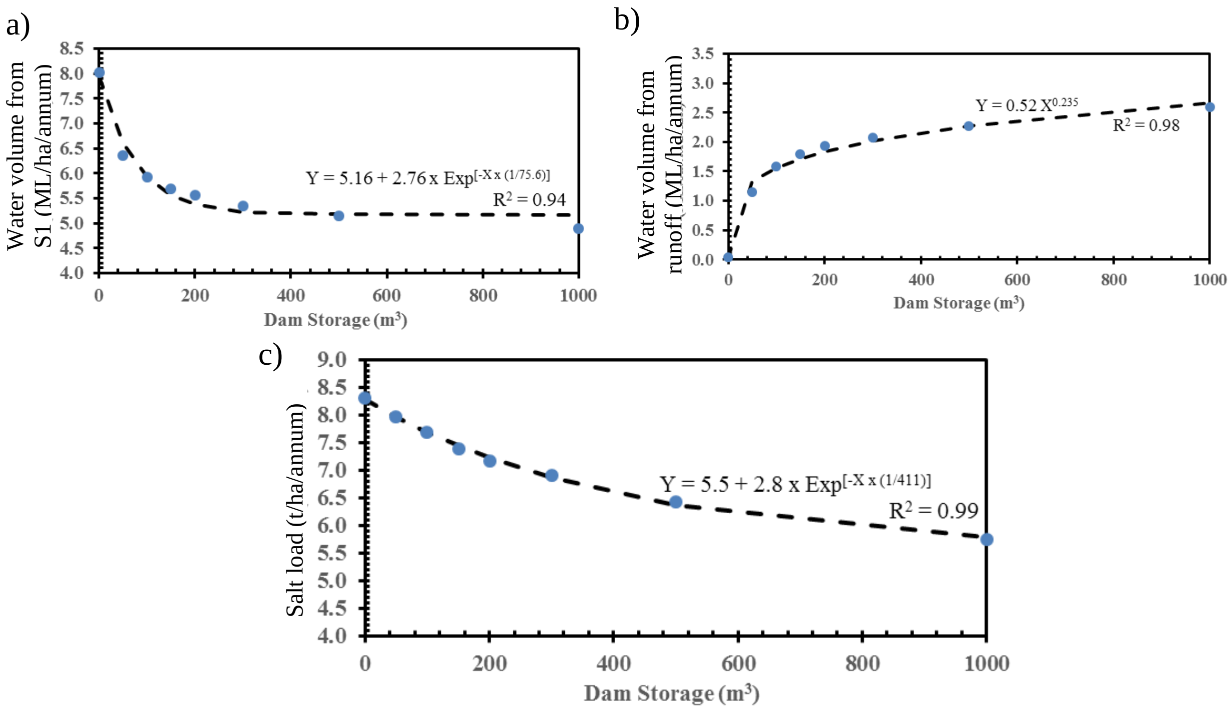

Figure 7–3. Annual median irrigation from a) reclaimed water, b) harvested rainwater and c) salt load associated with various storage capacity.

A recommended storage volume (300 m^3) was calculated based on salt load, where storage volume resulted in the required capture amount of roof runoff that leads to reduce salt load value by at least 50% of the maximum potential reduction of salt load. Under the Scenario #2 conditions, a storage volume of 300 m^3 could potentially collect ~64% of the total available runoff and could reduce the required irrigation portion from reclaimed water by ~34%. This could lead to a potential decrease in the salt load by ~17%.

7.5. Effect of crop cycle

Based on the survey conducted, farmers prefer to have production from the same crop type most of the year and consequently the starting month of the crop cycle could be different for various greenhouses. Three various crop cycles (10 months each: Jul-Apr, Sep-Jun and Nov-Aug) for capsicum were used under the same conditions of scenario #2 (see **Section: 7.2**) to examine the effect of starting month on the irrigation requirements. The highest total irrigation volume was found to be required for the crop cycle Jul-Apr (7.4 ML/ha/annum) followed by Sep-Jun (7.2 ML/ha/annum) then Nov-Aug (6.1 ML/ha/annum). The highest salt load was for the plant cycle between Jul-Aug (6.4 t/ha/annum), followed by plants' cycle between Sep-Jun (6.2 t/ha/annum) then between Nov-Aug (4.8 t/ha/annum). The crop coefficient values at the beginning of the crop cycle (first two months) is lower compared to that during the remaining period, and subsequently the irrigation volume requirement during the beginning of the crop cycle is lower compared to that during the remaining period. This suggest that less total irrigation water per cycle will be required if the planting time is during months with high temperature.

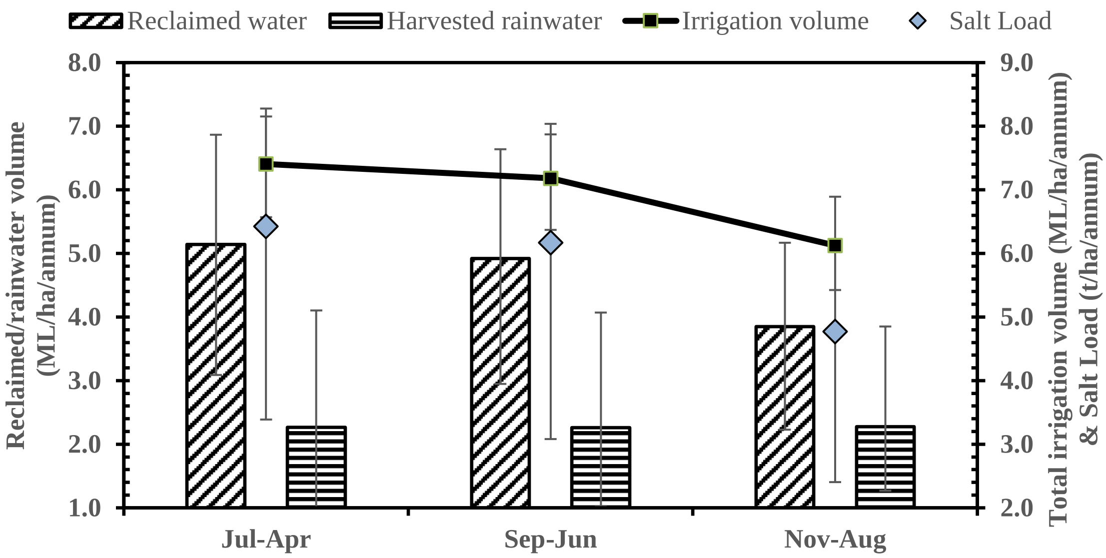

Figure 7–4. Annual median irrigation volumes and salt load associated with various crop cycle. The top and bottom bars represent the 90th %ile and 10th %ile respectively.

7.6. Desalination process tool

Decentralised brackish water reverse osmosis (BWRO) systems are commonly used within the NAP region to desalinate groundwater or reclaimed water to provide low salinity irrigation water. This increases the suitability of groundwater and reclaimed water for growing several crops and overcoming the limitation of saline water applications to only specific crops and for hydroponic-based crops. The current use of reverse osmosis (RO) desalination in the NAP region by horticultural enterprises, brine disposal method and management, governance of desalination and assessment of small-scale desalination by capacitive deionisation have recently been reported (Wimalasiri et al., 2018).

In the present project, we report models developed to predict (user selected climate models, see **Section 2.1**) the quantity of irrigation water and desalination capacity requirements (by RO, as used in the NAP region) based on the trigger values for TDS and chloride concentrations. Output from the water-blending models, i.e. qualities of feed water to the RO system and irrigation scheduling are linked to a treatment model. This tool was designed to support growers with regard to decision-making of desalination capacity requirements and expected water quality of irrigation water, including blended water. Outputs from this tool option include: 1) quantity and quality (measured as TDS) of RO feed, permeate, waste (brine) and product irrigation waters; 2) crop water requirements; and, 3) estimated required volume from various water sources. **Figure G–3** outlines the modelling approach while models and tool methodological description is presented in Appendix G - IW-QC2 software tool's methodological description.

To examine the effect of rainwater harvesting on the RO treatment process requirements, input parameters for Scenario #1 and Scenario #2 (see **Section 7.2**) were used for greenhouse planted by capsicum, under the following WQ threshold levels: 262 mg/L for chloride concentration (the trigger value for prevention of foliar injury) and 600 (target value by the growers within the NAP, survey outcome), 1540 (tolerance threshold for growth in sandy soil), 880 (for growth in loamy soil) and 495 mg/L (for growth in clayey soil) for TDS concentrations.

Table 7–2: Median values of annual treatment process requirements by RO.

		TDS =600 mg/L		Sandy soil; TDS = 1540 mg/L		Loamy soil; TDS = 880 mg/L		Clayey soil; TDS = 495 mg/L	
Parameter	**Unit\Scenario**	#1	#2	#1	#2	#1	#2	#1	#2
Irrigation volume	ML/ha/annum	6.8	6.8	7.6	7.6	7.4	7.4	6.7	6.7
Desalination Requirements									
Feed volume	ML/ha/annum	4.6	2.9	4.4	2.6	4.3	2.6	5.5	3.7
Concentrate volume	ML/ha/annum	1.4	0.9	1.3	0.8	1.3	0.8	1.7	1.1
Permeate volume	ML/ha/annum	3.2	2.0	3.1	1.8	3.0	1.8	3.9	2.6
Water sources									
Reclaimed water	ML/ha/annum	8.2	5.5	8.9	6.0	8.7	5.8	8.4	5.6
Runoff	ML/ha/annum	0.0	2.2	0.0	2.4	0.0	2.4	0.0	2.2
Total	ML/ha/annum	8.2	7.7	8.9	8.4	8.7	8.2	8.4	7.8
WQs									
TDS_{Irr} [a]	mg/L	600	465	670	517	670	517	495	384
TDS_P	mg/L	55	53	55	53	55	53	55	52
TDS_C	mg/L	3546	3399	3558	3438	3558	3438	3541	3368
TDS_F	mg/L	1102	1016	1106	1033	1106	1033	1101	1001

[a] TDS_{Irr} is the salinity level of irrigation water; TDS_P is the salinity level of permeate water (mg/L);.TDS_c is the salinity of concentrate water; TDS_f is the salinity level of feed water

Annual irrigation water quality and quantity are summarised on **Table 7–2**. Under these conditions and by using reclaimed water as a sole source of irrigation (Scenario #1), a Brine Water RO system (BWRO) that has a minimum capacity of 3.0 ML/ha/annum (measured as permeate volume) will be required to achieve target WQ. Consequently at least 1.3 ML/ha/annum of concentrate (brine) waste with a TDS level of ~3500 mg/L will be produced. Brine management and disposal method are required. Large evaporation ponds with HDPE lining are typically used as a brine disposal option for inland desalination plants which are the current brine management for regulated inland desalination in the horticultural industry. Based on the historical climate data within the region, it is estimated that for every 1 m^3 of reject brine produced, a surface area of 0.625 m^2 (area = volume/evaporation rate, (Ladewig and Asquith, 2011) is required for a brine disposal evaporation pond.

For a greenhouse planted with capsicum (under the same conditions of scenario #2 (see **Section 7.2**), using combined reclaimed water and harvested rainwater were found to reduce the volume of reclaimed water required for annual irrigation by 33% (**Table 7–2**). Subsequently this was led to reduce the RO requirement (measured as median annual value of feed water volume) by at least 33% and the concentrate volume by at least 35%.

8. Key findings and recommendations

Quantities and qualities of available water resources in the study region are shown in **Table 8–1** and **Figure 8–1**. A summary of various management approaches associated with using each of these water sources given in **Table 8–1**. Reclaimed waters supplied through the VPS and NAIS are key resources for irrigation purposes within the NAP and study region. The VPS distributes ~17 GL per annum while it is intended that the NAIS will distribute ~20 GL per annum (Stage1: 12 GL; Stage 2: 8 GL, **Table 8–1**). By using reclaimed water for irrigation purposes without any RO pre-treatment, it was determined that at least 4.2 and 5.1 t/ha/annum of salt are added to horticultural lands used for open-field based crops (**Table C–3**) and greenhouse crops (**Table 7–1**), respectively.

Stevens et al. (2003) reported that standard industry management practices include addition of gypsum, organic inputs and the use of 0.2 leaching fraction to flush salts, should maintain 'good' soil condition. Ryan and Kelly (2014) reported that following 14 years of irrigation with reclaimed water (VPS) on the NAP, there has been some significant changes in soil quality (e.g. soil boron concentration). However, the soils showed no significant changes in salinity and sodicity due to VPS water use. Currently, standard industry management practices within the NAP (based on the 2018 survey) includes the addition of gypsum, compost and soluble calcium. Sodicity is caused by the presence of Na^+ attached to clay in soil to the level that affects soil structure and leads to reduce water infiltration and drainage. Gypsum is primarily used on Na-affected soils, as a source of Ca^{2+} to displace Na^+ from soil's colloidal exchange complex (Sanchez and Silvertooth, 1996). Gypsum can also reduce the levels of exchangeable sodium in the soil and subsequently overcome depression, improve soil drainage and enhances crop production (Shahid et al., 2018).

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 > 7.1 (**Table B–4**), the addition of calcium in the form of lime is not recommended [lime is very slowly soluble at pH levels above 6 (Kelly et al., 2001)]. Addition of soluble calcium to irrigation water is another practice identified from the survey conducted. This is used in combination with gypsum addition to soils, to address water infiltration problems associated with excess sodium. Furthermore, applying liquid, soluble calcium to the irrigated water is used to address Ca deficiency in broad-leafed crops. Another common industry practice within the NAP region is addition of organic matter (by adding compost, chicken manure or crop rotation with cover crops, **Table B–1** and **Table B–2**) to improve and maintain soil structure, and nutrient supply as well as for the prevention of soil compaction and erosion (Jindo et al., 2016, Kelly et al., 2001).

Rainwater harvesting from greenhouse roofs is used currently within the NAP but this usage could be substantially increased as a supplementary source of low salinity (fresh) water for irrigation purposes. Horticulture practice in the NAP also includes discarding roof runoff to adjacent land areas, including near roads. This is due to the absence of a storage facility and perhaps a lack of understanding of the benefits of the reuse of roof runoff. A calculated water resource volume of ~5.7 GL (medium value, 10^{th} %ile: 2.7 GL and 90^{th} %ile: 8.9 GL) could potentially be captured from the existing greenhouses within the NAP (**Table 8–1**) and a further ~2 GL of water could potentially be captured from future commercial developments [this value was calculated based on the projected growth rate within the NAP region, i.e. 38% growth in greenhouse area per 10 years as reported by PIRSA Spatial Information Services (2017)]. Blending harvested rainwater with reclaimed water could reduce the volume of reclaimed water use required for irrigation by at least 36% as shown in **Table 7–1**.

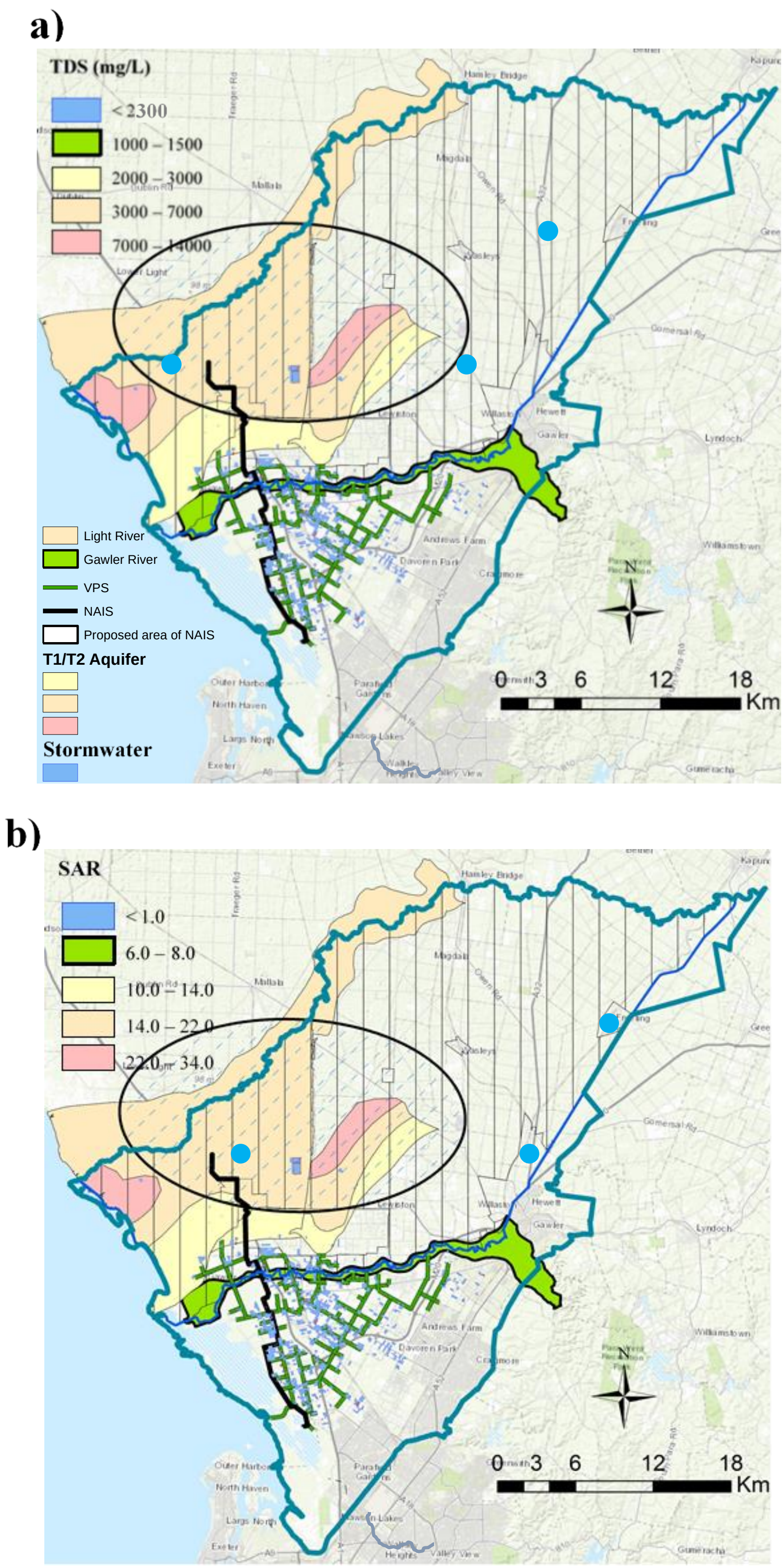

Figure 8–1. a) Average TDS values and b) SAR data for available water sources within the study region.

Table 8–1: Summary of water resources within the study region

Water source	Volume (GL/annum)	TDS (mg/L)	Chloride (mg/L)	SAR	More information	Note	Examples of possible management approaches that could be applied for each water source
Reclaimed water					**Section 3**		
VPS	17 (mainly within NAP)	1068	399	8.1	**Table D–1**	Current volume includes the NAP-PWA area	- Appropriate leaching, soil amendments (addition of compost) and cation exchange capacity control (addition of Gypsum) - For greenhouses: blending with harvested rainwater and/or desalination[a] - Subsurface storage will be required for 'winter' water
NAIS	12 (Stage 1) + 8 (Stage 2)	Similar to VPS but TDS capped to 1165 mg/L				50% from the existing DAFF and 50% from AWRP	
Surface water				**Section 4.1 & 4.1**			
Gawler River (GR)	9	1060	519	6.2	**Table E–1** **Figure E–3**	- Available during Jul-Sep - Highly variable, dependent on the climate conditions (10th %ile: 0.0 ML/annum)	- Subsurface storage will be required to balance seasonal supply and demand - Appropriate leaching, soil amendments (addition of compost and Gypsum) - For greenhouses: blending with harvested rainwater
Light River	0.7	> 4000	3390	17	**Table E–2** **Figure E–4**		- Subsurface storage will be required - Desalination process
Stormwater				**Section 4.3 & 4.4**			
Urban	5	235	35	1.6	**Table** E–4	Potentially from Dry Creek (outside of the study region)	- Subsurface storage will be required to balance seasonal supply and demand - Infrastructure will be required i.e. new distribution system or to be connected to the VPS and/or NAIS distribution system
	2.25				**Figure E–6**	Potentially from townships within the study region	
Rooftop runoff	4.6 (NAP-south of GR) +1.1 (NAP-north of GR) + 2 (future development)	90	13	< 1	**Table E–5**	Future development: based on 38% growth over 10 years	- Surface or subsurface storage will be required to balance seasonal supply and demand - Monitor the pH level and harvest runoff when pH < 8.5 - Do not harvest runoff immediately after application of chemicals (i.e. to remove of white-paint) that may be toxic to plants
Ground-water					**Section 5**		
NAP-PWA	T1: 7.3; T2: 19.8				**Table** F–2 **Table F–3**	2 to 3 GL: could be potentially available for additional extraction in the zones with TDS > 2000 mg/L	- Blending with harvested rainwater and/or by desalination process
North of the NAP PWA	1.0-1.5	3000-7000	1335-3115	14-22			
	< 0.5	> 7000	> 3500	22-34			

[a] For hydroponic industry, desalination is required even for water sources with low salinity level (survey outcome). Desalination (RO) is used extensively by the hydroponic industry and currently is not significantly applied in soil-based horticulture practices. However, may with improved RO desalination efficiencies and less expensive technologies, e.g. capacitance deionization, desalinated water for soil-based crops maybe feasible. This could be applicable where the water quality for target crops cannot be met through conjunctive blending use of recycled water with water and other available water resources.

These excess reclaimed waters could be used for future development within the NAP (by VPS) and/or north to the Light River (by NAIS). Blending harvested rainwater with reclaimed water could increase the irrigation area by 56% or more (146%, 56%, 104% and 100% for greenhouses planted with eggplant, capsicum, tomato and cucumber, respectively, see **Table 7–1**) compared with using the same volume of reclaimed water without harvesting the rainwater. This assumes the storage of water in a dam and factors in evaporation losses. Salinity levels of water samples collected from harvested rainwater were found to be low (< 110 mg/L) and the concentrations for other WQ parameters (i.e. ions, nutrients and metals, **Table E–5**) were found to be negligible. All values were less than the corresponding trigger values detailed in the ANZGFMWQ (ANZECC and ARMCANZ, 2000). Blending harvested rainwater with reclaimed water (and then proportionally reducing that volume of reclaimed water use) has the potential to concurrently reduce the salt load added to horticulture land systems by 36% or more (59%, 36%, 51%, 50% for greenhouses planted with eggplant, capsicum, tomato and cucumber, respectively, see **Table 7–1**) compared with using reclaimed water as the sole water resource irrigation.

However, it is suggested that the pH of the harvested rainwater from plastic/glass greenhouses be monitored as the use of chalk for whitening greenhouse roofs could lead to pH increase of the harvested rainwater especially during the first-flush. It is especially recommended that the first roof runoff post the dry season be tested and discarded if required when a specific chemical agent (e.g. sodium hydroxide base, Removit, Hermadix) has been applied for white-paint removal from the greenhouse roofs.

The Gawler River is a water resource that is seasonally available for irrigation within the study region. Although surface water could be extracted between July and September (medium total volume: ~9 GL, **Figure 4–1**), the available volumes (10^{th} %ile: ~ 0 GL; 90^{th} %ile: 10 GL) are highly variable based on the climate conditions, especially on rainfall amounts, duration and patterns, that influence catchment flows into the river. Therefore, water from Gawler River could be considered as a supporting resource for irrigation, depending on availability, its water quality at the time of extraction, and proximity of the supply to the horticulture practice. Storage facilities (surface storage and/or subsurface storage as per GWRS, **Table E–3**) would be required for harvesting (generally between Jul-Sep) and to continue reuse for growth cycles of crops. The water extractions from Gawler River could have environmental consequences and sustainable limits would need to be determined, factors that were not considered in this study.

No major differences were found in the salinity, chloride and sodium levels of waters collected from Gawler River and from VPS reclaimed water (**Table E–1**). Although the SAR values of water collected from Gawler River were slightly lower than waters from VPS, and similar to the reclaimed water, the Gawler River quality values falls into the category of 'depend on the soil properties and rainfall' of the soil structure stability curve (**Table D–1**), (ANZECC and ARMCANZ, 2000). Current industry management practices (i.e., the addition of gypsum, compost and soluble calcium) and blending harvested rainwater with Gawler River water where feasible, would support the optimised management of the quality of water for crop irrigation.

Surface water might also be extracted from Light River in the July-October period (medium total volume: ~0.7 GL at Station: A5050532, **Figure 4–2**; 10^{th} %ile: ~ 0 GL; 90^{th} %ile: 2 GL). The potential of this surface water as an irrigation supply is also highly dependent on the climate conditions experienced. Water from the Light River might be considered as a supplementary (or secondary) resource requiring opportunistic extraction (when the TDS was low/lowest), potential desalination (unless for salt tolerant crops) and storage in order to use this water for horticulture. The TDS levels of the Light River were found to be too high for horticulture use (TDS > 4000 mg/L), as shown in **Figure E–4**. Furthermore, the SAR values were significantly higher in water collected from the Light River (medium: 17.4) compared to waters from the Gawler River (6.2).

Desalination (e.g. ultrafiltration followed by reverse osmosis) of Light River waters and/or significant percentage blending with fresh waters would be needed to achieve qualities of irrigation supply waters needed for most horticulture practices. The water extractions from Light River could have environmental consequences and sustainable limits would need to be determined, factors that were not considered in this study.

Although the current use of groundwater from the T1 (3.4 GL/annum in 2014-15) and T2 (8.5 GL/annum in 2014-15) aquifers in the NAP-PWA is well below the allocated extraction limit (T1: 7.26 GL/annum; T2: 19.86 GL/annum), it is considered that the aquifer is over-allocated and use of the entire allocation would have adverse impacts (GIWR, 2016). Recommended limits of extraction are 3.5-3.8 GL/annum for the T1 aquifer and 15.9-16.8 GL/annum for the T2 aquifer (GIWR, 2016). Therefore, groundwater sources of the T1 aquifer in the NAP PWA cannot be considered as a significant available resource to support development. Groundwater within the T2 aquifer in the NAP PWA may be available (2 – 3 GL/annum in the zones beyond the better water quality extraction zones) to support expansion of horticulture, however the salinity of available groundwater 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 area studied in this project. Within the boundary of the study area, which extends to the Light River in the north, it was estimated that approximately 2 GL/annum of water could be available for irrigation. **Table 8**–**1** shows the estimated volume that could be extracted from the T1 aquifer at various salinity ranges. Currently there is no chemical water quality data available, aside from salinity and some selected major ions (**Table F**–**2** and **Table F**–**3**). Therefore, the suitability and management of water quality would need to be assessed prior to development and use of this groundwater resource in that area.

The 'IW-QC2' tool (detailed in **Section: 7**) was used to assess the capacity of using greenhouse roof runoff in conjunction with groundwater (at various salinity ranges) to achieve target water qualities (measured as TDS: 600 mg/L) to irrigate greenhouse soil-based crops. Based on median values, the target TDS value could only be achieved during a part of the growing period for greenhouses planted with cucumber (target TDS could be achieved between August-October for Cycle#1 and February-May for Cycle#2), tomato (between June-September), eggplant (May-October) or capsicum (June-October). Therefore, desalination (e.g. ultrafiltration followed by reverse osmosis) of the groundwater would be needed to achieve water qualities needed for horticulture.

The use of desalinated water in agriculture increases productivity and quality of agricultural produce. Campos and Terrero (2013) reported that using desalinated water for agriculture is most likely to be cost effective in a tightly controlled environments such as greenhouses, where agricultural practices involve efficient water use and where crop productivity is high. Desalination as a means of agricultural water supply has been proven to be cost-effective under certain circumstances, especially in hydroponic crop production. However, brine disposal is a major operational and environmental factor of concern when determining the overall cost effectiveness of desalination (Wimalasiri et al., 2018). This is particularly so for inland desalination practices where ocean disposal is not feasible (Barron et al., 2015).

Three reverse osmosis design models were used in this study to predict membrane performance (measured as TDS rejection and water recovery ratio) for brackish (bore well) water source. The computer models selected were, 1) Toray (TorayDS2: v2.1.5.157[14]), 2) Hydranautics (IMSDesign v1.222.81: Integrated Membrane Solutions Design[15]) and 3) CSM (CSMPRO v5.1[16]). Feed flow rates (**Figure 8–2b**) were selected to achieve a permeate flow rate equal to the 99th %ile value of required irrigation volume per event for various crop types (i.e. eggplant, capsicum, cucumber and tomato) at various groundwater salinity ranges (2000-3000 mg/L, 3000-7000 mg/L and 7000-14000 mg/L). **Table G–3** summarises the outcomes from each model. Highest recovery ratio (75%) was associated with a RO system used to treat groundwater that has the lowest TDS level (2,000 mg/L) followed by water with TDS of 3,000 mg/L (70%), TDS of 7,000 mg/L (65%) then waters with TDS of 14,000 mg/L (60%). These water recovery ratios were similar to those of RO desalination systems than currently used at the NAP region (**Table G–2**). Using these values, the desalination model of the 'IW-QC2' tool (**Section 7**) was used to estimate the monthly concentrate (brine) volumes. Median salinity levels and annual concentrate volumes are presented in **Figure 8–2d** and **Figure 8–2e:8-2h** respectively. For greenhouse soil-based crops, using an RO system to treat brackish waters with salinity levels of 2,000 mg/L, 3,000 mg/L, 7,000 mg/L and 14,000 mg/L would led to brine productions of 0.5-1.2 ML/ha/annum, 0.9-1.8 ML/ha/annum, 1.5-2.6 ML/ha/annum and 2.3-3.5 ML/ha/annum, respectively (**Figure 8–2**).

Large evaporation ponds with HDPE lining are typically used as a brine disposal option for inland desalination plants. This is the current brine management approach for regulated, inland desalination by the horticultural industry. This treatment comes at a significant financial cost and requires a land surface of ~625 m^2/ML (area = volume/evaporation rate (Ladewig and Asquith, 2011)). Furthermore, under the current legislative framework in South Australia, a SA EPA approved license is not required for RO operations where production of desalinated water does not exceed 200 kL/day and, where an enterprise produces less than 2 ML/year of wastewater (Environment Protection Act 1993, Schedule 1 (8)(6a)) and there is no general inspection regime for unlicensed operators as reported by Wimalasiri et al. (2018). Thus, it might be expected that localised increase in the number of smaller desalination operations has potential to lead to significant environmental concerns (2018 Farm Survey).

Due to the expansion of hydroponic operations and lack of knowledge related to disposal for small scale operations, there is a need for improved strategies for the management of brine wastewater and disposal options. It is considered that there could be economic benefits of effective brine disposal strategies including reducing the operational and environmental impacted footprints associated with the current conventional method, i.e. evaporation ponds. Potential alternative strategies for consideration might include: 1) mixing of brine waste with urban stormwater using existing stormwater harvesting systems; 2) recovery of salts (e.g. magnesium hydroxide, gypsum, sodium sulfate) from the brine; 3) local, decentralised-precinct and/or centralised deep well injection (to existing, sustainable, high saline aquifers after a full EIA process) (Morillo et al., 2014, Mansour et al., 2017, Kim, 2011).

Surface storage dams are commonly used by landholders within the NAP region to store more available, higher quality winter waters (i.e. reclaimed water, harvested rainwater and Gawler River) for reuse purposes when needed. Changes in the salinity and inorganic constituent levels are impacted by storage time which is minimised with increase in dam storage depth (**Figure D–5**). A common problem associated with using surface storage dams is the growth of algal blooms. Prevention of algal growth can be achieved by covering the dam (as shown in **Table D–6**) to minimise light that is available to algae/cyanobacteria and also by

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[14] https://ap3.toray.co.jp/toraywater/userLogin.do;jsessionid=53EE0991C5ED7F841ED633C1F08F465A.cw660_a41adm (Accessed December 2018)
[15] http://www.hydranauticsprojections.net/imsd/downloads/ (Accessed December 2018)
[16] http://www.csmfilter.com/ (Accessed December 2018)

reducing the storage HRT. Kelly et al. (2001) summarised approaches that could be used to control algal blooms that occur in farm dams. The storage of waters in dams can lead to loss of residual chlorine (in reclaimed water, as found in this study) and therefore there is risk of growth of various microorganisms, including bacteria of health consideration. In this study *Escherichia coli* (cfu/100 mL) was found to be higher in unlined dams compared with lined dams (**Table D**–**6**). Covering and lining (e.g. with HDPE) of dams are suggested practices to minimise risks associated with using surface storages.

ASR has the potential to provide significant storage for water resources that are available to support irrigation. 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/annum of storage, while larger storage is created with an ASR wellfield (e.g. NAIS ASR scheme of 4 GL/annum). Horticulture enterprise with a minimum of 60 ha of greenhouses' roof area would be required to provide a minimum volume of 200 ML/annum 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.

Landholders have legal access to stormwater runoff (as this is not a prescribed resource) and they could harvest, store (in surface storage or storage tank). However, in a prescribed groundwater area, a water license (South Australia Natural Resources Management Act, 2004) is required to extract water from an aquifer. This includes water that has been drained or discharged into an aquifer and is to be recovered (extracted). Stormwater that has been injected into the aquifer becomes 'groundwater' (DEW, 2011) and based on the current legislation, source water (stormwater) is subject to the extraction and management rules of native groundwater (Ward and Dillon, 2011). MAR recovery entitlements are differentiated from other types of entitlement to extract native groundwater.

MAR schemes in South Australia are regulated under the NRM Act 2004, and the Environmental Protection (EP) Act 1993, the Public Health Act 2011 and Development Act 1993, where applicable. The DEW, under the objectives and principles within the NRM Act 2004, regulates water affecting activities, such as construction of wells and drainage or injection of water into aquifers where the EPA is not the relevant authority.

The NRM Act 2004 focuses on managing the quantity of water (injection and extraction volumes) in relation to ensuring minimal negative impacts on natural water resources and other water users. MAR scheme proponents who intend to extract groundwater as part of a MAR scheme within a prescribed wells area will require a license (with an endorsed recharge allocation) or an authorisation[17] to extract the water. A water license provides the authority to take up to a certain volume but does not guarantee security of supply.

Outside of a prescribed wells area, the MAR proponent is not required to have a license or authorisation to extract water from the aquifer. The implications for the study area to the north of the NAP PWA must be considered. In this instance, MAR proponents do not have regulatory security to recover water that has been recharged.

The draining or discharging or water directly or indirectly into a well, watercourse or lake requires a permit (NRM Act) or a licence (EP Act) to discharge stormwater to underground aquifers or discharge to marine or

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[17] Where a water allocation plan is in place and the licensing framework is established. In prescribed areas where a water allocation plan is not yet adopted, and a licensing framework is not established, the extraction of groundwater as part of a MAR scheme operation may be authorised pursuant to section 128 of the *Natural Resources Management Act 2004*.

inland waters. A permit for draining or discharging into a well under the NRM Act is required when the water being drained or discharged:

- is stormwater (such as roof runoff) and is through a closed system from a catchment area less than 1 ha in the Greater Adelaide Metropolitan area or,
- does not contain antibiotic or chemical water treatments and is groundwater or mains water anywhere across the state and stormwater or watercourse water in areas outside of the Greater Adelaide Metropolitan Boundary
- does contain antibiotic or chemical water treatments but the volume to be discharged is less than 50, 000 kL per day.

The Environment Protection Authority SA is the main regulator of the quality of water discharged into an aquifer. The Environment Protection Act 1993 requires that you obtain a works or development approval before you build a MAR scheme and that you gain an environmental authorisation and Licence to inject before 'discharge' of waters to aquifers. All MAR schemes, regardless of their size or geographical location, are required to adhere to the requirements of this Act and to the Environment Protection (Water Quality) Policy 2015. Under the Public Health Act 2011, the Public Health (Wastewater) Regulations 2013 provide details about the management of wastewater systems, including the reuse of the recycled water. SA Health manages the human health aspects of the use of recycled water, such as stormwater and treated wastewater after the water is extracted from a MAR scheme. There is no formal approval step for this, but the EPA will refer applicable EPA license applications to SA Health for assessment. The Development Act 1993 provides for the consideration of any scheme that is deemed to be a 'development'. If certain elements of a MAR scheme (e.g. a dam or wetland) proposal are deemed to be a development, the proponent may need to submit a development application to the relevant planning authority (i.e. local government). In prescribed water resources areas, the development approval does not negate the requirement to obtain a licence or authorisation to extract water or, in all areas of the state, a permit or licence to discharge water into aquifer.

ASR has been successfully used within the Tertiary aquifers of the Adelaide Plains. Currently there is limited hydrogeological information to the north of the NAP PWA to assess ASR feasibility. While preliminary assessment indicates there is potential for ASR in the T1 aquifer, it is necessary to define the local condition to assess the feasibility of a scheme. Given the importance of salinity for horticulture end-uses of recovered water, 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.

8.1. Conclusions

- Using Bolivar WWTP sourced reclaimed water (currently supplied post DAFF) for horticulture without any desalination treatment will add at least 4.2 t/ha/annum of salt to the horticulture enterprises based on volume (3.7 ML/ha/annum) supplied. This has the potential to effect soil structure and crop growth depending on crop salt tolerant levels.
- Water from Gawler River could be extracted seasonally, generally between Jul-Sep, at qualities similar to VPS reclaimed water. However, the water available is highly dependent on local climate conditions i.e. rainfall intensity, durations and patterns. For use of such water resources, suitable storage facilities (surface storage and/or subsurface storage) and associated infrastructures (e.g. distribution pipelines and pumping) would be required and sustainable diversion limits would need to be established and adhered to.

- A significant amount of stormwater from rooftop runoff (i.e. ~50% of total water volume that will be distributed by the NAIS scheme- Stage 1) of low TDS (< 150 mg/L) could be captured from existing plastic /glass greenhouses within the NAP. Blending harvested rainwater with reclaimed water could reduce salt loads added to horticulture systems by at least 23%, reduce the volume of reclaimed water required for irrigation by at least 36% and achieve a target salinity level of 600 mg/L during most of the crop cycle (i.e. for soil-based greenhouses planted with capsicum, cucumber, eggplant or tomato).

- Despite the limitation of urban stormwater supply north of the Gawler River, it has been estimated that another ~5 GL per annum of urban stormwater with low salinity level could be captured from Dry Creek (outside of the study area). However, infrastructure does not currently exist to support such water resources for irrigation purposes within the NAP and north of Gawler River.

- ASR has the potential to provide significant storage for water resources that are seasonally available (e.g. rooftop stormwater runoff) and to buffer seasonal water shortages (i.e. during summer seasons) to support irrigation and expansion of horticulture. However, the incentive for stormwater harvesting and storage in an aquifer for later extraction appears to be limited from a landholder perspective based on current governance and 'water use entitlement' of stormwater once it has been injected into the ground.

- The potential for ASR in the T1 aquifer in the NAP PWA is limited to the western portion of the study area (west of the Port Wakefield Rd) while additional ASR schemes could be considered in the T2 aquifer in the NAP PWA to support expansion of horticulture. Although a preliminary assessment indicates there is potential for ASR in the T1 aquifer in the north of NAP PWA, it is necessary to assess the local conditions for feasibility of a scheme.

- Models and a software tool (IW-QC2, in Microsoft Excel) were developed for application with user selected climate models for determination of: 1) the quantities and qualities of irrigation water; 2) volumes of water that could be harvested from impervious greenhouse roofs and storage requirements; 3) outcomes when blending different sources of water such as harvested stormwater with other sources (e.g. reclaimed water and Gawler River water); and 4) to predict the quantity of irrigation water and desalination requirements (by RO, as used in the NAP region) based on the trigger values for TDS and chloride concentrations.

8.2. Recommendations for additional research

In order to further support productivity of the region there are a number of important knowledge gaps that have been identified by this project. Recommendation for additional research and investigation include:

- Reassessment of the spatial water resource availabilities and their water qualities should be made alongside development of NAIS scheme once it is implemented and operational. This includes treatment, storage and distribution needs for optimised use of those available water resources for horticulture purposes. The specific distribution network of NAIS was not known at the time of this study. Consequently, NAIS site specific determinations on water resources options for horticulture (e.g. blending harvested rainwater with reclaimed water and ASR storage) were not able to be undertaken during this study.

- Assess potential benefits of co-location of greenhouses for stormwater harvesting at scale that may be required for economic feasibility with ASR (200 ML/yr or more for each scheme)

- Reassessment of the current governance of managed aquifer recharge and recovery practices to facilitate expansion of ASR schemes for stormwater harvesting and reuse for and by the horticulture industry

- Development of improved technologies and strategies for brine waste management (e.g. from RO operations). This includes consideration of potential reuse opportunities; discharge options to receiving environments – e.g. coastal and marine via brackish-saline wetlands and and/or injection into sustainable and suitable aquifers. A brine waste management strategy should consider salt recovery management for small–scale desalination) units that operate without EPA SA license requirement (but wastewater management comes under local government authorities)

- Establish a monitoring network for groundwater resources north of the NAP PWA. This monitoring is necessary to support management of groundwater resources

- Assess hydraulic properties and water quality of T1 aquifer in locations prospective for water supply and/or ASR

- Conduct research to estimate short- and long-term fate of sodium (and other metal cations) in the NAP and study area associated with past, current and projected future climate conditions. This includes in surface waters, groundwaters and soils. The salt balances of the NAP and in the study area appear to be largely unknown. For example, the export of sodium from the region through plant production, harvesting and transport out of the region has not been estimated nor the export of sodium (and other metal cations) through natural catchment flows (average and extreme conditions) to the receiving marine environment. Furthermore, the transport of sodium within the NAP and study region is also largely unknown.

- Conduct research to investigate the potential and requirements to connect existing stormwater harvesting schemes located adjacent to VPS and NAIS pipelines.

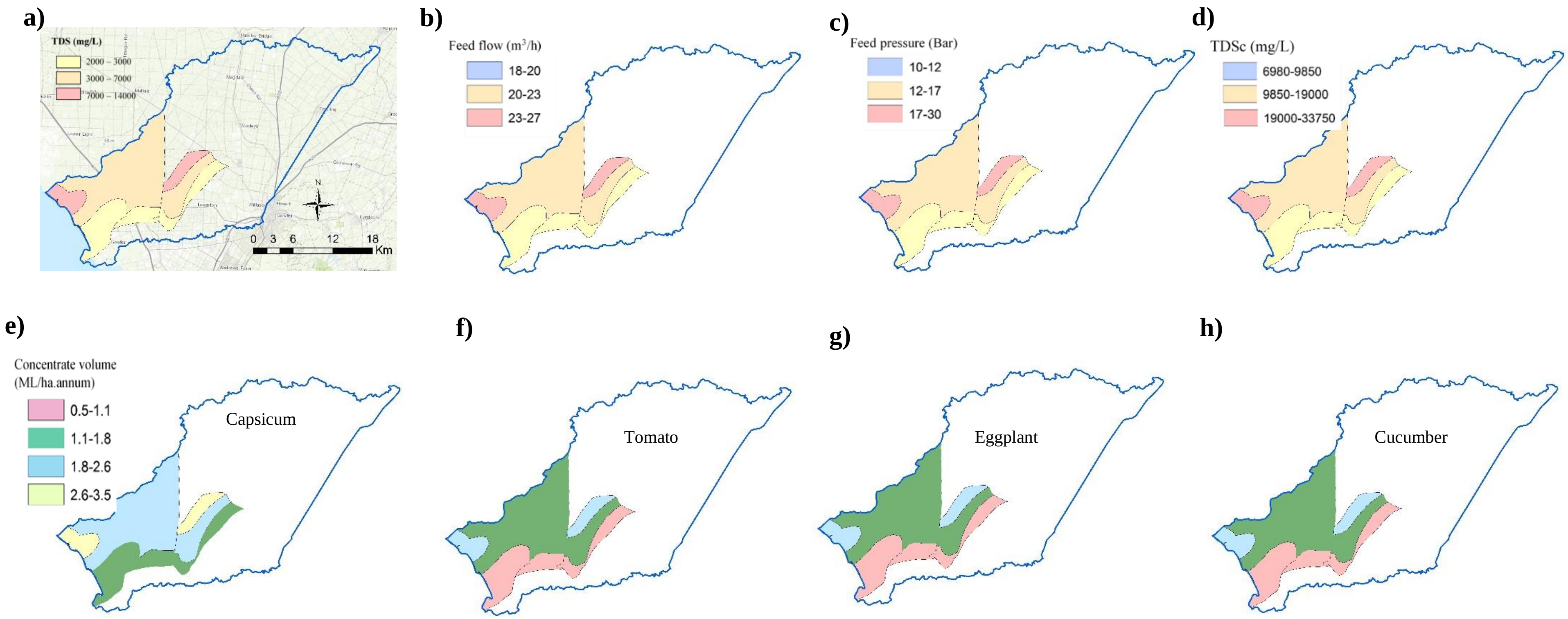

Figure 8–2. RO treatment for T1/T2 aquifer. a) T1/T2 salinity levels, b) feed flows, c) feed pressures, d) concentrate salinity levels and annual concentrate volumes for a hectare of greenhouses planted with capsicum (e), tomato (f), eggplant (g) and cucumber (h).

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Appendix A - Water use & climate data

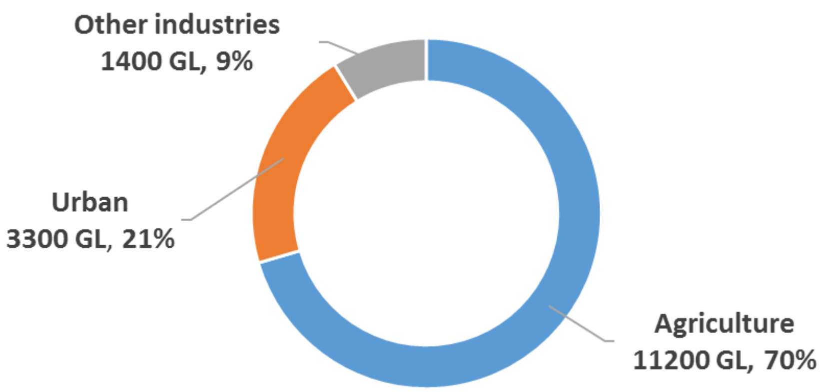


Figure A–1. Total water extractions in Australia by industry sector (2015-16) adapted from (BOM, 2017).

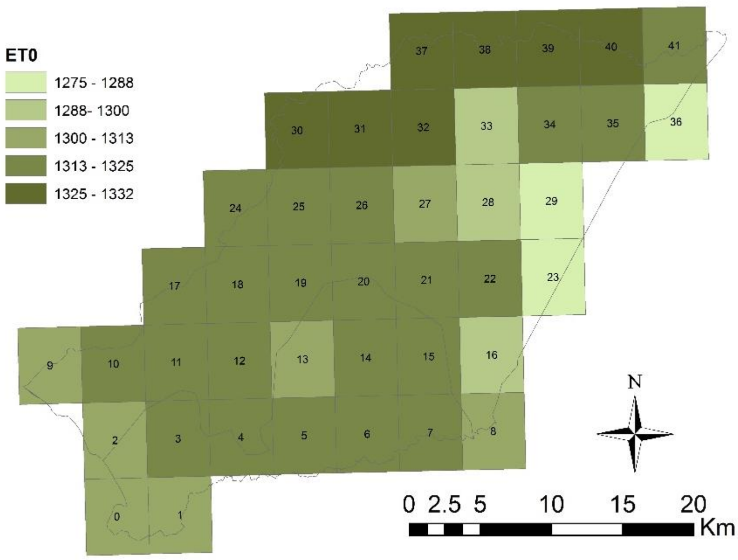


Figure A–2. Median annual ET_0 (mm) for each grid area.

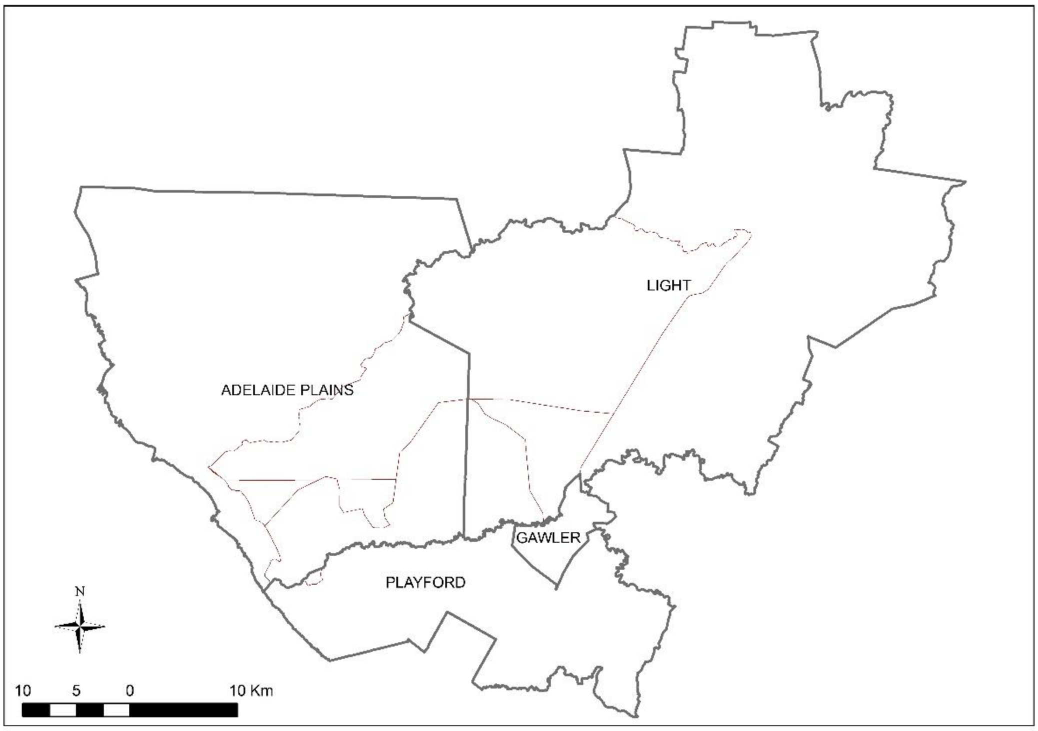


Figure A–3. Local government authorities within the study area.

Table A–1: 10th %ile, 50th %ile and 90th %ile of annual precipitation, evaporation and ET_0 values at gridded areas within the study region

Area No.	Precipitation (mm)			Evaporation (mm)			ET_0 (mm)		
	10th %ile	Median	90th %ile	10th %ile	Median	90th %ile	10th %ile	Median	90th %ile
NAP0	279	391	510	1763	1827	1880	1247	1310	1362
NAP1	293	397	529	1761	1829	1877	1250	1312	1365
NAP2	283	390	515	1776	1832	1886	1248	1313	1363
NAP3	280	392	512	1772	1832	1888	1253	1317	1367
NAP4	292	399	527	1769	1833	1881	1253	1316	1367
NAP5	299	405	535	1767	1832	1876	1258	1318	1370
NAP6	289	407	539	1757	1817	1862	1258	1318	1371
NAP7	295	413	543	1741	1793	1845	1252	1315	1365
NAP8	306	427	552	1727	1776	1828	1249	1313	1364
NAP9	279	379	512	1781	1830	1893	1245	1309	1359
NAP10	285	380	508	1784	1841	1902	1254	1316	1366
NAP11	281	382	506	1782	1843	1902	1256	1319	1370
NAP12	290	389	515	1781	1842	1899	1258	1322	1371
NAP13	315	425	554	1753	1807	1865	1245	1309	1361
NAP14	282	395	521	1769	1822	1882	1258	1322	1374
NAP15	289	408	540	1750	1796	1855	1250	1314	1368
NAP16	314	432	569	1718	1757	1816	1235	1298	1352
NAP17	280	383	516	1790	1844	1907	1257	1320	1371
NAP18	287	389	511	1788	1840	1906	1257	1322	1372
NAP19	283	390	507	1783	1834	1902	1258	1322	1374
NAP20	278	387	508	1780	1825	1893	1259	1322	1377
NAP21	288	400	533	1760	1801	1868	1251	1314	1372
NAP22	281	392	520	1753	1794	1860	1250	1317	1371
NAP23	327	458	597	1680	1712	1789	1219	1281	1336
NAP24	284	381	512	1793	1838	1909	1259	1323	1374
NAP25	281	389	513	1785	1829	1898	1259	1322	1375
NAP26	269	383	503	1783	1825	1898	1260	1323	1380
NAP27	289	401	528	1757	1794	1862	1247	1310	1370
NAP28	313	432	561	1720	1749	1821	1235	1295	1350
NAP29	322	467	621	1671	1699	1781	1215	1276	1330
NAP30	273	375	502	1796	1832	1910	1265	1326	1380
NAP31	264	375	499	1788	1825	1904	1265	1327	1381
NAP32	264	375	493	1780	1816	1894	1263	1327	1383
NAP33	321	431	566	1715	1747	1825	1235	1297	1351
NAP34	270	377	509	1752	1782	1861	1258	1321	1376
NAP35	270	377	509	1752	1782	1861	1258	1321	1376
NAP36	342	477	634	1660	1678	1773	1210	1275	1331
NAP37	259	370	488	1788	1820	1903	1268	1332	1387
NAP38	266	364	494	1774	1807	1889	1268	1331	1384
NAP39	276	367	514	1757	1789	1873	1265	1328	1382
NAP40	276	367	514	1757	1789	1873	1265	1328	1382
NAP41	271	377	518	1743	1769	1858	1261	1325	1378

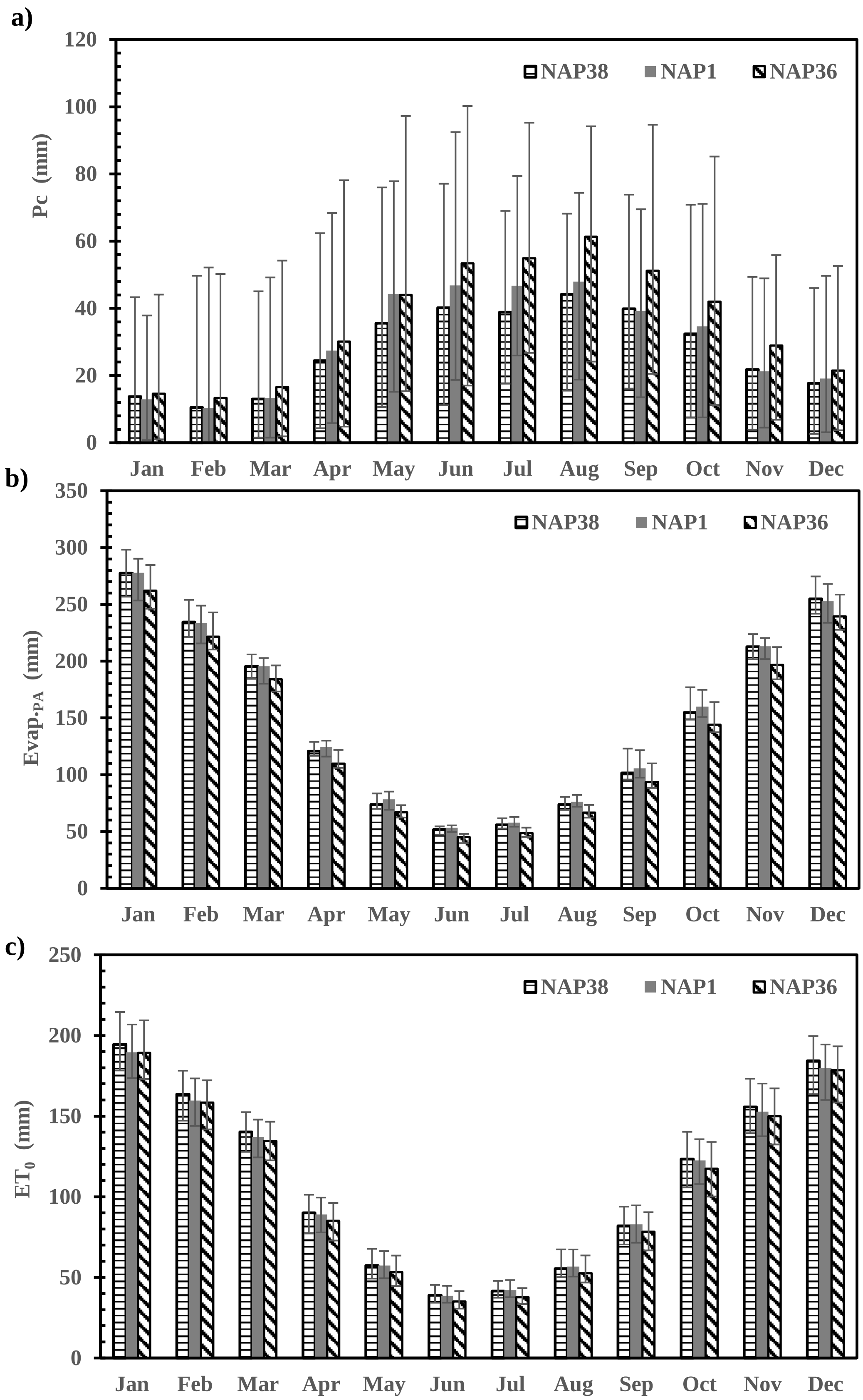


Figure A–4. Median monthly a) P_c, b) $Evap._{PA}$ and c) ET_0 at grid area number 1, 36 and 38. The top and bottom bars represent the 90th %ile and 10th %ile respectively.

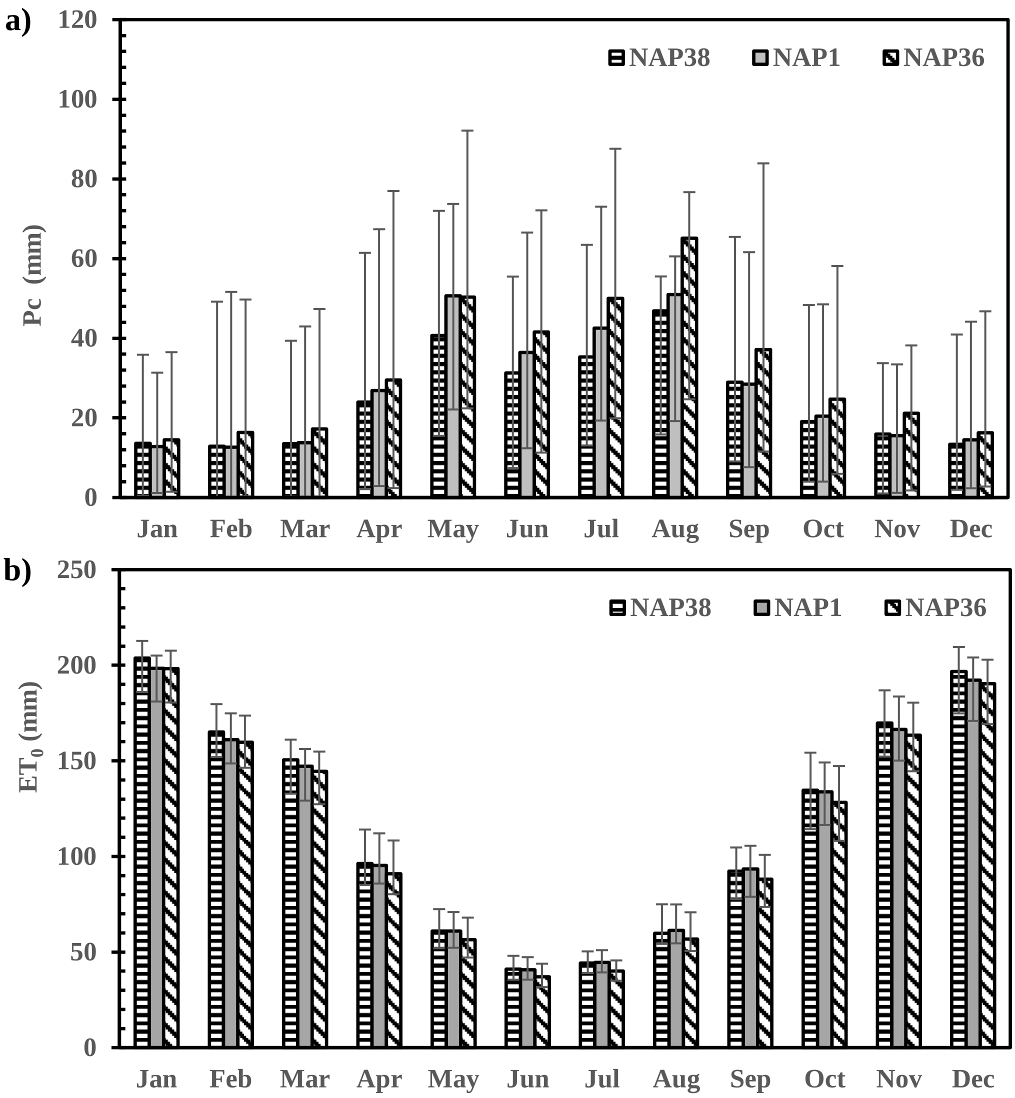


Figure A–5. Estimated monthly median values of a) P_c and b) ET_0 for grid area number 1, 36 and 38. The top and bottom bars represent the 90th %ile and 10th %ile respectively.

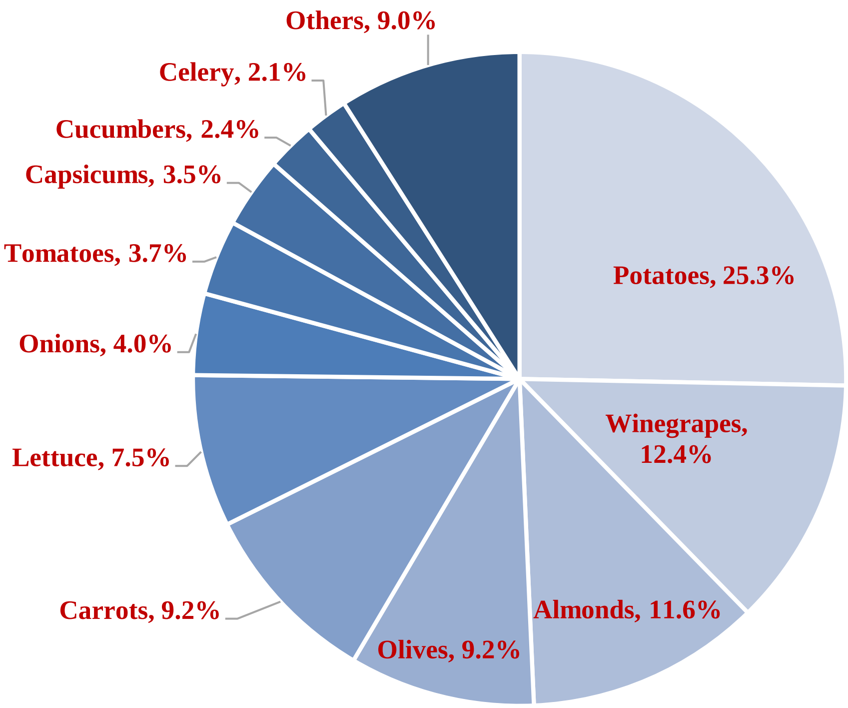


Figure A–6. Area of horticulture crops (%)[a]. [a] Source: Agriculture Food & Wine, Primary Industries and Regions SA – PIRSA (Jensen, 2013).

Table A–2: Estimate of Northern Adelaide horticulture production and prices ($/kg)

Crop type	Area (ha) (Jensen, 2013)	Production 11-12 (kg/m²) (Jensen, 2013)	Production 2014-15 (kg/m²) [a]	Production 2015-16 (kg/m²) [b]	Price 2014-15 ($/Kg) [a]	Estimated Value ($/m²)
Potatoes	1295	1.9	1.5	3.9	0.32	0.77
Winegrape	632	0.7	NA	0.8	0.87 [c]	0.65
Almonds	594	0.2	0.3	0.15	11.92	2.65
Olives	470	0.3	0.4	0.1	4.24	1.07
Carrots	469	7.4	5.6	4.95	0.30	1.80
Lettuce	385	2.5	1.3	2.2	1.67	3.37
Onions	206	6.6	6.6	6.3	0.35	2.27
Tomatoes	190	13.8	22.2	11.6	3.50	55.5
Capsicums	179	10.0	10.2	3.4	3.50	27.5
Cucumbers	124	10.3	20.1	NA	1.50	22.8
Celery	108	5.0	4.3	NA	0.60	2.78

[a] Source: Agriculture Food & Wine, Primary Industries and Regions SA – PIRSA

[b] Based on data for Adelaide and Mount Lofty Ranges region, 71210DO003_201415 Agricultural Commodities, Australia–2015-16, Australian Bureau of Statistics

[C] Source: 2017 SA Winegrape crush survey report (Wine Australia, 2017), Wine Australia, Primary Industries and Regions SA – PIRSA

Figure A–7. Gawler Water Reuse Scheme (GWRS).

Appendix B - Horticulturalists survey

UniSA Research and Innovation Services

Human Research Ethics Committee
CONSENT FORM

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this Committee, Tel: +61 8 8302 3118; Email: humanethics@unisa.edu.au

SECTION 1: CONTACT AND PROJECT DETAILS

Researcher's Full Name:	John Awad
Contact Details:	t: +61 8 8302 3758 | e: john.awad@unisa.edu.au | M: +61 470330821
Supervisor's Full Name:	John van Leeuwen
Contact Details:	t: +61 8 8302 5497 | e: John.vanleeuwen@unisa.edu.au
Protocol Number:	
Project Title:	Sustainable Expansion of Irrigated Agriculture and Horticulture in Northern Adelaide Corridor

SECTION 2: CERTIFICATION

Participant Certification

In signing this form, I confirm that:

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential, unless required by law.

Participant Signature	*Printed Name*	*Date*

Researcher Certification

I have explained the study to subject and consider that he/she understands what is involved.

Researcher Signature	*Printed Name*	*Date*

University of South Australia | Natural and Built Environments Research Centre

School of Natural and Built Environments
Participant Information Sheet

SECTION 1: CONTACT DETAILS	
Researcher's Name:	John Awad
Contact Details:	t: +61 8 8302 3758 | e: john.awad@unisa.edu.au | M: +61 470330821
Supervisor's Name:	John van Leeuwen
Contact Details:	t: +61 8 8302 5497 | e: John.vanleeuwen@unisa.edu.au

SECTION 2: GENERAL INFORMATION

- 'This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this Committee, **Tel: +61 8 8302 3118; Email: humanethics@unisa.edu.au**
- It is not anticipated that there are any risks to participation in this study beyond those encountered during everyday life
- Participation is voluntary, and you may withdraw from the research project at any stage and that this will not affect your status now or in the future. Data will be excluded from the study if you decide to withdraw from the research project.
- While information gained during the study may be published, you will not be identified (**data will be gathered anonymously without any identifiers**)
- Information collected as part of the study will be retained for five years. Data will be stored non-identifiable as a computer file on USB memory stick at the School Office, Mawson Lakes Campus.
- The final research report will be publicly available and can be downloaded from Goyder Institute Website (http://www.goyderinstitute.org/publications/technical-reports/). This report will be published at the end of the project (~May 2019).
- Participants or third parties who wish to lodge a complaint about either the study or the way it is being conducted should contact the Executive Officer of UniSA HREC in the first instance, **Email: humanethics@unisa.edu.au or Tel: 8302 3118**

SECTION 2: PROJECT DETAILS

Project title	Sustainable Expansion of Irrigated Agriculture and Horticulture in Northern Adelaide Corridor

- The study aims to find out the impact of the application of water from different sources (and their blending) on long-term soil suitability for different types of crops, long-term impacts on soil quality and the quality of receiving waters, and the availability of water of different quality at different times of the year
- Outcomes of this part of the project will include:
  - Identify water resources and qualities to potentially blend reclaimed water for fit-for-purpose and sustainable use in intensive horticulture and agriculture of the NAP
  - Develop understanding of the logistical and practical on-site (farmer level) requirements for blending of reclaimed waters and bore waters
  - Identify the treatment needs of available surface and groundwater resources along the Northern Corridor for fit-for-purpose use in intensive horticulture and agriculture, based on known water qualities
  - Develop knowledge of existing desalination technology application in the NAP and of brine management options for small scale, decentralized desalination that may also be suitable for the Northern Corridor water resources.
- **In this study, researcher would visit you on your own farm at a time convenient to you. The researcher will visit you on one occasion and the interview would last about 30-40 min. This will involve answering questions about your farm i.e. crop type, irrigation practices/regimes; crop waters; treatment system (if applicable).**

SECTION 1: CONTACT DETAILS	
Researcher's Name:	John Awad
Contact Details:	t: +61 8 8302 3758 | e: john.awad@unisa.edu.au | M: +61 470330821
Supervisor's Name:	John van Leeuwen
Contact Details:	t: +61 8 8302 5497 | e: John.vanleeuwen@unisa.edu.au

SECTION 2: General information

1. **What is the size of the planted area of your business?**

2. **Please choose that best characterizes the predominant soil texture of your horticulture business?** (e.g., Heavy clay, Clay loam, Loam, Sandy loam, Sand)

Clay ◯ — ◯ — **Loam** ◯ — ◯ — **Sand** ◯

SECTION 3: Crop types

3. **What are the crop types that you grow? (**Almonds, Vines, Potatoes, Carrots, Onion, Pistachio, Tomato, Cucumber, Capsicums**). And what is the size of your horticulture business planted by each crop type** (percentages should total 100 percent) **If you can, please detail variety.**
What is the various species for each crop type? Why did you select this specie (any consideration was given to salinity tolerance)?

Number	(A)	(B)	(C)	(D)	(E)
Crop type					
Specie					
Reason					
Consideration					
Area ( )					

Number	(F)	(G)	(H)	(I)	(J)
Crop type					
Specie					
Reason					
Consideration					
Area ( )					

1 | Page

4. How many cycles (1 or 2) of individual crops are generally grown per annum? What is the growth period for each cycle?

A) Crop type: ……………	B) Crop type: ……………	C) Crop type: ……………	D) Crop type: ……………
No. of cycles: …………………	No. of cycles: …………………	No. of cycles: …………………	No. of cycles: …………………
Growth periods:	**Growth periods:**	**Growth periods:**	**Growth periods:**
Cycle 1:	**Cycle 1:**	**Cycle 1:**	**Cycle 1:**
Plant (start): …………………	Plant (start): …………………	Plant (start): …………………	Plant (start): …………………
Harvest (End): …………………	Harvest (End): …………………	Harvest (End): …………………	Harvest (End): …………………
Cycle 2:	**Cycle 2:**	**Cycle 2:**	**Cycle 2:**
Plant (start): …………………	Plant (start): …………………	Plant (start):…………………	Plant (start): …………………
Harvest (End): …………………	Harvest (End): …………………	Harvest (End):…………………	Harvest (End): …………………
E) Crop type: ……………	**F) Crop type: ……………**	**G) Crop type: ……………**	**H) Crop type: ……………**
No. of cycles:…………………	No. of cycles:…………………	No. of cycles:…………………	No. of cycles:…………………
Growth periods:	**Growth periods:**	**Growth periods:**	**Growth periods:**
Cycle 1:	**Cycle 1:**	**Cycle 1:**	**Cycle 1:**
Plant (start):…………………	Plant (start):…………………	Plant (start): …………………	Plant (start):…………………
Harvest (End):…………………	Harvest (End):…………………	Harvest (End): …………………	Harvest (End):…………………
Cycle 2:	**Cycle 2:**	**Cycle 2:**	**Cycle 2:**
Plant (start):…………………	Plant (start):…………………	Plant (start):…………………	Plant (start):…………………
Harvest (End):…………………	Harvest (End):…………………	Harvest (End):…………………	Harvest (End):…………………

5. Is your horticulture practice open-field based or greenhouse (covered) – please give details for the crops you grow

A) Open-field based **(Skip to No. 17)** B) Covered-soil based C) Covered – hydroponic based

6. What is the area per each individual greenhouse structure and the number of greenhouses?

7. Do you manage/measure the climate conditions (temperature and humidity) inside the greenhouse?

Yes No **(Skip to No. 9)**

8. What is the target climate conditions inside the greenhouse?

9. Please could you detail the type of greenhouse you use

A) Shade-house (please specify the type, if possible)

A1. 50% Knitted Shade Cloth A2. 70% Knitted Shade Cloth

A3. 50% Woven Shade Cloth A4. 70% Woven Shade Cloth

A5. Others, please specify: ………………………………………………………………………………

B) Glass/Poly houses (please specify the type, if possible)

B1. Glass B2. Polythene (polyethylene) plastic film

B3. EVA (ethyl vinyl acetate) plastic film B4. PVC (poly vinyl chloride) plastic film

B5. Polycarbonate plastic sheeting B6. Polycarbonate plastic sheeting

B7. Acrylic (polymethyl methacrylate) plastic sheeting B8. Others, please specify: …………………

10. Do you whitening your greenhouses using chemical (e.g., Chalk)?

Yes | No **(Skip to No. 12)**

11. How much do you add per unit of greenhouse? [ ]

12. When do you add this chemical? Between [ ] **to** [ ]

13. Do you recover the rain water from the greenhouse roof?

Yes | No **(Skip to No. 16)**

14. What is the storage facility and capacity do you have?

A) Rain tank
Volume:

B) Surface storage i.e. reservoir
Area:
Depth:

C) Subsurface storage i.e. SR)

15. When do you use the recovered Rainwater for irrigation?

A) When it's available (during winter)
B) When it's needed; to improve the crop yield during specific growth stage (e.g., Nut growth, leaf development)
C) When it's needed; To manage soil salinity
D) When it's needed; Others, please specify:

(Skip to No. 17)

16. Please briefly describe reasons if you do not recover/reuse the rainwater

……

……

……

……

SECTION 4: IRRIGATION PRACTICES

17. What are the source(s) of the irrigation water used on your horticulture business? Check one or more options. **And what percentage of irrigation water used on your farm comes from each source** (percentages should total 100 percent). **And what is the price per KL (volume) for each source**

A) Reclaimed water
(%)
($/KL)

B) Groundwater
(%)
($/KL)

C) Mains water
(%)
($/KL)

D) Recover rain water
(%)
($/KL)

E) Other please specify:
(%)
($/KL)

Please Skip to Q. 19, if you are not using groundwater

18. If you use ground water, what is the approximate depth of the water? [ ]

18.1. If you use ground water, what is the aquifer type (e.g., T1, T2, Q)**?** [ ]

19. What method(s) do you use to schedule irrigation water applications? Check one or more options

A) Weather conditions (e.g., temperature, rainfall); **please go to Q.20**

B) Crop conditions (Growth stages); **please go to Q.21**

C) Soil moisture sensing device; **please go to Q.22**

D) Other please specify: ; **please go to Q.26**

20. What is the current irrigation water practices based on ambient temperature?

Temperature	< 20 °C	20 °C – 25 °C	25 °C – 35 °C	> 35 °C
No. of hours/day				
No. of days/week				
Pump rate (Unit)				

(Skip to No. 27)

21. What is the current irrigation water practices based on growth stage?

Growth stages	Stage (1)	Stage (2)	Stage (3)	Stage (4)	Stage (5)
No. of months					
No. of days/week					
No. of hours/day					
Pump rate (Unit)					

(Skip to No. 27)

22. Do you use automatic or manual irrigation system? Automatic (   ) Manual (   )

23. What is the soil moisture sensor type?

A) Soil Water Content-based

B) Tension-based

Other, please specify (
)

24. At what depth do you install the soil moisture sensor? ....

25. What are the soil moisture values you adjust the sensor to control the irrigation requirement?

Growth stages	Stage (1)	Stage (2)	Stage (3)	Stage (4)	Stage (5)
No. of months					
Soil moisture to start irrigation					

Soil moisture to stop irrigation **OR** No. of hours/day Pump rate (Unit)					

(Skip to No. 27)

26. What is the current irrigation water practices?

Growth stages	Stage (1)	Stage (2)	Stage (3)	Stage (4)	Stage (5)
No. of months					
No. of days/week					
No. of hours/day					
Pump rate (Unit)					

27. What is the irrigation method that you use?

A) Drip irrigation (**Skip to No. 30**)
B) Overhead sprinkler
C) Ground level sprinkler
D) Other; please specify:

28. Which type of sprinkler you are using?

A) Pop-up spray (One direction)
B) Pop-up gear rotor
C) Impact sprinklers
D) Micro sprinklers
E) Other; please specify:

29. Please specify the following information about the sprinklers?

A) Space between the sprinklers =
B) Space between the crop/tree rows =
C) Sprinkler heads rate:

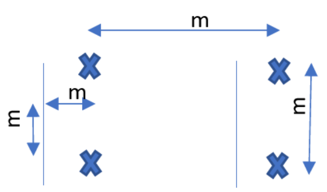
(Skip to No. 31)

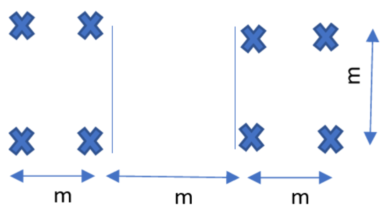
30. Please specify the following information about the drippers

A) Space between the drippers =
B) Space between the crop rows =
C) Drippers rate:

31. How much irrigation water was applied?

Crop type							Total
Volume							





SECTION 5: TREATMENT FACILITIES

32. Do you treat your water before using it for irrigation?

Yes No **(Skip to No. 39)**

33. What is the treatment process do you use?

Water source # ......

A) Pre-treatment (e.g., ultrafiltration, microfiltration, other, please specify:)

B) Reverse Osmosis system (capacity)

C) Other, please specify (capacity:)

34. What is the water quality required for your practices

A) Maximum TDS (mg/L):

B) Do you see Boron as a problem?

C) Any other water quality parameters:

35. What is the running cost (e.g., energy) associated with the used treatment process?

36. Do you see advantage in using treated water? Please specify

37. Do you see any problem associated with using this treatment technology? Please specify

38. Would you like to have more support from the government for brine management? Please specify

(Skip to No. 40)

39. Do you aim to use any treatment process in the future? Please specify

SECTION 6: Issues and Services Affecting Irrigators

40. Last financial year, did you encounter water supply problems?

A) Experienced a shortage of water (allocated water is not enough to meet crop demand)

B) Your reservoir did not store enough water to meet crop demand

C) A problem with poor well yield

D) Others, please specify:

41. What are the key factors restricting your plans to expand?

A) Cost of irrigation water, infrastructure and operation

B) Access to a suitable source of irrigation water

C) Access to irrigable land

D) Cannot obtain licenses or permits for irrigation

E) No market for crops economical to irrigate

F) Cost of labour

G) Others, please specify:

42. What % of expenditure are the costs of energy, and water for your operations?

43. Last Financial year, did you manage your soil salinity/available calcium concentration by addition of any treatment i.e. Gypsum, lime, organics? How much did you add (m3/ha/year; t/ha/year)?

44. Last Financial year, did you use any soluble calcium (L/ha) to manage/decrease the sodium level on the plant tissue?

45. Do you add any soluble additives to the saline water to mitigate the impact? Please specify

46. What is the important of in-situ sensors technology on your operations?

47. What sensor development, if any, would you like to see make available?

48. Would you like to add any other issues/comments?

Table B–1: Summary of 2018 Survey outcomes for open-field crops.

Crop Type	Potatoes	Carrots	Almonds [b]	Tomato	Broccoli	Lettuce	Cabbage	Cauliflower
Species	White Star; Nadine; Carisma	Romance & Nantes		Roma	Atomic			
Growing season	May/Jun To Nov/Dec	All year around; Summer: ready for harvest in 14 weeks; Winter: 16-18 weeks	Irrigation start: Aug-Sep; End: Feb-March	Oct/Nov to Jan/March	Jan-Apr; Oct.-Dec.	Feb To July; every 8 weeks cycle	Feb To July; every 12 weeks cycle	Feb To July; every 12 weeks cycle
Irrigation type	Overhead Sprinkler [a]	Overhead Sprinkler	Dripper	Dripper	Overhead Sprinkler	Overhead Sprinkler	Overhead Sprinkler	Overhead Sprinkler
Space (L X W)	12-15 m x 9 m	12 m x 9 m	0.9 m x 7 m	0.2 m x 0.4 m with 1.1 m path	12 m x 10 m	16 m x 9 m	16 m x 9 m	16 m x 9 m
Flow rate	~20 Lpm (19.2-21.5 Lpm)	~16 Lpm	3.5 Lph	2Lph	~20 Lpm	~19 Lpm	~19 Lpm	~19 Lpm
Actual irrigation	Example #1; Example #2	Example #3	Example #4; Example #5	--	--	--	--	--
Rotation	Two/three tears rotation with Cover-crop	Every 12-15 months with cover crops (May to Aug-Sep); max. 3 years rotation				Add organics (Oats) to control Ec of the soil		
Management practices	Gypsum & compost (e.g., 40 m³/ha)	Soil Fumigation: (every 3-4 years), Gypsum & compost (e.g., as top-dress 5-10 m³/ha)	Leaf analysis two/year (Oct - Dec.) and based on the results addition of soluble calcium (e.g., 100 L/ha); Soil test after harvest; Gypsum e.g., 2.5-5 t/ha	Soluble calcium (e.g., ~70 kg/ha x 3 times)				

[a] Pivot irrigation system has been used as well within the region (flow rate: 12 mm/h – two times per event/day)

[b] Rootstocks: Nemaguard; Not suitable for clayey soil and also don't tolerance to salt; Hybrid; reasonable but not better than GF-677; GF-677; best and has high tolerance to the salt

Table B–2: Summary of 2018 Survey outcomes for greenhouse-crops.

Crop Type	Cucumber [a]	Tomato [b]	Eggplants	Capsicum [c]
Species	Lebanese, Continental & Slicer	Cherry; Roma; Gourmet	Black beauty "Monika"	Blocky (10 x 10 cm); Lamuyo (10 x 15 cm)
Growing season	2 cycle per year (4-5 months; e.g., Aug. to Nov.-Dec. then Feb. to May)	For Roma; Gourmet: 1 cycle per year (8-9 months: e.g., Jan. to Sep.) then another cycle will be started; For Organic cherry: 2 cycles per year (4-5 months: e.g., Feb.-May; June-Oct.)	All year around up to 13 months	1 cycle per year (11 months: e.g., July To April-May)
Plant Density	Greenhouse dimensions (7 m x 50 m); number of plants (8 lines with plants at 0.6 m); ~640 plants/350 m2 (1.8 plant/m2); distance between two lines ~35 cm and pathway between the lines ~1.2 m	Greenhouse dimensions (7 m x 50 m); number of plants (10 lines with plants at 0.5 m); ~1000 plants/350 m^2 (2.8 plant/m^2); distance between two lines ~35 cm and pathway between the lines ~1.1 m	Greenhouse dimensions (7 m x 50 m); number of plants (5 lines with plants at 0.5 m); ~500 plants/350 m^2 (1.4 plant/m^2); distance between two lines ~1.4 m	Greenhouse dimensions (7 m x 50 m); number of plants (8 lines with plants at 0.4 m); ~1000 plants/350 m^2 (2.8 plant/m^2); distance between two lines ~60 cm and pathway between the lines ~1.1 m
Irrigation type	Dripper			
Space (W)	10-20 cm			
Flow rate	~1-2 Lph			
Actual irrigation	Example #6; Example #7		Example #8; Example #9	
Management practices	Gypsum (e.g., 8-10 t/ha); compost (~15-20 m^3/ha) and soluble calcium (50 L/ha)	Gypsum; compost (chicken manure 1.25 t/ha) and soluble calcium (50 L/ha)	Gypsum; compost (chicken manure 0.80 t/ha) and soluble calcium (50 L/ha)	Gypsum (e.g., 10 t/ha); compost (~20 m^3/ha) and soluble calcium (50 L/ha)

[a] Planting time:

Species	July	August	September	October	Novembe	December	January	February	March	April	May	June
Lebanese												
Continental												
Slicer												

[b] Planting time:

	July	August	September	October	Novembe	December	January	February	March	April	May	June
Tomato												

[c] Planting time:

	July	August	September	October	November	December	January	February	March	April	May	June
Capsicum												

Table B–3: Examples of actual irrigation used within the region.

Example #1: Potatoes in Clay-loam soil at NAP

	No. of events/month	Irrigation volume (mm)/event	Total irrigation (mm)
May	1	20	20
June	1	20	20
July	3	20	60
August	3	25	75
September	6	25	150
October	7	25	175
November [a]	8	20	160
December [b]	1	2	2
Total	**30**	**157**	**662**

[a] Based on the planted time, potato could be harvest in Nov. and consequently the irrigation volume for this month will be much less
[b] Pre-harvest irrigation

Example #2: Potatoes (summer crop) in sandy soil at Riverland; 450 ML/80 ha = ~5.6 ML/ha

Example #3: Carrots using Overhead Sprinkler with 12 m x 9 m spaces and ~16 Lpm flow rates; Everyday; Winter: 35 min.; Summer: 50 min. 15.5 ML/ha

Example #4: Almonds in three types of soil: Sandy loam (easy to manage and best to grow); 30-40 cm depth of clay layer, slow infiltration; Loam over heavy clay). Groundwater (TDS: 950 mg/L; used strategically on August-Sept and when only RW not enough); Reclaimed water (more than required at the most of the year; main source as the grower committed to the volume and he never use all of the allocated volume); Gawler Water (when it's available with TDS less than 950 mg/L at 2018 no water available). 375 ML/40 ha

Example #5: Almond in sandy loam soil: 200 ML/23 ha using micro-sprinkler 7 m x 5.5 m spaces with 70 Lph

Example #6: Cucumber with 10 cm space between drippers and 1.7 Lph flow rate

Temperature*	Young-plant (begging of the cycle)	Old-plant
< 20 ^{0}C	10-15 min./2-3 days per week	15-20 min./2-3 days per week
20 – 30 ^{0}C	20 min. every second day	20-25 min. every second day
> 30 ^{0}C	20 min. every day	20-25 min. every day

Example #7: Cucumber**;** from Aug. to Nov.-Dec. (Part of the land: area: 7*23m*60m) and from Dec. to March (Part of the land: area: 7*23m*48m)

Area	17388	m^2
Irrigation source	2.63 ML from mains; 4.7 ML rain waters	
Total irrigated water volume (2017/18)	7.63	ML
Irrigation volume	4.4	ML/ha
	439	mm
Cycle (4-5 months)		

Example #8: Greenhouses with Eggplant and capsicum (Area 4000 m^2)

	Hour of irrigation	Total (L)	L/ha	ML/ha	mm
Jul	1	43000	107500	0.1075	10.75
Aug	1	43000	107500	0.1075	10.75
Sep	2.3	100000	250000	0.25	25
Oct	7.2	314000	785000	0.785	78.5
Nov	7.2	314000	785000	0.785	78.5
Dec	8	350000	875000	0.875	87.5
Jan	8	350000	875000	0.875	87.5
Feb	8	350000	875000	0.875	87.5
Mar	6	260000	650000	0.65	65
Apr	6	260000	650000	0.65	65
May	0	0	0	0	0
Jun	0	0	0	0	0
Total	54.7	2384000	5960000	5.96	**596**

Example #9: Greenhouses with Eggplant and capsicum (Area 5000 m^2)

	Hour of irrigation	Total (L)	L/ha	ML/ha	mm
Jul	0.2	6500	13000	0.013	1
Aug	0.2	8600	17200	0.0172	2
Sep	4.2	173000	346000	0.346	35
Oct	8.4	350000	700000	0.7	70
Nov	12.0	500000	1000000	1	100
Dec	12.0	500000	1000000	1	100
Jan	13.2	550000	1100000	1.1	110
Feb	13.2	550000	1100000	1.1	110
Mar	13.2	550000	1100000	1.1	110
Apr	13.2	550000	1100000	1.1	110
May	0.0	0	0	0	0
Jun	0.0	0	0	0	0
Total	90	3738100	7476200	7.4762	**748**

Table B–4: Soil test results. Analysis done by SWEP Analytical Laboratories.

Soil No.		Unit	S1	S2	S3	S4	S5	S6	S7	S8
pH (1:5 Water)			8.1	7.5	7.7	7.8	8.9	7.7	7.9	7.1
Electrical conductivity	EC	µS/cm	654	635	236	833	235	1130	964	902
Total soluble salt	TSS	ppm	2158.2	2095.5	778.8	2748.9	775.5	3729	3181.2	2976.6
Calcium†	Ca	ppm	2360	2500	1224	2040	1910	2460	1748	2540
Magnesium†	Mg	ppm	433.2	601.2	181.2	747.6	452.4	666	472.8	489.6
Sodium†	Na	ppm	453.1	646.3	166.52	1156.9	365.7	954.5	570.4	400.2
Nitrogen	N	ppm	32.7	9.68	37.8	26.2	1.21	95	226	43.8
Phosphorus	P	ppm	55.9	27.7	55.3	20.5	37.2	105	119	135
Potassium	K	ppm	811.2	783.9	413.4	647.4	329.94	1513.2	1033.5	1170
Sulphur	S	ppm	189	208	19.4	143	14.4	144	96	361
Copper†	Cu	ppm	8.68	25.1	5.11	12.1	24.6	17.5	4.02	7.58
Zinc	Zn	ppm	6.96	16	9.98	4.44	7.52	16.3	10.4	38.3
Iron	Fe	ppm	5	4	4	4	5	5	10	7
Manganese	Mn	ppm	19	12	14	13	11	28	16	13
Cobalt	Co	ppm	3.78	3.89	3.12	4.76	1.89	3.79	1.52	2.13
Molybdenum	Mo	ppm	0.65	0.45	0.36	0.48	0.21	0.47	0.26	0.41
Boron	B	ppm	3.76	1.54	1.05	2	0.98	2	2.2	1.81
Total organic matter	OM	%	2	3.3	1.2	3.9	1.7	2.9	1.8	3.8
Total organic carbon	OC	%	1	1.65	0.6	1.95	0.85	1.45	0.9	1.9
Exchangeable calcium	Ca	meq/100g of soil	7.73	8.9	4.64	6.51	7.98	8.24	3.84	7.48
Exchangeable magnesium	Mg	meq/100g of soil	2.37	3.57	1.14	3.98	3.15	3.72	1.73	2.4
Exchangeable sodium	Na	meq/100g of soil	1.29	2	0.55	3.21	1.33	2.78	1.09	1.02
Exchangeable potassium	K	meq/100g of soil	1.36	1.43	0.8	1.06	0.71	2.6	1.16	1.77
Adj. exchang. hydrogen	H	meq/100g of soil	0.4	0.25	0.7	0.25	0	0.95	0.2	0.7
Exch. Sodium percentage	ESP		9.12	11.24	6.52	18.93	10.09	14.08	12.22	6.68
Calcium / magnesium ratio	Ca/Mg		3.27	2.5	4.05	1.64	2.53	2.22	2.22	3.11

Table B–5: Recommended fertiliser and calcium by SWEP Analytical Laboratories based on soil test results.

Soil samples		S1	S2	S1	S3	S4	S5	S6	S7	S6	S8	S6
Crop type		Spinach	Almonds	Cauliflower	Cauliflower	Vines	Vines	Cucumber	Cucumber	Eggplant	Capsicum	Capsicum
Total calcium requirement												
Gypsum	t/ha	2.58	5.62	2.58	0.42	10.06	4.43	8.67	3.78	8.67	2.82	8.67
Lime	t/ha	0	0	0	0	0	0	0	0	0	0	0
Dolomite	t/ha	0	0	0	0	0	0	0	0	0	0	0
Magnesium oxide	kg/ha	0	0	0	68	0	0	0	0	0	0	0
Total fertiliser requirement												
N	kg/ha	119	97	140	136	5	31	75	0	0	154	123
P	kg/ha	14	22	34	35	25	5	0	0	0	0	0
K	kg/ha	0	0	0	0	20	20	0	0	0	0	0
S	kg/ha	0	0	0	0	0	0	0	0	0	0	0
with trace elements:												
Copper	kg/ha	0	0	0	0	0	0	0	0	0	0	0
Zinc	kg/ha	0	0	0	0	4.5	0	0	0	0	0	0
Cobalt	kg/ha	0	0	0	0	0	0	0	0	0	0	0
Molybdenum	kg/ha	0	0.05	0	0	0.05	0.025	0.05	0	0.05	0	0.05
Iron	kg/ha	4	5	4	3.5	5	4	5	2.5	5	3.5	5
Manganese	kg/ha	2	4	2	2.5	4	3.5	0	2.5	0	3.5	0
Boron	kg/ha	0	0	0	0	0	0	0	0	0	0	0

According to Mikhail (2017) desirable exchangeable cation percentage values in soil are 65-70% for exchangable calcium, 12-15% for exchangable magnesium, 0.5-5% for exchangable sodium and 3-5% for exchangable potassium. Compared to these values, all soil samples were found to have higher exchangable sodium (ranges: 7%-21%), higher exchangable magnesium (15%-27%) but lower exchangable calcium (43%-61%). Consequently and based on the soil test reports, addition of gypsum is recommended for all farms (recommended gypsem between 0.42 t/ha to 10 t/ha).

Figure B–1. Greenhouses' roof runoff discharged to the rood (Photos adapted from Google map on 21st of Jan 2019).

Sample Description Gypsum Sample 2, Premium Grade

Analyte	Units	Result	Method of Analysis	L.O.D.
Calcium (Ca)	% (w/w)	18.8	3120 B, 3030 E	0.01
Sulphur (S)	% (w/w)	16.2	3120 B, 3030 E	0.01
Gypsum (Calc.from S)	% (w/w)	87.2	3120 B, 3030 E	0.01
Sodium	ppm	200	3120 B, 3030 E	1.0
Calcium as CaSO4.2H2O	% (w/w)	-	3120 B, 3030 E	0.01
Sodium as NaCl	ppm	510	3120 B, 3030 E	1.0
pH	pH Units	-	AS 3743 - 1996, App. D	-
Electrical Conductivity	dS/m	-	AS 3743 - 1996, App. D	0.05
Copper	ppm	<1.0	3120 B, 3030 E	1.0
Iron	ppm	900	3120 B, 3030 E	1.0
Potassium	ppm	220	3120 B, 3030 E	1.0
Magnesium	% (w/w)	0.24	3120 B, 3030 E	0.01
Manganese	ppm	12	3120 B, 3030 E	1.0
Phosphorus	ppm	<1.0	3120 B, 3030 E	1.0
Zinc	ppm	<1.0	3120 B, 3030 E	1.0
Cadmium	ppm	<1.0	3120 B, 3030 E	1.0
Lead	ppm	<1.0	3120 B, 3030 E	1.0
Mercury	ppm	-	3112 B	0.10
Cobalt	ppm	-	3120 B, 3030 E	1.0
Moisture Content @ 40°C	% (w/w)	0.62	Gravimetric	0.10
Material <2mm	% (w/w)	-	Gravimetric	0.10
Material <5.6mm	% (w/w)	-	Gravimetric	0.10
Total Kjeldahl Nitrogen	% (w/w)	-	4500 N org B	0.10
Boron	ppm	-	3120 B, 3030 E	1.0
Molybdenum	ppm	-	3120 B, 3030 E	1.0

Figure B–2. Chemical properties of gypsum (adapted from Complete Ag and Seed Supplies, Virginia).

				Sample 1	Guideline
	Product Name:			OC1017A	
	Product Type:			Compost	
	Manufacturing Site:			Jeffries	
	Manufactured Date:			19/03/2018	*(Mature Compost)*
	Quantity Supplied:			5 kg	
	Test Required:			CA-PACK-011	
	Australian Standard Applicable:			AS4454-2012	
Test Method - Appendix	Nutrient		Units	G5799/1	
B6	pH		na	6.2	>5
	Electrical Conductivity		dS/m	7.97	<10
	Soluble Phosphorus in solution	P	mg/L	8.4	≤5 see note 5
	Soluble Phosphorus dry mass equivalent	P	mg/kg	42	..
	Ammonium-N in solution	N	mg/L	130.6	<100
	Ammonium-N dry mass equivalent	N	mg/kg	653.0	..
I	Moisture Content		%	37	>25 see note 6
C5	Total Organic Carbon		%	24	≥20
	Organic Matter		%	41	..
	Total Nitrogen		%	1.4	≥0.8 see note 7
	Carbon: Nitrogen Ratio		%	17.1	..
D5.1.1	Sodium	Na	%	0.20	<1
	Calcium	Ca	%	2.87	..
	Magnesium	Mg	%	0.52	..
	Potassium	K	%	0.95	..
	Sulfur	S	%	0.23	..
	Phosphorus	P	%	0.26	≤0.1 see note 5
D5.1.1	Zinc	Zn	mg/kg	256	<300
	Iron	Fe	mg/kg	9,353	..
	Manganese	Mn	mg/kg	164	..
	Copper	Cu	mg/kg	89	<150
	Boron	B	mg/kg	32	<100
	Cobalt	Co	mg/kg	3.4	..
	Molybdenum	Mo	mg/kg	1.3	..
	Selenium	Se	mg/kg	<0.5	<5
	Cadmium	Cd	mg/kg	0.6	<1
	Lead	Pb	mg/kg	60	<150
	Arsenic	As	mg/kg	10.4	<20
	Chromium	Cr	mg/kg	28	<100
	Nickel	Ni	mg/kg	9.9	<60
	Mercury	Hg	mg/kg	<0.1	<1
	Aluminium	Al	mg/kg	6,445	..
	Silicon	Si	mg/kg	1,306	..
	Silver	Ag	mg/kg	<1	..
3.1 (C) see note 15	Polychlorinated Biphenyls		mg/kg	<0.1	<0.2
	Organochlorines - DDT, DDD, DDE		mg/kg	<0.02	<0.5
	Aldrin		mg/kg	<0.02	
	Dieldrin		mg/kg	<0.02	
	Organochlorines - Other see note 9		mg/kg	<0.02	<0.02
3.1 (C) see note 16	Salmonella		absent/25 g	Absent	Absent
	Faecal Coliforms		mpn/g	31	<1,000
G	Particle Size Grading > 16 mm Sieve		%	Nil	.. see note 10
	Particle Size Grading 5–16 mm Sieve		%	4.2	.. see note 10
	Particle Size Grading < 5 mm Sieve		%	96.5	.. see note 10
I	Plastics Light Flexible or film > 5 mm		%	<0.01	≤0.05
	Stones and Lumps of Clay > 5 mm		%	1.6	≤5
	Glass, metal and rigid plastics > 2 mm		%	0.0	≤0.5
E	Wettability		minutes	0m 33s	<5
B6	Nitrate-N in solution	N	mg/L	0.2	..
B6	Nitrate-N dry mass equivalent	N	mg/kg	1.0	≥10 see note 7
N3.2	Ammonium:Nitrate Ratio		Ratio	687.4	<0.5
F	Plant Growth Test (Bioassay) - Root Elongation		mm	44	60
O	Nitrogen Drawdown Index		NDI	0.11	>0.5
	Oxygen Consumption Rate		mgO2/Kg/min	0.77	..
	Specific Oxygen Uptake Rate		mgO2/gVVS/hour	0.15	≤1
M	Viable plant Propagules		21 days	Nil growth	.. see note 14

Figure B–3. Chemical properties of compost sample (adapted from Complete Ag and Seed Supplies, Virginia).

Appendix C - Crop water requirements

Crop water use is directly proportional to evapotranspiration and the monthly time-step actual crop evapotranspiration (ET_c) was calculated using Equation **C-1** as described in FAO56 (Allen et al., 1998):

$$ET_c = ET_0 \times k_c \qquad \textbf{(C-1)}$$

Where ET_c is actual crop evapotranspiration (mm); ET_0 is the reference evapotranspiration (the Food and Agriculture Organisation Paper 56 (FAO56) short crop, mm); and k_c is the crop coefficient.

For greenhouse crops, the value of monthly ET_0 was reduced by 60%. This was estimated based on information previously reported (Fernandes et al., 2003) and others as shown in Table C–**4**. For each selected crop, crop coefficient (k_c) value at each growth stage was sourced from FAO56 (Allen et al., 1998) and from (Skewes, 2016). Using the knowledge obtained from the survey, i.e. planting month and growth cycle, the monthly time-step k_c values for each crop type were estimated.

Table C–1: Monthly crop coefficients (k_c).

Crop type	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Potato	1.15	1.15	1.15	1.15	0.75						0.5	0.85
Winegrape			0.32	0.55	0.7	0.7	0.7	0.7	0.63	0.51		
Almond	0.36	0.26	0.4	0.7	0.95	1.05	1.05	1.05	1.05	0.9	0.75	0.36
Olives	0.5	0.5	0.65	0.66	0.68	0.69	0.7	0.7	0.7	0.7	0.7	0.58
Carrot [a] (cycle 1)	1.05	1.02									0.72	0.98
Carrot (cycle 2)			0.72	0.98	1.05	1.02						
Carrot (cycle 3)							0.72	0.98	1.05	1.02		
Onion	1.04	1.05	1.05	0.92	0.79						0.7	0.82
Tomato [b] (glasshouse)	1.15	1.15	0.8				0.6	1	1.15	1.15	1.15	1.15
Capsicum (glasshouse)	0.6	0.78	1.03	1.05	1.05	1.05	1.05	1.05	0.97			
Cucumber (glasshouse, cycle 1)	0.6	0.8	1	1	0.9							
Cucumber (glasshouse, cycle 2)						0.6	0.8	1	1	0.9		
Eggplant (glasshouse)	0.8	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.6

[a] Carrot crop cycle: 14 weeks during summer and 16-18 weeks during winter

[b] Information presented in this Table for greenhouse crops is just an example as the planning time and cycle period are different for each crop species.

From Equation **C-1** and the P values, the monthly net irrigation requirement (NIR) was calculate using Equation **C-2**:

$$NIR = ET_c - R_e \times P \quad \textbf{(C-2)}$$

Where NIR is net irrigation requirement (mm); R_e is rainfall effectiveness factor [0.65 for open-field crops (Irrigated Crop Management Services, 2001) and 0.0 for greenhouse crops]; P is the precipitation (mm).

The actual irrigation requirement (IR) was then calculated by adding an allowance for leaching requirement or for irrigation application uniformity to the NIR, depending on which was larger. Annual IR values for field-based crop types are presented in Table C–**3**.The leaching requirement was determined based on the salinity of the irrigation water (EC_W) and the salinity tolerance (EC_E) of each of the crops (Equation **C-3**) while the application efficiency of the irrigation water is estimated to be 17% of NIR (Irrigated Crop Management Services, 2001). The methodology for the calculation and salinity tolerance values were sourced from Ayers and Westcot (1989) and EC_E values for various yield reduction are summarised in Table C–**2**.

$$\text{Leaching Requirement} = \frac{EC_W}{5EC_E - EC_W} \quad \textbf{(C-3)}$$

Where EC_w is salinity of the irrigation water (dS/m); EC_E is salinity tolerance (dS/m)

Table C–2: Salinity tolerance (EC_E) values (dS/m) adapted from (Skewes, 2016).

Crop type	0% Yield Reduction	10% Yield Reduction	25% Yield Reduction	50% Yield Reduction
Potato	1.7	2.5	3.8	5.9
Almond	1.5	2.0	2.8	4.1
Carrot	1.0	1.7	2.8	4.6
Onion	1.2	1.8	2.8	4.3
Tomato	2.5	3.5	5.0	7.6
Capsicum	1.5	2.2	3.3	5.1
Cucumber	2.5	3.3	4.4	6.3
Eggplant	1.1	1.7	2.7	4.2

[a] Equation **C–4** (Mesmoudi et al., 2017) has been used to estimate the difference in air temperature.

$$T_{in} - T_{out} = \frac{\tau R \alpha}{\beta U_e + \gamma} \quad \textbf{(C–4)}$$

Where, T_{in} is the temperature inside the greenhouse (°C); T_{out} is the temperature outside the greenhouse (°C); τ is the greenhouse transmissivity to solar radiation (0.45 (Fernández et al., 2010); R is the solar radiation outside the greenhouse (W/m^2); U_e is the outside air speed in m/s (data for Edinburgh, South Australia station obtained from BoM website); α, β and γ are the equation coefficients (0.043, 0.612 and 0.091 respectively (Mesmoudi et al., 2017).

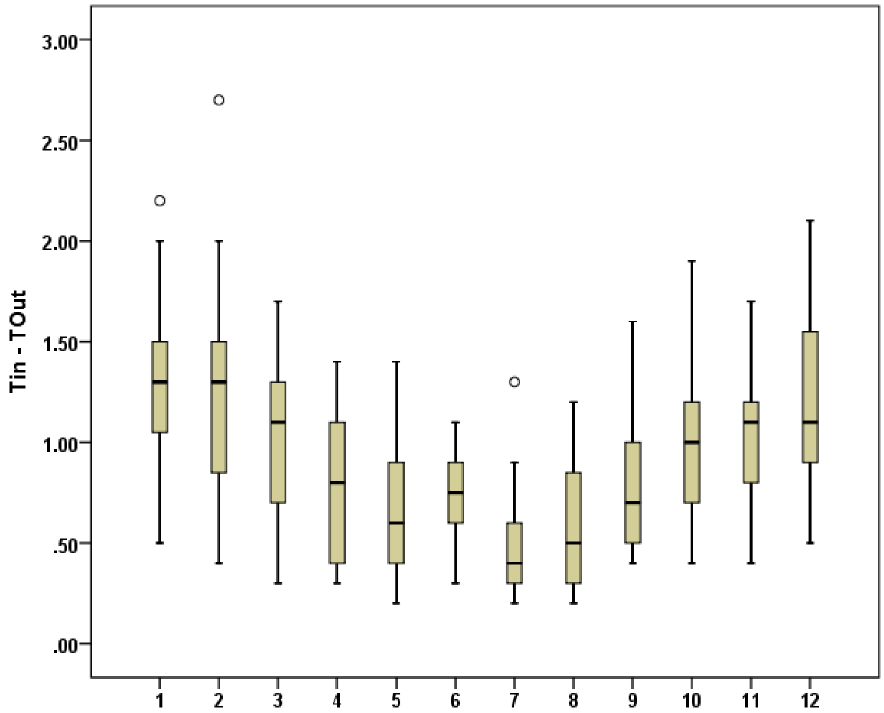


Figure C–1. Difference in air temperature between inside and outside greenhouses (between 03-2017 and 04-2018).

Table C–3: Annual irrigation requirements (IR, mm) at various irrigation water salinity (600 mg/L, 900 mg/L, 1200 mg/L and 1500 mg/L) for selected field-based crops

Annual (IR) mm	Irrigation water salinity levels [a]			
	600 mg/L	900 mg/L	1200 mg/L	1500 mg/L
Almond	1079 (1087-989) [a]	1244 (1254-1142)	1282 (1292-1176)	1282 (1292-1176)
Avocado	942 (1007-805)	1078 (1152-921)	1078 (1152-921)	1078 (1152-921)
Broccoli (summer)	676 (667-628)	676 (667-628)	705 (696-655)	756 (745-702)
Broccoli (winter)	180(241-103)	180 (241-103)	188 (252-107)	201 (270-115)
Carrot (per cycle)	417(443-371)	432 (459-384)	432 (459-384)	432 (459-384)
Onion	328(420-259)	366 (468-289)	366 (468-289)	366 (468-289)
Potato	336(414-284)	375 (463-317)	409 (503-345)	409 (503-345)
Winegrape	670(699-556)	773 (807-642)	796 (831-661)	796 (831-661)
Olives	716(764-587)	716 (764-587)	716 (764-587)	744 (794-610)

[a] Values were calculated based on median (10^{th} %ile – 90^{th} %ile) precipitation and evaporation values for NAP36 grid area.

Table C–4: Climate data and evapotranspiration values inside and outside greenhouses.

Ref.	With(out) whitening	Covered material	Temp.	Air relative humidity	Pressure (KPa)	Wind speed (m/s)	Evaporation (E_0) (mm d^{-1})	ET_0 (mm d^{-1})	k_c values
Fernández et al. (2010)	Without	Plastic film (0.2 mm-thick thermal polyethylene)	Mean: 1.0 ^{0}C > out	In: 65%-80% Out: 60%-70%	In: 1.2 Out:1.0	In: 0.1-0.3 Out:1.5-3.0	In: 1 (winter) – 5 (summer) Out: 2 (winter) – 9 (summer)	In: 1 (winter) – 4 (summer); (~64%) Out: 1.5 (winter) – 6.5 (summer)	
	With		Mean: 0.5 ^{0}C > out				Mean: 23.4% less than the In values In: max 3.8 Out: 2 (winter) – 9 (summer)	Mean: 21.4% less than the In values In: max 3.0 (~56%) Out: 1.5 (winter)–6.5 (summer)	
Fernandes et al. (2003)	Treated against UV radiation	Plastic film (0.1 mm transparent polyethylene)						In: mean weekly: 18 (~56%) Out: mean weekly: 32	
(GREENHOUSES)		Plastic film (0.1 mm thick PEBD)						In: 45% - 77% of the Out values (~61%)	
Singh et al. (2016)	1) 0.2 mm diffused (PAR 90% transmissivity and 42% diffusivity) film and 2) 0.2 mm clear UV stabilized film							In: 66% - 95% of the Out values (~85%)	In: 92%-97% of the Out values (~96%)

Appendix D - Reclaimed waters

Table D–1: Seasonal water qualities at the source (Bolivar DAFF filtered water after chlorine composite).Raw data obtained from SA Water

Element	Years	Guidelines		All seasons			Autumn			Winter			Spring			Summer		
		STV	LTV	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile
Physical Characteristics																		
TDS (mg/L; by EC)	01-11			2493	1038	1256	642	970	1093	625	986	1096	631	1145	1293	628	1144	1285
	12-17			1707	1068	1296	399	906	1180	429	1031	1230	455	1188	1462	424	1066	1304
pH (pH units)	01-11	6.5-8.5		22	7.1	7.4	24	7.2	7.8	26	7.2	7.6	20	7.1	7.5	21	7.2	7.9
	12-17			107	7.10	7.6	25	7.1	7.6	28	7.1	7.6	28	7.0	7.5	26	7.1	7.8
Major Ions (mg/L)																		
Alkalinity as $CaCO_3$	01-11			70	119	166	18	112	133	15	101	123	20	129	192	19	143	164[c]
	12-17			106	123	167	18	108	125	19	125	149	15	122	153	17	110	188[c]
Bicarbonate	01-11			110	167	277	40	140	271	47	152	248	42	167	291	41	179	271
	12-17			54	147	199	12	135	153	18	153	184	12	149	192	12	136	296
Calcium	01-11			123	38.2	45.7	28	35.7	45.5	29	37.2	45.7	35	39.6	47.14	31	38.7	48.5
	12-17			58	39.0	46.1	18	37.2	42.8	19	38.4	42.3	15	42.2	47	17	39.2	43.8
Chloride	01-11	S: <175; MS: 175-350; MT: 350-700; T: >700		123	412	506	28	355	445	29	380	461	35	447	544	31	451	545
	12-17			57	399	491	18	343	441	19	391	460	15	451	538	17	406	490

Element	Years	Guidelines		All seasons			Autumn			Winter			Spring			Summer		
		STV	LTV	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile
Magnesium	01-11			123	34.4	43.9	28	30.4	38.9	29	31.5	39.6	35	37.3	46.3	31	36.0	45.2
	12-17			58	30.7	41.8	18	27.5	34.7 [c]	19	31.5	35.5	15	35.5	48.4	17	30.1	42.0
Potassium	01-11			126	38.3	52.0	28	38.4	52.4	28	34.9	48.0	35	36.6	43.9	31	40.2	51.5
	12-17			58	38.7	43.4	18	38.4 [c]	42.2	19	37.0	40.7	15	39.9	43.4	17	39.7	43.1
Sodium	01-11	S: <115; MS: 115 -230; MT: 230-460; T: >460		130	285	343	28	261	324	29	261	312	35	309	367	31	311	371
	12-17			57	285	389	18	246	307	19	277	326	15	318	409	17	286	349
SAR	01-11			123	8.1	9.3	28	7.7	9.0	29	7.7	8.6	35	8.4	9.3	31	8.6	9.8
	12-17			57	7.6	9.8 [c]	12	7.2	8.3 [c]	18	8.0	9.2	15	8.9	10.4	12	7.8	9.8
Nutrients (mg/L)																		
Nitrate as N	01-11	25 – 125 as TN	5 as TN	367	9.64	18.1	88	9.01	19.90	86	12.75	18.23	103	9.56	15.68	91	4.98	13.18
	12-13[b]			81	0.00	0.00	27	0.00	0.00	18	0.00	0.00	13	0.10	0.10	23	0.00	0.00
Nitrite as N	01-11			368	0.00	0.09	90	0.00	0.02	54	0.00	0.21	98	0.00	0.18	85	0.00	0.06
	12-13[b]			52	0.10	0.10	17	0.10	0.10	17	0.10	0.10	14	0.10	0.10	15	0.10	0.10
TKN	01-11			226	2.03	7.50	53	2.36	7.46	59	2.00	7.60	59	2.12	10.5	55	2.0	5.09
	12-17			63	1.41	2.11	13	1.11	2.00	21	1.59	2.63	15	1.81	2.10	14	1.27	2.02
Phosphorus	01-11	0.8-12	0.05	192	0.67	3.70	46	0.53	2.64	48	0.62	4.21	48	1.15	4.64	50	0059	3.29
	12-17			57	0.08	0.53	12	0.29	0.30	18	0.34	0.47	15	0.10	0.50	12	0.10	0.55

Element	Years	Guidelines		All seasons			Autumn			Winter			Spring			Summer		
		STV	LTV	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile	N	Median	95^{th} %ile
Metals and metalloids (mg/L)																		
Aluminium	01-11	20	5	127	0.054	0.656	31	0.035	0.526	30	0.058	0.430	34	0.050	1.216	32	0.070	1.139
	12-17			57	0.056	0.452	11	0.048	0.155[c]	18	0.050	0.155[c]	15	0.069	0.164	12	0.076	1.571
Arsenic	01-11	2	0.1	192	0.001	0.004	46	0.001	0.004	48	0.001	0.004	50	0.001	0.005	48	0.002	0.005
	12-17			57	0.001	0.002	12	0.001	0.001[c]	18	0.001	0.002	15	0.001	0.001[c]	12	0.001	0.002
Boron - D	01-11		0.5	122	0.327	0.529	46	0.284	0.419	48	0.301	0.435	49	0.371	0.542	48	0.335	0.515
	12-17			57	0.334	0.529	12	0.249	0.419[c]	18	0.375	0.445	15	0.387	0.534	12	0.302	0.477
Copper	01-11	5	0.2	NA														
	12-17			57	0.0060	0.0265	12	0.0050	0.010[c]	18	0.0059	0.0136[c]	15	0.0079	0.027	12	0.0061	0.023
Iron	01-11	10	0.2	127	0.000	0.073	31	0.000	0.058	30	0.007	0.090	33	0.000	0.080	32	0.000	0.027
	12-17			57	0.006	0.018	12	0.009	0.014	18	0.006	0.018	15	0.005	0.018	11	0.006	0.01
Lead	01-11	5	2	NA														
	12-17			57	0.001	0.002	12	0.001	0.003	18	0.001	0.002[c]	15	0.001	0.002	12	0.001	0.001
Manganese	01-11	10	0.2	NA														
	12-17			57	0.0102	0.0499	11	0.0111	0.027	18	0.008	0.043[c]	15	0.0121	0.040	12	0.0098	0.045
Zinc	01-11	5	2	NA														
	12-17			57	0.025	0.068	12	0.024	0.038	18	0.041	0.062	15	0.029	0.072	12	0.011	0.040

Where, STV: short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved

Table D–2: Heavy metals and metalloids concentrations (mg/L) at the source (Bolivar DAFF filtered water post chlorination). Raw data obtained from SA Water

Element	Years	Guidelines		All seasons		
		STV	LTV	N	Median	95th %ile
Barium	2012-2016			57	0.0097	0.0152
Beryllium		0.5	0.1	57	0.0003	
Cadmium		0.05	0.01	57	0.0002	0.0005
Chromium		1	0.1	114	0.0003	0.0013
Cobalt		0.1	0.05	57	0.0007	0.0012
Copper		5	0.2	57	0.006	0.0265
Fluoride		2	1	57	0.51	0.812
Lead		5	2	57	0.0012	0.0021
Lithium		2.5	2.5	57	0.0072	0.0108
Mercury		0.002	0.002	57	0.0001	0.0002
Molybdenum		0.05	0.01	57	0.0052	0.0073
Nickel	2012-2016	2	0.2	57	0.0087	0.0127
Selenium		0.05	0.02	57	0.0006	0.0026
Vanadium		0.5	0.1	57	0.0046	0.0099

Table D–3: Qualities of reclaimed water (Bolivar DAFF filtered water after chlorine composite) compared to the threshold values of considered crop types.

		Area of NAP (%); 2011-2012	Roat Zone Salinity (EC_{se})[a]			SAR & EC	Alkalinity	pH	Chloride	Sodium	Metals[b]	
			Sand	Loam/Light Clay	Heavy Clay						LTV	STV
Crops	Almonds	9	Part of the year			Depends on Soil properties & Rainall	> 100 mg/L; Risk of corrosion	Between 6 and 8.5	foliar injury	foliar injury		
	Capsicums	4	Part of the year									
	Carrots	9		grow in sandy soil								
	Cucmbers	2		Part of the year	prefer sandy/loamy soil							
	Grapes	12	Part of the year		prefer sandy/loamy soil							
	Lettuce	8	Part of the year									
	Olives	12			Part of the year							
	Onions	4			prefer sandy/loamy soil							
	Potatoes	25	Most of the year									
	Tomatoes	4		Part of the year	grow in sandy/loamy soil							

		Area of NAP (%); 2011-2012	TN		TP		Residual sodium carbonate (RSC)[c]	Pesticide[d]	Chemicals[e]	Bacteria	AlgalToxin	Algae	BGA	BOD
			LTV	STV	LTV	STV								
Crops	Almonds	9	> 5 mg/L; Risk of leaching of N into groundwater and surface water; Decreasing yields; algal growth in surface water.		> 0.05 mg/L; To minimize the bioclogging of irrigation equipment only					~ 0.00 Cfu/mL; E.Coli and E.Coli Presumptive	< 0.01 µg/L; Microcystin toxins and Toxin producing BGA	< 32,000 cells/mL; No trigger value	< 10,000 cells/mL; No trigger value	< 10.0 mg/L; less than BOD values for freash waters
	Capsicums	4												
	Carrots	9												
	Cucmbers	2												
	Grapes	12												
	Lettuce	8												
	Olives	12												
	Onions	4												
	Potatoes	25												
	Tomatoes	4												

[a] 100% of the required waters from reclaimed waters; [b] Metals: Al, Arsenic, Boron, Iron, Zinc……etc.; [c] RSC = CO_3 + HCO_3 - (Ca + Mg); [d] Pesticide: 2 4 5-T, 2 4-D, Aldrin, Atrazine. …..etc.; [e] Chemicals: 2 3 4 5-tetrachlorophenol, 2 3 4 6-tetrachlorophenol, 2 3 5 6-tetrachlorophenol, …..etc. Red area: value exceed the irrigation guideline value, most of the year; Yellow area: value exceed the irrigation guideline value, part of the year; Green area: value less than the irrigation guideline value

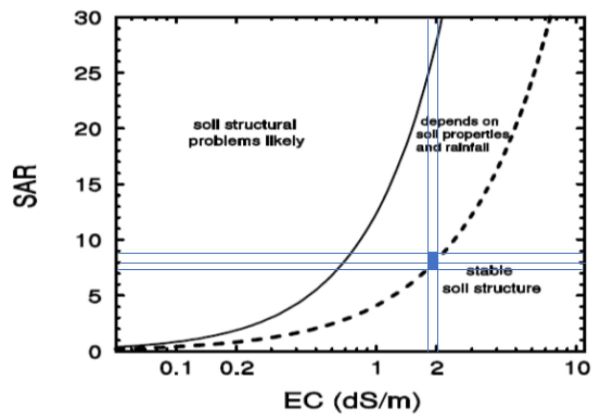


Figure D‒1. Median EC$_i$ and SAR values of VPS waters, with predicted soil structure stability.

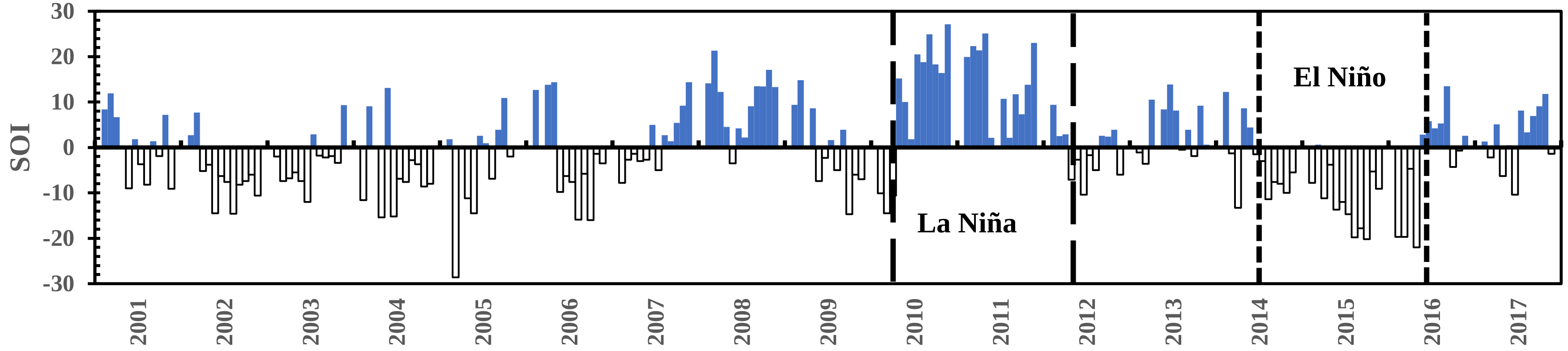


Figure D‒2. Southern Oscillation Index values between 2001-2017, sourced from BoM (http://www.bom.gov.au/climate/influences/timeline/).

Table D–4: Water qualities at the source (Bolivar DAFF filtered water after chlorine composite) during El Niño and La Niña events.

Element	Guidelines		LA Niña (Apr10-Mar12)			El Niño (Jun14 – May16)		
	STV	LTV	N	Median	95th %ile	N	Median	95th %ile
Physical Characteristics								
TDS (mg/L; by EC)			574	1080	1290	701	1021	1270
pH (pH units)	6.5-8.5		17	7.1	7.4 [c]	27	7.2	7.7
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			24	90	159	25	130	181
Bicarbonate			17	108	169 [c]	25	154	201
Calcium			24	38.5	49.5	25	37.4	42.4
Chloride	S: <175; MS: 175-350; MT: 350-700; T: >700		24	406	538	25	377	469
Magnesium			24	34	45	25	29	36
Potassium			24	37.4	41.9	25	38.4	44.5
Sodium	S: <115; MS: 115 -230; MT: 230-460; T: >460		24	266	340	25	274	373
SAR			24	7.6	8.8	25	8.0	9.3
Nutrients (mg/L)								
Nitrate as N	25 – 125 as TN	5 as TN	234	14	19.8	25	5.95	7.4
Nitrite as N			117	0.01	0.1	4	0.0	
TKN			24	2.4	3.8	29	1.27	2.0
Phosphorus	0.8-12	0.05	24	0.55	2.0	25	0.05	0.28
Metals and metalloids (mg/L)								
Aluminium	20	5	NA			25	0.07	0.59
Arsenic	2	0.1	24	0.001	0.003	25	0.001	0.002
Boron – D		0.5	24	0.28	0.37	25	0.28	0.55
Copper	5	0.2	NA			25	0.006	0.007
Iron	10	0.2	NA			25	0.008	0.027
Lead	5	2	NA			25	0.001	0.002
Manganese	10	0.2	NA			25	0.009	0.078
Zinc	5	2	NA			25	0.02	0.04

Where, STV: short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved.

Table D–5: Water qualities at the source (Bolivar DAFF filtered water after chlorine composite) during dry (2013) and wet (2016) year.

Element	Dry (D: 2013)			Wet (W: 2016)			Ratio (W/D)	
	N	Median	95th %ile	N	Median	95th %ile	Median	95th %ile
Physical Characteristics								
TDS (mg/L; by EC)	335	1093	1213	335	1240	1468	**1.13**	**1.21**
pH (pH units)	13	7.2	7.7	13	7.3	7.8	1.01	1.01
Major Ions (mg/L)								
Alkalinity as $CaCO_3$	13	110	135	13	110	127	1.00	0.94
Bicarbonate	13	135	165	4	125	148	0.93	0.90
Calcium	13	40	45	13	38	46	0.95	1.02
Chloride	13	397	471	13	461	541	**1.16**	**1.15**
Magnesium	13	34	38	13	36	48.6	1.06	1.28
Potassium	13	38.5	42.1	13	39	43	1.01	1.02
Sodium	13	264	295	13	323	390	**1.22**	**1.32**
SAR	12	7.61	8.1	7	8.87	9.29	**1.17**	**1.15**
Nutrients (mg/L)								
Nitrate as N	106	9.92	16.0	13	NA			
Nitrite as N	53	0.1	0.1	13	NA			
TKN	13	2	2.59	13	1.17	1.91	0.59	0.74
Phosphorus	13	0.13	0.68	13	0.03	0.29	0.23	0.43
Metals and metalloids (mg/L)								
Arsenic	13	0.0009	0.0016	13	0.0006	0.0013	0.67	0.81
Boron – D	13	0.3	0.41	13	0.39	0.52	**1.30**	**1.27**

Table D–6: Water qualities measured at the point of use (farm dams).

Element	Guidelines		Wet season (Sep 2017)			Dry season (Feb 2018)		
	STV	LTV	N	Median	90th %ile	N	Median	90th %ile
Physical Characteristics								
TDS (mg/L; by EC)			6	1042	1074	6	1193	2030
pH (pH units)	6.5-8.5		6	7.8	8.7	6	7.8	8.6
Turbidity (NTU)			9	3.4	32.6		6.3	57.6
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			6	132	145	6	155	182
Bicarbonate			6	130	145	6	149	180
Calcium			6	45	50	6	49	61
Chloride	S: <175; MS: 175-350; MT: 350-700; T: >700		6	548	566	6	481	849

Magnesium			6	43	44	6	37	59
Potassium			6	39	42	6	41	67
Sodium	S: <115; MS: 115 -230; MT: 230-460; T: >460		6	331	340	6	275	518
Sulphate			6	225	240	6	214	383
SAR			6	8.4	8.7	6	7.5	11.3
Nutrients (mg/L)								
Nitrate +Nitrite as N	25 – 125 as TN	5 as TN	6	4.4	6.1	6	0.1	4.9
TKN			6	0.9	1.15	6	1.05	1.43
Phosphorus	0.8-12	0.05	6	0.08	0.15	6	0.09	0.14
Metals and metalloids (mg/L)								
Aluminium	20	5	6	0.12	2.24	6	0.29	2.86
Arsenic	2	0.1	6	0.001	0.002	6	0.001	0.003
Boron – D		0.5	6	0.46	0.51	6	0.41	0.65
Copper	5	0.2	6			6		
Iron	10	0.2	6	0.13	2.23	6	0.21	2.72
Lead	5	2	6			6		
Manganese	10	0.2	6	0.015	0.025	6	0.016	0.034
Others (mg/L)								
Free chlorine			6	0.0	0.0	6	0.0	0.0
total chlorine			6	0.0	0.0	6	0.0	0.1
Microbiological and Algae								
E. coli (cfu/100 mL)			6	53	500	6	44	1553
Chlorophyll (RFU)			6	0.19	3.9	6	6.3	12.8
Blue Green Algae-PC (RFU)			6	0.22	0.57	6	0.4	1.0

Figure D–3. Algal blooms in storage dams.

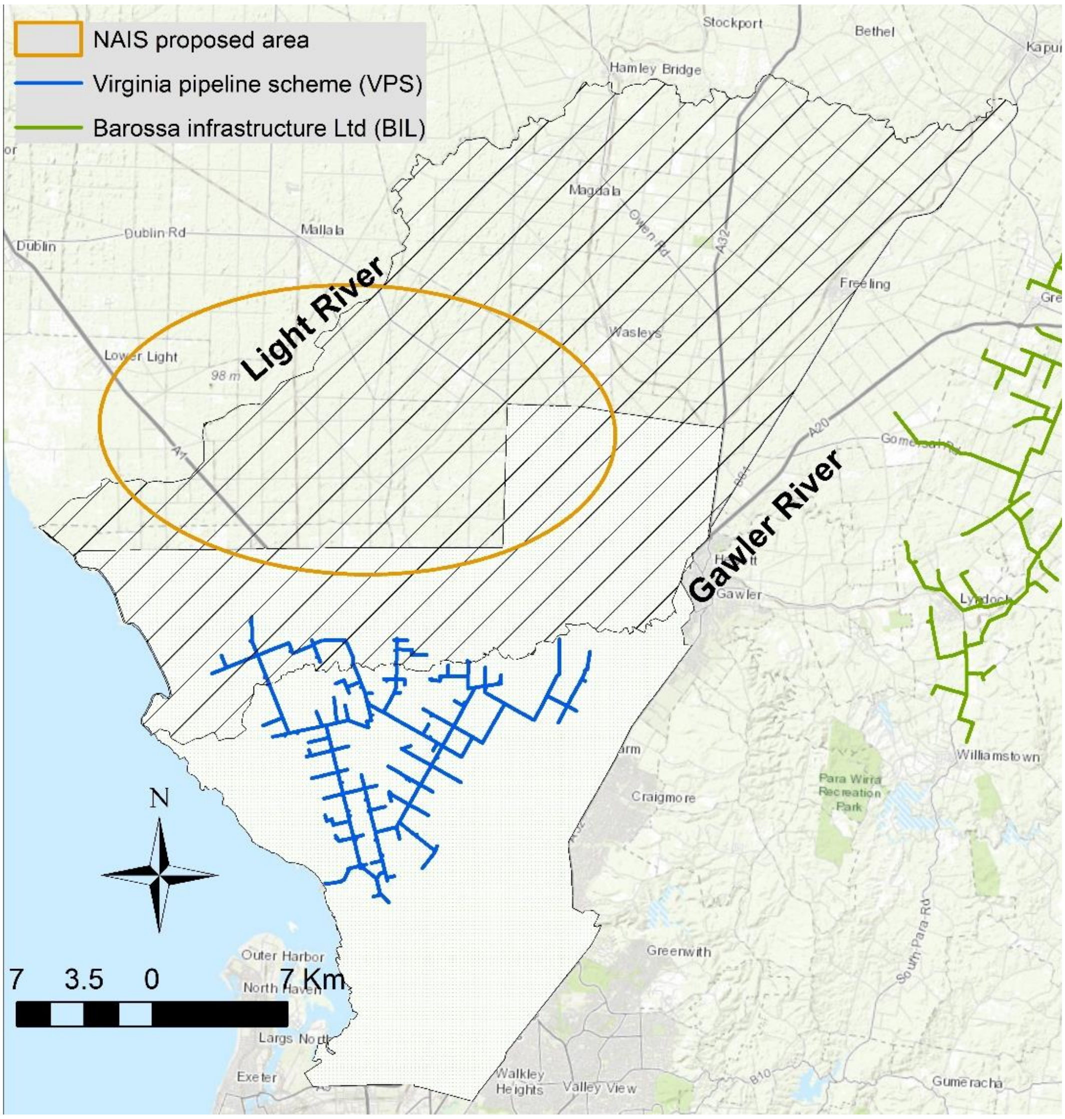


Figure D–4. Proposed area for NAIS Scheme (Data sources: NAIS project proposal template, Sep-2017[18]).

[18] https://www.sawater.com.au/__data/assets/pdf_file/0020/215714/Call-for-Project-Proposals-September-2017.pdf

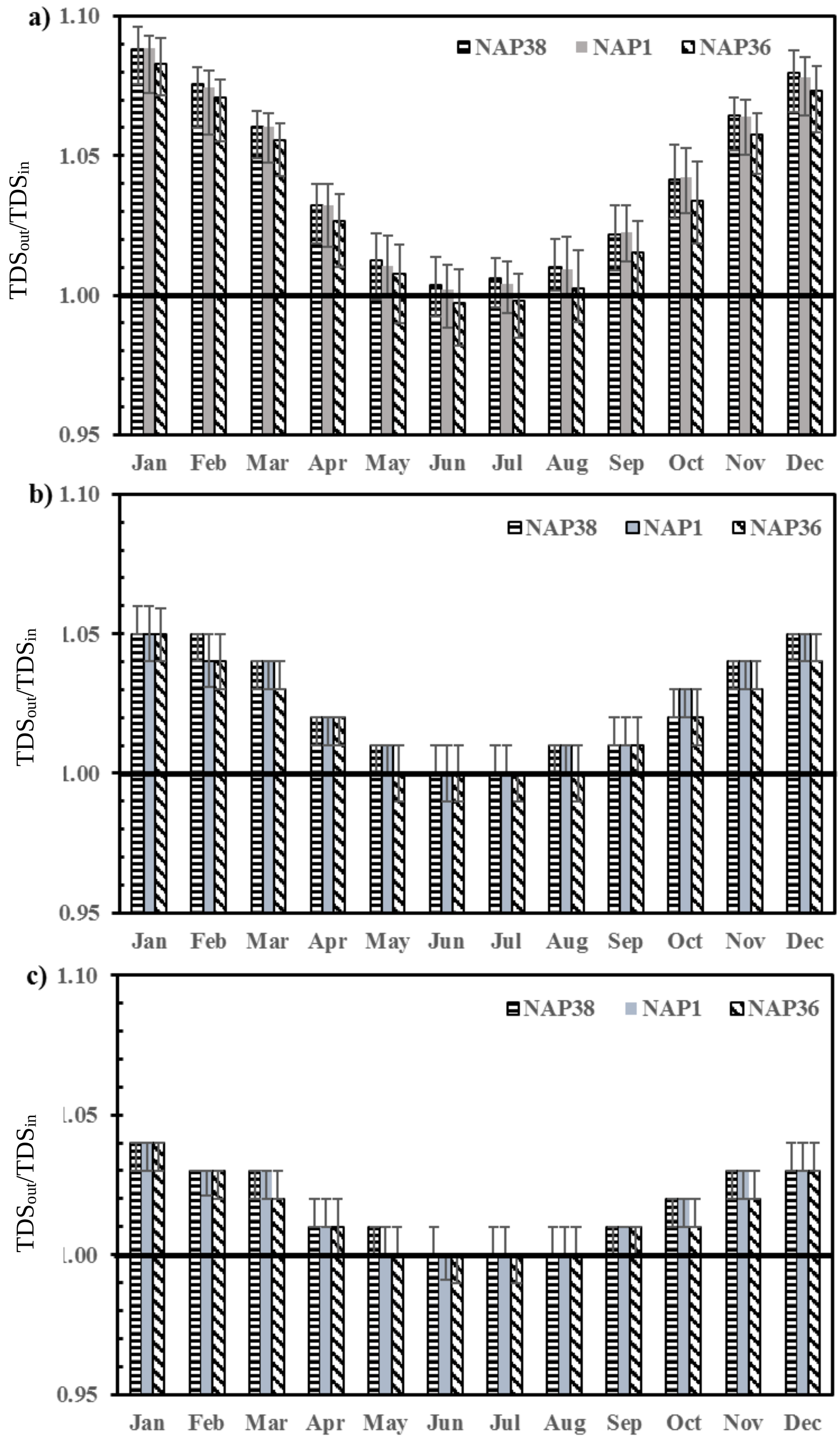


Figure D–5. Monthly median salinity ratio (based on 1 month of HRT and historical climate data) between water after and before surface storage for grid number: NAP38, NAP1 and NAP36 at different storage depth: a) 3 m, b) 5 m and c) 7 m. The top and bottom bars represent the 90th %ile and 10th %ile respectively.

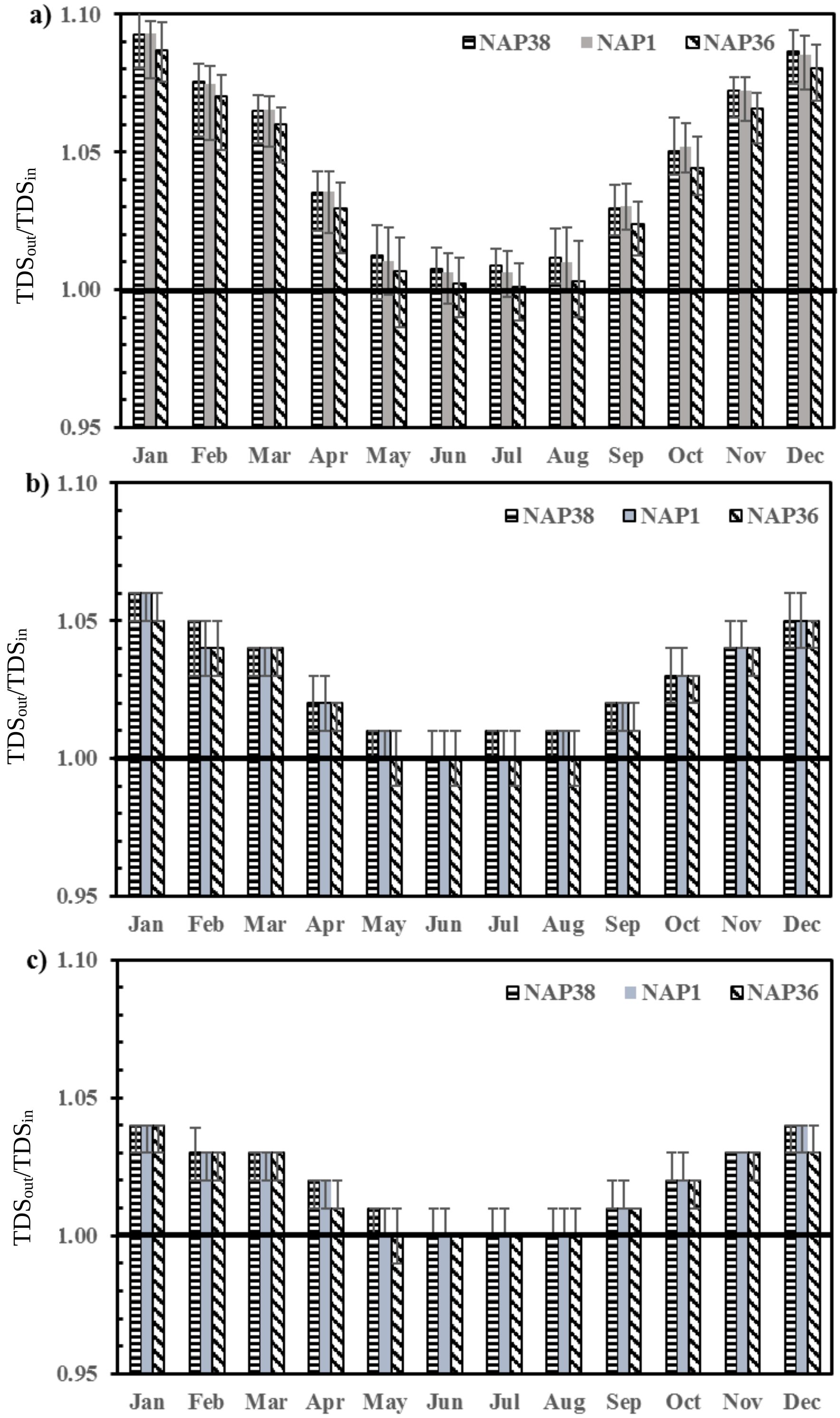


Figure D–6. Monthly estimated median salinity ratio (based on 1 month of HRT and climate change model) between waters after and before surface storage for grid number: NAP38, NAP1 and NAP36 at different storage depth: a) 3 m, b) 5 m and c) 7 m. The top and bottom bars represent the 90th %ile and 10th %ile respectively.

Table D–7: Qualities of injected and recovered waters from ASR storage during the second, third and fourth cycle of injection [data for ASR storage adapted from Barry et al. (2010)].

Element	Recycled water injected C2			Recycled water recovered C2			Recycled water injected C3			Recycled water recovered C3			Recycled water injected C4			Recycled water recovered C4[a]			Recycled water (Winters 2012-2017)	
	N	50th %ile	95th %ile	N	50th %ile	95th %ile	N	50th %ile	95th %ile	N	50th %ile	95th %ile	N	50th %ile	95th %ile	N	50th %ile	90th %ile	50th %ile	95th %ile
Physical Characteristics																				
TDS mg/L; by EC)	8	1150	1250	4	1240	1450	-			4	1070	1420	7	1110	1180	5	1160	1270	1031	1177
pH (pH units)	7	6.9	7.4	4	7.0	7.8	4	7.9	8.5	4	7.2	7.4	7	7.1	7.4	5	7.4	7.6	7.1	7.4
Major Ions (mg/L)																				
Bicarbonate	8	255	267	12	301	332	17	170	223	16	254	470	7	178	252	5	265	268	153	184
Chloride	14	414	478	12	461	580	17	409	478	16	436	581	7	437	452	5	444	492	391	460
Calcium	8	46.1	49.8	12	68.0	83.2	17	37.2	39.9	16	70.3	85.9	7	38.4	39.2	5	62.5	65.4	38.4	42.3
Magnesium	8	37.8	39.8	12	42.0	50.0	17	34.0	37.7	16	39.4	47.4	7	35.0	37.5	5	35.4	36.6	31.5	35.5
Potassium	8	50.1	52.2	12	46.0	47.2	17	40.6	42.2	16	39.2	49.0	7	37.5	42.7	5	38.9	40.0	37	40.7
Sodium	8	295	267	12	310	354	17	409	478	16	305	372	7	297	318	5	290	324	277	326
Nutrients (mg/L)																				
Nitrate +Nitrite as N	14	3.0	5.0	11	0.053	2.0	17	1.3	8.2	03	0.58	0.96	7	7.2	10.5	5	0.010	0.041	0.1	0.1
TKN	14	5.3	7.0	11	4.0	4.5	17	1.6	2.3	16	0.70	2.8	7	1.5	4.9	5	0.93	1.6	1.59	2.53
Phosphorus	14	2.1	3.6	11	1.0	1.6	17	0.40	3.0	16	0.54	3.1	7	2.6	5.3	5	1.2	1.6	0.34	0.47
Metals and metalloids (mg/L)																				
Arsenic	-			-			4	0.002	0.003	4	0.012	0.067	-			5	0.029	0.030	0.001	0.002
Iron	8	0.062	0.18	3	0.65	0.65	4	<0.03		-			-			5	0.37	0.59	0.006	0.018
Manganese	-			-			-			-			-			5	0.05	0.093	0.008	0.043

[a] Cycle 4: Recovery salinity limit was 1300 mg/L; Where, STV: short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved.

Table D–8: Water qualities at lagoons influent waters (Bolivar Secondary effluent raw to lagoons, 2012-17).

Element	Guidelines		All seasons		
	STV	LTV	N	Median	95th %ile
TDS (mg/L; by EC)			9	1128	1183
pH (pH units)			301	7.3	7.6
Major Ions (mg/L)					
Alkalinity as $CaCO_3$			151	152	198
Bicarbonate			119	183	224
Nutrients (mg/L)					
Nitrate + Nitrite as N			357	10.8	17.2
Nitrogen			300	15.1	24.9
Phosphorus			292	1.27	5.56
Algae (cells/mL)					
Algae			26	185000	2082000
BGA			26	169500	2068500
BGA – Toxin			18	0	609000 [c]

Appendix E – Surface water and stormwater

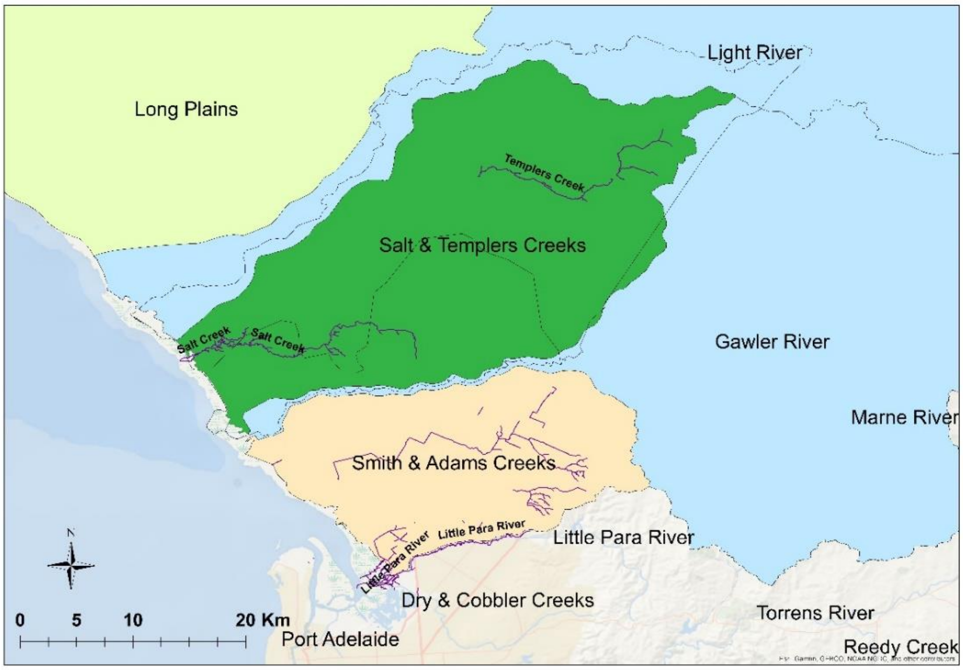


Figure E–1. Surface water catchment area within the study area.

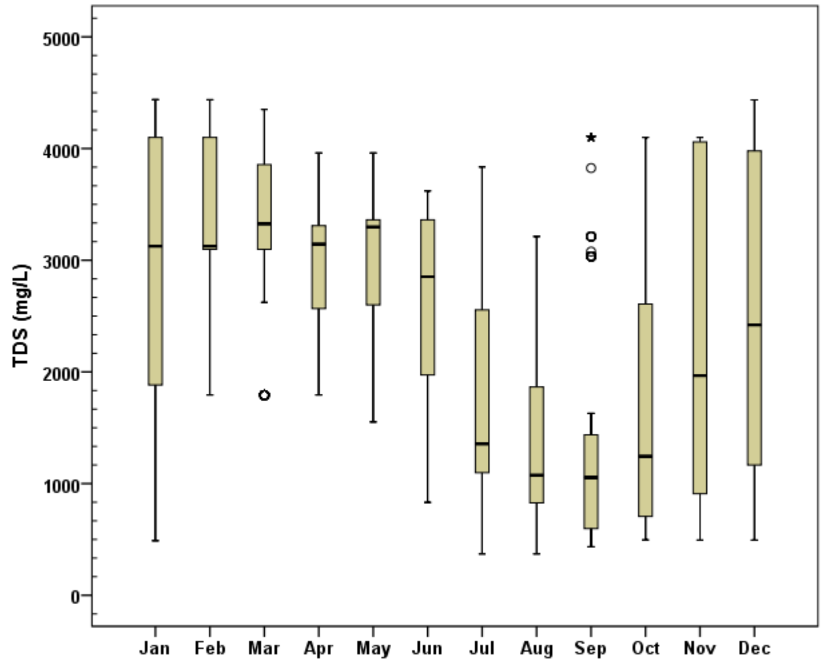


Figure E–2. Monthly salinity levels at Gawler River (data adapted from waterdata website: http://amlr.waterdata.com.au/PDFViewer.aspx?page=UserGuide between 2009 – 2016 at Station number: A5050510).

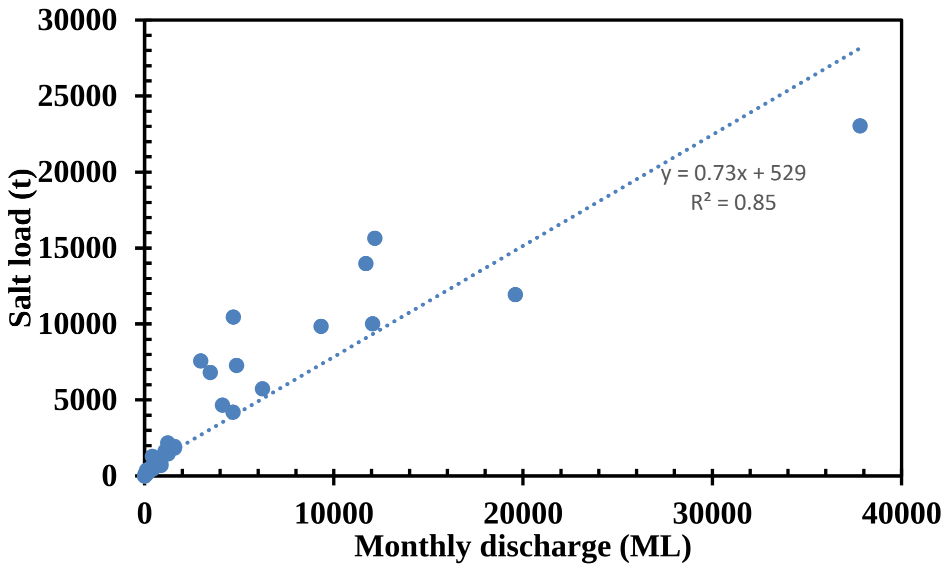


Figure E–3. Relation between monthly salt load and monthly discharge for Gawler River

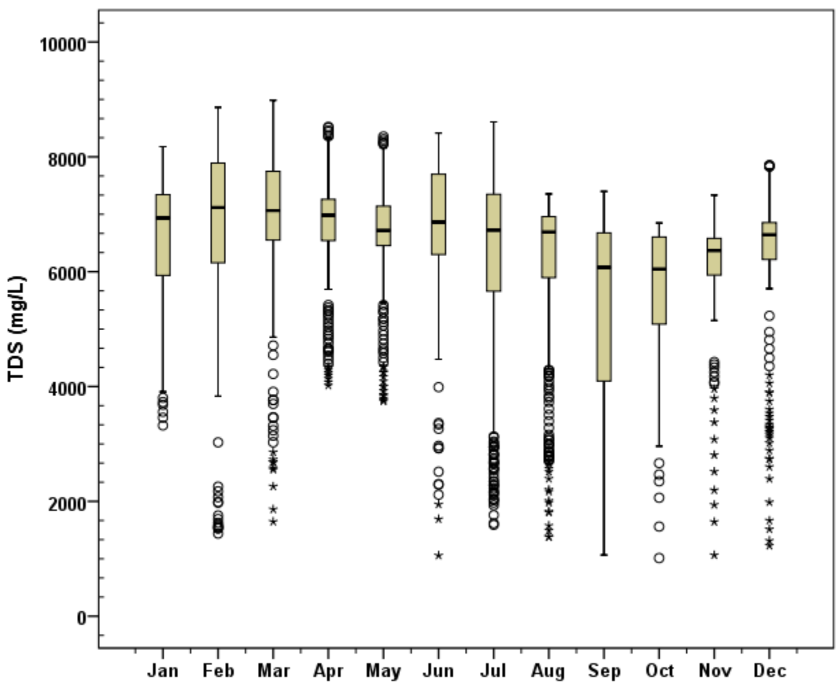


Figure E–4. Monthly salinity levels at Light River (data adapted from waterconnect website between 2002 – 2016 at Station number: A5050532).

Table E–1: Water qualities for Gawler River (between 2009 – 2016, Station: A5050510) and Light River (Jul. - Nov. 2016. Station: A5051003, data adopted from Water Data Services [a].

Element	Guidelines		All seasons			Autumn			Winter			Spring			Summer		
	STV	LTV	N	Median	95th %ile	N	Median	75th %ile	N	Median	75th %ile	N	Median	90th %ile	N	Median	90th %ile
Gawler River																	
pH (pH units)	6.5-8.5		38	8.2	8.9	8	8.1	8.3	9	8.2	8.6	10	8.1	8.9	11	8.1	8.7
Temperature(^{0}C)			38	18.9	25	8	17.2	19.9	9	11.4	11.9	10	19.3	19.8	11	21.7	27.6
Turbidity (NTU)			38	7.4	46.2	8	7.6	13.4	9	8.3	18.2	10	7.2	66.1	11	21.4	43.2
Nitrate +Nitrite	25 – 125	5 as TN	38	0.88	4.7	8	0.13	1.27	9	2.83	3.81	10	0.93	4.37	11	0.82	3.1
TKN			38	1.45	3.1	8	1.45	1.82	9	1.17	1.56	10	1.51	2.96	11	1.53	3.3
Phosphorus	0.8-12	0.05	38	0.32	1.43	8	0.57	1.23	9	0.2	0.92	10	0.25	1.16	11	0.35	1.55
Copper	5	0.2	38	0.003	0.02	8	0.002	0.003	9	0.003	0.008	10	0.003	0.22	11	0.003	0.01
Lead	5	2	38	0.0004	0.002	8	0.002	0.002	9	0.0004	0.0009	10	0.0008	0.004	11	0.0003	0.001
Zinc	5	2	38	0.015	0.1	8	0.02	0.03	9	0.01	0.03	10	0.02	0.1	11	0.01	0.04
Light River																	
Nitrate +Nitrite	25 – 125	5 as TN							6	0.2	0.9						
TKN									6	1.65	2.3						
Phosphorus	0.8-12	0.05							6	0.2	0.32						
Copper	5	0.2							6	0.01	0.017						
Lead	5	2							6	0.002	0.004						
Zinc	5	2							6	0.023	0.04						

[a] http://amlr.waterdata.com.au/WaterQuality.aspx?sno=A5050510&Report=trConcentrations

Where, STV: short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved.

Table E–2: Water qualities of water samples collected from Gawler River and Light River during the wet seasons (Sep. 2017).

Element	Guidelines		Gawler River			Light River		
	STV	LTV	N	Median	75th %ile	N	Median	75th %ile
Physical Characteristics								
TDS (mg/L; by EC)			4	1060	1081	4	5745	6003
pH (pH units)	6.5-8.5		4	7.8	7.9	4	8.2	8.3
Turbidity (NTU)			4	5.9	28.7	4	2.7	3.7
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			4	186	188	4	386	406
Bicarbonate			4	186	188	4	386	406
Calcium			4	48	51	4	181	189
Chloride	S: <175; MS: 175-350; MT: 350-700; T: >700		4	519	531	4	3390	3565
Magnesium			4	47	49	4	280	298
Potassium			4	9.5	11.5	4	35.5	38.5
Sodium	S: <115; MS: 115 -230; MT: 230-460; T: >460		4	252	260	4	1605	1707
Sulphate			4	102	108	4	583	623
SAR			4	6.2	6.2	4	17.4	17.9
Nutrients (mg/L)								
Nitrate +Nitrite as N	25 – 125 as TN	5 as TN	4	0.07	0.43	4	0.01	
TKN			4	0.3	0.6	4	0.35	0.6
Phosphorus	0.8-12	0.05	4	0.08	0.1	4	0.08	0.09
Metals and metalloids (mg/L)								
Aluminium	20	5	4	0.31	0.72	4	0.07	0.08
Arsenic	2	0.1	4	0.001		4	0.001	
Boron – D		0.5	4	0.2	0.2	4	0.9	1.0
Iron	10	0.2	4	0.66	1.47	4	0.11	0.13
Manganese	10	0.2	4	0.019	0.02	4	0.007	0.009

Table E–3: Water qualities measured at the GWRS.

Element	Guidelines		Wet season (Sep 2017)			Dry season (Feb 2018)		
	STV	LTV	N	Wingate	Hill D.	N	Wingate	Hill D.
Physical Characteristics								
TDS (mg/L; by EC)			1	1156	880	1	1051	1070
pH (pH units)	6.5-8.5		1	8.58	8.44	1	7.77	8.12
Turbidity (NTU)			1	1.87	1.47	1	4.57	7.5
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			1	202	149	1	138	164
Bicarbonate			1	202	137	1	138	164
Calcium - T			1	57	43	1	38	43
Chloride	S: <175; MS: 175-350; MT: 350-700; T: >700		1	647	466	1	416	420
Magnesium			1	58	36	1	30	32
Potassium			1	17	30	1	39	37
Sodium	S: <115; MS: 115 -230; MT: 230-460; T: >460		1	326	260	1	232	232
Sulphate			1	147	159	1	189	178
SAR			1	7.2	7.0	1	6.8	6.5
Nutrients (mg/L)								
Nitrate +Nitrite as N	25 – 125 as TN	5 as TN	1	0.61	2.5	1	0.82	0.17
TKN			1	0.4	0.8	1	0.7	0.8
Phosphorus - T	0.8-12	0.05	1	0.07	0.09	1	0.05	0.15
Metals and metalloids (mg/L)								
Aluminium-T	20	5	1	0.09	0.04	1	0.16	0.10
Arsenic - T	2	0.1	1	<0.001	<0.001	1	<0.001	<0.001
Boron – S		0.5	1	0.26	0.31	1	0.3	0.33
Iron – T	10	0.2	1	0.1	<0.05	1	0.16	0.14
Manganese- T	10	0.2	1	0.004	0.013	1	0.022	0.015
Others (mg/L)								
Free chlorine			1			1	0.0	0.0
total chlorine			1			1	0.2	0.0
Microbiological and Algae								
Escherichia coli (cfu/100 mL)			1	10	0	1	200	170
Chlorophyll (RFU)			1	0.39	3.24	1	0.87	1.12
Blue Green Algae-PC (RFU)			1	0.16	0.38	1	0.05	0.09

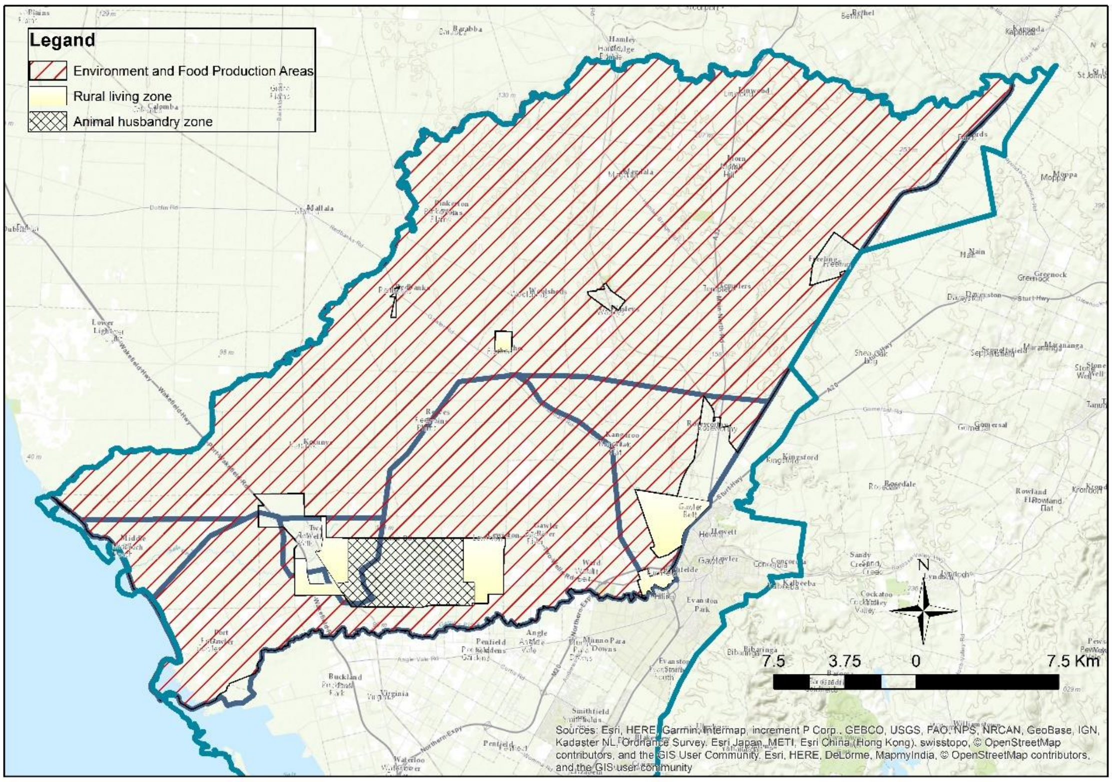


Figure E–5. Environment and Food Production Areas within the study area (adapted from Department of Planning, Transport and Infrastructure Development Division, SA Government).

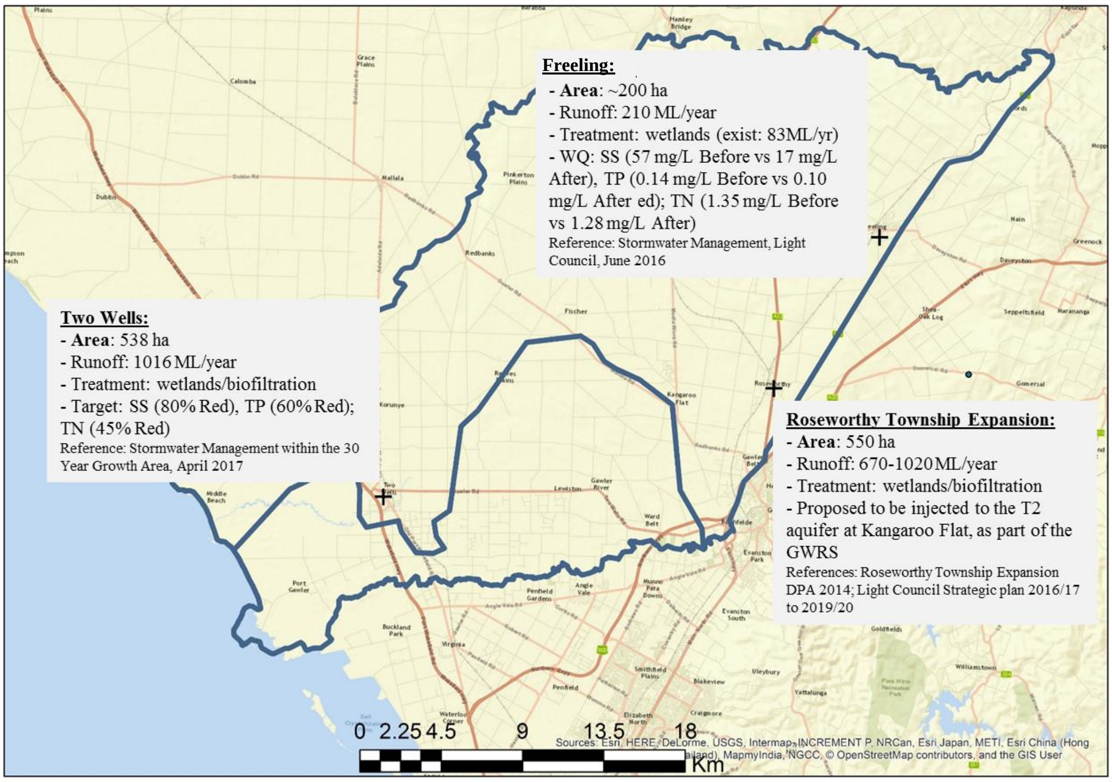


Figure E–6. Urban stormwater from townships within the study region.

Table E–4: Qualities of waters of urban stormwater at Parafield before treatment (by wetland) and after storage (by ASR); Adapted from (Page et al., 2013)

Element	Guidelines		Wetland inlet			Recovered waters		
	STV	LTV	N	Median	95th %ile	N	Median	95th %ile
Physical Characteristics								
TDS (mg/L; by EC)			79	130	975	39	235	710
pH (pH units)	6.5-8.5		85	7.7	8.8	39	7.8	7.9
Turbidity (NTU)			69	20	296	39	1.1	13
Major Ions (mg/L)								
Alkalinity as $CaCO_3$			49	53	132	15	145	228
Bicarbonate			64	67	155	22	165	228
Chloride	S: <175; MS: 175-350; MT: 350-700; T: >700		73	29	192	22	35	146
Calcium			71	17	54	26	39	47
Magnesium			71	3.7	20	24	8.3	152.2
Potassium			68	3.5	11	23	3.6	5.1
Sodium	S: <115; MS: 115 -230; MT: 230-460; T: >460		68	20	106	23	42	120
Sulphate			66	13	65	22	24	49
SAR				1.1	3.1	23	1.6	3.8
Nutrients (mg/L)								
Nitrate +Nitrite as N	25 – 125 as TN	5 as TN	81	0.17	0.98	27	0.03	0.15
TKN			79	0.77	2.94	28	0.18	0.63
Phosphorus	0.8-12	0.05	85	0.14	0.44	28	0.03	0.07
Metals and metalloids (mg/L)								
Aluminium	20	5	46	0.89	5.83	4	0.10	0.13
Arsenic	2	0.1	74	0.001	0.006	37	0.003	0.004
Boron – D		0.5	45	0.04	0.14	9	0.062	0.17
Iron	10	0.2	72	0.634	4.63	37	0.38	2.71
Manganese	10	0.2	74	0.038	0.225	34	0.04	0.13

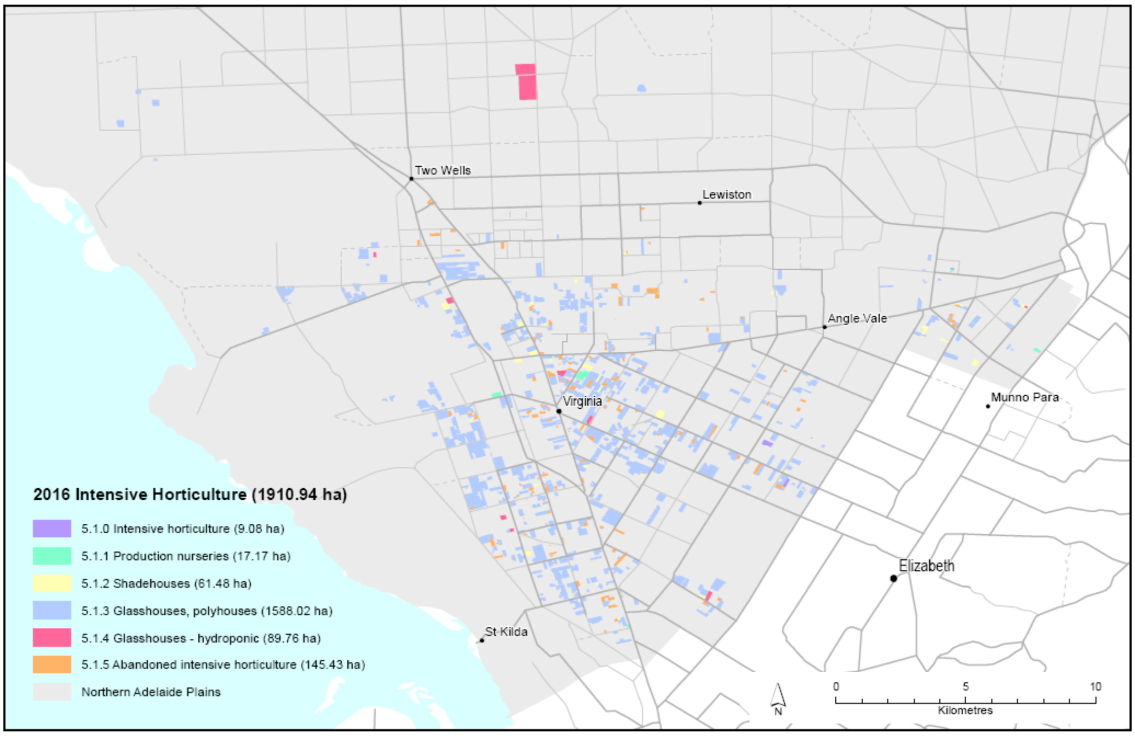


Figure E–7. Northern Adelaide Plains 2016 greenhouse (produced by PIRSA Spatial Information Services, 2018).

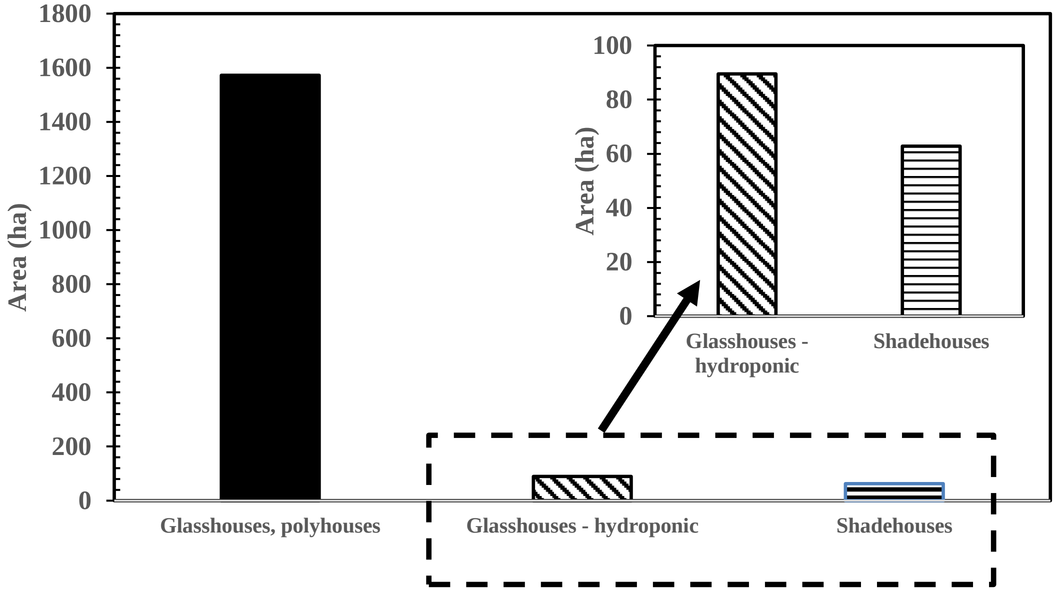


Figure E–8. Area of various greenhouses types within Northern Adelaide Plains 2016.

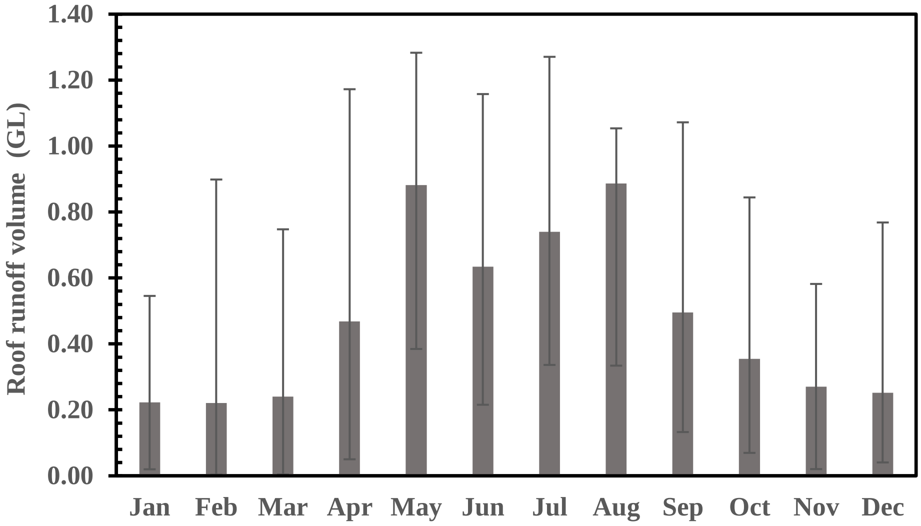


Figure E‒9. Estimated monthly roof runoff volume from the existing greenhouses area within the NAP.

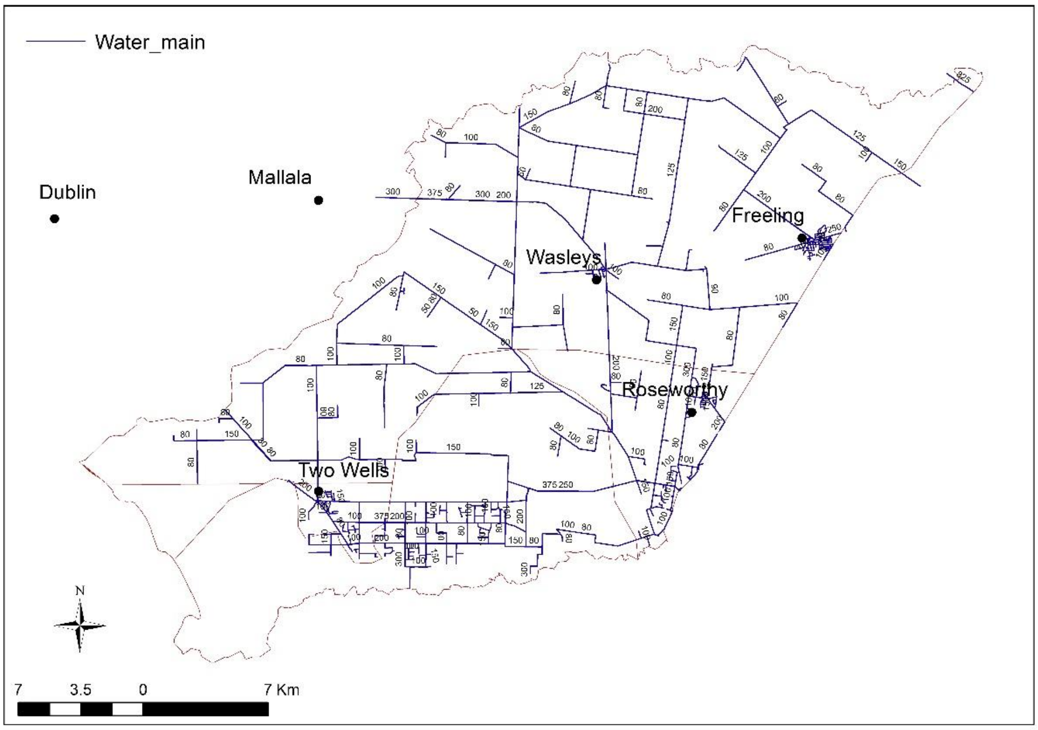


Figure E‒10. Mains distribution system within the study area (adapted from UniSA research data access portal) (SA Water, 2018).

Table E–5: Qualities of waters harvested from the greenhouse roofs

Element	Guidelines		May 2018			October 2018	
	STV	LTV	N	Median	75%ile	N	Median
Physical Characteristics							
TDS (mg/L; by EC)			5	74	184	2	109
pH (pH units)	6.5-8.5		5	7.4	8.2	2	8.2
Turbidity (NTU)			5	7	21		
Major Ions (mg/L)							
Alkalinity as $CaCO_3$			5	10	33	2	45
Bicarbonate			5	10	33	2	45
Calcium			5	0.15	0.58	2	0.3
Chloride	S: <175; MS: 175-350; MT: 350-700; T: >700		5	13	59	2	10
Magnesium			5	2	4	2	1.5
Potassium			5	3	9	2	2
Sodium	S: <115; MS: 115 -230; MT: 230-460; T: >460		5	0.4	1.7	2	11
Sulphate			5	6	41	2	6
SAR			5	0.65	2.9	2	0.82
Nutrients (mg/L)							
Nitrate +Nitrite as N	25 – 125	5 as TN	5	0.15	0.22		0.06
TKN			5	0.4	0.5		0.7
Phosphorus	0.8-12	0.05	5	0.12	0.2		0.14
Metals and metalloids (mg/L)							
Aluminium	20	5	5	0.26	0.9		0.5
Arsenic	2	0.1	5	<0.001	<0.05		<0.001
Boron – D		0.5	5	<0.05	<0.05		<0.05
Iron – T	10	0.2	5	0.21	0.80	2	0.4
Manganese- T	10	0.2	5	0.005	0.01	2	0.01
Microbiological and Algae							
Escherichia coli (cfu/100 mL)			5	1100	>2400	2	195

Where, STV: short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved.

Appendix F - Groundwater

F.1. Hydrogeology

A north-south hydrogeological cross section through the NAP PWA is presented in Figure F–1. This cross-section indicates the absence of Munno Para Clay to the north of the Gawler River coinciding with the presence of only one Tertiary aquifer; this tertiary aquifer is referred to as the T2 aquifer in Figure F–1. In the current report, the shallowest Tertiary aquifer that extends to the north, beyond the north western boundary of the NAP PWA (where the intervening Munno Para Clay confining layer is absent), is referred to as the T1 aquifer (S. Barnett, pers. comm.), not the T2 aquifer, as shown in **Figure F–1**.

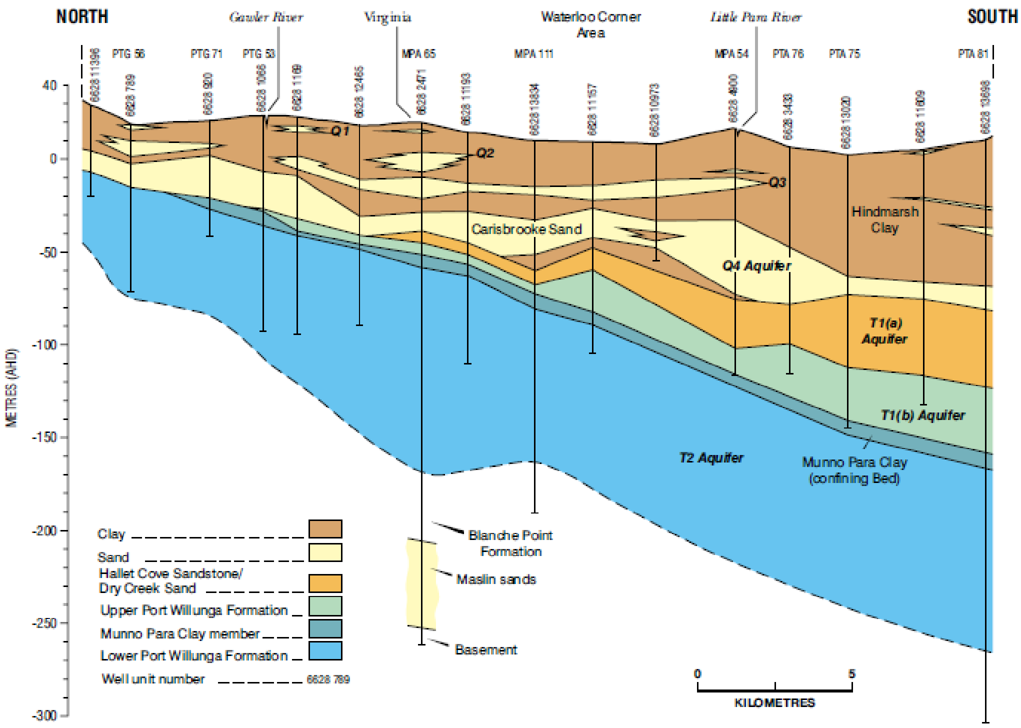


Figure F–1. North-south hydrogeological cross section through the NAP PWA (Source: GIWR, 2016).

F.2. Extent of the T1 aquifer

Beyond the northern boundary of the NAP PWA, there is limited use of the T1 aquifer and therefore this aquifer represents a potential groundwater resource (depending on water quality) and a potential target for MAR. It is important to understand the spatial extent of the T1 aquifer in order to assess its potential for water supply or storage.

Previously the T1 aquifer was depicted to extend from the coastline in the west to Hamley Bridge (Alma Fault) in the east and past Port Wakefield and Balaklava in the north (GIWR, 2016, Figure 4) (Figure F–2). Therefore, it was assumed that the hydrogeological cross section in the study area to the north of the NAP PWA was similar to that along the Gawler River, with a thick sequence of Port Willunga Formation present within the Redbank and Alma Faults (Smith et al., 2015) (Figure F–4). However, the physical extent of the Tertiary aquifers within the Adelaide Plains Numerical Groundwater Model 2011 (AP2011) (RPS Aquaterra, 2011) suggested the T1 aquifer did not extend east of the Redbank Fault (Figure F–5). Inspection of available drillhole logs in the study area revealed the absence of the T1 aquifer to the east of the Redbank Fault (Figure F–6). Thus, the hydrogeological cross-section between the Alma and Redbank Faults is considered similar to that in the vicinity of the Light River (Figure F–5). Further north the tertiary sands (T1) are believed to be present with fresh groundwater in the vicinity of Balaklava (GIWR, 2016, Figure 4). This reduced extent of the T1 aquifer has implications for water supply and storage within the study area of this project.

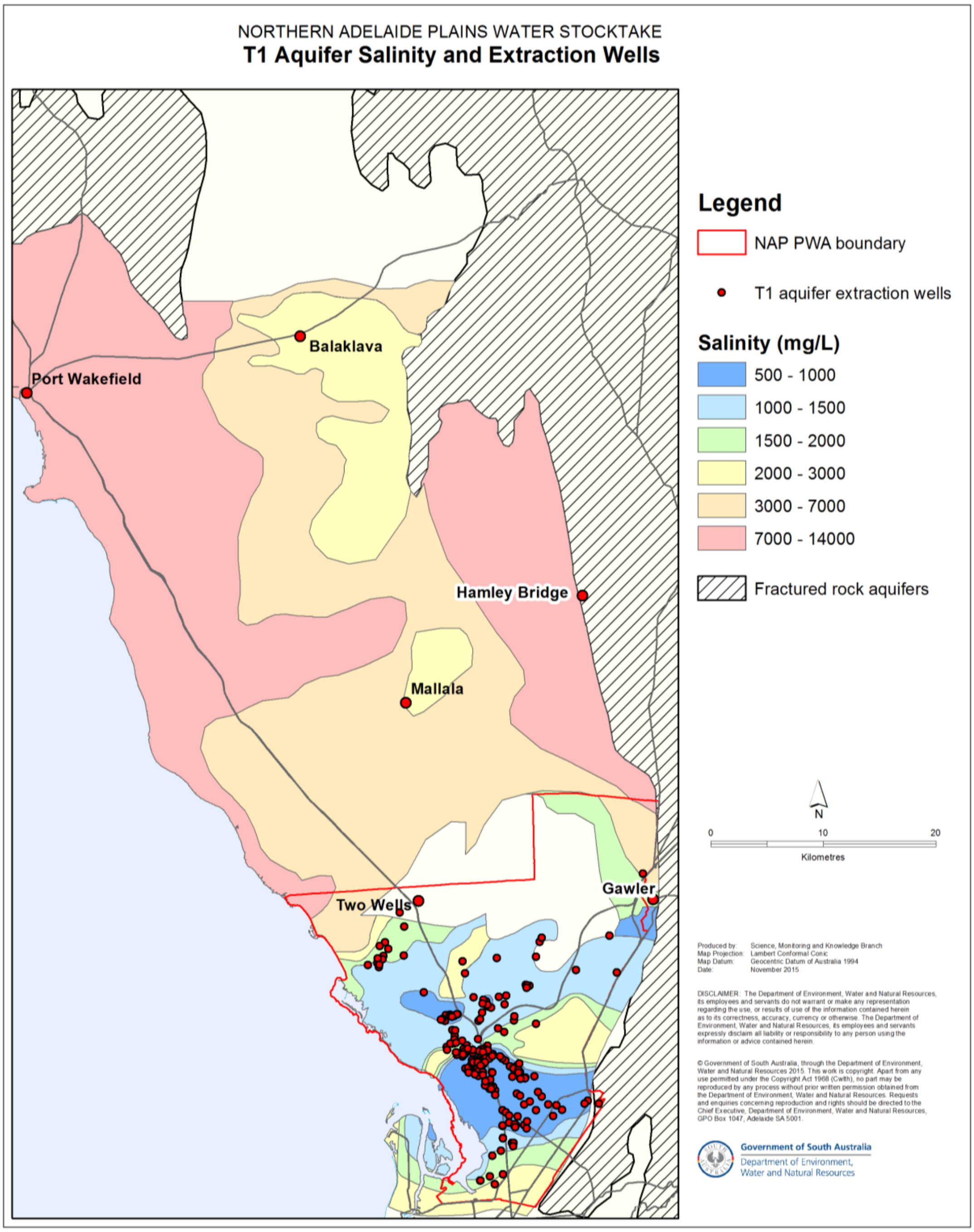
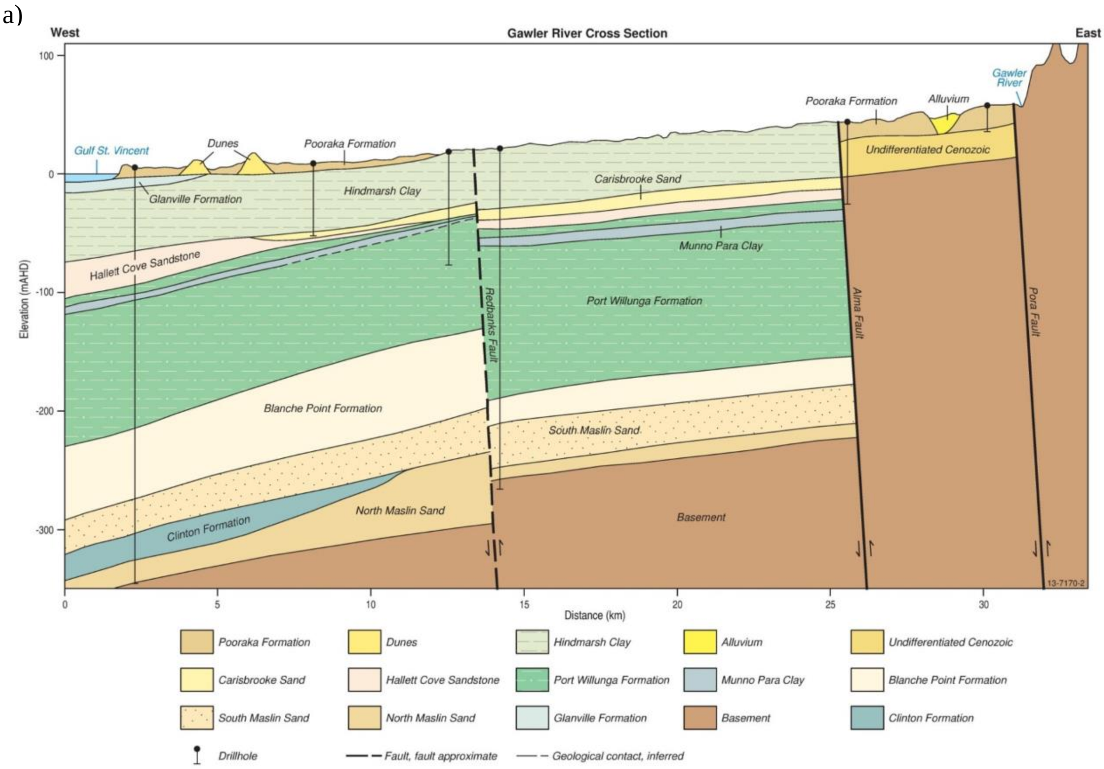


Figure F–2. Previous understanding of T1 aquifer salinity distribution and extraction wells (source: GIWR, 2016).

a)



b)

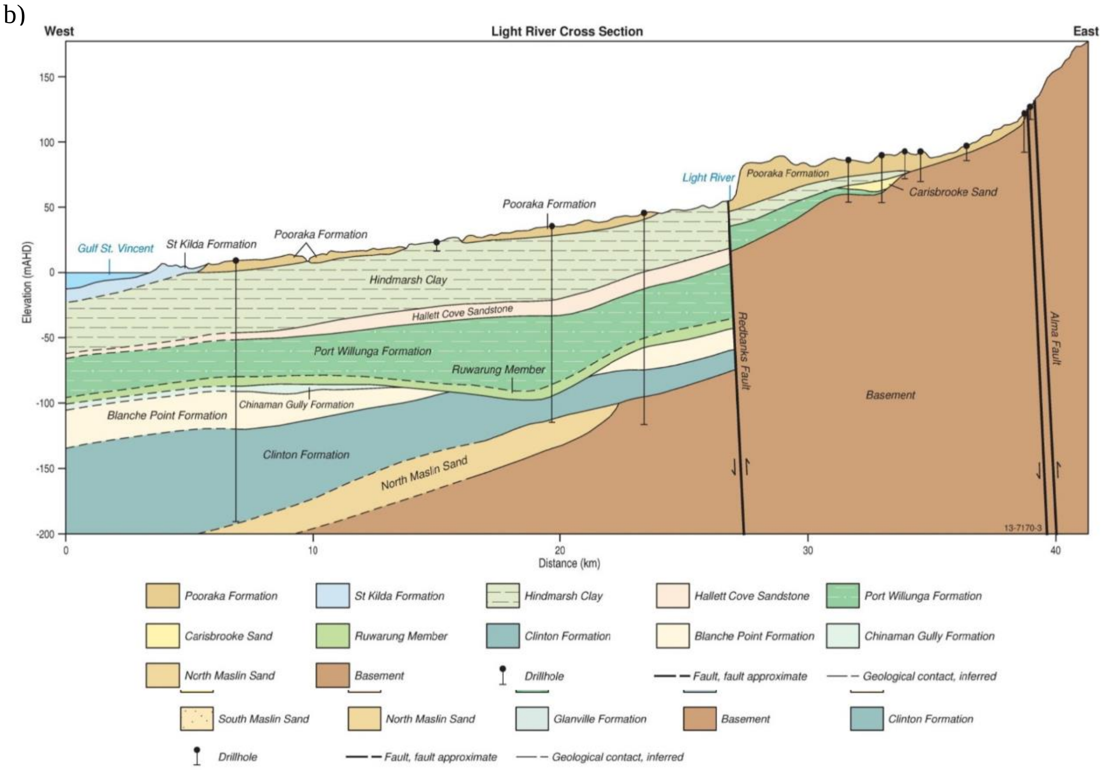


Figure F–3. Hydrogeological cross section in the vicinity of a) Gawler River and b) Light River (sourc: Smith et al., 2015).

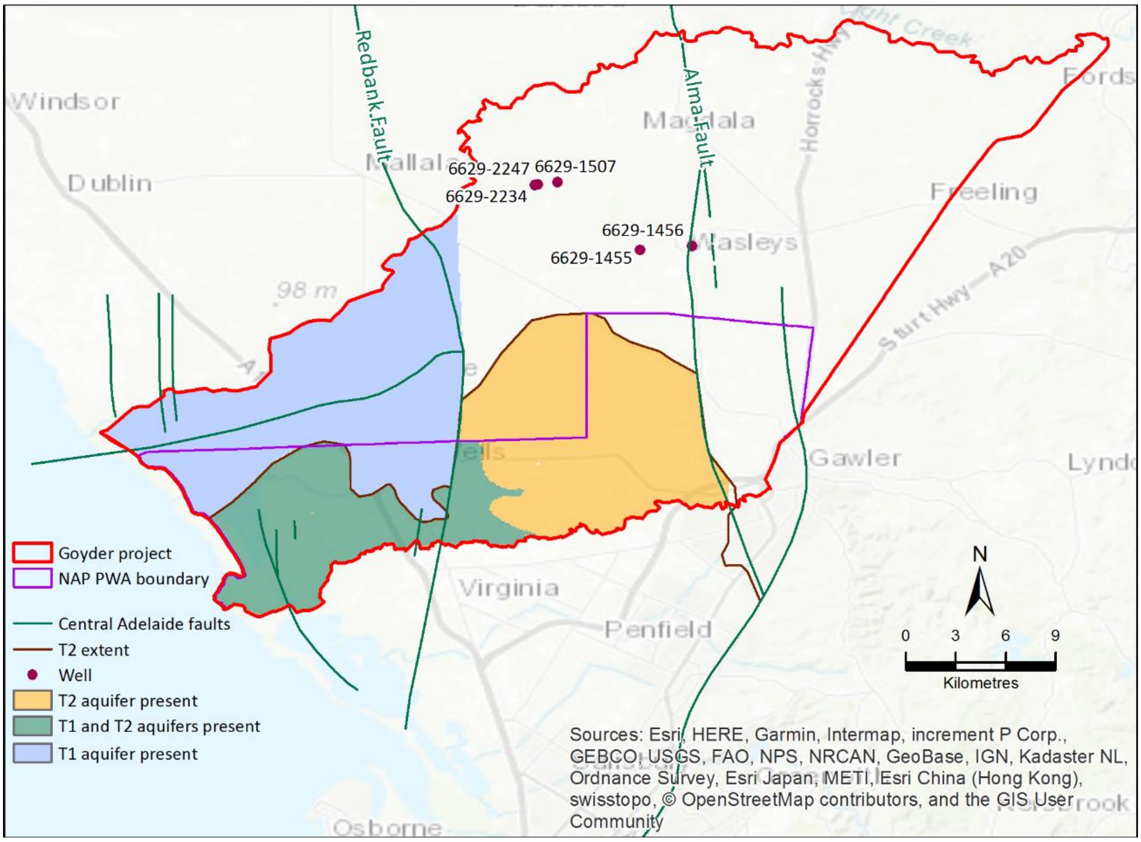


Figure F–4. Extent of Tertiary aquifers exported from the Adelaide Plains Numerical Groundwater Modell 2011 (AP2011) in relation to faults in study area and lithology. Locations are shown for wells where drillhole lithology was used to confirm the absence of the T1 aquifer between the Redbank and Alma faults.

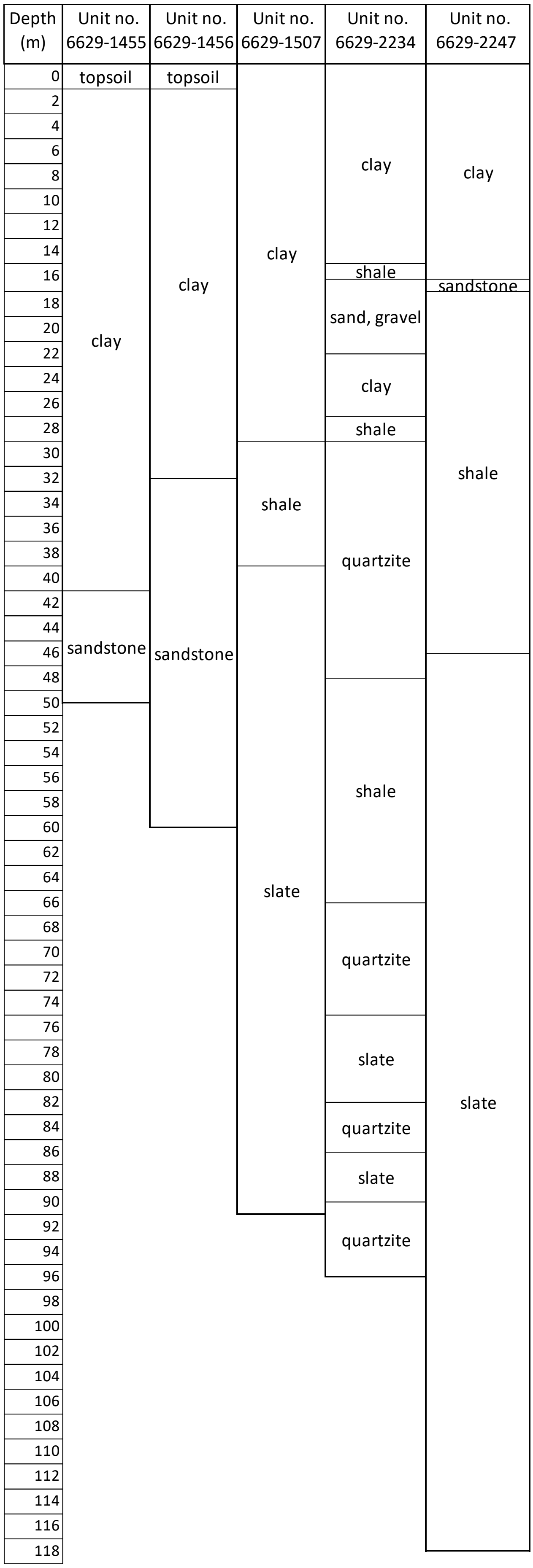


Figure F–5. Summary of available drillhole lithology between the Alma and Redbank Faults Well locations shown on Figure F–4.

F.3. Groundwater users, piezometric surface and salinity distribution

The location of extraction wells, the piezometric surface and salinity distribution is shown for the T1 aquifer in **Figure F–6** and for the T2 aquifer in **Figure F–7**.

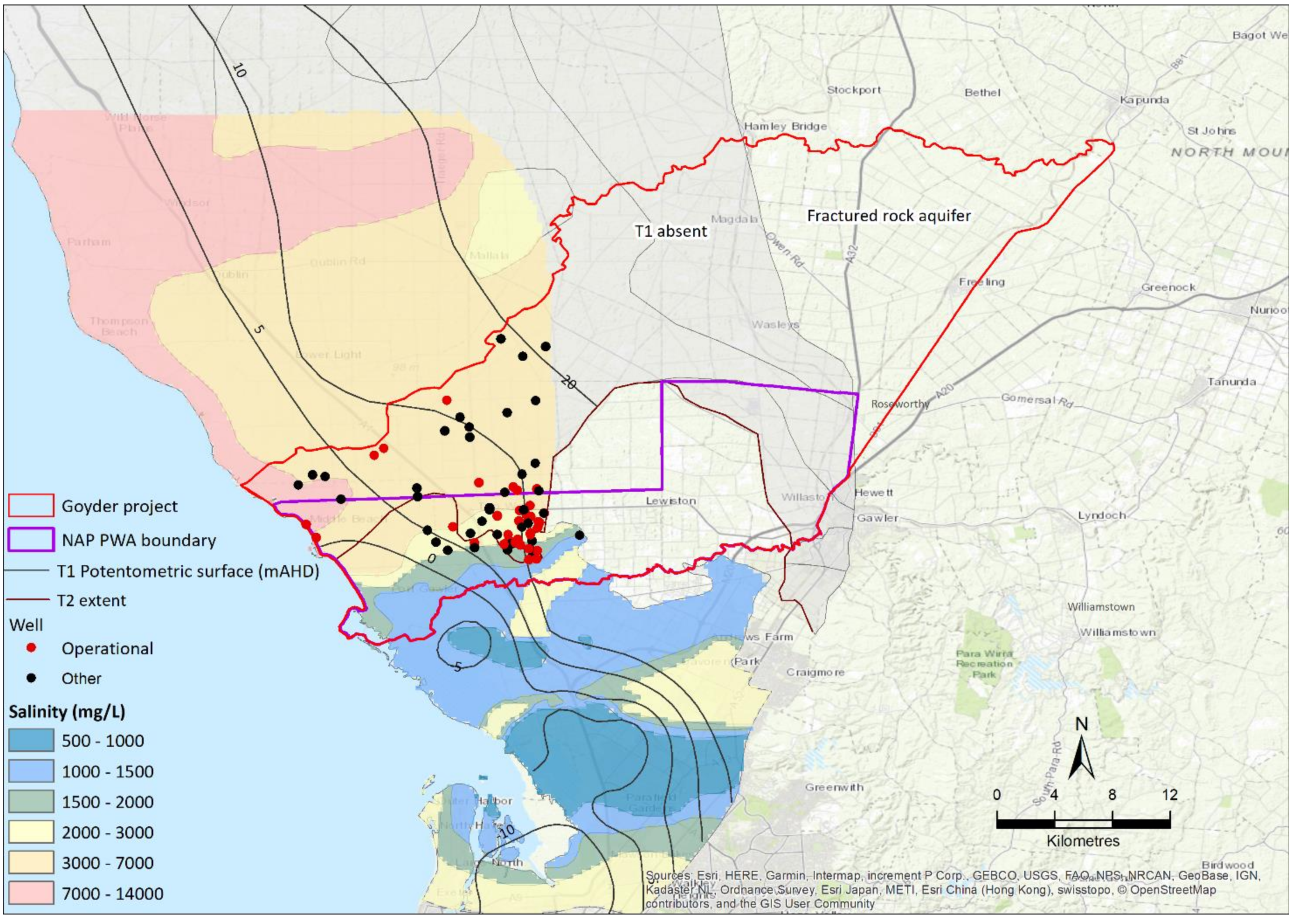


Figure F–6. T1 aquifer salinity distribution, extraction wells and piezometric surface (data sourced from DEW, 2017).

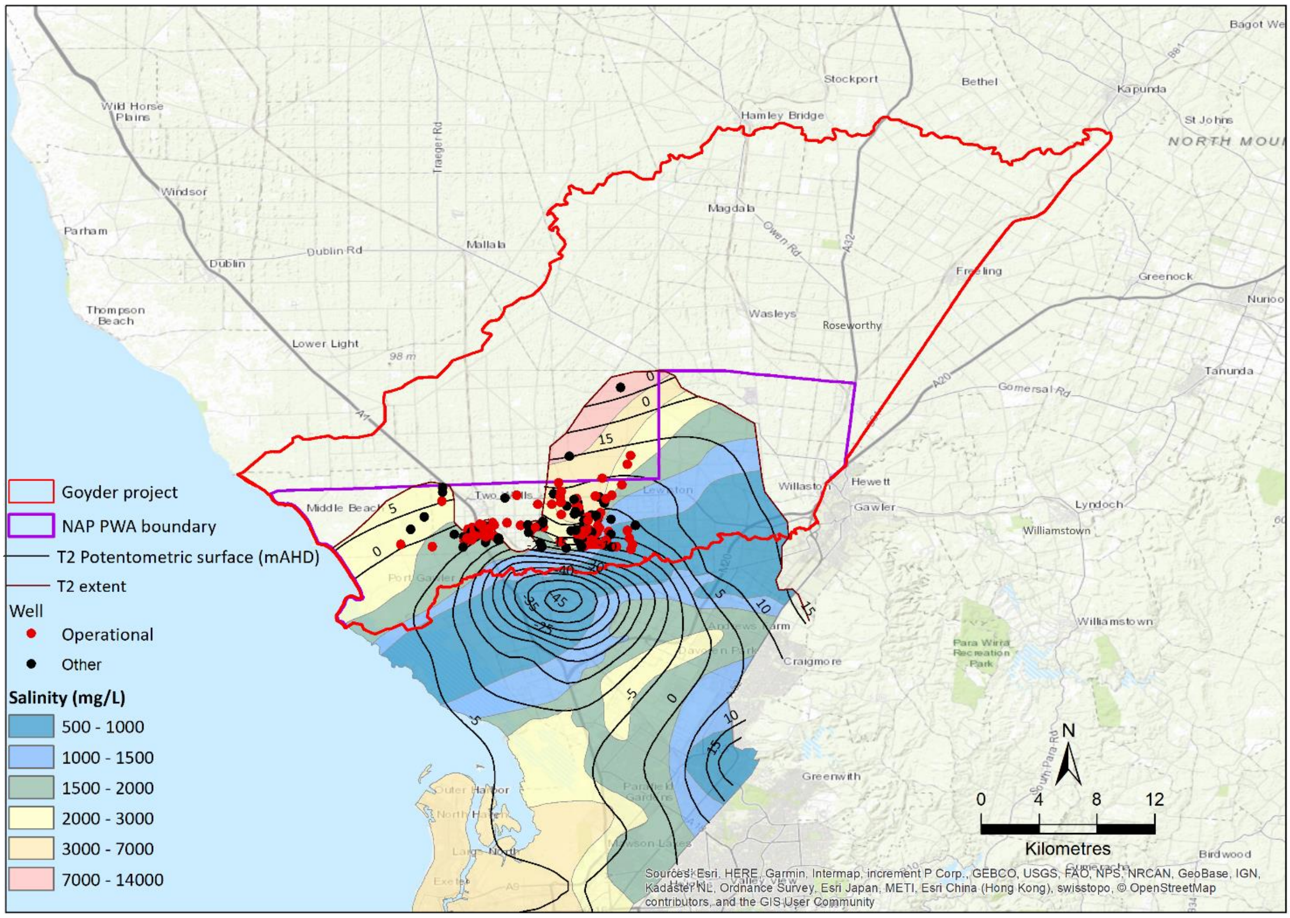


Figure F–7. T2 aquifer salinity distribution, extraction wells and piezometric surface (data sourced from DEW, 2017).

F.4. Environmental value of groundwater

The Environment Protection (Water Quality) Policy 2015 provides default environmental values for underground waters (groundwater) based on background total dissolved solids (TDS) (**Table F–1**). The environmental value of the aquifer is a key consideration to consider when assessing the feasibility of an aquifer for water supply or for storage using MAR. The proponent will need to consider relevant water quality considerations (guideline or trigger values) for the environmental value in accordance with the Australian Drinking Water Guidelines (NHMRC, 2011) or the Australian & New Zealand Guidelines for Fresh and Marine Quality (ANZECC-ARMCANZ, 2018).

Table F–1: Environmental values of underground waters based on background TDS (after SA EPA, 2015)

TDS (mg/L)	Drinking water for human consumption	Primary industries- irrigation and general water uses	Primary industries- livestock drinking water	Primary industries- aquaculture and human consumption of aquatic foods
TDS <1200 mg/L	X	X	X	X
1200 ≤ TDS < 3000 mg/L		X	X	X
3000 ≤ TDS < 13000 mg/L			X	X

F.5. Groundwater chemistry

Detailed groundwater chemistry data for the Tertiary aquifers is available for selected bore locations, shown in **Figure F–8**. This chemistry data is summarised in relation to salinity (TDS) classes in **Table F–2** and **Table F–3**

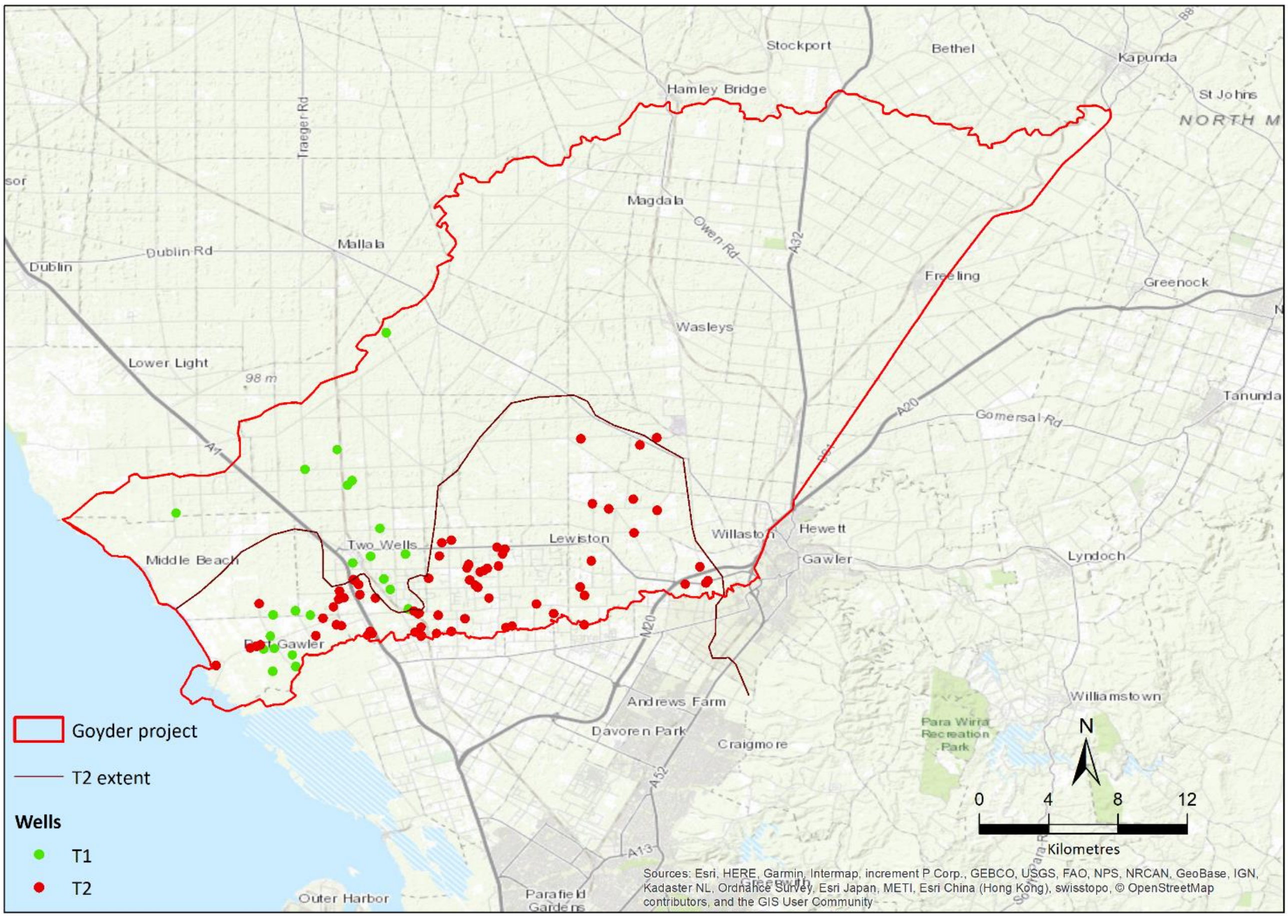


Figure F–8. Aquifer wells within the study area with detailed chemistry data available (data sourced from WaterConnect, 2017).

Table F–2: Average (number of samples) relative abundance of inorganic salts presented in T1 and T2 aquifer within the study area

Aquifer	TDS (mg/L) categories	Calcium (%)	Potassium (%)	Magnesium (%)	Sodium (%)	Bicarbonate (%)	Chloride (%)	Sulphate (%)
T1	500-1000	NA	0.82 (1)	NA	NA	40.6 (1)	NA	7.9 (1)
	1000-1500	3.3 (6)	NA	3.4 (6)	30.5 (6)	NA	38.1 (6)	11.4 (6)
	1500-2000	3.1 (8)	NA	3.5 (7)	28.9 (7)	21.7 (4)	40.4 (7)	11.0 (8)
	2000-3000	4.6 (8)	0.69 (2)	4.1 (8)	27.3 (8)	15.8 (3)	42.8 (8)	9.4 (8)
	3000-7000*	4.0 (1)	NA	3.3 (2)	29.5 (2)	NA	44.5 (2)	10.4 (1)
	7000-14000	2.3 (4)	NA	3.5 (3)	28.8 (4)	2.7 (3)	51.4 (4)	14.3 (4)
T2	500-1000	8.4 (27)	0.89 (23)	3.9 (27)	21.1 (26)	38.9 (24)	33.7 (27)	8.0 (27)
	1000-1500	5.1 (33)	0.79 (14)	3.8 (33)	26.7 (32)	28.2 (17)	40.5 (33)	8.8 (33)

	1500-2000	4.0 (27)	0.70 (10)	3.6 (27)	26.2 (27)	18.3 (16)	40.0 (27)	9.5 (27)
	2000-3000	4.0 (15)	0.55 (8)	3.4 (15)	24.4 (14)	15.2 (10)	38.8 (12)	7.5 (15)
	3000-7000	3.9 (3)	0.56 (2)	4.0 (3)	27.6 (3)	10.7 (1)	42.9 (3)	13.8 (3)
	7000-14000	NA	NA	NA	NA	NA	NA	NA
	>14000	3.8 (4)	0.39 (2)	2.7 (4)	29.7 (4)	5.3 (3)	52.5 (4)	7.5 (4)

*the majority of groundwater north of NAP PWA is within the 3000-7000 mg/L TDS category

Table F–3: Average water qualities in T1 and T2 aquifer within the study area

Element	Aquifer	Guidelines		TDS categories													
				500-1000		1000-1500		1500-2000		2000-3000		3000-7000*		7000-14000		>14000	
		STV	LTV	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
Physical Characteristics																	
pH (pH units)	T1	6.5-8.5								3	7.0						
	T2			13	7.6	10	7.6	4	7.3	8	7.5					3	6.6
Major Ions (mg/L)																	
Alkalinity as $CaCO_3$	T1					1	364	1	290	5	271	2	615				
	T2			7	221	12	237	13	260	6	317	1	330	1	774		
Bicarbonate	T1							2	325	4	341			3	262		
	T2			15	293	13	326	13	337	9	416	1	400	1	945	4	1320
SAR	T1									1	11.5						
	T2			2	4.3	6	6.7	8	11.0	2	12.0			1	21		
Nutrients (mg/L)																	
Nitrate as N	T1	25 – 125 as TN	5 as TN			4	<0.5	5	<0.5	6	<0.5						
	T2			13	0.3	11	0.3	5	0.1	5	4			2	0.3	4	13
Nitrite as N	T1									1	0.005						
	T2			2	0.005	5	0.005	2	0.4					1	0.01		
TKN	T1																
	T2			10	0.2	2	0.4	6	0.1	6	0.1						
Phosphorous	T1	0.8-12	0.05							1	0.01						
	T2			9	0.02	3	0.02	5	0.05	5	0.02			1	0.01		

Where, STV: short-term trigger value; LTV: long-term trigger value; T: total; S: sensitive crops; MS: moderately sensitive crops; MY-T: moderately tolerate crops; T: tolerate crops; and D: dissolved.

Element	Aquifer	Guidelines		TDS categories													
				500-1000		**1000-1500**		**1500-2000**		**2000-3000**		**3000-7000***		**7000-14000**		**>14000**	
		STV	LTV	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
Metals and metalloids (mg/L)																	
Aluminum	T1	20	5														
	T2			1	0.2			6	0.05	2	0.08			2	0.02		
Boron – D	T1		0.5														
	T2			2	0.2	2	0.4										
Copper	T1	5	0.2														
	T2			1	0.001			6	0.01	2	0.01						
Iron	T1	10	0.2							1	1.1						
	T2			12	0.3	7	2	7	3	5	0.6			1	4		
Lead	T1	5	2														
	T2					6	0.0008	1	0.0005								
Zinc	T1	5	2														
	T2					6	0.06	2	0.2								

*the majority of groundwater north of NAP PWA is within the 3000-7000 mg/L TDS category

F.6. Aquifer storage and recovery (ASR)

ASR is a direct injection MAR technique for targeting confined or deep aquifers. ASR refers to the use of the same well for injection and recovery and can be used to store water in aquifers of impaired quality (brackish) (**Figure F–9**). ASR is used extensively within the United States (USA) to store potable water (Pyne, 2005), while in Australia ASR is typically used to store urban stormwater and treated wastewater in confined Tertiary limestone aquifers for non-potable urban uses. Stormwater ASR schemes across the greater Adelaide region have a collective capacity of approximately 20 GL/year (Gilbert, 2009).

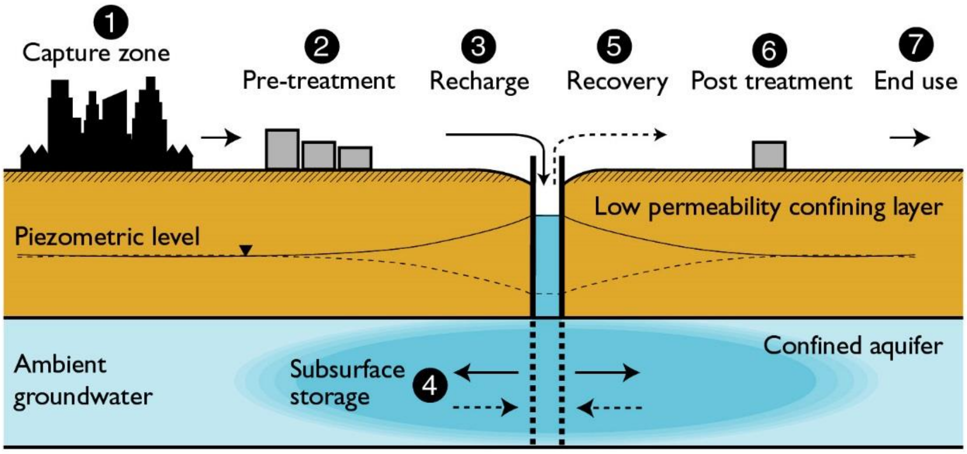


Figure F–9. Schematic diagram of an ASR scheme. The seven numbers represent the seven components that are common to all types of managed aquifer recharge MAR and are described in Table F–4 (after NRMMC-EPHC-NHMRC, 2009).

Table F–4. Seven common components of any MAR scheme in (after (NRMMC-EPHC-NHMRC, 2009)).

Component	Example
1. Capture zone	Harvesting using weirs and wetlands in urban stormwater catchments Connection to a recycled water pipe from a treatment plant
2. Pre-treatment	Passive treatments such as wetlands Engineered treatments to produce source water suitable for recharge
3. Recharge	Injection bore Infiltration basin
4. Subsurface storage	The aquifer that water is stored in and where passive treatment occurs
5. Recovery	Recovery bore
6. Post-treatment	Passive treatments such as wetlands Engineered treatments to produce water suitable for its intended use
7. End use	Drinking water; Irrigation

F.7. Existing ASR

Figure F–10 indicates the location of existing ASR schemes within the study area and directly to the south in the NAP PWA.

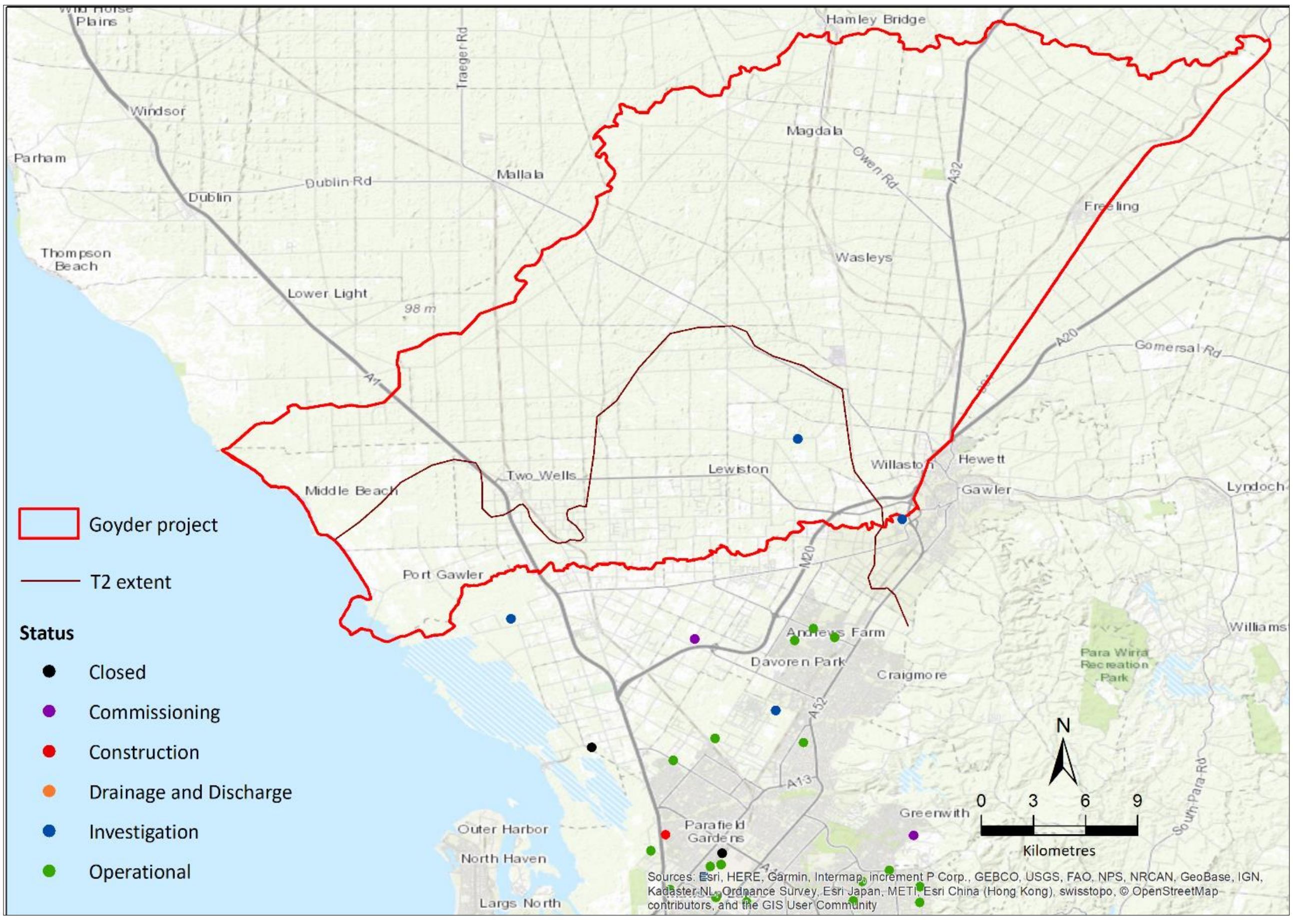


Figure F–10. Location of MAR schemes operating and under development (after Kretschmer, 2017).

F.8. Storage potential

Table F–5 outlines the attributes used to assess the suitability for ASR in the T1 aquifer north of the NAP-PWA based on NRMMC-EPHC-NHMRC (2009). These attributes are recommended for a preliminary assessment in a data-limited aquifer. **Table F–6.** describes some additional attributes requiring aquifer hydraulic properties to assess the suitability of Tertiary aquifers for ASR.

The environmental value of the aquifer is a key consideration to consider when assessing the feasibility of a MAR scheme **Figure F–11** and **Figure F–12**. There is no requirement for the source water for MAR (injectant in an ASR scheme) to meet the water quality criteria relevant to the aquifer environmental value. However beyond the extent of an acceptable zone, referred to in the MAR Guidelines (NRMMC-EPHC-NHMRC, 2009) as the attenuation zone, the groundwater will be required to meet certain water quality criteria. Establishing the environmental value of the aquifer is a priority for a proponent of MAR, followed by a discussion with the regulator regarding the implication of that environmental value on water quality criteria for the proposed scheme.

It follows logically that schemes proposing to inject water that is not drinking water quality (i.e., recycled water) may be simpler to manage from a water quality perspective if they do not target aquifers used to supply drinking water. The salinity contours for the T1 and T2 aquifers have a 1,500 mg/L category boundary, so do not specifically address the 1,200 mg/L TDS for drinking water environmental value. Given the contours were developed from sparse TDS data, this evaluation uses the 1,500 mg/L category boundary to indicate a possible drinking water environmental value. Groundwater salinity >1,500 mg/L is preferential for recycled water ASR from the perspective of protecting potential drinking water resources. However, as the salinity of the ambient groundwater increases the proponent will need to assess the potential impact of mixing with ambient groundwater on the salinity of the stored water.

Using these criteria, **Figure F–11** and **Figure F–12** indicates the Ward Belt ASR lies within a zone that may be of drinking water environmental value. However, the proponent confirmed that the local TDS exceeds 1200 mg/L (1390-1560 mg/L TDS) (P. Okely, pers. comm., 2018) and therefore consideration of the drinking water environmental value is not required. Based on salinity and potential environmental value, the majority of the T1 aquifer in the current study area is suitable for recycled water ASR (**Figure F–11**). Consideration of proximity to groundwater users is most relevant in the vicinity of Two Wells where groundwater salinity is 2,000-3,000 mg/L. ASR has been successfully used in the NAP PWA in aquifers with salinities of 2,000-3,000 mg/L. For ASR where the ambient groundwater salinity exceeds 3,000 mg/L it will be necessary to consider the impact of mixing on the salinity of the stored and recovered water.

Hydraulic impacts are the primary consideration in MAR feasibility assessment and require an understanding of the aquifer hydraulic properties. In this assessment, consideration of proximity to existing groundwater users (**Figure F–11** and **Figure F–12**), depth to the top (**Figure F–13** and **Figure F–14.**) and thickness (**Figure F–15.** and **Figure F–16**) of the aquifer and the depth to water (**Figure F–11** and **Figure F–12**) all relate to the hydraulic impacts of ASR, The proximity to existing groundwater users can also have water quality considerations. In South Australia, regulators typically require definition of a SOP for ASR schemes (P. Okely, pers. comm,), which can be estimated in the following ways.

The MAR Guidelines (NRMMC-EPHC-NHMRC, 2009) state the injection pressure should be selected to ensure that it never exceed the dry overburden pressure on the base of the aquitard. This pressure (p) can be conservatively estimated from $p < 15 \times d$ (kPa), where d is the depth in metres from the land surface to the base of the aquitard overlying, and assuming that the dry weight density exceeds 15 kN/m^3. Based on a conversion factor of 1 kPa = 0.10199 m head, this can be approximated as the maximum allowable impressed head may be up to 1.5 times the depth to the top of a confined aquifer (Dudding et al., 2006, Molloy et al., 2009).

Hodgkin (2004) calculates the maximum allowable impressed head (ΔH) for ASR in the Tertiary aquifers of the Adelaide Plains with the following equation, $\Delta H = 0.85 \times$ (depth to top of aquifer (m) + standing water level (m)).

Applying these methods to a confined aquifer with a depth to top of aquifer of 50 m and a standing water level of 10 m, would equate to a maximum impressed head or SOP of 50 to 75 m. SOP is better estimated with numerical modelling using site specific hydraulic properties and allowing for well interference in wellfields.

Based on the criteria outlined in **Table F**–**6**, aquifer thickness does not appear to be a general limitation for ASR, aside from a section of the T1 aquifer within the NAP PWA). Depth to the top of the aquifer seems to be suitable for ASR also. However, given the limited use of groundwater north of the NAP PWA, the depth to groundwater may be less than the preferred criteria, which will reduce the SOP of the ASR scheme. Again, it is necessary to define the local condition to assess the feasibility of a scheme.

Table F–5. Attributes used to assess the suitability of Tertiary aquifers for ASR adapted from NRMMC-EPHC-NHMRC, (2009)).

Attribute	Details	Criteria used in feasibility assessment
Groundwater environmental value	• Need to consider quality of source water for MAR in relation to groundwater environmental value • May influence acceptance (regulatory and social) of the MAR scheme	• Groundwater TDS>1500 mg/L recommended for recycled water MAR • Groundwater TDS<1500 mg/L may be of drinking water environmental value • Confirm environmental value, consult regulator and consider if non-potable sources of recharge may pose risk to this environmental value • Recommend Stage 2 investigation to confirm background ground water quality
Proximity to existing groundwater users	• Need to identify the extent of hydraulic impact using calibrated groundwater flow model • Increased pressure during injection can rupture an aquitard, create connection with aquifer of potential lower quality, result in failure of poorly completed wells or cause existing wells to become artesian • A reduction in pressure during recovery can increase energy requirements for pumping bores that are hydraulically influenced, excessive lowering of pressure can result in land subsidence, or failure of the aquitard • Need to identify extent of artesian zone and ensure preventive measures are in place to manage impact (i.e. reduce injection rate, wellhead seals) • Need to identify the extent of water quality impact and attenuation zone, beyond which environmental value of the aquifer will be met, extent of water quality impact < extent of hydraulic impact	• Document proximity to existing ground users and consider potential hydraulic and water quality impacts to these users Recommend confirm with Stage 2 investigation based on aquifer hydraulic properties derived from desktop study, pumping test and groundwater modelling • Finalisation of maximal risk assessment and residual risk assessment to ensure Safe Operating Pressure (SOP)
Depth to top of aquifer (m)	• Greater depth to top of aquifer allows a greater impressed head and drawdown • Define a Safe Operating Pressure (SOP) • Drilling and pumping costs increase with depth	• Depth >50 m preferred to allow greater impressed head and to ensure a greater Safe Operating Pressure (SOP) • Recommend confirm with Stage 2 investigation based on aquifer hydraulic properties derived from pumping test
Thickness of aquifer (m)	• Extent of impact will be reduced in thicker aquifer	• Thickness <20 m considered less favourable

		• Recommend confirm with Stage 2 investigation based on aquifer properties derived during drilling
Depth to water (m)	• Influences SOP • Influences extent of artesian conditions and impact on existing groundwater users • Greater depth to water will reduce injection costs	• SWL (m bgl) >10 • Recommend confirm with Stage 2 investigation based on aquifer properties derived during drilling

Table F–6. Additional attributes requiring aquifer hydraulic properties to assess the suitability of Tertiary aquifers for ASR (adapted from NRMMC-EPHC-NHMRC, (2009)).

Attribute	Details	Comment
Transmissivity	• Low transmissivity is a disadvantage due to low injection and recovery rates • High transmissivity allows higher injection and recovery rates • High transmissivity can result in decreased recovery efficiency / losses of stored water if extended storage periods occur	• Recommend Stage 2 investigation based on aquifer hydraulic properties derived from pumping test
Degree of confinement	• Can influence water levels in shallow aquifer system (i.e. risk of water logging)	• Recommend Stage 2 investigation based on aquifer hydraulic properties derived from pumping test
Well yield (L/s)	• >10 L/s • 15 L/s preferred for storage capacity of ~200 ML/ASR well based on injection of ~180 days	• Well yield of ASR wells in T1 aquifer typically lower than T2 aquifer and can be lower than 15 L/s (Kretschmer, 2017) • Well construction impacts on yield • Recommend Stage 2 investigation based on aquifer hydraulic properties derived from pumping test

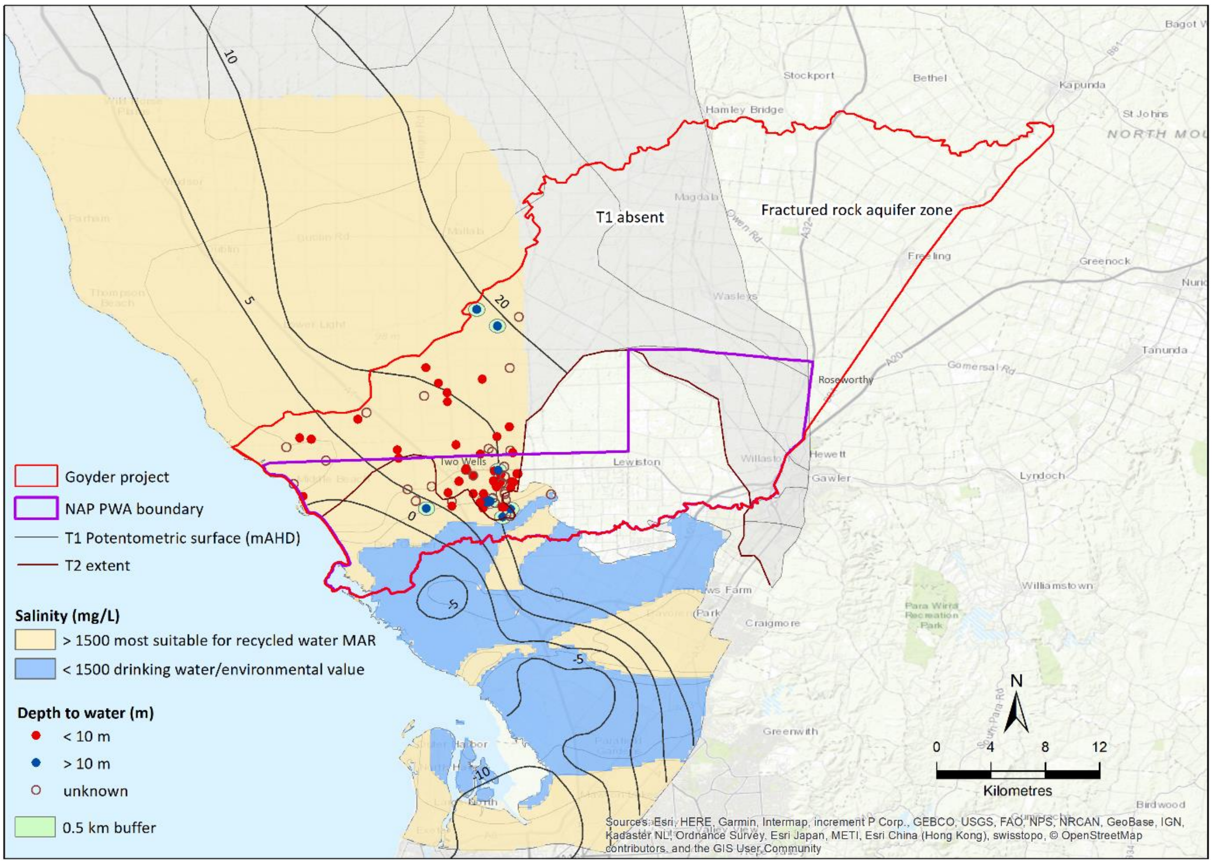


Figure F–11. Groundwater environmental value based on TDS, existing groundwater wells (0.5 km radius shown around operating wells) and depth to water (prefer SWL >10 m) for T1 aquifer in relation to potential for ASR.

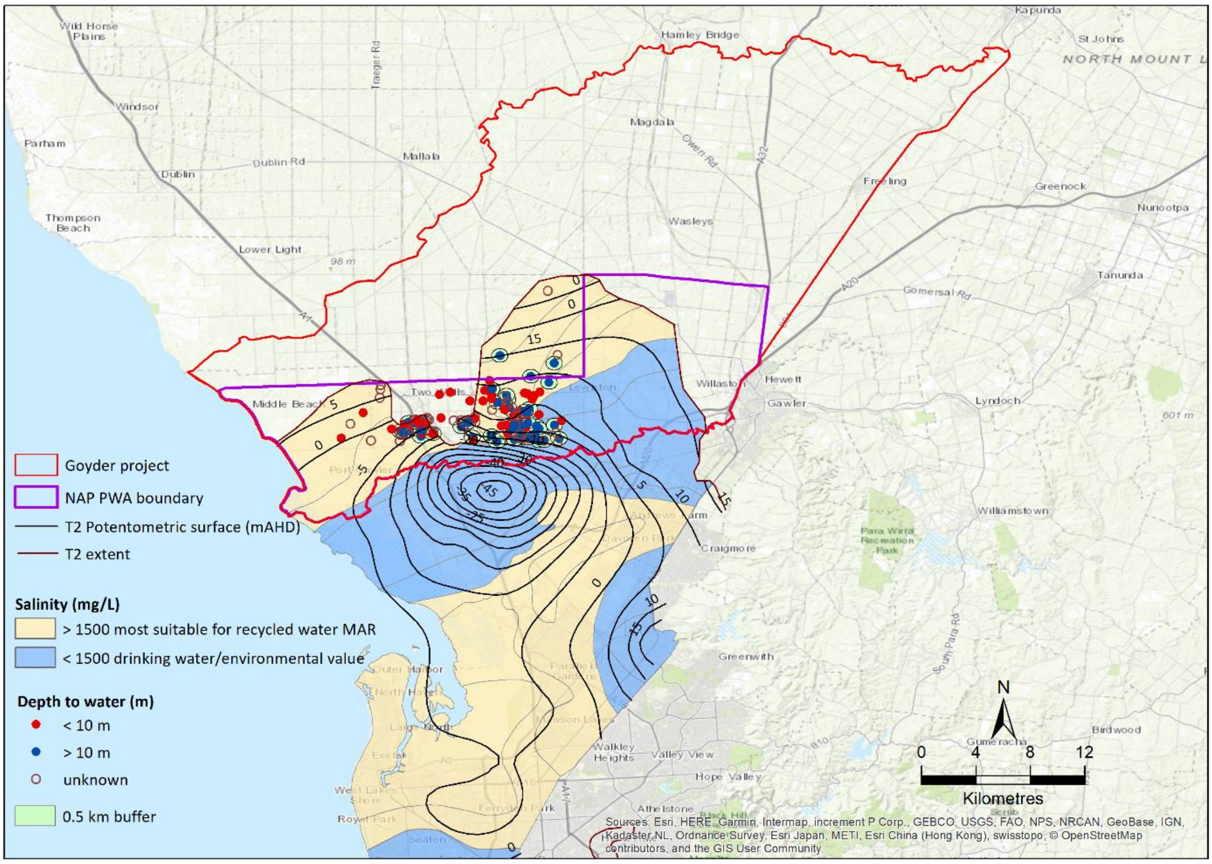


Figure F–12. Groundwater environmental value based on TDS, existing groundwater wells (0.5 km radius shown around operating wells) and depth to water (prefer SWL >10 m) for T2 aquifer in relation to potential for ASR.

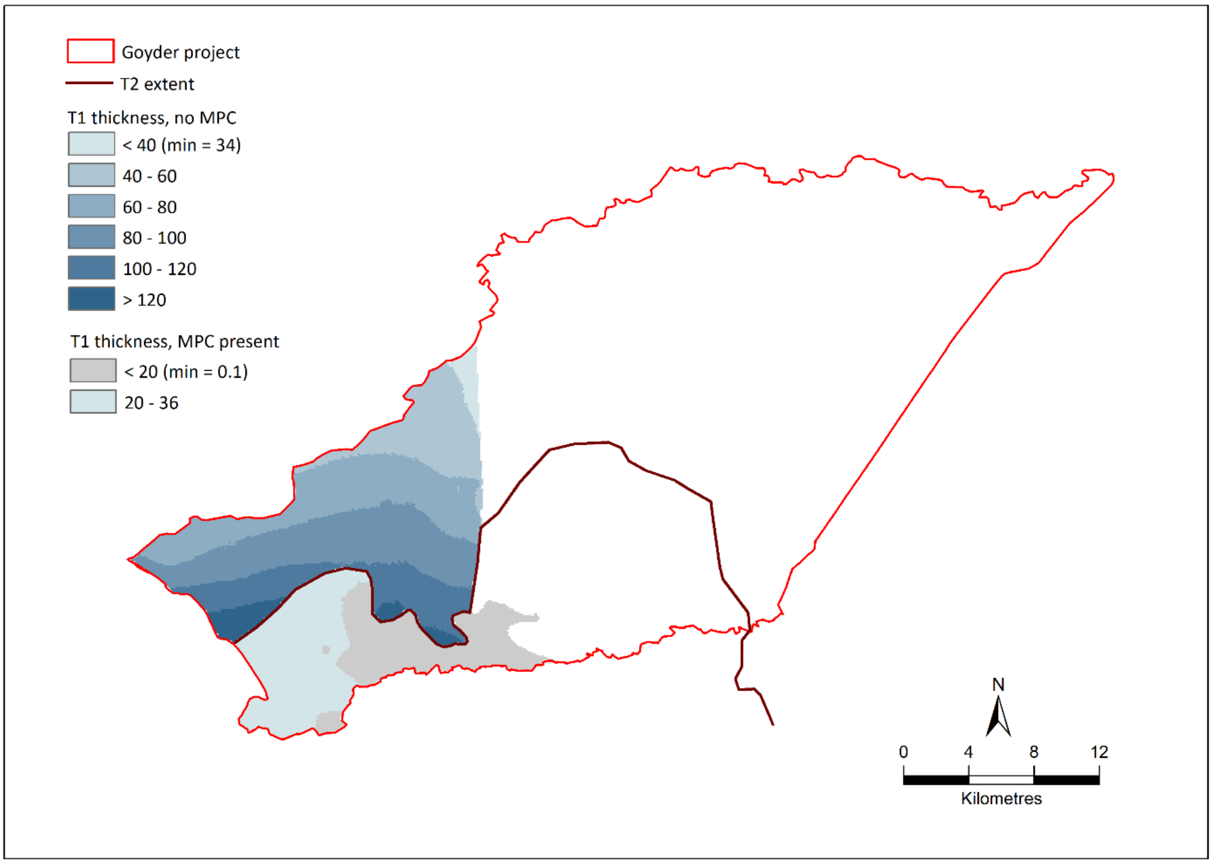


Figure F–13. Thickness of T1 aquifer (exported from AP2011); prefer thickness >20m in relation to potential for ASR.

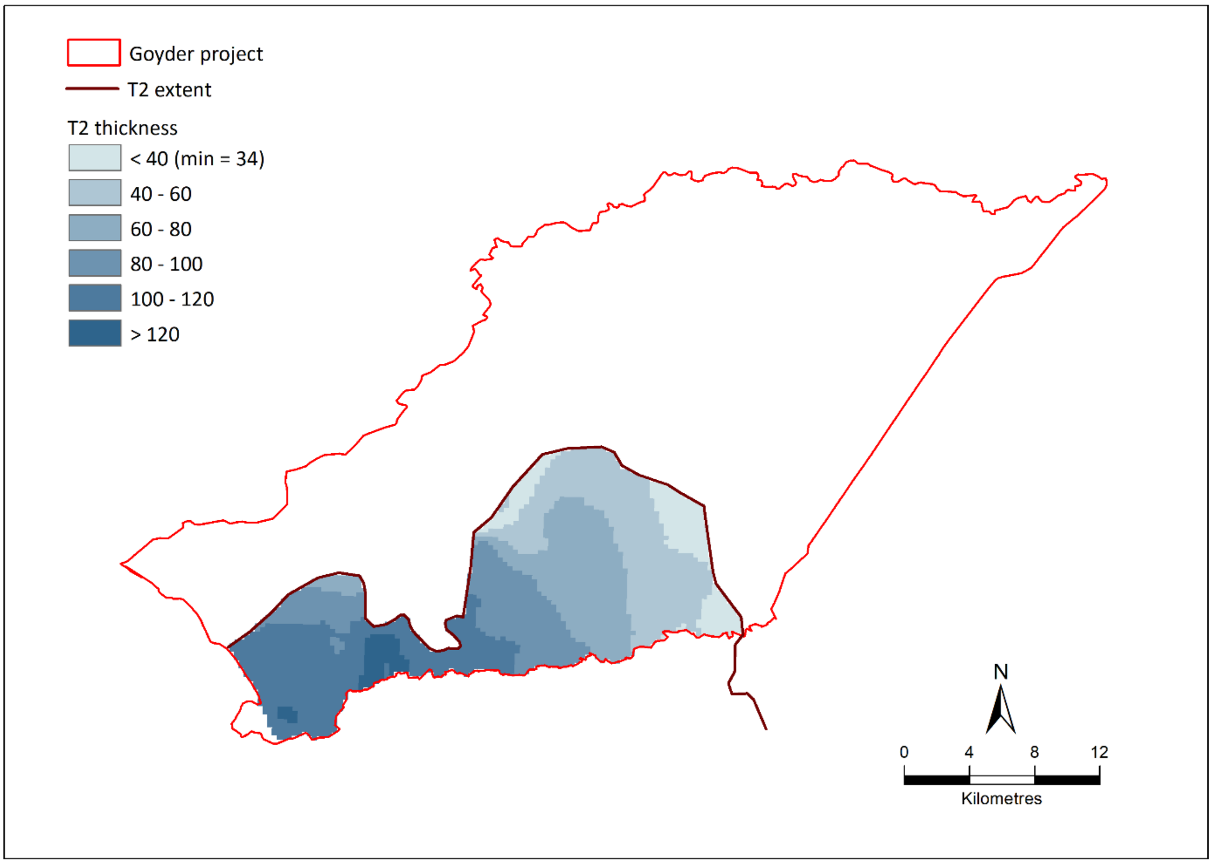


Figure F–14.Thickness of T2 aquifer (exported from AP2011); prefer thickness >20m in relation to potential for ASR.

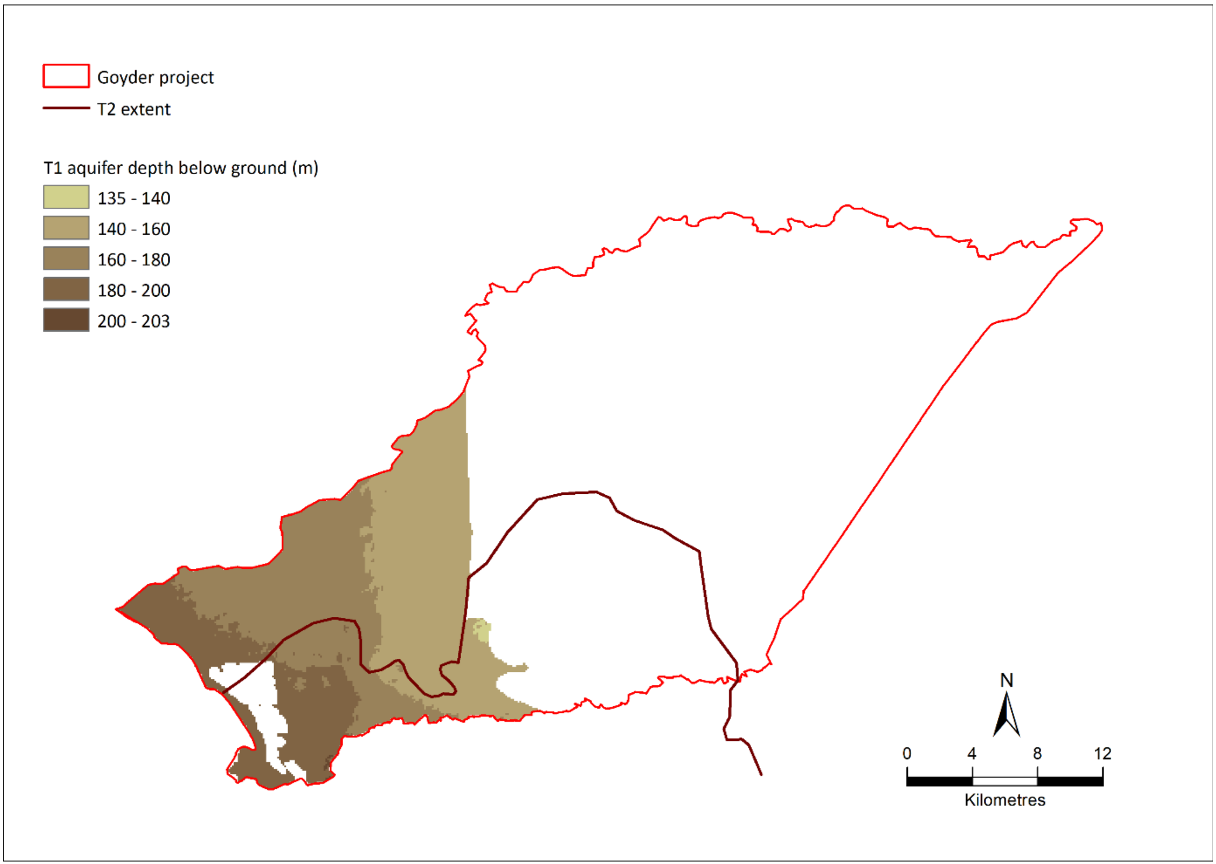


Figure F–15. Depth to top of T1 aquifer (exported from AP2011); prefer depth >50m in relation to potential for ASR.

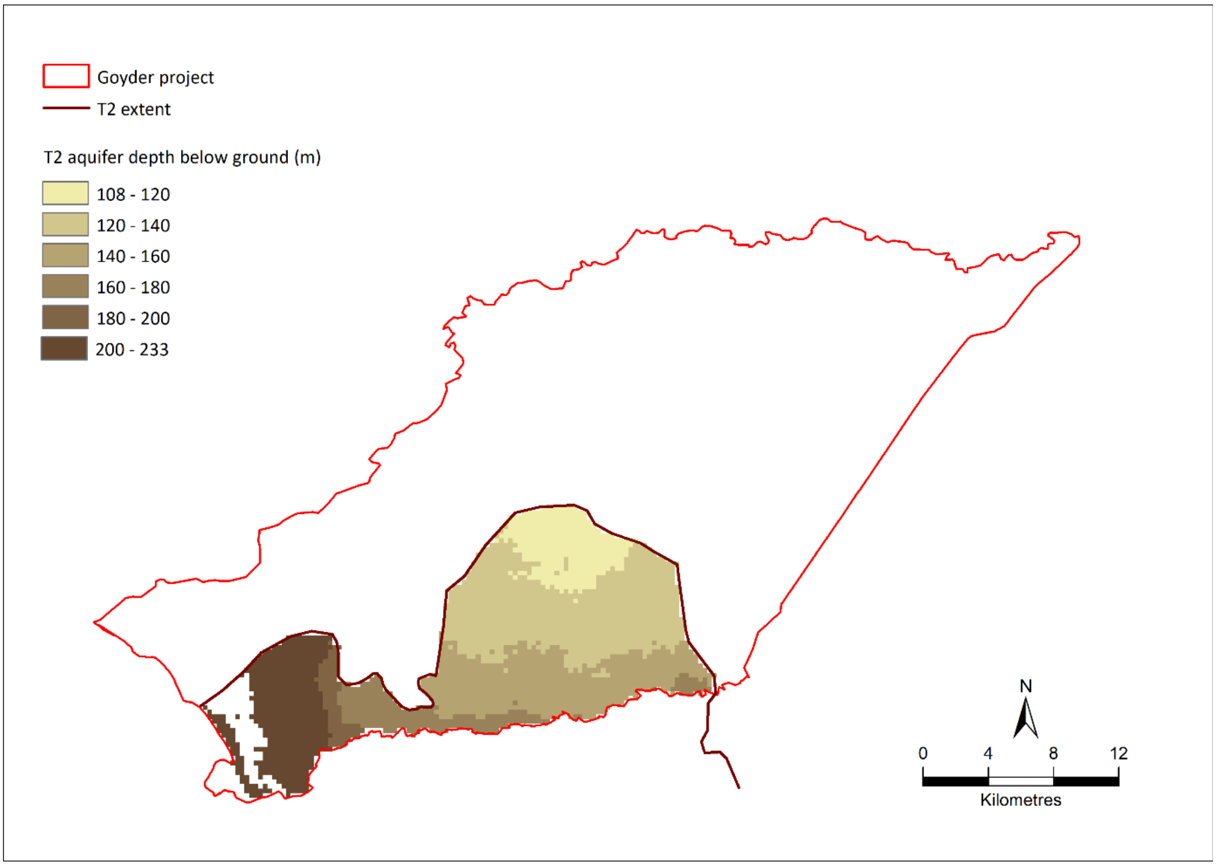


Figure F–16. Depth to top of T2 aquifer (exported from AP2011); prefer depth >50m in relation to potential for ASR.

Appendix G - IW-QC2 software tool's methodological description

G.1. Input parameters

G.1.1. For blending and/or treatment models

In order to use the water blending tool, the following parameters are required:

• **Runoff harvested from the greenhouse roof:** "To be used to achieve target WQ" to be selected from the drop-list if the harvested rainwater is intended to be stored and then blended with other water source(s), to achieve specific monthly TDS values (Model code #2). The option 'To be used when it is available' can be selected from the drop-list if harvested rainwater is to be directly used when it is available and then other source(s) will be used when needed (Model code #1).

• **Greenhouses' (Irrigated) area (m^2):** total size of the greenhouse area that will be irrigated.

• **Collection Roof area (m^2):** surface area of the greenhouses' roofs for rainwater harvesting. If the rainwater harvesting system (e.g., roof gutters, collection pipes) is not available, this value should be 0.0.

• **Storage volume (m^3):** total capacity of the storage facility i.e. surface storage and/or rain tank (required for Model code #1 only).

• **Min storage holding requirement (m^3):** minimum storage volume that is required to be detained at the storage facility to avoid pump problems (e.g., provide net positive suction head, stop air from entering the suction line), (required for Model code #1 only).

• **Surface area (m^2)** of the water storage: surface area (v/d) of the surface storage facility. Where v is the storage volume (m^3), and d is the storage depth (m), (required for Model code #1 only).

• **Average roof runoff TDS (mg/L):** salinity level of harvested roof water. If the salinity level is not measured, a default value of 85 mg/L is assumed (this is the median value of samples collected from the harvested roof water within the study region at the time of the project, **Table** E–5).

• **Greenhouse ET adjustment:** a factor used to convert evapotranspiration values measured outside greenhouse to inside greenhouse values. In this tool, 0.6 is used based on data previously reported, **Table C–4**. This value may be higher (approaching to 1.0) where the greenhouse is vented to closer match the humidity and temperature external of the greenhouse.

• **Crop type and cycle:** up to two types of crops and two cycles per annum can be selected from a list of greenhouse crop types commonly grown within the study region (i.e. tomato, cucumber, capsicum and eggplant). If there is no second cycle, the start and finish months of the second cycle should be equal (e.g., start: January; finish: January).

• **Climate data:** in this tool, climate data can be selected from a list of five different data sets, which currently are as follows: 1) Climate change model: the median daily values (between 2006 to 2100) for GFDL-ESM2M model for Edinburgh RAAF weather station; 2) Edinburgh_median values: the daily values (between Jan. 1970 to Jul. 2018) for Edinburgh RAAF weather station; 3) NAP1: the daily values (between Jan. 1889 to Jul. 2018) for NAP grid area Number 1, area present the median values within the region; 4) NAP36: the daily values (between Jan. 1889 to Jul. 2018) for NAP grid area Number 36 , area present the slightly wetter and slightly cooler values; 5) NAP38: the daily values (between Jan. 1889 to Jul. 2018) for NAP grid area Number 38 , area present the lowest annual Pc values with the highest annual ETo values.

- **Greenhouse ET adjustment:** factor used to convert evapotranspiration values measured outside greenhouse to inside greenhouse values. In this tool, 0.6 has been used based on data previously reported, **Table C–4**. This value could be higher (closer to 1.0) if greenhouse is vented properly.

After the selection of the climate data set from the drop-list, press 'Upload climate data' Upload Climate data ' button to upload the climate information to the model.

- **Water sources:** Up to two sources of water can be selected from a list of four water resource options: 1) Reclaimed water: monthly volume-licensed (ML) is required to be inserted while the median monthly values of WQs (TDS, sodium, calcium, magnesium, chloride and alkalinity) for Virginia pipeline scheme (VPS) data base can be used; 2) Gawler River water: monthly volume-licensed (ML) is required to be inserted while the median monthly values of WQs for Gawler River is used; 3) Stormwater: monthly volume-licensed (ML) is required to be inserted while the median monthly values of WQs for urban stormwater at Parafield, SA is used; 4) Others: to be used when other water source (e.g., groundwater) is available or when the actual WQs at the point of use are measured.

- **Plant Density & drippers:** This tool has been designed to calculate the irrigation volumes based on the actual practices and compare these to the theoretical irrigation volume that is calculated based on the methodology of Allen et al. (1998). Greenhouse dimensions (length (m) x width (m)), number of plants' lines per house, space between the drippers (m), dripper flow rate (Lph) are required to use this option.

- **Soil surface covered by plastic sheets:** Soil surface covered by plastic sheeting used to reduce evaporation losses from the soil surface. This could lead to increase in crop growth rates and vegetable yield, but the kc values decrease by an average of 10-30% as reported by Allen et al. (1998). The model has been adapted to reduce the standard kc values by 10% when surface mulching is used.

- **Irrigation Schedule**: This tool has been designed to schedule the irrigation events based on external air temperatures which have been categorized as follows: 1) < 20°C, 2) 20-25°C, 3) 25-30°C, 4) 30-35°C, 5) > 35°C. For each temperature category, the user can add 1) the number of irrigating days per week and 2) time for irrigation cycle per day (in minutes). Temperature categories were developed based on responses from a landholder/stakeholder survey on irrigation practices of soil based covered crop horticulture.

- **Target TDS**: monthly target TDS values (mg/L) for irrigation waters. Harvested rainwater from greenhouse roofs intended to be stored and then blended with other source(s) to achieve these target values during all or most of the growing period, when the volume of harvested rainwaters is sufficient, (required for Model code #2 only).

After input of all required parameters/options, then press 'Run the Model' button Run the Model to run the model.

G.1.2. For treatment models

Press the "**Desalination Model"** button to link output data from the blending models to the treatment process models.

- **TDS threshold value:** Required salinity level (mg/L) of the final water for irrigation. If the salinity threshold value is not known, data presented in **Table G–1** can be used as an estimate value based on the ANZECC and ARMCANZ (2000).

- **Chloride threshold value:** Required chloride level (mg/L) of water for irrigation. If the threshold value is not known, data presented in **Table G–1** can be used as an estimate value based on the ANZECC and ARMCANZ (2000).

- **TDS rejection value:** Percentage ratio of the different between TDS concentration at feed water (TDSf) and TDS concentration of permeate water (TDSp) to TDS concertation of feed water: $\left(\frac{TDS_F - TDS_P}{TDS_F}\right) \times 100\%$. This value ranges between 84% to 98% as previously reported, **Table G–2**.

Water recovery ratio: Percentage ratio of permeate flow rate (Qp) to feed water flow rate (Q_f). This value ranges between 60% to 90% as previously reported, **Table G–2**.

Table G–2 summarise the water recovery ratios and salt rejection ratios of different studies on BWRO plants found in literature and based on currently applied system within the region (2018 survey outcome). It is worth noting that Garg and Joshi (2014) and Khanzada et al. (2017) have used photovoltaic electricity to optimise the BWRO system in their studies, and therefore the low recovery ratios were achieved.

Table G–1: Trigger values of various WQs as reported by ANZECC and ARMCANZ (2000).

WQ parameter	Unit	Tomato	Cucumber	Capsicum
TDS for growth in sandy soil	mg/L	1925	2310	1540
TDS for growth in loam soil	mg/L	1100	1320	880
TDS for growth in clay soil	mg/L	660	770	495
Chloride	mg/L	175 - 350	350 - 750	175 - 350
Sodium	mg/L	115 - 230	230 – 460	115 - 230

Table G–2: Water recovery ratio and salt rejection ratio of BWRO plants

Location of study	Feedwater TDS	Water Recovery (%)	Salt Rejection (%)	References
NAP, South Australia	700 mg/L	75%		2018 Survey outcome
NAP, South Australia	1800 mg/L	75%	96.6%	2018 Survey outcome
NAP, South Australia	1000 mg/L	77.5%	96.6%	2018 Survey outcome
Islamabad, Pakistan	3500-4500 mg/L	30-45%	95-98%	(Khanzada et al., 2017)
Lahat, Israel	1852 mg/L	80—88%		(Drak and Adato, 2014)
Uttrakhand, India	1500-3000 mg/L	14-29%	84-91%	(Garg and Joshi, 2014)
California, USA	950 mg/L	79-90%		(Li and Noh, 2012)
Texas, USA		70-85%		(Greenlee et al., 2009)
United Arab Emirates	2500-7500 mg/L	60-75%	98%	(Almulla et al., 2003)

G.2. Model(s) development

G.2.1. Crop waters

Models have been developed to calculate theoretical irrigation volume based on the methodology of Allen et al. (1998). Equations, assumptions and monthly crop coefficient (k_c) values use to estimate the crop water requirement are summarise in Appendix C. Based on the survey (2018) outcome, the drip irrigation is the main irrigation system that growers use. Under drip irrigation, only a portion of the soil is wetted and the evapotranspiration values could be reduced subsequently (Savva and Frenken, 2002). The tool has been adapted to calculate the crop waters based on the ground cover using equations (**G-1** and **G-2**). Growers also use surface mulches to reduce evaporation losses from the soil surface and consequently the tool has been designed to reduce the standard k_c values by 10% when the surface mulches are in use (Equation **G-3**). In this tool, the following temperature threshold values are used to schedule irrigation events: temperature < 20°C, temperature between 20°C to 25°C, temperature between 25°C to 30°C, temperature between 30°C to 35°C and temperature > 35°C. The tool was also designed to calculate irrigation volume based on actual irrigation practice within the region using the following equations (**G-4**, **G-5** and **G-6**):

$$GC = \frac{W_1 \times No.of\ plants'\ lines\ per\ house}{W_2} \times 100 \quad \textbf{(G-1)}$$

$$\mathrm{IR}_{Drip} = IR\ x\ [0.1\ (GC)^{0.5}]\ x\ \mathrm{f}_{eff} \quad \textbf{(G-2)}$$

$$\mathrm{k}_{c\_modified} = \begin{cases} With\ plastic\ mulches & \mathrm{k}_c \times 0.90 \\ Without\ plastic\ mulches & \mathrm{k}_c \end{cases} \quad \textbf{(G-3)}$$

Where: GC is percentage ground cover (%); W_1 is wetted width per drip line (estimated to be equal to the distance between the plants: 0.5 m); W_2 is the greenhouse width (m); IR_{Drip} is the irrigation requirement by drip irrigation system; IR is irrigation requirement (see Appendix C: Appendix C - Crop water requirements); f_{eff} is inefficiency factors for drip irrigation (0.95); $\mathrm{k}_{c\_modified}$ is the modified crop coefficient based on using surface mulches by plastic sheets.

$$No.of\ drippers\ per\ house = \frac{No.\ of\ plants'\ lines \times greenhouse\ legnth}{Drippers\ sapces} \quad \textbf{(G-4)}$$

$$No.of\ drippers\ per\ total\ area = \frac{No.of\ drippers\ per\ house \times \text{total size of the planted area}}{greenhouse\ width \times greenhous\ legnth} \quad \textbf{(G-5)}$$

$$Irrigation\ volume\ per\ event = No.of\ drippers\ per\ total\ area \times dripper\ flow\ rate \times \text{time of irrigation} \quad \textbf{(G-6)}$$

G.2.2. Water sources volumes and irrigation water qualities

For the first option "Model Code #1: using the harvested rainwater when it is available", the tool has been designed to capture the roof runoff water based on the roof area (m^2) and available storage capacity (m^3) and reuse it when it's available to meet the crop demand and then use other source(s) of water if needed. This was done to reduce the required storage size and subsequently increase the total volume of runoff that could be capture. If two sources of water are available (e.g., reclaimed water and groundwater), the source that has lower salinity level (measured as TDS value) will be firstly used when the required volume is less than the volume-licensed of this source. Otherwise, the other source (source with higher salinity level) will be used. For Model code #1, the following mass balance equations (**G-7**:**G-11**) have been used to estimate the volume of water source(s) for each irrigation event while Equation **G-12** has been used to calculate the various quality parameters of irrigation water.

$$DS_t = \begin{cases} DS_{max} & at: (DS_{t-1} + Q_{Runoff_t} - Q_{Evap_t} - Q_{Irr_t}) > DS_{max} \\ DS_{min} & at: (DS_{t-1} + Q_{Runoff_t} - Q_{Evap_t} - Q_{Irr_t}) < DS_{min} \\ DS_{t-1} + Q_{Runoff_t} - Q_{Evap_t} - Q_{Irr_t} & at: DS_{min} < (DS_{t-1} + Q_{Runoff_t} - Q_{Evap_t} - Q_{Irr_t}) \le DS_{max} \end{cases} \quad \textbf{(G-7)}$$

$$Q_{Runoff_t} = \begin{cases} Q_{TRunoff_t} & at: (DS_{t-1} + Q_{TRunoff_t} - Q_{Evap_t} - Q_{Irr_t}) \le DS_{max} \\ DS_{max} - DS_{t-1} + Q_{Evap_t} + Q_{Irr_t} & at: (DS_{t-1} + Q_{TRunoff_t} - Q_{Evap_t} - Q_{Irr_t}) > DS_{max} \end{cases} \quad \textbf{(G-8)}$$

$$Q_{S_t} = DS_t - DS_{t-1} + Q_{Irr_t} + Q_{Evap_t} - Q_{Runoff_t} \quad \textbf{(G-9)}$$

$$Q_{S1_t} = \begin{cases} Q_{S_t} & at \begin{cases} TDS_{S1_t} < TDS_{S2_t}\ and\ Q_{S1_{M\_L}} < \sum_{i=1}^{t} Q_{S1_i} \\ TDS_{S1_t} > TDS_{S2_t}\ and\ Q_{S2_{M\_L}} > \sum_{i=1}^{t} Q_{S2_i} \end{cases} \\ 0.0 & at \begin{cases} TDS_{S1_t} < TDS_{S2_t}\ and\ Q_{S1_{M\_L}} > \sum_{i=1}^{t} Q_{S1_i} \\ TDS_{S1_t} > TDS_{S2_t}\ and\ Q_{S2_{M\_L}} < \sum_{i=1}^{t} Q_{S2_i} \end{cases} \end{cases} \quad \textbf{(G-10)}$$

$$Q_{S2_t} = Q_{S_t} - Q_{S1_t} \quad \textbf{(G-11)}$$

Where: DS_t is the water volume (m^3) inside the storage dam at time (t, d); DS_{max} is total capacity of the storage facility (m^3); DS_{min} is minimum storage volume that required to be detained on the storage facility (m^3); DS_{t-1} is the water volume (m^3) inside the storage dam at time (t-1, d); Q_{Runoff_t} is the actual harvested rainwater from the greenhouses' roof (m^3) at time (t, d); Q_{Evap_t} is the evaporated water volume from the storage facility (m^3) at time (t, d); Q_{Irr_t} is the total irrigation volume (m^3) at time (t, d); $Q_{TRunoff_t}$ is the total rainwater that could be harvested from the greenhouses' roof (m^3) at time (t, d); Q_{S_t} is the required water volume (m^3) from other sources (source #1: S1 and/or source#2: S2) at time (t, d); Q_{S1_t} is the required water volume (m^3) from S1 at time (t, d); Q_{S2_t} is the required water volume (m^3) from S2 at time (t, d); TDS_{S1_t} is the salinity level (mg/L) of water from S1 at time (t, d); TDS_{S2_t} is the salinity level (mg/L) of water from S2 at time (t, d); $Q_{S1_{M\_L}}$ monthly volume-licensed (m^3) of S1; $Q_{S2_{M\_L}}$ monthly volume-licensed (m^3) of S2.

$$WQ_{DS_t} = \frac{WQ_{S1_t} \times Q_{S1_t} + WQ_{S2_t} \times Q_{S2_t} + WQ_{DS_{t-1}} \times Q_{Evap_t} + WQ_{Runoff} \times Q_{Runoff_t} + WQ_{DS_{t-1}} \times DS_{t-1}}{Q_{S1_t} + Q_{S2_t} + Q_{Evap_t} + Q_{Runoff_t} + DS_{t-1}} \quad \textbf{(G-12)}$$

Where: WQ_{DS_t} is the water quality parameter (e.g., TDS, chloride, sodium…. etc.) inside the storage dam at time (t, d); WQ_{S1_t} is the corresponding WQ of water from S1 at time (t, d); WQ_{S2_t} is the corresponding WQ of water from S2 at time (t, d); $WQ_{DS_{t-1}}$ is the corresponding WQ of water inside the storage dam at time (t-1, d); WQ_{Runoff} is the corresponding WQ of water from roof runoff at time (t, d).

While for the second option "Model Code #2: using capture water to achieve target TDS", the tool has been designed to calculate the maximum volume of roof runoff water that could be captured based on the roof area (m^2) and climate data. Harvested rainwaters will be stored then blended with other water source(s) to achieve the required monthly TDS values if applicable. If two sources of water are available (e.g., reclaimed water and groundwater), the source that has lower salinity level (measured as TDS value) will be firstly used when the required volume is less than the volume-licensed of this source. Otherwise, the other source (source with higher salinity level) will be used. For Model code #2, the following mass balance equations (**G-13**:**G-21**) have been used to estimate the volume of water source(s) for each irrigation event while Equation **G-12** has been used to calculate the various quality parameters of irrigation water.

$$Q_{S_t}\text{ source} = \begin{cases} S1_t & at \begin{cases} TDS_{S1_t} < TDS_{S2_t}\ and\ Q_{S1_{M\_L}} < \sum_{i=1}^{t} Q_{S1_i} \\ TDS_{S1_t} > TDS_{S2_t}\ and\ Q_{S2_{M\_L}} > \sum_{i=1}^{t} Q_{S2_i} \end{cases} \\ S2_t & at \begin{cases} TDS_{S1_t} < TDS_{S2_t}\ and\ Q_{S1_{M\_L}} > \sum_{i=1}^{t} Q_{S1_i} \\ TDS_{S1_t} > TDS_{S2_t}\ and\ Q_{S2_{M\_L}} < \sum_{i=1}^{t} Q_{S2_i} \end{cases} \end{cases} \quad \textbf{(G-13)}$$

$$TDSs_t = \begin{cases} TDS_{S1_t} & at{:}\ Q_{S_t}\text{source} = S1_t \\ TDS_{S2_t} & at{:}\ Q_{S_t}\text{source} = S2_t \end{cases} \quad \textbf{(G-14)}$$

$$Q_{S_t} = \frac{Q_{Irr_t} \times TDS_{Target_t} - Q_{Irr_t} \times TDS_{Runoff_t}}{TDS_{S_t} - TDS_{Runoff_t}} \quad \textbf{(G-15)}$$

$$Q_{Runoff\_1_t} = Q_{Irr_t} - Q_{S_t} \quad \textbf{(G-16)}$$

$$DS_{Runoff\_1_t} = \begin{cases} DS_{max} = \frac{Roof\ area\ x\ 300}{10000} & at{:}\ (Q_{TRunoff_t} + DS_{t-1} - Q_{Runoff\_1_t}) > DS_{max} \\ DS_{min} = 0.2\ x\ DS_{max} & at{:}\ (Q_{TRunoff_t} + DS_{t-1} - Q_{Runoff\_1_t}) < DS_{min} \\ Q_{TRunoff_t} + DS_{t-1} - Q_{Runoff\_1_t} & at{:}\ DS_{min} < (Q_{TRunoff_t} + DS_{t-1} - Q_{Runoff\_1_t}) < DS_{max} \end{cases} \quad \textbf{(G-17)}$$

$$Q_{Runoff\_2_t} = \begin{cases} Q_{Runoff\_1_t} & at{:}\ Q_{TRunoff_t} - \left(DS_{Runoff\_1_t} - DS_{Runoff\_1_{t-1}}\right) > Q_{Runoff\_1_t} \\ Q_{TRunoff_t} - \left(DS_{Runoff\_1_t} - DS_{Runoff\_1_{t-1}}\right) & at{:}\ Q_{TRunoff_t} - \left(DS_{Runoff\_1_t} - DS_{Runoff\_1_{t-1}}\right) < Q_{Runoff\_1_t} \end{cases} \quad \textbf{(G-18)}$$

$$If \begin{cases} \frac{\sum Q_{Runoff\_2_t}}{\sum Q_{Runoff\_1_t}} < 0.90 & \rightarrow DS_{max} = \frac{Roof\ area\ x\ 300}{10000}\ x\ 1.25\ then\ repeat\ steps\ (17\ and\ 19) \\ \frac{\sum Q_{Runoff\_2_t}}{\sum Q_{Runoff\_1_t}} > 0.95 & \rightarrow DS_{max} = \frac{Roof\ area\ x\ 300}{10000}\ x\ 0.8\ then\ repeat\ steps\ (17\ and\ 19) \\ 0.9 > \frac{\sum Q_{Runoff\_2_t}}{\sum Q_{Runoff\_1_t}} < 0.95 & \rightarrow Stop\ iterations \end{cases} \quad \textbf{(G-19)}$$

$$Q_{S1\_f_t} = \begin{cases} Q_{S1_t} & at: Q_{Runoff\_2_t} = Q_{Runoff\_1_t} \\ Q_{Runoff\_1_t} - Q_{Runoff\_2_t} + Q_{S1_t} & at: Q_{Runoff\_2_t} < Q_{Runoff\_1_t} \end{cases} \quad \textbf{(G-20)}$$

$$Q_{S2\_f_t} = \begin{cases} Q_{S2_t} & at: Q_{Runoff\_2_t} = Q_{Runoff\_1_t} \\ Q_{Runoff\_1_t} - Q_{Runoff\_2_t} + Q_{S2_t} & at: Q_{Runoff\_2_t} < Q_{Runoff\_1_t} \end{cases} \quad \textbf{(G-21)}$$

Where: TDS_{Target_t} is the target TDS value of irrigation water at time (t, d).

G.2.3. Desalination process

The tool has been designed to recalculate leaching requirement values based on the TDS threshold value (Equation **C-3**) and consequently recalculate the irrigation volume requirement. While the RO treatment process (e.g., feed, permeate and concentrate water volumes) are calculated to achieve both TDS and chloride threshold values based on the RO system capacity (TDS rejection and water recovery ratio). The following equations (**G-22**:**G-29**) have been used to estimate the quality and quantity of irrigation water and RO treatment process.

$$TDS_{p_t} = \left(1 - \frac{TDS_{Rejection}}{100}\right) x\, TDS_{f_t} \quad \textbf{(G-22)}$$

$$Cl_{p_t} = \left(\frac{Cl_{f_t}}{TDS_{f_t}}\right) x\, TDS_{p_t} \quad \textbf{(G-23)}$$

$$Q_{p_t} = Max. \begin{cases} Q_{p1_t} \\ Q_{p2_t} \end{cases} \quad \textbf{(G-24)}$$

$$Q_{p1_t} = \begin{cases} 0.0 & at \quad TDS_{Threshold} \geq TDS_{f_t} \\ Q_{irr_t} & at \quad TDS_{Threshold} \leq TDS_{p_t} \\ Q_{irr_t} \times \left[\frac{TDS_{f_t} - TDS_{Threshold}}{TDS_{f_t} - TDS_{p_t}}\right] & at \quad TDS_{f_t} > TDS_{Threshold} > TDS_{p_t} \end{cases} \quad \textbf{(G-25)}$$

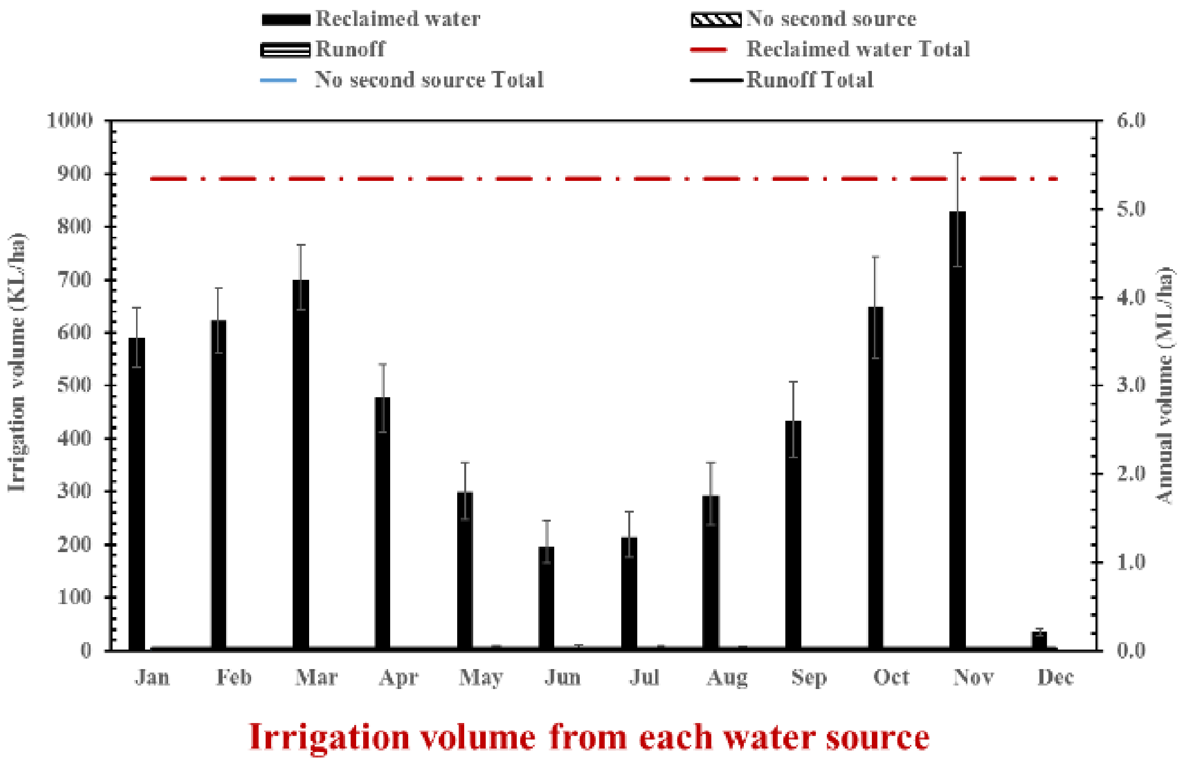
$$Q_{p2_t} = \begin{cases} 0.0 & at \quad Cl_{Threshold} \geq Cl_{f_t} \\ Q_{irr_t} & at \quad Cl_{Threshold} \leq Cl_{p_t} \\ Q_{irr_t} \times \left[\frac{Cl_{f_t} - Cl_{Threshold}}{Cl_{f_t} - Cl_{p_t}}\right] & at \quad Cl_{f_t} > Cl_{Threshold} > Cl_{p_t} \end{cases} \quad \textbf{(G-26)}$$

$$Q_{f_t} = \frac{Q_{p_t} \times 100}{Recovery\ Ratio} \quad \textbf{(G-27)}$$

$$Q_{C_t} = Q_{f_t} - Q_{p_t} \quad \textbf{(G-28)}$$

$$TDS_{C_t} = \frac{Q_{f_t} \times TDS_{f_t} - Q_{p_t} \times TDS_{p_t}}{Q_{C_t}} \quad \textbf{(G-29)}$$

Where: TDS_{p_t} is the TDS concentration of permeate water at time (t, d); $TDS_{Rejection}$ is the TDS rejection value (%); TDS_{f_t} is the TDS concentration of feed water at time (t, d); Cl_{p_t} is the chloride concentration of permeate water at time (t, d); Cl_{f_t} is the chloride concentration of feed water at time (t, d); Q_{p_t} is the permeate water volume at time (t, d); Q_{Irr_t} is the total irrigation water volume at time (t, d); $TDS_{Threshold}$ is the required TDS threshold value of water for irrigation;); Q_{f_t} is the feed water volume at time (t, d); Q_{C_t} is the concentrate water volume at time (t, d); TDS_{f_t} is the TDS concentration of concentrate water at time (t, d).



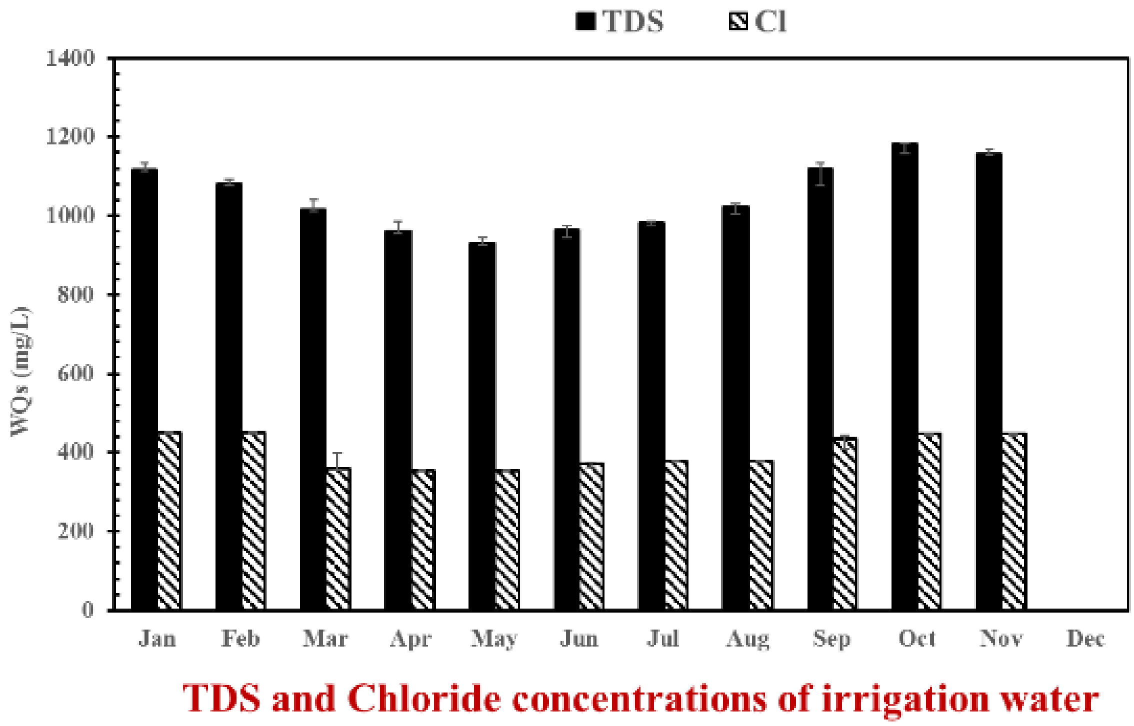


Figure G‒1. Monthly a) volume and b) WQ of irrigation water for eggplant irrigated by reclaimed water.

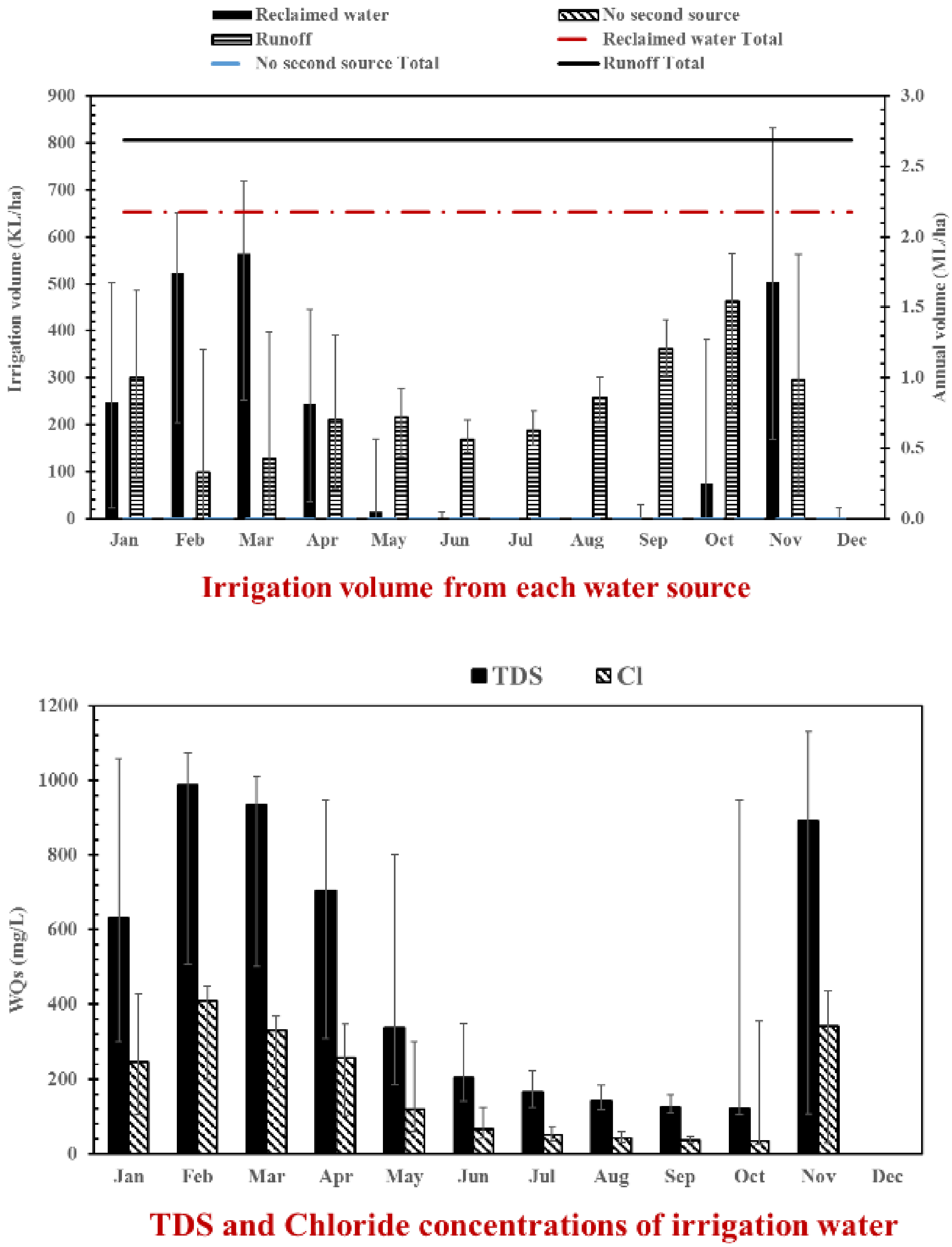


Figure G–2. Monthly a) volume and b) WQ of irrigation water for eggplant irrigated by blending water (reclaimed and harvested rainwater).

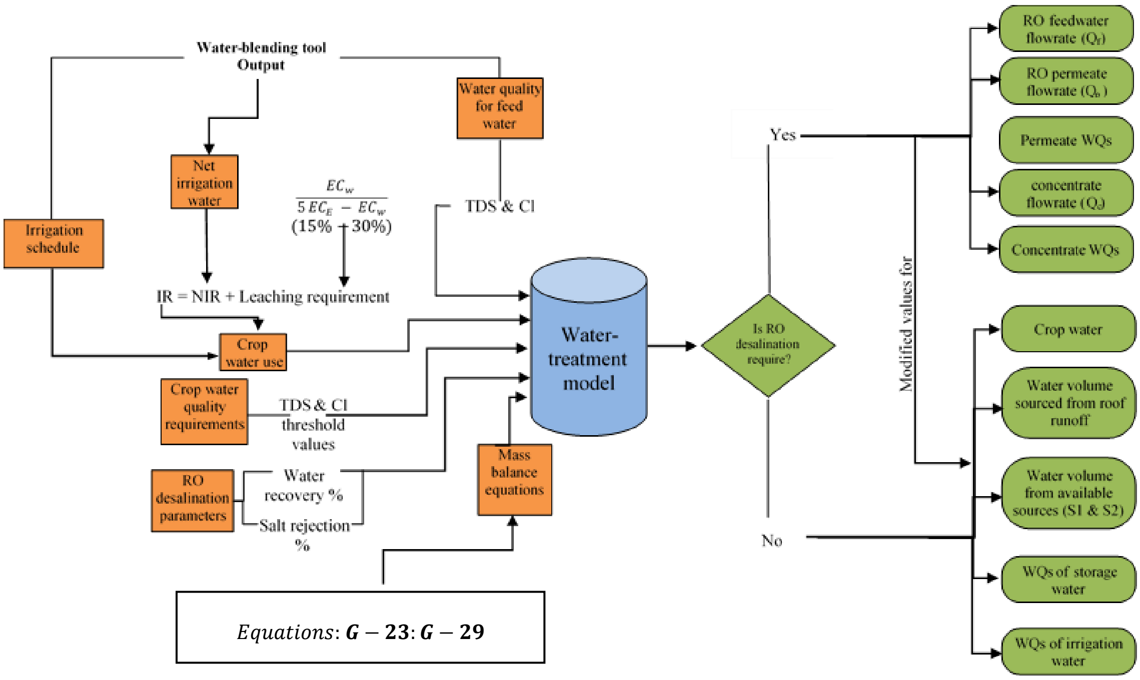


Figure G–3. Modelling approach for water treatment process by RO.

Table G–3: Water recovery ratios and characteristics of RO plants to treat groundwaters

TDS for feed water	2000 mg/L			3000 mg/L			7000 mg/L			14000 mg/L		
Model name	TorayDS2	IMSDesign[d]	CSMPRO	TorayDS2	IMSDesign	CSMPRO	TorayDS2	IMSDesign	CSMPRO	TorayDS2	IMSDesign	CSMPRO
Feed flow (m^3/h)	17.3	18.6	19.3	20	20	19.3	21	25	22.5	23	27.3	30.5
Feed pressure (bar)	11	8.51	9.54	13.2	10.8	11.3	16	17.2	17.5	30	28	31
Permeate flow (m^3/h)	13	13	13.5	14	14	13.5	15	15	13.5	15	15	16.8
Permeate TDS (mg/L)	50	59.1	27.8	63	98	44	288	199	117	394	392	130
Concentrate flow (m^3/h)	4.3	5.56	5.79	6	6	5.8	6.4	10	9	8	12.3	13.4
Concentrate TDS (mg/L)	7857	6487	6601	9856	9811	9897	22660	17298	17325	39271	31073	30940
Water recovery ratio (%)	75	70	70	70	70	70	70	60	60	65	55	55
No. of Pass	1	1	1	1	1	1	1	1	1	1	1	1
No. of stages	2	2	2	2	2	2	3	2	2	3	2	2
No. of vessels x elements for each stage	3x3[a] & 2x1[b]	2x6 & 2x6	2x4 & 2x4	3x3 & 2x2	2x6 & 2x6	2x4 & 2x4	3x4, 2x3 & 1x2[c]	2x6 & 2x6	2x5 & 2x5	3x4, 2x3 & 1x3	2x6 & 2x6	2x6 & 2x6
Membrane type	TMG 20-400	CPA5-MAX	RE8040-BE440	TMG 20-400	CPA5-MAX	RE8040-BE440	TMG 20-400	CPA5-MAX	RE8040-BE440	TMG 20-400	CPA5-MAX	RE8040-BE440

[a] No. of vessels x elements for stage 1; [b] No. of vessels x elements for stage 2; [c] No. of vessels x elements for stage 3; [d] three reverse osmosis design models were used in this study to predict membrane performance (measured as TDS rejection and water recovery ratio) for brackish (bore well) water source. The computer models selected were, 1) Toray (TorayDS2: v2.1.5.157[19]), 2) Hydranautics (IMSDesign v1.222.81: Integrated Membrane Solutions Design[20]) and 3) CSM (CSMPRO v5.1[21]).

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[19] https://ap3.toray.co.jp/toraywater/userLogin.do;jsessionid=53EE0991C5ED7F841ED633C1F08F465A.cw660_a41adm (Accessed December 2018)
[20] http://www.hydranauticsprojections.net/imsd/downloads/ (Accessed December 2018)
[21] http://www.csmfilter.com/ (Accessed December 2018)

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