On-Farm Desalination: Halophyte and Evaporation Pond for Reverse Osmosis Brine disposal

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Thesis declaration

I declare that this thesis by publication is my own account of my research and contains as its main content work that has not been previously submitted for a degree at any tertiary education institution.

Rowel De Paz
Abstract

Management of brine/reject from reverse osmosis (RO) systems has always been a major concern among the engineering and scientific community. The brine disposal of the RO in the arid region was the main concern in this thesis. The small scale RO plants, located inland need to work out different methods of a brine disposal.

The most common method to disposal brine on a small scale inland desalination plants is with evaporation ponds. But, the evaporation pond can be expensive and land-intensive. This thesis considering the potential way to minimize the area requirements of evaporation ponds by proposing a halophyte wetland upstream of an evaporation pond. Since halophyte can survive into the salty water, the brine from the RO unit can be fed into the wetland which would reduce the flow into the evaporation pond, consequently reducing the evaporation pond area.

An on-farm, solar-powered, small scale (500 L/hour) brackish water RO unit was set up at the Muresk Institute, Northam. The halophyte wetland was designed to reduce evaporation pond area requirements. A previously detailed evaporation pond design model was used to model the evaporation pond based on the outflow from the halophyte wetland. The evaporation pond reduced the size land area from 626 m² to 353 m² and saved 273 m² of land area. The halophyte wetland has reduction area benefits for the evaporation pond. The halophyte wetland was modeled for 431 m² land area for all seasons and fit to plant 86 old man saltbush (*Atriplex nummularia*).

The evaporation pond with halophyte wetland has the potential to give an extra source of income to the farmers. The seeds of the old man saltbush were used for food sources of aboriginal people and the plant used for livestock grazing. The salt harvesting in the evaporation pond estimated 10 t of salt in every summer season for industrial purposes.
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>BD</td>
<td>Bulk Density</td>
</tr>
<tr>
<td>BW</td>
<td>Brackish Water</td>
</tr>
<tr>
<td>BWRO</td>
<td>Brackish Water Reverse Osmosis</td>
</tr>
<tr>
<td>DoW</td>
<td>Department of Water</td>
</tr>
<tr>
<td>ESM</td>
<td>Equivalent Soil Mass</td>
</tr>
<tr>
<td>FBPR-RO</td>
<td>Fluidized Bed Pellet Reactor - Reverse Osmosis</td>
</tr>
<tr>
<td>GAWS</td>
<td>Goldfields and Agricultural Water Supply Scheme</td>
</tr>
<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
</tr>
<tr>
<td>kW</td>
<td>Kilo Watts</td>
</tr>
<tr>
<td>MCA</td>
<td>Multi-Criteria Analysis</td>
</tr>
<tr>
<td>NOID</td>
<td>Notice of Intent to Drain</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>PVRO</td>
<td>Photovoltaic Reverse Osmosis</td>
</tr>
<tr>
<td>RIB</td>
<td>Rapid Infiltration Basin</td>
</tr>
<tr>
<td>RO</td>
<td>Reverse Osmosis</td>
</tr>
<tr>
<td>SWRO</td>
<td>Seawater Reverse Osmosis</td>
</tr>
<tr>
<td>TBL</td>
<td>Triple Bottom Line</td>
</tr>
<tr>
<td>TDS</td>
<td>Total Dissolved Solids</td>
</tr>
<tr>
<td>WA</td>
<td>Western Australia</td>
</tr>
<tr>
<td>WAIV</td>
<td>Wind Aided Intensified Evaporation</td>
</tr>
<tr>
<td>ZLD</td>
<td>Zero Liquid Discharge</td>
</tr>
</tbody>
</table>
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1.0 Introduction

Goldfields and Agricultural Water Supply Scheme (GAWS) Centralised Water System supplies more than 300 million of portable water from Mundaring Weirs to Kalgoorlie-Boulder. The GAWS is managed and controlled by Water Corporation at an expensive operational cost and the water facilities are not long last to be serviceable. The water facilities reached 116 years old life service to supply clean water in approximately 9,600 km pipelines to an estimated 100,000 people in 33,000 households in the rural and town services at Wheatbelt regional area. AU$ 2 billion is the estimated cost to rebuild the GAWS water facilities (Water Corporation 2019).

Western Australia (WA) State Government has forethought for the GAWS to change the direction of the water system from centralizing to decentralize system and to embrace the sustainable and renewable energy as the source of energy to generate the effective form of sustainable water supply and hence, to lower the carbon footprint (Water Corporation 2019).

Wheatbelt region has a dramatic environmental problem in climate and weather conditions. Lack of rain in different seasons, however, heavy rain in winter season as shown in figure 1 (BoM 2019).

*Figure 1: Rainfall data in Northam in mm (BoM 2019)*

![RAINFALL](chart.png)
The underground water in the aquifer is another issue in the Wheatbelt region. The deep well water does not good for drinking water for humans and animals, hence only for irrigating halophytes plant in the agricultural land. So, therefore, there is a water scarcity problem in the region (Water Corporation 2019).

In 2018, Professor Wendell Ela suggested the solution was the small scale desalination plant and used the local product. And then, Water Corporation and Wheatbelt - Department of Regional Development funded the on-farm desalination project at Muresk Institute Farm, Northam. The project was to set-up a brackish water reverse osmosis (BWRO) desalination plant and powered by 5 kw solar PV (Ela 2018).

The ambitious project of Solar PVRO in Northam of Murdoch University will be the model in the water industry in terms of the decentralized water system. The solar PVRO desalination plant project at Muresk Institute Farm, Northam was a joint venture project of Water Corporation and Wheatbelt - Department of Regional Development. Murdoch University was the research team, and Moerk Water Solutions was the alliance of Murdoch University.

The RO desalination plant at Muresk Institute Farm has wastewater that required give more attention to it. The wastewater is called as the reject brine that has high salt content. The salty water was the extensive problem of the water provider to discharge it safely and environmentally. However, the different methods for discharging the brine existed for many years (Ahmed 2000).

In this paper focus on brine disposal method and recommend the suitable brine disposal method options fit for small scale desalination project in Muresk Institute, Northam.


1.1 Objectives

1. Determine the halophyte wetland + evaporation pond as the suitable brine disposal method for the on-farm desalination project at Muresk Institute, Northam.

2. Calculate the land area of the halophyte wetland in the summer season.

3. Define the land area reduction benefits of halophyte wetland to the evaporation pond.

4. Figure out the value of old man saltbush and salt harvesting to the farmers.

5. Generate potable water from the brackish water to supply the water demand of the farmers.

6. The project is to become a role model in a decentralizing water system to the GAWS.

2.0 Background

Brine disposal is a major issue in the water desalination industry mostly in the inland or agricultural area. The Department of Water stated that it requires a proper assessment of environmental risks and community concerns before the design and implementation of disposal methods that mitigate those dangers and concerns (DoW 2010). The physical or geographical location of the discharge point of the concentrate, and alike are factors methods of technology (Mickley M. 1993). These factors are significant to consider before deciding a plan for brine disposal that suits the project.

The on-farm desalination project is located at Muresk Institute Farm, Northam. The project site is located in the agricultural area and miles away to the ocean to disposed of the brine which is the normal work practice in the desalination industry.

The following brine disposal method options can give an idea in which is the suitable brine disposal method in the Muresk Desalination project.
2.1 Brine Disposal Methods

2.1.1 Overview of all brine disposal method options

2.1.1.1 Brine Deep Well Injection

The deep well injection method has many security issues, and for environmental protection purposes, it must comply with regulations (DoW 2010). Additionally, the brine water quality was the main focus to look at if they meet the requirements of the environmental policies. Some RO desalination plants have a low concentration of salt discharge and allowed to use the deep well injection (Ahmed 2000).

The adequate deep underground aquifer to separate from freshwater or brackish water (BW) aquifer is 500 m to 1500 m for this disposal method. Typically, brine disposal wells are consisting of three or more concentric layers of pipe: surface casing, long string casing, and injection tubing. It also has wellhead and a lined well shaft protected by multiple layers of casing and grouting (Lenntech 2018).

![Image of Brine Deep Well Injection](image)

Figure 2: Brine deep well injection (Lenntech 2018)
2.1.1.2 Coastal Discharge or Surface Water Discharge

Coastal discharge is a commonly used method to dispose brine from the seawater reverse osmosis (SWRO) desalination plant and brackish water reverse osmosis (BWRO) desalination plant, which is near the coast. This method is less costly but required to comply with the regulations of the brine disposal offshore.

2.1.1.3 Zero Liquid Discharge (ZLD)

The Zero Liquid Discharge (ZLD) technology has an enormous operation cost due to the high energy consumption and intended to ensure no liquid waste discharge in the RO desalination system (Heijman 2009). Furthermore, the technology concept is in practice, and mechanical evaporators are used, and the single-effect evaporators or vapor compression evaporators are widely used for automatic evaporation (Ahmed 2000).

Figure 3: Zero liquid discharge (ZLD) technology – wastewater treatment (SUEZ 2019)
2.1.1.4 Wind Aided Intensified Evaporation (WAIV)

The technology was aiming for a high reduction in evaporation pond sizes and cost-effective to a large evaporation pond. WAIV is running by wind energy to increase the evaporation rate of salty water (Hoque 2010). The climate conditions of Muresk Institute Farm, Northam are in favor of using the WAIV method. However, it is not practical simply because it is not feasible by cost (O'Sullivan 2018).

![WAIV Diagram](image)

*Figure 4: WAIV Diagram (O'Sullivan 2018)*

2.1.1.5 Brine Land Application

Usually, disposing brine with the land application is applied for the small size of the brackish water reverse osmosis (BWRO) desalination plant. The application of this method is constrained by climate, seasonal application, and the existence of available land and groundwater conditions. The two possible pathways in this method are spray irrigation of brine on salt-tolerant plants, and infiltration of brine through earthen rapid infiltration basin (RIBs) (Lenntech 2018).
2.1.1.6 Evaporation Ponds

The evaporation ponds were the most appropriate method to use for warm and dry climates with high evaporation rates and low land costs; and the most cost-effective means of saline water disposal in the inland (Mickey 1995). Furthermore, sun energy running the technology to evaporate the saltwater and to dry the salt into the evaporation pond bed (Lenntech 2018). The function of evaporation ponds is to transfer the salty liquid water in the pond to water vapor in the atmosphere above the lake (Mickley M. 1993).

The evaporation ponds contributed to the environmental and commercial value for the aquaculture, irrigation of halophyte plants, and alga-culture. The halophyte plants and algae are both salt-tolerant plants that grow in waters of high salinity. Moreover, both plants are a high-value source of biofuel and fodder for cattle (Mickley M. 1993).
2.1.2 Pros and cons of brine disposal method options

The pros and cons of the brine disposal method options are stated in table 1. The deep well injection, surface water discharge, and zero liquid discharge are inappropriate brine disposal options in the Muresk Institute Farm because no available deep confined saline aquifer, agricultural area and expensive to use. The halophyte wetland and evaporation pond are the suitable method options to apply because low-cost land value, the site location has a high evaporation rate and fit for small scale desalination unit.

Table 1: Comparison of brine disposal methods (Lenntech 2018)

<table>
<thead>
<tr>
<th>Brine disposal methods</th>
<th>Principle and description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water discharge</td>
<td>Brine is discharged on the surface of seawater. The most common method for all big SWRO and BWRO desalination facilities worldwide.</td>
<td>can be used for all plant sizes Cost-effective for medium to large brine flow rates</td>
<td>Brine harms the aquatic ecosystem Difficult and complex permit procedures</td>
</tr>
<tr>
<td>Deep well injection</td>
<td>Brine is injected into porous subsurface rock formations.</td>
<td>Suitable for inland desalination plants Moderate costs Low energy consumption</td>
<td>Possible only if the deep confined saline aquifer is available Potential groundwater pollution</td>
</tr>
</tbody>
</table>
Evaporation ponds

<table>
<thead>
<tr>
<th>Brine is allowed to evaporate in ponds while the remaining salts accumulate in the base of the pond.</th>
<th>Easy to construct and operate Inland and coastal use</th>
<th>Limited to small brine flows High footprint and costs</th>
</tr>
</thead>
</table>

Land application

<table>
<thead>
<tr>
<th>Brine is used for irrigation of salt-tolerant crops and grasses.</th>
<th>Easy to implement and operate Inland and coastal use</th>
<th>High footprint and costs Limited to small plants</th>
</tr>
</thead>
</table>

Zero Liquid Discharge (ZLD)

<table>
<thead>
<tr>
<th>ZLD is an advanced treatment process to remove all the liquid waste from the influent.</th>
<th>Meeting tight brine disposal government regulations Recovery of valuable materials in the waste streams Decreased waste volumes and management costs Recycling water on-site Reducing truck cost for off-site disposal</th>
<th>High costs Difficult and complex procedures</th>
</tr>
</thead>
</table>

2.1.3 Multi-criteria assessment (MCA) the different brine disposal options

(The adapted Triple Bottom Line (TBL) criteria and assessment by the URC 2010 as shown in table 2, table 3 and table 4). The result of the qualitative MCA was based on their project. The general conclusion which was the best brine disposal method is not possible to mention in this MCA because each method has advantages and disadvantages, and it is on a case-by-case basis for assessing the natural factors of parameters.

Based on the colors, the evaporation pond is the least problematic. The ZLD is possibly the most problematic owing to the high operational cost (URS 2010).

Table 2: Rank Descriptions (Financial) (URS 2010)

<table>
<thead>
<tr>
<th>Rank Descriptions</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expensive (total cost&gt;$2,000/ML)</td>
<td>Red</td>
</tr>
<tr>
<td>Moderately expensive (total cost: $1,501-$2,000/ML)</td>
<td>Yellow</td>
</tr>
<tr>
<td>Relatively inexpensive (total cost: $1,000-$1,500/ML)</td>
<td>Green</td>
</tr>
</tbody>
</table>
### Table 3: Rank Descriptions (Environmental and Socio-economics) (URS 2010)

<table>
<thead>
<tr>
<th>Rank Descriptions</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always problematic with complex mitigation measures</td>
<td>Red</td>
</tr>
<tr>
<td>Occasionally problematic with complex mitigation measures</td>
<td>Yellow</td>
</tr>
<tr>
<td>Rarely problematic with complex mitigation measures</td>
<td>Green</td>
</tr>
</tbody>
</table>

### Table 4: Multicriteria assessment (MCA) the different brine disposal options (URS 2010)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Evaporation pond</th>
<th>Deep well injection</th>
<th>Zero liquid discharge (ZLD)</th>
<th>Wind-aided intensive evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost (S/ML, based on 3.79 ML/day)</td>
<td></td>
<td></td>
<td>High operating cost owing to the energy requirement</td>
<td>Moderate operating cost owing to capital and land requirements</td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water receptors (e.g., aquatic species and habitat)</td>
<td></td>
<td>Ecological risks are low, unless if falls and discharges to surface water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air receptors (e.g., birds, insects, and air quality)</td>
<td>Some concentrations may contain constituents that pose a hazard to avian receptors</td>
<td>Some concentrations may contain constituents that pose a hazard to avian receptors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land receptors (e.g., plants, animals and habitat)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emissions</td>
<td></td>
<td>Owing to energy requirements</td>
<td>Owing to energy requirements</td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td></td>
<td></td>
<td>Because mechanical equipment is used</td>
<td></td>
</tr>
<tr>
<td>Socio-economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health (potential effect on human health)</td>
<td></td>
<td>Potential for migration to potable water supplies</td>
<td></td>
<td>Possibility of localized noxious odors</td>
</tr>
<tr>
<td>Visual amenity (facility’s effect on human amenity)</td>
<td>The Relatively large area of land required</td>
<td>Infrastructures can be obtrusive</td>
<td>Reduced area of land required, but infrastructures may be more obtrusive</td>
<td></td>
</tr>
<tr>
<td>Public acceptance (likelihood of public opposition)</td>
<td>Because of risk to groundwater</td>
<td>Because of energy consumption</td>
<td>Potential for the salt draft</td>
<td></td>
</tr>
<tr>
<td>Regulatory requirements/approval</td>
<td></td>
<td>Unknown regulatory environment</td>
<td>But maybe more problematic because of high GHG emissions</td>
<td>Marginally more assessment required for approval than the evaporation pond</td>
</tr>
</tbody>
</table>
2.2 Selection of most suitable brine disposal method

2.2.1 Option I – Halophyte wetland + evaporation pond

Option 1 is the combination of halophyte wetland and evaporation pond. The halophyte wetland land area must be modeled on the highest salt concentration which is in the summer season. The evaporation pond should be modeled in the highest flowrate which is in the winter season. And should be able to store saline water in all weather and climate conditions. In this option, the halophyte wetland performs a significant role in reducing the size of the evaporation pond. However, the halophyte wetland has the biggest challenge in the winter season because of the high flowrate and additional volume of the rain in the wetland.

![Option 1](image)

*Figure 7: Option 1, halophyte wetland + evaporation pond*

2.2.1.1 Halophyte Wetlands

Halophytes wetland has a public perception as an “environmentally unfriendly “. The traditional work practice irrigating halophyte plants by concentrated salty water has an environmental impact depositing saline water on soil structure and salinization (Suresh Panta 2015). In this project, the halophyte wetland has made of liner and trench drainage to become environmentally friendly. The halophyte wetland is considered an option to reduced the land area of the evaporation pond.
2.2.1.2 Criteria and Methods for Feasibility Assessment

Lenntech (2018) said the main feasibility factors for the use of the halophyte wetland for concentrate disposal are,

1. Climate – Dry and high evaporation rate
2. Availability and low cost of land
3. Irrigation needs to the halophytes
4. Salinity tolerance of the irrigated vegetation
5. The ability of the land application system operation to comply with pertinent regulatory requirements and groundwater quality standards

Loamy and sandy soils are typically suitable in the method. Neutral and alkaline soils are preferable to use it to minimize trace metal leaching (Lenntech 2018).

2.2.1.3 Halophyte Wetland Costs

Lenntech (2018) said the main factors affecting the cost of brine application are,

1. Brine volume and salt concentration
2. Land cost
3. Salt-tolerant plants cost
4. Warm and dry climate (local climate)
5. Evaporation pond
6. Soil type and groundwater level (earthwork cost)

2.2.1.5 Overview of halophyte options

Halophyte plants in Australia have different type of species as shown in table 3. It showing the growth attributes of halophyte plant species.
Table 5: Summary of the shrubs species growth attributes (Revell 2014)

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Salinity tolerance</th>
<th>Waterlogging tolerance</th>
<th>Preferred soil</th>
<th>Maximum Height (m)</th>
<th>Maximum Diameter (m)</th>
<th>Seedling frost tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluebush; yanga bush</td>
<td>Maireana brevifolia</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Nitre goosefoot</td>
<td>Chenopodium nitriariceum</td>
<td>Low</td>
<td>Medium</td>
<td>Very heavy</td>
<td>2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Old man saltbush</td>
<td>Atriplex nummularia</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>2.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Rhagodia</td>
<td>Rhagodia preissii</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>River Murray saltbush</td>
<td>Atriplex rhagadioides</td>
<td>Medium</td>
<td>Very heavy</td>
<td>Medium</td>
<td>2</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>River saltbush</td>
<td>Atriplex amnicola</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>1.5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Ruby saltbush</td>
<td>Enchylaena tomentosa</td>
<td>Medium</td>
<td>Low</td>
<td>Very heavy</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sandhill wattle</td>
<td>Acacia ligulata</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>4</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Tar bush</td>
<td>Eremophila glabra</td>
<td>Low</td>
<td>High</td>
<td>Very heavy</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Thorny saltbush</td>
<td>Rhagodia spinescens</td>
<td>Medium</td>
<td>Medium</td>
<td>Very heavy</td>
<td>1</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

Key:

- **High**
- **High Moderate**
- **Moderate**
- **Low**
- **All**
- **Medium-very heavy**
- **Light-medium**
- **Medium-heavy**

**2.2.1.6 Old Man Saltbush (Atriplex nummularia)**

In this study, *Atriplex nummularia* is also called an old man saltbush is the selected halophyte model into halophyte wetland. The reasons are the following:

1. The old man saltbush was survived on the whole year season 2011 re-vegetation of abandoned agriculture land project of Murdoch University in the various places of Wheatbelt region (L.L. Walden 2017).
2. The old man saltbush is the largest species of Australian saltbush (ERA Nurseries 2019).

3. The *Atriplex nummularia* is a livestock grazing plant and the seeds are used for food source of Aboriginal people (Tucker Bush 2019).

4. The *Atriplex spp.* has a 12.8 g/L salinity tolerance (Punta et al 2014).

The old man saltbush can absorb the concentrated salty water from the plant root to the leaves and capable of storing an excessive amount of salt in their tissues up to 39% (Barrett-Lennard 1996). The salt will stay on the leaves until the leaves fall or wash out by the rain. The salt is not a food of the halophyte so it will not disappear and eventually, it will back to the soil surface (Barrett-Lennard 1996).

Old Man Saltbush is the most suitable for planting in saline discharge areas. It is deep-rooted and tolerant of both high salinity levels and low rainfall. Old Man Saltbush stands should be productive for 10-20 years, but can survive for up to 50 years depending on management (Moore 2001).

*Figure 8: Old Man Saltbush (*Atriplex nummularia*), planted in rows in ploughed paddock*
2.2.2 Option II – Evaporation pond

Option 2 is solely the evaporation pond. It is modeled on the winter season to find the pond area.

The halophytes wetland + evaporation pond would be the suitable brine disposal method for the Muresk Institute Farm project. Because the location has dry and warm weather, high evaporation rates, and availability of land at a low cost.

2.2.2.1 Evaporation Pond

The evaporation ponds were the most appropriate method to use for warm and dry climates with high evaporation rates and low land costs; and the most cost-effective means of saline water disposal in the inland (Mickey 1995). Furthermore, sun energy running the technology to evaporate the saltwater and to dry the salt into the evaporation pond bed (Lenntech 2018). The function of evaporation ponds was to transfer the salty liquid water in the pond to water vapor in the atmosphere above the lake (Mickley M. 1993).

The evaporation ponds contributed to the environmental and commercial value for the aquaculture, irrigation of halophyte plants, and alga-culture. The halophyte plants and algae are both salt-tolerant plants that grow in waters of high salinity. Moreover, both plants have the high-value source of biofuel and fodder for cattle (Mickley M. 1993).

2.2.2.2 Pros and Cons of evaporation pond

The evaporation pond has pros and cons and stated the details in table 6. The price of the land property is the basic parameter to determined if the evaporation pond is suitable to install and use as the brine disposal in the BWRO because it requires a large surface area to efficiently
evaporate salty water by sunlight and exposure to the ambient temperature. The evaporation pond has the advantage to install in the arid region with a high-temperature climate and low-cost value of the land.

The disadvantages of the evaporation pond are limited land to install, weather and climate-dependent. The evaporation pond is inappropriate to install to the place where the rainfall rate is higher than the evaporation rate and expensive the land value.

Table 6: The advantages and disadvantages of evaporation ponds for disposing brine (Mickley M. 1993)

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low maintenance and little</td>
<td>Required for impervious liners of clay or synthetic</td>
</tr>
<tr>
<td>operator attention</td>
<td>membranes such as PVC or Hypalon.</td>
</tr>
<tr>
<td>Less mechanical equipment except</td>
<td>Potential of contaminating underlying potable water</td>
</tr>
<tr>
<td>for the pump</td>
<td>aquifers through seepage from poorly constructed evaporation ponds.</td>
</tr>
<tr>
<td>Least costly means of disposal,</td>
<td>Large tracts of land when the evaporation rate is low or the</td>
</tr>
<tr>
<td>especially in areas with high</td>
<td>disposal rate is high.</td>
</tr>
<tr>
<td>evaporate rates and low land costs</td>
<td></td>
</tr>
<tr>
<td>Easy to construct</td>
<td>Weather and climate-dependent</td>
</tr>
</tbody>
</table>

2.2.2.3 Pros and Cons of different type of evaporation pond

Table 7: The advantages and disadvantages of a small evaporation pond, large evaporation pond, series of small evaporation ponds, and combination of evaporation pond and wind-assisted intensified vaporization (WAIV) methods to dispose of brine. (Mickley M. 1993)

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Evaporation Pond</td>
<td>Monitor regularly;</td>
</tr>
<tr>
<td>Easy to manage mostly in windy condition;</td>
<td>Shut down the operation when occurring maintenance in the pond;</td>
</tr>
<tr>
<td>Easy to operate;</td>
<td>The high cost of transport to pick up the part of dry salt;</td>
</tr>
<tr>
<td>Low initial cost – labor and materials;</td>
<td>No spare reject brine disposal pond.</td>
</tr>
<tr>
<td>Low land cost – a small block of land.</td>
<td></td>
</tr>
<tr>
<td>Large Evaporation Pond</td>
<td>High risk to damage the leves by the wave action of the water in</td>
</tr>
<tr>
<td>Less cost of transport to pick up the</td>
<td>windy condition;</td>
</tr>
<tr>
<td>bulk dry salt.</td>
<td>Monitor regularly;</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Series of small evaporation ponds and valve piping system</td>
<td>Easy to manage for removal of dry salt; Easy to manage mostly in windy condition; Enable to control by the valves and pipes for the effluent storage pond; Easy to maintain and operate; Less chance to shut down the operation when occurring maintenance in the ponds; Available spare rejects brine disposal pond.</td>
</tr>
<tr>
<td>Combination of evaporation pond and wind-assisted intensified vaporization (WAIV)</td>
<td>Less land area; Highly effective to increase the evaporation rate; Highly effective to reduce the evaporation pond sizes.</td>
</tr>
</tbody>
</table>

**2.2.2.4 Potential Environmental Impacts**

The Australian policy for the evaporation ponds is to be constructed with impervious lining for the protection of underlying aquifers. The double-lined pond may require to be constructed if the brine contains high concentrations of toxic contaminants (e.g., high levels of trace metals) (Lenntech 2018).

**2.2.2.5 Criteria and Methods for Feasibility Assessment**

Evaporation ponds are climate and weather dependent with higher local temperature and solar irradiation. Solar evaporation is feasible only in relatively warm, dry environments with high
evaporation rates, low precipitation rates, and low humidity. The ideal location is flat terrain and low land cost (Lenntech 2018).

Evaporation ponds method is not applicable for regions with an annual evaporation rate < 1.0 m/y and annual rainfall rate > 0.3 m/y. Because the high rainfall rate reduces evaporation rates. This method is not viable if the yearly average humidity > 60% because the higher the humidity is the lower the evaporation rate (Lenntech 2018).

2.2.2.6 Evaporation Pond Costs

The cost of evaporation pond is based on the earthworks (excavation etc.), liner (HDPE liner and protection), site works (roads and fences, etc.), and pipework (plant to the pond) (O'Sullivan 2018).

2.2.2.7 Design Consideration of Evaporation Pond

The perfect evaporation pond must be capable of accept-reject brine at all times under all conditions. The evaporation pond is more useful to ensure that the average annual evaporation rate exceeds the depth of saltwater that would have to be stored in the pond. The design of evaporation ponds for leakage prevention must have the impervious linings or be provided with seepage-collection systems (Ahmed 2000).

The evaporation rate is a significant factor to be considered in designing the evaporation pond. The surface area, water storage, storage capacity for the salts, and freeboard for rainfall and wave action are components of the evaporation pond. The higher the evaporate rates the smaller the size of the ponds. However, the evaporation rate depends on the salinity of the water in the pond. Typically, as the salinity increases, the evaporation rate decreases (Ahmed 2000). The conventional method to find the evaporate rate is the standard evaporation pan
The evaporation rate in the pond is determined by the water balance equations (Cuenca 1989).

JDA and Hauck (2006) said that Western Australia (WA) evaporation basin guidelines for the disposal of saline water to find the area of the basin has three parameters,

1. the annual inflow
2. underground salinity (evaporation rate decreases, with increasing salinity).
3. potential Net Evaporative Loss (calculated as annual Class A pan evaporation minus rainfall)

The following has been used to provide the size of the evaporation pond:

- The Potential Net Evaporative Loss for the site is reported to be 1,700 mm/yr (JDA and Hauck, 2006).
- The salinity of the brine assumed to be 12,000 mg/L
- Average daily inflow assumed to be 15 kL/day, resulting in an estimated area for the basin of 8,000 m².
- All areas are based on internal embankment toe to toe, rather than crest to crest.
- Final sizing of the evaporation pond will occur once the specific RO units have been selected.

The Guidelines specify that all basins have depth, referenced from the top of the embankment, of 2.2 m for 50 years design life. This depth includes a 0.5 m freeboard, to allow for the effect of wind and waves within the basin and extreme rainfall events, and a 0.2 m spillway. A maximum water depth of 1.5 m is allowed over the life of the basin, which includes any precipitation of salt within the basin. The 2.2 m design depth is valid for basins located on flat topography. Where ponds are located on sloping land, the 2.2 m design depth should be taken as the depth at the deepest point of impoundment. The disposal of saline brine is covered by regulations requiring the landholder (owner or occupier) to notify the
Commissioner of Soil and Land Conservation before any discharge takes place. The landholder is required to lodge a notice of intent to drain or pump water (NOID) with the Commissioner. The assessment period has 90 days to determine whether land degradation is likely to occur as a result of the saline discharge.

2.3 Soil Salinity and Brine

The soil salinity is a measure of the minerals and salts that can be dissolved in water. In most cases, the following mineral ions are found in soil-water extract listed in order of importance: $\text{Na}^+$, $\text{Cl}^-$, $\text{Ca}^{++}$, $\text{SO}_4^{2-}$, $\text{HCO}_3^-$, $\text{K}^+$, $\text{Mg}^{++}$, $\text{NO}_3^-$

Increased soil salinity has progressive and often profound effects on the structure, microbial diversity, and plant activity of soil. Soil salinity is measured by using electrical conductivity (EC) measurements of a water-saturated soil. Soil salinity is extremely heterogeneous within a short distance, both horizontally and vertically, so adequate sampling is essential. There are also seasonal variations due to leaching. Soil salinity can be measured with electromagnetic-induction meters or from soil samples either in the field with a pocket EC meter, or in the laboratory (Moore 2001).

Sodium chloride (NaCl) is the major salt in soils in the medium and high rainfall zones of Western Australia where secondary salinity predominates. In low rainfall areas (<350 mm/annum), primary salinity is again mainly due to NaCl, but other salts causing high pH values may be present. (If the pH$_w$ > 8.5 refer to Soil alkalinity and soil sodicity; Section 5.2) (Moore 2001). Salt-affected plants usually appear normal, although they are stunted and may have darker green leaves. There is general stunting of plant growth, because as the salt concentration increases above a threshold level both the growth rate and ultimate size of the plant decrease. Shoot growth is frequently suppressed more than root growth.

A plant exposed to a high concentration of salts in the root zone will respond almost immediately by reducing the rate of leaf expansion. This short-term response is due to the
increased osmotic potential hindering water uptake by the roots. In the long-term, there is a build-up of salt in the leaves, especially the old leaves, resulting in necrosis. Net effects on the plant depend on the rate of leaf production compared with leaf necrosis.

There is considerable variation in the salt tolerance of agricultural plants and crops. In general, crops tolerate salinity up to a threshold level but above this, yields decrease approximately linearly with increasing salt concentrations.

In the field, the distribution of soluble salts is usually highly variable. The plant response is likely to be related to the weighted-mean salinity concentration, based on the amount of water absorbed at each depth and its salt content. Therefore, plants can probably withstand higher salt concentrations than those reported above, if part of the root zone has access to water with a low salt concentration (Moore 2001).

## 2.3.1 Effect of salinity on ground cover

In WA, most of the salt is brought in with the rainfall and accumulates in the soil over a long time. Rainwater on the west coast contains considerable concentrations of dissolved salts (13-27 mg/L NaCl), but the concentration decreases with distance inland. For example, the amount of salt deposited each year in rainfall at Geraldton, Salmon Gums and Merredin is 195, 30 and 18 kg/ha/year respectively. Some of the salt has also come from the weathering of rocks. For secondary salinity to occur only a small fraction of the total salt stored in the soil needs to be mobilized (Moore 2001).

<table>
<thead>
<tr>
<th>Depth to saline water table (m)</th>
<th>Effect of salinity on ground cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2</td>
<td>Negligible effect</td>
</tr>
<tr>
<td>&lt;1.8</td>
<td>Wheat yield decreased</td>
</tr>
<tr>
<td>&lt;1.5</td>
<td>Barley yield decreased</td>
</tr>
</tbody>
</table>

Table 8: Critical depth to saline water table (Moore 2001)
2.3.2 Indicator plant species and the approximate soil salinity

The indicator plant species is a common way to determine the approximate soil salinity. The halophytes plants with high salt tolerance can survive in the extremely saline soil condition. So, the halophytes plants are indicator plant species (Moore 2001). In every halophyte, the plant has own salt tolerance like the saltbush species has 12.8 g/L. The saltbush species will not be survived if the soil salt concentration is greater than 12.8 g/L (Suresh Panta 2015).

Table 9: Indicator plant species and the approximate soil salinity (Moore 2001)

<table>
<thead>
<tr>
<th>Soil Salinity</th>
<th>Indicator plant species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-saline</td>
<td>Agricultural plants not affected</td>
</tr>
<tr>
<td>Slightly saline</td>
<td><strong>Crops:</strong> Very salt-sensitive crops such as lupins are affected. <strong>Pasture:</strong> Fewer salt-sensitive species such as yellow serradella, strand, medic, rose and cupped clovers are present.</td>
</tr>
<tr>
<td>Moderate saline</td>
<td><strong>Crops:</strong> Wheat is affected: barley is the preferred alternative. <strong>Pasture:</strong> Fewer clovers, medics, and non-salt tolerant grasses are present.</td>
</tr>
<tr>
<td>Highly saline</td>
<td><strong>Crops:</strong> Cereals only return a satisfactory return yield when seasonal conditions are favorable. <strong>Pasture:</strong> Patchy grass and bare ground. Barley grass dominates and clovers, medics are usually absent. Balansa and Persian could be present.</td>
</tr>
<tr>
<td>Extremely saline</td>
<td><strong>Crops:</strong> Salinity to high for any crops. <strong>Pasture:</strong> Barley grass and other salt tolerance species may be present, however samphire and/or bare ground become dominant as the salinity increases.</td>
</tr>
</tbody>
</table>
2.4 Legislation/ Regulation/ Water Guidelines

The Western Australian (WA) state government is fully regulated for the water policy, guidelines and alike. The WA evaporation basin guidelines for the disposal of saline water 2006 are the effective guidelines to follow and comply with the minimum requirements to dispose of the brine in the on-farm desalination project at Muresk Institute Farm, Northam. The Australian Drinking Water Guidelines 2004 is the general rule to follow and comply with the drinking water in the BWRO desalination plant. The general rules and regulations given by the WA state government must be complied with before and after making a solution to the water scarcity problem in the project site.

Table 10: Western Australia Environmental Regulations and Guidelines

(Department of Primary Industries and Regional Development 2019)

<table>
<thead>
<tr>
<th>Policies</th>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Protection Act of 1986</td>
<td>For the prevention, control, and abatement of pollution and environmental harm, for the conservation, preservation, protection, enhancement, and management of the environment.</td>
</tr>
<tr>
<td>Soil and Land Conservation Act of 1945</td>
<td>To mitigate and prevent land degradation throughout Western Australia (WA).</td>
</tr>
<tr>
<td>Soil and Land Conservation Regulations 1992</td>
<td>To control the drainage of saline land in Western Australia (WA).</td>
</tr>
<tr>
<td>Australian Drinking Water Guidelines 2004</td>
<td>To provide information on acceptable water quality for human consumption and to offer information on measures to ensure their safety.</td>
</tr>
<tr>
<td>Western Australian Evaporation Basin Guidelines for Disposal of Saline Water 2006</td>
<td>To provide information and criteria for evaporation basin planning, design, construction, monitoring, and maintenance for purposes of disposal of water and storage of disposed of salts in dryland agricultural areas in WA.</td>
</tr>
</tbody>
</table>
3.0 Methodology

3.1 Soil Profile

The Muresk Institute Farm has a soil type called jelcobine surfaces, York soil series. The jelcobine surface is mainly loam and duplex soils formed from fresh gneissic rocks of the jimperding metamorphic zone. The predominates growing trees in this soil are wandoo and casuarina (Sawkin 2010).

![Soil type Jelcobine surface, York Soil Series](image)

*Figure 9: Soil type Jelcobine surface, York Soil Series*

The soil type in the project site is important to define if the old man saltbush will able to grow. It is confirmed that the jelcobine surface, York soil series was the soil type in the project site. The Muresk Institute Farm is located to Northam and it is part of the Central Wheatbelt as shown in table 9.

The soil group of the jelcobine is loamy and duplex soil type. It has nutrient deficiencies in nitrogen and phosphorous. However, the old man saltbush still can grow and survive in the soil type condition.
Table 11: Property of loamy duplex soil/ Jelcobine surface, York Soil Series (Moore 2001)

<table>
<thead>
<tr>
<th>Soil Texture Profile</th>
<th>Soil Group</th>
<th>Profile Hydrology Group</th>
<th>Possible Nutrient Deficiencies and Toxicities</th>
<th>Main Limitations to Sustainable Production</th>
<th>Distribution</th>
<th>Australian Soil Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Loamy Duplex (Loam over clay at 5-30cm)</td>
<td>Red Shallow Loamy Duplex: Red within top 30cm; Subsoil pH: neutral; Firm to hard setting surface</td>
<td>Medium to fine-textured soils (some permeability contrast soils)</td>
<td>Deficiencies P, N, (S)</td>
<td>Water erosion (Hardest surface)</td>
<td>Northern (Chapman Valley loam) and Central Wheatbelt (Avon Valley loam) Great Southern</td>
<td>Chromosols Sodosols</td>
</tr>
</tbody>
</table>

Table 12: Main parent material and intrinsic properties of soil of Jelcobine surface, York Soil Series (Moore 2001)

<table>
<thead>
<tr>
<th>Parent Material</th>
<th>Main Soils</th>
<th>Soil Properties</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid igneous and metamorphic rocks (eg. Granite, gneiss) weathered in situ</td>
<td>Red and brown, shallow and deep loamy duplex soils, red loamy earth, Friable red/brown loamy earth, Red and grey deep sandy duplex soils</td>
<td>Gritty (quartz, feldspars), acid to neutral pH</td>
<td>Kaolinite (80-100%) Illite (0-20%)</td>
</tr>
</tbody>
</table>

Table 13: Soil salinity rankings (USDI 1970)

<table>
<thead>
<tr>
<th>Parameter (mS cm⁻¹)</th>
<th>Non-Saline</th>
<th>Slightly Saline</th>
<th>Moderately Saline</th>
<th>Saline</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC*</td>
<td>&lt;4</td>
<td>4-8</td>
<td>8-16</td>
<td>&gt;16</td>
</tr>
</tbody>
</table>

* Measured on a water-saturated soil paste extract (USDI 1970)
3.2 Site Selection

The Muresk Institute Farm is located of uplands rejuvenated drainage zone (RDZ) and fertile soils of the Avon Valley (dtwd 2019).

This zone has an active drainage system with north–south-flowing branches of the Avon River that meet at Northam and break through the Darling Range to join the Swan River. The landscape is more dissected, often with variable soils formed from dissected laterite profiles and underlying crystalline rock. The sandplain north of Meckering and Cunderdin is bordered on the north, east and south sides by ancient drainage valleys, but has aeolian soils and upper valleys consistent with the RDZ further west (Department of Agriculture and Food, 2019).

The Muresk Institute farm is comprised of four main landscape units are Avon flats, jelcobine York, Hamersley, and steep rocky hills (dtwd 2019) Jelcobine York is the landscape located in the halophytes wetland and evaporation pond.

The hilly site location with undulating low granite hills and isolated lateritic remnants is the place where the halophytes will be planted.

*Figure 10: Site location of the on-farm desalination at Muresk Institute Farm*
3.3 Water Feed Quality

The bore water quality test was conducted on the 10th of June 2019. Results are shown in table 14, the water quality at the old well was in minimal results. The management was targeting to use the old well bore as the feed water to the RO desalination plant, produce fresh and clean water from it, and provide the treated water to the Muresk Institute Farm afterward. Used to be the first choice as a source of salty water was the piggery site. Unfortunately, unable to use it because of extremely high risk to be contaminated and high potential to be flooded during wintertime. However, the piggery site bore water has the lowest pH, the highest conductivity, and the highest amount of chloride, and sulphate among the three bore locations.

Due to access issues and water quality, water from the windmill site was too clean (low salinity) that additional treatment is not necessary. At this stage, the project focus to find the suitable bore in which the influent has the highly concentrated salt content in the salty water.
Muresk Institute Farm Water Quality – Summary of ENVIROLAB results

Parameters in red were tested on site

*Table 14: The bore water quality at Muresk Institute Farm Project (Muresk Institute Farm 2018)*

<table>
<thead>
<tr>
<th>Tested Parameter</th>
<th>Units</th>
<th>PQL</th>
<th>Windmill (Site 6) Average</th>
<th>Old well (Site 16B) Average</th>
<th>Piggery Site (in Cattle Yard) Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>mS/cm</td>
<td>0.885</td>
<td>1.988</td>
<td>11.75</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>21.7</td>
<td>20.9</td>
<td>21.8</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.3</td>
<td>7.22</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td>mg/L</td>
<td>17.1</td>
<td>9.0</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>1.60</td>
<td>2.37</td>
<td>3.54</td>
<td></td>
</tr>
<tr>
<td>Total Alk as CaCO₃</td>
<td>mg/L</td>
<td>129</td>
<td>465</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Total Alkalinity as CaCO₃</td>
<td></td>
<td>105</td>
<td>470</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Bicarbonate as CaCO₃</td>
<td>mg/L</td>
<td>5</td>
<td>105</td>
<td>470</td>
<td>1100</td>
</tr>
<tr>
<td>Carbonate as CaCO₃</td>
<td>mg/L</td>
<td>5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Hydroxide as CaCO₃</td>
<td>mg/L</td>
<td>5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Phenolphthalein Alk as CaCO₃</td>
<td>mg/L</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>mg/L</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>56</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>1</td>
<td>120</td>
<td>320</td>
<td>1700</td>
</tr>
<tr>
<td>Fluoride</td>
<td>mg/L</td>
<td>0.1</td>
<td>2.7</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Sulphate</td>
<td>mg/L</td>
<td>1</td>
<td>53</td>
<td>83</td>
<td>850</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>mg/L</td>
<td>0.1</td>
<td>16</td>
<td>30</td>
<td>570</td>
</tr>
<tr>
<td>Aluminium</td>
<td>mg/L</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Boron</td>
<td>mg/L</td>
<td>0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Barium</td>
<td>mg/L</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.24</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/L</td>
<td>0.5</td>
<td>3.2</td>
<td>26</td>
<td>160</td>
</tr>
<tr>
<td>Copper</td>
<td>mg/L</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.07</td>
</tr>
<tr>
<td>Iron</td>
<td>mg/L</td>
<td>0.02</td>
<td>0.04</td>
<td>&lt;0.02</td>
<td>0.11</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/L</td>
<td>0.5</td>
<td>0.8</td>
<td>5.7</td>
<td>12</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/L</td>
<td>0.5</td>
<td>7.6</td>
<td>71</td>
<td>475</td>
</tr>
<tr>
<td>Manganese</td>
<td>mg/L</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>3.35</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/L</td>
<td>0.5</td>
<td>160</td>
<td>310</td>
<td>1900</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg/L</td>
<td>0.05</td>
<td>0.2</td>
<td>&lt;0.05</td>
<td>0.62</td>
</tr>
<tr>
<td>Selenium</td>
<td>mg/L</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Silicon</td>
<td>mg/L</td>
<td>0.1</td>
<td>28</td>
<td>19</td>
<td>32</td>
</tr>
<tr>
<td>Strontium</td>
<td>mg/L</td>
<td>0.05</td>
<td>&lt;0.05</td>
<td>0.19</td>
<td>3.2</td>
</tr>
</tbody>
</table>
3.4 Salt Mass Balance of BWRO Desalination

The salt mass balance of the brackish water reverse osmosis (BWRO) is in figure 12. The components are the following:

Feed flowrate ($Q_f$) is the rate of salty water from the aquifer.

Permeate flowrate ($Q_p$) is the rate of water passing through the RO membrane.

Brine reject flowrate ($Q_r$) is the rate of concentrated saltwater from the RO.

![Salt Mass Balance Diagram](image)

*Figure 11: Salt mass balance of brackish water reverse osmosis*

3.5 Halophytes Wetland and Evaporation Pond (Option1)

In this thesis, the halophytes wetlands modeled have a liner underneath the soil surface to eliminate the infiltration to the soil. The wetland modeled in summer because summer and dry season have a higher evapotranspiration rate than the rainfall. And because of this climate, increasing salinity concentration. The salinity tolerance of the halophytes is significant and modeled the wetland to not over the concentration of the halophytes by equation 1, equation 2 and equation 3.

*Equation 1: Salt mass balance of halophytes wetland*

$$(Q_r * C_r) + (Q_{rain} * C_{rain}) = (Q_{ev} * C_{ev}) + (Q_{pond} * C_{pond})$$

*Equation 2: Salt mass balance of halophytes wetland*

$$(Q_r + Q_{rain}) = (Q_{ev} + Q_{pond})$$

*Equation 3: Halophytes wetland area*

$$A_{wetland} = Eq. 1 \& Eq. 2$$
Figure 12: Option 1, halophytes wetland + evaporation pond

Brackish Water

Reverse Osmosis (RO) Unit

Permeate: \( Q_P = 500 \text{ L/h}; C_P = 63.55 \text{ TDS} \)

Brine reject: \( Q_R = 150 \text{ L/h}; C_R = 5767 \text{ TDS} \)

\( Q_F = 650 \text{ L/h} \)
\( C_F = 1380 \text{ TDS} \)

Evapotranspiration

Rainfall

Halophytes

\( Q_{WR} = ? \)
\( C_{WR} = ? \)

Evaporation

Rainfall

Evaporation Pond
3.5.1 Halophytes Wetland Design System

Halophytes wetland design system has a limiting factor that must be considered. Each factor has a significant function and effect on the whole system. The following parameters are designed particularly in old man saltbush and maybe not suitable to the other halophyte plants.

1. Land cost – low cost (Lenntech 2018)
2. Land area – possible to lower the salt tolerance of saline water than the salt tolerance of the halophytes plant.
3. Land elevation - commonly slopes of up to 20% (Lenntech 2018).
4. Soil profile – fit for the old man saltbush.
5. Liner - HDPE liner and protection (O'Sullivan 2018).
6. Trench drainage – used for saline water passage at the edge of the wetland.
7. Halophyte plant:
   • Planting methods – seeds and cutting
     o Seeds – generally done by sowing the fruiting bracteoles (ANBG 2019)
       ▪ The seedling should not be planted into dry soil (Emms 2008).
       Germination within 2 – 4 weeks, growing stages 6 months (TreeProject 2019), and 1-year-old for early cutting or harvesting (Emms 2008). The best sowing times of seed are autumn, early winter, and spring (ANBG 2019)
     o Cutting – usually placed into a mixture of sand and potting mix.
   • Sowing time – late summer-early autumn, early spring (TreeProject 2019)
• Life span – 10 to 20 years. However, can reach up to 50 years depending on the plant management (Moore 2001).

• Salt tolerance – for *Atriplex species* 12.8 g/L (Punta et al 2014). The old man saltbush is not salt tolerance within the germination period.

• Drought tolerance – good (Emms 2008)

• Waterlogging tolerance – does not tolerate waterlogging (Emms 2008)

• Seedling frost tolerance – high (Revell 2014)

• Prepared soil – heavier textured soils, saline soil and other range soil type (Emms 2008)

• Fertilizer – recommended in some situations (Emms 2008)

• Height – maximum of 2.5 m (Revell 2014)

• Diameter – maximum of 2.5 m (Revell 2014)

• Availability – make an advance order to the nursery to prepare on time. A native plant is not always available, however, depending on the nursery (APACE 2019).

• Temperature – grows predominantly in the summer season but growth slows in below 10 °C (Emms 2008).

• Grazing/ cutting – more than 1-year-old for the early grazing and older old only for 5-10% of the original leaf remains. Grazed to this level within 6 weeks and recovery for 6 months. The old man saltbush will kill if continuously grazing (Emms 2008).

• Cost - $1.75 incl GST per plant (ERA Nurseries 2019)

8. Brine reject flowrate and salt concentration – data on the RO summary report at appendix F.

9. Evapotranspiration rate and salt concentration – the salt concentration is zero. The evapotranspiration rate data is in figure 17.
10. Precipitation rate and salt concentration - the rainfall rate data is in figure 16. The salt concentration is 0.027 g/L (Moore 2001).

11. Halophytes wetland discharge flowrate and salt concentration – calculated by equations 1 and 2. The calculated data at option 1 is in table 13.

*Equation 1: Salt mass balance of halophytes wetland*

\[(Q_r \times C_r) + (Q_{rain} \times C_{rain}) = (Q_{ev} \times C_{ev}) + (Q_{pond} \times C_{pond})\]

*Equation 2: Salt mass balance of halophytes wetland*

\[(Q_r + Q_{rain}) = (Q_{ev} + Q_{pond})\]

---

**Figure 13: Halophytes wetland design system**
3.5.2 Mathematical Method

The halophytes wetland salt mass balance parameters are rainfall, brine rejects, evapotranspiration and pond or wetland reject. In the salt mass balance concept, the input and output must be equal. This system is called an equilibrium.

Ave. per season

![Figure 14: Salt mass balance of halophytes wetland](image)

Figure 14: Salt mass balance of halophytes wetland

Equation 1 is the equation for the salt mass balance of halophytes wetland. In this equation, the data of brine reject, rainfalls and evapotranspiration flowrate are all given. The pond salt concentration or halophytes wetland salt concentration is assuming 10 g/L. The nominal salt tolerance of the halophytes plant is 5 g/L and the *Atriplex* spp. has 12.8 g/L salinity tolerance (Punta et al 2014). The value of evapotranspiration salt concentration is zero because the halophytes plant absorbing the salty water from the root up to the leaves and the salt stay on the leaves until it falls or washes out by the rain back to the soil surface. It means the salt is not disappeared or the food of the plant (Barrett-Lennard 1996).

Equation 2 is the equation to find the value of pond flowrate or the halophytes wetland reject flowrate. And equation 3 is to find the value of halophytes wetland land area by derived and combined equation 1 and equation 2. The halophytes wetland area is in the summer season which is 431 m² because in the summer season, the evapotranspiration rate is higher than the precipitation rate and the salt concentration is at the maximum level. The calculated land area of halophyte wetland (m²) is in the Microsoft Excel Spreadsheet.
Equation 4: Salt mass balance of halophytes wetland

\[(Q_r \times C_r) + (Q_{rain} \times C_{rain}) = (Q_{ev} \times C_{ev}) + (Q_{pond} \times C_{pond})\]

Equation 5: Salt mass balance of halophytes wetland

\[(Q_r + Q_{rain}) = (Q_{ev} + Q_{pond})\]

Equation 6: Halophytes wetland area

\[A_{wetland} = Eq. 1 & Eq. 2\]

Where:

- \(Q_r\) = Brine reject flowrate (L/month)
- \(C_r\) = Brine reject salt concentration (g/L)
- \(Q_{rain}\) = Rainfall flowrate (m/month)
- \(C_{rain}\) = Rainfall salt concentration (g/L)
- \(Q_{ev}\) = Evapotranspiration flowrate (m/month)
- \(C_{ev}\) = Evapotranspiration salt concentration (g/L)
- \(Q_{pond}\) = Pond flowrate or halophytes wetland reject flowrate (L/month)
- \(C_{pond}\) = Pond salt concentration or halophytes wetland salt concentration (g/L)
- \(A_{wetland}\) = Area of wetland (m²)

3.5.3 Size of evaporation pond (option 1)

The size of the evaporation pond in option 1 is modeled in the adapted evaporation pond modeling of Neetesha Dabeedooal's thesis in 2018.

It is modeled in the winter season and assuming the whole year is in the winter season. This modeling is in the worst scenario. The size of the evaporation pond is undefined because the annual evaporation rate in winter is 509.68 mm (BoM 2019) and the annual rainfall rate in winter is 7436.76 mm (BoM 2019). The difference between the annual evaporation rate and
annual rainfall rate is - 6927 mm. The potential net evaporative loss of - 6927 mm does not exist in figure 17. The annual rainfall rate is higher than the annual evaporation rate. However, the size of the evaporation pond in the summer season is 353 m².

3.6 Design & Salt Mass Balance Evaporation Pond (Option II)

This methodology focusing on solely evaporation pond as the brine disposal method modeled on-farm brackish water reverse osmosis (BWRO) desalination plant at Muresk Institute Farm Project. This methodology is adapted to Neetesha Dabeedooal's thesis in 2018. The evaporation land area is 626 m² for option 2. The land area is calculated by the annual brine inflow, water salt concentration, and potential net evaporative loss. Then, the difference between the annual pan evaporation and the mean annual rainfall is the potential net evaporative loss. The curves below described the area basin (ha) for a 100 ML/year annual inflow. The curves have different water salt concentration levels.

The size of the evaporation pond by the modeled of Neetesha Dabeedooal's 2018 was 15,196 m². The size of the evaporation pond was a decent size for the different seasons. However, this size of the pond was still not good enough for the winter season. In the winter season, the equation of JDA consultant hydrologist and Hauck 2004 is not practical to apply. When the rainfall rate is higher than the evaporation rate, the potential net evaporative loss will be negative and does not show in figure 17. In this worst scenario, the saline water will overflow to the evaporation pond. However, the salty water will be less salt concentration because of the large amount of water solution. The winter season has heavy rain in 3 months (BoM 2019).
Figure 15: Potential Net Evaporative Loss vs. Basin area (ha) for 100 ML/year inflow

(JDA Consultant Hydrologists and Hauck 2004)

Equation 7: Evaporation pond area (Dabeedooal 2018)

\[ A_b = A_{100} \times \frac{Q_i}{100} \]

Assuming negligible leakage

Where:

\( A_b \) = Area of required basin (ha)

\( A_{100} \) = Basin area (ha) for 100 ML/yr inflow (via graph)

\( Q_i \) = Annual design inflow (ML/yr)
3.7 Sizing of evaporation pond (Option II)

3.7.1 Pond depth

The evaporation pond must have a suitable depth to deposit the saline water and for the temporary storage of salt. The water in the evaporation pond will evaporate and the salt will become submerged. The pond depth must be ranged from 0.02 m to 0.5 m (Hauck and JDA Consultant Hydrologists 2004). The depth ranges of the evaporation pond have some results on the evaporation rate. The shallow pond has higher evaporation rates than a deeper pond (Voutchkov 2011).

*Equation 8: Minimum depth (Dabeedooal 2018)*

\[ d_{\text{min}} = E_{\text{ave}} f_2 \]

Where:

- \( d_{\text{min}} \) = minimum depth in m
- \( E_{\text{ave}} \) = average evaporation rate in m/d
- \( f_2 \) = factor that incorporates the effect of the length of the winter

3.7.2 Pond area

The pond area is significant to have an accurate result and capable of stored brine in all seasons.

*Equation 9: Open surface area (Glater 2003)*

\[ A_{\text{open}} = \frac{v_{\text{reject}} f_1}{E} \]

Where:
\( A_{\text{open}} = \) open surface \((\text{m}^2)\)

\( V_{\text{reject}} = \) volume of reject water \((\text{m}^3/\text{d})\)

\( E = \) evaporation rate \((\text{m/d})\)

\( f_1 = \) safety factor

### 3.7.3 Freeboard

The freeboard is also an important component in designing the evaporation pond and it is described as the height above the normal saline water surface (Mickley M. 1993). The parameters that need to considered to avoid spillage of salty water are evaporation rate and rainfall.

**Equation 10: Freeboard (Thandaveswara 2008)**

\[ F_B = \sqrt{C \cdot y} \]

Where:

\( F_B = \) freeboard in feet

\( y = \) depth in feet

\( C = \) coefficient \((1.5)\)

**Table 15: Estimation of freeboard through discharge (Thandaveswara 2008)**

<table>
<thead>
<tr>
<th>Q ((\text{m}^3/\text{s}))</th>
<th>Freeboard ((F_B)) ((\text{m}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.75</td>
<td>0.45</td>
</tr>
<tr>
<td>0.75 – 1.5</td>
<td>0.60</td>
</tr>
<tr>
<td>1.5 – 85.0</td>
<td>0.75</td>
</tr>
</tbody>
</table>
4.0 Results and Discussion

4.1 Results

The calculated wetland area as shown in table 16 in the summer season to the highest salt concentration. Assuming it is in a steady-state condition, the land area of halophytes wetland will be 431 m² in all seasons. The halophytes wetland reject concentration is changing depending on the value of the parameters in equation 1 and equation 2. The winter season has the lowest salt concentration in the halophytes wetland reject or the saline water discharging to the evaporation pond. The salt concentration can define in equation 8.

*Equation 11: Salt Concentration*

\[ C = mV \]

Where;

\( C \) = Concentration (g/L)

\( m \) = Mass of the solute dissolved (g)

\( V \) = Total volume of the solution (L)

For the rainfall data in table 14 and figure 16, Northam has poor results in rainfall. However, winter has still moderate rain at an average of 73.8 mm (BoM 2019). The winter season is the concern for the sizing of an evaporation pond. The flowrate in the halophytes wetland reject in the winter season has the highest rate which is 61973 L/month. Because of the high flowrate of the salty water from the halophytes wetland to the evaporation pond and less evapotranspiration rate, the modeled size of the evaporation pond is designed for the winter season. The modeling of the evaporation pond is adapted to Neetesha Dabeedooal's thesis 2018 in the Microsoft Excel spreadsheet.
Table 16: Calculated data on option 1

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Brine Reject Flowrate (L/month)</th>
<th>Ave. Rainfall (m/month)</th>
<th>Ave. Evapotranspiration (m/month)</th>
<th>Pond Flowrate (L/month)</th>
<th>Wetland Area (m²)</th>
<th>Pond Concentration (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>36004.8</td>
<td>0.0117</td>
<td>0.0469462</td>
<td>20777</td>
<td>431</td>
<td>10.00</td>
</tr>
<tr>
<td>Autumn</td>
<td>36004.8</td>
<td>0.0321</td>
<td>0.02352</td>
<td>38205</td>
<td>431</td>
<td>5.44</td>
</tr>
<tr>
<td>Winter</td>
<td>36004.8</td>
<td>0.0738</td>
<td>0.0084938</td>
<td>61973</td>
<td>431</td>
<td>3.36</td>
</tr>
<tr>
<td>Spring</td>
<td>36004.8</td>
<td>0.0246</td>
<td>0.02394</td>
<td>33071</td>
<td>431</td>
<td>6.29</td>
</tr>
</tbody>
</table>

The evapotranspiration in the summer season at Muresk Institute Farm has 214 mm (BoM 2019). Because of this high evapotranspiration rate, the halophyte wetland is modeled to the summer season. In the summer season, the salt concentration in the wetland is higher than the other seasons because less the volume of saltwater in the wetland. The land area modeling is considered the salt tolerance of the halophyte which is the assumption of 10 g/L.

Table 17: Average seasons rainfall for Northam in mm (BoM 2019)

<table>
<thead>
<tr>
<th>Station</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northam</td>
<td>24.6</td>
<td>11.7</td>
<td>32.1</td>
<td>73.8</td>
</tr>
</tbody>
</table>

Table 18: Average seasons evapotranspiration for Northam in mm (BoM 2019)

<table>
<thead>
<tr>
<th>Station</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northam</td>
<td>157</td>
<td>214</td>
<td>135</td>
<td>68</td>
</tr>
</tbody>
</table>

Notes: (Source: BOM 2019)

Spring – the three transition months September, October, and November

Summer – the three hottest months December, January, and February

Autumn – the transition months March, April, and May

Winter – the three coldest months June, July, and August
4.2 Discussion

The brine disposal method on-farm desalination plant at Muresk Institute Farm, Northam has selected two options. Option 2 is the sole evaporation pond. The evaporation pond is considered as the most cost-effective means of saline water disposal in the inland (Mickey 1995). This is the most common brine reject technique used in the BWRO desalination plant (Mickey 1995). The 626 m\(^2\) land area was the calculated result by the adapted evaporation pond model of Neetesha Dabeedooal's thesis 2018 in the Microsoft Excel spreadsheet to fit stored the saltwater in the winter season.

Then, option 1 is the halophyte wetland + evaporation pond. Option 1 method is the new innovative technology used for saline water disposal. The halophyte wetland by itself has a demand of 431 m\(^2\) land area. And then, the size of a small evaporation pond for option 2 comes up of 353 m\(^2\).

Because of the halophyte wetland, the evaporation pond reduced the size land area from 626 m\(^2\) to 353 m\(^2\) and saved 273 m\(^2\) of land area. In these results, the halophyte wetland has area reduction benefits. The halophyte wetland land area was determined by the mathematical methods equation 3 in the summer season. Because the summer season has the highest salt concentration to the other season, then halophyte wetland land area was 431 m\(^2\) for all seasons.

However, option 1 is only modeling and required further study. The halophytes wetland required ample time preparation before it becomes operational because the old man saltbush should be matured until becoming salt tolerance (APACE 2019).

The halophytes wetland has valuable benefits to the farmers. However, preparation and set-up are stressful and time-consuming. It should have a minimum of 6 months advance to set-up than the other equipment in the project site because the halophyte plant must be matured in
the operational condition. The old man saltbush is not salt tolerance when it is in the germination and growing period (ANBG 2019).

The BWRO desalination plant producing 500 L/hr. of drinking water to supply the water demand of the farmers.

The decentralized water system in the Muresk Institute Farm, Northam will be the role model project to the other site in the Wheatbelt region. Murdoch University is the leading researcher of the upcoming on-farm desalination project funded by the Water Corporation and Wheatbelt - Department of Regional Development.

5.0 Conclusion

The halophyte wetland + evaporation pond was the suitable brine disposal method option for the on-farm desalination plant project at Muresk Institute Farm, Northam. The halophytes wetland has an area reduction benefits to the evaporation pond.

The old man saltbush was the modeled halophyte plant in this thesis. It is potentially used for livestock grazing plant and the seeds are for food sources of the aboriginal people. The deposited salt in the evaporation pond as the parallel income of the farmer by harvesting and selling it to the salt market for industrial purposes. The harvested salt can be estimated to 10 t in every summer season.

The on-farm desalination plant project at Muresk Institute Farm, Northam is the solution to the dramatic water scarcity problem in Northam and Wheatbelt region.
6.0 Recommendation / Future Work

6.1 Halophyte Options

It is suggested to investigate these three recommended native in which is the most option to use as a halophyte plant in the wetland. Execute experimental research of the specific site to find the salt tolerance and crop factor, to improve the specific site parameters, and the application of the TBL to the following native plants: salt marsh rush, tall wheatgrass, and river saltbush. This will provide valuable facts on the relative cost and benefits of each halophyte plant.

Salt marsh rush
(Juncus Kraussii)

Tall wheatgrass
(Thinopyrum ponticum)

River Saltbush
(Atriplex amnicola)

6.2 Resource Recovery Options

It is recommended to develop the resource recovery options in the halophyte wetland and evaporation pond for the alternative source of income of the farmers. The halophyte plants have broad applications and benefits. It can use as human food, livestock grazing plant, medicine, biofuel and alike. In the evaporation pond, it can use as aquaculture, salt
harvesting, brine shrimp and others. It is recommended to develop the resource recovery options in the halophyte wetland and evaporation pond for the alternative source of financial income of the farmers. The halophyte plants have broad applications and benefits. It can use as human food, livestock grazing plant, medicine, biofuel and alike. In the evaporation pond, it can use as aquaculture, salt harvesting, brine shrimp and others.

\[\text{Figure 16: Resource Recovery Options}\]
References


Emms, Jason. SARDI. December 2008.


Revell, Dean and Emms, Jason. *Perennial forage shrubs — from principles to practice for Australian farms*. Future Farm Industries CRC. 2014.


Sawkin, D N, and Department of Agriculture and Food. “Landscapes and soils of the Northam district.” 2010.


https://www.nptel.ac.in/courses/105106114/pdfs/unit21/21_1.pdf.


