Managing desalination brine in inland agriculture

Options for the Murray-Darling Basin

ONE BASIN CRC

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Acknowledgement of Country

We acknowledge and pay respect to the Tradition Owners of the Murray–Darling Basin and their Nations. We pay respect to the Traditional Owners of the lands and the waters upon and around which our organisations are situated. We acknowledge their deep cultural, social, spiritual, environmental and economic connection to their lands and waters. We pay respect to their Elders – past, present and future.

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Citation: Mullins, M, Reeve, P, Leonard, M 2025, 'Managing Desalination Brine in Inland Agriculture: Options for the Murray–Darling Basin', Report, One Basin CRC, Australia.

Document status record

Issue No.	Date of issue	Description	Signatures/Authors	Approved
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1 Executive summary

The Murray Darling Basin (MDB), Australia's largest river system and agricultural region, is facing a hotter, drier climate. It is anticipated that water scarcity will increase. For the basin's irrigated agriculture sector, this means higher water prices and reduced reliability, especially during times of drought. One strategy to manage the risks posed by increasing water scarcity is to augment traditional surface water supplies with alternative water sources. Brackish groundwater represents the largest alternative water source in the basin, with an estimated 2000 GL thought to be available for sustainable use. Desalination has the potential to unlock this underutilised resource, but there are significant challenges which need to be overcome to achieve this end. One of the most significant challenges to adoption is how to safely and cost effectively dispose of brine, the concentrated, saline waste stream. This report explores the key brine disposal methods, evaporation ponds and aquifer injection, which have the potential to be suitable for agricultural contexts within the MDB. The benefits and costs of different brine disposal technologies, and associated barriers to their adoption, are explored with the aim of assisting potential desalination end-users to better understand the available technologies.

Evaporation ponds are the most common disposal method for inland desalination plants. They require substantial land area, proper design, and maintenance to mitigate environmental risks. Aquifer injection, a lesser used disposal method, requires detailed hydrogeological studies to ensure the receiving aquifer can accommodate the brine without causing environmental degradation.

The report discusses the challenges and opportunities associated with the adoption of these methods, including geographical factors, technical considerations, environmental compatibility, economics, and regulatory requirements.

This report highlights the varied regulatory requirements across jurisdictions in the MDB, and the benefits that could be derived from greater alignment. While the identified barriers represent areas that could be enhanced to enable the broader adoption of desalination technologies across the MDB, there is significant potential to increase the utilisation of brackish groundwater now. This report could be of use during the initial stages of planning for brackish groundwater desalination, to identify which methods of brine disposal could be most viable in the geographic region of operation. Further work could be devoted to better characterising the costs of inland brackish groundwater desalination, and to the implementation of demonstration sites in different geographic regions of the MDB.

2 Introduction

The Murray-Darling Basin (MDB) is Australia's largest river system and largest agricultural region, encompassing an area of over 1,000,000 km^2, spanning significant areas of Queensland, New South Wales, South Australia and Victoria, as well as the whole Australian Capital Territory. The MDB Authority (MDBA), a statutory agency in the Australian Government, was formed in 2008 in the latter half of the millennium drought to manage and plan the MDB's water resources. The MDBA released the MDB Plan (often referred to as the Basin Plan), which passed Australian Parliament in 2013. The Basin Plan aims to restore the MDB to a healthier status, that is sustainable for its continued use. Two key elements of the Basin Plan are sustainable diversion limits (SDLs), and water resource plans. SDLs and water resource plans limit how much water can be used in the basin by communities, farmers, and industries, to ensure water use that is sustainable for the environment. The Basin Plan requires that the MDBA maintains a register of water use, which is reported annually. Basin state governments and the federal government also play key roles in ensuring limitations are adhered to.

The MDB has a water storage capacity of approximately 22 million megalitres, which is was at 75% storage capacity (or 16.6 million megalitres) in 2024 [3]. In 2004-05, 83% of water consumed the MDB was used by the agriculture industry, followed by the water supply industry (13%), and households (2%)[4]. In 2020-21, the MDB accounted for 60% of irrigated land across Australia, and 62% of Australia's water use for irrigation (or 4.8 million megalitres) [5]. The largest use of water for irrigation in the MDB was cotton (25.25%), fruit trees, nut trees, and berry fruits (16.51%), pastures and cereal crops used for grazing (15.34%), cereals for grain or seed (12.08%), and rice (10.94%) (followed by grapevines, pastures for hay and silage, vegetables, other crops, and nurseries) [5].

Of the 5 million megalitres of water used in the MDB in 2020-21, 14% (or 700,000 megalitres) was sourced from groundwater, while 85% (or 4.3 million megalitres) was sourced from surface water resources, including rivers, creeks, lakes, and dams [5]. However, this fraction of water use increases significantly for dry years (particularly in droughts) as the availability of surface water resources decrease [6]. An example of this occurred in 2019, where water storages in the Gwydir, Namoi, and Macquarie catchments dropped to below 10% of their capacity, which led to supply issues for surrounding towns [6]. Subsequently, there was a major spike in the drilling of new bores, and groundwater use [6].

Brackish groundwater (total dissolved solids ranging from 1,000 to 15,000 mg/L) represents a significant proportion of the available groundwater resource in the MDB and indeed the largest alternative water source in the MDB, with an estimated 2000 GL/annum of sustainable yield thought to be available [7].

Worldwide, droughts and long-term climate change are pushing the agricultural industry to explore water resource alternatives, which includes desalination technology. Desalination is a process that removes dissolved salts from water. There are several different desalination technologies, which can be categorised as membrane-based or thermal-based. The most prominent membrane-based technology is reverse osmosis (RO), which is the most common desalination technology used in Australia, both for brackish water desalination and seawater desalination. RO desalination works by using a pressure to push water through a semipermeable membrane, causing water molecules to pass through, while rejecting charged ionic species and relatively heavy compounds [8]. This produces a low total dissolved solids (TDS) permeate stream, leaving a high-TDS concentrate stream, which is often referred to as brine [8]. RO operates at ambient temperature, and requires energy to pump water through the membrane [8]. Brackish water reverse osmosis plants are relatively small scale compared to seawater reverse osmosis plants, and are often used for power stations, mining industries, and food and beverage industries. Seawater reverse osmosis plants can be observed in most Australian capital cities, such as the Adelaide Desalination Plant, which was used to supplement use of the River Murray, especially during drought conditions[8]. Thermal-based technologies include, most commonly, multistage flash distillation, mechanical vapour compression, and multi-effect distillation. Thermal-based technologies are utilised less in Australia, due to their comparatively higher cost, though there are still some examples of this, such as the Mount Piper Power Station, which uses mechanical vapour compression to reduce the volume of brine produced from RO desalination [8].

Internationally, desalination in the agricultural industry has seen a significant increase over the last decades. High-use areas of desalination for agriculture include southeast Spain, northern Mexico, and Israel [8]; these high-use areas of desalination technology are correlated with using advanced irrigation systems for high value crops. It is expected that further improvements in desalination technology will result in increased usage of desalination technology for agriculture. Despite the increased uptake of desalination technology, desalinated water still only accounts for less than 2% of water sourced for irrigation worldwide [8].

Australia has seen limited use of desalination technology in agricultural contexts to-date. This is largely due to economic factors, as river water from the MDB can cost as little as $0.10/kL-$0.65/kL (higher-end of cost during droughts), while desalinated water typically costs over $1.00/kL [8]. For this reason, desalination technology for agriculture in Australia has greater applicability to high-value crops (e.g., almonds, grapevines) and protected cropping (e.g., greenhouses), as high profitability can offset high desalination costs. Key examples of desalination for agriculture in Australia include:

- Costa Group, Australia's largest horticultural company, which implemented a brackish water RO plant in their Guyra glasshouses, NSW, which have, at peak, a 302,400 m^2 growing area [8]. The RO plant had a capital cost of $375,000, and has a production rate of 1 ML/day for negligible operational costs [8]. It requires 1,230 kWh/ML, and has a recovery rate of 70% [8]. The desalination brine is disposed of by mixing brine with wastewater from filter backwashing, which is then used for pasture irrigation [8].
- The Chinchilla Beneficial Use Scheme desalinates water from Condamine River, QLD, to support irrigation along the river, as well as supplementing the Chinchilla town's water supply [8]. The seawater RO plant had an estimated capital cost of $156 million, and has a production rate of 89 ML/day for an operational cost of $1.90/kL (not including brine disposal) [8]. Brine management alone is estimated to cost $4.00/kL, which includes further brine concentration (to decrease volumes) for subsequent disposal in evaporation ponds [8].
- Sundrop Farms is a developer, owner, and operator of greenhouses that produce tomatoes for Coles in Port Augusta, SA [9]. The greenhouses feature an integrated energy system that uses solar power to thermally desalinate seawater sourced from the Spencer Gulf [8]. Brine is either used for cooling, or is discharged back into the gulf [8]. The entire facility was constructed for an estimated cost of $200 million, and produces 1.2 ML/day, for 17 million tonnes of produce per year [8].

The use of desalination technology is generally licensed by state environmental protection authorities, depending in the scale of the plant. The brine disposal method is also typically assessed by the state environmental protection authority.

3 Brine disposal

Brine is a by-product of the desalination process, and is water characterised by a high salinity concentration. Brine water quality, which is often defined by its TDS concentration, varies with the percent recovery (i.e., as the fraction of desalinated water recovered from feedwater increases, the TDS concentration of the brine increases), the quality of the feedwater that is being desalinated, the addition of any treatment chemicals, and the type of desalination technology used [10]. This means that the origin of the feedwater has a major impact on the quality of the brine. For example, brine from brackish desalination plants will generally contain less sodium, chloride, calcium, magnesium, and sulphate than brine from seawater desalination plants [11]. It is important to consider brine composition when selecting a brine disposal method, due to the potential environmental and health impacts caused by chemicals within the brine.

This section explores a range of factors relevant to brine disposal including the methods available for disposal, geographical constraints, technical considerations, and environmental considerations. Additionally, the costs and regulatory requirements associated with brine disposal are considered.

3.1 Disposal methods

There are a limited number of disposal methods, with evaporation being the most common method. Aquifer reinjection is an alternative method that is feasible under some conditions. Lastly, brine treatment is briefly explained.

3.1.1 Evaporation ponds

Evaporation ponds are the most common brine disposal method used in Australia for inland desalination schemes [8]. Evaporation is used to dispose of brine via discharge into a shallow evaporation pond, where it is directly exposed to sunlight. Water is evaporated from the brine, and precipitated salt remains, which is removed as necessary. The evaporation rate of a pond is dependent on its size (i.e., surface area and depth) and the local climatological conditions (i.e., solar radiation, temperature, and humidity) [12]. Ponds should be constructed such that lining on the base of the pond will minimise or prevent brine from leaking into the surrounding environment.

Brine minimisation, including zero liquid discharge, is an approach in desalination that aims to produce a minimal amount of brine, using various technologies. The total cost of brine minimisation, coupled with smaller evaporation lagoons, has the potential to be more cost effective than normal recovery RO and large evaporation lagoons.

This method is utilised by salt interception schemes. Salt interception schemes were designed and constructed to combat salinity in the River Murray in the late 1960s, and are still a central component of salinity management strategies today [13]. Typically, schemes use a bore and pump system to intercept and extract saline groundwater and irrigation effluent and pump it into either natural or constructed evaporation ponds away from rivers

[13]. Commercial operators harvest salt at some of the salt interception scheme locations, although the proportion of salt harvested is comparatively low compared to the total salt generated by schemes [13].

SOWT analysis of evaporation ponds for brine disposal

Strengths – internal factors	**Weaknesses** – internal factors
• Evaporation ponds provide an effective and well understood disposal method. • Generally, there is minimal operational expenditure required for ongoing operation. • Evaporation ponds can be readily scaled to suit the desalination application.	• Evaporation ponds can require a significant amount of land. In agricultural areas, where land is at a premium, sufficient space may not be available. • Design expertise is required to ensure the evaporation pond is appropriately sized to balance evaporation with inflow. • Precautions have to be taken to minimise the potential for environmental harm, for example through siting the pond away from flood zones, using an appropriate liner, and ongoing monitoring to detect leaks.
Opportunities – external factors	**Threats** – external factors
• The development of brine minimisation technologies, and the associated lowering in desalination lagoon size, may increase the overall cost-effectiveness of desalination. • Evaporation pond design improvements could help to mitigate environmental risks. • As salt and other minerals are concentrated in a small area, there is an opportunity to reclaim these materials.	• If managed incorrectly, evaporation basins could lead to land degradation. • Public perception and social acceptance could be problematic if there are concerns around land degradation. • Regulatory changes, e.g., increased monitoring or liner material requirements, could increase the capex and opex associated with construction and operation. • Evaporation ponds work less effectively in high rainfall areas.

3.1.2 Aquifer injection

Aquifer injection is particularly well suited to small, inland desalination plants where brine discharge rates are low [8]. Aquifer injection uses an injection well to dispose of brine into shallow or deep aquifers. The water quality of the receiving aquifer should not be degraded by the injection of brine, and it is thus a requirement that the brine should be of similar or better quality than the receiving aquifer [8]. To prevent contamination of adjacent pristine water resources, the receiving aquifer should be separated from other aquifers by an aquitard. Aquifer injection is only feasible under specific conditions, can be costly, and is therefore generally used where there are no suitable alternatives [14].

There are limited examples of brine disposal via aquifer injection in Australia. In contrast, deep well injection is a predominant method of waste disposal in the United States [12]. Deep well injection is used in the United States instead of shallow well injection, such that brine injected deep underground is less likely to contaminate surface and drinking water resources [8]. This, however, depends on the region, as some areas in the MDB have hypersaline shallow aquifers, with relatively fresh aquifers beneath.

SWOT analysis of aquifer injection for brine disposal

Strengths – internal factors	**Weaknesses –** internal factors
• Unlike evaporation basins, minimal land is required for aquifer disposal of brine, which could be advantageous in regions where agricultural land is at a premium. • Aquifer injection can be an efficient disposal pathway that is not impacted by climatological or seasonal factors. • The risks of surface-level environmental impacts are minimised by disposing brine underground.	• Awareness of this method in the Murray Darling Basin is limited, meaning it may not be considered during the planning and design of desalination systems. • Hydrogeological expertise is required to characterise whether local conditions are suitable for this method. • The hydrogeological information required to make decisions around the viability of aquifer disposal may be limited in some regions, meaning further investigation prior to an investment decision may be required.
Opportunities – external factors	**Threats –** external factors
• The utilisation of aquifers that are already saline and have limited scope for beneficial use. • The potential for longer-term disposal of brine: e.g. there is no need for disposal of accumulated salt. • The potential to lower the capital costs required to implement brackish groundwater desalination.	• Public perception and social acceptance could be problematic if there are concerns around, e.g., contamination of the environment. • Poor water quality, e.g., from dissolved iron, could cause clogging around the injection site, increasing operational costs and in the worst case causing system failure. • Regulatory requirements could impede the development of aquifer injection in some jurisdictions.

3.1.3 Other brine disposal methods

Brine can be disposed via discharge into pre-existing sewage systems and the ocean. Ocean discharge is commonly used by seawater desalination plants. Both methods are relatively cost effective but are geographically constrained: sewage systems do not exist in most rural, agricultural settings, and ocean discharge becomes less economically feasible with increasing distances inland. As these methods are generally not applicable in the MDB, they are not considered in this report.

Brine can be used for irrigation of crops or vegetation under specific crop, brine, and soil conditions. For instance, there are some emerging approaches in remote northern regions of South Australia, where unlined evaporation/infiltration basins are used with salt tolerant vegetation. These are site specific taking into consideration the source water and discharged salinity, any occurrence of shallow groundwater and the receiving soils. SA Water has developed a number of these systems at Oodnadatta (a licenced desalination plant), Marla and Marree (personal communication, Timothy Gubbin, 5 July 2024)., Given the scope of this report, the use of brine for irrigation is not considered, as feedwater is being desalinated for irrigation, and brine would therefore not be applicable to the selected crops.

Summary of other brine disposal methods:

- Ocean and sewage discharge are geographically out of scope in the agricultural landscapes of the MDB as connections to the ocean and sewage systems are unviable.
- While emerging methods such as the irrigation of salt-tolerant plants are promising, their applicability in agricultural settings is limited and further research and development is required.

3.2 Geographical constraints

Evaporation ponds are suited to arid regions with high temperatures, high evaporation rates and low rainfall. The effectiveness of evaporation ponds is dependent on the evaporation rate, which is dependent on local climatological conditions [14]. To estimate the effectiveness of evaporation ponds in the MDB, existing evaporation and rainfall data can be used [12]: mean annual evaporation and rainfall data for the MDB is readily available online. The difference between the mean annual rainfall and the mean annual evaporation can be used as an indicator of how surface water levels will increase or decrease across the MDB on average, as shown in Figure 1 (a). Note, as evaporation data is representative of pan evaporation, evaporation values are first multiplied by a pan coefficient of 0.70 [15]. Furthermore, as evaporation data represents the evaporation of freshwater, evaporation values are multiplied by 0.70 to account for the reduced evaporation rate of brine [12]. Other geographical constraints for evaporation ponds include level terrain and land availability.

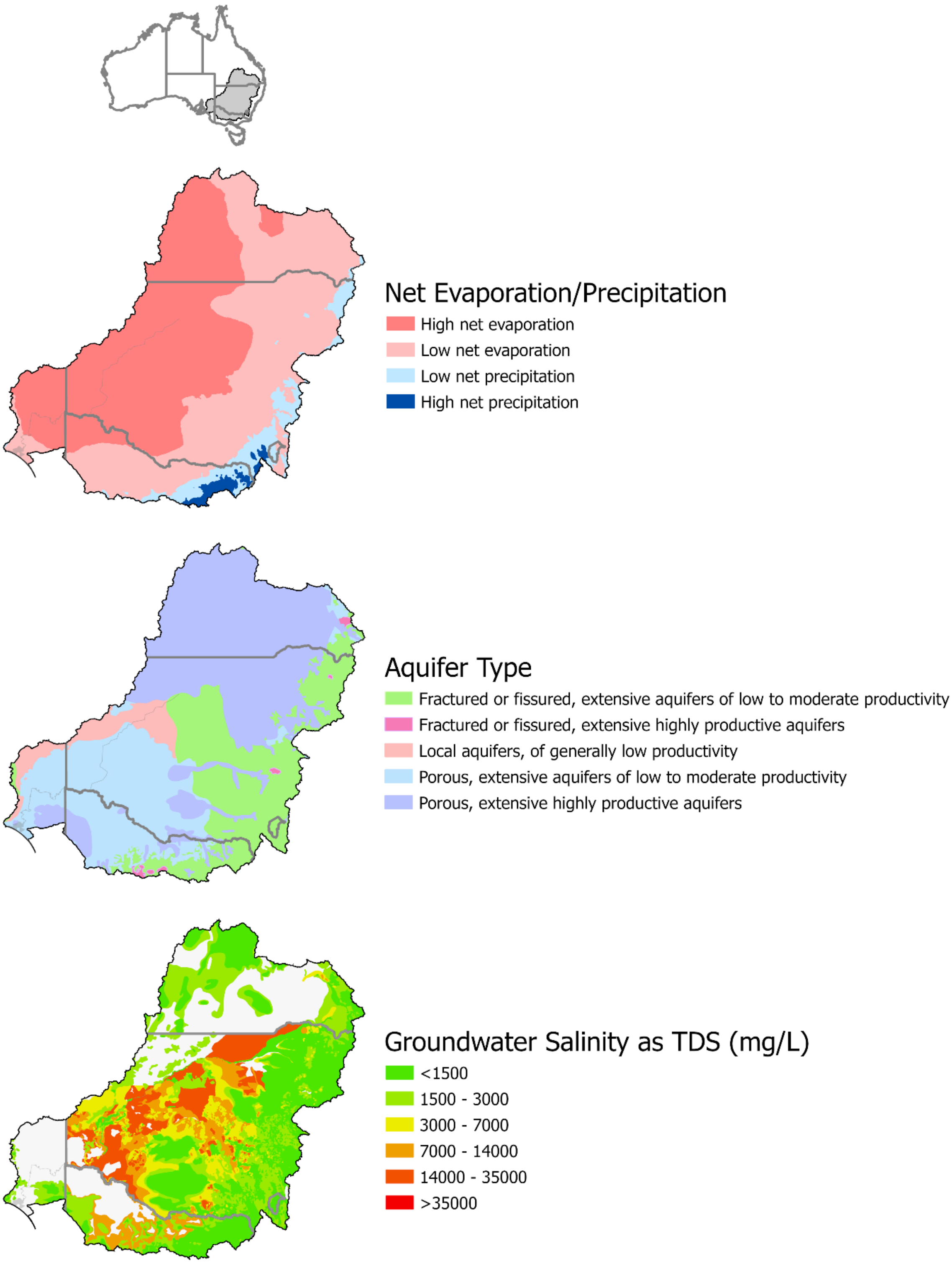

Figure 1. Maps of the Murray-Darling Basin showing the (a) net evaporation and precipitation (Bureau of Meteorology, 2006), (b) the types of aquifers and their relative productivity [1], and (c) regional water table salinity, where data is available [2].

Aquifer injection requires an aquifer that has a salinity which is equal to, or greater than, the salinity of the brine to ensure environmental degradation is avoided [8]. Groundwater data from well water samples is available for some regions online, and can be used to map the salinity of groundwater for different aquifers within the MDB. Lithological records from well drilling can be consulted to identify aquitards around aquifers intended for injection, and hydrogeological and environmental studies should be conducted to ensure that brine doesn't contaminate surrounding aquifers and surface waters. The aquifer must also have the capacity to receive the volume of brine produced over the intended life of the desalination plant, which makes more porous formations (such as limestone) better suited [16]. Figures 1(b) and 1(c) show the regional aquifer types (where porous formations are desirable), and the regional water table salinity (where higher salinity is desirable) respectively, as a regional guide to suitable locations.

Summary of geographical considerations:

- Data regarding evaporative conditions, required for designing an evaporation pond, is readily available data.
- Data at a fine enough scale is not consistently available for all regions in the MDB, meaning it may be necessary to invest in preliminary field sampling campaigns to collect the necessary data, such as water quality and aquifer porosity and permeability.

3.3 Environmental and regulatory considerations

Brine entering the environment can be harmful due to any chemical residuals from the desalination process, the presence of concentrated elements and compounds (e.g., salinity, boron) , along with the temperature of the brine itself [11]. These factors are dependent on the desalination process and feedwater [10]. Under certain conditions, chemicals may be required to aid in the efficient operation of desalination equipment. Such chemicals can include antiscalants, coagulants, reducing and oxidising agents, flocculants, and strong acids or bases [11]. While inland RO desalination plant brines have high salinities, they typically do not produce brines with residual chlorine, heavy metals, or high temperatures [10]. Therefore, in an agricultural context, the main impacts of desalination brine disposal into the environment are increased salinity in receiving groundwater, surface water, and soils, and the disposal of chemical substances (pre-treatment and membrane cleaning) [11]. Low recovery desalination can minimise or eliminate the need for chemical addition, making this approach compatible with approaches where brine is discharged to the environment via aquifer injection.

Evaporation ponds have the potential to contaminate groundwater resources if not managed appropriately [17]. This can occur via leakage through lining (e.g., if clay lining cracks), or overflows (e.g., if flooding occurs) [17]. For example, in Portland, Victoria, the effectiveness of evaporation ponds to dispose of smelter wastewater was investigated. The study found that the observed drop in pond level was primarily due to seepage, and a nearby wetland had been contaminated as a result [18]. The type of lining used plays a significant role in the likelihood of seepage [17].

Seepage monitoring can be useful to detect leaks in pond lining, and there are several methods of monitoring. Single-lined ponds, while not allowing for the detection of leaks prior to environmental contamination, can be monitored with external wells to enable early detection to minimise environmental harm [12]. Double-lined ponds allow for the detection of leaks prior to any environmental contamination, as the pond base can be designed such that leaks through the first liner will drain into a monitoring sump, where the leak will be detected [12]. This allows for repairs to be made to the pond prior to seepage through the second liner [12]. Where ponds are too large to effectively drain to a sump, moisture detectors can be placed between the two liners [12]. Double-lined ponds are recommended, particularly where evaporation ponds are constructed near environmental assets such as pristine aquifers.

In order to not degrade the quality of the aquifer used for brine discharge, the ambient groundwater in the receiving aquifer should be of poorer quality than the water quality of the brine being discharged. A sound understanding of the hydrogeological system is needed to manage the risk of brine disposal causing harm to surrounding environments [8, 19].

Governments, often through environment protection agencies, impose a range of legislative requirements to manage risks to the environment. Five state and territory governments, along with the Commonwealth Government have jurisdiction over the area of the MDB. Table 1 includes legislation and guidelines associated with the regulation of desalination plants and the use of evaporation ponds. Table 1 highlights that there is significant variation in legislation relevant to brackish groundwater desalination across MDB jurisdictions.

Table 1: Summary of legislation and guidelines relevant to the conduct of desalination, the use of groundwater, and to the disposal of desalination brine via evaporation basins and aquifers, for each Murray-Darling Basin jurisdiction*. This table has been partially adapted from Barron [8].

Jurisdiction*	Operation of a desalination plant	Groundwater use	Evaporation pond	Aquifer discharge
New South Wales	• The *Environmental Planning and Assessment Regulation 2021* classifies a desalination plant as a 'designated development' when the plant has an intended processing capacity of more than 2,500 persons equivalent capacity or 750 kL/d, or, if the plant is within an environmentally sensitive area, more than 20 persons equivalent capacity or 6 kL/d.	• The *Water Management Act 2000* regulates use of the state's water resources including groundwater • Water Sharing Plans are statutory plans that set extraction limits and rules for water access, available water determinations, account management and trade • Aquifer Interference Policy provides guidance on the requirements for obtaining water licences for aquifer interference activities. • The *Water Act 1912* regulates the construction of certain bores that are not covered by the *Water Management Act 2000*.	• The construction of evaporation ponds is allowed [8]. • Evaporation ponds relating to coal seam gas drilling and hydraulic fracturing activities are prohibited. • The construction of evaporation ponds is allowed [8].	• The Aquifer Interference Policy sets criteria for assessing the impact of an aquifer interference activity. Deep well injection would be considered an aquifer interference activity and would therefore be assessed under this policy. • Section 120 of the *Protection of Environment Operations Act 1997* prohibits the pollution of waters. This may limit opportunities for aquifer disposal of brine.
Queensland	• The *Environment Protection Act 1994* and *Environmental Protection Regulation 2019*, apply when the desalination plant produces greater than 500	• "Water Planning Act 2000 provides authority to take or interfere with water (including groundwater) • Planning Act 2016 authorises	• The construction of evaporation ponds is allowed [8].	• The *Environment Protection Act 1994* and *Environmental Protection Regulation 2019* allow release of brine (from water treatment) into the

Jurisdiction*	Operation of a desalination plant	Groundwater use	Evaporation pond	Aquifer discharge
	kL/d of permeate.	construction of groundwater wells” [8].		environment, including aquifers, under prescribed conditions.
South Australia	• *Environment Protection Act 1993* 8 (6a), when the desalination plant produces greater than 200 kL/d of permeate. • If the *Environment Protection Act 1993 8 (6a)* applies, then the *Environment Protection Regulations 2023* provide a number of encouragements, through the provision of fee discounts, for best practice for construction and operation to be followed. • *For desalination plants below licence thresholds, General Environmental Duty as per Section 25 of the Environment Protection Act 1993 applies and requirements under the Environment Protection Water Quality Policy 2015*	• Landscape South Australia Act 2019 regulates the use of water resources, including groundwater. • Significant water resources prescribed under the Landscape South Australia Act 2019 are required to have a Water Allocation Plan (WAP) to define how that resource may be used. • Extracting water from a well requires a licence from DEW if the water resource is prescribed. • Non-prescribed water resources are regulated through statutory regional landscape plans and water affecting activities control policies.	• Where a desalination plant meets the criteria of clause 8(6a) of Schedule 1 Part A of the • *Environment Protection Act 1993*, regulation 28 clause (2h) of the *Environment Protection Regulations 2023* applies and specifies the requirements for desalination plant wastewater discharged into a wastewater lagoon.	• A permit is required for the draining or discharging of water directly or indirectly into a well under section 104 of the Landscape South Australia Act 2019, which regulates how a Water Affecting Activity may be undertaken, including the drainage or discharge of water into a well. • However, if the water to be drained or discharged is sourced from a surface water capture area greater than one hectare within the Adelaide metropolitan area or specified areas of the City of Mount Gambier, or the water to be drained or discharged has undergone antibiotic or chemical water treatment with a discharge volume greater than 50 kilolitres per day, an authorisation

Jurisdiction*	Operation of a desalination plant	Groundwater use	Evaporation pond	Aquifer discharge
				issued by the Environment Protection Authority under section 40(1) of the Environment Protection Act 1993 is required instead. • Water Allocation Plans • Water affecting activities control policies
Victoria	• The *Environment Protection Regulations 2021* applies when the desalination plant is designed to process more than 1000 kL/d of feed water.	• Water Act 1989 regulates access to groundwater and construction of bores.	• The construction of evaporation ponds is allowed [8].	• Section 76 of the Water Act 1989 outlines the conditions under which underground disposal may be approved.

* For the purposes of this table, the Australian Capital Territory is not considered because of the low levels of agricultural productivity within this region.

While evaporation ponds are banned for petroleum production and coal seam gas activities in NSW and Queensland, this disposal method is still permitted in an agricultural context. Each state has their own requirements for pond design, construction, and operation. For example, the Environment Protection Authority South Australia (EPA SA) have published the Wastewater Lagoon Construction Guidelines for the construction of wastewater lagoons:

- To ensure brine in the pond cannot intersect the underlying water table.
- To ensure they are not liable to inundation or damage from flood waters.
- To ensure that brine does not overflow into waters or onto land where they can enter waters.
- With a liner that meets permeability criteria standards.
- With a proof-rolled and smooth subgrade.
- With an appropriate seepage detection system.

There are other requirements depending on the category of liner used. For example, EPA SA asks that proposals for evaporation ponds associated with desalination plants that meet their licence threshold are submitted for assessment, to demonstrate that the design meets environmental protection standards. Other environmental protection authorities may need to be consulted for requirements specific to desalination brine disposal, as most available information indicates disposal for coal seam gas activities.

In many contexts, the definition of waste is clear, for example, wastewater that contains chemicals, pathogens or temperatures that could pollute. However, in relation to brine, the variety of contexts makes the consistent definition of waste unclear. For example, the Australian Guidelines for Water Recycling: MAR (2009) states that MAR "is not a method for waste disposal", whereas in a different context, the Queensland *Environment Protection Act 1994* and *Environmental Protection Regulation 2019* allow release of brine from water treatment into the environment, including aquifers, under prescribed conditions.

More broadly, the discussion around aquifer reinjection is often unclear. For the case of reinjection of desalinated brackish groundwater, the salt is not surplus to what already existed in the environment. In South Australia, aquifer disposal may be permitted under the commitment to not cause 'environmental harm'. Salinity of the ambient groundwater and that of recharged water is one of the primary parameters used to determine whether environmental harm is likely to occur: the salinity of the recharged water must be lower than the salinity of the ambient groundwater. While this approach results in a similar or lower salinity in the aquifer used for recharge, salt has nonetheless been transferred from one area of the environment to another. Hydrogeological evaluation is required to determine the impact of this action. In other contexts of managed aquifer recharge schemes, it may be that the permeate from the desalination is desired for storage and reuse at a later point (and that the brine is disposed via other means, e.g. evaporation pond).

Summary of environmental and regulatory considerations:

- Both evaporation ponds and aquifer disposal both have the potential to cause environmental contamination if they are not appropriately managed.
- While environmental regulation exists in all MDB jurisdictions, interpretation can be complex and this is compounded by variations in regulatory requirements between jurisdictions. Careful attention to detail is required.
- The consistent definition of what constitutes 'waste', when considering desalination brine, can be unclear.

3.4 Disposal costs

The cost of brine disposal can vary significantly depending on the method chosen, local site conditions, and environmental compliance requirements. Two primary disposal options considered for inland desalination are evaporation ponds and aquifer (injection well) disposal. Each method has distinct cost drivers and operational constraints, and care must be taken when comparing them directly.

3.4.1 Evaporation Ponds

The cost of constructing and operating evaporation ponds is highly variable and depends on several site-specific factors. Primarily, these factors are the surface area required, which is influenced by both brine volume and the local evaporation rate, and the level of environmental protection mandated by regulatory authorities. Major cost components typically include land acquisition, earthworks, pond liners (ranging from clay to double-layered geomembranes), fencing, and ongoing operation and maintenance. Due to the scale and complexity of these requirements, evaporation ponds are generally the most expensive brine disposal option available for inland desalination schemes.

International estimates provide a broad range of indicative costs. For example, Panagopoulos *et al.* [11] report disposal costs of approximately $6.02–$18.45 per kilolitre of brine, assuming land costs similar to those in Australia. In a more infrastructure-focused estimate, Osmoflo [8] report capital construction costs of $70–$100 per square metre for lined evaporation ponds.

In the Australian context, costs can vary further depending on land value, regulatory stringency, and climatic conditions. Publicly available estimates for proposed evaporation pond projects in Australia are summarised in Table 2. These estimates demonstrate the influence of evaporation rate, liner type, and environmental safeguards on the total cost per hectare. For instance, in regions where environmental protection measures are more stringent, such as requiring double-liner systems with leak detection or construction above sensitive aquifers, costs may increase substantially. An older estimate cited in Sanciolo *et al.* [20]suggests that double-lined ponds can cost between $54,000 and $1.1 million per hectare, depending on design complexity and regulatory context.

These variations highlight the importance of considering local environmental and regulatory requirements when assessing the feasibility and cost of evaporation ponds for brine disposal.

Table 2: A selection of Australian desalination evaporation pond cost estimates.

Pond type	$/ha	Location	Year	Reference and notes
Clay lined	25,000	Darling Escarpment, WA	2011	[21]; 2 m annual evaporation
Membrane lined	135,000	Darling Escarpment, WA	2011	[21]; 2 m annual evaporation
Dual layered geomembrane, geofabric underlay and a confining earthen layer	295,000	Carnarvon, WA	2017	[22]; associated civil works included in estimate
Land and construction cost for a 1 ha membrane lined pond, considering a range of recovery scenarios from 75-99%	540,000-610,000	Horsham, Vic	2024	[20]; Cost information used in estimation was supplied by a local water authority

3.4.2 Aquifer Injection

The cost of aquifer injection is largely determined by well depth, which affects both drilling costs and required materials. Panagopoulos *et al.* [11] report that deep well injection systems in the US cost approximately $0.99–$4.87 per kilolitre of brine. However, these figures likely represent the upper end of the cost spectrum, as shallow well injection, which has greater relevance in some areas of the Murray–Darling Basin, would be expected to cost less. It is important to note that deep injection wells used in the US may not be directly applicable in Australia due to differing geological and regulatory conditions.

3.4.3 Comparison

Brine disposal costs are often reported in terms of dollars per kilolitre of brine, but this can obscure the true impact on the overall cost of desalinated water. In practice, the total cost to users depends not only on the method of disposal, but also on the system's recovery rate: the proportion of feedwater converted into usable freshwater. Lower recovery rates produce more brine for the same amount of product water, increasing disposal volumes and associated costs. Conversely, higher recovery reduces brine volume but may require more complex or energy-intensive treatment. As such, comparing disposal methods on a per-kilolitre-of-brine basis does not necessarily reflect their effect on the final cost of water delivered for agricultural use.

To provide a clearer comparison, Table 3 presents modelled results generated using the Brackish Water Desalination Cost Calculator (https://brackish.au/app/calc/). The scenarios assume a desalination plant located in Loxton, South Australia, treating feedwater with a TDS concentration of 12,500 mg/L. The plant is powered by the electrical grid and assessed over a 20-year cost recovery period. Three plant sizes were considered, 0.1, 1, and 10 ML/day, and two brine disposal methods were compared: evaporation ponds (at 60% recovery) and aquifer injection (at 30% recovery). A full list of assumptions can be found in the Methodology Report for Cost Calculator of Desalination of Brackish Groundwater for Agricultural Use (link).

The results show that aquifer injection leads to a lower levellised cost of water (LCOW) across all plant sizes. For example, at a scale of 1 ML/day, the LCOW is estimated at $1.10/kL for aquifer injection, compared to $1.70/kL for evaporation ponds. Despite the fact that lower recovery results in greater brine volumes requiring disposal, aquifer injection remains less expensive due to its lower capital and operational costs. These include savings on land acquisition, earthworks, and liner systems, which are major cost components for evaporation ponds.

Both disposal methods benefit from economies of scale, with unit costs declining significantly as plant size increases. For instance, at 10 ML/day, the LCOW falls to $0.67/kL for aquifer injection and $1.30/kL for evaporation ponds. This highlights the cost advantages of larger-scale infrastructure, particularly when fixed costs can be distributed across greater water output

It is important to note that these comparisons involve different recovery rates, and therefore do not represent strictly equivalent scenarios. Evaporation ponds, operating at higher recovery, extract more water per unit of feedwater and produce less brine. This could also influence energy demand and total water throughput.

Table 3: Comparison of the levellised cost of water (LCOW) for a range of desalination plant capacities, based on a desalination plant located in Loxton, South Australia, powered by the electrical grid, a feedwater quality of 12,500 mg/L TDS and a 20-year cost recovery period.

Disposal method	Recovery (%)	0.1 ML/day LCOW ($/kL)	1 ML/day LCOW ($/kL)	10 ML/day LCOW ($/kL)
Evaporation pond	60	2.70	1.70	1.30
Aquifer injection	30	2.20	1.10	0.67

4 Summary

The augmentation of traditional surface water sources with climate-independent alternative sources, such as desalinated brackish groundwater, has significant potential to enhance the resilience of the MDB's irrigation regions under a hotter, drier climate. The management of desalination brine represents one of the largest costs in the desalination process, and good design is critical to ensuring financial viability, and environmental sustainability. This report explored the key components for effective brine disposal in the Murray Darling Basin, encompassing geographical constraints, technical considerations, environmental impacts, costs, and regulatory requirements.

Geographically, evaporation ponds require significant land area, which is often scarce in agricultural regions. Aquifer injection necessitates a suitable aquifer with a salinity level comparable to or higher than the brine, as well as detailed hydrogeological data to ensure environmental safety. From a technical standpoint, the design of evaporation ponds demands precise expertise to balance evaporation rates and prevent leaks. Aquifer injection, on the other hand, relies heavily on hydrogeological data to assess feasibility and mitigate the risk of contaminating fresh water sources.

The uncertainty of costs associated with the implementation of evaporation ponds and aquifer disposal are also a considerable challenge, especially under the conditions found in the MDB. Evaporation ponds incur high initial and ongoing costs for land, liners, construction, and maintenance. Although aquifer injection is generally cheaper, costs can vary based on well depth and the necessary hydrogeological studies.

It is critical that the risks of causing environmental harm are appropriately managed through appropriate system design, management, and monitoring. Regulatory requirements aim to minimise the risks of causing environmental harm. Varying regulations across different jurisdictions and differing definitions and standards for brine as waste adds to the complexity to the planning and design of brackish groundwater desalination systems.

While it is likely that progress will be made naturally on a number of the barriers identified in this report, for example through improved data and technological gains, more targeted case studies are needed to demonstrate how barriers can be addressed. The development of centralised databases to share data on aquifer properties could help to reduce uncertainties and facilitate better planning and investment decisions.

The development of accessible tools to evaluate the costs associated with the implementation of brackish groundwater desalination, which includes the ability to compare differing types of brine disposal, could enhance the ability of potential end-users to evaluate whether brackish groundwater desalination would be viable in their local context.

Improved coordination of jurisdictions, for example at the Commonwealth level, could help to provide greater clarity regarding management of brackish groundwater resources. Establishing more consistent definitions and standards for desalination brine management, tailored to different environmental and operational contexts, has the potential to lower the complexity of current regulatory requirements.

Into the future, addressing these barriers has the potential to enhance the feasibility and adoption of brine disposal methods, and ultimately support the sustainable management of water resources in the Murray Darling Basin.

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