Centre for Agricultural Engineering

Assessment of Evaporation Mitigation Technologies in Queensland

FINAL REPORT – 21 July 2020

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1. Executive Summary

This draft final report integrates three sub-reports:

Part 1: A technical review and synthesis of research including case studies for selected products.

Part 2: A market assessment, based on a survey of manufacturers, suppliers, installers and users, with analysis and interpretation of market intelligence.

Part 3: Regional analysis of and recommendations for suitable locations for evaporation mitigation demonstration trials, to encourage the uptake of cost-effective Evaporation Mitigation Technologies (EMT's).

The report provides baseline information on the range of EMT's available to reduce evaporation from dams. It details their suitability for different dam types and sizes, the factors that make them economically viable and the barriers to their uptake.

Part 1 Synthesis of research results from previous research

Section 4 of this report provides a desktop review of studies that have been undertaken over the last 20 years into the effectiveness of EMT's. This section also provided detail on a range of EMT's and their potential water saving and cost.

Evaporation and seepage loss from water storages comprise the major on-farm water loss. For example accounting for approximately 45% of the water lost from on-farm irrigation systems in the Queensland Murray Darling Basin. Water saved through the adoption of cost effective EMT's would reduce the risk associated with growing irrigated crops, by increasing the security of water supply.

Estimating Evaporation Loss

Water balance models and using data from pressure-sensitive transducers located under the water, combined with Penman-Monteith FAO 56 evaporation estimates, allow accurate estimation of seepage and evaporative losses from a storage. The Irrimate™ Seepage and Evaporation Meter has been used widely to quantify these losses for landholders.

Mitigating Evaporation loss

EMT's can be broadly categorised into two classes i) structural and management strategies, and ii) storage covers.

Structural and storage management strategies

Reducing the surface area to volume ratio of a storage by dividing it into two or more smaller cells or by increasing wall height provides reliable long-term evaporative reduction but requires significant earthworks and may also need field reconfiguration.

The familiarity of landholders with the earthworks and machinery required to undertake structural modification of a storage as well as reliable estimates of evaporation saving through reconfiguration, has resulted in widespread adoption of this strategy to reduce seepage and evaporative loss.

Altering management practices to increase the depth and water residence time in at least one cell (reducing the surface to volume ratio), and by pumping water between cells and from distribution channels and sumps into the storage also reduces evaporative and seepage losses.

Storage covers

Suspended continuous covers

Of the four suspended cover options available in 2012, only one is currently available in the market. Familiarity of landholders with structures used to protect crops from weather damage may improve the adoption of this technology in some regions. More than ten units have been installed in Australia by a commercial company, one of which has been operating for 17 years with few technical challenges and limited maintenance. The capital cost is around $9/m^2$ for large storages (15ha) and increase to over $30/m^2$ for small storages (less than 2 ha).

Covers which block out light improve water quality by inhibiting algal growth and the evaporative reduction achieved depends on the shade cloth used but is typically >70% and potentially 90% shading.

Continuous floating covers

While potential water saving is high, market availability of floating covers is limited. Floating covers are best suited to storages less than 5ha in area and have a high capital cost of $15/m^2$ to $35/m^2$ (May 2020 prices).

Debris and weed growth may reduce the performance of covers left on the storage for a long time. Drainage of rainwater below the cover is a key challenge for impermeable floating covers. Many floating covers are now deployed in sections allowing installation on a portion of the storage, easy removal and installation. The evaporative reduction achieved by floating, continuous covers should be >90% for the covered area.

Modular floating covers

The biggest reduction in product availability is for floating modular covers, with only one product currently available commercially. Many of the products previously manufactured in Australia are no longer available.

A range of mechanical durability and technical constraints of these systems affect performance and cost effectiveness. Capital cost is high, generally around \$20-\$40/m^2 (May 2020 prices), and evaporation reduction is variable and dependant on packing and spacing between modules. The evaporative reduction performance of modules is linearly proportional to the surface area they cover. Spherical or cylindrical modules which expose fluid films to evaporative loss on rolling are less efficient in reducing evaporation than ballasted, non-rolling modules. The option to incrementally purchase and replace modules may assist with the adoption of this technology.

Floating, modular photovoltaic cells:

Modular, floating photovoltaic panels are a new development in Australia and internationally, dating from 2011. The driver for purchasing these units will be decentralised energy generation, with evaporative reduction proportional to the surface area covered by the modules a secondary benefit. Very little technical information is available on the specifications and performance of these units for evaporation mitigation. Guidelines and regulatory standards will be required to improve the efficiency and safety of these on or off-grid power generation systems.

Monolayers

Artificial monolayers are biodegradable chemicals which spread across the water surface, packing to a depth of one molecule to retard evaporative loss. Of the two chemical film products available in 2012, only one is currently available. Potentially, monolayers have the largest market share as they can be deployed across all size ranges of water storages (< 100 ha).

However, monolayers are not as reliable as other methods in reducing evaporation because they are biodegradable and wind, waves, UV radiation, water quality, algae and bacteria affect product spreading, film integrity and longevity. While laboratory results at the centimetre scale indicate very promising evaporation reduction (up to 60%) the timing of infield application with prevailing meteorological conditions at the macro and micro scales, and storage conditions heavily impact the performance of the products.

Artificial monolayers are best suited to intermittent application on medium to large water storages (10ha to 100ha), from multiple autonomous applicators programmed to operate only when wind speed is low (less than 3 meters per second).

The main advantage of monolayers is the low initial setup cost. Additionally, the product need be applied only when required, for example when the dam is full and during periods of high evaporation. Floating containment barriers can be used to keep the monolayer from becoming beached on the dam's embankment after moderate winds.

The main impediment for adoption of monolayer systems is the highly variable performance of chemical barriers and the uncertainty of water savings. Further research and development of products, application and monitoring systems is required for this technology to mature before it becomes a viable option.

Part 2 Market Assessment (Supplier and User Consultation)

Supplier analysis

The main factors limiting the uptake of evaporation mitigation products are marketing, the need to demonstrate cost/benefit and the value proposition, and the lack of objectively monitored and analysed local field trials.

Commercial suppliers exist for multi-molecular films (Aquatain), suspended shade cloth (NetPro), continuous floating covers (Layfields, Daisy Commercial and Darling Downs Tarpaulins) and floating modular systems (Hexa-Cover and AquaArmour). Details for each supplier are provide in Section 5.1. Table 17, Table 18 and Table 19 summarise suitability of generic product classes and approximate costs and performance of commercially available products.

Local demonstration and independent testing and cost-benefit analysis will improve the information available for marketing, and for prospective purchasers. A local track record in the fabrication and installation of similar products improves landholder confidence in evaporation mitigation products. The small scale of most local manufacturers limits the budget for marketing and the objective evaluation of field trials required to establish the cost-benefit of a product. The evaporation mitigation market is seasonal, driven by the severity and frequency of water scarcity and drought and most suppliers of evaporation mitigation products depend on markets other than evaporation mitigation to remain financially viable.

The potential cost of installing and operating an EMT per unit of water saved ($/ML) will be a function of installation and maintenance costs, annual and seasonal evaporation losses from the storage location, efficiency of the EMT in mitigating evaporation, and storage operating conditions.

In agriculture, annualised system costs need to be compared with the value of water to the landholder, in terms of increased crop production (gross margin per ML water), the cost of water to be purchased or the potential to trade water surplus.

A digital Evaporation Ready Reckoner tool allows site specific cost-benefit analysis of different evaporation mitigation strategies for a specific water storage. This tool is being redeveloped to update software architecture and functionality and integrate the latest evaporation and EMT information.

User analysis

Most industries are willing to participate in objectively monitored trials of evaporation mitigation products, provided participating growers are not financially 'worse off'. The main driver in local regional councils for covers to storages is to improve water quality and reduce water treatment costs. Evaporation saving cost-benefit is generally not assessed. Details of user requirements and case study examples are provided in section 5.2.

Prior positive experience and the development of trust with the supplier improves the likelihood of an evaporation mitigation technology being adopted. Securing the volume and quality of water to meet the demand of high value horticultural crops and animal welfare in feedlot enterprises are key drivers. Users must consider the impact of an evaporation mitigation product on water use efficiency at the enterprise scale, when deciding on an investment.

Evaluating the role of an evaporation mitigation technology in improving water security and water quality, and in reducing the cost of water treatment and the cost of maintaining water (irrigation) distribution systems will assist in adoption.

Barriers to adoption of evaporation mitigation technologies (EMT's)

Barriers to adoption of new technologies include financial, technical, biophysical, motivational and regulatory impediments.

Irrigators are more likely to adopt proven technologies with low capital outlay, and are reluctant to adopt new technologies in the absence of well documented demonstration trials, and technical and financial support.

While there do not appear to be institutional barriers to evaporation reduction investment by urban water authorities, the impact of EMT's on recreation, fishing, boating and the environmental is a concern and economic analysis is based on the price at which water can be sold.

Part 3 Regional Analysis and Recommendations for Product Demonstration

Thirty five locations to trial evaporation mitigation products have been identified, representing major agricultural industry groups (horticulture, nursery, sugar, cotton, dairy and livestock) as well as mining and regional town water supply enterprises. Recommendations on the size of dam and type of EMT to be evaluated at each location have been provided, based on potential for successful adoption.

Selection was based on the number and size of dams in Queensland's major river catchments, local rate of evaporation loss, potential water saving using an EMT, the annualised cost of the evaporation mitigation technology and the value of water to the selected enterprise. Section 7 provides detailed recommendations.

Further prioritisation needs to be guided by the Departments budget for a potential follow on project, and their approach for further detailed site selection, including engagement with landowners and technology suppliers. Industry groups should be approached to guide selection of demonstration sites and suppliers will need to fine tune product deployment preferences. The financial contribution of all parties towards installation cost will also determine the scale of future trials. Getting industry bodies involved at an early stage will improve promotion and adoption of successful solutions. Detailed site selection and prioritisation would form part of a follow on study and was beyond the scope of this project.

While the majority of storages in Queensland (99.9%) have a surface area less than 100 ha, storages larger than 100 ha account for 50% of the water lost (generally municipal and water supply scheme storages). The effective upper size limit of all EMT's (5 ha for floating continuous and modular covers; 15 ha for suspended continuous covers and 100 ha for chemical covers), was applied when modelling the potential saving of each individual EMT and guided recommendations for demonstration sites.

The annualised cost of each evaporation mitigation technology has been assessed using the cost per unit of water saved. This cost is a function of the capital cost of the product, installation and annual maintenance costs, offset against the annual and seasonal water lost from the storage, storage operating conditions and requirements, and the efficiency of the technology in reducing water loss. The cost-benefit of installing and operating an EMT has guided recommendations for product demonstration and evaluation, and was determined by comparing annualised cost of the EMT with the crop gross margin per megalitre (ML) of irrigation.

All product options would be cost-effective in most Queensland locations, for crops with gross margins exceeding \$2000/ML of irrigation applied. High-cost options such as modular floating covers (\$40/m^2) would only be cost-effective for crops with a gross margin exceeding \$2000/ML grown in a region of low evaporative demand (e.g. Gatton), or for crops with a gross margin exceeding $1500/ML grown in a region of high evaporative demand (e.g. St George).

Cost-effectively, enterprises producing high-value, permanent crops are able to pay significantly more for water or for a water saving technology, than enterprises producing lower value, annual crops. Returns vary between years, depending on yield and commodity prices, the amount of irrigation required and the irrigation system used.

2. Introduction and Scope

Queensland Department of Natural Resources Mines and Energy (DNRME) are seeking to understand the circumstances where evaporation mitigation technologies, including dam covers are able to economically reduce evaporation. DNRME is also seeking to understand barriers to their uptake, such as social, recreational, health and safety concerns, at sites where their use would be beneficial.

The purpose of this study is to provide baseline information on the range of products available to reduce evaporation from dams, their suitability for different dam types and sizes, the factors that make them economical and the barriers to their uptake. Consideration has been given by DNRME to a possible follow-on project on the location of demonstration sites across the state to show the economic benefit and encourage the uptake and use of evaporation mitigation technologies for saving water. The focus is on off-stream water storages (i.e. filled by pumping or overland flow), regardless of the industry and size of the storage facility.

The University of Southern Queensland delivered the project in four parts:

(1) Synthesis of research results (both national and international) into the range of products used / tested over the last 20 years (Chapter 4));

(2) Market assessment through interviews with suppliers, users and potential users of currently available technologies, user experiences and reasons why potential users do not choose to use them (Chapter 5);

(3) Regional analysis and recommendations for potential demonstration sites to encourage the uptake of the most cost-effective technological solution for reducing evaporation at that location (Chapter 6); and

(4) The rewrite and updating of the USQ economic ready reckoner on evaporation mitigation technology.

3. Methodology

A brief outline of the methodology for the four phases of this study is outlined below.

Part 1: Review of Evaporation Mitigation Technologies and Synthesis of Research Results (Chapter 4)

Chapter 4 summarises a desktop review of studies that have been undertaken over the last 20 years into the effectiveness of evaporation mitigation technologies.

Guidance is given on the latest products available to reduce evaporation losses from dams and the improvements made to overcome previous performance issues. Information collected includes:

- Review of previous work summarising evaporation losses from storage dams in Australia
- Review of economics of evaporation mitigation technologies and barriers to adoption
- Summary of the evaporation process, methods for estimating evaporation loss as well as biological and chemical processes at the air-water interface which impact the evaporation process
- Review of evaporation mitigation technologies including
    - approximate costs of product and of installation and maintenance
    - limitations and advantages of each technology
    - potential impacts including environmental (positive and negative), social/recreational and any others
    - the expected life of each system
    - the operating requirements of storages that contribute to the success of the technology
- Case studies for selected products.

Part 2: Market Assessment (Chapter 5)

Discussions have been held with manufacturers, suppliers, installers and users of products. Focus was on Queensland-based users and off-stream storages, representing the diversity of water storages and industries across Queensland, including large and small farm dams, and regional town supply and treatment storages.

Discussions with key stakeholders included meetings, phone calls and site visits as appropriate, and were guided by the questionnaire included as Appendix 2.

Barriers to uptake were discussed, and interviews were held with selected industry representatives from key bodies. Chapter 5 summarises the results of the market assessment.

Part 3: Regional Analysis and Recommendations (Chapter 6)

A regional analysis of the potential water saving and economic benefits from evaporation mitigation technology was undertaken based on a framework accounting for:

- The number, size and location of dams in the major river catchments of Queensland.
- The annual evaporation loss from each storage.
- The potential water saving that is achievable using different evaporation mitigation products, based on their evaporation saving performance and a range of adoption thresholds.
- The annualised cost of each product ($/ML evaporation saved).
- The annualised value of evaporation water saved.

Practical recommendations have been provided for specific field trials, based on the technology most likely to be adopted by landholders in that region. Recommendations have been based on storage dam size, evaporation saving potential, industry type and cropping system and the industries and crops within those regions that would reap economic benefits from the use of evaporation mitigation technologies.

Part 4: Rewrite and Update the Ready Reckoner

The web tool 'evaporation ready reckoner' developed by USQ in 2009 will be totally rewritten. The 'ready reckoner' is used to assess the economics of implementing various evaporation mitigation technologies, comparing the costs against the value of water in terms of increased crop production, the cost of water to be purchased, or the potential to trade surplus water. The tool is out of date in software architecture and functionality, and the latest evapotranspiration and other climatic data to support the model will be incorporated. Development is following the phases outlined below.

a) Technical Review & Update
b) Software Specification & Design
c) Software Development & Testing
d) Software Release

4. Part 1 - Synthesis of Research Results

4.1 Evaporative Loss from Storage Dams in Australia

Dryland agriculture traditionally depends on regularly spaced rainfall events during the growing season to provide sufficient water to meet crop demand. In the subtropics, most of the rain occurs in summer, with insufficient rain over the winter to sustain temperate horticultural and broad-acre crops. Dryland agriculture is restricted to heavier, deeper soils which can store sufficient water in the soil profile after a major rainfall event, to meet crop demand from sowing (or planting) to harvest. All other cropping is dependent on irrigation from ground or surface water. Australian agriculture is therefore highly dependent on farm dams. Storage sizes range from a few megalitres (ML) for stock and domestic supplies, to larger dams used for commercial irrigation.

Storage Dam Identification

Data on farm water storage across Australia, to estimate evaporation losses, are relatively difficult to obtain. Estimates on the size and location of dams are most commonly based on data routinely collected for licensing requirements, and data obtained through remote sensing (Baillie, 2008). Changes to legislation in various states has tightened the licensing requirements, potentially improving the quality of the data. In many cases local catchment exemptions from licensing, under-estimates the actual number of storages within a region. Conservative estimates suggest in excess of 8,000,000 ML is stored in farm dams (i.e., 9% of total stored water) and that there are more than 2 million farms dams across Australia (Australian Water Association, 2006). Baillie (2008) estimated the number of licensed on-farm dams in Queensland to be 6,371, storing about 1,700,000 mega litres (ML) (Table 1).

Data for Queensland in Table 1 are based on the statutory reporting requirements of farm dams in Queensland (Baillie et al. 2008), collected through licences for the abstraction of or interference with water courses and overland flow, a referable structure, or during the application process for the construction or modification of earthworks. Not all catchments regulate overland flow, but a licence is required for the storage of water in excavated structures that are within or connected to a watercourse. Licence conditions will vary with the Catchment Water Resource Plan, with some limiting the capacity of storages to 5 ML, whereas others only require prior approval and a licence when the proposed storage capacity exceeds 250 ML.

In catchments with unregulated overland flow, on-farm storages (farm dams, ring tanks) may be considered 'reportable' if dam failure poses a risk for properties or dwellings below the dam (Baillie et al. 2008). A failure impact assessment is now required for all storages with more than 10m in height and have a storage capacity of more than 1,500ML; or (b) more than 10m in height and have a storage capacity of more than 750ML and a catchment area that is more than 3 times its maximum surface area at full supply. The Water Entitlements Registration Database holds information on prospective or existing licensee or permit holders, the identifier of the land attached to the authority, the identifier of the land where the works are located, the location and source of the water supply, and technical information describing the proposed works.

Typical farm dams were assumed to have surface area of less than 100 ha, considered the lower limit of commercial water supply storages. The volume of water stored was assumed to range from 30% to 90% of the total storage capacity.

Table 1:Size and volume of water stored and the number of farm dams in Australia (Baillie 2008).

Volume in Storage

Storage Size (Ha)	Qld	NSW	ACT*	Vic	SA	Tas	WA	NT	Total
0 - 2	60 701		1 205	653 059	54 807	14 116	8 848		792 736
2 - 5	50 772			121 311	8 551	26 448	5 351		212 433
5 - 10	85 239			67 282	3 284	19 542	2 969		178 315
10 - 25	189 051					27 454	2 574		219 079
25 - 100	452 915					41 407	941		495 263
> 100	876 330					722 946			1 599 276
unavailable	164								164
Total (<100)	838 841	2 354 560	1 205	841 652	66 642	128 967	20 683		4 252 550
ABS (2006)	1 107 000	1 489 000		198 000	65 000	186 000	212 000		3 257 000
All Data	1 715 171	2 354 560	1 205	841 652	66 642	851 913	20 683		5 851 826

Number of Storages

Storage Size (Ha)	Qld	NSW	ACT*	Vic	SA	Tas	WA	NT	Total
0 - 2	4 503		1 107	334 613	20 994	3 250	3 584		368 051
2 - 5	682			1 363	129	1 268	127		3 569
5 - 10	403			210	20	569	30		1 232
10 - 25	373					316	9		698
25 - 100	283					182	2		467
> 100	127					65			192
unavailable									4 585
Total (<100)	6 244	361 590	1 107	336 186	21 143	5 585	3 752		735 607
All Data	6 371	361 590	1 107	336 186	21 143	5 650	3 752		735 799

**calculated from area of 18 237 Ha and a density of 6.07 dam / km^2;*

Unqualified satellite imagery in 2010 identified 92,000 water bodies in Queensland whereas registration and licensing records listed only 6,371, indicating registration records substantially under-estimate the actual number of on-farm water storages (Baillie et al. 2010). Farm dams in Queensland and New South Wales have the greatest storage capacity (Figure 1). The current DNRME waterbody database (Table 2) is based on ortho-photography, satellite imagery, and information from Geoscience Australia and identifies storages greater than 625sqm. Of the 243,000 storages identified, 96% are less than 2ha and 98% are less than 5ha. The Condamine catchment contains 17% of all storages, Flinders 14%, Burnett 13%, Brisbane 9% and Mary catchments 9%. The number of storages identified greatly exceeds those identified in Baillie et al (2010).

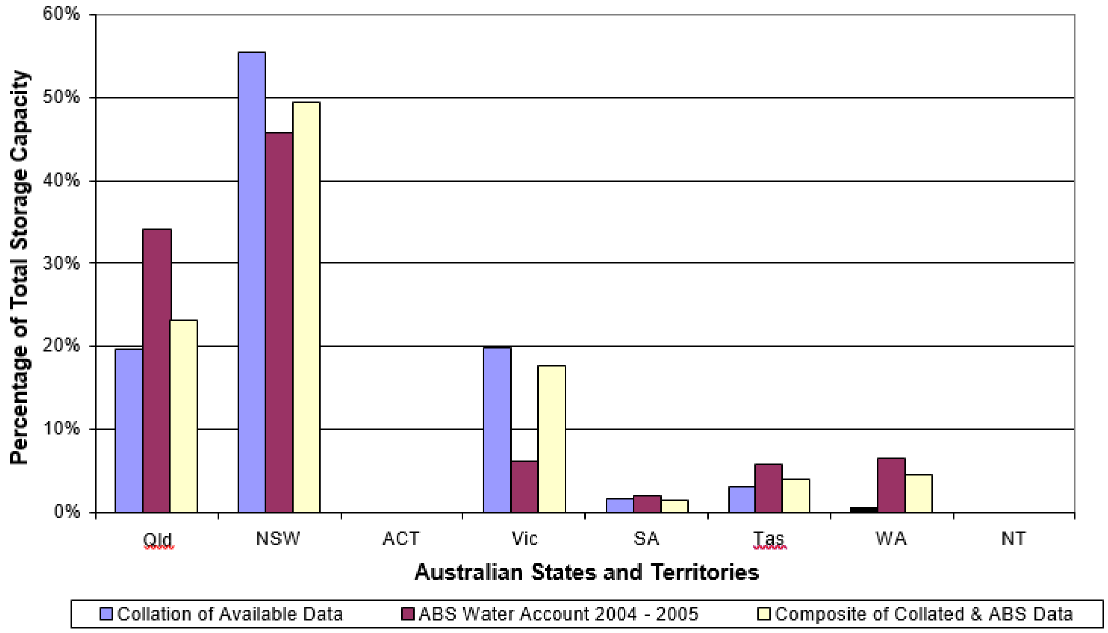


Figure 1: Distribution of farm dams across Australia.

Data are from Table 1 (Baillie 2008) and Australian Bureau of Statistics 2006.

Evaporation Loss from Storages

Accounting for evaporative losses from farm dams is difficult, given the large discrepancy between national estimates and the information collated on storage dam location and size. Evaporative loss as a percentage of the total storage capacity, the volume of water actually stored, the residence time and season complicate calculations. Baillie (2008) estimated annual evaporation from on-farm storages at 1,320,000 ML or as high as 2,880,000 ML, assuming 8 000 000 ML was stored in farm dams. Evaporative loss from small farm dams (< 10 ha capacity, <5 m depth) in subtropical Australia ranges from 4 to 7 mm day^{-1} in summer, to 10 mm day^{-1} when air temperature exceeds 40° C (Craig et al. 2007). To obtain more accurate regional estimates of evaporation loss from storages, accurate remote sensing data, identifying storage location, area and preferably changes in volume stored, should be intersected with meteorological data on storage evaporation loss.

In a water use efficiency study of the Queensland Murray Darling Basin (Baillie et al. 2010), potential on-farm water losses from tradable entitlements were estimated at 438 GL per year. Losses were greatest from water storages (198 GL or 45% of the total), with 191 GL (44%) lost in-field, and 48 GL (11%) lost from distribution systems (channels and/or pipes).

Table 2: Number of storage dams with area >625sq m in Queensland for various catchments and size classes (Source http://www.dnrm.qld.gov.au/mapping-data).

Catchment Name	< 2 ha	2 - 5 ha	5 - 10 ha	10 - 25 ha	25 - 100 ha	> 100 ha	Total	% Total
Barron	2,377	113	43	16	5	5	2,559	1%
Border Rivers	17,219	282	83	53	122	21	17,780	7%
Brisbane	20,850	282	69	42	9	11	21,263	9%
Bulloo-Bancannia	1,865	39	6	3	1	1	1,915	1%
Burdekin	11,569	740	215	118	56	13	12,711	5%
Burketown	699	24	6	2	1	3	735	0%
Burnett	30,368	604	202	77	27	10	31,288	13%
Channel Country	5,669	167	62	26	7	2	5,933	2%
Condamine	38,664	708	338	316	180	70	40,276	17%
Cooper Creek	11,884	165	48	23	9	4	12,133	5%
Curtis	7,600	136	45	23	9	1	7,814	3%
Fitzroy (QLD)	31,256	1,297	360	220	129	23	33,285	14%
Flinders	4,044	74	35	19	8	4	4,184	2%
Gilbert	4,400	242	69	34	13	4	4,762	2%
Gold Coast	7,836	109	18	9	3	5	7,980	3%
Lake Frome	2	-	-	-	-	-	2	0%
Leichhardt	971	33	14	17	20	8	1,063	0%
Mary	20,404	287	81	23	5	5	20,805	9%
Mitchell	2,571	217	46	31	13	2	2,880	1%
Princess Charlotte Bay	343	30	12	5	2	1	393	0%
Shoalwater Bay	2,790	168	71	54	26	2	3,111	1%
Warrego	7,299	68	16	8	9	1	7,401	3%
Weipa	147	10	1	4	1	1	164	0%
Whitsunday	2,327	198	82	37	14	3	2,661	1%
	233,154	5,993	1,922	1,160	669	200	243,098	100%
% Total	96%	2%	1%	0%	0%	0%	100%	

Potential on-farm savings associated with the adoption of water use efficiency technologies and associated management practices were estimated at 31 - 58 GL per year, with a water saving cost of 94 - 191 million dollars (present value over the life of the investment, assuming the full utilisation of tradeable water entitlements). The estimated water savings associated with reducing loss from on-farm storages was 20 - 36 GL per year, with a cost saving of $58 - $114 million dollars. The estimated average gross margin per ML of water used for crops in this region is $185 - $1,000 per ML (Baillie et al. 2010), indicating substantial gains in farm profitability can be achieved with the adoption of technologies to reduce evaporative loss and seepage.

Water seeping through the base and walls of the storage contributes to on-farm water losses, but are typically less than evaporative loss. In the Stanthorpe Water Management Area, a region producing high value deciduous fruit, wine grapes and vegetables, seepage losses account for 10% of on-farm water losses, with evaporation accounting for 60% (Schmidt and Scobie 2012; Table 3). Water saved through the adoption of technologies reducing these losses would reduce the risk associated with growing irrigated crops, by increasing the water supply available. However for landholders, any additional costs outlaid in reducing seepage and/or evaporative loss must meet the 'value for money' criteria (Akbar et al. 2013), where the marginal cost required to implement the mitigation strategy must be less than or equal to the value of the saved water.

Table 3: On-farm water losses in the Stanthorpe Water Management Area and the Granite Belt (Schmidt and Scobie 2012

Water Loss Category	Water loss (ML per year)	Water loss (% of total)
Storage evaporative loss	586	60%
Storage seepage loss	98	10%
Distribution loss	117	12%
In-field loss	173	18%
Total Loss	974 ML	

Key Findings on Evaporative Loss from Storage Dams:

- There is a large discrepancy between various estimates of location, size and volume stored in small dams. Some data is based on licensing requirements and other on satellite imagery and remote sensing. Farm dam numbers derived from the Water Entitlements Register Database are substantially below numbers calculated using satellite technology.
- Evaporation and seepage loss from on-farm water storages comprise the major water loss, accounting for approximately 45% of the water lost from on-farm irrigation systems in the Queensland Murray Darling Basin.
- Baillie (2010) found that water use efficiency technologies and management practices could save 31-58GL per year in the Queensland Murray Darling Basin of which 20-36GL/year could be saved by reducing losses from on-farm storages.
- Accurate regional estimates of evaporation loss from storages could be obtained by intersecting remote sensing data, identifying storage location, area and preferably changes in volume stored, with meteorological data representing point evaporation loss from a water surface.
- Water saved through the adoption of cost effective technologies reducing these losses would reduce the risk associated with growing irrigated crops, by increasing the water supply available.

4.2 Economics and Adoption of Evaporation Mitigation Technologies

In most areas in Queensland, the loss of water through evaporation is greater than gained through rainfall. The cost of this evaporation loss is significant. On-farm stored water can be assigned a price, even if the source is unregulated and not subject to water market prices (Peake et al. 2016). The cost of pumping unregulated overland flow into a storage may be of the order of \$40 ML^{-1}, whereas farmers pumping under licence during low river flows may be required to pay as much as \$80 ML^{-1}, a total of \$120 ML^{-1} including pumping costs. Management decisions on when to use stored water can also be allocated a cost, as the longer the water is stored, the greater the loss to seepage and evaporation. Irrigation inefficiencies may also substantially reduce water productivity (the ratio of crop output to water diverted or consumed), reducing the profitability of the entire farm enterprise.

These costing models allow water managers to compare the cost-effectiveness of different evaporation mitigation options for their specific enterprise. Section 4.7 discusses the various evaporation mitigation technologies and Appendix 1 provides detail on specific products. A Ready Reckoner costing model developed by the Co-Operative Research Centre for Irrigation Futures enables landholders to estimate the cost-benefit of different evaporation mitigation strategies for a specific water storage (Schmidt 2009). The cost of implementing evaporative mitigation technologies per ML of water saved is a function of the capital cost of the product, installation and maintenance costs (of the evaporative mitigation system), offset against the annual and seasonal water loss from the storage, storage operating conditions and requirements, and the efficiency of the technology in reducing water loss. The Ready Reckoner is ideal to assess on-site economics of various products, however it is dated, and requires an upgrade both in terms of functionality and integration of latest meteorological data and other data.

The value of the water can be determined from water productivity, or revenue that could be generated from additional crop produced from evaporation savings, as well as the cost (water purchasing and/or pumping costs), and the potential to trade surplus water. User input data into the Ready Reckoner (Schmidt 2009) includes site location (latitude and longitude) to estimate monthly evaporative loss, storage size and shape, storage operating conditions (years out of ten when water is stored, and the typical volume held as a percentage of the total capacity), anticipated seepage losses, and the evaporation mitigation system under consideration. The output is the estimated volume of water saved (ML) and the cost of the recommended storage modification required to save this water (\$ ML^{-1} saved per year).

Evaporation mitigation technologies encompass products for reducing evaporation loss, and the reconfiguration of storage dam geometry (deepening or installing cells), to reduce the surface per unit volume (surface to volume ratio) available for evaporation. Many landholders relate readily to reconfiguration of the storage (see Table 7 in Section 4e, and in section 1.1.1 to 1.1.6 in the Appendix), as they are familiar with the machinery and the scope of earth works required to build and modify these structures (Healthy Headwaters Program 2018). Craig et al. (2005) incorporated product costings and recommendations provided by manufacturers and/or retailers, and by landholders and project managers using different products to estimate the lowest, medium and highest ratio of costs for the purchase, installation, operation and maintenance of each system (Table 4). Two of the three products used in the analysis are available today. Updated information from manufacturer/retailer websites of the products in Table 4 is summarised in the Appendix (NetPro Appendix 1.2.2, and WaterSavr, Appendix 1.2.16).

Table 4: Summary of costs associated with the installation of three evaporation mitigation products on farm water storages (Craig et al. 2005).

Low, medium and high refers to the combination of purchase, installation, operation (including labour) and maintenance costs, and product durability based on detailed costing from manufacturer/retailer, and user information.

Product	Capital cost ($ ha^{-1})	Chemical cost ($ ha^{-1} yr^{-1})	Operating ($ ha^{-1} yr^{-1})	Maintenance ($ ha^{-1} yr^{-1})
Monolayer (WaterSavr) automatically applied				
Low	400.00	790.00	29.00	7.25
Medium	530.00	1185.00	41.75	16.38
High	3800.00	1775.00	466.00	386.60
Floating cover (EvapCap)				
Low	55,000.00	na	112.50	50.00
Medium	70,000.00	na	687.50	250.00
High	85,000.00	na	1187.50	450.00
Suspended cover (NetPro)				
Low	70,000.00	na	112.50	0.00
Medium	80,000.00	na	237.50	100.00
High	100,00.00	na	337.50	200.00

The market potential for various evaporation mitigation products is limited by the storage size in which these products are suited. Floating covers are generally limited to small storages less than 2 ha while suspended covers are applicable for storages up to 5 ha and even 15 ha with internal supports. The chemical barriers (i.e. monolayer products) can effectively operate across all of the class sizes considered, however the product performance, both in terms of chemical formulation and application method, needs to be improved and proven. Baillie

(2008) assessed the market potential for the evaporation mitigation technologies (Table 4), based on the storage size and volume information in Table 1. The potential market for floating covers is 14% of the total water stored on farm (assuming a 3 way share of 0-2 ha storages between EMTs; Figure 3). For suspended covers this equates to 20% (equal share between monolayers for 2-5 ha storages plus share of 0-2 ha storages described above) while for monolayers 66% (5 – 100 ha storages plus a share of 0 – 5 ha storages with other EMTs described). In terms of total numbers of farm dams the largest category of storage size was less than 2 ha (96% of the total; Table 1).

Assuming between 1,320,000 ML and 2,880,000 ML) of evaporation is lost from the estimated 8,000,000 ML stored in farm dams (Baillie 2008), between 480,000 and 700,000 ML of water could be saved by deploying these evaporation mitigation technologies. Monolayer technology offers the greatest potential across all storage size categories (Figure 2), with as much as 350,000 ML of water saved assuming monolayer deployment consistently reduced evaporative loss by 40%. The annual gross market sales (based on breakeven costs; Craig et al 2005) for the three product categories listed in Table 4 were estimated by Baillie (2008) to be.

- Floating covers @ $320/ML - $53.2 M per annum
- Suspended covers @ $340/ML - $62.8 M per annum
- Chemical barriers @ $130/ML (40% efficiency) - $45.3 M + per annum
- Chemical barriers @ $400/ML (15% efficiency) – $52.3 M per annum

This analysis assumes an even market share for the different EMT products depending on the various storage size categories that they are suited to (Figure 2). In reality, site complexities, product technical complexity, performance and reliability, and farmer preference will determine the most appropriate choice. The Economic Ready Reckoner will assist to determine site specific economics.

Adoption of Evaporation Mitigation Systems

Some landholders may be familiar with the costs and technology required to install suspended covers as similar structures have been commonly installed to provide protection from sun-scorch and hail damage in high value horticulture. Most landholders will have little or no experience with the application of chemical monolayers and floating covers, and may be reluctant to adopt these systems. Barriers to the adoption of new technologies include financial, technical, biophysical, motivational and regulatory impediments, which must be addressed to improve landholder confidence when considering the adoption of a novel system (See Text Box: Barriers to Adoption). Information obtained from a survey of 150 irrigators in the Queensland Murray Darling Basin indicated irrigators participating in seepage and evaporative loss monitoring programs were more likely to adopt water use efficiency technologies, with adoption in general limited to low capital, low technology options.

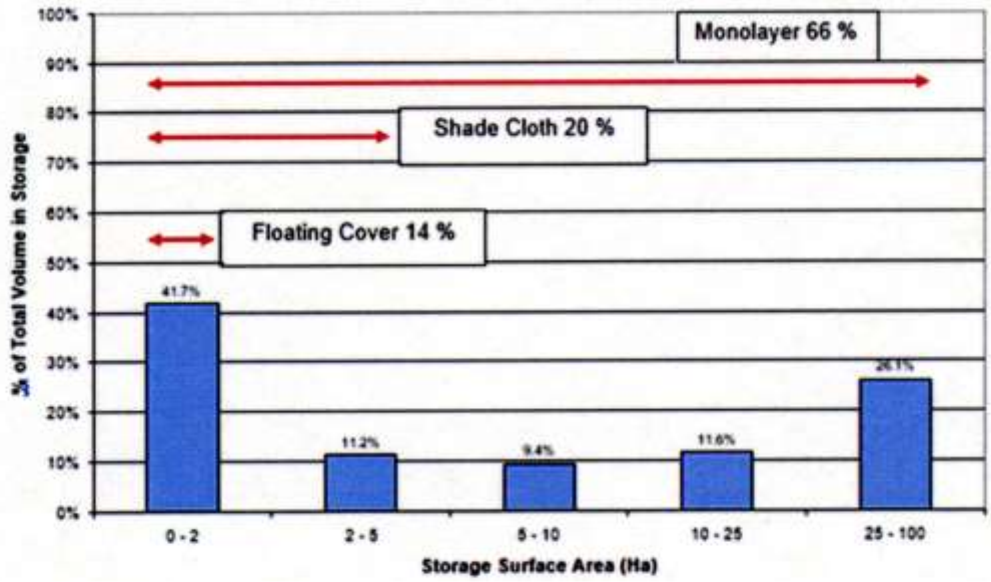


Figure 2: Suitability of the suitability of the three products in Table 4 for deployment on water storages of different size classes (Baillie 2008).

The % total volume is water stored relative to full storage capacity. The % listed after each product is % of all storages suitable for product deployment. Monolayer product was WaterSavr (Appendix 1.2.16), suspended continuous cover (shade cloth) was NetPro (Appendix 1.2.2), floating continuous cover was EvapCap (no longer available).

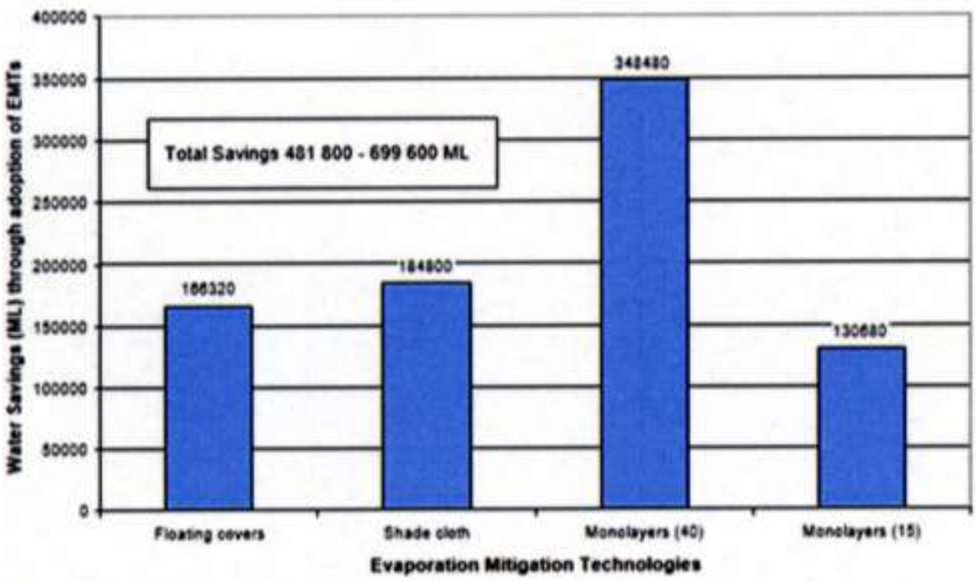


Figure 3: Estimated volume of water potentially saved by the adoption of the evaporation mitigation products in Table 4

The analysis assumes product adoption will be shared equally for storages less than 2 ha, the adoption of suspended covers (shade cloth) and monolayer will be equal for 2 – 5 ha storages, and only monolayer will be adopted for storages greater than 5 ha (Baillie 2008). Monolayer (40) and (15) refers to the water savings achieved with a 40% or only a 15% reduction in evaporative loss.

In Australia, irrigation may account for up to 60% of the water diverted from water courses and overland flow (Stoeckl and Inman-Bamber 2003). Drivers for improving water use efficiency were heightened by water scarcity during the millennium drought, even for those irrigators accessing 'free' water (See Text Box: Drivers for Improving On-Farm Water Use Efficiency). The development of more analytical and planning tools, including guidelines for calculating water savings and costs, decision support tools and training for the consultants likely to use them, and the potential for cost-sharing (Akbar et al. 2013), may provide the certainty landholders need when considering the suitability of different evaporation mitigation systems. The development of an investment case which adequately incorporates potential risks and returns, and cost-sharing between the irrigator and the State Government were key recommendations in the Baillie et al. (2010) report. Changes in rainfall patterns associated with climate change will make the competition for water more acute in the future, with higher value industrial and municipal users reducing the supply available for irrigators.

Institutional Issues

Most research into storage evaporation losses and savings has focussed on privately owned farm dams. In this situation, any evaporation reduction system is a private investment and the water savings are owned and used privately. However, the wider issue of evaporation reduction from water-authority dams needs addressing. Watts (2005) consulted 61 Water Authorities (27 responses) on these matters and summary responses are given in Text Box "Institutional Issues affecting adoption of evaporation mitigation technologies"

Water authorities had little confidence in the feasibility of evaporation reduction technologies. A potential lack of understanding of "gross" and "net" evaporation was apparent. Some water authorities believed that evaporation was not a great problem, as rainfall compensated some of the evaporative losses. However, most evaporation reduction technologies allow rainfall to enter the storage, and evaporation savings are maximised.

It seems that there are no institutional barriers to evaporation reduction investment. Nearly all respondents had avenues to allow investment (usually on a merits basis) and all could clearly state who owns water at any point in their supply and delivery chains (which is important when determining who receives any benefits of evaporation reduction). All respondents believed that whoever funds the evaporation reduction technology should receive the benefits (i.e. the saved water). The point at which the allocation of water occurs also defines the ownership of the water.

There appeared to be little or no understanding between rural water users and municipal suppliers on the drivers and constraints behind water use and the apparent benefits of evaporation reduction. Municipal suppliers tend to talk on terms of yield, water restrictions, water shortages and reliability of supply. Rural users tend to be most focussed with extra production from the water stored. Water that is stored in municipal storages can sometimes have a residency time (time between capture into the dam and outflow for use) greater than 12 months. Farm storages generally do not hold water for longer than 12 months.

The shared value of water resources is also a concern for water authorities. Issues such as recreation, fishing, boating and environmental impacts were raised, and how evaporation reduction will impact these uses of their water storages.

Water authorities can only make their economic analyses based on what they sell their water for (i.e. $/ML). Hence the ability of water authorities to pay for evaporation reduction technology is lower than a farmer who can generate profits from additional production using water savings. The interest from rural water users into saving water from evaporation seems to be greater than that from water authorities. Municipal authorities do gain by deferring the need for new infrastructure.

International Examples

Rising temperatures will increase rates of evaporative loss, providing greater incentives for water managers to reduce losses. In Texas, USA, the annual evaporative loss from 200 major reservoirs was estimated at 8.0 billion cubic metres (based on 32 years of satellite imagery), equivalent to 20% of the total storage capacity or 53% of the total annual water usage (Zhang et al. 2017).

In the Segura River Basin in Spain, the development of new irrigated horticultural enterprises has increased the total annual water consumption of the area by 80% (Martinez-Alvarez et al. 2008, 2009). Water is supplied by a total of 14,145 individual farm or collective water storages, with a total surface area of 4,910 ha. The estimated annual evaporative loss is 58.5 million cubic metres, equivalent to a depth of 1.404 m of water lost across all storages, or 8.3% of the total volume of water used annually for irrigated agriculture. The adoption of polyethylene liners and suspended shade covers was promoted at the time, with Spanish farmers now preferring floating, modular covers which require less technical expertise to install and maintain (personal communication V. Martinez-Alvarez 2020; Appendix 1, product 1.2.9).

Barriers to Landholder Adoption of

Evaporation Mitigation Systems (EMS)

Extracted from: Baillie C, Baillie J, Wigginton D, Schmidt E, Davis R, Scobie M, Muller B, Watts P (2010). An Appraisal to Identify and Detail Technology for Improving Water Use Efficiency in Irrigation in the Queensland Murray Darling Basin.

Financial Barriers:

Lack of cash flow due to a run of poor seasons.
Capital investment per ML by Government will be lower than current market value.
Total cost to irrigator is unknown.
Lack of feasibility studies to determine costs for irrigators.
An appreciating asset would be exchanged for a depreciating asset.

Technical Barriers:

Availability of proven, cost-effective EMS is limited.
The achievable savings with the implementation of EMS is uncertain.
The lifespan of EMS is uncertain so cost cannot be annualised.
Catchment regulatory restrictions may inhibit the adoption of some EMS.
Lack of guidance for consultants/irrigators to assess options and develop proposals.

Biophysical Barriers:

Climate variability.
Prolonged drought limits the opportunity to abstract water.
Farm layout, soil type and property boundaries may limit adoption.
Lack of a guaranteed water supply in regulated catchments may limit adoption.

Motivational Barriers:

Past rejection of submissions for other government incentives.
Negative perception of government involvement in water-related issues
Sceptical of motivation behind government policies and initiatives.
Programs seem complex and risky.

Regulatory Barriers:

Existing moratorium on works in some catchments, and regulatory uncertainty.
Reluctance to install and read water monitoring metres.
Uncertainty of how EMS outcomes may affect water entitlements.
Complexity in trading water-harvesting entitlements.
Risks to early adopters.

Investments in improving irrigation efficiencies (both at on-farm and off-farm scales) can be financed either by using the saved water on higher value crops or by apportioning saving costs as part of the overall water supply charges with a proportionate cost sharing arrangement among the stakeholders. Unless the costs are shared by all beneficiaries including environmental stewards, the real benefits at the irrigation system level may not be possible

(Akbar et al. 2013).

Drivers for Improving On-Farm Water Use Efficiency

Baillie J, Baillie C, Heinrich N, Murray A (2007).

On-farm water use efficiency in the Northern Murray-Darling Basin. Murray-Darling Basin Commission Northern Basin Program.

The drivers for water use efficiency (WUE) were examined for individual farming enterprises in the Northern Murray Darling Basin. Common themes were identified as the drivers for improvements to Water Use Efficiencies: reduced or lower reliability of supply; the need for labour savings, and the need for improved yield to maintain profitability.

'We wanted to reduce water use (per hectare) and increase yields. Essentially we wanted to make our water go further.'

'We only have two full time staff so the labour saving afforded by the lateral was also a consideration.'

'Initially we have implemented the systems so that we can accurately manage water supplies from the scheme. Under the new system we will lose water if we are inaccurate with our predictions of water requirements. With the current labour shortage we required better information and management to enable less skilled operators to become good irrigators. With the cost of water from the scheme rising from $6-$8 per ML to now around $40 per ML over the last 10 years and the rise in fuel costs the economic factors are more important than water use efficiency. Hence we haven't implemented these systems to save water but more so to save money.'

'The cost of water to us is insignificant, however its supply is critical so we needed to be more efficient with our water use.'

'We are facing a 50% reduction in our bore allocation over the next few years. Hence this has forced us to consider our next steps in improving WUE just so that we can maintain our current levels of production from a reduced water supply.'

'Installing a centre pivot was first considered for benefits in labour requirements, management, and WUE. It was installed primarily for our lucerne hay production where it offers an improved irrigation and crop uniformity, the ability to apply small volumes of irrigation, and an increase in the amount of 'cuts' per season.'

'Water is our most limiting factor. It is everything.'

'The initial driver to investment in WUE was simply that we were faced with a situation of diminished water availability. With a need to support the cost of capital, infrastructure, staff etc. we really had to maximize our production with the limited volume of water that was available. For the first time we had to focus on WUE.'

'Our infrastructure was worn out and this forced us to rethink our current practices. On a hot windy day the evaporation losses from the big gun traveller are clearly visible.'

'To increase productivity. It represents a win-win. Not only can we save water but we are growing more yield with less costs.'

Institutional Issues affecting adoption of evaporation mitigation technologies

Summary of 27 Water Authority Respondents - Source Watts (2005)

Q 1: Estimate of annual loss by evaporation.

Does your organisation have an estimate of the annual volume of water lost by evaporation from your water storages?

Response Summary: Varied responses ranging from full details collected and recorded, to some being modelled but not actually collected and some having no data at all. Evaporation is not a key issue. Approximately half of the responses have no record of evaporation from their storages. The other half of the responses estimated, modelled or measured evaporation losses.

Q2: Policy regarding the reduction of evaporation

Does your organisation have any specific policy regarding the reduction of evaporation from water storages?

Response Summary: The responses showed that the majority of the water authorities have no specific policy regarding the reduction of evaporation from their water storages.

Q 3: Investment in evaporation reduction and measurement

Has your organisation ever invested in research related to evaporation mitigation or measurement and if so describe the nature of this investment?

Response Summary: Generally no research has been undertaken. One organisation was participating in a study regarding the benefits of shade cloth on their storages.

Q 4 Evaporation reduction technology application

Does your organisation consider that cost effective evaporation mitigation technology will be applied within your industry in the foreseeable future?

Response Summary: Responses were generally sceptical about economics of evaporation reduction in the foreseeable future, due to the large surface areas of their storages. Some organisations considered economics an overwhelming factor in the adoption of this technology.

Q5 Impediments to evaporation reduction adoption

If a technology became available that clearly made substantial reductions to evaporation from your water storages at an economic price, what institutional or regulatory impediments would exist to its adoption?

Response Summary: Generally no institutional or regulatory impediments to the adoption of such technology were anticipated except for standard Governmental requirements.

Q 6 Ownership of water saved through evaporation reduction

If an evaporation reduction technology was applied to your water storages, this would effectively generate "new" water. Do you have a policy as to who would "own" that water?

Response Summary: The responses were brief but it was generally felt that whoever funds the evaporation reduction technology would own the water, whether private or public investment or ownership.

Institutional Issues affecting adoption of evaporation mitigation technologies (continued) Source Watts (2005)

Q7 Use of saved water through evaporation reduction

If “new” water became available, to what purpose would it be used? It could be used for: a) environmental flows b) to be sold as a new water allocation, or c) to improve the reliability of existing allocations.

Response Summary: It was generally stated that the use of the water would be dependent on stakeholder interest and dam purpose. The most common response was to improve reliability of existing allocations. However some respondents considered selling the water as a new allocation. Essentially, in these cases, a return on investment would be sought. Others felt that the environment would be an obvious beneficiary from Governmental funding into evaporation reduction technology.

Q8. Legislative Impediments to Water Saving Technology

If the relevant water legislation dictates that your organisation does not “own” the “new” water that would be produced, would this be an impediment to investment in water saving technologies?

Response Summary: It was obvious that this would be an impediment to investment. Organisations expect to benefit from their investment and this can only be done through ownership of the saved water.

Q 9. Outside Investment in Evaporation Reduction Technologies

If an investor came to your organisation with a business plan to generate “new” water by investing in evaporation reduction technologies on your water storages, is there a mechanism by which such a business could be developed?

Response Summary: Generally, yes, depending on the costs and benefits expected from the evaporation reduction technology. Respondents without defined policies or mechanisms were still open to proposals for new investment, and would judge each on a case-by-case basis.

In the arid regions of USA, evaporative loss exceeds rainfall gain, and at a residential water price of $US 1.00 per 3,785 L (1,000 gal) evaporative loss may cost up to $US 370 million per year (Friedrich et al. 2018). The impact of climate change on air temperature, rainfall reliability, the frequency and severity of drought and the rate of snow and glacial melt highlights water scarcity will be of increasing concern in the future. More accurate methods of predicting the water cycle and evaporative loss well in advance are required, to better manage water storage and delivery in a changing climate.

In South Korea the output of modelling the impact of climate change on two agricultural storages indicated shorter, more intense rainfall events will substantially increase evaporative loss, reducing the water supply available for irrigated paddy rice production (Park et al. 2009). A reduction in supply at the peak water demand phase of transplanting indicates reservoir management must adapt, to optimise the timing and duration of pumping for paddy rice (Reca et al. 2015), and to reduce evaporative loss (Craig et al. 2005). Improving agricultural water use efficiency through the adoption of improved technologies and management practices is a critical component of climate change adaptation, to better conserve and use the available water supply.

Key Findings on Economics of Evaporative Loss and Barriers to Adoption of EMT's:

- The potential cost of installing and operating an EMT per unit of water saved ($/ML) will be a function of installation and maintenance costs, annual and seasonal evaporation losses from the storage location, efficiency of the EMT in mitigating evaporation, and storage operating conditions.
- EMT costs need to be compared with the value of water to the landholder, in terms of increased crop production, the cost of water to be purchased or the potential to trade water surplus. A Ready Reckoner allows site specific cost-benefit analysis of different evaporation mitigation strategies for a specific water storage.
- The market potential for various evaporation mitigation products is limited by the storage size in which these products are suited. Floating covers are generally limited to small storages less than 2 Ha while shade cloth can cover storages up to 5 Ha. Chemical barriers (i.e. monolayer products) can effectively operate across all of the class sizes considered.
- Barriers to the adoption of new technologies include financial, technical, biophysical, motivational and regulatory impediments. Irrigators are more likely to adopt water use efficiency technologies, with adoption in general limited to low capital, low technology options.
- 2005 costing models based on case studies of three commercially available evaporation mitigation systems predicted monolayers had the greatest market potential.
- Landholders are reluctant to adopt new technologies in the absence of well documented demonstration trials, and in the absence of competent technical and financial support.
- Water authorities have little confidence in the feasibility of evaporation reduction technologies. It seems that there are no institutional barriers to evaporation reduction investment. The shared value of water resources is a concern for water authorities especially the impact of evaporation reduction technologies on recreation, fishing, boating and the environmental. Water authorities can only make their economic analyses based on what they sell their water for (i.e. $/ML). Hence the ability of water authorities to pay for evaporation reduction technology is lower.

4.3 The Evaporative Process

Knowledge of the evaporation process is important to understand factors affecting the performance of evaporation mitigation technologies, especially chemical films and monolayers. Evaporation occurs when water molecules at the surface gain sufficient energy to escape the cohesive force of subsurface molecules, escaping into the gaseous boundary layer immediately above the water surface (Pittaway et al. 2018). The nett attraction between water molecules is greatest in the bulk water phase, and lowest at the surface. The higher free energy of water molecules at the surface induces a spontaneous contraction of the surface area, which we refer to as surface tension. Heat is lost as water molecules evaporate (latent heat loss or evaporative cooling), with molecules in the cooler, dense surface 'skin' descending into the warmer water below (Wells et al. 2009). This thermal convection produces a cyclic motion at the millimetre scale, producing capillary waves (Figure 4). The laminar layer is the zone where forced plus thermal convection produces capillary waves, with bulk convection occurring in the bulk water phase below.

Under calm, warm (high solar radiation) conditions a warm surface skin may develop, damping capillary wave formation and increasing the depth of the liquid thermal boundary layer (Gladyshev 2002). Under these thermally stable conditions the resistance to evaporative loss is much greater than for an unstable, cold surface skin (reduced surface roughness, Fellows et al. 2015). Wind turbulence and low relative humidity increase the evaporation rate by reinstating a cold surface skin and capillary waves, reducing the resistance of the liquid thermal boundary layer (Figure 4), and reducing the vapour pressure immediately above the water surface (gaseous boundary layer in Figure 4). Factors which affect the rate of evaporative loss from water include net solar radiation, heat energy flux in and out of the water and sediment, saturation vapour pressure at and above the gaseous boundary layer, mean air density, specific heat of the air, vapour pressure deficit of the airflow, aerodynamic resistance at and above the gaseous boundary layer, and the resistance of the liquid thermal boundary layer.

Key Findings on the Evaporative Process

- Evaporation is driven by physical processes operating at the micro and macro scale.
- Capillary waves form at the micro-scale when heavier, cooler surface water molecules are replaced by lighter, warmer subsurface molecules (thermal convection; the normal state).
- Evaporative loss is greatest from a cold surface skin, with latent heat loss driving thermal convection and capillary waves (thermally unstable, increased surface roughness).
- Evaporative loss is least when a warm surface skin develops on thermally stratified water bodies during calm weather (thermally stable, reduced surface roughness).

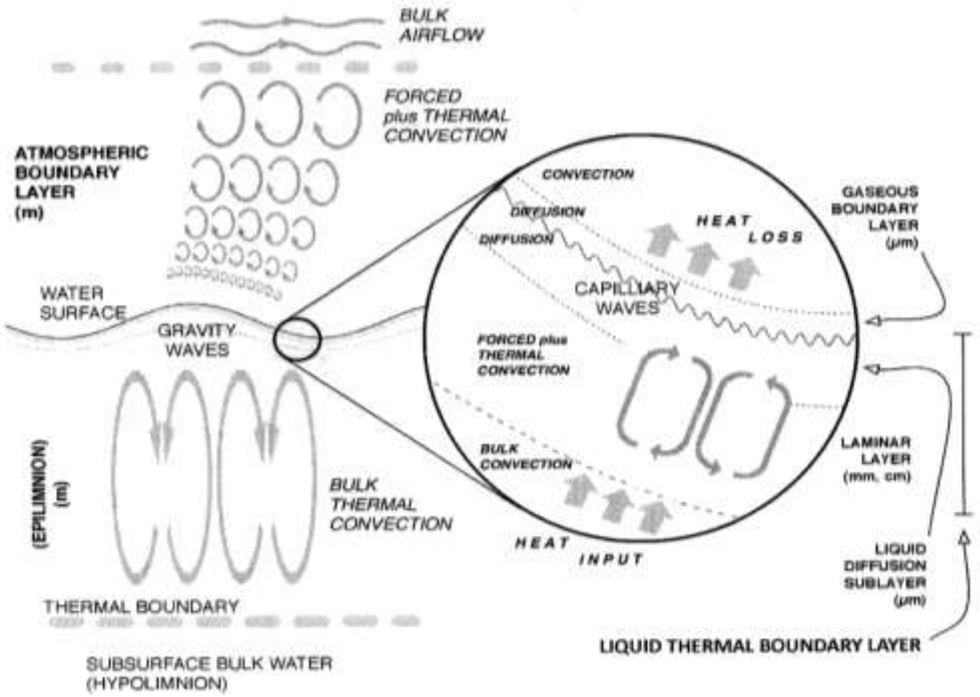


Figure 4: The scales at which evaporative loss occurs.

At the micro scale latent heat loss (evaporative cooling) increases the density of water molecules at the surface, which are replaced by warmer, lighter bulk phase molecules (thermal convection in the laminar layer). Bulk air flow and solar radiation operate at the macro scale, with wind turbulence, low humidity and high solar radiation increasing the evaporation rate. Reproduced from Hancock et al. (2011).

4.4 Estimating Evaporative Loss

Estimating evaporation loss before and after treatment is necessary when evaluating the performance of an evaporation mitigation technology. Many of the parameters affecting evaporation cannot be measured directly above, at or immediately below the water surface, but approximations have been developed. The most widely used is the Penman-Monteith equation, recommended by Food and Agriculture Organisation of the United Nations, FAO56 (Allen et al. 1998) and by government meteorological agencies, to estimate evaporation rates from open water storages in specific geographic locations (Pittaway et al. 2018). PM- FAO56 evaporation can also be calculated more accurately using automatic weather stations located adjacent to a specific water storage.

PM- FAO56 from the 1948 Penman equation is presented (in energy flux units, W m^{-2}) as:

$$\lambda E_0 = \frac{\Delta(R_n - G) + \Delta \rho C_p (e_s - e)/r_a}{\Delta + \gamma} \qquad (1)$$

where □ is latent heat of vaporisation of water, E_0 is the evaporation rate, R_n is the net radiation, G is heat flux to water and underlying sediment, Δ is the slope of the saturation vapour pressure temperature curve, ρ_a is the mean air density at constant pressure, C_p is the specific heat of air, (e_s - e) is the vapour pressure deficit (VPD) of the airflow (which increases as humidity decreases), γ is the psychrometric constant, and r_a is aerodynamic resistance (which decreases as wind speed increases). Using instantaneous values of each variable this equation is repeatedly evaluated to calculate E_0 in units of mm s^{-1}, summed in the AWS logger to produce the daily total E_0 in mm day^{-1}.

Equation (1) only provides an estimate of the evaporation rate, as the heat flux G into (by day) and out of (by night) the water is difficult to estimate, and the heat storage capacity of the water column and processes such as thermal stratification complicate the energy balance. The radiation flux R_n measured adjacent to a dam (measuring over the water surface is often impractical) does not account for the albedo (reflection factor) of incoming solar radiation, or the variation in the albedo of the water surface associated with the changing angle of the sun. The outgoing terrestrial radiation will also be in error due to the water/land temperature difference but this is less significant, except near dawn and dusk. Humidity and wind speed will also vary between an adjacent land surface and an open water surface as dam walls and embankments of large water bodies generate their own microclimate.

A standardised evaporation pan ('Class A pan', one foot deep and four feet diameter) is most commonly used to simulate the evaporation performance of a given water storage, in a specific geographic location. Class A pans may over-estimate actual evaporative loss 1.3 to 2.1 times above actual rates (Allen et al. 1998), as the atmospheric interactions, energy storage and heat flux of small and much larger water bodies are vastly different. PM-FAO56 provides a reliable estimate of daily evaporative loss in hot, arid countries as daytime, incoming solar radiation is the dominant driver. However, the results of energy balance methods indicate night-time evaporation can be 0 - 20% of the daily total (Craig et al. 2006). Using both methods, the rate of evaporative loss per day for an on-farm water storage in south-east Queensland was calculated as 5 mm day^{-1} over summer, ± 2 – 7 mm depending on meteorological conditions (Craig et al. 2007, McJannet et al. 2011).

Infra-Red scintillometry and barge-mounted eddy covariance (ECV) atmospheric measurements have be developed to assess evaporation above the actual water surface (McJannet et al. 2008a, 2011, 2013 and McGloin et al. 2014a, 2014b). The water surface energy balance is calculated as:

$$R_n - S_w - S_a + Q_r - Q_p - Q_s - H - E = 0 \quad (2)$$

where R_n is the net radiation (measured over the water surface), S_w is the change in heat stored within the water column, S_a is the change in heat stored in the air column below the net radiation measurement height, Q_r is the energy added through rainfall, Q_p is energy addition or removal via inflows or outflows, Q_s is energy transfer to sediments beneath the water, H is the sensible heat flux, and E is the latent heat flux.

The eddy covariance technique has been used successfully to provide more direct measurements of evaporative loss on large lakes in North America (Friedrich et al. 2018), but accuracy depends on measurements being taken over the reservoir (not by the shore) or immediately at the shoreline. The instruments are also expensive, and generate masses of data requiring sophisticated analysis. Energy balance methods remain the most cost-effective methods for routine monitoring, as well as in situ pan evaporation data incorporated into the national USA water model (NOAA).

Regional estimates of long term average evaporation from farm storages based on point potential evapotranspiration can be accessed through the Australian Bureau of Meteorology (BOM), and the on-line SILO database (Qld Department of Environment and Resource Management in co-operation with BOM) provides daily synthetic data on evaporation for any set of co-ordinates in Australia. This data is useful for regional analysis of evaporation loss, when combined with information on location and area of storage dams. The Ready Reckoner used for evaluating the economics of evaporation mitigation technologies uses such regional estimates of evaporation.

Key Findings on Estimating Evaporative Loss

- Penman-Monteith FAO 56 evaporation estimates are based on macro-scale processes only.
- Government Meteorological Bureau provide local estimates of evaporative loss using water balance models based on P-M FAO 56 incorporating data from automatic weather stations.
- Water balance methods, based on water depth changes, indicate the Penman-Monteith FAO 56 method does not account for night-time evaporation.
- Evaporation during the night may range from 0 to 20% of the daily total.
- Newer infra-red scintillometry and Eddy Covariance methods more accurately measure evaporative loss, but are expensive and technically sophisticated to operate and analyse.
- Energy balance methods remain the most cost-effective evaporation monitoring option.

4.5 Measuring Seepage and Evaporative Loss from Storages

Water balance methods have been used to distinguish between water lost to evaporation, and water lost to seepage (Craig 2006). Pressure-sensitive transducers calibrated for water temperature have proven accurate for measuring water depth fluctuations. Druck PMP4030 Pressure Sensitive Transducers (PSTs) have shown an accuracy of within ±1 mm and have their own battery and solar panel and data logger. The principle of operation is through a pressure difference across a diaphragm. One side of the diaphragm is exposed to air pressure through a vented cable, and the other is exposed to water pressure at the installed depth. The unit has a range of 0 to 3.5 m (water), with an accuracy of ±0.02 %. Thus, over a 3.5 m range, the accuracy is ±1 mm. This means that the recorded value of depth will be, at a maximum, either +1 mm or -1 mm from the real value. The sensor has a compensated temperature range from +0°C to +50°C, and should be operated within this range to maintain stated accuracy.

Regression techniques calculate the average daily seepage rate and a dam evaporation factor (k_{dam}), which can be used to convert a PM-FAO56 estimate of evaporative loss to an actual rate of evaporation for a specific water storage. Software has been developed by the University of Southern Queensland to automate analysis and the technology has previously been licensed to consultants to undertake storage assessment. The cotton industry has been particularly active in measuring storage seepage and evaporation losses as shown in Table 5 (Wigginton 2011), where evaporation losses were shown to be generally much greater than seepage losses.

Table 5: Seepage and evaporative loss rates from 136 cotton irrigation storages in the Condamine, Lower Balonne and Namoi catchments of Southern Queensland and Northern New South Wales.

The Irrimate™ Seepage and Evaporation Meter incorporated water depth data from pressure-sensitive transducers located under the water, and evaporative loss data from an automated weather station on the shoreline, to derive seepage and evaporative loss rates, and the dam factor correction for PM – FAO56 evaporation estimates produced by government meteorological services (from Wigginton 2011).

	Mean	Minimum	Maximum
Seepage (mm day^{-1})	2.3	0	38.1
Evaporation (mm day^{-1})	4.16	2.82	5.97
Dam factor (K_{dam})	0.97	0.67	1.31
Storage capacity (ML)	1,950	75	14,000
Storage area (ha)	44	1	303
Water depth (m)	3.5	1.0	9.1

The water balance approach provides a practical approach for estimating aggregate losses due to evaporation. The approach is based on a comparative volume flow analysis:

Change in volume = Inflow + Rain – Outflow – Seepage – Evaporation (3)

For periods when there is no inflow, outflow or rainfall and for small incremental time steps when surface area is constant, the equation simplifies to:

Change in water depth (mm) = Evaporation (mm) + Seepage (mm) (4)

Thus by measuring changes in water depth the net change in evaporation and seepage can be determined. When using the water balance method the usual unit is mm/day. The relatively poor accuracy of flow meters (in relation to the requirements for this application) suggests the best approach is to focus on periods when there is no inflow/outflow or rainfall. The accuracy of this method depends greatly on the accuracy of the equipment used to measure the change in water depth. Precision pressure sensitive transducers (PSTs) are now generally used at locations where stilling wells with floats and rotary encoders or capacitance or ultra sound probes cannot be used. Water level can be logged continuously at sub-millimetre accuracy and in short time steps to identify the changing rate of water loss.

The most difficult parameter to measure in Equation 4 is seepage. Potentially, soil analysis, infiltrometer readings and electromagnetic surveys undertaken before storage filling can be used to get some idea of seepage loss. However, these estimates, as well as point-based piezometer readings, are generally unreliable and not applicable to farm storages already holding water. The approach of most water balance studies is to record rate of change of water depth, calculate evaporation using the best available model and by subtraction deduce seepage (Craig et al 2005 and Craig, 2006). A regression approach can be used to account for systematic errors in evaporation estimation and determine statistical significance and appropriate confidence levels in the estimated seepage and evaporation rates. The Irrimate™ Seepage and Evaporation Meter is based on water balance analyses. Water level is monitored to a mm accuracy every 15 minutes using PSTs. Rainfall, wind velocity and water temperature is also logged for use in the analysis which requires at least 20 days quality data with no periods of rainfall and storage inflow/outflow.

The output of Irrimate divides storage losses into seepage and evaporation. Growers can reduce seepage losses by improving the compaction of the subsoil base, or by lining the base with clay or bentonite (Cotton Info 2018). The cost of inorganic liners (e.g. Clay or bentonite), is substantially less than fabric liners (e.g. Polyethylene or butyl rubber in Table 6), but where irrigation storages are limited in size (0.1 to 3 ha, 5 to 10 m depth) and the price of water is high (as in the horticultural region of South-eastern Spain; Martinez-Alvarez et al. 2008) fabric liners are considered cost-effective. Evaporative and seepage losses of up to 85% throughout the 17,000 km earthen channel system in the Wimmera region of Victoria, Australia motivated the Grampians-Wimmera-Mallee Water Authority (GWM Water) to replace the channels with 9,159 km of PVC pipe, at a cost of $688 million (GWM Water 2018).

Table 6: Relative cost of strategies to reduce seepage from water storages.

Soil with a high clay content can be compacted to form a lining, requiring a thickness of 300 to 600 mm. Fabric liners may be cost-effective, but issues such as uplift under groundwater pressure or wind turbulence, damage from exposure to ultraviolet light, and damage from tree roots and animals needs to be considered (from Table 6.2 in Lewis 2002).

Materials	**Material ($/m²)**	**Machinery ($/m²)**	**Manual Labour ($/m²)**	**Total Price Range ($/m²)**
Soil stabilisation				
Bentonite	7	4	1	2-10
Bitumen/soil mix	3	3	-	4-10
Cement stabilised soil	0.5	3	1	4-10
Compacted soil	-	3	-	2-15
Fabric Liners				
Black polyethylene	2	-	0.5	2-5
Woven polyethylene	3	-	0.5	4-8
PVC membrane	5	-	0.5	4-8
Hypalon	14	-	1	10-20
Butyl rubber	12	-	1	10-20

Key Findings on Measuring Seepage versus Evaporative Loss

- Water balance models using data from pressure-sensitive transducers under the water and Penman-Monteith FAO 56 evaporation estimates allow estimation of seepage and evaporative losses from a storage.
- The Irrimate Seepage and Evaporation Meter has been used widely to quantify these losses for landholders, improving their capacity to make cost-effective decisions before structurally modifying water storages, or before purchasing and installing liners or covers.
- Evaporation losses from storages have generally been shown to be much larger than seepage losses. However consideration needs to be given to reducing seepage losses when they are shown to be large.

4.6 Biological and Chemical Processes at the Air-Water Interface

The laminar layer and the capillary waves (Figure 4) form the microlayer, a zone exposed to high solar radiation where pollen, dust and other fine, particulate, humified organic matter concentrate under the force of surface tension. This zone has a significant impact on the evaporation process and in particular on the performance of molecular chemical films. Microbial activity feeding off the carboxylic acids, alcohols, aromatic rings and aliphatic chains (humic substances) within the microlayer is typically 10 to 100 times greater than within the bulk phase (Norkrans 1980, Cunliffe et al. 2011). Derived from the bark, leaf and stem litter washed into water courses or seeping down the soil profile to the water table, humic organic substances are responsible for the characteristic dark brown colour of many Australian water storages (Pittaway and van den Ancker 2010, Fellman et al. 2013).

The brown pigment acts as a chromophore, absorbing ultraviolet light which excites and modifies chemical bonds within the humic substances (Brinkman et al. 2003). The energy captured during this process may be released as chemically reactive compounds such as hydrogen peroxide (Garg et al. 2011), responsible for the 'cleansing' known to occur within natural microlayers. These often waxy, amphiphilic (containing a water-loving head and water-repellent tail), humic, organic compounds may pack together to form localised patches of high surface pressure, reducing the surface tension of the water. These calm, glassy or oily patches of water, often occur close to the shore where wind and wave action physically compress the compounds (Figure 5). The surface pressure induced by natural microlayer compounds is insufficient to reduce evaporative loss (Figure 4), as the molecules lack the uniformity and regularity required to increase the resistance of the liquid thermal and gaseous boundary layers (surface pressure range of 13 to 25 mNm^{-1} ; Barnes 2008).

Adaptations of aquatic microbes have evolved to exploit humic substances in the microlayer include the development of cellular hydrophobicity (required to enter this layer), and the secretion of biosurfactants to improve bacterial adhesion to these rich, microbial substrates (Bouchez-Naitali et al. 1999). Attached bacterial communities are highly diverse in the water column, as the organic aggregates they attach to are not evenly distributed, most commonly concentrating in the microlayer (or neuston; Cunliffe et al. 2011). Artificial 'aggregates' including floating covers and modules applied to the water surface to reduce evaporative loss, will also be colonised by these microbes (attached bacteria and algae, also referred to as periphyton). Attached algae may be more adapted to shading than free-living bacteria and algae, in part due to the relative stability of the physical structure they have attached to in the water column (Hill et al. 1995).

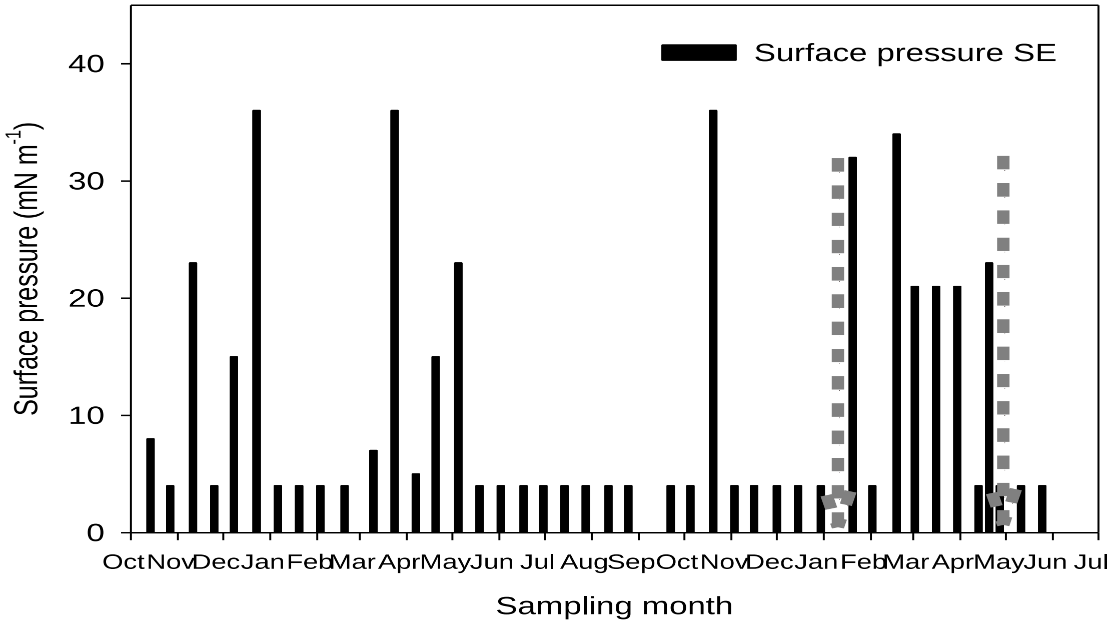


Figure 5: Surface pressure readings for the microlayer of an irrigation storage dam (Logan's Storage, Lockyer Valley).

Surface pressure readings were recorded every two weeks from a dinghy drifting parallel to and within 2 m of the South Eastern (SE) shore (from Pittaway and Matveev 2017). The average capacity of the dam was 509 ML (surface area 480 m x 350 m, maximum volume 700 ML, maximum depth 6 m; McJannet et al. 2013). Dotted arrows indicate the start and end of monolayer application, when surface pressure was within 13 to 25 mNm-1 range known to effectively retard evaporative loss (Barnes 2008).

Figure 6: Microcystis algal bloom beached on the shoreline of Logan's storage.

The calm water from the shore to where ripples in the water are evident is the surface pressure induced by the natural microlayer (Pittaway and Matveev 2017).

Free-living (planktonic) bacteria and algae more commonly residing in the bulk water, will also be affected by artificial substrates placed at the water surface, due to shading and thermal stratification (Wetzel 2001). Wind turbulence over open water generates surface waves, which in turn generate bulk thermal convection in the upper layer (epilimnion) of the bulk water (Figure 4). In the absence of wind, a warm surface skin may increase the thermal stability of the upper layer of the water, effectively isolating it from the colder, deeper layer (thermal stratification). Cyanobacteria (blue-green algae) have an advantage over green algae under conditions of stratification, as gas vesicles (a buoyancy adaptation) enable them to rise vertically into the warmer, lighter zone (Ganf and Oliver 1982). Photosynthesising cyanobacteria and algae exploit the inorganic nutrient loading of open, shallow water storages, which may affect water quality by reducing the dissolved oxygen concentration, increasing the organic solids and dissolved organic matter concentration, and in the case of some cyanobacterial species, by increasing the concentration of liver and neurological toxins and allergens in the water (Water Resources Management Committee 1994).

On-farm water storages are prone to algal blooms due to the accumulation of phosphorus in dam sediments (Ruan and Gilkes 2000), and from nitrates entering the storage in run-off from pastures and crops (Brainwood et al. 2004). Total P in 56% of pond and dam water samples monitored in the Western Australian study (Ruan and Gilkes 2000), exceeded the 0.02 mg L^{-1} concentration considered eutrophic (nutrient-enriched, increasing the likelihood of algal and/or cyanobacterial blooms). In the New South Wales study (Brainwood et al. 2004), even the minimum recorded concentration of total P in two of the three farm dams exceeded 0.02 mg L^{-1}. Total nitrogen in water from the three dams ranged from none, to well above the 0.65 mg L^{-1} concentration considered eutrophic (Dodds 2002). In a southeast Queensland study (Pittaway and Matveev 2017), total N and P were consistently above the thresholds considered eutrophic, and the total phytoplankton biovolume in summer consistently exceeded the Queensland algal bloom alert level of 4 mm^3 L^{-1}. These massive blooms of cyanobacteria were evident as an oily, dark green surface scum (Figure 6). Cyanobacteria are able to exploit high P concentrations and low dissolved inorganic N, as many species are capable of fixing atmospheric nitrogen (Havens et al. 1998). Deeper water storages are less prone to algal blooms as the nutrient-rich sediments may not be as regularly resuspended (increased turbidity) in the water column. Increasing the residence time of water within a storage also reduces nutrient concentrations, provided the resuspension of P from sediments is small (Schindler 2006).

Key Findings on Biological & Chemical Processes at the Air-Water Interface

- The microlayer is a biochemically, biophysically and biologically active micro-scale zone at the air-water interface of all water storages.
- Ultra-violet light absorbed by chemically complex organic molecules in the microlayer induces the chemical breakdown of organic compounds (photodegradation).
- Chemically complex, heterogeneous microlayer compounds compressed by wind or wave action are responsible for the localised calming of capillary waves (increased surface pressure).
- The surface pressure induced by natural microlayer compounds is below the threshold required to reduce evaporative loss.
- Surface-active aquatic algae and bacteria attach to physical substrates, including microscopic organic aggregates and larger floating structures (eg. floating covers).
- Total nitrogen and phosphorus concentrations in farm dams may often be above the levels likely to induce algal blooms over the warmer summer months.

4.7 Evaporation Mitigation Technologies

There are a range of evaporation mitigation approaches currently used in Australia, including structural and storage management strategies, suspended covers, floating covers and molecular chemical films. This section of the report reviews past international and local research on the performance of products and strategies in reducing evaporative loss, and their potential to adversely affect the environment and water storage infrastructure. Details of products and suppliers operating in Queensland have been given in Chapter 5.

Candidate products which have been objectively tested, including purpose-designed and manufactured products, and repurposed, recycled products have been included. Selection criteria for both types of product must include physical performance in reducing evaporative loss, durability and ease of containment to maintain the surface coverage necessary for optimal performance, 'food grade' materials unlikely to leach harmful chemicals into the environment, and the practicalities of installation, repair and removal. Care must be exercised when considering untested, low-cost options including bottles, tyres or other recycled 'waste', which are unlikely to meet these performance criteria.

Many plastic containers degrade when exposed to strong, ultraviolet light, potentially polluting the water both physically and chemically. Tethering the multiple units required to achieve adequate surface coverage would be difficult, with uncontained modules posing a hazard to downstream ecology and infrastructure. For example, 96 million spherical food-grade plastic balls 100 mm in diameter (designed to deter water birds from airport environs), had to be removed from a 175 ha municipal water storage in Los Angeles when they were implicated in the photochemical formation of the suspected carcinogen bromate (refer Section 4.7.4). These balls may also not have effectively reduced evaporative loss, as fluid films adhering to overturning surfaces readily evaporate. Larger low-cost options including tyres and inner tubes would also not meet the performance criteria, as these regulated waste products may leach toxic compounds into the water and are a physical hazard to downstream infrastructure.

Use of recycled waste or repurposed products in the absence of objective testing against specific performance criteria, is therefore not recommended.

4.7.1 Structural and Storage Management Strategies

Overview:

Structural modification most commonly involves raising storage wall height and/or splitting a single large storage into two or more cells. Evaporation mitigation is achieved by reducing the surface to volume ratio of each cell. Configuring a storage into multiple cells also reduces evaporative loss if the water level in at least one cell is managed to increase the depth and residence time, leaving other cells empty. The earth works required for structural modification incurs a high, one-off up-front cost, off-set in part by the opportunity to ameliorate seepage loss. A shelter belt of trees perpendicular to the prevailing wind of smaller (< 1 ha), regularly shaped storages may achieve a reduction in evaporation of up to 30%. Reducing evaporative loss by mixing thermally stratified water columns with bubble plumes generated by a submerged compressor may not be as effective as previously thought, due to the resistance to evaporation induced by a thermally stable, warm surface film.

Evaporative loss is much greater for shallow water storages with a high surface to volume ratio (Watts 2005). Strategies for reducing the surface to volume ratio include increasing dam wall height, and splitting a storage into multiple cells (Table 7and Figure 7). Building the storage to the maximum permissible height is the most immediate option for a storage designer to minimise evaporation losses. The cost of increasing storage embankment height is considerable, as the compaction required to retain the water in the storage is much higher (more passes of a sheep foot roller), and the width of the crest must also be greater for each incremental increase in height (Lewis 2002). The cost of structural storage management strategies in $/ML water saved is generally quite low (<$200/ML), and there are no additional ongoing operational costs with this approach.

Modifying an existing storage to reduce evaporation losses may have a number of constraints particularly where the storage volume needs to remain constant. Within the Federally funded Sustainable Rural Water Use and Infrastructure Program (SWUIP; implemented in Queensland as the Healthy Headwaters Program 2018) the main application for mitigating evaporative loss was to increase storage heights to 8 m. A major impediment for adoption within the SWUIP was compliance to ensure there was no increase in the take of water, as previous regulations limited storage height to 5 m. Height restrictions depend on the Water Resources Plans for each catchment. In some catchments height restrictions have been lifted from 5m to 8m. Exceeding this height requires additional compliance conditions such as a failure safety impact assessment.

Splitting a storage into multiple cells enables a maximum depth to be maintained in fewer cells over time, effectively reducing the surface to volume ratio (Watts 2005, McJannet et al. 2008a, and Appendix 1.1). Most commonly this is achieved by dividing the storage into two equal or unequal sized cells by constructing a new internal wall (Table 7), or adding a cell by constructing new embankments outside of the existing storage. Evaporation reduction will be maximised by managing the total volume of stored water within the smallest number of cells, completely emptying some cells as required (zero evaporative loss). Pumping water held in supply channels, sumps, head ditches and tail drains back into the major storage after irrigation and major rainfall events also effectively reduces the surface to volume ratio of the system, and therefore reduces the rate of evaporative (and seepage) loss.

Table 7: Structural management examples for reducing evaporation and seepage losses.

Reduction value is based on before and after evaporation and seepage per unit of water stored, calculated with the Evaporation and Seepage Ready Reckoner (www.readyreckoner.ncea.biz; Healthy Headwaters Program 2018. Details of these examples are in Appendix 1.1).

Property	Existing Storage	Modification	Evaporation Reduction	Seepage Reduction	Water Saved $/ML/yr
St Ruth, Darling Downs split storage x2	1,200 ML 22 ha	x2 573 ML x2 10.1 ha	53%	44%	$285
South Callandoon, Border Rivers split x2	3,963 ML 130 ha	x2 1,935 ML x2 62.6 ha	51%	48%	$15
Moorcroft, Darling Downs split x2	350 ML 7.5 ha	78 & 235 ML 1.7 & 5.3 ha	29%	20%	$170
Moolabah, St George Raise wall height	3.0m, 780ML, 29.9 ha	4.5m, 1460 ML, 33.9 ha	59%	61%	$161
Doondi, St George Raise wall height	5.0m 3850ML 74 ha	9.0m 7590ML 74 ha	51%	51%	$159
Armet Waters, St George, raise wall	5.0 m 900ML 23.1 ha	10.m 1620ML 23.1 ha	56%	56%	$163

Tree shelter belts close to a water storage can also effectively reduce the rate of evaporative loss by reducing wind energy (Hipsey and Sivapalan 2003, Helfer et al. 2009). Air passing over hot, dry land forms turbulent cells of very low humidity (eddies), with internal temperatures exceeding 40○C (Craig et al. 2006). The energy in eddies increases evaporation as wind blows across a water body (advection), with the impact greatest at the upwind boundary of the storage (the fetch). Trees increase surface roughness and evapotranspiration increases humidity, reducing the energy in these eddies.

Figure 7: Proposed storage structural modification to 130 ha farm storage dam

Storage dam at South Callandoon (see Table 7 and Appendix 1.1.2) Calculations based on the Evaporation and Seepage Ready Reckoner (www.readyreckoner.ncea.biz; Healthy Headwaters Program 2018).

An evaporation model with a shelter index (height of the trees, wind-permeability, the fetch, and the orientation of the tree belt to the prevailing wind) was developed and tested at two sites in south-western, Western Australia (Hipsey and Sivapalan 2003). A reduction of 30% in evaporation was recorded for small dams (area 3,600 m^2), but the reduction modelled for larger storages in Southeast Queensland with lower or no embankments and with fluctuating water levels (variable distance from water's edge to the shelter belt) was much lower (1.1 to 3.8% annually; Helfer et al. 2009). Root micro-channels extending into earthen embankments may also increase seepage, requiring one of the remedial strategies listed in Table 6.

For most larger, deep water storages currents induced by bulk thermal convection (Figure 4) regularly mix deeper cooler, nutrient-rich water with the upper warmer, lighter epilimnion (Wells and Sherman 2001). Energy balance studies predict the thermally stable stratification which may establish in water bodies during calm, warm weather should increase the rate of evaporative loss (Helfer et al. 2011). Methods which cost-effectively disturb the thermocline, mixing cold, deeper water with the heated upper layer should therefore reduce evaporative loss. Fluid entrainment in bubble plumes generated by an air compressor placed at the base of a storage has been considered one option. Evaporative reduction rates of 15% over a semi-arid summer and 9% over winter were calculated using energy mass balance principles for one 53 ha, 15 m deep Californian lake, but a study of paired, smaller storages instrumented with thermocouple sensors at 50 mm intervals below the surface indicated the evaporative reduction was only 1% (Youssef and Khodzinskaya 2019). Modelling results for a 17 ha, 6.5 m deep irrigation storage in the Lockyer Valley, Qld. indicate the bubble plume method may only reduce evaporative loss by 2.5% (Helfer et al. 2011).

New insights gained from similarly instrumented, paired tank studies with and without suspended covers in Toowoomba, Qld. (Pittaway et al. 2015b) and in glasshouse studies in southern Spain (Gallego-Elvira et al. 2013) indicate the warm surface film on thermally stratified water may provide a significantly greater resistance to evaporative loss than previously considered. Within the liquid thermal and gaseous boundary layers the transport of water molecules and heat is by diffusion (Gladyshev 2002). The surface roughness induced by capillary waves with a cold surface film reduces the resistance of the gaseous and liquid thermal boundary layers to molecular diffusion (Figure 4), increasing the rate of evaporation. Relatively minor changes including the imposition of a thermally stable, warm surface film (no capillary waves, therefore reduced surface roughness; Fellows et al. 2015) increase the resistance of these boundary layers to evaporative loss (refer section 4.3, The Evaporative Process). These dynamics may explain why methods such as bubble plume entrainment designed to remix stratified water may be counter-productive. The model the authors used for the impact of bubble plumes on evaporative loss would not account for these micro-scale boundary layers. They concluded better results may have been achieved with deeper storages (more than 18m; Youssef and Khodzinskaya 2019), prone to stratification (Helfer et al. 2011).

Key Findings on Structural and Storage Management Strategies

- Reducing the surface to volume ratio of a storage by dividing it into two or more smaller cells or by increasing wall height provides reliable long-term evaporative reduction.
- The familiarity of landholders with the earthworks and machinery required to undertake structural modification of a storage may assist with the adoption of this strategy to reduce seepage and evaporative loss.
- Improving the compaction of the storage base or lining the storage with bentonite or a fabric liner during earthwork modification also provides long-term seepage reduction.
- Altering management practices to increase the water depth and residence time in at least one cell and by pumping all water from distribution channels and sumps into the storage also reduces evaporative and seepage losses.
- The Evaporation and Seepage Ready Reckoner enables landholders to accurately quantify both the volume of water lost from their storage, and the dollar value of water that would be saved by undertaking the recommended structural modification.
- Pre-existing tree shelter belts perpendicular to the prevailing wind and close to a small storage (< 1 ha) may reduce evaporative loss by up to 30%, but roots may increase seepage.
- Macro-scale modelling of the increase in evaporation during thermal stratification has motivated researchers to use bubble plumes from a subsurface air-compressor to re-mix the water column. Micro-scale energy balance studies suggest the lack of success with this technique may be due to the resistance to evaporative loss imposed by a warm, thermally stable surface film.

4.7.2 Suspended Continuous Covers

Overview:

Shade cloth can be suspended above water surfaces by a cable structure which results in reduced net radiation and wind velocity at the water surface. Given the maximum span that the structure can be suspended over, which is around 120-150m, storage size is typically limited to under 5 ha. Larger storages (up to 15 ha) can be covered if support columns are constructed in the storage.

Evaporation mitigation with suspended covers is achieved by reducing wind and wave turbulence and the transmission of solar radiation. Rain passes through the porous cover, typically fabricated from woven, double or single layered polyethylene mesh. Algal growth is inhibited by covers reducing solar transmittance by more than 90%, improving water quality. Up-front costs are high as high tension cables, fabric seams, fixings and the anchorage system must withstand wind, snow and hail. Suspended covers facilitate regular storage inspection, sampling and maintenance.

Suspended, continuous covers were first deployed to protect high value horticultural crops from hail and storm damage. Suspended covers reduce evaporative loss by reducing wind turbulence and net radiation at the water surface, and by increasing the vapour pressure (Martinez-Alvarez et al. 2006). A double layered black woven polyethylene (PE) fabric was particularly effective in reducing evaporative loss (83.5% less than an uncovered tank; Table 8), and in capturing water vapour as condensate overnight. The reduction in wind turbulence beneath this cover induced a thermally stable, warm surface skin, stratifying water temperature at depth (Pittaway et al. 2015b). Temperature stratification was maintained until rain drops falling through the cover induced turbulence, reinstating a cold surface skin and forced convection.

Many potable water management authorities favour the use of suspended covers as the reduction in transmitted light (Figure 8) substantially reduces algal growth, reducing odour and equipment fouling problems (Hunter 2002, Finn and Barnes 2007, Maestre-Valero et al. 2011 and 2013). However, the high tension cabling and anchorage required to suspend covers are expensive and technically challenging to install and maintain, especially where hail and/or snow collect on the fabric surface (Finn and Barnes 2007). Product performance varies with the fabric and installation method. NetPro Pty Ltd first installed a cover on a 3.8 ha storage at Stanthorpe 17 years ago. Since then 10 covers have been installed for the protection of high value horticultural crops, shade for feedlots, evaporation reduction for council storages, and covers for treated wastewater. The canopy can be installed without or with water in the dam, using pontoons.

Suspended covers are preferred by managers of potable water storages as the elevation above the water surface (Figure 8, for product examples refer Appendix 1.2.1 and 1.2.2) allows for maintenance, operational access and inspection.

Suspended covers vary from cable-suspended net, tower-supported cable domes, post-supported cable domes, and air-supported covers (Levy 2010). The fabric used for suspended covers varies from aluminium mesh, coloured or black woven shade cloth, and black PE mesh (Martinez-Alvarez et al. 2006, Finn and Barnes 2007, Craig et al. 2005).

Key Findings on Suspended, Continuous Covers:

- The tensile strength of the fabric and the high tension cables, poles and anchorage required for suspended covers increases their cost. Costs reduced to around $9/m^2 for large storages (< 15 ha)
- Familiarity of landholders with structures used to protect crops from weather damage may improve the adoption of this technology in some regions. More than ten units have been installed in Australia by NetPro, one operating for 17 years with few technical challenges and limited maintenance.
- Suspended covers allow ease of access for basin monitoring, maintenance and management. Installation can also be undertaken on storages holding water.
- Covers which block out light improve water quality by inhibiting algal growth.
- The evaporative reduction achieved by suspended covers ranges from 50 to 90% but is typically over 70%.

Figure 8: A double-layer black woven polyethylene cover over a lined reservoir in Spain

Suspended covers allow ease of access for maintenance and sampling, and light exclusion reduces algal growth in potable water storages (photograph from V. Martinez-Alvarez).

Table 8: Efficacy of continuous, suspended and floating covers in reducing evaporative loss

Light reduction is the decrease in light transmitted through the cover. PE is polyethylene. Evaporation reduction is the reduction relative to an equivalent uncovered tank or storage.

Fabric	Installation Method	Light reduction (%)	Storage Area	Evaporation Reduction (%)	Authors
Single black monofilament shade cloth	High tension cables & poles	≥ 90%	10 m dia tank, 3.8 ha storage	68%, 70%	Craig et al. 2005
As above	Tented cable & poles	As above	x4 storages 0.09–1.0 ha	Estimated at 90%	Finn& Barnes 2007
Single/ double white PE shade cloth	Metal frame 0.3 m above water surface	48.9%, 61.5%	Class A evap pan	54.7%, 68.5%	Martinez-Alvarez et al. 2006
Single /double black woven PE	As above	93.6%, 99.2%	As above	75.1%, 83.5%	As above
Single green or blue PE shade cloth	As above	88%, 78.7%	As above	76.2%, 77.6%	As above
Aluminium mesh	As above	66%	As above	51.5%	As above
Double layer black woven PE mesh	High tension polyamide cables& posts	99.6%	0.24 ha	85%	Gallego-Elvira et al. 2011

4.7.3 Continuous Floating Covers

Overview:

Continuous floating covers are a single floating impermeable barrier that generally covers 100% of the water surface and are most commonly made of a plastic material (e.g. polyethylene) although numerous materials have been trialled. Impermeable covers can reduce evaporation from 70 to 100%. They are generally suitable for storages of less than 5 ha as a single cover. Tethering systems need to be designed to account for fluctuating water levels. Given the engineering challenges of deploying single floating covers across a storage, suppliers are now favouring placement in sections, tethered together and allowing easier removal.

Systems range from impermeable pool type covers designed for regular removal, to permanent, permeable covers for water storages which are anchored into embankment and support pedestrian access to reach hatches and vents for water sampling, drainage and pumping. Guidelines are available for liners and covers suitable for potable water storages. Tethering systems can be used to position a floating system, which covers only a portion of the dam.

Covers for excluding debris, insulating water temperature and reducing evaporative and chlorine loss in domestic and municipal swimming pools have been used for a long time. At worst, the equivalent of non-ultraviolet light stable 'bubble wrap' may be sold as a pool cover, at best the Pool and Spa Cover Association of Australia (PASCAA) have developed a Fit for Purpose Certification Scheme based on eight test requirements, to be conducted by an independent National Australian Testing Authority (NATA) approved testing facility (Anon 2012).

The capital cost of floating covers is high, with a lifespan of 5 to 10 years (Appendix 1.2). Covers must be tethered to avoid beaching and obstructing spillways and other reservoir infrastructure, and are not suitable for storages experiencing large water level fluctuations. Multiple covers can be deployed as a series of large, tethered rafts covering up to 1ha each, reducing the risk of structural failure.

The Layfield Group is a North American manufacturer of flexible geo-membrane products with a background dating back to 1978. They provide specialised engineered products and solutions in Australia for geo-membranes, floating covers, and soil reinforcement projects.

Daisy Pool Covers have a commercial division supplying and installing dam covers with material supplied by Sealed Air Australia. The company are able to supply the former EvapCap product, however they have their own similar product which has design improvements and is intended to be laid in sections (large modules).

Floating covers are generally manufactured from scrim-reinforced polypropylene, forming a complete seal over the surface of the storage, ballasted to keep the cover taught and aid in the collection of rainwater. A demonstration storage (E-EvapCap™) was established at St George in 2003. The product was a 'bubble-wrap,' lightweight, UV resistant, multi-layered, impervious polyethylene membrane 450 microns thick, with a life expectancy of 5 years (Craig et al, 2005).

The dense underside of 13mm ‘bubbles’ provided buoyancy, and multiple 25mm diameter apertures on the surface were permeable to rainwater. The cover was anchored in a trench or tethered to the sides of the storage. Of the five floating cover options available in 2012, four are available locally in 2020, EvapCap, the Layfield REVOC product, the Daisy Dam Cover and Fabtech product. Typically evaporation savings are 70 % to above 90% for a fully covered storage (Table 9).

Guidelines exist for flexible membrane covers and linings for potable water reservoirs (AWWA 2000, SA Water 2019), including a comprehensive glossary of terms used to describe the components of covers, supporting structures, and the pipes and maintenance schedule required for the reservoir to function. In the South Australian Standard (SA Water 2019), the recommended design life of covers and liners is 25 years, and products must comply with AS/NZS 4020: Testing of Products for Use in Contact with Drinking Water. In accordance with these standards, liners for use on potable water storages should not support the growth of microbial biofilms, or harbour bacteria or the growth of fungi. A rainwater removal system should also be included in the design and installation of continuous floating covers. Design considerations include site selection, climatic conditions, air vents, projections, wind, access and drainage, piping, material selection, extractives, seams, and quality control. Standards are also provided for civil construction of embankments, system functionality and water quality, and the installation, operation, inspection and maintenance of floating covers and linings, as well as testing criteria and performance specifications.

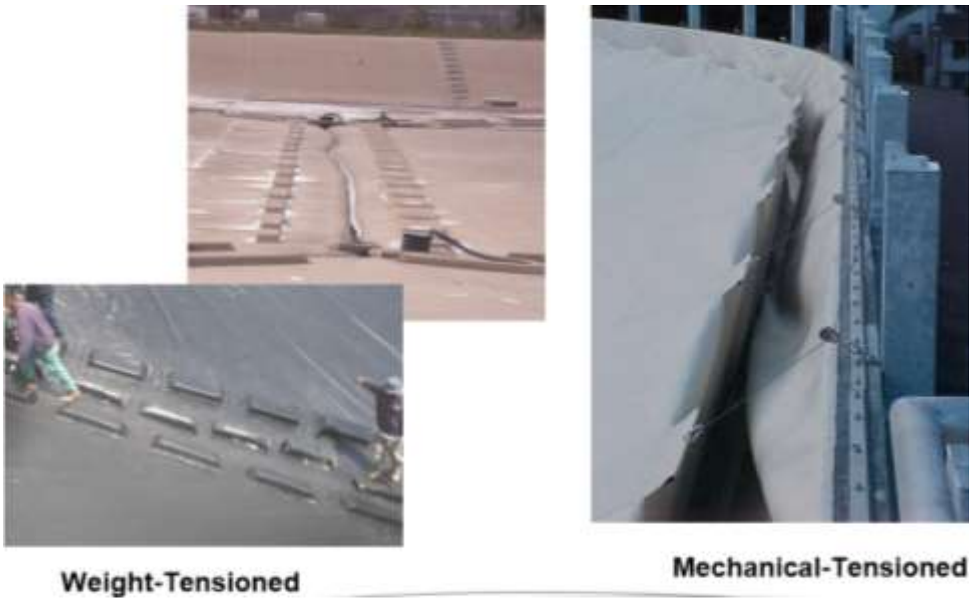


Figure 9: Tethering systems for permanent, continuous floating covers

Weight-tensioning allows for pedestrian access across the cover for maintenance inspections (Cooke 2008).

Floating covers do not require high tension cables, supports and anchorage but do require stabilisation at the perimeter (Figure 9), and proximity to the water makes access for storage basin maintenance difficult (Craig et al. 2005). The mode of attachment or stabilisation also affects the efficacy of the cover in reducing evaporative loss (Table 9), and deployment may be limited to smaller, more regularly shaped storages (less than 2 ha) requiring the regular removal of the cover (Yao et al. 2010). Debris collects on the surface the longer the cover remains installed, resulting in weed colonisation and submergence (Craig et al. 2005). Holes designed to allow rainwater collecting on the surface to drain into the storage also promote the capillary rise of stored water onto the fabric, increasing the rate of evaporative loss (Assouline et al. 2010).

Equations for estimating evaporative loss from different sized perforations in covers and from open water between modules can be used to compare the performance of floating covers and modules in reducing evaporative loss (Assouline et al. 2010 and 2011). The scale of openings in perforated floating covers and between modules varies from millimetres to centimetres. The vapour pressure over multiple, smaller openings coalesces over the entire cover surface, reducing the resistance of the gaseous boundary layer to evaporation. Fewer, larger holes maintains a higher vapour pressure, improving the efficiency of the cover in reducing evaporative loss.

Table 9: Efficacy of continuous floating covers in reducing evaporative loss

Light reduction refers to the decrease in light transmitted through the cover. Evaporation reduction refers to the reduction relative to an equivalent uncovered tank or storage.

Fabric	Installation Method	Shading (light reduction %)	Storage Area	Evaporation Reduction (%)	Authors
PE white surface, black 'bubble' base	Floating with sealed edges	n.a.	10 m dia tank	ave 96% (94 – 100%)	Craig et al. 2005
As above	Floating with open edges	n.a.	As above	ave 91% (83 – 97%)	As above
As above	Desktop modelling study	n.a.	31.2 km^2	Estimated 73%	Yao et al. 2010

The evaporation reduction efficiency (ε; Assouline et al. 2011) is calculated as:

$$\varepsilon = 1 - \beta \frac{(T_w - T_a)_c}{(T_w - T_a)} \quad (5)$$

Where β is the proportionality constant, T_w and T_a are the temperature of the water and air surfaces, for the uncovered and covered (c) portions of the surface. The authors concluded suspended covers were less efficient than floating covers in reducing evaporative loss. Results from Martinez-Alvarez et al. (2006) and Pittaway et al. (2015b) suggest this may not necessarily be the case when the suspended fabric substantially reduces wind turbulence below the cover, and when vapour diffusing into the air under the cover during the day condenses during the night, falling back into the water.

Key Findings on Floating, Continuous Covers:

- Australian Industry Certification Scheme, and State (SA) and Industry (USA AWWA) Guidelines for floating covers and supporting structures, installed over potable water storages, are available and may improve adoption by potable water managers.
- Floating covers best suit storages less than 2 ha in area and save and have a high capital cost ($8/m^2 to >$20/m^2 2012 prices).
- Debris and weed growth will reduce the performance of covers left on the storage for a long time. Drainage of rainwater below the cover is a key challenge.
- Fewer, larger apertures in a cover increases the resistance to evaporation relative to multiple, smaller apertures of the same total surface area.
- Effective in reducing solar incidence and reducing water temperature for control of algae in treated waste water ponds.
- The evaporative reduction achieved by floating, continuous covers ranges from 73 to 96% but should be >90% for a fully covered storage with sealed edges.

4.7.4 Modular Floating Covers

Overview:

Modular covers consist of a series of individual floating units typically constructed from food-grade, high density polyethylene (HDPE) plastic which can be tethered or contained within a specific area. Modules may be purchased and replaced incrementally, with the reduction in evaporation proportional to the total surface area of the water covered by the units. Ballasted modules are more effective in reducing evaporation than rotating spheres (eg. unballasted bird balls), as thin water films on an overturned surface evaporate rapidly. Modular covers must be tethered or contained on storages with spillways and other infrastructure, to avoid obstruction.

Floating, modular covers were initially developed to inhibit bird access on water bodies close to airport runways (bird balls). More technical design analyses have improved the stability and packing of modules, reducing evaporative loss by up to 90% with full surface coverage. Modular covers are best on storages of up to 5 ha with a longer water residence time, or on lined storages where the likelihood of modules sticking in mud is low. The attachment of aquatic microbes to modules over time may pose a risk to potable water quality.

Modular, floating covers were first deployed as simple spherical floats, to prevent water birds from accessing water bodies close to airport runways (bird balls). Sufficient balls would be released onto the water surface, with as little space between as possible. The concept was extended to the design of floating modules to reduce evaporative loss (Assouline et al. 2010 and 2011). Smaller diameter, spherical bird balls with multiple, smaller openings between modules were not as efficient in reducing evaporative loss as larger, semi-submerged spheres packing less tightly (for product examples refer to Appendix 1.2.8 to 1.2.12). Floating modules with fewer, larger areas of open water between units will increase the evaporation reduction efficiency of a partially covered system, relative to the same area of open water surface subdivided into multiple, smaller openings (as in some continuous floating covers).

Other authors have adopted a theoretical, proportionality approach to the design of floating modules (Figure 10), which reduce evaporative loss by reducing wind turbulence and solar radiation under and between adjacent modules (Segal and Burnstein 2010; Table 10). The white, non-toxic polyethylene circular floats had a convex, sealed air-filled upper section for buoyancy (planar area 0.363 m^2), and a lower, submerged, perforated pan that filled with water to ballast the module against excessive drift and overturning. Overturning or rolling increases evaporative loss due to the exposure of thin water films adhering to the surface of the module, to wind and solar radiation (Busuttil et al. 2011; Table 10). Over time algae may also attach to floating modules (periphyton), increasing the adhesion of water (increasing evaporative loss) if the modules are susceptible to overturning.

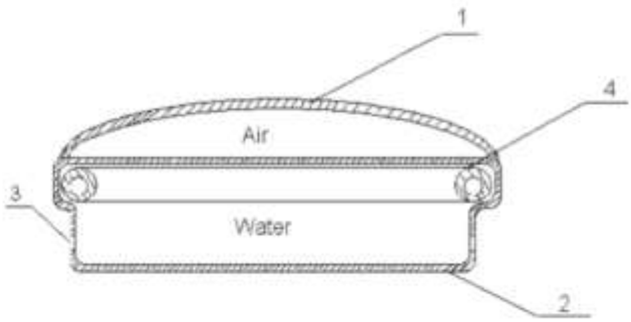


Figure 10: Design criteria for a floating module

See Segal and Burnstein 2010 in Table 10. The module has a convex, air-filled chamber to shed water (1), a partially submerged base (3) with perforations for water ballast (2), and a sealed air-filled torus for buoyancy (4).

Floating modular covers have a very high capital cost (in excess of \$15-20/m^2), which can be off-set by incremental purchase. Systems evaluated in Australia included a prototype circular design (AquaCaps; Howard and Schmidt 2008 in Table 10) and a hexagonal design (AquaArmour; Symes et al. 2009 in Table 10) as well as a product developed in Israel (NeoTop; Scobie and Schmidt 2018 in Table 10), and a prototype rectangular design (Raftex; Craig et al. 2005 in Table 10). None of these products are currently marketed in Australia. Only one of the twelve modular systems reviewed by Schmidt and Scobie (2012), is available in 2020 (Appendix 1.2.8). The product Hexa-Cover originating from Denmark, is now marketed and will soon be manufactured in Australia (Appendix 1.2.14). Selection criteria (Howard and Schmidt 2008) for floating modular covers for evaporation reduction should include:

- The product must not bend or twist out of shape, and must be ballasted for greater wind and wave stability.
- Modules must be UV-stable, and must not fragment.
- The removal and disposal of modules at the end of their design life must also be considered.
- On large storages with only partial cover coverage, modules must be aggregated or tethered.
- Modules must shed water and must not overturn.

Modular floating covers reduce the surface area available for evaporation, wind and wave turbulence, and solar transmission. The maximum evaporative reduction achieved is a function of the sum of the uncovered space between units at full surface coverage. In one prototype trial on a 1 ha storage (Nylex 'AquaCap' trial at North Parkes Rio Tinto Mine in NSW; Howard and Schmidt 2008; Table 10), the total surface area covered by the modules was 90%, achieving an 85% reduction in evaporative loss. At less than full coverage, evaporative reduction is linearly proportional to the reduction achieved at full coverage. Free floating modules may concentrate on the downwind margins of storages, where evaporation rates are greatest (Craig et al. 2005). Some companies (eg. AQUA Guardian Group, AquaArmour modules) recommend tethering or containing modules, to reduce gaps between units and to reduce the risk of obstructing spillways and other downstream infrastructure.

The AquaArmour hollow hexagonal pods (no longer available) were constructed from High Density Polyethylene (HDPE) with six sealed flotation chambers located around the perimeter. Water ballast entered vents located at the top and base, partially submerging the modules to improve wind and wave stability (Symes et al. 2009; Table 10). At full capacity 64 modules covered 81% of the surface area of a 10 m diameter tank at the University of Southern Queensland Toowoomba (USQ), achieving an evaporation reduction of 73%.

Raftex was a prototype modular cover consisting of a perforated rectangular plastic pipe (50 or 75 mm diameter) frame 12 m by 2 m, braced internally with plastic rods placed every 2m, and externally with several layers of UV stabilised adhesive film wrapped around the frame. Holes in the film and pipe partially filled with water, improving wind and wave stability (Craig et al. 2005; Table 10). At full capacity five modules covered 68% of the surface area of a 10 m diameter tank at USQ, with an evaporation reduction of only 56%.

The NeoTop Top-Up System developed in Israel is made of two identical half shells, with a sealed float in the middle (Scobie and Schmidt 2018; Table 10). Water entering holes on the top, bottom and sides partially submerges each module, improving wind and wave stability. At full capacity 595 modules covered 70% of the surface area of a 10 m diameter tank at USQ, reducing evaporative loss by 70%. Reducing the number of units to 416 (70% capacity) reduced the evaporation reduction to 49%, and with 179 units (30% capacity) the evaporation reduction was 21%. These results indicate the reduction in evaporative loss is linearly proportional to the combined surface area covered by the modules and linear regression equations can be used as a guide to the cost-effectiveness of modular cover deployment (Symes et al. 2009, Scobie et al. 2018, Lehmann et al. 2019; Table 10). IN another study larger discs (200 mm diam. 20 mm thick styrofoam) were more effective in reducing evaporative loss than smaller spheres (40 mm diam. polyethylene), but the different radiative properties of black versus white modules of the same size class had no significant impact (Lehmann et al. 2019). Totally covering large water surfaces with modules may be impractical, especially where the water level may fluctuate widely, and where modules stuck in dried sediment may not readily re-float (Craig et al. 2005; Table 10). Some products (e.g. NeoTop and AquaArmour) are promoted to recondense water evaporating in the module, thereby improving evaporation mitigation.

Figure 11: Floating modules drifting across a 10 m diameter tank in Toowoomba.

See Symes et al. 2009 in Table 8. Sixty four of the 1.006 m^2 hexagons covered 81% of the surface area.

More practical approaches have included recycling low-cost, locally available materials including recycled polyethylene terephthalate water bottles part-filled with soil (to prevent rolling; Simon et al. 2016; Table 10), and date palm leaf fronds (Al Hassoun et al. 2011; Table 10). The floating palm fronds did not adversely affect water quality over the eight month duration of the trial, achieving a 55% reduction in evaporation when the pool surface was fully covered, and a 25% reduction when half-covered (Table 10). Water quality issues forced manages of a potable Los Angeles municipal water storage to remove modular 'bird balls' (96 million 100 mm diam. HDPE spheres covering the 175 acre surface area of the storage; Kavanaugh 2016), due to the formation of the suspected carcinogen bromate in the water. A light-impermeable, suspended cover was installed instead, to exclude the solar radiation responsible for the photochemical conversion of bromide and chlorine to bromate.

Table 10: Efficacy of floating modular covers in reducing evaporative loss

Surface coverage is the total area of the water surface covered by modules. Evaporation reduction refers to the reduction relative to an equivalent uncovered tank or storage

Module Description	Module Planar Area	Reservoir Surface Area	Surface Coverage (%)	Evaporation Reduction (%)	Authors
PVC pipe frame with layers of adhesive, UV-stable film. Pipes perforated for ballast. (Raftex)	12 m x 12 m square	10 m dia tank, 0.7 m depth	x5 units 68% coverage	56%	Craig et al. 2005
Circular white polypropylene discs that semi-submerge in water. (AquaCap)	1.15 m dia	0.63 ha	Estimated 80 – 90%	85%	Howard & Schmidt 2008
HDPE hexagon with x6 flotation chambers, vents top and base for ballast. (AquaArmour)	1.006 m^2	10 m dia tank, 0.7 m depth	x64 units 81.4% coverage	73%	Symes et al. 2009
Convex, circular air-filled top, perforated base for ballast.	0.68 m diam.	0.5 m dia tank, 1 m depth	80%	51%	Segal & Burnstein 2010
Date palm fronds on wooden frame with corner floats	Frame 1 m x1 m	10 m x 5 m, 1.5 m depth	95%	55%	Al Hassoun et al. 2011
Tennis balls, clean polyethylene (PE) balls, slimed PE balls	0.063 m, 0.052 m dia	0.37 m^2 surface area	29% tennis balls, 17% PE balls	32% > evap tennis b. 36% clean, 34% slimed	Busuttil et al. 2011
Recycled water bottles, in tanks at x2 locations (Mildura, Sydney)	0.065 m diam.	1.05 m square tank	x16 units 68%, x8 34%	37%, 20% arid site, 43%, 27% coastal site	Hassan et al. 2015
Recycled PE terephthalate water bottles, soil for ballast.	500 mL volume	1.5 m dia tank, 270 mm depth	'Packed surface' (no data)	40%	Simon et al. 2016
White convex, circular discs, central sealed float. Perforated top & base for ballast. (NeoTop)	0.33 m diam.	10 m dia tank, 0.7 m depth	850 units at 100%, x 595 at 70%, x 255 at 30%	70% 48%, 21%	Scobie & Schmidt 2018
Counter-weighted (5 g) HDPE spheres	0.1 m diam.	1.00 m^2 pans	91%	86%?	Han et al. 2019
White or black polyethylene spheres, white or black 40 mm thick styrofoam discs	Spheres 0.04 m dia, discs 0.2m	1.2 x 1.2 m^2 tank, 0.16 m depth	91%	70% B& W spheres, 80% B& W discs	Lehmann et al. 2019

Floating modules have also been used in salt gradient, solar thermal pools to improve heat storage in the lower convective zone (equivalent to the epilimnion in Figure 4). In this application the modules are used to reduce wind and wave turbulence, with a thermally stable surface skin and thermal stratification (no convective mixing) increasing heat storage (Ruskowitz et al. 2014, Silva et al. 2017). Transmitted solar radiation stored as heat is used in renewable energy applications including domestic heating, power production and agricultural crop dehydration. In one laboratory study evaporative loss (latent heat loss) was reduced by 47% when 88% of the surface was covered with transparent discs (petri dish lids), increasing heat storage by 22% (Ruskowitz et al. 2014). In another study hollow, fused silica spheres (20 mm diameter) reduced thermal loss by up to 50%, with the loss in solar radiation only 5% (Tetreault-Friend et al. 2018). The silica spheres resist the corrosive effect of the brine and are highly transparent to solar radiation, reducing convective, radiative and latent heat loss (evaporation).

Key Findings on Floating, Modular Covers:

- Only two of the modular systems reviewed by Schmidt and Scobie (2012), are available in 2020, a new product Hexa-Cover is soon to be manufactured locally.
- A range of mechanical, durability and technical constraints will affect the cost effectiveness of a product when the cost is amortised over its life.
- Capital cost is high, generally around \$20-\$40/m^2, with evaporation reduction a function of the packing and space between modules.
- The evaporative reduction achieved by floating modules covering at least 68% of the water surface is 85%. Evaporative reduction at less than full modular coverage is linearly proportional to the total surface area covered.
- Spherical or cylindrical modules which expose fluid films to evaporative loss on rolling (eg. bird balls) are less efficient in reducing evaporation than ballasted, non-rolling modules.
- Multiple, smaller diameter apertures between modules will be less efficient in reducing evaporative loss than fewer larger apertures.
- The option to incrementally purchase modules and a decision support tool to compare products and the evaporative reduction associated with the number of modules deployed may assist with the adoption of this technology.
- Aquatic algae attaching to floating modules may adversely affect water quality, and modules may not re-float once stuck in the mud of empty storages.

4.7.5 Modular Floating Photovoltaic Cells

Overview:

The design of modular floats to support photovoltaic (PV) cells on water storages has reduced the land footprint of solar PV systems, with reduced panel temperature improving the efficiency of power generation. The up-front cost is high, and guidelines need to be developed to improve the safety of power transmission over water. Floating PV systems are suited to storages with a long water residence time, where the high cost is offset by the power generated. The evaporation mitigation efficiency of this system will be proportional to the surface area covered by the modules. The prime motivation for floating PV systems will be solar energy generation, with evaporative reduction proportional to the surface area of the water covered by modules.

The greatest advance in floating modular covers which also reduce evaporative loss over the last 20 years has been in floating photovoltaic (PV) cells (Sahu et al. 2016, Ranjibaran et al. 2019; Figure 12 and Figure 13). Floating PV systems reduce the land footprint and evaporation, with the reduction in panel temperature improving power generating efficiency by 11%. Floating PV modules have application in improving the renewable energy efficiency of pumped hydroelectric power systems (Liu et al. 2019), in reducing evaporative loss and the cost of pumping for shrimp farms (Campana et al. 2019), irrigated agriculture (Santafe et al. 2014), and lagoon wastewater treatment systems (Rosa-Clot et al. 2017). Most of these projects are in the early stages of development, with few, well monitored and documented case studies of the power generation and evaporation reduction capacity of these systems (Table 11). Several modelling and optimisation studies indicate this technology could be widely deployed, providing cost-competitive on- and off-grid renewable energy and water-conserving power generation systems (Rosa-Clot et al. 2017, Pouran 2018, Campana et al. 2019, Liu et al. 2019, Spencer et al. 2019).

The capital cost of floating PV systems is slightly higher or comparable to land-based systems, and as the economy of scale improves, the deployment of new systems should be cost-competitive in countries with ambitious renewable energy targets and high solar PV feed-in tariffs (World Bank Group 2018). In 2017, China established the biggest floating PV solar power plant (70 MW capacity) on the 148.4 ha surface of a flooded, abandoned coal mine, covering 43% of the surface area with 194,700 solar panels and 52,000 floating parts (Pouran 2018; Table 11). The environmental impact of the structural, floating elements used to construct PV solar arrays on water chemistry is considered minimal (Casini et al. 2018), but safety issues relating to conveying electrical power from the water to the land will need to be addressed (Sahu et al. 2016).

Figure 12: Design specifications of the Spanish Isifloating modular floats to support photovoltaic panels

The Photovoltaic panels are purchased separately. The system has the capacity to power 138 Wp / m2 with 350 Wp panels. Each float weighs 240 kg. The 5○ tilt angle is designed to resist wind turbulence. (https://www.isifloating.com/isifloating/).

Figure 13: Floating photovoltaic panels installed at the East Lismore Sewage Treatment plant

The photovoltaic panels were supplied and installed by Suntrix, using Ciel et Terre floats and solar PV panels (Griffiths 2018, and Appendix 1.2.15).

Clear, specific regulations and guidelines will need to be developed, and local pilot projects may need to be established to realise the potential of this system for both on-farm, municipal, and industrial water storages. The potential of this rapidly growing, emerging technology to replace fossil fuel-based power generation with decentralised, renewable, on- or off-grid floating PV arrays is high (Spencer et al. 2019, World Bank Group 2018, for product examples refer to Appendix 1.2.13 to 1.2.15), with the prediction floating PV power plants deployed across as little as

12% of the surface area of 27% of the 24,419 man-made water storages in continental United States could replace 10% of the current national power generation capacity (Spencer et al. 2019).

Table 11: Efficacy of floating photovoltaic cells in reducing evaporative loss and generating renewable energy

Surface coverage is the total area of the water surface covered by modules.

Module Description	Reservoir Surface Area	PV Surface Coverage (%)	Evaporation Reduction (%)	Energy Generation	Authors
Medium density PE pontoon 2.3 x 2.3 m with x2 PV panels (pilot x30 pontoons, full scale x750)	Maximum storage capacity 20,000 m^3	Prototype 7% (350 m^2), full-scale 4490 m^2	Full scale, 25% stored water saved	Prototype 28,349, full scale 2940,549 kWh/yr	Ferrer-Gisbert et al. 2013, Santafe et al. 2014
194,700 solar panels on 52,000 pontoons, 8.5 MW power plant in China.	148.4 ha flooded disused coal mine	63,58 ha (43% coverage)	Estimated 80% reduction (no data)	70,005 kW capacity (no data)	Pouran 2018
Ciel et Terre International floating PV system Japan	3.1 ha potable water reservoir	1.16 ha (38% coverage)	As above	1180 kW capacity (no data)	As above
Ciel et Terre International floating PV system UK	128 ha potable water reservoir	5.95 ha (5% coverage)	As above	6338 kW capacity (no data)	As above
Floating PV potential in Australia & Oceania	4,991 km^2 (254 water storages assessed)	Scenarios of 1%, 5%, 10% coverage @ 5, 25 & 50 GWp capacity	Not considered	6,713 GWh/yr @ 1%, 33,565 @ 5%, 67,131 @ 10%.	World Bank Group 2018

Key Findings on Floating, Modular Photovoltaic Cells:

- Floating PV systems are more efficient in generating solar power than land-mounted systems due to the lower temperature of the panels, and their reduced land foot-print.
- The potential for increasing renewable energy production with floating PV units is great, but there are very few well documented case studies available.
- Guidelines and regulatory standards will be required to improve the efficiency and safety of these on or off-grid power generation systems.
- The prime motivation for floating PV systems will be solar energy generation, with evaporative reduction proportional to the surface area of the water covered by modules.

4.7.6 Mono-Molecular Chemical Films

Overview:

Artificial monolayers are biodegradable chemicals which spread across the water surface, packing to a depth of one molecule to retard evaporative loss by up to 70%. Artificial monolayers mimic the natural microlayer, with minimal impact on gas transfer across the water surface and on aquatic ecology. Variable field performance is due to high wind speed during the trial, and the photodegradation potential of the stored water. Monolayer products differ in their susceptibility to indirect photodegradation, and must be matched to the water quality of the storage.

Monolayers are not as reliable as other methods in reducing evaporation because they biodegrade, with wind, waves, UV radiation, water quality, algae and bacteria affecting film integrity and longevity. Artificial monolayers are suited to repeat, intermittent application on storages of any size up to 100 ha, from multiple autonomous applicators programmed to operate only when wind speed is low (≤ 3 ms-1). After application a monolayer film is visible as a glassy region of calm water.

The main advantage of monolayers is the low initial setup cost and the ease of repeat application only when required, for example when the dam is full and during periods of high evaporation. Floating containment barriers may be used to prevent the film from beaching on embankments.

The main impediment for adoption of monolayer systems is the highly variable field performance and the uncertainty of water savings. Further research and development of products, application and monitoring systems is required for this technology to mature before it becomes a viable option. Technologies associated with the use of monolayers are still relatively immature and the products are not considered market ready until consistent savings of around 30% can be demonstrated at a commercial storage dam scale.

Artificial monolayer products which spread spontaneously over the water surface to induce a surface pressure within 13 to 25 mNm^{-1} (range that retards evaporative loss), have been investigated since the 1960s (Barnes 2008, McJannet et al. 2008b). Only one commercial product has been readily available (WaterSavr – Appendix 1.2.17), a 1:9 mixture of the long-chain, fatty alcohols cetyl (C16OH; hexadecanol) and stearyl (C18OH; octadecanol) alcohol, formulated with hydrated lime as a carrier and dispersing agent. Other products which have been used experimentally in field and laboratory trials include emulsions of cetyl or stearyl alcohol (Herzig et al. 2011), and various formulations based on the compound ethylene glycol monooctadecyl ether (C18E1; Prime et al. 2012). Barriers to the commercial adoption of this technology include highly variable field performance (Table 12), and lack of an autonomous application system optimising the timing and rate of application to match local storage management requirements and micrometeorological conditions (Brink et al. 2011; Figure 14).

The most common method to validate the performance of candidate monolayer compounds has been laboratory-scale Langmuir troughs (surface area and depth at the mm scale) filled close to over-topping with high quality water (distilled or reverse osmosis). The instrumentation available with this apparatus has enabled researchers to investigate the physical chemistry contributing to the spontaneous spreading and evaporative reduction properties of mono and duo-layer formulations, enabling the design of more effective formulations (Henry et al. 2010, Leung et al. 2014, Li et al. 2014, Machida et al. 2003, Morei et al. 2004, Prime et al. 2012, 2013, Yiapanis et al. 2013, Wu et al. 2015). Performance criteria applied in these studies include a high equilibrium spreading pressure and spreading rate, and resistance to evaporative loss, wind stress and volatilisation. Monolayer candidates must also be biodegradable, with a sufficient half-life to cost-effectively retard evaporative loss (Barnes 2008). Results from these studies confirm the relative susceptibility of C16OH, C18OH and C18E1 to volatilisation, the improved spreading rate of C18OH formulated with the non-ionic surfactant Brij 78 (Herzig et al. 2011), and the greater stability and higher equilibrium spreading pressure of C18E1 (Prime et al. 2012).

Larger scale laboratory research has been conducted to calculate monolayer spreading rates and dispersion, to calibrate and deploy the autonomous dispensing units required to effectively cover the surface of a water storage with monolayer (Brink et al. 2017, Wandel et al. 2017). Tanks (5.8 m diam. 0.3 m depth) exposed to wind turbulence generated by an axial flow fan, were used to determine the monolayer drift velocity and the spreading angle. A model was developed to predict the angle and rate of spread of a C18OH emulsion at different wind speeds, to optimise the number and deployment of dosing units and the timing of monolayer application on a specific water storage. Other larger scale laboratory research includes the use of wave tanks (15 m x 0.46 m, 0.85 m depth), equipped with a wave paddle and wind tunnel (Palada et al. 2012, Schouten et al. 2012). Results from these studies confirm the better wind resilience of the C18E1B formulation over an emulsion of C18OH. (Table 12).

A more intensively instrumented, glasshouse mass balance study using class A evaporation pans and fans (zero, 1.5 m s^{-1} and 3 m s^{-1} wind speed) concluded the poorer spreading rate of the C18OH emulsion at wind speeds above 1.5 m s^{-1} reduced evaporative reduction below the performance of the commercially available C16OH:C18OH product (Gallego-Elvira et al. 2013, in Table 12). The C18E1 monolayer had the greatest wind resistance but in the absence of wind, performance was equal to the C16OH:C18OH powder. A key finding of this research was monolayer application conferred no additional resistance to evaporative loss when a warm surface film prevailed in the absence of wind (Figure 15). Under a positive, downward convective flux with no wind, monolayers still retarded heat conductance from the warm microlayer to the colder subsurface, but the resistance imposed by the warm surface skin was of a similar order of magnitude to the condensed monolayer (a reduction in surface roughness; Fellows et al. 2015). The increased resistance imposed by a warm surface skin also prevails under suspended covers which induce water stratification (Pittaway et al.

2015b, Figure 14). No additional evaporative loss was measured when a monolayer was applied under a double-layered, black polyethylene cover (Gallego-Elvira et al. 2010). Autonomous dosing systems need to be programmed to apply monolayer only at low wind speed (≤ 3 m s^{-1} in Table 12), when they will be most effective.

Figure 14: Experimental compound C18E1 spreading from an automated applicator on a brown water storage (Logan's Dam, Lockyer Valley) during monolayer application.

Desktop modelling using energy balance and Penman-Monteith evaporation models concluded monolayer application over extended periods (greater than 3 months) would result in an increase in heat storage, with evaporative retardation reducing as the new equilibrium heat storage capacity established (McJannet et al. 2008b). The annual savings in evaporation was calculated as 10%, substantially less than the figures reported from larger scale trials in Table 12. However, energy balance and Penman-Monteith models do not accurately represent the micro-scale dynamics of the liquid thermal and gaseous boundary layers (Figure 4), or the dual nature of condensed artificial monolayers in buffering subsurface water from convective heat fluxes (Fellows 2015, Gladyshev 2002, Gallego-Elvira et al. 2013).

The application of an artificial monolayer increases the viscosity of the surface, slowing down the cyclic motion of thermal convection at the air/water interface (Figure 4, Section 4.3). Thermal convection occurs at a slower rate (Saylor et al. 2000), reducing the energy available at the surface for water molecules to evaporate (greater resistance in the liquid thermal boundary layer). Theoretically, suppressing evaporation should increase heat storage (eg. McJannet et al 2008b). However, over night the slower rate of thermal convection exposes water molecules at the surface to the cooler air for a longer period, increasing heat loss relative to a clean water surface (Saylor et al. 2000). This dual property of a monolayer (increasing heat gain under a downward convective heat flux and increasing heat loss under an upward convective heat flux) may explain why repeat application of a monolayer under wind speeds of less than 3 m s^{-1} does not increase water temperature (Gallego-Elvira et al. 2013, Pittaway et al. 2015b). The formation of a condensed monolayer is also transient, readily disrupted by wind speed greater than 3 m s-1 and the much greater scale of thermal convection operating in the bulk air and water flows (Figure 4).

Figure 15: Sampling the microlayer from under a suspended cover

Sampling using a vacuum pump (not shown) attached to a floating, surface-skimming pipe (Pittaway et al. 2015b).Sensors attached to the central cover support recorded temperature at 0.5, 0.3 and 0.1 m above the base of the tank.

Figure 16: Sampling the microlayer with a perforated, Teflon plate

Surface water adhering to the partial vacuum of the honey-comb base of the plate is collected in a sterilised, non-stick pan (Pittaway and van den Ancker 2010).

Table 12: Efficacy of artificial monolayers in reducing evaporative loss

Evaporation reduction refers to the reduction relative to an equivalent tank or storage with no monolayer applied. C16:C18OH 1:9 is the commercial WaterSavr product formulated with hydrated lime (CaOH). Results from smaller scale trials have not been included, as these studies may over-estimate the efficacy of monolayers (Hancock et al. 2011).

Product Description	Application mode & rate	Reservoir location & size	Trial duration & repeat application	Evaporation Reduction (%)	Authors
C16OH: C18OH 1:9	Manual, 0.15 g m^{-2}	10 m dia tank, USQ Toowoomba	12 months Every 3 days	Ave 26% (10 – 40%)	Craig et al 2005
As above	Automatic 0.15 g m^{-2}	4.2 ha storage, Capella Qld	6 months Not specified	Ave 0% (0 – 0%)	As above
As above	As above	120 ha Dirranbandi Qld	6 months Every 3 days	Ave 19% (0 - 31%)	As above
As above	Automatic 350 g ha^{-1}	84 ha Bedok, Singapore	4 months, daily repeat application	25 – 40%	Babu et al. 2010
C18E1A & C18E1B exp formulation as suspension	Manual 18x mono-molec layer	18 x7.5m tanks 135 m^2 surface Dookie Vic.	14 days, 6x mono- molec every 3 days	C18E1A 0% C18E1B 50 – 60%	Prime et al. 2012
As above	As above	220 m^2 area channel Yanco NSW	As above	C18E1A 10 – 20%, C18E1B 20 – 30%	As above
As above, and C18OH suspension	As above	Wave tank 15 x 0.46 m Wind $3ms^{-1}$	2 days, Single dose only	C18E1A 18.2%, C18E1B 49.7%, C18OH 26.6%	Schouten et al 2012
C18OH suspension	As above	As above, wind $1.3ms^{-1}$	As above	C18OH 45%	Palada et al 2012
C16OH:C18OH 1:9, C18OH, C18E1 as suspensions	Manual, 6x monomolec layer	Evap pan wind 0, 1.5, 3 ms^{-1} glasshouse, Spain	7 days, 6x monomolec every 2 days	C16:C18OH 41, 68, 20% for wind 0, 1.5, $3ms^{-1}$ C18OH 13, 58, 32%, C18E1 40, 71, 58%	Gallego-Elvira et al 2013
C16OH, C16OH:C18OH 1:1, C18OH as emulsions	Manual 0.15g m^{-2}	Evap pans Touggourt, Algeria	33 days, 0.15g per m^2 every 3 days	C16OH 22.2%, mix 22.5%, C18OH 16.2%	Saggai et al 2018
C16OH:C18OH 1:9 , + and - CaOH	Manual 5x monomolec layer	0.04 m^2 tanks, wind 0, 3, 9 ms^{-1} Tehran, Iran	2 days, one application only	– CaOH wind 0, 3, 9 ms^{-1} 41, 15, 8% + CaOH, 59, 23, 13%	Mozafari et al 2019

Results from smaller scale trials may also over-estimate the performance of a given monolayer applied to a larger water storage (Hancock et al. 2011). At the millimetre scale (eg Langmuir troughs), the depth of water may be too shallow to allow for thermal convection operating below the microlayer. At the centimetre scale, the shelter provided by the edge of the bucket or trough protruding above the water and the limited fetch (reduced wind turbulence) may increase the evaporative retardation result achieved with a monolayer at a specific wind speed relative to the same conditions on a larger water storage. Only results from larger scale trials (metre scale) were included in Table 12.

Early monolayer research established C16OH was readily degraded by aquatic bacteria (Barnes 2008), due to the similarity of the long-chain fatty alcohol monolayer molecules to microbial storage compounds and to humified organic compounds present in natural microlayers (Pittaway and van den Ancker 2010). Other studies concluded monolayer application would reduce dissolved oxygen concentrations in the water by impeding gaseous diffusion and increasing water temperature, adversely affecting aquatic ecology (Barnes 2008, McJannet et al. 2008b). Results from a 10 m diam. tank study sampling the microlayer and water at depth with and without repeat application of a C18OH emulsion indicated monolayer application over 14 weeks did not increase water temperature, the biochemical oxygen demand or humified organic matter, and did not reduce dissolved oxygen (Pittaway et al. 2015c,Figure 14). Chemical extractives from a replacement liner, in the absence of monolayer application were more toxic to aquatic algae than C18OH, with species richness substantially reduced. However, a temporary increase in pH associated with the inclusion of hydrated lime in the C16OH:C18OH commercial product (product summary is provided in Appendix 1.2.16), was detected using a microlayer sampling method (no monolayer pH 7.9, C18E1 monolayer pH 8.1, C16OH:C18OH monolayer 10.2; Hancock et al. 2011; Figure 13). This rapid increase in pH may adversely affect microlayer ecology and surface-breathing aquatic larvae, and highlights the need to sample from the microlayer as well as subsurface water when undertaking toxicity studies.

Part of the highly variable performance of artificial monolayers applied to open water storages (Table 12) may relate to the micro- and macro-scale forces (Figure 4) driving evaporative loss during the trial. The other less apparent factor is the susceptibility of monolayer molecules to photodegradation within the microlayer (Pittaway et al. 2015a). Photodegradation is the fragmentation of chemical bonds resulting from the energy released when chromophoric molecules (aromatic or humified organic compounds containing unsaturated bonds) absorb ultraviolet light. Direct photodegradation occurs when the absorbed light energy fragments the chromophore molecule itself. Indirect photodegradation occurs when highly reactive chemical species released by the chromophore, fragment other adjacent molecules.

None of the available monolayer compounds are prone to direct photodegradation (they are not chromophores). C18E1 resists microbial degradation better than C160H or C18OH, but is the most susceptible of the available monolayer compounds to indirect photodegradation (Table 13). C18OH is more microbially resistant than C16OH, and resists indirect photodegradation. The photodegradation potential of the water needs to be considered when selecting a candidate monolayer product for application to a specific water storage (Brink et al. 2009).

Current research conducted by the University of Melbourne and funded by the Cotton Research and Development Corporation and the Federal Department of Agriculture and Water Resources is focussing on developing new products to mitigate against wind impacts on monolayers, including trials using barrier technology to minimise the impact of wind.

Table 13: Half-life (hours) of three monolayer compounds applied to clear, brown and black (humic) water exposed to sunlight (MJ/m2).

The potassium permanganate index (KMn I; permanganate chemical oxygen demand divided by dissolved organic carbon, mg KMnO4 consumed L-1, mg-1 of DOC) was used to characterise the concentration and chemical resilience of organic compounds present in microlayer water samples (methods Pittaway and van den Ancker 2010).

	Low Photodegradation (clear water)			**Moderate Photodegradation (brown water)**			**High Photodegradation (humic water)**		
	MJ/m^2	Hours	KMn I	MJ/m^2	Hours	KMn I	MJ/m^2	Hours	KMn I
C16OH	46.49	37	7.22	31.88	26	4.81	15.92	13	2.61
C18OH	59.35	47	7.22	41.97	34	4.81	19.11	15	2.61
C18E1	70.72	57	7.22	28.27	23	4.81	11.16	9	2.61

Key Findings on Mono-Molecular Chemical Films (Monolayers):

- Monolayers are not as reliable as other methods in reducing evaporation because they biodegrade and film spreading, integrity and longevity is affected by wind, waves, UV radiation, water quality, algae and bacteria.
- Variable field trail results (0 – 71%) can be explained by differences in wind speed during the trial, the wind resistance and spreading rate of different monolayer formulations, and the susceptibility of monolayer formulations to microbial and photo-degradation.
- Artificial monolayers must be re-applied to be effective, as they are similar to natural microlayer compounds and biodegrade within 2 to 3 days.
- The main advantage of monolayers is the low initial setup cost and the ability to intermittently apply only when required, for example when the dam is full and during periods of high evaporation.
- The main impediment to adoption is the highly variable field performance of monolayer films and the uncertainty of water savings.
- Further research and development of products, application and monitoring systems is required for this technology to mature before it becomes a viable option.
- Only one commercial product and two research formulations have been used in field trials (WaterSavr, C16OH & C18OH; a C18OH emulsion; a formulation based on C18E1.)
- Monolayer products are not considered market ready until consistent savings of around 30% can be demonstrated at a commercial storage dam scale.
- The impact of monolayer formulations on aquatic ecology must be assessed at the water surface (the microlayer), using microlayer sampling methods.
- Monolayer formulations must be matched to the water quality of the storage they are to be deployed on, and should be applied from autonomous dosing units only when wind speed is less than 3 m sec^{-1}.
- The dispersion angle and spreading rates of different monolayer formulations must be determined to inform the number and placement of automatic dosing units required on a specific storage, to achieve good monolayer coverage.
- Monolayer should not be applied during periods of water stratification, as the evaporative resistance imposed by a warm surface film is similar to or greater than the resistance imposed by a compressed monolayer.
- The adoption of this technology will depend on the development of a decision-support

4.7.7 Multi-Molecular Chemical Films

Overview:

Multi-molecular films develop when hydrophobic, water-immiscible chemicals form a slick over the water surface. Application rates are higher than for monolayers, with a longer half-life. The thickness of multi-molecular films may impede gas transfer across the water surface, adversely affecting dissolved oxygen concentrations and surface-active aquatic ecology. Multi-molecular films are suited for longer term, intermittent application to water storages where the integrity and diversity of aquatic ecology is a low priority.

Very few multi-molecular chemical films have been developed due to the adverse physical impact of thick surface films on biological processes (eg. increased resistance to oxygen diffusion). One product based on a silicone oil (polydimethylsiloxane or siloxane in Table 14) is considered relatively benign, as it biodegrades to carbon dioxide, water and silica or silicic acid once in contact with soil and water (van de Graaff 2007). However, the results of water quality testing on grab samples of bulk water are inconclusive, as no microlayer samples were analysed (Figure 15 and Figure 16) offer two sampling options) and key indices most likely to be affected by the surface film (dissolved oxygen and the biochemical oxygen demand) were not measured. When applied to 1 m diameter tanks, the product appeared as a highly reflective surface film (attracting flying insects at night), which resisted wind turbulence and heat gain (Hancock et al. 2011). The highly reflective nature of this film suggests the evaporative reduction associated with this product may be due to the albedo, with the slick reflecting incident solar radiation.

One large-scale trial (Tarcoola in Table 14; Bosshammer 2007) calculated a 50% evaporation reduction factor. However, the control storage used for this study was an evaporation pan, with a much smaller surface area than the 0.4 ha Tarcoola storage (McJannet et al. 2008b). The rate of evaporative loss from the smaller tank would be 10 to 15% greater than the larger storage, indicating the actual evaporative reduction value from the water storage was less than 50%. A recent survey of information available on the Aquatain website (Appendix 1.2.17) indicates the original Aquatain product based on silicone oil has been reformulated with a microbial insecticide, and is now marketed for mosquito control. A new product (WaterGuard) is being promoted. The product blends a polymer with the silicone oil and, according to suppliers, this results in improved evaporation mitigation capability. The product is typically applied at between 10l/ha and 50l/ha every 3 weeks. According to suppliers, a wide range of studies on environmental aspects and confirming non-toxicity of WaterGuard which is certified for application to drinking water in the US.

The only other published study on the performance of a multi-molecular film in reducing evaporative loss is from a small-scale, salt gradient solar pond where liquid paraffin was applied to the surface to reduce the heat loss associated with evaporation (latent heat loss; Sayer et al. 2017; Table 14). In this application, ambient temperature, humidity and evaporative loss reduced substantially after the 0.5 cm thick paraffin oil film was applied, with very little impact on solar radiation. Salinity gradient solar ponds are unlikely to harbour a diverse aquatic ecosystem, so the impact of thick oil films on gaseous exchange across the microlayer is unlikely to be of concern.

Table 14: Efficacy of multi-molecular chemical films in reducing evaporative loss

Evaporation reduction refers to the reduction relative to an equivalent uncovered (control) tank or storage with no monolayer applied. Evaporation reduction for the siloxane film is an over-estimate, as an evaporation pan was used as the control for the 0.4 ha farm storage (McJannet et al. 2008b).

Product Description	Application mode & rate	Reservoir location & size	Trial duration & repeat application	Evaporation Reduction (%)	Authors
Siloxane, a silicone-based commercial oil	7 L ha^{-1}	Tarcoola Dalby, 0.4 ha storage	Every 10 days	< 50%	Boshammer 2007
Liquid paraffin	0.5 cm layer	1 m^2 surface area salt gradient solar pond	Applied 12 days after control readings	100%	Sayer et al. 2017

Key Findings on Multi-Molecular Chemical Films:

- The physical property responsible for evaporation suppression in multi-molecular films is very different to mono-molecular monolayers.
- The impact of multi-molecular films on biophysical and biological process at the air-water interface will also be very different, and should be monitored using microlayer sampling techniques.
- The product Aquatain forms a highly reflective slick over the water surface, and most likely reduces evaporative loss by reflecting incident solar radiation (albedo effect).
- Wind resistance of multi-molecular films is likely to be greater than monolayers, and resistance to microbial and photodegradation may also be higher.
- The potential for thicker films to reduce gaseous diffusion across the air-water interface, adversely affecting aquatic ecology, indicates these products should be used on water bodies with low aquatic biodiversity, or where maintaining biodiversity is a low priority.

4.8 Conclusions from Literature Review

Adoption of storage dam evaporation mitigation systems in Australia has the potential to reduce evaporation losses by between 480,000ML/yr and 700,000ML/yr (Baillie et al, 2008). Reducing the water lost to evaporation and seepage in on-farm water storages in Queensland has the potential to save more than one hundred million dollars in tradable water. Water loss from storage dams is significant, typically accounting for 45% of the water lost on an irrigated cotton property. Given the average gross margin per ML of water can range from $185 to over $1,000 per ML these losses substantially reduce farm profitability (Baillie et al. 2008).

Estimates of the number of on-farm water storages derived from the Queensland Water Entitlements Registration Database may substantially underestimate the actual number, as satellite imagery in 2010 identified of the order of 92,000 water bodies (Baillie et al. 2010) and the current Queensland Government waterbody database indicates 243,000 water storages.

Monitoring evaporation and seepage is the first step to adopt strategies to reduce these losses. The Irrimate™ Seepage and Evaporation Meter has been used widely to quantify these losses for landholders, improving their capacity to make cost-effective decisions before structurally modifying water storages, or before considering purchase or installation of an evaporation mitigation system.

Many impediments to adoption of evaporation mitigation technologies remain. Climate variability and the uncertain cash flow associated with poor seasons and other financial, technical, biophysical, motivational and regulatory barriers must be addressed for landholders to have the confidence required to adopt the most appropriate evaporative mitigation system for their location and enterprise.

Product Selection

The selection of an evaporative mitigation system (Table 15) will depend on the size of the water storage, systems technical constraints, the capacity of the customer to outlay up-front capital costs, the value of the water (which may change at different phases of the crop production or water management cycle), and the value of the water storage as an ecological habitat.

The potential cost of installing and operating an evaporation mitigation system per unit of water saved ($/ML) will be a function of installation and maintenance costs, annual and seasonal evaporation losses from the storage location, efficiency of the system in reducing evaporation, and storage operating conditions. In agriculture, annualised system costs need to be compared with the value of water to the landholder, in terms of increased crop production, the cost of water to be purchased or the potential to trade water surplus. Urban water authorities make their economic analyses based on wholesale or retail price of domestic or industrial water, or in extreme cases the cost of alternative water supplies.

Structural and storage management strategies

Structural modification, such as deepening and introduction of cells, and the adoption of storage management strategies, may be most appropriate for dams with a surface area of more than 5 ha (estimated at 17% of licensed farm dams in Queensland (Table 1), but only 2% of all dams identified by satellite (Table 2), provided the storages are seasonally dry and the farmer can outlay the large, up-front costs of labour and earth-moving machinery. Familiarity with earthworks construction and machinery, and the ability to quantify with reasonable accuracy the quantity and cost of water saved will improve adoption. Structural modification offers the greatest storage management flexibility, achieving evaporative reduction of between 30 to 60%. The impact on water quality and aquatic ecology is minimal, once the earthworks are complete. Reconfiguring a storage into multiple cells has the advantage of increasing the depth and residence time of water in at least one cell (reducing the surface to volume ratio), which could be used to deploy floating photovoltaic cells. Power generated by the PV cells would offset the costs of pumping, but the design and purchase of the solar power system adds to the up-front costs.

Suspended continuous covers

Landholders in high-value horticultural production regions familiar with suspended covers (usually shade cloth) installed over crops to reduce weather damage, are more likely to adopt suspended covers as an evaporative mitigation system. Suspended covers are considered most appropriate for storages less than 5 ha, but can be used on storages up to 15 ha, potentially reducing evaporation by 50 to 90% (Table 16). Capital cost increases from around $\$9/m^2$ for a 15 ha storage to above $\$30/m^2$ for a 1 ha storage. Adoption is also more likely when an improvement in water quality is required, as the reduction of transmitted light by a suspended cover may substantially reduce algal growth with no impact on dissolved oxygen or rainfall ingress. The Australian company NetPro (Appendix 1.2.2) has recently increased the light reduction capacity of their woven fabric to > 90%.

Continuous floating covers

Continuous floating covers are best suited to storages less than 5 ha in area. The evaporative reduction achieved should be >90% for a fully covered storage but the system has a high capital cost and typically retailed at $\$8/ m^2$ to $>\$20/ m^2$ (2012 prices). Debris and weed growth will reduce the performance of covers left on the storage for a long time. Drainage of rainwater below the cover is a key challenge. Tethered, floating covers with pedestrian access and vents for pumps and water sampling are suitable for potable water storages, provided regular access to the storage basin is not required (Table 15). The availability of Guidelines and Standards for floating or tethered covers suitable for potable water may improve adoption (Table 16).

Modular floating covers

In Queensland, more than 80% of licensed farm water storages (Table 1), and 98% of all storages identified by satellite imagery (Table 2) have a surface area less than 5 ha, and are likely to be seasonally dry. There is the option of incrementally purchasing floating modules, however only two of twelve floating modular systems reviewed by Schmidt and Scobie (2012), are currently available. High capital cost, typically greater than $\$20/ m^2$ as well as a range of mechanical durability and technical constraints, are likely to limit adoption. The evaporative reduction potential achieved by floating modules is linearly proportional to the surface area they cover and can be up to 90%. Attached algae on both floating, continuous and modular covers may adversely affect water quality, and covers and modules may need to be removed from water storages during periods of low volume to avoid immobilisation in the sediment.

Tree shelter belts

Pre-existing tree shelter belts may provide a cost-effective evaporative reduction for farm dams less than 1 ha in surface area (Table 15), if the shelter belt is impermeable to wind, and is aligned perpendicular to the prevailing wind. However, there is significant variability in the actual evaporation mitigation of the tree shelter belts depending on the configuration of the storage, trees and prevailing winds.

Mono and Multi-molecular chemical films

The strategy considered by many to have the greatest market potential across all storage size classes has been the application of artificial monolayers. The ability to apply the film intermittently, at critical crop and water management periods is highly attractive to landholders. However, extreme variability in field trials, lack of informed technical guidance, the very limited availability of commercial monolayer products and applicators, and the technical knowledge required to select the right product and application system, discouraged landholders from adopting this strategy. Major advances over the last 20 years in the susceptibility of the three most commonly used monolayer products to microbial and photodegradation, in their spreading angle and rate, wind resistance and evaporative mitigation performance at the micro-scale, can be incorporated into decision support tools for the selection and cost-effective use of a monolayer and an application system.

The susceptibility of formulations based on C18E1 to indirect photodegradation has hindered recent product development. Formulations of C18E1 perform well on clear water with low concentrations of humified organic matter, but poorly on brown or black water storages where the half-life of the compound is reduced by up to 16% (Table 13). The only commercially available monolayer product (WaterSavr; Appendix 1.2.16) is less resilient to wind and microbial biodegradation than C18E1, but is more resistant to photodegradation. Any new formulations will need to be thoroughly researched and trialled, to enable landholders to confidently select the most appropriate product and deployment system for their farming enterprise (Table 16). The ability to apply the compound when the weather conditions are suitable is a significant driver to the cost benefit assessment of this product. More research and development will also be required to commercialise autonomous monolayer application systems.

The technical advances in monolayer science over the last 20 years does not apply to multi-molecular films, as the mode of action, application and spreading rate, susceptibility to microbial and photodegradation, and the physical and biological impact of the film on microlayer processes and aquatic ecology are very different. The application of multi-molecular chemical films may be limited to water storages where the reduction in gas transfer across the surface and the maintenance of aquatic biodiversity is a low priority (Table 15). Transparent, multi-molecular chemical films (eg liquid paraffin; Table 13) are highly effective in retarding evaporative loss and wave turbulence in salt-gradient, solar thermal ponds where the extremes of temperature and salinity would severely limit biodiversity. More information on the adverse effects of the commercial Aquatain product at the water surface (Table 15), and on the mechanism and minimum thickness of the film required to reduce evaporative loss, is required to improve the technical information available for prospective users.

Floating modular photovoltaic cells

The greatest technical advance in floating modular covers over the last 20 years has been in photovoltaic (PV) cells. While the prime motivation for floating PV systems has been solar energy generation, there is the secondary advantage of evaporative reduction proportional to the surface area of the water covered by modules. Floating PV systems are more efficient in generating solar power than land-mounted systems due to the lower temperature of the panels, and their reduced land foot-print. Guidelines and regulatory standards will be required to improve the efficiency and safety of these on or off-grid power generation systems.

Looking ahead

In a world of increasing water scarcity, selecting the most appropriate evaporative mitigation strategy has the potential to realise annual savings of hundreds of dollars per ML of stored water. However, financial, technical, biophysical, motivational and regulatory impediments must be addressed to provide the confidence and certainty landholders require to adopt new technologies. Decision-support tools are already available to assist landholders to compare structural modification options (eg. Evaporation and Seepage Ready Reckoner used in Table 6 and Appendix 1.1), and participation in storage monitoring programs are known to improve adoption and should be actively supported. Objectively monitored demonstration trials and financial support will also be required to realise the potential these evaporation mitigation strategies and systems offer to improve on-farm water use efficiency under changing, challenging climatic conditions.

Further research is required to develop a decision support tool for selecting a monolayer product suitable for the water quality of a storage, and for calculating the number required and the siting of applicators around the storage. Organisations receiving government funding to develop new monolayer products should be required to fully characterise the wind, microbial and photodegradation resilience of the product, and the angle and rate of spread.

The registration process of both mono-molecular and multi-molecular chemical formulations for use in Australia should specify the testing of treated microlayer and subsurface water samples for toxicity to aquatic organisms, and to gaseous diffusion across the air-water interface after the application of the formulation at recommended manufacturer rates and cost-effective field trail rates.

The development of standards and guidelines for the safe and cost-effective deployment of floating photovoltaic cells for solar energy generation on water storages.

Table 15: Summary of the performance and storage suitability of evaporation mitigation strategies

Strategy	Storage Operational Scale	Storage Suitability	Evaporative Reduction Potential	Implementation Costs
Tree shelter belt	< 5 ha	Tree belt must be perpendicular to prevailing wind	< 30%	Must be pre-existing
Structural & management change	5 to > 100 ha, regularly shaped (e.g. App 1.1)	Must be dry for earthworks	30 – 60%	High one-off cost with short payback period
Suspended covers	< 2 ha, up to 15 ha with support in dam	Potable water storages for algal control	50 – 90%	High, requires specialised installation, with 25 year lifespan
Floating continuous covers	< 2 ha	Potable water storages or swimming pools requiring regular cover removal	70 – 100%	High, requires tethering and edge sealing, with 10 to 25 year lifespan
Floating modular covers	< 5 ha	Lined storages as modules may stick in mud when storage empty.	20 – 85% proportional to surface area covered	High, tethering or containment may be required, with 15 - 25 year lifespan
Floating PV cells	Depends on power requirement	Power generation a higher priority than evaporation reduction	Proportional to surface area covered.	High, requires specialist installation, cost offset by on or off-grid power generation.
Chemical mono-molecular film (monolayer)	< 100 ha	Intermittent application, at critical water demand times. Must re-apply every 2-3 days	0 – 70% depends on monolayer suitability & applying when wind < 3 ms^{-1}	Low, but must have autonomous applicators programmed to local AWS for repeat doses.
Chemical multi-molecular film (slick)	< 10 ha	Agricultural or industrial storages where aquatic ecology not a priority. Must re-apply every 10 days	< 50%, (product application rate much higher than monolayer)	Low, but manual or automated or aerial application required for repeat doses.

Table 16: SWOT Analysis of Evaporation Mitigation Technologies.

Examples are of products previously as well as currently available in Australia. Refer Appendix 1 for a summary of structural modification strategies and currently available commercial products.

Mitigation Technology	Strengths	Weaknesses	Opportunities	Threats
Structural Modification (Increased wall height)	• One-off cost for long-term reduction in evaporative and seepage losses. • Improves water management options for reducing evaporative loss. • Easy to quantify water saving. • No ongoing maintenance cost.	• High up-front labour and mechanised plant costs. • Requires additional infrastructure (pumps, pipes etc.) • Construction cost increases significantly wit embankment height. • May increase seepage rate.	• Technical and practical design and construction experience is readily available. • Opportunity to combine two sallow storages into one deep storage of same volume.	• Regulatory limitations may restrict wall height • Farm distribution layout and conveyancing losses may offset water savings.
Structural Modification (Storage cells)	• Allows water depth to be maximised while reducing surface area • Reduced wind action • Easy to quantify water saving based on reduced area • Particularly useful for reducing losses during periods of low water availability.	• Lose volume (unless combined with increased wall height or external cells) • Effective if each cell is emptied completely • System has additional operational costs (labour, energy).	• Technical and practical design and construction experience is readily available. • Multiple cell management may be an advantage for the deployment of floating PV cells.	• Farm distribution layout and conveyancing losses may offset water savings
Suspended, Continuous Covers (eg NetPro, Superspan, Canvacon)	• High evaporation reduction potential. • Not affected by fluctuating water levels. • Permeable, flexible cover allows rain ingress & debris removal. • Easy access for pumping, water quality testing and maintenance. • Low ongoing operating costs.	• High up-front capital and specialist installation costs. • High cable tension & support requirements limit option to storages < 5 ha surface area (<15 ha with in-dam support). • Anchorage may be difficult in some soil types	• Cover selection for > 90% light exclusion substantially inhibits algal growth, improving potable water quality. • Existing expertise and experience available for design and installation.	• Specialist engineering skills required for design and installation.
Floating, Continuous Covers (eg Aquaguard, Daisy Dam Covers, Elite Pool Covers, Aquacon, Fabtech, Enviro Dam Covers, Layfields)	• Highest average evaporation reduction potential • Lowest variability in evaporation mitigation performance	• High capital and maintenance costs • High winds can damage cover. • Multiple small drainage holes required and may reduce efficacy.	• Reduces light penetration and potentially reduces algal growth. • Applicable for use on treated waste water storage dams	• Adversely affects aquatic ecology & wildlife access. • Cover must be removed for storage basin maintenance.

	• Relatively easy to install and remove • Guidelines and Standards are available for cover selection.	• Use of covers limited to < 2 ha • Debris build-up may damage fabric & cause submergence. • Tethering may be required to stabilise cover. • Access to storage basin may be difficult.		• Water saving will not be realised when storage is dry.
Floating, Modular Covers (eg Aqua Armour, AquaCap, E-EvapCap, , Hexa-Cover, Evapo-Control, NeoTop)	• Progressive purchase spreads cost over time. • Individual modules can be repaired or replaced. • Lightweight, easy to install. • Long-term evaporative reduction is proportional to the surface area covered.	• Very high capital cost. • Difficult to completely cover surface area. • Limited to storages < 10 ha • Modules may stick in mud. • Attached algae may affect water quality. • Modules physically disrupt wildlife.	• Easy to install and maintain. • Reduced light transmission may improve water quality.	• Modules may be beached by high wind and wave action
Floating, Photovoltaic Covers (eg Ciel et Terre, FloatPac Solar, Global NRG Afloat Solar, DNV GL, Suntrix Solar)	• Reduces land footprint of solar power generation. • Provides on/off-grid power for pumping etc. • Long-term evaporative reduction is proportional to the surface area covered.	• No guidelines available to reduce risk associated with power conveyance over water. • Very high capital cost & technical expertise required for design and installation.	• Off-grid power will reduce pumping costs. • Reduced panel temperature improves power generation efficiency.	• Very few case studies documented to-date. • Greater safety risks in conveying power over water. • Floats often sold separately to PVs
Mono-Molecular Chemical Films (eg WaterSavr)	• Biodegradable, ultra-thin film with low environmental impact. • Low capital outlay & intermittent application for medium to large storages. • Autonomous applicators improve cost-effectiveness. • Low risk investment for ephemeral storages as product applied only when needed.	• Requires repeat application under specific wind conditions. • Products are susceptible to indirect photo degradation. • Very limited range of commercially available products & applicators. • Low and highly variable evaporation reduction potential. • Monitoring of presence of product and performance is very difficult.	• Monolayer film can be applied to small, medium or large storages up to 100 ha. • Food-grade compounds degrading in 2 to 3 days minimises adverse impact on ecology and recreation. • Application can be reserved for critical water management times.	• Technical advice is required to select the product, the number of applicators and timing of application required for a specific water storage. • Environmental quality concerns • Actual performance and water saving is less certain.

	• Potentially viable system for large storages (>10ha)	• Not suitable in windy locations.	• Products can potentially be matched to suit different water quality.	
Multi-Molecular Chemical Films (eg WaterGuard by Aquatain)	• As above for mono-molecular • Longer half-life than monolayer. • Requires fewer repeat applications.	• As above for mono-molecular • Thick slick at surface may reduce oxygen diffusion. • Physical slick may adversely affect aquatic ecology • Very limited product range.	• As above for mono-molecular • Product may be applied by aircraft. • Application can be reserved for critical water management times.	• As above for mono-molecular • Mode of operation is different to monolayers, with greater environmental risk.

5 Part 2 - Market Assessment

Manufacturers, suppliers and users of a range of evaporation mitigation systems in Queensland were interviewed to assess the market for evaporation mitigation technologies and impediments to their uptake. Agriculture was the primary focus, with regional town water storages also considered. Discussions were guided by the questionnaire included in Appendix 2.

All suppliers indicated an interest in participating in demonstration trials. Case studies are included in Section 5.2 and Appendix 3.

Results are summarised in Section 5.3 and Table 17 which provides performance and pricing information for products currently supported in Australia. Table 18 provides information on the suitability of generic product classes, and Table 19 gives a checklist for considering the suitability of different product types.

5.1 Supplier Assessment

The following section summarises discussions held with current manufacturers, suppliers and installers of Evaporation Mitigation Technologies in Australia.

Overview:

The main factors limiting the uptake of evaporation mitigation products are marketing, the need to demonstrate cost/benefit and the value proposition, and the lack of objectively monitored and analysed local field trials. Recent changes in tax regulations allowing primary producers to write-off investments in drought-proofing may improve adoption, but landholders must still be convinced of the cost-benefit.

Commercial suppliers exist for multi-molecular films (Aquatain), suspended shade cloth (NetPro), continuous floating covers (Layfields, Daisy Commercial and Darling Downs Tarpaulins) and floating modular systems (Hexa-Cover and AquaArmour).

Some technologies have adapted and improved over at least 20 years of local experience (eg. NetPro shade cloth), whereas others (eg AquaGuard, AquaCap and NeoTop) are no longer available locally. Some are in the prototype phase (Quit-Evap). Some previously restricted by importation costs (eg. Hexa-Cover) are commencing local manufacture.

Local demonstration and independent testing and cost-benefit analysis will improve the information available for marketing, and for prospective purchasers.

5.1.1 Suspended Continuous Covers

NetPro

The only supplier of suspended continuous covers operating in Australia is NetPro Canopies (Appendix 1.2.2). NetPro have their headquarters in Stanthorpe, Queensland and have been operating for over 20 years. They have a purpose-built R&D facility, and provide site-specific engineered solutions. Their main business has been developing hail netting, livestock shade structures and commercial structures (eg vehicle storage and waste management covers). Evaporation covers are a small but important part of the business. The shade cloth fabric imported from South Korea to specification is installed by NetPro's own teams and also under subcontract. They have installed evaporation covers for water channels and storage dams for urban, agriculture and cattle feedlot applications (Figure 17).

Figure 17: View from below a NetPro suspended shade cloth cover at Stanthorpe used to reduce evaporation and increase security of supply to irrigated apple orchards.

a) Market Information

The potential size of the evaporation mitigation market is related to the number of storage dams, their size, and the economic drivers motivating landholders to invest in specific technologies. NetPro have installed more than ten structures for evaporation reduction, and hundreds for orchard and livestock protection and as commercial shade structures. One of their evaporation covers is over 20 years old and still operating well (see Case Study 1). Approximately 100 quotes have been issued over the past 20 years, indicating interest in suspended covers for evaporation mitigation. However, NetPro do not have a good understanding of that market.

NetPro shade cloth is promoted by the company for horticulture, feedlot water protection and potable municipal and waste water protection. There has been much interest in the product for evaporation mitigation but this has varied seasonally, especially with drought conditions, with perceived affordability being the main impediment to uptake.

New tax regulations (Small Business Measures No. 2 Bill 2015), now enable primary producers to claim an immediate deduction for capital expenditure on water facilities and fencing (Legislated on 22nd June 2015), including water conservation. This 100% write-off in one year for primary producers investing in evaporation mitigation technologies, is likely to incentivise adoption.

NetPro recently appointed a full-time evaporation product marketing member and sees opportunity to grow this area of business. However, the cost/benefit needs to be demonstrated. The technical design and installation of suspended shade structures is mature and optimised. Modular systems are not considered cost-effective. Promotion and demonstration of the value proposition is key to uptake, and NetPro believe government can play a role in this. Many potential customers are sitting on the fence and close to contracting, with drought a key driver. No external funding has been received to support product development or deployment. However, they co-invested in a demonstration site in Stanthorpe as part of a previous Queensland Government program (RWUEI 2 in 2005).

The main factors limiting uptake are marketing, and the need to demonstrate cost/benefit and the value proposition.

b) Technical Information

Description of the product and technical material is available on the company website www.netprocanopies.com

The shade cloth canopy can be installed at either bank level or elevated, depending on storage operational requirements. Installation can be undertaken with or without water in the storage. Installation when the storage is full is achieved using pontoons. Support poles can be installed within the storage, or a suspension system may be used, depending on storage size, shape and the distance to be spanned. Typically, central support is provided on 50-60m spacing, but spans over 100m, up to 150m are possible.

The cable size has been increased from 7.4mm to 12mm to achieve a fourfold increase in strength from 3t to 12t carry load. NetPro shade cloth is knitted rather than woven, conferring strength advantages. A new design of connectors and cable joins have increase structural strength, as has an improved internal pole plate design.

The grade of shade cloth has been increased from 85% density to 95% to improve evaporation reduction and water quality, although this has not been objectively assessed. The new shade cloth fabric is also lighter with better stretch capability, and canopy panel widths have increased to reduce the installation cost of the system. Previous tests at USQ have shown the 85% cloth weave reduced UV transmission and light penetration (depending on incident light angle during the day), and significantly reduced wind speed under the cover.

Key advantages are long life, low maintenance and ease of repair, and the structure provides minimal visual impact when installed at bank level. There have been few management, repair and maintenance issues at sites with NetPro evaporation canopies. The maintenance cost of one structure installed over 20 years ago is less than 1% per annum. The potential for hail and snow load damage has been addressed recently, by cable strengthening. Fire is a risk, especially when vegetation control and site maintenance is poor. Damage can be readily repaired, and is generally covered by insurance.

NetPro would welcome trials to evaluate product performance and cost-benefit, and have offered to work with the DNRME to identify suitable sites from existing or potential clients.

NetPro expect the new product to save up to 90% evaporation. In previous work, USQ found a 70% saving for the 85% density shade cloth. Greater than 80% savings are anticipated when using the 95% density cloth. However, this needs to be objectively assessed.

Other perceived advantages and disadvantages of the product are:

Advantages:

- Improves water quality and reduces algal blooms
- Reduces UV light and contamination from wind-blown debris
- Reduces storage bank erosion by minimising wind and wave impact
- 90% wind reduction under cover
- Increases access security and detection of unauthorised entry, by creating a barrier which limits access to the storage.

Disadvantages:

- Relatively high cost /m^2
- Difficult to scale above 15ha
- Adverse impact on recreation and visual amenity in some jurisdictions (eg councils).
- May impede direct stock access for watering

The main environmental concerns are the potential social (site access), visual and site management impacts during construction (especially in urban and government contracts). Detailed technical specifications are developed as part of each project.

NetPro have considered photovoltaic (PV) generation integration with the product based on impregnation of shade cloth, but this requires further R&D.

c) Economic Information

The capital cost varies with design and scale. Indicative costs are given below.

- 1ha = $300k (bank level) $30/m^2
- 1ha = $400k (elevated with sides) $40/m^2
- 5ha = $650k (bank level) $13/m^2
- 15ha = $1.4m (bank level) $9/m^2

Site-specific cost depends on the need for a pontoon for wet installation as well as remoteness of the site (transport/labour). Further price reduction is unlikely, as 20 years of experience has optimised the design. However, the use of a bigger grid, lighter material and/or less labour may reduce the price in the future.

Benefits of the product need to be compared with the value of the additional crop produced and the cost of water. At the time of writing, the township of Stanthorpe are running 9 trucks, 4x per day to deliver water from half-way to Warwick at a cost of $10,000/ML.

Repair and maintenance costs are typically < 1% of capital cost per annum, and are likely to be between $0.03/m^2 and $0.05/m^2 per annum. The life expectancy and warranty is 15 years on shade cloth, and 30 years on the structure.

An economic assessment of the NetPro product at the Golden Valley Orchard site (Stanthorpe) is included in Section 5.2. Information on the economic benefit of suspended shade cloth products at other sites in Queensland is given in section 6.4.1

d) General information and Case Study sites

NetPro mainly supply shade cloth for orchard and commercial protection, but recognise evaporation control is an important area for future growth. The company would be interested in participating in future product evaluation programs.

Factors affecting market expansion include:

- Demonstrating the value proposition
- Raising the company and product profile
- Government support through demonstration trials and performance evaluation as well as funding incentives
- Agricultural business tax benefits

Case studies for two NetPro sites have been given in Appendix 3 (Case study 1 and 6). Future monitoring sites could include the two enterprises below, who recently received quotes for suspended shade covers.

- Southern Downs Regional Council, at Killarney (municipal water storage)
- Canning Downs South Pty Ltd, at Elbow Valley (feedlot water storage)

5.1.2 Continuous Floating Covers

Continuous floating covers can be sourced through a number of companies including the Layfield Group, Darling Downs Tarpaulins, Daisy Dam Covers and C.E. Bartlett Pty Ltd.

The Layfield Group product covers the entire storage and is trenched into the embankment using an anchor trench. Other suppliers such as Darling Downs Tarpaulins and Daisy Covers supply continuous floating covers which are installed as modules (typically from $25m^2$ to $2{,}500m^2$ in area) on storages >1ha, tethered together for stability and ease of removal and reinstallation.

Layfield Group

The Layfield Group supply full continuous covers which are primarily used in urban and industrial applications, but also in agriculture. Layfield are a North American manufacturer of flexible geo-membrane products established in 1978, and have been operating in Australia for 10 years. They provide specialised, engineered products and solutions for geo-membranes, floating covers, and soil reinforcement projects in Australia (Figure 18).

Figure 18: Example of a Layfield continuous floating cover

a) Market Information

Demand for evaporation products fell 5 years ago. However, there has been renewed market interest in the last two years. All material is imported from the USA and fabricated either in the USA or locally. Local contractors are used for installation.

In Queensland the main demand has been from corporate clients in the oil, gas and municipal sectors. Nationally, market breakdown is estimated to be 10% agriculture (irrigation storage and stock water installations), 30% municipal and 60% mining and industrial. The Layfield product is highly specialised and more expensive, and therefore marginally cost-effective for agricultural applications. Appendix 1.2.7 provides further details of the company and product.

b) Technical Information

Layfield supplies only continuous covers trenched into the embankment, and comply with international and local standards in design, WHS and Environmental impact. The company predict evaporation savings of up to 99%, depending on local conditions.

Covers on potable water storages reduce algal growth and wind-blown contamination, reducing the chlorine dosage required for disinfection. Cover life expectancy depends on the chemical quality of the water. Bore and groundwater are fairly benign, but high-strength industrial water and water treated with reverse osmosis may oxidise the fabric. Water quality testing is undertaken as part of the Layfield design process.

The cover ("Enviroliner") is made from Polyethylene, and is marketed under the tradename REVOC. It is ballasted to allow vertical movement with water level change, and is tensioned uniformly across the cover to manage wind loading, with the sides trenched into the bank. Rain drains into a channel gutter, which must be pumped out and transferred into the storage.

The maximum size that can be managed is 30ha, but may be limited to 5ha for rural installations using lower specification and lower cost material. Key challenges include ember attack from bushfires, wind-blown debris, animal and vermin damage, and dust and algae accumulating at the downward edge of the cover. Regular cleaning and maintenance of the gutters and the cover is required. Cyclones can be a problem, however heavy rain preceding most strong winds adds ballast to stabilise the cover. The cover will rest in the bed of a storage when empty and re-float upon filling, with no apparent problem.

c) Economic Information

The lower cost solution for agricultural applications is a 0.75mm membrane with a 15 year life, cover costing $\$7.5/m^2$ and an installed cost of $\$23/m^2$. For industrial applications the specifications increase to a 1,14mm membrane with a 35 year life and an installed cost of $\$75/m^2$. The higher temperature and UV incidence in Australia increases the rate of oxidation of the cover in contact with the water. Operating costs are limited to surface cleaning, and pumping water from the gutters. Information on the economic benefit of continuous floating cover products across Queensland is given in section 6.4.2.

d) General information and Case Study sites

Layfield have offered to provide more detailed Case Studies for Queensland if required. They also supply a modular (2.4m x 12.2m), insulated product marketed in cold climates for thermal control (eg. optimising water temperature for microbial wastewater treatment). The Bird Balls marketed by Layfield in the USA (Appendix 1.2.8), are not supported locally, as they are susceptible to rotation which limits evaporation mitigation.

Darling Downs Tarpaulins

Darling Downs Tarpaulins (DDT) have been in business for over 30 years and have two divisions, DDT Fabrication and DDT Liners for installations and contracting. Their main business is general agricultural tarpaulins for grain covers and storage seepage liners. The company hasn't been active in supplying covers for evaporation mitigation over the last 5 years. C.E. Bartlett Pty. Ltd. are also suppliers of liners and tarps and work with DDT in some projects. C.E. Bartlett no longer have on-site installation capacity, which is generally subcontracted to DDT Liners.

On large storages DDT would deploy continuous floating covers without edge trenching, in sections or as large modules (e.g. 50mx50m), which can be prone to silt build up, rainwater ponding, and wind and wave displacement. Installing the cover in sections allows for deployment only on the portion of the storage that always contains water, with cable tethers anchored on the bank allowing the cover to rise and fall with the water level. DDT anticipate the maximum size of each module would be 2,500sq m, which could be tethered together to cover a larger surface area.

a) Market Information

DDT have installed a range of seepage and evaporation control products for agriculture, mining, industry and cattle feedlot applications. Continuous floating covers are used primarily in high-value horticulture, stock water storages and also for covering industrial effluent and by-products such as dunder water in the sugar industry. For more than 15 years DDT have supplied and installed the 'EvapCap' product sourced from Sealed Air Australia, with the largest installation at St George undertaken as part of an earlier DNRME project (RWUEI 2 in 2005) project. The cover at this site is no longer functional. Based on this experience, future designs for large storages would be to deploy smaller modular sections as described above. DDT are now promoting a new product based on Aquacon™ 345 supplied by Gale Pacific, and have a small installation at a Wainui feedlot in Bowenville, Queensland.

Market interest was highest during the millennial drought, but has waned over the last 5 years. The main factors limiting uptake and adoption are price and limited information on cost-benefit. DDT believe the new Aquacon product may have more market potential, but needs objective field evaluation which they would be happy to participate in.

b) Technical Information

EvapCap

The EvapCap product was developed by Warwick Hill (Evaporation Control Systems). The company has not been active for several years. The product was produced by Sealed Air Australia who still manufacture for sufficiently large orders. DDT prepare the product to size and undertake installations. The product is different to the pool covers produced by Sealed Air Australia, with increased light exclusion through heavier material and drainage holes to allow rainfall to enter the storage.

The product is best installed when the dam is full or nearly full, and will reduce algal growth significantly. The trenched configuration also requires the water level in the storage to be reasonably static, as stretching the product may lead to early failure. Wave action in the storage is significantly reduced, which reduces bank erosion. The warranty on EvapCap is 5 years (UV Protection).

Aquacon

The latest Aquacon cover is fabricated from physically cross-linked polyolefin foam, sandwiched between two layers of Aquacon™ 345 polyfabric film (developed as a dam liner), 2mm or 3mm thick depending on application. The layers are flame bonded together and are extremely resistant to delamination, even at high temperature. The closed cell foam layer provides excellent insulation, is water repellent and resistant to chemical degradation, while the outer woven layers confer strength and durability. The cover is installed in panels up to 50x50m, with tethering (wire rope) and ballast provided by a shallow curtain weighted with a chain to resist wind under draft. Tethering may not be required on small storages. The product has a 10 year UV resistant warranty.

The cover has very low water absorption and vapour transmission rates and will not absorb water and moisture over time (Figure 19). The polyfabric surface reduces drag, making it easier to deploy onto and to retract from the water surface. 20mm diameter holes are provided on 1.5m spacing for drainage of surface water.

High-strength woven HDPE scrim reinforcement and engineered, UV-stabilised polyethylene coatings provide outstanding puncture and abrasion resistance to withstand harsh installation and environmental conditions.

Figure 19: The Aquacon product comprised of foam, sandwiched between two layers of Aquacon™ 345 polyfabric.

Aquacon is made from 100% recyclable materials with no chlorine or heavy metals in the product, ensuring minimal adverse impact on the environment. The system is predicted to retard evaporative loss by >90% from the covered portion of the dam.

Gale Pacific is investigating the feasibility of installing flexible solar panels on tarpaulins such as grain covers and industrial covers, with the University of Newcastle undertaking some development work. However, the price point seems to be restricting uptake.

c) Economic Information

The current installed price for an EvapCap system is approximately \$22-\$25/m^2 installed. The base price of the new Aquacon product is approximately \$11/m^2. The site-specific design and installation price would be within the range of \$15/m^2 to \$25/m^2. The Aquacon product is sturdier than EvapCap and carries a 10 year UV Warranty. Repair and maintenance costs on both products are not expected to exceed 0.5% of capital cost per year unless regular cleaning is required.

Section 5.2 provides case studies of the EvapCap and Aquacon products for a feedlot and irrigation storage holding treated waste water. Information on the economic benefit of continuous floating cover products across Queensland is given in Section 6.4.2

d) General information and Case Study sites

A number of potential sites for product testing were discussed with the suppliers. Key factors affecting market expansion are the cost of installation and need for objective information on the economics of product and potential saving and return on investment. Government could play a key role in facilitating the adoption of evaporation mitigation technologies through demonstration sites with accurate measurements of performance and costs.

Daisy Commercial

Daisy Commercial have a commercial division supplying and installing pool and dam covers since 1983 and 1997 respectively, using material supplied by Sealed Air Australia. The company market their own 5.24 x5.24 m modular covers, and are able to supply the former EvapCap product Figure 20. The Daisy Pool product is made from the same material with design improvements, and has no draining holes. Cover fabrication is in Perth and Sydney, with nationwide distribution. Appendix 1.2.3 provides further details.

Figure 20: Daisy Dam cover installed as 5.24m by 5.24m square sections

a) Market Information

Markets for the product include agriculture, treated wastewater and potable water applications. Market interest for evaporation mitigation is growing but is seasonal, driven by drought and water scarcity. The size of this market is not known. Interest is increasing with a higher demand for quotes over the last 2-3 years. Four systems have been installed in 2020.

They do not market the product strongly and focus on the pool cover market. Understanding cost-benefit is the key driver limiting agricultural uptake.

b) Technical Information

Technical details are available on the Daisy cover 600micron specification sheet, and the company web page https://daisypoolcovers.com.au/shop/daisy-dam-covers/

Daisy Dam Covers are predicted to reduce evaporation by >95% for covered areas holding water for most of the time. The evaporation rate will still be high in the gaps between modules. By not trenching into the embankment, overland flow and rain will enter the storage without flooding the cover, and livestock can access the water. Improvements in water quality will be less than for trenched covers, as debris and sediment will wash into the storage.

The covers are 600µm thick polyethylene with a white top to reflect light and an opaque black base to reduce light transmission, but are vulnerable to puncturing from sharp objects. A 10 to 15cm wide skirt partly submerges each module to minimise wind and wave lift. Water runs off the impermeable cover to the narrow edge, minimising the requirement for regular cleaning.

The standard module size is 5.24m x 5.24m which can be increased in length to 10, 20 or 30m, tethered together with rope. Modules are delivered for self-installation in rolls of up to 250m weighing 175kg, and can be removed and reinstalled as required. Installation is in four steps, unfold, set up, tether together and pull into place on the dam surface.

The flexible sizing option, ease of installation and removal, and self-cleaning are seen as a marketing advantage.

c) Economic Information

The product cost for a 5.24x30m module (157m^2) is $1,549.00 plus freight of $147 to $497 depending on location. This equates to $2,046.00 for a remote site or $13/m^2. Installation will depend on whether the owner or a contractor is used, which could increase the price to between $15/m^2 and $20/m^2.

Repair and maintenance costs are likely to be less than 0.5% of the installation cost, but will increase with the frequency of removal. Daisy Pool Covers meet the Pool and Spa Cover Association of Australia durability standard, with a 5 year pro-rata warranty and an expected life span of 10 years.

Information on the economic benefit of continuous floating cover products across Queensland is given in Section 6.4.2.

d) General information and Case Study sites

The company would be keen to work as part of a product evaluation program to confirm technical performance and cost-benefit. A case study has been provided in Section 5.2 of an installation at a waste water storage facility in Kenilworth.

The company also sells the AquaSaver pool chemical product for evaporation reduction which is imported from the US and expected to achieve 30% savings (https://daisypoolcovers.com.au/shop/aquasaver/). The main purpose of the product is to reduce evaporation and heat loss from swimming pools. AquaSaver is non-toxic, and is promoted to provide up to 1 month of evaporation mitigation per dose.

5.1.3 Modular Floating Covers

A number of modular floating covers have been developed and promoted in Australia over the last 20 years (see Appendix 1.2). Marketed as Bird Balls, AquaArmour, AquaCap, AquaGuard and NeoTop, all are small diameter circular or hexagonal modules, typically between 100mm and 1.2m in diameter. Most of these products are no longer supported in the Australian market, primarily due to the high capital cost.

The only products currently available commercially are Hexa-Cover and AquaArmour. A third QUIT Evap is a prototype currently being developed for local evaluation.

Hexa-Cover

a) Market Information

Hexa-Cover® Floating Cover was developed in Denmark over 15 years ago to control gaseous emissions, evaporation, organic growth, odour, heat loss and to deter waterfowls, on lagoons, reservoirs, containers, ponds and tanks. Details are given at the company web site http://www.hexa-cover.dk/uk/hexa-cover-floating-cover.aspx. The product is distributed locally by Earth, Water Infrastructure Pty Ltd (http://www.e-wi.com.au/) who will manufacture the product in Melbourne from July 2020, using injection moulding equipment.

b) Technical Information

Hexa-Cover is made from polypropylene and has a specific density of 0.6. The product R114 recommended for evaporation mitigation is 228 mm in diagonal, length, 70mm high, weighing 243 g, with 28 modules covering 1 square m (Figure 21). No additional ballasting or buoyancy is required, with an evaporation reduction of up to 95% predicted for a fully covered surface. Delivery is in a bag (100 cm x 130 cm x 250 cm), weighing approximately 275 kg.

Figure 21: Hexa-Cover showing the tight modular packing achieved with the hexagonal, scalloped design (photo from company website http://www.e-wi.com.au/)

The “scalloped” edge interlocks the modules to cover up to 90% of the surface, with rain draining from the impermeable surface into the reservoir. The modules withstand wind turbulence up to 32 m/s.

Installation involves emptying modules from the bags into water from the edge of a reservoir. The top and base are the same, stabilised by protruding ribs which assist the modules to spread evenly over the water surface. The scalloped edges interlock, to improve surface coverage. Installation can be on a full or empty storage with automatic distribution across the water surfaces. The system adapts to changes in water level, fits all shapes and geometries, and has the advantage of incremental module purchase and replacement over time.

The Hexa-Cover product is accredited by the Australian Water Quality Centre to AS4020:2018, confirming suitability for potable water storages.

Hexa-Cover substantially improved the quality of water in a regional municipal storage in East Gippsland. Results from tests conducted at the Omeo potable water treatment plant 12 months after installation are summarised below:

- Total Biovolume 95% Reduction
- Potentially Toxic Biovolume 98% Reduction
- E.coli 89% Reduction
- Coliforms Dramatic Reduction
- Turbidity 57% Reduction
- pH Less variation

c) Economic Information

The price is approximately $35/m2 from Melbourne plus transport costs. The main interest has been from water authorities for evaporation and water quality management. The product is UV stabilized with a life expectancy of 20-25 years. Operating costs are considered minimal.

d) General information and Case Study sites

A key limitation is the $60 per m^2 price ex Denmark, which will reduce significantly once local manufacture commences. A limitation to adoption is inadequate scientifically-based, in-situ monitoring of evaporation saving performance, and a cost-benefit analysis.

The company would be keen to participate in a product evaluation program to confirm technical performance and cost-benefit. The North Burnett Regional Council installation could be used as a monitoring site.

A Case study for North Burnett Regional Council is provided in Section 5.2. Section 6.4.2 provides information on the economic benefit of continuous floating cover products across Queensland.

AquaArmour

AquaArmour was previously developed by the Aqua Guardian Group. It is now manufactured under license by IPS (Innovative Plastic Solutions) Pty Ltd and sold and distributed by HydroTerra.

AquaArmour has not had active sales and the last deployment was for East Gippsland Water four years ago, for a domestic water storage and control of blue green algae. Each module weighs 4kg and has a maximum width of 1.18m and height of 412mm. Modules are delivered in two halves which are clipped together on site. Six flotation pods are inserted in each module for buoyancy and water infiltrates the module to provide stability in the water, giving an average ballast weight of 80kg. The modules need to be contained using a floating containment perimeter (typically plastic pipe) to ensure they do not drift onto the edge of the storage and empty of water ballast, when they can become vulnerable to being blow away by the wind, owing to the large diameter and low weight. This occurred at a site in Ouyen in an older system without a containment perimeter.

The expected life of the product is >20 years and the manufacture cost is indicatively $\$35/m^2$ to which transport and installation and assembly costs need to be added. The weight of a delivery pallet with 75 pods is around 370kg.

QUIT Evap

The product QUIT Evap is a modular floating cover that is only in prototype development. The inventor is in discussion with Darling Downs Tarpaulins for the production of trial modules. The target market is agriculture (especially horticulture and high value crops) and mining.

Product development is at an early stage and trials are needed to demonstrate technical performance. The prototype is designed for deployment on storages from <1 ha to 100 ha in size. Collaboration with an industry partner is required to bring the product to market.

The product capital cost would decrease with an increase in storage size. Module price estimates are being developed with C.E Bartlett and Darling Downs Tarpaulins, based on the Aquacon 355 geo-membrane supplied by Gale Pacific. Cheaper alternative materials are available in Australia, but are of a lower quality with a lower life expectancy. Preliminary estimates indicate the modular covers, anchoring system and installation equipment may exceed $20/m2.

The design assumes only partial coverage of the surface, with the slope of the earth embankment uncovered. The modules are predicted to mitigate evaporation by

>95% on covered sections. Opportunities to spray a chemical film over the uncovered portions of the storage could be considered. The modules would act as a containment grid for the chemical, improving film integrity by reducing wind and wave action.

The developer would be interested in working with DNRME to do some product evaluations, initially on small scale installations to assess technical performance and cost-benefit. Financial assistance from Federal and State Government grants and subsidies applicable to evaporation control products would be required.

5.1.4 Molecular Chemical Films

Aquatain

The only commercial supplier of chemical films for evaporation reduction in the Australian market is Aquatain Products Pty Ltd who market the multi-molecular WaterGuard chemical film (Appendix 1.2.19). Aquatain have been producing silicone-based evaporation mitigation chemical films since 2007. The products are manufactured in Melbourne by a contract liquid blending company, to specification.

a) Market Information

Aquatain consider their market potential extends from farm dams to municipal reservoirs. The company have focussed marketing and development on 'Aquatain AMF', a mosquito control product. Demand for the evaporation mitigation product WaterGuard is seasonal, with water scarcity and drought a key driver. More testing of WaterGuard under Australian field conditions would improve product development. Aquatain have suggested that linking to a larger commercial company to take responsibility for manufacture and distribution would help develop the market.

WaterGuard is a white coloured, self-spreading liquid poured from the bank of the storage. The use of multiple bank-mounted or floating applicators under light wind conditions would improve distribution and coverage. However, spreading angle and rate have not been established for this product, to optimise large scale application. Small scale trials indicate a recent modification of the formulation has improved the evaporation reduction performance of the product. The company benefits from government R&D tax incentives but haven't received any grants or external funding.

The company sees greatest potential in agriculture, viticulture and mining. WaterGuard is sold through rural resellers such as Landmark, Elders and CRT. Sales (South Australia), with most sales in NSW.

Through the summer of 2019-20, approximately 150 individual customers purchased WaterGuard in drum sizes from 20 litres up to intermediate bulk containers (1,000L). Aquatain Pty Ltd supplied 50 customers directly, with resellers supplying 100. Little marketing is undertaken as sales are restricted to 5 months of the year, yet sales have increased by 20% annually. Sales are online or through resellers as continuing customers.

With a limited marketing budget, Aquatain have concentrated on the year-round demand for the mosquito control product Aquatain AMF in export markets. The product has been approved for sale in more than 60 countries, exempted from registration in many due to its non-toxic nature. Aquatain AMF meets the World Health Organization standards for efficacy, safety and quality, and has been accredited for use by the UN and other international bodies.

In Australia, Aquatain have found councils reluctant to use the product on public recreation and potable water supply reservoirs, despite NSF International accreditation for safety and quality.

b) Technical Information

WaterGuard is a mix of Silicone and an inert Polymer. The Silicone does not vaporise and self-spreads due to low surface tension. Silicone is also the base for The Aquatain mosquito product, but it is quite permeable and does not effectively reduce evaporation. The Polymer silicone blend is less permeable, achieving better evaporative retardation. Other additives including ethyl alcohols were tested, with the WaterGuard polymer-silicone blend achieving the best spreading and evaporative reduction rates.

Several years ago, Aquatain looked at becoming a distributor for WaterSavr (a Canadian powdered product based on the long-chain alcohols Hexadecanol and Octadecanol), but did not proceed due to application difficulties, weak spreading ability and short duration under Australian conditions. WaterSavr is not currently available in the Australian market.

Aquatain consider there are no storage size limitations for WaterGuard application, but do not have experience with very large reservoirs. Aquatain are concerned the poor performance of an unrelated mosquito control product (Agnique) in South Australian field trials has adversely affected the public perception of their products. However, the chemistry of WaterGuard is different from Agnique and WaterSavr, and users have not reported any build-up of product on the lee shore of large water bodies.

Aquatain have conducted over 2,500 laboratory trials on product spreading rates and longevity. WaterGuard can be poured onto the water directly from the drum, or can be applied by air or through mechanical applicators onto larger storages. The company believes the current recommended dosage rate of 10l/ha/application may be too light. They have done

A number of product field and laboratory trials have been undertaken:

- Barona Creek Evaporation Trials : 67% saving
- Sycuan Golf Resort (USA) Evaporation Trials: 74% saving (Figure 22)
- Tarcoola (Australia) Evaporation trials : 50% saving
- Lab Evaporation Trials : 50% saving

Figure 22: 0.5ha storage at Sycuan (USA) where evaporation savings were 74% when compared with a neighbouring "control" dam.

The results of some trials may be over-stated as the rate of evaporation from a standard Class 'A' Pan Evaporimeter used as an experimental control is faster than a large open water storage, and seepage rates from adjacent storages also need to be standardised. The Sycuan Californian trial results are likely to be accurate as baseline data was used to account for different seepage rates. Aquatain have expressed a strong interest in having more rigorous, independent assessments.

Main advantages are:

- Ease of application
- Non-toxic
- May be applied intermittently when there is water in the storage or during high evaporation periods
- No or low upfront capital costs
- Storage and handling of the product is simple and safe

Main Disadvantages are:

- Difficult to see the film once it has been applied, potentially leading to the suspicion that it needs to be reapplied
- Efficacy is unproven on very large reservoirs
- Re-application is required every 3 weeks.

- The product is viscous in cold weather (temperature < 5 deg C), making application more difficult. Product advice is to apply only when temperature exceeds 10 deg C.

Once the film is in place, it will move slowly over the surface, but resists wind and wave disruption. Rain penetrates the film, without disturbing film integrity.

There are no known environmental impacts related to the product. The components of WaterGuard are used in food and pharmaceutical applications, and are considered non-toxic. An application for certification of WaterGuard for drinking water is currently underway. A list of certifications for toxicity, environmental impact chemistry and health approvals are available.

The West Australian Department of Health assessed 'Aquatain' when it was first introduced, and approved it for use on potable water storages in Western Australia. The company have not been able to find an Australian Federal authority willing to certify WaterGuard for use on potable water.

c) Economic Information

WaterGuard is supplied to the retailer at $10-$11/litre, on-sold typically at $13-$15/litre. Recommended dosage rate is 10l/ha although there are suggestions this should be increased to 50l/ha. Further research on application rates and efficacy is required.

Costs based on repeat 3 week application are:

- 10l/ha @ 3 weeks = 173l/ha @ $14/l = $2,426/ha/yr
- 50/ha@ 3 weeks = 866l/ha @ $14/l = $12,133/ha/yr

Assuming 2hr labour per application @ $30/hr would add = $1,040/year to the operating cost.

d) General information and Case Study sites

Medium-scale trials are needed to confirm the appropriate application rate as preliminary, small-scale trials indicate that a higher application rate can significantly improve the performance. Large-scale trials are required to monitor performance of optimum application rate and cost-benefit. Microlayer testing is also required to validate the product does not adversely affect gas exchange across the water surface.

The main factors affecting market expansion are in marketing. Adoption would be improved by the availability of cost-benefit analyses from independent trials on large water bodies, and industry-specific case study sites. Many tests and approvals have been done on the safety of the product on potable water storages for human consumption, but have not included an analysis of the impact of the multi-molecular film on gaseous exchange across the microlayer.

Aquatain suggest the product should be applied at a higher application rate than on the current label. However, this could become uneconomical – particularly with the retail mark-up affecting rural customers. An independent cost-benefit analysis at the higher rate of application is required. A WaterGuard Case Study is given in Appendix 3 (Case Study 7). Section 5.2 provides an assessment of the WaterGuard product for Aspley Nursery and Section 6.4.2 provides information on the economic benefit of chemical film products across Queensland

Experimental mono-molecular product – Melbourne University

Current research conducted by the University of Melbourne and funded by the Cotton Research and Development Corporation and the Federal Department of Agriculture and Water Resources is focussing on developing new products to mitigate against wind impacts on monolayers, including trials using barrier technology to minimise the impact of wind.

The experimental mono-molecular product E1 has shown potential for 30%-35% evaporation savings when movement by wind can be minimised. Urrent trials are trialling in storage wind barriers. Dosage at a rate of 0.5kg per hectare every 5 days is envisaged with a product cost of $1/kg. Wind barrier costs are expected to be around $4m^2$ to $5m^2$. Further experimental trials are required before commencement of commercial scale testing.

Key Findings from Supplier Assessment:

- A local track record in the fabrication and installation of similar products improves landholder confidence in evaporation mitigation products.
- The small scale of most local manufacturers limits the budget for marketing and the objective evaluation of field trials required to establish the cost-benefit of a product.
- The evaporation mitigation market is seasonal, driven by the severity and frequency of water scarcity and drought.
- Most suppliers of evaporation mitigation products depend on markets other than evaporation mitigation to remain financially viable.
- Demonstration trials to evaluate products supported locally should be considered. Shortlisted products are WaterGuard chemical film supplied by Aquatain, NetPro's suspended shade cloth structure, REVOC floating cover supplied by Layfields, Daisy Dam Cover supplied by Daisy Commercial and Aquacon floating cover supplied by Darling Downs Tarpaulins and the floating modular system supplied by Hexa-Cover or HydroTerra (AquaArmour).

5.2 User Assessment

An assessment of the consumer side of the market for evaporation mitigation technologies was undertaken. The purpose of the assessment was to investigate the opinions and perceptions from current and potential users, as well as understand the industry-specific constraints and requirements that may apply to a range of industries across Queensland.

Overview:

Many agricultural and horticultural industries in Queensland depend on a secure water supply for irrigation. The source of water, the management of the water level in the storage, storage size and the dollar value of produce per ML of water used varies substantially between industries. Improving water quality to improve disease control and palatability to cattle, and to reduce clogging of irrigation nozzles are also key drivers. Most industries are willing to participate in objectively monitored trials of evaporation mitigation products, provided participating growers are not financially 'worse off'.

The main driver in local regional councils for covers to storages is to improve water quality and reduce water treatment costs. Evaporation saving cost-benefit is generally not assessed.

A number of discussions with key industry stakeholders and peak bodies were undertaken to understand the industry perspective, experience, interest and any unique requirements that each industry may have that differentiate them from other industries. The following section summarises discussions.

Horticulture Industry (GrowCom)

GrowCom represent approximately 30% of Queensland horticultural growers across a range of commodities. The 2017/2018 Australian Bureau of Statistics data reports that horticulture in Queensland has a gross production value of $2.8 billion, of which, more than $2.52 billion is derived from irrigated horticulture.

Water storages on a typical horticultural farm can range from a 1ML rain-fed turkeys nest to a large 100ML ring tank used to store groundwater, surface water or municipal recycled water. Many storages on horticultural farms are maintained at or near full supply level as an insurance against drought, and to satisfy the need to finish a crop. In these cases permanent installations of continuous and modular covers as well as suspended covers have market potential. GrowCom suggest that with continuous pumping in and out of storages, the application of chemical covers may not be effective as they may be pumped out with irrigation water.

The rate of degradation of floating, continuous and modular covers, and any poles within the storage may increase when water in the storage is mixed with recycled or effluent water.

GrowCom have seen some interest in saving both seepage and evaporation in the past 20 years and have been involved in various water use efficiency and reef related programs in Queensland. They have contacts who are willing to cooperate and co-invest in Evaporation Mitigation technologies as demonstration sites, but suggest the co-investment should be 50:50 between government and farmer.

GrowCom believe there will eventually be a pipeline from Wivenhoe dam to the Lockyer Valley for irrigation purposes, and have indicated growers are willing to pay

$1,500 -$2,000/ML. An objective assessment of the return on investment is needed to encourage uptake.

> *“Most horti growers don’t know what they are losing to start with, so they are not able to put a price on the water they lose. We need to measure their losses first, then talk about how we save that water”*

Sugarcane Industry (CANEGROWERS)

The 2017/2018 Australian Bureau of Statistics data reports the sugarcane industry in Queensland has a gross production value of $1.23 billion, of which, more than $665 million is derived from irrigated production. Irrigation is important for 60% of Queensland’s sugarcane production, and growers need access to reliable supplies of water at a realistic cost. Irrigated sugarcane accounts for 80% of Queensland's irrigation water use. Efficient use of irrigation water is essential to improve sugarcane productivity and profitability.

There are relatively low numbers of on-farm water storages in the sugarcane industry, as many growing areas are serviced by water supply schemes and/or have good groundwater supplies. However, some supply schemes were designed to offer water on a roster basis with farmers encouraged to have some form of buffering storage on-farm (although few actually do).

The sugar industry is located near the coast with relatively high rainfall and low evaporation, reducing the impact of evaporation from storage, when compared with other industries. The gross margin of sugarcane generated with each ML saved is also lower than most crops, limiting the adoption of most evaporation mitigation products. The industry does not see evaporation from storages as a priority, and strategies for improving water use efficiency are focussed more on irrigation application systems.

Nursery Industry (Nursery and Garden Industry Queensland)

The 2017/2018 Australian Bureau of Statistics data reports the nursery, cut flowers and turf industries (combined) in Queensland have a gross production value of $265 million, of which, more than $226 million is derived from irrigated production.

The Nursery and Garden Industry Queensland (NGIQ) represent production and seedling nurseries across Queensland. They have previously been involved in Rural Water Use Efficiency projects with the Queensland State Government.

Discussions with NGIQ indicate more than 70% of production nurseries in Queensland have some form of on-site water storage, although most storages are less than 10ML in capacity. Levels in storages are maintained where possible, however this is not always within the control of the grower, and there is evidence of growers going bankrupt (or coming close) as a result of drought and insufficient water supply.

Based on the relatively small size of storages and the high value of production, the NGIQ suggest that suspended and floating covers have the highest potential. NGIQ has access to farm water balance calculators and are willing to invest in an economic assessment of water stored, water lost and the financial return per ML on six farms.

While gross margins in the nursery industry can be very high, there is little understanding or use of the metric "$/ML" in the industry. Rural Water Use Efficiency projects have certainly increased grower awareness, but few growers have good records or understand how much water (ML/ha) is required to grow a crop.

> *"All nurserymen are time poor, and adding in an additional daily or weekly task to their busy schedule* [i.e. adding chemical covers] *is going to be a difficult thing to sell."*

Dairy Industry (Queensland DPIF)

The 2017/2018 Australian Bureau of Statistics data reports the dairy industry in Queensland has a gross production value of $230 million, of which, more than $104 million is derived from irrigated production.

All production dairies in Queensland have at least one on-farm water storage to capture wastewater from parlour wash-downs. This water may be shandied and used to irrigate pastures, although many dairies also have a clean water storage on the property to be used in conjunction with groundwater supplies. Storage sizes range from 2ML up to more than 700ML.

Many dairies with on-farm water storage for irrigation also use the storages for cattle drinking water, and may require cattle access to the water. This may limit the use of floating or suspended covers, unless extra tanks and troughs are provided. The dairy industry also needs assurance leachate from physical covers and chemical films will be non-toxic to animals, and will not chemically contaminate milk and dairy products.

The dairy industry are economically restricted and the cost-benefit of any investment is important. Many on-farm dairy storages are lined to limit seepage in Queensland, some to meet effluent pond management regulations, and some are clean water storages. Farmers recognise seepage loss can be mitigated, but assume evaporative loss is either unavoidable or is too expensive to reduce. While there have been few water trades recently, the industry expects farmers would value water at approximately $500/ML. Most farmers base their irrigation economics on tonnes of dry matter produced, not on milk production per ML and farm profitability. Many farmers are not aware of the marginal production per megalitre of irrigation water applied.

> *"Farmers talk about losing a foot of water from storages but see this as inevitable and not something that can be changed – We need better awareness!"*

Cotton Industry (Cotton Australia)

The 2017/2018 Australian Bureau of Statistics data reports the cotton industry in Queensland has a gross production value of $880 million, most of which is derived from irrigated production.

Cotton Australia is the peak body for cotton producers and provide a direction for research and development, stewardship, natural resource management and cotton production issues. Discussions with Cotton Australia indicate the industry has focussed on storage reconfiguration, generally dividing a large storage into two or more cells to reduce the surface to volume ratio of the variable volume stored. Most cotton irrigation storages are designed by professional engineers and are well constructed from locally available clays which have low permeability, conferring low seepage rates.

A unique feature of cotton storages is overland flow or floodplain harvesting is often a primary source of water. The water level in a cotton storage changes substantially through the season and may be completely empty for 12 months or more in dry times. Permanent covers may not be cost-effective as water may only be held in a storage 50% of the time. Cotton storages are often large (500ML – 2,000ML, some up to 6,000ML) to supply irrigation water for an entire season. Pumping stations in the cotton industry are often remote, not connected to mains electricity and are diesel powered. There has been significant interest in solar pumping in the cotton industry and the potential of floating Solar PV as an evaporation mitigation technology, but are discouraged by the limits to feed-in tariff schemes.

Cotton storages harvesting overland flow require periodic de-silting and cleaning out, requiring access to the floor of the storage.

Farmers in the cotton industry have a higher level of understanding of the critical nature of water management and have benefitted from a number of water use efficiency and irrigation efficiency research and development projects. Perhaps due to the rural and remote locations of cotton-growing areas, many farmers struggle to find labour for farm work, and many current initiatives in the industry are focussed on saving labour. Successful evaporation mitigation technologies in the cotton industry will need low on-going labour requirements, and regular access to the storage floor.

Cotton Australia expect well managed demonstration sites collecting objective data will improve the adoption of any proven EMT. The industry would prefer local demonstration sites and have suggested a co-funding model ensuring participating growers are 'no worse off' (economically) as part of the programme. Cotton Australia feel that they would have no trouble finding suitable candidates for well monitored case studies of EMT products.

"The cotton industry is full of early adopters for new technologies, providing they can see a return on investment"

Intensive and Extensive Livestock industry (Meat and Livestock Australia)

Production in the Queensland Meat and Livestock industry in 2017/18 was approximately $8,600, representing approximately 43% of Queensland's agriculture and food sector. The industry is dominated by beef cattle raising (62%), following by meat processing (28%), poultry (6%) and pigs (3%). Sheep and lambs and other livestock each constitute less than 1% of the industry.

Evaporation saving from storages has not been a key issue for the industry. Feedlots and meat processing works are the most likely target market, and a number of Case Studies for Feedlots have been provided in Section 5.2.2.

Water for stock is a critical issue for the industry especially in areas with low rainfall and high water evaporation rates, and limited surface water resources. Underground water sources in many areas are too saline for stock use.

Water use efficiency has typically focussed on better ways to more effectively capture water in farm dams and preventing loss to evaporation once the water is harvested. Evaporation saving has focussed on appropriate dam design to increase storage depth to reduce surface area, and physical management strategies like shading and windbreaks.

Evaporation control covers were reviewed in earlier work by Australian Wool Innovation Ltd in South Australia, as part of the Sheep SA Connect partnership. Chemical film application was considered most affordable as films are not permanent, and can be applied seasonally when required. Chemical films have limited impact on aesthetic appeal, but are less efficient than physical structures in reducing evaporative loss, algal growth and water temperature.

The best evaporation reduction in small to medium sized dams will be achieved by shade cloth or a floating modular system. For large dams, chemical film application will be the most cost-effective technology.

5.2.2 Current and Potential Users

A range of current and potential users of Evaporation Mitigation Technologies were contacted to discuss their experiences and perceived value of the technology. The following section details these discussions.

Nursery and Garden Industry - Aspley Nursery (Chemical Cover)

Site and storage details

Aspley Nursery is a family-owned Commercial Nursery operating since 1952 from two sites north of Brisbane. They are recognised as market leaders and innovators in nursery management. They provide plant supply, landscape design and delivery of landscape projects, supplying a wide range of exotic and native species. An on-site water storage at their nursery in Morayfield holds 20 ML with a surface area of 0.6 ha (150m x 50m x 4m deep)

Decision drivers

Water management has been an ongoing concern. Local rain-runoff is captured from their operations and recycled for irrigation after treatment. They are otherwise reliant on buying in potable water from Unity Water at $1,42/kl or trucking in water at four times this price. Aspley need an assured water supply to produce high-value nursery plants for the landscaping sector.

Technical detail

Aspley Nursery have been using Aquatain, and more recently WaterGuard for over eight years, applying it every 2-3 weeks over the dry season and during periods of high evaporation (Oct. to March), from 20l containers at a rate of 10l/ha at a cost of $14/litre. Evaporation is approximately 1800mm/yr, with 60% occurring between October and March.

After application, the even spread of the product over the surface is visible as a film. Aspley Nursery have no environmental concerns as the storage at Morayfield (Figure 23) has a very healthy Perch, Eel and Turtle population. Key benefits to the nursery are the low capital cost, product application only when required, and a low risk investment. The product is biodegradable, with no apparent environmental impact after 8 years of use.

Economic drivers

An economic assessment of the storage operated by Aspley Nursery (Morayfield) is given below. Assuming the product saves 1.4ML/yr by applying 10L/ha every 3 weeks, the product would cost $586/ML/yr.

- Evaporation saving: assume 20%
- Application: 10l/ha every 3 weeks between October and March (inclusive)
- Product Cost: $14/litre
- Operating / labour: $0.025/m^2/year

Water Saving Scenarios and Economics

- Water Saving: 1.4ML/yr (assuming always full)
- Cost to save water: $586/ML (assuming always full)

Saving cost is not affected when the storage is empty or when the water level varies, as the dosage rates can be modified to suit.

Figure 23: Aspley nursery site with a central 20ML pond for irrigation (photo: Google).

Intensive Livestock Industry - Wainui Feedlot (Continuous Floating Cover)

Site and storage details

North Australian Pastoral Company (NAPCo) operate Wainui Feedlot and Farms near Bowenville. In 2012, Wainui Feedlot expanded from a capacity of 7,200 head to 14,240 head, making it the 14th largest feedlot in Australia. The feedlot operate three 'turkey's nest' storages, providing water for livestock, feed processing and dust suppression. Two of the three storages are lined and covered with continuous floating covers. The two covered storages are filled using bore water and the third (uncovered) storage is filled with surface water.

Decision drivers

NAPCo recognised water security for cattle consumption was of prime significance and any measures to ensure a reliable supply were considered. At the time the HDPE liners were installed to mitigate seepage, the decision was also made to cover the storage to create a large, enclosed 'water tank'. Staff noted water from the 'tanks' was cooler, and more palatable for cattle. Clean (bore) water was pumped and piped without using earthen channels, with the reduction in silt and sediment reducing the frequency of trough cleaning from 3 times per week to once per week. The covers also excluded water birds, reducing the risk of zoonotic disease transmission.

Technical detail

NAPCo have two floating covers supplied and installed by Darling Downs Tarpaulins. EvapCap covers were installed on the first storage (Figure 24), with an Aquacon cover (Figure 25) installed later on the second storage. Both covers are trenched into the side of the bank as the water levels in both storages are maintained with bore water. Both of the storages are approximately 0.16ha and store 5 ML each.

Economic drivers

NAPCo did not receive any funding or grants, and could justify the expense based on the value of water security for animal welfare, the water quality improvements and the reduction in trough cleaning.

Repair and maintenance costs over the life of the products have been low. On occasion stock have strayed onto the cover, with the damage caused by their hooves repaired (Figure 24) at a cost of $6,000. There has been no other damage for 3-4 years.

Figure 24: EvapCap continuous floating cover installed at Wainui Feedlot showing maintenance repair in the bottom right (Photo: Matt Siebur)

An Evaporation Ready Reckoner assessment was undertaken to estimate the economics of saving water using a floating continuous cover at the Wainui site.

- Evaporation saving: 95%
- Capital Cost: $25/m2 = $38,000
- Life: 10yrs
- Repair and Maintenance: $1.00/m2/year = $1,534/yr

Figure 25: Aquacon Continuous floating cover installed at Wainui Feedlot (Photo: Matt Siebur)

Water Saving Scenarios and Economics

- Water Saving: 3.0 ML/yr (assuming always full)
- Cost to save water: $2,227/ML (assuming always full)
- Cost to save water: $2,679/ML (assuming 25% less water held each month)
- Cost to save water: $2,969/ML (assuming in 25% of years the storage is dry)

Figure 26: Aerial photograph of Wainui Feedlot showing three circular 'turkeys nest' storages in the upper right (Photo: Beef Central)

Horticulture Industry - Redbank Plantation (Continuous Floating Cover)

Site and storage details

Robyn Lubach owns and operates Redbank Plantation in the Lockyer Valley. She irrigates avocados from an on-site water storage filled from groundwater and treated wastewater from the Gatton Municipal Water Treatment facility. Annual evaporation at the site is 2,000mm.

The storage is a turkey's nest ring tank, which does not catch any overland flow. The storage was constructed from compacted clay, with a surface area of one ha and a depth of > 10 m, minimising the surface to volume ratio.

Decision drivers

Reducing the environmental footprint by improving water use efficiency was a key driver. Redbank Plantation is able to access daily inflows from bores as well as recycled municipal effluent from Gatton. The volume of water pumped to the Avocado trees varies with crop demand through the year. Avocadoes are a high value crop and water must be managed to optimise the production of good quality fruit. The water level in the storage is constantly changing, and a cover to reduce evaporation from the variable water level was sought.

Technical detail

The EvapCap cover is 75m x 62m, covering only 10%of the 350m x 126m surface area of the storage, anchored to the banks with a series of cables connected to winches which adjust the cover to the water depth (Figure 27).

Economic drivers

The USQ Evaporation Ready Reckoner was used to undertake an economic assessment of the cost of saving evaporation using the cover.

- Evaporation saving: 90% to 95% for covered area
- Capital Cost: $20/m^2$
- Life: 15years
- Repair and Maintenance: $0.05/m2

Water Saving Scenarios and Economics

- Water Saving: 8.3ML/yr
- Cost to save water: $1,050/ML/yr
- Cost to save water: $1,128/ML (25% less water held each month)
- Cost to save water: $1,430/ML (25% of years storage dry)

Figure 27: Partial coverage of the storage at Redbank Plantation with an EvapCap continuous floating cover.

Horticulture Industry - Golden Valley Orchards (Suspended Cover)

Site and storage details

Renato Andretta owns and manages Golden Valley Orchards near Applethorpe on the Granite Belt in Queensland. The primary irrigation water storage is 350m x 126m x 5m deep with a surface are of 3.6 ha and a full supply volume of 130ML. The site near Applethorpe has a long-term average annual evaporation of 1,690mm/year and a long-term average annual rainfall of 750mm.

Decision drivers

Renato had previous experience with NetPro shade cloth canopies for hail and bird protection for his apple orchards, and was confident of the durability of the product and the potential to reduce evaporation. Renato was a partner in the Rural Water Use Efficiency Initiative Phase 2 program, investigating the measurement and assessment of a range of evaporation mitigation technologies, partly funded by the Queensland Government. Golden Valley orchards are unable to buy in water. They collect local runoff and extract groundwater. Water is limiting, a key driver in Renato's decision to invest in an evaporation saving technology. Seepage rates are low, as the bed material of the storage is a well compacted clay.

Technical detail

The installation was completed in November 2003 when the storage was empty, using 85% shade cloth, which should achieve an evaporation reduction of 70% and has 7.4mm galvanised steel cables anchored to the bank with 2m anchors (Figure 28). The structure has internal supports at 60m spacing. Annual evaporation loss in Stanthorpe is around 1600mm/yr.

Economic drivers

Based on an evaporation reduction of 85% and the long-term annual evaporation rate, the USQ Evaporation Ready Reckoner tool was used to determine the average cost to save each megalitre (ML) from evaporation.

- Evaporation saving: 85%
- Capital Cost: $13/m^2$ (30% of cost is shade cloth fabric) = $470,000.00
- Life: Shade cloth 15yrs; Structure 30yrs
- Repair and Maintenance: $0.05/m^2$ = $1,814/yr

Water Saving Scenarios and Economics

- Water Saving: 52ML/yr (assuming always full)
- Cost to save water: $733/ML (assuming always full)
- Cost to save water: $815/ML (25% less water held each month)
- Cost to save water: $978/ML (25% of years storage dry)

The impact on apple fruit quality and marketable yield is substantial if the crop is near maturity and a critical irrigation is missed. The value of water at this critical crop development phase is likely to exceed $2,000.00/ML, depending on season and market demand.

Figure 28: NetPro Shade coth canopy over an irrigation water storage (photo: Erik Schmidt)

Horticulture - State Government Department of Agriculture (Suspended Cover)

Site and storage details

Stanthorpe has limited water supplies and 15 years ago the Queensland Department of Agriculture and Fisheries (QDAF) purchased an allocation of treated municipal wastewater from Stanthorpe Council for their research farm. Overland flows are also captured in three other storages and water is mixed with the treated wastewater in the 10 ML covered irrigation storage. The water is used to irrigate field trials, which require a secure water supply. Apple and stone fruit are irrigated using a trickle system.

Decision drivers

The primary driver was to improve the quality of the water for trickle irrigation, by reducing algal and water-weed growth in the treated wastewater. The suspended shade cover reduces light transmission and water temperature, and provides security and limited human and animal access to the storage.

Technical detail

The storage has a double layer of compacted clay to reduce seepage and holds 10 ML of water. Evaporation is around 1.7m per year.

The structure is suspended on 7.4mm galvanised steel supports anchored to the bank with 2m anchors, and central in-storage supporting poles. The cover was installed when the storage was full using floating pontoons. The original shade cloth had an 84% shade factor, which should achieve an evaporation reduction of 70% (USQ Trial results). New NetPro products have a 95% shade factor and are expected to reduce evaporation by >85%.

Economic drivers

The payback for this installation has not been calculated as the driver was to secure irrigation water for research trials on this government research facility. QDAF currently pay $190 per ML for the treated effluent water. The NetPro cover cost $52,000 when originally installed 15years ago. Based on the current replacement cost, the cost to save water using NetPro product would be around $730/ML/year.

Waste Water – North Burnett Regional Council (Hexa-Cover Floating Modules)

Site and storage details

North Burnett Regional Council operate five sewage treatment plants. Hexa-Cover floating modules were installed on the final effluent water treatment lagoons at two of the plants at Gayndah (three years ago) and Mundubbera (this year). Each storage has an approximate capacity of 1ML (Figure 29).

Figure 29: Aerial photo of Gayndah sewerage treatment works

Decision Drivers

Water is used to irrigate parkland and the cover was installed to improve water quality by reducing *E.coli* levels, algal and water-weed growth.

Technical detail

Hexa-Cover R114 has a diagonal length of 228 mm and adjusts readily to changing water levels, re-floating and interlocking to maximise surface cover with rain flowing off the impermeable surface into the storage.

The North Burnett Council representative considers the modules would be easy for farmers to install on irrigation storages, with no maintenance or management issues.

Economic drivers

The main economic driver was to improve water quality to reduce water treatment costs. The cost-benefit has not been quantified. The product cost was around $70/m^2, imported from Denmark. A reduction in cost to $35/m^2 should be achievable once local production in Melbourne commences in July.

Waste Water Treatment – Kenilworth Sewage Treatment Plant (Floating Cover – Daisy Dam Cover)

Site and storage details

The Unitywater Kenilworth sewage treatment plant in Queensland uses a floating wetland to improve the quality of treated waste water stored in ponds by reducing the nutrient and sediment loading. A Daisy Dam Cover was installed in March 2020, to further reduce algal growth by reducing light transmission (Figure 30).

Figure 30: Daisy Dam Cover over a treated effluent pond in Kenilworth Queensland (photo: Clarity Aquatic)

Decision drivers

The synergy between reduced algal growth and the uptake of nutrients by the floating islands would reduce the nutrient loading and the suspended solids in water exiting the ponds. Reducing water treatment and maintenance costs by improving water quality was the key driver.

Technical detail

Six sections of 7.5m by 30m covers were installed by treatment plant workers between the floating wetland modules, using tethering and ties. Prior to installation eyelet holes were inserted into the covers, to release gas emitted from the waste water.

Economic drivers

The main economic driver was to improve the quality of the wastewater for forestry irrigation. The delivered price of the Daisy Dam Cover was $13/m^2. Clarity Aquatic designed the system, and selected the Daisy product on the cover design and price point.

Intensive Livestock Industry - Sandalwood Feedlot (Continuous floating Cover)

Site and storage details

Sandalwood feedlot are in the process of lining their 10.9ML (0.3ha) storage using Darling Downs Tarpaulins (Figure 31), and have requested a quote for installing an Aquacon continuous floating cover. The feedlot carrying capacity is 15,290 Standard Cattle Units (SCU), making it the 15th largest feedlot in Australia. The feedlot is managed by the ex-manager of the Wainui Feedlot, who has extensive experience with continuous floating covers. The long term annual average evaporation at the site is 2,037mm/year.

Decision drivers

The decision to invest in liners and a floating cover was based on the prior experience of the manager with covered water storages at Wainui. The driver was to improve water quality and temperature by reducing sediment and light transmission, and access to birds. Water from the lined and covered storages at Wainui is more palatable to cattle, and the cover has reduced the risk of zoonotic disease transmission.

Technical detail

The quote provided by Darling Downs Tarpaulins specified the Aquacon continuous floating cover. The feedlot manager also requested a quote for the EvapCap product, which was either not available or too costly. The manager did not seek quotes from any other suppliers as past experience with Darling Downs Tarpaulins as a supplier and installer has been very positive. The Aquacon product will cover the entire surface area of the storage and will be tethered to the bank of the turkeys nest.

Economic drivers

Water in the storage must be maintained for animal welfare. The evaporation saving of the completely covered system was based on an evaporation rate of 1.5m per year.

The USQ Evaporation Ready Reckoner tool was used to determine the average cost to save each megalitre from evaporation. The following table summarises the calculations.

- Evaporation saving: 95%
- Capital Cost: $25/m^2$ = 66,508
- Life: 10yrs
- Repair and Maintenance: $1.00/m^2$ = $2,660/yr

Water Saving Scenarios and Economics

- Water Saving: 5.1ML/yr (assuming always full)
- Cost to save water: $2,227/ML (assuming always full)
- Cost to save water: $2,643/ML (25% less water held each month)
- Cost to save water: $2,969/ML (25% of years storage dry)

Figure 31: Location of the turkeys nest clean water storage at Sandalwood to be covered by an Aquacon continuous floating cover (Photo: Google Maps)

Intensive Livestock Industry - Canning Downs South Feedlot (Suspended Cover)

Site and storage details

Canning Downs South Pty Ltd are investigating the use of a suspended cover. They operate a 10,000 head beef cattle feedlot at Elbow valley near the Queensland/New South Wales border and have recently upgraded the facility to cover the entire feed pen area with a roofed shed to provide both shade for cattle and a rainfall catchment area for clean water. The feedlot manager recently requested a quote from NetPro to supply and install a suspended cover over the clean water storage to reduce evaporation (Figure 32).

Decision drivers

The primary driver was to reduce evaporation from the clean water storage. Having spent so much money capturing the rainfall, the manager did not want to lose it to evaporation.

Technical detail

The clean water storage has a surface area of 0.5 ha and holds 11ML at full supply level. The quote of the NetPro suspended cover was about $100,000, requiring a 20 year return on investment. The feedlot manager is currently investigating ozonation of wastewater as an alternative, as this may be more cost-effective and is less likely to be affected by hail storms.

Economic drivers

At this stage the manager is not investing in the suspended cover. The following analysis indicates the economics of the NetPro cover that had been quoted.

- Evaporation saving: 70%
- Capital Cost: $\$22.10/m^2$ (30% of cost is shade cloth fabric) = $100,225
- Life: Shade cloth 15yrs; Structure 30yrs
- Repair and Maintenance: $\$0.03/m^2$ = $136/yr

Water Saving Scenarios and Economics

- Water Saving: 5.6 ML/yr (assuming always full)
- Cost to save water: $1,339/ML (assuming always full)
- Cost to save water: $1,661/ML (25% less water held each month)
- Cost to save water: $1,785/ML (25% of years storage dry)

Figure 32: Aerial photograph of Canning Downs South Feedlot before installation of the covered pens. (Photo: Google)

Key Findings from User Assessment:

- Prior positive experience and the development of trust with the supplier improves the likelihood of an evaporation mitigation technology being adopted.
- Securing the volume and quality of water to meet the demand of high value horticultural crops and animal welfare in feedlot enterprises are key drivers.
- Users must consider the impact of an evaporation mitigation product on water use efficiency at the enterprise scale, when deciding on an investment.
- Evaluating the role of an evaporation mitigation technology in improving water security and water quality, and in reducing the cost of water treatment and the cost of maintaining water (irrigation) distribution systems will assist in adoption.

5.3 Summary

A summary of costs and performance expectations for various products is provided in Table 17. Costs vary depending on remoteness and the size of the installation as well as site-specific design and operational constraints. These costs are only indicative, and users should obtain detailed quotes when comparing specific evaporation mitigation technology options for their enterprise. The evaporation reduction potential of a product depends on a number of factors, including prevailing meteorological conditions and the surface area of the storage covered by the product. Many of the suppliers of physical covers have at least 10 years' experience in design and installation in related applications, with the seasonality and variability in demand for evaporation mitigation products considered a more limited market. The ability to apply the multi-molecular chemical film only as required is attractive to users, but the very limited information available on the performance and cost-benefit of this product is an impediment to adoption. The performance of this product requires further monitoring and assessment on commercial-scale storages.

Table 18 provides information on the overall suitability and benefits and constraints of different generic product classes, while Table 19 gives a checklist when considering suitability of different product types.

Table 17: Evaporation Mitigation Technology supplier cost summary

	Multi-molecular film	**Suspended Shade cloth**	**Continuous Floating cover**	**Continuous floating cover (laid in sections)**	**Continuous Floating cover (laid in sections)**	**Floating Modular covers**
Company	Aquatain	NetPro	Layfields	Daisy Commercial	Darling Downs Tarpaulins	Hexa-Cover or HydroTerra
Product	WaterGuard	Suspended Shade cloth	REVOC	Daisy Dam Cover	a) EvapCap b) Aquacon	Hexa-Cover or AquaArmour
Capital Cost	NA	\$9/m^2 to \$30/m^2	\$23/m^2 agric \$75/m^2 industry	\$15/m^2 to \$20/m^2	a) \$22/m^2 to \$25/m^2 b) \$15/m^2 to \$25/m^2	\$35/m^2 - \$40/m^2
Operating Cost	\$14/litre @ 10-50 litre/ha every 2-3 weeks + labour	<0.05% of capital per year	<0.05% of capital per year	<0.05% of capital per year	<0.05% of capital per year	<0.05% of capital per year
Product Life and Warranty	NA	15 year cloth 30 year structure	15 year agric 35 year industry	5yr warranty 10yr expected life	a) 5 year b) 10 year	25year
Evaporation reduction potential	< 50% depending on application strategy and storage conditions	Up to 90%	Up to 99%	95% on covered area	Up to 95% for covered area	Up to 95% for covered area
Storage area limitations	Unlimited but <10 ha without distributed application	<5 ha or <15 ha with in-dam support	< 5ha rural, up to 30ha potential	Typically <2ha	Typically <2 ha	Typically <5ha

Table 18: Suitability of generic product classes

	Chemical films 1) mono-molecular film (monolayer) 2) multi-molecular film	Continuous covers 1) suspended cover 2) floating cover	Floating modular covers 1) modular covers 2) modular photovoltaics
Product installation & durability	1) repeat application via manual or automated applicator every 2 to 3 days	1) specialist installation of tensioned cables & supports, in place for 25 years, self-cleaning	1) modules may need tethering, ballasting or containment, product life span 15-25 years.
	2) repeat application via manual or automated applicator every 10 to 21 days	2) tethering and edge sealing required, regular cleaning, life 10-25 years	2) specialist installation of power generation system required.
Storage operational scale	1) < 100 ha	1) < 5 ha or < 15 ha with in-storage supports	1) < 5 ha
	2) < 10 ha	2) < 2 ha	2) depends on power requirement
Storage suitability	1) current product best on clear water, applied in light wind only.	1) all storage types, shading slows weed & algal growth, improving water quality	1) lined dam or permanent water avoids need to re-float units stuck in mud
	2) current product best where aquatic biodiversity is not a priority	2) all storage types, slows weed & algal growth, improving water quality	2) permanent water to avoid damaging floating power transmission cables
Cost	1) No current commercial product in Australia	1) $9/m^2 to $30/m^2	1) $20/m^2 to $40/m^2
	2) 10 to 50 litre/ha per application at $14/litre	2) $15/m^2 to $30/m^2	2) Function of PV requirement feed in tariffs will offset costs
Evap reduction potential (with full surface cover)	1) 0%to 70% depending on product, wind & water quality	1) 50 to 90%	1) proportional to surface area covered (up to 90% with full coverage)
	2) < 50% depending on rate of application	2) 70 to 100%	2) proportional to surface area covered (will be < 70% due to panel access needs)
Strengths	1) intermittent application when required, no impact on aquatic biodiversity	1) experienced installers are available, allows unimpeded access to basin and water	1) modules can be replaced & purchased incrementally, no expertise required.
	2) intermittent application, lasts longer than mono-molecular films	2) cover can be removed when installed in sections	2) can offset pumping power costs & provide off-grid, renewable power
Weaknesses	1) only one product not locally available, needs autonomous applicator to be cost-effective	1) installation is specialised	1) Attached algae may be a problem. Potentially vulnerable to wind
	2) only one product available, chemical film may restrict natural oxygenation of water	2) basin access difficult. Accumulated debris may damage and submerge cover, unless installed in sections	2) power generation system first, evaporation reduction is a lower priority. Highly specialist installation required

Table 19: Checklist when considering suitability of different product types

	Mono-molecular film (monolayer)	Multi-molecular film	Suspended continuous cover	Floating continuous cover	Floating modular covers
Duration of use	Intermittent	Intermittent	Permanent	Permanent	Permanent
Water storage size suitability	< 100 ha	< 10 ha	<5 ha or <15 ha with in-dam support	<2 ha	<5 ha
Water level suitability	Not applicable	Not applicable	Not affected by water level	Remove before dam dries	May not re-float from mud
Evaporation reduction (full surface cover)	< 70% depending on wind speed	< 50% depending on rate applied	50 – 90% depending on fabric	70 – 100% depending on edge seal	20 – 90% ballasted units best
Impact on water quality & ecology	Low, as biodegrades in 2 to 3 days	Slick may affect surface life & surface processes	High shading inhibits algae, low impact on water quality	Inhibits access, inhibits algae, may impact ecology and water quality	Inhibits access, inhibits algae, may impact ecology and water quality
Weather resilience and risks	Only applied with wind < 3 m per sec	Only applied under low wind speed	May tear in hail & strong wind, damage by fire	May submerge in heavy rain, damage by strong wind and fire, potential loss through spillway during flood	May beach in strong wind, potential to be blown into neighbouring fields, potential loss through spillway during flood
Site preparation & installation	Hand or automated applicator	Hand or automated applicator	Requires specialist installers	Requires tethering to wall anchors	Containment may be required
Upfront & on-going costs	Low, with repeat application costs	Low, with repeat application costs	High, then minor	High, labour for removal & cleaning	Incremental option, labour for handling
Maintenance	Application every 3 days when required	Application every 10 – 21 days when required	Minimal, tension adjustment	Possible cleaning & removal if dam dries	Possible cleaning & removal if dam dries
Product life & availability of standards	Food-grade polymers designed to biodegrade	Silicone-based film combined with polymer, designed to chemically degrade	15 years cloth 30 years structure	15 - 25 years	15 - 25 years, replacement incremental

6 Part 3 - Regional Analysis and Recommendations

Regional recommendations of the potential economic benefits from evaporation mitigation technology have been provided in the sections below, to inform the next step in this program, of seeking opportunities for suppliers to demonstrate their products.

Regional recommendations are based on an analysis of:

a) The number, size and location of dams in the major river catchments of Queensland
b) Trends in annual evaporation loss from storages
c) The potential water saving that is achievable using different evaporation mitigation technologies, based on their evaporation saving performance and a range of adoption thresholds.
d) The economics and annualised cost of each product ($/ML evaporation saved)
e) The annualised value of evaporation water saved, in terms of
    - Gross margin of irrigated production per ML irrigation water ($/ML/yr)
    - Value of tradable water

6.1 The number, size and location of dams in the major river catchments of Queensland

Overview:

- Queensland government maintains a Geographic Information System (GIS) database on the water storages across Queensland. This database was interrogated and modelling was undertaken combining regional water storage data with evaporation data from the Australian Bureau of Meteorology.
- Results show the majority of storages (99.9%) have a surface area less than 100 ha, however storages larger than 100 ha account for 50% of the water lost (generally municipal and water supply scheme storages).
- The effective upper size limit of all Evaporation Mitigation Technologies (5 ha for floating continuous and modular covers; 15 ha for suspended continuous covers and 100 ha for chemical covers), was applied when modelling the potential saving of each individual EMT.
- Local, accurate evaporation rates (not catchment averages) were used when assessing individual storage losses, with results presented on a catchment basis.
- Potential savings for Queensland are based on i) the on-site evaporation rate , ii) the efficiency of the EMT, iii) the surface area of the storage, and iv) the adoption rate for each technology.

Information on the location of water storages greater than 625m^2 (including location and surface area at full supply level), and a range of metadata including river systems, sub-catchments and storage type in Queensland were extracted from the DNRME mapping database. The database holds records for over 243,000 water storages, many of which may be temporary and do not hold water all year round. Calculations are based on the potential for a storage to lose water through evaporation rather than actual measured loss, as information on the seasonal water holding status of each storage was not available.

The water storages across Queensland catchments were categorised according to surface area (Table 20). Results indicate 79% of all water storages in Queensland have a surface area of < 0.5ha. Of these 16% are <0.1ha and 63% are between 0.1 – 0.5ha.

The catchments which contain the majority of these storages (53% of the total or ~126,000 storages) are the Condamine, Fitzroy, Burnett, and Brisbane. Figure 33 shows that spatial distribution of storages in Queensland categorised by surface area.

The surface area of the vast majority of the >40,000 water storages in the Condamine catchment is between 0.1 – 0.5 ha (Figure 34). This is common across most catchments in Queensland, the only exceptions being the Lake Frome and Weipa catchments which have comparatively few storages.

Table 20: Number of individual water storages in each catchment in Queensland grouped by surface area.

Catchment Name	<0.1 ha	0.1 - 0.5 ha	0.5 - 1 ha	1 - 2 ha	2 - 5 ha	5 - 10 ha	10 - 15 ha	15 - 25 ha	25 - 100 ha	> 100 ha	Total	Percent of total
Lake Frome	-	-	2	-	-	-	-	-	-	-	2	0%
Weipa	-	57	65	21	10	1	4	-	1	1	160	0%
Princess Charlotte Bay	1	165	104	71	30	12	-	5	2	1	391	0%
Burketown	121	373	139	66	24	6	-	2	1	3	735	0%
Leichhardt	219	479	196	77	33	14	8	9	20	8	1,063	0%
Bulloo-Bancannia	124	1,124	521	96	39	6	1	2	1	1	1,915	1%
Barron	197	1,500	455	225	113	43	10	6	5	5	2,559	1%
Whitsunday	280	1,473	340	234	198	82	27	10	14	3	2,661	1%
Mitchell	182	1,574	505	310	217	46	18	13	13	2	2,880	1%
Shoalwater Bay	336	1,765	425	264	168	71	33	21	26	2	3,111	1%
Flinders	592	2,493	771	188	74	35	10	9	8	4	4,184	2%
Gilbert	345	2,751	898	406	242	69	23	11	13	4	4,762	2%
Channel Country	509	3,344	1,377	439	167	62	16	10	7	2	5,933	2%
Warrego	754	5,277	1,088	180	68	16	2	6	9	1	7,401	3%
Curtis	1,723	5,108	532	237	136	45	15	8	9	1	7,814	3%
Gold Coast	2,615	4,618	424	179	109	18	4	5	3	5	7,980	3%
Cooper Creek	905	7,323	3,142	513	165	48	10	13	9	4	12,133	5%
Burdekin	778	6,429	2,976	1,386	740	215	67	51	56	13	12,711	5%
Border Rivers	3,053	11,697	1,882	584	282	83	24	29	122	21	17,780	7%
Mary	6,532	11,873	1,369	630	287	81	14	9	5	5	20,805	9%
Brisbane	4,827	14,163	1,300	559	282	69	23	19	9	11	21,263	9%
Burnett	6,986	20,021	2,400	957	604	202	52	25	27	10	31,288	13%
Fitzroy (QLD)	2,887	20,069	5,883	2,417	1,297	360	118	102	129	23	33,285	14%
Condamine	5,400	28,344	3,794	1,125	708	338	167	149	180	70	40,276	17%
Total	39,366	152,020	30,588	11,164	5,993	1,922	646	514	669	200	243,092	
Percentage of Total	16%	63%	13%	5%	2%	1%	0%	0%	0%	0%		

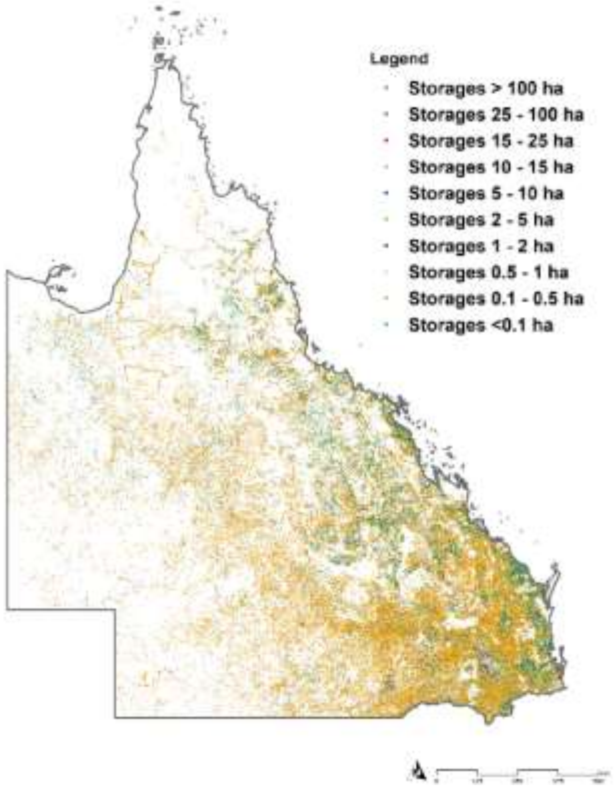


Figure 33: Location of water storages of different surface area in Queensland

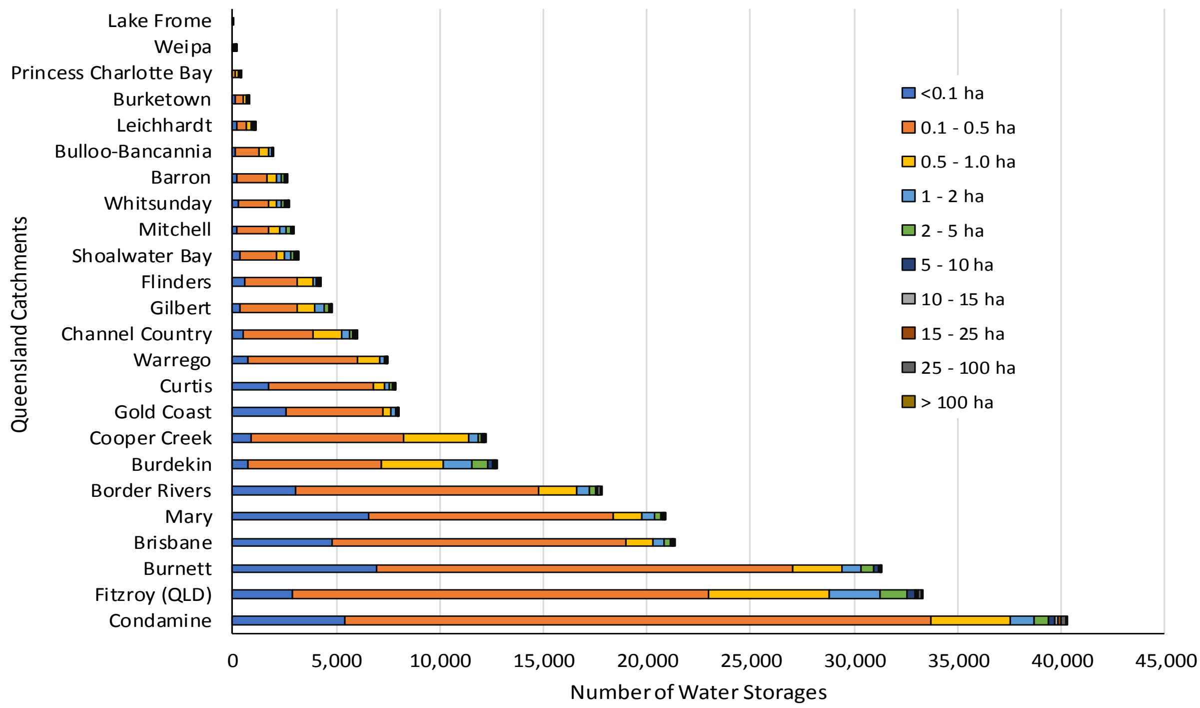


Figure 34: Number of storages in Queensland Catchments (classed by surface area)

The water lost through evaporation from a storage is a function of the surface area exposed to evaporation. The total surface area susceptible to evaporation across

Queensland is more than 311,000ha (Table 21). Totals for each of the catchments are shown in Figure 35.

Table 21: Total surface area of water storages in each catchment in Queensland (grouped by surface area)

Catchment Name	<0.1 ha	0.1 - 0.5 ha	0.5 - 1 ha	1 - 2 ha	2 – 5 ha	5 - 10 ha	10 - 15 ha	15 - 25 ha	25 - 100 ha	> 100 ha	Total	Percent of total
Lake Frome	-	-	1	-	-	-	-	-	-	-	1	0%
Weipa	-	19	44	29	27	8	46	-	35	135	344	0%
Princess Charlotte Bay	0	55	73	97	90	78	-	93	58	102	646	0%
Burketown	10	88	103	89	72	41	-	41	31	823	1,298	0%
Leichhardt	17	112	140	102	93	103	98	175	996	3,925	5,761	2%
Bulloo-Bancannia	10	318	351	130	118	48	11	39	39	863	1,927	1%
Barron	17	376	315	311	336	300	112	107	183	10,792	12,848	4%
Whitsunday	24	344	237	323	622	572	327	198	676	5,167	8,491	3%
Mitchell	15	406	356	432	646	326	220	251	578	3,570	6,800	2%
Shoalwater Bay	28	413	296	366	520	495	397	385	1,090	1,116	5,107	2%
Flinders	48	615	528	250	220	241	121	178	326	727	3,254	1%
Gilbert	28	710	625	569	723	481	280	212	472	1,234	5,335	2%
Channel Country	42	860	963	575	505	433	195	196	274	434	4,477	1%
Warrego	62	1,396	702	243	205	104	21	109	550	137	3,529	1%
Curtis	139	1,061	365	333	412	306	170	156	282	6,434	9,659	3%
Gold Coast	204	903	290	244	322	116	50	90	108	3,512	5,840	2%
Cooper Creek	74	2,011	2,111	663	501	331	112	241	447	489	6,979	2%
Burdekin	64	1,763	2,073	1,899	2,256	1,478	833	967	2,740	29,627	43,701	14%
Border Rivers	246	2,758	1,274	787	884	567	289	585	6,265	6,047	19,703	6%
Mary	519	2,403	941	860	864	532	164	171	193	1,552	8,198	3%
Brisbane	383	2,857	885	763	842	464	273	362	433	20,352	27,613	9%
Burnett	560	4,301	1,649	1,315	1,869	1,414	625	482	1,184	13,089	26,489	9%
Fitzroy (QLD)	234	5,218	4,025	3,324	3,909	2,468	1,416	1,963	5,742	19,920	48,218	15%
Condamine	441	6,726	2,537	1,535	2,219	2,422	2,026	2,834	9,000	25,185	54,927	18%
Total	3,166	35,711	20,886	15,239	18,255	13,330	7,785	9,837	31,705	155,232	311,146	
Percentage of Total	1%	11%	7%	5%	6%	4%	3%	3%	10%	50%		

Most (50%) of the storage surface area susceptible to evaporation is located in very large storages greater than 100 ha (Table 20 and Table 21), which may not be suitable for the deployment of evaporation mitigation technologies. Storages in the Burdekin and Barron catchments are larger and fewer in number.

The largest number of storages across almost all catchments is in the 0.5 – 1.0 ha category, which may be suitable for the deployment of evaporation mitigation technologies.

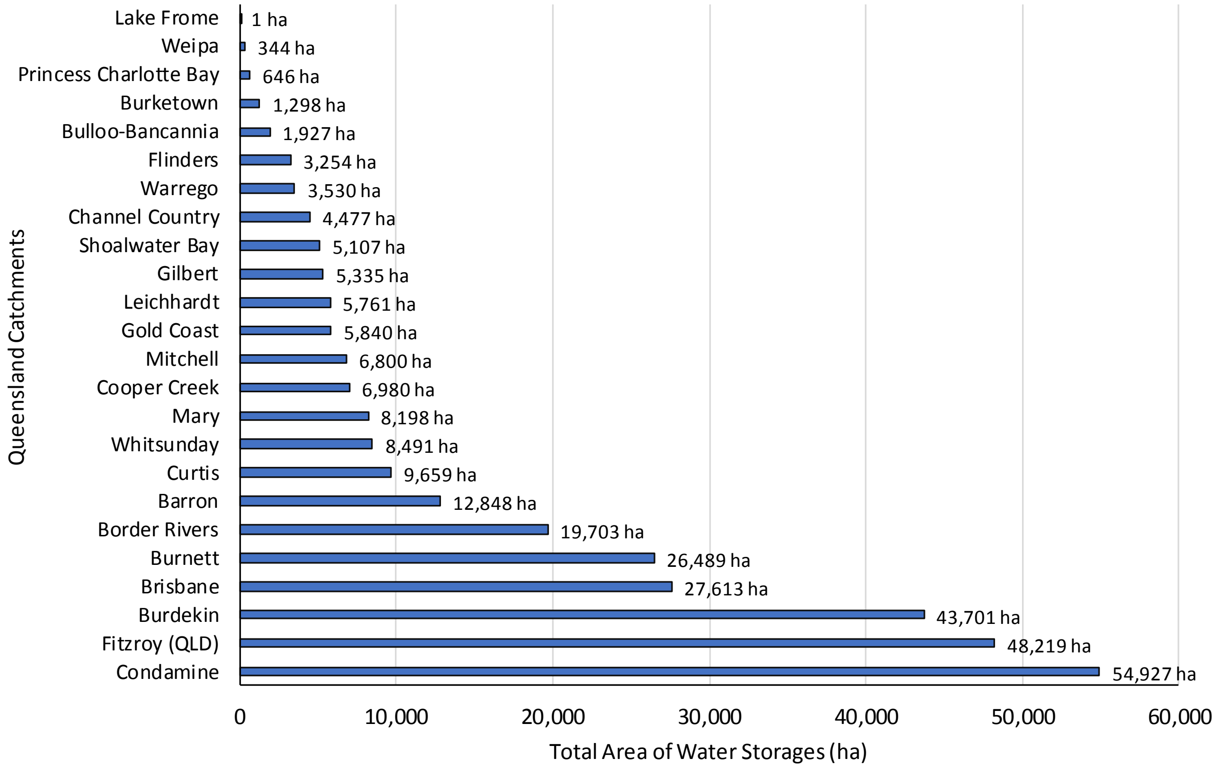


Figure 35: Total area of water storages in Queensland Catchments

6.2 The annual evaporation loss from each storage

A spatial analysis of the Point Potential Evaporation across Queensland and data from the Bureau of Meteorology was used to estimate the total water lost to evaporation. The method most commonly used to estimate evaporative loss (Morton's Point Potential Evapotranspiration; PPET), uses elevation, latitude and longitude to account for spatial variation in precipitation, temperature and vapour pressure across the landscape.

Long-term monthly average data from 713 meteorology stations across Australia were summed to provide an annual average at each point in a 0.1-degree (Latitude and Longitude) grid (Figure 36). The grid was overlaid with the Queensland DNRME water storage database (used for the spatial analyses above) to give the annual average evaporation for each of the storage locations in each of the Queensland catchments.

Evaporation across Queensland varies from approximately 1,700mm in the Condamine catchment to 3,000 mm in the north and western catchments (Figure 34).

Variation across a single catchment (eg Condamine) can be substantial (1,709mm near Stanthorpe to 2,587 mm near Dirranbandi), highlighting the errors associated with using a catchment mean or median for modelling exercises.

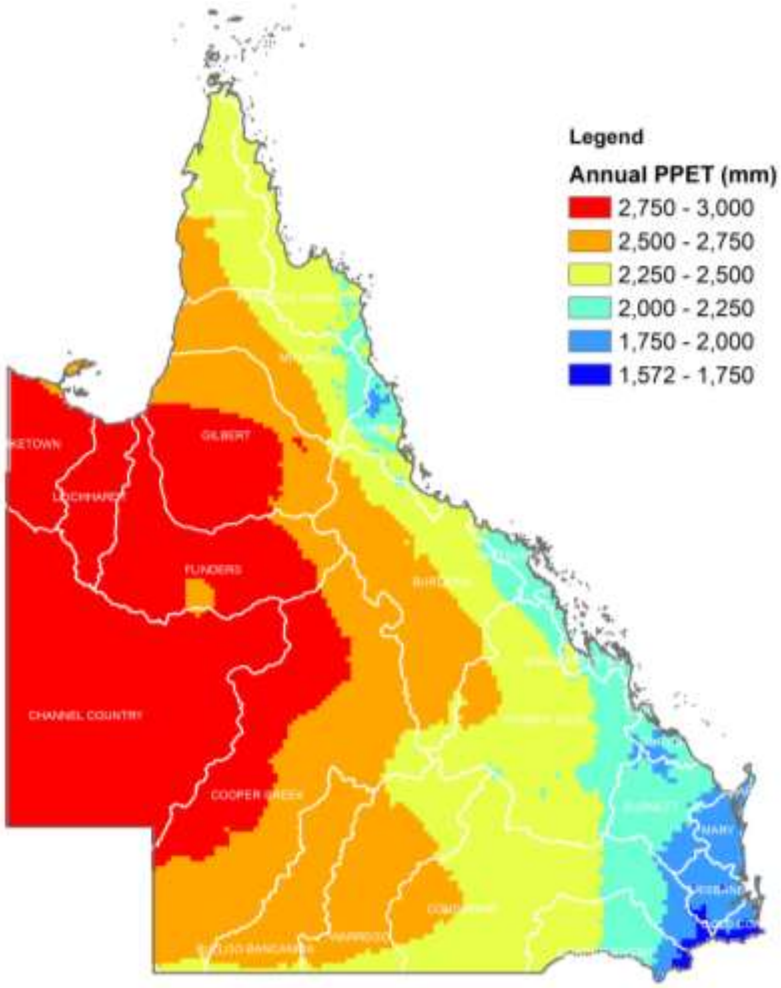


Figure 36: Spatial distribution of Point Potential Evapotranspiration (PPET) across Queensland catchments

To calculate the annual potential loss from each storage, the annual Point Potential Evapotranspiration was multiplied by the surface area of the storage. The total potential water loss from evaporation in Queensland is 7.1 million ML or 7,100GL. More than 5,000 GL is potentially lost to evaporation in the Condamine, Fitzroy, Burdekin, Brisbane, Burnett and Border Rivers catchments. Of the > 311,000 ha of water stored in Queensland, only 50% (155,000ha) is held in storages of a size class suitable for the deployment of Evaporation Mitigation Technologies (< 100ha; the blue storages in Figure 33).

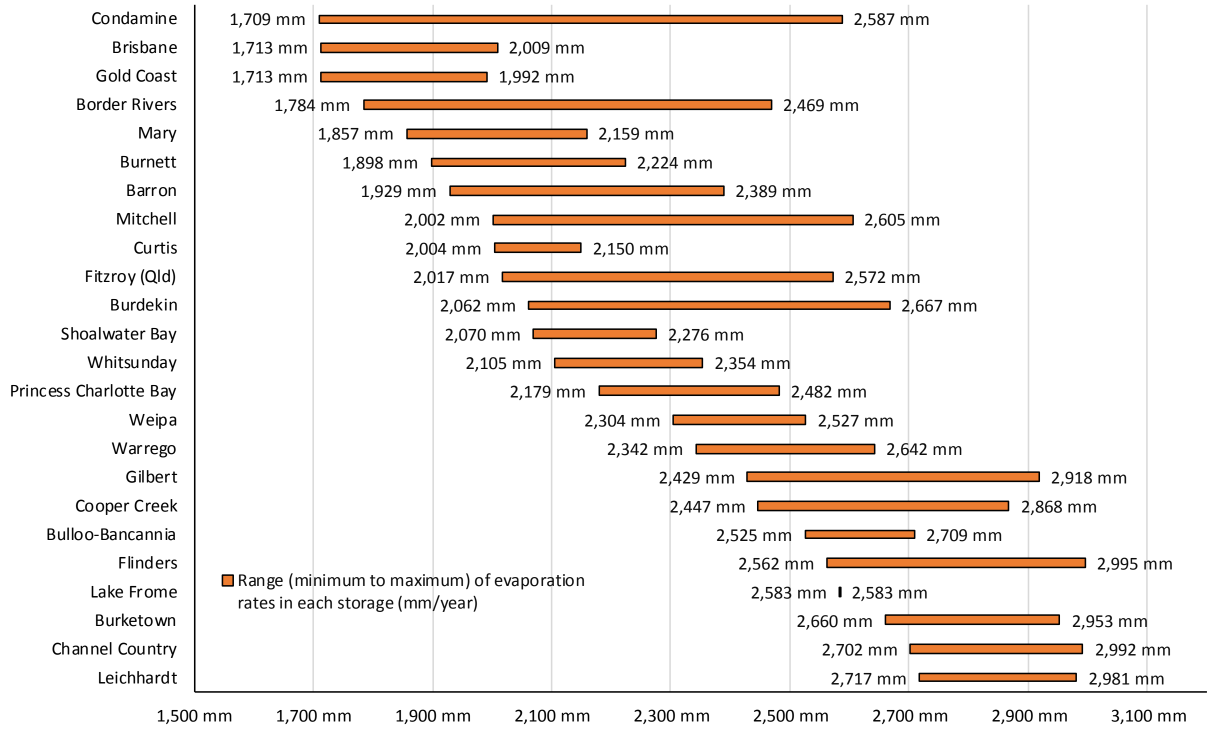


Figure 37: Range in Point Potential Evapotranspiration across Queensland Catchments

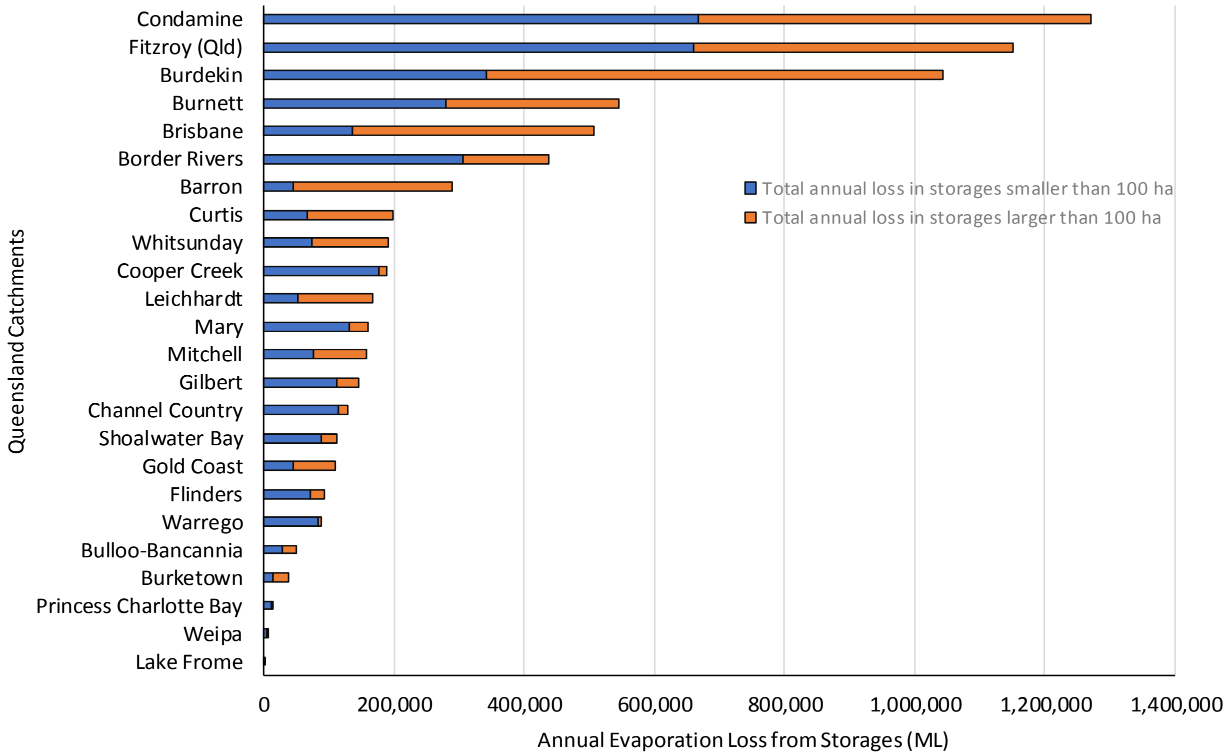


Figure 38: Annual loss to evaporation from storages in each Queensland catchment

6.3 Potential water saving using Evaporation Mitigation Technologies

Estimates of the potential evaporative water saving was based on the evaporation reduction performance of each product class and three adoption rates:

- 0.01% (i.e. 1 in 1,000 storages adopt EMT)
- 0.1% (i.e. 1 in 100 storages adopt EMT)
- 0.5% (i.e. 1 in 20 storages adopt EMT)

The potential water savings with suspended covers deployed across water storages in each Queensland catchment is based on the following assumptions:

- can only be installed on storages with a surface area of less than 15 ha
- at full surface coverage the evaporation reduction is 85% of total annual evaporation.

Within Queensland there are more than 241,697 storages with a surface area of less than 15 ha (total of 114,362 ha). If 5% of these storages across Queensland installed a suspended cover, a total of 111,099 ML/year could be saved from evaporation (Table 22).

Table 22: Potential savings with suspended covers at adoption rates of 0.1, 1.0 and 5.0%.

The evaporation reduction figure used (assuming full surface coverage) was 85%.

Catchment	Combined area of storages less than 15 ha	*Assume Adoption of 0.1%*	*Assume Adoption of 1%*	*Assume Adoption of 5%*
		Potential water saving (ML/year)	Potential water saving (ML/year)	Potential water saving (ML/year)
Lake Frome	1	0	0	1
Weipa	162	3	34	168
Princess Charlotte Bay	393	8	78	390
Burketown	403	10	97	486
Leichhardt	666	16	161	807
Bulloo-Bancannia	986	22	220	1,100
Barron	1,767	34	336	1,681
Gold Coast	2,130	34	342	1,709
Whitsunday	2,450	47	465	2,326
Shoalwater Bay	2,516	47	467	2,337
Mitchell	2,401	48	479	2,397
Flinders	2,023	49	487	2,436
Curtis	2,786	50	497	2,485
Warrego	2,733	58	578	2,889
Gilbert	3,416	79	789	3,943
Channel Country	3,572	87	869	4,344
Brisbane	6,466	103	1,035	5,173
Mary	6,282	105	1,047	5,235
Border Rivers	6,805	125	1,251	6,256
Cooper Creek	5,802	134	1,341	6,703
Burnett	11,733	207	2,073	10,363
Burdekin	10,366	215	2,149	10,746
Condamine	17,907	336	3,356	16,779
Fitzroy (QLD)	20,595	407	4,069	20,345
Total	114,362 ha	2,222 ML	22,220 ML	111,099 ML

The potential water savings with floating covers deployed across water storages in each Queensland catchment is based on the following assumptions:

- can only be installed on storages with a surface area of less than 5 ha
- at full surface coverage the evaporation reduction is 90% of total annual evaporation

There are more than 239,131 storages with a surface area of less than five ha (total of 93,257 ha) suitable for a floating continuous or floating modular cover (Table 23). If 5% of these storages across Queensland adopted floating covers, a total of 95,977 ML/year could be saved from evaporation.

Table 23: Potential savings for various adoption rates of Continuous or Floating Modular systems (assuming a 90% saving potential)

Catchment	Combined area of storages less than 5 ha	Assume Adoption of 0.1%	Assume Adoption of 1%	Assume Adoption of 5%
		Potential water saving (ML/year)	Potential water saving (ML/year)	Potential water saving (ML/year)
Lake Frome	1	0	0	2
Weipa	118	3	26	130
Princess Charlotte Bay	315	7	66	331
Burketown	362	9	92	462
Leichhardt	464	12	119	597
Bulloo-Bancannia	927	22	219	1,094
Barron	1,355	27	273	1,363
Whitsunday	1,550	31	311	1,555
Shoalwater Bay	1,624	32	318	1,592
Gold Coast	1,964	33	334	1,668
Mitchell	1,855	39	392	1,962
Flinders	1,661	42	424	2,118
Curtis	2,310	44	436	2,179
Warrego	2,608	58	584	2,919
Gilbert	2,655	65	649	3,244
Channel Country	2,944	76	758	3,789
Brisbane	5,730	97	970	4,850
Mary	5,587	98	984	4,920
Border Rivers	5,949	116	1,157	5,787
Cooper Creek	5,359	131	1,312	6,558
Burdekin	8,054	177	1,773	8,864
Burnett	9,694	181	1,810	9,048
Condamine	13,459	269	2,694	13,472
Fitzroy (QLD)	16,711	349	3,494	17,471
Total	93,257 ha	1,920 ML	19,195 ML	95,977 ML

The potential water savings with a multi-molecular chemical film applied to water storages in each Queensland catchment is based on the following assumptions:

- can only be used on storages with a surface area of less than 100 ha
- at full surface coverage the evaporation reduction is 20% of total annual evaporation
- the chemical film is applied every 10 days for the entire year

There are more than 242,882 storages with a surface area of less than 100 ha (total of 155,868 ha) that would be suitable for a chemical film (Table 24). If 5% of these storages across Queensland regularly applied the film throughout the year, a total of 35,859 ML/year could be saved from evaporation.

Table 24: Potential savings for various adoption rates of Chemical Films (assuming a 20% saving potential)

Catchment	Combined area of storages less than 100 ha	*Assume Adoption of 0.1%* Potential water saving (ML/year)	*Assume Adoption of 1%* Potential water saving (ML/year)	*Assume Adoption of 5%* Potential water saving (ML/year)
Lake Frome	1	0	0	0
Weipa	162	1	8	40
Princess Charlotte Bay	544	3	25	127
Burketown	475	3	27	135
Bulloo-Bancannia	1,064	6	56	279
Gold Coast	2,328	9	88	440
Barron	2,057	9	92	460
Leichhardt	1,836	10	104	521
Curtis	3,224	14	135	677
Flinders	2,526	14	143	716
Whitsunday	3,324	15	149	746
Mitchell	3,230	15	152	761
Warrego	3,393	17	169	845
Shoalwater Bay	3,992	17	175	875
Gilbert	4,101	22	223	1,114
Channel Country	4,043	23	231	1,155
Mary	6,646	26	261	1,303
Brisbane	7,261	27	274	1,368
Cooper Creek	6,490	35	353	1,764
Burnett	13,400	56	558	2,788
Border Rivers	13,656	61	611	3,055
Burdekin	14,073	68	684	3,421
Fitzroy (QLD)	28,299	132	1,321	6,604
Condamine	29,742	133	1,333	6,665
Total	155,868 ha	717 ML	7,172 ML	35,859 ML

The potential market for suspended and floating covers and chemical films in Queensland is substantial, and would contribute to improving water security for agricultural and municipal use. Actual adoption rates will depend on the confidence users have in the expertise and experience of suppliers, and in the quality and objectivity of information available on product performance and cost-benefit. In this modelling exercise only evaporative savings were estimated, whereas in reality, savings associated with improvements in water security, water quality and reduced maintenance may be of greater importance to an enterprise than evaporative reduction alone.

6.4 Economics of Evaporation Mitigation Technologies

Overview:

The annualised cost of an evaporation mitigation technology should be assessed using the cost per unit of water saved as the primary metric. This value can be compared with the additional crop produced and revenue generated using the saved water, or compared with the cost to purchase water.

The annual cost of an evaporative mitigation technology per ML of water saved is a function of the capital cost of the product, installation and annual maintenance costs, offset against the annual and seasonal water lost from the storage, storage operating conditions and requirements, and the efficiency of the technology in reducing water loss.

The Economic Ready Reckoner is a useful tool for undertaking the site-specific analysis required to inform potential users of the cost-benefit of each technology.

The Economic Ready Reckoner (https://kmsi.usq.edu.au/readyreckoner/) was used to estimate the volume of water saved from evaporation (water saving potential) within selected sites of Queensland, with the purchase, delivery and installation of a generic evaporation mitigation product. The sites represent the range in evaporation rate across the state, from Stanthorpe (1,686mm/yr) to Mt Isa (3,133mm/yr; Table 25).

The evaporation reduction value and cost used for a generic suspended continuous cover, a floating continuous or modular cover, and a multi-molecular chemical film were based on data from the Literature Review (Table 17) and information collected from suppliers. Low, moderate and high cost scenarios were calculated for each product. The annual amount of water saved with the installation or application of a product assumes each product is installed or applied to totally cover the water surface within each storage. Different water storage management scenarios (eg. full all year, every year, or less water held, or years when the storage is dry) were used, to indicate the sensitivity of the cost-benefit ratio to altered management practices and seasonal conditions.

Table 25: Sites used in economic assessment and mean annual evaporation from a storage dam (mm/yr)

	Evaporation (mm)							
	Stanthorpe	Gatton	Dalby	Bundaberg	Ayr	Theodore	StGeorge	Mt Isa
January	207	229	246	225	223	262	309	321
February	166	186	201	187	186	215	253	265
March	163	185	205	193	197	222	251	286
April	118	142	153	159	169	175	181	244
May	81	107	111	131	147	135	124	193
June	63	90	88	116	133	111	93	159
July	73	102	99	126	142	119	102	173
August	101	129	127	153	163	150	141	221
September	140	166	169	181	191	193	194	272
October	175	201	213	210	227	236	250	325
November	189	215	231	216	231	245	277	331
December	213	235	254	231	234	266	315	344
Annual	1686	1985	2097	2127	2243	2328	2489	3133

6.4.1 Suspended Continuous Cover:

The generic product assumptions listed below are based on the NetPro product (Appendix 1.2.2).

Product assumptions:

- Evaporation saving: 85%
- Capital Cost: Varied from $9/m^2$, $13/m^2$ to $30/m^2$
- Life: Cover 15yrs; Structure 30yrs
- Repair and Maintenance: $0.05/m^2$

Water saving potential assuming the storage is 100% full, all year, every year, and the surface is completely covered:

- Stanthorpe 14.4 ML/ha/yr
- Gatton 17.0 ML/ha/yr
- Dalby 18.0 ML/ha/yr
- Bundaberg 18.2 ML/ha/yr
- Ayr 19.2 ML/ha/yr
- Theodore 19.9 ML/ha/yr
- St George 21.3 ML/ha/yr
- Mt Isa 26.8 ML/ha/yr

Economics:

The annualised cost of a suspended cover (Table 26) for each location for low, medium and high capital cost scenarios used the following scenarios on the amount of time the storage holds water:

- 100% full: *Storage full all year every year*
- Month storage -25%: *25% less water held each month*
- Years storage -25%: *25% of years storage is dry*

Product annualised cost can be compared with the Gross Margin of the additional crop produced per ML of water applied through irrigation (Section 6.5).

The annualised cost of an installed suspended cover costing $13/m^2$ on a storage that is always full, ranges from $733/ML/yr (Stanthorpe – low evaporation site) to $394/ML/yr (Mt Isa – high evaporation site; Table 26). If the storage is empty 25% of years, or holds 25% less water (implying reduced surface area), the cost increases but is less than $1,000.00 /ML/yr in all cases. The cost for saving water ($/ML/yr), using an evaporation control product, will escalate as the amount of time the storage is dry or holds less water increases.

Most high-value horticulture crops have a gross margin greater than $1,000/ML/yr, which suggests the product would be cost-effective for this industry sector (Table 26) If the capital cost increased to $30/m^2$ the annualised cost would increase to between $1000-$2000/ML/yr for most locations, making the adoption of a suspended cover cost-prohibitive for some crops or enterprises.

Table 26: Economic analysis for suspended cover in eight locations indicating cost to save water $/ML/year

	Suspended Continuous Cover								
	Capital Cost ($/ha)								
	$9/sqm			$13/sqm			$30/sqm		
	100% Full	Month Storage-25%	Years storage-25%	100% Full	Month Storage-25%	Years storage-25%	100% Full	Month Storage-25%	Years storage-25%
Stanthorpe	506	562	675	733	815	978	1652	1836	2202
Gatton	430	478	573	623	693	830	1403	1560	1871
Dalby	407	452	542	585	651	781	1328	1476	1771
Bundaberg	401	446	535	582	646	775	1309	1456	1746
Ayr	380	423	507	554	616	738	1242	1381	1656
Theodore	366	407	488	531	580	708	1196	1330	1595
St George	342	381	457	497	552	662	1119	1244	1492
Mt Isa	272	303	363	394	439	526	889	988	1185

<500ML/yr	$500-$1000ML/yr	$1000-$1500ML/yr	$1500-$2000ML/yr	>$2000ML/yr

6.4.2 Continuous Floating Cover

Generic product assumptions for a continuous floating cover are based on a Daisy Dam Cover (Appendix 1.2.3) or EvapCap (Appendix 1.2.4) product.

Product assumptions:

- Evaporation saving: 90%
- Capital Cost: Varied from $15/m^2, $20/m^2 to $25/m^2
- Life: 10yrs
- Repair and Maintenance: $0.05/m^2

Water saving potential assuming 100% full all year, every year, and complete surface coverage:

- Stanthorpe 14.9 ML/ha/yr
- Gatton 17.8 ML/ha/yr
- Dalby 18.6 ML/ha/yr
- Bundaberg 18.9 ML/ha/yr
- Ayr 20.0 ML/ha/yr
- Theodore 20.6 ML/ha/yr
- St George 22.2 ML/ha/yr
- Mt Isa 27.4 ML/ha/yr

Economics:

The annualised cost of an installed floating cover costing $20/m^2, on a storage which is always full, ranges from $1,795/ML/yr (Stanthorpe – low evaporation site) to $735/ML/yr (Mt Isa – high evaporation site; Table 27). If the storage is empty 25% of years or holds 25% less water (reduced surface area) the cost increases and is generally between $1,000.00/ML/yr and $2,000.00/ML/yr. Product annualised cost can be compared with the Gross Margin of the additional crop produced per ML of water applied through irrigation (Section 6.5).

Many high value horticulture crops have a Gross Margin > $1,000/ML/yr which suggests a floating cover would be affordable for crops such as Avocado (Table 34).

Table 27: Economic analysis for continuous floating cover for eight locations indicating cost to save water $/ML/year.

	Continuous Floating Cover								
	Capital Cost ($/ha)								
	$15/sqm			$20/sqm			$25/sqm		
	100% Full	Month Storage-25%	Years storage-25%	100% Full	Month Storage-25%	Years storage-25%	100% Full	Month Storage-25%	Years storage-25%
Stanthorpe	1355	1504	1806	1795	1992	2394	2236	2482	2981
Gatton	1131	1255	1508	1499	1664	1998	1866	2071	2489
Dalby	1086	1205	1448	1439	1597	1919	1793	1990	2390
Bundaberg	1065	1182	1420	1412	1567	1882	1758	1951	2344
Ayr	1008	1119	1344	1336	1483	1781	1663	1846	2218
Theodore	978	1086	1303	1295	1437	1727	1613	1790	2151
St George	908	1008	1210	1202	1334	1604	1498	1663	1998
Mt Isa	735	816	980	974	1081	1299	1213	1346	1618

<500ML/yr	**$500-$1000ML/yr**	**$1000-$1500ML/yr**	**$1500-$2000ML/yr**	**>$2000ML/yr**

6.4.3 Modular Floating Cover

Generic product assumptions listed below for a modular floating cover is based on the Hexa-Cover product (Appendix 1.2.14).

Product assumptions:

- Evaporation saving: 85%
- Capital Cost: Varies from $30/m^2, $40/m^2 to $50/m^2
- Life: 20 yrs.
- Repair and Maintenance: $0.05/m^2

Water saving potential assuming 100% full all year every year, with complete surface coverage.

- Stanthorpe 14.4 ML/ha/yr
- Gatton 17.0 ML/ha/yr
- Dalby 18.0 ML/ha/yr
- Bundaberg 18.2 ML/ha/yr
- Ayr 19.2 ML/ha/yr
- Theodore 19.9 ML/ha/yr
- St George 21.3 ML/ha/yr
- Mt Isa 26.8 ML/ha/yr

Economics:

The annualised cost of a modular floating cover (self-installed) costing $40/m^2 on a storage always full, ranges from $2,400/ML/yr (Stanthorpe – low evaporation site) to $1,298/ML/yr (Mt Isa – high evaporation site; Table 28). If the storage is empty 25% of years or holds 25% less water (reduced surface area), the cost increases. The cost for saving water using an evaporation control product will increase as the amount of time the storage is dry or holds less water increases. Product annualised cost can be compared with the Gross Margin of additional crop produced per ML irrigation (Section 6.5).

The capital cost of the product will determine the economic viability of this system. Hexa-Cover indicate a cost ex Melbourne of around $35/m^2$. Some high value crops have a gross margin greater than $2,000/ML/yr, suggesting modular covers would be affordable in areas of high evaporation potential (Table 34).

Table 28: Economic analysis for modular floating cover for eight locations indicating cost to save water $/ML/year

	Modular Floating Cover								
	Capital Cost ($/ha)								
	$30/sqm			$40/sqm			$50/sqm		
	100% Full	Month Storage-25%	Years storage-25%	100% Full	Month Storage-25%	Years storage-25%	100% Full	Month Storage-25%	Years storage-25%
Stanthorpe	1809	2011	2412	2400	2669	3201	2992	3326	3989
Gatton	1506	1675	2008	1998	2222	2665	2491	2769	3321
Dalby	1437	1598	1916	1906	2120	2542	2376	2642	3168
Bundaberg	1401	1557	1868	1858	2066	2478	2316	2576	3089
Ayr	1338	1488	1785	1776	1975	2368	2213	2461	2951
Theodore	1293	1438	1724	1716	1908	2288	2138	2378	2851
St George	1203	1337	1604	1596	1775	2128	1989	2212	2652
Mt Isa	975	1084	1300	1293	1438	1725	1612	1793	2150

<500ML/yr	$500-$1000ML/yr	$1000-$1500ML/yr	$1500-$2000ML/yr	>$2000ML/yr

6.4.4 Molecular Chemical Film

Generic product assumptions listed below were based on the WaterGuard multi-molecular chemical film (Appendix 1.2.19).

- Evaporation saving: 20% or 40%
- Application: Every 3 weeks 10L/ha or 50L/ha during high evaporation month from October to March (inclusive)
- Product Cost: $14/litre
- Operating / labour $0.025/m^2$ (Based on $30/hr and 2hr per application Oct-Mar)

Water saving potential:

Chemical films are only applied intermittently, when water is in the storage and the evaporative demand and/or the value of the water to the enterprise is high. Savings of greater than 50% for multi and mono-molecular films have been achieved in small-scale, controlled environment laboratory trials. Results from field trials are highly variable, and further scientific evaluation is required to more accurately calculate the cost-benefit of chemical films applied to storages in different Queensland catchments. The optimum dosage rate to achieve savings with the WaterGuard formulation under field conditions has not been objectively established. In this analysis a range of product performance levels and dosage rates were assumed.

Table 29: Evaporation water saved (ML/ha/year) for two performance levels

Location	20% evaporation saved	40% evaporation saved
Stanthorpe	2.26	4.52
Gatton	2.55	5.10
Dalby	2.76	5.52
Bundaberg	2.60	5.19
Ayr	2.62	5.24
Theodore	2.93	5.86
St George	3.36	6.71
Mt Isa	3.67	7.33

Economics:

The annualised cost of a multi-molecular chemical film was calculated for each location using evaporation savings of 20% and 40% at application rates of 10L/ha and 50L/ha (Table 30) and a product cost of $14/l. Results are based on application during the months of water scarcity and high demand, October to March. The cost is not influenced by dry periods or the water level in the storage as the product is only applied when necessary, at a rate which accounts for the surface area of the storage at the time of application.

The application rate and evaporation saving achieved will determine the cost-effectiveness of applying a multi-molecular chemical film (Table 30). The annualised cost for applications of 10 l/ha at $14/l is <$500/ML/yr, even at a 20% evaporation reduction. Aquatain believe the current recommended dosage of 10l/ha should be increased to up to 50l/ha to achieve the evaporative reduction of 40% measured in small-scale trials. Increasing the dosage to 50l/ha with an evaporation reduction of 40% increases annual costs to between $830/ML/yr and $1,350/ML/yr.

Table 30: Multi-molecular film economic analysis for eight sites.

Multi-Molecular Chemical Film				
	Application Rate 10l/ha		Application Rate 50l/ha	
	20% Evaporation saving	40% Evaporation saving	20% Evaporation saving	40% Evaporation saving
Stanthorpe	586	293	2700	1350
Gatton	520	260	2400	1200
Dalby	480	240	2212	1106
Bundaberg	508	254	2348	1174
Ayr	502	251	2320	1160
Theodore	452	226	2088	1044
St George	394	197	1816	908
Mt Isa	360	180	1660	830

<500ML/yr	$500-$1000ML/yr	$1000-$1500ML/yr	$1500-$2000ML/yr	>$2000ML/yr

6.4.5 Conclusion

The annualised cost of an evaporation mitigation technology, per unit of water saved, is site specific, affected by the capital, operating and maintenance costs and the life expectancy of the product. The evaporation savings achieved will depend on local evaporation rates, storage characteristics and operating conditions, and the efficiency of the technology in reducing water loss.

The Economic Ready Reckoner is very effective in comparing the site-specific cost-benefit of the different product options, offering potential purchasers to 'try before you buy'. Up-front capital costs are a major consideration, and any cost-benefit analysis will require a current, accurate quotation of any site-specific design and installation requirements, delivery and installation costs.

The value of the water per $ of enterprise output ($ per ML per year) will have a major impact on the cost-effectiveness of an evaporation mitigation option. Enterprise factors including the value of the crop, the impact of a water deficit at critical crop development phases on crop quality and marketability, the cost to purchase water, and the potential to trade water must be compared with the annualised cost of the evaporation mitigation option.

Typical gross margins for a range of crops per unit irrigation (Table 34) were compared with the annualised costs of the different generic options expressed as a function of the mean annual evaporation (Figure 39). The analysis assumes the storage is full all year, every year, and the product is installed or applied to cover the full surface area. The costs of the evaporation mitigation products used in the analysis were:

- Suspended continuous cover (cost $9/m^2, $13/m^2, $30/m^2)
- Continuous floating cover, potentially laid in sections (cost $15/m^2, $20/m^2, $25/m^2
- Modular floating cover (cost $30/m^2, $40/m^2, $50/m^2)
- Multi-molecular chemical film (Dosage 50l/ha and 10/ha and 20% and 40% evaporation saving)

Thresholds have been included for very high, high, medium, low and very low annual costs (Figure 39). The typical crop gross margin per unit irrigation (Table 34) is based on the total irrigation water usage. The marginal increase in yield and return from the additional unit of water saved from evaporation would in many cases be worth more.

All product options would be cost-effective in most locations, for crops with gross margins exceeding $2000/ML of irrigation applied (Figure 39). High-cost options such as modular floating covers ($40/m^2) would only be cost-effective for crops with a gross margin exceeding $2000/ML grown in a region of low evaporative demand (e.g.

Gatton), or for crops with a gross margin exceeding $1500/ML grown in a region of high evaporative demand (e.g. St George).

For permanent installations, such as suspended and floating covers, having the storage empty 25% of years would increase the annualised cost of the EMT by approximately 33%. A key marketing advantage of chemical films is the ability to apply intermittently, only when water is in the storage, at rates matched to the surface area of the water. However, reducing the evaporation reduction performance from 40 to 20%, doubles the annualised cost (Figure 39), and reducing the dosage rate from 50 to 10l/ha reduces costs by 80%. Further objectively monitored field trials on large commercial storages are required to objectively calculate the evaporative reduction potential of WaterGuard at the revised rate of 50l/ha.

Regional trials are also required, as the seasonal peak in evaporative demand when chemical films are most likely to be used, varies substantially across Queensland. In Dalby 64% of annual storage evaporation occurs between Oct-Mar compared to 59% at Bundaberg, which has a similar mean annual evaporation.

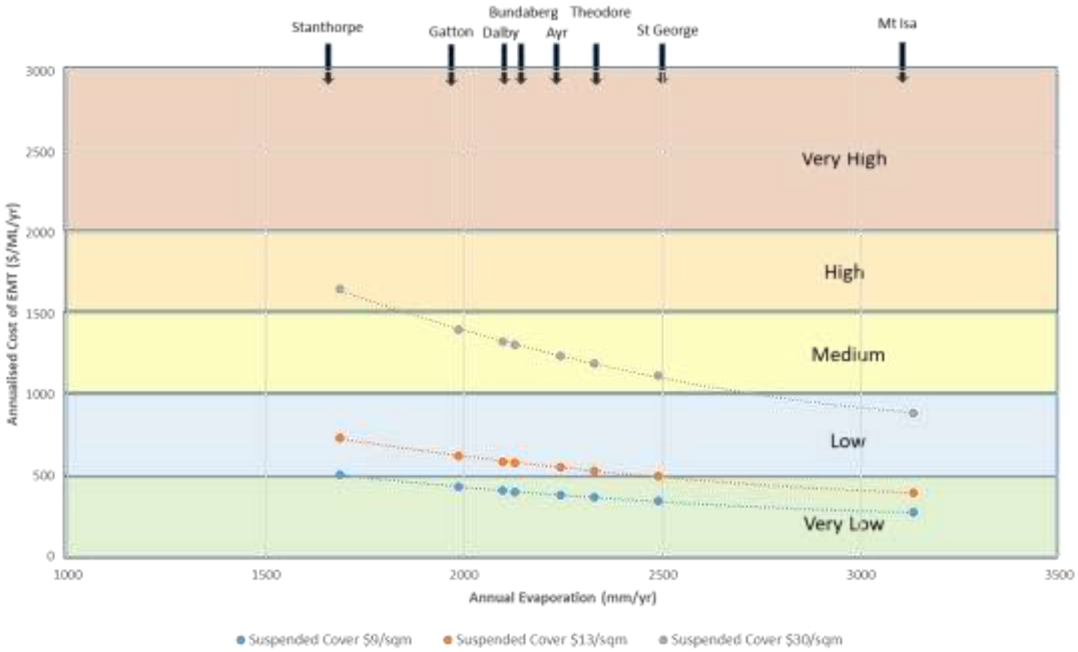


Figure 39a: Trend in annualised cost of Suspended continuous cover against annual evaporation.

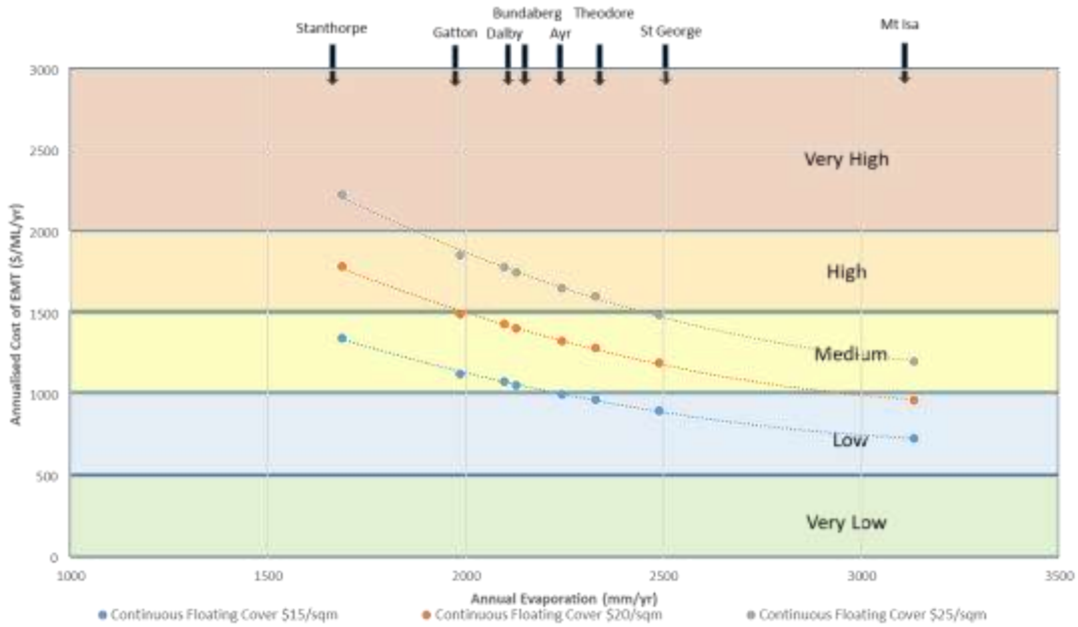


Figure 39b: Trend in annualised cost of Continuous floating cover against annual evaporation.

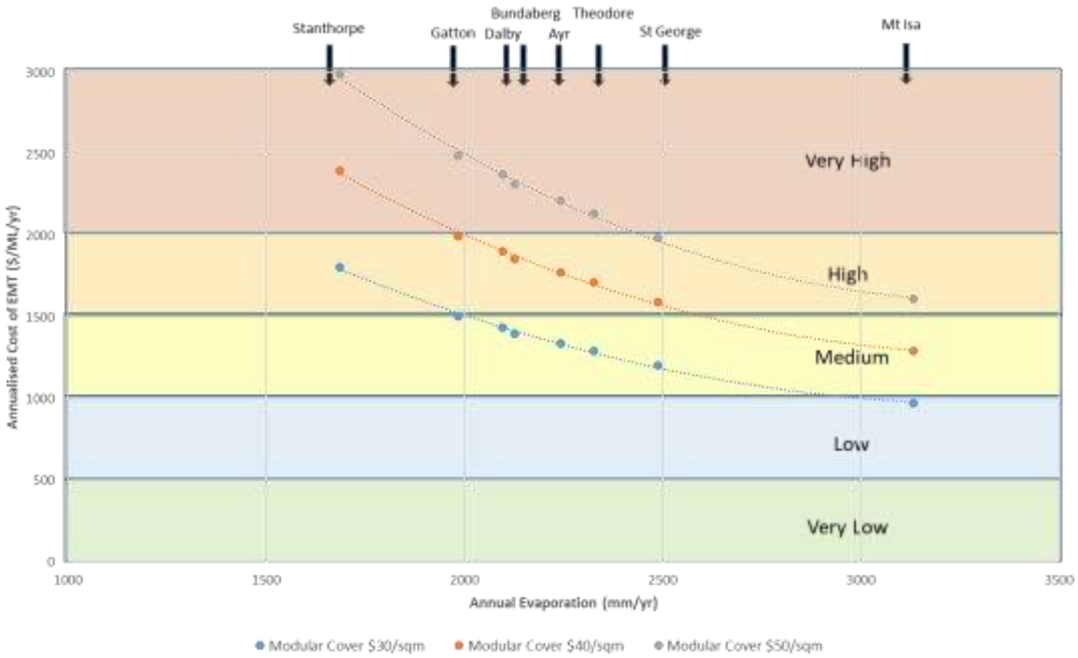


Figure 39c: Trend in annualised cost of Modular floating cover against annual evaporation.

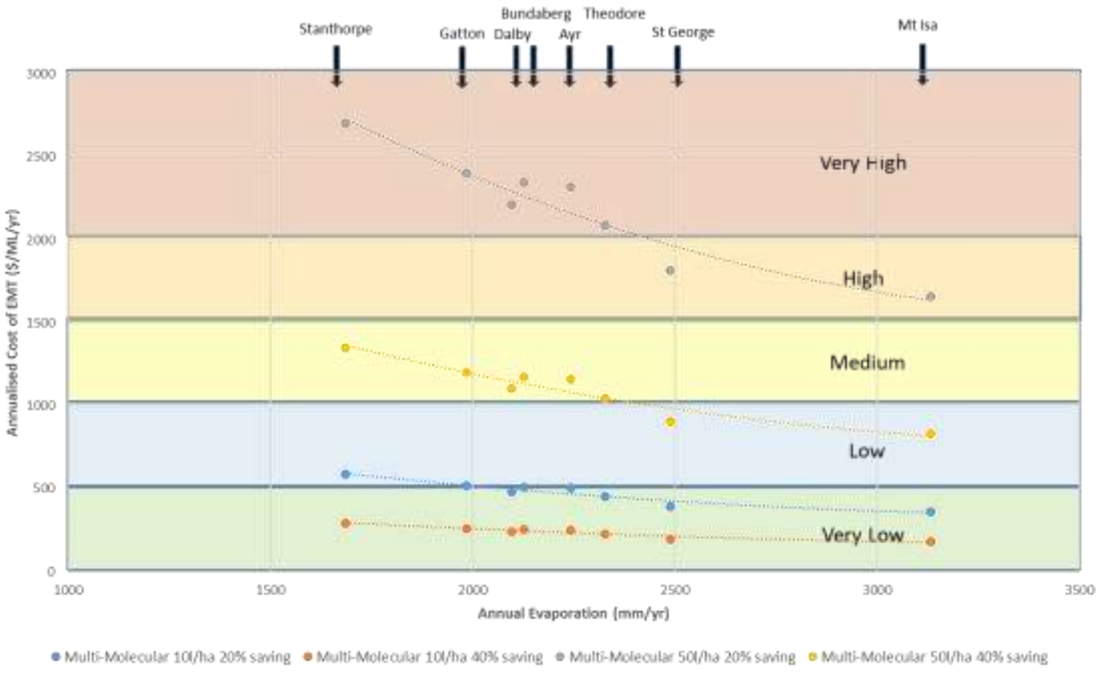


Figure 39d: Trend in annualised cost of Molecular Chemical film against annual evaporation.

Key Findings from Economics Assessment of Generic Evaporative Mitigation Products:

- Suspended Continuous Cover costs between $9m² and $30/m² to install. The annualised cost to save water is between $390/ML/yr and $733/ML/yr with capital cost of $20/m², 85% evaporative reduction, storage full all year every year.
- Continuous Floating Cover costs between $15m² and $25/m² to install. The annualised cost to save water is between $735/ML/yr and $1795/ML/yr with capital cost of $20/m², 90% evaporative reduction, storage full all year every year.
- Modular Floating Cover costs between $30m² and $40/m² to install. The annualised cost to save water is between $1,293/ML/yr and $2,400/ML/yr with capital cost of $40/m² 85% evaporative reduction and storage full all year every year).
- The evaporative reduction achieved with a multi-molecular chemical film is 20% to 40%, depending on the application strategy and dosage rate. The annualised cost to save water is between $360/ML/yr and $586/ML/yr with product cost $14/l, dosage rate 10l/ha every 3 weeks and 20% evaporative reduction, or between $830/ML/yr and $1,350/ML/yr , dosage rate 50l/ha every 3 weeks and 40% evaporative reduction.
- All products would be cost-effective at all locations for crops with gross margin exceeding $2000/ML irrigation.
- For permanent installations (suspended and floating covers), an empty storage in 25% of years increases the annualised cost 33%. A key advantage of chemical films is the ability to apply intermittently, at a dosage proportional to the surface area of the water in the storage.

6.5 Gross Margin of Crop Production

Overview:

The cost-benefit of installing and operating an EMT per unit of water saved ($/ML/yr) is determined by the value of water to the landholder, in terms of increased crop production and/or quality, the cost of water to be purchased, and/or the potential to trade surplus water.

Gross margin crop production data available from the Queensland Government AgMargins web site https://agmargins.net.au/ was used to calculate irrigated gross margins by dividing the crop gross margin by the water used to produce the crop (gross margin per megalitre, $/ML).

Cost-effectively, enterprises producing high-value, permanent crops are able to pay significantly more for water or for a water saving technology, than enterprises producing lower value, annual crops. Returns vary between years, depending on yield and commodity prices, the amount of irrigation required and the irrigation system used.

Establishing the cost-benefit of evaporation mitigation (water saved) is a key driver in investment decisions. The potential cost of installing and operating an EMT per unit of water saved ($/ML/yr; Section 6.4) is a function of:

- installation and maintenance costs, determined by location and site-specific requirements, and installation issues,
- annual and seasonal evaporation losses from storages at that location,
- efficiency of the EMT in reducing evaporation, and
- storage operating conditions.

These costs can be compared with the value of water to the landholder, in terms of increased crop production or quality, the cost of water to be purchased, and/or the potential to trade surplus water.

Where water trading is not practiced, the cost of installing and operating an EMT per unit of water saved ($/ML/yr) is primarily a function of the annualised gross margin of the crop produced, using the water saved ($/ML).

Gross margins are generally quoted per unit of the most limiting resource, for example land, labour, capital or irrigation water. In key Australian production regions, water is the key limiting input to expanding crop production. Therefore, the metric '*gross margins per megalitre*' represents the estimated volume of water required to produce the gross income. This allows producers to understand the economic return per unit of water (megalitre) utilised in various crop production systems. Irrigated gross margins are calculated by dividing the crop gross margin by water usage, to determine a gross margin per megalitre ($/ML).

AgMargins™ has been developed by the Queensland Government to provide farmers, consultants and researchers with current estimates of commodity gross margins (Table 31). Indicative gross margins and their key components (yield, market price, variable cost) are available at the Queensland Government AgMargins web site https://agmargins.net.au/.

A gross margin is the difference between the gross income and variable costs of producing a commodity. Variable costs include those associated with crop operations, harvesting and marketing. Gross margins are quoted on a per hectare basis, and also per ML for irrigated crops, enabling the Gross Margin per ML water irrigated to be calculated. Gross margins are sensitive to variation in yield and the price of outputs (Table 32 and Table 33), and the cost and level of inputs. These vary from region to region, farm to farm, paddock to paddock and year to year.

Table 31: Gross Margin per hectare for cotton grown under two irrigation systems in the Daring Downs extracted from the Queensland Government website AgMargins (https:// agmargins.net.au/).

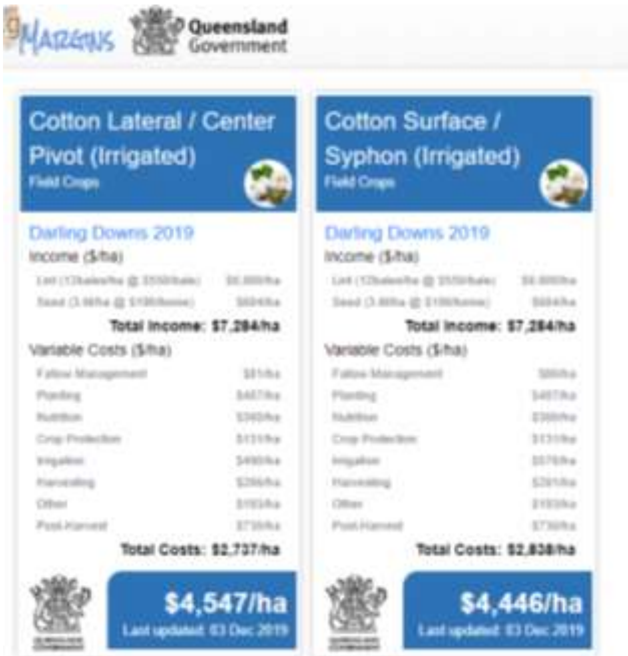


Table 32: Impact of Yield and Price on Gross Margin of cotton per ML for a surface irrigated system applying 8 ML/ha in the Darling Downs

Effects of Yield and Price on Gross Margin per ML (assuming 8.0ML/ha is used).

Lint Yield (bales/ha)	Seed Yield (t/ha)	$440.00/bale $152.00/tonne	$495.00/bale $171.00/tonne	$550.00/bale $190.00/tonne	$605.00/bale $209.00/tonne	$660.00/bale $228.00/tonne
8.40	2.52	$159	$222	$285	$348	$411
9.60	2.88	$231	$303	$375	$448	$520
10.80	3.24	$303	$384	$466	$547	$628
12.00	3.60	$375	$466	$556	$646	$736
13.20	3.96	$448	$547	$646	$745	$845
14.40	4.32	$520	$628	$736	$845	$953
15.60	4.68	$592	$709	$826	$944	$1,061

Table 33: Impact of Yield and Price on Gross Margin of cotton per ML for overhead irrigation system applying 7ML/ha in the Darling Downs

Effects of Yield and Price on Gross Margin per ML (assuming 7.0ML/ha is used).

Lint Yield (bales/ha)	Seed Yield (t/ha)	$440.00/bale $162.00/tonne	$495.00/bale $171.00/tonne	$550.00/bale $190.00/tonne	$605.00/bale $209.00/tonne	$660.00/bale $228.00/tonne
8.40	2.52	$196	$268	$340	$412	$485
9.60	2.88	$278	$361	$443	$526	$608
10.80	3.24	$361	$454	$546	$639	$732
12.00	3.60	$443	$546	$650	$753	$856
13.20	3.96	$526	$639	$753	$866	$980
14.40	4.32	$608	$732	$856	$980	$1,103
15.60	4.68	$691	$825	$959	$1,093	$1,227

Crop yield and price are key factors in the Gross Margin per ML of water used (Table 32 and Table 33) and must be considered when evaluating the cost-benefit of an evaporation mitigation technology for a specific enterprise and location. Multi-season data on gross margin is not widely available. However, the AgMargins site provides a useful tool for producers to investigate the impact of different cost and price assumptions on the financial viability of a cropping system (Table 34). The return on investing in a water saving technology will be much greater for the increased production achieved with a high value, permanent crop, than with a lower value, annual or field crop (Table 34).

Table 34: Indicative Gross Margin per ML irrigation water for selected crops.

Crop	Region	Irrigation ML/ha	Gross Margin per unit irrigation ($/ML) Low	Median	High
Cotton (surface irrigated)	Darling Downs	8	$ 159.00	$ 556.00	$ 1,061.00
Cotton (Overhead irrigated)	Darling Downs	7	$ 196.00	$ 650.00	$ 1,227.00
Peanut	Darling Downs	5	$ 187.00	$ 515.00	$ 932.00
Chickpea	Darling Downs	1.5	$ 637.00	$ 1,465.00	$ 2,513.00
Wheat	Darling Downs	2.5	$ 218.00	$ 632.00	$ 1,158.00
Sweet Corn	Lockyer Valley	5	-$ 404.00	$ 830.00	$ 2,401.00
Onion	Lockyer Valley	5	-$ 1,447.00	$ 872.00	$ 3,823.00
BlueBerry	Lockyer Valley	2	$ 17,276.00	$ 71,702.00	$ 140,972.00
Macadamia	Northern MDB	6.5		$ 2,100.00	
Citrus	Northern MDB	7		$ 2,500.00	
Avocado	Northern MDB	8		$ 2,750.00	
Mango	Northern MDB	3		$ 3,800.00	

Values in the top section of the table were extracted from AgMargins™ for low, medium and high yield and price. Values for the Northern Murray Darling Basin (MDB) were provided by the company Riparian Capital Partners.

The data in Table 34 represents the average Gross Margin per ML of irrigation applied, and does not take into account the changing value of water at different phases of crop growth. The value of water saved from evaporation to meet the demand of a high-value crop at a critical time, will have a much larger impact on crop quality and the market price-point than the $/ML metric indicated. The resulting marginal return can be many times greater than that determined by the total irrigation applied. A more accurate assessment would be to determine the marginal return on the additional ML of water available. The marginal return on the last ML when moving from 4ML to 5ML, can be determined from the additional yield and price, divided by the additional irrigation applied, less variable costs (typically irrigation, harvest and transport costs) associated with the extra crop produced.

Key Findings from Gross Margin Assessment:

- Gross margin per ML irrigation water typically varies between $500/ML and $1,000/ML for crops such as cotton, peanuts, wheat, sweet corn and onion. This increases to >$2,000/ML for high value horticulture, and can exceed $10,000 for some crops and nursery products.
- Gross margin returns vary between years and are influenced by yield and commodity prices. Grower-specific data needs to be considered to quantify returns accurately.
- The figures provided represent the average return on total irrigation applied. The marginal return on an additional ML of water made available through evaporation savings is likely to result in a much higher return.

6.6 Tradable Water

An alternative to using the Gross Margin to assess the value of water saved through reducing evaporation is to understand the tradeable value of water as a commodity. Queensland has three operating water markets (Water Allocation Market, Seasonal Water Assignment Market, and the Relocatable Licence Market) for licence or allocation holders to trade their water holdings.

6.6.1 Water Allocation Market

The Purchase of a water allocation is not restricted to landholders and does not require a land title. However, trading is restricted to limit the buying and selling across water management zones. Trading can be done as a permanent or temporary trade, and prices reflect the permanency or period of lease. In 2018-19 more than 70,000 ML of supplemented surface water was permanently traded in Queensland, with an average value of $2,419/ML.

6.6.2 Seasonal Water Assignment market

A temporary water trade is referred to as the Seasonal Water Assignment Market. Both supplemented (water delivered from a water supply scheme) and un-supplemented (all other ground and surface water) water can be temporarily traded. However, the uncertain nature of un-supplemented water means that it is subject to additional governmental restriction.

6.6.3 Relocatable Licence Market

A water licence is attached to parcel of land and is therefore different to a water allocation. Trading or transferring a water licence means the receiver must adhere to the existing rules that apply to that parcel of land. These trades or transfers are specific to individual catchments, which each have their own conditions. In 2018-19 more than 38,000ML of water was traded in the Central Condamine Alluvium Groundwater Management area, within the range of $1,800 - $5,000. The majority of these transfers were buy-backs under the Commonwealth Water Recovery scheme.

Insufficient data was available to calculate the market value of tradable water for this report. The factors influencing the trading price of surplus water as a commodity will include the cost-effectiveness of the Evaporation Mitigation Technology used, location, time of year, and season.

7 Recommendations

7.1 Product Trials

Overview:

Thirty five sites to trial evaporation mitigation products have been identified. Selection was based on the number and size of dams in Queensland's major river catchments, local rate of evaporation loss, potential water saving using an EMT, the annualised cost of the evaporation mitigation technology and the value of water to the selected enterprise.

Further prioritisation needs to be guided by the Departments budget, and their approach for further detailed site selection, including engagement with landowners and technology suppliers. Industry groups should be approached to guide selection of demonstration sites and suppliers will need to fine tune product deployment preferences.

The financial contribution of all parties towards installation cost will also determine the scale of future trials. Getting industry bodies involved at an early stage will improve promotion and adoption of successful solutions.

Of the 243,100 water storages located in 24 catchments across Queensland 79% have a surface area of less than 0.5ha, considered suitable for the deployment of at least one of the evaporation mitigation products studied. Chemical films offer the greatest flexibility in the timing and rate of application, to storages up to 100ha in size (Figure 40). Suspended covers installed over storages of up to 15ha improve water quality by reducing light penetration and water turbulence. Floating continuous and modular covers can be installed and removed by the landholder, and are best suited for storages of less than 5ha. Storages over 100ha responsible for 50% of the total amount of water lost annually to evaporation, are less suitable for the deployment of these technologies.

The 79% of storages suitable for the deployment of at least one EMT are predominantly located within the Condamine, Fitzroy, Burdekin, Border Rivers, Burnett, Cooper Creek, Brisbane and Mary catchments (Table 35). On the basis of the analyses undertaken in this report, we have matched the most cost-effective evaporation mitigation technology with a specific industry operating within each of these catchments. Individual enterprises selected from these regions could be used for objectively monitored field trials of the recommended technology. The criteria used for our recommendations are outlined for each catchment, in Sections 7.1 to 7.7.

Evaporation mitigation products currently marketed in Australia have been discussed in Chapter 5.1. Sites to trial these products have been identified, based on the following:

- Number and size of dams in major river catchments (Chapter 6.1),
- Associated annual evaporation loss (Chapter 6.2),
- Potential water saving using an appropriate EMT (Chapter 6.3),
- The annualised cost of the evaporation mitigation technology (Chapter 6.4), and
- Value of water to different enterprises (Chapter 6.5).

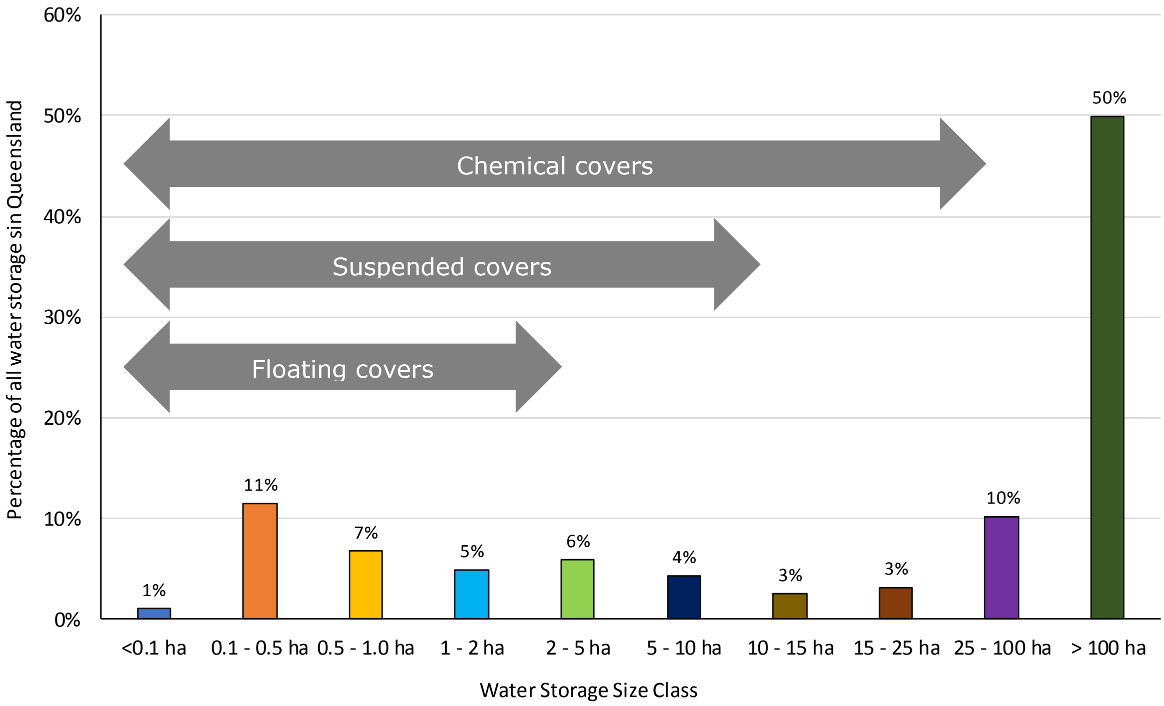


Figure 40: Product suitability for different storage size class and percentage of Queensland's total storage surface area in each size class.

Table 35: Top eight Queensland catchments for annual loss from storages less than 100 ha

CATCHMENT	TOTAL ANNUAL LOSS FROM STORAGES LESS THAN 100HA
CONDAMINE	666,507 ML
FITZROY (QLD)	660,386 ML
BURDEKIN	342,126 ML
BORDER RIVERS	305,457 ML
BURNETT	278,779 ML
COOPER CREEK	176,404 ML
BRISBANE	136,772 ML
MARY	130,335 ML

The prominence of high value horticulture, irrigated broad acre cropping, intensive livestock and mining, and the annual evaporation rate within the selected catchments (Table 35), the value of water security and the cost-benefit of candidate EMTs on key enterprises, were considered when formulating the recommendations (). The additional benefit of a candidate EMT on reducing the water treatment and reticulation maintenance costs of enterprises including municipal potable water, wastewater treatment and reuse were also considered (Sections 7.1 to 7.7). The 35 recommended trial/test sites (Table 36) may exceed the intended scope of DNRME, for this project. Further prioritisation would be guided by the budget, DNRME priorities, and engagement with landowners and technology suppliers. The participation of industry groups (eg GrowCom (Horticulture), NGIQ (Nursery), Canegrowers (Sugarcane), Cotton Australia (Cotton), QDO (Dairy)), in the selection of specific sites and systems is also recommended, with suppliers consulted on site-specific product deployment preferences. All of the suppliers contacted are willing to participate in trials. Some suppliers have nominated existing installations that could be used, or have clients currently considering quotes who might participate in a trial. The financial contribution of all parties will also determine the scale of future trials, and the involvement of industry bodies at an early stage will improve the promotion and adoption of demonstrated cost-effective solutions.

Chemical Covers

The only chemical cover currently available commercially is WaterGuard (Appendix 1.2.19), which can be applied to small and large storages. However, full coverage on storages over 10 ha is likely to require multiple, automated applicators which are not currently supplied by the company. The product has been approved for use in potable water applications and is sold quite widely into agricultural markets.

The physical impact of this multi-molecular film on gaseous exchange and ecological processes across the air-water interface have not been investigated. The experimental mono-molecular film (known not to adversely affect these processes) being developed by the University of Melbourne is not ready for commercial testing, and would need to be integrated into a system of wind-suppression barriers.

Demonstration trials for the WaterGuard product could be considered for the horticulture (Brisbane and Burnett catchment), nursery (Brisbane catchment) and sugarcane (Burdekin catchment) industries, spread by hand on small storages (<10ha). Performance on large storages (>10ha), using automated applicators developed for mono-molecular products could be considered for the cotton sector (Condamine and Border Rivers Catchment). The cotton industry have invested extensively into research to reduce evaporation from large >50ha storages, and has a strong preference for environmentally friendly chemical films.

Structural modifications

The strategy of reducing evaporative loss by reconfiguring a storage into cells or increasing the depth of water retained in at least one cell (reducing the surface to volume ratio) was well received by the cotton industry. However, the rate of adoption and the actual cost-benefit of the structural modifications recommended by the 2018 Healthy Waterways Project (Appendix 1.1.1 to 1.1.6) have not been assessed. As part of any further phase of this current DNRME project we recommend the evaporation reduction of storages that were reconfigured, and the value of the saved water to the specific enterprise should be assessed as a case study. Most of the landholders who participated in the 2018 study were located within the Border Rivers and Condamine catchments.

Continuous floating covers

Continuous floating covers are most feasible on storages of less than 5ha. The REVOC cover manufactured by Layfield is designed to cover the entire storage and is trenched into the embankment (Appendix 1.2.7). In addition to reducing evaporative loss the cover excludes rainwater, overland flow, light and water birds. The advanced technical skill required for installation and the high cost per m^2 indicate this EMT will be most cost-effective for mining, industrial and urban applications. Price depends on the quality and life expectancy of the membrane, which is determined by the quality and reactivity of the stored water. Management costs are low when water remains in the storage all year round, with maintenance generally restricted to pumping rainwater from the collection gutters in the cover. Recommended sites include urban wastewater applications in the Brisbane and Mary catchments (Table 36), and industrial/mining applications in the Fitzroy catchment.

The Aquacon (Darling Downs Tarpaulins, Appendix 1.2.6) and Daisy Dam Cover products (Appendix 1.2.3) are generally installed by local contractors and farmers as large floating modules tethered together. The covers can be removed and reinstalled using winches, and as a partial cover over a central portion of the storage to secure a specified volume of water. Both products can be trenched into the storage embankment to provide 100% cover, but this is recommended only for storages <0.5ha. These floating covers are likely to be most cost-effective for high value horticulture in the Fitzroy, Border Rivers and Brisbane catchments, and the nursery industry in the Brisbane catchment. The annualised installation, operation, repair and maintenance costs of a floating cover is most likely to be offset by the value of a secure water supply to these enterprises. Partial covers could also be cost-effective for irrigated cotton/grain enterprises to secure high value water in smaller cells within the storage, to meet crop demand at critical growth phases. This could be undertaken as an update of the structural modification strategy referred to above, in the Condamine and Border Rivers catchments. Floating covers may also be cost-effective for feedlots and livestock water supplies (Fitzroy and Condamine catchments), mining (Fitzroy catchment), industrial and municipal water treatment applications (Brisbane and Mary catchments) where the improvement in water quality, palatability and the reduction in water treatment and maintenance costs offsets the higher cover and installation costs.

Modular floating covers

A wide range of modular floating covers developed and tested in Australia (see Appendix 1.2.8 to 1.2.14) are no longer commercially available. The Hexa-Cover product imported from Denmark (Appendix 1.2.14) and AquaArmour (Appendix 1.2.11) are marketed locally for evaporation reduction. AquaArmour does not appear to be as active in the market as Hexa-Cover. Hexa-Cover costs are likely to reduce with the commencement of production in Melbourne in July. Costs are high (>$35/m^2$) relative to other EMT options, likely to be cost-effective for urban waste water treatment lagoons (Brisbane catchment) and industrial/mining applications (Fitzroy catchment). The advantage of incremental purchase and replacement, and suitability for water storages which are periodically dry or with fluctuating water levels would improve the cost-effectiveness of floating modules for high value nursery and agricultural enterprises (Brisbane region). Initial tests on the local prototype, QUITEvap should be conducted at the USQ evaporation test facility, before deployment at the commercial scale in the Brisbane region (high value nursery and agriculture).

Suspended continuous covers

The suspended continuous cover sold by NetPro Pty Ltd (Appendix 1.2.2) has widespread potential across a range of high value industries, with the potential to reduce costs associated with weed and wildlife exclusion, water treatment, reticulation and maintenance. Suspended covers are most cost-effective for storages with a fluctuating water level, where access to the water or storage basin is required for regular testing and maintenance. Installation is specialised and costs are high relative to other EMT options, in part offset by the long life expectancy of the supporting structure and cover, and low maintenance. A suspended cover would be most cost-effective for high value horticulture (Fitzroy, Border Rivers and Brisbane catchments), and nursery (Brisbane catchment) applications, as well as for cotton/grain storages where high value water is concentrated within smaller cells to ensure supply at a critical crop growth phase (Condamine catchment). The product would also be applicable to the dairy industry (Mary catchment) and for municipal potable water and wastewater treatment storages (Brisbane and Mary catchments).

Table 36: Recommendations for Evaporation Mitigation Technology demonstration trials in Queensland

<table>
<tr><th>EMT Product Class</th><th>Supplier (Product)</th><th>Target Storage Area for Evaluations</th><th>Target Industry</th><th>Target Catchments and locations</th><th>Comments</th></tr>
<tr><td rowspan="3">Multi- Molecular Film</td><td rowspan="3">Aquatain (WaterGuard)</td><td rowspan="3">< 10ha manual application</td><td>Horticulture</td><td>Brisbane (Lockyer Valley)
Burnett (Bundaberg/ Childers)</td><td rowspan="3">Select small storages to trial manual application of WaterGuard to evaluate product performance and cost-benefit and develop case studies.</td></tr>
<tr><td>Nursery</td><td>Brisbane (Northside)</td></tr>
<tr><td>Sugarcane</td><td>Burdekin (Ayr)</td></tr>
<tr><td>Multi-Molecular Film</td><td>Aquatain (WaterGuard)</td><td>>10ha automated application</td><td>Cotton/grains</td><td>Condamine (St George)
Border Rivers (Goondiwindi)</td><td>Target large storages in Cotton industry for whom research into monolayers and chemical films is topical. Deploy using automated applicator systems.</td></tr>
<tr><td>Mono-Molecular Film</td><td>Novel Polymer E1 – Uni of Melbourne</td><td>>10ha automated application</td><td>Cotton/grains</td><td>Consider once product available</td><td>New polymer product E1 not yet available. Only to be considered when ready for commercial scale testing.</td></tr>
<tr><td rowspan="6">Suspended Continuous Cover</td><td rowspan="6">NetPro (Shade cloth)</td><td rowspan="6"><15ha</td><td>Horticulture</td><td>Burdekin (Ayr/ Home Hill)
Border Rivers (Stanthorpe)
Burnett (Bundaberg/ Childers)
Brisbane (Lockyer Valley)</td><td rowspan="6">Target all sizes of storage <15ha

For Cotton, install on smaller cells in a larger storage (15ha), securing high value water for critical crop growth phases as part of a broader water management plan</td></tr>
<tr><td>Nursery</td><td>Brisbane (Southside)</td></tr>
<tr><td>Sugar</td><td>Burnett (Bundaberg/ Childers)</td></tr>
<tr><td>Cotton/grains (high value water)</td><td>Condamine (Cecil Plains)</td></tr>
<tr><td>Dairy/Livestock storage</td><td>Mary (Gympie)</td></tr>
<tr><td>Urban, potable and treated waste water</td><td>Brisbane (rural township)
Mary (Maryborough)</td></tr>
<tr><td rowspan="2">Continuous Floating Cover</td><td rowspan="2">Layfield (REVOC)</td><td rowspan="2"><5ha</td><td>Urban, potable and treated waste water</td><td>Brisbane (rural township)
Mary (rural township)</td><td rowspan="2">High cost product and specialised installation. Target urban and industrial applications.</td></tr>
<tr><td>Industrial , mining application</td><td>Fitzroy (Blackwater/Moranbah)</td></tr>
<tr><td rowspan="6">Continuous Floating Cover (laid in Sections)</td><td rowspan="6">Daisy Commercial (Daisy Dam Cover)
&
Darling Downs Tarpaulins (Aquacon)</td><td rowspan="6"><5ha</td><td>Horticulture</td><td>Fitzroy (Emerald)
Border Rivers (Stanthorpe)
Brisbane (Lockyer Valley)</td><td rowspan="6">Demonstrate both products available across a target catchment/region.

For Cotton, install on smaller cells in a larger storage (15ha), securing high value water for critical crop growth phases as part of a broader water management plan</td></tr>
<tr><td>Nursery</td><td>Brisbane (Northside)</td></tr>
<tr><td>Cotton/grains</td><td>Condamine (Dalby)</td></tr>
<tr><td>Feedlot/Livestock storage</td><td>Fitzroy (Rockhampton)
Condamine (Dalby)</td></tr>
<tr><td>Urban treated waste water</td><td>Brisbane (rural township)</td></tr>
<tr><td>Industrial, mining</td><td>Mary (rural township)
Fitzroy (Blackwater/Moranbah)</td></tr>
<tr><td rowspan="3">Modular Floating Cover</td><td rowspan="3">Hexa-Cover (or AquaArmour)</td><td rowspan="3"><5ha</td><td>Nursery</td><td>Brisbane (Southside)</td><td rowspan="3">Higher cost product targeted at nursery and urban and industrial applications, with storages that are periodically dry or are managed with fluctuating water levels.</td></tr>
<tr><td>Urban treated waste water</td><td>Brisbane (rural township)</td></tr>
<tr><td>Industrial, mining</td><td>Fitzroy (Blackwater/Moranbah)</td></tr>
<tr><td rowspan="3">Modular Floating Cover</td><td rowspan="3">QUITEvap</td><td rowspan="3"><5ha</td><td>Horticulture</td><td>Later consideration</td><td rowspan="3">Product is at proto-type phase only. Pre-evaluation tests at USQ Evaporation trial facility to assess evaporation mitigation performance and structural integrity and durability. Consider industry tests for Horticulture/Nursery for post-evaluation, commercial scale trials</td></tr>
<tr><td>Nursery</td><td>Later consideration</td></tr>
<tr><td>USQ Prototype Evaluation</td><td>Toowoomba (USQ Evap trial station</td></tr>
<tr><td>Storage structural reconfiguration</td><td>Storage Deepening or introduction of cells</td><td>All</td><td>Cotton</td><td>Condamine
Border Rivers</td><td>Revisit storages that have already had structural modification recommendations (Appendix 1.1to document the actual evaporation mitigation and cost-benefit of saved water, develop Case Studies</td></tr>
</table>

Further detail and justification for the selection of recommended trial is provided in Section 7.1 – 7.7 below.

7.1.1 Condamine Catchment

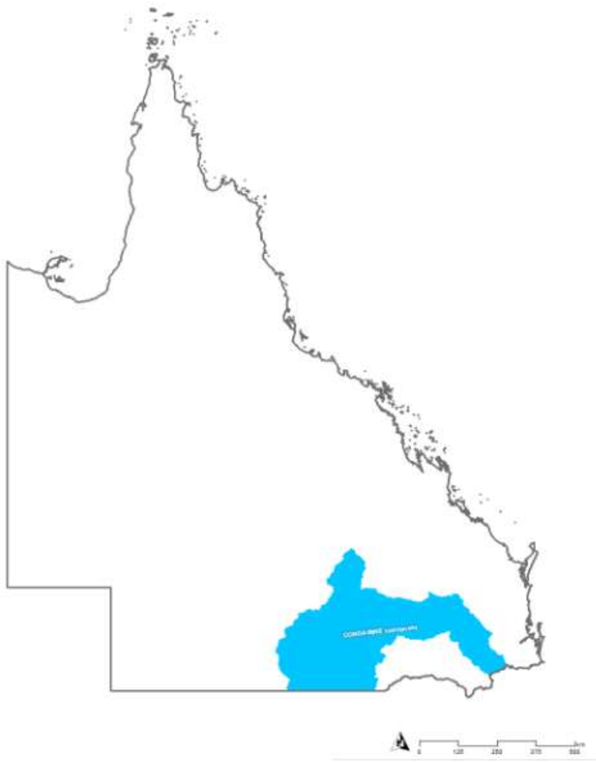
Total area	173,887 km^2
Number of Storages (<100 ha)	40,206
Area of storages (<100 ha)	29,742 ha
Potential Annual Loss	**666,507 ML/year**

The Condamine catchment potentially loses 666,507ML/year from open water storages. The key industries within this catchment are annual cotton and grain crops, irrigated from open water storages (and ground water). Cotton growers are considered rapid adopters of a proven technology.

The Darling Downs is one of the largest irrigated and dryland grain producing areas in Queensland. A number of beef cattle feedlots have co-located with the supply of summer and winter grains on the eastern Darling Downs. Drinking water security for cattle is a high priority, with all feedlots relying on some form of water storage on-site.

Recommendations:

- To trial the multi-molecular chemical film WaterGuard, applied to a 60 - 100 ha storage using an automated applicator on a cotton farm. A storage of this size is likely to be located in the lower reaches of the catchment **(St George)**
- To trial a suspended continuous cover (NetPro) on a small high value cotton water storage < 15ha on the Central Darling Downs **(Cecil Plains)**
- to trial a continuous floating cover (Daisy or Aquacon) on a cotton water storage on the Central Darling Downs **(Dalby)**
- To trial a continuous floating cover (Daisy or Aquacon) on a water storage on a beef cattle feedlot **(Dalby)**
- Investigate storage reconfiguration (deepening of storage or construction of cells) **(St George / Dirranbandi)**



7.1.2 Fitzroy Catchment

Total area	171,7801 km^2
Number of Storages (<100 ha)	33,285
Area of storages (<100 ha)	28,299 ha
Potential Annual Loss	**660,386 ML/year**

The Fitzroy catchment potentially loses 660,386ML to evaporation each year. The catchment is home to the largest cattle population in Australia, as well as cotton, grains and small crop production. It is the only catchment in the list of 8 with a large mining industry.

Recommendations:

- Trial a continuous floating cover (REVOC) on a water storage at a mine site **(Blackwater/Moranbah)**
- Trial a continuous floating cover ((Daisy or Aquacon) on a horticulture farm **(Emerald)**
- Trial a continuous floating cover (Daisy or Aquacon) on a beef cattle feedlot **(Rockhampton)**
- Trial a continuous floating cover (Daisy or Aquacon) at a mine site **(Blackwater/Moranbah)**

7.1.3 Burdekin Catchment

Total area	155,093 km^2
Number of Storages (<100 ha)	12,711
Area of storages (<100 ha)	14,073 ha
Potential Annual Loss	**342,126 ML/year**

The Burdekin is the largest sugarcane producing region in Australia, divided into the Burdekin – Horton Water Supply Scheme Area (supplemented water supply scheme) and the Delta (lowland flats dominated by groundwater irrigation).

There are also a range of horticultural and small crops farms in the catchment

Recommendations:

- Trial a chemical Multi Molecular film (Aquaguard) on a storage < 10 ha using manual application on a sugarcane storage **(Ayr)**
- Trial a suspended continuous cover (NetPro) on a horticulture farm **(Ayr/ Home Hill)**

7.1.4 Border Rivers Catchment

Total area	48,417 km^2
Number of Storages (<100 ha)	17,777
Area of storages (<100 ha)	13,656 ha
Potential Annual Loss	**305,457 ML/year**

The Border Rivers is one of the largest cotton producing regions in Queensland. Most irrigated cotton farms depend on on-farm storages. Cotton growers are rapid adopters of proven technology.

The upper reaches of the Border Rivers is also one of the most significant small crops and stone fruit growing regions in Queensland.

Recommendations:

- Trial the multi-molecular chemical film (WaterGuard) on a storage > 10 ha using an automated applicator on cotton farm **(Goondiwindi)**
- Trial a suspended continuous cover (NetPro) on a horticulture farm on the Granite Belt **(Stanthorpe)**
- Trial a continuous floating cover (Daisy or Aquacon) on the Granite Belt **(Stanthorpe)**
- Investigate storage reconfiguration (deepening of storage or construction of cells) **(Goondiwindi)**

7.1.5 Burnett Catchment

Total area	48,873 km^2
Number of Storages (<100 ha)	31,284
Area of storages (<100 ha)	13,400 ha
Potential Annual Loss	**287,779 ML/year**

The Burnett catchment is highly diverse, with irrigated sugarcane, horticultural small crops, a rapidly expanding horticultural fruit and nut tree industry, and extensive beef and dairy cattle grazing operations.

Recommendations:

- Trial the multi-molecular chemical film (WaterGuard) on a storage <10 ha by manual application on a horticulture farm **(Bundaberg/ Childers)**
- Trial a suspended continuous cover (NetPro) on a horticulture farm **(Bundaberg/ Childers)**
- Trial a suspended continuous cover (NetPro) on a sugarcane farm **(Bundaberg/ Childers)**

7.1.6 Brisbane Catchment

Total area	19,128 km^2
Number of Storages (<100 ha)	21,251
Area of storages (<100 ha)	7,261 ha
Potential Annual Loss	**136,772 ML/year**

The Brisbane Valley is the one of the largest irrigated small crop production regions in Queensland. The Lockyer Valley produces high value horticultural fruit and vegetable crops for export interstate and overseas, irrigating mainly from on-farm water storages. A large number of plant nurseries produce high value stock for the urban market.

Recommendations:

- Trial the multi-molecular chemical film (WaterGuard) on a storage <10 ha by manual application on a horticulture farm **(Lockyer Valley)**
- Trial the multi-molecular chemical film (WaterGuard) on a storage <10 ha by manual application at a Nursery **(Brisbane Northside)**
- Trial a suspended continuous cover (NetPro) on a horticulture farm **(Lockyer Valley)**
- Trial a suspended continuous cover (NetPro) at a Nursery **(Brisbane Southside)**
- Trial a suspended continuous cover (NetPro) on a municipal water storage either potable or treated wastewater **(rural township)**
- Trial the continuous floating cover (REVOC) on a municipal water storage either potable or treated wastewater **(rural township)**
- Trial the continuous floating cover (Daisy or Aquacon) on horticulture farm **(Lockyer Valley)**
- Trial the continuous floating cover (Daisy or Aquacon) at a nursery **(Brisbane Northside)**
- Trial the continuous floating (Daisy or Aquacon) cover on a municipal water storage either potable or treated wastewater **(rural township)**
- Trial the floating modular cover (Hexacover or AquaArmour) at a Nursery **(Brisbane Southside)**
- Trial a floating modular cover (Hexacover or AquaArmour) on a municipal water storage either potable or treated wastewater **(rural township)**

7.1.7 Mary Catchment

Total area	18,144 km^2
Number Storages (<100 ha)	20,800
Area of storages (<100 ha)	6,646 ha
Potential Annual Loss	**130,335 ML/year**

Dairy is a major industry in the Mary River and Mary Valley, with the southern limit of irrigated sugarcane in Queensland grown in Maryborough. All Queensland dairy farms have at least one on-farm wastewater storage and a second of higher water quality for wash-down and stock watering.

Recommendations:

- Trial the suspended continuous cover (NetPro) on a dairy farm **(Gympie)**
- Trial the continuous floating cover (REVOC) on a municipal water storage either potable or treated wastewater **(rural township)**
- Trial the continuous floating cover (Aquacon or Daisy) on a municipal water storage either potable or treated wastewater **(rural township)**

7.2 Monitoring and evaluation

Monitoring and assessment of the efficacy of the EMT, and of actual losses and savings in both evaporation and in associated water quality, reticulation, treatment and maintenance costs will provide a more accurate cost-benefit analysis for a specific enterprise. Recommendations for monitoring are given below.

7.2.1 Monitoring of evaporation loss

Measurement of evaporation from open water storages can be undertaken using a number of different methods. The most appropriate is to monitor the atmospheric demand using an Automatic Weather Station (capital cost $8,500), and calculate water surface evaporation using methods discussed in Section 4.4. Automatic Weather Stations can operate remotely and provide data via a cloud-based platform to nominated users.

7.2.2 Measuring seepage and evaporation loss

The majority of earthen water storages in Queensland are not lined on the bed and banks to mitigate seepage, with both evaporation and seepage contributing to the total volume of water lost from a storage. Water balance methods with partition losses into seepage and evaporation are recommended (Section 4.5). The Centre for Agricultural Engineering at the University of Southern Queensland have developed hardware and software systems for measuring the changes in water level every 15 minutes using high accuracy pressure sensitive transducers (PST). Using a proven model, the loss data can be split into the evaporation and seepage components of the water balance (purchase cost $12,500 per site, equipment can be leased).

The use of two adjacent storages is recommended to provide a control storage and a storage with an EMT to accurately determine evaporation saving performance. The alternative is to measure the water balance during a suitable pre-installation period to set a baseline in evaporation loss.

Extended periods (>20days) when there are no major pumped inflows or outflows from the storage are required to improve accuracy, and should be considered when selecting a site for evaluation.

Steps in the analytical process are:

- Data collection (depth loggers, rainfall measurement and AWS data for estimation of evaporation).
- Selection of data not affected by pumping inflows/outflows.
- Determination of seepage rates.
- Derivation of evaporation loss.
- Comparison of evaporation loss with/without an EMT product.

7.2.3 Operational and mechanical durability monitoring

The operational requirements and mechanical durability of the EMT need to be documented, using field notes, photos and records of the mechanical performance of each product, and discussions with the site operator and supplier on installation, repair and maintenance requirements. Product suppliers would be approached to provide site-specific technical information for their product.

Each EMT would also be assessed for its practicality and impact on normal operational use of the water storage, and any associated benefits deployment has conferred on the enterprise. Consideration would be given to labour and the degree of supervision, cleaning, repairs and maintenance required for each EMT. Impacts from external factors such as livestock, wind and hail would be closely monitored throughout the project.

Costs for each EMT including monitoring, maintenance and operating would be recorded for use in a benefit-cost assessment.

7.2.4 Cost-benefit analysis

All installation, maintenance and operating costs would be analysed using the Evaporation Ready Reckoner. Site operators would be approached to provide an understanding of the value of water saved in terms of increased crop production and gross margin. This would allow cost-benefit analyses to be included in the Case Study.

7.2.5 Water Quality

Improvements in water quality and associated reductions in water treatment and reticulation costs and maintenance will be documented as part of the suspended and floating cover trials.

Water quality parameters which may already be monitored by potable and wastewater managers include the biochemical and chemical oxygen demand, chlorophyll A, coliform counts and algal cell counts. The impact of the multi-molecular chemical film on water quality has only been undertaken on the toxicity of samples collected from the water column, for human consumption. Further testing of the impact of the WaterGuard chemical film on gaseous exchange across the air-water interface (where the product concentrates), and on surface-active aquatic organisms is recommended. The Best Management Practice protocols implemented by industry organisations such as the Cotton Industry include minimising any adverse impact on ecological systems. Adoption by growers complying with BMPs will be improved once microlayer testing results of the WaterGuard product are available.

7.2.6 Development of case studies to promote industry adoption

Case studies would need to be prepared and field days hosted in association with suppliers, industry bodies and land owners.

Cases studies should address the industry specific concerns as detailed in Chapter 5 to allow comparisons of various EMTs across regions. Cases studies should be kept to a maximum of three pages and can be published in industry media such as Australian CottonGrower, CaneGrower, Fruit and Vegetable News.

7.2.7 Evaporation Economic Ready Reckoner

The Evaporation Ready Reckoner tool is an established and useful digital tool for individuals potentially investing in an EMT to 'try before they buy'. The tool utilises site-specific data on the evaporation rate, storage geometry and usage (monthly estimates of how much water is in storage), to calculate the water lost to evaporation each year.

The Evaporation Ready Reckoner is dated, and requires redevelopment and promotion. Components requiring upgrading and/or redevelopment include:

- User Interface (UI) and User Experience (UX)
- Model and calculation
- Output and reporting

UI/UX upgrades

- Improved user registration and login process
- The ability to draw a polygon on a google map interface over an existing storage dam to automatically calculate the full supply area of the storage.

- Improved data entry pages with modern controls
- Removal of redundant and obsolete links

Model and Calculation upgrades

- Automatic calculation of volumes based on polygon size and geometry and ability to set volume if known
- Update costs of EMT products and ranges and ability to enter total cost of system if known from a supplier quote (rather than $/m^2)
- Improve calculations for cell division and the ability to apply an EMT over a cell
- Improved initial scenario evaluation capability and sensitivity analysis

Output and reporting upgrades

- Improved readability of report pages.
- Ability to compare a series of scenarios side by side
- Ability to save scenarios for later recall

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Appendix 1: Structural options and commercial products for reducing evaporative loss from water storages

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Structural Options and Commercial Products for Reducing Evaporative Loss from Water Storages.

Whole farm water balance studies indicate an average of 63% of all water available on-farm is used by crops, 25% is lost in storages, 11% is lost in fields and only 1% is lost in channels and drains (Healthy Headwaters Program 2018). On individual farms as much as 45% can be lost from storages. Strategies to reduce storage losses will substantially improve on-farm water productivity (the ratio of crop output per unit of water diverted or consumed: Peake et al. 2016). Common drivers motivating farmers to improve water use efficiency include a reduced or less reliable water supply, an increase in the cost of water and/or the fuel and infrastructure required to pump it, the need for labour savings, and the need to improve yield to remain financially viable (Baillie et al. 2007).

Structural Modifications

The capital cost of earthworks to reconfigure an existing water storage to reduce seepage and the surface to volume ratio (reducing evaporation) is high, with the cost effectiveness dependent on the volume and length of time the water is stored and the volume of water saved. Many growers are comfortable with the type of earthworks required to implement structural modifications, but will still need to be convinced of the cost-effectiveness of the strategy. Six of the 15 case studies compiled under the Healthy Headwaters Program (2018) have been summarised in Appendix 1.1. The case studies utilise the web-based Evaporation and Seepage Ready Reckoner developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz), using data obtained from the Irrimate Seepage and Evaporation Meter to estimate average daily seepage and evaporative loss rates. Data including the residence time of water in the storage is used in the Ready Reckoner to estimate the losses in ML of water per year, the capital cost of the structural modification required to reduce these losses, and the cost per ML of water saved averaged over the predicted 60 year lifespan of the reconfigured storage. This 'try before you buy' opportunity allows farmers to compare options, before implementing them.

Commercial Covers and Products

The installation of physical covers or the application of chemical films depends on the availability and cost-effectiveness of commercially developed products. In Appendix 1.2 information provided by the manufacturers or suppliers of different options has been summarised to indicate what is currently available. A table at the start of this section lists products that were available in 2012 (Schmidt and Scobie 2012), including the estimated cost per m^2 of water surface, and the availability of the product in 2020 (cost estimates in 2020 have yet to be sourced). Of the four suspended cover options available in 2012, only one is available in 2020. Of the five floating cover options in 2012, four are available in 2020. The biggest reduction in product availability is for floating modular covers, with only three of the options available still available in 2020. Of the two mono-molecular chemical film products available in 2012, one is available in 2020. The one multi-molecular chemical film available in 2012 (silicone oil-based Aquatain) has been reformulated for aquatic insect control (Aquatain AMF), with a new product released for evaporation mitigation (WaterGuard; Case Study 1.2.19). No technical information is available on the chemical formulation of this product, which may or may not be based on silicone oil.

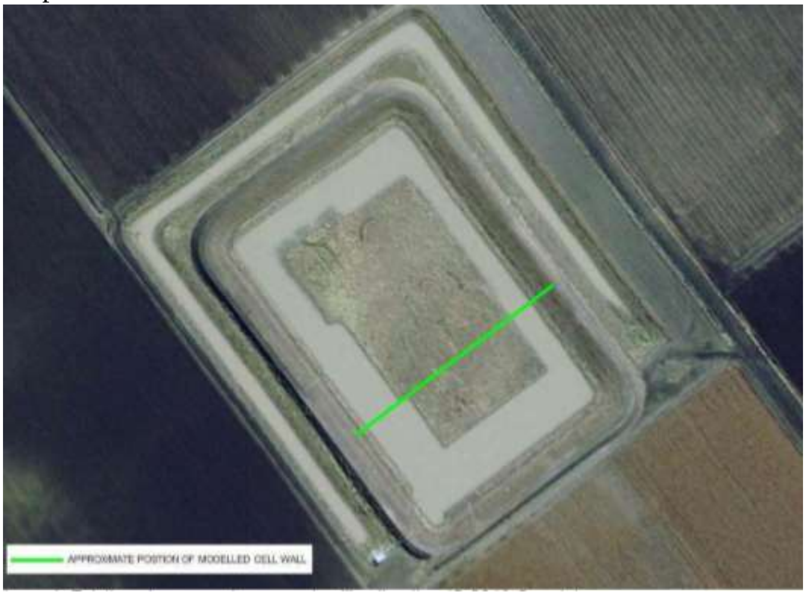
A shift in product availability has also occurred in Spain over the last 10 years (personal communication Professor Victoriano Martinez-Alvarez), with the double mesh Atarsun suspended cover (Figure 8) no longer commercially available. The cost and complexity of installing the cover was much greater than the costs associated with tensioned floating covers (which they still produce), and more recently developed floating modular covers (for example, Evapo-Control, Product Summary 1.2.9). The uptake of floating modular covers in Spain and not in Australia may be due to the smaller size of Spanish on-farm storages (Martinez-Alvarez et al. 2008, 2009), which are most commonly lined, reducing the incidence of modules stuck in empty basins not re-floating. Modular, floating photovoltaic panels are a new development in Spain, Australia and many other countries (Pouran 2018), dating from 2011 at the earliest. The driver for purchasing these units will be decentralised energy generation, with evaporative reduction proportional to the surface area covered by the modules. Very little technical information is available on the specifications and performance of these units.

Appendix 1.1 Modelling Structural Modifications of Existing Water Storages to Improve On-Farm Water Storage Efficiency.

Summarised from case studies in the Healthy Headwaters Program 2018.

1.1.1 Structural Modification St Ruth: Property Name: St Ruth, Darling Downs	Split storage into two cells Reference Healthy Headwaters Program 2018
Storage volume before & after Modification x1 1,200 ML into x2 573 ML cells	Description  A 300 ha dryland and irrigation property located on the Darling Downs owned and operated by PrimeAg Pty Ltd., with irrigated cotton grown during summer and dryland wheat throughout winter. Irrigation water is sourced from a combination of bores, overland flow and river water harvesting. Storage volume is < 30 % capacity in most years.
Performance	The potential savings of 31.8 ML per year and the annual cost of the reconfiguration of $285 per ML per year are based on average storage volume data.
Estimated capital cost	Earthworks required to construct the dividing wall, would cost $162,150. Increase in annual maintenance costs for this new wall ($500 pa) is included. Total cost annualised over a 60 year period (the estimated lifespan of the earthworks) using a discount rate of 5 per cent is $285 per ML of water saved per year.
Supplementary Information	The Evaporation and Seepage Ready Reckoner is a web-based tool developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz) It performs simple, site-specific economic assessments of evaporation and seepage mitigation options. Customised information for individual sites can be entered. Ready Reckoner calculates the volume of water saved (in ML) for each scenario and the cost of the evaporation or seepage mitigation option used to save this water ($/ML/year).

1.1.2 Structural Modification South Callandoon	Split storage into two cells
Property Name: South Callandoon, Border Rivers.	Reference Healthy Headwaters Program 2018
Storage volume before & after Modification x1 3,963 ML into x2 1,935 ML cells	Description  A grazing and irrigation property with 1793 ha of irrigated cultivation near Goondiwindi, owned and operated by Brian Duddy. Water is sourced from overland flow and river harvesting. There are three on-farm storages.
Performance	The projected water savings are 1011 ML per year in seepage and evaporation losses. Typical volume of water stored is < 50%, so the second cell does not receive any water with zero water lost.
Estimated capital cost	Earthworks required to construct the dividing wall would be $278,050. A small increase in annual maintenance ($500 pa) is also included. Annualised over a 60 year period (the estimated lifespan of the earthworks) using a discount rate of 5 per cent the cost is $15 per ML of water saved per year.
Supplementary Information	The Evaporation and Seepage Ready Reckoner is a web-based tool developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz) It performs simple, site-specific economic assessments of evaporation and seepage mitigation options. Customised information for individual sites can be entered. Ready Reckoner calculates the volume of water saved (in ML) for each scenario and the cost of the evaporation or seepage mitigation option used to save this water ($/ML/year).

1.1.3 Structural Modification Moorcroft Property Name: Moorcroft, Darling Downs	Split storage into two cells Reference Healthy Headwaters Program 2018
Storage volume before & after Modification x1 350 ML into x1 78 ML cell & x1 235 ML cell.	Description  FK Gardner and Sons are the owner operators of 'Moorcroft', a 260ha irrigation property near Cecil Plains on the Darling Downs. Summer production is irrigated cotton with dryland wheat in winter. Irrigation water is sourced from bores and overland flow. Storage volume is < 30% full capacity most years.
Performance	Splitting the cells will allow water to be concentrated in a smaller cell when water volumes are low, saving 37.7 ML per year in evaporation and seepage losses.
Estimated capital cost	Earthworks would have a capital cost of $111,780, including small increase in annual maintenance costs ($500 pa). The total annualised cost over 60 years (estimated lifespan of the earthworks) with a discount rate of 5% is $170 per ML of water saved per year
Supplementary Information	The Evaporation and Seepage Ready Reckoner is a web-based tool developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz) It performs simple, site-specific economic assessments of evaporation and seepage mitigation options. Customised information for individual sites can be entered. Ready Reckoner calculates the volume of water saved (in ML) for each scenario and the cost of the evaporation or seepage mitigation option used to save this water ($/ML/year).

1.1.4 Structural Modification Moolabah Property Name: Moolabah, St George	Raising wall height Reference Healthy Headwaters Program 2018
Storage volume before & after Modification Existing eastern storage 3.0 m wall 780 ML. Existing western storage 680 ML to be decommissioned. Reconfigured eastern storage with 4.5 m wall 1,460 ML.	Description (no photo provided) Moolabah is an irrigation property north of St George, operated by Hamish Macintyre. Water for irrigation is sourced from Sunwater channels and capture of on-farm runoff. Moolabah currently has two on farm storages with a combined storage capacity of 1460 ML. From the water storage use pattern, Moolabah's storages typically hold water in 80 per cent of years. In these years, the storages are most likely to receive water over spring and summer. The evaporation and seepage losses from Moolabah's storage have been measured by WaterBiz using the Irrimate™ Seepage and Evaporation Meter. Seepage losses were quite low at 1.9 mm/day which equates to 0.7 metres per year when the storage contains water year round. Annual evaporation loss was around 1.3 metres.
Performance	Raising the wall height of the eastern storage to a level that maintained Moolabah's total on-farm storage capacity would reduce surface area evaporation losses with a saving of 549 ML per year in evaporation and seepage losses.
Estimated capital cost	Earthworks of $1,685,000 would be required to move 561,652 m^3 of soil, annualised over a 60 year period (the estimated lifespan of the earthworks) using a discount rate of 5% is $161 per ML of water saved per year.
Supplementary Information	The Evaporation and Seepage Ready Reckoner is a web-based tool developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz) It performs simple, site-specific economic assessments of evaporation and seepage mitigation options. Customised information for individual sites can be entered. Ready Reckoner calculates the volume of water saved (in ML) for each scenario and the cost of the evaporation or seepage mitigation option used to save this water ($/ML/year).

1.1.5 Structural Modification Doondi Property Name: Doondi, St George	Raising wall height Reference Healthy Headwaters Program 2018
Storage volume before & after Modification Existing northern storage wall 3m with 3,850 ML capacity. Existing eastern storage 3685 ML to be decommissioned. Reconfigured northern wall 9m with 7,590 ML capacity.	Description (no photo provided) This property is an irrigation farm south of St George. Water for irrigation is sourced from river harvesting and capture of on-farm runoff. On farm water storage includes three storages; the northern, eastern and western. The allocation of water is such that some water is carried over from one season to another. Water is held on farm in 70% of years, usually received in winter and used over the summer months. The evaporation and seepage losses from the storage have been measured by WaterBiz using the Irrimate™ Seepage and Evaporation Meter. Seepage losses were 3.5 mm/day, an annual loss of 1.3 metres when the storage contains water year round. The potential annual evaporation loss was 1.9 metres.
Performance	Increasing the wall height of the existing 3850 ML northern storage from 5 metres to 9 metres saves 2065 ML per year in evaporation and seepage losses associated with the decommissioned eastern storage.
Estimated capital cost	Moving 2,084,242 cubic metres of soil for the wall would cost $6,252,726, annualised over a 60 year period (the estimated lifespan of the earthworks) at a discount rate of 5% the annual cost is $159 per ML of water saved per year.
Supplementary Information	The Evaporation and Seepage Ready Reckoner is a web-based tool developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz) It performs simple, site-specific economic assessments of evaporation and seepage mitigation options. Customised information for individual sites can be entered. Ready Reckoner calculates the volume of water saved (in ML) for each scenario and the cost of the evaporation or seepage mitigation option used to save this water ($/ML/year).

1.1.6 Structural Modification Armet Waters Property Name: Armet Waters, St George.	Raising wall height Reference Healthy Headwaters Program 2018
Storage volume before & after Modification Western storage wall 5 m with 900 ML, eastern storage 720 ML to be decommissioned. Reconfigured 10 m wall for western storage will hold 1,620 ML.	Description (no photo provided) An irrigation property five on-farm storages situated on the Balonne River. Water is sourced from river harvesting and capture of on-farm runoff. This analysis focuses on the reconfiguration of two of these storages; the western and eastern storages. The western storage has a full capacity of 900 ML and the eastern storage a full capacity of 720 ML. The storage use pattern indicates that water is held on-farm in 90% of years. Water is received in winter and used summer and autumn. The evaporation and seepage losses were measured by WaterBiz using the Irrimate™ Seepage and Evaporation Meter. The western storage had a seepage rate of 2 mm/day or 0.7 metres per year when it contains water year round. The eastern storage had a seepage rate of 3.4 mm/day, or 1.25 metres per year if it contains water for the whole year. Annual evaporation losses of 1.1 and 1.3 metres would be expected given the storages tend to hold water all year.
Performance	Raising the wall height of the western storage from 5 to 10 m and decommissioning the eastern storage saves 585 ML per year in evaporation and seepage losses.
Estimated capital cost	Moving 600,000 cubic metres of soil for the wall would cost $1,800,000 annualised over a 60 year period (the estimated lifespan of the earthworks) at a discount rate of 5% the annual cost is $163 per ML of water saved per year.
Supplementary Information	The Evaporation and Seepage Ready Reckoner is a web-based tool developed by the National Centre for Engineering Agriculture (www.readyreckoner.ncea.biz) It performs simple, site-specific economic assessments of evaporation and seepage mitigation options. Customised information for individual sites can be entered. Ready Reckoner calculates the volume of water saved (in ML) for each scenario and the cost of the evaporation or seepage mitigation option used to save this water ($/ML/year).

Appendix 1.2 Commercial Products Accessed in 2012 and Revisited

Source for 2012 information is Schmidt and Scobie 2012. Updated information on currently available products is given in Section 5 of this report

Product Category	Product name (manufacturer or retailer in Australia)	Estimated cost 2012	Availability in 2020
Suspended continuous covers	Aquaspan (Gale Pacific)	\$33.00 /m^2	no, floating covers only
	NetPro (NetPro Protective Canopies)	\$12.50 – 19.00 /m^2	yes
	NICOSUN (Maccaferri)	n.a.	not for covers
	Superspan (TechSpan)	n.a.	no
Floating continuous covers	EvapCap (Evaporation control systems)	\$11 – 18 /m^2	yes
	Enviro Dam Covers (Dam Covers Now)	\$8.00 /m^2	no
	Fabtech (Fabtech Geomembrane Dam Liners & Covers)	\$7.00 /m^2	yes
	REVOC Tensioned Floating Covers (Layfield Group)	\$30 /m^2	yes
	Daisy Pool and Dam Cover	n.a	yes
Floating modular covers	Aqua Armour (AQUA Guardian Group)	\$46/m^2	yes
	Aquacap (Nylex)	\$17/m^2	no
	Aquaguard (Fabric Solutions International)	\$6.0 – 6.60 /m^2	no
	BirdBalls (Environmental Controls Company USA)	n.a.	yes
	CURV (Propex)	\$3.50 /m^2	not for covers
	Euro-matic Bird Balls	n.a.	no
	Layfield Modular Covers (Layfield Group International)	n.a.	no
	LemTech Cover System (Lemna Technologies USA)	n.a.	no
	MOD-E-VAP (Merit Lining Systems	\$3.00 – 3.50 /m^2	not for covers
	QUIT Evap	\$6.00 – 8.00 /m^2	yes (prototype)
	Raftex (F Cubed Australia)	\$4.00 – 5.00 /m^2	no
	Water Innovations Modular Covers	n.a.	no
	Hexa-Cover	n.a	yes
Mono-molecular chemical films	WaterSavr (Flexible Solutions)	\$18 /kg at 0.5 - 1 kg / ha, repeat every 3 days	no
Multi-molecular chemical films	WaterGuard	n.a.	yes

1.2.1 Enviro Cover suspended continuous cover

Product name	Web Site Reference
Enviro Cover	https://www.fabricsolutions.com.au/pool-debris-covers/

Manufacturer or Supplier	Product Description
Fabric Solutions International	 Tensioned suspended cover for domestic pool debris exclusion. Equivalent to 500 µm pool cover. Permeable to rain water. Optional floats to support centre of cover. Available in woven dark blue or green fabric. Custom made to fit pool shape.
Performance	Reduces evaporation by up to 70%. Reduces chlorine consumption.
Durability	10 – year pro-rata warranty
Estimated cost	
Supplementary Information	1-page pdf brochure on pool debris cover.
Contact Details	Phone Free call 1800 039 996 Email info@fabricsolutions.com.au www.fabricsolutions.com.au/pool-debris-covers/ Address 21-23 Access Ave, Yatala, QLD 4207 AUSTRALIA

1.2.2 Water Canopies suspended continuous cover	
Product name	Web Site Reference
Water Canopies	https://www.netprocanopies.com/index.php/water-protection-canopy-2/

Manufacturer or Supplier NetPro	Product Description  Specially designed high-tensile steel cable, terminations and a modified knitted high-density shade-cloth cover.
Performance	Reduces evaporation by 80%-90%. Stabilises water temperature and reduces algae and plant growth.
Durability	15 years for cloth, 30 years for structure
Estimated cost	Ranges depending on design. For bank level systems typically ranges between \$9/sqm (15ha), \$13/sqm (5ha), \$30/sqm 1ha.
Supplementary Information	Internal supports are used for spans over 100m. Product has been improved by strengthening the cables and increase of canopy cloth with 95% density (previously 84%). Repair and maintenance cost are minimal and the product is designed to withstand hail. Vulnerable to fire damage. Pdf brochure on results of trials conducted by the National Centre for Engineering in Agriculture: Craig I, Green A, Scobie M, Schmidt E (2005): Controlling Evaporation. Schmidt E (2007) NCEA Publication 100058013
Contact Details	Phone 07 4681 6666 Email sales@netprocanopies.com Website www.netprocanopies.com Address Lot 1 Sullivan Drive Stanthorpe Qld 4380 Australia

1.2.3 Daisy Dam floating continuous cover (deployed in sections)

Product name	Web Site Reference
Daisy Dam Cover	https://daisypoolcovers.com.au/shop/daisy-dam-covers/

Manufacturer or Supplier	Product Description
Daisy Commercial	 Sections measuring 5.24m x 5.24m or extended lengths eg5.42 x (10,20 or 30m). Modules are tethered together with rope. Rolled up and delivered to site. Self-installation. Covers can be put on and removed as required. Made from robust 600um material. Edging (wind-skirting- 10-15cm) to pull edges just underwater to avoid wind lift. No drainage holes.
Performance	Reduces evaporation by up to 95%.
Durability	10 years extended warranty.
Estimated cost	$\$13/m^2$ plus self-installation. Likely installed cost will be $\$15$ to $\$20/m^2$
Supplementary Information	Info sheets available on extra services, installation and product flyers.
Contact Details	Phone: 1300 55 18 11 or 08 9251 7999 Email: commercial@diasypoolcovers.com.au Website: Address: Head Office & WA Plant Daisy Pool Covers & Rollers Administration Centre 31 Furnace Road, Welshpool WA 6106 NSW Manufacturing and Distribution Newton Road, Wetherill Park NSW 2164

1.2.4 Evap Cap floating continuous cover

Product name	Web Site Reference
Evap Cap	https://ddtliners.com.au/dam-covers/

Manufacturer or Supplier DDT Liners	Product Description  EvapCap was developed for use in Evaporation Control Covers by Evaporation Control Systems (Warwick Hill, Ph: 07 4665 6144, M: 0746 656 395, Email: croypk@bigpond.com) and was previously marketed by Darling Downs Tarps. The product is no longer supported. It is designed to float on top of the dam, protecting the water from evaporation. In the event of rain, there are drainage holes throughout the material, allowing water to seep into the storage facility. Made from HDPE, LDPE, or PP (reinforced, or unreinforced), non-bubble floating covers need supplementary buoyancy to be added. Best installed when pond/dam is full, or nearly full.
Performance	Evaporation can be reduced by 95% for every m^2 covered by EvapCap. Reduces algae and bank erosion caused by wave action.
Durability	5 year warranty (10 years for thicker version).
Estimated cost	\$22/m^2 to \$25/m^2
Supplementary Information	The product would typically be deployed as sections (large modules) typically up to 50mx50m
Contact Details	Phone Michael Ryan (07) 46342166 Email michael@ddt.com.au Address 20 Carroll St, Toowoomba West, QLD 4350 Australia

1.2.5 Fabtech floating continuous cover

Product name	Web Site Reference
Fabtech	https://www.fabtech.com.au/products/agricultural-products/covers

Manufacturer or Supplier Fabtech Geomembrane, Dam Liners and Covers	Product Description  Tensioned, oscillating floating cover, commonly PVC or woven polyethylene. Ballast lines bordered by floats form rainwater sumps which can be pumped away. Optional features include reinforced eyelets, rope, webbing and welded pockets to suit individual applications. On-site seams have large overlaps on the underside of the cover, reducing the risk of impregnation of foreign matter and bacteria. Design, supply & install custom dam covers for odour control, evaporation control, rainwater harvesting, and/or the prevention of algal growth.
Performance	Fabtech Australia received a High Commendation at the Australian Water Association's South Australian Water Awards 2013 in the SA Infrastructure Project category for the design, supply, and installation of Wattle Park Reservoir Liner and Cover project.
Durability	All covers and membranes meet QA/QC accreditation (ISO9001:2000).
Estimated cost	
Supplementary Information	Website lists multiple projects deployed using Fabtech floating covers. Company also fabricates a range of dam and channel liners.
Contact Details	Phone 1300 664 776 08 8347 31111 Email: reception@fabtech.com.au Website https://www.fabtech.com.au/ Address Level 1 33 Richmond Rd Keswick, SA 5035

1.2.6 Aquacon floating continuous cover

Product name	Web Site Reference
Aquacon 345 & Canvacon floating covers	https://www.galecommercial.com/en_ap/applications/floating-cover

Manufacturer or Supplier Gale Pacific	Product Description  Aquacon 345: Polyethylene scrim reinforced poly fabric with UV stabilised coatings.  Canvacon woven polyethylene fabric available in a range of grades and colours.
Performance	Generic, not specific for evaporative reduction or water quality improvement. No information on installation.
Durability	10 year defects warranty.
Estimated cost	
Supplementary Information	DDT supply the Aquacon product comprising linked polyolefin foam, sandwiched between two layers of Aquacon™ 345 polyfabric film
Contact Details	Phone 1800 331 521 Email Address 145 Woodlands Drive Braeside Vic, 3195

1.2.7 REVOC floating continuous cover

Product name	Web Site Reference
REVOC floating covers	https://www.layfieldgroup.com/FloatingCoverProducts.aspx

Manufacturer or Supplier	Product Description
Layfield Group (USA-based company with Australian representative)	 REVOC floating and floating, tensioned covers suitable for potable water. The company design, construct, install, and maintain floating covers for different water applications, as well as geomembranes for ponds, reservoirs, and tanks. Cleaning and maintenance services fare also provided for all potable water installations including floating cover inflation, disinfection, pond cleaning, and reservoir lining and repair.
Performance	Can walk on REVOC tensioned cover for cleaning and maintenance. Main panel of the cover is flat and easily cleaned. Tensioners are reusable for cover replacement. Sheds rainwater readily, less subject to damage by ice.
Durability	Tensioned Cover designs, installation techniques, and maintenance protocols fully meet the requirements of AWWA M25 Lining and Floating Cover Guidelines. 15 years for 0.75mm product 35yrs for 1.14mm product.
Estimated cost	\$23/m^2 to \$60/m^2 depending on application and water quality which impacts membrane selection (0.75mm or 1.14mm).
Supplementary Information	Product details, specifications, product profiles, technical notes, drawings and brochures are provided. Includes pdf of floating covers from Hydroprocesses 2015.
Contact Details	Phone Alex Gersch (Australia) +61 4 3467 6548 Email containment@layfieldgroup.com

1.2.8 Ball covers floating modular cover	
Product name	Web Site Reference
Ball covers	https://www.layfieldgroup.com/Geosynthetics/Floating-Cover-Products/Ball-Covers.aspx

Manufacturer or Supplier Layfield Group (USA-based company Australian contact)	Product Description  4" (100mm) in diameter 44 g (water-filled are 245 g) completely sealed lightweight UV stable HDPE grade polyethylene balls that float on top of a water containment, usually covering 91% of the surface. A 12m "high cube" shipping container will hold 84,600 balls, which is 786 m^2 of surface area. A pond with a 10,000 m^2 surface area will need 12 containers of balls. The balls arrive in trucks or containers packaged in mesh bags.
Performance	UV-stable plastic balls that float on the surface to deter birds. Cover about 91% of the surface area of the liquid. Self-levelling and arrange to adapt to changes in water level. Adapt to any shape of pond. Do not interfere with pond equipment.
Durability	15-20 years
Estimated cost	\$22-\$25/m^2
Supplementary Information	Layfield's Australia indicate that this product is not supported locally
Contact Details	Phone Alex Gersch (Australia) +61 4 3467 6548 Email containment@layfieldgroup.com

1.2.9 Evapo-Control floating modular cover

Product name	Web Site Reference
Evapo-Control	https://evapocontrol.com/producto/

Manufacturer or Supplier Arana Water Management. (Spanish-based company, no Australian contacts)	Product Description  Hexagonal plastic modules 0.03 m^2 in surface area. Concave base produces suction to improve stability. The light weight of the modules reduces the mass of plastic per m^2 of surface area from 5 kg with competing products to 1.5 kg with Evapo-Control.
Performance	Hexagonal modules pack to cover up to 95% of the water surface area, reducing evaporative loss by up to 80%
Durability	Evapo-Control is a system based on floating modules developed from recyclable, reusable materials with a durability of more than 15 years.
Estimated cost	
Supplementary Information	Website includes a product specification and details of research collaborations into the product the company is undertaking with researchers from the Polytechnic University of Cartagena, Spain.
Contact Details	Phone 0034 968 47 7581 Email jm.gimeno@arana-wm.com Address Arana Water Management SL Street of the Alamo 23, ID. CP 30800, Lorca Spain.

1.2.10 Hollow Plastic Balls Floating modular cover

Product name	Web Site Reference
Hollow plastic balls	https://eccllc.us/

Manufacturer or Supplier ECC, LLC Hollow Plastic Balls. (USA-based company, no Australian contacts)	Product Description  High density polyethylene hollow floating balls (black or white). Diameter of balls range from ⅜ inch to 4 inches. Designed to rotate to reduce attached algal growth.
Performance	The percentage of area covered by the floating ball cover is independent of the ball diameter, being the ratio of a circle to the hexagon which surrounds it. This equates to 91% of the liquid surface area. The frictional contact points ensure that each floating ball cover remains stable when subjected to increased liquid or air turbulence. 92% evaporation savings if a double row of balls used, 87% if single row.
Durability	
Estimated cost	
Supplementary Information	
Contact Details	Phone (910) 799-4411 Email Sales@ECCLLC.US Address ECC, LLC | Hollow Plastic Balls P.O. Box 15192 Wilmington, North Carolina, 28408

1.2.11 AquaArmour floating modular cover

Product name AquaArmour	Web Site Reference https://www.hydroterra.com.au
Manufacturer or Supplier HydroTerra Melbourne	Product Description   Product is manufactured by Innovative Plastic Solutions Pty Ltd in Melbourne. The license was provide from original developers AquaGuardian Group. Product is marketed by HydroTerra.
Performance	88% evaporation reduction. Water ballast to stabilise in water Module weight 4kg 1.18m maximum width, 412mm height 95% UV reduction to water Flotation pods and clips to join sections
Durability	The expected life time is >20 years.
Estimated cost	$35/sqm plus transport and installation
Supplementary Information	Each pod covers one square meter of water surface and as a rule of thumb, 93% of the water surface gets covered to leave some space for the pods to move around and tessellate. The weight of a pallet with 75 pods is around 370kg.
Contact Details	Phone (03) 8683 0091 Email E mpotter@hydroterra.com.au Address 42/328 Reserve Road, Cheltenham, Victoria 3192

1.2.12 Hexprotect floating modular cover

Product name	Web Site Reference
Hexprotect floating cover	https://www.awtti.com/rhombo-hexoshield/

Manufacturer or Supplier Advanced Water Treatment Technologies (company based in Texas USA, no Australian contact)	Product Description  Each 220 mm diameter tile is made from UV resistant, virgin HDPE. The cover self ballasts, increasing its weight more than 260%, making it suitable for high wind applications. The proprietary features and manufacturing process ensures the cover floats with slightly more than 50% of its shell above water.
Performance	Decrease liquid loss through evaporation by up to 95%. Reduces penetration of UV rays: prohibits growth of algae and clogging weeds.
Durability	The expected life time is 25 years.
Estimated cost	
Supplementary Information	Ave total weight dry is 178 g, on water is 445 g. 28 units per m^2, wind resistance 80 km hr^{-1}.
Contact Details	Phone 1-541-716-5255 Email contact@awtti.com Address 2211 W Lincoln St. St #310 Harlingen TX 78552

1.2.13 Top-Up Ball floating modular cover

Product name Top-Up Ball	Web Site Reference https://www.neotopwater.com/topup-ball
Manufacturer or Supplier NeoTop Israel	Product Description   The ball is made of two 330mm identical half shells, with a float in the middle. The shells have holes at their extremities and openings on their sides which fill half-way with water when the balls are placed in water. As the sun's energy hits the ball, instead of heating the reservoir water and causing its evaporation, most is reflected back and the rest generates evaporation inside the ball. The water that evaporates from the bottom half rises into the top half and perpetually condenses, returning back down. This evaporation-condensation process creates thermal distillation, which kills parasites and enhances water quality. The inner evaporation creates a difference in pressure within the top half shell which results in a difference in temperature. Thus the temperature of the ball and ultimately, the water in the reservoir, is reduced. Due to the inner process each ball serves as mini cooling tower.
Performance	Reduces evaporation by ~70% of the area covered (i.e. 100% coverage saves 70% evaporation, 70% coverage saves 49% of evaporation, 30% coverage saves 21% of evaporation)
Durability	The expected life time is 25 years.
Estimated cost	$15-$20/sq m
Supplementary Information	
Contact Details	Zeev Birger Address: Ben Gurion 32, Ramat Hasharon, Israel Email: zeevbirger@gmail.com https://www.neotopwater.com/topup-ball

1.2.14 Hexa-Cover floating modular cover

Product name Hexa-Cover	Web Site Reference http://www.hexa-cover.dk/uk/hexa-cover
Manufacturer or Supplier Hexa-Cover Denmark 	Product Description  Hexa-Cover is made from polypropylene. The hexagonal product R114 has a diagonal measure of 228 mm, height of 70mm and weight of 243 g. There are 28 units deployed per square metre of storage. Delivery is in a bag (100 cm x 130 cm x 250 cm) weighing approximately 275 kg. Wind tests have shown it withstands wind up to 32 m/s.
Performance	Reduces evaporation by up to 95% of the area covered. A unique overlap edge detail helps achieve up to 99% surface cover of a water surface
Durability	The expected life time is 25 years.
Estimated cost	$35/sq m
Supplementary Information	
Contact Details	Paulus Des Anges 0484220956 Email : http://www.e-wi.com.au/hexa-cover/

1.2.15 FloatPac Solar Floating modular photovoltaic panel

Product name	Web Site Reference
FloatPac Solar	https://floatpac.com/floating-solar/benefits/

Manufacturer or Supplier FloatPac	Product Description  The FloatPac Solar proprietary pin system allows for ease of joining on both land and water, reducing installation times and cost. FloatPac Solar's east – west configuration lends itself to maximising power generation whilst reducing wind loads and maximising installed densities of solar panels.
Performance	80% or more cover of a body of water, up to 70% evaporation reduction. FloatPac Solar floatovoltaics improves solar panel efficiency by 11 – 21%.
Durability	
Estimated cost	
Supplementary Information	No technical specifications on floats or solar panels. No indication of power output.
Contact Details	Phone +61 (0) 3 9548 4700 Email info@floatpac.com Website www.floatpac.com Address Factory 7, Spectrum Business Park, 21-35 Ricketts Road, Mt Waverley, Victoria, Australia 3149

1.2.16 Afloat Solar floating modular photovoltaic panel

Product name	Web Site Reference
Global NRG 'Afloat Solar'	https://www.globalnrg.com.au/afloat-solar

Manufacturer or Supplier Global NRG Renewable Energy (Multinational company with an address in Australia)	Product Description  AFLOAT SOLAR Systems are completely modular and adapt to virtually any width to achieve the desired power outcome targets. By harnessing the water's ability to reflect and amplify sunlight on the water's surface the Afloat System allows the panels to capture and absorb a larger % of sunlight into the PV panels.
Performance	The total volume of saved water depends on the size of the floating Solar system, eg 11,000 square meters equates to around 1MWp (MW peak) saving 5.5 million litres of water per year, or 5.5ML/ year per MWp of a floating system.
Durability	
Estimated cost	
Supplementary Information	None available.
Contact Details	Phone Email info@globalnrg.com Website Address 263-271 Wells Road, Chelsea Heights Victoria Australia 3196

1.2.17 Suntrix Floating Solar floating modular photovoltaic panel

Product name	Web Site Reference
Suntrix Floating Solar	http://www.suntrix.com.au/what-we-do/solar-solutions/floating-solar/?nabe=5164923301396480:1

Manufacturer or Supplier	Product Description  Suntrix utilise the French-designed Hydrelio© floating solar system produced by Ciel et Terre, who have specialised in floating PV systems since 2011.
Performance	No objective information provided on Suntrix website.
Durability	
Estimated cost	
Supplementary Information	Ciel et Terre supplied the 100 kW Lismore Community Floating Solar Farm installed on one of the council's sewage treatment plants to supply the facility with 16% of its electricity needs (https://www.pv-magazine-australia.com/2020/01/14/sa-water-unveils-major-solar-and-storage-plans-for-2020/?utm_source=Bibblio&utm_campaign=Network)
Contact Details	Phone: 1300 884 898 Email: info@suntrix.com.au Website: Address: Head Office 95 Graves Street, NEWTON SA 5074

1.2.18 WaterSavr mono-molecular chemical film

Product name WaterSavr	Web Site Reference https://www.flexiblesolutions.com/products/watersavr/default.shtml
Manufacturer or Supplier (company based in USA, no Australian contacts)	Product Description  Hydrated lime powder with hydroxyl alkanes (hexadecanol and octadecanol) forms an invisible film over the water surface. Application rate is 10 g per 100 m^2.
Performance	Evaporative reduction of 35%. Certified to ANSI60 Drinking Water Treatment Chemicals.
Durability	Film reforms after wind or wave action and degrades within 2 to 3 days. WaterSavr should be reapplied every 3 days.
Estimated cost	
Supplementary Information	Project information is available as well as x3 methods for applying (flour sifter manual method, auto spreader WSS-25, pump spreader JV-225 for surfaces larger than 20 ha).
Contact Details	Phone International: 250-477-9969 Email infowatersavr@flexiblesolutions.com Website Address Flexible Solutions International Ltd 6001 54th Ave Taber, AB T1G 1X4

1.2.19 WaterGuard multi-molecular chemical film

Product name	Web Site Reference
WaterGuard	https://www.aquatain.com/WaterGuard.html

Manufacturer or Supplier	Product Description
Aquatain Products Pty. Ltd.	 WaterGuard is a new, improved formulation manufactured by Aquatain Products Pty Ltd which is even more effective and more economical for reducing evaporation from farm dams, reservoirs and pools. WaterGuard is a unique liquid which spreads over the surface of water to form a very thin film and reduce evaporation.
Performance	Trials in the US have achieved evaporation savings of 50% and above. Once the film is in place, it is very resistant to disturbances. Further commercial testing of performance is required.
Durability	Depends on dosage rate and local conditions. Replacement every 3 weeks is recommended. The product is a mix of silicone and a polymer insert. The polymer improves evaporation suppression and the silicone provides spreading capability
Estimated cost	Cost supplied to retailer $10-$11/litre. Sold by retailer at $13-$15/litre. Dosage 10l/ha suggest could increase to 50l/ha. Applied every 3 weeks.
Supplementary Information	WaterGuard can be poured on to the water directly from the drum, to spread rapidly across the surface. For larger applications, it can be applied by air or by automated dosing equipment.
Contact Details	Phone 0409 250 240 Email graham@aquatain.com Website www.aquatain.com Address Aquatain Products Pty Ltd PO Box 1007 Kyneton VIC 3444 AUSTRALIA

Appendix 2: List of Questions for Evaporation Control Suppliers and Users

List of Questions for Evaporation Control Suppliers

Question/Discussion Point
Contact Details
1. Contact details and email, phone, webpage, address No years in business
2. Information on manufacturer, supplier, installer services
Market Information
3. What is the size of the market and your estimated market share?
4. Number and location of units installed?
5. What are the industries your product would best serve (agriculture (which crops/livestock), mining, urban)?
6. What has been general interest in the product? Trends in regions, industries requesting quotes
7. What are you future plans for product development and marketing? Do you approach different market segments differently?
8. Has any grant / external funding been received to support development or deployment?
9. What factors are limiting uptake / adoption?
Technical Information
10. Provide general description of the product or installation and any technical material (info sheet/web page)
11. What is the product testing regime and research and development path?

12. What is the maximum and minimum pond area capability and influencing factors?
13. Provide technical specifications/details, including type of polymer used including UV stabilisers
14. What are the management issues that affect product performance?
15. What is the repair and maintenance schedule required for best product performance?
16. Provide examples of installations and information that can be used in case studies
17. What is the evaporation saving using the product (% saved or ML/ha/yr for example sites) What are the water cost savings ($/yr or $/ha/yr) for specific sites
18. What are the Pros and Cons of the product?
19. Are there any operational requirements of storage that will contribute to performance of the product to control evaporation?
20. Are there any potential environmental impacts elated to the product?
21. Are there any standards of compliance that have had to be met (technical/environmental)?
22. Are there any site limitations for product installation (eg dry storage/ wet storage, other)
23. Has considerations been given to integration of solar PV into the systems?
Economic Information
24. What is the maximum and minimum area that can be installed? What is the Capital Cost and Price point for different scale (1ha, 10ha, 100ha)
25. What are the repair and maintenance costs $/yr or $/ha/yr and component costs?

26. What is the durability, life expectancy and warranty?
27. What are the annual operating costs?
General Information
28. Can you recommend potential sites for product testing?
29. What factors are affecting market expansion?
30. What support can government provide to facilitate adoption of evaporation mitigation technologies?

List of Questions for Evaporation Control Users

Question/Discussion Point
Contact Details
1. Property location. Contact details and email, phone, webpage, address No years in business
2. Type of cover used. Information on manufacturer, supplier, installer services
Market Information
3. Why did you decide to use a cover?
4. Has any grant / external funding been received to support development or deployment?
5. Are you aware of others who use covers?
6. Has there been any interest locally in your cover?
Technical Information
7. Number of storages on property? Number of storages with covers?
8. Storage volume at FSL (ML) Storage area at FSL (ha) Maximum storage depth (m)
9. Size of cover (ha)?
10. Installation date?
11. Reason for using specific cover?
12. Do you have any information on water saved by cover or system (% or ML/ha/yr or ML/yr)

Economic Information
13. What is the Capital/purchase cost of the system $ or $/ha? What was the installation cost $ or $/ha?
14. What are the repair and maintenance requirements and costs $/yr or $/ha/yr
15. What are the annual operating costs?
16. What are the water cost savings $/yr or $/ha/yr?
17. What is the expected life span of the product yr?
General Information
18. What have been the performance outcomes (satisfactory or not)
19. What are the pros and cons of the product?
20. Are there any potential environmental impacts elated to the product?
21. Any recommendations for product enhancement?
22. Any other comments or concerns?
23. Would you be interested in a cover trial?

Appendix 3: Case Studies

Case Study 1

Product Type : Suspended Shadecloth cover
Supplier : NetPro Environmental Solutions Pty Ltd

Title:
Water Storage Golden Valley Orchards - Stanthorpe

Client: Golden Valley Orchards Pty Ltd
Industry: Irrigated agriculture - Apples
Location: Stanthorpe

Contact Details: Renato Andreatta - Golden Valley Orchards Pty Ltd: Ph 0402 331 026

Business Requirement

In 2003, Golden Valley Orchards installed a NetPro cover as part of a research project funded by Qld Government evaluating the effectiveness of (among others) NetPro's suspended shadecloth cover.

The storage dam holds approximately 133ML, and has a surface area of 3.8ha. Golden Valley Orchards operations extend over 83ha, with irrigation primarily used for apple production. The storage has a length of 300m and width of 126m and is 6m deep.

Golden Valley orchards are unable to buy in water. They collect local site runoff and extract groundwater. Water is therefore limiting, prompting interest in evaporation saving technology. Seepage rates are considered low as the bed material is a well compacted clay.

Recent drought in Stanthorpe has raised again the importance of saving water from storages. Water is currently trucked in for domestic supply. On a number of occasions in recent years Golden Valley orchards have been able to irrigate from this covered storage, when surrounding farmers have been without water. This has helped them to produce high quality apples at premium price.

Solution

The installation was completed in November 2003, when the storage was empty, using 85% shade cloth and 7.4mm galvanised steel cables, which are anchored to the bank with 2m anchors. Original trial results at USQ showed that for the shade cloth used, an evaporation saving of around 70% - 80% could be expected. The structure has internal supports at 60m spacing. Annual evaporation loss in

Stanthorpe is around 1600mm/yr. Based on 80% evaporation saving the structure would save 49ML/yr
Economic Information
The capita costs of the system was $200k of which $80k was subsidised by government. In today's terms the cost of the structure would be around $13/sqm. Based on current prices, the expected life of the product (30yr structure, 15yr shadecloth) and 80% evaporation saving, the annualised cost of the system would be around $850/ML. Apple production typically has a high gross margin per ML water used. Further calculations of cost-benefit of the structure will be undertaken as part of the next phase of this project
Benefits
• Evaporation Control - The original shadecloth is expected to reduce evaporation by 70%-80%. With latest NetPro product this saving could be increased to around 80%-85%. • Water Quality – The storage cover significantly restricts UV light, windblown debris and discourage bird and animal access, resulting in improved water quality. • Reduction in Bank Erosion – the cover limits wind interaction with the water surface thus eliminating waves and slowing down wall deterioration therefore saving costs in maintenance. • Reduction in Weed and Reed Growth - Combating the continual growth of weeds and reeds in water storages has become an expensive and ecological challenge. Covering the storage helps control noxious weeds.
Challenges
The structure was damaged in 2019 with a break of one of the cables. This has caused sections of the cover to subside. Current plans are to restring the affected cables and refit impacted sections of shade clothe. The system originally installed at Golden Valley orchards used 85% protection shade cloth with 7.4mm cabling. The latest product supplied by NetPro uses 95% protection shade cloth with better stretch capability and 12mm cable giving 4 times the structural strength. Carry load has increased from 3t to 12t. Improved connectors and cable joints have also been designed. Apart from this repair and maintenance has been negligible.
Quotation
Include quotes from client and supplier:
In 2008, Renato Andreatta indicated "We are very happy with it (the cover). It reduces evaporation losses by over 90%, so you could say there has hardly been any evaporation." Owners are being contacted for updated feedback and further economic calculations will be undertaken during the next phase of this project.
Other

Case Study 2

Product Type : Floating modular
Supplier: Previously Aqua Guardian Group. Currently HydroTerra Pty Ltd

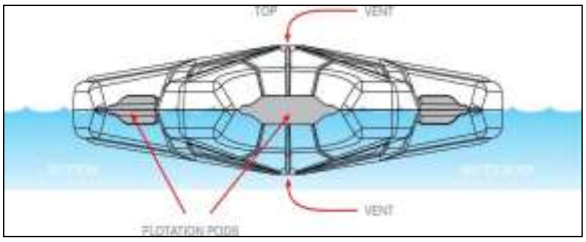
Title: Assessment of the water saving potential of AquaArmour™ floating modules

Client: Aqua Guardian Group Limited
Industry: Product applicable to multiple industries
Location: USQ Agriculture Plot, Toowoomba

Contact Details: Erik Schmidt
Address: Centre for Agricultural Engineering
University of Southern Queensland,
Email: Erik.Schmidt@usq.edu.au

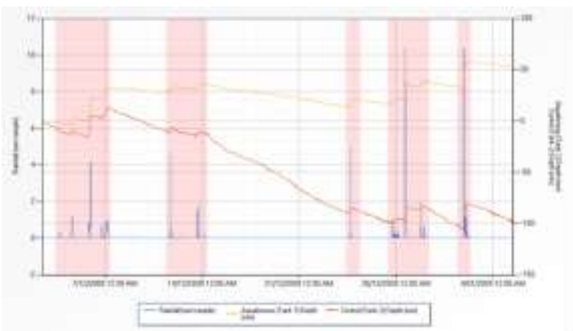
Business Requirement

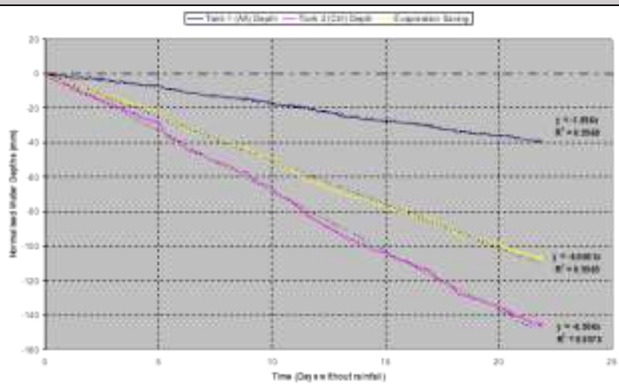
AquaArmour™ is a floating system of hollow hexagonal pods constructed from High Density Polyethylene (HDPE) and arranged into a free-form floating lattice to mitigate the losses through evaporation from open water storages. The pods are self-anchoring by design in which water is allowed to enter the hollow portion of the pod through vents at the centre of each face, top and bottom. Water captured in the pod provides a 'water ballast' to anchor the pods in place and reportedly resist against lifting in high winds.



Aqua Guardian Group requested an evaluation of the product to provided independent evidence for use during product promotion. Trials were performed at the University of Southern Queensland in Toowoomba, during December 2008 and January 2009, to assess the impact of the AquaArmour™ system on evaporation loss, temperature and water quality. The trials were conducted in two 10m diameter tanks, one acting as a control and the other with the AquaArmour™ pods installed to cover 81.4% of the water surface.

Solution





USQ deployed pressure sensing transducers in three x 10m diameter lined tanks. The high resolution sensors reported the pressure at the bottom of each tank, which is directly related to the depth of water in the tank. The first tank was covered with the AquaArmour™ pods (yellow line, left side figure), the second tank was uncovered and acted as a control (red line, left side figure above). After removing periods of rainfall from the analysis, to focus on evaporation trends (right side figure above), evaporation losses from the AquaArmour™ tank (blue line) and control tank (purple line) could be determined as well as the evaporation saving (yellow line).

Results show an average rate of evaporation for the AquaArmour™ tank of 1.86mm per day over the study period. Evaporation for the uncovered control tank (representing the rate of evaporation when not deploying the pods) was 3.7 times greater at 6.91mm per day. This result represents evaporation savings of greater than 73% when deploying AquaArmour™ pods at a coverage of 81.4%. Greater savings would be expected as total surface area coverage increases towards 100%.

Trials indicated a high level of mixing of the top layers of the water in the uncovered control tank and reduced mixing of water in surface layers under the AquaArmour™ pods. This was due to the reduced wave action caused by the stilling effect of the pods on the water surface. Results on the impact of the pods on algal growth are inconclusive, due to differences in the initial species composition and population density in the two tanks

Economic Information

No economic information was collected for the product. The AquaArmour™ product does not appear to be currently available in Australia. It was marketed by HydroTerra Environmental Monitoring Solutions. https://www.hydroterra.com.au/assets/AquaArmour-Brochure-HTBranded-SS.pdf

Benefits

- Trials at the University of Southern Queensland in Toowoomba suggest evaporation savings of 73% when deploying AquaArmour pods at a coverage of 81%. Greater savings than those reported here would be expected as total surface area coverage increases towards 100%.
- Deployment of modules will result in reduced light penetration and reduced mixing of the water under the modules but has been shown to not adversely affect oxygen levels.
- Easy to install and remove and scalable to a range of storage sizes
- Resistant to high winds due to water ballasting and can be used with booms to hold pods in place.

Challenges

- While evaporation saving results for the product were positive, the availability of the product in Australia is now in question and further attempts to contact supplier will be made.

Quotation

Include quotes from client and supplier:
N/A

Other

3,500 Aqua Armour pods were installed by Gippsland Water at Hayfield, East Gippsland, Victoria during May-June 2016. The primary aim was to prevention/reduction of algal growth on a treated waste water pond. Booming was installed in 20mx20m cells to prevent product from moving during strong winds. Water quality data was collected. No results have been sourced at this stage.

Case Study 3

Product Type : Floating modular
Supplier : NeoTop

Title: Assessment of the water saving potential of NeoTop Top up Balls

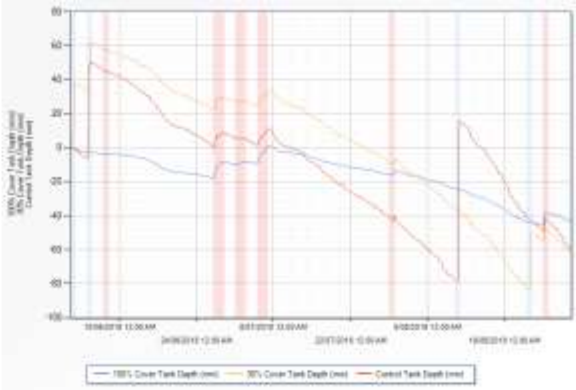
Client: Cotton Research and Development Corporation
Industry: Multiple
Location: USQ Agriculture Plot, Toowoomba

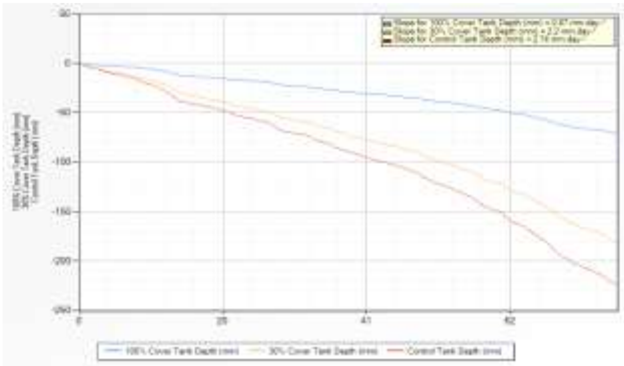
Contact Details: Zeev Birger
Address: Ben Gurion 32,
Ramat Hasharon, Israel
Email: zeevbirger@gmail.com

Business Requirement

The Cotton Research and Development Corporation (CRDC) funded a short research experiment to test the effectiveness of the Top-Up Ball floating modular cover from NeoTop (an Israeli based company). The University of Southern Queensland (USQ) have had had a long commitment to evaporation mitigation research including the construction of a product testing facility and the development of specialist software for analysing evaporation data.
NeoTop had previously had their product assessed in Israel and wanted a similar assessment under Australian conditions.

Solution





USQ were able to deploy pressure sensing transducers in three x 10m diameter lined tanks. The high resolution sensors reported the pressure at the bottom of each tank which is directly related to the depth of water in the tank. The first tank was covered with the Top-Up balls, the second tank was open (no Top-Up Balls) and the third tank was partially covered (either 30% or 70% at different stages of the experiment.

The data from the pressure sensors was downloaded weekly along with weather station data and water temperature data at three depths in the tank for assessment.

The USQ software EvapCalc was used to assess the data and calculate the percentage of water that was saved in the tanks with the Top-Up Balls. Results from 18 months of testing indicate that the product mitigates evaporation by ~70% of the area covered (i.e. 100% coverage saves 70% evaporation, 70% coverage saves 49% of evaporation, 30% coverage saves 21% of evaporation)
Economic Information
• No economic information has been provided. The manufacturer was waiting to see the results of the water saving experiment before selecting a price point
Benefits
• Lowers water temperature allows oxygen exchange at water surface • Reduces algal growth • Easy to install and remove • Scalable to a range of storage sizes • Resistant to high winds due to water ballasting
Challenges
• While evaporation saving results for the product were positive, the availability of the product in Australia is now in question, with the manufacturer withdrawing from the Australian market.
Quotation
NA
Other
Floating modules offer the flexibility of being able to add modules in batches over time as farm finances permit. There is potential for the modules to become lodged in mud or sediment id a storage is emptied and filled.

Case Study 4

Product Type : Monolayer
Supplier : Prototype automated monolayer applicator.

Title:
Smart system for applying monolayers to water storages.
Demonstration on Logan’s Dam, Forest Hill Qld.

Client: Queensland Urban Water Research Alliance
Location: Field trial on Logan’s Dam (27o34’25.93” S, 152o20’27.45”E; altitude88 m), an elevated, rectangular storage 480 x 350 m, total volumetric capacity 700 ML, maximum depth 6 m. Trial 2009-2011

Contact Details: NA

Business Requirement

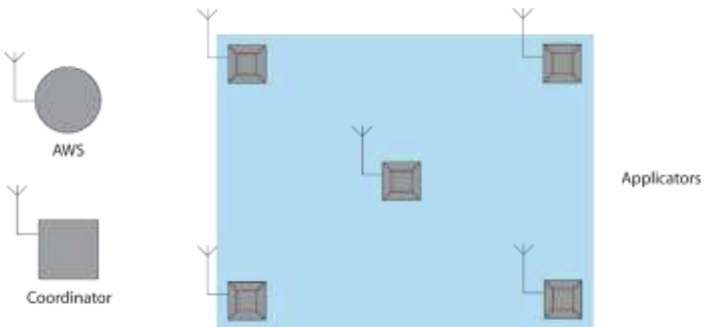
Monolayer chemical covers offer significant flexibility in the ability mitigate evaporation from water storages that do not contain water all year round. Unlike structural or floating modules chemical monolayers are only applied when required and do not have a large upfront capital cost.

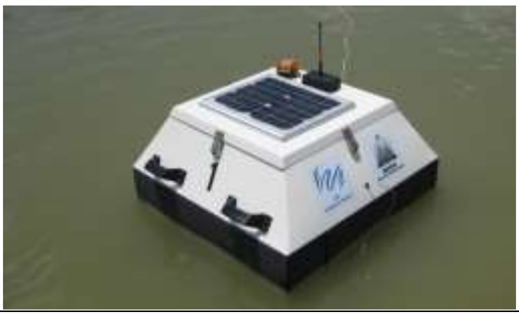
Monolayer are non-toxic chemicals that when applied to water will spread and create a very thin film or skin on the water surface. This film has minimal impact to the natural oxygenation of water so does not impact aquatic wild life and photo degrades after 1-4 days. The thin film acts as a barrier to evaporation and may save up to 40% of evaporation loss. However the chemical needs to be very light in order to sit on the water surface which means that is easily moved by wind and waves.

Once the chemical is deposited on the bank of a water storage, it is unlikely to be redistributed across the water surface at which point it no longer mitigates evaporation. This means that the monolayer chemical need to be applied regularly and only when the conditions are such to give it the best chance to work. Applying monolayer from the bank of a water surface several times per week is time consuming and access to the leeward side of a water storage may not always be possible.

Solution

A smart system has been designed as a network of monolayer applicators that connect remotely to a coordinator which interprets weather (windspeed, direction, rainfall) data and makes decision on not only when to apply the monolayer chemical but also where in the storage the chemical should be applied to ensure that it is able to be spread without being deposited on the shore of the storage



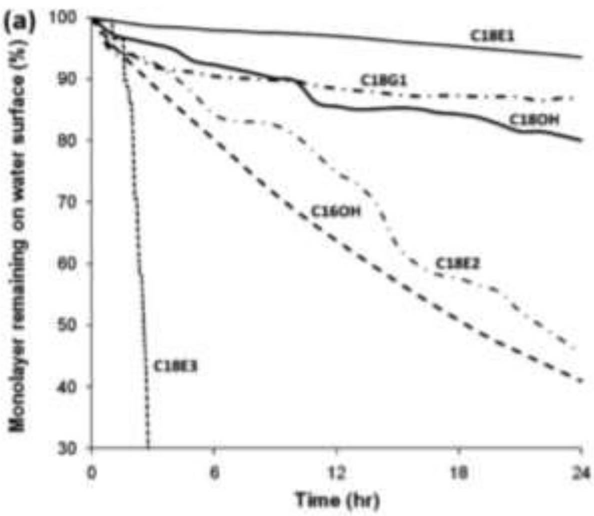


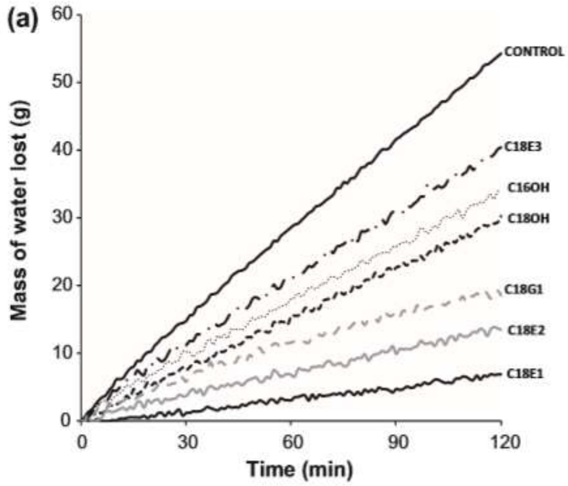
The solution has been tested in a number of agricultural storages and was deployed on Logan's Dam in the Lockyer Valley as part of a demonstration trial during 2009-2011. The system was shown to be an effective method for timely application of the chemical monolayer although product performance in evaporation reduction was poor.
Economic Information
• This smart system has been developed at a prototype only, however should be considered an integral part of a monolayer evaporation mitigation system
Benefits
• Automatic control of application of product only applies where and when necessary • No waste, only applies when necessary • Floats on the storage and can be easily moved/ removed • The system is scalable to any size storage but practically up to 100ha • Relocatable
Challenges
• Works best with liquid monolayer products • Floating pods need to be filled regularly depending on the rate of application
Quotation
NA
Other

Case Study 5

Product Type : Experimental monolayer formulation C18E1 Supplier : Melbourne University Polymers	
Title: Field trial of C18E1 monolayer emulsion on Logan's Dam, Forest Hill Qld.	
Client:	Co-Operative Research Centre (CRC) for Polymers, Melbourne University.
Industry:	Product applicable to evaporation mitigation across range of industries.
Location:	Field trial on Logan's Dam (27°34'25.93" S, 152°20'27.45"E; altitude88 m), an elevated, rectangular storage 480 x 350 m, total volumetric capacity 700 ML, maximum depth 6 m. Trial period 2009-2011
Contact Details:	Erik Schmidt, National Centre for Engineering in Agriculture (NCEA; now Centre for Agricultural Engineering), USQ Toowoomba.
Business Requirement	

CRC for Polymers was developing novel artificial monolayer products with improved resistance to wind, volatilisation and microbial degradation. In laboratory-scale trials the monolayer formulation based on ethylene glycol monooctadecyl ether (C18E1) was the most resistant (left-hand figure below), and reduced evaporative loss by 91% (right-hand figure below). Hexadecanol (C16OH) and Octadecanol (C18OH), the compounds on which the commercial monolayer product WaterSavr is based, only reduced evaporative loss by 38 and 47% respectively (Prime et al. 2012. Colloids and Surfaces A: Physiochem. Eng. Aspects 415: 47-58).





Under laboratory conditions with a wind speed of 25 km hr^{-1} (7.0 m sec^{-1}) the C18E1 formulation had the high spreading pressure and surface pressure required to rapidly cover a water body from the point of application, and to reduce evaporative loss. The CRC for Polymers subcontracted the NCEA to apply the new product from multiple sites around Logan's Dam, during the testing of eddy covariance and scintillometry technologies to accurately assess evaporative loss from a water body (McJannet et al. 2013, Agric. And Forest Meteorol. 168: 93-107).

NCEA staff applied the product only during conditions of low wind speed from at least nine locations around the perimeter of the storage, to maximise rapid coverage of the water surface with the C18E1 monolayer. Three separate trials were conducted over summer and autumn, using manual and automated (refer Monolayer Application Case Study) application methods.

Solution
Visual evidence after product application confirmed the monolayer rapidly spread over the water surface, including directly under the path of the scintillometer (glassy patches in the photograph below) measuring evaporative loss directly above the water surface.  Results from the more direct energy balance calculations of evaporative loss were inconclusive (McJannet pers. comm.). Water temperature sensors detected the monolayer as a rapid increase in surface (skin) temperature, which rapidly declined 3 hours later. Two factors which may account for these inconclusive results are: 1) The water in this storage regularly stratified in the afternoon, and the warm, thermally stable surface skin would have reduced evaporation at much the same order of magnitude as the artificial monolayer - confounding the detection of any monolayer effect. 2) NCEA testing ranked C18E1 as the most susceptible to photodegradation (a natural cleansing process), C16OH intermediate, C18OH the most resistant (Pittaway et al. 2015, Water Sci. and Technol. 72: 1334-1340). The brown water in Logan's Dam had a high photodegradation potential, which would have reduced the half-life of the C18E1 monolayer.
Economic Information
• The novel C18E1 monolayer formulation is only suitable for application to water storages with a low photodegradation potential (clear water only). • Autonomous application should only be programmed during light wind, and not when the water is thermally stratified.
Benefits
• CRC Polymers research has established the lab-scale testing and selection criteria for novel artificial monolayer compounds that reduce evaporative loss, but more research is required to develop and commercialise new cost-effective products.
Challenges
• Susceptibility to direct and indirect photodegradation must be included in the selection criteria for improved monolayer products. • New product spreading angle and rate must also be established, to inform landholders of the number and location of applicators required for good surface coverage on a specific storage.
Quotation
Discussions with Prof Greg Qiao of Melbourne University indicate that the Federal Department of Agriculture and Water Resources and the CRDC are currently funding a 3 year program to further develop these systems including use of barriers to minimise wind drift.

Case Study 6

Product Type : Suspended Shadecloth cover Supplier : NetPro Pty Ltd	
Title: Stanthorpe QDAF – Treated wastewater storage	
Client: Stanthorpe Department of Agriculture and Fisheries Industry: Irrigated agriculture – Research Trials Location: Stanthorpe	
Contact Details: Andrew Douglas – Department of Agriculture & Fisheries (DAF) 0459 871 335 Andrew.Douglas@daf.qld.gov.au.	

Business Requirement

Stanthorpe has limited water supplies and 15 years ago there was opportunity to purchase a water allocation of treated wastewater from Stanthorpe Council. The water is used to irrigate QDAF field trials, which require high security water. Apple and stone fruit are irrigated using a trickle system. Overland flows are captured in three storages and water transferred when required to this storage which meets high risk need.

Solution

The storage is not lined, though it has a double layer of clay to limit seepage. It holds approximately 10 ML of water. Evaporation is around 1.7m per year.
The structure comprises 7.4mm galvanised steel anchored to the bank with 2m anchors. Central supporting poles have been included.
The cover was installed when the storage was full using floating pontoons. The original shade clothe had an 84% shade factor. Trial results at USQ showed saving of around 70% evaporation could be expected for this product.

Economic Information

The payback for the system has not been investigated since it was installed to meet strategic irrigation needs of critical research trials on the research farm. QDAF currently pay $190 per ML for the treated effluent water. The NetPro cover cost $52,000 when originally installed 15years ago. Based on current replacement cost, the cost to save water using NetPro product would be around $730/ML/year.

Benefits

• Primary reason was to limit algae and weed growth in the treated wastewater. Combating the continual growth of weeds and algae in water storages with treated wastewater is a significant challenge. Reducing UV and light has assisted. • The cover also provides security and limits access to the storage for humans and animals. • Evaporation Control - The structure is expected to reduce evaporation by between 70-80%.
Challenges
The cover was damaged by fire at the edges in 2019. Surrounding grass needs to be kept short and should be mowed regularly. Shade cloth was replaced, with the latest product which has a 95% shade factor, and is more flexible and lighter. This is easier for labour installation. The new product will also improve evaporation savings and reduce light penetration further. The cover was also replaced after a heavy hail storm under an insurance claim. The latest NetPro product has a stronger lattice of cabling and should address this.
Quotation
Andrew Douglas indicated that they have been happy with the product and that consideration is being given to install a similar cover on a 1.3ha storage at the Hermitage research station in Warwick. A quota indicates the current price to be around $13/sqm

Case Study 7

Product Type : WaterGuard Molecular Chemical Film Supplier : Aquatain Pty Ltd	
Title:	Assessment of the water saving potential of WaterGuard
Client: Industry: Location:	Aspley Nursery Nursery Morayfield
Contact Details: Address: Phone:	Noel Percy 37 J.Dobson Road Morayfield, Queensland http://www.aspleynursery.com.au/ (07) 5498 5652

Business Requirement

Aspley Nursery is a family owned Commercial Nursery operating from two sites north of Brisbane. They have been operating since 1952 and are recognised as market leaders and innovators in nursery management.

Water management has been an ongoing concern. They capture local rain-runoff from their operations and then recycle for irrigation after treatment. They are otherwise reliant on buying in potable water from Unity Water at $1,42/kl or trucking in water at four times this price. They produce high value nursery plants for the landscaping sector.

They operate from two sites a 5acre site at Aspley and 10acre site at Morayfield, and pump water from onsite storages 4ML and 20ML. This Case study is for the 20ML storage in Morayfield.


Solution

Aspley Nursery have been using WaterGuard for over eight years. They apply the product every 2-3 weeks from 20l containers at a rate of approximately 10l/ha. The product costs approximately $14/litre. They typically apply product when water is short over the dry season and during periods of high evaporation loss (eg Oct-March). Evaporation is approximately 1800mm/yr of which 60% occurs between October and March.

They have no quantitative data on the performance of the product but believe it performs well. They can see the distribution of the product when applied to the water. They have no environmental concerns and the storage at Morayfield has a very healthy Perch, Eel and Turtle population.
They would be very interested to get better information on the evaporation saving potential of the product but this is very difficult to measure.

Economic Information
The storage surface is 0.6ha and based on 20% evaporation saving and application of 10l/ha every 3 weeks between October and March and a cost of $14/l the water saving is estimated to be 1.4ML/yr at an annual cost of $586/ML/yr. This is well below the cost of buying water from Unity water at $1,420/ML. Typically the operation carries $2m worth of stock and maintaining production and quality through irrigation is critical. The gross margin /ML for nursery crops is highly variable, depending on product and market conditions, but is expected to be well above $1,500/ML
Benefits
• No significant capital cost and product is only applied when required. • Low risk investment • Biodegradable with no apparent environmental impact after 8 years of use. • Doesn't require frequent application and has good spreading capability
Challenges
• Difficult to quantify evaporation savings
Quotation
Noel Percy indicated "At Aspley Nursery we are regarded as industry leaders in seeking efficiency improvements. A recent example has been our work in energy management under the QFF Energy Savers program. We are very pleased with the performance of WaterGuard and have been regular users over 8 years with little evidence of environmental impact. It would be useful to have reliable information on expected evaporation savings. This is difficult to measure in a commercial storage. "

Case Study 8

Product Type : Continuous Floating Cover Supplier : Evaporation Control Systems EvapCap
Title: Water Storage at Redbank Plantation – Lockyer Valley
Client: Redbank Plantation Industry: Irrigated Horticulture - Avocados Location: Lockyer Valley
Contact Details: Robyn Lubach 0408661457 Robyn.Lubach@rplantations.com.au
Business Requirement

With increasing environmental concern and concentration upon irrigation water use efficiency, there is considerable pressure to optimize as far as possible the use of precious water resources. The rate of evaporation in the district is around 2m per year.

The storage used by Redbank Plantation avocado farm in the Lockyer Valley is a turkey's nest style ring tank which means that it does not catch any overland flow. The storage has been constructed out of compacted clays and has a surface area of just over one hectare and is in excess of 10 m deep. This smart design minimises the water surface exposed to evaporation while maximising the water storage capacity.

The storage has daily inflows from bores as well as recycled effluent from the township of Gatton. The volume of water pumped to the trees will vary depending on the crops requirements through the year. This means that the water level in the storage is constantly changing. Where a cover is to be used to reduce evaporation from the storage it must be able to accommodate significant changes in the level in the water storage.

Solution

An Evaporation Control Systems E-VapCaps® product was chosen to cover the storage and reduce evaporation because it is a highly efficient evaporation saving cover and the floating installation allows for the cover to be repositioned with the change in storage level.


The cover was installed in 2008 and contains buoyancy cells, similar to bubble wrap or existing swimming pool cover products, but is made from much tougher material to resist degradation from sunlight.

The multi-layering enables it to reflect some of the sun's heat as the top of the material is white, while the under layers are black, completely eliminating the transmission of light to the water underneath. This helps reduce algae growth. Tests have demonstrated that when well managed the cover is over 90% effective in reducing evaporation from open storages

The EvapCap® covers the centre portion of the storage (75 m x 62 m - 41% when full, and more than 50% during summer when dam levels are lower) and has a buoyancy and tether system which allows the cover to be repositioned depending on the volume of water in the storage. There is a weighted curtain under the water level which allows the cover to resist lifting off the surface under windy conditions.

After more than 10 years in use the product is still performing well according to the owner. They are not certain of the evaporation saving but the studies from USQ tank trials suggest good savings. The storage is the main water source and is full 3 to 4 months of the year and never empties. Water is very valuable. Water is applied by sprinkler with typically 400l/tree per day, and is sometimes used to cool the canopy.

Economic Information

Based on a capital cost of $20/sq m, life expectancy of 15 years, local evaporation data and a 95% evaporation saving the annual evaporation saving by the floating cover would be approximately 8.3ML/yr and the annualised cost of the system would be around $1,050/ML/yr.

Assuming an Avocado yield of 11t/ha/yr and selling price of $4,500/t, income would be $48,730/ha. Assuming variable costs of $27,100/ha the Gross margin would be $21,630/ha. If 8ML/ha is applied this equates to Gross Margin/ML of $2,704 which is more than double the cost of the floating cover.

Benefits

- The product has worked well for an extended period of more than 10 years
- The product has been sized to cover that portion of the storage always holding water.

Challenges

- There are still algae problems (given use of treated wastewater) which is expected since less than 50% of the area is covered.
- Main technical problems have been at corner connections to stabilising drums which wear out.
- The original product supplier is no longer operating, however other suppliers are available for new orders (eg Darling Downs Tarps and Sealer Air Australia)

Quotation

The owner Robyn Lubach indicated "The product still works well on site after 10years. Better information on water saving and cost benefit would be valuable".