Evaporation Reduction by Suspended and Floating Covers: Overview, Modelling and Efficiency

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

Chris Davis
Chair, Urban Water Security Research Alliance

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1. INTRODUCTION

This report has been prepared for the SEQ Urban Water Security Research Alliance for the purposes of assessing the potential for floating and suspended covers to reduce evaporation from water storages in South East Queensland (SEQ). In SEQ, large water storages or dams are the primary drinking water supply. The volume of water lost through evaporation each year is roughly equivalent to the SEQ water usage. This considerable loss of water indicates that research into innovative techniques for reducing evaporation could prove beneficial as demand increases in SEQ with rapid population growth. This report forms one of a group of reports, each of which assesses the applicability of different evaporation mitigation techniques to SEQ water supply systems.

2. MECHANISM FOR REDUCING EVAPORATION

This report examines suspended and floating covers and the influence they have on evaporation reduction.

2.1. Suspended Covers

Suspended covers are horizontal sail-like structures that are suspended over water surfaces and are supported externally by steel cables and poles. Suspension systems can be characterised by their span and their cover weight. The cover material can vary from porous shade screens (Finn and Barnes, 2007) to impermeable plastic (Martínez Álvarez *et al.*, 2006). The cover reduces evaporation by blocking incoming solar radiation incident upon the water surface, thus reducing thermal energy input into the reservoir surface waters, which in turn reduces the water surface temperature and the potential for evaporation. The covers also reduce surface wind action by lowering the vapour pressure gradient over the water. The covers can also trap water vapour at the water surface that would otherwise be replaced by dry air, thus raising the moisture level (Finn and Barnes, 2007; Martínez Álvarez *et al.*, 2006). The water-saving efficiency is dependent upon how the covers are installed and the rate at which water vapour can pass through the material.

2.2. Floating Covers

Floating covers include modular and flat sheet covers that float on the water surface. They reflect a proportion of the incoming solar radiation and act as physical barriers to the passage of water vapour both vertically and horizontally. Unlike suspended covers, the floating covers are supported by the water itself. However, they do need to be fixed on the water surface using some form of anchoring mechanism when used on large dams. While most floating cover products are designed to withstand strong wind forces, it is evident they have been designed predominantly for small storages and have not been rigorously tested on larger reservoirs.

Various colours, materials and shapes have been applied in practice. Modular covers predominately do not fully cover the water surface, which allows water to vaporise through the uncovered gaps. As a result, the energy input is only partially reduced and wind can still blow away humid air. It is believed that floating covers will allow for more dissolved O_2 transfer to take place at the water to air interface compared to some suspended covers. This is due to the open gaps existing between each of the modules in a floating cover grid allowing some sections of the surface water to be exposed directly to the atmosphere. The water-saving efficiency is dependent upon the design and the shape of the modules, as well as the material.

A thorough evaluation of the full range of evaporative loss reduction technologies including floating modules and suspended shading covers has been detailed by the National Centre for Engineering in Agriculture (NCEA) (Howard and Schmidt, 2008). In this study, floating modules were found to out perform all other evaporative loss reduction techniques.

3. COMMERCIALLY AVAILABLE PRODUCTS

Four main types of suspended or floating cover are currently available in Australia:

1. Floating modules;
2. Floating bubble-wrap type sheets;
3. Suspended permeable (shade cloth) covers; and
4. Suspended impermeable covers.

Figure 1 depicts several examples of suspended and floating covers. NetPro and SuperSpan are suspended permeable and impermeable covers, E-VapCap is a floating bubble wrap sheet type cover and AquaCap is a floating module system.

In this report, E-VapCap is considered to be a suspended impermeable cover, as it fully covers the surface water underneath. Accordingly, floating covers are only referred to as “AquaCap” hereafter.

Table 1 provides information on their cost, efficiency, and estimated life span. A list of similar products has been compiled by the NCEA (Howard and Schmidt, 2008). This report only considers a limited number of covers, as its objective is to provide an overview into this type of evaporation reduction device, detailing its strengths and limitations and also highlighting areas of concern that require further study. Consequently only one example of each type of cover is explored in detail. A full list of available types is detailed in Appendix 1.

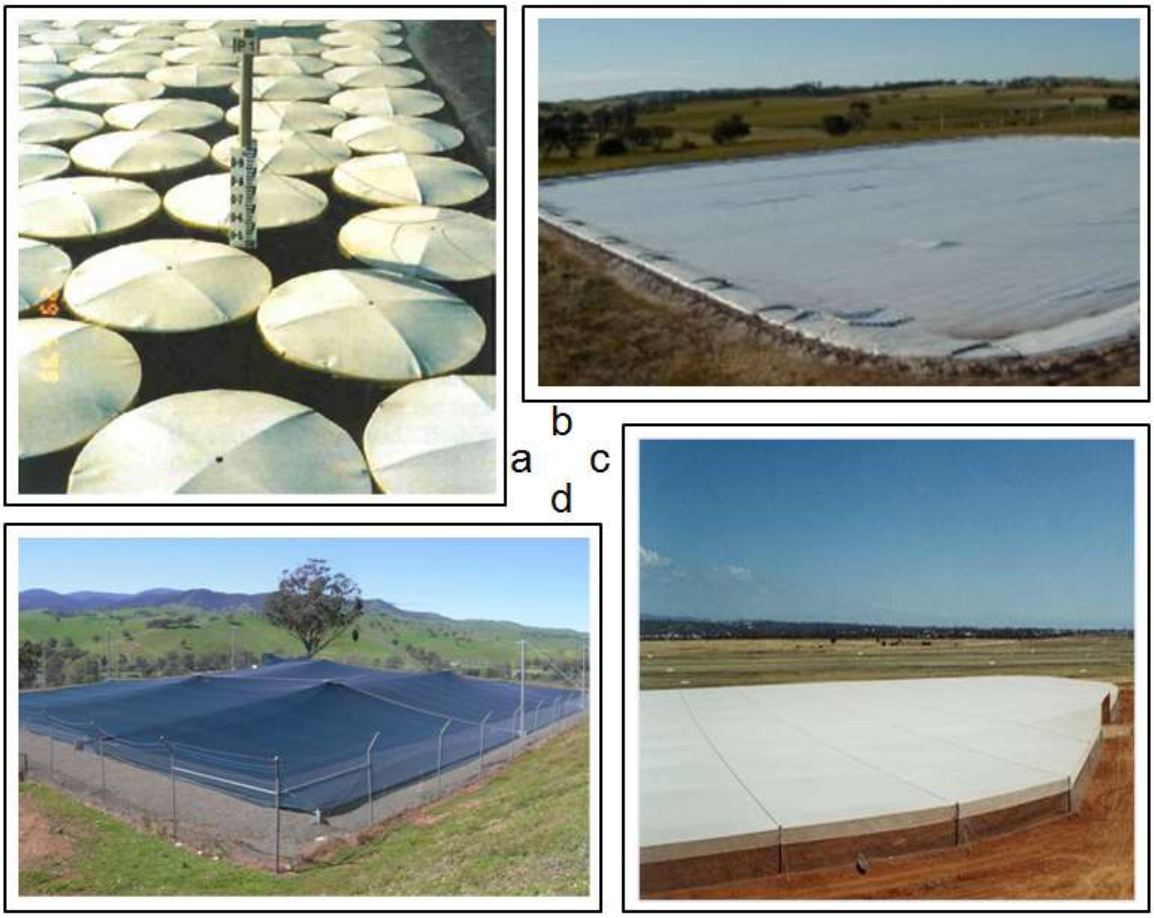

Figure 1: Four examples of evaporation-reducing cover products available in Australia: (a) AquaCap floating modules (Burston, 2002); (b) E-VapCap floating bubble wrap type sheets (Evaporation Control Systems, 2006); (c) Suspended permeable (shade cloth) covers (Source: Netpro Protective Canopies) and (d) SuperSpan suspended impermeable covers (Finn and Barnes, 2007).

Table 1: Summaries of the Cost, Efficiency and Estimated Life Span of the Four Example Cover Products (see Appendix 1 for further details of the products listed here).

Product	Description	Cost ($ per m²)	Efficiency Claimed	Estimated Life Span
AquaCap™	Round, dome-shaped floating module type cover	22	70%	10-year
E-VapCap	'Bubble-wrap' floating sheet type floating cover	6	90%	15-year
NetPro	Suspended permeable (shade cloth) cover	8	70%	15-year cloth 30-year structure
SuperSpan	Suspended permeable (shade cloth) cover	30	90%	20-year

Note: Cost per m^2 does not make any allowance for fixing or anchoring of covers.

4. REVIEW OF EXISITING STUDIES

A large body of literature exists, detailing potential methods of evaporation mitigation (Department of Natural Resources and Mines, 2003; Watts, 2005). It is understood that suspended and floating covers are the most effective evaporation reduction mechanisms, as they significantly reduce incoming solar radiation, trap vaporised water and decrease wind speed over water (Burston, 2002; Craig *et al.*, 2005; Department of Natural Resources and Mines, 2003; Finn and Barnes, 2007; Watts, 2005). Other systems, such as destratification plumes, do not reduce incoming solar radiation.

The efficiency of the four cover products mentioned above has been studied in the field at varying levels of detail (Table 2). Overall, these previous studies suggest that covers can provide an evaporation efficiency of greater than 60%, along with a likely reduction of algae, reduced surface water temperatures and lower dissolved oxygen levels.

Burston and Akbarzadeh (1995) studied an AquaCap prototype and found that it offered reasonable efficiency (65.4%) while still allowing oxygen dissolution and the penetration of solar radiation into the water body. Burston (2002) demonstrated that if the AquaCap system was modified from plate to dome-shaped, efficiency levels could increase to as much as 89%.

Craig *et al.* (2005) found that E-VapCap was the most efficient of the four cover products, cutting evaporation rates by up to 95%. Finn and Barnes (2007) studied SuperSpan in a number of locations over a two-year period and found that in water bodies with little nutrient input the application of SuperSpan could lead to reduced algae growth combined with a reduction in evaporation of approximately 90%.

Unfortunately, past studies have primarily focused on the water-saving efficiency of these covers, with little quantification of their ecological impact on large water bodies. This is an area that requires significant further study before covers can be approved for large-scale long-term use on reservoirs.

Table 2: A Summary of Studies Testing the Efficiency of the Four Cover Products in Mitigating Evaporation.

Source	Product	Location	Size of water body (km^2)	Duration	Efficiency
Burston (2002)	AquaCap	Bundoora Pyramid Hill	0.000056 0.00042	4 months 6 months	72% 73%
Burston and Akbarzadeh (1995)	AquaCap	RMIT University	Swimming pool (unknown size)	56 days	65.4%
Craig et al. (2005)	E-VapCap	Toowoomba St George	0.0061 0.0412	3-5 days	85-95%
	NetPro	Toowoomba Stanthorpe	0.0061 0.038	3-5 days	60-80%
Finn and Barnes (2007)	SuperSpan	Swifts Creek Cann River Sarsfield Orbost	0.0024 0.0009 0.0016 0.0083	1 year	90%

5. DESKTOP MODEL PREDICTION

5.1. Study Domain

A preliminary model study was carried out evaluating the application of various water cover systems on Wivenhoe Dam (27.4944 S, 152.6889 E). This dam was chosen for preliminary model assessment due to the availability of suitable data. Surface area and water storage data for Wivenhoe Dam was provided by Seqwater. At full supply level (when the water surface is 67 m above sea level), Wivenhoe Dam has a surface area of 107.514 km^2 and a capacity of 1165238 ML. During 2007, the elevation of water surface varied between 50.72 to 53.40 m. For simplicity, the water surface was assumed to be fixed at 52 m elevation with the water mixing depth also fixed at 5 m. In this state, the surface area of the dam is about 31.2 km^2, and the corresponding water storage is about 0.2 million ML.

Meteorological and calibration data in 2007 was provided by both Seqwater and the Bureau of Meteorology (BoM). The water column temperature profile data used in the model was supplied by Seqwater. The meteorological data was obtained from a University of Queensland weather station (site No. 040082; 27.5436 S, 152.3375 E) located approximately 35 km from Wivenhoe Dam (Figure 2). The monthly evaporation data from the region was sourced from a Gatton QDPI research station (site No. 040436; 27.5456 S, 152.3286 E). Wind speeds were measured at 10 m above ground. Air temperatures and vapour pressures were measured at 1.2 m above ground. These values were converted into an equivalent 2 m height as required by the Penman-Monteith equation, which was used as the primary evaporation equation in this modelling exercise.

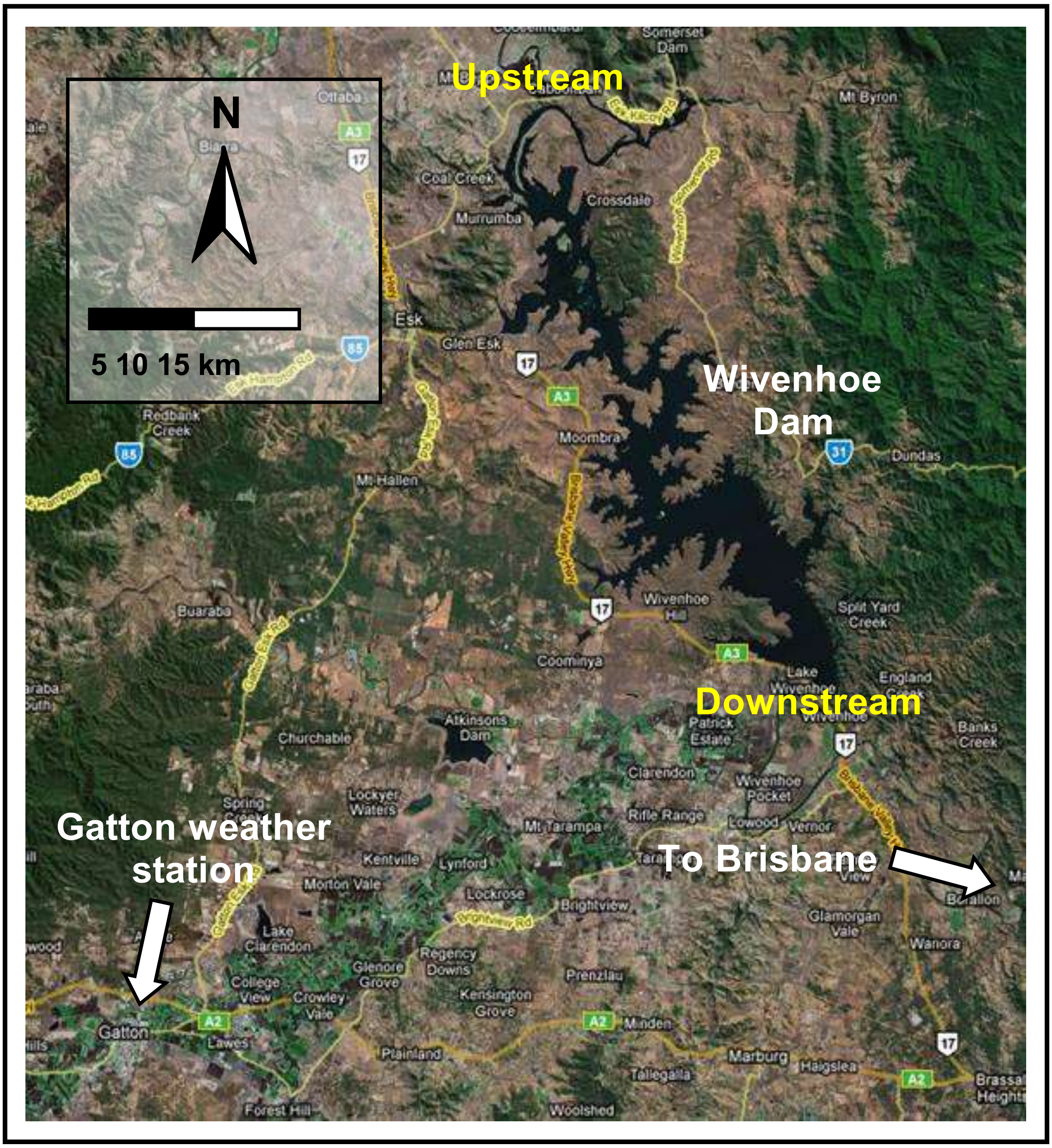

Figure 2: Satellite map of Wivenhoe Dam and the Location of the University of Queensland Gatton Weather Station from which Meteorological Measurements were Sourced (Source: Modified from Google map data, © 2008 Mapdata Sciences Pty Ltd, PSMA).

5.2. Basic Evaporation Model - Penman-Monteith Equation

To keep consistent with McJannet *et al.* (2008a,b), the Penman-Monteith model (Monteith, 1965) was employed for the estimation of open surface water evaporation rates. When applied to open water bodies, the Penman-Monteith approach must account for changes in the amount of energy available for evaporation based on changes in heat storage within the water body.

The Penman-Monteith equation (Monteith, 1965) (Equation 1) is used to produce a time series of the evaporation rate from a water body based on prescribed water surface temperature, air temperature, wind speed and vapour pressure. The Penman-Monteith equation is (Finch and Hall, 2001; McJannet *et al.* 2008a,b):

$$E = \frac{1}{\lambda}\left(\frac{\Delta_w (Q^* - N) + 86400\rho_a C_a (e_w^* - e_a)/r_a}{\Delta_w + \gamma}\right) \tag{1}$$

where

λ (MJ kg^{-1}) is the latent heat of vaporisation;

Δ_w (kPa °C^{-1}) is the slope of the temperature saturation water vapour curve at water temperature;

Q^* (MJ m^{-2} d^{-1}) is net radiation;

N (MJ m^{-2} d^{-1}) is change in heat storage in the water body;

ρ_a (kg m^{-3}) is density of air;

C_a (MJ kg^{-1} ^{o}K^{-1}) is specific heat of air;

e_w^* (kPa) is saturated vapour pressure at water temperature;

e_a (kPa) is vapour pressure at air temperature;

r_a (s m^{-1}) is aerodynamic resistance;

γ (kPa °C^{-1}) is the psychometric constant.

This model requires four sets of meteorological data as described earlier in the study domain: air temperature (T_a); vapour pressure (e_a);wind speed (u_{10}); and incoming solar radiation ($K \downarrow$).

T_a influences Q^* and water temperature (T_w). e_a influences the vapour pressure gradient and T_w. u_{10} affects r_a and T_w. $K \downarrow$ affects Q^*, N, Δ_w and T_w. T_w is a critical parameter in evaporation estimation, as all input data influences the output by influencing T_w.

For the purpose of easy comparison, the formulations for the parameters involved remains consistent with the formulations derived by McJannet *et al.* (2007).

5.3. Evaporation Modelling with Covers

Suspended Covers

A suspended cover made of porous cloth was considered first. For this case, the radiation energy balance at the water surface is influenced by the reflective, transmissive and absorptive properties of the cover, which depends on the cover material and cover colour. When the surface water is shaded by suspended covers, the net radiation balance equation becomes:

$$Q^{*}{}_{cover} = K\downarrow_{cover} + L\downarrow_{cover} - L\uparrow_{cover} = \beta_{ts}K\downarrow + \beta_{tl}L\downarrow - \beta_{rl}L\uparrow \tag{2}$$

where: β_{ts} is the short-wave radiation transmission ratio through the suspended cover; β_{tl} is the long-wave radiation transmission ratio through the suspended cover; β_{tr} is the long-wave radiation reflected ratio by the suspended cover; $K\downarrow$ and $L\downarrow$ are incoming short-wave and long-wave radiation; and $L\uparrow$ is the outgoing long-wave radiation from the water body.

The wind speed, U_{10} is reduced by (Martínez Álvarez *et al.*, 2006):

$$U_{10}^{cover} = 0.086\frac{\ln(2/z_o)}{\ln(0.15/z_o)}U_{10} \tag{3}$$

where: U_{10}^{cover} is the equivalent wind speed at 10 m height with a suspended cover; and U_{10} is the wind speed at 10 m height without a suspended cover.

Equation (3) is derived from the measured wind speed data with shade covers presented in Martínez Álvarez *et al.* (2006). The wind speed is then converted to different heights as required by the model (Condie and Webster, 1997):

$$U_{0.15}^{cover} = 0.086 \cdot U_2 \tag{4}$$

$$U_h = \frac{u^*}{\kappa}\ln(\frac{h}{z_o}) \tag{5}$$

where $U_{0.15}^{cover}$ is the wind speed at a height of 0.15 m after using covers. The reduced wind due to the suspended cover affects the aerodynamic resistance to evaporative mass transfer.

Floating Sheet Covers

Floating sheets were chosen as the non-porous floating covers in this study. The radiation balance for these floating sheets was calculated as follows:

$$Q^{*}{}_{cover} = K\downarrow_{cover} + L\downarrow_{cover} - L\uparrow_{cover} = \beta_{as}K\downarrow + \beta_{al}L\downarrow - L\uparrow - Q_A \tag{6}$$

where: β_{as} is the short-wave absorption ratio of the floating sheets; β_{al} is the long-wave absorption ratio of the floating sheets; and Q_A is the sensible heat transfer from the surface to the air.

The surface temperature due to the floating cover and the sensible heat transfer, Q_A is estimated using (Cooley, 1970):

$$T_s = \left[\frac{\beta_{as}}{\beta_{al}} \frac{K\downarrow}{\sigma} + \frac{L\downarrow}{\sigma} \right]^{\frac{1}{4}}$$

$$Q_A = \frac{\rho_a c_a \kappa^2 U_z (T_s - T_a)}{[\ln(z/z_0)]^2}, \tag{7}$$

where σ is the Stefan-Boltzman constant for blackbody radiation.

To assess the effectiveness of the floating covers the annual evaporation according to different levels of coverage was calculated by the expression:

$$E = (1 - x) \cdot E_{base} + x \cdot E_{\mathrm{cover}} \tag{8}$$

where: E is the daily evaporation; x is the fraction of covered area, ranging from 0 to 1; E_{base} is the daily evaporation without the use of covers; and E_{cover} is the daily evaporation with 100% coverage.

With both types of cover, the water advection between the covered and uncovered area due to the thermal difference caused by different levels of solar energy input and the cooling effect of wind was assumed to be negligible.

6. DESKTOP MODELLING RESULTS

The modelled evaporation data compared to the measured data is shown in Figure 3. In August and September the model provided a larger estimate of evaporation compared to the measured values. This is because no model verification was available for the winter period, when the net storage was significantly different to that in summer. The estimated annual evaporation was 1466.8 mm/y compared to the BoM measured evaporation of 1841.6 mm/y. The pan coefficient was calculated to be 0.79 which is within the range of 0.5 to 1.5 expected for a large and deep water body (Martínez Álvarez *et al.*, 2007).

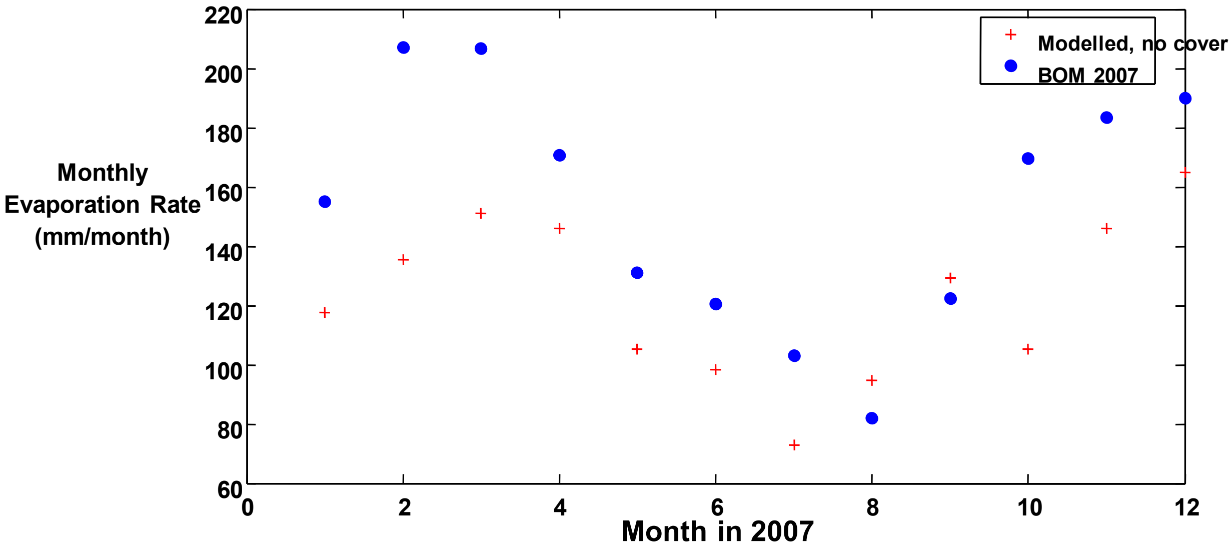

Figure 3: Monthly Measured and Modelled Evaporation Rates for Wivenhoe Dam in 2007.

Evaporation Reduction with Covers

For the suspended covers, existing black polyethylene cover optical parameters derived by Martínez Álvarez *et al.* (2006) were used in the modelling process. The comparison between the open water and suspended cover evaporation rates in 2007 are shown in Figure 4. The overall evaporation reduction rate difference occurring between the open water and the suspended covers was calculated to be 91%. Additionally, Figure 4 shows that the suspended covers provided their lowest efficiencies from May to July. Also, Table 3 shows a summary of the levels of total evaporation reduction calculated for both suspended and floating covers.

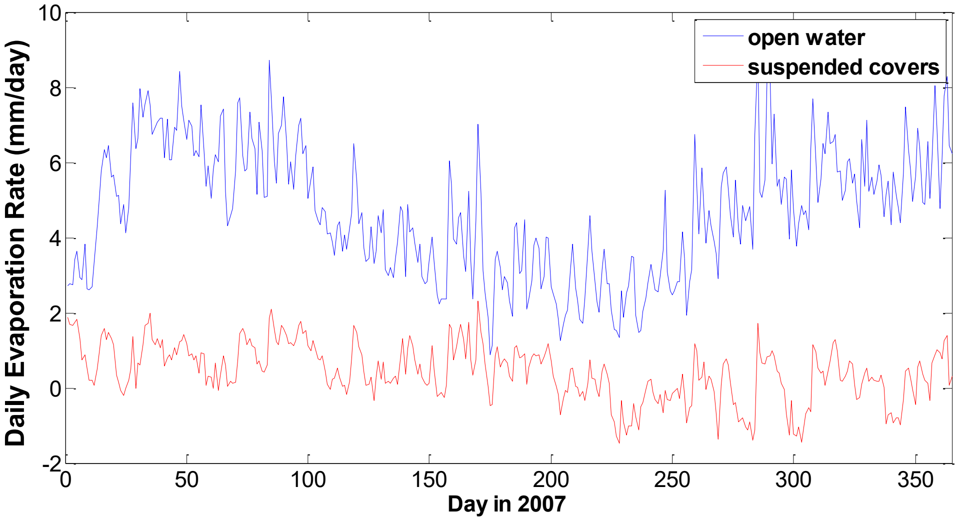

Figure 4: **Daily Evaporation Rate Comparison between Open Water and Open Water with a Suspended Cover.**

Table 3: **Summary of the Evaporation Reduction with Suspended and Floating Covers.**

	Baseline	**Suspended cover** (σt=6.4%)	**Floating sheet cover**
Annual evaporation rate (mm/y)	1466.80	153.21	0
Annual efficiency (%)	–	91	100
Evaporation reduction (mm/y)	–	1334.79	1466.80
Saved water (ML/y) *	–	41645	45764

– Not needed
* Based on a surface area for Wivenhoe Dam of 31.2km^2

The amount of evaporation reduction is dependent on the cover material. Ideal covers should have a low transmission ratio along with high reflection and absorption ratios. This relationship between total coverage and the estimated annual evaporation for two different example materials is depicted in Figure 5.

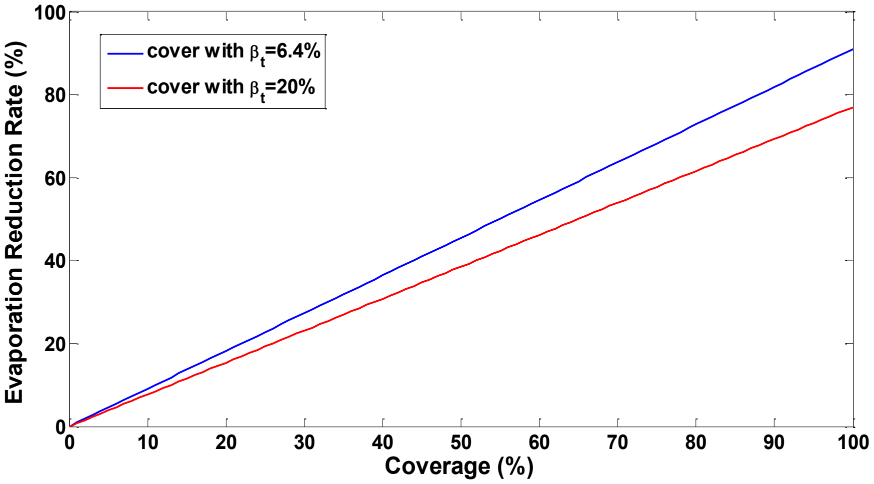

Figure 5: The Estimated Influence on Annual Evaporation by Suspended Covers on Wivenhoe Dam in 2007.

For impermeable floating sheet covers no evaporation takes place across the covered area (Cooley, 1970). Therefore, the evaporation reduction in these cases will always be 100%. Due to the large size of Wivenhoe Dam, it is more realistic to consider partial covering of the surface. However, the present model does not take into account horizontal advection and diffusion and as a result the annual evaporation decreases linearly with increasing coverage. Consequently, in future studies it will be essential to employ a 3D model to examine the effectiveness and efficiency of various covers.

Both suspended and floating covers reduce the net radiation energy and as a consequence the surface water temperature changes. Figure 6 shows the variation in water surface temperature in the open water and covered scenarios across the entirety of 2007. The water temperature measured underneath the floating covers is dependent upon the incoming radiation energy and the absorption and emittance ratios of the cover material.

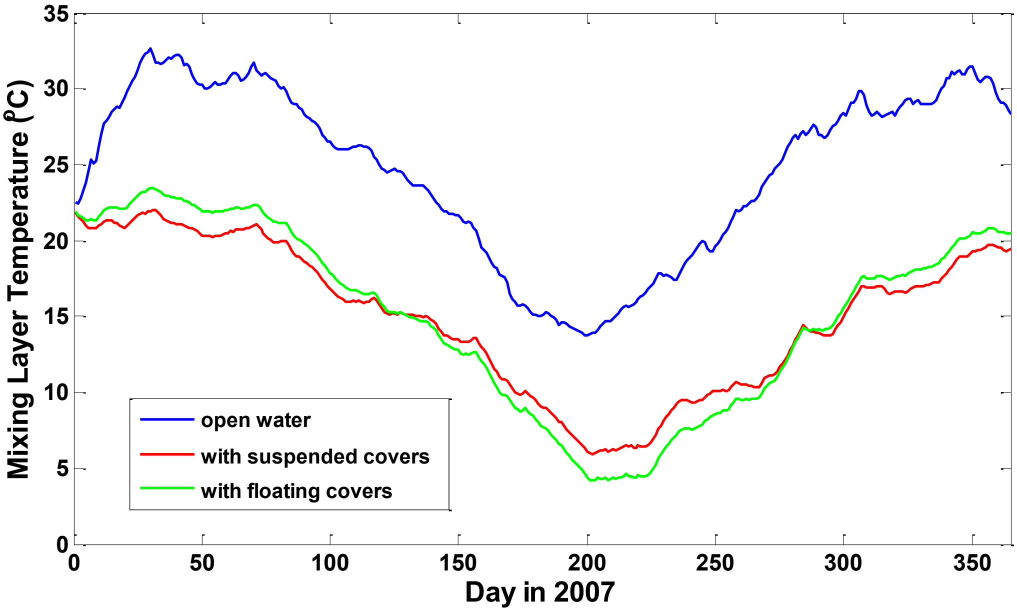

Figure 6: Surface Water Temperatures with Open Water and With Covers.

7. POTENTIAL EFFECTS ON STORAGE WATER QUALITY AND BIOLOGY

7.1. Suspended Covers

A partly or fully covered water body can cause severe deterioration of the local ecosystem. The substantial number of recreational fishing activities taking place at Wivenhoe Dam implies that it supports a relatively complex trophic web. Once sunlight is blocked, damage to primary producers is likely to occur. The elimination of the oxygen transfer from air to water (which can result from the application of covers) may lead to lower water quality, and if this occurs, a reduction in local recreational activities such as fishing. Potential economic loss requires further assessment but can only be estimated by conducting long-term investigations on covered evaporation systems and their direct influence upon water quality.

Previous studies have not adequately assessed the biological and environmental impacts that suspended covers can cause. Indeed, blocking sunlight can greatly reduce algae levels, but this benefit may be trivial when compared with other adverse impacts. As Wivenhoe Dam is the upstream source of the Brisbane River these negative impacts have the potential to affect the welfare of people living downstream. Hence, detailed biological impact studies need to be undertaken before any extensive application of suspended covers can proceed.

7.2. Floating Modular Covers

Existing floating covers do not offer 100% coverage. This allows for some sunlight to directly penetrate the water surface and for oxygen dissolution to occur within the uncovered area. However, potential impacts are still essentially similar to those from suspended covers and may depend upon the amount of free space between the modules. However, this is difficult to predict without further field studies.

Additionally, as floating covers are in direct contact with the water, the progressive leaching of chemicals from the cover material into water could become a water quality issue. However, the materials currently used in floating covers (UPVC and HDPE) have a long history being used as water supply pipelines. AquaCap^{TM} and AquaArmour^{TM} are constructed of polypropylene and high density polyethylene which both conform to food grade standards (Baldwin, 2010). So this is unlikely to cause problems. According to Australian Standard AS4020 "Testing of products for use in contact with drinking water", any material in contact with potable water should be tested to ensure no reduction in water quality will occur. It should be noted that according to their manufacturers these covers are not harmful to the environment.

8. COST EFFICIENCY

Taking into account an estimated life span of 10 years for each cover type the cost efficiency in using the covers was estimated. These results are displayed in Table 4. Compared with a monolayer (McJannet *et al.,* 2008b), E-VapCap and NetPro were about half the price to apply for a 10 year period.

The price per ten-year cycle shown in Table 4 includes only the cost of the initial installation and does not allow for regular maintenance and replacement costs due to damage. The costs also do not cover the mechanisms used to anchor these products on the site. Traditionally, they have been allowed to float freely on the water surface, but in large storages they will need to be controlled. As no studies have investigated suitable controlling mechanisms (Baldwin, 2010), the pricing for this operation remains unknown. Furthermore, fences may be required to prevent tampering and vandalism by humans and access by land animals to the top of the covers.

Table 4: Cost Efficiency of the Different Covers for Saving Water Assuming a Surface Area of 31.2km^2 for Wivenhoe Dam taking into Account Different Life Spans for Each of the Covers (see Table 1).

Product	Efficiency	Water saved annually (ML)	Cost ($) per year - based on life span**	Cost ($) per kL water saved
AquaCap*	73%	33407	58,344,000	1.75
E-VapCap*	90%	41187	12,480,000	0.30
NetPro*	70%	32034	16,640,000	0.52
SuperSpan*	90%	41187	46,800,000	1.14

*Cost does not include anchoring structures and annual maintenance
** NB: The unit price for AquaCap is $18.7/m^2 (or $22/cap) and have a life span of 10 years, while SuperSpan has a price of $30/m^2 and have a life span of 20 years.

The location of the covers also plays an important role in evaporation reduction, as they influence the hydrodynamic and thermodynamic conditions in the dam. This cannot be fully resolved until full 3D hydrodynamic reservoir models are developed and enough information is gathered to validate the application of floating or suspended hard covers. The cost for anchoring and controlling the location of the units is also an unknown factor at this stage.

9. SOCIAL IMPACTS

For safety reasons, it will be necessary to restrict all public access to covered sections within water bodies, which will reduce the number of available boating and fishing areas. The aesthetic value of a water body may be reduced after the installation of a cover, but with appropriate positive publicity it is likely the public will accept their use. Other social impacts, including potential reduction in water quality and the cost of installation and maintenance, must also be considered if the covers are to be installed. Presently, there is no legislation that specifically prohibits the use of floating covers on gated or non gated dams. The use of suspended or floating covers would generally increase the risk to dam safety for gated dams, due to the possibility that the covers could detach from their initial position and catch in the dam gates. Baldwin (2010) conducted an assessment of floating hard covers on large water storages within SEQ. This is particularly pertinent to flood situations, where dam gates must be fully operational. Therefore, significant studies are required to evaluate:

1. mechanisms to ensure the covers can be maintained/contained in areas away from dam gates and spillways;
2. deployment arrangements for the covers that ensures they maintain their structural integrity. For example, making sure that floating covers do not pile up on each other which would create a safety concern and loss of evaporation reduction effectiveness; and
3. maintenance strategies that minimise risk to the operators.

10. FACTORS AFFECTING EFFICIENCY AND APPLICABILITY

- Structure material, shape and colour.
- Variations in meteorological parameters such as incoming solar radiation and wind speed.
- Water depth, especially for shallow reservoirs where solar radiation is able to penetrate down to the bed. Covers will reduce this impact, but at this point in time the influence is unknown.

- Water quality impacts resulting from the use of hard covers are unknown, thus limiting their applicability for covering large storage areas. It is expected that the water quality for smaller covered areas will be less influenced by surface covers, but this needs to be determined.

- Gases (such as methane) trapped within the water following the application of the surface covers may have a negative impact upon the health of aquatic organisms and also may degrade water quality.

- How both the suspended and floating covers respond to atmospheric stressors such as ultraviolet radiation over a long time period. This has to be investigated in order to fully quantify the environmental conditions in which the floating covers will be most useful.

- The covers are relatively expensive and thus initial outlays are high, despite the fact that they do have significant water saving potential.

11. SUGGESTIONS FOR FURTHER RESEARCH

This study has employed a 2D model to estimate evaporation rates on Wivenhoe Dam. The effectiveness of suspended and floating covers in facilitating evaporation reduction has also been modelled and evaluated. More accurate assumptions and knowledge are required if highly precise evaporation reduction calculations are to be made using modelling techniques in the future.

The water temperature under and above covers is different due to the different amounts of solar energy received and the cooling effect of wind. The water advection driven by the thermal gradient was not included in the model used for this report. It is suggested this 2D model can be further developed into a full 3D model to account for horizontal temperature differences, which will ensure evaporation rates are better estimated. Alternatively, industry standard 3D models could be used and modified to include floating structures such as floating and suspended covers. However, there is still a great deal to be learnt about the exact nature and properties of hard covers which will limit the accuracy of the 3D model outputs. Therefore, knowledge gaps must be filled and appropriate mathematical relationships developed;

Errors in the modelling of the water surface temperature will certainly result from data being measured at different locations across a water body. Thus, data consistently measured in one location is required to ensure complete accuracy.

The physical properties of the various products require significant testing. The parameters that require detailed knowledge development include:

- Solar radiation and wind reduction levels;
- Permeability;
- Thermodynamic processes under the covers. This will be particularly important for floating covers as they are in constant contact with water and serve as heat-conducting media;
- Water quality impacts;
- Structural integrity over time; and
- Anchoring mechanisms.

Cover location and the area covered should be studied as the covers may cause a decrease in water quality and the health of aquatic life. Accordingly, long-term studies (> 1 year) on large water bodies (> 1 km^2) are recommended.

The system by which the covers can be anchored requires significant investigation. This will require input from dam operators, experienced engineers and the manufacturers who possess detailed knowledge of their own products.

It is assumed that the floating modules will be easier to deploy across dams in comparison to the suspended covers as they can just be thrown over the side of a boat or from the shore line. At this stage it is unclear how to best extract them from a large water body and how to relocate them if they are displaced after severe weather. Further investigations need to be carried out in order to answer this question.

12. KEY MESSAGES

- Suspended and floating covers have great potential in reducing evaporation through the reduction of energy input.
- The variety of solid covers continues to grow as new manufacturers enter the market. Each product will require an individual study in order to fully determine its performance capability and suitability for large dams.
- The ease of installation, structural integrity and efficiency of the suspended and floating covers will most probably be reduced significantly with increases in wave and wind action at the water surface.
- It is assumed that the difficulty of installing both suspended and floating covers will escalate with an increase in water surface area.
- The installation of suspended covers may be difficult on top of large reservoirs, whereas floating covers are easier to install, maintain and retrieve due to their modular design.
- The results from the modelling show that if Wivenhoe Dam is fully covered, the annual efficiency of evaporation reduction reaches 76% for suspended covers and 68% for floating covers. If there is only partial coverage the efficiency changes linearly from zero to full coverage.
- The evaporation model should be extended into 3D for more accurate assessment of evaporation-reducing techniques.
- The efficiency of both covering methods is subject to strong seasonal variation with maximum efficiencies occurring in summer and minimum efficiencies occurring in winter.
- The biological impact of these covers on the aquatic ecosystem in large reservoirs is unknown and further studies are essential. It needs to be known how these covers influence gas transfer rates and how induced fluctuations in solar radiation levels influence underwater biological and chemical activity.
- The covers are relatively expensive and thus initial outlays are high, despite the fact that they do have significant water saving potential. For example, AquaCapTM costs $18.7/m2 or $18.7 million per km2 (Baldwin 2010): to completely cover the surface area of Wivenhoe Dam (31.2 km2) would cost approximately $58.3 million per year, assuming a ten-year life cycle of the product.
- This report finds that, for the cost per unit water saved, ‘bubble-wrap’ floating sheet type covers and suspended impermeable covers ($0.30 to $0.52 per kL) cost less than suspended permeable (shade cloth) covers or floating modules ($1.14 to $1.75 per kL).
- Safe deployment and operation is a concern that must be fully addressed before covers can be applied to reservoirs. Further research must investigate the possibility that the covers could block a dam gate or spillway.
- The floating modules may clog spillways and pipelines attached to dams. However, this is dependent upon the material that the floating module is made out of. If a floating module is made from softer, more pliable materials they may pass through and/or break up and not cause any blockages.
- Public perception and safety are other issues that require further consideration.

APPENDIX 1 - SUMMARY OF CURRENTLY AVAILABLE EVAPORATION-REDUCING COVER SYSTEMS

(Note: This list is not exhaustive and should be used as a guide only)

Structure Type	Brand	Manufacturer	www reference site (if applicable)
Floating Modular and 'Bubble Wrap Type' Systems	Raftex	F Cubed Australia	http://www.fcubed.com.au/pdf/RAFTEX-InfoSheet.pdf
	BirdBalls	Environmental Controls Company (USA)	http://www.eccllc.us/
	AquaCap	Nylex, Royal Melbourne Institute of Technology	http://www.aquacap.com.au/specs.asp
	Water Innovations Modular Covers	Water Innovations	http://www.waterinnovations.com.au/
	LemTec Insulated Covers	Lemna Technologies (USA)	http://www.lemnatechnologies.com/supportpages/products/index.htm
	REVOC – Insulated Covers	Layfield (USA)	http://www.layfieldgroup.com/splash.cfm
	HexDome	Indusium	NA
	MOD-E-VAP	Merit Lining Systems	http://www.merit-linings.com.au/
	Polynet	Designed by Ken Gordon, Tel/Fax: (02) 6847 1381 (NSW)	NA
	AquaArmour	AQUA Guardian Group	http://www.aquaguardiangroup.com/ag/index.cfm?pageID=147 And http://www.aquaguardiangroup.com/ag/uploads/AquaGuardian_ProductOverviewJuly2008.pdf
	QUIT Evap	SMEC Australia	Peter.Chapman@smec.com.au
Floating Sheets	E-VapCap	Evaporation Control Systems	http://www.evaporationcontrol.com.au/
	Aquaguard	Fabric Solutions International	http://www.fabricsolutions.com.au/evaporative_covers.htm
	REVOC - Hypalon	Layfield (USA)	http://www.layfieldgroup.com/splash.cfm
	Evap-Mat	DeVere Mining Technologies	http://www.deveremining.com/final-web-pages/dam-cover.html
	Fabtech	Fabtech	http://www.fabtech.com.au/
	RTD Enterprises	RTD Enterprises	http://www.rtd-enterprises.com/index.html
	Enviro Dam Covers	Dam Covers Now	http://www.damcoversnow.com.au/news.php#
Suspended Permeable Sheets	NetPro	NetPro Protective Canopies	http://www.netprocanopies.com
	Aquaspan	Aquaspan (UK)	NA
	MuzCov	Designed at the Dalby Agricultural College	NA
	NICOSUN®	Tencate	http://www.tencate.com.au/wawcs0136912/anti-evaporation_covers.html
	Superspan	TechSpan	http://www.superspan.com.au/water.html

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