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REDUCTION OF EVAPORATION FROM FARM DAMS

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EXECUTIVE SUMMARY

Evaporation reduction from farm dams in Australia is regarded as one of the few areas where there are real water savings to be made. At this stage, there are a number of commercial evaporation reduction systems available that use either a hard or polymer cover. Currently these systems are deemed to be viable (M. Durack *pers. comm.*, 2004) for high value crops such as table grapes but are generally not financially viable for lower value crops such as sorghum or cotton. The Department of Natural Resources and Mines, Queensland (NR&M) has invested $650,000 to test a number of evaporation systems. There is likely to be other private and public research occurring.

The Sustainable Irrigation Program requested the following question be scoped:

> ***Are there any areas of research that Sustainable Irrigation can invest in that will provide a quantum leap in the development and introduction of systems that will reduce evaporation by at least 80% that are affordable for medium value commodities such as cotton and grains crops?***

Other review work has been done on reduction of evaporation losses from on-farm storages such as Brown (1988), Sainty and Associates (1995), NR&M (2002), GHD (2003) and the current NCEA project. While there is a reasonable theoretical understanding of evaporation in the published literature and a general agreement that evaporation is one of the largest water losses facing farmers and water authorities, the practical implementation of evaporation reduction techniques is sporadic and minimal. This report reviews the previous studies and extends recommendations beyond evaporation reduction systems only.

In principle, systems that reduce evaporation from farm dams need to:

- Reduce the amount of energy available to cause evaporation,
- Restrict the boundary layer at the water surface, or
- Modify the wind and humidity above the water surface.

The types of systems that have been tested in the past include:

- Systems that limit solar energy input such as shade cloth, floating modular units or complete roofing.
- Systems that restrict the water-surface boundary layer such as chemical monolayers.
- Systems that alter the wind speed across the surface of the farm dam such as windbreaks or shade covers.
- Systems that limit the exposed surface area of the water such as making dams deeper or confining water in cells.

There are a limited number of commercially available systems for Australian farmers to choose from.

In the past, there have been several reviews of evaporation reduction systems as mentioned above. Currently, there is only one significant research project underway in Australia. This is being undertaken at the National Centre for Engineering in Agriculture (NCEA) in Toowoomba.

The following are our conclusions regarding different evaporation reduction systems.

1. Monolayers have a long history and, despite many attempts, have not been shown to be viable and effective in the long term (Brown 1988). Schmidt (*pers. comm.* 2005) suggests that their evaporation reduction efficiency varies from 0% to 40% but the reasons for this variability are, as yet, unknown. However, monolayers may be the only solution for dams with a large surface area.
2. Emergent or floating vegetation does not offer an effective solution.
3. Various floating, modular devices are effective (60% to 90% reduction) and offer viable solutions in some circumstances. However, there are cost and practical issues.
4. Complete (air-tight) surface covers are expensive and pose significant practical problems for larger dams.
5. Shade cloth is probably the best-bet option at this stage. It provides a significant evaporation reduction (70%) and is not reliant on a 'perfect' seal over the dam surface. Rainfall can easily enter the dam. If further practical design work can reduce capital costs, then shade cloth covers will become viable in an increasing number of situations.

It is our view that, for small to medium sized dams, the best-bet evaporation reduction systems for further research and industry adoption are either shade cloth-type coverage systems or floating modular covers. For large dams, monolayers may be the only viable solution but their performance has been very variable in recent studies. It is recommended that, before further publicly-funded research is undertaken into monolayers, a detailed literature review of the work that has been undertaken in the past 50 years be completed. Lessons learnt from this review should be analysed before designing and conducting further field-scale research.

It is impossible at this stage to estimate the Australia-wide benefit of the adoption of evaporation reduction technologies on farm dams. This is because:

1. Most State agencies do not have good data on the number, capacity, surface area or usage of farm dams in their states. Hence, it is simply not possible to quantify the magnitude of the annual evaporation loss from farm dams.
2. We can find no long-term, good-quality measurements of evaporation losses from farm dams. Current estimates of evaporation from farm dams is based on Class 'A' pan evaporation or Penman-type formulae. The accuracy of both estimates is questionable. No evaporation estimation models with a sound theoretical basis exist for farm dams in Australia. Hence, it is not possible to estimate evaporation losses accurately.
3. Without either the number of farm dams nor an accurate estimate of the current evaporation loss, the benefit of evaporation reduction systems, in terms of GL saved, cannot be quantified.

It is recommended that both these data deficiencies (number of farm dams and good-quality evaporation measurements) be addressed.

Our rough estimate of evaporation from farm dams in the Queensland section of the Murray Darling Basin alone is 7,040 GL/yr. While there is considerable error with this estimate, it indicates that considerable water savings must be possible.

It is recommended that the PST technology, developed by NCEA to directly measure evaporation (and seepage) from farm dams, be further developed and implemented to collect good-quality evaporation (and seepage) data. Models need to be developed to accurately estimate evaporation from farm dams.

It is generally agreed that evaporation reduction systems are already economically viable for some crops in high evaporation areas. However, the extent of wider applicability is unknown. It is recommended that a simple economic assessment tool be developed to allow farmers to make assessments of the economic viability of evaporation reduction systems for their own situations.

For several reasons, it is recommended that further research on evaporation reduction be limited to farm dams, rather than larger storages administered by water authorities.

It is recommended that an Australian Standard be developed for automatic weather stations used to calculate evaporation. Siting, design, calibration and calculation formulae should be standardised.

1. INTRODUCTION

Evaporation reduction from farm dams in Australia is regarded as one of the few areas where there are real water savings to be made. At this stage, there are a number of commercial evaporation reduction systems available that use either a hard or polymer cover. Currently these systems are deemed to be viable (M. Durack *pers. comm.*, 2004) for high value crops such as table grapes but are generally not financially viable for lower value crops such as sorghum or cotton. The Department of Natural Resources and Mines, Queensland (NR&M) has invested $650,000 to test a number of evaporation systems. There is likely to be other private and public research occurring.

The Sustainable Irrigation Program requested the following question be scoped:

> ***Are there any areas of research that Sustainable Irrigation can invest in that will provide a quantum leap in the development and introduction of systems that will reduce evaporation by at least 80% that are affordable for medium value commodities such as cotton and grains crops?***

Other review-type work has been done on reduction of evaporation losses from on-farm storages such as Brown (1988), Sainty and Associates (1995), NR&M (2002), GHD (2003) and a current NCEA project. While there is a reasonable theoretical understanding of evaporation in the published literature and a general agreement that evaporation is one of the largest water losses facing farmers and water authorities, the practical implementation of evaporation reduction techniques is sporadic and minimal. This report reviews the previous studies and extends R&D recommendations beyond evaporation reduction systems only. In part, this study reviews the current evaporation control technologies and discusses the reasons behind the poor level of technology adoption.

2. NCEA ACKNOWLEDGEMENT

At present, the only significant work being done in Australia on evaporation reduction from farm dams is that being done by the National Centre for Engineering in Agriculture (NCEA). NR&M in Queensland funded their work. The final report is due in April 2005 and, as such, their final conclusions have not yet been published. However, they have provided generalised preliminary results and supporting information for this study. FSA Consulting would like to acknowledge the assistance of Erik Schmidt and Ian Craig from NCEA in preparing this report.

3. GLOSSARY / DEFINITIONS

All of the following terms have the units of mm/day.

E_a	Actual Evaporation from any surface
E_{OW}	Gross Evaporation from an open-water surface
E_{NOW}	Net Evaporation from an open-water surface after compensation for precipitation
E_{ROW}	Reduced Evaporation from an open-water surface after effect of evaporation control device (reduction of E_{OW})
ET_O	Reference Crop Evaporation (FAO 56)
E_P	Class 'A' Pan Evaporation
P	Precipitation

Other terms

AWS	automatic weather station
Evaporation Reduction Efficiency (%)	$(E_{OW} - E_{ROW}) / E_{OW}$
K_{OW}	Open Water Pan Coefficient (E_{OW} / E_P)
K_P	Crop Pan Coefficient
a	albedo (short-wave reflectivity of the ground or water surface)
Gigalitre (GL)	1,000 megalitres, or 1×10^9 litres
Megalitre (ML)	1,000 kilolitres, or 1 million litres or 1000 m^3
Ring Tank	Name given to farm dams constructed above ground level. Not always circular as the name suggests

4. PRINCIPLES OF FARM DAM EVAPORATION REDUCTION

4.1. Evaporation – The Basics

In the context of this report, evaporation is the net transfer of water, from a liquid state in a dam, to a gaseous state in the atmosphere above and away from the dam. It is usually expressed as a loss in millimetres of water but can be expressed as an energy loss (W/m^2). For this to occur, three conditions must be met.

1. There must be a source of **ENERGY** to provide latent heat of vaporisation to convert water in a liquid phase to water in a gaseous phase.
2. There must be a free **SURFACE LAYER** through which the vapour molecules can move.
3. There must be a suitable **AIR MOVEMENT** above the water surface to transfer the water vapour away from the dam.

It is using an understanding of the three basic factors that all evaporation reduction systems are based.

4.2. Energy Source Reduction

The most common energy source for evaporation from farm dams is the sun – solar energy. Other energy sources include sensible heat advected horizontally from surrounding hot, dry areas over the evaporating water surface and thermal energy stored in the water body itself.

Hence, limiting available energy sources can reduce evaporation. The most common method is to shade the surface of the water thus reducing the solar energy input. Solid shading (roofing) has been used. Also, shade cloth suspended above the surface of the water or solid objects floating on the water have been used to limit incoming energy.

Where advected energy from surrounding hot, dry surfaces contributes to evaporation, the solution is to prevent the wind blowing across the water surface of the dam. Little can be done to influence the thermal mass of the water body itself.

Hence, while solar radiation is the primary energy source for evaporation, there are other sources. Thus, evaporation – at a reduced rate – can occur from a farm dam at night.

4.3. Boundary Layer Control

For evaporation to occur, water molecules must pass through the surface of the water and enter the atmosphere. Hence, any system that restricts the transfer of water molecules through the surface layer or limits the size of the surface area will reduce evaporation.

Surface layer restrictions can range from complete seals such as plastic covers to partial restrictions such as caused by chemicals being placed over the surface of the dam.

Surface area restriction is usually achieved by making a given storage deeper or by partitioning the dam into segments and confining the available water to particular segments. Surface area restriction could be achieved by partial covering of a dam.

4.4. Air Movement Control

Given an adequate source of energy and an unrestricted surface layer, the rate of evaporation from a dam surface (*E_a*) is determined by a function of wind speed (u) and air humidity (vapour pressure deficit, saturated vapour pressure (e_s) less actual vapour pressure (e_a)) above the water surface. This is expressed through Dalton's Equation.

$$E_a = f(u)(e_s - e_a)$$ **EQUATION 1**

Hence, to restrict evaporation, air movement (wind speed) should be reduced or vapour deficit minimised.

Wind speed across the water surface of a dam can be reduced by suspending shade cloth or similar over the water surface or by placing floating objects on the surface. Wind speed can also be decreased by surrounding the water surface with a windbreak (e.g. tall trees or high embankments) or by planting tall emergent vegetation in a dam.

Little can be done to control humidity levels in the air above the dam surface.

4.5. Combined Systems

Many systems use a combination of the three factors listed above to achieve a reduction in evaporation.

These include the division of storages into cells. When the storage is not full, the water can be moved into particular cells such that a greater depth is maintained, hence reducing the surface area available to absorb energy and evaporate. The lower surface area also reduces the area available for air movement, removing vaporised water from the dam surface. The additional embankments in the storage also disrupt the airflow over the water surface, reducing wind speed. The use of cells within storages also lends itself to the partial use of covers. For instance, if a particular storage is split into four cells, then possibly one or two of the cells could have a cover installed (i.e. shade cloth or plastic covers). This reduces the initial cost of covering the storage, and provides the greatest reduction in evaporation loss when the water is needed most (when water stored is less than half of capacity). Similarly, the suspension of shade cloth over a water surface serves two purposes. Firstly, the shading effect reduces the amount of energy entering the water body. However, if the shade cloth is suspended above the water surface, a zone of low wind speed and high humidity is created, thus further reducing evaporation rates.

Also, monolayers have been used in conjunction with floating modules (Brown, 1988) to obtain a combined evaporation reduction effect.

5. Water Balance of Farm Dams

Figure 1 shows a schematic diagram of the water balance of a farm dam. Evaporation is only one of several water inputs and outputs and, on a daily basis, is generally a small amount of water. Hence, the direct measurement of evaporation is notoriously difficult as all other inputs and outputs must be measured very accurately. Also, any evaporation reduction device must be designed to allow the other water transfers to occur without restriction.

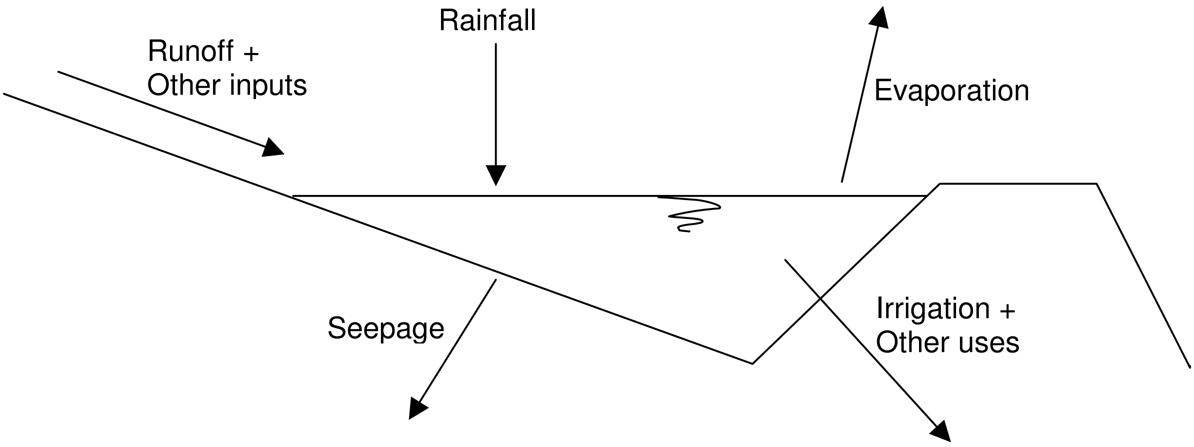


Figure 1 – Schematic Water Balance of a Farm Dam

5.1. Rainfall

Just as evaporation is a loss from a dam, rainfall on the water surface is a water gain. When describing or modelling evaporation from dams, most hydrologists refer to net evaporation loss being gross evaporation loss less gain from rainfall. That is,

Net Evaporation (E_{NOW}) = Gross Evaporation (E_{OW}) – Rainfall (P)   Equation 2

However, most evaporation reduction systems allow rainfall to enter the dam. This should be regarded as an essential design feature of any evaporation reduction system. Hence, when discussing the effectiveness of evaporation reduction systems, it is assumed that all rainfall enters the dam and that the evaporation reduction efficiency is the percentage reduction in gross evaporation, not net evaporation.

5.2. Seepage

Seepage is the loss of water from a dam through deep drainage through the bed and sides of the dam. Seepage is a very difficult parameter to measure directly but in some instances can be of the same order of magnitude as evaporation. Hence, uncertainties in the quantification of seepage can lead to a misleading estimation of actual evaporation loss. This could underestimate the effectiveness of evaporation reduction systems.

6. Practical Methods of Evaporation Reduction

There are several practical methods of evaporation reduction that have been tried. These will be discussed below in light of the preceding theoretical discussion.

6.1. Shade Cloth / Roofing

One practical method of evaporation reduction is to suspend shade cloth over the surface of a dam or even to build a conventional roof. This method does not attempt to form an airtight seal but rather to alter the micrometeorological conditions above the water surface so that evaporation rates are reduced. The net radiation flux (R_n) retained by the water below the shade cloth is substantially reduced compared to an unshaded dam (see Figure 2). Also, a zone of still air (low wind speed) is created above the water surface further reducing evaporation rates.

Two advantages of this system are that rainfall can freely permeate through the shade cloth (but not a solid roof) and that a perfect, airtight seal is not required. However, the practical problem of keeping the shade cloth in suspension above the water surface must be solved. Fluctuating water levels, storm damage and UV degradation of the shade cloth need to be addressed. There is also probably a maximum surface width that can be practically spanned by such a system if suspended from the side banks of the dam.

The cost of installation of wide-span shade cloth structures can be high. Shade cloth has the potential to have high evaporation reduction capacity and it also has the ability to allow rain into the storage. However, there are some practical issues with installing shade cloth on large storages.

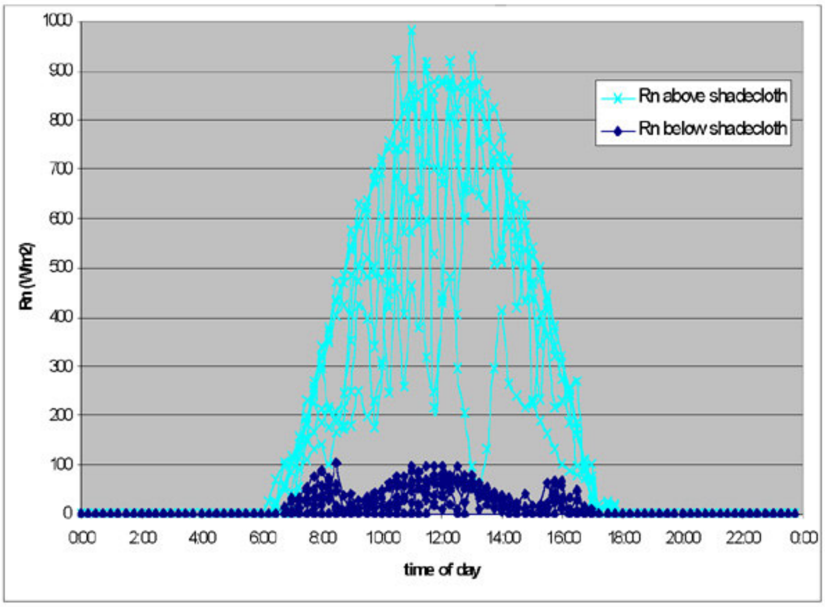


Figure 2 – Reduction of Net Radiation under Shade Cloth

(Courtesy of NCEA, www.ncea.org.au/index.htm)

6.2. Monolayers

Monolayers are not a new technology and have been in existence for more than 50 years. They usually consist of a fatty alcohol that is applied to the water surface and forms an invisible layer one molecule thick that retards evaporation. Various figures quoted indicate an evaporation saving of between 20% and 55% (37% in Section 8.4.1). The monolayer is biodegradable and requires re-application every few days.

Brown (1988) in his review of evaporation reduction systems states that monolayers were trialled in Australia as far back as the 1950's and that there is a substantial body of research data available. Brown (1988) cites review work done by Frenkiel (1965) who cited 240 other references on monolayers.

Monolayers have no effect on the energy balance of the water storage nor do they affect wind speed above the water surface. Their only mechanism for evaporation reduction is to restrict the free transfer of water molecules through the boundary layer.

The cost of one monolayer application is low but the monolayers must be regularly replaced. The effectiveness of the monolayer is affected by wind and the chemical could be lost if a dam overflows. Monolayers can conform to any surface shape and are therefore applicable to a wider range of storages that some other methods. They are also one of the few methods that can cover very large storages. There are issues – perceived or real – regarding the effects of the monolayer chemical on water quality.

Monolayers can have very varied evaporation reduction results. In some cases, they work well and others they seem to have very little effect. An advantage of monolayers is that they need only to be applied when there is water in the storage (or even only when nearly full) and due to the nature of farm water storages, there can be extended periods of no water when covers are not necessary. Similarly, they can only be applied in summer months when evaporation rates are high. This can reduce their net cost per ML saved.

6.3. Modular Floating Covers

Modular floating covers are those systems that consist of individual floating modules or sections on the surface of the dam. These modules can be free floating or attached to each other by some form of fastener. The modular system can offer significant advantages as the shape of the storage is irrelevant and intrusions and obstructions within the dam can be easily accommodated. The width of the dam is also less relevant provided that the modules are not blown to one side of the dam. Rainfall can freely drain off the modules and enter the dam. There is also the potential to gradually cover a surface by only purchasing and installing a smaller amount of modules at a time over an extended period. Unfortunately the range of commercially available modular covers is extremely limited at this point in time.

Modular covers do not attempt to provide a complete seal over the water surface. They restrict air movement by a combination of reducing the area of free water exposed and by lowering the effective wind speed over the exposed water. Depending on the colour, material type and thickness of the modules (albedo), the energy input to the water body should be reduced. The cost of modular covers can be high. Brown (1988) gives a good review of the different types of materials used and their effectiveness. A disadvantage is that they must be removed from a dam before it runs dry or the modules can get, literally, stuck in the mud. Also modular covers in some instances may get wet and the film of water on the surface of the module will evaporate, reducing the effectiveness of the module cover.

Floating modular covers are effective and practical. However the limited commercial availability (and corresponding high cost) limits their applicability to farm dams. As their availability and use increases (and cost decreases), they can and will be a very effective means of evaporation mitigation. The ability to purchase floating modular covers in stages is also an advantage.

6.4. Complete Surface Covers

Systems currently exist where a complete airtight seal is achieved over a water storage. These covers are generally installed over waste treatment ponds and are intended to capture odour or methane (for later use). In this application, a complete seal is essential and it is usual to exclude rainfall. In the context of the previous theoretical discussion, these systems work by creating a complete seal on the surface boundary layer.

When applied to farm dams, these systems have two disadvantages. Firstly, they are expensive. Secondly, the design requirement to allow rainfall to enter becomes a contradictory design requirement to have a complete seal.

Complete surface covers are very effective means of mitigating evaporation, with reductions of up to 100% possible. However, allowing rainfall to enter generally compromises their effectiveness and may allow water to move on top of the cover, increasing evaporation rates beyond what would have been encountered had the cover not been there in the first place. These systems can also be effective at limiting algal growth. However the lack of oxygen transfer can be detrimental to water quality.

6.5. Storage Design and Management

It is often stated that up to 50% of the stored water in ring tanks can be lost to evaporation (e.g. Sainty and Associates, 1995). There have been very few, if any, good-quality studies that have measured actual evaporation losses from ring tanks so this statement is generally the opinion of cotton farmers who observe large declines in their storages due hot, dry weather. Their opinion, that evaporation constitutes a 50% loss of their stored water, is supported by the knowledge that their dam is 4 m deep and that local evaporation is 2000 mm (2 m) per year.

Not surprisingly, in response to losses of this magnitude, cotton growers have looked for innovative storage designs that can reduce water loss by evaporation considerably. The usual method is to reduce the exposed surface area. Increasing the height of storage embankments can increase the stored volume to surface area ratio (by reducing the surface area), reducing the relative evaporative loss. This is a viable option for existing storages, as it requires no ‘new’ land in order to increase storage capacity. For new storages, higher embankments mean that not as much land is lost to construction of the storage. However, the cost of construction increases rapidly with increasing embankment height (Sainty & Associates, 1995, NR&M, 2002).

Splitting a storage into cells also achieves a similar result, as greater depths of water can be maintained with varying volumes of water stored (NR&M, 2002). Building dividing embankments through the storage splits the storage, and infrastructure allowing water transfer between the cells is installed. Essentially water is drawn from one cell at a time, until it is empty, at which point water is drawn from another cell. This maintains the maximum depth of water in all cells but the one in use, maximising the stored volume to surface area ratio. However, this system has additional operational costs (labour, energy) and is only effective if each cell is completely empty. A shallow layer of water in the base of a cell will lose as much evaporation as if it was half full.

Management can also reduce losses to evaporation and seepage. Emptying supply channels, sumps, head ditches and tail drains back into the major storage, after irrigation, will reduce the volume stored to surface area ratio, reducing the water loss.

However, these attempts to reduce evaporation need to be examined carefully. For example, consider a large ring tank near Dalby where the farmer is considering doubling the depth of the storage to reduce evaporation losses by half.

Mean annual pan evaporation is about 2000 mm and mean annual rainfall is about 600 mm. Assuming an open water pan coefficient, K_{OW}, (see Section 10.4) of 0.74, then the net annual evaporation loss, E_{NOW}, from the ring tank would be:

E_{NOW} = pan coefficient (K_{OW}) x pan evaporation (E_P) less rainfall (P)

= (0.74 x 2000 – 600) mm/yr

= 880 mm/yr

That is, theoretically, the net annual evaporation loss from the ring tank should be less than 1 m – not the 2 m most farmers believe. As it is not possible for a farmer to distinguish between evaporation and seepage, it is possible that this difference is annual seepage loss, which would equate to about 3 mm/day. Preliminary information from the NCEA work indicates that seepage could be of the same order of magnitude as evaporation in some circumstances.

Hence, by halving the surface area of the ring tank, net evaporation would be halved but this may not be so for seepage. The area over which seepage would occur has been reduced but the average depth of water has increased. Theoretically, seepage should increase with increased head of water. Hence, a deeper ring tank may actually have more seepage than the shallower storage. Thus, the considerable expenditure of doubling embankment height may not have been as economically viable as anticipated.

Until further research is undertaken on actual evaporation and seepage from ring tanks, care should be taken making expensive changes to ring tank configurations.

6.6. Windbreaks

In theory, windbreaks on the surface of a farm dam or constructed around the outer edges could reduce evaporation by altering the wind speed across the evaporating surface. Regarding the effectiveness of windbreaks, Sainty & Associates (1995) stated:

Condie and Webster (1995) reported on the work of Crow and Manges (1967), who discussed the effects of a windbreak in terms of the ratio of windbreak distance to windbreak height. There was minimal effect on evaporation reduction with a ratio of 50 while a ratio of 16 showed only a 9% reduction. Condie and Webster showed in their computer modelling a reduction of 20% is achieved with a wind speed of 11 km/hr at the distance/height ratio of 10 with plants orientated at 90 degrees to prevailing winds or planted in north/south rows to maximise the shade in summer. The roots of trees planted as windbreaks along embankments pose a problem to the banks themselves. However, water-tolerant trees such as Melaleuca could grow on purpose-built banks within the storage. Rows of trees at strategic spacings would not only act as windbreaks but provide shade and dampen wave action. A diagram showing the possible integration of windbreak and cell construction was included.

While theoretically rigorous, the rows of tress proposed by Condie and Webster (1995) are quite impractical (see Figure 3). Furthermore, there are several practical problems associated with planting trees in close vicinity to farm dam embankments. As their roots seek out water, they can threaten the integrity of the embankment and may even draw water out of the water storage. Furthermore, their presence in close proximity (or on) the embankment makes routine embankment access and maintenance difficult.

Given the difficulties in achieving a large windbreak height-to-dam-fetch ratio (greater than 10), it is unlikely that windbreaks will be widespread methods for evaporation reduction.

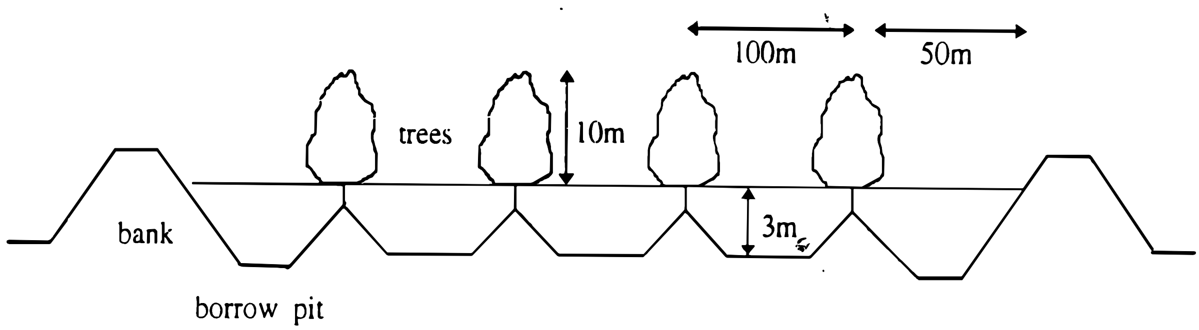


FIGURE 3 – WINDBREAK CONFIGURATION PROPOSED BY CONDIE & WEBSTER (1995)

6.7. Floating or Emergent Vegetation

It has sometimes been suggested that, if the free open water surface could be replaced by vegetation (aquatic plants), then evaporation would be reduced due to the reduced exposure of free water. This proposal ignores some basic biology and physics. Firstly, any living vegetation matter, either floating on the surface or emergent deep-rooted, will actively transpire (depending on the species) and thus water loss continues to occur. Furthermore, the enhanced surface roughness of vegetation may enhance water vapour transfer rates compared to the aerodynamically smooth water surface. Also, net radiation exchanges can be increased if the albedo of the vegetation is less than open water.

Adcock (1995) and Burston and Akbarzadeh (1995) provided data on the effectiveness of floating *Azolla filiculoides* as a means to reduce evaporation. It had no effect. However, Linacre *et al.* (1970) compared evaporation rates from a swamp with those from a nearby lake near Griffith, NSW. Despite a slightly higher surface temperature, evaporation from the swamp was, on average, one third less than from the lake. They attributed this reduction in a significant reduction of wind speed at the water surface due to the shelter provided by the reeds.

There are significant practical issues with maintenance of a vegetation cover. The vegetation must be able to cope with fluctuating water levels, predation and winds. Hence, vegetation is not regarded as a practical solution for evaporation reduction.

7. CURRENTLY AVAILABLE EVAPORATION REDUCTION PRODUCTS

There is a range of evaporation reduction products currently available. Most have been developed in Australia. There does not appear to be many products available for overseas.

7.1. E-VapCap™

The E-VapCap™ is a 'bubble-wrap' style floating cover containing buoyancy cells. It is a multi-layered, polyethylene membrane 450 microns thick. The product is UV resistant with a greater than 5 year expected life. The cover is a lightweight, impervious, black and white, polyethylene, which has a dense covering of 13mm 'bubbles', formed into its underside. These bubbles make the plastic sheet extremely buoyant and the cover floats on top of the water surface. The cover is anchored in a trench or tethered to the sides of the storage and 25mm diameter holes are drilled in various places in the cover to allow the passage of rainwater into the storage. The cover retails for around $\$8/m^2$ with a design life of approximately 15 years. The product is available through Evaporation Control Systems (http://www.evaporationcontrol.com.au/) / Darling Downs Tarpaulins (http://www.ddt.com.au/). E-VapCap™ is an all Australian Product. Manufactured by Sealed Air Corporation with Darling Downs Tarpaulins/DDT Liners being Approved Fabricators and Installers. This is one of the products being evaluated by NCEA (see Section 8.3).

PHOTOGRAPH 1 - E-VAPCAP™ AT ST GEORGE

(Photograph taken from Darling Downs Tarpaulins website)

7.2. Water$avr

Water$avr is a monolayer of C16-18 hydroxy alkane that self-spreads across the surface of reservoirs, canals and rivers one molecule thick. It is supplied by Ondeo-Nalco Flexible Solutions (http://www.flexiblesolutions.com/). Water$avr has been tested by NCEA (see Section 8.3) and in California (see Section 8.4.1). Water$avr is a powder with a stearyl/cetyl alcohol base and a lime carrier and is designed to self-spread over a water surface at speeds up to 10 km/hr. It is applied at a rate of 0.5-0.75 kg/ha every 2 to 3 days. Wind and waves will "break-up" the monolayer although it will rapidly reform after this occurs. The product has received NSF and United Nations approval as environmentally sound technology and suitable for potable water. The product currently retails for $12.50 to $15.00 per kg although, with local manufacture, this is expected to reduce to less than $10 /kg. This equates to approximately $0.10 to $0.14 /m^2/year if used all year round. One of the benefits of the monolayer is that it need only be applied when there is water in the storage or during the summer months when evaporation rates are at their highest, resulting in a considerable reduction in the costs associated with the saved water.

7.3. NetPro Shade Cloth

NetPro is a company that designs and installs shade cloth over orchards. These structures are traditionally expensive and cost $20+ /m^2. Traditionally the technology involves placing a high-density shade cloth on a pole and wire structure that is installed over aquaculture ponds etc when empty. The NetPro product uses a high tensile, webbed cable structure from which the 300g/m^2 shade cloth is suspended using plastic clips. The supporting cables have a maximum span of 120 m and are secured to the perimeter of the storage using screw anchors. The product is installed flush with the dam wall in order to reduce wind effects and eddies. This product has an installed cost of approximately $8/ m^2 although the manufacturer feels that the cost could be reduced to around $6/ m^2 using a different shade cloth to that of the NCEA trial.

PHOTOGRAPH 2 – INSTALLATION OF WIRE SUPPORTS FOR SHADE CLOTH COVER

(Photograph courtesy of NCEA)

7.4. BirdBalls

“BirdBalls” is a commercially available product from the USA (http://www.enquip.com/BirdBall2.html) and is simply 100 mm diameter balls that are UV treated and weighted to prevent wind lift. Bird Balls retail for approximately $ 50/m^2 and are installed by simply emptying a container onto the water surface. They are primarily sold to prevent bird roosting on chemical effluent ponds. Talks with manufacturers have indicated there is a potential to construct a similar system for less than $ 6/m^2 should the quantities involved justify the initial tooling costs. A critical feature of this concept would be onsite manufacture from bulk delivered plastics - reducing transport costs - which do represent over 50% of the cost of the current product on the market (i.e. shipping a lot of air). Automated blow moulding machines are portable and easily remotely managed.

7.5. FabTech, SA

FabTech is a South Australian based company, that uses a number of different products to manufacture lightweight floating covers. These covers are generally manufactured from scrim-reinforced polypropylenes. Stevens 45-mil tan/white material is especially well suited to this application. The white underside of the floating cover allows maximum visibility for divers inspecting the installation, essential in large reservoirs and dams. These covers form a complete seal over the surface of the storage and are ballasted to keep the cover taught and aid in the collection of rainwater.

These covers have not been tested as part of the NCEA project and the price is unknown.

7.6. Fabric Solutions International

Fabric Solutions International (FSI) is an Australian company based in Ernest, Queensland specialising in the custom design, fabrication and installation of membrane fabric products and structures. Information on their evaporation reduction products can be found at http://www.fabricsolutions.com.au/evaporative_covers.htm. Figure 4 shows details on the material used to cover storages.

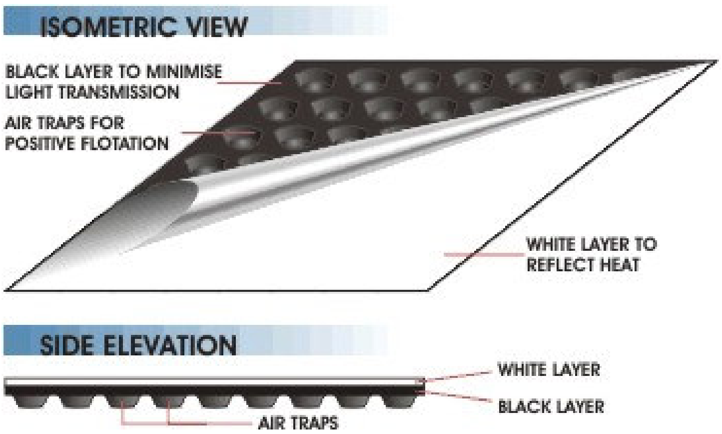


FIGURE 4 – FSI EVAPORATION REDUCTION DAM COVER MATERIAL

8. CURRENT EVAPORATION REDUCTION RESEARCH

8.1. Australian research

In recent years, a number of review papers have been written on evaporation loss reduction from farm dams and urban storages. These include Brown (1988), Sainty and Associates (1995), GHD (2003) and NR&M (2002).

Some review work is being done in the mining sector but this research is currently unavailable due to confidentially. The project (P881 – Review to reduce process water evaporation) is being co-ordinated by AMIRA International, which is an industry association that manages collaborative research for its members in the global minerals industry. The research providers include CSIRO Atmospheric Research, EWL Sciences Pty Ltd, Sustainable Resource Processing CRC and URS Australia Pty Ltd. Fraser (*pers. comm.*, 2005) stated that the research was very similar in summary to GHD (2003) and NR&M (2002). The mining sector has similar requirements to agricultural sector, that is, targeting cost-effective alternatives. However several are not yet in commercial manufacture. Water conservation is a mining industry imperative. (Fraser, *pers. comm.*, 2005)

8.2. Aquacaps – RMIT Project No RM15

Burston and Akbarzadeh (1995) measured the effectiveness of a surface cover device known as Aquacap. These were 380 mm diameter floating rings with a white reflective surface (as well as two other variations that were assessed). Their effectiveness was tested in swimming pool size tanks over a 56-day period from 10 February 1995 to 7 April 1995. Class 'A' pan evaporation was measured and there was a reference swimming pool with no covers. Over this period, reference pool evaporation was 254 mm, which was 0.8 of Class 'A' pan evaporation (316.7 mm). The evaporation loss from the swimming pool with covered Aquacaps was 88 mm. Hence, the evaporation reduction efficiency was 65.4%. Burston and Akbarzadeh (1999) have carried out additional testing of Aquacaps. Work has been undertaken to commercialise the product with price per m^2 being a major barrier.

8.3. NCEA Evaporation Reduction Project

The only major research project that is currently being undertaken on evaporation reduction from water storages involving actual field measurements is the work underway at the National Centre for Engineering in Agriculture (NCEA) at the University of Southern Queensland (USQ) in Toowoomba.

The Queensland Government has invested $650,000 in Evaporation Mitigation Trials at various sites in Queensland and at the Toowoomba campus. The project is testing available types of dam cover technology to minimise evaporation loss and their effectiveness in improving water use efficiency. As part of the Rural Water Use Efficiency Initiative of NR&M, this project involves undertaking case studies to evaluate the performance of a range of commercially available evaporation control products.

The project is monitoring the evaporation loss reduction at five sites. They include:

1. A 120-ha storage at Dirranbandi where a grid system of pipes is being used to distribute a monolayer evenly across the storage (Water$avr).
2. A dam operated by the Peak Downs Shire Council at Capella in the Central Highlands where a monolayer is being applied (Water$avr).
3. A floating cover over a ring tank near St George (E-VapCap™)
4. A 90% black monofilament shade cloth cover over a dam at Stanthorpe (NetPro)
5. Experimental tanks at the NCEA. The three 10 m diameter experimental tanks at USQ are currently being changed over to evaluate more products. Tests have included the modular system from Integrated Packaging and the poly acryl amide (PAM) from Ciba Specialty Chemicals.

One of the difficulties in evaluating the various evaporation control techniques is obtaining an accurate measurement of evaporation losses with and without the products installed. To overcome this, NCEA has developed a method for measuring evaporation and seepage losses from water storages. This technique involves the accurate measurement of water depth in the storage and allows the user to delineate between evaporation and seepage (Figure 5 and Figure 6). This allows daily calculations of seepage and evaporation losses and, when coupled with a detailed land or hydrographic survey, enables the landholder to determine the actual volume of water 'lost' through evaporation and seepage.

The measurements are made using a PST (pressure sensitive transducer). Photograph 3 shows a PST. The device consists of a pressure sensitive diaphragm that measures the difference in pressure from one side to the other. One side of the diaphragm is exposed to the pressure due to the depth of water and the other side is exposed to atmospheric pressure. The pressure difference is then transposed into millimetres of depth.

PHOTOGRAPH 3 – PST

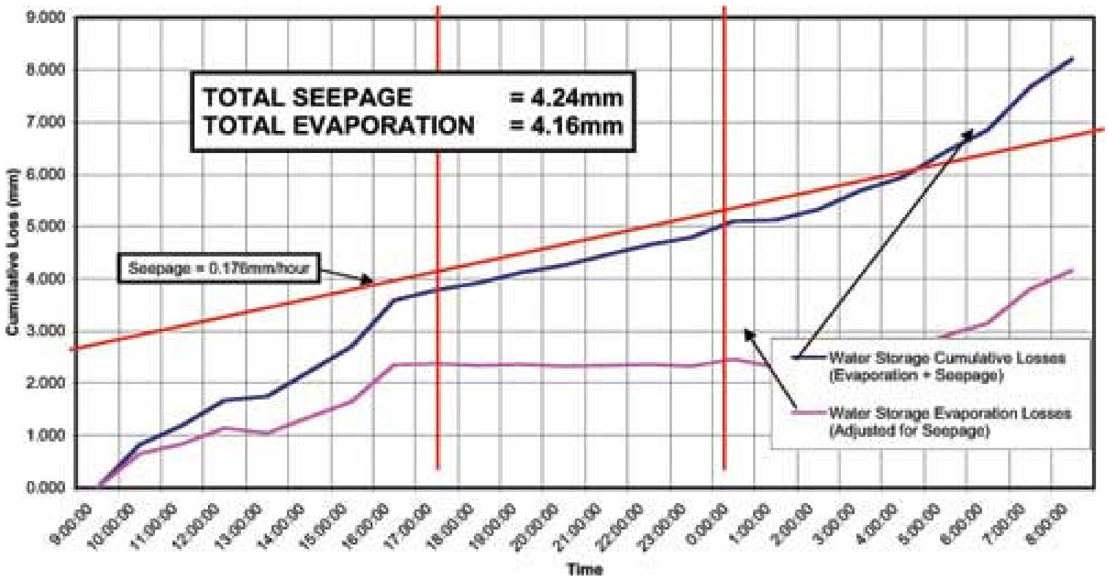


FIGURE 5 – EVAPORATION & SEEPAGE MEASUREMENTS (NCEA)

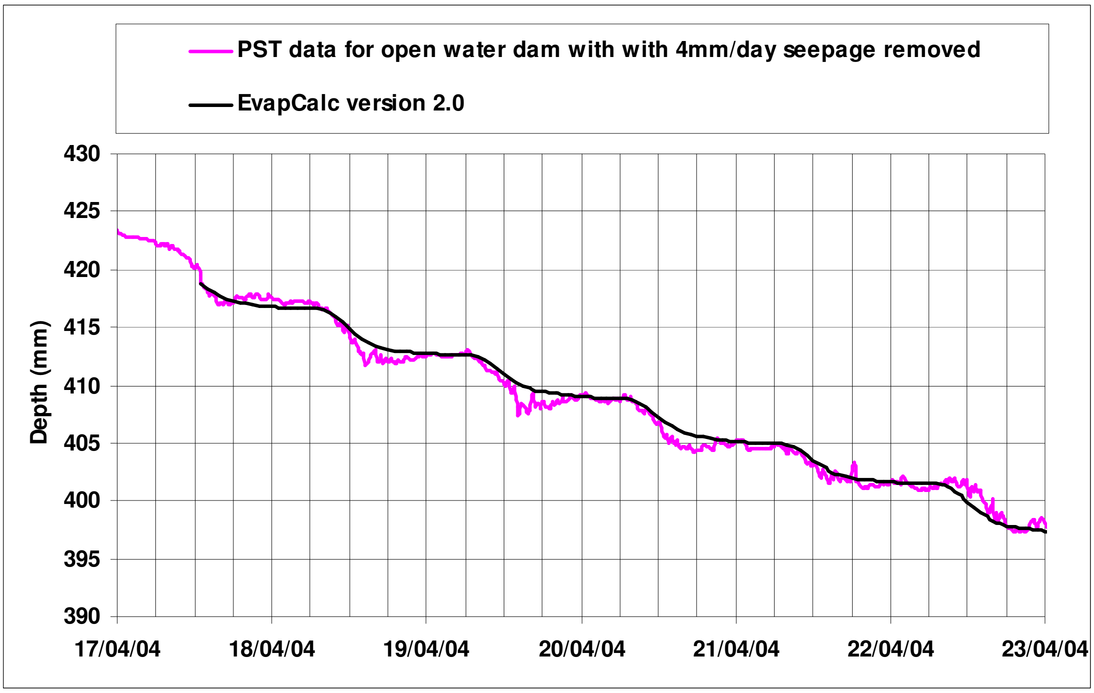


FIGURE 6 – EVAPORATION LOSS MEASURED BY NCEA USING PST TECHNOLOGY

The final report for this project is not due for completion until April 2005 and only limited results are known at this stage. In summary, the outcomes of the project are:

- New measurement technology (PST) has been used and with additional development will be a useful tool.

- The effectiveness of evaporation mitigation products ranges greatly and is very dependant on conditions and installation and maintenance.
- A number of the products work well in the experimental tanks at NCEA but experience practical issues when applied to a large, real-life situation.
- More research on economic benefits needs to be carried out.
- Four main factors influencing profitable results from evaporation mitigation options.
    - location
    - cost of product capital and maintenance
    - performance of product
    - opportunity time (% of time storage contains water)

The NCEA in Toowoomba (http://www.ncea.org.au/index.htm) should be contacted for further information.

8.4. Overseas Research

A limited search for research on evaporation control indicated that little work is currently being done overseas. It is probable that the issue is not regarded as sufficiently serious yet, but with the increasing demand for fresh water worldwide this is likely to change.

8.4.1. Monolayer study – California

As no other details could be found, the following information has been reproduced verbatim from the Flexible Solutions website.

6 January 2005

Flexible Solutions Announces 37% Evaporation Savings from Owens Lake, California Water$avr Trials

VICTORIA, BRITISH COLUMBIA, Jan.6, 2005– FLEXIBLE SOLUTIONS INTERNATIONAL, INC. (AMEX: FSI, FRANKFURT: FXT)

FSI, the developer and manufacturer of environmentally safe water conservation and anti-scaling technology, today announced the positive results from evaporation control testing conducted at Owens Lake, California during September and October 2004. A simultaneous toxicity study was performed by McGuire Environmental Consultants Inc of Denver, Colorado to determine if any water quality change occurs as a result of application of Water$avr to a large body of water.

The evaporation control results were as follows:

- Evaporation reduction for 2 and 3-day application cycles over September and October were 37% and 30% respectively.
- Evaporation savings were as high as 54% and as low as 22% on individual days depending on environmental factors.

With respect to the environmental impact testing performed in Colorado the results were as follows:

- No effect on odour
- * No effect on invertebrates
- * No effect on vertebrates
- * No anticipated effect on any current drinking water treatment processes
- * Biodegradability reconfirmed independently.

Dan O'Brien, CEO of Flexible Solutions, states, "These excellent results were expected given our previous successes in other trials around the world, however, most significantly, this test was performed in California funded by the Metropolitan Water District of Southern California. This, combined with the definitive toxicity report executed by a highly respected American laboratory and previous NSF, ANSI, CDA and UNEP certification, serves to enhance Watersavr's position of worldwide product acceptance." (NSF - National Sanitation Foundation; ANSI - American National Standards Institute; CDA - California Department of Agriculture; UNEP - United Nations' Environmental Program Center.)

9. SUMMARY OF VARIOUS EVAPORATION REDUCTION OPTIONS

Based on the preliminary work of NCEA and other research work, Table 1 lists the various reduction methods and the evaporation reduction efficiencies likely to be achieved by each method. Brown (1988) gives a more comprehensive listing but the results are similar.

TABLE 1 – SUMMARY OF VARIOUS EVAPORATION REDUCTION OPTIONS

Method of Reduction	Evaporation Reduction Efficiency	Reference
Monolayers	37%	Flexible Solutions (2005)
Monolayer - Water$avr	20%^	Schmidt, *pers. comm.* (2005)
E-VapCap	90%^*	Schmidt, *pers. comm.* (2005)
Polystyrene bead	39%	Myers & Frasier (1970)
Wax Blocks	64%	Cooley & Myers (1973)#
Lily pads	16%	Cooley & Idso (1980)#
Polystyrene beads	39%	Myers & Frasier (1970)#
White butyl rubber	77%	Cooley (1970)#
White plastic spheres	78%	Crow & Manges (1967)#
Plastic Sheeting (suspended)	90%	Drew (1972)#
Foamed Rubber	90%	Dedrick *et al.* (1973)#
Polystyrene rafts	95%#	Cluff (1972)#
Shade Cloth	70%^	Schmidt, *pers. comm.* (2005)
Aquacap	65%	Burston and Akbarzadeh (1995)

sourced from Condie and Webster (1995)
^ preliminary results for evaporation reduction
* 10 m tank only

The following are our conclusions.

6. Monolayers have a long history and, despite many attempts, have not been shown to be viable and effective in the long term (Brown 1988). Schmidt (*pers. comm.* 2005) suggests that their evaporation reduction efficiency varies from 0% to 40% but the reasons for this variability are, as yet, unknown. However, monolayers may be the only solution for dams with a large surface area.
7. Emergent or floating vegetation does not offer an effective solution.
8. Various floating, modular devices are effective (60% to 90% reduction) and offer viable solutions in some circumstances. However, there are cost and practical issues.
9. Complete (air-tight) surface covers are expensive and pose significant practical problems for larger dams.
10. Shade cloth is probably the best-bet option at this stage. It provides a significant evaporation reduction (70%) and is not reliant on a 'perfect' seal over the dam surface. Rainfall can easily enter the dam. If further practical design work can reduce capital costs, then shade cloth covers will become viable in an increasing number of situations.

10. ESTIMATION OF EVAPORATION LOSS FROM FARM DAMS

10.1. Introduction

In order to assess the returns from evaporation reduction systems for farm dams, it is necessary to estimate the current evaporation loss from Australian farm dams. To achieve this, it is necessary to:

1. Estimate the number and dimensions of farm dams in Australia,
2. Estimate the actual evaporation loss from farm dams in different locations across Australia, and
3. Duration of water storage in each dam.

10.2. Methods of Estimating Net Evaporation

Direct measurement of evaporation loss from farm dams is very difficult and cannot be routinely undertaken at this stage, as it requires an accurate determination of all components of the dam's water balance. Hence, indirect estimates are made. There are essentially two methods of routine evaporation estimation. They are:

1. Evaporation pans (pan evaporimeters)
2. Evaporation calculation formulae

Evaporation is a very poorly-reported meteorological parameter. Often, evaporation is simply stated as "daily evaporation in mm" without specific reference to the method of estimation or measurement. The various evaporation estimates vary widely but, without knowledge of the estimation method, the use of the data is fraught with problems. Evaporation definitions need to be standardised.

10.2.1. Evaporation pans

The standard evaporation pan used in Australia is the US Class 'A' pan. It is a circular tub of 1200 mm internal diameter; 250 mm deep and constructed of one millimetre thick galvanised sheet steel. The pan is placed on a raised timber platform about 150 mm above ground level. Pans are usually (but not always) covered with an open wire mesh to exclude animals and birds. Evaporation is determined by measuring the daily change in water level in the pan.

Due to the factors that influence evaporation rates from open water surfaces (see Section 3), evaporation rates from Class 'A' pans can vary due to conditions other than local climate. Wind speed across the evaporating surface can vary due to the provision (or otherwise) of a mesh cover and by surrounding features (fences, trees). Brown (1988) reports that bird guards reduce evaporation loses by 7%. Advection can be a significant issue if the pan is located in a hot, dry environment. A Class 'A' pan sited at the local Post Office (in an urban environment) may not be representative of the surrounding agricultural or forested land. Hence, the data from Class 'A' pans can be non-representative of the general locality.

Furthermore, there is the question of how the evaporation rate from a small, steel pan is related to the evaporation rate from a large, extensive, deep water body (e.g. farm dam). It is usual to estimate open-water evaporation from pan evaporation data by applying an open water pan coefficient, K_{OW}. Reported pan coefficients range from 0.4 to 1.2 (Weeks, 1983 & Turner *et al*., 1993) and are claimed to vary with season and locality.

Weeks (1983) presented lake evaporation pan coefficients for a range of locations in Queensland. These coefficients were calculated through comparison of measured Class 'A' pan evaporation figures with calculated 'lake evaporation'. Two methods of calculating 'lake evaporation' were used - the Penman method and the Morton method. Pan coefficients were determined by comparing Class 'A' pan evaporation to an average of these methods. The Morton method is not appropriate for use in arid climates and as such the Penman method was used for inland sites. Hence, the pan coefficients so often quoted from Weeks (1983) are NOT derived from any actual measurements of evaporation from open water surfaces.

Since the publication of the Weeks paper, various improvements have been made to the Penman equation and have since superseded the original Penman equation in calculating evaporation. The inherent inaccuracy of Class 'A' pan readings also confounds the use of the Weeks calculated pan coefficients.

Daily Class 'A' pan readings also vary widely in comparison to current calculations of evaporation from meteorological variables (see Section 10.3) and as such any coefficient chosen may have the same variation.

Hence, the choice of an appropriate coefficient is problematic and thus the estimation of actual farm dam evaporation loss is fraught with error.

10.2.2. Evaporation Calculation Formulae

Evaporation can be estimated using various formulae that take account of the meteorological factors that influence evaporation. These factors include solar radiation, wind speed, humidity and air temperature. Most of these formulae are designed to estimate evaporation from a wide expanse of freely-transpiring grass (evapotranspiration). This is called potential evaporation or reference-crop evapotranspiration, ET_O. Exact definitions will not be discussed here.

There are a large number of formulae that have been developed for calculating evaporation. It is not appropriate in this report to review all of the formulae that have been developed (for more information, see Kashyap and Panda, 2001, Conroy *et al.*, 2003 and Prenger *et al.*, 2001). Some of the formulae that have been developed are:

- Penman (original 1948)
- Morton
- Dalton
- Priestly Taylor
- Penman Monteith
- FAO 56
- Kimberly-Penman
- Jensen-Haise

- FAO-Penman
- Turc-Radiation
- Blaney-Criddle
- Hargreaves
- FAO-Radiation
- Corrected Penman
- Various variations of the above.

It should be noted that the estimates of evaporation vary widely and some formulae have been shown as unreliable and should not be used, even for ET_O. These include Blaney-Criddle (based on air temperature only), original Penman 1948, Jensen-Haise (based on air temperature and daily integrated solar radiation).

The FAO Penman-Monteith method is selected as the method by which the evapotranspiration of the reference surface can be unambiguously determined, and as the method which provides consistent ET_O values in all regions and climates. The definition of a reference crop is:

> *"A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s.m and an albedo of 0.23"*

The reference surface closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water. The requirements that the grass surface should be an extensive and uniform result from the assumption that all fluxes are one-dimensional upwards.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

EQUATION 3

where

ET_O	reference evapotranspiration (mm/day)
R_n	net radiation at the crop surface ($MJ/m^2/day$)
G	soil heat flux density ($ML/m^2/day$)
T	mean daily air temperature at 2m height (°C)
u_2	wind speed at 2m height (m/s)
e_s	saturation vapour pressure (kPa)
e_a	actual vapour pressure (kPa)
e_s-e_a	saturation vapour deficit (kPa)
Δ	slope vapour pressure curve (kPa/°C)
γ	psychrometric constant (kPa/°C)

With the growing proliferation of automatic weather stations, there is a growing database of meteorological data that could be used to calculate ET_O. However, at this stage, all automatic weather stations do not use the same formulae to calculate ET_O and therefore the ET_O data from automatic weather stations should be used with caution.

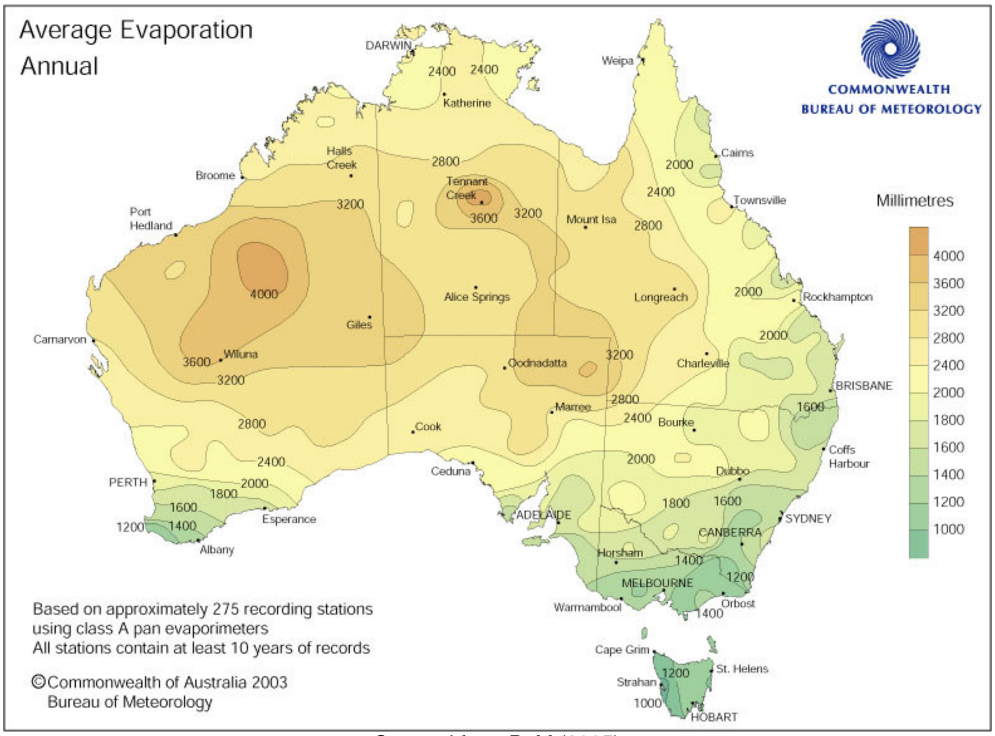
There is considerable debate as to which of the above formulae best estimates the evaporation rate from an open-water surface as most formulae are designed to estimate evapotranspiration and do not take account for thermal storage in the water body or advection of energy from the surrounding environment. Condie and Webster (1997) investigated evaporation from 'fetch-limited reservoirs' (i.e. farm dams) and they developed a complex model that incorporates the advection of heat and moisture. The model requires land-based meteorological information (readily available from an AWS) of solar heat flux, upwind air temperature, upwind 2 m wind speed and land roughness length, in addition to three empirical values. This work addresses the problem of energy advection into isolated reservoirs such as farm dams and thermal mass of the water body itself. Some data are presented on changes in dam water temperature diurnally, vertically and downwind across the dam surface. The thermal lag of the water body itself is discussed and its effect on night time evaporation. They even discuss the effect of water turbidity on the heat balance of the dam.

This is the type of fundamental modelling work that is required to gain an understanding of the factors that influence farm dam evaporation and more work in this area is required. However, the authors did not extend their work into a readily applicable formula that a practicing engineer could use. They presented no comparison of their estimation of evaporation from their dam against ET_O or pan evaporation. Hence, the practical application of this excellent fundamental work is limited.

10.3. Differences between Evaporation Estimates

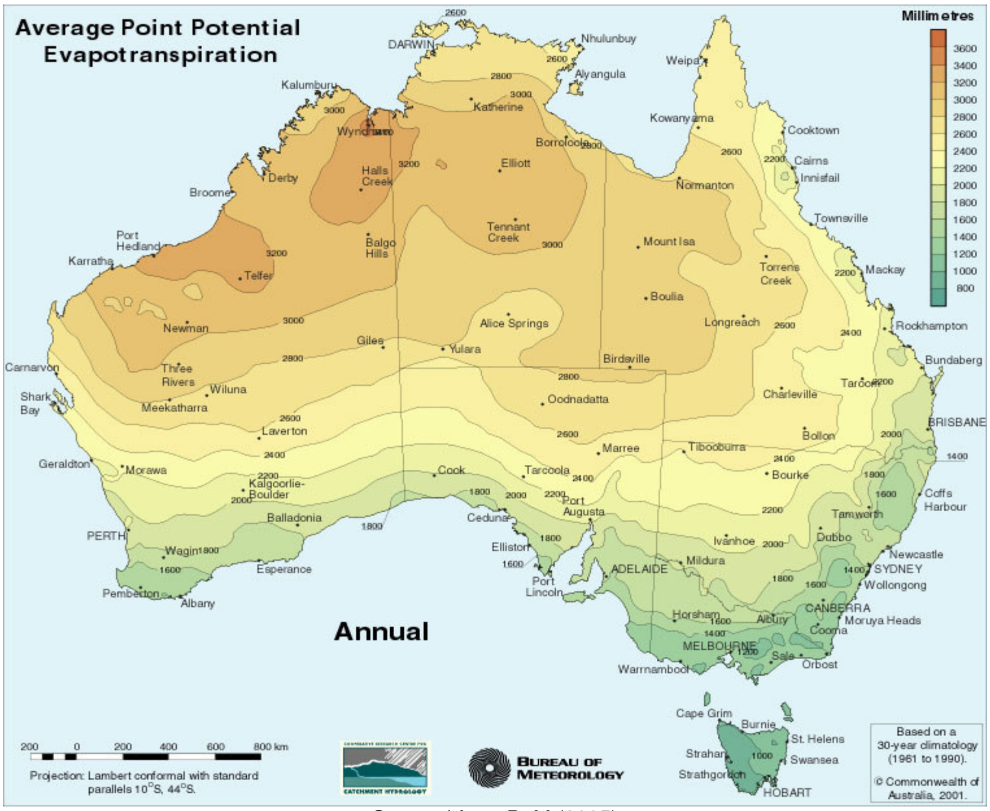
To illustrate the differences between different estimates of evaporation, two maps from the Bureau of Meteorology are presented. Figure 7 is a map showing the variation in mean annual Class 'A' pan evaporation, E_P, across Australia. Figure 8 shows the average point potential evapotranspiration variation across Australia. This is calculated using Morton's potential evapotranspiration and is thus not ET_O calculated by FAO56. While generally similar, the patterns of mean annual evaporation are significantly different.

This simply emphasises that there is a poor data available to estimate evaporation from farm dams in Australia.



Sourced from BoM (2005)

FIGURE 7 - AVERAGE ANNUAL PAN EVAPORATION FOR AUSTRALIA



Sourced from BoM (2005)

FIGURE 8 - AVERAGE ANNUAL POINT POTENTIAL EVAPOTRANSPIRATION FOR AUSTRALIA

10.4. Examples of Evaporation Estimates for the Darling Downs

In order to demonstrate the difficulties in estimating evaporation loss from farm dams, data from various sources on the Darling Downs was obtained and compared. The Darling Downs is a well-established farming area with a long history of climate recording.

The data sources include:

- Bureau of Meteorology Class 'A' pan at Dalby
- Darling Down Cotton Growers Association automatic weather stations (AWS) (There are a number of AWS maintained by Darling Down Cotton Growers Association across the Darling Downs. They are mainly used for spray drift monitoring.)

Two methods of calculating evaporation from a farm dam near Dalby are presented and demonstrate the difficulties in calculating evaporation from an open-water storage.

1. Estimate Open-Water Evaporation using a Class 'A' Pan

   Weeks (1983) derived the open water pan coefficient K_{OW} to be 0.74 for this region. Therefore calculating gross open-water evaporation is a simple calculation using mean annual pan evaporation data (2000 mm/yr).

$$E_{OW} = K_{OW} \times E_P$$
$$= 0.74 \times 2000 \text{ mm/yr}$$
$$= 1480 \text{ mm/yr}$$

2. Estimate Open-Water Evaporation Using FAO 56 Penman Monteith

   It has been suggested that, without better information, FAO 56 Penman Monteith (ET_O) is a reasonable estimate of open-water evaporation. Wu *et al.* (1999) use a pan to ET_O factor of 0.8 for large storages and 1.1 for small (1 to 5 ha) storages but the justification for this is unclear. Therefore, evaporation from a farm dam near Dalby could be calculated using data from the nearest automatic weather station. The cumulative evaporation calculated using this data from the closest station to Dalby (Nandi) is 1940 mm/yr.

This shows that, in this circumstance, the FAO 56 Penman Monteith evaporation calculation overestimated the Class 'A' pan estimate by more than 30% (1940 mm compared to 1480 mm) with no clear indication as to which estimate is most reliable. This shows the large variation and difficulties encountered when calculating farm dam evaporation.

It is unknown which of these two methods of calculation is the better estimate so an evaluation of both the weather station data and the pan evaporation data has been carried out. Figure 9 shows ET_O calculated using data from two automatic weather stations situated approximately 60 km apart on the Darling Downs (Nandi and Brookstead). The two sites are essentially in the same climatic area. This shows a good correlation (r^2 = 0.92) between the data sets as would be expected.

Figure 10 shows the correlation between ET_O at Nandi and the Class 'A' evaporation pan at Dalby. This shows poor correlation. Watts (1983) compared daily evaporation from two Class 'A' pans situated only 3 km apart and found a similarly poor correlation (Figure 11). This demonstrates that Class 'A' pan is an unreliable device to estimate daily evaporation.

However, Figure 12 shows a cumulative plot of ET_O calculated using data from AWS (Nandi, Brookstead and Norwin) and E_P for Dalby for a 349 day period in 2004. This figure shows some unexpected results. After 11.5 months, pan evaporation is 2016 mm, while the ET_O for Nandi, Brookstead and Norwin are 1944, 1751 and 1724 respectively. Hence, it appears that the Nandi AWS data is anomalously high (12% higher than the average of the other AWS) This could be due to a faulty radiation instrument but this would not be obvious without calibration of the instrument. It shows that, to convert the Dalby E_P data to ET_O (calculated for the Nandi AWS), a pan coefficient, $K_{OW,}$ of 0.96 should be applied – not a factor of 0.74 as suggested by Weeks. However, if data from the other AWS were used, a different estimate of dam evaporation would have been obtained (0.86). Interestingly, Meyer *et al*. (1999) compared ET_O to Class 'A' pan evaporation in Griffith and found that a pan factor of 0.93 was appropriate.

There is a tendency to assume that AWS data will be better than Class 'A' pan data but, clearly, this is not always the case.

It is unknown where the inaccuracy in the evaporation calculation methods lies. It could be

- The measurement of pan evaporation at Dalby
- The pan coefficient that is applied
- The formula used with the AWS data, or
- The AWS data that is collected (i.e. modules of the weather station not working correctly).

In any event, this demonstrates that it is not possible to accurately predict the annual evaporation from a farm dam on the Darling Downs.

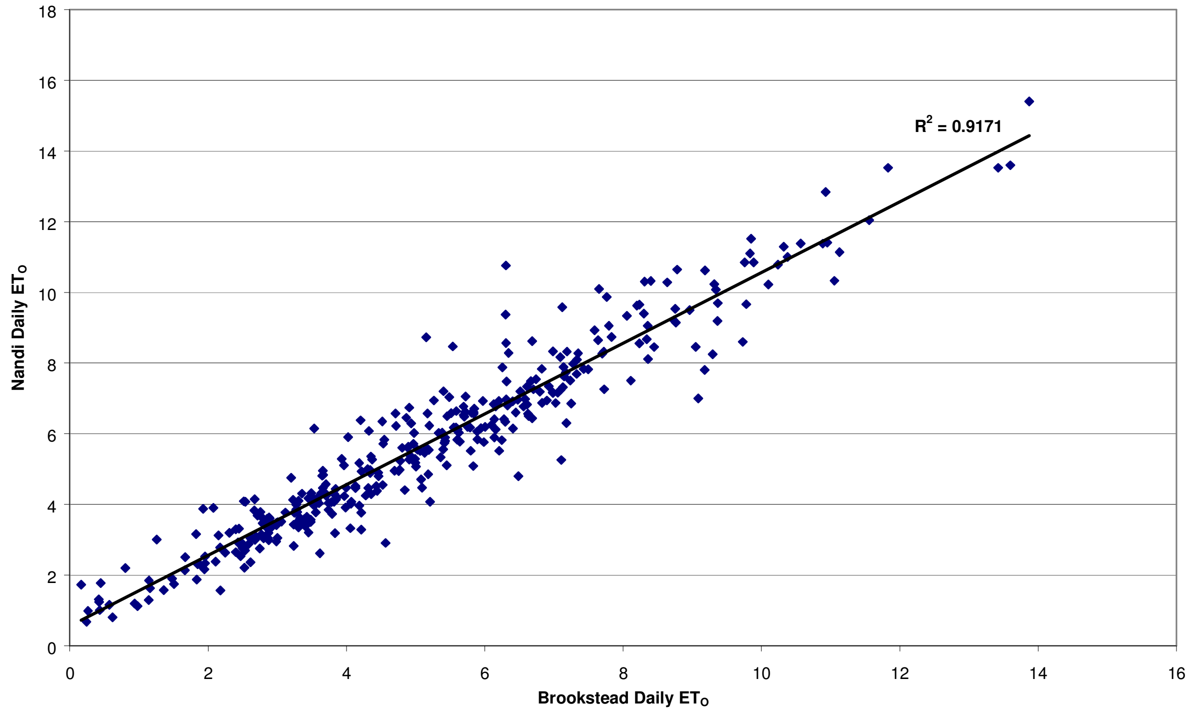


FIGURE 9 – DAILY AWS EVAPORATION FROM TWO NEARBY STATIONS

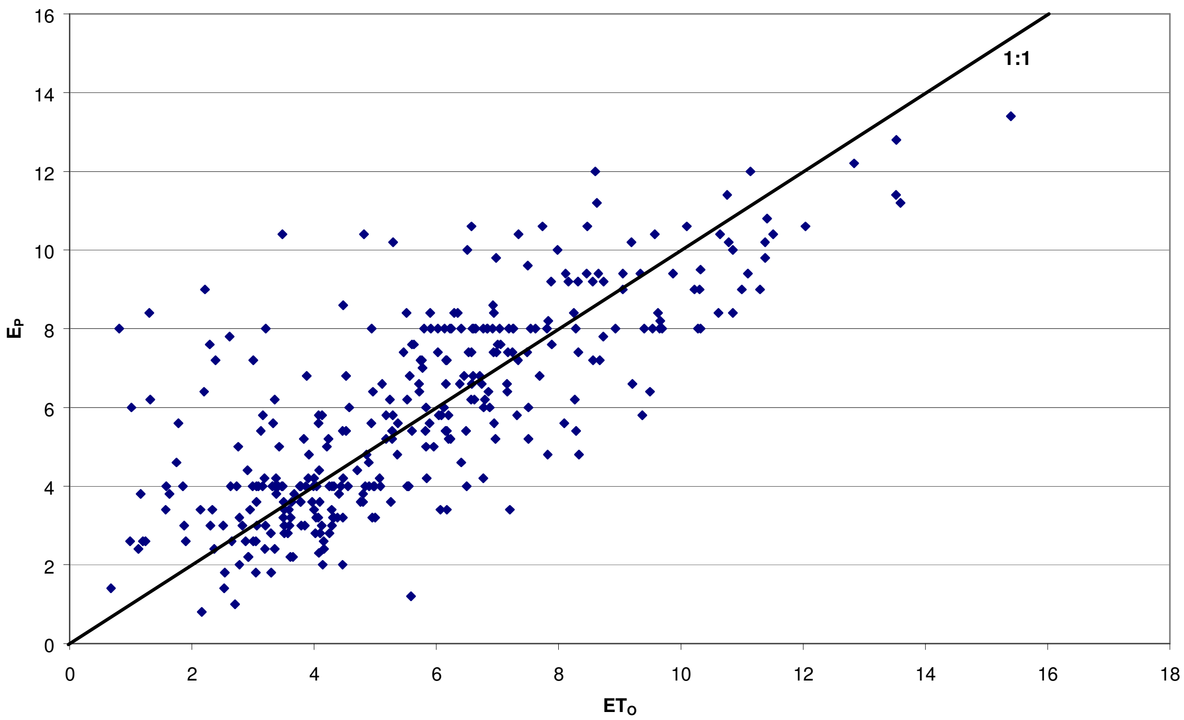


FIGURE 10 – DAILY ET$_O$ (NANDI) VS E$_P$ (DALBY)

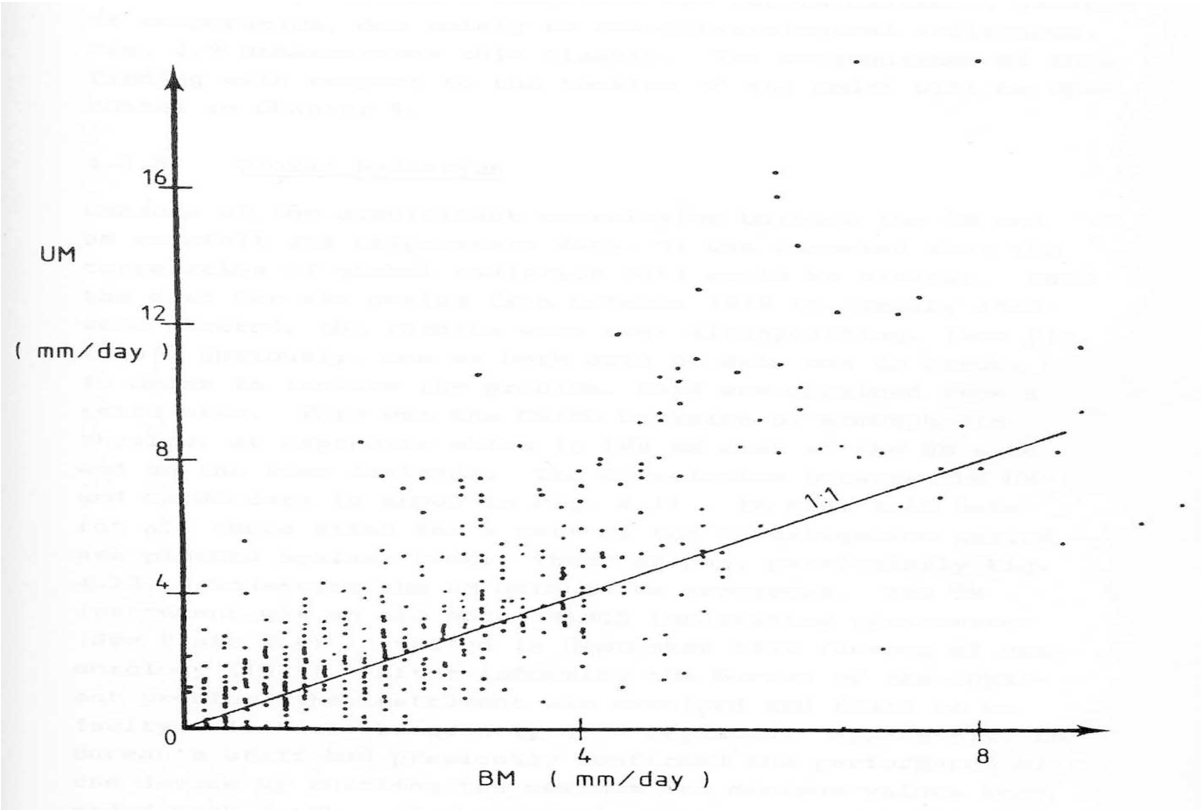


FIGURE 11- COMPARISON OF E_P BY WATTS (1983)

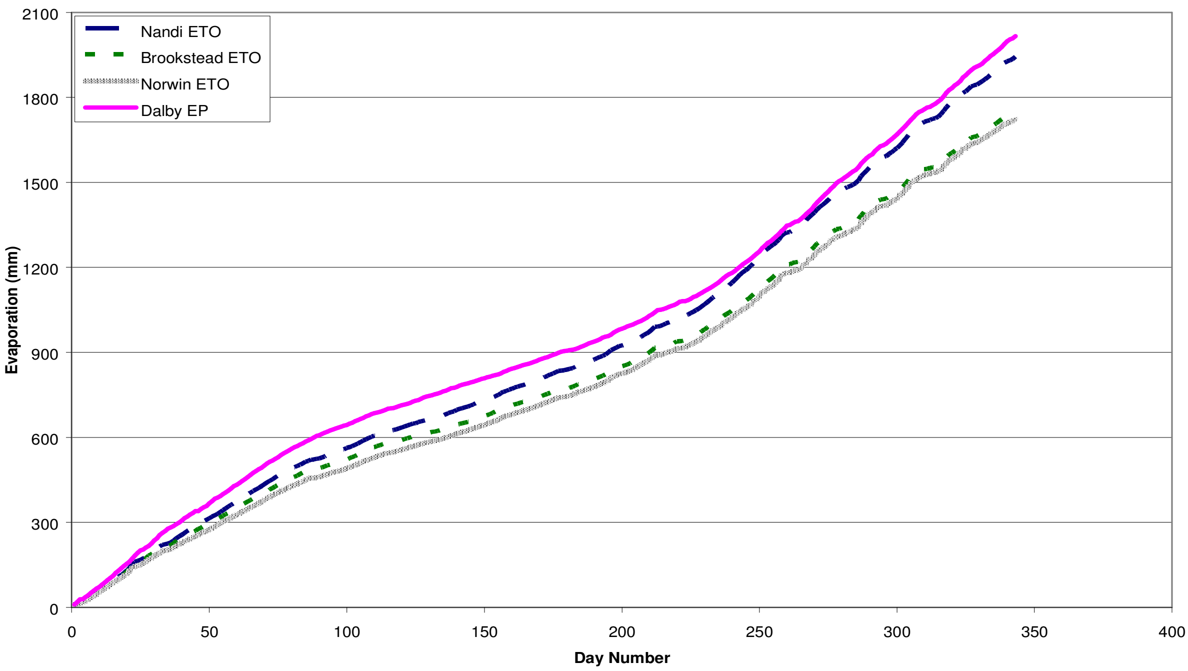


FIGURE 12 – CUMULATIVE AWS AND CLASS 'A' PAN EVAPORATION (DALBY)

11. Number of Farm Dams in Australia

Requests were made to each State's relevant Government Department about data of farm dams. A short summary of the contact process and data obtained is listed below.

11.1. Australian Capital Territory

Environment ACT was contacted with regard to the number of farm dams in the ACT. They have very little information on the number of farms dams. The request was passed on to the extension officers' section and there has been no response to date.

11.2. New South Wales

The Department of Infrastructure, Planning and Natural Resources was contacted. They have no information on the number, size or location of farm dams in the state. There are licences for some dams, although this information only gives the total number of dams. There is no record of size, location or surface area.

Data Summary

No relevant data exists on the number of farm dams in New South Wales.

11.3. Northern Territory

The Department of Infrastructure, Planning and Environment was contacted, and the enquiry was directed to the Land and Water Conservation branch. A fax was sent detailing our data requirements. However no formal reply was made within the time frame given. The overriding indication was that no data was kept with regard to numbers of farm dams.

Data Summary

It is apparent that no relevant data exists on the number of farm dams in the Northern Territory.

11.4. Queensland

NR&M was contacted and they commented that there was very little data available. Most catchments in Queensland are currently in the process of WAMP, WRP and ROP. As a part of the ROP, data is collected on farm dams all across the catchment. The data that is being collected includes volume, depth, surface area when full, age and a number of other factors. This process is still in its' initial stages and will not be completed for the whole state for a number of years. Rough estimate data could be gathered using satellite imagery and GIS queries. Data for the Queensland Murray Darling Basin was requested and delivered. It must be emphasised that this data is an estimate only due to the fact that satellite imagery is at a scale of 250 000 and that small stock dams are not included. There is also a chance that some storages that are filled solely from overland flow are not included in this query process. This data will be fine tuned as the ROP process is completed. Data of this quality may be available from other areas of the state but this was not requested. Figure 13 shows the Queensland Murray Darling Basin and the location of the storages that were identified in this process. Figure 14 shows a selected portion of this data (central Darling Downs). The total area of the Queensland Murray Darling Basin is 26 079 100 ha and the estimated surface area of the storages in the area is 502 700 ha. The surface area of farm water storages represents approximately 2% of the Queensland Murray Darling Basin.

Data Summary

At this stage, there is no accurate data regarding farm dams in Queensland. A rough estimate of the surface area of irrigation dams in the Queensland Murray Darling Basin was the best available data. There will be accurate data available regarding irrigation water storages after the ROP process is completed for each catchment.

11.5. South Australia

The Department of Water, Land and Biodiversity Conservation (DWLBC) was contacted and they concluded that data did exist on farm dams in SA. A data CD was supplied. The point was made that the data is not complete, but limited to areas of concern for the state’s water resources.

Data Summary

Good data is available, in both GIS and statistical formats, of numbers and surface areas of individual dams in areas of SA where sustainability of water resources is in question. However this excludes the areas of higher evaporation such as the SA Far North, the SA Mallee and Eyre Peninsula.

11.6. Tasmania

Tasmania’s Water Information Management System database on the Department of Primary Industries, Water and Environment website was located, which contained all the relevant information required. However, extracting all of the information was cumbersome and time consuming, and as such the Department was contacted and the entire database was sent in electronic format to FSA Consulting.

Data Summary

Excellent data received, in spreadsheet format. Information included dam location (easting and northing), dam capacity, wall height, crest length, storage area (limited data), dam status (existing or proposed), dam type (catchment or on-stream), hazard rating and stream name (if on-stream).

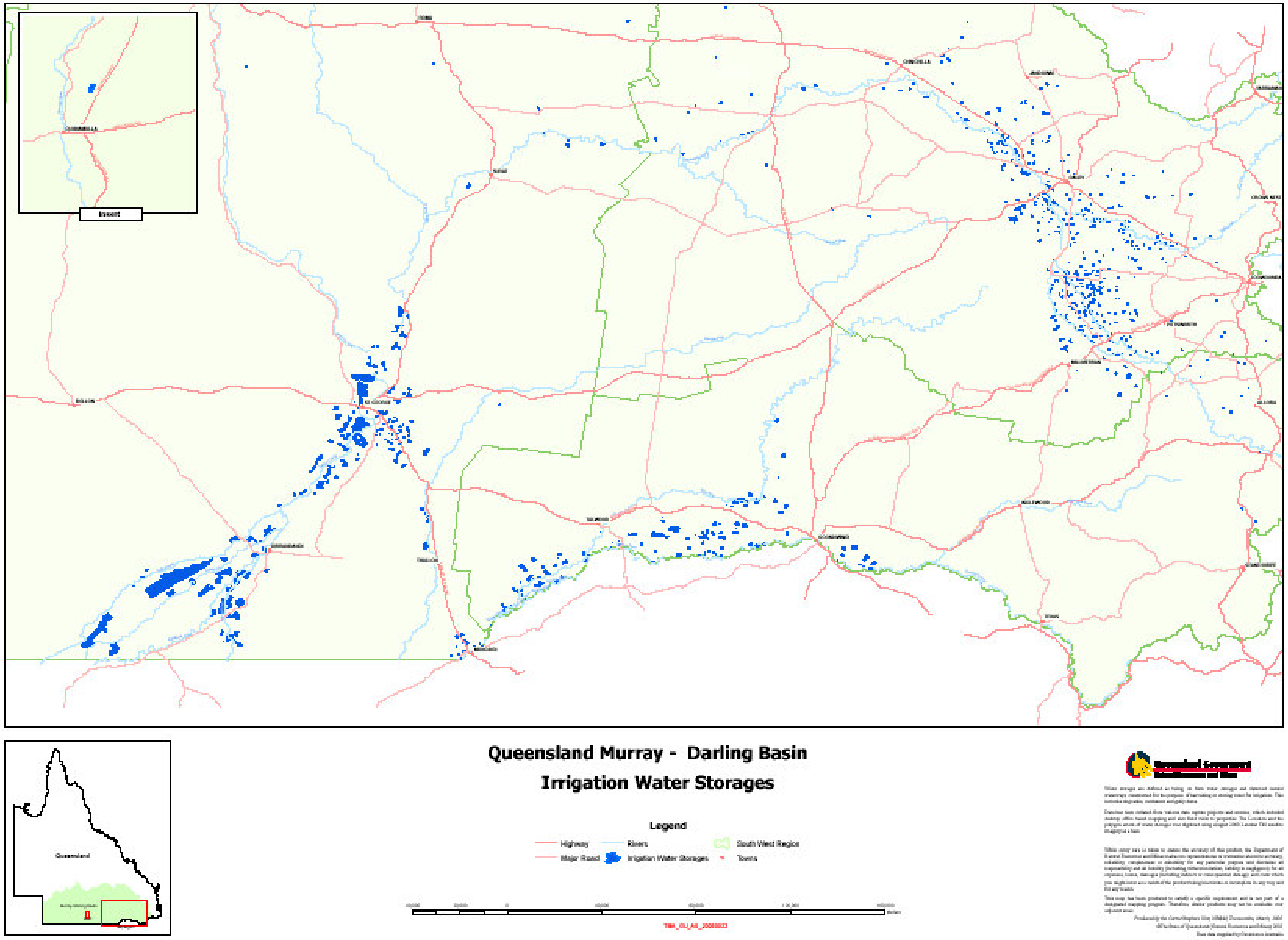


FIGURE 13 - LOCATION OF WATER STORAGES IN QUEENSLAND MURRAY DARLING BASIN

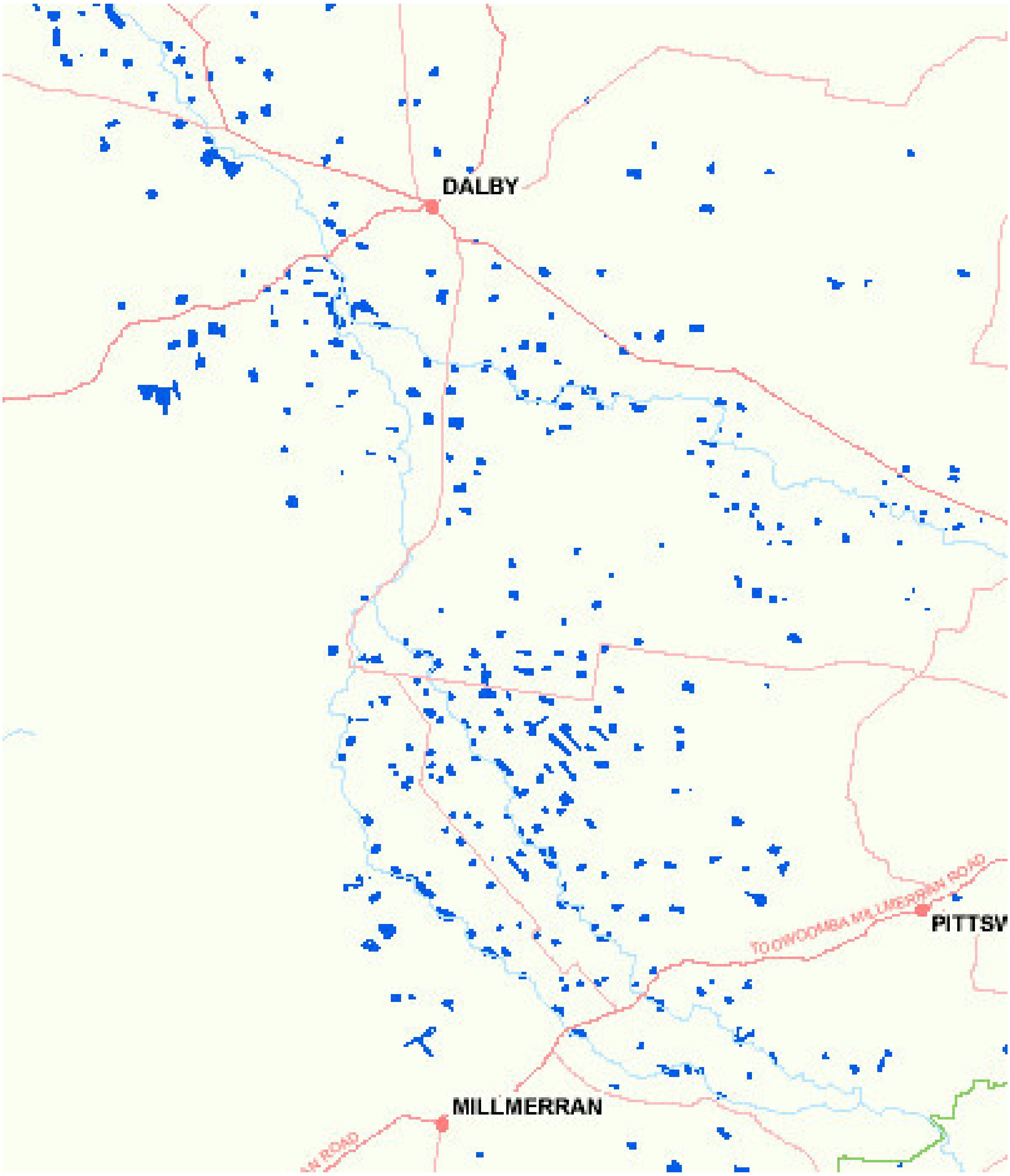


FIGURE 14 - EXAMPLE OF DATA NEAR DALBY

11.7. Victoria

Regional Water Authorities were contacted initially. They are currently going through the process of trying to document all commercial (irrigation) dams in the state. Each region is responsible for their area. The process is in its' infancy and it is believed that it will not be completed for another 2 years. An estimate of the number of dams was not even possible.

Data Summary

No relevant data currently exists on the number of farm dams in Victoria. However, data is currently being collected and will be available in the approximately 2 year's time.

11.8. Western Australia

The Department of Environment, WA was contacted but, to their knowledge, no information existed in their Department. Further correspondence with a data management representative at the Department of Environment, WA confirmed that no data exists of this nature. It was suggested to try the Department of Land Information or Agriculture WA. The Department of Land Information did not keep any data, other than simple topographic data. Just recently legislation has been introduced where applications are required to sink any new dams, however no historical data exists. The Department of Agriculture, WA was contacted; however no information exists in this department. It was suggested to try the Department of Environment or the Australian Bureau of Agricultural and Resource Economics (ABARE). ABARE was contacted, however no response was received.

Data Summary

No relevant data exists on the number of farm dams in Western Australia.

12. POTENTIAL WATER SAVING IN AUSTRALIA FOR FARM DAMS

As shown in Section 11, data on actual numbers of farm dams across Australia is extremely limited, and almost non-existent for the areas where evaporation is highest. Coupled with this is the uncertainty in accurate evaporation estimation for farm dams (see Sections 10.2 and 10.3). Hence calculating an accurate figure of potential water saving from farm dams on a national scale is impossible at this point in time.

Nevertheless, an analysis using the Queensland Murray Darling Basin area is provided to show the potential for water saving from farm dams.

Many factors impact on the potential for water saving on a regional scale, as listed below:

- Number of dams
- Individual surface area of each dam
- Evaporation reduction technology used
- Percentage on-farm adoption of reduction technology
- Percent effectiveness of technology adopted
- Percentage of time dam contains water (available for evaporation).

The actual depth of each dam will impact the relative water saving (i.e. ML saved per ML in storage).

Each factor has a reasonable amount of variation that will significantly alter the potential for water saving estimate. A number of different scenarios are presented to cater for some of these variations.

12.1. Initial Data

The total surface area of farm dams in the Queensland Murray Darling Basin (QMDB) is estimated to be approximately 502,700 ha (G. Knight, *pers. comm.*, 2005). It is noted that this figure is approximated using satellite imagery, and does not include all irrigation storages or stock and domestic dams. Assuming an average water depth of 4 m, the total volume of farm storage is **20,100 GL** (502,700 ha x 4000 mm / 100). **THIS IS A ROUGH ESTIMATE BUT THE ONLY ESTIMATE POSSIBLE AT THIS TIME.**

Long-term pan evaporation (E_P) data for the QMDB varies greatly. Table 2 shows this variation. The mean gross annual volume of water lost from farm dams in the QMDB to evaporation was calculated using the long-term annual pan evaporation (E_P) for Dalby of 2000 mm/yr. This estimate assumed that all dams have water in them for the whole 12 months. Hence, this estimate does not apply in drought years.

Hence, mean annual gross evaporation loss, E_{OW} =

$$\begin{aligned} E_{OW} &= K_{OW} \times E_P \text{ (mm)} / 100 \times \text{Surface Area (ha)} \\ &= 0.7 \times 2000 / 100 \times 502{,}700 \\ &= 7{,}040{,}000 \text{ ML/yr.} \\ &= 7{,}040 \text{ GL/yr.} \end{aligned}$$

TABLE 2 – VARIATION IN EP ACROSS QUEENSLAND MURRAY DARLING BASIN

Location	E_P (mm/yr)
Charleville	2630
Thargomindah	2590
Gilruth Plains	2450
Dalby	2000
Mitchell	1830
Miles	1750
Inglewood	1720

Data sourced from (BoM, 2005).

Section 12.2 assumes that all the practical issues involved with the evaporation reduction measures (installation, maintenance, etc) have been solved. The percentage effectiveness figures quoted are preliminary results supplied to FSA Consulting from the NCEA (E. Schmidt *pers. comm.*, 2005) from their project for the NR&M. *It is stressed that these figures are indicative only.*

12.2. Potential Savings for the QMDB

Table 3 shows approximate potential evaporative savings across the QMDB for each of three mitigation measures trialled by the NCEA. The potential savings are calculated using the following equation:

Water Saved from Evaporation per Year (ML) = K_{OW} x E_P (mm) / 100 x Mitigation Efficiency x Adoption x Surface Area (ha) x Time Full Factor

Where K_{OW} is 0.7 and E_P is 2000mm (Dalby).

The total surface area of each particular class of dam size has been estimated, but was believed to be indicative with regard to dam location and assumed purpose. The rates of adoption were accepted after discussions with the NCEA (M. Durack, E. Schmidt, *pers. comm.*, 2005).

TABLE 3 – POTENTIAL EVAPORATIVE SAVINGS FOR THE QMDB

Storage Surface Area (ha)	Total Surface Area (ha)	Product Most Applicable for Dam Size	Efficiency (%)	Time Full Factor (%)	Adoption (%)	Actual Potential Savings (ML/yr)	Evaporation Reduction (%)
0-5	5,000	E-VapCap™ / Shade Cloth	90	75	20	9,450	0.13
				50		6,300	0.09
				33		4,158	0.06
5-10	95,000	Shade Cloth	70	75	20	139,650	2.0
				50		93,100	1.3
				33		61,446	0.9
10+	400,000	Monolayers	20	75	70	588,000	8.4
				50		392,000	5.6
				33		258,720	3.7
Total	500,000						

The numbers presented in Table 3 provide an indication of the potential water savings. However, they are subject to a number of different variables unable to be accounted for in an analysis such as this. For instance, the percentage reduction in evaporation given is a comparison to the evaporation for an entire year. However, the storages are presented as having water in them for only 75, 50 and 33% of the year. In addition to this, the *time* of year that the storage has water in it will also change these values, as evaporation rates vary widely from winter to summer.

12.3. Economic Analyses

An economic analysis of the products is also important information when considering installation of these products. A simplistic economic analysis has been carried out for each product to provide ballpark comparisons but the deficiencies of this analysis are recognised. In Section 15.7, it is recommended that a sound economic analysis model be developed. This would include operating costs and repairs & maintenance. It would also include a method for taking into account changes in water surface area as the volume in a storage changes.

Providing shade cloth could be installed at $6/m^2, this is an installed cost of $60,000/ha with a design life of 15 years. ($4000/ha/year). Assuming 2000 mm E_P per year, and the shade cloth has an evaporation reduction efficiency of 70%, then it has the potential to save 14 ML/ha/yr at a cost of approximately $286/ML.

Assuming a Monolayer costing $13/kg is applied at a rate of 0.625 kg/ha every 2.5 days, the cost is approximately $1180/ha/yr if used all year round. With 2000 mm E_P and a 20% evaporation reduction efficiency this has the potential to save 4 ML/ha/yr at a cost of $295/ML.

If E-VapCap™ is installed for $8/m^2$, this equates to an installed cost of $80,000 a hectare with a design life of 15 years ($5,300/ha/year). With 2000 mm of E_P per year, and the cover preventing 90% of evaporation, then it has the potential to save 18 ML/ha/yr at a cost of approximately $294/ML.

As part of their project for the NR&M, the NCEA has undertaken detailed economic analyses of each of the mitigation measures trialled. The ranges of costs per megalitre of water saved from evaporation are listed in Table 4.

TABLE 4 – RANGE OF COSTS PER MEGALITRE ($/ML) OF SAVED WATER

Mitigation Measure	Lowest	Average	Highest
E-VapCap™	211	378	508
Shade Cloth	251	339	502
Monolayer	110	330	2,253

It is noted that if water is only stored for 6 months of the year, the cost per megalitre for each of the physical covers (E-VapCap™ and Shade Cloth) increases by a factor of 1.45. For the monolayer, the cost per megalitre *decreases* by a factor of 0.75.

As adoption rates increase and manufacturers of the reduction products are able to achieve efficiencies through economies of scale, the cost of these products would be expected to drop significantly, improving the cost effectiveness.

13. INSTITUTIONAL ISSUES

13.1. Background

The original Scope of Works for this project only addressed farm dams – that is, privately-owned storages only. 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. Who owns water savings achieved from evaporation reduction? What is the mechanism for allocation of the saved water (to the farmer or to the environment)? Is this an impediment to investment in saving evaporation? What is the attitude of water authorities to investment in reducing evaporation?

These questions were addressed by consultation with a wide range of water authorities via a questionnaire. However, with the short time frame for the project, responses from all water authorities did not arrive. Nevertheless, a best-guess synopsis of the attitude of water authorities to investment in evaporation saving is presented based on the responses obtained.

13.2. Attitude of Water Authorities

In order to determine the attitude of various water authorities, a standard letter plus questionnaire was circulated. The list of water authorities contacted is given in Appendix A. The following questions were posed.

Question 1 – Does your organisation have an estimate of the annual volume of water lost by evaporation from your water storages?

Question 2 – Does you organisation have any specific policy regarding the reduction of evaporation from water storages?

Question 3 – Has your organisation ever invested in research related to evaporation reduction or measurement and if so briefly describe the nature of this investment?

Question 4 – Does your organisation consider that cost effective evaporation reduction technology will be applied within your industry in the foreseeable future?

Question 5 – 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?

Question 6 – 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?

Question 7 – If “new” water became available, to what purpose would it be used? It could be used:

a) for environmental flows
b) to be sold as a new water allocation, or
c) to improve the reliability of existing allocations.

Question 8 – 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?

Question 9 – 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?

Responses to each question are summarised below. More complete responses are given in Appendix B.

13.3. Estimate of annual volume lost by evaporation

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

Response Summary

There were varied responses to this question, ranging from full details collected and recorded, to some being modelled but not actually collected and some having no data at all. In addition to these responses, some of the water authorities do not have open water storages and use bores and covered tanks. Therefore evaporation is not an issue to them. In general, it appeared that approximately half of the responses have no record of evaporation from their storages. The other half of the responses estimated their evaporation, modelled their evaporation losses or measured their evaporation losses. There was no detail outlining how the estimations were reached or information of modelling parameters.

13.4. Policy regarding the reduction of evaporation

Does you 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.

13.5. Investment in Evaporation Reduction / Measurement

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

Response Summary

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

13.6. 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 thought it is possible but economics is the overwhelming factor in the adoption of this technology.

13.7. 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.

13.8. 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.

13.9. Use of Saved Water through Evaporation Reduction

If "new" water became available, to what purpose would it be used? It could be used:

a) *for 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.

13.10. 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.

13.11. 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.

13.12. Summary of Water Authority Attitudes

Only one Water Authority asked to see the outcomes of our study. The lack of evaporation reduction research by water authorities shows that they have 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 made up some of the evaporative losses. However, most evaporation reduction technologies allow rainfall to enter the storage, and as such the water savings resulting from the use of evaporation reduction technology amount to a certain proportion of the *gross* evaporation.

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.

Some respondents raised the issue of water quality after the installation of evaporation reduction technology. This is a legitimate concern, which needs to be addressed upon consideration of any new evaporation reduction works. For example, as part of the project being carried out by the NCEA, monolayers are in use on a municipal (potable) water supply and this is, presumably, an acceptable system. Also, as part of the work carried out in this particular project, only one participant has carried out independent water testing to assess the effects of monolayers on water quality. This participant is a rural water user. Despite less than perfect results with their trial, they are still very keen to pursue research into evaporation reduction technology.

There appears 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 (i.e. they do not keep water for the season after next). Hence the benefits of a better depth to surface area ratio in the municipal supply dams is offset by the fact that the water may be subject to more than 1 year's evaporative loss.

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). This value is much less than what a farmer could make with that same megalitre. For instance, water authorities may sell their water for $10-50/ML, whereas farmers may be able to generate up to $50,000/ML (M. Durack, *pers. comm.*, 2005). Hence the ability of water authorities to pay for evaporation reduction technology is much less than a farmer, in terms of return on investment.

There seemed to be good confidence in the legislative ownership of water along the supply chain. However responses to the final question were somewhat superficial (maybe due to a perception that the question was academic in nature).

The interest from rural water users into saving water from evaporation seems to be greater than that from water authorities. FSA Consulting clients, through an interest in accurate farm water measurement, have displayed this. This may be due to the fact that the benefits of investment in evaporation reduction are more tangible in a rural production setting.

14. KNOWLEDGE GAPS

The following is a summary of the areas where insufficient knowledge currently exists on evaporation reduction from farm dams in Australia.

14.1. Actual Evaporation Loses from Farm Dams

Almost a quarter of a century ago, Weeks (1983) noted that "*considering the importance of evaporation in the water balance of reservoirs, it is surprising that so few detailed research projects have studied the problem*". Little has changed.

Our estimate of evaporation loss from farm dams in the Queensland Murray Darling Basin alone is 7,040 GL/yr. Despite the size of this major loss, there are no good-quality studies where evaporation (and seepage) has actually been measured from farm dams in Australia. In the past, this has been technically extremely difficult due to the need to measure all of the inflows and outflows very accurately. With the PST technology developed by NCEA, the opportunity exists to undertake long-term, good-quality studies. Good-quality evaporation and seepage data could allow rational decisions to be made about various evaporation reduction options, particularly making ring tanks deeper.

14.2. Calculation of Evaporation from Farm Dams

All evaporation estimates from farm dams are based on questionable assumptions. It is generally agreed that open water pan coefficients with Class 'A' pan evaporation is a poor method for estimating actual evaporation losses from farm dams. Similarly, theoretically-based formulae that use meteorological data are designed to estimate the evapotranspiration loss from extensive grass surfaces, not open water in an isolated farm dam. It is known that, as well as the usual meteorological parameters, actual evaporation from farm dams is also dependent on advected heat from surrounding areas and thermal storage in the water body. Condie and Webster (1997) have provided a theoretical model for this but this remains in the realm of academics. The Condie and Webster model should be made available to practitioners in a more suitable form.

14.3. Number of Farm Dams in Australia

There is simply no good data on the number, capacity, surface area, geographic location and usage of farm dams in Australia. Without this data, the true significance of the magnitude of evaporation losses (and potential reductions) cannot be made.

14.4. Practical Solutions

A number of evaporation reduction systems have been shown to be effective at a laboratory scale but fail in the field due to practical construction and maintenance issues. Research is needed on practical, durable solutions.

14.5. Effectiveness of Partial Covers

It is sometimes suggested that a farm dam could be partially covered due to either economic or physical constraints on full coverage. However, there is no data to support the contention that a 50% coverage will have 50% of the effect of full coverage. It could be that thermal transfers within the water storage would reduce the net effect. If partial coverage is promoted, it should be supported with factual evidence.

14.6. Ecosystem Modification

There is no doubt that evaporation reduction systems must alter the ecosystem within a farm dam. Evaporation reduction systems add chemicals, exclude light, exclude oxygen or alter thermal environments. They potentially exclude wildlife such as birds and amphibians. There is no understanding about whether these changes are beneficial or not.

14.7. Economic Analysis

It is generally agreed that evaporation reduction systems are economically viable in situations of high evaporation, high-value water and/or high value crops. It is unclear when evaporation reduction systems become economically unviable. There is no simple economic tool available for farmers to use to determine if an evaporation reduction system is appropriate for their situation.

15. RECOMMENDATIONS FOR FUTURE RESEARCH

15.1. Farm Dam Focus

When undertaking this review, both farm dams and larger water-authority storages were included. It is our opinion that further research should focus primarily on farm dams rather than water-authority storages. The reasons for this recommendation are as follows.

1. Most current methods of evaporation reduction have practical installation or maintenance issues that limit their ability to cover wide distances effectively. Hence, it is far more likely that viable solutions for evaporation control will be found for smaller farm dams compared to larger water-authority dams. Solutions are currently viable for dams < 2ha in area but this needs to be increased to dams of up to at least 40 ha area.
2. Many responses from water authorities noted that they have multiple uses for their storages including recreational activities. The current evaporation reduction products could not be used on storages where recreation activities occur.
3. On average, farm dams are shallow compared to water-authority storages. Hence, the evaporation loss, as a percentage of the total storage capacity, is likely to be higher for farm dams. Hence, the benefits of employing evaporation reduction systems are likely to be better.
4. Farm dams are usually privately owned and there are no regulatory or bureaucratic impediments to actions on evaporation reduction.
5. For farm dams, the economic assessment of the viability of an evaporation reduction system can be done on a single case basis, usually with a single crop in mind. For a water authority, it is probable that the water will be used for a range of crops or other uses. As such, the economic viability of an evaporation reduction system would be based on the average cost of water, not the highest value crop.
6. In many cases, concerns were raised by water authorities about the impact of evaporation reduction systems on water quality. Evaporation reduction systems could add costs to these authorities if water treatment costs increase.

15.2. Long-term Evaporation Data Collection and Modelling

Long-term good-quality evaporation (and seepage) measurements from farm dams across Australia should be undertaken. Specifically, the activities to be undertaken should include:

- The PST technology developed by NCEA needs further development to make the technology robust, reliable and durable for long-term data acquisition usage in a wide range of climatic conditions.

- The methodology for separation of seepage from evaporation using the PST technology needs to be experimentally validated using paired trials in field scale experiments. The issue of night time evaporation needs to be theoretically and experimentally addressed. The theoretical work of Condie and Webster should shed light on the issue of night time evaporation rates.

- The improved PST equipment should be installed in a series of farm dams across Australia in situations where there are nearby evaporation pans and/or automatic weather stations. Data should be collected for at least one full year (summer and winter conditions).

- Using the data collected above and an improved theoretical understanding of evaporation from isolated farm dams, formulae for calculating evaporation from farm dams using automatic weather station data should be developed.

15.3. Evaporation Terminology

Evaporation definitions for ET_O and Open Water Storages, $E_{OW,}$ should be added to ANCID Rural Water Industry Terminology and Units.

15.4. Automatic Weather Stations

With the proliferation of automatic weather stations, there is a requirement for standardisation and calibration so that the data collected can be trusted. It is recommended that an Australian Standard be developed to define the instrumentation, calibration and calculation methods for automatic weather stations used for evaporation estimations. The basis for standard calculations should be taken from Meyer (1999) and Meyer *et al.* (1999).

15.5. Lack of Adoption

While there has been research into evaporation reduction technologies for many years, the level of adoption is very poor. This is despite the now-agreed view that some systems are economically viable for high-value crops.

The reasons for the lack of adoption should be investigated. They could be:

- Lack of awareness by farmers that the technology even exists.
- Lack of belief that practical and durable technologies exist.
- Lack of belief that real evaporation savings can be made.
- Lack of belief that any system is economically viable.

If the reasons for the lack of adoption can be understood, then research could be better targeted.

15.6. Selection of Appropriate Systems

Although it can be argued that different evaporation reduction systems suit different applications, it is clear that some systems have already been researched and further public investment is not warranted. This includes aquatic vegetation and airtight covers.

Monolayers have a long history and, apparently, poor success. However, as the value of water increased, the economic viability of monolayers might improve. Furthermore, monolayers, while imperfect, may be the only solution for large and irregularly-shaped storages. Before further publicly-funded research into monolayers is undertaken, it is recommended that:

1. An economic analysis is undertaken to determine under which circumstances monolayers become economically viable.
2. A detailed literature review should be undertaken of the considerable research data that exists for monolayers. This literature review should provide lessons that have been learnt from past experience and it should ensure that previous work and mistakes are not repeated.

It is recommended that further research concentrate on floating modular covers and shade cloth systems as these offer the best potential to provide an economically viable solution for small to medium sized farm dams.

15.7. Economic Ready - Reckoner

It is clear that concerns about economic viability are a deterrent to adoption of the technology. It is also clear that evaporation reduction technology is economically viable in some circumstances. It is recommended that a fairly-simple economic 'ready-reckoner' be developed (e.g. as an Excel spreadsheet) to allow farmers to determine under what circumstances an evaporation reduction system would be economically viable for them. The economic model would include:

- Details of the farm dam (capacity, depth, surface area).
- Local climatic data (rainfall, evaporation).
- Estimate of operating conditions of the storage (e.g. % of time when water is in storage, change in surface area).
- Capital, operating and repairs & maintenance cost of the evaporation reduction system.
- Estimated life of the components of the system.
- Estimate of the evaporation reduction efficiency of the system selected.
- Current value of alternative water ($/ML).
- Current gross margin ($/ML & $/ha) for the crop grown.
- Appropriate interest rates.

When all of these (and probably other) parameters are included in an economic analysis, a better understanding of when systems become economically viable will emerge.

15.8. Economic Incentives for Irrigators

Once, the PST technology has been further developed to a more field-practical level, considerable data could be collected if farmers installed the equipment in their farm dams. It is recommended that economic incentives, such as devolved grants that were used under the rural water use efficiency scheme, be explored to promote rapid adoption of this technology.

15.9. Effect on ecosystems

In general, the effect of evaporation reduction systems on ecosystems in and around farm dams needs investigation before widespread adoption of the technology can be recommended. In particular, if evaporation reduction systems are to be applied to drinking water storages, the effects on ecosystems and water quality need to be researched.

15.10. Seepage versus Evaporation

The issue of alteration of dam configuration (deeper ring tanks, internal cells) needs to be thoroughly investigated. We have postulated that the savings in evaporation may be offset by increased seepage but there is no evidence to support the contention either way. It is strongly recommended that long-term studies of actual evaporation from farm dams include an assessment of seepage losses.

15.11. Potential Researchers / Research Groups

Apart from NCEA, it is clear from the lack of evaporation research currently occurring in Australia that research capacity is limited. Table 5 gives a list of possible researchers for different research areas.

It is recommended that, for any future research in this area, there is a balance in the research team between highly, technically-skilled researchers (such as CSIRO and university staff) and practitioners (such as consulting engineers and farmers).

TABLE 5 – POSSIBLE RESEARCHERS FOR FARM DAM EVAPORATION WORK

Research Areas	Possible Researchers
Micrometeorology – fundamental analysis	CSIRO, ANU, USQ (Nigel Hancock)
Dam Evaporation Monitoring Technology	NCEA, Aquatech, FSA Consulting
Dam Design and Performance Assessment	FSA Consulting, Aquatech
Monolayer Development and Applications	NCEA, Nalco, UQ (Geoff Barnes)
Shade Cloth Designs	Netpro, Civil Consulting Engineers
Floating Covers	Evap-Cap, Darling Downs Tarpaulins
Policy Considerations	CRC for Irrigation Futures
Environmental Implications	CRC for Irrigation Futures, MDBC Fresh Water Ecology Labs
Economic Analysis	NCEA, CRC for Irrigation Futures
Modular Floating Covers	NCEA, Ian Burston

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Appendix A. LIST OF WATER AUTHORITIES CONTACTED

Water Authority	Response Received
ACTEW Corporation	✗
Barwon Water	✓
Boondooma Water Board	✗
Callandoon Water Supply Board	✓
Central Highlands Water	✗
Central Irrigation Trust	✓
City West Water	✗
Coleambally Irrigation	✓
Coliban Water	✗
Condamine Plains Water Board	✗
Cradle Coast Water	✗
Crowley Vale Water Board	✗
Department of Land & Water Conservation	✗
Department of Natural Resources & Mines, QLD	✓
Dept of Natural Resources & Environment	✗
East Gippsland Water	✓
East Kimberley District Water Corporation	✗
Esk Water Authority	✗
First Mildura Irrigation Trust	✓
Gippsland Water	✗
Gladstone Area Water Board	✓
Glamorgan Vale Water Board	✓
Glenelg Regional Water Authority	✗
Goulburn- Murray Water	✗
Goulburn Valley Water	✓
Grampians Wimmera Mallee Water Authority	✓
Harvey Water	✓
Hobart Water Authority	✗
Hunter Water Corporation	✓
Lethebrook Water Board	✗
Lower Murray Water	✓
Melbourne Water	✓
Mount Isa Water Board	✗
Mulgildie Water Board	✗
Murray Irrigation Ltd	✓
Murrumbidgee Irrigation	✓
North Burdekin Water Board	✗
North East Water	✗
Ord Irrigation Co-operative	✗
Palmgrove Water Board	✗
Pioneer Valley Water Board	✗
Portland Coast Water	✓
Power and Water	✗
River Murray Water	✗

Riversdale-Murray Valley Water Management Board	×
SA Water	✓
SEQ Water	×
South Burdekin Water Board	×
South East Water	×
South Gippsland Water	✓
South West Water Authority	✓
Southern Rural Water	✓
State Water	✓
State Water DLWC	×
SunWater	✓
Sydney Water Corporation	✓
Water Corporations	×
West Gippsland Catchment Management Authority	✓
Western Water	×
Westernport Water	✓
Yambocully Water Board	×
Yarra Valley Water	×
TOTAL RESPONSES RECEIVED	**27/61**

Appendix B. RESPONSES FROM WATER AUTHORITIES

16.1. Estimate of annual volume lost by evaporation

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

Barwon Water – Barwon Water does not have an accurate estimate of the annual volume lost by evaporation from water storages.

Callandoon Water Supply Board – The Board have no storages – the property owners have storages.

Central Irrigation Trust – The nine irrigation districts managed by our business do not include storages or dams. We pump direct from the River Murray through closed pipeline schemes that provide fully metered supplies to our 1800 irrigation customers.

Coleambally Irrigation Co-Operative Ltd – CICL have no specific storages other than the extensive channel system. We do not have an estimate of evaporation losses from the system.

Department of Natural Resources and Mines, QLD – No data on evaporation on the small number of storages that the Dept. owns. The Dept. Rural Water Use Efficiency Initiative has estimated that there is a total capacity of 2500 GL in farm storages around Queensland, and estimates are that around 40-50% of capacity is lost to evaporation.

East Gippsland Water – 420 ML/year less 280 ML/year rainfall = 140 ML/year loss (however 420 ML actual evaporation).

First Mildura Irrigation Trust – ~ 50 ML/year at present. 800 ML storage proposed, which will have an estimated 230 ML/year loss to evaporation.

Gladstone Area Water Board – An estimate of evaporation is included in our model of Awoonga Dam.

Glamorgan Vale Water Board – All storages covered (tanks) and hence evaporation is negligible.

Goulburn Valley Water – Yes, we estimate about 690 ML/annum gross loss to evaporation, from about 26 small reservoirs and town storages spread over about 20 000 sq. km.

Grampians Wimmera Mallee Water Authority – Significantly reduced due to drought as storages get lower and surface area reduces. This is estimated for forward planning, but is a moving target. We measure Class A pan evaporation at one of our storages and we use this to estimate reservoir evaporation.

Harvey Water – We estimate it as about 10% of the volume at the start of the summer irrigation season.

Hunter Water Corporation – Evaporation is explicitly allowed for in Hunter Water's modelling programs. Surface water evaporation is estimated to be in the order of 30 GL/year.

Lower Murray Water – The Authority sources water from the Murray River and does not own or manage any open storage related to the provision of domestic potable water. However, the Authority does manage an off river storage (Lake Cullulleraine) which holds water for stock and domestic supply, irrigation and recreational purposes. Losses from this storage due to seepage and evaporation may be in the order of 4000 ML/annum.

Melbourne Water – Melbourne Water monitors the evaporation at the location of a majority of Melbourne's storage reservoirs. The measured evaporation rates assist in estimating the volume of water lost from the storages.

Murray Irrigation Ltd – Murray Irrigation Ltd has 3800 km of open channels which are subject to evaporation losses but do not have any company owned storages therefore questions 1 to 5 are not applicable.

Murrumbidgee Irrigation – The Company does keep records and estimates of the volume lost to evaporation for its storages. In addition a detailed surface water balance model was undertaken with the aim of assessing methods to improve the operating efficiency of the system.

Portland Coast Water – All storages are covered and water supply from bores, so very little evaporation.

SA Water – SA Water keeps daily records of evaporation at its major reservoir sites and uses these to calculated water lost by evaporation from its water storages.

Southern Rural Water – No. Although evaporation readings are forwarded to the BoM who may calculate those figures.

South Gippsland Water – We do not have any estimates of annual evaporation losses.

South West Water Authority – We do have estimations on the evaporation on all our storage and it is calculate and costed on an annual basis.

State Water (NSW) – We report annually on the evaporation from each of our water storages. We can source long-term evaporation data from DIPNR for each of our storages.

SunWater – SunWater undertakes regular water balances accounting of inflows, outflows and losses.

Sydney Water – Sydney Water's reservoirs are either covered or belowground, and therefore have no information available to assist in your study.

West Gippsland Catchment Management Authority – No. The CMA does not own or operate any storages.

Western Port Water – Yes.

16.2. Policy regarding the reduction of evaporation

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

Barwon Water – There is no policy regarding the reduction of evaporation from water storages although this will be one of the benefits of our strategy to move towards a closed distribution system. Several of our large service basins will be covered or replaced

Callandoon Water Supply Board – N/A.

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – No.

Department of Natural Resources and Mines, QLD – The Dept. has a policy of encouraging re-use, re-cycling and efficiency improvements before new storages. With the introduction of the Water Act 2000, the maximum height of a non-referable dam has been increased from 5 m to 8 m, thus encouraging deeper farm dams that will reduce evaporation losses as a proportion of stored volume.

East Gippsland Water – No specific policy. Plans to cover many storages over next few years, which will halve evaporation loss (estimate).

First Mildura Irrigation Trust – No specific policy as losses are offset by bulk entitlements allocation which includes factors for losses.

Gladstone Area Water Board – GAWB has no specific policy in respect to evaporation from Awoonga Dam. All other storages are fully roofed.

Glamorgan Vale Water Board – N/A.

Goulburn Valley Water – No specific policy.

Grampians Wimmera Mallee Water Authority – Yes, to try and keep water in the storages that have the best volume to surface area ratio. Some of our storages are empty for this reason, in addition to record low inflows for the past nine years.

Harvey Water – No.

Hunter Water Corporation – No explicit policies regarding the reduction of surface water evaporation, however, Hunter Water utilisation strategies incorporate evaporation in models to minimise the risk of water shortage.

Lower Murray Water – No.

Melbourne Water – Melbourne Water keeps a watching brief on the evaporation reduction measures, as well as other technological advances that enable a more efficient management of Melbourne's water resources. Melbourne Water also covers major service basins for water quality purposes, which assist in reducing evaporation losses.

Murray Irrigation Ltd – N/A.

Murrumbidgee Irrigation – No specific policy regarding evaporative losses from water storages. However, guiding principles are in place to provide an integrated approach to address system losses, of which evaporation is part.

Portland Coast Water – N/A.

SA Water – SA Water does not have a specific policy regarding the reduction of evaporation from water storages. However, evaporation loss is one of the parameters that is considered in the overall optimisation of the major water pumping and transfer systems.

Southern Rural Water – No.

South Gippsland Water – We don't have any specific policies on evaporation.

South West Water Authority – It is an issue that has been reviewed and discarded on the Net Present Value (NPV) cost.

State Water (NSW) – The storages and water supply systems are operated in a manner that minimises storage evaporation. This policy has the biggest impact in valleys with downstream off-river storage. These storages are used to satisfy demand rather than supplying from the more efficient upstream storages.

SunWater – No.

Sydney Water – N/A

West Gippsland Catchment Management Authority – No.

Western Port Water – The Authority has covered all service storages. It has no plans to cover the new water storage/reservoir.

16.3. Investment in Evaporation Mitigation / Measurement

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

Barwon Water – No.

Callandoon Water Supply Board – No.

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – No.

Department of Natural Resources and Mines, QLD – The Dept. has engaged the National Centre for Engineering in Agriculture (NCEA) to conduct trials on evaporation mitigation from farm dams.

East Gippsland Water – No. However EGQ are participating in a study to measure the benefits of shade cloth on our storages.

First Mildura Irrigation Trust – No.

Gladstone Area Water Board – No.

Glamorgan Vale Water Board – N/A.

Goulburn Valley Water – No.

Grampians Wimmera Mallee Water Authority – No.

Harvey Water – No.

Hunter Water Corporation – No. However, we have considered a number of propositions in the past, none of which have been feasible for the scale the Corporation would be looking at.

Lower Murray Water – No.

Melbourne Water – Melbourne Water monitors evaporation at most of its storage reservoirs.

Murray Irrigation Ltd – N/A.

Murrumbidgee Irrigation – No.

Portland Coast Water – N/A.

SA Water – SA Water has undertaken investigations to determine operating strategies aimed at minimising evaporation losses in response to reduced allocations for pumping from the River Murray due to drought conditions. SA Water has also investigated modelling approaches for the inclusion of evaporation losses in its operations optimisation systems.

Southern Rural Water – No.

South Gippsland Water – We have not investigated any research in evaporation.

South West Water Authority – Our investment in evaporation is the installation of Class A pans at all our reuse sites and the monitoring and recording of the data weekly.

State Water (NSW) – No significant investment.

SunWater – Most of the research is associated with distribution of water through channel systems.

Sydney Water – N/A.

West Gippsland Catchment Management Authority – No.

Western Port Water – Yes. The Authority invested in research as part of analysing its long term water supply options.

16.4. Evaporation Mitigation Technology Application

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

Barwon Water – Barwon Water is no aware of any evaporation mitigation technology currently being considered by the industry.

Callandoon Water Supply Board – Yes.

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – Possibly. Yet to be proven.

Department of Natural Resources and Mines, QLD – Depends largely on the final results of the NCEA trials.

East Gippsland Water – No as I believe that cost effective technologies do not exist as yet.

First Mildura Irrigation Trust – Would be interested if savings for mitigation were economically achievable. At present losses have not warranted such investigation works.

Gladstone Area Water Board – Awooga Dam covers 6700 ha, and as such mitigation technology is not likely to become cost effective in the foreseeable future.

Glamorgan Vale Water Board – N/A

Goulburn Valley Water – Yes, for systems where the value of water is high enough to warrant evaporation mitigation technology.

Grampians Wimmera Mallee Water Authority – Not for large storages.

Harvey Water – Unlikely given large surface areas. Interested to see trials.

Hunter Water Corporation – We would envisage adopting technology that is environmentally appropriate and cost effective. However, Hunter Water doubts that this will occur in the foreseeable future, as the major water source covers an area of approx. 25 sq. km.

Lower Murray Water – Yes, particularly if risk or perceptions about potential environmental risk can be addressed.

Melbourne Water – This is a speculative question. Melbourne Water maintains a watching brief on research trends to ensure we are aware of the latest technology.

Murray Irrigation Ltd – N/A.

Murrumbidgee Irrigation – In the long period of R & D into evaporative losses, very few cost effective technologies have been developed for large storages. It is difficult to see cost effective technology being developed in the near future.

Portland Coast Water – N/A

SA Water – Clearly SA Water already considers cost effective evaporation mitigation in the development of its operating strategies. SA Water is aware of technology developments in development of surface applications to reduce evaporation.

Southern Rural Water – No.

South Gippsland Water – We consider it unlikely that cost effective evaporation methods will be employed in South Gippsland.

South West Water Authority – No.

State Water (NSW) – Maybe, the technology would also need to be sensitive to the environment of the storages and the downstream systems.

SunWater – If the value of water saved exceeds the cost of technology application then industry will make the investment.

Sydney Water – N/A

West Gippsland Catchment Management Authority – No.

Western Port Water – It may be possible.

16.5. Impediments to Evaporation Mitigation 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?

Barwon Water – It would need approval for use in potable water supplies.

Callandoon Water Supply Board – No idea. Nature is an unknown factor!

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – None. Current arrangements facilitate that the party investing in the water saving receives the benefit of the water saving initiative i.e. CICL invests in a water saving initiative then the water saved could be distributed to our customers.

Department of Natural Resources and Mines, QLD – There are no institutional or regulatory impediments to adoption.

East Gippsland Water – No impediments.

First Mildura Irrigation Trust – None.

Gladstone Area Water Board – Refer to Q4. Project evaluation to Departmental requirements

Glamorgan Vale Water Board – N/A

Goulburn Valley Water – I am not aware of institutional impediments. A regulatory impediment could be demonstrating that there are no deleterious effects on consumption of the water.

Grampians Wimmera Mallee Water Authority – Other than for the recreational value of our storages (boating, fishing), there would be no impediment. Economics must include operating and maintenance costs.

Harvey Water – No control over water resource (owned by the Water Corporation)

Hunter Water Corporation – Depending on the technology available, the regulatory hurdles include: Environmental Planning and Assessment Act (requires an environmental impact assessment), Protection of the Environment Operations Act (requires that the operation of the system did not impact on water quality, air quality or pollute the surrounding environment, Hunter Water (Special Areas) Regulation (specifies a range of activities that can and cannot be undertaken within the water supply catchment area.

Lower Murray Water – None that we are aware of, the Victorian Government White Paper, *Securing our Water Future Together* is supportive of measures which result in water savings.

Melbourne Water – The institutional or regulatory impediments would be dependent on the potential short and long-term consequences of applying evaporation reduction measures. The majority of Melbourne's water supply is unfiltered. Therefore there would be a range of water quality and public health requirements to be assessed prior to adopting the technology.

Murray Irrigation Ltd – N/A.

Murrumbidgee Irrigation – Difficult to answer not knowing what the technology is. However any option would be assessed on its merits and would consider operational constraints, O&M costs, lifecycle and environmental impacts such as water quality.

Portland Coast Water – N/A

SA Water – SA Water would consider any development of new technology in this area provided it was economically viable, did not impact on water quality or the environment and was acceptable to our customers and community considerations.

Southern Rural Water – Probably none, although it would depend on the type of technology available, its impact on water quality and our role in flood management.

South Gippsland Water – If the solution is chemically based there may be an increased risk to drinking water. The action of sun and wind currently provides some treatment prior to our treatment plants.

South West Water Authority – The biggest regulatory impediment would more than likely be in the realms of OH&S for the operation staff. The approach of the Board would most likely be very favourable.

State Water (NSW) – The implementation of the technology may trigger a range of environmental legislation, i.e. environmental impact assessments, due to changes in water quality, temperature, aquatic habitat, etc.

SunWater – SunWater holds loss entitlements for its distribution systems which include balancing storages. SunWater does not hold any loss entitlements associated with major storages.

Sydney Water – N/A

West Gippsland Catchment Management Authority – Don't know.

Western Port Water – It depends on the method of mitigation, but the usual environment, health and water quality hurdles would have to be satisfied.

16.6. Ownership of Water Saved through Evaporation Mitigation

Question 6 – 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?

Barwon Water – If "new" water became available it would be owned by Barwon Water.

Callandoon Water Supply Board – N/A. The property owner – it's his water, no one else's!

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – CICL has as part of its bulk water licence a specific component for losses. A water saving would facilitate the activation of a portion of that loss allowance (equivalent to the water saving) to other consumptive purposes. CICL's shareholders (the same as CICL's customers) would effectively own the water. It is not new water but a rebadging as such.

Department of Natural Resources and Mines, QLD – Any water efficiency gains remain with the infrastructure owner.

East Gippsland Water – Whoever funds the water saving technology would own the water.

First Mildura Irrigation Trust – Ownership belongs to those who bear costs, in proportion to amount of funding provided.

Gladstone Area Water Board – No policy. In essence the Government, who issue allocations for water use would own the water.

Glamorgan Vale Water Board – N/A

Goulburn Valley Water – No.

Grampians Wimmera Mallee Water Authority – Who ever pays for the works is entitled to the savings. For example the environment receives an entitlement from the new Northern-Mallee pipeline due to the money that the State and Federal Government contributed to the pipeline. With the MDBC cap in place the only "new" development can only come from selling the saved water that we paid for in the pipeline.

Harvey Water – Any water in the dams is owned by the licensees. Any water saved would be shared amongst the licensees.

Hunter Water Corporation – The water access licence held by Hunter Water with the NSW DIPNR is structured such that any water saved would be owned by Hunter Water. Hunter Water owns and operates both of the dams that it uses.

Lower Murray Water – No, however we question the assertion that the technology would generate "new" water, more likely this would generate saved water. If the water has been delivered to on-farm storage through a bulk entitlement, this water is owned and any savings made here would be owned by the end user. If the savings are made at major dams such as Lake Dartmouth (where the allocation process commences), then saved water could be considered "new" water and could be traded to users. In this case the storage owner would own the saved water.

Melbourne Water – Policies on the ownership of water are formulated by the State Government. The Department of Sustainability and the Environment is the responsible authority.

Murray Irrigation Ltd – If the company generated "new" water the company would own the water and use it to improve the reliability of existing allocations.

Murrumbidgee Irrigation – The Company would own the "new" water saved from storages owned and operated by the Company.

Portland Coast Water – N/A

SA Water – I am unable to comment on this question at this stage. SA Water would need to consider its position in regard to any proposed legislative or regulatory developments with regard to evaporation losses.

Southern Rural Water – Yes, i.e. the Bulk Entitlement arrangements.

South Gippsland Water – We don't have a policy on who would own the water.

South West Water Authority – Yes. The entire infrastructure is owned by the Authority as would the "new" water.

State Water (NSW) – State Water operates within the National and NSW framework that suggests whoever makes the investment gets the savings. However, resolving ownership, amending Water Sharing Plans, and issuing entitlements may be a significant barrier to such a proposal.

SunWater – In Queensland membership of any water savings for major storages would have to be negotiated with NR&M who are responsible for catchment water resources plans and the allocation of water.

Sydney Water – N/A

West Gippsland Catchment Management Authority – No.

Western Port Water – Refer to the (Victorian) Government's White Paper for details of ownership.

16.7. Use of Saved Water through Evaporation Mitigation

Question 7 – If "new" water became available, to what purpose would it be used? It could be used:

- ❑ for environmental flows
- ❑ to be sold as a new water allocation, or
- ❑ to improve the reliability of existing allocations.

Barwon Water – It would be used to improve the reliability / security of existing allocations.

Callandoon Water Supply Board – N/A. Expand the acreage cropped.

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – Probably c), but this would be a determination made by the Board.

Department of Natural Resources and Mines, QLD – It would be a matter for the infrastructure owner, but would have to be within the terms of the relevant Resource Operation Plan and Resource Operation Licence.

East Gippsland Water – All are obvious beneficiaries, however return on investment may be required.

First Mildura Irrigation Trust – Depends on stakeholder interest. First priority is environmental flows, then possibly income through trading the saved water (temporary or permanent)

Gladstone Area Water Board – Improve reliability of existing allocations.

Glamorgan Vale Water Board – N/A

Goulburn Valley Water – This has not been addressed by GVW. However, I expect the "new" water would be used to reduce the raw water extractions, which would improve reliability of existing allocations. Increasing environmental flows would be subject to directions from the Dept. of Sustainability and Environment.

Grampians Wimmera Mallee Water Authority – This is solely up to the person/organisation that came up with the funds to generate the water savings. If it was Government, then the water would most likely go to the environment. If we paid, either to new users or improving the security of existing entitlements.

Harvey Water – All options are possible, depending on dam purpose.

Hunter Water Corporation – Evaporation reduction would presumably allow the next source augmentation to be deferred by increasing the yield. In addition, the evaporation reduction would increase the reliability of supply in a long drought.

Lower Murray Water – An end user could temporarily or permanently trade the savings. Savings could be used to expand production or to supply urban growth (in the case of an Authority). For large storages such as Lake Dartmouth, all of the above uses could be possible.

Melbourne Water – Under the ongoing water reforms, the ownership of water resources will be allocated to Melbourne's three retail water companies and the environment. The State Government, in consultation with the stakeholders, would make any decisions on the ownership of any new water.

Murray Irrigation Ltd – If the company generated "new" water the company would own the water and use it to improve the reliability of existing allocations.

Murrumbidgee Irrigation – Use ultimately determined by the Board of Directors, subject to meeting contractual obligations to shareholders.

Portland Coast Water – N/A

SA Water – I am unable to comment on this question at this stage. SA Water would need to consider its position in regard to any proposed legislative or regulatory developments with regard to evaporation losses.

Southern Rural Water – It depends according to storages, for some used for irrigation it could be used to improve reliability of existing allocations. For others, it would be decided at a DSE level (Department).

South Gippsland Water – The "new" water would improve reliability of supply to customers.

South West Water Authority – A) We have no water suitable for environmental flows and draw on surface water supply. B) This "new" water would be part of the saleable supply. C) The losses sustained would not be sufficient to alter the reliability of existing supply.

State Water (NSW) – All of these options are possible.

SunWater – Subject to above SunWater would seek a return on any investment through sale of allocation.

Sydney Water – N/A

West Gippsland Catchment Management Authority – Not b)!

Western Port Water – Refer to the (Victorian) Government's White Paper for details of the allocation of water.

16.8. Legislative Impediments to Water Saving Technology

Question 8 – 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?

Barwon Water – If Barwon Water did not own the water, it would be a significant deterrent to investment in the technology.

Callandoon Water Supply Board – What a preposterous idea!

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – Yes, unless someone else invested in the saving. No incentive whatsoever if the party making the investment didn't receive the benefit.

Department of Natural Resources and Mines, QLD – Not applicable to NR&M.

East Gippsland Water – Why would EGW invest in technology that will not benefit EGW?

First Mildura Irrigation Trust – Unless the Trust became the owner of the water, or through agreement with the Government, then status quo would prevail.

Gladstone Area Water Board – Not necessarily. However, business case for investment much more difficult as benefits are more tangible.

Glamorgan Vale Water Board – N/A

Goulburn Valley Water – Not if there was a proven benefit to GVW.

Grampians Wimmera Mallee Water Authority – It would be hard to justify to our customers if there was no benefit to them through either increased income from selling the water or improvements to our security of supply. We are obliged to run as a business and cannot be expected to make large scale investments without a return being available. So it would be an impediment.

Harvey Water – Yes. If we put up some of the funds for the technology we expect to share in the benefits.

Hunter Water Corporation – The issues raised are not relevant to Hunter Water Corporation.

Lower Murray Water – Investment in developing water saving technologies, we expect, would occur irrespective of who owns the water saved. However, if an individual or Authority did not own the water saved in its own storages, it is hard to imagine that they would utilise technologies to save evaporative losses as there would be no opportunity for gain.

Melbourne Water – Melbourne Water is a government owned business, as are Melbourne's three retail water companies. Investment on preserving or protecting the water resources currently falls under Melbourne Water's responsibility.

Murray Irrigation Ltd – Yes.

Murrumbidgee Irrigation – N/A, given the response to Q6 and 7.

Portland Coast Water – N/A

SA Water – I am unable to comment on this question at this stage. SA Water would need to consider its position in regard to any proposed legislative or regulatory developments with regard to evaporation losses.

Southern Rural Water – No.

South Gippsland Water – Unless there was a clear advantage to us (see Q5) we would be against other people "controlling" our storages.

South West Water Authority – Yes.

State Water (NSW) – It would be an impediment to State Water making the investment. It may not preclude other agencies making the investment, or other joint ventures taking up the investment.

SunWater – Dependent on negotiations with NR&M.

Sydney Water – N/A

West Gippsland Catchment Management Authority – N/A

Western Port Water – No. Refer to the (Victorian) Government's White Paper for investment in water saving directions.

16.9. Outside Investment in Evaporation Reduction Technologies

Question 9 – 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?

Barwon Water – Before adopting any technology, consideration needed for impacts on water quality, environmental benefits, capital costs, operational and maintenance costs, and savings due to deferral of future augmentations.

Callandoon Water Supply Board – Years away!

Central Irrigation Trust – N/A.

Coleambally Irrigation Co-Operative Ltd – Yes. CICL has the capacity to negotiate such an outcome.

Department of Natural Resources and Mines, QLD – Not applicable to NR&M.

East Gippsland Water – No specific mechanism. EGW free to form business partnerships provided business was relevant to core functions.

First Mildura Irrigation Trust – Yes. It would help if the process was accredited or approved by the relevant State Government to fast track any outcomes from this work.

Gladstone Area Water Board – Any new investment would have to be carried out through the normal tendering process.

Glamorgan Vale Water Board – N/A

Goulburn Valley Water – There is no formal mechanism. The normal approach would be for officers to submit a justification case for Board adoption.

Grampians Wimmera Mallee Water Authority – Address each proposal on its merits, with a key requirement that it would not disadvantage existing entitlement holders. We would also be loath to allow someone to do this if their plan was to then on sell the water for commercial gain. The final decision would be made on whether or not we believed the project to be viable.

Harvey Water – Yes – depending on costs and reliability of shares expected.

Hunter Water Corporation – Would consider any proposition on its merits. However, serious consideration would only be given to well prepared and scientifically substantiated propositions.

Lower Murray Water – If the business plan and technology produced a positive outcome for the Authority a standard contractual arrangement could be entered into.

Melbourne Water – This would be assessed on a case-by-case basis.

Murray Irrigation Ltd – Yes. Murray Irrigation has set up a business unit to investigate proposals from investors.

Murrumbidgee Irrigation – Any approach to the company would be considered by the Company on its merits. Any further development of business opportunities would need consideration from the Board.

Portland Coast Water – N/A

SA Water – I am unable to comment on this question at this stage. SA Water would need to consider its position in regard to any proposed legislative or regulatory developments with regard to evaporation losses.

Southern Rural Water – Yes.

South Gippsland Water – We don't have a mechanism but are always interested in improving our services.

South West Water Authority – The investor would have to have a proven plan and be subject to the Authority's tender process, depending on the capital cost. We have had joint venture projects in the past where resource sharing has been to the benefit of both parties.

State Water (NSW) – Yes, State Water could be the proponent and seek regulatory approval.

SunWater – The nature of the investment required and returns would have to be carefully considered in relation to regulatory requirements.

Sydney Water – N/A

West Gippsland Catchment Management Authority – N/A

Western Port Water – Refer Question 8.