Controlling Evaporation Loss from Water Storages

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EXECUTIVE SUMMARY

Evaporation losses from on-farm storage can potentially be large, particularly in irrigation areas in northern New South Wales and Queensland where up to 40% of storage volume can be lost each year to evaporation. Reducing evaporation from a water storage would allow additional crop production, water trading or water for the environment. While theoretical research into evaporation from storages has previously been undertaken there has been little evaluation of current evaporation mitigation technologies (EMTs) on commercial sized water storages.

This project was initiated by the Queensland Government Department of Natural Resources and Mines (NRM) with the express aim of addressing this gap in our knowledge. Its focus was on;

- Assessment of the effectiveness of different EMT's in reducing evaporation from commercial storages across a range of climate regions.
- Assessment of the practical and technical limitations of different evaporation control products.
- Comparison of the economics of different EMT's on water storages used for irrigation.
- Preliminary assessment of the effect on water quality of the various EMTs.

This project has in large part met all of its objectives and has resulted in;

- Detailed investigation of the evaporation mitigation efficiency of five products Water$avr (monolayer), E-VapCap (floating cover), NetPro shade cloth (suspended cover), Raftex (modular cover) and Polyacrylamide (chemical) on research tanks located at the University of Southern Queensland (USQ), Toowoomba.
- Field demonstrations and evaluations of evaporation reduction efficiency at four commercial storages (Capella (Water$avr), Dirranbandi (Water$avr), St George (E-VapCap) and Stanthorpe (NetPro shade cloth).
- Assessment of the mechanical durability, and practical and technical limitations, of the products evaluated at commercial storages.
- An economic assessment of the EMTs for a range of climate regimes, based on capital and operating costs and the anticipated evaporation reduction performance.
- An initial assessment on potential impact on water quality of each product.
- Substantial and significant interaction with agency representatives, farmers and EMT suppliers resulting in much interest in and support for the adoption of evaporation control products.

A major outcome of the project has been increased awareness of the potential for evaporation reduction on water storages. The project has been highly successful in this regard, with significant interest being shown by landholders, agencies and private companies in the work undertaken. The combination of detailed experimentation at USQ, commercial scale demonstration sites and wide publicity, through field days, workshops, scientific papers and popular articles, has raised expectations on the potential for cost effective evaporation control solutions. Already a number of private

companies, product suppliers and agency funding bodies are exploring the possibilities for further research, product development and commercialisation in this area.

An important outcome of the project has been the development of methodologies which allow the accurate measurement of seepage and evaporation rates, both from open water storages and storages with an EMT product in place. The methodology utilised accurate pressure sensors linked to data loggers and automatic weather stations. While further development and testing of this methodology is required, already a number of private irrigation consultants are investigating the use of this technology to provide recommendations to farmers on improved evaporation and seepage management.

Table I indicates the range in measured evaporation reduction at the USQ research tanks for the products tested commercially. While efficiency in reducing evaporation was less favourable at commercial test sites, potential savings on commercial storages have also been given, based on the results and experiences of this study. A range of expected installation and operating/maintenance costs are also given and this has been translated into an estimated breakeven cost ($/ML water saved). It is anticipated that the low cost operating and maintenance scenario is most representative given good product installation and management.

Table I Summary table on product performance.

Product	Evaporation Reduction (%)		Installation Cost ($/m^2)	Operating & Maintenance Cost $/ha/yr	Breakeven Cost ($/ML saved)
	Measured Small Tanks	Potential Commercial Storage			
		High - Med - Low	Low - High	Low - High	Low - Med - High
E-VapCap	100% - 94%	95% - 90% - 85%	$5.50 - $8.50	$112 - $572	$302 - $319 - $338
NetPro	71% - 69%	80% - 70% - 60%	$7.00 - $10.00	$112 - $537	$296 - $339 - $395
Water$avr	40% - 10%	30% - 15% - 5%	$0.00 - $0.38	$826 - $4,050	$130 - $397 - $1191

1) Estimated breakeven cost is based on 2200mm potential evaporation, all year water storage, low cost scenario and range in evaporation reduction performance (Low- Med- High).
2) High operating and maintenance costs represent worst case scenario and are unlikely in most cases.
3) Evaporation reduction performance of Water$avr product has been shown to be highly variable and in some trials 0%.

Breakeven cost is shown to vary from $130 - $1,191 depending on product and evaporation reduction performance. Under situations where potential evaporation losses from storage exceed 2000mm/year and 'medium' evaporation reduction performance the breakeven cost is likely to range between $300/ML-$400/ML saved. The cost per ML water saved is influenced by the amount of time the storage holds water. Chemical monolayers can be selectively applied only in hot months or when there is water in storage which reduces cost per ML water saved. Considering the gross margin per ML water used of many crops ($100/ML - $1000/ML), it is likely that investment in these products will be viable in many situations. Investment in EMTs would also appear to be viable for high value crops in southern areas.

This project did not intend to recommend a single best evaporation control solution and it is envisaged that various EMTs would be appropriate in different situations, depending on the surface area, location and storage operational requirements. For example, floating covers are most appropriate on storages less than 1ha in size with all year water storage. Shade cloth structures would also be most viable on storages with permanent water and are likely to be limited to less than 5ha in size. Chemical monolayers would be most viable on large storages (greater than 10ha) and where the dam is likely to be dry for significant periods. Modular systems are likely to be best suited to intermediate storage areas less than 10ha.

While the volume of water in Queensland farm storages is not accurately known, one estimate from NRM (2,500,000ML) would equate to some 55,000ha of storage. With appropriate selection of different EMT products to storage area and some assumptions on storage size distribution potentially 300,000ML of evaporation loss could be saved with 100% adoption of EMTs. Even 10% adoption would save a significant amount of water (30,000ML).

Only a preliminary water quality assessment was undertaken in this project and no significant negative impacts were evident. Reduced light penetration and lower temperatures occur under floating and shade cloth covers and dissolved oxygen is lower under floating covers. These factors will limit algal growth but may impact on other flora/fauna. The monolayer did not create any negative impact on the waters physical quality parameters measured, although a more comprehensive analysis would be required before this product can be widely accepted.

Given the large interest raised by this project further work will be required, particularly in the following areas;

- Fundamental research on evaporation processes for storage dams accounting for thermal storage in the water body and advection from surrounds, leading to improved prediction of evaporation losses from weather data and storage characteristics.
- Further testing of the instrumentation developed in this project for seepage and evaporation determination and methodologies to separate seepage and evaporation components of water loss.
- Further development of depth sounder systems developed at USQ for storage basin mapping to provide a cheap and accurate system for mapping the storage basin when filled with water.
- Information on the extent and area categories of storages in each state leading to information on likely water savings from EMTs.
- Fundamental research on the potential for monolayers particularly in terms of distribution characteristics, application methods, evaporation reduction performance and environmental impact.
- Further large scale testing of commercial products in conjunction with suppliers to assess evaporation mitigation efficiency and mechanical durability.
- Support for quality control, collection and analysis of data being collected commercially by a number of irrigation consultants to facilitate better understanding of factors impacting seepage rates and regional evaporation losses from storage.
- Extension and communication of results to a wide range of irrigators and stakeholders to ensure the current high level of interest is maintained.

The current interest by EMT product suppliers and landholders and operators in the agricultural, mining and municipal sectors needs to be supported by continued widespread publicity of the potential for evaporation water savings and cost/benefit of water savings.

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  - Andrew Davis – Nalco
- E-VapCap
  - Warwick Hill – Evaporation Control System (ECS)
  - Max Brady – Darling Downs Tarpaulins (DDT)
- NetPro Shade structure
  - Graham Minifie – NetPro
- Raftex
  - Peter Johnstone – F Cubed Aust Pty Ltd
- Polyacrylamide
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Thank you to the landholders who provided access to water storages for evaluation of the EMTs. It was a requirement of the project that normal storage operations were to be maintained throughout the project, this required ongoing communication and collaboration with the project team to liaise on monitoring requirements.

- Capella – Peak Downs Shire Council
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- Dirranbandi farmers (Cubbie Station)
  - Greg Grainger, John Grabbe, Richard Lancaster
- St George farmers (Moonrocks)
  - Andrew Moon, David Moon, Jeffery Moon
- Hampton farmer
  - Graeme Thomas
- Stanthorpe farmer
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1 INTRODUCTION

Evaporation losses from on-farm storages can potentially be large, particularly in irrigation areas in northern NSW and Queensland where evaporation rates are higher than in southern states. While accurate estimates of on-farm storage volumes are not available, NRM's project brief for this study estimated that farm water storages in Queensland alone equate to a total capacity of 2,500,000ML. Most of these storages are shallow (water depth 4 to 5 metres) and the annual evaporation loss could be as high as 40%. This equates to an annual evaporation loss of 1,000,000ML which is sufficient to irrigate about 125,000 hectares and generate an annual gross value of approximately $375million. While the above assumptions are broad they indicate the potential savings that can be made through evaporation reduction. These savings are available for additional crop production or water transfer to other user groups such as to meet environmental targets. While the focus of this project was on on-farm storages the potential to achieve savings on large storages operated by water supply authorities is equally compelling.

In April 2002, a national workshop was held in Toowoomba to discuss the current understanding of evaporation losses from farm water storages. This workshop was in response to a project initiated by the National Program for Irrigation Research and Development (NPIRD) & the Department of Natural Resources & Mines (DNRM) which resulted in publication of a framework for further research in this area (NPSI, 2002). A review paper prepared by GHD, 2003 funded by NRM was also commissioned during this period. Both projects recognized that while substantial theoretical research had been undertaken there was a need for research and development on promising techniques applied at a commercial scale. As a consequence, NRM through the Rural Water Use Efficiency Initiative (RWUEI) funded this project which aimed to define the viability of utilizing evaporation mitigation techniques on a commercial scale as a sustainable mechanism for reducing evaporation.

Of specific interest was the effectiveness of current evaporation mitigation technologies (EMTs) to reduce evaporation on commercial sized storages, the practical and technical limitations of different products, variability in performance across climate regions, the impact on water quality and the economics of different EMTs.

The project was not intended to provide a single best solution since it was envisaged that various EMTs would be appropriate in different situations depending on surface area, location and storage operational requirements. An important outcome of the project was to develop guidelines on which EMT methods are appropriate under various conditions and quantification of the economics of investing in evaporation control products. Equally important was the need to raise awareness of the potential for the control of evaporation from on-farm storages.

2 PROJECT SCOPE AND OVERVIEW

The overall aim of the project was to assess the viability of utilizing evaporation mitigation technologies (EMTs) as a viable means to reduce evaporation losses from farm storages. Important objectives and the sections of the report addressing these objectives are;

- Assessment of the effectiveness of different EMTs in reducing evaporation from commercial storages (Section 3.2 and Section 5.1),
- Assessment of the practical and technical limitations of different EMT products (Section 3.3 and Section 5.2),
- Economic analysis of different EMTs applied to on farm irrigation storages (Section 3.4 and Section 5.3), and
- Effect on water quality of different EMT products (Section 3.5 and Section 5.4).

A range of evaporation control products have been developed and in some cases are commercially available to control evaporation losses from storages. These products range from floating covers, modular covers, shade structures, chemical monolayer covers and biological and structural/design methods. Appendix 1 reviews the various generic methods for evaporation control and provides a detailed list of products currently available. This project tested three products (floating cover, shade cloth and chemical monolayer) on a commercial scale. These products and an additional two products (modular cover and chemical product) were also evaluated at a research facility established at the University of Southern Queensland. The research facility allowed detailed comparison of different products while the on-farm sites allowed demonstration of performance on a large scale installation and identification of practical limitations of each product.

Selection of both products for testing and storages on which the products could be tested was transparent and open. This process was guided by a Technical Advisory Panel (TAP) comprising a range of experts in the field. Expressions of Interest were invited from potential EMT suppliers and landowners willing to conduct trials on their farm. A selection process was undertaken and agreements then executed with landowners and product suppliers (Section 3.1). Landowners were specifically sought where storages were in commercial operation and could be used as demonstration sites. EMT products for the farm storage tests were sought which were already in commercial use.

Accurate determination of evaporation losses from storages has confounded scientists and practitioners for many years. A literature review of the broad range of experimental approaches used for measuring evaporation has been included (Appendix 2). Based on this review, a water balance approach using high performance water depth sensors was chosen as the most suitable approach for this project.

An important part of the project was development, sourcing and installation of instrumentation allowing accurate measurement of evaporation losses. Equipment development is discussed in Section 4 of this report. The methodologies developed rely on accurate pressure sensitive transducers (PSTs) in a water balance approach for evaporation determination. While there is a need for further refinement, these methods have been an important output of the project. An important aspect in selecting PSTs was the need for accurate affordable methods that could be installed on operating storages in a harsh environment.

Methods used to quantify EMT performance were based on accurate measurements of water level change through time as recorded by the PSTs. Water level recordings were taken where possible on a control storage as well as the covered storage. Climatic data was also used to determine evaporation based on Penman Monteith evaporation calculation methods. An analysis procedure had to be developed accounting for periods of rainfall and pump flow to the storage, inferior quality data and importantly to separate seepage from evaporation losses. Appendix 3 gives an overview of this methodology. Evaporation reduction performance for each product and site is given in Section 5.1 and Appendix 4.

The mechanical durability of each EMT was assessed during the 18 month monitoring period. Mechanical durability, repairs and maintenance are potentially a significant component of the total system cost. Section 5.2 provides an assessment of the durability of each product which was also the basis for determining likely repair, maintenance and operating costs for each EMT. Specific investigations were undertaken on the E-VapCap floating cover by consulting engineer Bligh Tanner (Appendix 5).

An important component of the project was to provide a broad economic assessment of each product for a range of climate regions based on measured product performance and costs. Section 3.4 outlines the framework used for the economic assessment and Section 5.3 and Appendix 6 summarises the cost of each product tested per ML of water saved for a range of scenarios.

Extensive testing of the impact of each product on the aquatic environment did not form part of the project brief, however simple parameters such as dissolved oxygen, pH, temperature, EC and in some instances algal count were measured to get an indication of potential water quality impacts. Section 5.4 provides a review of the water quality assessment.

The project aimed to provide the first broad assessment of EMT performance on a commercial scale in Australia. An important outcome was the increased awareness of the potential for evaporation control in rural storages. This was achieved through targeting operating storages in a range of regions and promoting awareness of potential for evaporation reduction at field days, seminars and workshops. A list of engagements with the public is given below.

Industry Publications:

- Australian Grain – Jan Feb 2004
- Australian Cotton Grower – Jan Feb 2004
- IAA conference, Adelaide – May 2004
- Irrigation Australia – Summer 2004
- Australian Grain – Nov Dec 2004
- IAA Conference, Townsville – May 2005

Field days:

- Roma – Feb 2004
- Moree – Mar 2004
- Melbourne – Apr 2004
- St George – Jun 2004
- NCEA board – Jun 2004
- Surat – Jun 2004
- Bongeen – Aug 2004
- EMT workshop, Toowoomba – Sep 2004
- Colonsay – Sep 2004
- IAA field day, Goondiwindi – Oct 2004
- St George – Jan 2005
- Dirranbandi – Jan 2005
- Moree – May 2005

3 METHODOLOGY

3.1 Product and site selection

3.1.1 Products

In early 2003, a public invitation for expressions of interest was launched nationally and internationally to identify as many potential collaborators as possible. Firms were asked to provide a capability statement and track record of the applicant's organization, technical specifications and performance data on their respective products as well as suggested retail price to industry.

A selection panel was established with a broad cross section of technical specialities including academics, irrigators, environmental specialists and departmental support staff. The selection panel considered all applicants and short listed EMT products that demonstrated the range of technologies available within the budget constraints of the project. Appendix 1 provides a comprehensive list of currently available EMT products. Following selection, a formal contract of purchase and a collaboration agreement was negotiated with each supplier.

Five different EMTs were selected for evaluation in this project;

1. Water$avr – monolayer (Nylex)
   http://www.flexiblesolutions.com/products/watersavr/
2. E-VapCap – floating cover (Evaporation Control Systems)
   http://www.evaporationcontrol.com.au/index.1.htm
3. NetPro shade cloth – suspended cover (NetPro)
   http://www.netprocanopies.com/npcge.php
4. Polyacrylamide – PAM chemical (CIBA Specialty Chemicals)
5. Raftex – modular covers (F Cubed Aust Pty Ltd)

Water$avr consists of a cetyl/stearyl alcohol which forms a one molecule thick film or monolayer on the water surface (Figure 3-1). The Water$avr product takes the form of a white powder as the alcohol is combined with a hydrated lime carrier which acts as bulking agent and flow aid. The product is made of food grade chemicals which are biodegradable in 2.5 to 3 days and it is permeable to oxygen.

Figure 3-1 The Water$avr product comes in a bag and is applied to the water surface where it spreads itself across the surface creating a thin film to mitigate evaporation.

E-VapCap is a floating cover made from a heavy duty polyethylene 'bubble wrap' style product with a white surface to reflect heat and a black bubble underside which provide flotation and stops light penetration (Figure 3-2). Both of the layers are UV stabilised and 10mm diameter holes are positioned at 1000mm centres to allow rainfall penetration and the release of gases from the storage.

Figure 3-2 E-VapCap has a black side with air filtered bubbles which sit on the water (left hand side) while the white side is exposed to the sun to help reflect incident radiation. Drainage holes in the cover allow rainfall to enter the water storage.

NetPro is a shade cloth (Figure 3-3) made using a high tension cable, incorporating long life plus black monofilament shade cloth ($300 g/m^2$ – 90%). The cable design in essence acts as a giant spider web, with all cables spliced at crossover points to disperse the load evenly and also to eliminate product creep due to wind.

Figure 3-3 NetPro shade structure uses 90% UV shade cloth and high tension cables to support the cover above the water surface.

Raftex is a modular cover that floats on the water surface and each module consists of a fully enclosed rectangular plastic pipe frame with maximum dimensions of 12m by 2m (Figure 3-4). The plastic pipes are 50 or 75mm diameter and are joined using force fit right angle joiners. The frames are also strengthened with plastic brace rods every 2m. The frame is easily assembled on site with the pre-drilled holes for the brace rods. Once the frame is assembled then a machine wraps multiple layers of UV stabilised adhesive film which totally encloses the frame to form a module. Holes are then drilled through the film and pipe to allow the module to partially fill with water which acts as an anchor for the raft in windy conditions. This EMT was only evaluated on research evaporation tanks at USQ.

Figure 3-4 Raftex is a modular EMT which utilises a polythene pipe frame with timber bracing to support a thin plastic film wrapped around and around the frame.

PAM is a chemical that is incorporated throughout the entire body of water. PAM stands for polyacrylamide which is a chemical that is added to water in low concentrations to thicken it and therefore reduce evaporation The PAM used in this trial was called Magnafloc 1011. It may also have other benefits including reducing seepage and as a flocculant. This EMT was only evaluated on research evaporation tanks at USQ.

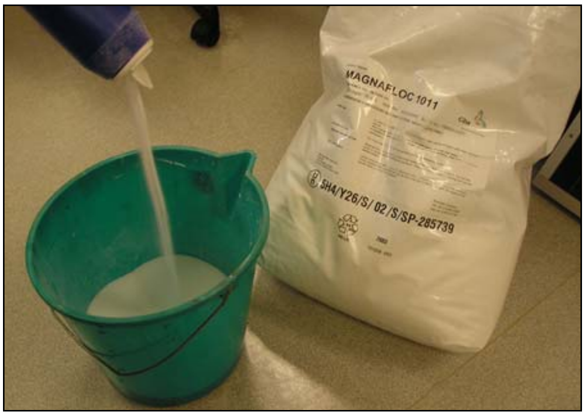

Figure 3-5 Polyacrylamide is incorporated through the water body and increases viscosity.

3.1.2 Sites

A process was initiated to identify growers willing to collaborate and assist with evaporation mitigation trials. The process involved extensive liaison with growers, catchment groups and Queensland Government's Department of Natural Resources & Mines (NRM). For each site offered, the technical feasibility and the relative cost was evaluated. A memorandum of understanding (MOU) regarding the implementation of the program was then signed covering issues such as in-kind support offered and access to all relevant on-farm data records regarding storage performance.

A large initial list of potential sites was rationalised to achieve the best mix of site, industry and product. Sites finally chosen had a variety of sizes and were geographically dispersed from Stanthorpe in the south to Capella in the north and St George and Dirranbandi to the west. Controlled trials using 10m diameter tanks also took place at the Agricultural Field Station (Ag plot) site at the University of Southern Queensland (USQ) at Toowoomba. A list of the products tested and locations they were tested is given in Table 3-1.

Table 3-1 **Products tested by the NCEA and the locations they were tested.**

Product	Toowoomba	Capella	Dirranbandi	St George	Stanthorpe
Monolayer	Y	Y	Y		
Floating cover	Y			Y	
Suspended cover	Y				Y
Modular cover	Y				
PAM	Y				

The sites selected for the trials are summarized in Table 3-2 and Table 3-3. Sites ranged from Central Queensland to the Granite Belt. Information for both the open (control storage) and the storage on which the EMT was tested is provided as well as information on the storage geometry, product tested and instrumentation used.

The Ag plot site at the University of Southern Queensland has three 10m diameter tanks that are approximately 0.7m deep (Figure 3-6). These three tanks allowed for a control tank and two EMTs to be intensively assessed at the same time. The tanks were cleaned and flushed between each trial to ensure EMTs were tested on clean water uncontaminated from another product. Since the tanks were lined no seepage occurred from these tanks.

Figure 3-6 **Three 10m diameter tanks used to test evaporation mitigation technologies. A maximum of two products were tested at the same time to allow for a control tank to calculate the evaporation saved by the various products.**

The storages at Capella are part of the local municipal water supply for Peak Downs Shire Council (Figure 3-7). The Council were already using Water$avr monolayer on one of their storages. This 4.2ha storage had two storages beside it, which provided for control storage. A hydrographic survey of the storage profile was undertaken to determine the relationship between water volume and change in depth at a known water level.

Figure 3-7 Control storage at Capella with the EMT storage nearby used to evaluate Water$avr.

Cubbie Station at Dirranbandi was chosen to test Water$avr monolayer on a larger scale (Figure 3-8). The storage used for the monolayer trial had a surface area of 120ha and had a storage that could be used for control measurement nearby. This larger storage was chosen with the understanding that if the monolayer could work on this size storage then it would be expected to work on smaller storages.

Figure 3-8 The Dirranbandi storage was used to trial Water$avr product using an automatic applicator.

St George was chosen for the testing of the E-VapCap floating cover on 4.2ha storage (Figure 3-9). The floating cover storage has a surface area of 4.2ha and it has a control storage beside it. The floating cover was already installed prior to the project getting under way and therefore saved time in the setup and installation.

Figure 3-9 The E-VapCap cover just after it had been installed on a 4.2ha water storage at St George.

A NetPro shade cloth cover was tested on a 3.8ha storage at Stanthorpe which had two control storages beside it (Figure 3-10). A hydrographic survey of the storage profile was done to be able to determine the relationship between water volume and change in depth at a known water level.

Figure 3-10 NetPro shade cloth structure over a 3.8ha storage at Stanthorpe showing orchard with hail protection on two sides of the storage.

Table 3-2 Details of the EMT storages at the various commercial and research sites.

Details	Capella	Dirranbandi	St George	Stanthorpe	Toowoomba
Owner	Peak Downs Shire Council	Cubbie Station	Moonrocks	Andreatta	USQ
Storage – surface area	4.2ha	120ha	4.12ha	3.8ha	2 x 78m^2
Storage – capacity		7200ML	240ML	132ML	0.055ML
Storage – wall height	5.0m	7.0m	5.0m	3.0m	1.0m
Shape	Rectangle	Pentagon	Rectangle	'L'	Circle
EMT product	Water$avr	Water$avr	E-VapCap	NetPro shade	All
How is it filled	Pump	Pump	Pump	Pump	Tap
Equipment					
PST	2	3	2	3	5
AWS	1	1	2	2	1
RL	1	1	2	1	3
Other					

* PST – pressure sensitive transducer; AWS – automatic weather station; RL – relative level

Table 3-3 Details of the open/control storages at the various commercial and research sites.

Details	Capella	Dirranbandi	St George	Stanthorpe	Toowoomba
Owner	Peak Downs Shire Council	Cubbie Station	Moonrocks	Andreatta	USQ
Storage – surface area	4.0ha	410ha	3.72ha	0.8ha	78m^2
Storage – capacity		12,084ML	160ML		0.055ML
Storage – wall height	5.0m	5.0m	5.0m	3.0m	1.0m
Shape	Rectangle	Rectangle	Rectangle	Triangle	Circle
How is it filled	Pump	Pump	Pump	Natural	Tap
Equipment					
PST	2	2	3	2	2
AWS				1	
RL	1	1	1	1	1
Other		Class A pan	Class A pan		Class A pan

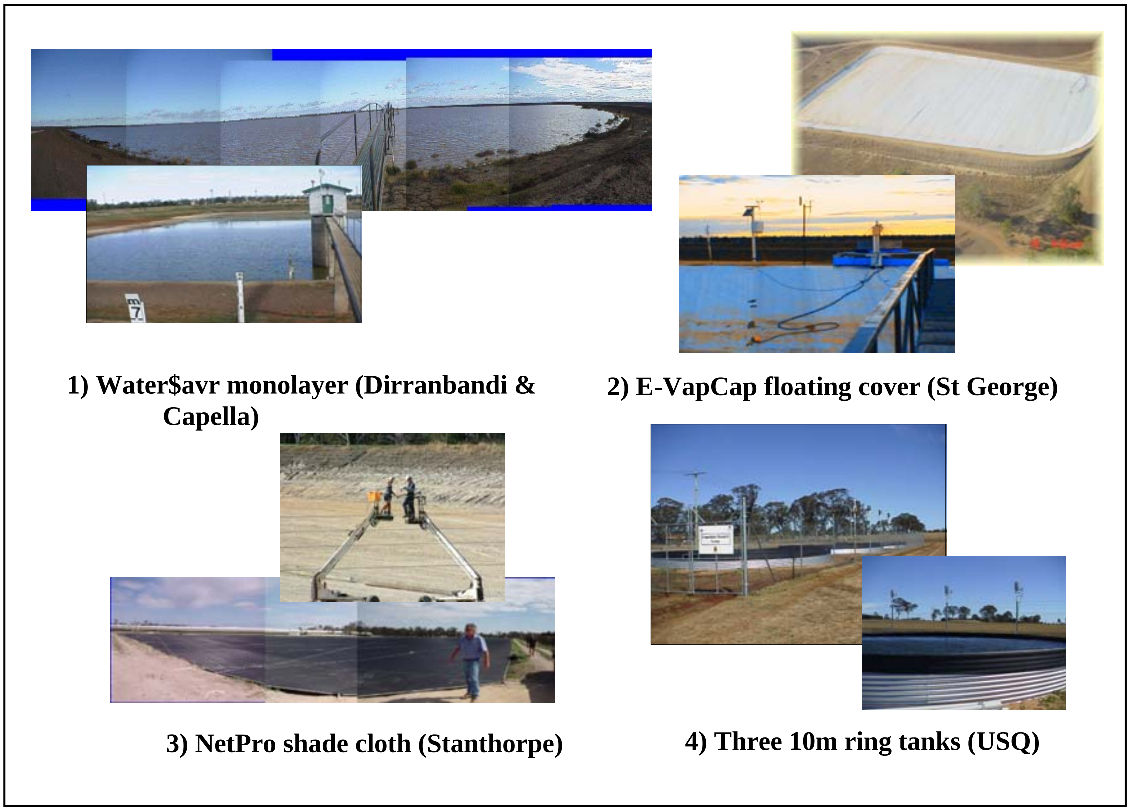

Figure 3-11 Commercial and research sites for trialing the evaporation mitigation technologies.

3.2 Evaporation mitigation assessment

This project investigated the performance of commercially available evaporation mitigation technologies (EMTs). The overall performance of each EMT needed to include the efficiency in reducing evaporation, operational requirements and mechanical durability. From this data, an economic assessment was conducted to calculate the cost per megalitre of water saved. The methodology to determine the EMT efficiency in reducing evaporation is discussed below. Further detail on analysis procedures is given in Appendix 3.

EMT evaporation reduction efficiency was determined by comparing evaporation loss from a storage with an EMT with evaporation that would have occurred had no EMT been present. Evaporation with no EMT was derived where possible from an adjacent control storage equipped with a depth logger. Where no data was available from the control storage, an estimate of open water evaporation was derived from a climate based evaporation equation (Penman-Monteith FAO56).

Figure 3-12 illustrates steps for determination of EMT evaporation reduction effectiveness using data for an EMT treated storage (left column), control storage (middle column) and AWS station (right column). Important steps include:

- Data collection (depth loggers, rainfall measurement and AWS data for estimation of evaporation using Penman-Monteith),
- Selection of data not affected by pumping inflows/outflows (or volumetric conversion using Digital Terrain Model (DTM)),
- Determination of seepage rates,
- Derivation of evaporation loss, and

- Comparison of evaporation loss with/without an EMT product.

Evaporation loss from the storage was determined using a water balance approach and accurate pressure sensitive transducers (PSTs) recording the change in water depth continuously every 15 minutes. The PSTs are designed to provide an accuracy of 0.04% for an operating range of 0 to 3.5m or ±1.4mm actual water depth.

The water balance approach was simplified by focussing on periods when there was no inflow, outflow or rainfall. The only parameters left to consider during these periods were seepage and evaporation. Although flow meters were fitted to most inflow and outflow points, issues of poor accuracy and incomplete records made it prudent to focus on periods when no pumping occurred. Given that the storages monitored were 'working' storages, this limited the periods when data could be used in analyses.

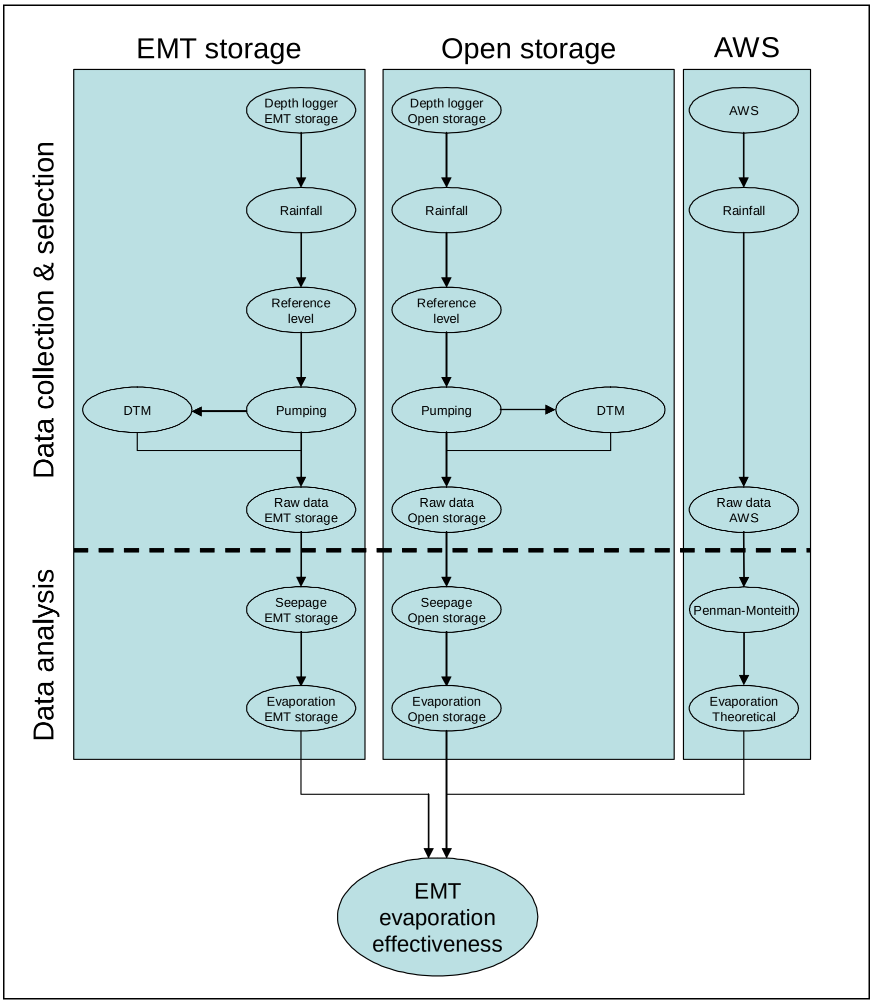

Figure 3-12 Flowchart illustrating steps taken to calculate evaporation reduction effectiveness of the EMT.

3.2.1 Data collection

Data collection and selection are crucial steps in determining the performance of each EMT. The protocol for collecting data within this project (Figure 3-12) included the following steps.

1. Download the depth logger (DL), which recorded the date, time and depth of water in the storage. The average, minimum and maximum depths were recorded every 15 minutes from a reading taken every second.
2. Download data from the automatic weather station (AWS) that is recording date, time, air temperature, wind speed, wind direction, solar radiation, relative humidity, rainfall, wind run and peak wind gust over three seconds. All of these parameters were recorded every 15 minutes.
3. Download data from flow meters that record date, time and water volume every 15 minutes.
4. Record the reference level (RL) for the storage.

Data sets were inspected for completeness and any equipment errors or failures. Data was used for analysis if it contained sufficient days without rainfall and pumping and included a full set of DL data. Checking the RL against the change in water level recorded by the PST was essential to identify any depth logging problems. Complete depth logger data sets for the EMT storage and a nearby open storage were selected for comparison. Alternatively the AWS was used to predict a theoretical evaporation for the period.

3.2.2 Data analysis

The approach used had two steps;

1. Determine seepage from night time water depth changes,
2. Subtract seepage estimate from total loss to get an evaporation rate.

Step 1: Determination of seepage rates

Seepage rates were determined from night time changes in water depth, during periods when evaporation would be negligible or at a minimum.

It was assumed that the seepage rate did not change significantly for a particular analysis period if overall water head in the storage remained fairly constant.

The accuracy of estimated evaporation and hence EMT performance is thus dependent on the accuracy of the PST and the accuracy with which seepage can be determined. Hence, an error in seepage rate of one millimetre per day in a storage that has an evaporation of 6mm/day would result in a 16.6% error in estimated evaporation. Table 3-4 below summarises these errors for a 1mm/day error in seepage determination.

Table 3-4 The percentage error in evaporation measurement as a result of the 1mm/day error in seepage for a particular evaporation.

Daily Actual Evaporation(mm)	Error (%)
1mm	100.0
2mm	50.0
3mm	33.0
4mm	25.0
5mm	20.0
6mm	16.6
7mm	14.2
8mm	12.0
9mm	11.1
10mm	10.0

The following issues also needed to be addressed to minimise the error in calculated seepage rate. (Appendix 3 provides further detail.)

- **Accounting for night time evaporation**
  The role of night time evaporation plays a big part in being able to accurately determine seepage rate. Initially it was assumed that the change in water depth at night between 10:00pm and 4:00am was entirely attributable to seepage. However during periods when evaporation rates are high, evaporation occurs both during the day and night. In some situations, evaporation can occur for the entire 24 hour period. Windy periods that continued through the night also affect seepage rate determination.

  From the above it could be assumed that seepage rate is best determined using data from winter or cool periods when night time rate of change in water depth (slope of the PST trace) will be less influenced by evaporation. The impact of water temperature and viscosity could however influence seasonal seepage rates. This was not investigated in this study.

- **Penman-Monteith based estimates of night time evaporation**
  Seepage rate for open storages in summer can be improved by subtracting a theoretical night time evaporation rate from the measured water level change. Theoretical/modelled night time evaporation was calculated using Penman-Monteith (FAO56) using weather station data. Appendix 3 describes this approach in greater detail. However, theoretical evaporation can only be determined for open storages and not storages covered by an EMT.

  For storages with an EMT, Penman-Monteith cannot be used to derive evaporation losses at night because the night time evaporation will have been affected by the EMT. The seepage rate for these storages is best determined using data collected from winter or cooler periods when the night time evaporation rate is negligible. In storages where the EMT is applied intermittently throughout the year (monolayer), Penman-Monteith can be used to help estimate a seepage rate during periods when the water body is acting as an open storage. This estimate of seepage is valid only for that particular water level in the storage.

  Where the EMT was a permanent fixture, then periods prior to the EMT installation can be selected or cool periods need to be used to derive seepage rates. Since these permanent EMTs typically are more effective at reducing evaporation, night time evaporation under these covers will however be minimal and potential inaccuracies are reduced.

- **Data recording errors**
  In some cases PST traces were affected by data recording errors or cable noise (Appendix 3) making it more difficult to accurately determine seepage rate. In particular statistical methods became less reliable and seepage rates were best estimated visually over a number of consecutive days.

  Consideration was given to a suitable method for accurately determining the seepage slope of the pressure sensitive transducer (PST) trace at night. Various statistical methods were investigated to determine seepage slope (Appendix 3). The analysis method needed to be repeatable, accurate and statistically sound.

Ultimately visual interpretation of the PST trace was determined to be superior. This method proved to be repeatable and easy to use while rigorous statistical methods were influenced by the selected start and end time and outliers in the data. Eye fitting methods also allow the experience of the user at the site to be brought into calculations particularly in identifying data problems.

It is important to recognize that seepage and hence evaporation needs to be determined over a number of consecutive days to improve accuracy.

Step 2: Determination of evaporation rate
Evaporation represents the difference between total water loss from a storage and the seepage component (during periods of no inflow/outflow or rainfall). While seepage over the analysis period is assumed constant, evaporation rate will vary from one day to the next as a result of the weather. The total from a number of consecutive days was typically used to assess EMT performance.

The EMT evaporation reduction efficiency was determined by comparing evaporation from the EMT treated storage against evaporation from an open storage.

3.3 Mechanical durability assessment

An assessment of the mechanical durability of the three evaporation mitigation technologies (EMTs) tested on commercial sites (E-VapCap, NetPro and Water$avr) was undertaken. The Raftex and PAM products were not tested to the same extent as they were not subject to the detailed field evaluation. Written notes, photos and records of the mechanical performance of each EMT and repair and maintenance requirements were kept during the project. Data was also collected from the product suppliers and landowners of each trial site. In addition contact was made with other users of the various products to get comment on relevant mechanical durability issues.

Product suppliers also provided where appropriate technical specifications for their product which included information such as water permeability, Material Safety Data Sheet (MSDS), tensile strength and other structural properties and accelerated UV testing results.

Each EMT was assessed for its practicality and impact on normal operational use of the water storage. Consideration was given to the degree of supervision, cleaning, repairs and maintenance required for each EMT. Impacts from external factors such as wind and hail were closely monitored throughout the project.

Costs for each EMT in terms of monitoring, maintenance and operating were noted for use in the economic assessment. A detailed technical assessment of the E-VapCap product was carried out by an independent consulting engineering company to address installation problems at the St George site.

3.4 Economic assessment

3.4.1 Economic framework

Table 3-5 provides the framework used to assess the economics of investing in evaporation control products. Evaporation water saved represents the depth of water that can be saved annually by a product. This will be based on the location (potential evaporation from an open storage) as well as the effectiveness of the product in reducing evaporation (eg 80%). Thus a product able to provide an 80% saving in evaporation loss at a location with a climate potential annual evaporation loss of 2500mm, will provide 2000mm annual water savings. This is illustrated in Table 3-6 for a range of scenarios.

The annual evaporation saving and cost (value) of water ($/ML) will determine the breakeven investment in an EMT. Thus if water is worth $300/ML and a water saving of 2000mm per year is achievable then there is a breakeven investment of $6000 per year per hectare for the EMT (Table 3-5).

This also implies that an investment in the EMT of $6000 per year per hectare would cost $300/ML water saved. This value also represents the opportunity cost of water saved. It would be viable to invest in the evaporation control product if;

- The gross margin on the crop irrigated per ML water is greater than $300/ML,
- The value of a temporary water sale is greater than $300/ML,
- The cost of water for irrigation is greater than $300/ML.

Table 3-5 Framework for assessing the economics of investing in evaporation control products.

COST OF WATER	EVAPORATION SAVING				
AUD$ PER ML	mm PER YEAR				
	1000	1250	1500	1750	2000
	Breakeven Investment - AUD$/ha/yr				
$100	$1,000	$1,250	$1,500	$1,750	$2,000
$200	$2,000	$2,500	$3,000	$3,500	$4,000
$300	$3,000	$3,750	$4,500	$5,250	$6,000
$400	$4,000	$5,000	$6,000	$7,000	$8,000
$500	$5,000	$6,250	$7,500	$8,750	$10,000
$600	$6,000	$7,500	$9,000	$10,500	$12,000
$700	$7,000	$8,750	$10,500	$12,250	$14,000
$800	$8,000	$10,000	$12,000	$14,000	$16,000
$900	$9,000	$11,250	$13,500	$15,750	$18,000
$1,000	$10,000	$12,500	$15,000	$17,500	$20,000

Table 3-6 Evaporation savings as a function of potential evaporation loss and product performance.

PRODUCT PERFORMANCE	POTENTIAL EVAPORATION LOSS				
% Reduction in Evaporation	mm/yr				
	1500	1750	2000	2250	2500
	EVAPORATION SAVING (mm/yr)				
20%	300	350	400	450	500
25%	375	438	500	563	625
30%	450	525	600	675	750
35%	525	613	700	788	875
40%	600	700	800	900	1000
45%	675	788	900	1013	1125
50%	750	875	1000	1125	1250
55%	825	963	1100	1238	1375
60%	900	1050	1200	1350	1500
65%	975	1138	1300	1463	1625
75%	1125	1313	1500	1688	1875
80%	1200	1400	1600	1800	2000
85%	1275	1488	1700	1913	2125
90%	1350	1575	1800	2025	2250
95%	1425	1663	1900	2138	2375

3.4.2 Factors impacting evaporation savings

A number of factors will affect the amount of evaporation water that can be saved using an EMT. The three main factors that will affect evaporation reduction are the evaporation potential, storage characteristics (such as area, demand pattern, and duration of water in storage) and EMT effectiveness.

Evaporation potential

The potential evaporation loss from small water bodies will vary with location based on temperature, humidity, wind, radiation and other factors. Currently the recommended method to obtain regional data on long term average evaporation from small storages is based on point potential evapotranspiration (ET) figures provided by the Australian Bureau for Meteorology (http://www.bom.gov.au). Figure 3-13 illustrates the average annual potential ET distribution for Australia. Point potential ET varies from approximately 3200mm/yr in Northern Territory to 1400mm/yr in Victoria. Most major agricultural areas have values ranging between 1800mm/yr to 2400mm/yr. Alternatively class A pan evaporation figures can be used and multiplied by a pan factor to convert to free water evaporation.

The economic assessment undertaken in this project used a range of locations representative of the spread of potential evaporation losses from storage across the country.

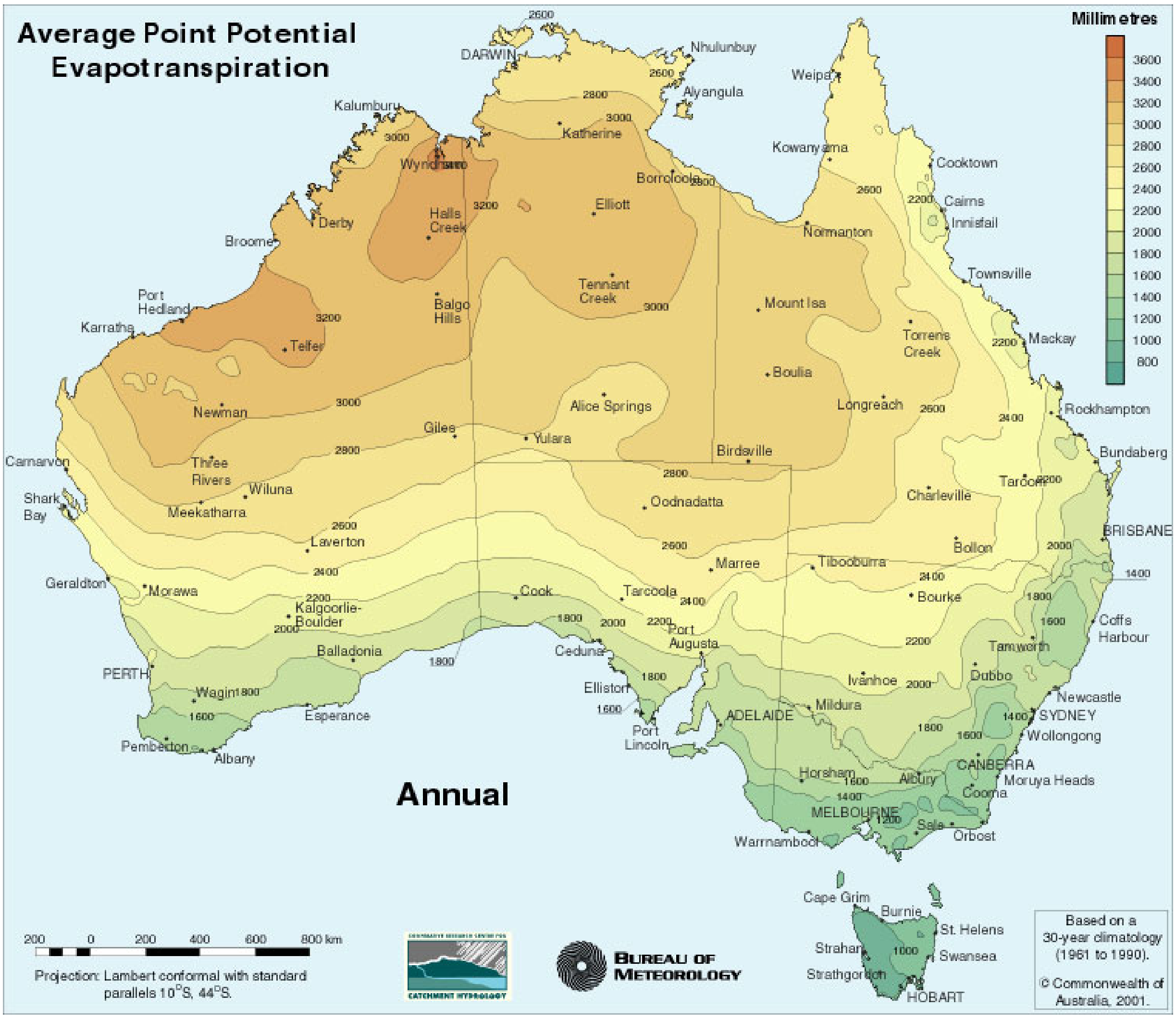

Figure 3-13 Annual average point potential evapotranspiration.

Storage characteristics

A number of physical factors relating to the storage will affect evaporation losses. These include surface area/volume relationship. A deep storage with small surface area is more efficient in minimizing evaporation losses. Wind breaks and local topography will also impact evaporation losses. Storages can also be managed to limit evaporation, for example by maintaining reserve water in storages with low evaporation or pooling together.

Another important consideration is the amount of time the storage holds water. This is illustrated in Table 3-7 below for a site with evaporation from storage of 2600mm/yr. If the storage only holds water between October and March (50% of year) the amount of evaporation loss will be 1795mm (69% of annual total). Table 3-7 also illustrates how application of a chemical evaporation control product would be best over the October – March season when evaporation rates are highest.

Table 3-7 Illustration of evaporation loss during periods of storage

Months of Storage	12	8	6	4
Period of Storage	Jan-Dec	Sep-Apr	Oct-Mar	Nov-Feb
Evaporation over Storage Period (mm)	2600	2177	1795	1259

Periods when a storage has water will vary between years depending on;

- Weather patterns,
- Catchment runoff and water supply, and
- Irrigation abstractions.

Performance of EMT

The performance of various EMTs is important in determining economic viability. Product performance will vary based on a wide range of factors, including;

- Product design,
- Installation issues (including size of storage),
- Seasonal variations, and
- Repair and maintenance issues.

Based on the potential performance of each product under ideal conditions at the USQ Ag plots and the commercial performance at collaborator sites performance figures have been assessed in this project.

3.4.3 Economic assessment

A discounted cash flow analysis was undertaken for each of the products. The net present value (NPV) of the investment and annuity to finance this investment was determined. The dollar value of the annuity per megalitre (ML) water saved was also determined to allow comparison between regions and cost scenarios.

A detailed assessment of the capital, operating, maintenance and repair costs of each product was undertaken based on discussions with suppliers and storage landowners. Capital and variable costs will vary significantly depending on local situation and a range of expected cost structures was assumed.

The cost per ML saved can be compared against the value of water determined either as the opportunity cost of water lost (in terms of production and profit forgone), the revenue earned from a water sale or the cost of a water purchase.

3.5 Water quality assessment

Physical and chemical covers have the potential to alter the quality of the water contained within a storage by interfering with various natural chemical and biological processes. Certain biological and chemical parameters can be used as indicators to detect any significant changes in water quality. However, in a natural system there are many factors that will influence the level or rate of any given parameter chosen to monitor water quality.

The scope of studies for this project did not include a comprehensive analysis of water quality impacts associated with the various evaporation mitigation technologies tested. The tests undertaken were designed to identify any major or large-scale changes in water quality and were based on a limited number of sample repetitions over a short monitoring period. The selected parameters were simple to analyse and provide a first assessment of potential changes in water quality attributable to the products tested.

Although the water storages monitored were primarily farm storages (except Capella) design of the water quality monitoring program recognised the potential for the EMTs to be used on water storages that have more sensitive values i.e. recreational waters or waters valued for their aquatic habitats or even for municipal drinking water supply (as is the case for Capella).

Each of the four field trial sites and the USQ agricultural field station site required different water quality monitoring plans since each site varied in size, flow regime, accessibility and a number of other site specific parameters. Appendix 7 details the sampling protocol for each site. All sampling was conducted in accordance with QLD Environmental Protection Agency's Water Quality Sampling Manual 1999.

Portable water quality meters were used to analyse pH, dissolved oxygen, conductivity, temperature and turbidity for the sites. Laboratory analyses were performed on samples taken from selected sites where the chemical monolayer had been applied. Parameters tested included;

- chlorophyll '*a*',
- total phosphorus,
- filterable reactive phosphate,
- total nitrogen,
- ammonium, and
- turbidity.

Successive samples for the Dirranbandi site were laboratory analyzed for chlorophyll '*a*', and algal count and identification at the Dirranbandi site. This monitoring was performed as a result of concerns over the monolayer's potential to increase algal growth.

4 EQUIPMENT DEVELOPMENT AND USE

This project required the sourcing, development, testing and commissioning of a significant amount of scientific monitoring equipment. A system using pressure sensitive transducers (PSTs) and associated solar powered data logger systems was developed to obtain accurate water depth change information. Automatic weather stations, flow meters, and associated calibration equipment were also installed at the various trial site locations (Section 3.1).

A pump application system was also developed to apply monolayer to the larger storage. The pump applicator and pipe distribution network was specifically developed for this purpose since nothing else was commercially available. The applicator proved very effective in applying the monolayer at the 120ha Dirranbandi site. Additionally, three dimensional depth surveys of selected dams were carried out using boat mounted GPS/sonar equipment (Gibbings and Raine, 2005).

4.1 Water balance equipment

The water balance method was selected as the most appropriate way of determining evaporation for this project. The water balance is essentially a mass flow analysis:

Change in volume = Inflow + Rain – Outflow – Seepage – Evaporation

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

Change in depth = Evaporation + Seepage

Thus, by measuring changes in water depth the net change in evaporation and seepage can be determined. The accuracy of this method depends greatly on the accuracy of the pressure transducer sensors and associated equipment developed for this purpose.

4.1.1 Pressure sensitive transducer

Pressure sensitive transducers (PSTs) were used to accurately measure water depth and therefore determine seepage and evaporation loss. The transducer selected was a Druck, type PDCR 4000 Series (350mBar sensor), with an improved accuracy of ±0.04% of the range, equivalent to ±1.4mm over 3.56m. Further information is available at the following website:-
http://www.davidson.com.au/products/pressure/druck/sensors/auto/pmp-4000.asp

A data logger system was required to accurately measure and log the change in depth over a 24h period. The system comprised a PST (Figure 4-1), 12 bit data logger, 12V battery, solar panel, regulator and a water resistant enclosure (Figure 4-2). The PST was suspended above the storage floor out of the silt on a float with a rope and sinker (Figure 4-3). The placement of the PST in the storage can help remove some of the cable noise evident in some of the data collected.

The data logger used was an Intech Nomad GP-HR general data logger (Figure 4-4) (Website: http://www.intech.co.nz/instrumentation-minipd/minipd.html).

Parameters measured every one second, time averaged and recorded every 15min included;

- time and date,
- point water depth (mm),
- average water depth (mm),
- minimum water depth (mm), and
- maximum water depth (mm).

Figure 4-1 Druck PMP 4030 pressure sensitive transducer improved accuracy was used to accurately measure the change in water depth.

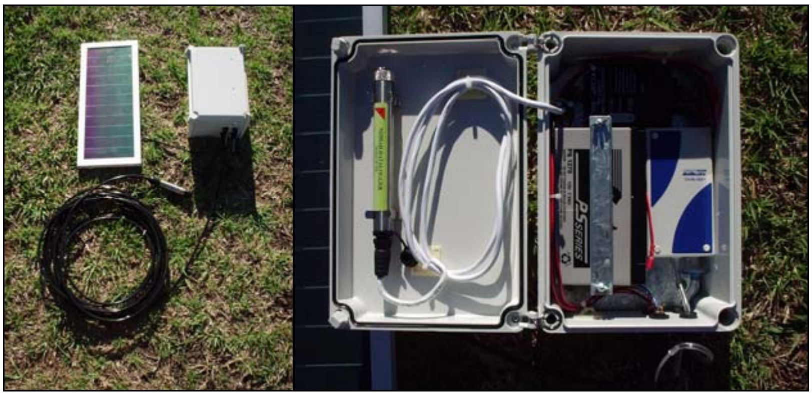

Figure 4-2 Depth logger comprising a pressure sensitive transducer, 12 bit data logger, 12V battery, solar panel, regulator and a water resistant enclosure.

Figure 4-3 Float, rope and sinker used to locate the pressure sensitive transducer out of the silt but in a constant spot.

Figure 4-4 Nomad GP-HR general purpose data logger from Intech used to log the depth from the pressure sensitive transducer. The 12 bit logger has three analogue inputs (individually configurable) and one digital pulse input channel.

4.1.2 Automatic weather station

A theoretical value of evaporation was calculated using AWS data (Penman-Monteith FAO 56) as a backup for actual evaporation measured from a control storage. The instrumentation required to do this was a commercially available Environdata – WeatherMaster 2000 (Figure 4-5). (Website: http://www.environdata.com.au/index.php?option=com_content&task=view&id=12&Itemid=47).

Parameters measured every 1sec and recorded every 15min included;

- time and date,
- air temperature (ºC),
- wind speed (kph),
- wind direction (º),
- solar radiation (W/m^{2}),
- relative humidity (%),
- rainfall (mm),
- wind run (km), and
- peak wind gust over 3sec (kph).

Figure 4-5 WeatherMaster 2000 weather station used to measure the parameters required to run Penman-Monteith.

4.1.3 Flow meters

An accurate flow meter was required to measure all flows in and out of the storage. The accuracy of the flow meter will influence the accuracy of the conversion from volume of water to a change in depth. The ABB – Electromagnetic flowmeter, type AquaMaster S used by this project is shown in Figure 4-6.

Parameters measured every 1sec and recorded every 15min;

- time and date, and
- average flow (m^3/sec).

Figure 4-6 The ABB AquaMaster S flow meter was installed at Stanthorpe to accurately measure the flows in and out and to log the time that they occurred.

Flow volume can be converted to a change in depth using a digital terrain model (DTM) (Figure 4-7). Traditionally the storages have been surveyed by hand but the storage needs to be empty. Recent research at the University of Southern Queensland has demonstrated that it is possible, using low-cost hydrographic mapping techniques, to obtain these measurements more rapidly and cheaply when the storage has water in it. The hydrographic technique involves the use of a GPS and low-cost external depth sounder mounted on a boat (Figure 4-7). The depth sounder is calibrated on site to overcome the impact of water quality differences between storages. The boat is navigated around the walls of the storage and then in transects across the storage with a series of depth soundings recorded at fixed time and/or spatial intervals. For each sounding, the three-dimensional position of the dam floor is measured using the GPS position, the offset distance between the GPS antenna and depth sensor, and the depth obtained from the sounder.

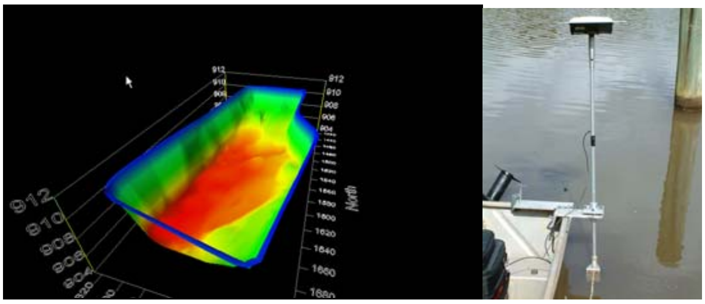

Figure 4-7 Digital terrain model of the covered storage at Stanthorpe enables changes in volume to be converted to a change in depth for a known water level. This is a DTM created using a hydrographic map from the global positioning system and depth sounder shown.

4.1.4 Class A pan

Although the accuracy of the Class A Pan (Figure 4-8) for measuring evaporation is highly questionable, three Class A pans were installed at the St George, Dirranbandi and the Ag plot sites for comparison purposes.

Figure 4-8 Class A pan used at three sites for the comparison with the actual evaporation at St George, Dirranbandi and Toowoomba.

4.2 Calibration equipment

Calibration equipment was required to check data collection throughout the duration of the project. Initially the weather stations were calibrated against each other at the Ag plot side-by-side and all pressure sensitive transducer were immersed into 3.0m of water. Calibration occurred every few months on all of the equipment. The data was checked for any errors on a regular basis and when equipment was brought into the office.

4.2.1 Pressure sensitive transducer

The PST was calibrated for depth/pressure using a Druck DPI 802 – portable calibrator Figure 4-9 and a Druck PV 211P – hand pump Figure 4-10.

Figure 4-9 Druck DPI 802 portable calibrator used to regularly check the calibration of the Druck PMP 4030 pressure sensitive transducer.

Figure 4-10 Druck PV 211P hand pump used in conjunction with the Druck DPI 802 to apply pressure to the sensors.

4.2.2 Automatic weather station

Items that were calibrated include wind speed, relative humidity, temperature and solar radiation. The calibration equipment used for this was a Kestrel 3000 hand held weather station Figure 4-11 which measured wind speed, relative humidity and temperature. The solar radiation was measured using a net radiometer from Campbell Scientific Figure 4-12.

Figure 4-11 Kestrel 3000 is a hand held weather station used to check the calibration of the Environdata WeatherMaster 2000.

Figure 4-12 Net radiometer from Campbell Scientific used to check the solar radiation on the Environdata WeatherMaster 2000 weather station.

4.3 Monolayer applicator and grid system

An automatic applicator to apply the Water$avr (monolayer) product to the water storage at Dirranbandi was designed and built by Bio-Systems Engineering (Figure 4-13). The system used water from the storage to carry and distribute the monolayer across the water surface. The grid system had nine outlets evenly spaced over the 120ha (Figure 4-14). This resulted in only one emitter per 13ha, a very large area covered per emitter but at relatively low installation cost.

Figure 4-13 Automatic applicator to apply the Water$avr (monolayer) product to a 120ha water storage at Dirranbandi.

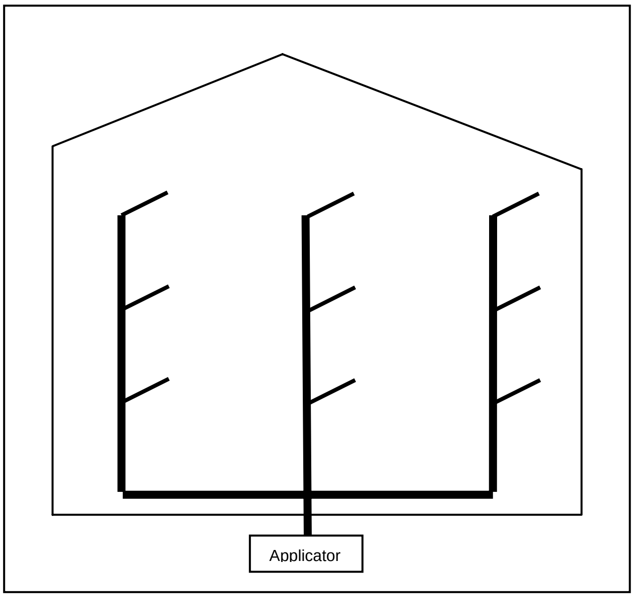

Figure 4-14 Grid system used to distribute the Water$avr product had nine outlets evenly spaced over the 120ha.

The powder is metered out of the hopper (Figure 4-15) using a screw auger and into a mixing chamber (Figure 4-16) where the dry powder is mixed with water. From there the water and monolayer is pumped using a diesel Deutz (Figure 4-17) into the grid system and then evenly distributed on the water surface where the monolayer spreads itself. The applicator is designed to warm up by filling all of the pipes and then distribute the water/monolayer followed by a cool down which flushes all of the monolayer out of the pump and grid system. The hopper holds enough monolayer for one week of application and it requires a knocker to stop the powder bridging. The hopper is located on top of the storage wall for ease of filling, while the pump is located lower down the wall closer to the water level to reduce suction height.

Figure 4-15 Water$avr powder is metered out of the hopper using a screw auger.

Figure 4-16 Dry powder is mixed with water from the storage in the mixing chamber.

Figure 4-17 Diesel powered pump runs automatically on a timer setup. It has a Murphy system on it to shut down if there are any mechanical problems with the motor.

The main distribution lines are 50mm poly pipe and each riser has 10-20m of flexible hose with its own float system Figure 4-18.

The poly pipe floats on the surface of the water and is tied at either end to hold the outlet points in the right position (Figure 4-19). However, the pipe ideally needs to be placed on the floor of the storage as the wind and waves were observed to have an affect on the pipe grid system.

While some specific problems initially occurred with the applicator (including air locks in the positive displacement pump, problems in metering the monolayer owing to bridging) the system has generally worked very effectively. Other methods for application of the monolayer include application by hand or aerial application by plane or helicopter.

Figure 4-18 Nine outlets are evenly spaced across the 120ha storage. The main distribution lines are 50mm polythene pipe and then each riser has 10-20m of flexible hose with its own float system.

Figure 4-19 The polythene pipe floats on the surface of the water and is tied at either end to hold the outlet points in the right position. Ideally the pipe should be placed on the floor of the storage as the wind and waves affect the pipe grid system.

5 RESULTS

5.1 Evaporation mitigation assessment

Between six and fifteen months of storage performance data was collected at each site (Table 5-1). At commercial sites (Capella, Dirranbandi, St George and Stanthorpe) data was limited by;

1) periods of pumping in and out of the storage,
2) no water in the storage, and
3) instrumentation problems.

Storages on collaborator properties were run as commercial storages and experimental or trial requirements were second to operational requirements. It was nevertheless envisaged that a limited number of quality data sets would suffice to determine product performance on a commercial level.

Table 5-1 Table of data sets collected from the various trial sites.

		2003	2004											2005		
		D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
USQ	**EMT**					√	√	√	√	√	√	√	√	√	√	√	√
	Open					√	√	√	√	√	√	√	√	√	√	√	√
Capella	**EMT**	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Open								√	√	√	√	√	√	√	√	√
Dirranbandi	**EMT**									√	√	√	√	√	√	√	
	Open									√	√	√	√	√	√	√	
St George	**EMT**	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
	Open	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Stanthorpe	**EMT**				√	√	√	√	√	√	√	√	√	√	√		
	Open					√	√	√	√	√			√	√	√		

Notes

USQ
PST units were installed in the USQ Ag plot tanks on the 15 April 2004 and logged continuously until March 2005.

Capella
PSTs were installed in the EMT storage at Capella on the 2nd December 2003 and removed on the 22 December 2003. They were then reinstalled on the 23 January 04. PSTs were installed in the open dam on the 23 July 2004.

Dirranbandi
PSTs were installed in both the open and the EMT storage on the 1 August 2004. The first application of monolayer was not until 24 August.

St George
PSTs were installed in both the open and the EMT storage on the 16 December 2003.

Stanthorpe
PSTs were installed in the EMT storage on the 2 March 2004 and in the open storage on the 31 March 2004. The open storage was essentially dry from the 2 September to the 18 October 2004.

Results from the experimental USQ research tanks provided 'best' or potential performance figures for each product given the controlled environment with intensive instrumentation and no seepage. Results from the commercial sites provide an indication of likely performance at a commercial scale, but are overall less accurate than the USQ trials. Lower accuracy at commercial sites related mainly to seepage rate determination which, in the water balance approach used, affects measured evaporation.

The average evaporation saving for the products tested at the USQ research tanks ranged from 26% to 96% of potential evaporation (Table 5-2).

Table 5-2 **Measured evaporation savings at the USQ research tanks.**

PRODUCT	Average (%)	Range (%)
Water$avr	26	10 – 40
E-VapCap - trenched	96	94 – 100
E-VapCap - tethered§	91	83 – 97
NetPro shade cloth	70	69 – 71
Raftex§	87	80 – 100
PAM	37	31 - 43

§ Area adjusted to cover 100% of the water surface.

Based on the commercial storage sites indicative evaporation reduction performance is given below in Table 5-3.

Table 5-3 **Evaporation savings at the commercial test sites.**

PRODUCT	Average (%)	Range (%)
Water$avr (Capella)	0	0 – 0
Water$avr (Dirranbandi)	19	0 – 31
E-VapCap (St George)	n/d¥	n/d¥
NetPro shade cloth (Stanthorpe)	68	50 - 87

¥ Not determinable

The sections below provide selected example datasets for each product illustrating either EMT evaporation performance, analysis methods or some features in the datasets. Further information is given in Appendix 4.

The figures below take the form of a graph of water depth with time as recorded by the PST. The ‘y axis’ is normalised water depth recorded in millimetres, whether it be measured with a PST or calculated with weather data using the Penman-Monteith equation. The ‘x axis’ is the date, with the position of the date label indicating 00:00am (midnight) on the start of that day. Each day has been split into four equal periods of six hours (which may be referred to as six hour boxes). A night-time period is therefore identified as the two boxes either side of a midnight line, and the corresponding day period, the other two boxes.

5.1.1 Monolayer

Potential Performance – Toowoomba

USQ Evaporation Research Facility 10m diameter polythene lined tank tests revealed that the evaporation saved through the application of monolayer was of the order of 26% (range 10 - 40%). Assessments were carried out during five separate test phases, each approximately three weeks in duration. Monolayer was applied at a rate equivalent to 0.5kg/ha of water surface area every 48 hours from the upwind side of the tank.

Under low wind conditions the monolayer spread reasonably quickly across the surface. During moderate to high winds the product did not distribute evenly over the water surface and it built up on the leeward side of the tank. This appears to be one of the main reasons for varied evaporation savings recorded. The monolayer was measured and applied by hand which has inherent human errors that also may contribute to the varied results. Monolayer requires careful application so a fine layer of the product is applied to the waters surface. If large amounts of monolayer are applied quickly, the product forms small beads on top of the waters surface which limit distribution.

Some results suggest that the performance of the monolayer is affected by algae and bacteria, present in the water due to wildlife. La Mer (1962) provides some evidence for the degradation of cetyl alcohol by microbes. Laboratory tests would readily confirm this hypothesis (Barnes, pers. comm.).

Figure 5-1 Application of monolayer at the USQ Ag plots was repeated at 9:00am every second day during the product's trial.

Figure 5-2 Tendency of monolayer to form small beads on top of the water surface when applied by hand.

Figure 5-3 illustrates the normalised water depth results for the period between 2 March and 8 March 2005. The EMT tank was treated with monolayer at a rate of 0.5kg/ha every 48 hours. A separate tank was kept as a control with no monolayer being applied. Average daily evaporative loss from EMT tank averaged 7.3mm/day which compared to12.2 mm/day from the control tank. The evaporation saving attributed to the application of the Water$avr in the tank was therefore approximately 40%.

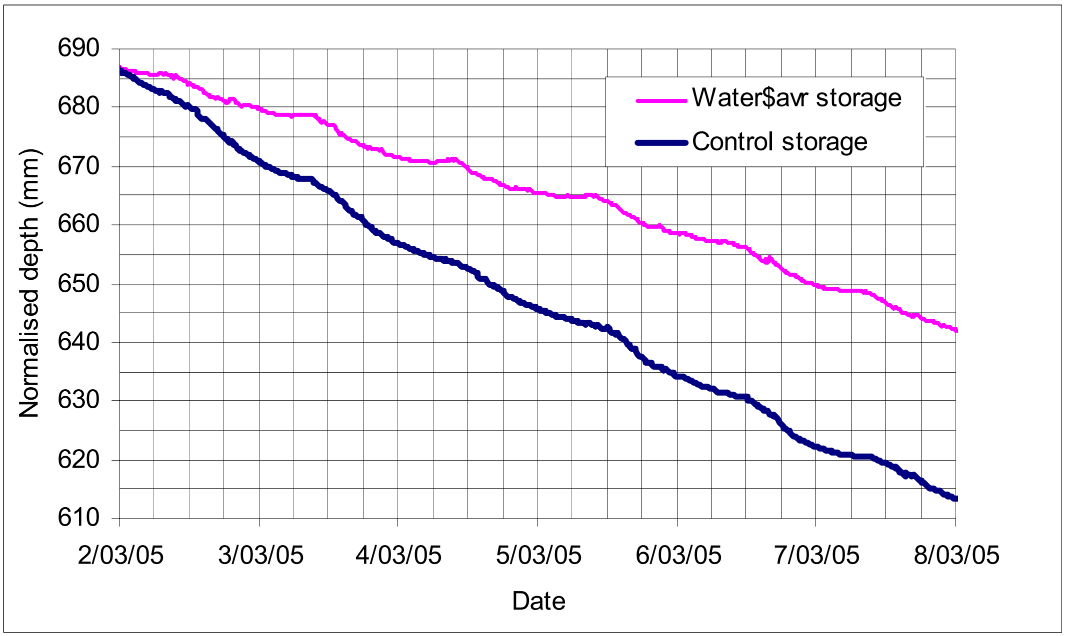

Figure 5-3 Water depth in open tank and monolayer tanks during March 2005.

Commercial assessment – Capella

A monolayer (Water$avr) trial was conducted at Capella on the Peak Downs Shire Council municipal water storage. Monolayer was only applied during summer over peak periods of evaporation. Results obtained from Capella showed little effect in terms of evaporation reduction produced by the monolayer. More research is required to explain this unexpectedly poor result.

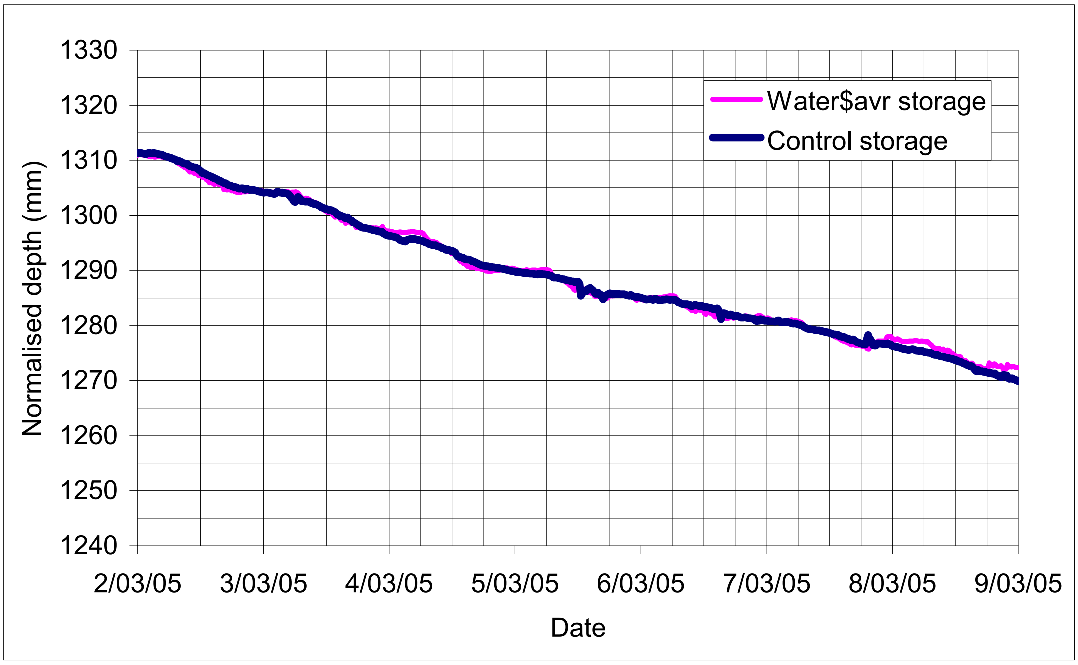

Figure 5-4 Graph of PST in the Water$avr and control storages with the seepage removed from both traces.

Figure 5-4 shows a graph of the effect of the Water$avr product being applied to the storage at Capella. Monolayer was applied at a rate of 0.375kg/ha on the 2, 4 and 7 March 2005. The monolayer was applied from the upwind bank by hand between 9:00am and 12:00pm.

The application of monolayer over this period showed no reduction in evaporation. With evaporation rates of around 6mm/day during this period an error of 0.5mm/day in seepage estimation would translate to an 8% error in estimated evaporation saving. Nevertheless the results from four similar independent trails at Capella suggest that there was no reduction in evaporation as a result of the monolayer being applied.

Commercial assessment – Dirranbandi

Trials were also conducted at Dirranbandi, Cubbie Station to test the effectiveness of the Water$avr monolayer. This water was used to irrigate cotton and is part of the overall water storage at Cubbie Station. The Top Shed storage was used as the EMT storage with three PSTs installed and the larger Corrawa storage was used as the open storage with two PSTs installed. Monolayer was applied every second day to the EMT storage.

The average amount of evaporation saved through the application of monolayer at Dirranbandi was 19% (range 0 - 31%).

The EMT storage at Dirranbandi has an area of 120ha and application of the monolayer by hand was not a feasible option. The automatic monolayer applicator described in Section 5.3 of this report was used to distribute the monolayer powder evenly over the surface of the storage. The system proved fairly effective however specific measurements of monolayer distribution from the nine discharge points (one outlet per 13.3ha) could not be determined. A number of factors will affect monolayer distribution including wind and wave action. This tends to give highly variable performance of the product, especially on large storages. For the product to be commercially successful on larger storages more research will be required on distribution patterns and the role of poor quality water in product breakdown.

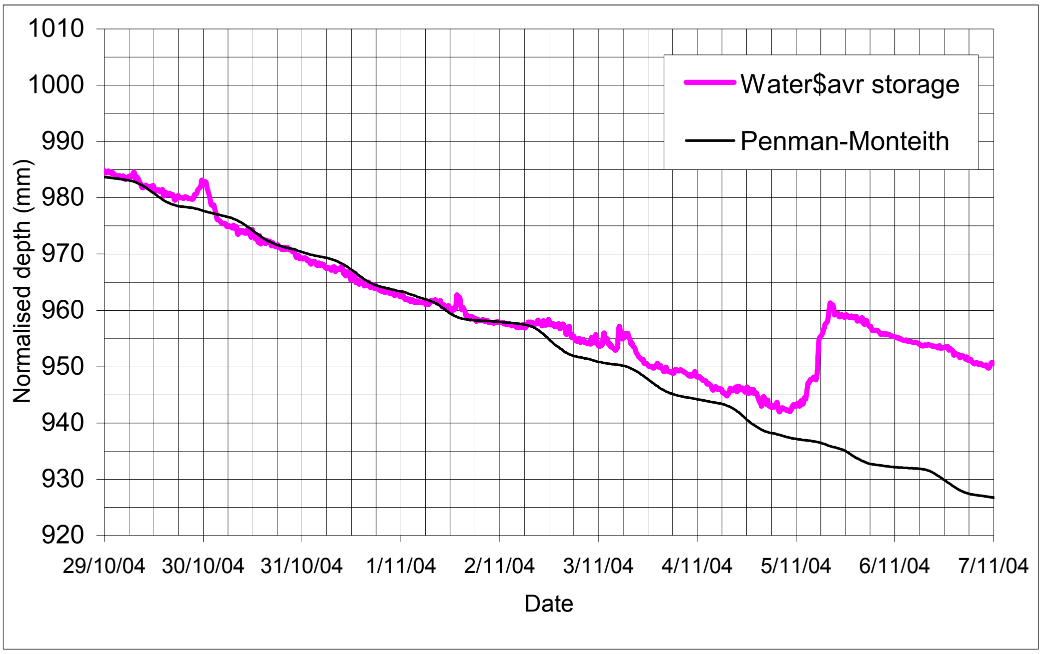

Figure 5-5 Graph showing the losses from the EMT storage at Dirranbandi during early November.

Figure 5-5 shows the change in water level in the EMT storage at Dirranbandi during November 2004. The thin black line is the AWS estimation of evaporation as predicted by the Penman-Monteith equation. Data from the AWS located on the southern bank of the storage recorded 19.2mm of rainfall between midday on the 4 November and midday on the 5 November 2004. This is also obvious in the increase in water level recorded by the PST (18.5mm) in the storage during this time.

The EMT storage had no monolayer applied 29 October to 1 November 2004 and then application started at 0.5kg/ha every second day. The PST trace shows total losses from the storage (seepage and evaporation) where as Penman-Monteith only predicts evaporation. Analysis indicated a seepage value close to zero for this particular storage.

The Penman-Monteith model follows the PST trace in the EMT storage prior to the 1 November and then the monolayer starts to reduce evaporation. The total loss from the EMT storage between midnight on the 1 November to 6:00pm on the 4 November from the PST data was 18.3mm. The Penman-Monteith model predicted 25.0mm for the same period. Therefore the estimated saving of evaporation that can be attributed to the application of the EMT during this trial was 27%.

5.1.2 Floating cover

Potential performance– Toowoomba

USQ tank trials were conducted over six phases, each approximately three weeks in duration. There were two variations in the installation method used. The first consisted of a tethered system in which 98% of the tank was covered (Figure 5-6). In the second method, the cover was cut slightly larger than the tank and the edges were secured with a steel band providing 100% cover of the tank (Figure 5-7). The second installation used the later heavier material with less infiltration holes. The second design relates more closely to in-field installations where the cover is trenched or buried in the storage embankment.

The average amount of evaporation saved through the E-VapCap product was 96% (range 94 - 100%) for the trenched design and 91% (range 83 - 97%) for the tethered design.

Figure 5-6 Tethered design E-VapCap which floats on the surface of the water but with out being secured to the side of the tank.

Figure 5-7 Trenched design E-VapCap tied over the edge of the tank.

Figure 5-8 shows the PST traces in the EMT and control tanks between the 7 and the 12 January 2005. The PST recorded water level indicates that the covered tank lost less than 0.4mm/day over the period, whereas the control tank lost on average 8.4mm/day. The evaporation saving produced by the E-VapCap floating cover for this period was therefore approximately 95%.

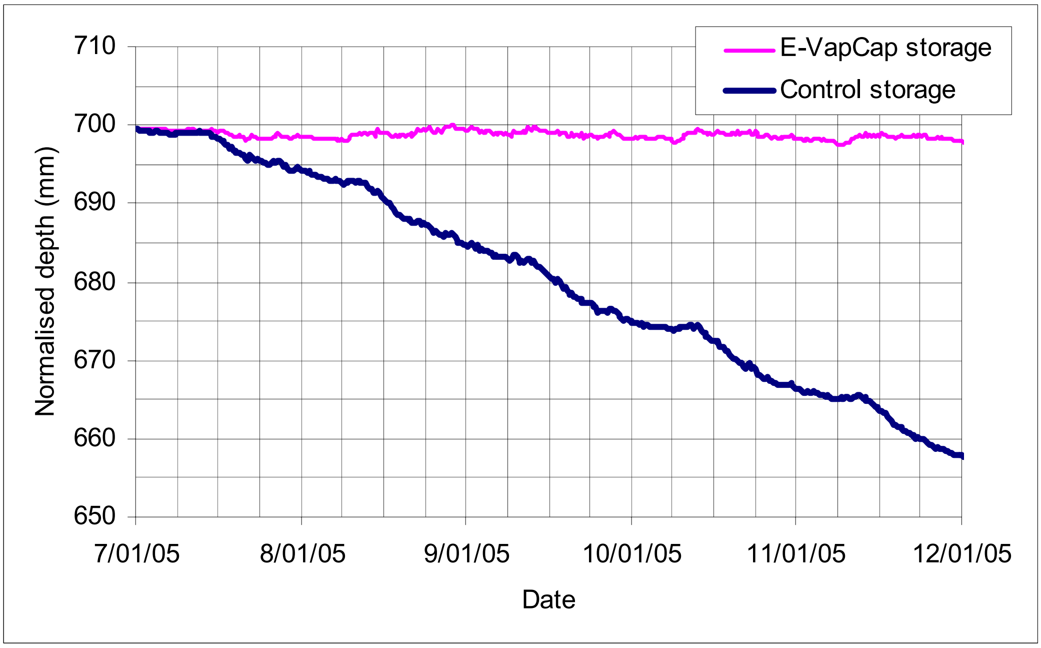

Figure 5-8 Water depth in open tank and buried edge E-VapCap during January 2005.

Commercial assessment – St George

The E-VapCap floating cover was also assessed at St George. Despite evaporation reduction performance figures of approximately 95% being determined for the E-VapCap floating cover at the USQ Ag plot trial site, the performance of the E-VapCap in operation in the field at St George was unfortunately not able to be determined.

The PSTs revealed that there were very few pump free days at the St. George storages and this together with instrumentation problems meant that reliable estimates on product performance could not be accurately provided. Originally it was envisaged that there would be several weeks with no extraction from the EMT storage, but due to the hot dry year, a lot more water was used than first anticipated. Multiple daily withdrawals and crude estimates of the flows from these pumps meant that evaporation could not be accurately assessed.

Other problems at St George included the occurrence of silt, weeds and surface water above the cover (see Figure 5-9, and Figure 5-11). During rainfall events, the storage banks were eroded and silt was deposited onto the cover. Additionally, wind blown material collected on the wet surface of the cover. This contributed to sinkage of the cover at the southern and eastern edges of the storage. These problems have not been found on other installations (eg Hampton storage Figure 5-10) where free drainage of rainfall is rapid and no silt deposition has occurred.

The area of E-VapCap covered by water was typically only around 5%. There were however periods when a large portion of the cover was inundated by a thin layer of water (Figure 5-9). A thin layer of water above the cover will cause temporary increase in evaporation loss. Further research work would be required to quantify this effect.

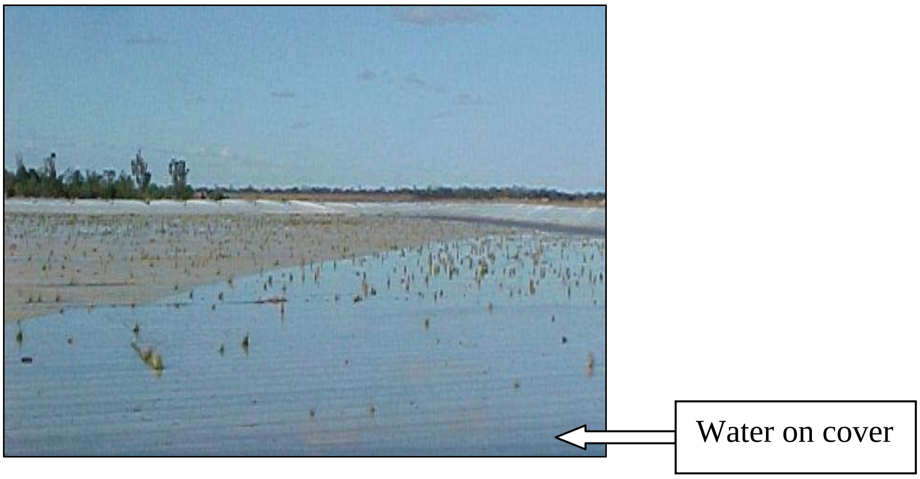

Figure 5-9 Thin layer of water may cover a large area of the E-Vap-Cap after rain or strong wind event. This should drain through the cover into the storage after the wind or rain ceases.

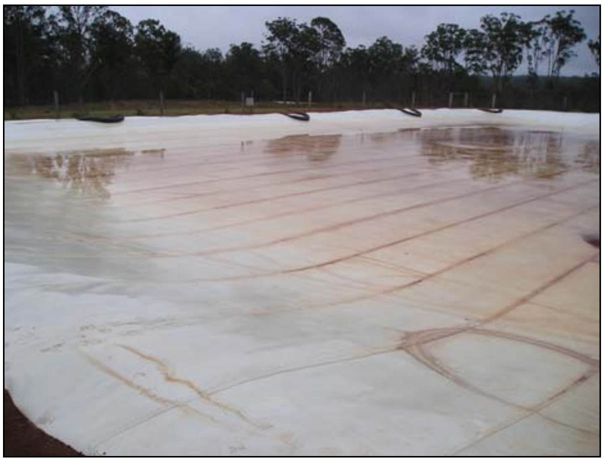

Figure 5-10 A 0.28ha storage at Hampton during a rain event showing thin layer of water on the surface which drains through the drain holes once the rain ceases.

Figure 5-11 The E-VapCap cover with weeds growing out of the drainage holes and restricting drainage of rain off the cover. Weeds from seeds blown onto the cover during dust storms should be dealt with at the earliest opportunity after germination, with a low strength spray application. No other covered storages have reported such problems.

Figure 5-12 shows PST data from St George which was obtained during the last week in August. During this week, pump free days were negotiated with the owners to ensure no pumping from either the covered storage or the open storage. The PST trace confirms that there were no major pumps operating from 6:00pm on the 25 August to 6:00am on the 27 August 2004 giving a 36 hour period. There was another 36 hour period from 6:00pm on the 28 August to 6:00am on the 30 August 2004.

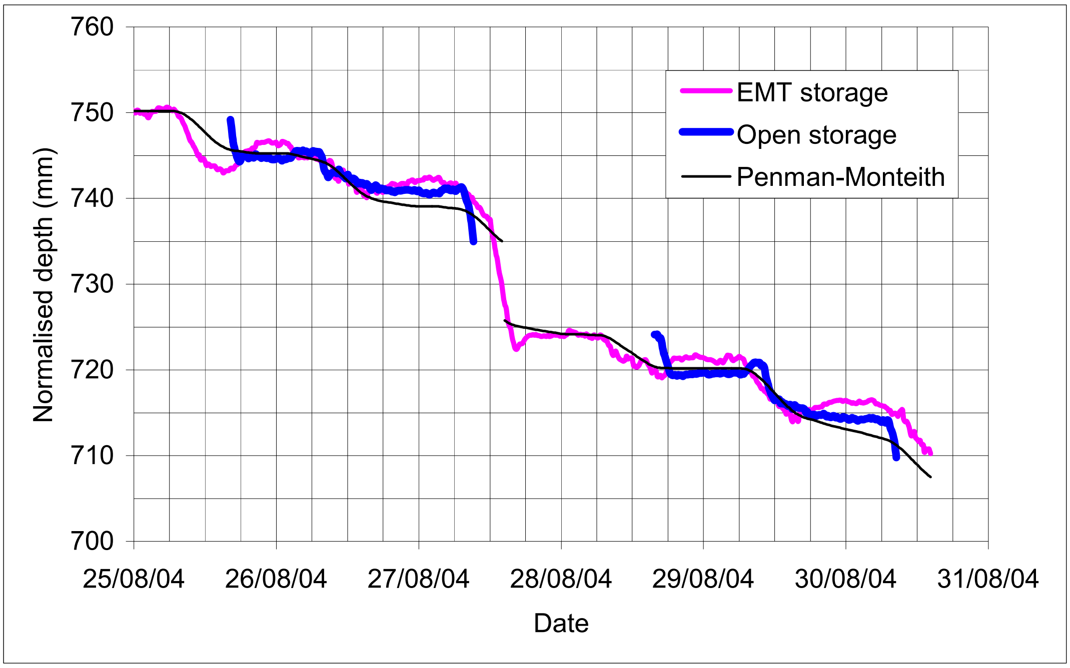

Figure 5-12 Graph comparing PST outputs from the 23 to the 31 August for the covered storage and the open storage at Moonrocks Farm, St George. The best data from St George had only two 36 hour periods where there was no major pumping.

While the PST traces of the EMT and open storage suggest in this dataset little different in evaporation rates the lack of sufficient data from this site limits our ability to draw conclusions. A period of five to nine days in a block is generally required to be able to determine seepage and evaporation rates accurately.

5.1.3 Suspended cover

Potential performance – Toowoomba

NetPro shade cloth was tested at the USQ tanks during three test phases, each three weeks in duration. A disc and wire structure held the tensioned shade cloth fabric 0.5m above the surface of the water.

The average amount of evaporation saved through the shade cloth at the USQ Ag plot was 70% (range 69%-71%).

Figure 5-13 illustrates results for the period 26 to 30 November 2004. The lighter line represents the PST recorded water depth of the covered tank which illustrates a significantly lower average daily rate of water loss (less than 2mm/day) compared to the control tank (greater than 6mm/day). The percentage of evaporation saved by the shade cloth in this case was 70%.

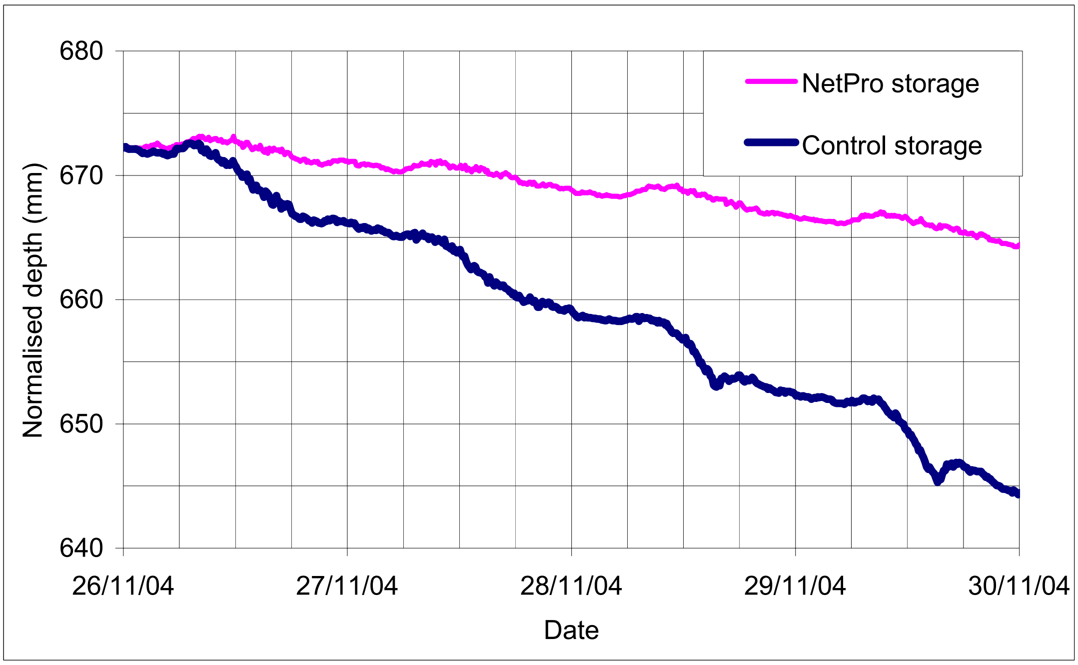

Figure 5-13 Water depth in open tank and NetPro shade cloth covered tank during November 2004.

The shade cloth product performed very consistently during the trials conducted at the USQ evaporation research tanks. Due to the timing in which the sample of the product reached USQ, only summer tests were conducted. The in-field trials conducted at Stanthorpe have a wider range of results collected over all seasons and as such show a wider variation in the products performance.

Commercial assessment –Stanthorpe

Using the PST/AWS method described previously, the effectiveness of the shade-cloth cover has been successfully assessed in the Stanthorpe field site and accurate figures have been derived for the percent savings in evaporation. This was attributable to large amounts of good quality pump free data obtained at this site.

The average evaporation savings throughout the year was 68% (50-87%). The NetPro shade cloth at Stanthorpe demonstrated a 80-87% reduction in evaporation during the summer months and a 50-56% saving during the winter months. The percentage evaporation reduction in winter was based on a total loss of only 1mm/day and will be sensitive to any error in estimated seepage.

The lower performance figures during the winter are thought to be due to cold/freezing water and the thermal insulation effect of the shade cloth during the winter. As both total evaporation rates and evaporation reduction performance are low during winter for the site at Stanthorpe evaporation savings will be small.

Figure 5-14 illustrates the performance of the shade cloth covered storage versus the open storage at Stanthorpe during mid November 2004. Seepage rates determined from running averages taken from preceding months were 0.5mm/day for both storages. The diagram clearly shows that the shade-cloth covered storage evaporated at a rate of less than 1mm/day, comparing to almost 5mm/day for the open control storage. The latter curve was in excellent agreement with the Penman-Monteith based estimate. The evaporation saving produced by the shade cloth was in this instance 87%.

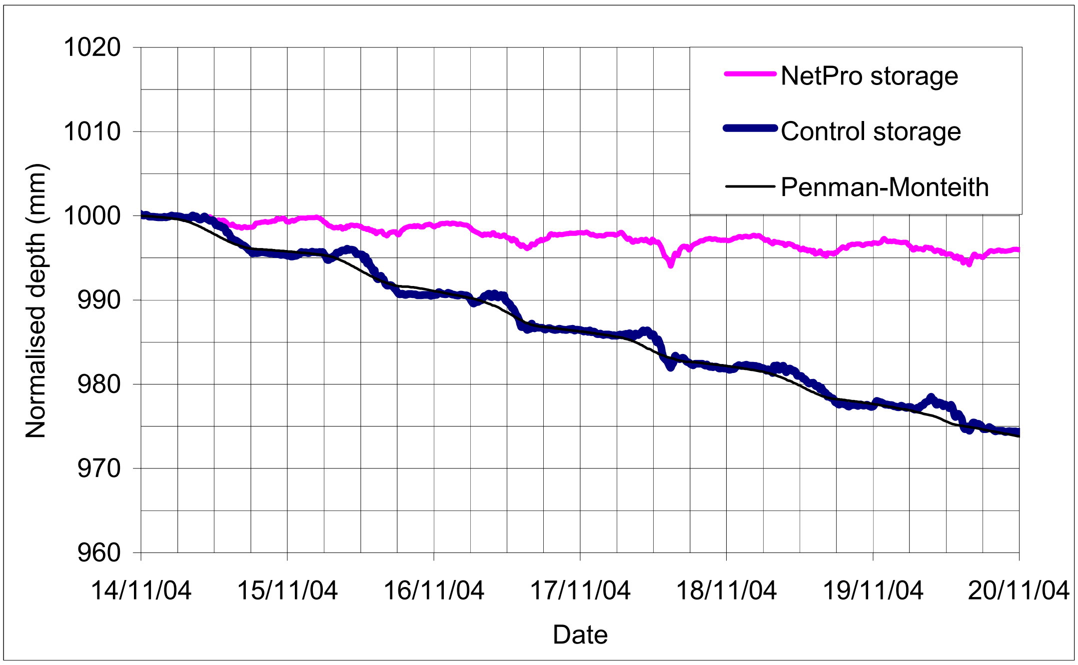

Figure 5-14 Graph showing PST recorded depth of EMT and control storages from the 14 to 20 November 2004 at the Stanthorpe.

5.1.4 Modular cover

Potential performance – Toowoomba

The Raftex modules used at the USQ trial sites consisted of five individual modules covering 68% of the surface of the 10m trial tanks (Figure 5-15, Figure 5-16 and Figure 5-17). Evaporation reduction performance figures have been adjusted to account for a 100% cover of the water surface.

The average amount of evaporation saved through the Raftex modules at the USQ Ag plot site was 56%, representing a potential saving of 87% (80 - 100%) if there were 100% cover of the water surface.

Figure 5-15 The five Raftex modules in the trial tanks at USQ.

Figure 5-16 Water pooling on top of the Raftex modules after rain or wind events.

Figure 5-17 Warping or twisting of the Raftex modules as a result of the module being blown off the tank and snapping a wooden cross brace.

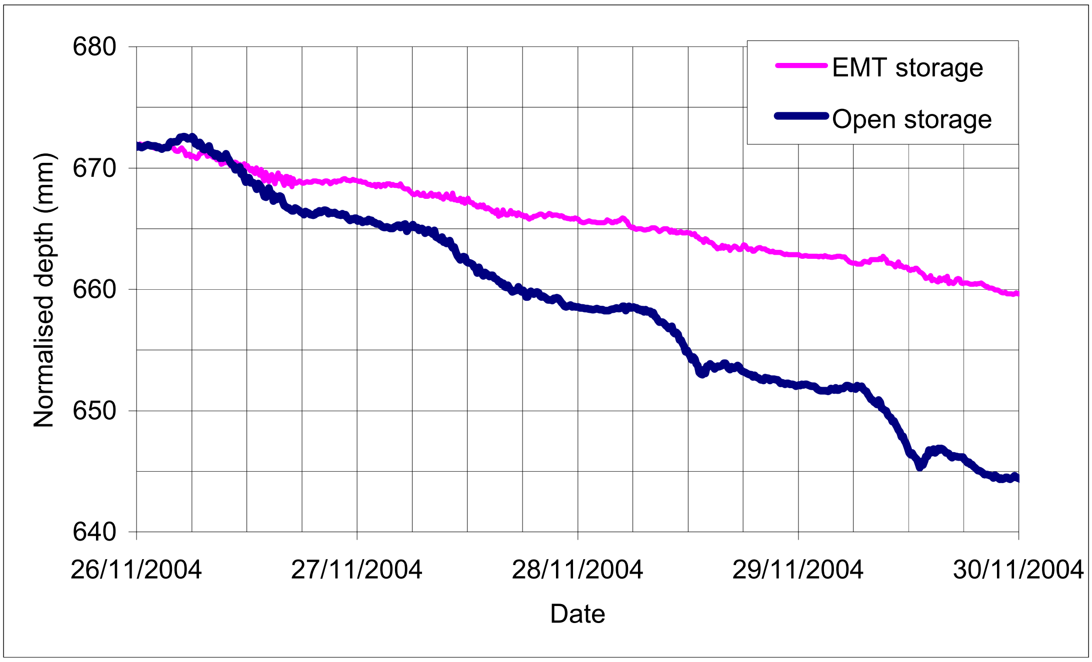

Figure 5-18 **Shows PST traces from the open tank and Raftex tank during November 2004.**

Figure 5-18 shows the total losses from the open and the Raftex tank between 26 and 30 November 2004. The Raftex covered tank lost an average of 3.0mm/day which compares to 6.8mm/day with the control tank, representing a 56% reduction in evaporation produced by the module. In this test, the modules covered only 68% of the water surface area of the tank, but if they were able to cover 100% of the water surface then the potential evaporation saving would be 82%.

5.1.5 Polyacrylamide

Potential performance – Toowoomba

Only two trials with PAM were conducted in August 2004 and January 2005 over a three week period, with the white powder applied to the tank for the first two weeks. This enabled the life (carry on effect) of the product and its ability to reduce evaporation after application had stopped.

The average amount of evaporation saved through the application of PAM at the USQ Ag plot was 37% (range 31 - 43%).

The application of PAM to the USQ trial tanks required the chemical to be sprinkled on slowly in front of a water stream from a small centrifugal pump. The water in the tank was then pumped through the same pump for approximately 45 minutes to ensure that product was well mixed. If the product was not added slowly enough, it would form lumps and would not disperse into the water. Mixing on a large storage would have practical problems given the need to thoroughly mix the product into the water storage.

Figure 5-19 Application of PAM was done by hand and the use of a centrifugal pump to circulate the water and distribute the PAM throughout the water body.

Figure 5-20 Impact of PAM on viscosity of water by binding the water molecules together.

Figure 5-21 shows the results of a test (PAM applied at the rate of 100ppm on 19 August, 2004). The average daily loss from the PAM treated tank was 2.9mm/day which compares to 5.0mm/day with the control tank. In this case, the evaporation saving that can be attributed to the application of PAM during this period was 43%. It should be noted that variation in the PST trace for the PAM tank highlights the affect of cable noise, but this did not impact on the determination of products performance (Appendix 3.4).

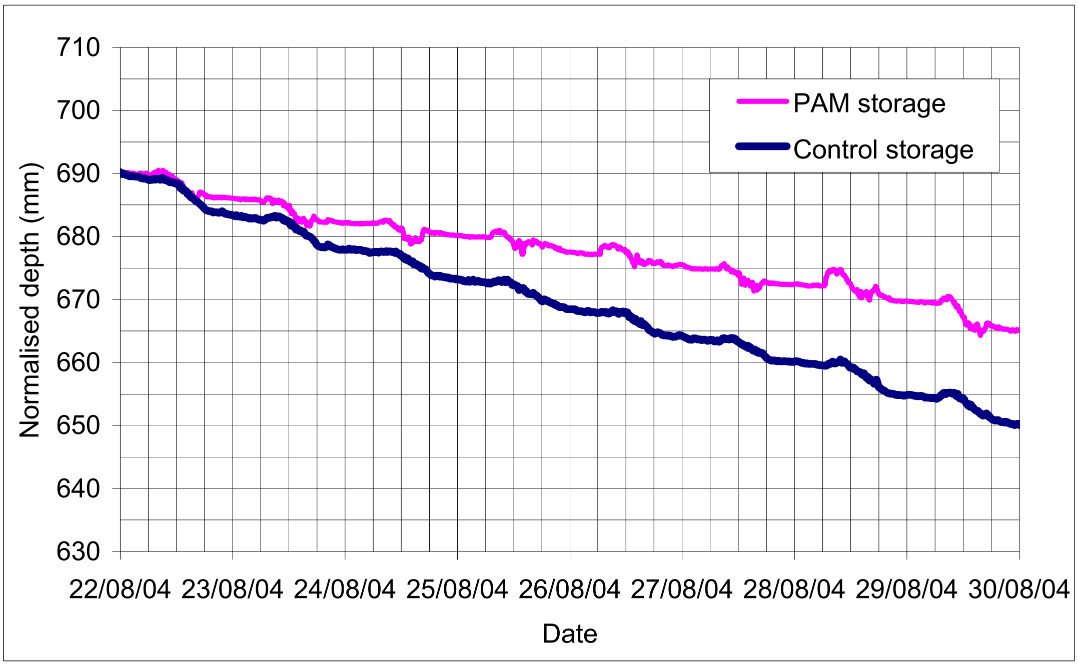

Figure 5-21 PST traces from the open and PAM treated tanks during August 2004.

5.2 Mechanical durability assessment

An evaporation mitigation technology (EMT) that reduces evaporation and has low set up costs is not necessarily a great product. A product that has a short life span or high repair or operating costs may have limited use or suitability. A mechanical durability assessment was therefore an important part of this project. This section of the report identifies issues, problems and solutions associated with each of the EMTs trialled.

As most of the EMTs on the market are fairly new products, there may be long term problems with the technology that this project has not identified. What has been apparent is that even within the timeframe of this project manufacturers have made changes to improve the durability and suitability of their products.

Mechanical durability was assessed by recording problems and issues for each product at each site. Comments were then received from the landholders of the trial sites as well as other users of the product. Manufacturers and suppliers also provided information on product mechanical durability. Ultimately this information was translated into repair, maintenance and operating costs used in the economic assessment.

5.2.1 Monolayer

The Water$avr monolayer is a chemical product which creates a thin film on top of the water surface (Figure 5-22). It is a self spreading product applied at a rate of 0.50 to 0.75kg/ha, that breaks down in two to three days. The most common method of application is by hand but this can be very time consuming if the storage is remote or if it has a large surface area. An automatic applicator was developed therefore for the 120ha storage at Dirranbandi. Monolayers do not reduce evaporation as much as permanent structures but have the advantage of only being applied when needed, that is when evaporation is high and wind is low and when there is water in the storage.

Figure 5-22 Water$avr creates a thin film on the water surface which is self spreading.

Poor performance can generally be attributed to the monolayer being broken down by ultraviolet light, consumed by algae or bacteria, or poor distribution across the water surface. Application method and distribution of the monolayer are thus crucial to increase water savings. The application system needs to be able to apply the product evenly and repeatedly every 2-3 days during high evaporation periods.

Factors that affect the distribution of the monolayer are typically wind/weather, waves and any physical barriers (Figure 5-23). Wind can be used to help distribute the product across a storage, but may potentially reduce evaporation savings if the product is blown onto an embankment or spread unevenly over the surface. 'Dumping' of the Water$avr onto the water surface (rather than careful placement) may also produce white beads (Figure 5-24) of product that are repelled by the water and are therefore ineffective in reducing evaporation. Over saturation of the monolayer makes the molecules drop into the water body and reduce its effectiveness. All of the above will result in high variability in evaporation reduction performance.

Figure 5-23 Wind can help in the initial distribution of the EMT but the wind and waves will also affect the uniformity of cover.

Automatic application with a grid system can reduce the inefficiencies of hand application as the EMT is able to be distributed more evenly over large surface areas. There are however potential mechanical problems with automatic application. The automatic applicator developed for this project mixed the dry powder with water and pumped it out through a pipe system over the storage. While the system generally worked well ongoing monitoring of the hopper, mixing chamber, pump suction and grid distribution system required. Application as a slurry from the air has not been investigated but could have potential on large storages.

Figure 5-24 Tendency of monolayer to form small beads on top of the water surface when applied by hand.

The storage used to trial the Water$avr product at Dirranbandi had water in it before the trial started. This meant the polythene pipe used in the grid system could not be buried into the floor of the storage. As a result the polythene pipe floated on the water surface and was affected by the wind and waves (Figure 5-25). The grid system would pull apart at the joints or break the rope that helped locate the outlets.

Figure 5-25 The polythene pipe floating on the water surface would pull apart at the joints or break the rope that was used to tie in place. This problem can be overcome by burying the pipe underground.

Interpretation of weather forecasts and likelihood of high evaporation would allow for the Water$avr product to be applied when it is likely to be most effective at reducing the evaporation. This will reduce the overall cost of using the product. The time cost of labour to apply the monolayer needs to be accounted for in economic assessment and could be significant. An automatic applicator reduces the labour requirements on an everyday basis but is a capital cost that may not be utilised for long periods of the year.

5.2.2 Floating cover

E-VapCap is a physical structure that has a design life of approximately 12 years. Marley Plastics (NATA registered laboratory) carried out accelerated weathering tests on the older product and said that after 10 years equivalent there was no change to the surface. The most common method for securing E-VapCap to the storage is by trenching the entire perimeter into the wall. The other method currently used is a tethered system which does not have to cover the entire water surface (Figure 5-26). E-VapCap is best suited to storages holding water all year every year owing to high capital costs. The cover design must account for the likely change in water level to ensure the floating cover is not stretched beyond its elasticity limits. Management and maintenance of the E-VapCap cover is essential in prolonging the life and allowing it to effectively reduce evaporation. Management and maintenance were significant contributors to the problems at St George. Example of sites with good management and maintenance have been included in Figure 5-10, Figure 5-26 and Figure 5-34.

Figure 5-26 The 0.25ha E-VapCap product covers 60% of the surface area of the storage at Quantong, Victoria at the client's request and uses a tethered method rather than the trenched method.

The greatest risks with this technology are physical breakdown/damage of the material, anchoring problems and keeping the cover free from debris. Careful installation is crucial to ensure potential evaporation savings are achieved and operating, repair and maintenance costs are minimised. Significant problems arose with the installation at St George. This installation represents the largest to date and was based on early technology. A number of site operational issues also affected the installation as discussed below. In particular erosion of silt onto the cover, weed growth and inundation with water to varying degrees has affected performance and has required significant maintenance and cleaning costs. The St George installation does not represent the experience of many other successful installations of the product. The experiences at St George are now being addressed by the suppliers in current designs. Detailed recommendations by consulting structural engineers (Appendix 5) which formed part of this project have assisted in this regards.

Installation must consider the shape and size of the storage as this will determine the most appropriate method/technique to anchor the product (either trenched or tethered, see Figure 5-27). Ideally the cover will have a smooth fit on the water when the storage is full and enough elasticity to cope with changing water levels. Since there is limited elasticity in the product a tethered system provides greater flexibility.

Figure 5-27 Welding of the seams during installation on a 1.3ha storage in the Barossa Valley, South Australia.

A trenched system requires extra material to be laid up the bank or in the trench (Figure 5-28). There is a trade off thus between purchasing extra material in a trenched system and installing a tethered system where the entire water surface may not be covered.

Figure 5-28 The anchor point along the bank used in the trenched system is susceptible to erosion especially if the bank is graded inwards. Alternatively, a gutter with drains can eliminate this potential problem.

Problems can occur with a trenched anchorage if there is considerable variation in the water level. If there is insufficient elasticity in the cover to remain in contact with the water surface when the water level is low the risk of wind tunnelling or ballooning (Figure 5-29) increases. When the cover is floating on the water it creates a suction to help hold the cover down and stop the wind from getting underneath. Any gaps (example around gate valves and walkways) will be wind entry points. Appendix 5 provides a detailed assessment of wind impacts and alternative design configurations that are being implemented to reduce risk.

Figure 5-29 Wind under the cover has the potential to make small tears larger and 'pump' water on top of the cover. Any subsequent addition to structures after completion of cover should be in consultation with the installer.

During installation a floating barge is used to weld strips of the product together Figure 5-27. It is difficult to install on a storage that is not full. The installation process will be made more difficult and costly if the cover has to be constructed on site, the storage is in a remote location, during windy weather conditions and if there is limited access for machinery.

Anything that leads to breakdown or damage of the cover will reduce performance and life span. Ultraviolet light will breakdown the polyethylene and can affect the elasticity of the product with time and exposure. The elasticity of E-VapCap is 2.5% when it is new and the geometry of the storage needs to be taken into account to ensure stretching is within design parameters. The elasticity properties of the cover are something that can be managed by limiting the time when water levels are low. In practice the E-VapCap cover should not reach the critical level of elasticity (2.5%) as water level varies.

Physical problems with the cover can lead to reduced evaporation saving and possible complete failure of the EMT. It is therefore advisable to address and repair any problems as soon as possible (Figure 5-30). This was not always possible at St George.

Figure 5-30 Tears should be addressed immediately by sand bagging the torn edges and contacting the installer to arrange repairs. Damage done to this cover was repaired as soon as possible after the tear to limit further damage and maintain effectiveness of the cover. The photo on the right shows the cover after the repairs had been done.

Tears can be caused by animals (Figure 5-31) or wind lifting the E-VapCap and tearing seams. An animal proof fence around the storage will decrease the risk of damage. These may start off small but can be disastrous as they allow more wind to get under the cover. Any major tears will need to be repaired by an expert with specialised equipment.

Wind intensity can be reduced by the use of trees around the perimeter to protect the storage. Given that the product floats on the water surface careful design and consideration need to be taken into account for a storage with large uncontrolled inflow or outflow.

Figure 5-31 Minor damage caused by animals may initiate large tears in the cover.

In a hail event the cover will sink until sufficient amount of the hail has melted to enable the cover to float to the surface. The cover is more vulnerable to hail damage on the dry batters but to date there has been no reported damage due to hail impact. The latest E-VapCap design does not have any manufactured holes on the storage walls of the cover.

Most of the seams are welded in the factory where possible and then on site using a floating barge for the larger storages. Problems with the welded seams that occur after installation are not easily repaired. The landholder can put a patch over the area (Figure 5-32), alternatively specialised equipment is required.

Figure 5-32 Damage to welded seams should be repaired as soon as possible. The tear can become much larger if wind is allowed to blow under the cover.

Keeping the E-VapCap cover clean is essential since silt can cause the cover to be submersed with water lying on top of the cover. The silt can be a result of runoff and erosion from the storage wall or wind and dust that blows in from nearby areas (Figure 5-33). The debris problem at St George was a result of wash off from the embankment top which sloped towards the water. The thin layer of silt can be easily removed from the cover when the water level is low enough to expose the silt as shown in Figure 5-33 This problem could be overcome by going to a tethered system or an alternative design with a shade cloth perimeter which is being developed to address this sort of problem. A secure fence will reduce the incidence of animals damaging the cover.

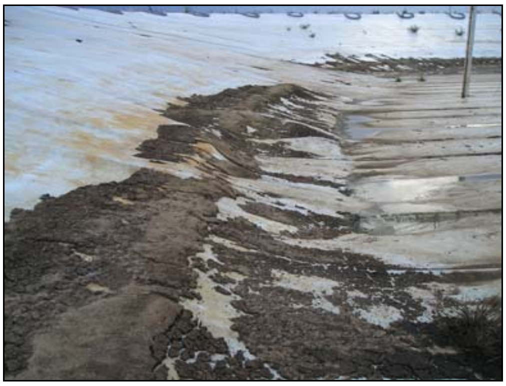

Figure 5-33 Silt and wind blown debris have the potential to stretch the cover and allow water to sit on top of the cover. Silt and debris should be removed, without damage to the cover, while the water level is low to allow the cover to float as the water level rises.

Weeds can block drainage holes, use water and could eventually damage the cover (Figure 5-11). The weeds located in these holes are in a hydroponic environment and therefore are able to grow very well. If the holes are blocked with weeds, rain can be restricted from entering the storage. Weed problems have only occurred at the St George site as a result of the wash off problems outlined previously. Management and maintenance of the weeds before they get to big is the best option for control of this problem.

Water can be pumped onto the cover through the drainage holes by waves created by wind (Figure 5-9). Inundation with water will provide temporary stabilisation during a storm however a small proportion of the water will not enter the storage and this will be lost due to evaporation.

Access to the storage floor to service gate valves, foot valves and suction lines will be limited unless an opening has been installed (Figure 5-34). Repairs to the storage walls will all have to be done from the outside. Removal and disposal of the E-VapCap, as for other products, at the end of its life also needs to be considered.

Figure 5-34 The 1.3ha storage in the Barossa Valley, SA had a removable panel installed to service a floating pump.

As stated many of the issues and problems identified during this project have now been addressed by manufacturers through improved design and installation. The owners of the St George storage believe not withstanding the problems specific to their site the E-VapCap product has potential in appropriate application. A detailed structural analysis of the E-VapCap systems was undertaken by consulting engineers as part of this project. Key recommendations are given in Appendix 5 and include;

- Two modifications to current E-VapCap system
    - Shade cloth perimeter around E-VapCap on water surface
    - Modular system anchored to storage walls
- Further research
    - Long term stretch characteristics of the E-VapCap
    - Test suction characteristics of E-VapCap to water surface
    - Trench requirements for various soil types
- Recommendations
    - Increasing resistance to tearing of the E-VapCap
    - Installations should avoid unrestrained discontinuities in the material that could lead to tearing under stress

Further research is required to study the suitability of either a fully tethered system or a modular system. Unless a modular system is introduced the maximum area for a floating cover system is likely to be less than 1ha.

5.2.3 Suspended cover

The NetPro cabled shade cover is a physical cover suspended above the water and made from high tension cable and black monofilament shade cloth. The cable framework looks like a giant spider web with the cables being spliced at the crossover points (Figure 5-35). The cables are anchored into the storage wall and the EMT covers 100% of the water surface. The structure itself has a design life of 30 years with the shade cloth expected to require replacement after 15 years as estimated by the supplier. This type of EMT is best suited to storages with permanent water. Changes in the water level do not affect the cover as it is free standing and not in contact with the water.

Figure 5-35 Installation of the high tension cables which are anchored into the wall of the storage.

Potential failures are a result of physical breakdown or damage of the shade cloth and the framework or structure. Good installation is crucial to ensure the EMT reduces evaporation and the operating and repairs & maintenance are minimised.

The shape and size of the storage will determine the structure or framework required to support the shade cloth. Being a physical structure the biggest concern is wind getting under the cover causing tunnelling and ballooning. Installation is best done with the storage empty as access is required to insert the poles and to fix the shade cloth to the wire cable. The limiting factor for the size of storage covered is the ability for the shade cloth to span from one bank to the other.

Anything that leads to breakdown or damage of the cover will not only reduce its performance but also decrease its life span. Ultraviolet light will breakdown the shade cloth over time and exposure. It is also advisable to repair any tears, holes and split joints as soon as they are noticed. Tears can be caused by animals or wind lifting the shade cloth and can potentially be serious as they allow more wind to get under the cover. Any major tears will need to be repaired by an expert with specialised equipment or alternatively sections of shade cloth may need to be replaced.

Clips that join the shade cloth together can break or rip out of the shade cloth itself (Figure 5-36). This can be a result of an excessive load being placed on the shade cloth by wind or material sitting on the shade cloth. During a hail storm the hail needs to be carried by the structure until it melts and drains through the shade cloth.

Figure 5-36 The seams in the shade cloth are joined by wires and clips. Any damage to the seams should be repaired as soon as possible to avoid even further damage.

During rainfall events water flows to the centre of each shade cloth strip and then through. A small proportion of the water will not flow through the shade cloth and this water will evaporate.

Figure 5-37 Water sitting in the hollows after a rainfall event.

The evaporation mitigation performance will be reduced if the water level in the storage is above the cover. The shade structure will also sag when wet. Silt and debris can be deposited onto the cover around the water perimeter by the wind and needs to be removed as soon as possible. A curtain is used to stop silt build up and wind tunnelling under the cover (Figure 5-38). As the cover is not in contact with the water weeds are not likely to grow on the shade cloth.

Figure 5-38 Around the perimeter of the main shade cloth structure is a curtain that hangs over the edge of the to reduce the amount of wind getting under the cover but still allow any silt that is eroded off the storage bank not to sit on top of the cover.

Access to the storage floor to service gate valves, foot valves and suction lines will be limited by the size of the opening in the shade cloth (Figure 5-39). Any repairs to the storage walls will all have to be done from the outside. Removal and disposal of the shade cloth at the end of its life needs to be considered.

Figure 5-39 A gateway entrance was retrofitted to the cover to allow access under the cover.

NetPro is a proven structure and has been widely used with hail protection nets over orchards. The shade cloth can be purchased in a range of UV ratings to suit the need of the landholder.

5.2.4 Modular cover

Raftex is a modular cover that forms a floating physical barrier on the water surface to reduce water evaporation. Because it is a modular system and each module is not tied together, it does not cover 100% of storage. The percentage covered will depend upon the shape and size of storage.

This type of EMT is best suited to storages with water in them all year every year to spread the high initial investment costs a greater volume of water saved. Changes in the water level do not affect the cover as the modules are free floating on the water.

Potential failures are a result of physical breakdown or damage of the plastic wrap, framework and not covering the water surface. Wind is the biggest factor likely to affect the modules by blowing them out of position or damaging them. Shifting of the modules around the storage as a result of the wind is not a concern except where the modules are blown on top of each other or off the water surface completely. In these situations they will have to be physically put back into place. This is less of a problem for the modules around the perimeter but it may be very difficult to gain access to the modules in the middle. Limited or difficult access to modules in the centre of storage will hinder repairs and maintenance and the practicality of the EMT. The effect of wind will be minimised if the modules have enough weight in them or are shaped to be stable under windy conditions. Additional weight makes modules less buoyant and more difficult to handle but provides better protection against the wind. Partially filling the module with water is one way of adding ballast without making the module any heavier to transport. The size and shape of each module will also have an impact on the ability of wind to disturb the product.

The life of the plastic film will be the biggest determinant in how often the modules need to be removed and replaced. With potentially only a short life of the plastic wrap, access for repair or replacement will be important. The possibility of turning the modules over and using the second side could be considered.

Water sitting on the cover (Figure 5-40) will have a high evaporation rate and is caused by rain and also wind/wave action. This problem can be overcome by raising the centre of the frame to produce a self draining pyramid shape.

Figure 5-40 Water sitting on the modules gets there by rain or by the wind blowing and waves going over the edge. The water does not drain off here and will only evaporate.

Damage to modules by birds and other wildlife resting on the structure (Figure 5-41) can be a problem.

Figure 5-41 Ducks use the modules as little islands and they have the potential to put holes in the plastic wrap.

Frames can bend or twist out of shape resulting in the module not sitting flat on the water surface (Figure 5-42). Frame deformation can occur naturally or when the plastic wrap is applied or changed.

Figure 5-42 A portion of the bent frames tend to sit out of the water or under water. When the Raftex is in this state the efficiency of the product is reduced.

Consideration needs to be given to removal and disposal of material at the end of its design life. Many of the issues and problems that were identified during the project have now been addressed by product suppliers. Given that the product floats on the water surface it is not suitable for uncontrolled in flow or out flow.

5.2.5 PAM

PAM is a polyacrylamide which is a chemical binding product that is added to water to increase viscosity and reduce evaporation. For the best result the PAM needs to be mixed throughout the entire water body. There remains a lot of unknowns about the product such as rate, frequency of application and how to incorporate the PAM into the water body (Figure 5-43). During trialling by the NCEA the PAM was applied at a rate of 100ppm every 7 days. Results showed that at this application rate and in these tanks about one week was the optimum time to reapply the product.

This type of EMT does not reduce the evaporation as much as the permanent structures but it has the advantage of only being applied when evaporation is high or there is water in the storage.

Figure 5-43 Application of PAM requires the contents of the storage to be completely mixed.

The rate of breakdown through UV, and performance under dirty water locations are not well understood. The distribution of PAM throughout the water body also requires further investigation as this will influence selection of application and mixing system. Consideration also needs to be given to the affect on the environment (Figure 5-44).

Figure 5-44 The product becomes very sticky and glue like when wetted. This may create problems in field applications.

5.3 Economic assessment

This project has evaluated a number of evaporation mitigation technologies (EMTs). The performance of each product, in terms of reduced evaporation loss has been assessed and operational costs of using each product have been evaluated. This section provides a regional economic assessment of the potential for evaporation reduction across Australia using the products. A full economic analysis was conducted for three of the EMTs (E-VapCap, NetPro shade cloth and Water$avr). It was assumed that there was little or no salvage value for any of the EMTs at the end of their life. This may change in the future or if the location of the recycling centre is close.

5.3.1 Factors impacting evaporation savings

A number of factors will (evaporation potential, storage characteristics, product evaporation reduction performance) will affect the amount of evaporation water that can be saved using an evaporation control product.

Evaporation potential

For the purposes of this regional economic assessment, five broad categories of potential evaporation from storage were selected (Table 5-4). The spatial variation in potential ET based on Australian Bureau of Meteorology data (http://www.bom.gov.au) illustrated variation in point potential ET from approximately 3200mm/yr in Northern Territory to 1400mm/yr in Victoria. The Australian Bureau of Meteorology provide maps of the average annual point potential ET (Figure 3-13) and recommend use of this information when estimating evaporation from small storages.

Table 5-4 Potential evaporation classes and locations used in economic assessment.

Potential Evaporation	Evaporation from storage (mm/yr)	Location
Very High	3000	Northern Territory
High	2600	Central Queensland
Moderate	2200	Eastern Queensland
Low	1800	Central NSW
Very Low	1400	Victoria

Table 5-5 Seasonal distribution of evaporation at five locations across Australia.

	Very High Evaporation		High Evaporation		Moderate Evaporation		Low Evaporation		Very Low Evaporation	
	Evaporation (mm	% of Total	Evaporation (mm	% of Total	Evaporation (mm)	% of Total	Evaporation (mm)	% of Total	Evaporation (mm)	% of Total
Jan	**245**	**8.2%**	**340**	**13.1%**	**268**	**12.2%**	**261**	**14.5%**	**214**	**15.3%**
Feb	**204**	**6.8%**	**268**	**10.3%**	**223**	**10.2%**	**203**	**11.3%**	**178**	**12.7%**
Mar	**245**	**8.2%**	**258**	**9.9%**	**201**	**9.1%**	**189**	**10.5%**	**161**	**11.5%**
Apr	**235**	**7.8%**	**186**	**7.1%**	**168**	**7.6%**	**121**	**6.7%**	**89**	**6.4%**
May	**224**	**7.5%**	**113**	**4.4%**	**112**	**5.1%**	**77**	**4.3%**	**54**	**3.8%**
Jun	**204**	**6.8%**	**83**	**3.2%**	**101**	**4.6%**	**58**	**3.2%**	**45**	**3.2%**
Jul	**204**	**6.8%**	**93**	**3.6%**	**101**	**4.6%**	**68**	**3.8%**	**45**	**3.2%**
Aug	**245**	**8.2%**	**134**	**5.2%**	**134**	**6.1%**	**87**	**4.8%**	**54**	**3.8%**
Sep	**276**	**9.2%**	**196**	**7.5%**	**168**	**7.6%**	**116**	**6.5%**	**80**	**5.7%**
Oct	**327**	**10.9%**	**279**	**10.7%**	**223**	**10.2%**	**165**	**9.1%**	**134**	**9.6%**
Nov	**316**	**10.5%**	**310**	**11.9%**	**235**	**10.7%**	**213**	**11.8%**	**161**	**11.5%**
Dec	**276**	**9.2%**	**340**	**13.1%**	**268**	**12.2%**	**242**	**13.4%**	**187**	**13.4%**
Totals	**3000**	**100.0%**	**2600**	**100.0%**	**2200**	**100.0%**	**1800**	**100.0%**	**1400**	**100.0%**

Seasonal patterns of evaporation are important since a disproportional high amount of evaporation loss will occur over summer months. Evaporation control products like Water$avr can be selectively applied only during these periods to improve economic performance.

Table 5-6 shows the amount of winter and summer time evaporation for each of the five regions. It shows that where the potential evaporation is very high then there is not much difference between winter and summer but for very low evaporation regions summer accounts for nearly 75% of the total yearly evaporation.

Table 5-6 Winter and summer evaporation rates for each of the five regions.

	Very High Evaporation		High Evaporation		Moderate Evaporation		Low Evaporation		Very Low Evaporation	
	Evaporation (mm	% of Total	Evaporation (mm	% of Total	Evaporation (mm)	% of Total	Evaporation (mm)	% of Total	Evaporation (mm)	% of Total
Apr-Sep	**1388**	**46.3%**	**805**	**31.0%**	**782**	**35.5%**	**527**	**29.3%**	**366**	**26.1%**
Oct-Mar	**1612**	**53.7%**	**1795**	**69.0%**	**1418**	**64.5%**	**1273**	**70.7%**	**1034**	**73.9%**
Total	**3000**		**2600**		**2200**		**1800**		**1400**	

The seasonal distribution of evaporation for sites typifying each of these zones is given in Table 5-5 and Figure 5-45. Figure 5-45 shows the locations that were used as a basis for representing seasonal distribution of evaporation. For the economic analysis it is assumed the EMT works on a percentage saved and the different climatic classes have no effect on EMT performance and this performance does not change throughout the year.

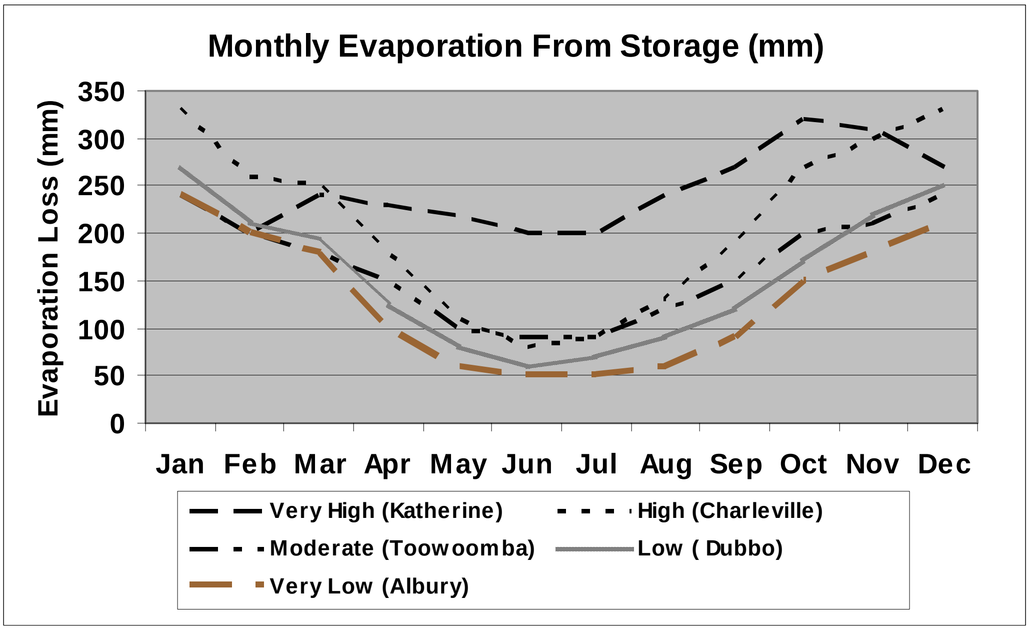

Figure 5-45 **Seasonal distribution potential of evaporation from storages in different climatic zones.**

Storage characteristics

An important consideration is the amount of time the storage holds water (Section 3.4.2). The regional analysis undertaken in this report used four scenarios of water hold in storage;

- Jan – Dec (12 months)
- Sep – Apr (8 months)
- Oct – Mar (6 months)
- Nov – Feb (4 months)

Performance of EMT in reducing evaporation

Based on the potential performance of each product measured under ideal conditions on the USQ Ag plot research tanks and the commercial performance at collaborator sites, performance scenarios were developed for the regional economic evaluation (Table 5-7). The economic analysis was undertaken for the three products tested on a commercial scale.

Table 5-7 **Evaporation reduction performance indices used in economic analysis.**

Product	**Performance of EMT (% evaporation mitigation)**		
	Low	**Moderate**	**High**
E-VapCap	85%	90%	95%
NetPro shade cloth	60%	70%	80%
Water$avr	5%	15%	30%

5.3.2 Cost of EMTs

A detailed assessment of the capital, operating, maintenance and repair costs of the three commercially evaluated EMT products was undertaken based on discussions with suppliers and storage landowners. Appendix 6 summarizes the detailed cost breakdown for each product. Capital costs for the E-VapCap and NetPro structures will vary depending on a range of factors including product specification, site location, access, installation specifics, wind, storage geometry and surface area. In discussion with product suppliers a representative range of capital costs was determined.

The Water$avr product can be applied manually and has no capital costs. However, a mechanical pump applicator and grid piping system can be used to reduce labour and would incur a capital cost.

Repairs, maintenance and operating costs have been detailed in Appendix 6. For the E-VapCap and NetPro structures these include visual checks, removal of debris, soil and weeds (E-VapCap) and repairs to tears. For the Water$avr product operating costs include application of the product costs, labour or pump operating costs, inspections and repairs to and maintenance of the pumping system.

A summary of key costs used in the analysis is given in Table 5-8. A range of cost scenarios (low, medium and high) was used to represent the likely spread in capital, operating and maintenance costs. The normal operating and maintenance costs for each of the EMTs is considered to be at the low cost scenario. The high cost scenario represents worst case conditions and is unlikely to arise under good management

Table 5-8 Summary of costs in economic analysis.

	E-VapCap	NetPro shade cloth	Water$avr (automatic application)	Water$avr (hand application)
Capital Cost			Pump applicator	
Low	$5.50/sqm	$7.00/sqm	$80,000(large storage)	-
Medium	$7.00/sqm	$8.00/sqm	$53,000 (medium storage)	-
High	$8.50/sqm	$10.00/sqm	$19,000 (small storage)	-
Design Life	12 years	15 year cloth 30 year structure	20 years applicator	
Chemical Cost				
Low			0.50kg/ha every 3 days @ $13.00/kg	
Medium			0.50kg/ha every 2 days @ $13.00/kg	
High			0.75kg/ha every 2 days @ $13.00/kg	
Operating Cost				
Low	$112.50/ha/yr	$112.50/ha/yr	$29.00/ha/yr	$520.00/ha/yr
Medium	$187.50/ha/yr	$237.50/ha/yr	$41.75/ha/yr	$649.00/ha/yr
High	$322.50/ha/yr	$337.50/ha/yr	$466.00/ha/yr	$2,275.00/ha/yr
Maintenance Cost				
Low	$0.00/ha/yr	$0.00/ha/yr	$7.25/ha/yr	
Medium	$150.00/ha/yr	$100.00/ha/yr	$16.38/ha/yr	
High	$250.00/ha/yr	$200.00/ha/yr	$386.60/ha/yr	

5.3.3 Economic assessment

A discounted cash flow analysis was undertaken for each of the products. A real discount rate of 5% was assumed. A sixty year projection was used to give a common investment cycle for all products. The net present value (NPV) of the investment and annuity to finance this investment was determined. Table 5-9 gives the NPV of the investment and annuity value for each evaporation control product.

Table 5-9 NPV and equivalent annuity for each product and cost scenario.

EMT	Cost Range	NPV	Annuity
E-VapCap	Low	$119,593	$6,318
	Medium	$155,888	$8,235
	High	$192,372	$10,163
NetPro	Low	$98,691	$5,214
	Medium	$116,745	$6,167
	High	$148,120	$7,825
Water$avr	Low	$16,248	$858
(Automatic Applicator)	Medium	$24,337	$1,286
	High	$55,199	$2,916
WaterSaver	Low	$24,797	$1,310
(Hand Applicator)	Medium	$34,735	$1,835
	High	$76,664	$4,050

The dollar value of the annuity cost per megalitre (ML) of water saved varies for each EMT and with performance. Table 5-10 provides the annualized cost per ML of water saved for;

- Three products, E-VapCap, NetPro and Water$avr (automatic and hand application)
- The evaporation performance figures for each product (Table 5-7)
- The product cost scenarios (Table 5-8 and Table 5-9)
- The potential evaporation classes (Table 5-4)

Table 5-10 illustrates a number of important trends that are summarised in the figures below.

Figure 5-46 illustrates the cost of each product per ML water saved ($/ML) assuming a low cost scenario (Table 5-8 and Table 5-9) and moderate evaporation reduction efficiency (Table 5-7). It is likely that given increased demand for evaporation mitigation technologies, economies of scale and associated product development, the low cost scenario is achievable. The 'moderate' evaporation reduction efficiency of each product is also considered to be achievable on commercial storages following current initiatives in product development. Cost per ML saved increases as potential evaporation from storage reduces (moving south). That is the same investment or outlay now saves less water. Therefore it is easier to justify an EMT in an area of potentially very high evaporation than a very low evaporation area. The cost per ML is not markedly different between the products, especially the E-VapCap and NetPro products. Automatic application of the Water$avr application is likely to be more cost effective especially on small storages but would need to deliver at least 15% reduction in evaporation.

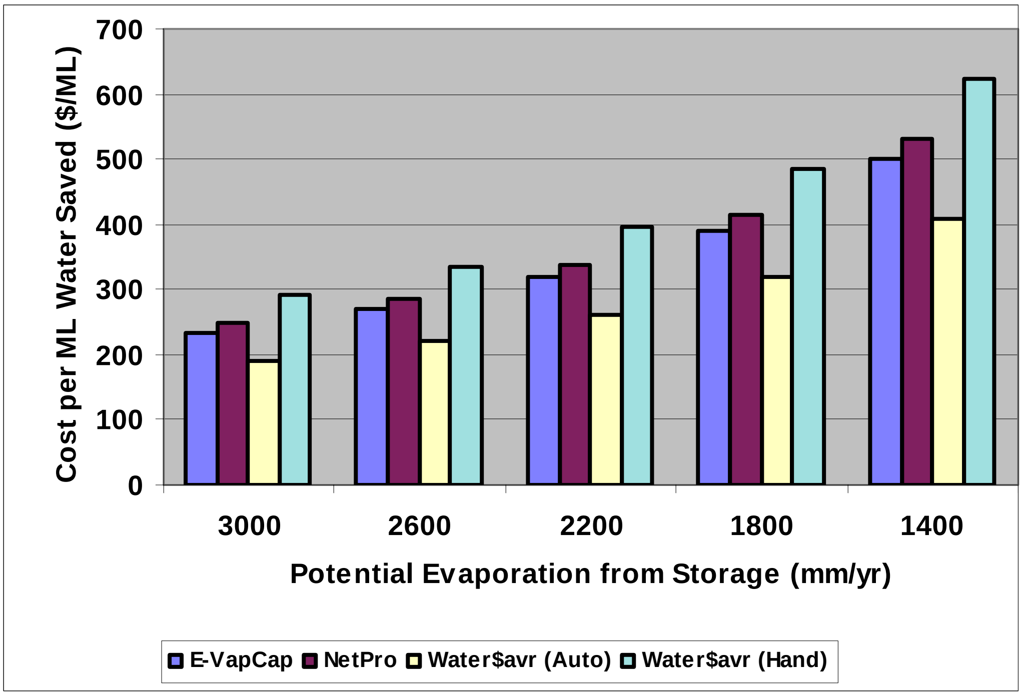

Figure 5-46 Cost of each product per ML water saved ($/ML) (Low cost scenario and moderate evaporation reduction efficiency).

Figure 5-47 illustrates the cost of each product per ML water saved ($/ML) for a location with potential evaporation from storage of 2200mm for a range of installation costs (low to high). A moderate evaporation reduction efficiency (Table 5-7) is again assumed as being achievable for each product. The influence of increased capital, repair and operating costs is indicated. The Water$avr product becomes very expensive under 'high' cost scenarios which generally represent the relatively large investment made in an applicator (automatic application) or the high relative labour costs (hand application) associated with small storages.

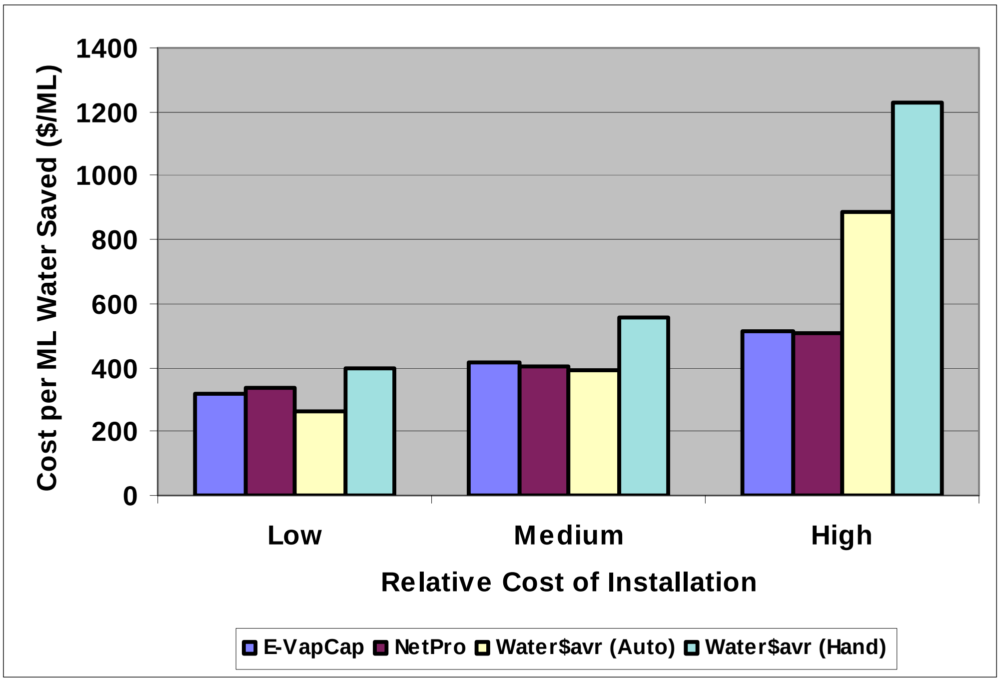

Figure 5-47 Cost of each product per ML water saved ($/ML) for 2200mm potential evaporation from storage (Moderate evaporation reduction efficiency).

Figure 5-48 illustrates the cost of each product per ML water saved ($/ML) for a location with potential evaporation from storage of 2200mm for a range of evaporation reduction efficiencies (low to high). A low cost scenario is again used in this assessment. The influence of high evaporation reduction performance is illustrated. The Water$avr product has shown high variability in evaporation performance and achieving only a 5% reduction in efficiency will increase costs/ML significantly.

The above graphs have illustrated the trends affecting the cost per ML water saved for each product. Under situations where annual evaporation from storage exceeds 2000mm and given achievable evaporation reduction efficiency ('moderate' - Table 5-7) and product cost scenarios ('low' cost scenario – Table 5-8) the cost of each product per ML water saved is likely to range between $250/ML and $400/ML water saved.

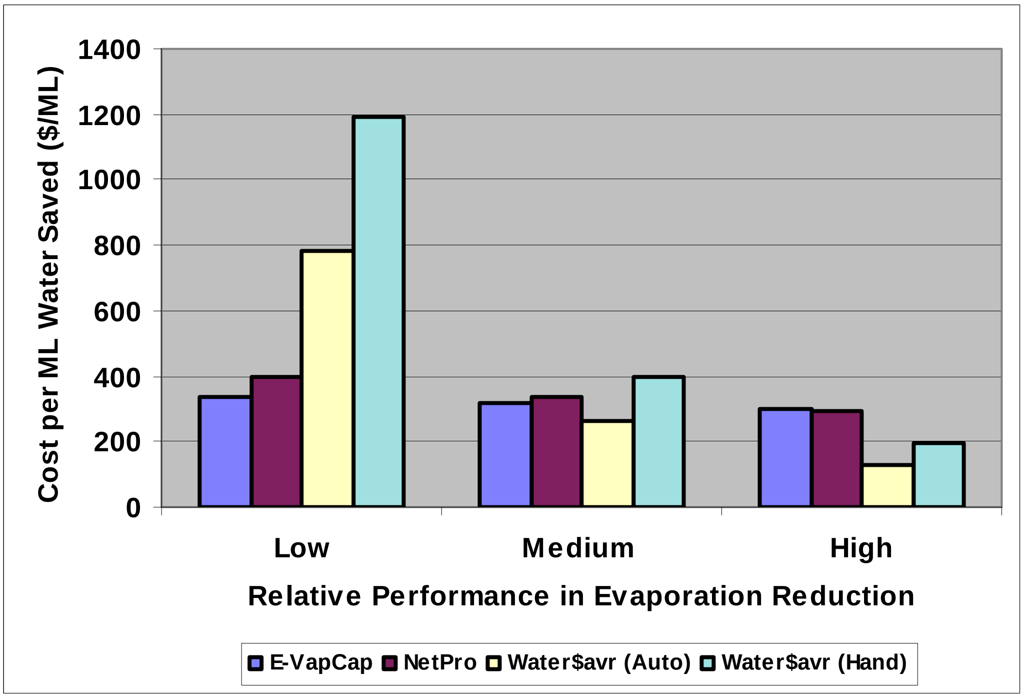

Figure 5-48 Cost of each product per ML water saved ($/ML) for a location with 2200mm potential evaporation from storage (Low cost scenario).

Table 5-11 illustrates the effect of the number of months the storage has water in it. For the permanent EMTs the costs increase as the number of months with water decreases. That is the cost of these products per ML saved will increase substantially if the storage is empty for periods. But for the EMTs that can be applied when water is in the storage it can decrease the cost per ML of water saved to 64% of the original cost. It is best for all permanent EMTs to have water in them 365 days per year to help spread the costs.

The Water$avr product has the advantage that capital investment is limited, especially under hand application. Thus the product can be applied judiciously during periods of high evaporation and not applied when the storage is empty. This means that the Water$avr can be applied only during the peak evaporation periods to reduce the cost per ML of water saved.

Table 5-10 **Cost of EMT (annuity cost per ML of water saved).**

E-VapCap		Very High Evaporation			High Evaporation			Moderate Evaporation			Low Evaporation			Very Low Evaporation		
		Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)		
Cost	Annuity ($/ha/yr)	85%	90%	95%	85%	90%	95%	85%	90%	95%	85%	90%	95%	85%	90%	95%
		$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML
Low	$6,318	$248	$234	$222	$286	$270	$256	$338	$319	$302	$413	$390	$369	$531	$501	$475
Medium	$8,235	$323	$305	$289	$373	$352	$333	$440	$416	$394	$538	$508	$482	$692	$654	$619
High	$10,163	$399	$376	$357	$460	$434	$411	$543	$513	$486	$664	$627	$594	$854	$807	$764

NetPro		Very High Evaporation			High Evaporation			Moderate Evaporation			Low Evaporation			Very Low Evaporation		
		Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)		
Cost	Annuity ($/ha/yr)	60%	70%	80%	60%	70%	80%	60%	70%	80%	60%	70%	80%	60%	70%	80%
		$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML
Low	$5,214	$290	$248	$217	$334	$286	$251	$395	$339	$296	$483	$414	$362	$621	$532	$466
Medium	$6,167	$343	$294	$257	$395	$339	$297	$467	$400	$350	$571	$489	$428	$734	$629	$551
High	$7,825	$435	$373	$326	$502	$430	$376	$593	$508	$445	$725	$621	$543	$932	$798	$699

Water$avr - Auto		Very High Evaporation			High Evaporation			Moderate Evaporation			Low Evaporation			Very Low Evaporation		
		Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)		
Cost	Annuity ($/ha/yr)	5%	15%	30%	5%	15%	30%	5%	15%	30%	5%	15%	30%	5%	15%	30%
		$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML
Low	$860	$573	$191	$96	$662	$221	$110	$782	$261	$130	$956	$319	$159	$1,229	$410	$205
Medium	$1,288	$859	$286	$143	$991	$330	$165	$1,171	$390	$195	$1,431	$477	$238	$1,840	$613	$307
High	$2,929	$1,953	$651	$325	$2,253	$751	$376	$2,663	$888	$444	$3,255	$1,085	$542	$4,185	$1,395	$697

Water$avr - Hand		Very High Evaporation			High Evaporation			Moderate Evaporation			Low Evaporation			Very Low Evaporation		
		Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)			Evaporation Reduction (%)		
Cost	Annuity ($/ha/yr)	5%	15%	30%	5%	15%	30%	5%	15%	30%	5%	15%	30%	5%	15%	30%
		$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML	$/ML
Low	$1,310	$873	$291	$146	$1,008	$336	$168	$1,191	$397	$198	$1,456	$485	$243	$1,871	$624	$312
Medium	$1,835	$1,223	$408	$204	$1,412	$471	$235	$1,668	$556	$278	$2,039	$680	$340	$2,621	$874	$437
High	$4,050	$2,700	$900	$450	$3,115	$1,038	$519	$3,682	$1,227	$614	$4,500	$1,500	$750	$5,786	$1,929	$964

Table 5-11 Impact of different periods of water storage on $/ML cost of each product (%).

	Very High Evaporation				High Evaporation				Moderate Evaporation				Low Evaporation				Very Low Evaporation			
No Months Water in Storage	12	8	6	4	12	8	6	4	12	8	6	4	12	8	6	4	12	8	6	4
Months Water in Storage	Jan-Dec	Sep-Apr	Oct-Mar	Nov-Feb	Jan-Dec	Sep-Apr	Oct-Mar	Nov-Feb	Jan-Dec	Sep-Apr	Oct-Mar	Nov-Feb	Jan-Dec	Sep-Apr	Oct-Mar	Nov-Feb	Jan-Dec	Sep-Apr	Oct-Mar	Nov-Feb
Days Water in Storage	365	242	182	120	365	242	182	120	365	242	182	120	365	242	182	120	365	242	182	120
Evaporation Loss from Storage (mm)	3000	2122	1612	1041	2600	2177	1795	1259	2200	1753	1418	994	1800	1510	1273	919	1400	1204	1034	740
E-VapCap	100%	141%	186%	288%	100%	119%	145%	207%	100%	125%	155%	221%	100%	119%	141%	196%	100%	116%	135%	189%
NetPro	100%	141%	186%	288%	100%	119%	145%	207%	100%	125%	155%	221%	100%	119%	141%	196%	100%	116%	135%	189%
Water$avr (Automatic)	100%	96%	96%	102%	100%	81%	75%	73%	100%	85%	80%	79%	100%	81%	73%	70%	100%	79%	70%	67%
Water$avr (Hand)	100%	94%	93%	95%	100%	79%	72%	68%	100%	83%	77%	73%	100%	79%	71%	64%	100%	77%	67%	62%

5.3.4 Economic value of water

The assessment given above provides broad guidelines on cost of investing in various EMTs per ML saved for different locations and conditions. This project looked at the costs associated with saving water by reducing evaporation and it is up to each individual to determine a return for that water. This would require an assessment of the economic value of water. If a farmer knows the value of water then the viability of investing in a selected EMT can be assessed. The value of water can be related to a range of factors including the opportunity cost of water lost (in terms of production and profit forgone), the revenue earned from a water sale or the cost of a water purchase.

To compare the costs associated with saving water by reducing evaporation with the profit from additional crop produced from this water, requires the use of irrigated crop profit figures. These net profit figures are found by subtracting the additional gross income (yield x price) of the crop less the extra variable and fixed costs associated with growing the crops. The variable costs are usually associated with the seed, fertiliser and chemicals needed to grow the crop where as the additional fixed costs relate to the extra annual capital (including interest payments on new loans) and labour costs associated with the saved water used on the crop. There may also be additional establishment costs if the saved water is used on new crops such as grapes or tree crops. An indication of additional crop and profit using saved evaporation water is given by considering the gross margin per ML water saved. Table 5-12 illustrates for example the gross margin per ML water for a range of crops in the Darling Downs area (DPI, 2002 http://www.dpi.qld.gov.au/fieldcrops/10808.html).

The gross margin ($/ML) ranges from $130/ML for soyabeans to $664/ML for wheat on irrigated crops on the Darling Downs. Most of the EMTs would be viable to save water for additional wheat production but none for additional soyabean production (Table 5-12). The costs are particularly sensitive to selling price which will change depending on market conditions. A risk based assessment done over several years would be required to assess the cost/benefit of each crop.

Temporary water trades would also be possible with water savings. The selling price of water will depend on demand/supply conditions and could range from $50/ML to $300/ML. The timing of water availability, for example water being available for a critical irrigation or at the end of a dry spell would command better prices. The cost of purchasing water will be affected by the same factors as well as the costs of infrastructure to pump, store and convey water.

It is clear that assessing the cost benefit of investing in evaporation mitigation is very dependent on local conditions. The information in Table 5-12 provides a useful basis for assessing investment cost per ML of water saved which can be compared with the economic value of water for the grower. Site, crop, grower and timing conditions need to be accounted for when doing a full cost benefit. Such an assessment needs to account for risk both in terms of when storage is empty (a function of within and between year water demand and supply patterns) and the fluctuating value of water and crop production.

5.3.5 Conclusions

Evaporation mitigation technologies have been shown to be potentially economically viable to reduce evaporation and save water. The decision to install a system will depend on the value of water to the landowner in terms of increased crop production, cost of water and potential to trade water surplus.

Table 5-12 Gross margin per ML irrigation water for selected crops.

Irrigated Crop Profits ($/ML) Darling Downs Source: QDPI (2002)	
Crop	**$/ML**
Peanuts	$190
Maize	$170
Sorghum	$236
Cotton	$598
Wheat	$664
Barley	$501
Sunflower	$141
Soyabeans	$130

The potential cost of installing and operating an EMT ($/ML) has been illustrated in the report for a range of scenarios. Cost of water per megalitre ($/ML) will be a function of;

- installation and maintenance costs which are very dependent on site situation and installation issues,
- annual and seasonal evaporation losses from storage at the location, and
- efficiency of the EMT in reducing evaporation.

The report illustrates that for a site with annual open water evaporation potential of 2200mm and competitive (low) installation and operating costs, the product costs per ML water saved would vary, depending on the efficiency of product in reducing evaporation (Table 5-13). For each product, the medium evaporation reduction performance scenario is considered achievable based on the results of this study and assuming continuing product development.

Table 5-13 Water cost per megalitre for a range of evaporation mitigation performances.

	Evaporation reduction performance		
	High	**Medium**	**Low**
E-VapCap	$302	$319	$338
NetPro shade cloth	$296	$339	$395
Water$avr (auto)	$130	$261	$782
Water$avr (hand)	$198	$397	$1191

The E-VapCap and NetPro shade cloth structures require high initial capital investment while costs associated with monolayer (Water$avr) are primarily a variable cost related to amount of product applied.

The cost/ML saved will be influenced by the amount of time the storage holds water. Water$avr can be selectively applied only in hot months or when there is water in storage which will reduce $/ML water saved. For example, for storages only holding water during the six month period (Oct-March) the unit cost given above for E-VapCap and NetPro would increase by 145% while for the Water$avr product they would reduce to 75%.

Gross margins per ML water used for increased crop production can range from $100/ML to over $1000/ML. Saving water by reducing evaporation therefore would be a viable option in many instances.

5.4 Water quality assessment

A simple water quality monitoring program was designed to determine if there was any large scale changes in the quality of water in the presence of any of the EMTs tested. The water quality monitoring undertaken was dependant on access, budget, timing, staff and a number of other constraints. Therefore the frequency and number of parameters monitored at each site was variable. Water quality varies naturally under the influence of a range of processes, therefore, the results from this water quality monitoring program could not definitively assess if the EMT was the primary cause of the change in water quality. However, it was able to highlight areas of change and areas that require further investigation.

The following results from each of the monitoring programs provide examples of analyses undertaken. Due to the varying natural and site specific parameters affecting water quality, results can not be reported on a 'by EMT' basis. Instead the results have been reported on a 'by site and EMT' basis. Where available the water quality results from the storage with the EMT have been compared to an open or control storage. Again, due to site specific parameters (soil properties, pumping schedule, water source, etc), there may be natural variation between the two storages even if they are within fairly close proximity to one another. This means that two storages side by side would not necessarily have the same water quality however the control storage can be considered a reasonable baseline for comparison.

The results from the water quality monitoring programs undertaken at each site did not indicate any large scale changes in the quality of the water in storage (Table 5-14). At both the Ag plot and the field site at St George, the temperature and the Dissolved oxygen levels under the E-VapCap cover were slightly lower than in the control storages. The temperature was also slightly lower under the shade cloth and the Raftex systems when compared with the control storage at the USQ Ag plot. None of the EMTs appeared to have any impact on the pH or conductivity of the water in storage. The monolayer product did not appear to have significant impact on any of the water quality determinants.

Table 5-14 Changes apparent in water quality parameters in both field scale trials and at the USQ Ag plot.

	pH	Dissolved oxygen	Temperature	Electrical conductivity	Algae
Monolayer	-	-	-	-	-
E- VapCap	-	↓	↓	-	Not analysed but reducing sunlight will reduce algal populations
Shadecloth	-	-	↓	-	Not analysed but reducing sunlight will reduce algal populations
Raftex	-	-	↓	-	Not analysed but reducing sunlight will reduce algal populations
PAM	-	-	-	-	Not investigated

5.4.1 USQ Ag plot

In-situ water sampling was conducted on the evaporation tanks using hand held water quality meters. As several trials were conducted for each site, the results presented in this section are representative of the data collected and analysed.

Monolayer

The Water$avr product did not have any significant impact on the water quality determinants measured (EC, temperature, pH, DO). An example (Figure 5-49) of the pH results during August 2004 shows little variation over time between treatments. Similar results were observed for the other parameters analyzed during the monolayer trials which included dissolved oxygen (Figure 5-50).

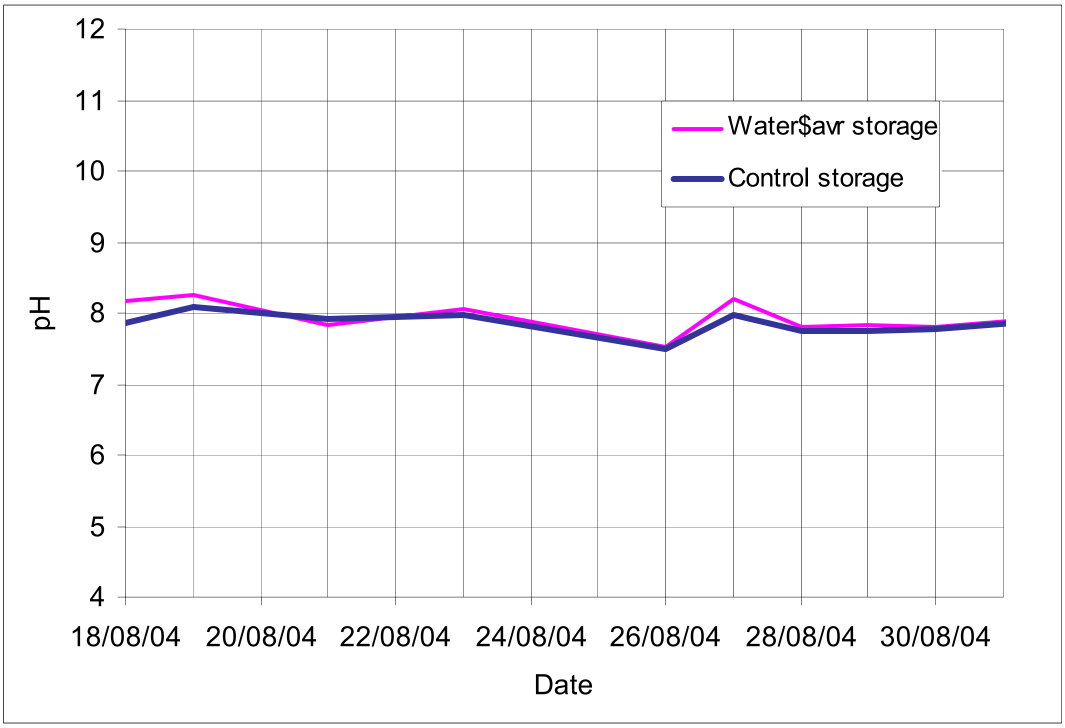

Figure 5-49 Example of the pH levels in the monolayer and the control storages at the USQ Ag plot before and after installation of the cover.

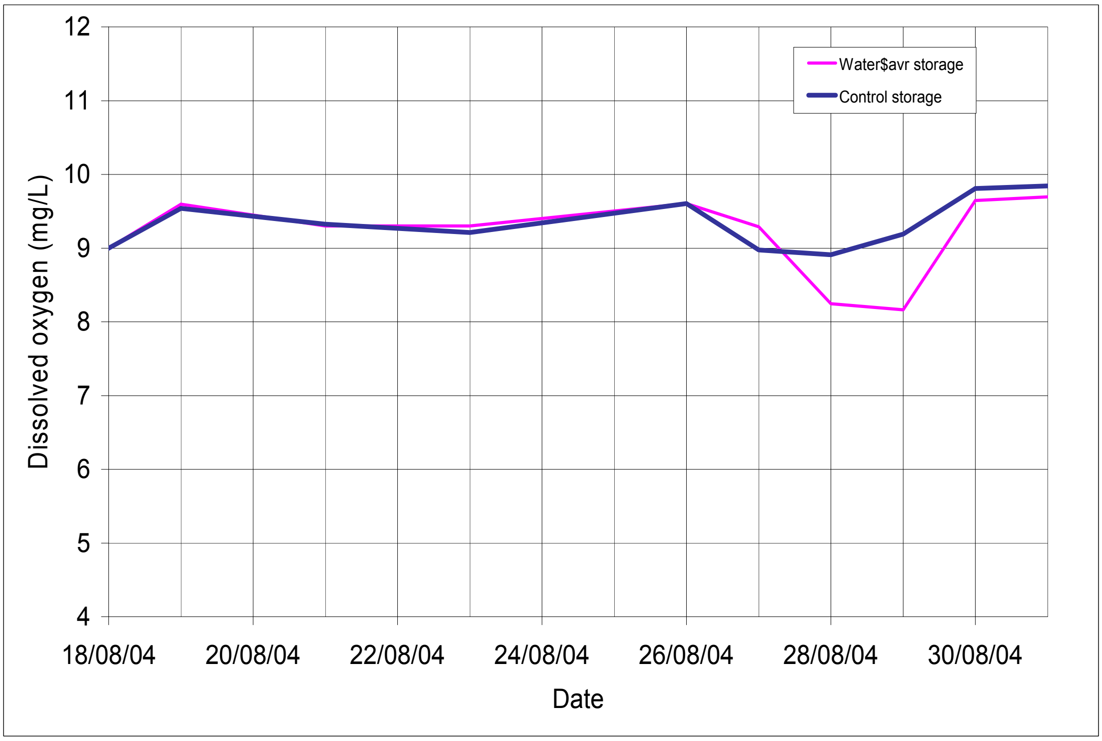

Figure 5-50 Example of the dissolved oxygen in the Water$avr and the control storages at the USQ Ag plot before and after installation of the cover.

E-VapCap

Water quality assessment was only undertaken for the ‘buried edge’ E-VapCap cover. Due to the installation of the ‘buried edge’ E-VapCap (i.e. strapped to the outside of the tank) monitoring was restricted to measurements before the installation and following removal of the EMT.

Dissolved oxygen and temperature were reduced by installation of E-VapCap. For example the initial dissolved oxygen levels on 13 December 2004 (8.7mg/L) were similar in the E-VapCap and Control storages as they had both been recently cleaned and refilled. When the EMT cover was removed (17 January 2005) after 5 weeks the dissolved oxygen levels in the E-VapCap storage were marginally (0.7mg/L) lower than the DO in the storage which was open to the air at all times. Similar trends were found at the full scale trial for E-VapCap at St George.

Over the 5 week period of treatment the temperature in the control storage increased from 25^{o}C to 27^{o}C while in the E-VapCap storage decrease from 24^{o}C to 23.5^{o}C. Water in the E-VapCap storage was thus 3 to 4^{o}C cooler than the water in the control storage. Similar trends were found in the trials at St George discussed later. With the exception of dissolved oxygen and temperature, other parameters measured at this site have shown little or no variation between the EMT storage and control storage.

Shade cloth

The water quality monitoring undertaken during the NetPro shade cloth trial at USQ could also only be taken before and after installation of the EMT. Other than temperature which was reduced by the shade cloth all other determinants were not affected.

For example over the analysis period 13 December 2004 to 17 January 2005 water recorded in the NetPro and control storages were as recorded in Table 5-15.

Table 5-15 Temperature in NetPro and control storage at USQ Ag plot.

Site	Temperature (^{o}C)	
	13 December 2004	17 January 2005
NetPro storage	21.2	22.7
Control storage	25.0	27.1

Table 5-15 illustrates that the NetPro storage remained at 3.8 to 4.5^{o}C cooler than the water in the control storage. The different temperatures recorded in each storage before the installation of the shade cloth can be attributed to the fact that the shade cloth storage was filled somewhat later than the control storage. The control storage would have had more chance to adjust to the ambient air temperature than the shade cloth storage. The final temperatures were recorded after each storage had been left for a month indicating the cooling effect of the shade cloth cover. All other parameters analysed (pH, dissolved oxygen and conductivity) during the shade cloth trials were not significantly different to those found in the control storage.

Raftex

The water quality parameters (DO Figure 5-51) under the Raftex floating structure were found to be similar in both the covered and control storage. The only exception to this was that the temperature of the water in the Raftex storage was slightly cooler than in the control storage (Figure 5-52).

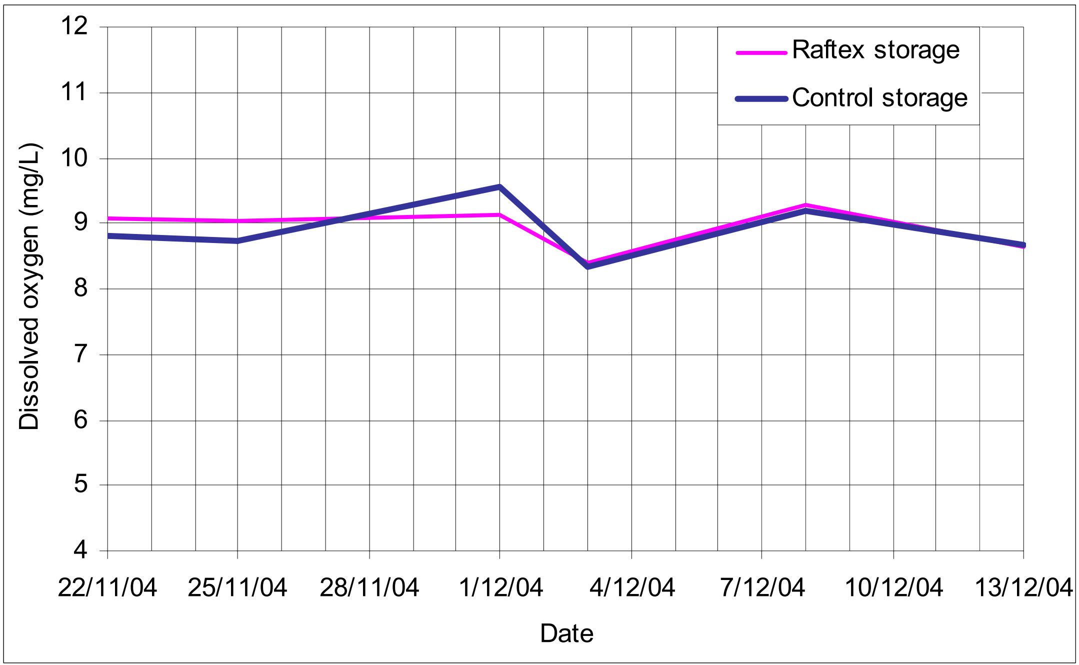

Figure 5-51 Example of the DO in the Raftex and the control storages at the USQ Ag plot.

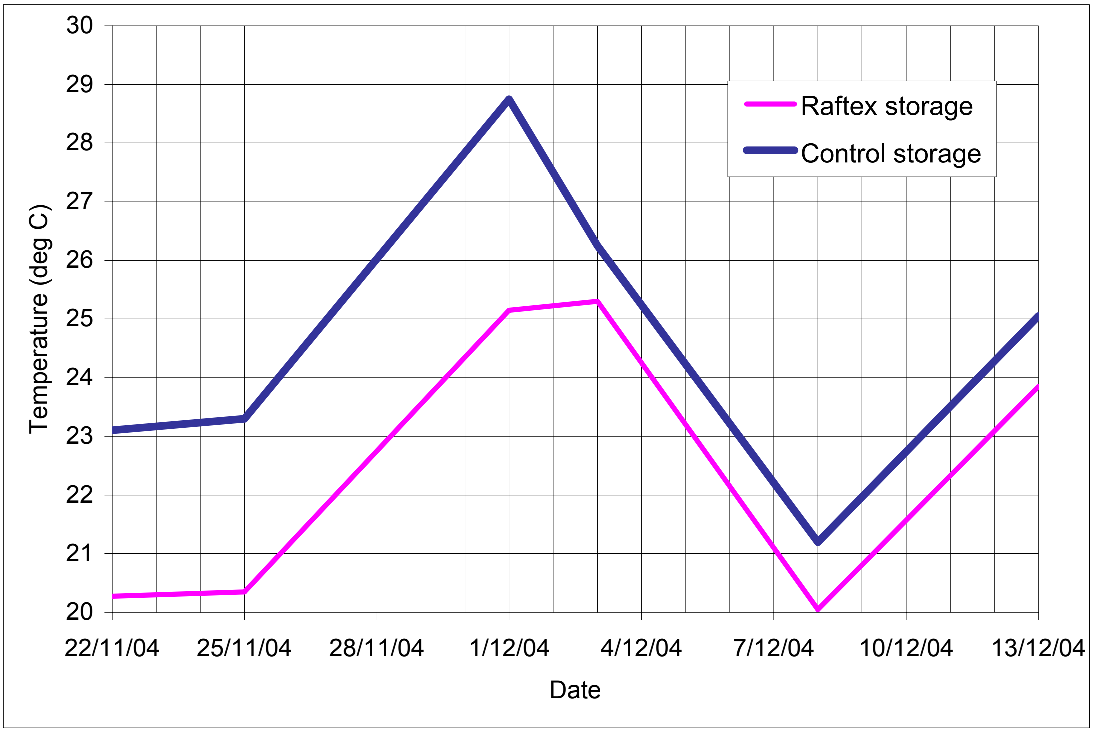

Figure 5-52 Example of the surface water temperature in the Raftex and control storages at the USQ Ag plot.

Polyacrylamide

The water quality monitoring program for the PAM EMT was similar to the monitoring program for the monolayer. Access to the water was unhindered which allowed for a higher sampling frequency. Similar to the Monolayer, the measured pH (Figure 5-53) and DO (Figure 5-54) showed little variation over time or between the EMT storage and the control storage. Other parameters including temperature and conductivity were also constant between the two storages.

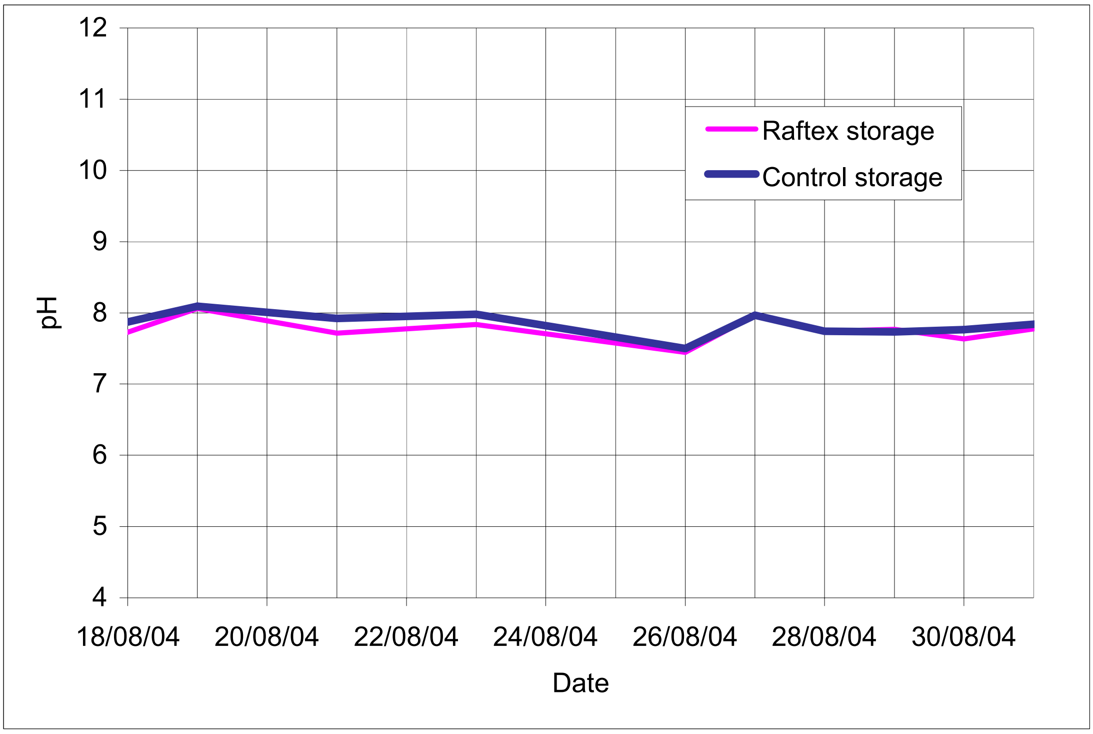

Figure 5-53 Example of the pH in the PAM and control storages at the USQ Ag plot.

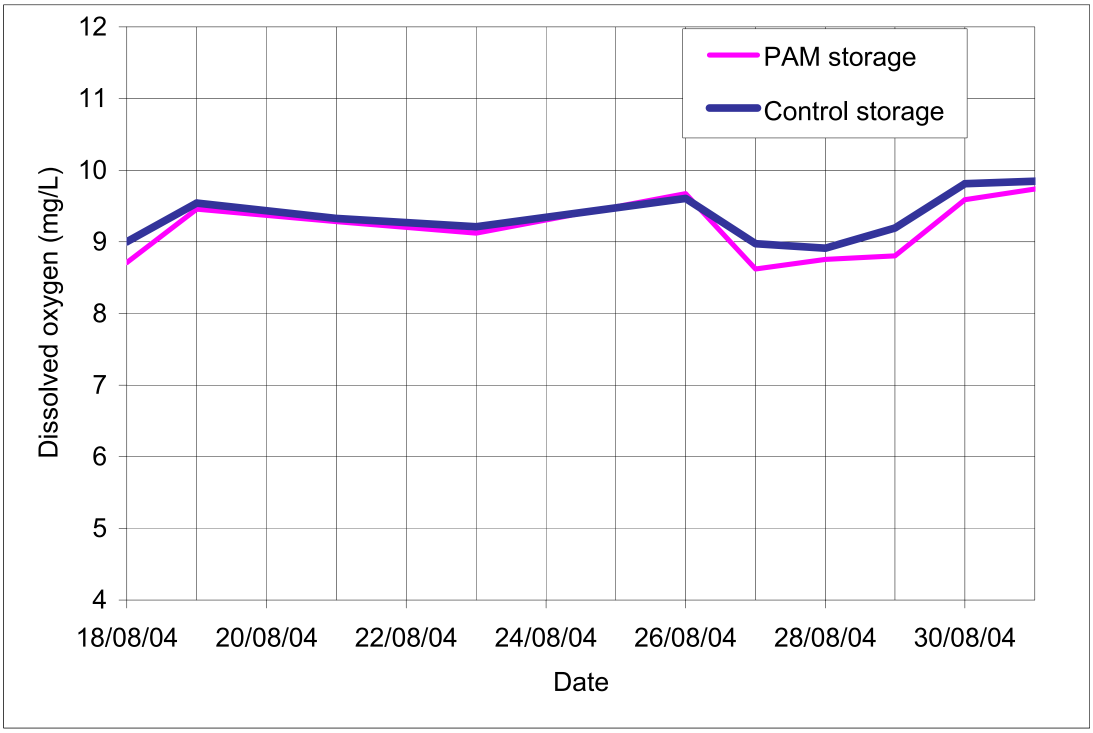

Figure 5-54 Example of the dissolved oxygen in the PAM and control storages at the USQ Ag plot.

5.4.2 Capella

Water quality analysis undertaken at Capella was conducted by Peak Downs Shire Council as part of their regular monitoring program for assessment of algal populations. The actual sampling sites did not allow comparison of results between the EMT and control storage. Water quality monitoring from the EMT storage over the period October 2004 to March 2005 indicate application of monolayer had no negative impact on algae cell count. The results from this sampling program will provide an insight of historical water quality at the Peak Downs Shire Council's municipal water supply storage.

5.4.3 Dirranbandi

Water quality monitoring at Dirranbandi was conducted on both the EMT and the control storage. In addition to the in-situ sampling using portable water quality meters, water samples were regularly sent for laboratory analysis. The first set of samples analysed at the laboratories included several parameters to characterise the water in the two storages. Subsequent laboratory analyses included chlorophyll 'a' and an algal count and identification. The laboratory analysis incorporated the estimation of algal populations because algae may use the monolayer as a food source and therefore has the potential to increase algal populations.

Figure 5-55 shows the level of chlorophyll 'a' in both the EMT and the control storages at Dirranbandi during the October and November monolayer trials. The shaded area represents periods of monolayer application. Each point represents an average of three samples taken at different positions in the storages. The laboratories limit of detection is (5mg/m^3). Samples taken on 26 October and 12 November were below these limits indicating that chlorophyll 'a' levels had not increased and were within the ranges of natural variation.

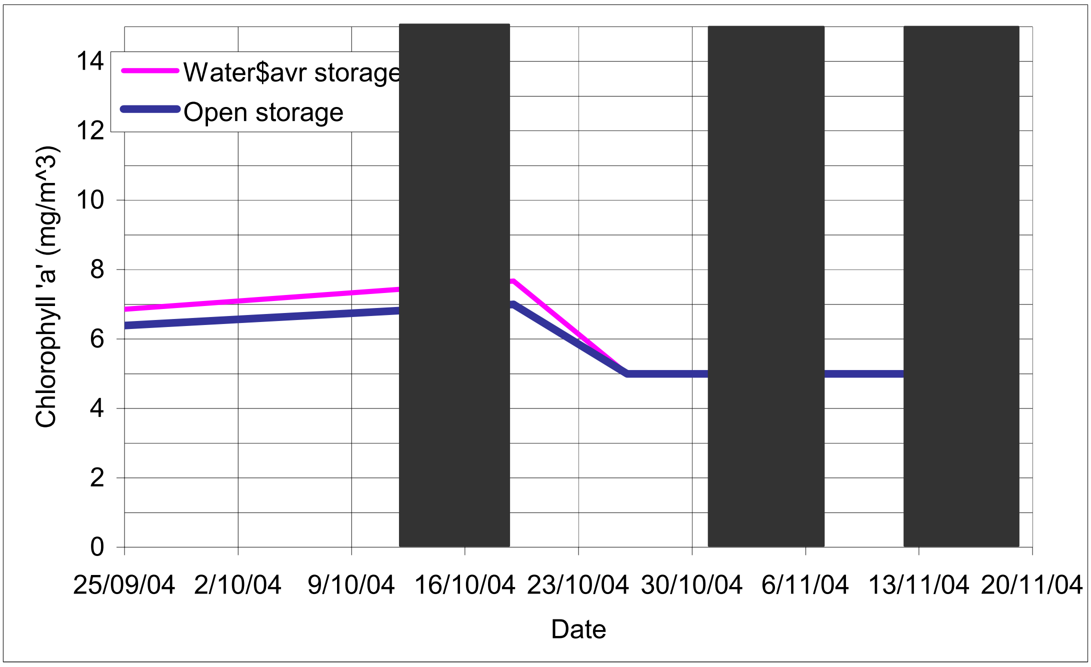

Figure 5-55 Results from chlorophyll 'a' analysis in the Monolayer and control storages at Dirranbandi (shaded columns indicates monolayer application dates).

Figure 5-56 shows the total algal cell count recorded in both the EMT and the control storages during the monolayer trials at Dirranbandi. The results show that the control storage had a lower total cell count at each of the sample events than the storage with monolayer being applied but no trend of increase in algal cell count in the monolayer storage was evident.

The in-situ analysis for parameters including pH, dissolved oxygen (Figure 5-57), conductivity, turbidity and temperature (Figure 5-58) at Dirranbandi showed little difference between the treated and untreated storages during the trials.

There is no apparent impact of the application of the monolayer on dissolved oxygen. The dissolved oxygen levels in the control storage varied between 8 and 9mg/L throughout the trial periods. The DO levels in the monolayer storage vary between 8.5 and 9.5mg/L for the same period. There is only a small amount of variation in the DO in the monolayer storage between periods of application and periods of no application. The DO levels in these two storages have greater variation than the trials undertaken at the USQ Ag plot but this is expected due to the size and nature of the water bodies involved. The temperature in both storages show a similar seasonal trend as the months become warmer (Figure 5-58).

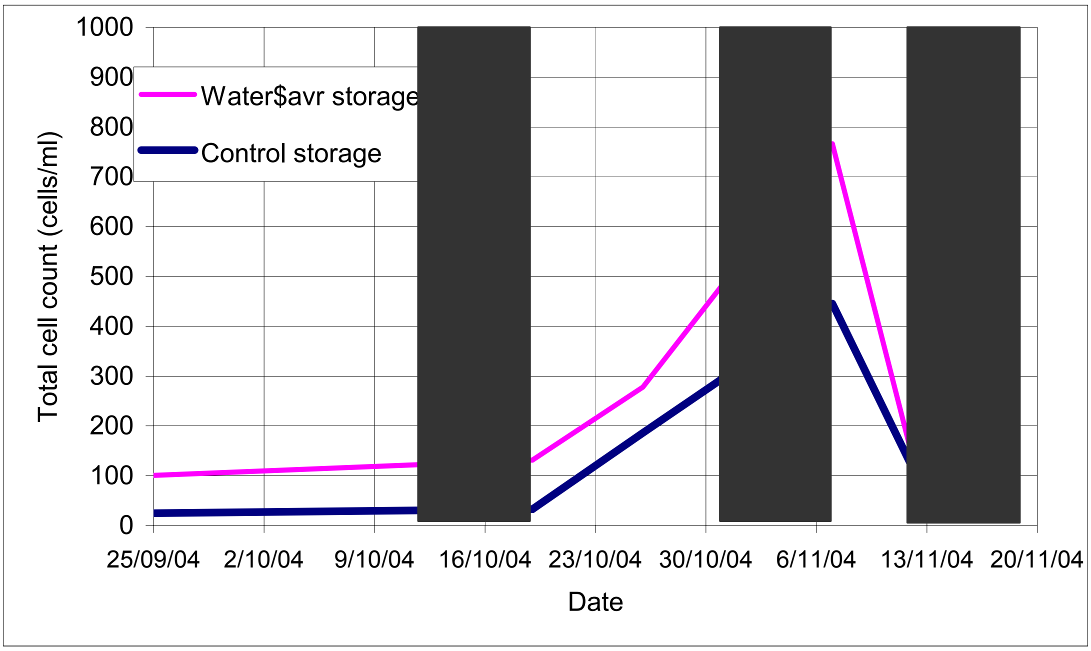

Figure 5-56 **Total cell counts from the monolayer and the control storages at Dirranbandi.**

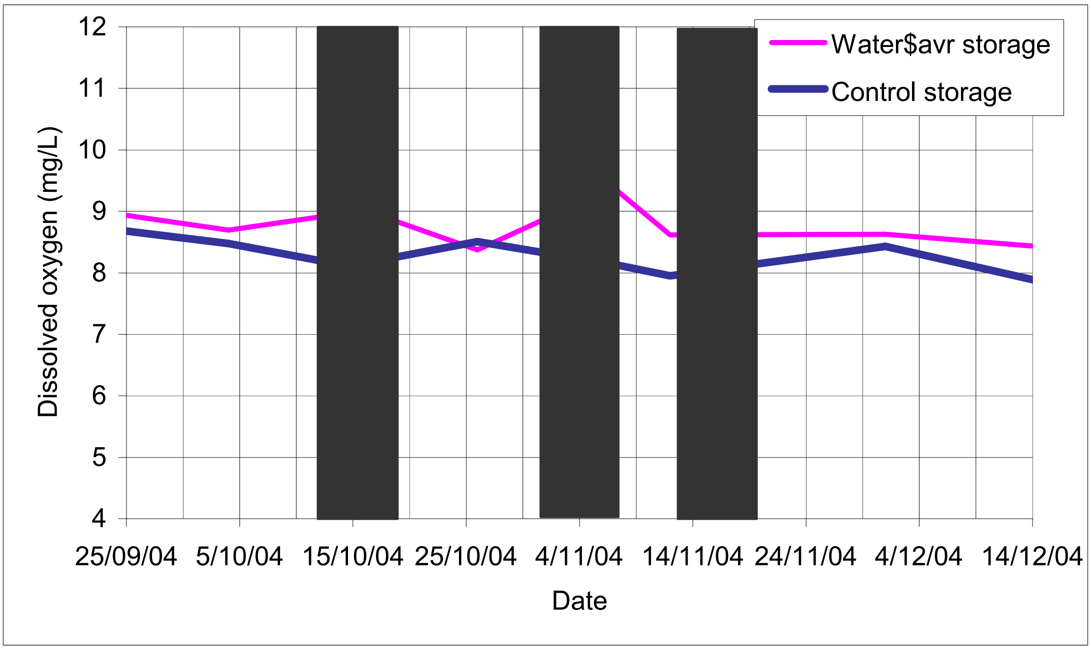

Figure 5-57 **Dissolved oxygen in the EMT and control storage at Dirranbandi.**

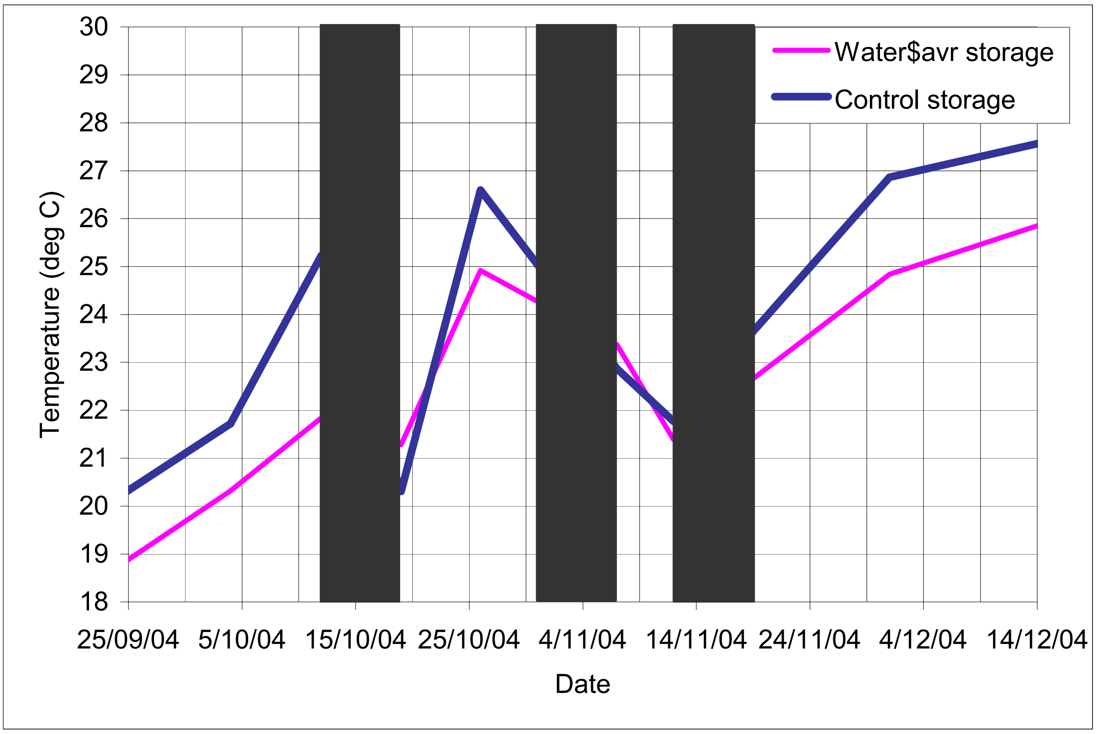

Figure 5-58 Temperature in the EMT and control storage at Dirranbandi.

5.4.4 St George

Water quality monitoring was conducted at St George on both the E-VapCap and the control storage. Unless otherwise specified the comparisons between the EMT storage and the control storage are conducted using water quality information from under the cover. No laboratory analysis was undertaken on samples from this site. When water was found to be lying on top of the E-VapCap cover, samples were taken and analysed for the standard parameters (pH, dissolved oxygen, conductivity, turbidity and temperature).

Figure 5-59 shows temperature data collected from three locations. The first is from the water pooled on top of the E-VapCap cover, the second is from the surface of the control storage and the third from beneath the cover in the E-VapCap storage. An obvious seasonal trend is apparent as the sampling moves into warmer months. The water pooled on top of the E-VapCap was on average 1^{o}C warmer than the control storage and 4^{o}C warmer than water under the cover. The water below the cover was on average 3^{o}C cooler than water in the control storage. This variation in temperature between the water in the E-VapCap storage and the control storage was also evident in the USQ Ag plot storage trials.

The dissolved oxygen in the covered storage was 1-5mg/L less than the levels found in the control storage (Figure 5-57). There is some variation in the parameter over time, which could be due to natural variations or the pumping regime during sampling.

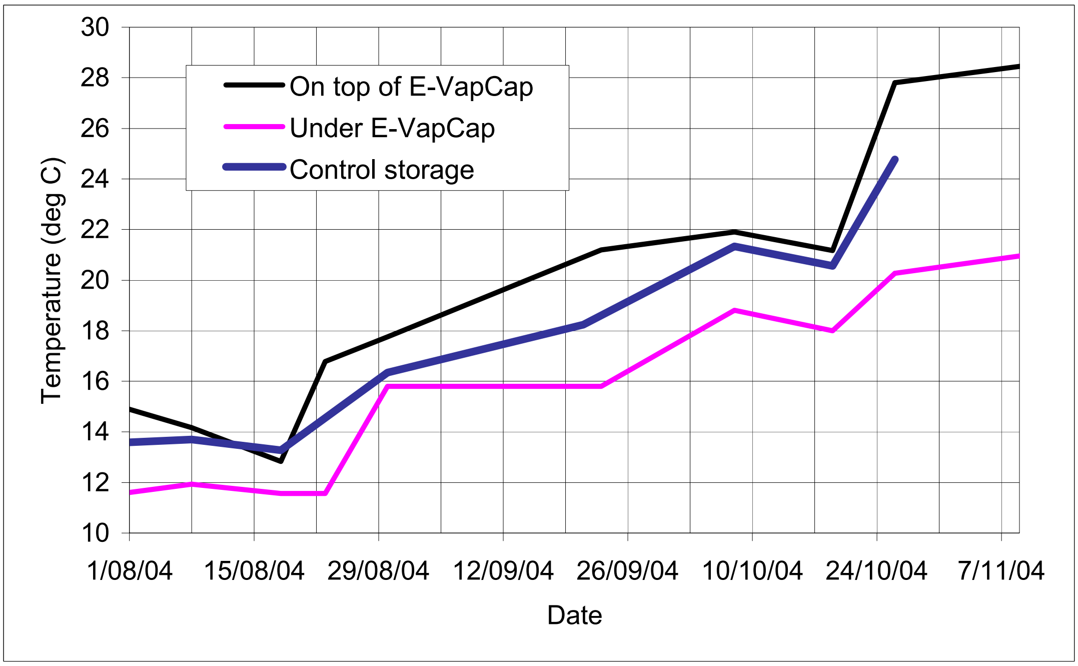

Figure 5-59 Temperature variation in both the E-VapCap and the control storages at the St George.

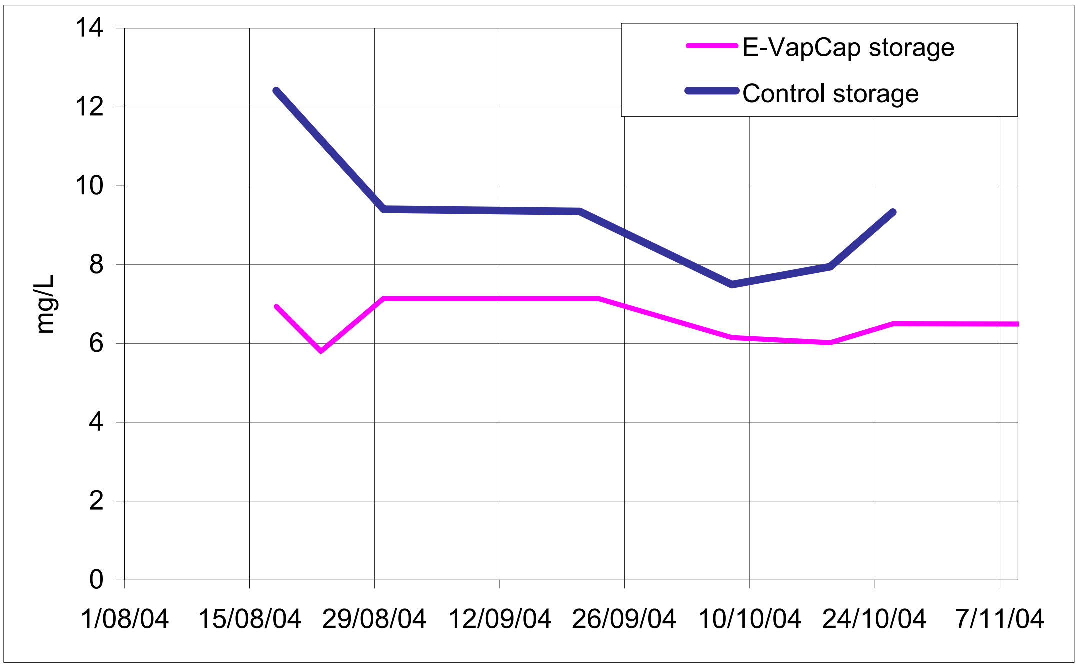

Figure 5-60 Dissolved oxygen levels in both the E-VapCap and the control storages at St George.

5.4.5 Stanthorpe

Water quality sampling was undertaken at Stanthorpe from the covered storage only. The control storage was not monitored for two reasons viz: the control water storage alternated between two storages and the actual level of water in either of the control storages was often too low to allow meaningful sampling. The water quality sampling undertaken at Stanthorpe was useful to observe changes in the water quality over time. The results from the water quality monitoring program showed little variation outside of what would be considered natural variation given the pumping regime and seasonal change.

6 SUMMARY AND RECOMMENDATIONS

6.1 Summary

This project was initiated to assess the effectiveness of various commercial evaporation mitigation technologies (EMTs) in terms of performance in evaporation reduction, practical and technical limitations, impact on water quality and economic potential. Evaluations were carried out on experimental tanks located at the University of Southern Queensland as well as on commercial storages located at Capella, Dirranbandi, St George and Stanthorpe.

A major outcome of the project has been the increased awareness of the potential for evaporation reduction on water storages. The project has been highly successful in this regard, with significant interest being shown by landholders, agencies and private companies in the work undertaken. The combination of detailed experimentation at USQ, commercial scale demonstration sites and wide publicity, through field days, workshops, scientific papers and popular articles, has raised expectations on the potential for cost effective evaporation control solutions. Already a number of private companies and agency funding bodies are exploring the possibilities for further research and commercialisation in this area.

6.1.1 Regional assessment of potential to reduce evaporation losses in Queensland

The project brief suggested that farm dams in Queensland could amount to some 2,500,000ML storage. Other estimates have suggested this could be an underestimate buy a factor of ten or more. Assuming an average depth of 4.5m this equates to some 55,000ha of storage. Table 6-1 provides a first indication of the potential for various evaporation control products in terms of evaporation water saving. It has been assumed that each product type is best suited to a storage size category. A distribution of percentage of the total 55,000ha falling in each size category has been assumed with a weighting to larger storages. It should be noted that there is no information substantiating these assumptions and this is an area for further research. Information on likely number of storages in each size category is also indicative and based on representative storage size. Based on the expected evaporation saving performance of each product the theoretical water saving is given as well as the water saving as a percentage of the total.

Assuming 100% adoption the theoretical water saving for EMTs is ~300,000ML. High value crop producers would typically have smaller storages and the opportunity cost of water could increase adoption in this segment of the market. Application of a chemical monolayer is primarily a variable cost which would make adoption of this EMT on large storages more compelling. Even 10% adoption across the size classes equates to some 30,000ML water saving. While the numbers given below are theoretical and not based on measured storage size distributions they illustrate the potential for a range of evaporation control products to save significant amounts of water with a bias towards large storages in terms of potential water savings.

Table 6-1 Illustration of potential impact of EMT products on farm storage evaporation savings in Queensland.

Product	Storage Size Category (ha)	Percentage Total Surface Area in Size Category (%)	Surface Area (ha)	Number Storages in Size Category	Product Evaporation Saving Efficiency (%)	Theoretical Water Saving (ML)	Water Saving (%)
Floating Cover	<1ha	5.0%	2,750	5,500	90%	49,500	16%
Shade Cloth	<5ha	5.0%	2,750	1,100	70%	38,500	13%
Modular System	<10ha	10.0%	5,500	1,100	80%	88,000	29%
Chemical Monolayer	>10ha	80.0%	44,000	2,200	15%	132,000	43%
	TOTAL	100.0%	55,000	9,900		308,000	100%

Note: Assumptions = 2,500,000ML (55,000ha) total farm dam storage (area); Potential evaporation 2000mm/yr; 100% adoption of EMT's; All year water storage

6.1.2 Water balance method used to assess evaporation reduction efficiency

The methodology employed to determine the efficiency in reducing evaporation was based on a water balance approach, focusing on periods of no pumping or rainfall. This method has shown much potential in determining both seepage and evaporation losses from storage, but requires further development and testing. Depth logger (DL) integrated with automatic weather stations (AWS) were utilised to measure changes in water level to millimetre accuracy. A water balance approach provides the only feasible method for estimating evaporation rates from storages with an EMT. Problems were encountered in a number of the pressure sensitive transducers (PSTs) in terms of fluctuations in the signal or measured water level. This posed a significant constraint in data analysis particularly at certain sites. Various modifications have been proposed and similar systems are now being used by consultants at a range of sites to provide further commercial testing of the system. Following further development and testing, the water balance method is considered to offer a viable system for evaporation and seepage determination on commercial storages.

Analysis relied on comparison between water level change in an open or control and EMT storage. Where data for a control storage was not available, the Penman-Monteith equation was used to estimate potential evaporation loss from an open water surface using an on-site AWS. The derivative of Penman-Monteith used in this project proved an accurate method for estimation of open water evaporation.

The water balance method proved a viable method to determine seepage and evaporation from both an open and EMT storage. To be confident of the results blocks of five to nine days are required with no pumping and no rainfall, meaning no in or out flow. Further intensive investigations are required on a range of storages to further develop the methodologies developed in this project to determine seepage and thereby evaporation.

6.1.3 Evaporation mitigation assessment

Five EMTs were tested at the USQ research tanks where 'potential' evaporation mitigation performance under ideal conditions was determined to be;

Monolayer (Water$avr)	26%	(10%-40%)
Floating cover (E-VapCap)	96%	(94%-100%)
Suspended cover (NetPro shade cloth)	70%	(69%-71%)
Modular cover (Raftex)[¤]	87%	(80%-100%)
Polyacrylamide (PAM)	37%	(31%-43%)

[¤] Area adjusted to cover 100% of the water surface.

Evaporation mitigation at the commercial demonstration sites was generally less favourable owing to the practical challenges of implementing EMTs on large storages. Commercial storages were under continual operation and in some cases there were limited periods of no pumping, a requirement for assessment of evaporation mitigation. Instrumentation problems also limited the amount of good quality data that could be used. Evaporation mitigation performance determined at each commercial site should therefore be treated as indicative only. The Raftex and PAM products were only evaluated at the USQ site. Evaporation reduction at commercial sites was determined to be;

Monolayer - Water$avr (Dirranbandi)	19%	(0%-31%)
Monolayer - Water$avr (Capella)	0%	(0%-0%)
Floating cover - E-VapCap (St George)[§]	N/A	
Suspended cover - NetPro shade cloth (Stanthorpe)	68%	(50%-87%)

Note: [§] No reliable estimate based on continuous operation of multiple pumps.

6.1.4 Mechanical durability assessment

The Water$avr monolayer showed potential to achieve 30% water savings but the results were highly variable. Variable performance is related to the monolayer being broken down by ultraviolet (UV) light and possibly algae or bacteria as well as poor distribution across the water surface as a result of wind and waves. This product needs to be applied every 2 to 3 days. An automatic applicator was developed and used on the 120ha Dirranbandi storage and proved effective although application from the air may be preferable for larger storages. A major advantage of chemical application is the potential to apply the product only during periods of high evaporation loss that is when water is stored in summer, thereby reducing application costs. The monolayer product is likely to be the only product that can be applied on large scale storages (greater than 10ha) and results suggest that evaporation savings of around 15% are achievable. Large storages offer greatest potential to save large volumes of evaporation loss on a national scale. It is for this reason that further research needs to be undertaken on factors affecting monolayer distribution and performance.

The E-VapCap floating cover showed potential to achieve 96% mitigation in evaporation on the research tanks. The commercial trial at St George did not provide sufficient data to undertake a meaningful assessment of commercial performance. Continuous pumping from multiple pumps of varying capacity meant insufficient data for reliable performance assessment. Problems at St George resulted in erosion of silt onto the cover leading to weed growth, cover deformation and regular movement of water from below to above the cover. Water on the surface of the cover reduces evaporation mitigation performance. Inadequate long term elasticity in the material and the trenched anchorage system may contribute to this problem. The stretching may be a result of wind, silt, debris or changes in water level. There is potential for damage from wind if it can infiltrate under the cover and tears due to wildlife or at joints/seams require urgent repair. Alternative design and tethering arrangements which address some of these issues have been developed for the E-VapCap product by structural engineers Bligh Tanner Pty Ltd through this project. In practice a continuous E-VapCap should generally be limited to small storages and would be expected to give in excess of 90% reduction in evaporation. A modular system or modular derivative of the E-VapCap product could be used on larger storages and could be expected to give in excess of 80% evaporation mitigation depending on percentage area covered.

The NetPro shade cloth product showed potential to achieve 70% reduction in evaporation loss. These results were also achieved on the commercial storage in Stanthorpe. The structural support required is likely to limit the size of storage to less than 5ha and the shape and size of the storage will dictate structural arrangements. Being suspended above the water, evaporation mitigation is not influenced by silt and debris accumulation or water inundation. Installation generally needs to be undertaken on an empty storage. The shade cloth will perish due to UV light and requires replacement approximately every 15 years.

6.1.5 Economic assessment

EMTs have been shown in this study to be potentially economically viable to reduce evaporation losses. The decision to install a system will depend on the value of water to the landholder in terms of increased crop production, cost of water or potential to trade water surplus. The potential cost of installing and operating an EMT per unit of water saved ($/ML) will be a function of;

- installation and maintenance costs which are very dependent on site situation and installation issues,
- annual and seasonal evaporation losses from storage at the location,
- efficiency of the EMT in mitigating evaporation, and
- storage operating conditions.

For a site with an annual evaporation potential of 2200mm, water all year and potential ‘low’ installation and operating costs, the product costs per ML water saved would vary depending on evaporation mitigation performance (Table 6-2). Medium evaporation mitigation performance is considered achievable from commercial storages based on the results of this study.

Table 6-2 Cost per ML water saved (annual evaporation of 2200mm all year water storage).

	Evaporation mitigation performance		
	High	**Medium**	**Low**
E-VapCap	$302/ML	$319/ML	$338/ML
NetPro shade cloth	$296/ML	$339/ML	$395/ML
Water$avr (auto application)	$130/ML	$261/ML	$782/ML
Water$avr (hand application)	$198/ML	$397/ML	$1191/ML

Under situations where annual evaporation from storage exceeds 2000mm and given ‘medium’ evaporation mitigation performance and ‘low’ product cost scenarios the cost per ML water saved is likely to range between $250/ML and $400/ML water saved.

E-VapCap and NetPro shade cloth structures require high initial capital investment. Costs associated with the Water$avr product are primarily a variable cost related to amount and frequency of product applied. The cost per ML water saved will be influenced by the amount of time the storage holds water. Water$avr can be selectively applied only in hot months or when there is water in storage which will reduce costs per ML water saved. For example, for storages only holding water during the six month period from October to March the unit cost ($/ML) given above for E-VapCap and NetPro would typically increase by 45% while for the Water$avr product they would reduce to 75%.

Gross margins per ML of water used for crop production can range from $100/ML to over $1000/ML. Saving water by reducing evaporation therefore seems a viable option in most instances.

6.1.6 Water quality assessment

Only a preliminary water quality assessment was undertaken in this study. Results indicate that an E-VapCap will reduce temperature and dissolved oxygen (DO) in the water. This together with reduced sunlight penetration may result in lower algal production but is also likely to impact other flora and fauna. NetPro shade cloth structures will reduce sunlight penetration and temperature but DO concentrations are unaffected. The Water$avr product seemed to have no significant impact on chlorophyll ‘a’, total cell count or other water quality parameters (electrical conductivity, pH, DO, temperature). Further more detailed water quality analyses are recommended for this product if it is to be used on commercial storages.

6.2 Recommendations for future research

This research has reviewed a range of evaporation assessment methods. Class A pan data has largely been discredited in the literature while Penman-Monteith (FAO 56) has been shown to provide good estimates of ET_0 (potential evapotranspiration) from storage dams. Other methods (Bowen Ratio, Eddy Correlation and Optical line/area based methods) are based on expensive/sensitive instrumentation requiring extensive data analysis and are more appropriate for research projects. A water balance approach using accurate depth sensors provides a robust methodology for use in field trials and is the only method applicable for covered storages. While Penman-Monteith has been used in this study for estimation of evaporation using an AWS, the equation does not account for thermal storage in the water body or advection from the surrounds. Further fundamental research on factors affecting evaporation from a water storage and methods to predict evaporation loss based on measured weather and storage characteristics are required. Some work is currently being undertaken by the NCEA through a PhD project investigating evaporation from storages using Eddy Correlation method.

Regional estimates of ETo have been given by the Australian Bureau of Meteorology. Maps of point potential evapotranspiration based on Morton (1986) have been recommended, and used in this study, as the best regionalised information for evaporation loss estimation from small water bodies. Recent work on regional application of the Penman-Monteith equation (Fitzmaurice et al, 2005) needs to be assessed for its appropriateness for estimating evaporation from larger storages.

The methodology employed to determine evaporation loss in this project was based on a water balance approach. While the methodology has shown much potential in determining both seepage and evaporation losses from storage further development and testing is required. This relates both to improving performance of the PSTs in terms of reliability, addressing cable noise that have been evident in data collected in this study and in improving the methodology to identify seepage rates from the data. While determination of seepage rates by eye fitting techniques proved preferable for this project, advanced statistical methods may provide alternative more accurate and repeatable estimates of seepage rate. The prospects of determining seepage using the methods developed in this study proved a significant outcome.

Tables for estimating the cost of the EMTs ($/ML water saved) have been provided. These tables provide generalised information and a simple calculator would allow site specific assessments to be undertaken accounting for local climate data, capital, operating and maintenance costs, EMT evaporation mitigation performance, product life, interest rates, duration of water stored and the value of water.

Both irrigators and EMT suppliers have shown great interest in the results of this project. Further development and testing of floating, suspended and modular covers has already been initiated by suppliers in response to demand. More fundamental research is needed on the potential to improve the monolayer product, distribution, degradation and optimum application method. Monolayers are likely to offer the best options for evaporation mitigation on storages greater than 10ha in area at this point in time. Combinations of different methods should also be investigated by suppliers (eg floating cover in centre of dam surrounded by monolayer or shade cloth). Further commercial development of the EMTs is likely to follow increased demand for these products.

The water balance methodology is being trialled commercially by a number of irrigation consultants. A program to support the quality control, collection and analysis of this data would provide essential information on factors impacting seepage rates, regional evaporation losses, leading to improved understanding of evaporation and seepage losses across a range of regions and storage situations. This would also lead to better AWS based evaporation equations and more accurate regional maps on evaporation loss from storage.

The market for EMTs includes farm dams, mining storages and urban storages operated by water supply authorities. Significant interest has been shown by the agricultural and mining sectors but little interest has been shown to date from water supply authorities. A questionnaire review of water authorities was conducted by FSA, 2005 which suggests that water authorities are less likely to adopt EMTs. This is suggested to be due to the size of water authority storages, uncertainty in ownership and value of water, environmental impacts and bureaucratic impediments (FSA, 2005). The potential for EMTs on large storages both in terms of practical solutions and adoption issues needs further investigation.

An aggregate estimate of evaporation water loss from farm storages is difficult to make without information on the number and size of storages. There is a dearth of information available in this regard. A detailed assessment, possibly using satellite imagery, of storage areas and size classes will provide valuable information on potential water savings through evaporation mitigation. Information on percentage of storages in different size classes will help determine the likely impact of various EMTs on national water savings and the investment that would be required to achieve these savings.

This project has provided groundbreaking work to assessing the performance of EMTs. While the depth loggers developed require further testing and development, these tools provide the basis for a simple water balance monitoring system for water storages. Linking accurate measurements of change in water depth with depth-storage information will provide information on volumetric change which is the basis for water in and out flow measurement. Further development of the depth sounder system recently developed at USQ for storage basin mapping will provide the basis for a cheap and accurate system for mapping the storage basin when filled with water.

The results of this study provide valuable information that requires on going promotion to encourage further adoption of both seepage and evaporation management systems.

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APPENDIX 1

EVAPORATION MITIGATION TECHNOLOGIES

1 EVAPORATION MITIGATION TECHNOLOGIES

There are several methods for reducing evaporation from water storages and they include physical/mechanical, chemical, biological, structural/design and management methods. This appendix provides an overview of these methods. Table A 1-1 provides a broad summary of commercially available EMT's and their key advantages and cost. Section 1.6 of this Appendix gives more details of the EMTs that are commercially available.

Physical covers are more permanent than chemical applications which in general need to be applied frequently as the product is bio-degradable. Physical covers in general provide better performance in evaporation reduction than chemical products.

Reducing evaporation should be part of storage design. This may include increasing depth, cellular construction and provision of wind breaks if feasible. Management of the water can also reduce evaporation for example by maintaining one full dam rather than four quarter full dams.

Table A 1-1 List of evaporation mitigation technology products currently available.

Cover Type	Cover Name	Key Advantages	Cost
Chemical (Monolayer Covers)	*Water$avr	Very low initial setup costs and relatively low ongoing maintenance costs.	$18.00/kg with an application rate of .5-1kg/ha.
	Hydrotect	Very low initial setup costs requiring minimal capital expenditure.	$ 5.00/kg with an application rate of 1.5kg/ha.
Floating Covers	*Evaporation Control System E-VapCap	Reduction of salt build up, improved water quality, reduction in algae growth, reduction in wave action and reduced bank erosion.	$7.00/m^2 but these costs are dependant on transport costs and may be site specific.
	Aquaguard Evaporation Cover	Reduces algae growth, allows rainwater to enter the storage, reduces erosion from wind and wave action, slower salt build up.	The estimated cost is $6.00-$6.60/ m^2 installed. Cost subject to site location.
	CURV	The product is relatively cheap and long lasting.	The estimated cost is around $3.50/m^2 or more.
	C.W. NEAL Corp Defined Sump floating cover	Long lasting and prevents light from entering the storage and so eliminates algal growth and increases water quality.	The anticipated cost is $30/m^2 but this price is subject to size of site and the site conditions.
	Evap-Mat	Heat reflective, self-protecting in high winds (up to 150kph) whether empty or full and it is simple and easy to install, the cover is also suitable for all storage sizes, shapes and profiles up to 2 km wide.	$3.50/m^2 for complete installation.
	Fabtech	Reduces algae growth in the storage which can cause problems with irrigation sprinkler blockages, this is due to the fact that no light passes through the cover.	$7.00/m^2 but this price does not include any earthworks required for the installation.
	REVOC floating cover	The cover is able to be inflated for maintenance and inspection of the storage.	The anticipated cost is $30/m^2 but this price is subject to size of site and the site conditions.
	RTD Enterprises	Reduces algae growth and wave action.	$28.38/m^2-$63.86/m^2 or US $21.53/m^2- $48.44/m^2. The cost of this product is site specific and therefore it may vary.

Cover Type	Cover Name	Key Advantages	Cost
Shade Structures	***NetPro cabled shade cover**	The cover does not float on the water so there are no problems with changing water levels.	$7.00 - $10.00 $6.00-7.50/m^2
	Aquaspan	The structure is long lasting and the cover is not affected by changing water levels.	The cover costs approximately $33.00/m$^{2.}$
	MuzCov	The cover allows easy access to the storage for maintenance operations.	The anticipated costs are $7.50/m$^{2.}$
Modular Covers	***Raftex**	Easy to install and remove form the storage.	The anticipated cost of this product is $4.00-$5.00/m^2.
	AQUACAP	Minimal bank erosion and turbidity due to reduced wave action there will also be a reduced concentration of nutrients and salts in the water and possibly a reduction in algal booms.	The estimated cost is $17/m ^{2} installed.
	Euro-matic Bird Balls	Reduce light penetration and therefore algae growth and they are virtually maintenance free. They allow rainfall to penetrate the storage and they adjust with changing water levels.	The approximate cost is $22.80/m^2.
	Layfield Modular Cover	Maintenance is easy to carry out on the cover due to the fact that damaged modules may be removed independently and with ease.	Unavailable
	LemTec Modular Single Sheet Cover System	Reduces algae and also reduces the amount of total suspended solids in the storage and this product is relatively easy to install.	Information unavailable.
	HexDome™	It has been shown to greatly reduce the effects of wave action, and it is easily installed by the customer.	The anticipated cost is between $4.50-8.00/m^2
	MOD-E-VAP	Easy to install by the land owner and it is easy to remove the cover if necessary. There is no need for an anchor trench and maintenance costs are expected to be minimal.	The product has an estimated cost of $3.00-$3.50/m^2 depending on the catchment area shape.
	POLYNET	Quick and easy to install.	The anticipated cost is $2.50/m$^{2.}$
	QUIT Evap Modular Floating Cover	Lightweight and easy to install.	The estimated cost is around $6.00-$8.00/m^2 plus transport and installation.
Chemical (PAM)	***CIBA PAM**	PAM can reduce erosion and nutrient runoff in the field and also reduce seepage from the water storage.	It is expected to cost $25ML.

* Indicates the products evaluated in this project.
(Note information provided in this table is based on the promotion material provided for each product).

1.1 Physical/mechanical methods

Floating Covers

Floating covers in general act as an impermeable barrier that floats on the water surface to reduce evaporation. In general these products will cover 100% of the water surface. This type of cover is one of the most effective means of reducing evaporation. Most of these products have a high capital and low ongoing/running costs but all have a limited lifetime. Many different materials have been trialled in the past including polyethylene, wax, foam and polystyrene.

Tensioning systems vary from a self tensioning system that relies on the elasticity of the impermeable cover or sand bags with central floatation to a series of wire rope and mechanical tensioning systems.

These products are highly effective at reducing evaporation and may improve some water quality aspects by reducing light penetration and algae. Disadvantages of these products are the relatively high capital outlay, impact on some water quality aspects, restriction for animal life (birds and fish), difficulty in installation on large storages and potential high repair and maintenance costs, especially following storms and winds.

The maximum suitable size of a storage is approximately four hectares as a single cover. The systems are more suited to storages and locations where every drop of water saved counts and they have water in them all year round. Installation of this type of EMT is very dependant on good weather with little or no wind, as a result the time to install will be increased.

Modular Covers

Modular floating covers act very similar to floating covers but are modular that is rather than being a continuous cover they comprise multiple individual units. Each module is often free floating or not restrained to the water surface. But the modules can be connected together to form a larger module.

This method allows for easier installation but these systems generally do not cover the entire water storage. Therefore the percentage evaporation reduced by modular covers is lower than floating covers. Most of these products have a high capital and low ongoing/running costs but all have a limited lifetime.

Shape of modules can be circular and square or everything in between. Each module is usually small in size therefore thousands of modules will be required to cover the storage. As a result of the shape and size of the modules not always 100% of the surface area is covered.

Advantages of these products are that they are effective at reducing evaporation but not as effective as floating covers. They may improve some water quality aspects by reducing algae and an individual module can be repaired or replaced.

Disadvantages of these products could include a relatively high capital outlay, wind damage, impact on some water quality aspects and difficult to install (eg. under windy conditions).

These systems are ideally suited to storages and locations where every drop of water saved counts and they have water in them all year round. Some modules will be prefabricated or built on site.

Shade Structures

Shade structures in general are suspended above the water surface using cables creating a web like structure with shade cloth fitted between the cables. The shade cloth can come in a range of UV ratings. This is a rating to describe the amount of UV blocked by the shade cloth.

Shade structures reduce solar radiation, wind speed and trap humid air between the structure and the water surface, which are all factors that effect evaporation. Most of these products have high capital and low ongoing/running costs but all have a limited lifetime. They are more appropriate to small storages given the need to suspend the shade cloth above the water.

In general shade structures are not as effective in reducing evaporation as floating covers. They do not have the same impact on water quality with free flow of oxygen to the water although algae may be reduced owing to less light penetration.

Disadvantages of these products are the relatively high capital outlay and difficult to install under windy conditions. The maximum suitable size of a storage is approximately five hectares as a cover. The limiting factor is the ability to construct the cable structure. If this can be done then the shade cloth can be fitted to the cable. Installation of the shade cloth is very dependant on good weather with little and no wind.

Bladders
Water storage bladders use a similar principal to a wine cask bladder. Bladders are generally made from polyethylene and provide an impermeable lining both above and below the water body. Rain does not have anyway of entering the bladder. The top cover raises and lowers with any change in volume in the bladder. This can lead to wear in the lining when the storage is continuously changing volume. The size and shape of the bladder can be restrictive in some situations. In terms of evaporation control it simply acts as a floating cover but it is also lined to stop seepage.

1.2 Chemical methods

Monolayer
Monolayer is a long chain chemical used to create a thin alcohol layer on the water surface. As these layers are biodegradable there is a need to reapply every one to four days. Chemical methods are not as effective as physical methods in reducing evaporation.

The monolayers can be applied at low rates by hand or automatically and they rely on the self spreading ability of the chemical.

Advantages of these products are the low capital cost to get up and running and the product can be applied only when needed, for example only in periods of high evaporation. Disadvantages of these products are that they may not be suited to windy locations and may impact on some water quality aspects such as algae growth.

Currently monolayers are the only EMT suitable to cover large water storages above ten hectares. These larger storages suit automatic application as the time consumed by the hand method starts to get very expensive. They are suited to storages that do not have water in them all year and every year.

Polyacrylamide
Polyacrylamide (PAM) is a chemical used to bind the body of water together. These are broken down by ultraviolet light and therefore need to be reapplied regularly. In general chemical methods are not as effective at reducing evaporation as the physical controls.

Advantages of these products are low capital costs to get up and running, In general they have a low reduction of evaporation but can be applied when needed and they have little restriction to animal life (birds and fish). Disadvantages of these products include may not be suited to windy locations and may have impact on some water quality aspects. Not a lot is known about the use of PAMs for evaporation control. The product is proven to reduce seepage but not really proven as a method to reduce evaporation.

1.3 Biological methods

Some biological covers such as lily pads and duckweed, have the potential to reduce evaporation from the water surfaces they live on. At the same time these plants require water to survive and transpire. Therefore the net result might mean they increase evaporation and not decrease it. The evaporation reduction efficiency is much lower than other methods available and these methods have had little emphasis placed on them.

Biological methods also require water all of the time to survive and can result in infestation and damage to the environment when washed down stream. Biological methods have not been proven to a large degree.

1.4 Structural/design methods

Water storages may be constructed or altered to proportionally reduce the evaporation rates by reducing the surface area exposed to evaporation or by reducing the rate of evaporation. Methods used to do this include deeper storages with smaller surface areas, cellular construction which divides large storages into smaller ones to reduce wind action and allows water depth to be maximised by shifting water between cells and using windbreaks around the storage. Benefits of these methods are easily quantified based on exposed area and reduced wind speed. Disadvantages of this method are that it is generally easier to build a new storage, when site selection can be altered rather than retrofitting into an existing storage.

1.5 Management methods

When more than one storage is owned different management methods can reduce total evaporation. Water can be pumped between storages to minimise surface area per unit volume of water stored. Storages kept full by bores or overland flow will increase the total volume without significant increase in surface area. Water circulation could also reduce water surface temperature and decrease the rate of evaporation.

1.6 List of currently available EMTs

Details of the current EMTs available listed below were supplied by the manufacturer of each product.

1.6.1 Monolayers

Water$avr

Description:

Water$avr is a white powdered product which is comprised of hydrated lime with a cetyl/stearyl alcohol flow aid which forms a film on the waters surface.

This product is made of food grade chemicals which are biodegradable in 2 ½ to 3 days and it is permeable to oxygen.

Manufacturer/Supplier:

ONDEO Nalco Australia Pty Ltd. and Flexible Solutions Int. Inc.

Flexible Solutions International Ltd.
615 Discovery Street
Victoria, BC
Canada V8T 5G4
Tel: 250-477-9969
Fax: 250-477-9912
Email: infowatersavr@flexiblesolutions.com
Website: http://www.flexiblesolutions.com/products/watersavr/

Performance as stated by the manufacturer:
Water$avr reduces evaporation by up to 30%.

Costs:
$18.00/kg with an application rate of .5-1kg/ha.

Durability:
Breaks down in 2 ½ to 3 days.

Installation:
Very easy to apply with a patented self applicator, by hand or with a boat. The wind direction must be taken into consideration when applying the product so as to gain an effective unbroken film.

Pros:
Very low initial setup costs and relatively low ongoing maintenance costs.

Hydrotect

Description:
Hydrotect is a water evaporation retardant which is an emulsion of 60% water and 40% aliphatic alcohols. This product is claimed to be non-toxic, biodegradable and suitable for application to drinking water.

Manufacturer/Supplier:
Swift and Co Ltd.
Neil Clifford
Business Manager
Tel: 61 3 8544 3159
Fax: 61 3 8544 3259
Mob: 0425 724 085
Email: nclifford@im.aust.com
Website: www.swiftco.com.au

Performance as stated by the manufacturer:
Hydrotect is claimed to reduce evaporation in larger storages by 25-35%.

Costs:
$ 5.00/kg with an application rate of 1.5kg/ha.

Durability:
The product has to be reapplied daily.

Installation:

Very easy to apply by machine or by hand with a boat. The wind direction must be taken into consideration when applying the product so as to gain an effective unbroken film.

Pros:
Very low initial setup costs requiring minimal capital expenditure.

1.6.2 Floating covers

Evaporation Control System E-VapCap

Description:
E-VapCap is a heavy duty polyethylene 'bubble wrap' style product with a white surface to reflex heat and a black bubble underside which provide flotation and stops light penetration. Both of the layers are UV stabilised and 10mm diameter holes are positioned at 1000mm centres to allow rainfall penetration and the release of gases from the storage.

Manufacturer/Supplier:
Sealed Air Australia Pty Ltd (SAA), Evaporation Control Systems Pty Ltd (ECS) and Darling Downs Tarpaulins Pty Ltd (DDT)

Evaporation Control Systems Pty Ltd (ECS)
Tel: 07 4665 6144
Fax: 07 4665 6395
Website: http://www.evaporationcontrol.com.au/index.1.htm\
Approved installers:
Darling Downs Tarpaulins Pty Ltd
Website: http://www.ddt.com.au/
C E Bartlett Pty Ltd
Website: http://www.bartlett.net.au/
Ertech Pty Ltd. Western Australia
Website: http://www.ertech.com.au/

Performance as stated by the manufacturer:
E-VapCap has been shown to reduce evaporation by as much as 90-95%.

Costs:
\$7.00/m^2 but these costs are dependant on transport costs and may be site specific.

Durability:
E-VapCap offers a 5 year warranty with and expected life of 12 or more years.

Installation:
The ease of installing this product is site specific and also dependant of the weather conditions as wind can create problems during installation.

Pros:
Reduction of salt build up, improved water quality, reduction in algae growth, reduction in wave action and reduced bank erosion.

Aquaguard Evaporation Cover

Description:

The cover is manufactured from a laminated polyethylene bubble with a beige/white top and black underside; the light top reflects heat while the black underside eliminates light. The material has positive buoyancy due to the "bubble" material and so floats on the waters surface.

Manufacturer/Supplier:
Fabric Solutions by PyramidDOME Australia Pty Ltd.

Fabric Solutions International
9A Production Avenue
Ernest Qld 4214
Tel: (07) 55633755
Email: info@fabricsolutions.com.au
Website: http://www.fabricsolutions.com.au/evaporative_covers.htm

Performance as stated by the manufacturer:
Up to a 90% reduction in evaporation.

Costs:
The estimated cost is \$6.00-\$6.60/m^2 installed. Cost subject to site location.

Durability:
UV resistant long life material.

Installation:
The cover is installed by Fabric Solutions and the ease of installation is related to the site conditions, size and weather conditions.

Pros:
Significantly reduces algae growth, allows rainwater to enter the storage, and reduces erosion from wind and wave action, slower salt build up.

CURV

Description:
A new form of polypropylene sheet made in a patented process, the sheets are 0.3mm thick and they are attached to cables on either side of the storage. Smaller strips of the product can then be interwoven for stability. The product floats on the surface and is kept in tension by the cables.

Manufacturer/Supplier:
Still in its development stage.

Performance as stated by the manufacturer:
Unknown at this stage.

Costs:
The estimated cost is around \$3.50/m^2 or more.

Durability:
It is expected to be highly durable and long lasting.

Installation:
Not known at this stage.

Pros:
The product is relatively cheap and long lasting.

C.W. NEAL Corp Defined Sump floating cover

Description:
The defined sump style cover is constructed with a polyester fabric reinforced geomembrane such as Hypalon or polypropylene with thicknesses ranging from 0.91mm to 1.14mm.The cover uses ballast tubes in the centre to keep it taught. The cover is also impermeable, so storm water collects in the ballast lines where a choice of either gravity removal through a network of hoses or electric pumps.

Manufacturer/Supplier:
C. W. Neal Corporation
8625 Argent St
Santee, CA 92071
USA
Tel: (619) 562-1200
(800) 377-8404
Fax: (619) 562-1150
E-Mail: info@cwneal.com
Website: http://www.cwneal.com/floatingcover.htm

Performance as stated by the manufacturer:
Reduce evaporation by up to 95%

Costs as at December 2004:
The anticipated cost is $30/m^2 but this price is subject to size of site and the site conditions.

Durability:
This product is said to last 20-30 years

Installation:
To install this product the storage is required to be empty and the cover is installed by C.W. Neal Corp.

Pros:
The cover is long lasting and prevents light from entering the storage and so eliminates algal growth and therefore increases water quality.

Evap-Mat

Description:
The cover is comprised of laminated 20 micron, stainless steel mesh and 0.4mm bubble HDPE sheet. The cover is anchored to the storage floor by cables attached to a buried polyethylene pipe. It is designed to only cover 90% of the waters surface area.

Manufacturer/Supplier:
Reservoir Covers Australia (Pty Ltd proposed extension).

Performance as stated by the manufacturer:
May reduce evaporation by up to 90% depending on the water level of the storage.

Costs:
$3.50/m^2 for complete installation.

Durability:
Life expectancy of 30 or more years. Resistant to UV and oxidation.

Installation:
Not available.

Pros:
Heat reflective, self-protecting in high winds (up to 150kph) whether empty or full and it is simple and easy to install, the cover is also suitable for all storage sizes, shapes and profiles up to 2km wide.

Fabtech

Description:
High density polyethylene (HDPE) or unsupported polypropylene with a thickness of 0.5 to 1mm with flotation material attached and sand filled ballast tubes in the centre to take up the slack in the cover due to changes in the water level. The sand tubes also form sumps from which rainwater can be pumped into the storage using small submersible pumps. The cover is secured in a 600mm deep anchor trench around the storage wall.

Manufacturer/Supplier:
Fabtech SA Pty Ltd
53 South Terrace
Winfield SA 5013
Tel: (08) 8347 3111
Email: lorri@fabtech.com.au
Website: http://www.fabtech.com.au/Covers/covers.html

Performance as stated by the manufacturer:
Estimated to reduce evaporation by up to 95%.

Costs:
$7.00/m^2 but this price does not include any earthworks required for the installation.

Durability:
Design life of a minimum of 15 years.

Installation:
The storage is required to be empty.

Pros:
Reduces algae growth in the storage which can cause problems with irrigation sprinkler blockages, this is due to the fact that no light passes through the cover.

REVOC floating cover

Description:
Scrim reinforced Hypalon or scrim reinforced Polypropylene with flotation material attached and sand filled ballast tubes in the centre form sumps from which rainwater can be pumped into the storage using small submersible pumps. The cover is attached to

patented self tensioners around the perimeter to keep the cover taught allowing people to walk all over the cover.

Access ports are also incorporated into the design to allow for maintenance and also to allow the cover to be inflated for ease of repair under the cover.

Manufacturer/Supplier:
C. W. Neal Corporation
8625 Argent St
Santee, CA 92071
USA
Tel: (619) 562-1200
(800) 377-8404
Fax: (619) 562-1150
E-Mail: info@cwneal.com
Website: http://www.cwneal.com/floatingcover.htm
Layfield Environmental Systems Corp
Dba CW Neal.

Performance as stated by the manufacturer:
Reduce evaporation by up to 95%

Costs as at December 2004:
The anticipated cost is $30/m^2 but this price is subject to size of site and the site conditions.

Durability as stated by the manufacturer:
The Hypalon cover has 30 year warranty.

Installation:
The storage is required to be empty.

Pros:
The cover is able to be inflated for maintenance and inspection of the storage.

RTD Enterprises

Description:
This floating cover is made from reinforced products such as Hypalon or polypropylene. This cover is typically incorporated with a liner to totally seal the storage.

Manufacturer/Supplier:
RTD Enterprises
P.O. Box 247, 196 Old Point Avenue
Madison, Maine 04950
USA
Tel: 207 696 3964
Fax: 207 696 0815
Email: info@rtd-enterprises.com
Website: http://www.rtd-enterprises.com/

Performance as stated by the manufacturer:
No information available.

Costs as at December 2004:
$28.38/m^2-$63.86/m^2 or US $21.53/m^2- $48.44/m^2. The cost of this product is site specific and therefore it may vary.

Durability:
The cover is made from long lasting product.

Installation:
Not available.

Pros:

1.6.3 Suspended covers

NetPro cabled shade cover

Description:
High tension cable, incorporating long life 300g/m^2 90% plus black monofilament shade cloth. The cable design in essence acts as a giant spider web, with all cables spliced at crossover points to disperse the load evenly and also to eliminate product creep due to wind.

Manufacturer/Supplier:
NetPro Pty Ltd.
NetPro Protective Canopies
Lot 1 Sullivan Drive
Stanthorpe, Qld 4380
Free Call: 1800 501 337
Phone: +61 7 4681 6666
Fax: +61 7 4681 6600
Email: sales@netprocanopies.com
Website: http://www.netprocanopies.com/npcrd.php

Performance as stated by the manufacturer:
It has been shown to reduce evaporation by around 75%

Costs:
$6.00-7.50/m^2

Durability:
It is expected that the shade cloth will have a life of over 30 years.

Installation:
The storage is required to be empty for the installation of the pole supports.

Pros:
The cover does not float on the water so there are no problems with changing water levels.

Aquaspan

Description:

Aquaspan is comprised of a patented polymer fabric which is suspended above the water storage via the use of steel support posts and cable. The fabric used is purpose designed and blocks 98% of light and reduces temperatures beneath by 31%. The fabric is a densely knitted membrane which reduces and stabilises the water temperature reducing vapour pressure adjacent to the surface and effectively insulating the water.

Manufacturer/Supplier:
Aquaspan Pty Ltd and Gale Pacific Limited.
Aquaspan Pty Ltd
Gary Gale
P.O. Box 367
Braeside Vic 3195
Australia

Performance as stated by the manufacturer:
Evaporation is reduced by 76-84%.

Costs:
The cover costs approximately \$33.00/m$^{2.}$

Durability:
The fabric is UV stabilised and supported by a 20 year warranty against UV breakdown.

Installation:
The cover is able to be installed regardless of the water level in the storage.

Pros:
The structure is long lasting and the cover is not affected by changing water levels.

MuzCov

Description:
The cover is comprised of high tension cables supported by poles with shade cover panels attached to the cables. The high tension cables give the structure stability while still allowing some natural movement. The structure is designed to allow heavy machinery access to the storage for maintenance and operational activities with minimal disruption.

Manufacturer/Supplier:
Designed at the Dalby Agricultural College and it is still in its initial concept stage.
Murray Choat
Dalby Agricultural College
PO Box 398
Dalby Qld 4405
Tel: (07) 4672 3100

Performance as stated by the manufacturer:
Unknown at this stage.

Costs:
The anticipated costs are \$7.50/m$^{2.}$

Durability:
Unknown at this stage but it is expected to have a long life span.

Installation:
Unknown at this stage.

Pros:
The cover allows easy access to the storage for maintenance operations.

1.6.4 Modular covers

Raftex

Description:
Raftex modules comprise a fully enclosed rectangular plastic pipe frame with maximum dimensions of 12m x 2m. The plastic pipes are 2" or 3" diameter and are joined using force fit right angle joiners. The frames are also strengthened with plastic brace rods every 2 metres.
The frame is easily assembled on site with the pre-drilled holes for the brace rods.
Once the frame is assembled it is then machine wrapped in multiple layers of UV stabilised adhesive film which totally encloses the frame to form a raft. Holes are then drilled through the film and pipe to allow the raft to partially fill with water so as act as an anchor for the raft in windy conditions.

Manufacturer/Supplier:
IPEX Bulk Systems International Pty Ltd, Trading as F Cubed (F^3)
Peter Johnstone
35 Robins Avenue,
Humevale Victoria 3757
Tel: (03) 9716 1195
Mob: 0413 949007
Fax: (03) 9716 1541
Email: pjjohnstone@ipstretch.com

Performance as stated by the manufacturer:
This product is still in its trial stage.

Costs:
The anticipated cost of this product is \$4.00-\$5.00/m^2.

Durability:
The product is UV stabilised and the film has an anticipated life of 5 years. At the end of this time F^3 will provide complete refurbishment. However the frame is expected to have a much longer working life.

Installation:
This cover is easy to install and may be carried out by the owner.

Pros:
Easy to install and remove form the storage.

Aquacap

Description:

Aquacap is a free-standing floating modular cover with individual modules with a diameter of approximately 1m. These modules have specific design attributes to maximise their effectiveness in reducing evaporation loss from open water storages. The modules are used to cover up to 90% of the surface area of a water body.

Aquacap modules have unique suction properties that make them stable on a water surface.

Manufacturer/Supplier:
The product was designed by Ian Burston and it is not yet commercially available but it is expected to be sometime in 2005.
Website:
http://www.rmit.edu.au/browse/News%20and%20Events%2FNews%2FOpenline%2F1999%2FAquacaps%20to%20save%20water/

Performance as stated by the manufacturer:
Field studies have shown that Aquacap reduces evaporation by an average of 70% when 80% of the water surface is covered.

Costs:
The estimated cost is $17/m^2$ installed.

Durability:
It is expected to have a long lifespan.

Installation:
The cover may be easily installed by the owner.

Pros:
Minimal bank erosion and turbidity due to reduced wave action there will also be a reduced concentration of nutrients and salts in the water and possibly a reduction in algal booms.

Euro-matic Bird Balls

Description:
Bird balls are hollow black balls that form a floating cover, they are made of high density polyethylene (HDPE) or polyethylene and they come in arrange of sizes ranging from10mm diameter to150mm diameter.

Manufacturer/Supplier:
Euro-matic Bird Balls
Head Office
Contact: Adrian Wilkes – Director
Euro-Matic Ltd
Clausen House
Perivale Industrial Park
Horsenden Lane South
Greenford
Middlesex UB6 7QE
United Kingdom
Tel: + 44 20 8991 2211
Fax: + 44 20 8997 5074

Email: sales@euro-matic.com
Website: http://www.enquip.com/BirdBalls.html

Performance as stated by the manufacturer:
They may reduce evaporation by up to 90%.

Costs:
The approximate cost is $22.80/m^2.

Installation:
Bird balls are very easy to install and may be carried out by the owner.

Durability:
The balls are UV stabilised and are long lasting.

Pros:
Reduce light penetration and therefore algae growth and they are virtually maintenance free.
They allow rainfall to penetrate the storage and they adjust with changing water levels.

Layfield Modular Cover

Description:
A typical floating module would measure 50 x 50 feet (15.24 x 15.24m) or 100 x 100 feet (30.48 x 30.48m), the modules are floated out onto the storage and then lashed together by ropes or webbing. In storages with fluctuating levels special panels can be made to take up slack around the perimeter.

Manufacturer/Supplier:
Layfield Plastics Inc.
Head Office in Seattle, Washington USA
Tel: 425-254-1075
Email: international@layfieldgroup.com
Website: http://www.geotextile.ca/projectprint.cfm?productID=143&id=corC. W.

Performance as stated by the manufacturer:
Unavailable

Costs:
Unavailable

Durability:
The modules are made from long lasting material and so are expected to have a long working life.

Installation:
Modules are manufactured in ideal conditions in the factory and then installation is easily carried out by floating the modules into position on the storage. Installation does not necessarily require a trained professional.

Pros:
Maintenance is easy to carry out on the cover due to the fact that damaged modules may be removed independently and with ease.

LemTec Modular Single Sheet Cover System

Description:

The LemTec modular cover system uses 10 year UV resistant, High Density Polyethylene (HDPE) geomembrane sheets with encapsulated, closed-cell, lateral extruded-polystyrene insulation for flotation. These sheets are laced together during installation to form a complete cover. The edges of the cover are anchored to perimeter of the storage with LemTec's unique anchoring system.

Manufacturer/Supplier:

Lemna Technologies, Inc.
2445 Park Avenue South Minneapolis, Minnesota
USA 55404-3790
Tel: (612) 253-2002
Fax: (612) 253-2003
Email: techsales@lemna.com
Website:
http://www.lemnatechnologies.com/pdf/productSummaries/LemTecCoverProductSummary.pdf

Performance as stated by the manufacturer:

Information unavailable.

Costs:

Information unavailable.

Durability:

Made from long lasting HDPE material which is 10 year UV resistant.

Installation:

For installation of this cover fewer people are required than other products on the market. No heavy equipment is needed and the storage does not need to be empty.

Pros:

Reduces algae and also reduces the amount of total suspended solids in the storage and this product is relatively easy to install.

HexDome™

Description:

It is and independent modular system made from UV resistant recycled plastic. Each module covers one square metre.

Manufacturer/Supplier:

Indusium Pty Ltd and tested by the Queensland University of Technology
Stoph Vanwensveen
Email: stvn@bigpond.com

Performance as stated by the manufacturer:

Reduce evaporation by up to 90%

Costs:

The anticipated cost is between $4.50-8.00/m^2

Durability:
Expected life of more than 25 years.

Installation:
This cover may be easily installed by the owner.

Pros:
It has been shown to greatly reduce the effects of wave action, and it is easily installed by the customer.

MOD-E-VAP

Description:
This product consists of simple and easy to install modular plate system of polyethylene pipe, fittings and sheeting.
Each modular has a rigid framework of high density polyethylene (HDPE) pipe and fittings restraining, via plastic sheet clips, linear low density polyethylene sheets (LLDPE). The individual plates are then inter-connected utilising manufactured polyvinyl chloride 'nuckle joints'.

Manufacturer/Supplier:
Merit Lining Systems Pty Ltd
6 Lombark Street
Acacia Ridge Qld 4110
Tel: (07) 3275 3950
Fax: (07) 3275 3960

Performance as stated by the manufacturer:
Not known at this stage.

Costs:
The product has an estimated cost of \$3.00-\$3.50/m^2 depending on the catchment area shape.

Durability:
It is expected to be long lasting.

Installation:
The modular cover is easy to install.

Pros:
Easy to install by the land owner and it is easy to remove the cover if necessary. There is no need for an anchor trench and maintenance costs are expected to be minimal.

Polynet

Description:
Polynet is a floating modular product that is comprised of expanded 20mm thick polystyrene sheets wrapped in a net and secured into pockets in the net in sections. Each section is prefabricated into 50m x 5m sections which can then be floated out onto the storage.

Manufacturer/Supplier:

The product was designed by Ken Gordon but it is still in its concept stage.
Ken Gordon
1 Euro Street
Gilgandra N.S.W
PO Box 33 2827
Tel/Fax: (02) 6847 1381

Performance as stated by the manufacturer:
Not known at this stage.

Costs:
The anticipated cost is $2.50/m^{2}.

Durability:
It is expected to be long lasting.

Installation:
This product is relatively easy to install and could be done by the owner.

Pros:
Quick and easy to install.

QUIT Evap Modular Floating Cover

Description:
Quit Evap is a rectangular modular floating cover, manufactured from 0.5-.75mm thick polypropylene sheet with polystyrene floats. The modules are interconnected by Velcro straps. The full scale modules are up to 5m x 25-30m.

Manufacturer/Supplier:
SMEC Australia Pty Ltd.
Peter Chapman
1st floor, 105 Denham Street
Townsville Qld 4810
Tel: (07) 4771 6119
Fax: (07) 4771 6120
Email: Peter.Chapman@smec.com.au

Performance as stated by the manufacturer:
Can effectively achieve 90-95% coverage of the waters surface and reduce evaporation by 85-90%.

Costs:
The estimated cost is around $6.00-$8.00/m^2 plus transport and installation.

Durability:
The cover has a minimum life span of five years with a potential life of 8-10 years, the cover is also UV stabilised.

Installation:
Installation of this product is easy and may be done by the owner.

Pros:

Lightweight and easy to install.

1.6.5 Polyacrylamides

CIBA PAM

Description:

PAM stands for polyacrylamide which is a chemical that is added to water in low concentrations to thicken it and therefore reduce evaporation.

Manufacturer/Supplier:

Ciba Specialty Chemicals Pty Limited
235 Settlement Road
PO Box 332
Thomastown 3074
Victoria
AUSTRALIA
Tel.: +61 3 9282 0600
Fax: +61 3 9465 9070
Email: customerservice.au@cibasc.com
Website: http://www.cibasc.com/ind-agr.htm

Performance as stated by the manufacturer:

The performance is not known at this stage.

Costs:

It is expected to cost $25ML.

Durability:

Not available.

Installation:

Very easy to apply to the water.

Pros:

PAM can reduce erosion and nutrient runoff in the field and also reduce seepage from the water storage.

APPENDIX 2

EVAPORATION LITERATURE REVIEW

2 EVAPORATION LITERATURE REVIEW

2.1 Introduction

Evaporation can occur at any water/air interface. Evaporation occurs when some water molecules leave the water and move into the air. Similarly, some of the water molecules in the air can re-enter the water. If the rates of each process are equal, then there is no net movement of water molecules across the interface and therefore no net evaporation (or net condensation). If some water molecules are allowed to disperse upwards, that is they are effectively removed from the air close to the water surface, then a net transfer of water molecules from water to air takes place and evaporation occurs.

Evaporation of a free water surface is therefore defined as net movement of water molecules from water to air. The rate of evaporation depends upon the rate at which the water molecules are dispersed away from the surface. This is a function of wind speed and the water vapour deficit. Water vapour deficit is a function of the temperature and humidity of the air.

It is difficult to measure the evaporation from an open storage let alone one that is covered by an evaporation mitigation technology (EMT). Appendix 2.2 and Appendix 2.3 review methods for estimating evaporation from storage including the water balance of Penman-Monteith approaches used in this study.

2.2 Summary of various evaporation assessment methods

Possible methods for measuring evaporation loss from water storages include the water balance approach used in this study, Class A evaporation pans, automatic weather station (AWS) based estimates, Bowen ratio and Eddy Correlation. More advanced but more expensive area based methods could include infrared large aperture spectroscopy (LAS) or laser radar (LIDAR). A summary of the advantages and disadvantages of the various methods and their appropriateness to the present study is described in Table A 2-1.

This project needed to measure the effectiveness of an evaporation mitigation technology (EMT) in reducing evaporation. To do this the actual evaporation from the storage needed to be measured on a daily basis for both open and covered storages.

Most of the methods reviewed in Table A 2-1 are suitable for open storages but not for covered. The method needed to be simple enough that the technique could be used to measure evaporation on existing storages.

Loss of water due to evaporation is more commonly discussed in the context of growing a crop, that is, water transpired from the soil through the roots and plant zylem and out through the leaves as well as what evaporates directly from wet plant surfaces and the soil. This is referred to as evapotranspiration or ET.

It is important to distinguish between *actual* and *potential* ET. Potential ET implies no shortage in water available to the crop while actual ET refers to a rate of evapotranspiration limited by available water in the soil. Similarly *area* potential ET or evaporation refers to that which would take place from an area so large that that the effects of any upwind boundary transitions are negligible and local variations are integrated to an area average. *Point* potential ET/evaporation refers to and area so small that the local ET/evaporation effects do not alter local air mass properties.

Point potential ET is generally assumed most appropriate for estimating evaporation of water from a small water body such as farm storage as covered in this report. Regional maps of long term average point potential ET are given on the Bureau of Meteorology website: - http://mirror.bom.gov.au based on the work of Morton (1983).

Table A 2-1 Summary of the advantages and disadvantages of various methods to measure evaporation and their appropriateness to the present study.

Method	Brief description	Advantage	Disadvantage	Appropriateness to project
Water balance using PST technology	A very accurate pressure sensitive transducer is used to record small changes in water depth with time.	Simple, robust, most accurate, able to place several sensors in several storages at a reasonable cost.	Dependant on accuracy of depth measurement and ability to separate seepage from evaporation. Require several days of data to obtain reliable evaporation and seepage rates.	Very appropriate to project as it is the only method suitable for covered storages.
Pan (Class A)	Simple pan of water, refill rate is a measure of the of evaporation rate. Related to crop ET via a simple "Pan" factor.	Simple, robust, Pan factors have been widely accepted/used for irrigation scheduling purposes.	Difficult to keep clean & maintain, can give erroneous data, water/pan can heat up, complex wind speed effects associated with lip.	Simple, easy to operate and maintain during short term trial. The three lined tanks (USQ) may be considered as well maintained large pans.
Penman-Monteith (FAO 56)	Accepted standard method for estimating evaporation from standard (single height) meteorological data.	FAO 56 now widely established and used. FAO 56 considered superior to other ET formulae eg Blaney-Criddle, Priestly-Taylor	Few disadvantages, except not as accurate as Bowen ratio or Eddy Correlation.	Very appropriate to present study. FAO 56 PM will be calculated using data from AWS. May require acquisition of accurate net radiation sensors.
Bowen Ratio (BR)	Measures temperature and humidity gradient across two heights close to evaporating surface.	Well established and can be very accurate if set up correctly with accurate sensors.	Humidity sensors of the required accuracy eg cooled mirror hygrometer are very expensive. Equipment can be temperamental. Point measurement.	Not appropriate as equipment impossible to acquire and set within time frame of project. Also, superseded by EC.
Eddy Correlation (EC)	Uses 3 axis sonic anemometry and fast response infra-red sensors to detect the difference in upward verses downward moving air.	Now a well established, affordable, up to date technique for evaporation assessment. Particularly suited to measurements close to open water surfaces.	Equipment still too expensive for routine farm use but affordable for researchers with a reasonable budget. Point measurement.	Would be very appropriate for this study. The only method which is accurate in a fetch limited situations that is most farm storages.
Optical line/area based methods	Large Aperture Scintillation (LAS) IR/FTIR/UV absorption spectroscopy, LIDAR, Microwave radar Remote sensing Airborne survey	Lasers can scan horizontally and through the humidity plume. Can map variability of water vapour concentration across a water surface thus assessing fetch /advective effects.	Laser methods need extensive scientific support and are very expensive. Only suited to large scale, intensive research projects.	Would be nice but an expensive and possibly time/effort consuming option for this study.

2.3 Detailed assessment of methods for assessing evaporation

2.3.1 Water balance

The water balance method using accurate PSTs was selected as the most appropriate way of determining evaporation from both open and covered storages for this project. It is the only method that can be applied to a covered storage and the instrumentation is both affordable and robust enough for use on operating farm storages in remote sites. This method looks at the factors that increase and decrease the water volume as seen in Figure A 2-1.

The technical performance evaluation is based on a comparative volume flow analysis as per the following equation:

Change in volume = Inflow + Rain – Outflow – Seepage – Evaporation

Therefore:

Evaporation = Inflow + Rain – Outflow – Seepage – Change in volume

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

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

Thus by measuring changes in water depth the net change in evaporation and seepage can be determined. When using the water balance method the usual unit is mm/day.

The accuracy of this method depends greatly on the accuracy of the equipment used to measure the change in water depth.

The most difficult parameter in this equation to measure is seepage. Potentially soil analysis and electromagnetic surveys undertaken before storage filling can be used to get some idea on seepage loss. This was however not accurate enough to determine daily seepage required in the study and is not applicable to farm storages already holding water.

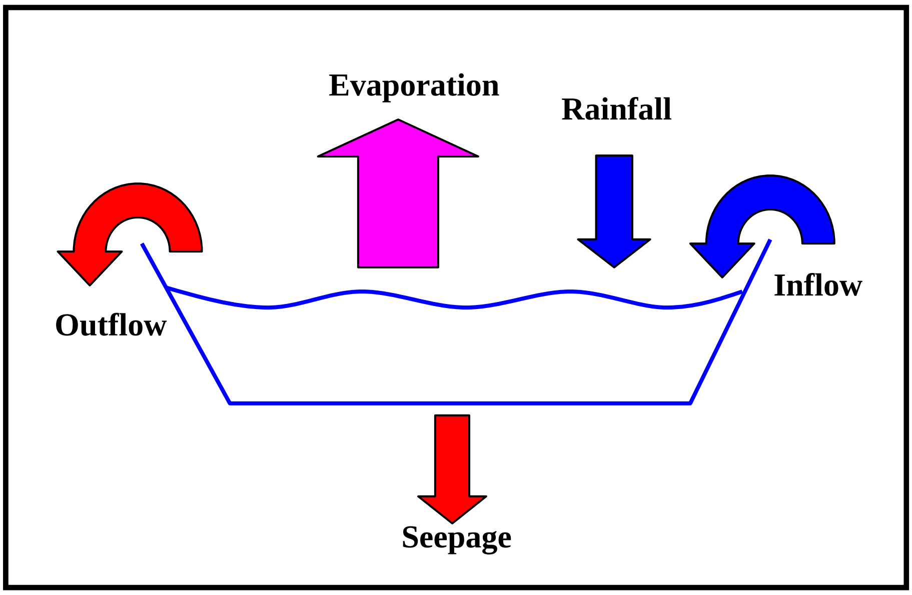


Figure A 2-1 Factors that effect a change in water volume.

The rate of water level change during the period of the night when evaporation is minimal (typically 12:00am to 6:00am) and when there is no inflow/outflow to the storage and no rainfall provides a good assessment of seepage losses. Consecutive measurement of this rate over a number of nights gives a reliable estimate of seepage losses. It can be assumed that seepage is a constant for short periods of five to nine days when the total water depth does not change significantly.

The above approach is a simplification of the full water balance assessment where inflow and outflow are measured using flow meters and there is an accurate digital terrain model of the storage to relate change in depth to change in volume. The questionable accuracy of flow meters and unreliable records make the simplified approach a better approach although periods of pump flow have to be excluded form the analysis which can limit data.

Ham and DeSutter 1999 provide a summary of the water balance technique, applied to waster water lagoons in the US. Differences in their approach compared to the present study include;

i) depth change was measured using float based recorders in stilling wells (linear displacement transducers on the recorders had full scale ranges of 635mm and resolutions of 0.16mm), or
ii) an infrared transducer with a 15 degree field of view was used to measure the temperature of the waste surface.

The approach of most water balance studies is to record rate of change of water depth, calculate evaporation using the best available model and remove to deduce a seepage rate. A study of the water balance of Lake Powell, Glen Canyon storage, Arizona was provided by Myers et al (1999). Water balance studies of waste lagoons were reviewed by Louden and Reece (1983) and further studies have been provided by Glanville et al (1999), Ham (1999) and Ham and DeSutter (1999). An error analysis of the water balance method was provided by Ham (2002).

The change in the water level of the storage can either be measured using pressure transducer based depth sensors, siphon weighing systems (Glanville et al 1997) or floating recorders (Ham, 1999). Inflow and outflow to the storage in addition to seepage have to be determined very accurately in order to obtain a meaningful evaporation estimation. The aim of this type of experimental approach may be summarized in Figure A 2-2.

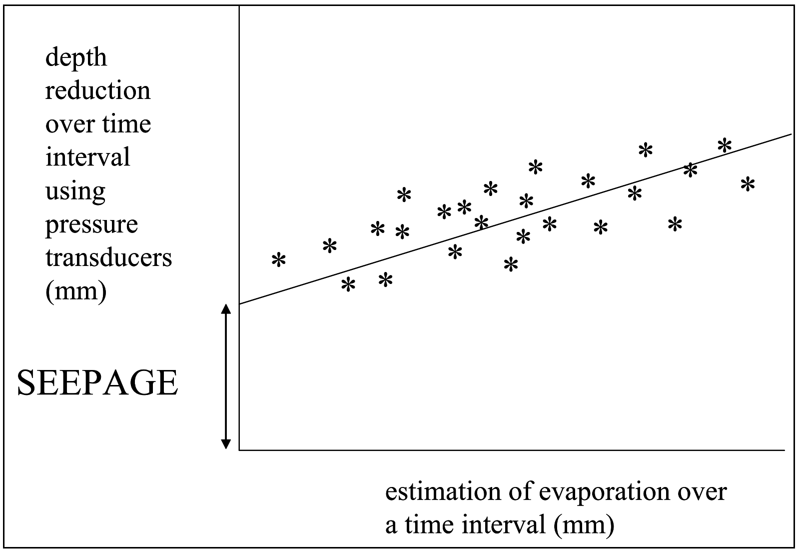


Figure A 2-2 Principle of physical measurement of evaporation of a water storage using flow mass balance method.

The main challenge is to determine seepage accurately. As part of the present study which is to evaluate the effect of various covers in reducing evaporation, three lined tanks have been set up with nil seepage. With other water storages, depending upon the quality of the liner, there is usually some loss due to seepage. The best method to determine the seepage rate is to accurately measure the change in water level over night when there should be minimal evaporative loss. This necessitates the use of very accurate transducers (accurate to ±1mm/day or better). Waste level recorders description were rigorously tested by Ham and DeSutter (1999) and found to be extremely accurate and stable (±0.16mm).

Wind effects can be a substantial cause of data variability (Glanville et al 1997) and Ham (2002). For example wind induced waves superimpose a signal noise on depth measurements which has to be carefully removed. More seriously, wind can effectively pile up water along the downwind shoreline of a water body. Sample calculations using the approach of White and Denmead (1989) indicated that depth errors caused by wind drag would be less than 1mm. There is also the tidal effect which may be a few mm for large water bodies.

2.3.2 Penman-Monteith (automatic weather station)

The project required estimation of evaporation from an open and covered storage to determine the effectiveness of the evaporation mitigation technology (EMT). The best way of achieving this was to measure the actual evaporation from an open and covered storage. This is done using the water balance method described above. Where open (control) storage was not available or data was poor an alternative was required.

Although essentially designed to estimate evapotranspiration from well watered grass 0.12m tall, the Penman-Monteith (PM) FAO56 method was considered to be the best available method for estimating open water evaporation using AWS derived parameters that is solar radiation, wind speed, temperature and humidity. This is supported by a number of references (eg Brutseart). There have been several recent studies that have confirmed that the PM FAO56 equation generally out performs the other equations. Kashyap and Panda (2001) have clearly indicated this in their study comparing ten evapotranspiration methods to grassed weighing lysimeter data obtained in India (Table A 2-2).

Table A 2-2 Ranking of ETo estimation methods based upon root mean square error (after Kashyap and Panda, 2001).

Rank	*Estimation method*	*Mean deviation from measured values (%)*	*Coefficient of determination (R^2)*	*RMSE (mm per day)*
1	Penman-Monteith	-1.36	0.91	0.080
2	Kimberly-Penman	-1.51	0.74	0.211
3	FAO-Penman	-3.60	0.76	0.234
4	Turc-Radiation	+2.72	0.70	0.260
5	Blaney-Criddle	+3.16	0.72	0.289
6	Preistley-Taylor	-6.28	0.77	0.316
7	Penman	+11.87	0.78	0.317
8	Hargreaves	+8.34	0.70	0.358
9	FAO-Radiation	+17.89	0.75	0.540
10	Corrected Penman	+22.32	0.81	0.756

Notes: (1) Blainey-Criddle based on mean air temperature only
(2) Priestly-Taylor
(3) Jensen-Haise based on air temperature and daily integrated solar radiation

Until research is carried out to determine precise aerodynamic and surface resistance values for open water, it is recommended that the world industry standard PM FAO56 equation provides the best method for predicting open storage evaporation.

This method is only suitable to open storages and not to ones with an EMT. PM was also used to determine likely evaporation during night time hours to improve the accuracy of seepage determination.

The PM method has two distinct advantages over the other methods given in Table A 2-2. Firstly, it is has a physical basis implying the equation can be used on a global basis without the need for empirically derived constants relevant to specific regions. Secondly, the equation has received the most through experimental validation against other methods, mainly weighing lysimeters and soil moisture measurements. A disadvantage of the PM method however is the relatively high data requirement including air temperature, wind speed, relative humidity and solar radiation, although Allen, 1998 pointed out alternative ways of estimating solar radiation and humidity using simpler or fewer measurements.

Basic evaporation theory

At any water and air interface which is above absolute zero, some water molecules leave the water and move into the air. Similarly, some of the water molecules in the air reenter the water. If the rates of each process are equal, then there is no net movement of water molecules across the interface and therefore no evaporation. If however some water molecules are allowed to disperse upwards that is they are effectively removed from the air close to the water surface, then a net transfer of water molecules from water to air takes place and evaporation occurs.

Evaporation of a free water surface is therefore defined as net movement of water molecules from water to air. The rate of evaporation is E, (mm/h) depends upon the rate at which the water molecules are dispersed away from the surface. This is a function of wind speed *f*(u) and the vapour pressure deficit (VPD). VPD is a function of the temperature and humidity of the air (Figure A 2-1)

Partial pressure, e, (Pa) is a convenient way to express the water vapour content or humidity of air. The humidity of air is a function of temperature and is defined by saturated vapour pressure (e_{sat} or e_s) curve. The gradient of the e_s curve ($\delta e/\delta T$) at any temperature T is defined as Δ_T.

Consider a parcel of air with temperature T and an actual water vapour partial pressure e_a. If the parcel of air is cooled adiabatically (that is no transfer of heat), T and e change along a line which has a negative gradient equal to the psychrometric constant, λ. Once the e_s curve is reached that is the air is fully saturated. The temperature at which this occurs is known as the wet bulb temperature (T_w). λ has an approximate value of 67Pa/K. λ is not strictly a constant as it is a weak function of both temperature and air pressure.

Relative Humidity (RH) is simply e/e_s expressed as a percentage. Absolute humidity is the concentration of water vapour in air, expressed in ppm or in $\mu g/m^3$. Keeping temperature constant (isothermal), the amount by which water vapour pressure, e (Pa) would have to increase so that the e_s curve was reached (that is the air becomes completely saturated) is known as the Vapour Pressure Deficit or VPD. VPD is commonly expressed in formulas as ($e_s - e_a$).

Where f(u) is a wind speed function, Daltons formula (alternatively referred to as the 'bulk aerodynamic formula') for potential evaporation, or the aerodynamic drying power of the air, E_a, is expressed as follows:

$$E_a = f(u)(e_s - e_a) \qquad 1.$$

Use of the Dalton formula represents the most basic method for estimating evaporation and is useful if meteorological data is poor or limited. If a reliable function for wind speed can be found. Dingham, 1994 applied a simple constant to the wind velocity equal to 1.26×10^{-4}s/mb per day. This is the basis of the Surface Energy Balance Model (SEBAL) Bastiaansen and Bandara, 2001.

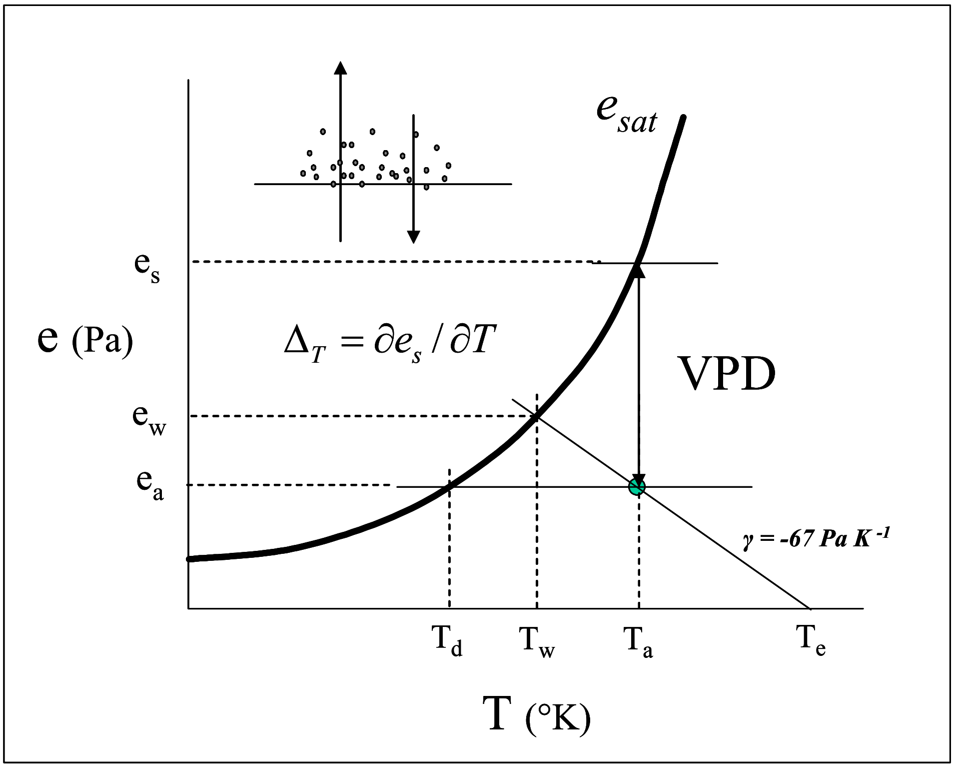


Figure A 2-3 Principle of evaporation.

Variations upon the Dalton formula are also referred to as the vapour pressure deficit (VPD) method (Howell and Dusek, 1995) or the Bulk Aerodynamic method (Lakshman, 1972, Stewart and Rouse 1976, DeBruin 1978) have been used in a number of evaporation studies, including the Snowy River Mountain scheme (AWRC, 1971 and Hoy and Stevens 1977). Estimation of the evaporation from the lake of Aswan High Dam (Lake Nasser, Egypt) using the bulk aerodynamic method was undertaken by Omar and ElBakry, 1980.

Penman-Monteith theory

Combination methods were first introduced by Penman (1948) and account for the energy required to sustain evaporation and the mechanism required to remove the vapour. Penman showed that the rate of evaporation from an open water surface (mm/day) could be expressed as;

$$E_o = (\Delta Q + \gamma E_a)/(\Delta + \gamma) \qquad 2.$$

where Q is the evaporation equivalent of the net flux of radiant energy to the surface, where the corresponding aerodynamic or ventilation term is;

$$E_a = 0.26(e_s - e_a)(1 + U/100) \qquad 3.$$

where e_s and e_a are the actual and saturated values of vapour pressure at 2m above the surface and U is the corresponding wind run, in miles per day. γ is the thermodynamic value of the pschrometric constant, equal to 0.66mb/K and Δ is the slope of the saturation-vapour pressure versus temperature curve for water at air temperature in mb/°C (Thom and Oliver, 1977).

The more commonly used 'general form' of the equation (Kashyap and Panda 2001) is as follows:

$$ET_o = \frac{1}{\lambda}\left[\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n - G) + \left(\frac{\gamma}{\Delta+\gamma}\right) f(u)(e_s - e_a)\right] \quad 4.$$

where ET_o is the evaporative flux (mm/day)

λ is latent heat of vapourisation (MJ kg^{-1}) = *2.501-0.002361T (°C) ≈ 2.45*

R_n is net radiation (MJm^{-2} day^{-1})

G is the soil or water heat flux (MJm^{-2} day^{-1})

Δ is the slope of the svp-t curve (kPaC^{-1}) = *0.2{0.00738T + 0.8072}^{7} – 0.00016*

γ is the psychrometric constant (kPaC^{-1}) = *$c_pP/0.622\lambda$ ≈ 0.067*

$f(u)$ is a function of wind speed = 6.43(1+0.0536u_2)

e_s is the saturated vapour pressure (kPa)

e_a is the actual vapour pressure (kPa)

Originally, Penman (1948), originally proposed the following equation for the wind speed function;

$$f(u) = 0.26(1 + 0.54u_2) \quad 5.$$

where u_2 is wind speed in ms^{-1} at 2m above the surface (the constants assume E in mm/day and vapour pressure in mbar). The constant 1 was later altered by Penman (1956) to 0.5, although Thom and Oliver (1977) regarded 1 as preferable. Based on lysimeter measurements, Doorenbos and Pruitt (1975) suggested that 0.54 be altered to 0.86. This highlights the requirement for a single standardized method that is FAO56.

Alternatively, the Penman (1948) equation is expressed as follows;

$$\lambda E = \frac{\Delta(R_n - G) + \Delta\rho_a c_p (e_s - e)/r_a}{\Delta+\gamma} \quad 6.$$

$$\text{or } E = (1/\lambda)\frac{\Delta(R_n - G) + \Delta\rho_a c_p (e_s - e)/r_a}{\Delta+\gamma} \quad 7.$$

where r_a is a wind speed dependant aerodynamic resistance term. In 1965, Monteith presented a modified version of the Penman equation incorporating a crop surface resistance term and this forms the basis of the Penman-Monteith method and is;

$$\lambda E = \frac{\Delta(R_n - G) + \Delta\rho_a c_p (e_s - e)/r_a}{\Delta+\gamma^*} \quad 8.$$

where ρ_a is the mean air density at constant pressure

c_p is the specific heat of air

γ^* is a modified psychrometer constant as follows;

$$\gamma^* = \gamma(1 + r_s / r_a) \quad 9.$$

where r_s is the surface (or canopy, leaf, stomatal) resistance (s/m) term controlling release of water vapour to the surface

r_a is the aerodynamic (or ventilative) resistance (s/m) term controlling the removal of water vapour away from the surface.

The aerodynamic resistance, r_a, which is now the wind speed function term, is defined according to FAO 56 as;

$$r_a = \frac{\ln\left[\frac{z_m - d}{z_{om}}\right]\ln\left[\frac{z_h - d}{z_{oh}}\right]}{k^2 u_2} \qquad 10.$$

where z_m is the height of wind measurements (m)

z_h is the height of humidity measurements (m)

d is the zero plane displacement height (m)

z_{om} is the roughness length governing momentum transfer (m)

z_{oh} is the roughness length governing transfer of heat and vapour (m)

k is the von Karmon constant = 0.41

u_2 is the wind speed at height 2m (ms^{-1})

The (bulk) surface resistance, r_s, is defined as;

$$r_s = r_{stom} / LAI_{active} \qquad 11.$$

According to FAO 56, the method has been developed from the Penman-Monteith Equation by Allen et al 1998. A reference crop is used consisting of watered mown grass 0.12m high. r_a is assigned a value of $208/u_2$ s/m and r_s is assigned as value of 70s/m. Assuming an albedo of 0.23 then leads to the FAO 56 formula for reference transpiration ET_0 (mm/day). The evapotranspiration of a particular crop ET_c is then related to ET_0 as follows;

$$ET_c = K_c ET_o \qquad 12.$$

Penman-Monteith equations used in this project

Equations used in this project were based on Penman-Monteith equations taken from FAO 56 (Allen et al, 1998). These equations were applied on a 15 minute time step.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad 13.$$

$$\Delta = \frac{4098\left[0.6108 \exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \qquad 14.$$

$$\gamma = \frac{c_p P}{\varepsilon\lambda} = 0.067 \qquad 15.$$

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26} \qquad 16.$$

$$e_s = 0.6108 \exp\left[\frac{17.27T}{T+237.3}\right] \qquad 17.$$

$$e_a = \frac{\overline{RH}.e_s}{100} \qquad 18.$$

$$R_n = (1-\alpha)R_s - R_l \qquad 19.$$

$$R_s = \{a + b(n/N)\}R_a \qquad 20.$$

$$R_l = \alpha\overline{T^4}(0.34 - 0.14\sqrt{e_a})(1.35R_s / R_{so} - 0.35) \qquad 21.$$

where:-

ET_0	reference transpiration (mm/day)
Δ	slope of the saturated vapour pressure temperature curve where T is air temperature (°C)
R_n	net radiation ($MJ/m^2/day$)
G	soil heat flux ($MJ/m^2/day$)
γ	psychrometric constant 0.067 ($kPa°C^{-1}$)
u_2	wind speed at 2m height (m/s)
c_p	specific heat at constant pressure 1.013 x 10^{-3} ($MJ\ kg^{-1}\ °C^{-1}$)
P	atmospheric pressure 101.3 (kPa) where z is elevation above sea level (m)
ε	ratio of the molecular weight of water vapour / dry air 0.622
λ	latent heat of vapourisation, 2.45 ($MJ\ kg^{-1}$) (1/2.45 = 0.408)
e_s	saturated vapour pressure (kPa)
e_a	actual vapour pressure (kPa) where RH is the relative humidity (from AWS)
α	surface albedo (assumed 0.23)
R_s	total radiation from AWS, or calculated from eqn 19, where a= 0.25, b= 0.5, n is actual duration of sunshine hours, N is maximum possible duration of sunshine hours (for clear skies n=N and $R_s = R_{so}$) and R_a is the average daily extraterrestrial solar radiation (from tables)
R_l	long wave radiation ($MJ/m^2/day$) where σ is Stefan-Boltzmann constant = 4.903 $MJ/m^2/K^4/day$

2.3.3 Evaporation pans

Evaporation pans (Figure A 2-4) have been and still are used extensively throughout the world to estimate reference evapotranspiration for crop surface, or evaporation from a bare soil or water surface (Kadel and Abbe, 1916). Evaporation pans (Class A pan, USDA or US Weather Bureau) consist of a circular pan, generally four feet in diameter and 10 inches deep. They should be mounted on a slatted timber base on level short mown grass and equipped with a bird guard.

Figure A 2-4 Typical evaporation pan with weeds growing and no bird guard. The pan is also not filled to the top so there will be significant errors associated with the aerodynamics of the lip

A floating evaporation pan setup has been described by Ham (1999). Differences between water body and pan conditions that can affect pan data include (Burman and Pochop, 1994);

1. differing water temperature variations with depth
2. storage of heat within the pan
3. differences in wind exposure
4. differences in the turbulence, temperature and humidity of air above the water surface
5. heat transfer through the sides and bottom of the pan.

Since pan evaporation (E_{pan}) normally exceeds evaporative losses from larger water bodies (E_{ws}), researchers commonly adjust the pan data as follows:

$$E_{ws} = E_{pan}.K_{pan} \qquad 22.$$

where K_{pan} is a pan coefficient which generally varies from about 0.6 to 0.9 (Brutsaert, 1982) or 0.6-1.2 (Clewitt, 1980) depending on the pan and the surrounding environment. Calculation of pan coefficients for pans across Queensland was carried out by Weeks, 1983 who concluded 0.7 to 1.0 was typical.

Brutseart in his famous book "Evaporation Into The Atmosphere" describes evaporation pans in terms of "uncertain and often dubious applicability as a measure of evaporation in nature". Watts and Hancock (1985) reaffirm Brutsaert's statement and assert that all evaporation pan data should be regarded as "untrustworthy". The authors list the problems associated with operating pans as follows;

(i) dirt on the metal pan,
(ii) contamination of the water,
(iii) other inputs (rain, splash-in),
(iv) other outputs (bird and animal drinking, splash-out),
(v) ventilation changes below pan (change of grass length),
(vi) thermal property variations,
(vii) presence of birdguard (reduction of both radiation input and ventilation),
(viii) possible shade at low sun angles (eg. surrounding trees),
(ix) wave action and overtopping in windy conditions,
(x) surface tension problems when refilling to needle point, and
(xi) correction for rainfall.

Even with properly maintained pans the energy exchange, heat storage and airflow characteristics for the shallow water in the pan is likely to be very different to that of open water or a crop (Figure A 2-5). However, a number of studies (Doorenbos and Pruitt 1975) have demonstrated that pans can work well when properly maintained. Pans may work well if evaporative conditions are not too severe. An evaluation of Class A Pan coefficients in humid locations has been carried out by Irmak et al 2002. The problem of heat conduction in evaporation pans has been addressed by Oroud, 1998.

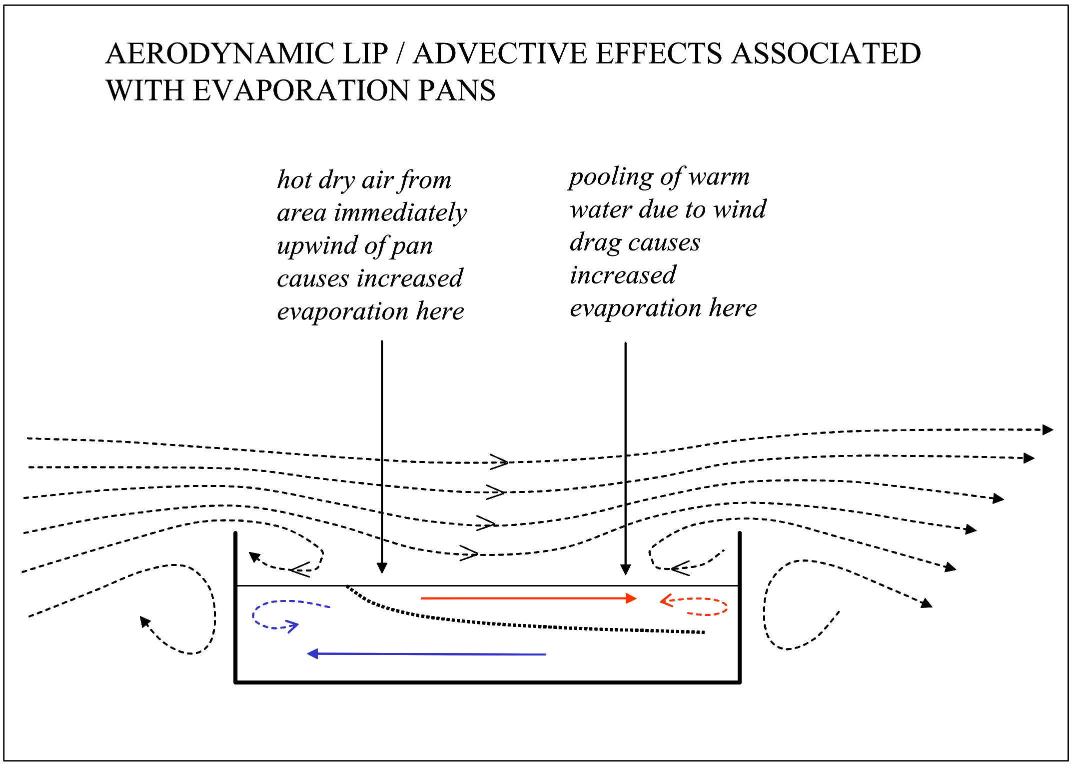


Figure A 2-5 Aerodynamic lip/advective effects associated with evaporation pans

Many problems associated with small pans can be eliminated if the size of the pan is increased. At University of Southern Queensland (USQ), trials with very large pans or tanks are taking place. With these pans, the height of the lip is small compared to the overall width of the pan, so lip errors are significantly reduced. However, these pans still suffer from the problem of fouling by wildlife. At USQ, fouling by ducks were initially quite a problem and bird scarers had to be installed at the facility (Figure A 2-6).

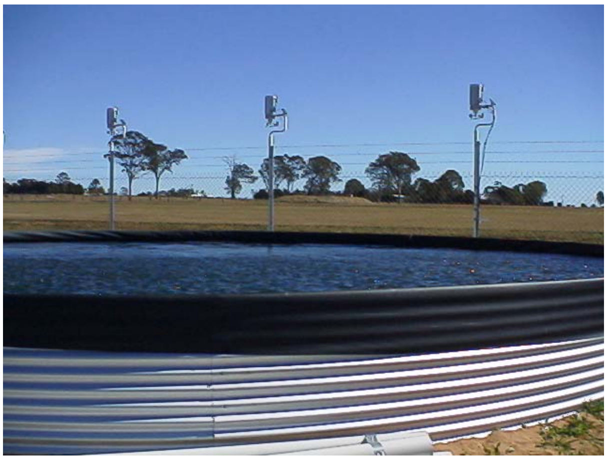


Figure A 2-6 Evaporation research facility based at USQ Ag plot. The experimental trial consists of three lined 10m diameter x 0.8m deep tanks which are being used to accurately assess the effectiveness of different evaporation control methods.

2.3.4 Bowen Ratio

Net radiation (R_n) is either absorbed as ground heat flux (G) or transferred to the air above in the form of sensible heat flux (H) and latent heat flux (λE). The latter is defined as the energy expended in converting liquid water into water vapour. Thus, the heat energy balance may be expressed as follows:

$$R_n - G - H - \lambda E = 0 \qquad 23.$$

This may be rearranged as follows:

$$\lambda E = \frac{R_n - G}{1 + \beta} \qquad 24.$$

where β is the Bowen Ratio that is the ratio of sensible to latent heat flux (Bowen,1926). Bowen used this ratio to estimate evaporation. Equation 5 is most accurate when β is small (Brutseart, 1982). β is measured experimentally using Bowen Ratio apparatus which determines the temperature and humidity gradients over a height interval δz.

$$\beta = \frac{H}{\lambda E} = \lambda\left(\frac{\partial T}{\partial e}\right) = \gamma \frac{K_h}{K_e}\left(\frac{\partial T/\partial z}{\partial e/\partial z}\right) \qquad 25.$$

Bowen Ratio apparatus is required to accurately measure small differences in temperature and humidity over a small height interval above the evaporating surface. Traditionally, the equipment features a net radiometer and a pair of rotating precision aspirating psychrometers (Hancock, pers comm.).

The net radiometer, example Funk type (Funk, 1959, 1962) consists of a thermopile (series of thermocouple junctions) between an upper and lower blackened surface. The temperature difference between the two surfaces is a function of the net radiation (that is the difference between incoming and ground reflected radiation). The unit is enclosed within a polythene dome fed with a slight positive pressure of dry nitrogen to ensure no ingress of moisture.

The two rotating psychrometers (each consisting of wet and dry bulb thermometers located inside white cylindrical radiation shields) mounted on a motor driven interchange system so that their heights are automatically alternated after each pair of measurements. This provides both the temperature and humidity gradient information with successive readings being averaged to cancel out any small calibration differences between the two psychrometers.

An even more accurate approach to measuring Bowen Ratio is to use a cooled mirror hygrometer (CMH). Usually, there is only one CMH unit and air is ducted from the high and low sample positions alternatively. The air sample is passed over a mirror which is cooled using a liquid nitrogen supply. The temperature at which dew first starts to form on the mirror (detected using an infra red beam) is then a function of the original humidity of the air sample.

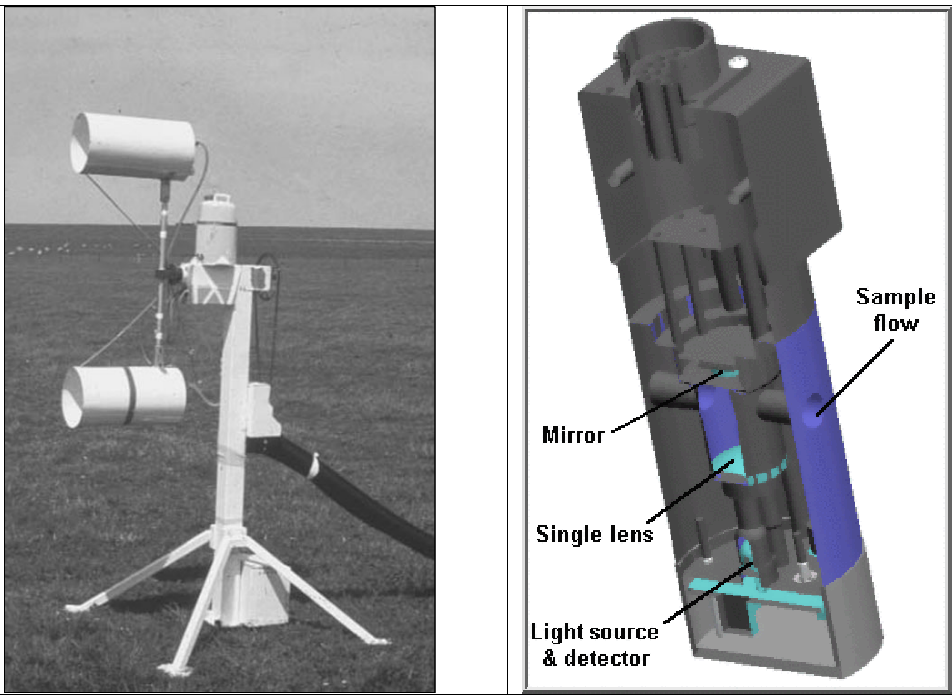


Figure A 2-7 Rotating Arm (paired aspirating psychrometers) and Alternate Flow (cooled mirror hygrometer) units used in accurate Bowen Ratio measurements.

Due to the expense and difficulty of maintaining these systems, later Bowen Ratio systems have moved to solid state temperature and humidity measurement systems consisting of usually ceramic Al/Si oxide porous material or polymer film or carbon coated plate alternatives. Temperature and relative humidity (RH) is calculated directly from changes in the electrical properties of the material (that is capacitance, resistance, impedance). These systems are cheap, robust and reliable, but are not accurate enough for precise Bowen Ratio work. Their use is mainly intended for the main market which comprises of standard meteorological stations. Reviews of the various humidity measurement techniques have been conducted by Scott 1996 and Wielderhold 1997.

Bowen ratio methods have been extensively used to measure biosphere-atmosphere exchange methods as part of the OASIS program (Leuning et al 1995, Raupach et al 2003) and as part of the FLUXNET program (Wilson et al 2002). An evaluation of the Bowen Ratio method for Australian conditions was carried out by Angus and Watts, 1984. Other Australian studies include McIlroy, 1972 and McLeod et al, 1998.

Some of the problems associated with the BREB method that is in obtaining balance or 'closure' have been investigated by Brotzge and Crawford, 2003. A full error analysis of the Bowen Ratio method has been performed by Watts 1983. This highlighted that there are quite large errors in very dry conditions (that is large B). For a freely evaporating surface ($-0.2 < B < +0.2$) there can be errors of up to 30% in B which lead to errors in LE of less than 5%.

2.3.5 Eddy Correlation

The measurement of vertical transfer of heat and water vapour by eddies was first described by Swinbank, 1951. Since then, micrometeorologists have long held that eddy correlation techniques offer the most promise for providing accurate measurements of evaporative flux with a sound theoretical basis (Kaimal and Gaynor, 1991). The method is offering an attractive alternative to other more cumbersome methods such as weighing lysimeters and

Bowen Ratio. A comprehensive manual invaluable to the experimental practitioner of the method is provided by Dijk, 2003.

The major challenge associated with the Eddy Correlation method is the response time limitations of the sensor instrumentation (Table A 2-3 and Figure A 2-8). Developments in electronics in recent years have resulted in new sensors with the required speed and accuracy.

Table A 2-3 Components of a typical eddy correlation system.

Sensor	Parameter	Example
3 axis sonic anenometer	wind speed (u±u', v±v',w±w')	CSAT3§
IR/UV absorption hygrometer	specific humidity (q±q')	LiCor§, Krypton§ KH20
Fine wire thermocouple	temperature (t±t')	13 micron

Note: § available from Campbell Scientific Pty Ltd

Eddy correlation theory (Figure A 2-9) describes the turbulent transport of properties such as momentum flux, sensible heat flux and latent heat flux. The method relies on accurately measuring the fluctuations in airspeed, temperature and humidity.

Considering motion in the vertical direction, w, latent heat flux is defined by;

$$\lambda E = \rho \lambda w q \qquad 26.$$

where E is the instantaneous latent heat flux (W/m^{-2})
ρ is the instantaneous air density
λ is the instantaneous latent heat of vapourisation of water (J/g)
q is the instantaneous specific humidity (g/g)

λE can be converted to water vapour flux by dividing by λ, and then to a conventional evaporation rate by dividing by the density of water.

Each component in the equation can be partitioned into a mean value plus an instantaneous deviation from the mean. The instantaneous deviations of air density and latent heat of vapourisation can be assumed to be zero. The long-term mean vertical wind velocity over a flat uniform surface can be assumed to have a value of zero (Dyer, 1961). Applying these assumptions and the rules of statistical averaging, the mean vertical flux for an averaging period longer than a few seconds becomes;

$$\overline{\lambda E} = \rho \lambda \overline{w'q'} \qquad 27.$$

where $\overline{w'q'}$ is defined as the covariance of vertical wind speed and specific humidity. Thus, over a level, uniform surface, the latent heat is entirely due to eddy transport, with no contribution from mean vertical flow.

A similar analysis can be applied to the sensible heat flux, yielding;

$$\overline{H} = \rho C_p \overline{w'T'} \qquad 14$$

where $\overline{H}$ is the mean sensible heat flux (W/m^2)
C_p is the specific heat of air (J/kg^{-1}K^{-1})

$\overline{w'T'}$ is the covariance of vertical airspeed and temperature (Kms^{-1})

Fine wire thermocouples are usually used for the fast response temperature measurement.

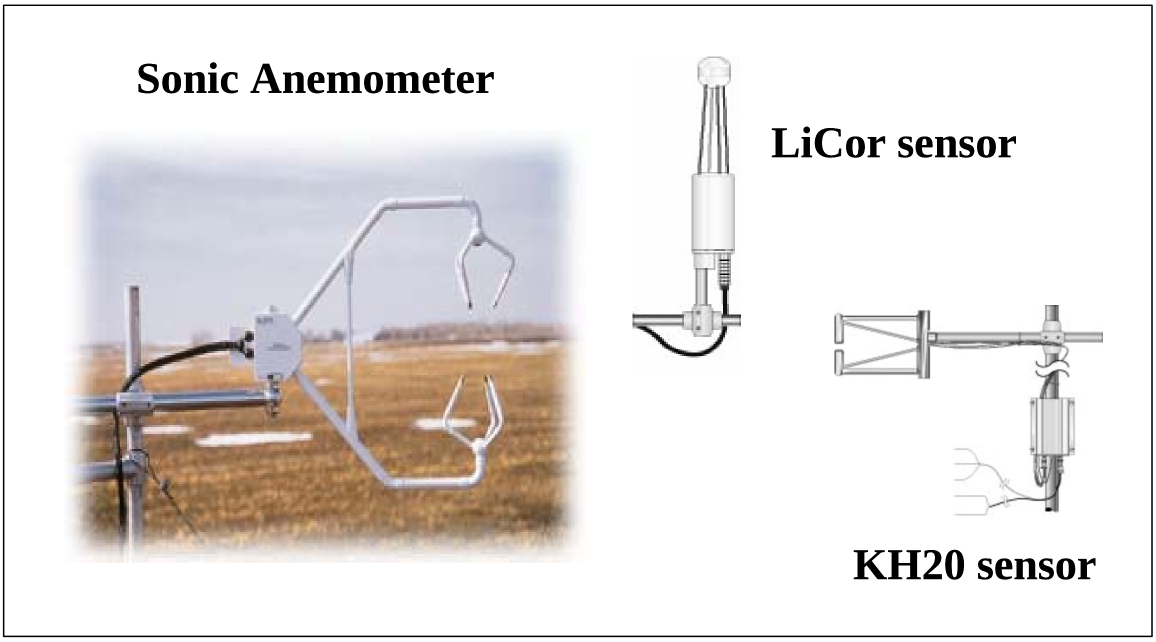


Figure A 2-8 Typical eddy correlation equipment including 3 axis sonic anemometer and LiCor (IR) or KH20 (UV) based fast response humidity sensors (pictures are courtesy of Campbell Scientific Australia).

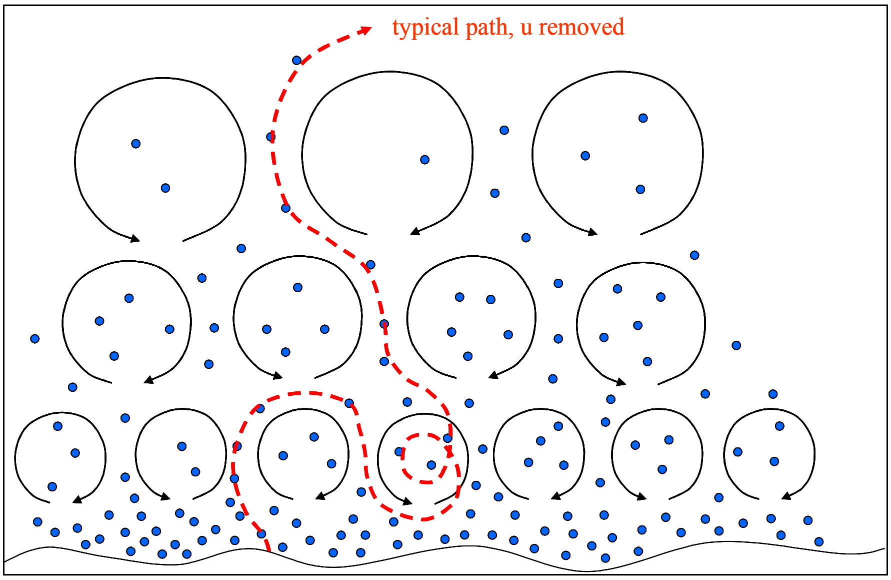


Figure A 2-9 Principle of operation of eddy correlation system - the humidity (concentration of water molecules) of upward verses downward moving air is compared to give the humidity flux.

Absorption hygrometers utilizing either infrared radiation (Staats et al 1965), Lyman-alpha radiation (Randall et al 1965, Miyake and McBean 1970, Buck 1976, Redford et al 1980) or the krypton UV radiation method (Campbell and Tanner 1985). An Infra Red fluctuation hygrometry method was described by Raupach in 1978.

The LiCor open path unit features an IR beam which is chopped using a grating rotating at 9000rpm. Detection of water vapour is via absorbance at 2.59µm using a Pb-Se detector.

Advantages reported for the LiCor unit are a more stable calibration under wet conditions and longer radiation tube life.

2.3.6 Optical line/area based methods

In reality, the evaporation of water from a small farm dam is not a uniform process, but varies significantly both spatially and temporarily. The reasons for this are also poorly understood but probably include advection of hot air across the dam, aerodynamic lip effects, warm water pooling and other heat driven effects including circulation. The magnitude of this variation is at present unknown, and further research using eddy correlation and/or optical line/area based techniques is required to elucidate the nature of this variation. This would provide some useful data, which if supported by some high quality Computational Fluid Dynamics (CFD) modelling would lead to fuller understanding of all the physical processes involved in the evaporation of water from a small dam. This line of investigation was considered too expensive and involved for the present study, but it is hoped that future studies might incorporate this approach.

In hot climates, advection plays a very important role in evaporation of water storages and therefore cannot be ignored. Hot dry cells or thermals form as a result of air passing over hot dry land. Inside the cells, the temperature may exceed 40°C and humidity may approach zero. As these cells pass over a water body, extra energy is provided to locally increase evaporation rates at the upwind margin of the water body. This has the effect of depressing the mean humidity contours at the upwind margin of a water body (Figure A 2-10).

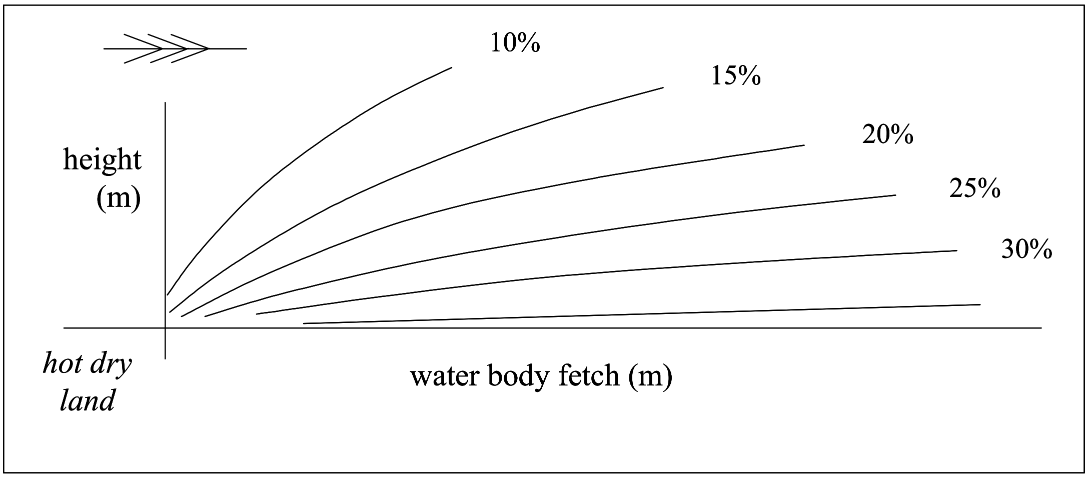


Figure A 2-10 Principle of added evaporation energy due to the oasis effect. Relative Humidity contours predicted by the model of Webster and Sherman, 1995 are depressed at the upwind margin of the water body, due to advection of hot dry air from an adjacent land mass.

For most evaporation measurements, the fetch (area upwind of point of measurement with similar surface characteristics) must be sufficiently long to develop a constant flux layer. This happens at some distance downwind from the upwind margin of a water body where equilibrium conditions are reached that is temperature and humidity profiles do then not change significantly as one progresses further downwind across the water body. Some argument exists as to the minimum length of this fetch. Slatyer and McIlroy, 1961 recommend an instrument height to fetch ratio of 1:100. This means that if the instrument measuring evaporation is set at a height of 1m above the water surface, then it should be situated at least 100m downwind from the bank of the water body. The problems with measuring evaporation using Penman-Monteith for water bodies less than a few hundred metres across is therefore highlighted.

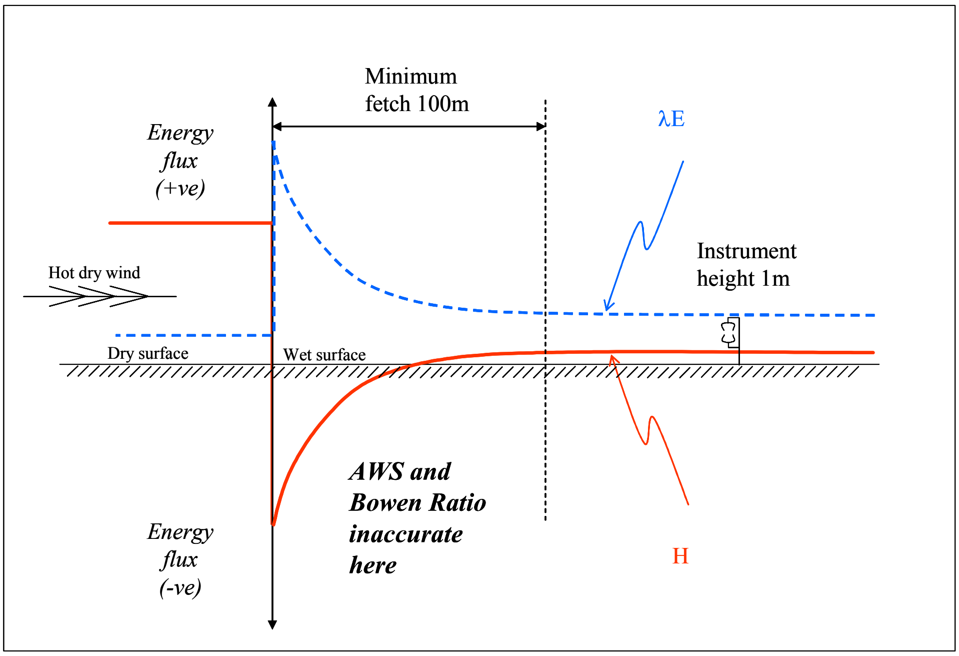


Figure A 2-11 Simplified representation of local advection (after Oke, 1987).

For small water storages (less than a few hundred metres across), advective effects are taking place across the active water storage (Figure A 2-11). Temperature, humidity, wind speed and therefore evaporation will all vary both spatially and temporally across the surface of the dam. Hourly or minute meteorological data is therefore of little use in this situation. To truly estimate evaporation over small water storages in hot climates, we therefore require meteorological data with millisecond resolution. The Eddy Correlation method is able to provide this temporal resolution. Additionally, air stability will vary markedly through the day in hot climates and this has an important effect on evaporation. The Eddy Correlation technique is able to calculate stability directly from the three axis wind direction and speed information gained from the sonic anemometer component of the apparatus. However, Eddy Correlation is still only a point measurement. Laser and remote sensing methods are really required to measure the spatial variability of humidity fields to fully take account of advective effects.

Under most climates that have sufficient rainfall to support ET, λE is generally some fraction of net radiation R_n. However, in areas where the air mass is strongly modified by dry desert conditions, the ratio of λE to R_n can exceed 1.5 (Allen 1999). In the case of an oasis in a desert environment, hot dry air moving sideways in the form of major eddies provides a major input of extra energy into the system (Webster and Sherman, 1995, Condie and Webster, 1997, Brutsaert and Stricker 1979, Brutsaert 1982). Where A_d is the extra energy due to advection, the sum of energies is now;

$$R_n + A_d - G - H - \lambda E = 0 \qquad 28.$$

With fast response meteorological data, the Penman approach could still be used to calculate evaporation for rapidly fluctuating conditions. To remind us once more, the Penman Equation may be expressed as;

$$\lambda E = \frac{\Delta R_n}{\Delta + \gamma} + \frac{\gamma E_a}{\Delta + \gamma} \qquad 29.$$

The first term is usually referred to as the radiation term and the second term the ventilative, aerodynamic or convection term. Brutsaert (1982) however prefers to call the first term the equilibrium term and the second term the non-equilibrium term, or the drying power of the air arising from large scale advection.

Consider a boundary layer that is air in close contact with the water which is completely uniform and saturated (Figure A 2-12). The second term of this equation is zero, but there is still some evaporation because of the first 'radiation' term which represents the lower limit of evaporation from moist surfaces. The radiation term may be thought of informally as incoming photons knocking water molecules out of the surface of the water, which then knock other water molecules out of the boundary layer into the air above. More formally, the first term is considered as representing evaporation under equilibrium conditions, and the second term, the evaporation arising as a result of the departure from equilibrium conditions that is advection (Brutseart and Stricker, 1979).

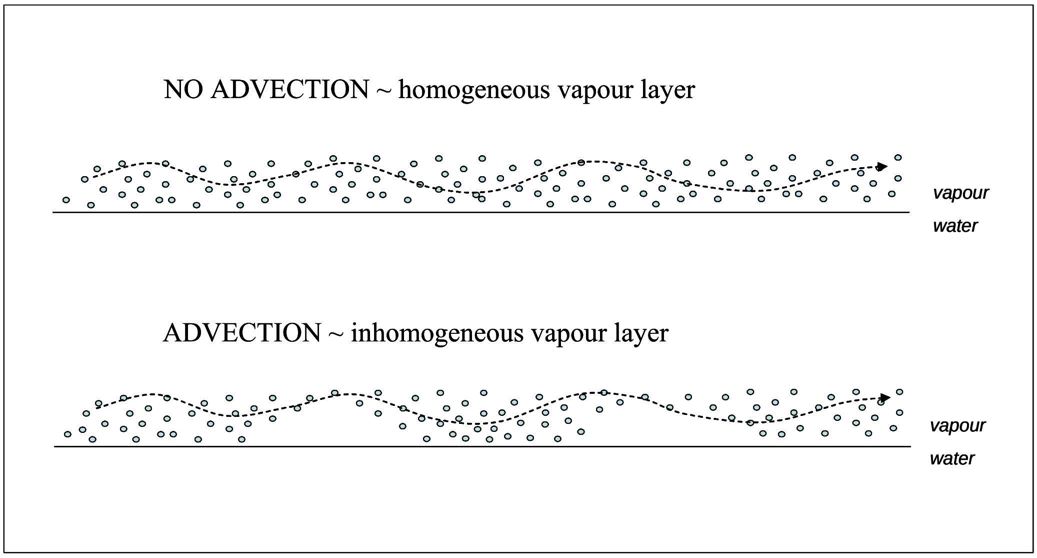


Figure A 2-12 Concept of equilibrium and homogeneity associated with local scale advection.

The atmospheric boundary layer however is almost never uniform but unsteady which tends to maintain a humidity deficit, even over the oceans. True equilibrium conditions are probably never encountered. Over a number natural surfaces described as saturated and essentially advection free, Priestley and Taylor (1972) noted that departure from equilibrium conditions produced evaporation values approximately 1.26 – 1.28 times greater than that predicted by the radiation term alone. This data was also supported by Davies and Allen (1973), Thompson (1975), Stewart and Rouse (1977). It is notable that land surfaces covered with vegetation, which is not wet but has ample water available, yields roughly the same evaporation as free water surfaces. This may be due to the larger roughness of the vegetative surface compared to the water surface. This is not true for wet canopy surfaces which are capable of evaporating at much greater rates (Watts and Hancock, 1984). This also may not be true in hot, dry, windy conditions experienced over water bodies in arid climates where waves on the surface of the water will increase roughness length of the surface.

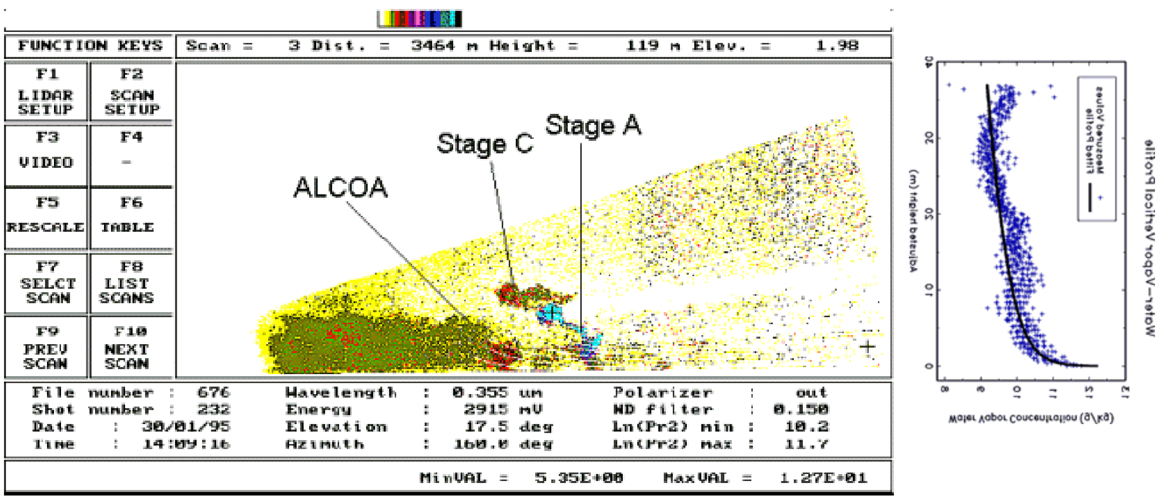
Line/area based methods with potential for investigating evaporation of water bodies include the following:

1. Satellite Remote Sensing. This uses information in the Infra Red sensitive to ground moisture content has been used extensively for catchment evaporation evaluations (Bastiaanssen and Bandara, 2001). The recession of the shores of Lake Eyre drying up

after a flood has been carefully mapped out with time using satellite data (Prata, A.J.), but seepage, rainfall, in/out flows were neglected.

2. Low Level Airborne Survey. This took place over Lake Alexandrina (Kotwocki, 1994). Measurement of sensible and latent heat fluxes were carried out using a GROB G109B research aircraft flying at 5-10 height above water surface. Evaporation from the lake was determined to be about 1m year. Another airborne hygrometry study was described by Silver and Hovde, 1998.
3. Microwave Radar. This has been carried out by CSIRO, Australia and is described by Hill and Long, 1995.
4. Large Aperture Scintillometry (LAS). This method is based on the analysis of intensity fluctuations (known as scintillations) of a near infrared (0.94µm) light beam (Gieske and Meijninger, 2003).
5. LIDAR (UV laser based scanning radar). Originally developed by the US Military, this is now a standard research instrument at several institutions eg. University of California Davis, Munich, Iowa & the Los Alamos Laboratory. LIDAR consists of a pulsed UV laser with Raman backscatter at 273nm. A 1 km range, 1m resolution and 95% accuracy is claimed (Figure A 2-13 and Figure A 2-14).

Figure A 2-13 Truck transportable LIDAR machine. The technology uses a scanning UV laser to detect humidity fields and thus deduce total evaporation rates over water bodies.



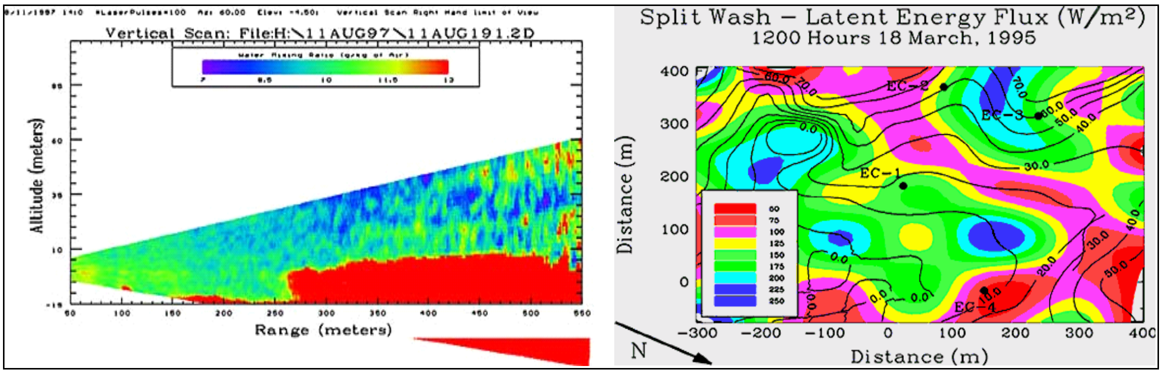


Figure A 2-14 Typical output data from the LIDAR unit.

APPENDIX 3

METHODOLGY TO DETERMINE EVAPORATION AND SEEPAGE

3 METHODOLOGY TO DETERMINE EVAPORATION AND SEEPAGE

3.1 Evaporation and seepage determination using PST data

Evaporation and seepage can be estimated using pressure sensitive transducer (PST) water depth data alone (Figure A 3-1) if night time evaporation is zero. The daily evaporation loss is simply the total daily water loss minus the seepage losses determined from night time water level change. The slope of the PST trace at night represents seepage rate.

The seepage rate at a particular dam site is best determined during cooler periods when evaporation during the night is negligible. Steps to determine seepage and evaporation comprise;

1. Graph PST trace
2. Look at each night time period
3. Select the period of minimum slope
4. Draw a line through this slope over a 24 hour span
5. Determine the slope which represents rate of seepage
6. Determine evaporation loss (total loss minus seepage loss).

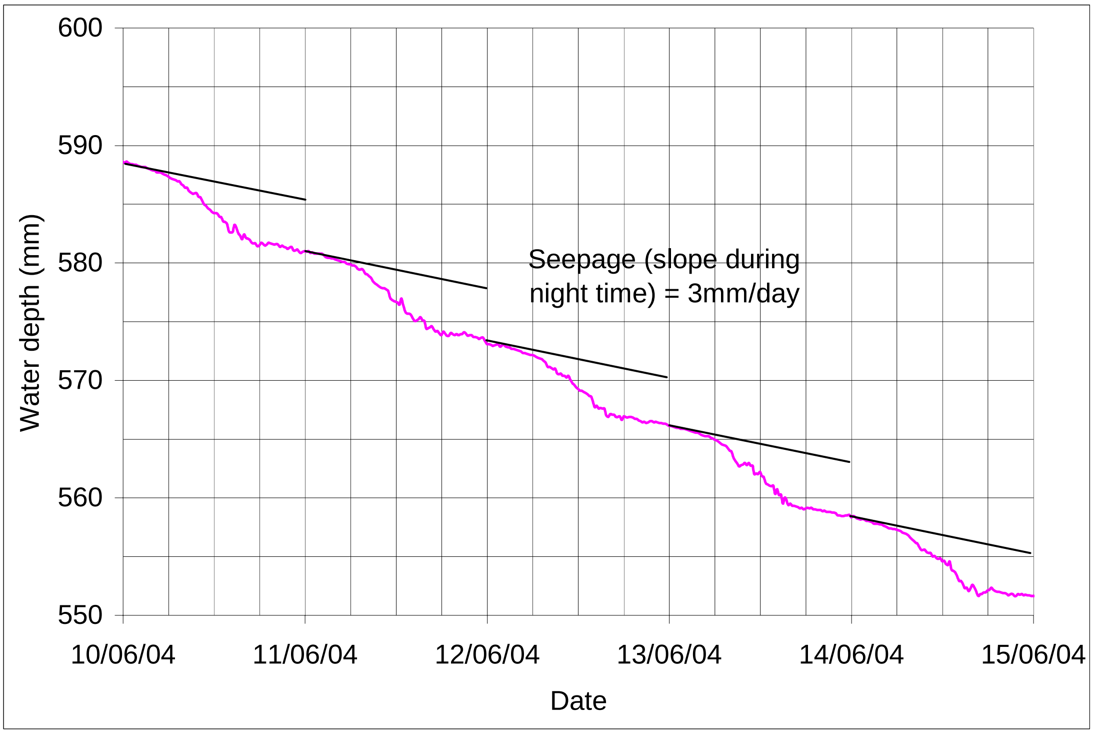


Figure A 3-1 A typical pressure sensitive transducer (PST) trace illustrating the change in water depth of storage in June 2004 and the night time slope to determine seepage.

3.2 Estimating evaporation from AWS data

Where PST data was not available for a control storage evaporation was estimated from AWS data. EvapCalc v2.0 a spreadsheet calculator based upon Penman-Monteith theory and the equations taken from the FAO56 manual (Allen et al 1988) was used to estimate evaporation.

The Penman-Monteith equation uses meteorological data collected by an AWS. In order of importance, these meteorological parameters include solar radiation, air temperature, wind speed and relative humidity. The full list of equations used in the spreadsheet model are summarised in the evaporation literature review (Appendix 2). An example of the format of the EvapCalc v2.0 spreadsheet for calculating evaporation is in Figure A 3-2.

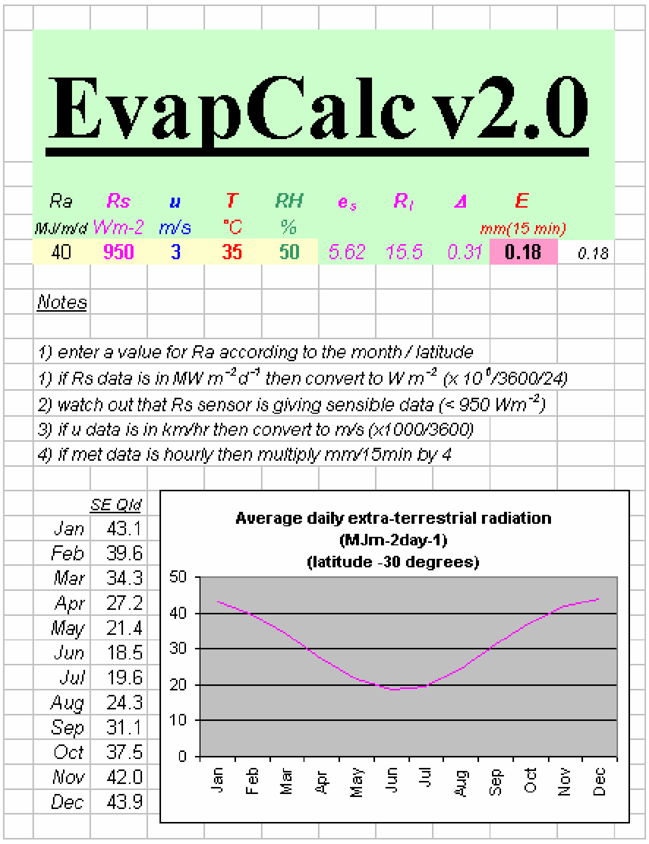


Figure A 3-2 The spreadsheet EvapCalc v2.0 uses Penman-Monteith equations to calculate the theoretical evaporation for a 15 minute period.

3.3 Evaporation and seepage determination using PST and AWS data

If more accurate evaporation and seepage determination is required, one cannot assume that night time evaporation is zero. An AWS based estimate for night time evaporation (Penman-Monteith) is therefore required.

Ham (2002) provides evidence that for night time evaporation rates being as high as 25 to 40% of a total daily evaporation of about 5mm/day in Kansas USA. Ham (2002) also reported errors in evaporation of between 0.3 – 1.2mm/day in his water balance studies on waste lagoons using floating recorders.

In Queensland Australia, the night time evaporation could be 10 to 20% of the daily total (due to higher summer time midday solar radiation). It would therefore be reasonable to assume that night time evaporation of open water in Queensland would be generally less than 1mm, but could be as much as 2mm on particularly warm, windy nights.

Seepage rate can thus be derived by subtracting night time evaporation from the total night time losses comprising seepage plus evaporation (see Figure A 3-3). The PST provides total night time losses and Penman-Monteith is used to calculate the night time evaporation component. Penman Monteith can only be used to estimate evaporation losses on control storages or during periods when no EMT is in use.

Steps to determine seepage and evaporation comprise;

1. Graph PST trace – total loss
2. Theoretical evaporation (Penman-Monteith) over the total loss – starting at the same point
3. Adjust the slope of the PST to overlap Penman-Monteith focusing on night time slope
4. Slope adjustment is the seepage rate.

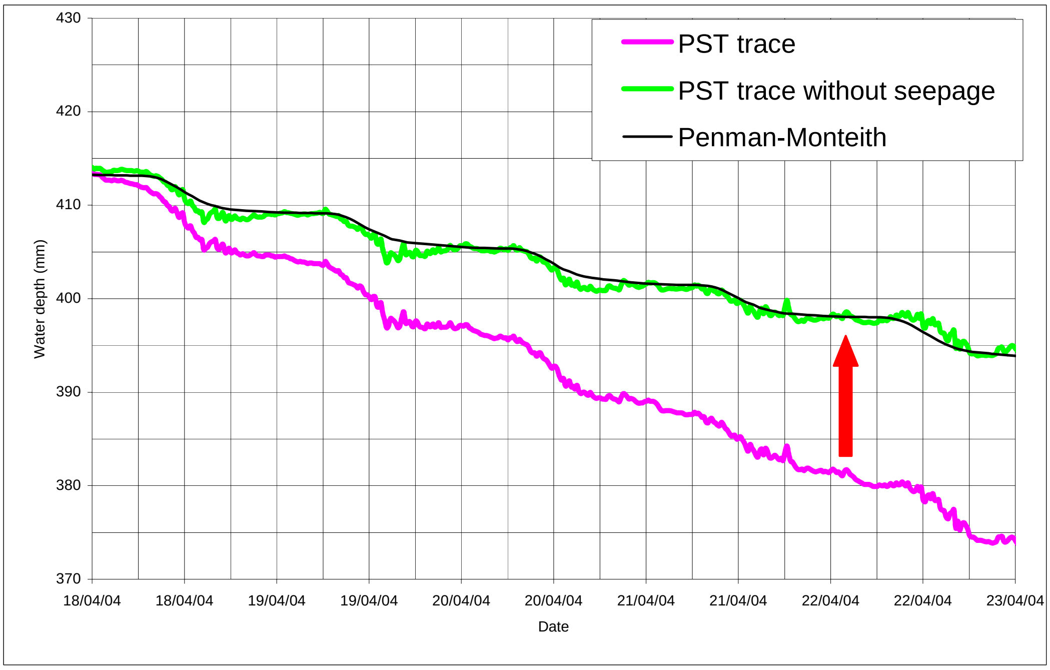


Figure A 3-3 A typical pressure sensitive transducer (PST) trace illustrating the change in water depth in April 2004. The PST data then has 3.5 mm/day of seepage removed, and the Penman-Monteith prediction for the period.

3.4 Problems related to interpretation of PST data

The standard configuration of the PST units comprised a 20m cable with the logger set to take an average water depth every 15 minutes. Unexplained fluctuations in the water level data were apparent in a significant amount of data. Various combinations of the configuration including altering cable lengths, data logging frequency etc were trialled to determine the best configuration. Illustration of these tests is given below. Based on these trials it has been determined that cable length should be limited to 20m (10m if possible) and that 15 minutes logging of data is adequate for analyses.

3.4.1 Wave action

A significant amount of data was affected by 'noise' in the PST trace and had to be rejected. Some 'noise' can be attributed to wave action. Figure A 3-4 indicates the three signals recorded by the depth logger (average - average of 1 minute data points over a 15 minute time interval, maximum - maximum depth over the time interval, minimum - minimum depth over the time interval). The maximum and minimum depths represent the range induced by wave action. By using the average depth over the time interval wave effects are effectively removed.

3.4.2 Cable noise

Problems with voltage fluctuations in the power cable to the PST sometimes resulted in 'noise' which is also indicated in Figure A 3-4 and resulted in data rejection. The average depth trace shows an unexpected shape in daytime water level change. This 'cable noise' occurred mainly on long PST cables (greater than 20m) but was also related to variation in the input voltage and temperature of the PST itself. The combination of these factors result in either a positive or a negative anomaly, which usually only occurred during the day. In general where this did not affect the night time trace, seepage and aggregate daily evaporation could still be determined.

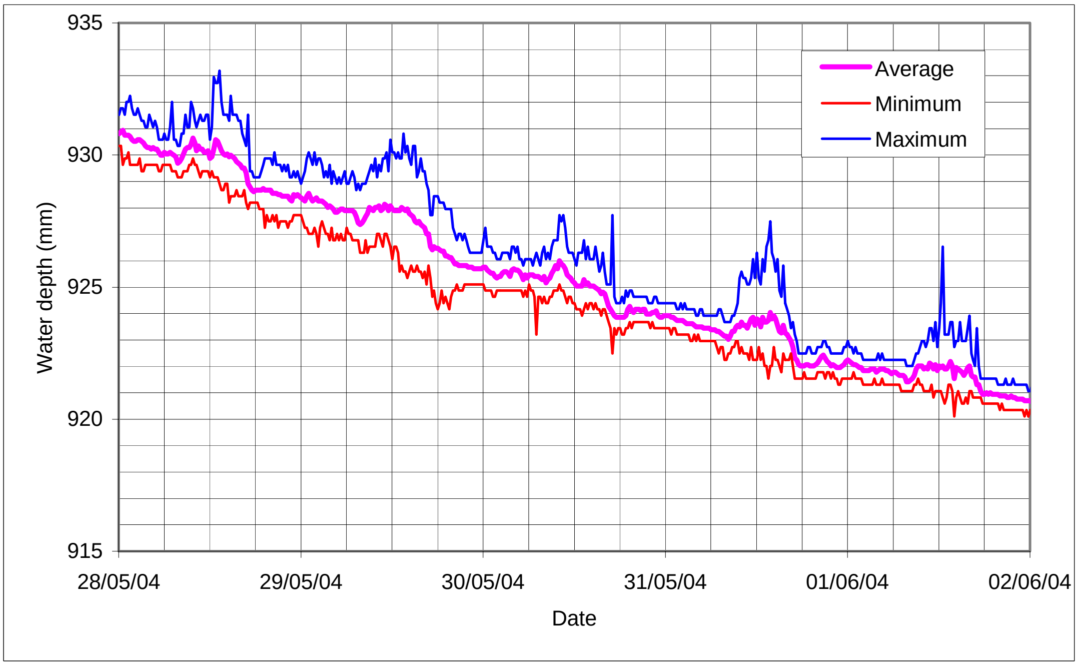


Figure A 3-4 Graph showing typical PST data, with three signals. Lines are drawn through the night time periods and depict seepage happening at the storage.

Figure A 3-5 illustrates the trace for two PST's in the same water tank at the USQ Ag plots. The trace from one PST1 showed a zero and sometimes slightly upward slope during the night whereas the PST2 had a downward night time slope which suggests seepage losses. This is obviously not that case with both sensors located in the same lined tank.

Although the traces are not aligned, when calculated from midnight to midnight in the usual manner the losses per day and the weekly total are the same. Problems would occur if similar data is found in a field trial since estimation of seepage is reliant on night time slope determination.

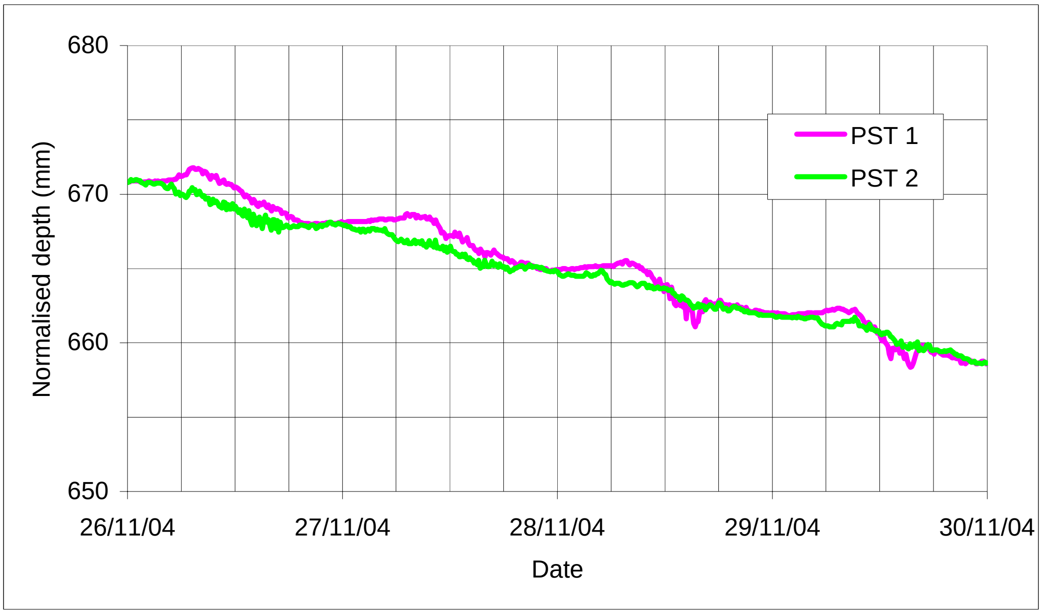


Figure A 3-5 **Graph showing the variation between two PST traces in the same water storage.**

3.4.3 Logging intervals

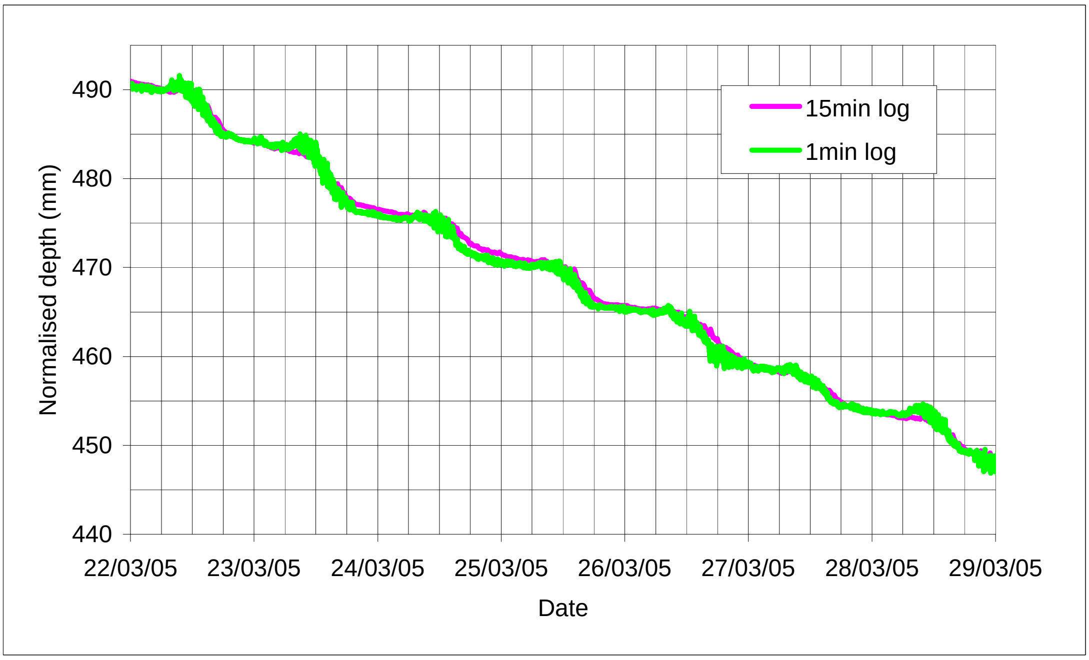


Figure A 3-6 **Graph showing data collected at 15 minute intervals and data being collected at 1 minute intervals.**

Figure A 3-6 and Figure A 3-7 illustrate PST output based on collecting and averaging data every 1 minute, 15 minutes and 1 hour. The 1 minute data shows a greater amount of noise, possibly due to wave action. There appears to be little loss in resolution when logging at 1 hour intervals. The 15 minute logging time step selected provided an appropriate compromise between capturing enough data to plot a curve of reasonable resolution while limiting data storage and frequency of field visits to download data.

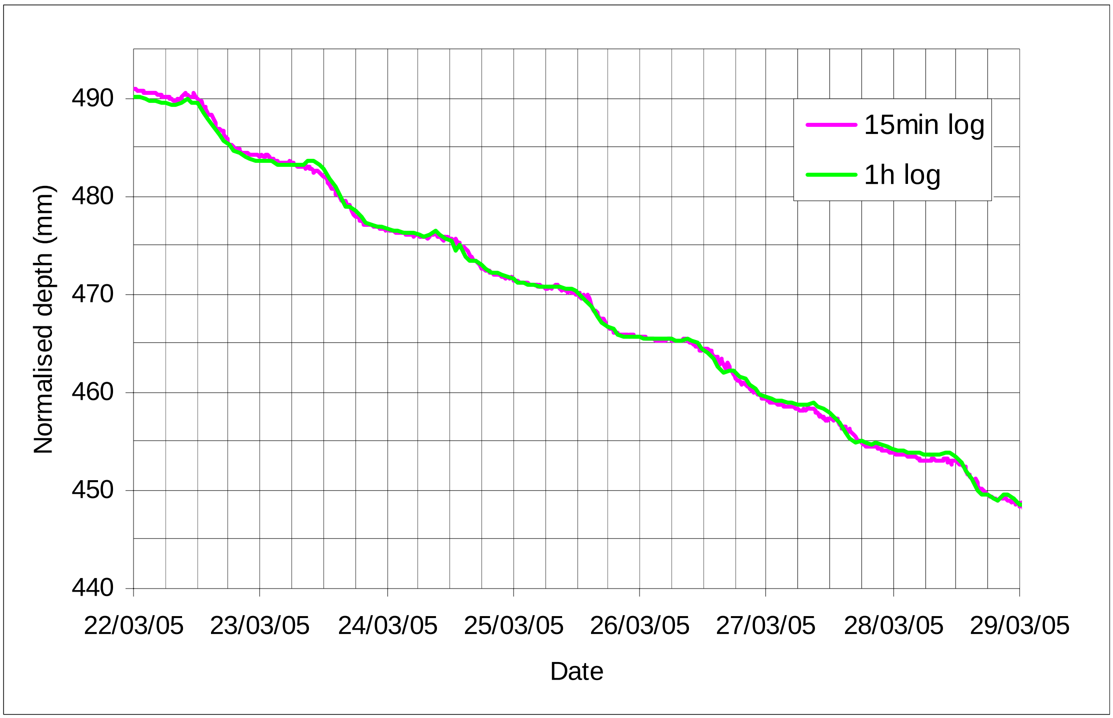


Figure A 3-7 Graph showing data collected at 15 minute intervals and at 1 hour intervals.

3.4.4 Cable length

The cable that connects the PST to the logger includes a power supply line (taking power to the PST unit), a signal line (returning a signal back to the logger) and an air feed line which provides atmospheric pressure to the PST for internal calibration. The shorter the cable the less chance of voltage fluctuation and cable noise. However, short cables limit the distance of the PST can be placed in a storage dam from the data logger position.

Various tests were undertaken to assess length of cable (Figure A 3-8 and Figure A 3-9), limiting either the length of the signal line (Figure A 3-10), power supply (Figure A 3-11) or air feed line (Figure A 3-12) and providing a voltage regulator (Figure A 3-13).

In Figure A 3-8 the 20m cable shows an increase in water depth overnight which is not shown in the 10m cable. The 10m cable provides a more accurate representation of water level change but limits placement of the PST. This graph also shows that the total losses when taken from midnight to midnight were the same for both PST traces which indicates no problem in measuring aggregate water depth change.

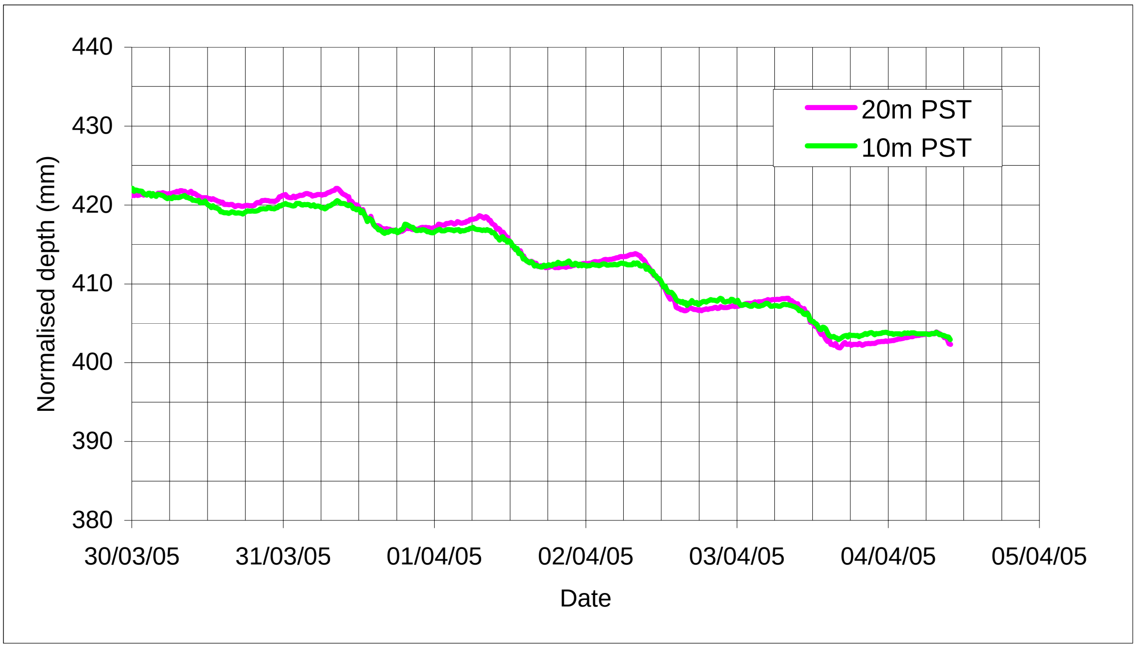


Figure A 3-8 Graph showing the variation between a 20m cable and a 10m cable logging at 15 minute intervals.

To test the limit of the length of cable that may be used, a PST and logger unit was set up using an 80m cable (Figure A 3-9).

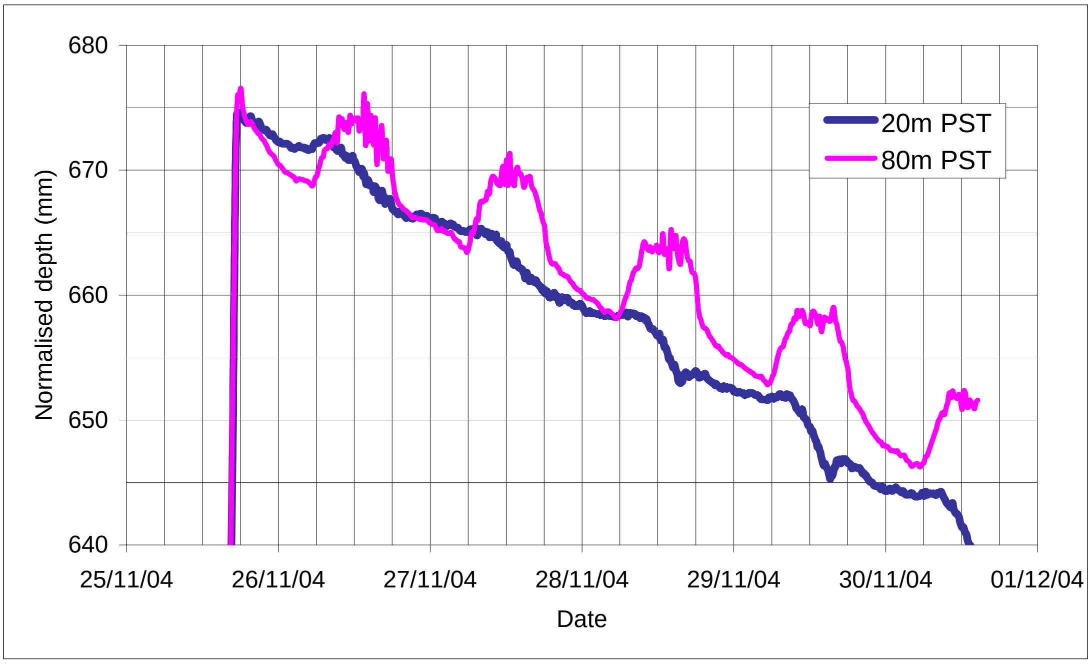


Figure A 3-9 Graph showing the variation between a 20m cable and a 80m cable logging at 15 minute intervals.

The 80m cable showed significant noise during the daytime periods. The total losses between the two cables don't match one another due to an average offset and gain being used to calibrate the two loggers. If a correct offset and gain are developed for an 80m cable then it is likely that the total losses in the 80m cable would be the same as the 20m cable.

The cable consists of three components (power line, signal line and air feed line) which affect the quality of data received at the logger. In order to assess the amount of noise that can be attributed to each component, one line was cut down to the default 20m whilst the other two lines remained at 80m.

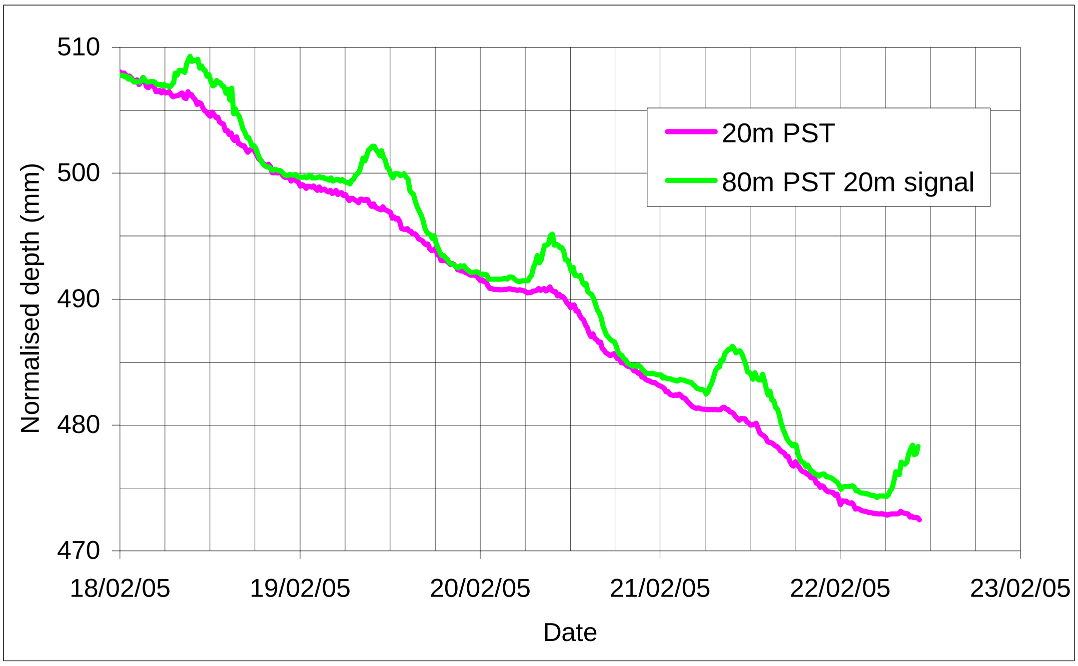


Figure A 3-10 Graph showing the variation between a 20m cable and a 80m cable with the signal cut down to only 20m logging at 15 minute intervals.

Figure A 3-10 illustrates results with the signal line shortened to 20m and the power and air lines left at 80m. The intensity and duration of the day time spikes in the 80m cable are significantly reduced by reducing the length of the signal line.

The next trial (Figure A 3-11) involved reducing the length of the power line from the battery to the PST to 20m and leaving the signal and the air lines at 80m in length. Cutting the power line showed a reduction in noise in the 80m cable. This also gave a result for the night time slope closer to that given by the 20m cable.

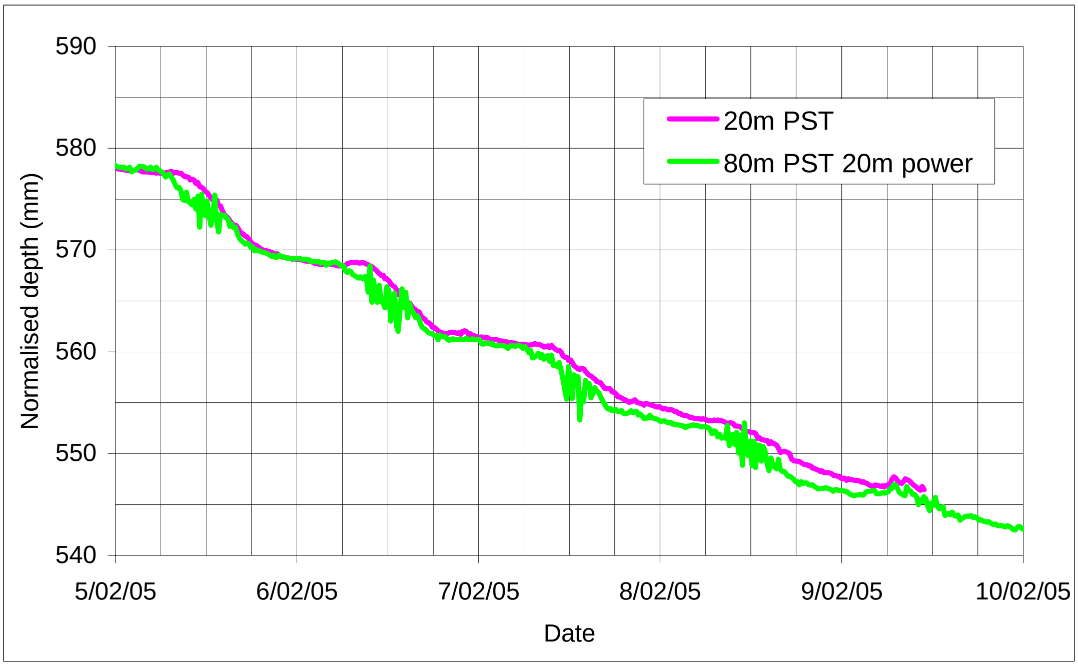


Figure A 3-11 Graph showing the variation between a 20m cable and a 80m cable with the power cut down to only 20m logging at 15 minute intervals.

Figure A 3-12 shows the default configuration of the PST and logger unit being compared to the 80m configuration with the air line cut to 20m. Again it can be seen that by cutting the air line to 20m the output form the 80m cable more closely reflects the 20m cable.

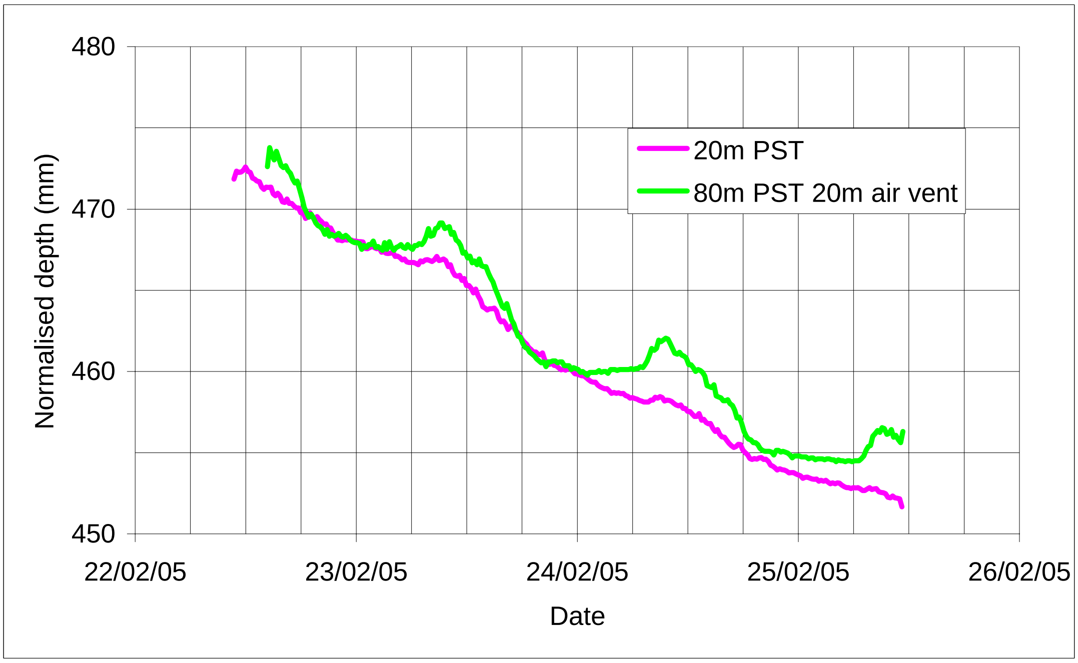


Figure A 3-12 Graph showing the variation between a 20m cable and a 80m cable with the power cut down to only 20m logging at 15 minute intervals.

The above three tests show the affect that the power, signal and air lines have on the noise associated with using an 80m cable. Cutting the air and signal lines down to only 20m reduces some of the noise, however by cutting the power line down to 20m, a result similar to using a 20m length of cable is achieved.

As the DL/PST setup is powered by a solar panel there are voltage fluctuations that may influence the data. A test to check if this was the case was undertaken by installing a 10V regulator into the DL setup. Figure illustrates that there is very little variation between the trace form the unit using the 10V regulator and the unit without.

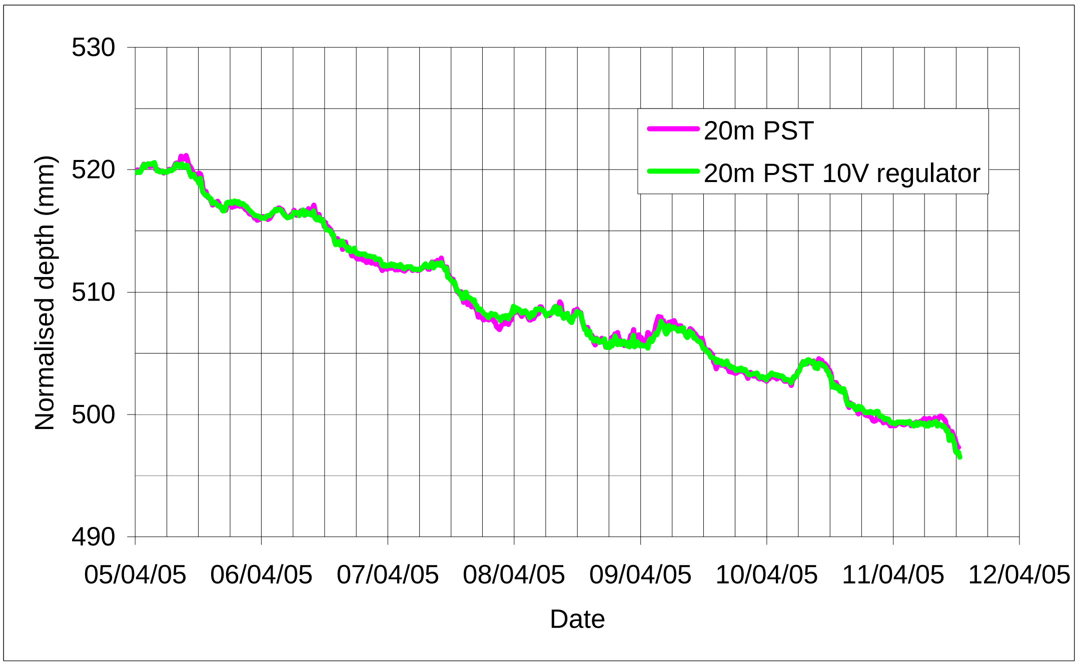


Figure A 3-13 Graph showing the variation between a PST unit configured normally and a unit with a 10V regulator installed.

3.4.5 Inflows/outflows to storage

Water flow into or out of storage will affect the determination of evaporation and seepage. Inflow could be due to rainfall, runoff or water being pumped into storage. Outflow could be due to pumped or gravity releases. The best method for dealing with periods of in/out flow was to exclude this data from analysis.

To do a full water balance incorporating water in/outflow would require intensive flow monitoring with very accurate and expensive flow meters deemed too expensive and unnecessary for this project. The flow meter would be required to log the date, time and volume of water flowing out every 15 minutes. Also required would be an accurate depth storage relationship (digital terrain model (DTM) to give the storage profile and relationship of change in volume to a corresponding change in depth at a given reference level.

In general sudden changes in slope evident in the PST trace are indicators of in/outflows. Knowing when rain occurred or a pump was switched on and allows identification of data sets which should not be analysed.

Figure A 3-14 illustrates periods of inflow to a storage on the PST trace. Both inflows were a result of rain and the first one was 3mm and the other one was 5mm. These periods are excluded from analysis to determine seepage and evaporation.

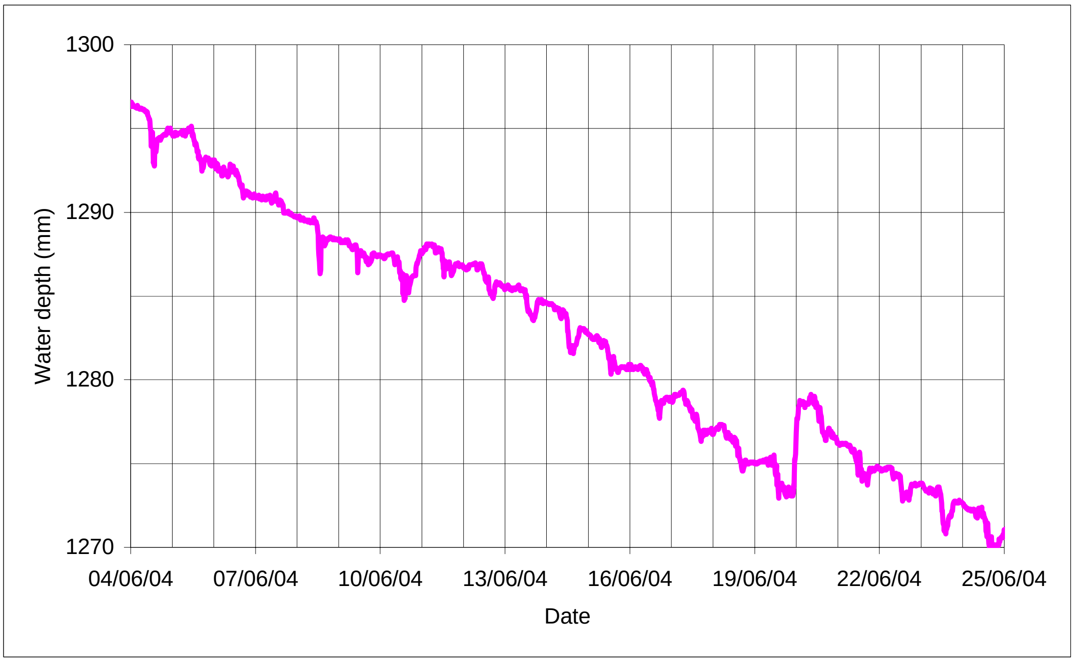


Figure A 3-14 PST trace showing two periods of rainfall over the three week period.

In/outflow affected data is usually easy to recognise as there is usually a sharp transition evident in the PST trace (total loss) when the pump is switched on and then off.

Low pump flow rates or periods of light rainfall can be difficult to identify in the PST trace. Automatic weather stations and good flow meters and pumping records can generally be used to isolate such periods.

3.5 Linear regression and by eye techniques to determine seepage

Recorded change in water depth for periods of no inflow/outflow or rainfall is a result of seepage and evaporation. In order to work out the evaporation component it was necessary to determine the seepage value.

Seepage is derived by selecting a data set which is free from pumping and rainfall and preferably during the winter or colder months of the year. A line of best fit is drawn through the minimum slope during the night time data set. The slope of this line is the rate of total water loss at night. The reason for using winter data is that it is assumed that the night time evaporation during winter is negligible and as such the losses are a result of seepage only. Once a value for seepage is defined, the evaporation losses are simply the total loss minus the seepage. This calculation is best performed over periods of a number of days to reduce errors from using only single days of data.

Difficulty arises in deriving a suitable method for accurately determining the slope or seepage rate of the pressure sensitive transducer (PST) trace at night.

Various methods were assessed analyse the PST data and included computed linear regression to determine slope and interpretation by eye. Based on the analyses undertaken the manual method of interpreting slope by eye was used to determine seepage. This method proved to be repeatable and easy to use while rigorous statistical methods were influenced by the selected start and end time and outliers in the data. Eye fitting methods also allow the experience of the user at the site to be brought into calculations particularly in identifying data problems.

The following sections illustrate various approaches for a selected set of data (21 Aug – 29 Aug 2004). The analysis method needed to be repeatable, accurate and statistically sound. Repeatability means that everybody would repeatedly come up with the same result. Historical data and theoretical prediction can be used to check the accuracy of the analysis method. The accuracy is improved by removing outliers. Using linear regression analysis slope was determined for a range of start and end times;

1. 10:00pm to 4:00am
2. 12:00am to 4:00am
3. 10:00pm to 2:00am
4. Varied based on shape of PST trace.

Linear regression 10:00pm to 4:00am

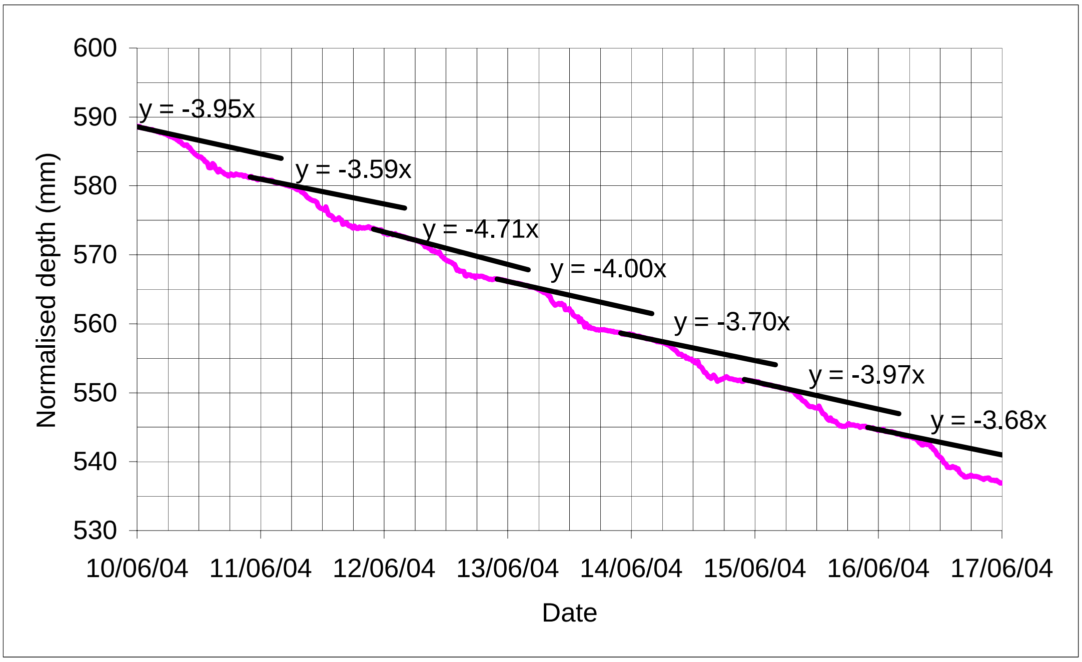


Figure A 3-15 PST graph shows the daily seepage rates or night time slopes obtained using linear regression between 10:00pm and 4:00am.

Linear regression analysis was undertaken to accurately define the slope of the data set during the night time period. The first analysis was performed by fitting a line through all points between 10:00pm and 4:00am. It was assumed that the evaporation rate at this time of night would be negligible. The slope of the regression line equates to the seepage rate for that day. From Figure A 3-15 the daily slopes range from 3.59mm/day to 4.71mm/day and with an average daily seepage rate of 3.94mm/day. When this is subtracted from the total loss, the average daily evaporation is 3.49mm/day.

Linear regression 12:00am to 4:00am

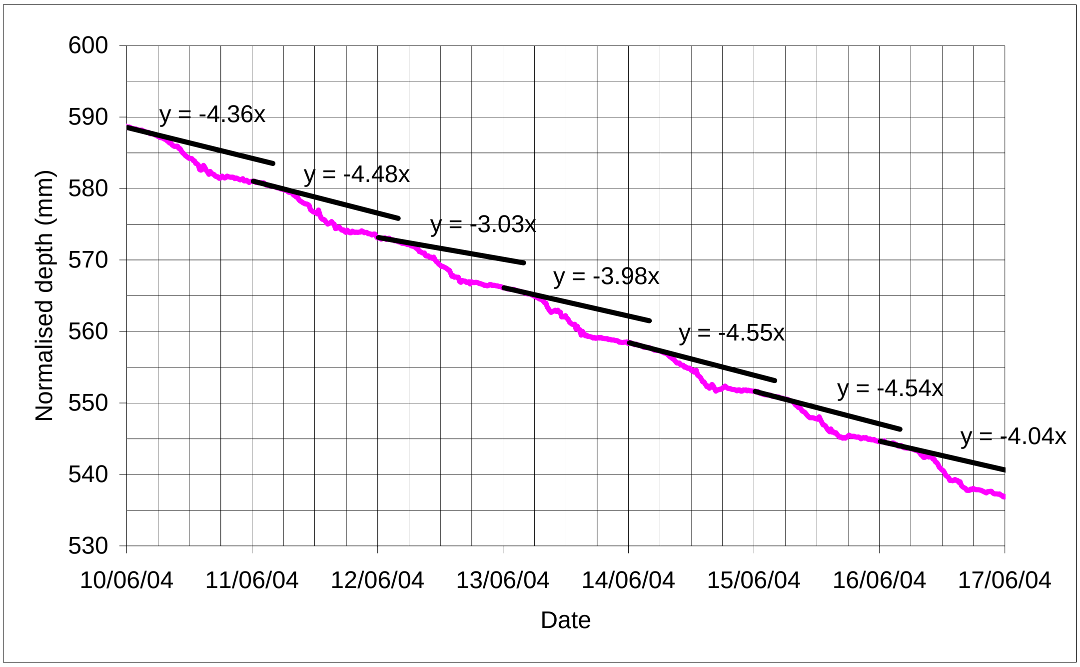


Figure A 3-16 PST graph shows the daily seepage rates or night time slopes obtained using linear regression between 12:00am and 4:00am.

The second analysis was performed by fitting a line through all points between 12:00am and 4:00am. From Figure A 3-16 it can be seen that the daily slopes range between 3.03mm/day and 4.55mm/day. It is unlikely that seepage would change by 1.52mm/day over the period of a few days with no major pumping to change water level in the storage. The average seepage rate for the data set was 4.14mm/day.

When the seepage rate is subtracted from the total loss, the average evaporation estimate for this period is 3.22 mm/day.

Linear regression 10:00pm to 2:00am

The third regression analysis undertaken was similar to that above. The same data set was used but the analysis period was shifted to between 10:00pm and 2:00am. Again based on the assumption that the evaporation would be negligible at this time of night, the linear regression was undertaken to determine if there were significant variations on the seepage estimate based on the period of time assessed.

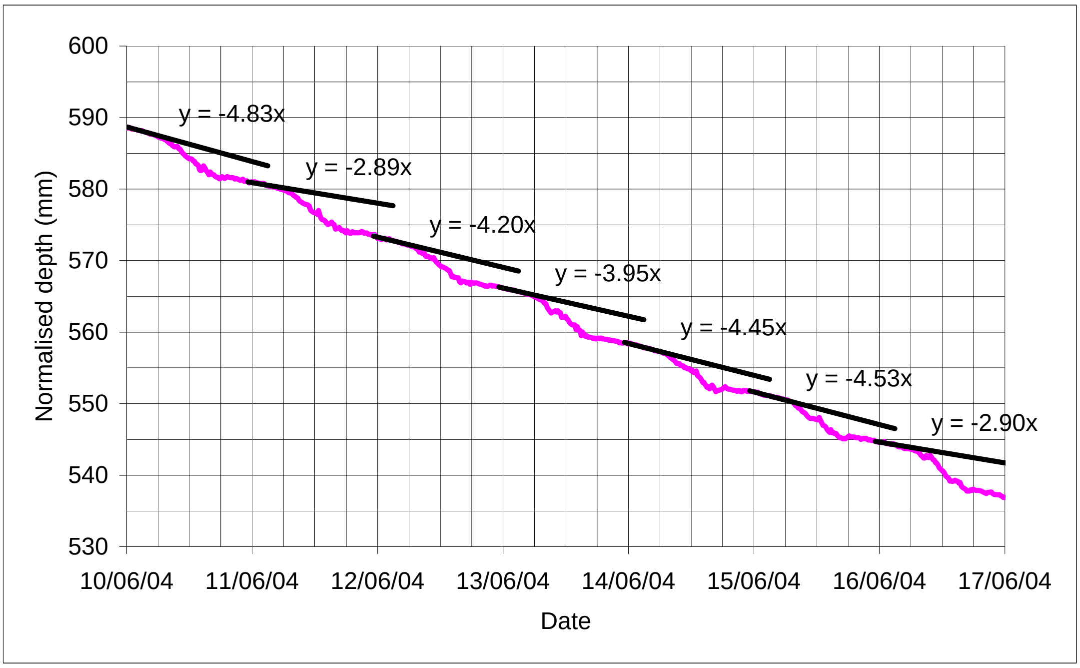


Figure A 3-17 PST graph shows the daily seepage rates or night time slopes obtained using linear regression between 10:00pm and 2:00am.

The slopes of the 10:00pm to 2:00am regression line ranged from 2.89mm/day to 4.83mm/day. When the average daily seepage of 3.96mm/day is subtracted from the total loss the evaporation rate is 3.46mm/day.

Linear regression with eye interpretation of start/finish times

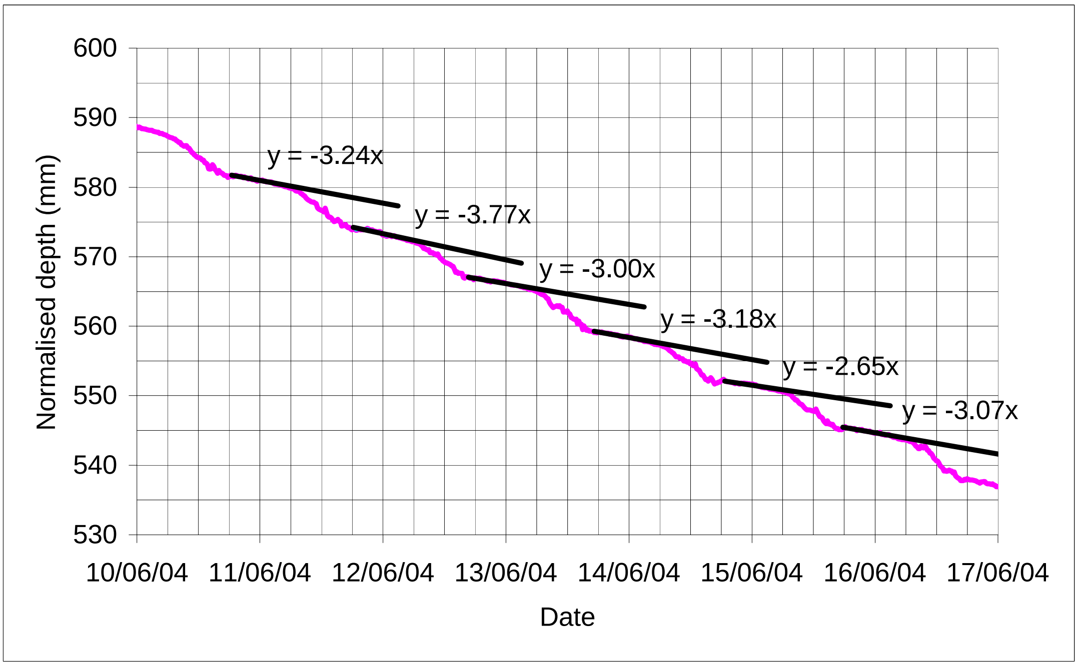


Figure A 3-18 PST graph shows the daily seepage rates or night time slopes obtained using linear regression when the period of just seepage is selected by eye.

The final linear regression introduced an element of user judgment. Instead of using data between two specific points, the user defined the boundaries of the linear regression based on the knowledge that the period of minimum slope was the time for calculating seepage.

Figure A 3-18 shows the linear regressions performed when the user defines the period of data used for the analysis.

The range of seepage estimates achieved by using the user defined boundaries for the linear regressions (2.65mm/day to 3.77mm/day) is smaller than when using the other three methods. When the average seepage estimate found in this method (3.15mm/day) is subtracted from the total loss during the period, the average daily evaporation rate is 4.28mm/day.

Determination of slope by eye on paper
The method of determining seepage by fitting a line through the night time slope based purely on the users estimate and knowledge of the site. There was no computer to analyse the line using linear regression, it was all by eye.

Figure A 3-19 is a graph of the PST trace was printed out on paper and from here a ruler was used to draw a line through the night time period of minimum slope. Previous history of the storage was taken into account and any outliers were removed from the analysis. The most likely cause of outliers is cable noise and wind.

The results for three users independent assessment are given below.

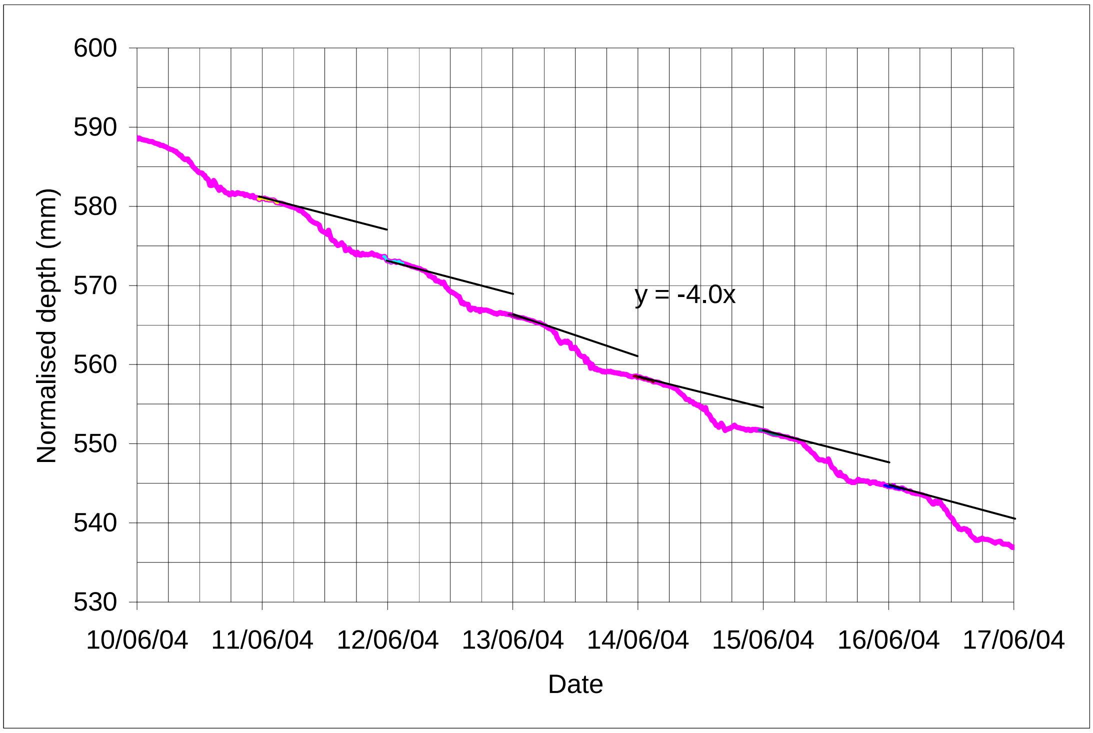


Figure A 3-19 PST graph shows the daily seepage rates or night time slopes obtained using a bye eye method onto paper.

From Table A 3-1 it can be seen that even though linear regression analysis with set boundaries for night time slope have not been set, the by eye method is highly repeatable. It should also be mentioned that the by eye method is by far faster than generating a seepage estimate based on computer analysis. It is also easier to drop any seepage rates that are outliers.

Table A 3-1 The results from these three different users analysing the same data set.

	Average seepage (mm/day)	Average evaporation (mm/day)
User 1	4.0	3.4
User 2	4.0	3.4
User 3	4.0	3.4

A summary of the different methods to determine seepage are shown in Table A 3-2. With good data set it does not matter which method is used to calculate the seepage and evaporation rates. But if the data set had some cable noise or wind effected data in it then the analysis method may change the seepage and evaporation rates.

A second illustration is given using inferior quality data.

Table A 3-2 Summary of the different methods used to determine evaporation.

Method	Seepage		Evaporation
	Range	Average	
Linear regression – 10:00am to 4:00am	1.12mm/day	3.94mm/day	3.49mm/day
Linear regression – 12:00am to 4:00am	1.52mm/day	4.14mm/day	3.29mm/day
Linear regression – 10:00pm to 2:00am	1.94mm/day	3.96mm/day	3.46mm/day
Linear regression – By eye	1.12mm/day	3.15mm/day	4.28mm/day
By eye – user 1	1.5mm/day	4.0mm/day	3.4mm/day
By eye – user 2	1.5mm/day	4.0mm/day	3.4mm/day
By eye – user 3	1.0mm/day	4.0mm/day	3.4mm/day

Linear regression 10:00pm to 4:00am

The data set selected has a small amount of cable noise in the PST trace. From Figure A 3-20 the range of daily seepage rates varied from 0.10mm/day to 2.32mm/day. It is unlikely that seepage rate in a single storage will vary by 2.22mm/day over a week without significant changes to the water level. This data set has an average daily seepage rate of 1.36mm/day and an evaporation rate of 1.14mm/day.

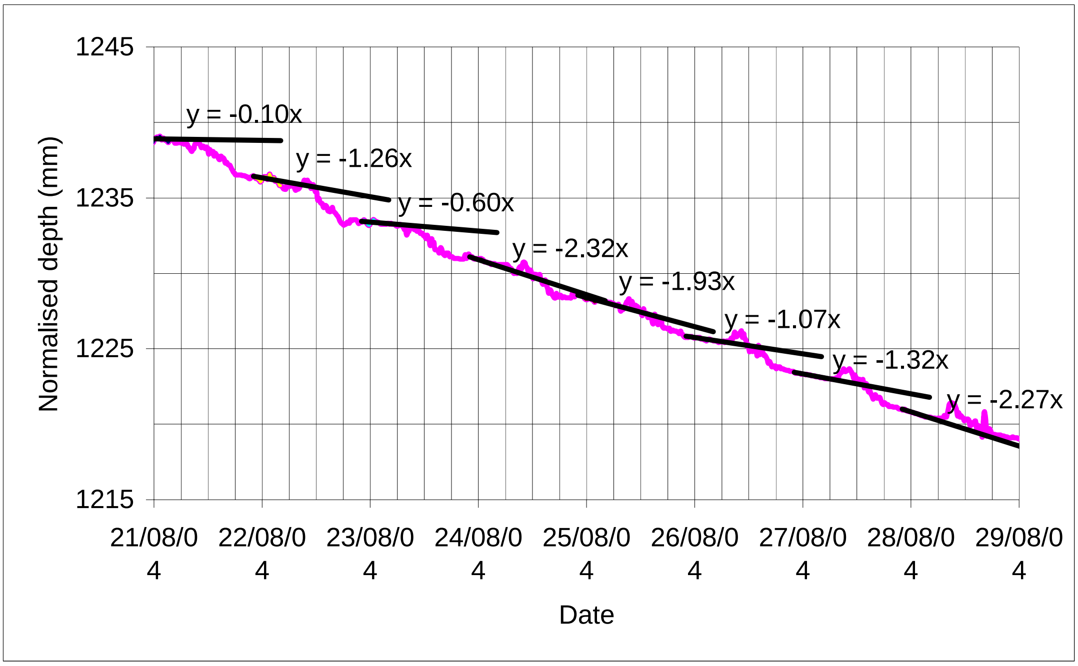


Figure A 3-20 PST graph shows the daily seepage rates or night time slopes obtained using linear regression between 10:00pm and 4:00am.

Linear regression 12:00am to 4:00am

Using the same data set from above but this time doing a linear regression between 12:00am and 4:00am resulted in similar variation in daily seepage rates from 0.87mm/day to 3.19mm/day (Figure A 3-21). It is unlikely that seepage rate in a single storage will vary by just over 2 mm/day over a week without significant changes to the water level.

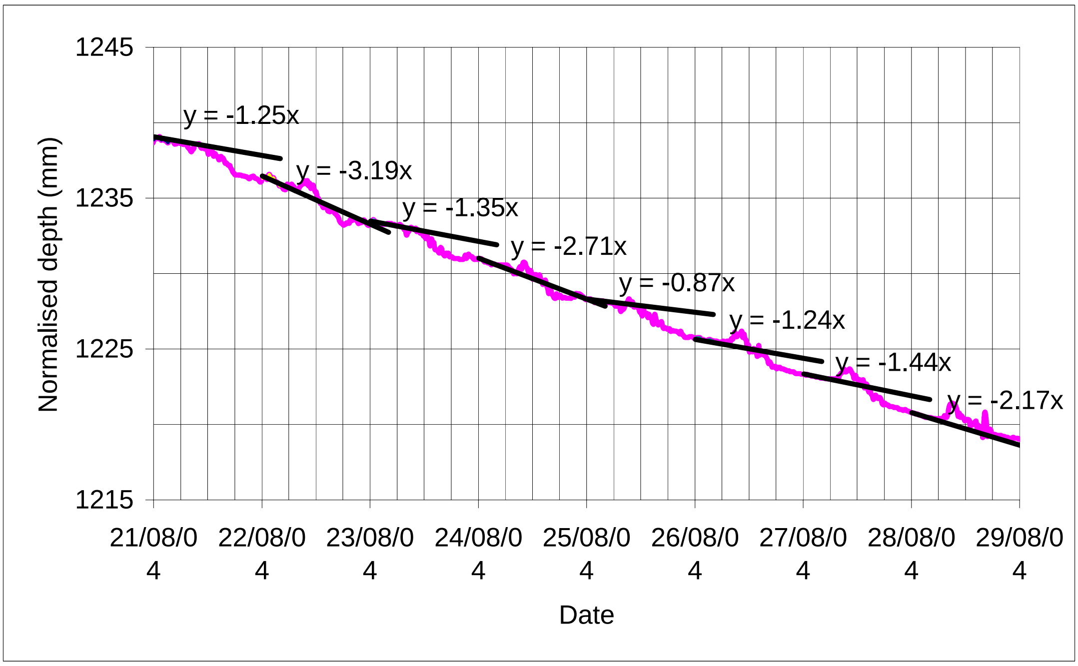


Figure A 3-21 PST graph showing daytime and night time slopes and therefore the assumed seepage from this data set using a linear regression from 12:00am to 4:00am.

The evaporation loss based on the average daily seepage rate (1.78mm/day) from the data set is 0.72mm/day.

Linear regression 10:00pm to 2:00am

Figure A 3-22 shows the same data set as in with regression analysis performed between 10:00pm and 2:00am each evening. The range of slopes for this analysis is even greater than in the 12:00am to 4:00am analysis. The first two days of the analysis period have yielded positive slopes for seepage estimation. This illustrates errors when using a poor quality data and a short analysis period. The positive slopes were included when calculating the average seepage slope. The calculated evaporation based on an average seepage estimation of 1.67mm/day is 0.83mm/day.

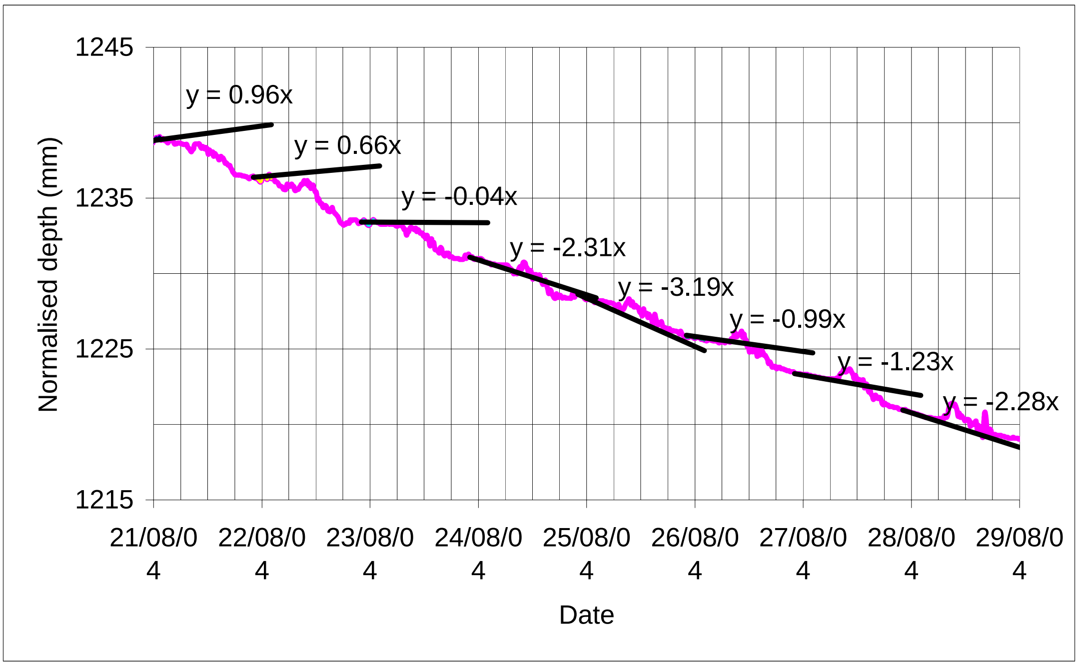


Figure A 3-22 PST graph showing daytime and night time slopes and therefore the assumed seepage from this data set using a linear regression from 10:00pm to 2:00am.

Linear regression with eye interpretation of start/finish times

The by eye estimate of the seepage only periods has given all negative slopes as would be expected and a variation between days of only 0.71mm/day (Figure A 3-23). This method yields reasonably consistent seepage estimates, however does not allow for any historical knowledge of the site by a human user. The daily evaporation based on an average seepage estimate of 1.37mm/day is 1.13mm/day.

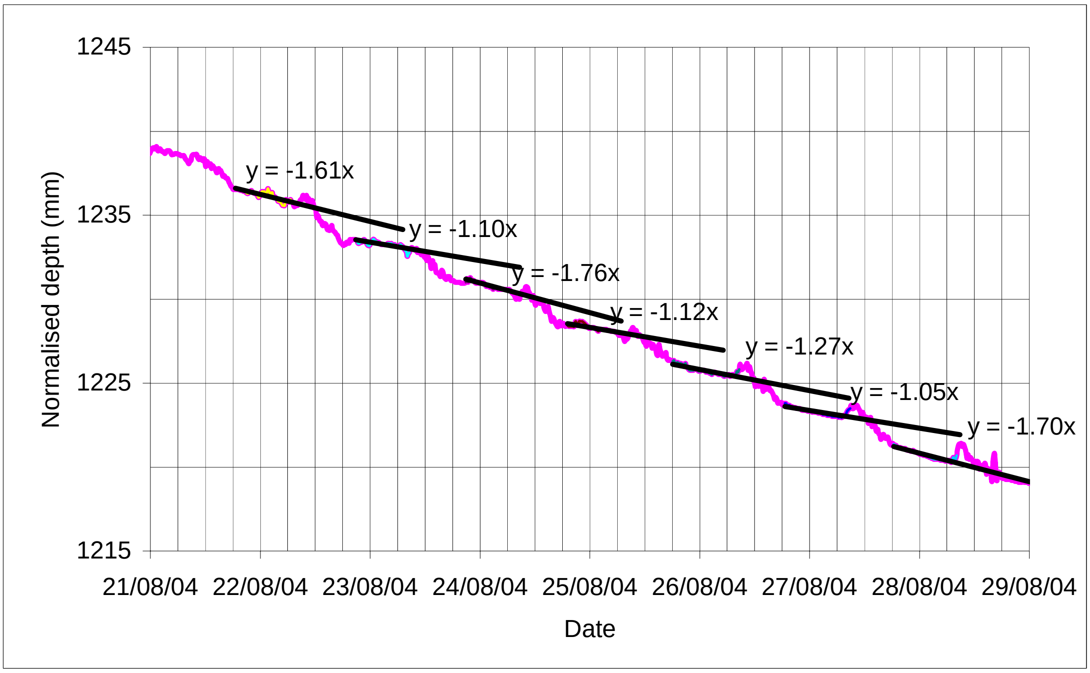


Figure A 3-23 PST graph showing day time and night time slopes and therefore the assumed seepage from this data set using by eye method to select an appropriate period for the linear regression analysis.

Determination of slope by eye on paper

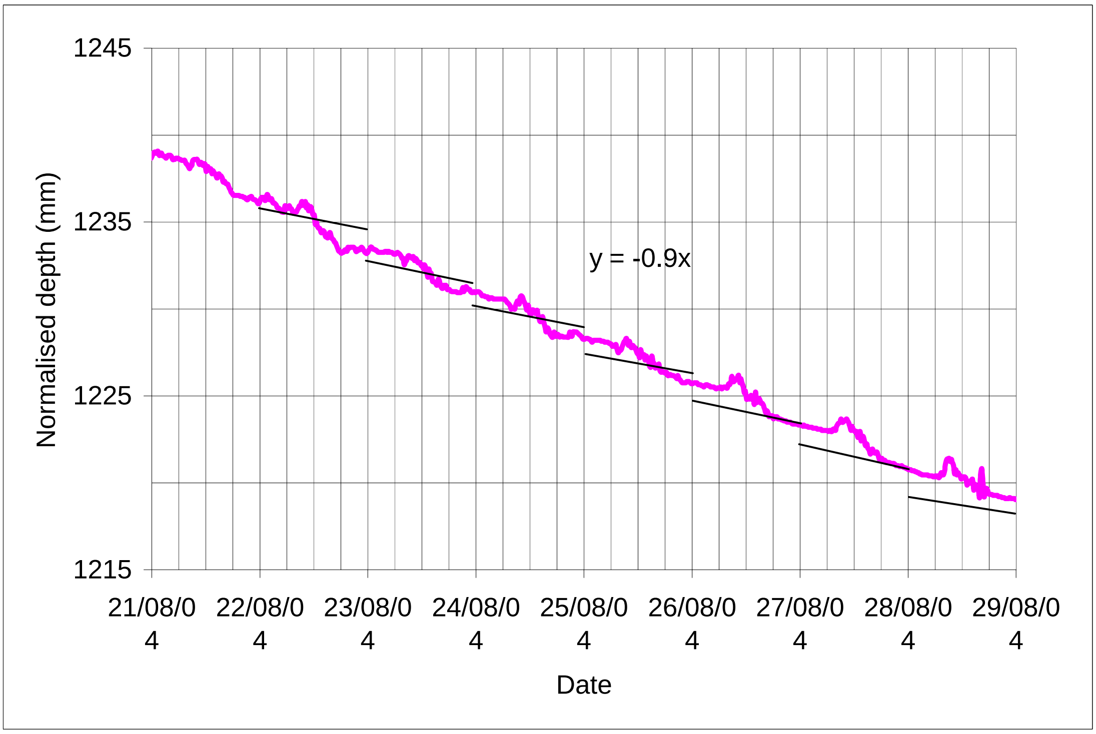


Figure A 3-24 PST graph showing day time and night time slopes and therefore the assumed seepage from this data set using by eye method onto paper

Figure A 3-24 is a graph of the PST trace was printed out on paper and from here a ruler was used to draw a line through the night time period of minimum slope. Previous history of the storage was taken into account and any outliers were removed from the analysis. The most likely cause of outliers is cable noise and wind.

When the seepage estimates for this data set were calculated by eye without the use of computer analysis for linear regression, again very repeatable results were attained.

Table A 3-3 The results from the three different users analysing the same data set.

	Average seepage (mm/day)	Average evaporation (mm/day)
User 1	0.9	1.6
User 2	0.9	1.6
User 3	1.0	1.5

From Table A 3-4 it can be seen that the linear regression method with set boundaries has a large range of slopes. But the by eye method was repeatable by the three users and had a low range. It is also easier to drop any seepage rates out that are outliers.

Table A 3-4 Summary of the different methods used to determine evaporation.

Method	Seepage		Evaporation
	Range	Average	
Linear regression – 10:00am to 4:00am	2.22mm/day	1.36mm/day	1.14mm/day
Linear regression – 12:00am to 4:00am	2.32mm/day	1.78mm/day	0.72mm/day
Linear regression – 10:00pm to 2:00am	3.15mm/day	1.67mm/day	0.83mm/day
Linear regression – By eye	0.71mm/day	1.37mm/day	1.13mm/day
By eye – user 1	0.6mm/day	0.9mm/day	1.6mm/day
By eye – user 2	0.8mm/day	0.9mm/day	1.6mm/day
By eye – user 3	0.7mm/day	1.0mm/day	1.5mm/day

Conclusions

Based on the analyses undertaken the manual method of interpreting slope by eye was used to determine seepage. This method proved to be repeatable and easy to use while rigorous statistical methods were influenced by the selected start and end time and outliers in the data. Eye fitting methods also allow the experience of the user at the site to be brought into calculations particularly in identifying data problems.

Seepage needs to be determined over a number of days and cannot be realistically used on a single 24h period. The more data used the more accurate the results for seepage and evaporation rates.

APPENDIX 4

EVAPORATION MITIGATION ASSESSMENT

4 EVAPORATION MITIGATION ASSESSMENT

This Appendix provides selected example datasets for each product and site (Table A 4-1). Examples were chosen to;

- illustrate EMT evaporation performance for selected periods of analysis at each site,
- illustrate the approach used to determine evaporation loss, or
- highlight typical features in the datasets.

Table A 4-1 Summary of periods analysed for the evaporation mitigation results.

EMT	Site		Start	Finish	Saving	Avg for EMT
Monolayer	Capella	1	3-Sep-2004	11-Sep-2004	0%	0%
		2	15-Sep-2004	22-Sep-2004	0%	
		3	14-Feb-2005	20-Feb-2005	0%	
		4	2-Mar-2005	9-Mar-2005	0%	
	Dirranbandi	1	12-Oct-2004	16-Oct-2004	31%	19%
		2	29-Oct-2004	7-Nov-2004	27%	
		3	13-Nov-2004	20-Nov-2004	0%	
	USQ	1	20-Aug-2004	25-Aug-2004	38%	26%
		2	25-Aug-2004	30-Aug-2004	17%	
		3	26-Oct-2004	30-Oct-2004	10%	
		4	2-Mar-2005	8-Mar-2005	38%	
		5	2-Mar-2005	8-Mar-2005	40%	
E-vap Cap (burried edge)	St George	1	30-Apr-2004	4-May-2004	N/A	N/A
		2	19-May-2004	24-May-2004	N/A	
		3	17-Jul-2004	20-Jul-2004	N/A	
		4	23-Aug-2004	31-Aug-2004	N/A	
		5	24-Nov-2004	30-Nov-2004	N/A	
	USQ	1	30-Oct-2004	4-Nov-2004	94%	96%
		2	29-Dec-2004	3-Jan-2005	100%	
		3	7-Jan-2005	12-Jan-2005	95%	
E-vap Cap (open edge)	USQ	1	17-Apr-2004	22-Apr-2004	97%	91%
		2	12-May-2004	18-May-2004	83%	
		3	21-May-2004	26-May-2004	94%	
Shadecloth	Stanthorpe	1	28-Jul-2004	31-Jul-2004	50%	68%
		2	27-Oct-2004	31-Oct-2004	56%	
		3	14-Nov-2004	20-Nov-2004	80%	
		4	29-Nov-2004	3-Dec-2004	87%	
	USQ	1	26-Nov-2004	30-Nov-2004	71%	70%
		2	2-Dec-2004	8-Dec-2004	71%	
		3	7-Jan-2005	12-Jan-2005	69%	
Raftex	USQ	1	26-Nov-2004	30-Nov-2004	82%	87%
		2	1-Dec-2004	7-Dec-2004	85%	
		3	29-Jan-2005	1-Feb-2005	100%	
		4	16-Feb-2005	22-Feb-2005	80%	
PAM	USQ	1	22-Aug-2004	30-Aug-2004	43%	37%
		2	29-Jan-2005	1-Feb-2005	31%	

Figures take the form of a graph of water depth with time. The 'y axis' is water depth recorded in millimeters, whether it be measured with a PST or calculated with weather data using the Penman-Monteith Equation. The 'x axis' is the date, with the position of the date label indicating 00:00hrs midnight on the start of that day. Each day has been split into four equal periods of six hours (which may be referred to as six hour boxes). A night time period is therefore identified as the two boxes either side of a midnight line, and the corresponding day period, the other two boxes

4.1 Monolayer

4.1.1 USQ research facility

Figure A 4-1 shows the change in water level in the control and Water$avr tanks between 20 and 25 August 2004. The total loss from the control tank for the period of 20 August to 25 August was 29mm, averaging 5.8mm/day. The total loss from the monolayer tank was 18mm for a daily average of 3.6mm/day. Therefore the evaporation saving that can be attributed to the application of the monolayer is calculated to be 38%.

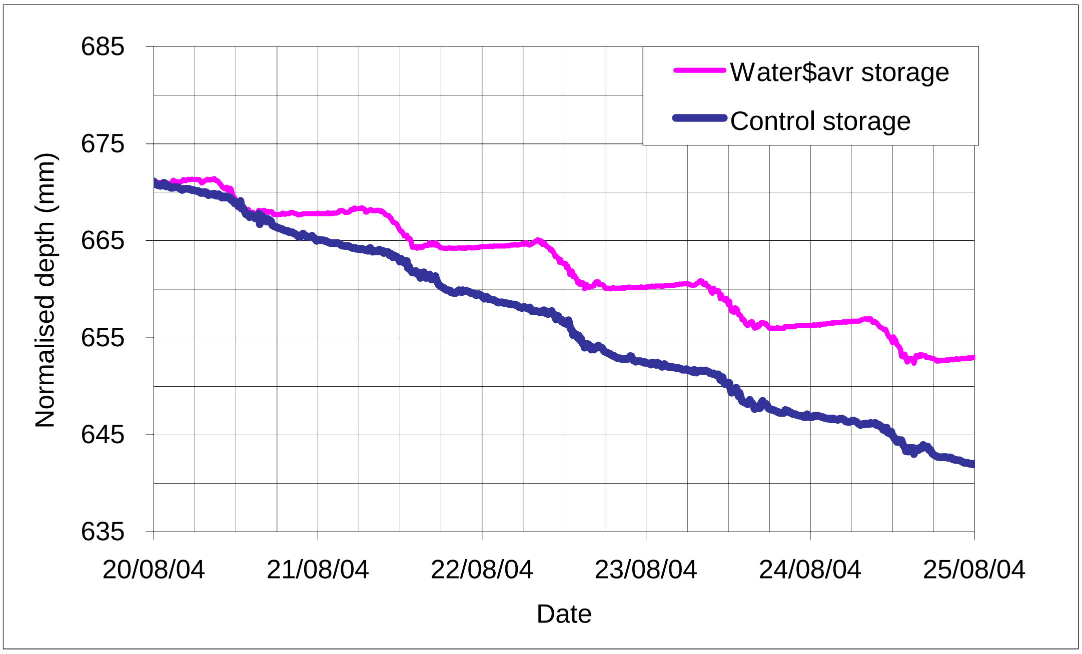


Figure A 4-1 Water depth in control tank and monolayer tank during August 2004.

The shape of the steps in the pressure sensitive transducer (PST) data, particularly the control tank, indicates some inconsistencies related to cable noise. Water level determined at night is however not affected. For storage tanks with no seepage, the analysis is not compromised. Determination of seepage rates on commercial storages using such data would not be possible.

Figure A 4-2 shows the total loss from the control tank for the period of 26 October to the 29 October was 25.5mm, averaging 8.5mm/day. The total loss from the monolayer tank was 23.0mm for a daily average of 7.7mm/day. This example illustrates that the evaporation saving attributable to the monolayer is 10%.

The amount of evaporation saving that the Water$avr can provide has been shown to be highly variable. Certain parameters including weather may have a major impact on the effectiveness of the produce. During windy conditions the product may not distribute evenly over the surface of the water and therefore can not perform to its potential. No evaporation saving was evident over the first few days of this trial. When assessed against the automatic weather station data, it was found that there were windy conditions, up to 36kph winds over this period.

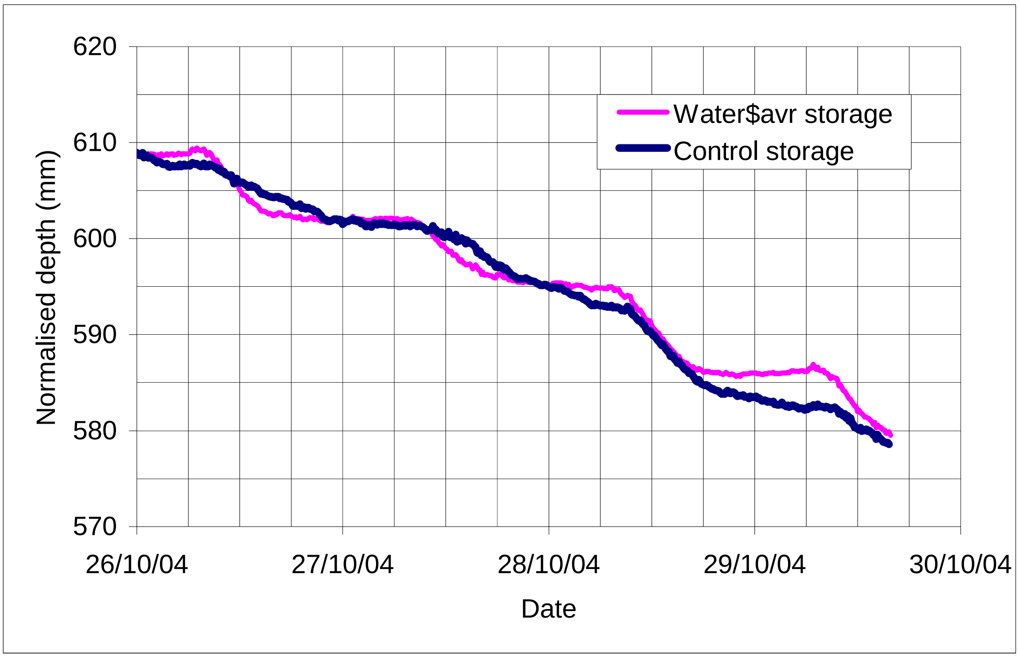


Figure A 4-2 Water depth in control tank and monolayer tank during October 2004.

4.1.2 Capella

Figure A 4-3 shows a comparison between the Water$avr and control storages at Capella during September 2004. There were seven days of pump free data for the monolayer storage, but only three were available for the control storage. Adjustments for seepage values of 3mm/day for the Water$avr storage and 1mm/day for the control storage have been made based on seepage rate assessments for the site.

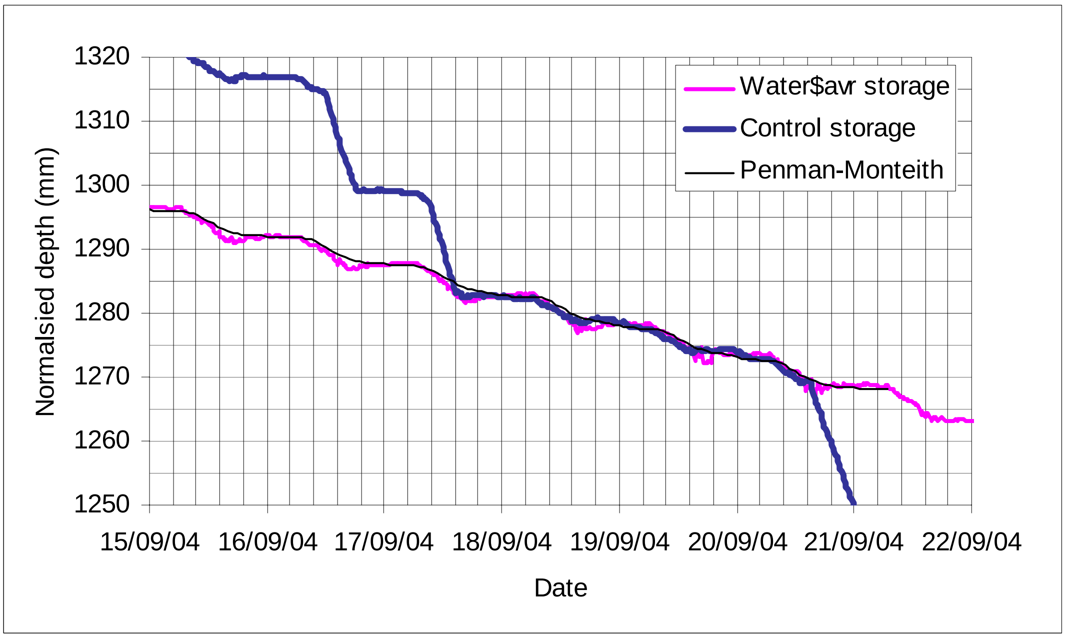


Figure A 4-3 PST outputs from the 15 to 22 September 2004 for the EMT and control storages at Capella. The EMT storage received monolayer three times during this period.

The Penman-Monteith evaporation calculation has been included for comparative purposes. There is close agreement between evaporation losses from the control dam and Penman Monteith with both data sets indicating a daily evaporation rate of approximately 5mm/day. The similarity between the data for the monolayer treated and control dams suggests little reduction in evaporation.

Figure A 4-4 provides trends for the period late September to early October 2004. High temperatures (over 30°C) resulted in daily evaporation values increasing to above 7mm/day. There is close agreement between measured water levels and Penman-Monteith model predictions of evaporation loss.

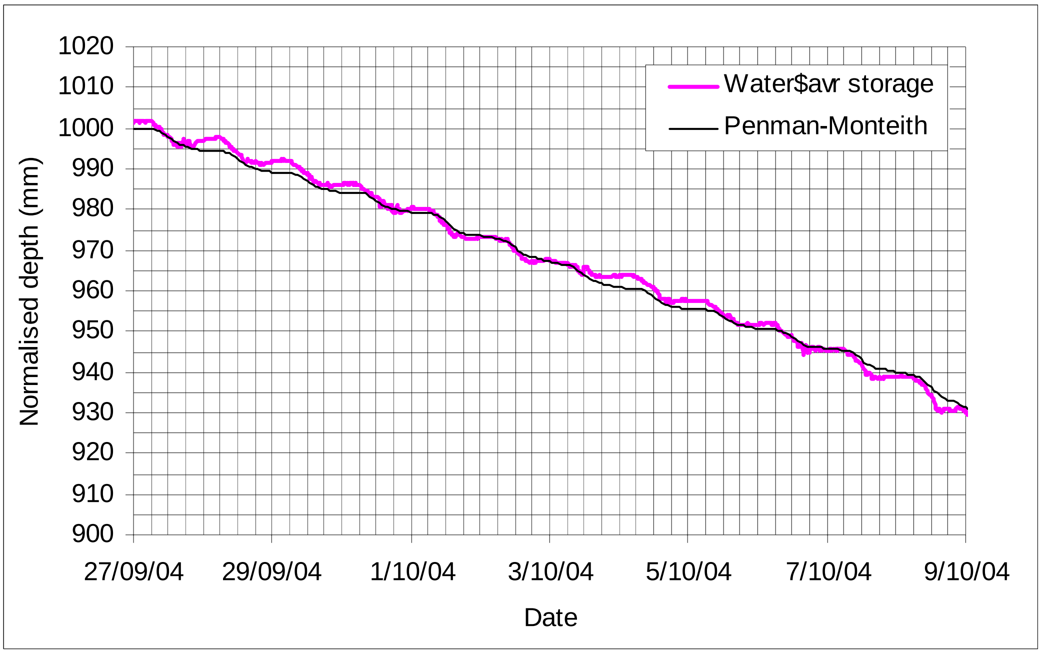


Figure A 4-4 PST output from the Water$avr storage at Capella from the 27 September to the 9 October 2004 and Penman-Monteith modeled evaporation.

The sigmoidal shapes of the two traces are very similar with close approximation of daily and night time water losses. Monolayer was applied on the 27 September and again on the 4 October 2004. The above graph demonstrates that the actual evaporation does not differ from the model even in the presence of Water$avr.

Figure A 4-5 shows the losses from the Water$avr and control storages. The seepage from each of the storages has been accounted for and the trace on the graph represents only the change in water level due to evaporation. Water$avr was applied on the 14, 16 and 18 of February 2005. From the graph is can be seen that the product has not had a significant effect on the water loss form the Water$avr storage.

Gaps in the open storage PST are a result of removing large spikes in the data. The spikes were a result of poor electrical connections between the sensor and the logger.

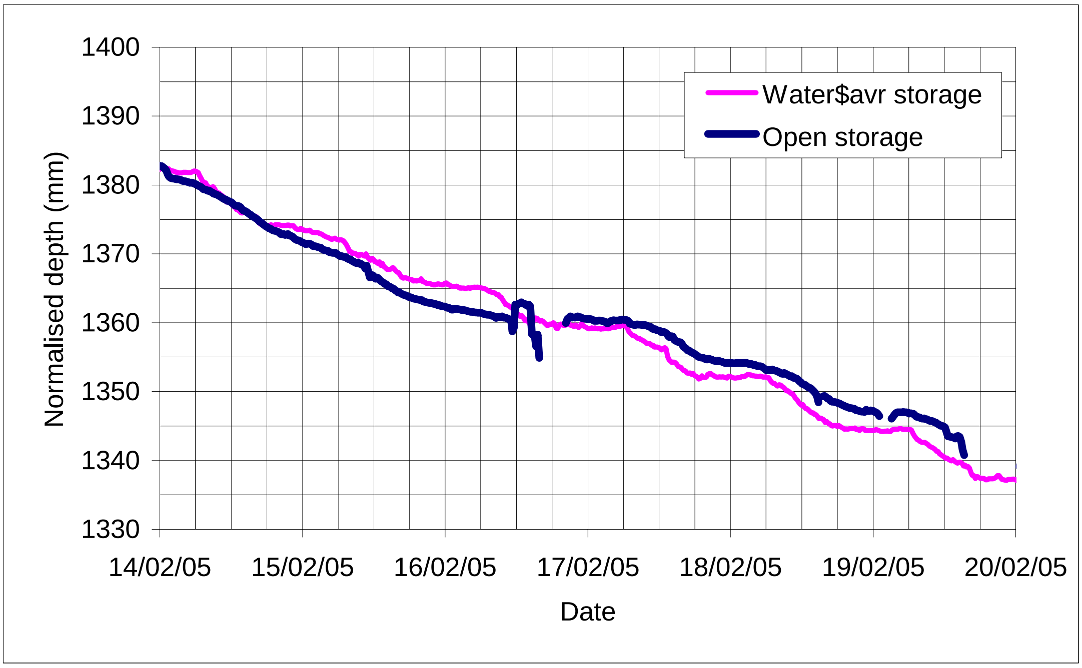


Figure A 4-5 Losses from the Water$avr storage and form the control storage at Capella during February 2005.

4.1.3 Dirranbandi

Figure A 4-6 shows the total losses from the storage at Dirranbandi during early August 2004. No monolayer was applied during this period. The Penman-Monteith modelled estimate of evaporation is superimposed on the graph indicating close agreement between the model and the measured water depth. Daytime anomalies in recorded PST data are evident.

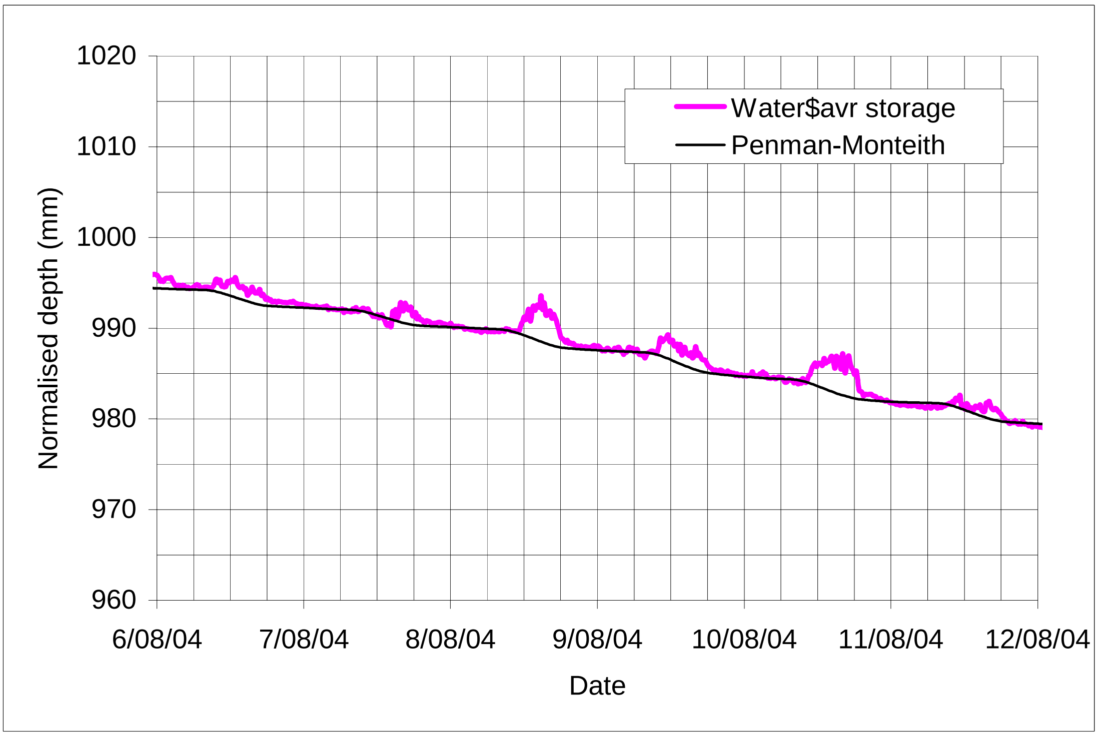


Figure A 4-6 Illustration of the agreement between model (Penman-Monteith) and the evaporation losses from the EMT storage when no monolayer has been applied.

Seepage losses at this site have been determined to be negligible (less than 1mm/day due to the accuracy of the instumentation). The close representation of losses indicates good agreement between the Penman-Monteith model and the measured PST traces.

Figure A 4-7 shows the change in water level in the Water$avr treated and control storage during November 2004. The PST trace for control storage has been adjusted to compensate for seepage through the storage floor and walls. The Penman-Monteith predicted evaporation for the same period is included.

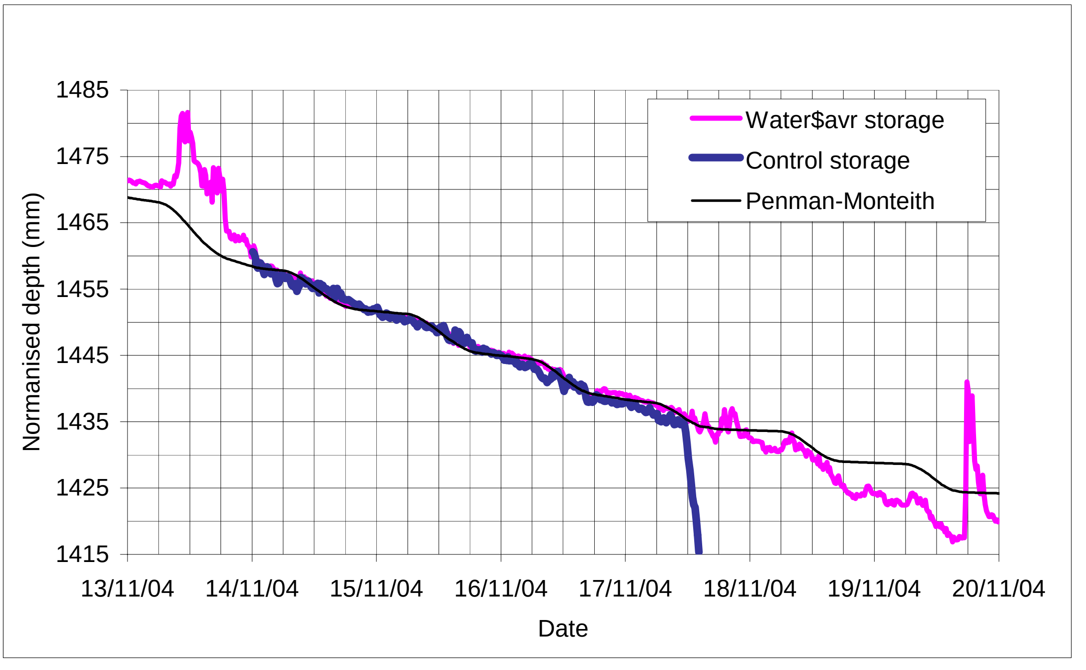


Figure A 4-7 Graph showing the losses from the EMT, and storage at Dirranbandi during mid November 2004.

The schedule for the application of Nylex's Water$avr monolayer product for the third trial was as follows:

13 November	30kg at 8:00am
14 November	60kg at 8:00am
16 November	60kg at 8:00am
18 November	60kg at 8:00am

Recorded data collected from Dirranbandi during this period was heavily influenced by pumping. Between the 14 and 17 November 2004 the evaporation from the EMT storage was the same as the evaporation from the control storage. Both of these PST traces agreed quite closely with the Penman-Monteith prediction of the evaporation during this period. The monolayer showed no saving of evaporation over this period of assessment.

Around the 13 and 19 of November the PST trace is shown to deviate from the Penman-Monteith predicted evaporation loss. This coincides with periods of high winds (in excess of 50kph) which would affect water displacement in the storage.

4.2 Floating cover

4.2.1 USQ research facility

Figure A 4-8 shows the result of the tethered E-VapCap mitigating evaporation from a storage tank. During the week of 12 to 18 May 2004 the total loss from the control tank was 9 mm with a daily average of 2.3mm/day.

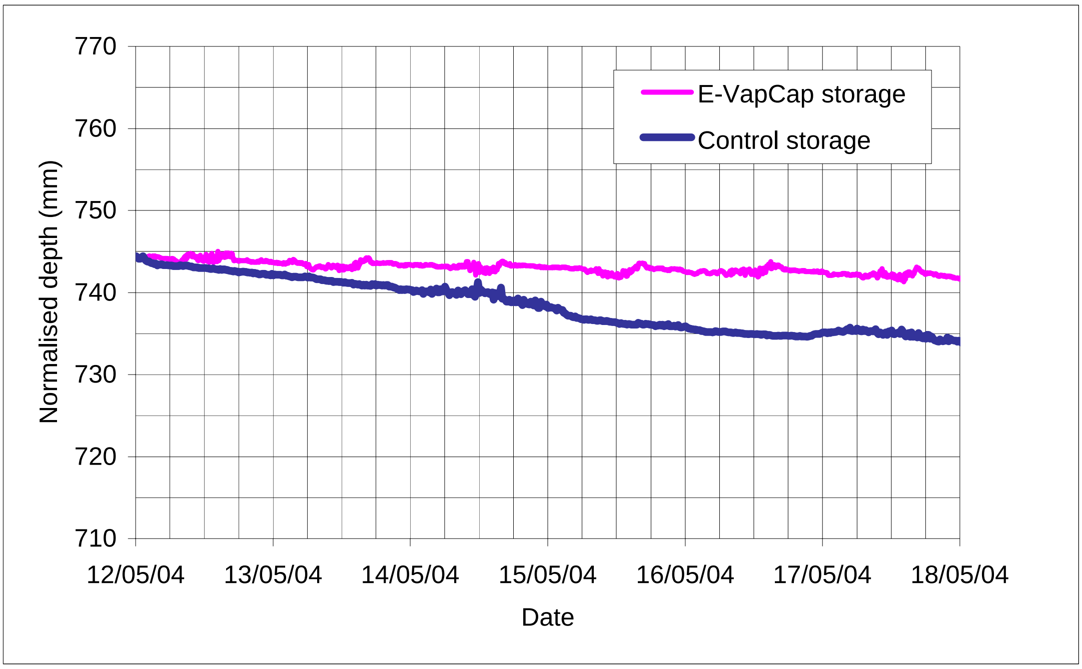


Figure A 4-8 Water depth in control tank and tethered (open edge) E-VapCap during May 2004.

Losses from the E-VapCap tethered (open edge) tank totalled 1.5mm. and a daily evaporation of 0.3mm/day. The trace indicates that there was a very slight increase in water depth on the 18 May 2004. This increase in water level is a result of incident rainfall which has been reported by the automatic weather station for the same day. By calculating the difference between the tanks as a percentage of the unmitigated loss from the control tank, the percentage of evaporation saved due to the effect of the E-VapCap is 83%.

Figure A 4-9 shows the losses from both the E-VapCap and the control tank. Again, as expected the control tank evaporates faster than the E-VapCap tank. The traces indicate that there was a slight increase in water depth on the 25 May 2004. This increase in water level is a result of incident rainfall which has been reported by the AWS for the same day.

As in the previous example this day was disregarded when analysing the evaporation losses from the tanks. Losses from the control tank from 21 to 25 May totalled 9mm and averaged 2.3mm/day. Losses from the E-VapCap tethered design (open edge) tank totalled 0.5mm. By calculating the difference between the tanks as a percentage of the unmitigated loss from the control tank, the percentage of evaporation saved due to the effect of the E-VapCap is 94%.

On occasion either incident rainfall or water from the tank sat on top of the cover. This may be an explanation to the increased losses from the EMT tank which occurred between the 12 May to the 18 May 2004 yielding 83% reduction as opposed to 94% the following week and 95% during April.

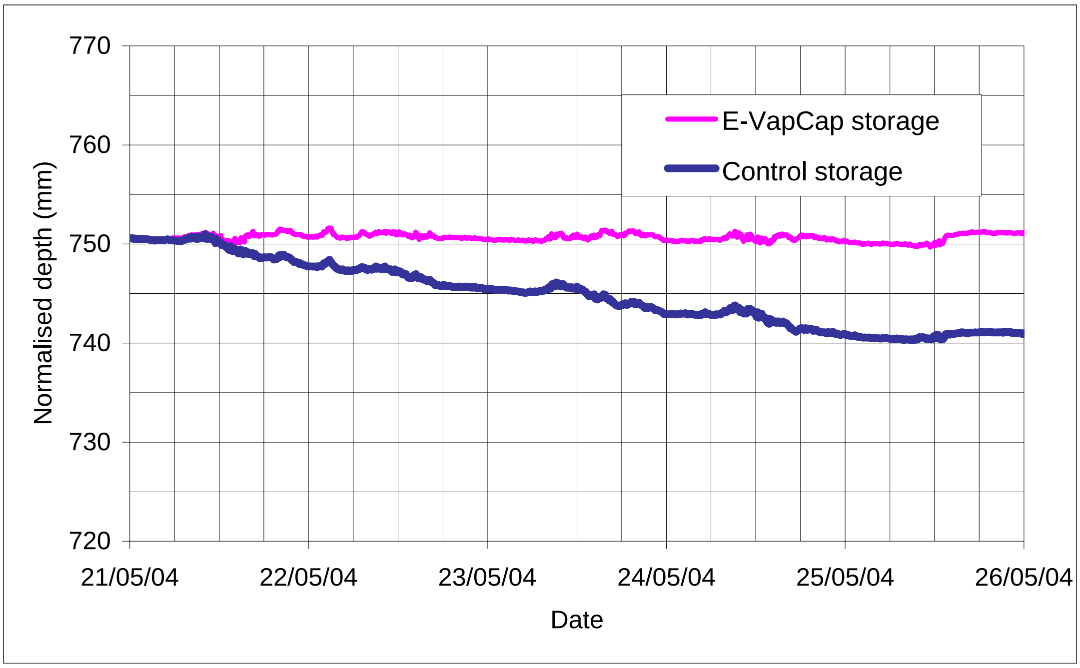


Figure A 4-9 Water depth in control tank and tethered (open edge) E-VapCap during May 2004.

Although this installation technique yielded evaporation savings on average of 91% it does not accurately reflect the actual in field installations of the product. The field installations at St George were installed by trenching or burial of the edge of the floating cover into the wall of the water storage.

Figure A 4-10 indicates results for a trial of the buried edge E-VapCap product at USQ. The recorded water level indicates that the control tank lost 28.5mm through evaporation through the week of 30 October to 4 November 2004, averaging 5.7mm/day. The buried edge E-VapCap tank lost 4.5mm during the week of which 2mm was lost in the first day of the trial. The calculated evaporation saved by the buried edge E-VapCap was 84%. Due to the method of installation and there being drainage holes in the product, when the EMT is fitted to the tank some water ends up on top of the cover. These shallow pools of water tend to evaporate within the first day or two. This is likely the reason for the faster evaporation rate on the first day of the trial. If the first day of the trial is excluded the evaporation saving for the buried edge E-VapCap during the above period increased to 91% and the average for the product increased to 94%.

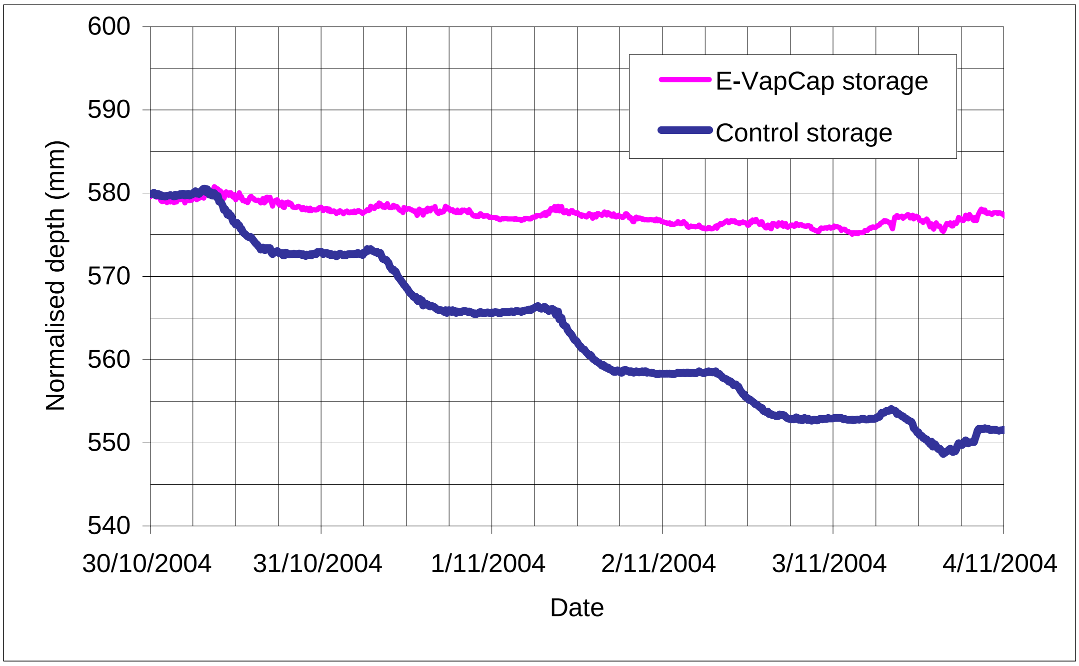


Figure A 4-10 Water depth in control tank and trenched (buried edge) E-VapCap during October and November 2004.

4.2.2 St George

Figure A 4-11 shows a typical PST trace from the E-VapCap storage at St George. There are numerous periods over these three days where large pumps were operating (Table A 4-2). It is unknown whether there were any small pumps operating as this was not always recorded by the landowners.

Table A 4-2 Operating times of large pumps in the EMT storage at St George for the 25th to 27th February 2004.

	Operating time	
Date	**Start**	**Finish**
25-Feb-04	9:00am	12:30pm
25-Feb-04	1:30pm	3:00pm
25-Feb-04	7:30pm	9:00pm
26-Feb-04	9:00am	12:00pm
26-Feb-04	12:30pm	3:30pm
26-Feb-04	7:00pm	9:00pm
27-Feb-04	8:00am	3:30pm

These pumping times in Table A 4-2 were typical of the data collected at St George and without a digital terrain model (DTM) of the storage it is impossible to get a figure for the seepage or evaporation rate for this storage. Owing to operational needs, little data unaffected by pumping was available.

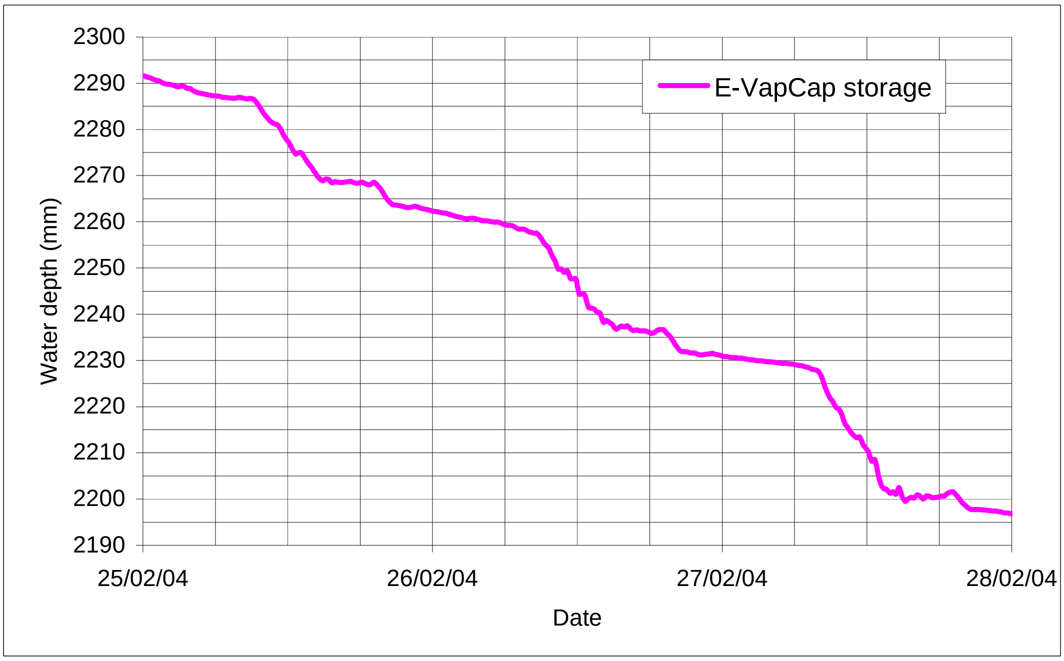


Figure A 4-11 Typical PST trace from the covered storage at St George indicating periods of pumping activity. Three periods of approximately six hours in duration indicate a drop in water level in excess of 20 mm.

Figure A 4-12 shows a graph of the PST data from the control storage with 1.5mm/day of seepage removed. The evaporation rate averaged 6.2mm/day in late November 2004. The graph illustrates the agreement between the Penman-Monteith model and measured water level data. As evaporation rates increase and become large relative to any error sources and noise it is easier to determine the evaporation rate from the storage. The corresponding PST data for this period from the E-VapCap storage was unavailable due to pumping activity.

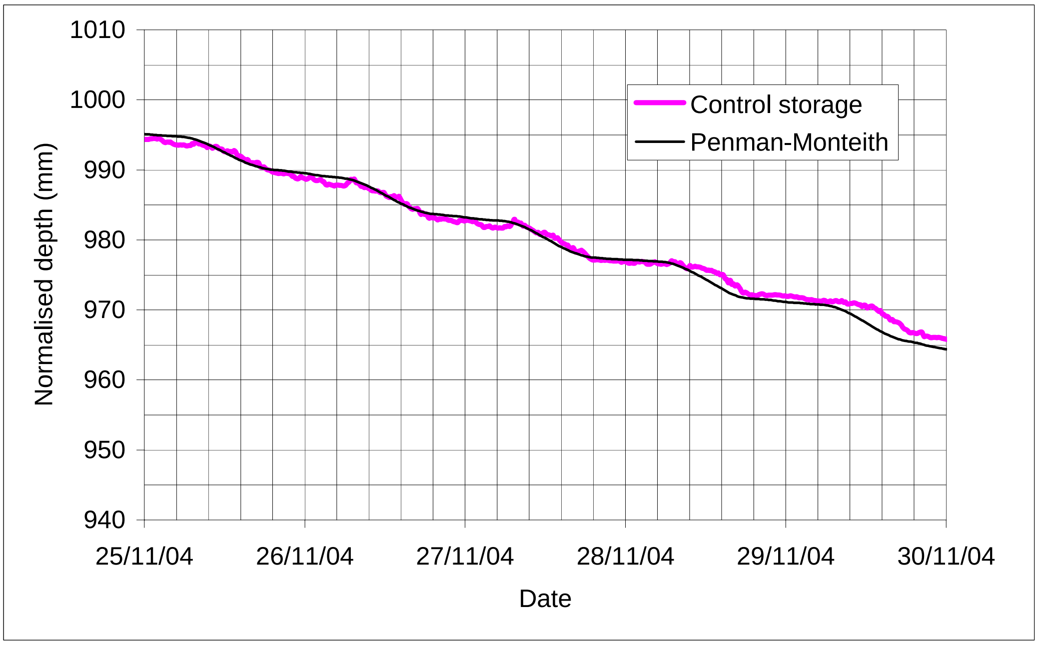


Figure A 4-12 Graph of PST output from the control storage at St George indicating a good fit with the Penman-Monteith estimation of evaporation from the AWS data collected.

In the absence of pumping, agreement between seepage adjusted PST water depth and the Penman-Monteith model theoretical evaporation was generally excellent for the control storage at St George.

4.3 Suspended cover

4.3.1 USQ research facility

Figure A 4-13 shows the PST traces from the control and NetPro shade cloth EMT tanks at the USQ Ag plot. Towards the end of the monitoring period, the PSTs indicated that there was a substantial rise in the water level in both control and EMT tanks. The AWS located next to the tanks confirmed that rain fell during this period which was excluded from analysis.

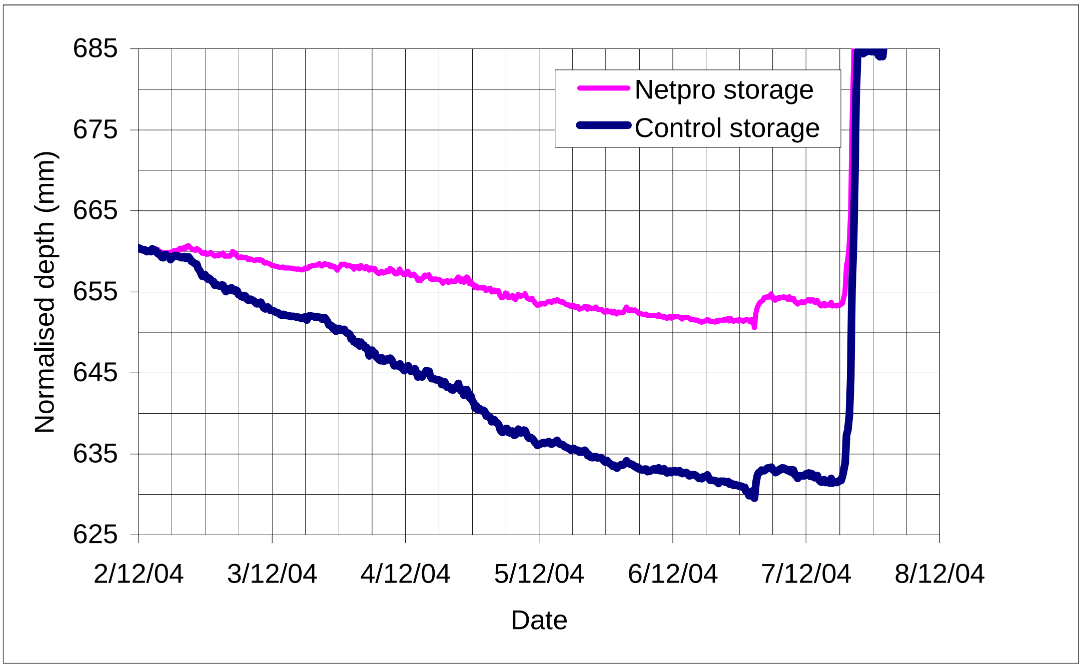


Figure A 4-13 Water depth in control tank and NetPro shade cloth covered tank during December 2004 with rain falling on the 6 and 7 December.

The total loss from the control tank totalled 28mm and averaged 7.0mm/day, whereas loss from the shade cloth tank totalled 8mm for a daily average of 2.0mm/day. The percentage of evaporation saved due to the effect of the shade cloth was again 71%.

4.3.2 Stanthorpe

Figure A 4-14 shows PST data from the control and NetPro storages for winter conditions at Stanthorpe. In the cold temperatures (occasionally down to freezing at night), daily evaporation rates recorded by the PSTs located in the control storage were only around 1 mm/day. Most of this evaporation would have occurred in the warmer mid afternoon. Penman-Monteith cannot successfully model this scenario, as the temperature input taken for the calculation is measured at two metres height rather than directly at the water surface. Therefore the Penman-Monteith theoretical evaporation for this same period was a lot higher.

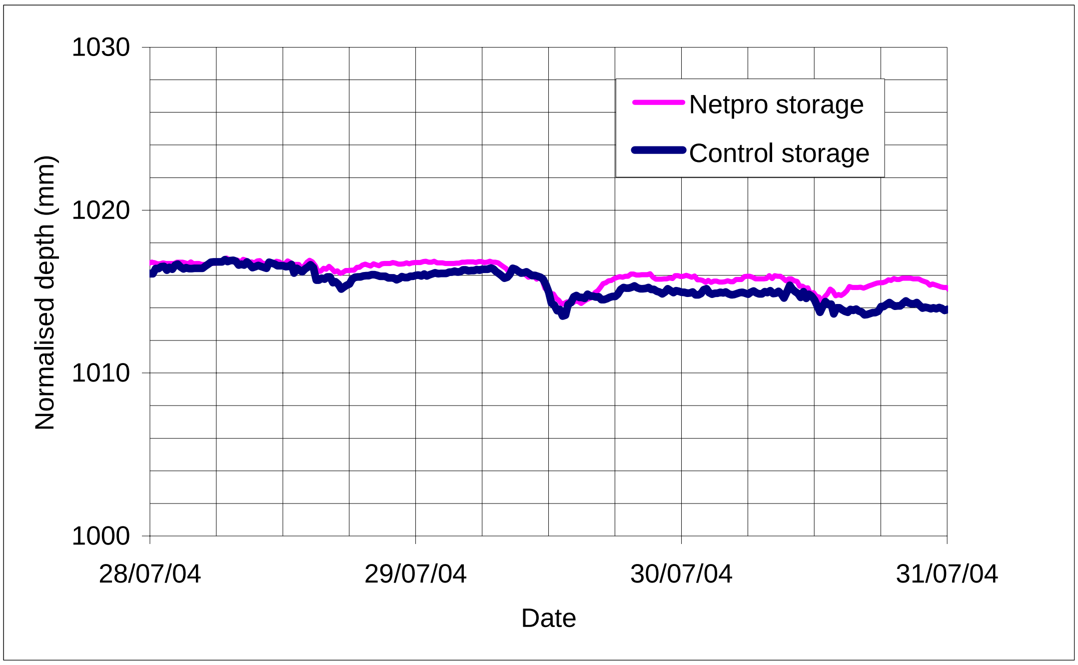


Figure A 4-14 PST data collected from the control and EMT storages at Stanthorpe for winter conditions at Stanthorpe.

An evaporation rate of only 0.5mm/day is at the limit of accuracy of the PST instruments. A value for seepage of 0.5mm/day has been removed from this data for both storage sites. The graph shows that the evaporation over three days was 1.5mm for the NetPro storage, compared to 3.0mm for the control storage indicating that the evaporation saving due to the shade cloth was 50%.

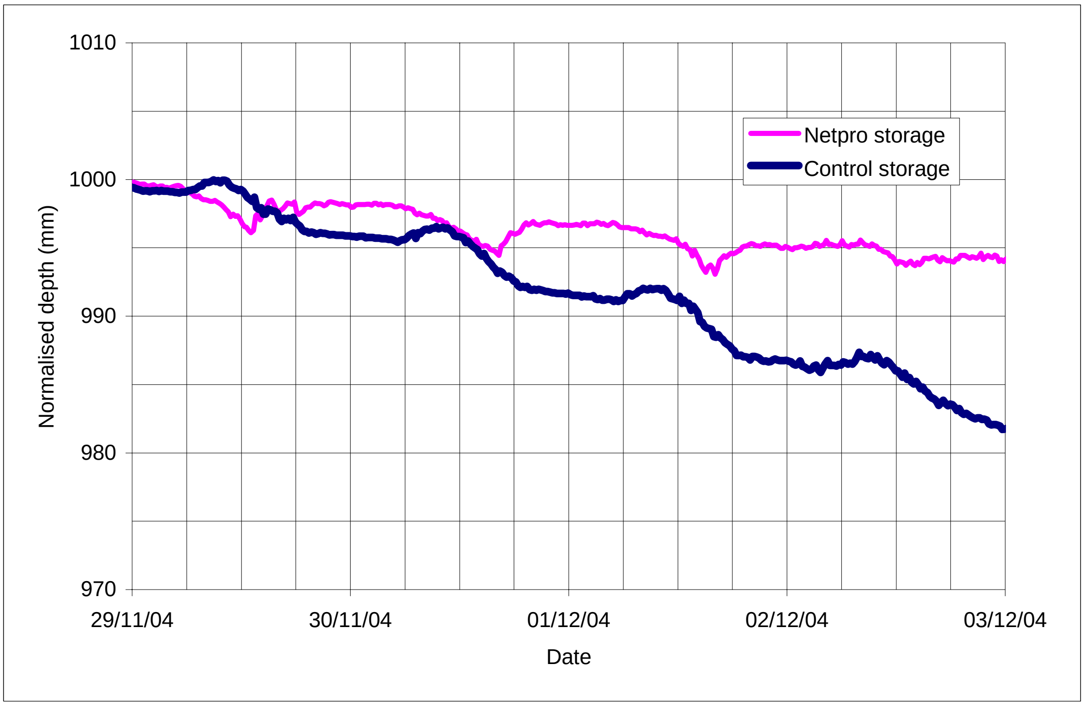


Figure A 4-15 PST traces from the control and EMT storages at Stanthorpe for summer conditions.

Figure A 4-15 shows some late November/early December 2004 data from Stanthorpe. The total loss from the control storage for this period was 18mm, with a seepage rate of 0.5mm/day, therefore a daily evaporation of 4.0mm/day. The seepage rate for the EMT storage was 0.5mm/day and a total loss of 4mm for this period, therefore an average evaporation of 0.5mm/day. The NetPro shade cloth reduces evaporation by 87% compared to the control storage.

Figure A 4-16 depicts total incident solar radiation plotted against time of day, recorded at the Stanthorpe trial site for approximately one week in March 2004. The sensors used to record radiation were solid state semiconductor units supplied as standard in all the AWS used. Solar radiation recorded by the sensor placed above the shade cloth rises to approximately 900 to 950W/m² during the midday period, whereas, radiation for the sensor placed below the shade cloth rises to only 100W/m².

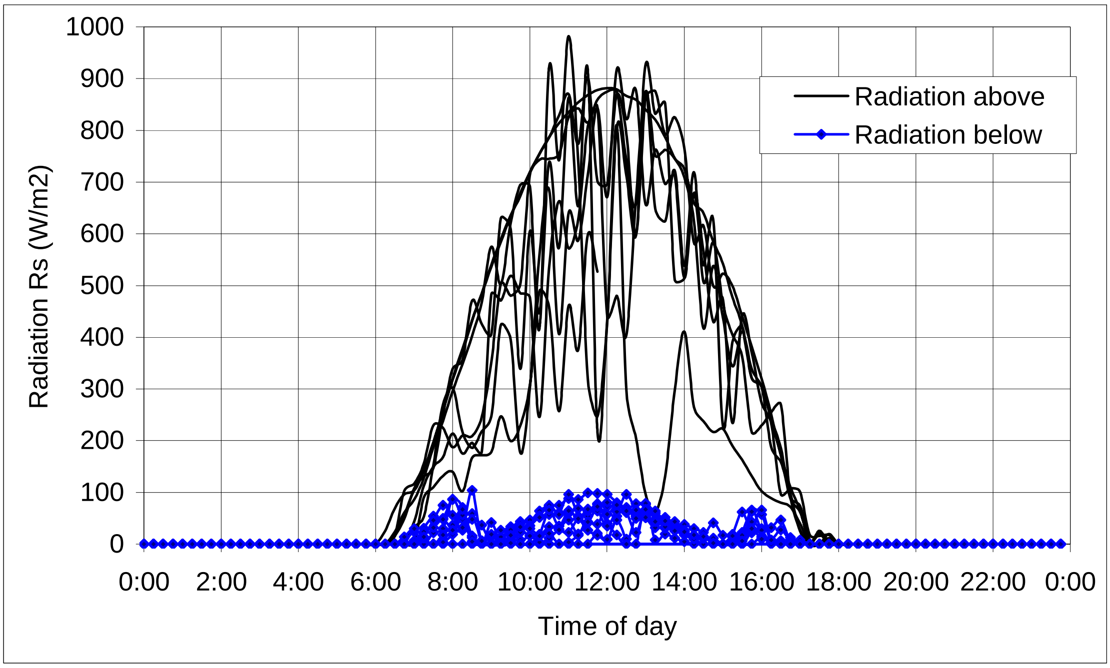


Figure A 4-16 Measured radiation above and below the shade cloth at Stanthorpe.

This data illustrates that the reduction in the total radiation received at the AWS is at least 90% due to the presence of the shade cloth. The solar radiation penetrating the shade cloth has an early morning and a late evening peak in addition to the midday peak. This may be a cloth weave reflection or refraction effect which is dependant upon the angle of incidence of the sun.

Figure A 4-17 illustrates another important effect of the shade cloth that is reducing wind speed across the surface of the storage. Although wind speed is not such an important parameter as solar radiation and temperature, reduced wind speeds will assist in minimizing evaporation. For a wind speed above the shade cloth of 15kph the wind speed reduction is approximately 90%. For wind speeds of below 5kph wind speed below the cover is reduced to 0kph.

Based on the Penman-Monteith model reduction of wind speed from 15kph to 1.5kph, with average values entered for all other parameters, the reduction in predicted evaporation is of the order of 20%.

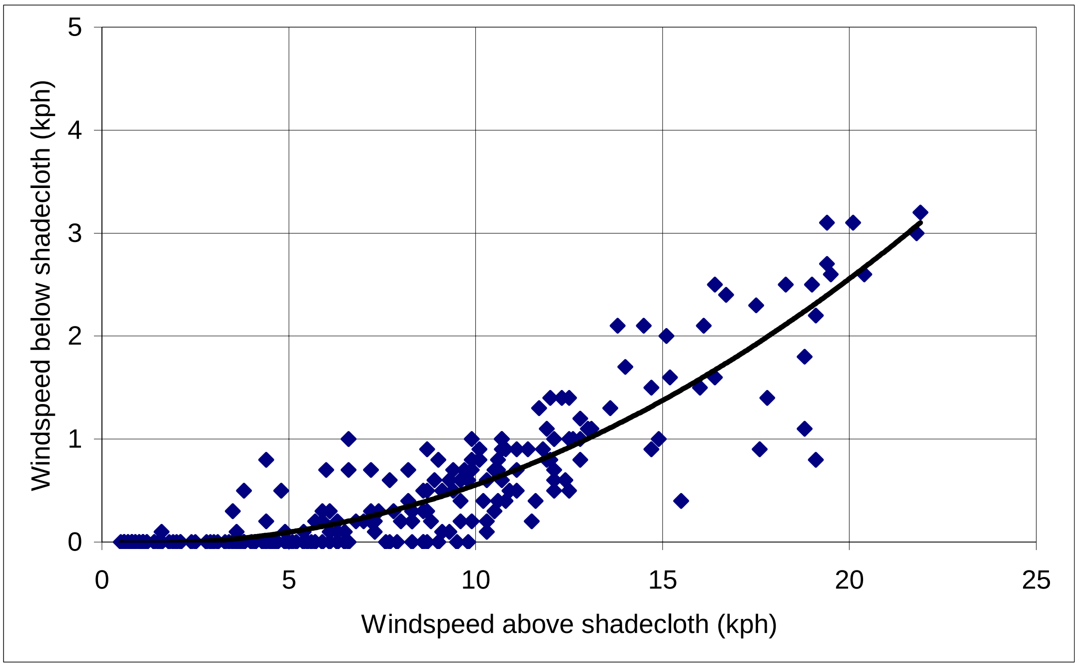


Figure A 4-17 Effect of shade cloth on reducing wind speed.

4.4 Modular cover

4.4.1 USQ research facility

Figure A 4-18 shows the change in water level in the control and Raftex tanks from the 1 to 7 December 2004. The increase in water level between midday and 6pm on the 6 December 2004 is consistent with rainfall recorded by the automatic weather station adjacent to the tanks.

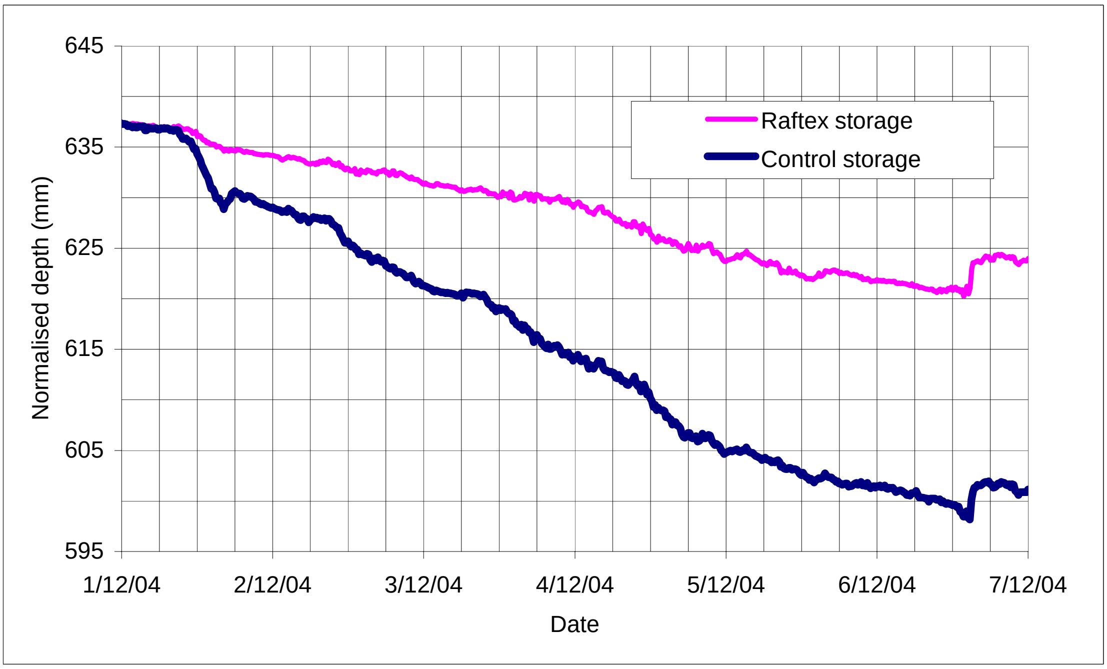


Figure A 4-18 Shows PST traces from the control tank and Raftex tank during December 2004.

In calculating the performance of the EMT only data between midnight on the 1 to 6 December 2004 has been used. The total loss from the control tank during these five days was 36mm, a daily average evaporation of 7.2mm/day. The evaporation losses from the Raftex tank were 15mm for this same period which is an average of 3.0mm/day. The calculated evaporation saved by the Raftex at the trial site during this period was 58%. If the Raftex were to cover the entire surface of the tank, the theoretical saving would have been as high as 85%.

Figure A 4-19 shows the total losses from the control and the Raftex tanks from 29 January to 5 February 2005. The total losses from the control tank between the 29 January and midday on the 1 February 2005 were 23mm which is daily average of 9.1mm/day. The total losses from the Raftex tank were 9mm for the period. The daily average evaporation for the Raftex tank was 2.6mm/day. The average evaporation saving that can be attributed to the installation of the Raftex was 71%. The theoretical evaporation saving when the areal adjustment is taken into account is around 100%.

The sudden 10mm drop in the Raftex tank between midday and 6:00pm on the 1 February 2005 coincided with winds (36kph) blowing one small and one medium sized raft out of the tank, damaging the large raft and resulting in water in the tank overlapping the edge. The increase in water level between midday and midnight on 2 February was a result of rainfall at the site. The large spike in the Raftex PST trace was the result of waves in the tank caused when the two modules were reapplied after they had blown out the day before. Detailed analysis of the water level data provides much information on management of the storage.

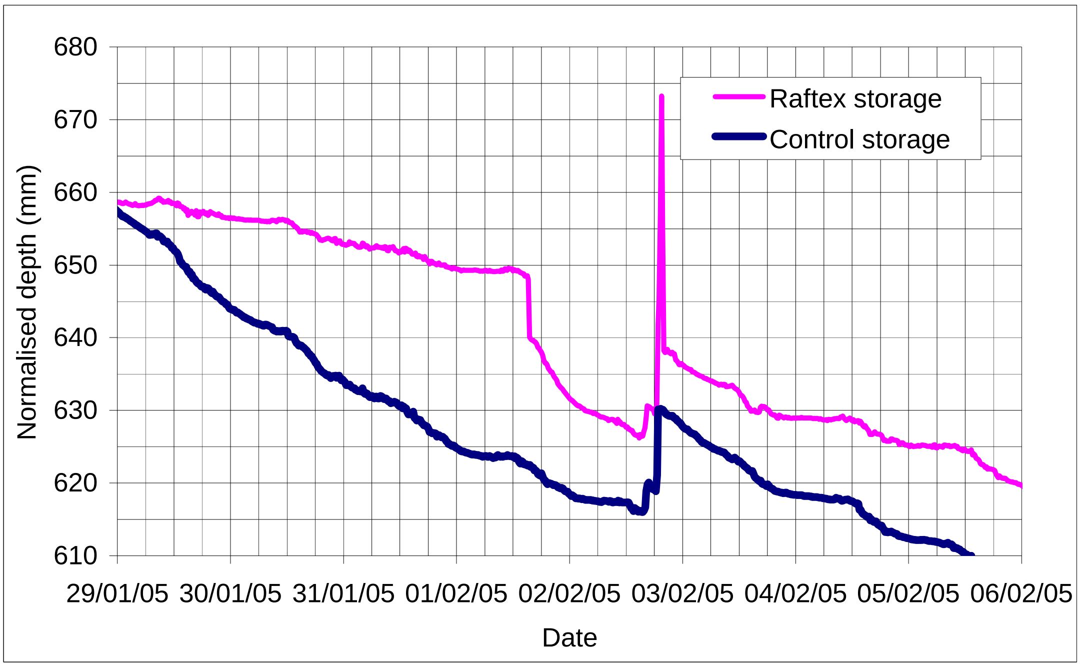


Figure A 4-19 Shows PST traces from the control tank Raftex tank during February 2005.

There was reduced effectiveness of the Raftex product after 3 February owing to the damaged modules which no longer provided effective cover of the storage.

4.5 Polyacrylamide

4.5.1 USQ research facility

Figure A 4-20 shows the change in water level in the control and the PAM tanks between 29 January and the 7 February 2005. The PAM was applied at 100ppm on the 27 January 2005 adding the powder to a flow of pumped water and then pumping the entire contents of the tank for 45 minutes.

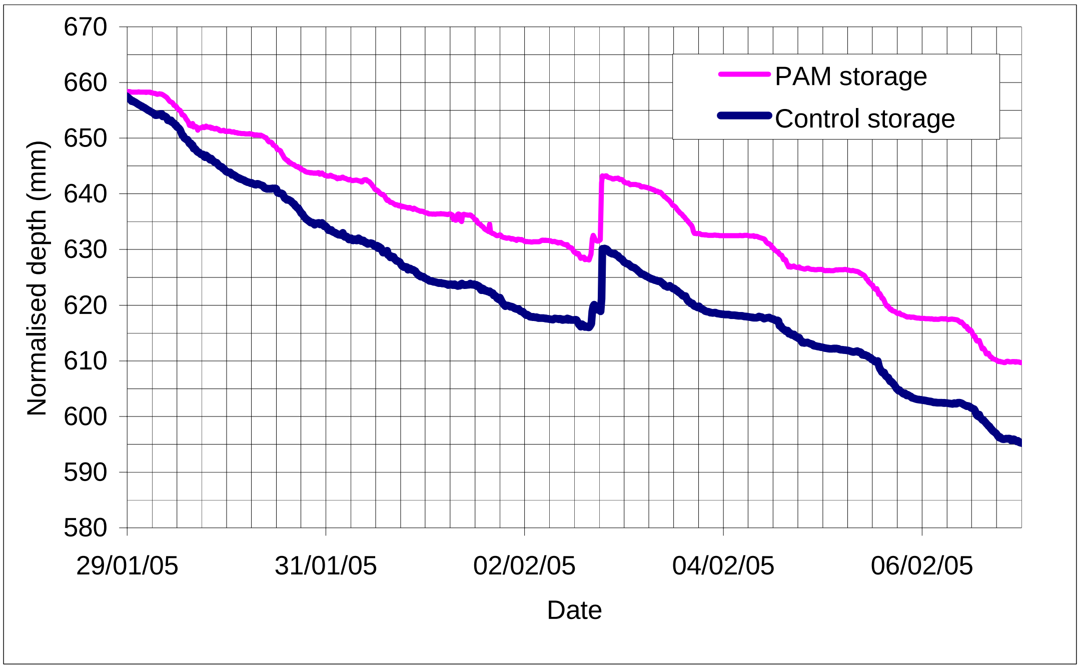


Figure A 4-20 PST traces from the control and PAM tanks during February 2005.

Data recorded by the automatic weather station adjacent the tanks recorded 15mm of rainfall on the 2 February 2005. This coincided with the obvious increase in water level in both tanks by 15mm. The product performance below was calculated between the 29 January and the 2 February 2005. The losses from the control tank for this period were 39mm which is a daily average of 9.8mm/day with no seepage. The evaporation loss from the EMT tank was 27mm with no seepage, a daily average evaporation of 6.8mm/day. Therefore the performance of the PAM over this period was 31%.

It should be noted that following the rainfall and the increase in water level in the tanks on the 2 February 2005, the losses from the PAM tank were equal to the losses from the control tank. This means that after the rainfall the PAM had no effect on the evaporation rate from the tank.

Figure A 4-21 shows the change in water level in the USQ evaporation trial tanks between 16 and 22 February 2005. The PAM product in this trial was added to the tank as a ‘top up’ dosage after an initial one week of 100ppm applied at the beginning of the week. The application rate for this trial was 20ppm with the method of application being the same as in previous trials.

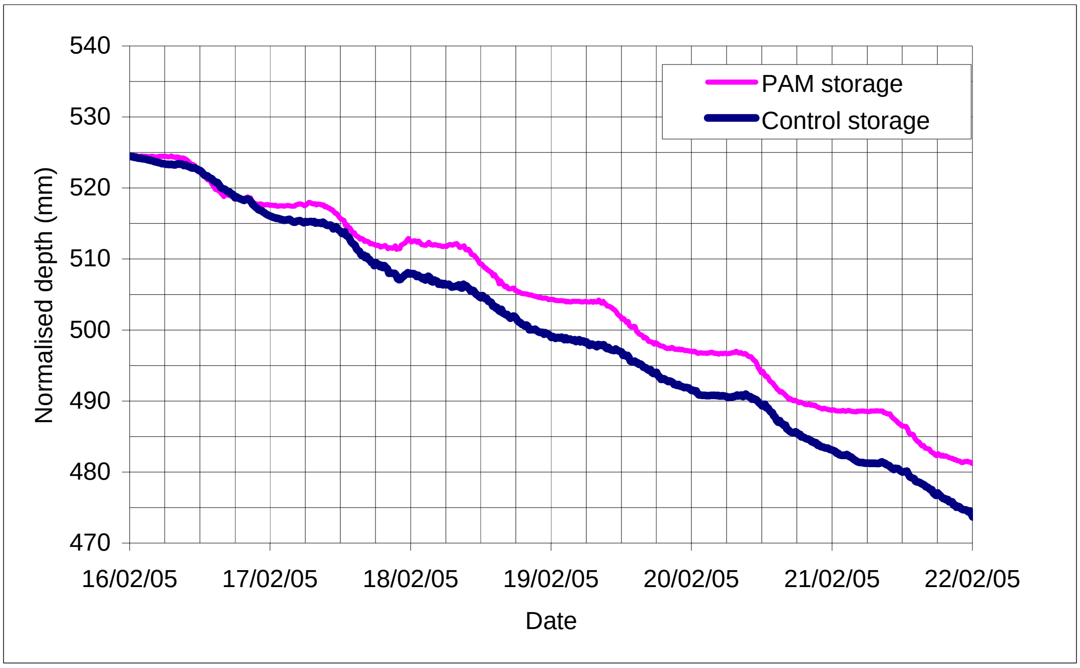


Figure A 4-21 PST traces from the control and PAM tanks during February 2005.

The total loss from the control tank between the 16 and 22 February 2005 was 51mm which averages 8.5mm/day. The evaporation losses from the PAM tank totalled 46mm for the period and an average of 7.2mm/day. From these figures the average evaporation saving that can be attributed to the application of PAM is 16%.

APPENDIX 5

MECHANICAL DURABILITY ASSESSMENT

5 MECHANICAL DURABILITY ASSESSMENT

This appendix looks at the report done by Bligh Tanner Pty Ltd on the E-VapCap product. In April 2004, Darling Downs Tarpaulins (DDT) & Evaporation Control Systems (ECS) commissioned a study of E-VapCap evaporation control system. Bligh Tanner Pty Ltd; a civil, environmental and structural engineering company, was chosen to evaluate the engineering aspects of the system with consideration to current applications and future developments. This study did not evaluate the efficiency of evaporation mitigation, as this was under investigation directly by the NCEA.

The objectives of the study were to;

- Develop understanding of material behaviour in service to help inform statements of product lifespan,
- Undertake study of behaviour under wind loading to assess storage size limitations and edge restraint requirements, and
- Consider methods of dealing with very large storages.

E-VapCap ® -

Evaporation Control Covers

BLIGH TANNER PTY LTD

Civil, Environmental and Structural Engineers

23 March 2005

TABLE OF CONTENTS

1.0 INTRODUCTION

Bligh Tanner was commissioned in March 2004 by Evaporation Control Systems (ECS) and Darling Downs Tarpaulins (DDT) to undertake a process of engineering development of the *E-VapCap* evaporation prevention covers for dams.

The *E-VapCap* system is currently being installed on dams using methods developed by ECS and DDT. Funds made available through an NCEA grant has enabled ECS/DDT to commission this study to prove and develop current procedures.

The work undertaken by Bligh Tanner is limited to issues of structural integrity rather than efficiency of evaporation control or other environmental performance characteristics.

2.0 PROJECT OBJECTIVES

- Develop understanding of material behaviour in service to help inform statements of product lifespan
- Undertake study of behaviour under wind loading to assess dam size limitations and edge restraint requirements
- Consider methods of dealing with very large dams

3.0 THE CURRENT SYSTEM

3.1 General

The *E-VapCap* cover consists of Heavy duty UV stabilised Polyethylene Bubble Plastic which floats on the surface of the dam to prevent evaporation loss. Prefabricated panels of the material are welded together using a thermal welding machine mounted on a floating platform on the dam surface. The cover is then restrained around the perimeter by burying the edge within a trench on the top of the dam wall or for covers which float free of the dam wall by tethering a stiffened and ballasted edge back to the dam wall with ropes and anchors. Drainage holes are punched through the cover to enable rain water to pass through and for gas to escape.

The system was principally developed for control of evaporative losses on farm irrigation dams. Irrigation ‘ring’ dams are generally constructed using a cut and fill process such that the dam wall extends above the level of the surrounding land.

3.2 Dam Geometry

The product has applications throughout Australia and in many different applications. The largest dam covered to date is 42,000m² with typical sizes in the order of 4 -5,000m². Typical cattle feedlot dams are in the order of 60m long.
Ring Dams are generally constructed with a water side batter of 1 Vertical:
3Horizontal and a land side batter a bit steeper. The dam wall height on the water side is typically up to 7m with corresponding land side height up to 5m. The top of the dams are between 1m to 3m wide.

3.3 Edge restraint systems

3.3.1 Trenched

The cover is pulled up the batter, over the top of the dam wall and buried in a trench which is set back with 1m clearance from the top of the batter and is typically 500mm deep and 300mm wide. The cover is returned up the far side of the trench by 200mm. The trench is backfilled and compacted by rolling with the wheels of a Landcruiser.

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Aspects of the trenched restraint are:

- Complete sealing of edges for prevention of uplift at the dam wall and consequent wind 'tunnelling'.
- Complete water coverage for maximum evaporation prevention (and also odour control, algal growth control or other additional benefit that may be sought).
- Trenching deals well with water level variation as there is no danger of losing effectiveness of edge ballast. However as the edge is completely restrained, there are limits on water level variation that can be accommodated for narrow dams with steep sided banks due to the change in length(stretch) required.
- Only option for lined dams (on permeable soil sites) as it is not practical to tether through the lined surface of a dam. In this situation the *E-VapCap* cover shares the liner trench.
- Cannot cater for uneven or rocky banks.
- Siltation problems for trenches located on dam walls with dispersive soils where the top of the dam slopes inward. Eroded soil can wash on to the cover surface causing the cover to sink below the surface at the perimeter and exposing the water over to evaporation. This is generally not considered to be an important issue as the majority of dams slope toward the outer bank to prevent erosion of the inner wall.
- 'Ballooning' of loose material on the leeward bank under sustained high wind events as discussed in detail later in the report.

3.3.2 Tethered

With the tethered restraint, the edge of the cover floats free of the dam wall. The free edge is stiffened and tethered with polyester rope to anchors in the dam wall at the water line. The edge is also ballasted to resist wind uplift. This system is currently considered in the following situations:

- Rocky or uneven dam walls that are difficult to trench
- Partial dam coverage

- Small, steep sided dams with significant water level variation that would require excessive stretch in the material for the trenched edge restraint. It is noted that the tethering system in this situation would need to deal with the water level variation.
- Dams with the embankment top sloping toward the water such that a build up of silt may occur over the cover.

To date, there have only been 3 installations with a tethered system (Stanthorpe treated waste water) and these dams were not subject to significant water level variation. Tethered covers have not been used widely to date due to the greater certainty of prevention of access to 'wind tunnelling' available with a trenched edge, as well as the notion that 100% of evaporation control should be provided.

During this study, the economy of partial dam coverage (using a tethered system) has been raised as an issue for dams which are not often full. It may be more cost effective to provide for instance, only 70 % coverage, rather than having the *E-VapCap* cover dry portions of the dam wall for much of its life.

Aspects of the tethered restraint are:

- The edge ballast system is critical for preventing lift off from water surface from pressure reduction in the vicinity of dam walls during wind events and wave action. To prevent wind from penetrating under the cover in the circumstance of temporary lifting of the edge due to wave action or wind gusting, the edge ballast must include a 'curtain' of material with additional ballast at its base.

3.4 Drainage Holes

A grid of 15mm diameter holes at 3.5m centres is currently adopted to enable rainwater drainage and escape of gas. This system is currently working well in terms of the return of the cover back to the surface following rainfall. Other aspects relating to the system of holes are as follows:

- The sparse array of holes does not significantly reduce the effective strength of the cover.

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4.0 DESIGN LIFE AND WARRANTY

The current Memorandum of Agreement that is used by ECS/DDT to set out supplier and purchaser responsibilities removes liability from the supplier for failure of the cover due to excessive (or extreme) wind event beyond a mean hourly wind speed of 82 km/hr.

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The covers are wind sensitive in that the only likely failure mechanisms are due to wind action. The Australian Standard for Wind Action, AS/NZ1170:Part 2(2002) does only make reference to Structures and it could well be argued that the *E-VapCap* covers are not structures, however in the absence of any alternative guide to design wind speed the use of AS/NZ1170:Part 2(2002) is considered correct.

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Considering some of the winds that the installed covers have been exposed to during the course of this project, this 82 km/hr design mean hourly ultimate wind speed is considered to be appropriate. It corresponds to a force 9 to 10 storm on the Beaufort scale.

Other aspects which will impact on the warranty are:

- Openings in the cover which may allow access to wind tunnelling and also make the cover vulnerable to tearing due to lack of continuous edge support.
- Dam water level – depending on the dam geometry, restraint system and liner.
- Gas production under the cover in some specialised applications
- Water level at time of installation

5.0 IN-SERVICE BEHAVIOUR

5.1 Basic mechanisms

- The cover floats on the surface due to the integral bubbles with the drainage holes clear of the water such that no water sits on the surface in normal conditions. Due to weld shrinkage at the seams, the cover has a slightly rippled surface such that in normal conditions, approximately 85% of the cover is in contact with water.
- Effective suction induced by contact of the cover of the material with the water restrains the membrane to prevent lift off under wind action. Observation of a sample of material floating in a clear vessel indicates that although some air bubbles are likely to be trapped under the cover, in particular at the weld induced ripples, in general the underside of the cover appears to be in complete contact with the water surface i.e. the top cover skin does not float clear of the surface with contact only on the bubbles. This balancing of buoyancy provided by the bubbles with the fabric weight is probably crucial to maximise the effective suction and avoid water entry onto the surface.
- The white top surface layer reflects sunlight, while the black bottom layer minimises passage of remaining light to minimise heat on the water surface and algal growth

5.2 Water Level Variation

An important feature of the *E-VapCap* system is that water level variation in dams is catered for by change in length of the cover through elastic extension and contraction of the material. This differs from mechanisms adopted for other floating cover systems identified by USQ researchers which used systems of folded excess material moving between rollers. These systems do not appear applicable to large scale low cost covers such as *E-VapCap*. Further aspects relating to water level variation are as follows:

- The cover is generally installed with the dam as near to full as possible. The reasons for this are:

a) The floating welding platform cannot operate on dry banks making welding of the cover difficult

b) If the cover is installed on a full dam, then any change in water level will only tighten the cover rather than produce excess loose material as the dam level rises and exacerbation of the 'ballooning' phenomenon on the leeward bank.
ECS/DDT are currently discussing methods of dealing with dams that are not full at installation, including excavation of trenched edges and tightening when the dam is full.

The geometry of the dam is important for assessment of the ability of a restrained edge cover to cater for water level variation. The current procedure is to determine the maximum extension that can occur by comparing the cover length required for a full dam with the length of the dam base (dry dam) between restraints (trenches).

ECS and DDT are currently advising a maximum extension of 2.5% based on advice from the material manufacturer (Sealed Air Australia). The longer a dam becomes in relation to depth, the less is the influence of water level variation on the material stretching.

- The material testing that has been undertaken as part of this study has found that although the material has an initial plastic (permanent) deformation at this 2.5% strain level when held for 1 hour, the material returns to its original length within 24 hours i.e. the testing undertaken supports this range of working strain, although additional testing is required as discussed later to confirm the performance over the life span of the cover.
- Non-linear finite element analyses undertaken for various dam geometries indicate that the cover will not necessarily follow the water level down past a certain level as the cover may span across the dam with sag of less than the change in water depth. For instance, a cover installed with zero prestress on a 50m x 50m square dam, will sag a maximum of 3m without support so that for water level change of greater than 3m, the cover will hang clear of the water. This assumes that the 'suction' affect of the water is not sufficient to drag the cover down further – this is an aspect that will require greater understanding. At this stage, water level drop below the fabric is cause for concern due to the potential for unrestrained wind uplift.

5.3 Wind

Behaviour under wind loading and control of wind effects is a critical issue for success of the system. The cover relies on a relatively small amount of ballast around the perimeter and the effective suction induced by contact with the water and ground to prevent lift off so a thorough understanding of the wind regime is required.

5.3.1 Basic Actions

The principal wind actions are:

- Wind blowing across the surface induces a frictional drag force which causes the cover to stretch towards the leeward.
- Wind blowing across the dam walls which protrude up to 5m above the surrounding land causes pressure reduction in the vicinity of the walls and potential uplift of the cover. Wind tunnel testing has been undertaken to investigate pressure profiles on both windward and leeward banks.
- A wind effect that would cause failure if it was allowed to develop is tunnelling of wind under an exposed and lifted edge. This study has not looked in any detail into this mechanism as the task is to avoid lift off the cover in the first place.

An additional less significant action is:

- The wind drag on the membrane can cause a long amplitude flat 'swell' in the water/membrane. This swell can induce pumping of the water through the holes on to the surface which can provide useful ballast to the surface.

5.3.2 Observed behaviour under wind loading

5.3.2.1 Ballooning in trenched covers

- During a sustained high wind event, loose material and trapped air gathers at the leeward bank due to friction on the surface. This loose material derives from a combination of initial slack in the cover (particularly if installation was at a lower water level) and stretch in the cover due to frictional forces. The loose material then billows up due to pressure reduction adjacent to the dam wall. In a couple of instances this effect has thrown the ballast tubes off the cover, although to date there has been no pull out from the trench. At the Moon's property at St George the cover has ripped in such an event. This cover used a lesser grade of membrane and had been extensively damaged by kangaroo paws which would have lead to tear propagation under stress. The Moons cover also incorporates drainage holes in the region of the batter (although these are probably insignificant compared with the kangaroo paw tears) which we now consider can be detrimental for pumping up of the loose material.

5.3.2.2 Tearing

- The covers are vulnerable to tearing if wind can locally tunnel under access points such as pipe access points or if there are un-reinforced or unrestrained discontinuities such as 90°corners or existing tears such as at Moons Dam at St George.

5.4 Waves

For tethered systems (and during construction) the cover edge is exposed to waves. Generally it has been observed that waves act to help prevent lift off due to the water being pushed over the top of cover and providing effective ballast. During construction, as the wave size reduces close to the dam wall with reduced fetch, the potential for lift off of the unrestrained edge increases. For completed covers the influence of waves is minimal as the fetch between the dam wall and tethered edge is small.

5.5 Hail

The *E-VapCap* cover caters well for hail events as the weight of hail is supported directly by the floating cover and water. The cover will sink until sufficient amount of hail has melted to enable the cover to float to the surface.

The cover is probably more vulnerable to hail damage on the dry batters however to date there has been no reported damage due to hail impact. Further testing on this issue is probably warranted.

6.0 MATERIAL PROPERTIES AND TESTING

6.1 Manufacturer's Specification

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6.2 Testing

Laboratory testing of samples of the material has been undertaken on a test rig that University of Queensland had made for determining stretch compensation factors for patterning of fabric structures.

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7.0 WIND TUNNEL TESTING

Wind tunnel testing has been undertaken at the University of QLD facility by Dr Rob Roy on behalf of Bligh Tanner. The testing determined pressure profiles on both windward and leeward banks of a typical dam configuration with various relative water levels and the design frictional drag co-efficient.

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7.1 Discussion of results

7.1.1 Dam wall pressure co-efficients

- At the windward bank very large uplift co-efficients were derived with a maximum of -1.1 at the top of the bank reducing to approximately -0.7 at the base of the batter and then to -0.2 at a distance out in to the dam for a length of approximately equal to the batter length.
- At the leeward bank the pressure co-efficients were considerably less with a maximum of -.55 occurring at the top and only small pressure reductions occurring at the water

7.1.2 Frictional drag

- The frictional drag co-efficient of 0.012 was close to Code derived values.

8.0 ANALYSIS AND DESIGN OF CURRENT SYSTEMS

Various aspects of wind action on the covers have been investigated to determine the limiting criteria for installation and to explore potential weak points in the system that require further development.

8.1 Frictional Drag effects

- Throughout the study, the assumed maximum strain that the material should be subject to is about 2.6% to avoid permanent stretch. This value was as originally advised by Sealed Air Australia. The laboratory testing undertaken indicated that in the range of 1% to 2.5% strain an initial plastic (set) strain of about .5% occurs but the material then returns to its original shape within 24 hours. The test result shown in Figure 5 of Appendix B for stretch up to 6 % indicates that while the material does not yield anywhere near 2.5%, the stiffness (modulus) reduces. A strain of 2.5% corresponds to a stress of about 1kN/m which is 1/5th of the ultimate failure load of 5kN/m. This ‘safety’ factor of 5 is consistent with values normally adopted in the membrane structure industry (this factor of 5 was originally based on the stress level that was required to prevent propagation of tears – as the *E-VapCap* material does not consist of woven fibres, this correlation is not necessarily applicable). For all these reasons presented above and without greater knowledge on the long term performance of the material after many stretch cycles, the 2.6% maximum strain is considered an applicable maximum value.

- A potentially more critical effect of the stretch is the ballooning discussed previously. The amount of loose material that gathers at the leeward bank will depend not only on the frictional stretch component but also the amount of initial slack material at the time of installation and the water level at the time of a wind event. For this reason it is important that the cover is installed with water level as high as possible and as tight as possible to avoid a loose cover in service. For the 1.2m excess material derived in the above example, it is possible that a 2.5 high balloon could form if spread over a 10m width. For 5m width, the height would reduce to 1.8m. The potential problems that are foreseen with the balloon formation are:

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- A significant potential advantage of tethered covers is the ability of the excess material to simply stretch out over the surface rather than forming a balloon behind the trenched restraint.

8.2 Uplift at Windward bank

- Wind tunnel testing indicates very high pressure reduction occurring over the dam wall and extending out in to the dam. This could be expected to cause problems of the cover lifting up off the batter and dam surface however as there exists only a limited volume of air under the cover, any lift off of the cover will induce a pressure reduction that balances that due to wind flow over the dam wall and the cover will settle again.

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- Uplift of the cover could become a significant problem if water level variation is such that the cover hangs above the water surface as is possible in smaller dams (refer to the discussion in Section 5.2). In this situation there would be ample volume of air available to enable the cover to rise significantly. Dam geometries and water regimes should always be checked for this possibility.
- The situation of an empty lined dam is also considered to be at risk as without the water or mud contact it is possible that sufficient air could be sucked in through the array of drainage holes away from the batter.

8.3 Trench capacity

- The capacity of the current trench detail is dependent on the friction/cohesion of the cover to trench soil interface. The capacity will be significantly higher in soil with high shear strength particularly with the bubbles embedded in the soil.

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8.4 Tethered covers

- Various aspects of the tethered cover system are discussed above in section 3.3.2. A further reason that tethered covers have not been widely used is that the system has not been developed in detail. Recent discussions between ECS/DDT and Bligh Tanner have led to the following basic system components. These components are all subject to further refinement.

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9.0 SYSTEM DEVELOPMENT

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APPENDIX 6

ECONOMIC ASSESSMENT

6 ECONOMIC ASSESSMENT

This appendix looks at the assumptions made for the economic assessment. It was based on information collected from the suppliers, manufacturers, landholders, National Centre for Engineering in Agriculture (NCEA) staff and other owners of the evaporation mitigation technology (EMT). The expected operating and maintenance costs for each of the evaporation mitigation technologies (EMTs) is considered to be at the low cost scenario. The high operating and maintenance costs are the worst case scenarios and are highly unlikely in well managed and maintained systems.

6.1 Monolayer – applied automatically

Table A 6-1 A summary of the range of costs associated with the installation and operating the Water$avr being applied automatically for the full 12 months.

	Low	Medium	High
Capital cost ($/ha)	**$400.00**	**$530.00**	**$3800.00**
Chemical cost ($/ha/year)	**$790.00**	**$1185.00**	**$1775.00**
Operating cost ($/ha/year)	**$29.00**	**$41.75**	**$466.00**
Maintenance cost ($/ha/year)	**$7.25**	**$16.38**	**$386.60**

The assumptions made to generate the costs for the initial capital outlay, chemical, operate and maintain the monolayer product being applied automatically.

Capital cost
The capital costs were based upon a 20 year life for the automatic applicator which includes the pump and distribution system and with no residual value at the end of it life. Where the installation costs range from;

- Low (200ha storage)
  - $50,000 automatic applicator $250.00
  - $30,000 grid system $150.00 $400.00
- Medium (100ha storage)
  - $35,000 automatic applicator $350.00
  - $18,000 grid system $180.00 $530.00
- High (5ha storage)
  - $17,500 automatic applicator $3500.00
  - $1500 grid system $300.00 $3800.00

Chemical cost
The maintenance costs were based upon a per hectare per year basis. It was assumed that the Water$avr product would cost $13.00 per kilogram and a person would cost $25.00 per hour. The chemical costs range from;

- Low - ½kg/ha every 3 days $790.00 $790.00
- Medium - ½kg/ha every 2 days $1185.00 $1185.00
- High - ¾kg/ha every 2 days $1775.00 $1775.00

Operating cost
The operating costs were based upon a per hectare per year basis. It was assumed that Water$avr was applied at half a kilogram per hectare every two days and a person would cost $25.00 per hour. The operating costs for Water$avr - applied automatically include general

checking of the storage, refilling the hopper, fuel and oil for the motor. The diesel cost was assumed to be $1.00 per litre and oil $5.00 per litre. The operating costs range from;

- Low (200ha storage)
  - Check up every week - 1h (52 events) $6.50
  - Refill hopper with product - 2h (52 events) $13.00
  - Fuel for pump - 1800L $9.00
  - Oil changes for pump - 20L $0.50 $29.00
- Medium (100ha storage)
  - Check up every week - ¾h (52 events) $9.75
  - Refill hopper with product - 1½h (52 events) $19.50
  - Fuel for pump - 1200L $12.00
  - Oil changes for pump - 10L $0.50 $41.75
- High (5ha storage)
  - Check up every week - ½h (52 events) $130.00
  - Refill hopper with product - 1h (52 events) $260.00
  - Fuel for pump - 360L $72.00
  - Oil changes for pump - 4L $4.00 $466.00

Maintenance cost

The maintenance costs were based upon a per hectare per year basis. It was assumed that Water$avr was applied at half a kilogram per hectare every two days and a person would cost $25.00 per hour. The maintenance costs for Water$avr - applied automatically to include the diesel motor, pumps, hopper & mixing unit and the distribution grid system. The maintenance costs range from;

- Low (200ha storage)
  - Diesel motor - 20% of fuel $1.80
  - Pumps - 10% of fuel $0.90
  - Hopper & mixing unit - $1.00/day $1.82
  - Grid pipe system - $1.50/day $2.73 $7.25
- Medium (100ha storage)
  - Diesel motor - 20% of fuel $2.40
  - Pumps - 10% of fuel $1.20
  - Hopper & mixing unit - $1.50/day $5.48
  - Grid pipe system - $2.00/day $7.30 $16.38
- High (5ha storage)
  - Diesel motor - 20% of fuel $14.40
  - Pumps - 10% of fuel $7.20
  - Hopper & mixing unit - $2.00/day $146.00
  - Grid pipe system - $3.00/day $219.00 $386.60

6.2 Monolayer – applied by hand

Table A 6-2 A summary of the range of costs associated with the installation and operating the Water$avr being applied by hand for the full 12 months.

	Low	Medium	High
Capital cost ($/ha)	**$0.00**	**$0.00**	**$0.00**
Chemical cost ($/ha/year)	**$790.00**	**$1185.00**	**$1775.00**
Operating cost ($/ha/year)	**$520.00**	**$650.00**	**$2275.00**
Maintenance cost ($/ha/year)	**$0.00**	**$0.00**	**$0.00**

The assumptions made to generate the costs for the chemical and operating of the monolayer product which was applied by hand.

Capital cost
The capital costs for applying the monolayer by hand are nil because there is no equipment required.

Chemical costs
The maintenance costs were based upon a per hectare per year basis. It was assumed that the Water$avr product would cost $13.00 per kilogram and a person would cost $25.00 per hour. The chemical costs range from;

- Low - ½kg/ha every 3 days $790.00 $790.00
- Medium - ½kg/ha every 2 days $1185.00 $1185.00
- High - ¾kg/ha every 2 days $1775.00 $1775.00

Operating cost
The operating costs were based upon a per hectare per year basis. It was assumed that Water$avr was applied at half a kilogram per hectare every two days and a person would cost $25.00 per hour. The operating costs for Water$avr - applied by hand include general checking of the storage and application by hand. The operating costs range from;

- Low (10ha storage)
  - Check up every week – ½h (52 events) $65.00
  - Hand application – 3½h (52 events) $455.00 $520.00
- Medium (5ha storage)
  - Check up every week – ½h (52 events) $130.00
  - Hand application – 2h (52 events) $520.00 $650.00
- High (1ha storage)
  - Check up every week – ¼h (52 events) $325.00
  - Hand application – 1½h (52 events) $1950.00 $2275.00

Maintenance cost
The maintenance costs for applying the monolayer by hand are nil.

6.3 Floating cover

Table A 6-3 A summary of the range of costs associated with the installation and operating the E-VapCap.

	Low	Medium	High
Capital cost ($/ha)	**$55,000.00**	**$70,000.00**	**$85,000.00**
Operating cost ($/ha/year)	**$112.50**	**$187.50**	**$322.50**
Maintenance cost ($/ha/year)	**$0.00**	**$150.00**	**$250.00**

The assumptions made to generate the costs for the initial capital outlay, operate and maintain the E-VapCap product.

Capital cost
The capital costs were based upon a 12 year life for the cover with no residual value at the end of it life. Where the installation costs range from;

- Low of $5.50/m^2
- Medium of $7.00/m^2

- High of $8.50/m^2

Operating cost

The operating costs were based upon a per hectare per year basis. It was assumed that a person would cost $25.00 per hour. The operating costs for E-VapCap include general checking of the storage, weed control and cleaning of the cover. The operating costs range from;

- Low
  - Check up every month - ¼h (12 events) $75.00
  - Check up after storm events - ¼h (6 events) $37.50 $112.50
- Medium
  - Check up every month - ½h (12 events) $150.00
  - Check up after storm events - ¼h (6 events) $37.50 $187.50
- High
  - Check up every month - ½h (12 events) $150.00
  - Check up after storm events - ¼h (6 events) $37.50
  - Chemical and application (1 event) $35.00[§]
  - Cleaning (dirt and dust) - 4h, (1 event) $100.00 $322.50

Note: [§] This cost is only available when the aerial sprayer is in the vicinity and is able to do it as part of another job.

Maintenance cost

The maintenance costs were based upon a per hectare per year basis. It was assumed that a person would cost $25.00 per hour. The maintenance costs for E-VapCap include tears to the cover. The maintenance costs range from;

- Low – nil $0.00 $0.00
- Medium
  - Small tears - ½h (4 events) $50.00
  - Medium tears - 4h (1 event) $100.00 $150.00
- High
  - Small tears - ½h (4 events) $50.00
  - Medium tears - 4h, (2 events) $200.00 $250.00

6.4 Suspended cover

Table A 6-4 A summary of the range of costs associated with the installation and operating the NetPro shade cloth.

	Low	Medium	High
Capital cost ($/ha)	**$70,000.00**	**$80,000.00**	**$100,000.00**
Operating cost ($/ha/year)	**$112.50**	**$237.50**	**$337.50**
Maintenance cost ($/ha/year)	**$0.00**	**$100.00**	**$200.00**

The assumptions made to generate the costs for the initial capital outlay, operate and maintain the NetPro shade cloth product.

Capital cost

The capital costs were based upon a15 year life for the shade cloth and 30 year life for the cable framework and with no residual value for either the shade cloth or the framework at the end of life. It was assumed that the shade cloth was 25% of the total cost and the framework was 75%. Where the installation costs range from;

- Low of $7.00/m^2$
- Medium of $8.00/m^2$
- High of $10.00/m^2$

Operating cost

The operating costs were based upon a per hectare per year basis. It was assumed that a person would cost $25.00 per hour. The operating costs for NetPro shade cloth include general checking of the storage and cleaning of the cover. The operating costs range from;

- Low
    - Check up every month - ¼h (12 events) $75.00
    - Check up every storm event - ¼h (6 events) $37.50 $112.50
- Medium
    - Check up every month - ½h (12 events) $150.00
    - Check up every storm event - ¼h (6 events) $37.50
    - Cleaning debris - 2h (1 event) $50.00 $237.50
- High
    - Check up every month - ½h (12 events) $150.00
    - Check up every storm event - ¼h (6 events) $37.50
    - Cleaning debris - 2h (3 events) $150.00 $337.50

Maintenance cost

The maintenance costs were based upon a per hectare per year basis. It was assumed that a person would cost $25.00 per hour. The maintenance costs for NetPro shade cloth include tears to the cover. The maintenance costs range from;

- Low – nil $0.00 $0.00
- Medium
    - Tears - 4h (1 event) $100.00 $100.00
- High
    - Tears - 8h (1 event) $200.00 $200.00

APPENDIX 7

WATER QUALITY ASSESSMENT

7 WATER QUALITY MEASUREMENT PROTOCOL

The following sections outline the detailed water quality sampling methodology for each site.

7.1 USQ Ag plot

Several Evaporation Mitigation Technologies (EMTs) were tested at the USQ trial site over the duration of the project. Water quality analyses were conducted for all of the EMTs tested. Due to the varying physical constraints of each product, the actual water quality monitoring plan varied for each EMT. The table below outlines the basics of the water quality monitoring plans for the USQ trial site.

Table A 7-1 Summary table of the water quality monitoring plan for the USQ Ag plot trial site.

Equipment	A TPS 90FL portable water quality meter was regularly calibrated and used to test the water in the three trial tanks. The water quality meter has data logging capability. On occasion, a Horiba water quality meter was used. This meter had the added advantage of being able to measure turbidity.
Locations	The location from which the water quality samples were taken was independent of which EMT was being tested. Samples were always taken from the north western side of the tank, arms length away from the edge of the tank to reduce the effects of heat from the side of the tank. Samples were taken at the surface and at 0.5m below the surface.
Frequency	As mentioned above the frequency of water quality sampling was dependant on the EMT being tested. Chemical EMTs (monolayer and PAM) and the modular system (Raftex) allowed for full access to the water for sampling at all times. As did the modular EMT (Raftex), this meant that water quality samples were able to be taken at any time during the trial. The floating cover and the suspended cover however, were secured to the outside of the tank which only allowed for water quality samples to be taken before and after the application of the EMT.
Parameters	All samples tested using the TPS 90 water quality meter were analysed for pH, Dissolved Oxygen, Conductivity and temperature. Sampled tested using the Horiba water quality meter also included the analysis of turbidity.
Technique	The water quality meters were regularly calibrated as per the instruction manual. The water quality probes immersed directly into the water body and moved through the water slowly to allow a flow past the dissolved oxygen membrane. The measurements were then stored directly into the built in logger in the TPS90 The probes were rinsed in between each sample and stored as per the manual between sample runs. All sampling was conducted in accordance with QLD Environmental Protection Agency's Water Quality Sampling Manual 1999.

7.2 St George

Water quality analyses had previously been undertaken at the St George dams. However due to the timing of the sampling and the parameters analysed the data is of little use. The EMT field installation at St George was similar to that of the buried edge E-Vap Cap trials undertaken at the USQ Ag Plot.

Table A 7-2 Summary table of the water quality monitoring plan for Moonrocks at St George.

Equipment	An extension pole with a scoop on the end was often used to take the grab samples from both storages. This was to ensure that there was minimal disturbance of the bottom sediments, as this would have affected the results of the sampling. The Horiba Water quality meter was used to analyse in-situ parameters.
Locations	Both the covered and the open (control) dam had water quality measurements taken. The sample sites from the covered dam were: • Midway along the walkway on top of the cover at surface and 0.5m below surface • Midway along the eastern side of the storage on top of the cover • North-eastern corner of the storage on top of the cover • North western corner of the storage on top of the cover • Midway along the western side of the storage • South western corner of the storage • At the end of the walkway a surface, 0.5m below and 1.0m below the water surface. Water quality samples were taken from the open dam at the following locations: • Northwest corner of the storage adjacent to the PST and data logger • Southeast corner of the storage adjacent to the PST and data logger • Southwest corner of the storage adjacent to the PST and data logger Unless there were issues with site access other technical problems, the same locations were monitored on each sample run to allow for direct comparison over time.
Frequency	Water quality sampling was undertaken when the PST data was downloaded from the data loggers. This occurred generally fortnightly between August and October 2004 with a break until after January 2005 before restarting in February 2005. In total there were 11 sample runs conducted for this site.
Parameters	The Horiba water quality meter that was used measured pH, Dissolved Oxygen, Conductivity, Temperature and Turbidity. No laboratory analyses were undertaken.
Technique	The water quality meters were regularly calibrated as per the instruction manual. Where possible the water quality meter immersed directly into the water body and moved through the water slowly to allow a flow past the dissolved oxygen membrane. If it was not possible to take the measurement directly from the water samples were taken using the extension pole. The measurements were then taken immediately from the grab sample. The results were recorded on to a pre printed field data collection sheet and returned to the NCEA for data entry. The probes were rinsed in between each sample and stored as per the manual between sample runs. All sampling was conducted in accordance with QLD Environmental Protection Agency's Water Quality Sampling Manual 1999.

7.3 Dirranbandi

Table A 7-3 Summary table of the water quality monitoring plan for Cubbie Station at Dirranbandi

Equipment	In most cases samples were able to be taken directly from the bank but if this was not the case, the extension pole with a scoop on the end was used to take the grab samples. The Horiba Water quality meter was used to analyse in-situ parameters. At various intervals s sample were also taken for Laboratory analysis. This

	involved HDPE bottles supplied by Australian Laboratory Services (ALS) with any preservatives required being added by ALS, all eskies and freezer bricks were also
Locations	Water quality analysis was undertaken on both the EMT and the open storage at Cubbie station. As there is no physical cover (cf St George) access to sample sites is much easier. The location of the sample sites from the EMT storage are as follows: • Southern end of the storage at the surface and 0.5m below the surface • South-western corner of the storage at the surface and 0.5m below the surface • North-western corner of the storage at the surface and 0.5m below the surface • North-eastern corner of the storage at the surface and 0.5m below the surface • South-western corner of the storage at the surface and 0.5m below the surface • End of the walkway at the surface, 0.5m below and 1.0m below the surface Water quality samples were taken from the open dam at the following locations: • Northern end of the storage at the surface and 0.5m below the surface • Southern end of the storage at the surface and 0.5m below the surface • Eastern end of the storage at the surface and 0.5m below the surface • End of the walkway at the surface, 0.5m below and 1.0m below the surface Unless there were issues with site access other technical problems, the same locations were monitored on each sample run to allow for direct comparison over time.
Frequency	In-situ water quality sampling using the Horiba U-10 or TPS90 Water quality meters was undertaken when the PST data was downloaded from the data loggers. This occurred generally fortnightly between August and November 2004. In addition to this, samples for laboratory analysis were taken from the EMT and open storage on the following dates: • 1 August 2004 • 19 October2004 • 26 October 2004 • 7 November 2004 • 12 November 2004 The dates of these laboratory analysed samples were set to coincide with the trials of monolayer application. In total there were 12 sample runs conducted for this site.

Parameters	As mentioned earlier, both In-situ and laboratory based analysis was conducted at Cubbie Station. **In-situ** The Horiba water quality meter that was used measured pH, Dissolved Oxygen, Conductivity, Temperature and Turbidity. **Laboratory analysed** A comprehensive set of parameters as defined by the ANZECC Water Quality Guidelines 2000 for the protection of Aquatic Ecosystems[1] was used to characterise the EMT and open storage prior to the application of monolayer was undertaken on 1 August 2004. These parameters included: • chlorophyll '*a*' • total phosphorus • filterable reactive phosphate • total nitrogen • ammonium • turbidity The 4 successive laboratory analyzed samples were tested for Chlorophyll *a* and algal count and identification. This monitoring was performed as a result of concerns over the monolayer's potential to increase algal growth.
Technique	**In-situ** The water quality meters were regularly calibrated as per the instruction manual. Where possible the water quality meter immersed directly into the water body and moved through the water slowly to allow a flow past the dissolved oxygen membrane. If it was not possible to take the measurement directly from the water samples were taken using the extension pole. The measurements were then taken immediately from the grab sample. The results were recorded on to a pre printed field data collection sheet and returned to the NCEA for data entry. The probes were rinsed in between each sample and stored as per the manual between sample runs. **Laboratory analysed** Samples requiring laboratory analysis from Cubbie Station at Dirranbandi were sent to Australian Laboratory Services in Brisbane. ALS is NATA Registered to perform all analyses conducted except the algal counts and ID which was outsourced to Brisbane City Council's Water testing laboratory. The appropriate paperwork was completed to ensure that the samples reached ALS within recommended holding times. All results from ALS have undergone QA/QC procedures. (Laboratory Duplicates (DUP); Relative Percentage Difference (RPD) and Acceptance Limits, Method Blank (MB) and Laboratory Control Samples (LCS); Recovery and Acceptance Limits, Matrix Spikes (MS); Recovery and Acceptance Limits.) A copy of a field data collection sheet, sample submission form, and laboratory results including QA/QC checks have been included in this appendix. All sampling was conducted in accordance with QLD Environmental Protection Agency's Water Quality Sampling Manual 1999.

7.4 Stanthorpe

Table A 7-4 Summary table of the water quality monitoring plan for Andreatta's farm at Stanthorpe.

Equipment	A TPS 90FL portable water quality meter was regularly calibrated and used to test the water in the covered storage. The water quality meter has data logging capability which reduced any errors that may have occurred in transcribing data

[1] Although the EMT storage at Cubbie Station is not an Aquatic Ecosystem, the monolayer product has the potential to be used in such ecosystems and hence the selection of 'Aquatic Ecosystem' as the environmental value of the water body.

	from the readout in the field.
Locations	Water quality sampling was only conducted on the covered storage at Stanthorpe. The sampling locations were as follows • Adjacent to the southern data logger • Adjacent to the northern data logger • Adjacent to the pump inlet As the EMT at Stanthorpe is a permanent fixture with only one entrance to under the cover, sampling this storage proved quite difficult. If the water level was close to the top of the storage access to the sampling points was restricted. For this reason, there is a limited amount of data for this site.
Frequency	Water quality sampling was undertaken when the PST data was downloaded from the data loggers. This occurred generally each 6 weeks to 1 month between November 2004 and January 2005. In total there were 5 sample runs conducted for this site.
Parameters	All samples tested using the TPS 90 water quality meter were analysed for pH, Dissolved Oxygen, Conductivity and temperature. Sampled tested using the Horiba water quality meter also included the analysis of turbidity.
Technique	The water quality meters were regularly calibrated as per the instruction manual. The water quality probes immersed directly into the water body and moved through the water slowly to allow a flow past the dissolved oxygen membrane. The measurements were then stored directly into the built in logger in the TPS90 The probes were rinsed in between each sample and stored as per the manual between sample runs. All sampling was conducted in accordance with QLD Environmental Protection Agency's Water Quality Sampling Manual 1999.

7.5 Capella

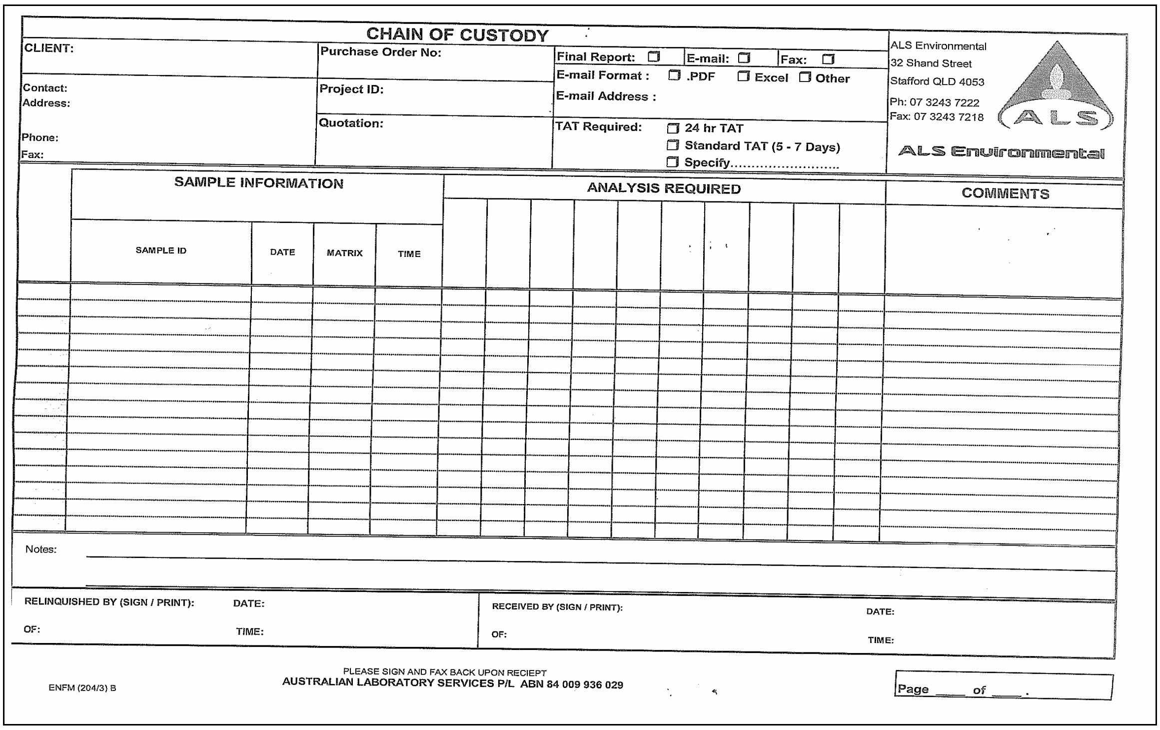
Water quality monitoring was not undertaken by the NCEA at Peak Downs Shire Council's Capella water treatment plant. The water quality results are from Peak Downs shire's own water quality analysis. The analysis has been undertaken by Queensland Health Scientific Services for assessment against the National Health and Medical Research Councils Drinking Water Guidelines. Therefore, the parameters are different to those used to assess environmental waters.

The water quality sampling was undertaken before the application of monolayer to the EMT dam and has not been repeated since. Therefore the Water quality data from Peak Downs shire's is of limited use in determining the affects that the EMT may have on the quality of water in storage but does provide some background if any further water quality studies are undertaken.

Table A 7-5 Summary table of the water quality monitoring plan for Peak Downs Shire Council's municipal water supply at Capella.

Equipment	Sample bottles were provided by Queensland Health Scientific Services with any required preservatives.
Locations	The samples were taken from Dams 1 and 2 at the following locations • Dam 1 at the surface, 0.5m below, 2.6m below, 4.5m below and 6.5m below (no further detail given) • Dam 2 (no further detail given)
Frequency	Samples were taken at irregular intervals between November 2003 and March 2004. In total there were 6 sample runs conducted at this site.
Parameters	The parameters analysed were • an algal count and identification • cyanobacteria
Technique	Queensland Health Scientific Services are NATA accredited for the count and identification of algae and cyanobacteria analysis.

Sample Submission Form/ Chain of Custody


CHAIN OF CUSTODY

CLIENT:
Purchase Order No:
Final Report: ❒ E-mail: ❒ Fax: ❒
E-mail Format : ❒ .PDF ❒ Excel ❒ Other
E-mail Address :
Contact:
Address:
Project ID:
Quotation:
TAT Required: ❒ 24 hr TAT ❒ Standard TAT (5 - 7 Days) ❒ Specify..........................
Phone:
Fax:

ALS Environmental
32 Shand Street
Stafford QLD 4053
Ph: 07 3243 7222
Fax: 07 3243 7218

ALS Environmental

SAMPLE INFORMATION: SAMPLE ID | DATE | MATRIX | TIME
ANALYSIS REQUIRED
COMMENTS

Notes:

RELINQUISHED BY (SIGN / PRINT): DATE:
OF: TIME:
RECEIVED BY (SIGN / PRINT): DATE:
OF: TIME:

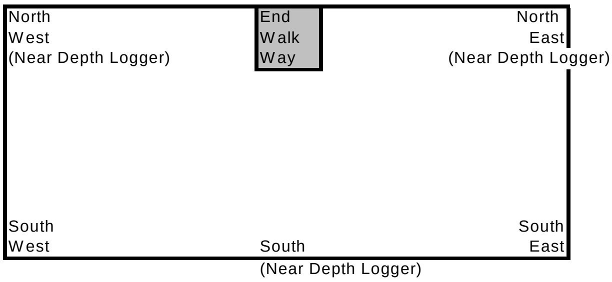
ENFM (204/3) B
PLEASE SIGN AND FAX BACK UPON RECIEPT
AUSTRALIAN LABORATORY SERVICES P/L ABN 84 009 936 029
Page ____ of ____.

Example of a field sampling sheet

Cubbie Station Monolayer (Treatment) Dam

Date		Sampler		Meter	Horiba/TPS

Site ID	Time	Site Detail & Depth	pH	Electrical Conductivity	Turbidity	Dissolved Oxygen	Temperature	Salinity	Further Observations
				mS/cm	ntu	mg/L & % saturation	oC	%	sheen, discolour, etc.
CT1		South 0.0m							
CT2		South 0.5m							
CT3		South West 0.0m							
CT4		South West 0.5m							
CT5		NorthWest 0.0m							
CT6		NorthWest 0.5m							
CT7		NorthEast 0.0m							
CT8		NorthEast 0.5m							
CT9		South East 0.0m							
CT10		South East 0.5m							
CT11		End Walk Way 0.0m							
CT12		End Walk Way 0.5m							
CT13		End Walk Way 1.0m							



Air Temp	Time	
		Start
		Finish