REDUCING EVAPORATION LOSSES - OPPORTUNITIES FOR COST EFFECTIVE WATER SAVINGS

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ABSTRACT

Annual evaporation losses from irrigation storage dams and channels are significant: it is estimated that there are more than 2,000,000 farm dams across Australia (Australian Water Association, 2006) representing some 8,000,000 ML water stored. Annual evaporation losses from these storages are estimated to be around 1.32GL/yr and up to 2.88GL/yr (Baillie, 2008).

This suggests investing in infrastructure to reduce such evaporative losses would be an attractive option for modernising irrigation systems.. Various products are already being used commercially for evaporation management, but come at high capital cost and are not considered appropriate for large areas.

This paper discusses opportunities for cost effective water savings using evaporation mitigation technologies. Technologies for measuring seepage and evaporation losses from dams are described and the economic viability of investing in evaporation control products is discussed, using case studies. The performance of different products is compared using an online Economic Ready Reckoner for evaporation mitigation systems and data from the case studies.

The CRC for Irrigation Futures has been researching the potential for using chemical monolayers for evaporation management since 2004. A brief review of this research is provided, including an assessment of the performance of monolayer products, factors affecting performance, and the development of monolayer application, monitoring and control systems.

INTRODUCTION

Australian agriculture is highly dependant on farm dams. Storage sizes range from a few megalitres (ML) for stock and domestic supplies to larger dams used for commercial irrigation. Conservative estimates suggest that in excess of 8,000,000 ML is stored in farm dams (i.e. 9% of total stored water) and that there are more than 2 million farms dams across Australia (AWA, 2006). Evaporation from bulk distribution channels in regulated irrigation systems also amounts to a significant loss.

Statistics on farm dams are generally based on data that is routinely collected to fulfill licensing requirements, and data obtained through remote sensing (Baillie, 2008). These information sources have typically been incomplete. However, recent information published by the Murray-Darling Basin Commission (2008) provides a more comprehensive database for the Murray Darling Basin.

Whilst data available at the time did not fully account for the storages estimated nationally, Baillie (2008) provided a first estimate of evaporation losses from farm storages based on a national total storage volume of 8000 GL, regional trends in

Irrigation and Drainage Conference 2009, Irrigation Australia Ltd, Swan Hill, Vic, Australia, 18-21 Oct 2009.

potential evaporation and scenarios of percentage time water is held. It was estimated that evaporation losses from on farm storages ranged between 1,320,000 ML and 2,880,000 ML. The employment of various evaporation reduction technologies could reduce these losses by 480,000 to 700,000 ML (Baillie, 2008). The large range in water saved reflects the variation in storage size and operating conditions, highlighting that different evaporation reduction products will be required for different markets. For larger storages, the performance of chemical barriers i.e. monolayers, will have a major impact on the upper estimate of water conserved using evaporation reduction technologies. Significant opportunities exist for effecting evaporation water savings, particularly in the northern parts of the Murray Darling Basin (Baillie et al., 2007).

The need to accurately measure seepage and evaporation losses, and to manage such losses through both traditional and new products has been increasingly recognised over the last decade (Watts 2005, Hipsey, 2006). The National Centre for Engineering in Agriculture undertook an evaluation of commercial evaporation mitigation technologies (EMTs) in 2005 (Craig et al., 2005). This work suggested an attractive option for irrigation system modernisation would be to invest in infrastructure to reduce such evaporation losses.

This paper provides an overview of the various products available commercially for evaporation management. The economic viability of investing in evaporation control products is provided using an online Economic Ready Reckoner for evaporation mitigation systems, and data from case studies.. New technologies for measuring evaporation and seepage losses from storage dams are also described.

The CRC Irrigation Futures has coordinated a program which has focussed on the use of chemical monolayers for evaporation control. Chemical monolayers demonstrate highly variable performance but could offer the most cost effective solution for storages greater than 5ha.

Current research on the performance of monolayer chemicals in reducing evaporation is discussed, including an assessment of the impacts of wind, water quality, dosage rates and volatilisation of the monolayer on monolayer spreading, performance and degradation rates. Research into systems for optimally applying monolayers using smart autonomous application systems is also described.

MEASURING EVAPORATION LOSSES FOR FARM DAMS

It is difficult to accurately measure evaporation from an open storage. Evaporation of a free water surface is the result of complex processes affected by incident solar radiation, wind speed, air temperature and humidity, and the energy stored in the water body, especially surface water temperature.

Regional estimates of long term average evaporation from storage dams, based on point potential evapotranspiration, can be accessed through the Australian Bureau for Meteorology. An online database (SILO) developed by the Queensland Department of Environment and Resource Management in co-operation with the Bureau of Meteorology provides access to daily synthetic data on evaporation for any set of coordinates in Australia.

It is important to quantify evaporation losses in order to assess the feasibility of investing in evaporation mitigation technologies. Methods for measuring evaporation loss from water storages include 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 LIDAR (Light Detecting and Ranging). A summary of the advantages and disadvantages of the various methods and their appropriateness is described by (Craig et al., 2005). In most cases these methods require sophisticated and expensive instrumentation and only provide measurement within the laser path, i.e. a single line integration of evaporation loss across the dam.

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

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

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 relatively poor accuracy of flow meters (in relation to the requirements for this application) suggests the best approach is to focus on periods when there is no inflow/outflow or rainfall.

The accuracy of this method depends greatly on the accuracy of the equipment used to measure the change in water depth. Precision pressure sensitive transducers (PSTs) are now generally used at locations where stilling wells with floats and rotary encoders or capacitance or ultra sound probes cannot be used. Water level can be logged continuously at sub-millimetre accuracy and in short time steps to identify the changing rate of water loss.

The most difficult parameter in this equation to measure is seepage. Potentially, soil analysis, infiltrometer readings and electromagnetic surveys undertaken before storage filling can be used to get some idea of seepage loss. However, these estimates, as well as point-based piezometer readings, are generally unreliable and not applicable to farm storages already holding water.

The approach of most water balance studies is to record rate of change of water depth, calculate evaporation using the best available model and by subtraction deduce seepage (Craig et al 2005 and Craig, 2006). A regression approach can be used to account for systematic errors in evaporation estimation and determine statistical significance and appropriate confidence levels in the estimated seepage and evaporation rates

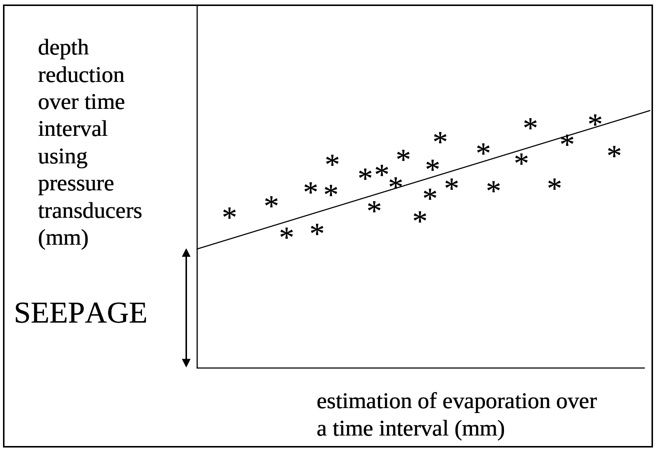

Figure 1 : Determination of storage dam seepage and evaporation from regression of measured reduction in water depth due to evaporation and seepage and estimated evaporation (Craig et al 2005).

The monitoring systems and data analysis techniques described above have recently been commercialised by Aquatech Consulting as the Irrimate™ Seepage and Evaporation Meter. The Irrimate™ Seepage and Evaporation Meter (Figure 2) uses an accurate PST to measure changes in water level every 15 minutes. Rainfall, wind velocity and water temperature is also logged for use in the analysis which requires at least 20 days worth of quality data with no periods of rainfall and storage inflow/outflow.

Figure 2 - Irrimate™ Seepage and Evaporation Meter

Data analysis is achieved by using the regression techniques described above to compare measured water level changes and estimates of evaporation loss. This process allows the evaporation and seepage components of the total loss to be separated, thus determining an average seepage rate and evaporation rate. Software (EvapCalc), developed by the CRC for Irrigation Futures through the National Centre for Engineering in Agriculture is used to undertake the analysis.

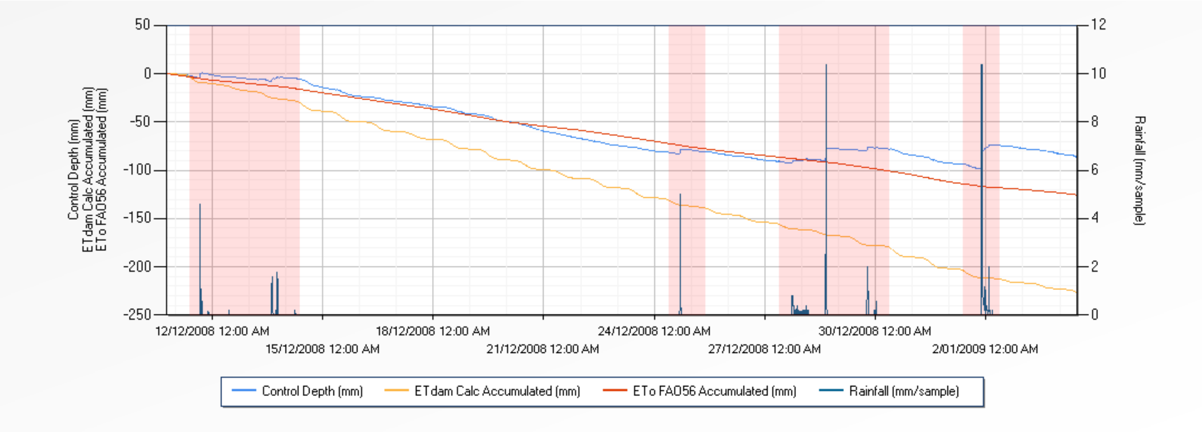

Figure 3 – Example of the EvapCalc software being used to determine seepage and evaporation.

PRODUCTS FOR REDUCING EVAPORATION

There are a wide range of products available for controlling evaporation loss (Figure 4). These systems include:

- Continuous Floating Covers
- Modular Covers
- Shade Structures
- Chemical Covers

A useful resource describing these products has been developed, initially through funding from Queensland Department of Environment and Resource Management and more recently through the CRC Irrigation Futures and National Program for Sustainable Irrigation NPSI: http://www.ncea.org.au/www/Evaporation%20Resources/index.htm.

Key factors in cover selection are percentage water saving achieved, capital, operating and replacement costs, impact on water quality and deployment and dam safety issues. A brief overview of these products is provided below, based on the above mentioned resource.

Continuous Floating Covers

Continuous floating plastic covers act as an impermeable barrier that floats on the water surface and can achieve above 90% evaporation savings for full cover of the dam. Most of these products have a high capital cost and replacement life varies (typically between 10 and 20 years). The structural integrity of the product under windy conditions and fluctuating water levels is important. Water quality can be impacted by reduced dissolved oxygen, light penetration and change in water temperature. This can have a positive impact in for example, reducing algal growth. Significant difficulties can be encountered with installation on large storages above 5ha. In some cases these covers can be deployed as a series of large rafts covering up to 1ha.

Modular Systems

Modular floating covers come in a range of sizes typically up to 3m^2 in area and act in a similar manner to floating covers. However, they do not have the structural challenges of a continuous sheet. Modular floating covers can also be deployed to cover only a portion of the storage, for example that portion always holding water. Modules can be free-floating or connected together to form a larger raft. Modules are typically made from a plastic material and can generally provide up to 90% savings for 100% area covered. Actual area covered will depend on number, shape and size of the module and storage characteristics. Generally these systems have a very high capital cost (in excess of $20/m^2). Repair and replacement of modules is possible and water quality impacts will depend on the relative area covered, and changes in oxygen transfer, light penetration and in water temperature.

Figure 4: Examples of Evaporation control products: Top left : Continuous floating cover; Top right : Modular System; Bottom left : Shade Cloth Structure; Bottom Right: Chemical Monolayer

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. Evaporation savings of 70% to 80% have been demonstrated in trials. Floating shade cloth modules or rafts have recently been marketed. Most of these products have relatively high capital cost. In general shade structures are not as effective in reducing evaporation as floating covers. However, they allow free flow of oxygen to the water, although wind velocity and wave action will be reduced, affecting dissolved oxygen levels. Algal growth may be reduced due to lower light penetration.

Chemical Covers

Chemical covers have been promoted as a low cost method to reduce evaporation losses. Some products are true monolayers (i.e. a single molecule thick) while others are multilayered, with different water saving characteristics and water quality impacts. These products are generally biodegradable and there is a need to reapply frequently (between three and ten days). Water savings have been shown to be highly variable, from less than 10% to up to 50%, and are impacted by prevailing wind, temperature and water quality.

True monolayers are applied at very low application rates and rely on the self spreading ability of the chemical. Advantages of these products are the low capital cost and choice to apply only when needed. Monolayers offer much potential for effecting evaporation savings, however it is recognised that further research is required to optimise their performance. The CRC for Irrigation Futures is conducting a comprehensive research program in this regards which is discussed later in this paper.

Storage Design and Management

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: (i) deeper storages with smaller surface areas, (ii) 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 (iii) using windbreaks around the storage. Benefits of these methods are easily quantified based on exposed area and reduced wind speed. Disadvantages of these methods are that it is generally easier to build a new storage, when site characteristics can be altered, rather than retrofitting an existing storage. When more than one storage is owned, water can be pumped between storages to minimise surface area per unit volume of water stored. Vertical water circulation (‘destratification’) can also reduce water surface temperature to decrease the rate of evaporation.

ECONOMIC VIABILITY

The cost benefit of evaporation control is a key driver in investment in the technologies described above. 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 storages at the location,
- efficiency of the EMT in mitigating evaporation, and
- storage operating conditions.

This needs to be compared with the value of water to the landholder in terms of increased crop production, the cost of water to be purchased or the potential to trade water surplus.

A Ready Reckoner has been developed by the CRC for Irrigation Futures (http://www.readyreckoner.ncea.biz) to help undertake such an economic analysis. The calculator allows site-specific assessment of evaporation mitigation systems. The user enters appropriate data to customise the ‘Ready Reckoner’ to their site. The

‘Ready Reckoner’ returns the volume of water saved (in ML) and the cost of the evaporation mitigation system used to save this water ($/ML saved/year). Inputs include:

- Site location (Latitude and Longitude) to estimate monthly evaporation loss
- Storage dam size and shape
- Storage operating conditions in terms of years out of ten the dam is expected to hold water and typical percentage full.
- Anticipated seepage losses
- Evaporation mitigation technology to be used.

Figure 5: Ready Reckoner to determine the economics of evaporation mitigation systems

Two examples are given for the Ready Reckoner below to illustrate its use.

Example 1:
Cotton Storage Dam at Moree (Rectangular Ring Tank)

- Volume : 2500ML
- Surface Area : 70ha
- Wall Height : 5m
- Annual Evaporation : 2,300mm
- Water held all year

Table 1: Case study on economics of three evaporation mitigation options for storage dam irrigating cotton at Moree.

Option 1 : Increase Wall Height	**Option 2 : Floating Cover**	**Option 3 : Chemical Monolayer**
Earthworks : 330,000m3 @ $3/m3 Evaporation Saved: 208ML/year Earthwork Cost : $1million Cost to save water : $256/ML/yr	Product cost $10/m2 Evaporation saving 95% Capital Cost : $6,8million Evaporation Saved : 1,458ML/year Cost to save water : $610/ML/yr	Product cost $15/litre Application 2 litre/ha every 10 days Evaporation saving 40% Evaporation Saved: 262ML/year Cost to save water : $254/ML/yr

Example 2:
Cherry and Grape Storage Dam at Orange (Gulley Dam)

- Volume : 50ML

- Surface Area : 1ha
- Wall Height : 10m
- Annual Evaporation : 1,500mm
- Water held all year

Table 2: Case study on economics of three evaporation mitigation options for storage dam irrigating cherries and grapes at Orange.

Option 1 : Increase Wall Height	**Option 2 : Shade Cloth**	**Option 3 : Chemical Monolayer**
Earthworks : 6,500m3 @ $3/m3 Evaporation Saved: 1ML/year Earthwork Cost : $20,000 Cost to save water : $1,600/ML/yr	Product cost $15/m2 Evaporation saving 70% Capital Cost : $150,000 Evaporation Saved: 6,8ML/year Cost to save water : $1,706/ML/yr	Product cost $15/litre Application 2 litre/ha every 10 days Evaporation saving 30% Evaporation Saved: 2,4ML/year Cost to save water : $428/ML/yr

The examples provided above are only intended to be illustrative and site specific assessment is required. The Ready Reckoner is ideal for this purpose. The cost benefit can be determined by comparing the annual cost to save a megalitre of water with the value of water to the operation or cost of a temporary water trade. For example, raising the dam wall to increase water depth to affect evaporation savings per unit of water stored is a viable option when the wall volume is small relative to surface area (e.g. Example 1) but expensive when relative wall volume is large (e.g. Example 2). Monolayers provide a potentially affordable solution but will be highly dependent upon evaporation saving achieved, as contrasted between Example 1 and 2. High evaporation rates in northern areas will result in lower relative cost per unit of water saved. The percentage of time the storage holds water will be critical, particularly for high capital cost products (e.g. shade cloth and floating covers) which are also less likely to be suitable for large storages (e.g. Example 1) given the capital outlay.

CURRENT RESEARCH INTO MONOLAYERS FOR EVAPORATION CONTROL

Chemical ‘monolayers’ (layers of one molecule thickness which can impede evaporation) provide an attractive option for reducing evaporation losses given low capital costs and suitability for large storages. However, inconsistent evaporation saving performance has limited their adoption in Australia. The CRC for Irrigation Futures (CRC-IF) recognised this as a key research area which led to a project currently underway.

The key objectives of the project are:

- to develop standardised methods for evaporation and seepage monitoring of storage dams based on depth sensing technologies and analytical procedures, and use of meteorological based evaporation estimates;
- to improve our understanding of monolayer product performance and factors that affect this performance;
- to develop improved monolayer products; and
- to develop monolayer application, monitoring and control systems and recommendations for best management practice

A summary of project activities and progress to date is provided below with reference to more detailed reports and publications.

Standardised methods for evaporation and seepage monitoring

Systems for measuring evaporation and seepage from storage dams described earlier are now being commercialized through the Irrimate™ network of consultants and Aquatech Consulting. The National Water Commission have funded a project aiming to improve the water efficiency of on-farm storages in the cotton industry by monitoring water losses to improve irrigator awareness and decision-making leading to system re-configuration. This project, delivered through the CRC Cotton Catchment Communities, is using CRC-IF monitoring technologies to benchmark storage performance on a target of 200 storages.

Product performance and understanding factors affecting performance.

A range of studies to identify performance and best management practices for monolayer systems have been completed (Morrison et al. 2008). Further studies are being conducted at Yanco by the NSW DPI. The studies have demonstrated wide variability in product performance with evaporation savings ranging from zero to 70% (Table 3). Much of the testing of performance of monolayer products has been focussed on small-scale replicated bucket and trough trials.

The main surface layer-forming chemicals trialled to date are:

- 'Water$avr' – hexadecanol (cetyl alcohol, 'C16'), known to form a mono-molecular layer (a 'monolayer') on a water surface, formulated with hydrated lime as a 'filler';
- 'Aquatain' – a silicone based oil (Si Oil) of unpublished composition.

Table 3: Results for all trough and bucket trials at 3 times recommended dosage for all three products aggregated by season and weighted according to the evaporative demand and duration of each trial (Morrison et al 2008).

	Weighted Mean Saving % [number of trials]			
Product	**C16**		***Si Oil***	
Vessel	Troughs	Buckets	*Troughs*	*Buckets*
Summer	**7 [3]**	**10 [3]**	***11 [3]***	***12 [3]***
Winter	**2 [2]**	**19 [4]**	***8 [2]***	***10 [3]***
Whole year	**6 [5]**	**15 [7]**	***10 [5]***	***11 [6]***

Despite standardising water containers, eliminating leakage and replicating treatments, considerable variability in the evaporation mitigation performance of all of the products was observed (Morrison et al., 2008). Consistently improved performance has been found with dosage rates up to three times the recommended rate. Subsequent analyses indicate that the Water$avr product formulation (a mixture of 5% active ingredient and 95% hydrated lime filler) is likely to have rendered the actual rate of application of the active ingredient on small surface areas uncertain (Hancock et al. 2009).

Although the results set out in Table 3 have been weighted with respect to differing evaporative demand from trial to trial, variability related to differing weather conditions remains. In particular wind conditions (Figure 6) and water surface temperature will independently affect evaporation. Figure 6 indicates the evaporation saving by a monolayer under different wind conditions in both bucket and tank trials (Pittaway et al., 2009). The results indicate that when 61% of the trial had wind conditions less than 10km/hr the evaporation loss was between 30% and 40% of the open water control. Increased windspeed results in poorer performance, particularly for the trough containers with a larger surface area.

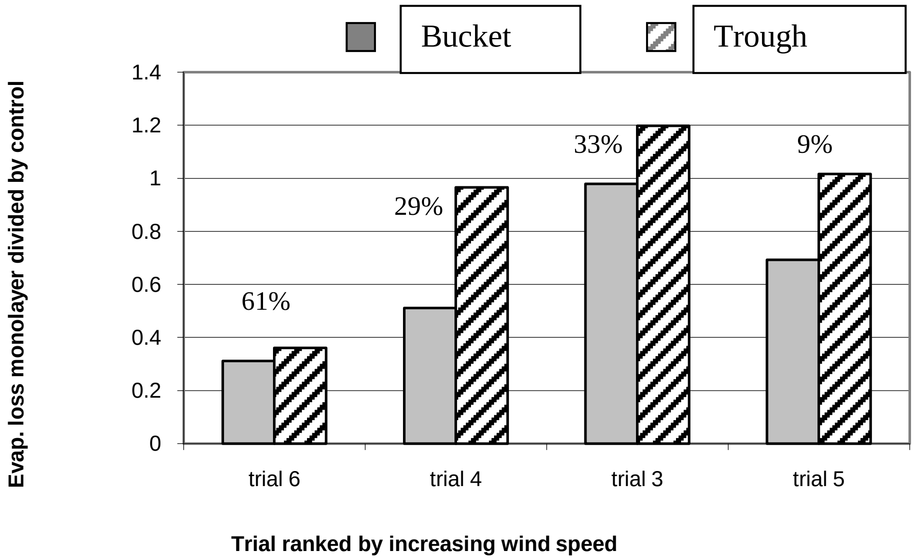

Figure 6: Evaporative loss with a monolayer compound applied, divided by the control (no surface film). Trial results are ranked from the left in order of wind speed. The proportion of the trial when the wind was less than 10 km/hr is listed as a percentage. Better bucket performance reflects less wind turbulence (after Pittaway et al., 2009)

A series of experiments were performed to explore and evaluate the wind-stress performance of the same commercially-available products for evaporation mitigation (McMahon et al., 2008). The difficulties of surface film detection and measurement, and the need to control windspeed, necessitated a laboratory study with a range of application rates (x1, x3 and x10 with respect to the manufacturers' recommended application rate), water temperature, 20^{o}C and 30^{o}C; and water quality – tap water and small surface water dam water were evaluated.

It is concluded that materials had limited resistance to the drag forces imposed by wind, but significant differences were also observed. The silicone oil was the most generally resistant to wind stress and its performance was improved at higher application rates (x3). Otherwise its performance was independent of both temperature and water quality (McMahon et al., 2008). The performance of hexadecanol was improved with much higher application rates (x10) and also at higher water temperatures. Water quality (tap water versus dam water) had no discernable impact on the wind stress performance of any product.

Interaction between water quality and natural microlayers and artificial monolayers.

Variations in product performance are also influenced greatly by the presence and development of natural microlayers present on all natural waters (Pittaway and van den Ancker, 2009). Microlayers are natural surface films derived from hydrophobic organic compounds that form on most lakes and streams. The role of natural microlayers in reducing monolayer performance has not previously been investigated (Pittaway and van den Ancker, 2009). A comparison of the properties of natural microlayers and artificial monolayers has been provided by Pittaway et al. (2009).

Recent work characterising microlayer and subsurface water samples from six water storages in Queensland for water quality indices (biochemical oxygen demand, permanganate index and ultraviolet light absorbance, Pittaway and van den Ancker, 2009) has indicated the enrichment of the surface water (microlayer) relative to subsurface water.

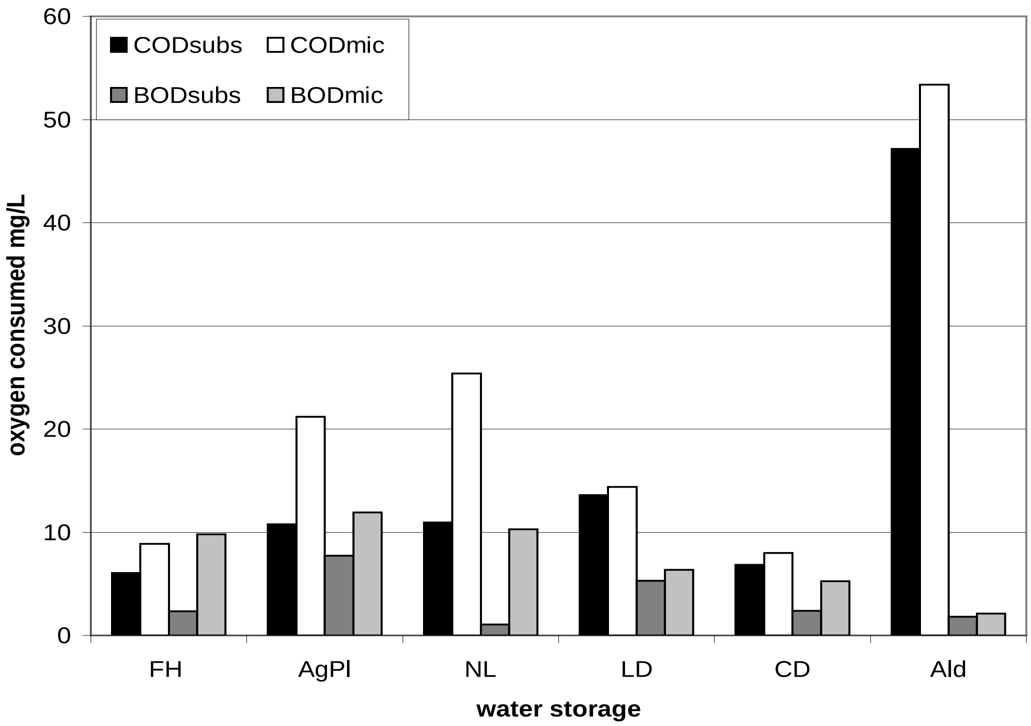

Figure 7 : A comparison of the permanganate chemical oxygen demand (COD) and the 5-day biochemical oxygen demand (BOD) for microlayer (mic) and subsurface (subs) water samples from six open storages located in southeast Queensland. FH is Forest Hill, AgPl is the Agricultural Plot tank at the University of Southern Qld, NL is Narda Lagoon, LD is Lake Dyer, CD is Cooby Dam and Ald is the Alderton water storage (Pittaway et al. 2009)

Results indicate that microlayer compounds may disrupt monolayers in at least three ways: As substrates for microbes capable of degrading monolayer compounds, as chromophores accelerating photodegradation, and as impurities disrupting the molecular packing required to reduce evaporative loss. The knowledge gained from studying natural microlayers can be used to benchmark novel monolayer compounds, to minimize their environmental impact on freshwater ecosystems (Pittaway and van den Ancker, 2009).

Development of improved monolayer products

A key challenge in efficient monolayer evaporation control systems will be the development of new products with consistent performance that can be applied optimally. An alliance between three Cooperative Research Centres (Irrigation Futures, Polymers and Cotton Catchment Communities) during 2007/2008 focussed on the development of improved monolayer materials which have shown improved performance over current commercial products.

Monolayer application, monitoring and control systems

Research into monolayer application monitoring and control systems is focussed on developing improved application methods and strategies. Two approaches are now well advanced.

Firstly, progress is well advanced in the design of a ‘Demonstrator System’ to both demonstrate and explore the practicalities of ‘smart’ autonomous application of chemical monolayer to open water surfaces (Brink et al., 2009a). The system will include a decision-making component capable of individually and adaptively controlling the monolayer dosage rate for each applicator according to spatial dthe evaporation rate of water and volatilisation of monolayer.

The design requirements for the smart application system include sensors to monitor changing environmental conditions that influence monolayer performance (e.g. evaporation rate, air temperature, wind speed and direction, solar radiation, relative humidity and rainfall). An overview of the demonstration system is provided in Figure 8. The sensors, coordinator and applicator all communicate wirelessly. Data is sent from an Automatic Weather Station (AWS) and an Irrimate™ Seepage and Evaporation Meter (SEM) to the Coordinator Unit for analysis. Once the coordinator has calculated the required application rate this information is sent to the applicator for action (Brink et al., 2009a).

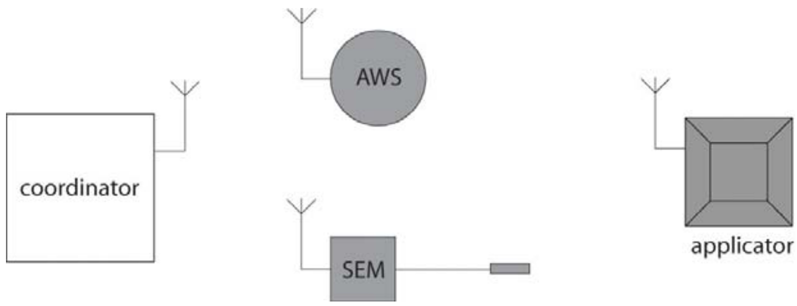

Figure 8: Schematic overview of the prototype ‘smart’ autonomous system for monolayer application (Brink et al 2009a).

The second approach involves the development of a generic ‘Universal Design Framework’ (UDF) for smart monolayer application (Brink et al., 2009b). The UDF has been formulated to facilitate optimum deployment of monolayer application systems, for any climatic situation and for all dam sizes. The UDF informs the selection of appropriate equipment, including the design and number of applicators, their arrangement on-site and application strategies for a given dam site; and also ensures sustained autonomous operation is efficient, both as regards evaporation reduction and monolayer use. Key factors accommodated by the UDF include:

- Water storage factors (Surface area, depth and shape of the farm water storage).
- Topography and local microclimate.
- Climate (meteorological data).
- Water quality and biological factors.
- Monolayer product choice.
- Water value.

Monolayer Detection

Detection of monolayers on a water surface will be crucial for managing application rates to attain maximum cover with minimum product. A range of approaches have been trialled for automatic detection (Coop et al., 2008). Such systems include spectrometry, fluoroscopy, polarisation, horizontal tension measurements, laser detection, lipid dyes, indicator oils and temperature measurements.

While a number of methods can detect a monolayer in the laboratory, detection in the field under unstable conditions is more difficult. The most promising method uses accurate temperature sensing as a means of detecting a monolayer based on the reduced evaporative cooling. The presence of a monolayer on a water surface 'insulates' the surface from evaporative cooling. The sensor detects this insulating effect by exposing the isolated water surface sample to a fan sequence of varying velocity, analysing the temperature differentials (Figure 9). Further work is being done on optimising this approach with field trials planned.

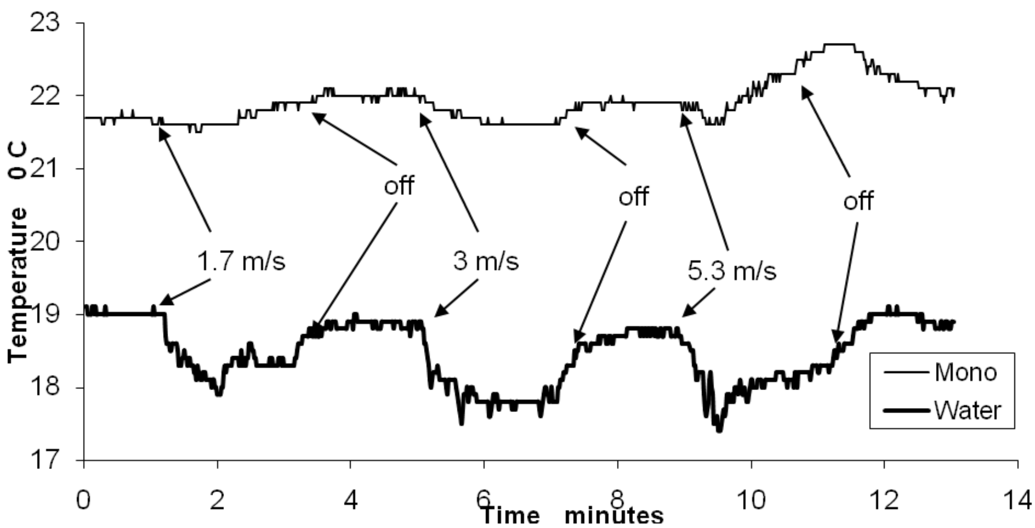

Figure 9. Remote infrared thermometer measurement of water surface temperature with fan sequence under free water and monolayer (C16) covered water conditions (Coop et al 2008).

CONCLUSIONS

Annual evaporation losses from irrigation storage dams and channels in Australia are significant. This suggests investing in infrastructure to reduce evaporative loss would be an attractive option for irrigation system modernisation
It is important to quantify evaporation losses from storages in order to assess the feasibility of investing in evaporation mitigation technologies. Methods for measuring evaporation and seepage losses from storages have been developed based on a water balance approach. These methods have now been commercialised as the Irrimate™ Seepage and Evaporation Meter, and are being used by a number of industry consultants.

There are a wide range of products available for controlling evaporation loss including continuous floating covers, modular covers, shade structures and chemical monolayers. Key factors in cover selection are percentage water saving achieved, capital, operating and replacement costs, impact on water quality and deployment and dam safety issues. The cost-benefit of evaporation control is a key driver in investment in these technologies, and a Ready Reckoner has been developed by the CRC for Irrigation Futures to undertake site specific economic analysis.

Monolayers provide an attractive option for reducing evaporation losses given low capital costs and suitability for large storages. Inconsistent evaporation saving performance has limited their adoption in Australia. The CRC for Irrigation Futures recognised this as a key research priority.

Recent research has improved our understanding of monolayer product performance and factors affecting this performance. Research is also focussing on the development of improved monolayer products and smart monolayer application, monitoring and control systems.

The studies have demonstrated significant variability in product performance with evaporation savings ranging from zero to 70%. Despite standardising water containers, eliminating leakage and replicating treatments, considerable variability in the evaporation mitigation performance of all monolayer and evaporation mitigation film products was observed. Consistently improved performance has been found with dosage rates up to three times the recommended rate. There is also evidence that variability in product performance is related to wind velocity and the condition of the water in terms of micro-scale differences in temperature and in the biochemical and biophysical characteristics of the natural microlayer.

New monolayer products are showing improved performance over current commercial products while good progress has been made in development of ‘smart’ autonomous monolayer application systems capable of individually and adaptively controlling the monolayer dosage rate in response to changing environmental conditions that influence monolayer performance.

Detection of monolayers on a water surface will be crucial for managing application rates to attain maximum cover with minimum product. While a number of methods can detect a monolayer in the laboratory, the most promising method for field application uses accurate temperature sensing as a means of detecting a monolayer based on the reduced evaporative cooling.

RECOMMENDATIONS

More accurate information on the location and characteristics of storage dams is required. While good information is now available for the Murray Darling Basin

(Murray-Darling Basin Commission, 2008), similar programs/projects? should be implemented nationally. Combining information on storage dam location and area with regional evaporation data would generate useful regional information on evaporation losses, at a sub-regional scale.

Commercial systems for measuring evaporation and seepage losses from storage dams are now available. Widespread use of these technologies will allow benchmarking of losses from storage dams leading to the prioritisation and selection of site-specific management strategies to reduce these losses.

A range of commercial products are now available to control evaporation. Uptake of these products will be driven by the cost-benefit of deployment. Further adaptation of these systems for deployment on a large scale at an affordable price is required. The management and maintenance of these systems and their impact on dam safety and water quality will become an issue, particularly on large multi use storages.

Further research is required on the factors impacting the performance of monolayer evaporation retardants. Standard testing protocols need to be developed which will lead to consistent testing procedures. In particular, further research on the role of wind speed and duration, and on microlayer and subsurface water quality is needed to interpret monolayer field performance. Large scale trials of monolayer products on commercial sized storages are required now that we have a better understanding on the processes affecting their performance.

New monolayer products with enhanced performance will be key to the successful commercialisation of these technologies. Current work being undertaken needs to be expanded.

Monolayer application systems that can adaptively manage monolayer dosage in response to changing environmental conditions which influence monolayer performance will lead to significant improvements in water savings. Current demonstration units will require robust field testing prior to commercialisation.

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