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Reducing Loss from Evaporation

Report to Cotton Research
and Development Corporation

July 1995

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Waterplants and Wetland Management

Reducing Loss from Evaporation

BACKGROUND

Evaporation mitigation from farm storages in the cotton valleys:

Evaporative loss from off-allocation stored water in the cotton industry in NSW is estimated at around 150 000 megalitres each year. This can mean a loss of 1.5 to 2 metres of water depth from any one storage in a year, with about 80% of that loss occurring between October and April. The marginal value of a megalitre of water is put at \$300 or more by the cotton industry. About \$45 million dollars worth of cotton could be produced from 150 000 megalitres of water.

THE STUDY:

Commissioned in November 1994, it was funded equally by the Cotton Research and Development Corporation (CRDC) and Sainty and Associates with a budget of \$47 000 and the following work was undertaken:

1. *Azolla* evaporation study (University of Western Sydney).
2. Floating ring evaporation study (RMIT, Melbourne).
3. Evaporation mitigation from on-farm water storages (CSIRO Centre for Environmental Mechanics).
4. Study tour of six cotton farms (CSIRO Division of Water Resources, Sainty and Associates).

1. *Azolla* evaporation study:

This work was carried out by Mr Peter Adcock, Water Research Laboratory, University of Western Sydney, Hawkesbury. The study showed that *Azolla filiculoides* **does not reduce evaporation significantly** enough to warrant further testing (refer to appendix 1).

Practical implications of the study: The results suggest that *Azolla* increases loss of water by transpiration on days of low pan evaporation. This could lead to the practical conclusion that **any form of cover should be removed from the water surface during the cooler/cold months of the year.**

2. Reflective ring evaporation study:

This work has been carried out by Mr Ian Burston and Dr Ali Akbarzadeh at the Royal Melbourne Institute of Technology (RMIT) Bundora Campus, Melbourne. Their report is in the appendix. *Azolla filiculoides* was placed in the middle of the floating rings to ensure an even cover over the water surface. However, the RMIT experiments confirmed the findings of the University of Western Sydney (see 1 above) that *Azolla* does not significantly reduce evaporation. In the same experiment floating reflective rings (Aquacaps) **reduced evaporation by 66%**. Further, the work estimated a pay back period of about 3 years when Aquacaps are costed at \$1 per square metre (refer to page 19–20 of their report in appendix 2).

Future work: The researchers have recommended field testing of Aquacaps. They estimate a cost of around \$28 000 for sufficient Aquacaps to cover a surface area of 1000 square metres and instrumentation to record the changes. Additional costs would be for dam construction, water, and supervision of the project for 2 years. Two water storages adjacent to each other and of the same dimensions would be necessary for comparison.

3. Evaporation mitigation on farm, and literature search:

This work was carried out by Mr Scott Condie and Dr Ian Webster CSIRO Centre for Environmental Mechanics (CEM), Canberra. Their report is in the appendix (3). They concluded:

Significant reductions in evaporation can be made on farms by maximising depth and dividing storages into cells. Such measures are already operating effectively on a number of farms and have been shown to be cost effective over 3–4 years.

Planting windbreaks within the storage has the potential to significantly reduce evaporation. The windbreaks would also protect the outer bank from erosion.

Further study: More work is necessary to determine the value of windbreaks and the Centre for Environmental Mechanics has indicated how this can be done. The complete study would entail two laboratory components and a field-based experiment at a total cost of \$31 600. The cost of the laboratory work could be greatly reduced by incorporating this study with another larger windbreak study already planned for 1995/96 (refer to page 14 of CEM report, appendix 3).

4. On-farm study:

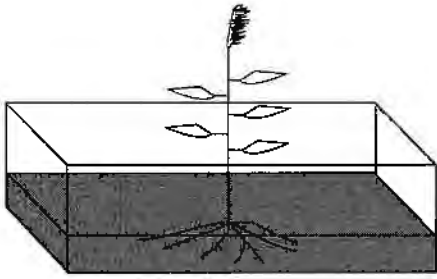
The on farm study was carried out by Dr Anthony Scott (CSIRO Division of Water Resources), Mr Scott Condie (CEM) and Mr Geoff Sainty. A report by Anthony Scott is in the appendix. The study focussed on the shape and management of storages to minimize loss from evaporation. Six farms were visited and advice from Barrett Purcell and Associates, irrigation engineers, was received.

Further work: Leading cotton growers are adopting most of the practices that lead to reduced evaporation on farm. However the cotton industry would benefit from the production of a **booklet** that describes the best practices to reduce water loss on farm, and the cost/benefit from doing the work.

RECOMMENDATIONS

- (a) Studies with *Azolla filiculoides* indicate that no further testing with floating aquatic plants is warranted.
- (b) Floating reflective rings significantly reduce evaporation and larger scale tests are recommended using two small dams.
- (c) Initial studies with windbreaks indicate that evaporation might be reduced, and further laboratory and field tests are proposed.
- (d) Produce a booklet for the cotton industry which outlines best practices for reducing evaporation.

APPENDIX 1



Microcosm Experiments

Peter Adcock, Water Research Laboratory, University of Western Sydney, Hawkesbury,
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Aim:

- 1) To measure water loss from *Azolla* at 0, 25, 50, 75, and 100% plant cover.
- 2) To compare water loss from *Azolla* with *Lemna* and pan evaporation.

Methods:

Waterplants were grown in large plastic tubs. The tub dimensions were 1.4 x 0.7 metres, and 0.6 metres deep. Plant cover was controlled with the use of floating rings. Water loss was measured using calipers. Three measurements were taken for each reading and then averaged.

Results:

Results were accumulated over a three month period. During the trial, evaporation rates between the treatments fluctuated with no apparent trend evident. In an attempt to assess long term trends aggregate water loss was calculated for each treatment (Table 1). This showed that over the entire length of the trial the variations in water loss had not been consistently higher in any one of the treatments. The lowest amount of water lost was in the tub with a 100 % cover of *Lemna* (279 mm), and the highest was in the tub with a 100 % cover of *Azolla* (289 mm). The tub with no plant cover lost 286 mm of water. These results were not significantly different.

Table 2 shows the average daily water loss from each treatment. The results fluctuated between 3.70 mm/day and 3.85 mm/day. During the length of the trial there were larger fluctuations, but once again no treatment was consistently higher or lower than any other treatments.

Discussion

There is one component of the study that tables 1 and 2 do not show. That is the performance or water loss from the tubs during periods of high and low pan evaporation. Pan evaporation should only be used as an indicator because water loss from the tubs was always higher than pan evaporation. It is still possible however, to compare the relative performance between different treatments (plant coverage).

The variations in water loss are responses to variable climatic conditions including temperature, wind speed, and humidity. All of which effect both evaporation and evapotranspiration. As shown in the results there were fluctuations between treatments during the experiment, however when the data was aggregated there was not a significant difference, hence no one treatment had consistently lost water at a higher or lower rate than other treatments. In effect days of high water loss from a tub were being compensated by days of a relatively low water loss. This could be explained by the evapotranspiration of the plants having less extremes than evaporation. Evaporation is driven purely by physical processes, evapotranspiration is driven by biological processes. In high evaporation conditions water loss may be restricted to a maximum level by the plants, in such conditions evaporation from open water could be higher than evapotranspiration. In low evaporation conditions plants will still be releasing water from their stomates, and this water loss may be higher than evaporation.

Another component of plants and their influence on water loss from water storages is the effect the plants have on the recharge of rainfall directly into the storage basin. Whether plants or physical structures are used to restrict water loss they should not obstruct rainwater from reaching the water column. Some aquatic plants do this, catching water on their leaves which is evaporated off the leaves at a quicker rate than water which has reached the water column.

Table 1 Aggregated water loss from different treatments over the entire length of the trial.

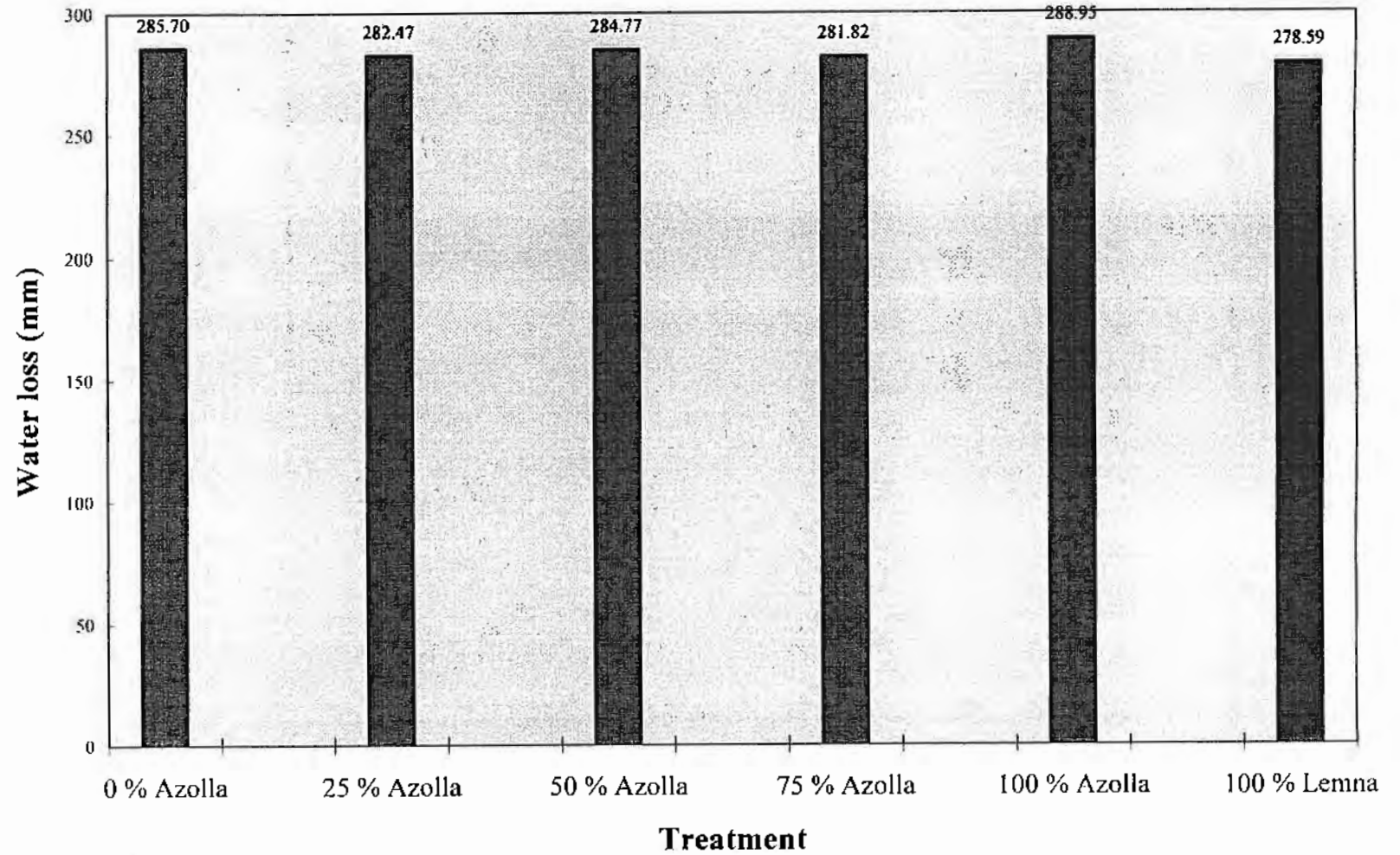
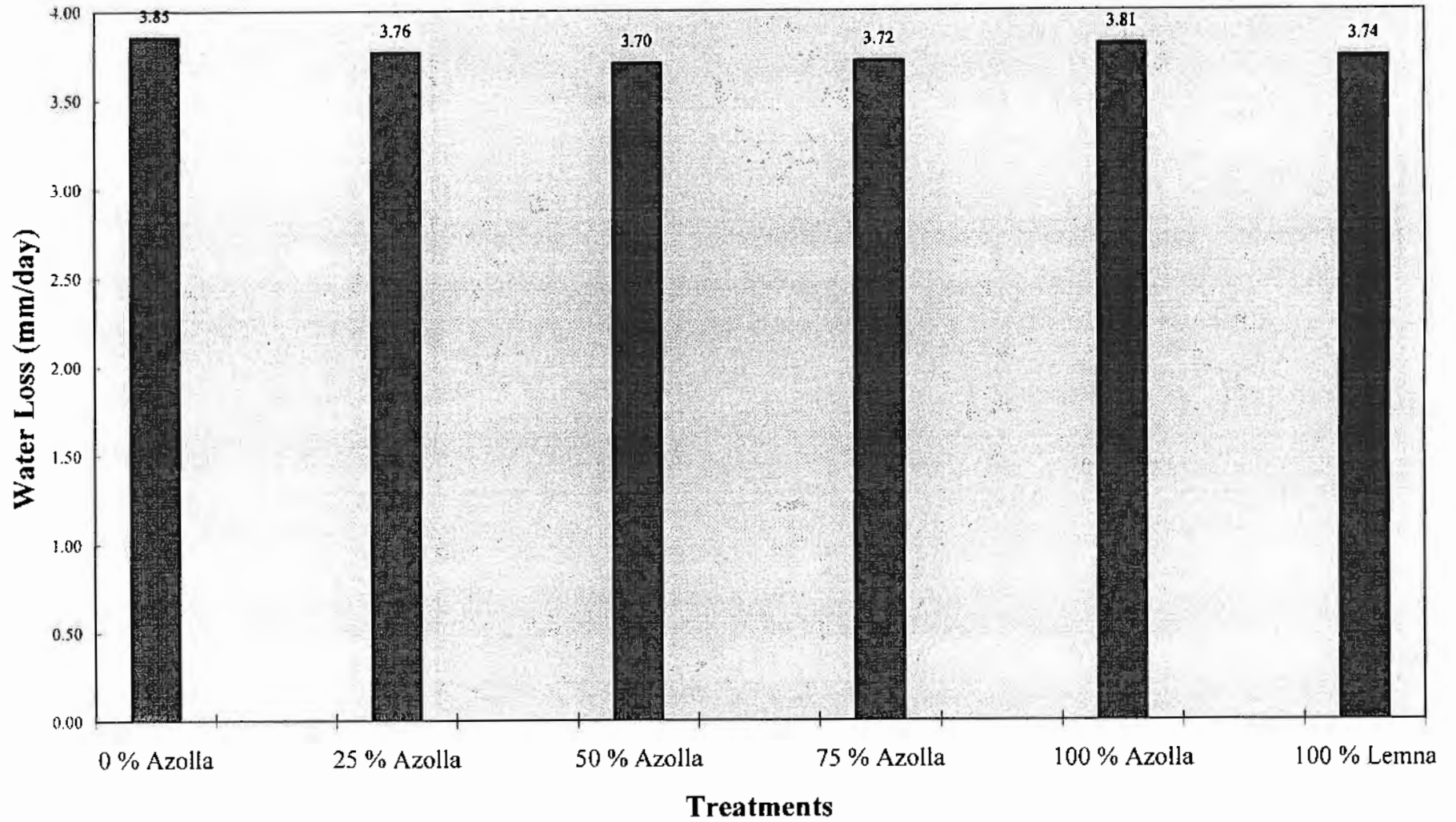


Table 2 Average daily water loss from each treatment



APPENDIX 2

FRESH WATER STORAGE - EVAPORATION RESEARCH

FINAL REPORT

Evaporation Study

June 1995

Authors

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FRESH WATER STORAGE - EVAPORATION RESEARCH

FINAL REPORT

Evaporation Study

June 1995

1. Introduction

In November 1994, the Energy CARE Group within the Department of Mechanical Engineering at RMIT was approached by Mr. G. Sainty of Sainty and Associates working in conjunction with the Cotton Research and Development Corporation, to consider ways in which evaporation could be reduced from constructed fresh water storages in the cotton growing valleys of NSW. The storages vary in volume from between 1000 to 4000 megalitres (ML) and can have dimensions in the order of 1000 metres (m) by 200m with depths between 4 and 7 metres.

Previous research carried out in 1981 by Dr. Akbarzadeh et al. had considered ways in which floating rings could reduce surface mixing in solar ponds. Based on the information obtained from this research, it was decided to investigate methods in which floating rings could be used to assist in reducing evaporation from fresh water storages.

The module of a floating ring was considered suitable for investigating three different methods for reducing evaporation. Firstly, the rings only in water, secondly, the rings as a means of stabilising the location of Azolla, a water borne fern and thirdly, to support a plastic cover. Initially three above ground swimming pools (ponds) were considered for the study, each being filled with fresh water. A fourth pond was later added as a reference pond containing fresh water only.

In January 1995, four above ground swimming pools were constructed at the RMIT Bundoora East Campus. Instrumentation at the site consisted of a standard 203 millimetre (mm) diameter rain gauge and a Class A evaporation pan which included a Six's minimum / maximum thermometer. Full meteorological data for the area has been obtained from a nearby weather station.

2. Report

2.1 Pond Construction and Filling

Construction of the four 4.5m diameter by 0.8m high ponds commenced on 13 January. Due to problems associated with the availability of materials, the last pond was not completed until 31 January. Each pond was filled to a depth of approximately 700mm allowing a freeboard of 100mm. The ponds have been given the following designation:

- P1: Pond with rings only;
- P2: Pond with rings and azolla;
- P3: Pond with rings and caps; and
- P4: Reference pond.

2.2 Ring Construction and Placement

Two types of material were experimented with to determine the most suitable for the study. Opal coloured high density polyethylene (HDPE), 1.5mm thick with a specific gravity (SG) of 0.96 was found to be too flexible and with insufficient buoyancy. An alternative using white low density polypropylene (LDPP), 3.0mm thick with SG 0.91 was decided upon for its rigidity, buoyancy, ability to reflect solar radiation and availability. Sheets of the LDPP were cut into strips 1200mm long and 50mm wide. The strips were then bent into circles and fastened with steel staples forming a ring of diameter 380mm with a depth of 50mm.

Covers for the rings (caps) were made from 10mm diameter bubble plastic (used normally for packaging). The plastic was cut into 500mm diameter circles and fastened to the rings with a white adhesive tape. Holes were punched in the plastic to ensure that water did not collect on its surface and the surface was then painted with a white acrylic paint to reflect as much solar radiation as possible.

The rings were installed in the pond by firstly placing them at the edge then progressively pushing them towards the centre. The number of rings varied for each pond. The pond with rings only (P1) has 118, the azolla pond (P2) has 113 although it could take more and the pond with rings plus caps (P3) has 115 due to the thickness of the bubble plastic. Sufficient rings were placed in P1 and P3 to ensure the surface was covered while allowing the rings to move freely. It was not considered necessary to place more rings in P2 as the azolla was performing as required. Figure I, Figure II and Figure III show that the ponds are well established on 27 February with the rings in place.

FRESH WATER STORAGE - EVAPORATION RESEARCH

Evaporation Study

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FRESH WATER STORAGE - EVAPORATION RESEARCH

Evaporation Study

Executive Summary

During this research, three possible concepts for reducing evaporation were investigated using plastic rings floating on water filled pools. The concepts were: 1) pool covered with rings only; 2) pool covered with rings and a water borne fern (*Azolla*) and 3) pool covered with rings supporting a cap to provide a modular pool cover. To check the validity of the concepts, the results were then compared with the results of a 'reference pool'.

An analysis of the results indicates that the concept of rings only decreases surface actions but the net effect on evaporation reduction is minimal at 0.4% compared to the reference pool. The concept of rings plus *Azolla* worked well in stabilizing the location of the *Azolla*, however the option does not appear viable with only a 5.5% reduction of evaporation compared to the reference pool.

The rings plus caps concept shows great potential and demand for further research with a 65.4% reduction of evaporation compared to the reference pool.

This report emphasises the need for additional research on the rings plus caps concept (referred in this report as an *Aquacap*), particularly in the areas of production of a prototype and field testing the prototype in an area under the conditions for which it is required.

The study identifies that in order to get some reliable information, any future study should focus on *Aquacaps* being tested on a minimum size water surface area of 1000m². Two water storages adjacent to each other and of the same dimensions would be necessary for comparison.

In addition, the study points out the need for instrumentation to provide meteorological data on a daily basis. Also, the duration of any future study would need to be sufficient to obtain data for at least two seasons of evaporation.

This study has shown that a significant reduction of water loss due to evaporation from a water storage is possible using *Aquacaps* with an estimated pay back period of about 3.3 years.



Figure I. Pond P1 with rings in place.



Figure II. Pond P2 with rings and azolla in place, 31 days after planting.



Figure III. Pond P3 with rings and caps in place.

2.3 Planting of Azolla

Approximately 30 kilograms (kg) of wet azolla was evenly distributed across the surface of the pond to ensure that each ring and between the rings contained some of the plant. The azolla was placed in the pond on Friday, 27 January. By Tuesday, 31 January, an even layer of azolla covered the pond with only a couple of rings not completely filled (Figure IV).

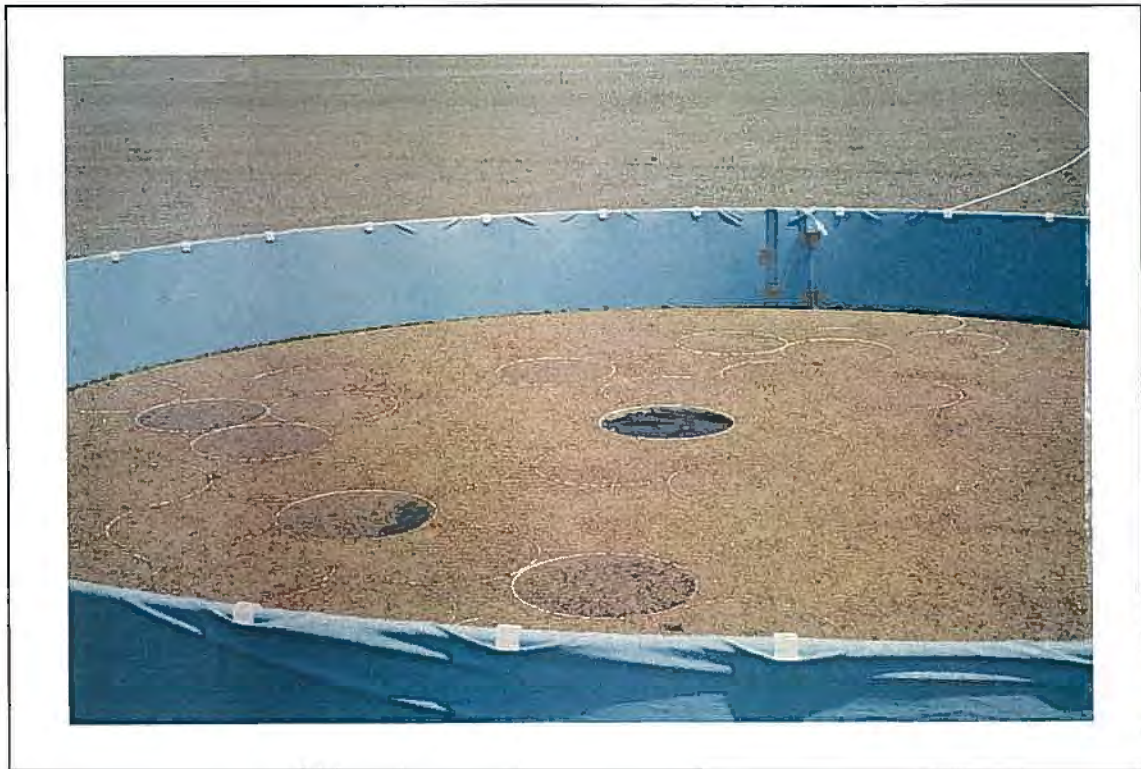


Figure IV. Azolla and rings four days after planting.

2.4 Observation Period

Recording of levels in the ponds commenced on 1 February, however the period of observation was taken from 10 February (after all equipment and procedures were fully established). The observation period continued until 7 April, after that the amount of daily evaporation had considerably reduced. Data was taken during the observation period close to 9 am each Monday, Wednesday and Friday.

2.5 Data, Instrumentation and Evaporation Measurement

Most of the data for the study was recorded manually as power was not available close to the ponds and it was not considered necessary to monitor them continuously.

During each observation, the following information was recorded:

- level of water in ponds;
- the number of buckets of water required to refill each pond;
- the ambient temperature and pond temperatures;
- Class A pan evaporation with minimum and maximum temperatures; and
- rainfall.

Full meteorological information from a nearby weather station was available for the duration of the study.

Two simple methods were used to measure evaporation:

- 1) Observed - change in water level from datum;
- 2) Calculated - change in water level from volume of water added to each pond.

Pond water levels were taken using a plastic hose to syphon water from the pond. The hose was held against a ruler attached to the side of the pond and the level of water was observed. Having recorded the pond levels, they were then refilled to datum level using buckets of water. The volume of water taken to refill each pond was converted into litres which in turn provided the amount of evaporation in millimetres for the respective surface area of each pond.

Rainfall was considered when calculating evaporation and in all cases it was taken as positive evaporation. No water was physically removed from the ponds when rain filled them above datum. In these cases, natural evaporation was relied upon to bring the level back to datum.

Measurement of evaporation from the Class A pan has been carried out in accordance with standard practice which involves either adding or removing water after each observation.

Pond temperatures were taken from three levels; 100mm, 300mm and 700mm from the bottom of the pond to identify bottom, middle and surface temperatures. This was achieved using a thermocouple attached to a sliding pole. The thermocouple was connected to a digital thermometer.

2.6 Results

The results for the period of observation, i.e. 10 February to 7 April, 1995 are shown in the following charts. The observed cumulative evaporation for the ponds and the Class A pan are shown in Figure V. The corresponding results for calculated cumulative evaporation are shown in Figure VI.

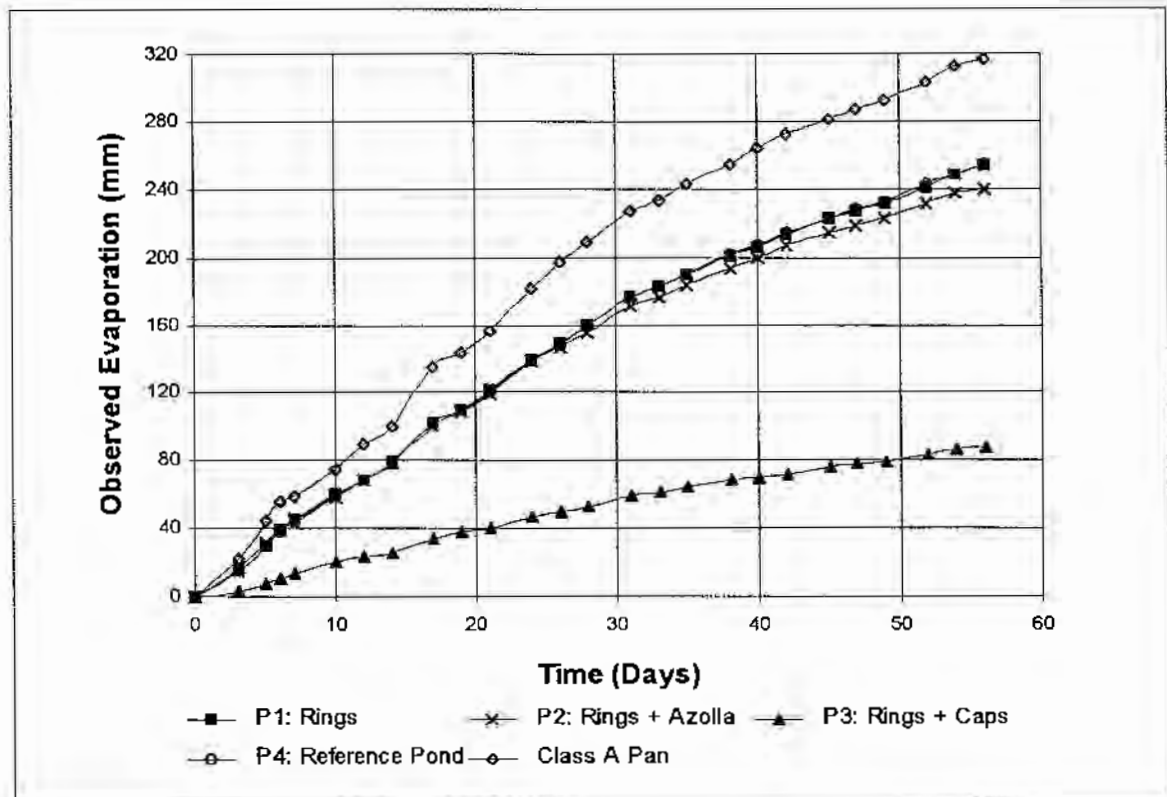


Figure V. Cumulative Evaporation - Observed (10 Feb. - 7 April, 1995).

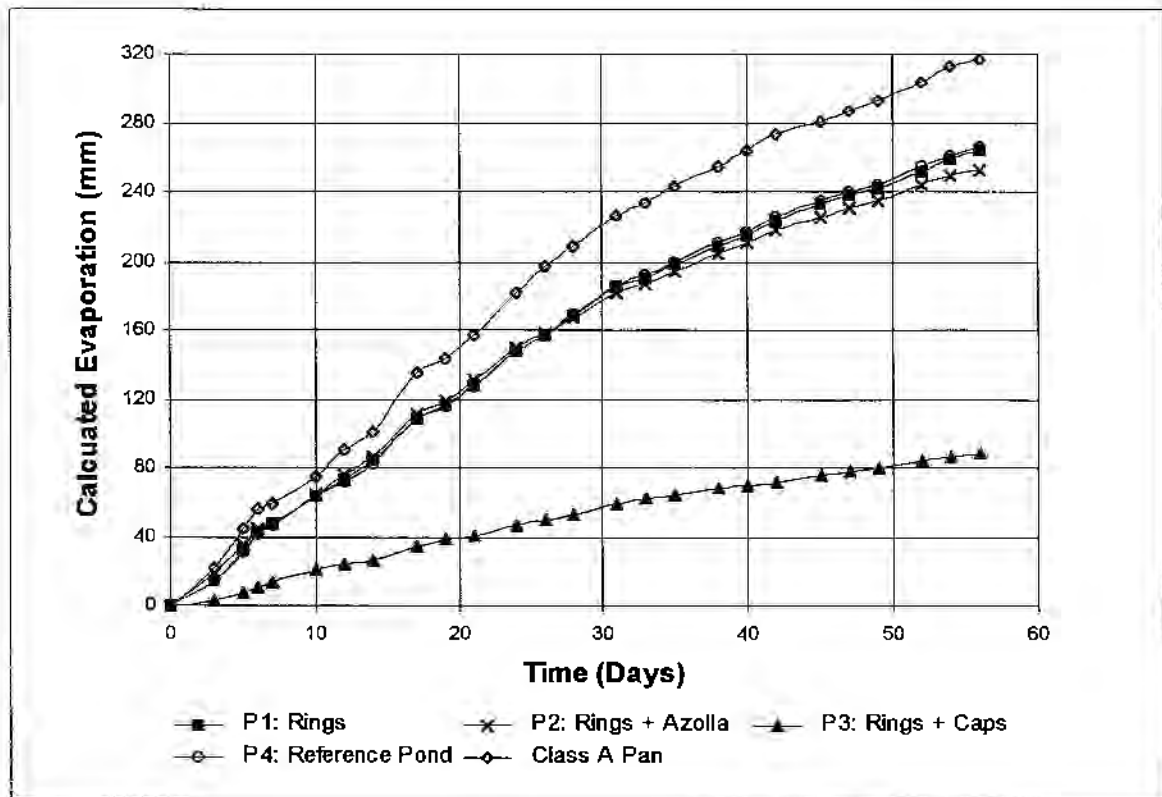


Figure VI. Cumulative Evaporation - Calculated (10 Feb. - 7 April, 1995).

The charts show that there are noticeable differences between the observed and calculated cumulative evaporation's for ponds P1, P2 and P4. These differences, varying between 4% and 10% are not considered significant in the study and are covered in the analysis. For the purpose of the report, only the observed results in Figure V are discussed.

The total observed evaporation for the period 10 February to 7 April, 1995 for the ponds and the Class A pan are shown in Table 1.

POND	TOTAL EVAPORATION (mm)
P1 Rings Only	253.0
P2 Rings + Azolla	240.0
P3 Rings + Caps	88.0
P4 Reference	254.0
Class A pan	316.7
Rainfall for the period:	120.0

Table 1 Total observed evaporation and rainfall for the study period.

The Class A pan evaporation is greater than that of the reference pond, which is to be expected as a coefficient is normally applied to the pan evaporation to estimate the evaporation for a larger body of water.

The average reduction of evaporation from the reference pond for the study period is given in Table 2.

POND	AV. REDUCTION (from Ref. pond)
P1 Rings Only	0.4%
P2 Rings + Azolla	5.5%
P3 Rings + Caps	65.4%

Table 2 Average evaporation reduction for the study period.

It should be noted here that evaporation reductions from the reference pond at different times, in particular the pond with azolla, are not consistent. This can be seen in Figure V after day number 24 when the azolla pond (P2) started evaporating less water. This subject is covered further in the analysis.

3. Analysis and Discussion

3.1 Pond Performance and Assessment for the Application

The evaporation from each pond and hence performance, has initially been considered in terms of cumulative evaporation over the observation period. As discussed in section 2.5, two methods were used to measure the amount of evaporation; namely *observed* and *calculated*. This procedure was adopted to minimise reading errors by cross checking results and to provide the greatest accuracy while refilling the ponds to datum. Figure V and Figure VI show a discrepancy for the final values of ponds P1, P2 and P4. The results have shown that for each pond the calculated evaporation was slightly greater than the observed and varied between an increase of 0.2% for P3 (rings + caps) and 10% for P2 (rings + azolla). For each pond, the errors have been reasonably consistent and can be attributed largely to the irregular shape of the ponds where the sides are not always vertical therefore affecting the volume of water added. The difficulty in reading the level of water in the plastic syphon tube due to the meniscus was another source of error. As the variations are minor they are not considered significant, however the conservative *observed* results are used in the analysis.

The reduction in evaporation from the reference pond for each of the other three ponds has been found to vary during the study period as expected. This is attributed largely to the varying weather conditions over the period but has also been influenced by the above mentioned errors.

Pond P1: Rings Only

The ring concept (reference A. Akbarzadeh) was originally designed to reduce wave height and associated mixing in the surface zone of solar ponds. The rings have been studied here to assess whether the reduction of surface mixing has an affect on evaporation. The rings performed well by reducing the observed wave action considerably compared to the reference pond. The study has considered a relatively small water surface area (16.47m²) compared to that of the proposed end use (hundreds of square metres) and the average annual evaporation of the study area is considerably less than that of the proposed end locations. While the rings reduced wave action on the pond surface, it is not considered that the 0.4% average reduction in evaporation from the reference pond could be improve upon in the environment for which they are proposed.

The performance of this concept indicates that for the purpose of reducing evaporation, rings only does not look a viable option.

Pond P2: Rings plus Azolla

The azolla was planted on 27 January and initially the surface of the pond was well covered. Evaporation observations commenced on 10 February (day "0") and after this two week period, the thickness of the cover was observed to be less. The thinning continued slowly until fertilizer was added to the pond on 24 February (day "14"). One kilogram of blood and bone based fertilizer powder was mixed with the make-up water and spread around the pond. The amount of fertilizer was determined by limiting the phosphorus content to 5ppm using a 5% phosphorus mix. It was considered that a maximum of 10ppm could be tolerated if necessary. As the thickness of cover improved from this point, no more fertilizer was added.

From Figure VII it can be seen that up until day 26 when heavy rain fell, the evaporation from the azolla pond was much the same as the reference pond and on some occasions allowed slightly more evaporation to occur. After the heavy rain and presumably as a result of the fertilizer, the cover became very thick and the pond showed a net reduction in cumulative evaporation by the end of the study period. At the time of writing this report in June, the cover had become very thin again although evenly spread across the pond.

The average reduction in evaporation from the reference pond for the duration of the study utilising rings plus azolla was 5.5%. The rings in this case were used to stabilise the location of the azolla and in this regard they were observed to work well; however the azolla was also expected to perform well but the results are contrary to our expectations. Figure VII shows the performance of the pond relative to the reference pond.

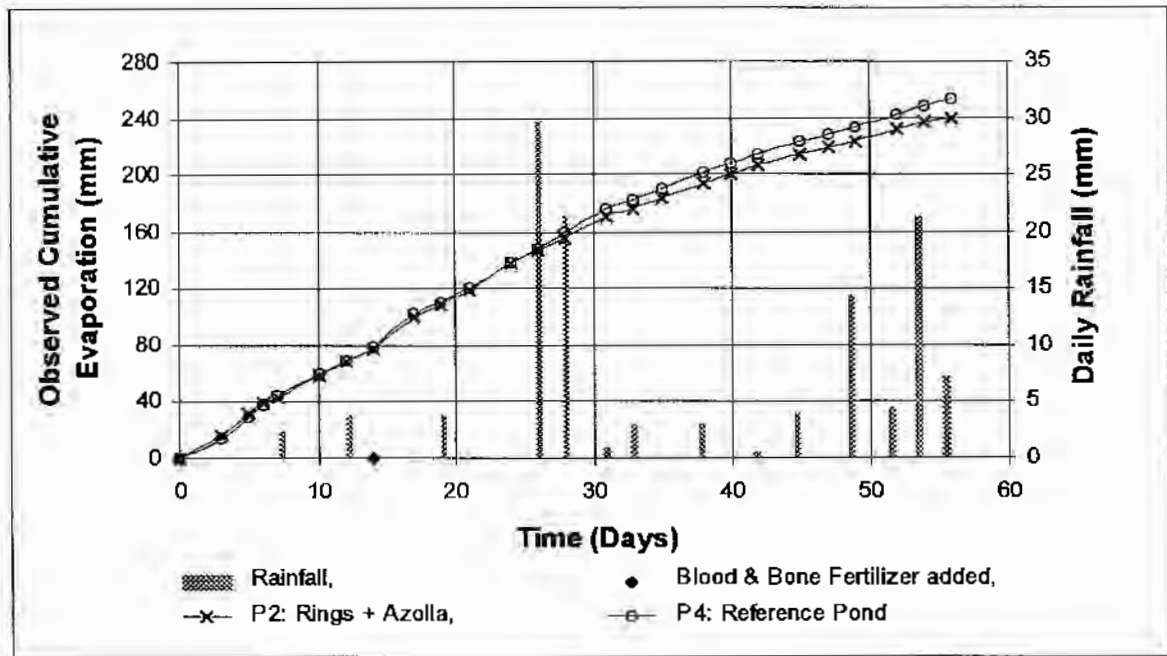


Figure VII Azolla evaporation relative to the reference pond.

During the study period the variation from the reference pond was not consistent and as the overall evaporation reduction has been approximately 5%, it appears not to be a worthwhile option to study further.

Pond P3: Rings plus Caps

The average reduction in evaporation from the reference pond for the duration of the study utilizing rings plus caps, hereafter referred to as *Aquacaps*, was 65.4%. The circular shape of the Aquacap was a natural progression from the ring concept which was easier to construct than a polygon. It was also considered ideal as a module that would accommodate surface movements without being restrained and be least likely to ride up on each other under destabilizing conditions. In this study, the Aquacaps have covered approximately 90% of the pond surface area in the most compact arrangement possible (a triangular or hexagonal arrangement). The reduction of evaporation is quite significant and possibly the best that can be achieved without covering the entire water surface area to ensure contact with the atmosphere is not possible.

A comparison of evaporation from the aquacap pond and the reference pond for each of the 25 observations (ref. appendix) during the study period is shown in Figure VIII. From this chart it can be seen how the ratio of evaporation varies between one observation and the other and is particularly noticeable when comparing Observation Numbers 4 and 5.

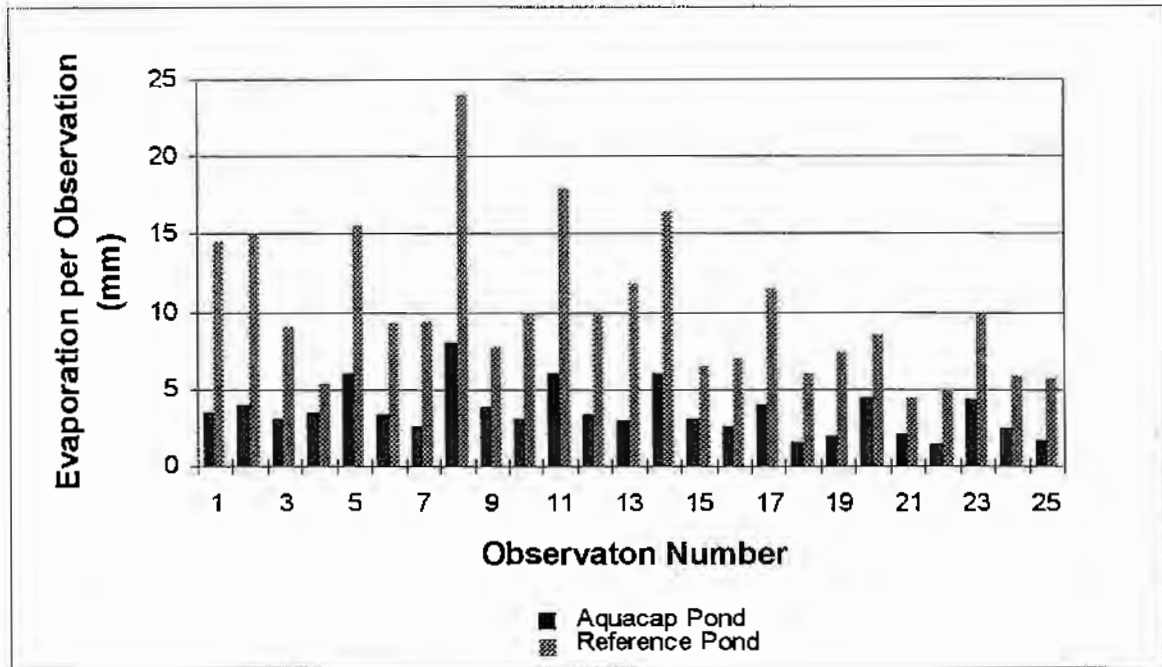


Figure VIII Comparison of evaporation from Aquacap pond and Reference pond for the 25 observations made during the study period, 10 February to 7 April, 1995.

To understand the variation in the evaporation ratio and to assess what causes it, an evaporation reduction coefficient has been developed as follows:

$$R_e = \frac{E_R - E_{Aq}}{E_R}$$

Where: R_e is the reduction coefficient for evaporation using Aquacaps,
 E_R is the reference pond evaporation and
 E_{Aq} is the aquacap pond evaporation.

For example: Observation No. 4, $R_e = 0.37$ or 37% reduction
 Observation No. 5, $R_e = 0.61$ or 61% reduction
 Observation No. 13, $R_e = 0.76$ or 76% reduction

The reduction coefficient for each observation has been calculated and a plot of them is shown in Figure IX with the observed rainfall at the site. It is interesting to note from the chart that the lowest coefficients occurred during periods of low rainfall and the highest coefficients occurred mostly during periods of no rain. It can be assumed from this information that the Aquacap is more effective in dry conditions.

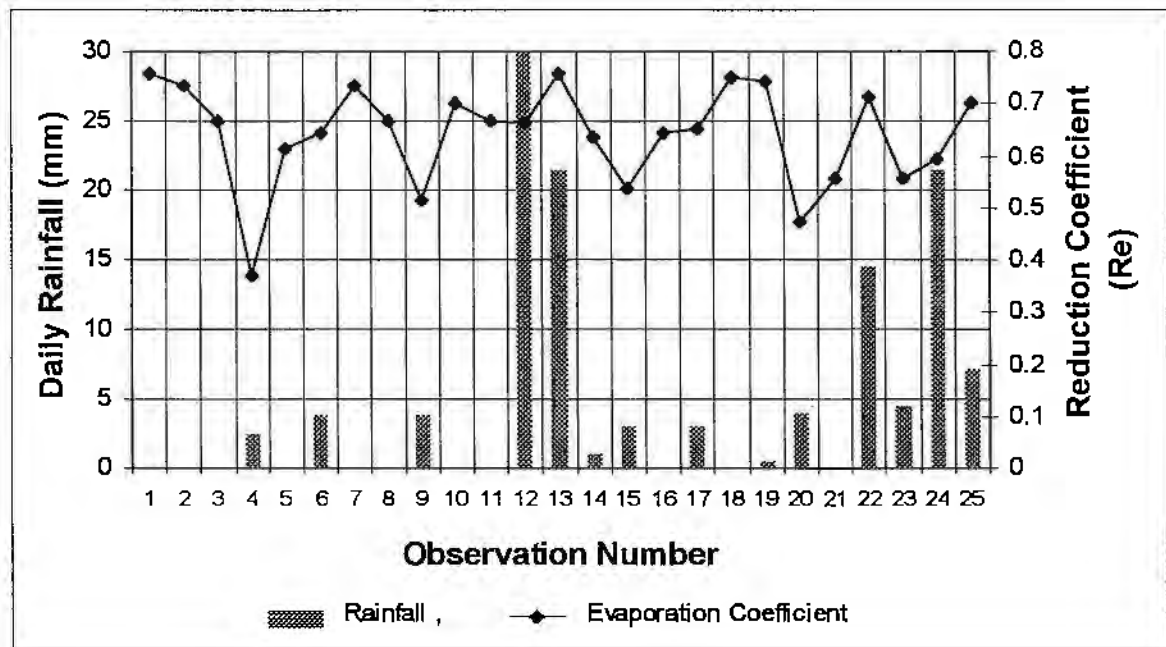


Figure IX Aquacap evaporation reduction coefficient (R_e) and rainfall recorded at the RMIT site.

Comparing the coefficients with maximum recorded class A pan temperatures (Figure XII), it also appears that the Aquacap performs particularly well in hot conditions.

From the performance study of each pond and the results in Table 2, it appears that the most effective means of reducing evaporation is by use of rings and caps (pond P3) and the report therefore concentrates on this option.

To enhance the study further, additional data from the Bureau of Meteorology was used in this study which has been made available from the La Trobe University School of Agriculture located some 5 kilometres from the pond site. A statistical comparison of the information with the on site data reveals that it does not provide any additional support to the study, however, it can provide some other useful information regarding site specific data recorded on a daily basis and how it would be useful in further studies.

Figure X compares the class A pan evaporation for both RMIT and LA Trobe University sites with the reduction coefficient. La Trobe University experienced less evaporation over the same period however the trend was similar. The chart also shows that while minimum coefficients tend to occur with minimum evaporation, the converse is not necessarily the case. Information recorded on a daily basis along with other meteorological information would be of benefit here in understanding whether the aquacap performance could be improved upon.

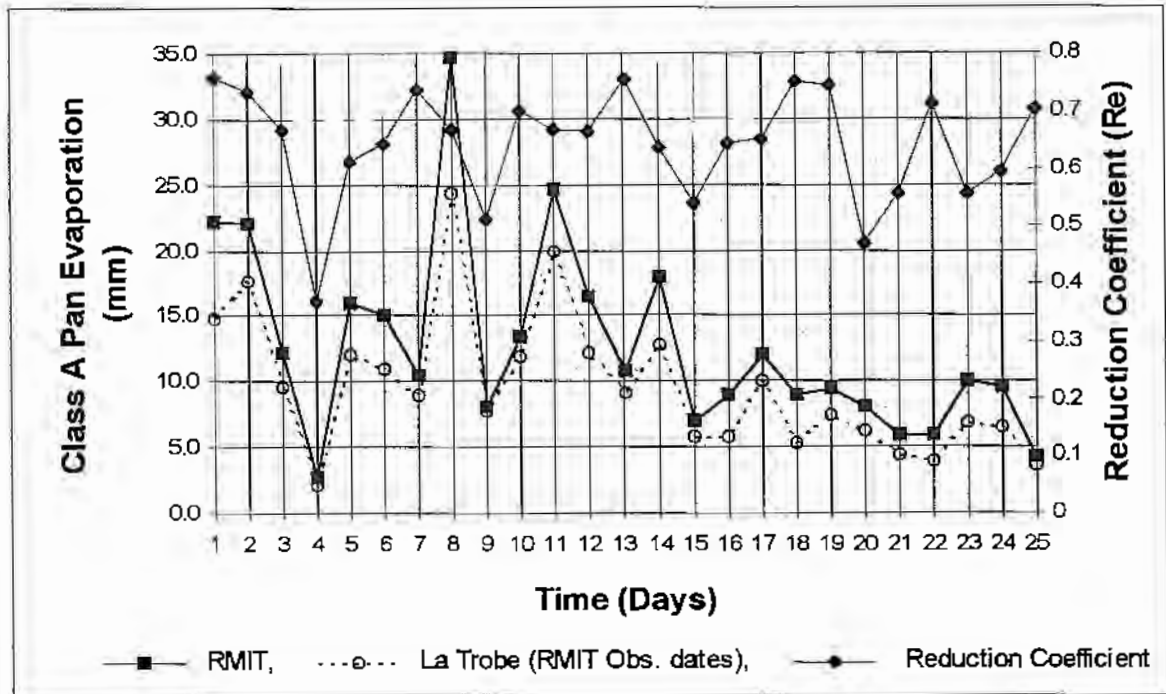


Figure X Aquacap reduction coefficient (R_e) and class A pan evaporation.

Figure XI shows the evaporation reduction coefficient compared to La Trobe University windrun. More specific information here would show how much effect the wind has on the Aquacaps performance. From this information, a better understanding of the Aquacaps suitability to the location would be known and ways of improving its design could be considered. This could also indicate how wind fetch affects its performance. A chart comparing the reduction coefficient to relative humidity would also be of value in assessing its suitability to a location.

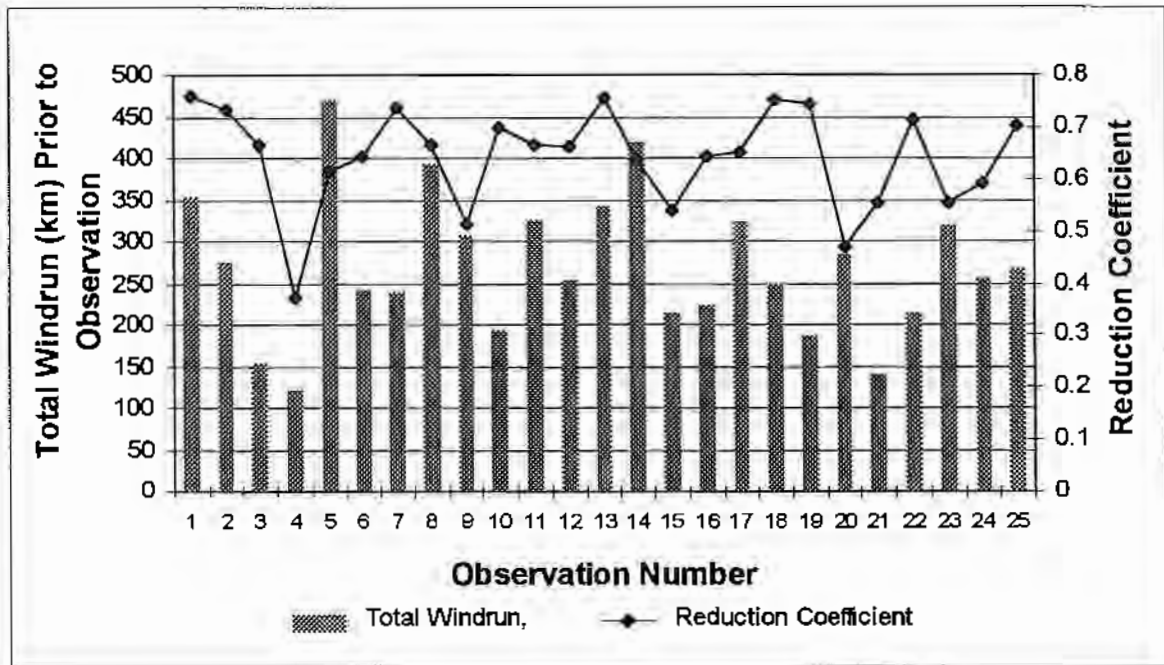


Figure XI Aquacap evaporation reduction coefficient and La Trobe University windrun.

3.2 Concluding Remarks on Aquacaps

The reduction of evaporation achieved by the Aquacap concept observed in the study pond is significant enough to consider it as a viable means for reducing evaporation from a natural or constructed water storage in an area of high evaporation. Prior to producing a larger module for testing, more information about the design requirements by end users would be useful as well as manufacturing techniques. Having obtained this information, a field study at a typical location where evaporation is a problem would be necessary to evaluate the economic viability of the Aquacap and how its efficiency may be improved upon. This would involve establishing two ponds side-by-side to experience the same conditions and have sufficient instrumentation to automatically record data on a daily basis.

3.3 Pond Temperatures

Pond temperatures were taken during evaporation observations and are shown with the minimum and maximum temperatures recorded from the class A evaporation pan floating Six's thermometer (Figure XII).

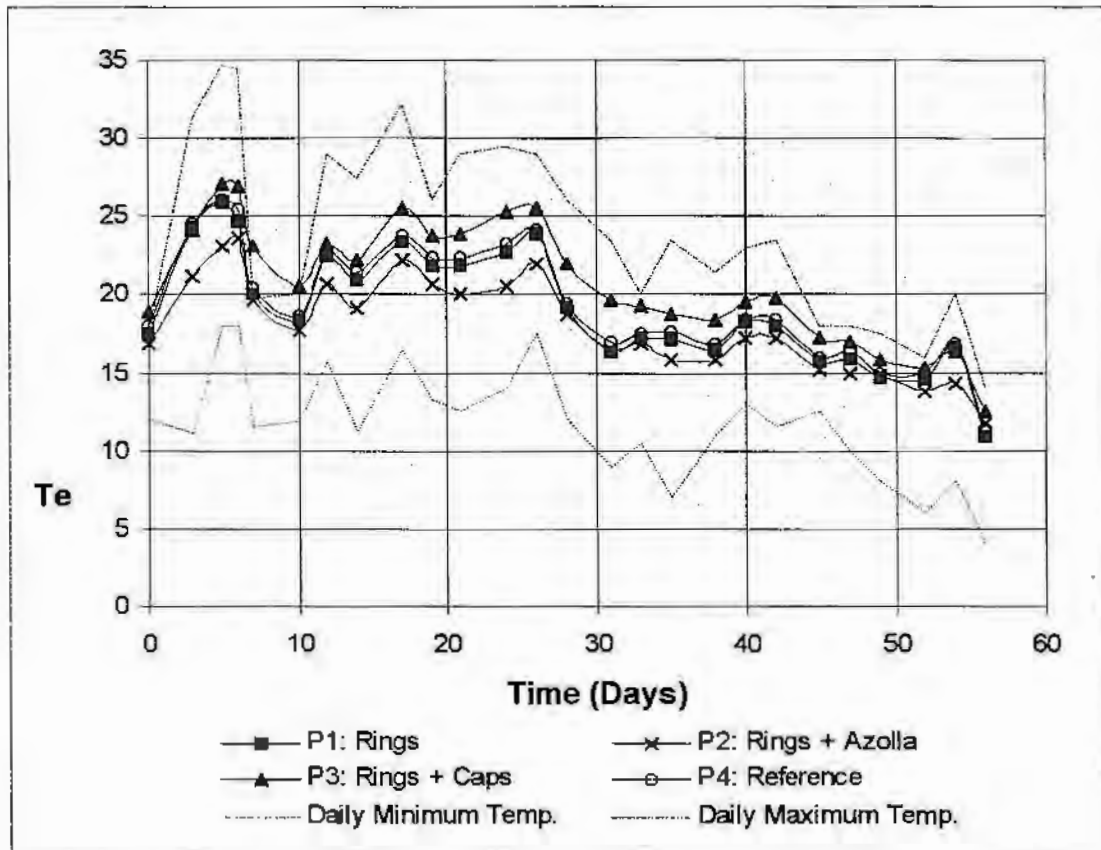


Figure XII Pond temperatures and maximum and minimum temperatures (Class A evaporation pan) taken on observation days.

Variation of temperature between the surface and bottom of the individual ponds was insignificant. It is interesting to note that the Aquacap pond (P3) recorded the highest temperatures and the Azolla pond (P2) recorded the lowest. It is important to keep water temperatures as low as possible to minimise evaporation and this should be taken into consideration when assessing the colour and type of material for further trials of Aquacaps. A comparison of the aquacap evaporation reduction coefficient with maximum diurnal temperatures is also valuable in assessing the suitability of the concept to a particular location.

4. Areas Requiring Further Research

4.1 Aquacap Design and Testing

Further research into the application of the Aquacap would be well worthwhile based on the information obtained from this study and discussed in section 3.1, Pond P3: Rings plus Caps.

The nature of this research should be in the form of a field study in which a larger prototype aquacap could be tested in an environment for which it is initially required. Further information on the design and manufacturing requirements should be obtained before the prototype is decided upon. Information obtained from the end users would be valuable in this regard.

A location for field testing the Aquacaps should be decided upon based on two equal sized ponds being constructed adjacent to each other and being subjected to the same conditions. The ponds should each have a surface area of at least 1000 square metres and have facilities for automatic collection of data. Sufficient instrumentation should be available to obtain daily information on evaporation, rainfall, temperatures and wind velocity.

The period of observation should span at least two seasons where high evaporation is experienced and the Aquacap pond should go through one cycle of being emptied and refilled. This should be done to obtain sufficient information on the Aquacap's ability to reduce evaporation and to observe its performance and durability under storage operating conditions.

4.2 Rough Cost Estimation for Future Study

A detailed estimate of costs has not been included in this study, however some thoughts and rough estimates are given to assist in that regard.

Assuming the marginal value of a megalitre of water for the cotton industry is say \$300 and the Aquacap concept reduces evaporation by an average annual amount of 65% (i.e. $R_e = 0.65$), then a pay back period for the Aquacap can be considered as follows:

→ water cost = \$0.30/m³ and $R_e = 0.65$, assume 1.5m evaporation per year

∴ annual saving = $0.30 \times 0.65 \times 1.5 \approx \0.30

If the Aquacap cost is \$1/m², the pay back period is $\$1/0.3 = \underline{3.3 \text{ years}}$.

From the preliminary enquires made to date, it is not unrealistic to expect a mass produced Aquacap, 1m in diameter, to be available at a cost of \$1.00.

For the purpose of a research pond, a 1m diameter prototype aquacap would cost in the order of \$6 to \$7.

Assuming a 1000m² research pond and with a 90% coverage which is achieved by using a circular Aquacap, the approximate number of Aquacaps required would be 1100.

Therefore, for a 1000m² research pond it is likely that the Aquacaps would cost in the order of \$8,000. The cost of equipment and instrumentation has not been investigated, however a starting point of \$20,000 is considered reasonable. Additional costs for land, pond construction, administration and personnel need to be considered when estimating the cost of research facilities.

5. Conclusion and Recommendations

The study has identified one highly satisfactory concept for reducing evaporation from water storages. The concept using rings and caps has been found to reduce the average evaporation from a research pond by 65%. An analysis of the results indicates that this figure could be achievable in a natural storage situated in an area that experiences high evaporation.

It is recommended that the concept of rings and caps, referred as *Aquacaps* in this report, should be investigated further particularly in the areas such as:

1. develop a prototype Aquacap for field testing;
2. establish two research ponds, each of minimum size 1000m², to field test the prototype in an environment for which they are initially required.

Acknowledgments

The production of this research report is the result of an idea being developed by many cooperative and enthusiastic people, plus the funding provided by the Cotton Research and Development Corporation and Saintry and Associates.

The study would not have been possible without the site and facilities made available by Professor Nelson Chen, RMIT, Head of Department, Manufacturing Systems Engineering and would not have come to fruition without the enthusiasm to pursue the matter shown by Dr. Keith Garzoli, ANU and Mr. John Blackwell, CSIRO.

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Appendix

OBSERVATION DATES

Observation No.	Day No.	Date (1995)
Start	0	10 February
1	3	13 Feb.
2	5	15 Feb.
3	6	16 Feb.
4	7	17 Feb.
5	10	20 Feb.
6	12	22 Feb.
7	14	24 Feb.
8	17	27 Feb.
9	19	1 March
10	21	3 March
11	24	6 March
12	26	8 March
13	28	10 March
14	31	13 March
15	33	15 March
16	35	17 March
17	38	20 March
18	40	22 March
19	42	24 March
20	45	27 March
21	47	29 March
22	49	31 March
23	52	3 April
24	54	5 April
25	56	7 April

APPENDIX 3



Centre for Environmental Mechanics

Technical Report No. 90 June 1995

Report to : Geoff Sainty and Associates

Evaporation Mitigation from On-farm Water Storages

Scott A. Condie. Ian T. Webster

Evaporation mitigation from on-farm water storages

Report to Geoff Sainty and Associates

Scott A. Condie & Ian T. Webster

CSIRO Centre for Environmental Mechanics

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June 1995

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CSIRO Centre for Environmental Mechanics Technical Report No. 90

Summary

It is estimated that the cost of evaporation to cotton farms in the Gwydir Valley alone typically exceeds \$50M per annum. This report suggests that there is considerable potential for more widespread adoption of mitigation strategies such as the construction of deeper reservoirs with multiple cells. Such measures are already operating effectively on a number of farms and have been shown to be cost effective (over 3-4 years) when compared with the real cost of water in these regions.

A sophisticated computer model has also been used to study evaporation. Results indicate that wind is a strong determinant of evaporation and it is suggested that vegetative windbreaks placed on banks within reservoirs may significantly reduce losses. While the reductions would clearly be less than those associated with impermeable floating covers, the relatively low cost of windbreaks is likely to result in a more cost-effective solution. Windbreaks would also provide additional benefits, such as damping wave action to reduce bank erosion.

1. Introduction

This report forms part of a larger study aimed at developing cost effective strategies for reducing evaporation from large farm storages. It incorporates the following components:

- (i) Results from inspections of seven cotton farms and discussions with growers.
- (ii) A review of relevant evaporation research.
- (iii) Results from modelling studies completed at the CSIRO Centre for Environmental Mechanics (CEM).
- (iv) Detailed strategies for evaporation mitigation based on findings from the three components above.

2. Farm visits

Seven cotton farms were visited in the Narrabri, Moree and Goondiwindi districts from the 13th to the 17th March 1995. Storage and pumping facilities were viewed and extensive discussions conducted with the growers.

Growers were clearly aware of the magnitude of the evaporation problem. They noted that water availability limits cotton production during most seasons and estimated that they lose up to 50% to evaporation, most of this between October and April. While the problem was universally recognised, there was considerable differences in the implementation of mitigation measures between individual farms. Hence, some of the strategies outlined below have already been adopted by a small number of the most innovative growers.

3. Review

Determinants of evaporation

The evaporation from any water body is a function of the heat budget through the water surface. In particular, the heat input associated with solar and longwave radiation is offset by losses to the atmosphere through emitted longwave radiation, sensible heat and latent heat of evaporation. When the incoming radiation exceeds the heat losses the water temperature increases, and vice versa. Incoming radiation is clearly dependent on the time of day and the season, while losses increase with water temperature. The sensible and evaporative losses also increase with wind speed over the water. Since all heat must ultimately be returned to the atmosphere by some mechanism, evaporation can only be reduced by either impeding the incoming radiation or modifying the heat loss budget in favour of longwave and sensible heat.

Evaporation rates have traditionally been estimated using bulk aerodynamic formulas which are a function of the air humidity and wind speed. The most commonly used formulas are summarised in Table 5 of Henderson-Sellers (1986). These representations are largely empirical and ignore horizontal variations in temperature and humidity which may be significant over small water bodies such as agricultural storages. The discontinuity in surface temperature and humidity at the shoreline can change the airflow stability and vertical transport over the water and thereby increase evaporation (Weisman and Brutsaert 1973). Even in cases where the airflow remains stable, evaporation is higher due to the low humidity of the air as it first moves over the water (Webster and Sherman 1995).

Evaporation reduction techniques

There is a substantial body of literature devoted to evaporation mitigation. Most of the techniques utilise floating chemical films to impede moisture transfer, or suspended floating covers to shade the water or reduce the exposed surface area.

Chemical films

Monomolecular films have reduced evaporation rates in laboratory studies from 20% to 60% under ideal conditions. However, in larger reservoirs, they tend to be rapidly destroyed by wind and surface waves. As a result, no practical applications have been found and any future use will almost certainly rely on incorporation of some type of wind baffles. A detailed technical review has recently been presented by Jones (1992, Chapter 8).

Floating or suspended materials

A more promising approach is the use of reflective materials which reduce the incident solar radiation. If the material is floating, it may also reduce the exposed water surface area. Results from studies covering a diverse range of materials are summarised in Table 1. The materials listed have a wide range of costs and lifetimes. For example, polystyrene is damaged by sun, wind and frost, and would not be expected to last more than 10 yrs. The cost effectiveness of the various options has only been analysed for relatively small storages (Cooley and Myers 1973, Nicholaichuk 1978, Cooley 1983). However, Nicholaichuk's (1978) calculations suggest that more resilient materials such as lightweight concrete may be more than 20% cheaper than polystyrene per unit of water saved.

Wind breaks

Wind increases evaporation by both carrying dry air over the water body and promoting the vertical exchange of air. These effects are only partially offset by the surface cooling effect of wind, through both mechanical overturning of the water and evaporative cooling. The influence of wind baffles distributed over the water surface have been studied by Crow and Manges (1967). They found that evaporation decreased as the ratio of baffle separation to baffle height fell. However, even for solid baffles this ratio needed to be less than 50 to have any effect and still achieved only a 9% reduction when the ratio reached 16.

Table 1: Evaporation reduction for various floating materials

<i>Material</i>	<i>Evaporation Reduction (%)</i>	<i>Reference</i>
<i>Lily Pads</i>	16	<i>Cooley & Idso 1980</i>
<i>Polystyrene beads</i>	39	<i>Myers & Frasier 1970</i>
<i>Wax blocks</i>	64	<i>Cooley & Myers 1973</i>
<i>White butyl rubber</i>	77	<i>Cooley 1970</i>
<i>White plastic spheres</i>	78	<i>Crow & Manges 1967</i>
<i>Continuous wax</i>	87	<i>Cooley & Myers 1973</i>
<i>Plastic sheeting (suspended)</i>	90	<i>Drew 1972</i>
<i>Foamed rubber</i>	90	<i>Dedrick et al. 1973</i>
<i>Polystyrene rafts</i>	95	<i>Cluff 1972</i>

Sheltering can also be provided by natural or introduced vegetation. While this approach has not previously been viewed as a strategic means of reducing evaporation, there are a number of studies which have examined the influence of emergent plants on evaporation from natural water bodies. Linacre et al. (1970) compared evaporation rates from a swamp with those from a nearby lake near Griffith NSW. Measurements showed that the swamp had near-surface winds at least a factor of two smaller than those over the lake, while the near-surface humidity of the swamp was between 10 and 40% higher. Despite a slightly higher surface temperature, evaporation from the swamp was on average one third less than that from the lake. The shelter provided by the swamp reeds clearly had a substantial effect on the near-surface microclimate. The associated fall in evaporation more than offsets transpiration losses from the reeds. This conclusion is generally supported by other studies with similar vegetation types and

densities (Eisenlohr 1966, Rijks 1969, Lafleur 1990). However, the differences in evaporation rates between swamp and open water can be as small as a few percent (Price 1994).

There do not appear to be any previous studies which consider the influence of large trees on evaporation. However, the modelling study described below suggests that such an approach may have significant potential.

4. Results from the CEM Evaporation Model

The Centre for Environmental Mechanics has developed a sophisticated computer model to study evaporation rates from reservoirs with differing characteristics. It consists of an atmospheric model which can exchange moisture, heat and momentum with the water below. Both the humidity and temperature of the air evolve across the water body and modify the evaporation. However, the major advance on previous models is the inclusion of an active water body whose temperature and motions change in response to the radiation and wind levels (based on the model of Blumberg and Mellor 1983). It can therefore make realistic estimates of evaporation with diurnal and seasonal variations in atmospheric conditions.

The major results of the modelling study can be summarised as follows:

- (i) Evaporation increases substantially with wind speed. For example evaporation doubles when winds increase from 4 km/hr to 18 km/hr (figure 1).
- (ii) The depth of the reservoir has almost no effect on the evaporation per unit area. When the depth was increased from 1.0 m to 6.0 m evaporation fell by less than one percent.
- (iii) The evaporation per unit area decreases moderately with increasing reservoir size (figure 2).
- (iv) Turbidity (sediment load) of the water has no significant effect on evaporation. A twenty-fold increase in turbidity increased evaporation by only 0.25%.

Figure 1: Evaporation as a function of wind speed

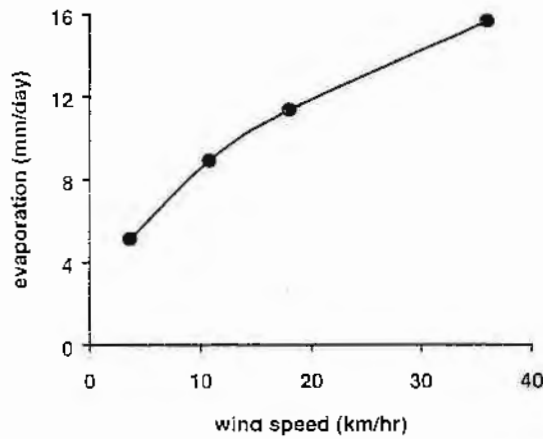
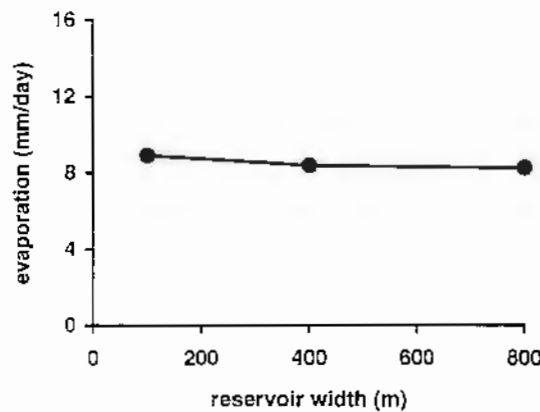


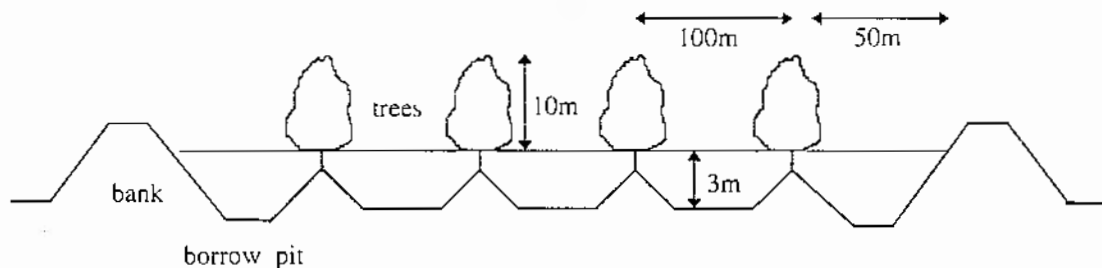
Figure 2: Evaporation as function of reservoir size for 11 km/hr winds



The strong influence of wind (figure 1) motivated further modelling work on the potential effects of vegetative windbreaks. Discussions with cotton growers confirmed that trees could not be located on reservoir walls because of their tendency to remove moisture and increase the risk of wall failure. However, sheltering effects can also be achieved by planting water-tolerant trees along banks (perhaps purpose built) within the reservoir itself. The system modelled to test this hypothesis is shown schematically in figure 3. Daily cycles of air temperature and humidity typical of those found in the Narrabri region during January were used. The windbreaks had approximately 50% porosity, which would correspond to a line of medium density trees with foliage

extending down to the water line. At moderate wind speeds of 11 km/hr, evaporation dropped more than 20% from 7.5 mm/day to 5.9 mm/day when windbreaks were introduced. These figures do not take into account water used by the trees or additional savings associated with shading of the water. However, there appears to be considerable potential in this approach and a need to pursue it further through laboratory tests or small-scale field trials.

Figure 3: Windbreak configuration used in the computer model



5. Strategies for reducing evaporation from cotton storages

In developing new strategies, there is an obvious need to consider factors such as practicality of construction and deployment, cost effectiveness of the strategy over its lifetime, and environmental consequences of the strategy.

Deepening reservoirs

An obvious approach to reducing evaporation is to increase the volume to surface area ratio of storages by increasing their depth. While this approach is now being more widely adopted, storages still range in depth from 2 m to 7 m. This suggests that there is considerable potential for deepening existing storages, without any associated loss in cropland. The main arguments against deep storages are the higher excavation costs and the increased risk of catastrophic losses through failure of the reservoir bank. However, the calculations in Appendix A suggest that the additional costs associated with

constructing a 6 m high 500 MI storage rather than a 3 m high 500 MI storage are recovered in reduced evaporation over a period of only 3-4 years.

Multiple reservoirs

If water can be exchanged between a series of tanks, then the number containing water at any one time can be minimised. This cuts the water surface area, as well as reducing the potential losses associated with failure of the reservoir banks. Furthermore, new reservoirs can often be added without the need for additional pumping facilities. For example, an existing lift pump can be used to fill an existing reservoir, which gravity feeds any excess water into a new reservoir. When their combined holdings falls below the capacity of the old reservoir, the new reservoir can be emptied along a channel which feeds back to the lift pump. At least one grower currently uses this system, with reservoirs distributed throughout the farm and interconnected by a network of elevated channels. Calculations in Appendix B suggest that the costs associated with dividing an existing 500 MI storage in half would again be recovered in 3-4 yrs.

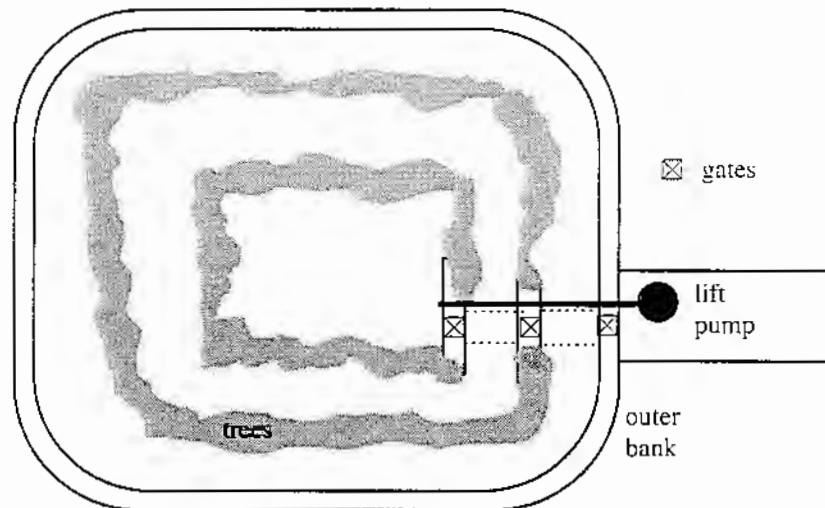
Windbreaks

Evaporation rates are very strongly influenced by wind speeds and results from the modelling study indicate that windbreaks have significant potential for reducing farm losses. Trees cannot be planted along the banks, since the resulting reduction in soil moisture would increase the risk of failure. However, shallow regions inside the borrow pit zone (perhaps purpose-built banks) could be planted with rows of water-tolerant trees such as *Melaleuca* to shelter all or part of the reservoir. Rows should be spaced at around ten tree heights, perpendicular to the prevailing winds or orientated north-south to maximise summer shading. The water used by the trees would be a relatively small fraction of that saved. The trees would also provide additional benefits, such as substantially damped wave action and reduced bank erosion, along with improved wildlife habitat.

A strategy which combines the benefits of windbreaks and multiple cells is illustrated schematically in Figure 4. When the water level drops to the height of the planted banks, they effectively divide the reservoir into separate cells. Water can then be used from the outer cell for both irrigation and maintaining the level of the inner cells.

Integrating these two strategies maximises the cost effectiveness of constructing the banks inside the reservoir.

Figure 4: A configuration integrating windbreaks and multiple cells.



Floating materials

Floating materials are by far the most costly, but also potentially the most effective means of reducing evaporation. A number of examples are summarised in Table 1, but none have been tested on the scale of large agricultural reservoirs. New work on this approach is described in an adjoining report.

Conclusion

Deep reservoirs with multiple cells are cost effective and have already been extensively adopted by some innovative growers. Since these strategies are now proven, it appears to be an opportune time for their more widespread implementation. The use of windbreaks is a promising avenue for the future and now warrants further investigation through laboratory modelling or small-scale field trials. Such a program is outlined briefly in Appendix C.

Appendix A: Costing for deeper reservoirs

Consider a typical bank such as that shown in Figure A1. The cross-sectional area is given by

$$A = H^2 \left(\frac{W}{H} + \frac{1}{2\alpha} + \frac{1}{2\beta} \right) \quad (\text{A1})$$

where the symbols on the right hand side are defined in Figure A1. For a square tank of width L , the total cost of excavation is approximately

$$C_{ex} = 4LA c_{ex} \quad (\text{A2})$$

where current excavation costs are around $c_{ex1} = \$0.75 \text{ m}^{-3}$ for $H < 4 \text{ m}$ and $c_{ex2} = \$0.90 \text{ m}^{-3}$ for $H > 4 \text{ m}$. The cost of evaporation from such a reservoir is

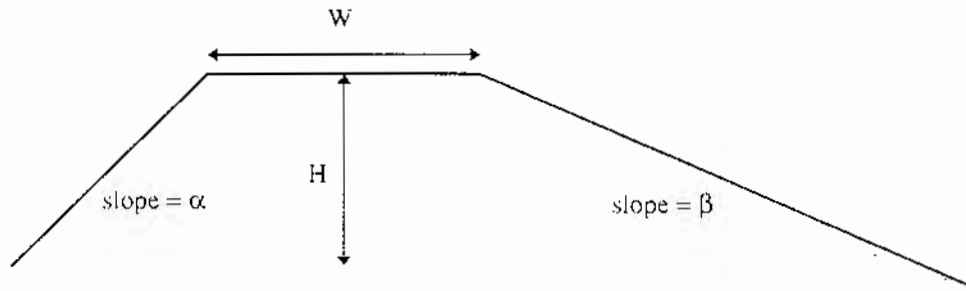
$$C_{ev} = EL^2 c_w t \quad (\text{A3})$$

where t is time, E is the evaporation rate and c_w is the real value of the water based on lost production (assumed here to be $\$400 \text{ Ml}^{-1}$). Costings can only be compared for reservoirs of equal storage volume $V = HL^2$. Therefore, replacing L by $(V/H)^{1/2}$ in (A2) and (A3), and assuming $W \approx H$ in (A1), the increase in C_{ex} associated with increasing the depth from H_1 to H_2 can be equated with the corresponding decrease in C_{ev} to give a payback time of

$$t = \frac{(c_{ex2} H_1 H_2^{5/2} - c_{ex1} H_1^{5/2} H_2)}{c_w E V^{1/2} (H_2 - H_1)} \left(4 + \frac{2}{\alpha} + \frac{2}{\beta} \right). \quad (\text{A4})$$

For a typical 500 Ml storage with $\alpha = 0.5$, $\beta = 0.2$ and $E = 1.5 \text{ myr}^{-1}$, the excavation costs are around $\$50\text{K}$ for a 3 m storage and $\$168\text{K}$ for a 6 m storage. However, because of the high real cost of evaporation, the payback time for selecting the deeper option is only 2.4 years. There is also a small saving in cropland acreage of around 8 Ha for this example. These estimates do not include interest on the additional cost of the deeper storage, which would bring the payback time close to 3 years.

Figure A1: Typical cross-section of a reservoir bank.



Appendix B: Costing for divided storages

The excavation costs associated with dividing an existing reservoir into two smaller storages is

$$C_{ex} = LAc_{ex} \quad , \quad (B1)$$

where the terms are defined in Appendix A. If the second storage could be kept empty half of the time, then the evaporative cost savings would be

$$C_{ev} = 0.25EL^2c_w t \quad . \quad (B2)$$

Equating these gives a payback time of

$$t = \frac{4c_{ex}}{Ec_w} \left(\frac{H^5}{V} \right)^{1/2} \left(1 + \frac{1}{\beta} \right) \quad (B3)$$

where $\alpha = \beta$ for a dividing bank. For a 500 Ml of 5 m depth, the payback time is approximately 2.8 years. Even when the costs associated with feeder channels back to the lift pump and interest are added, the payback time would still be less than 4 years.

Appendix C: Program for further research on evaporation mitigation using windbreaks

The CSIRO Centre for Environmental Mechanics will be conducting a large laboratory and field program on the flow and turbulent transport of tracers behind vegetative windbreaks during 1995-96. This represents an excellent opportunity to utilise the results of this study and extend its capability to encompass evaporation from reservoirs. "Piggybacking" on the larger windbreak study would provide a very cost-effective means of investigating the related reservoir problem.

The complete study would entail two laboratory components and a field-based experiment. Laboratory wind-tunnel experiments can provide detailed measurements over a broad range of closely controlled conditions. Field measurements are more expensive, but can be applied directly to the reservoir problem, as well as being used to validate and calibrate the wind-tunnel results.

(i) Wind-tunnel experiments on tracer transport over relatively smooth surfaces behind windbreaks. This would involve detailed measurements of both the flow field behind a scaled-down windbreak and the associated turbulent transport of tracers such as water vapour. The results would be used in estimating the potential influence of windbreaks on evaporation for a range of tree densities and row spacings. Since a substantial portion of the experimental work forms part of the larger windbreak study, costs are reduced substantially.

Research Scientist: 5 days at \$800 per day	\$4000
Senior Technical Officer: 2 days at \$750 per day	\$1500
Laboratory expenses	<u>\$ 200</u>
Total	\$5700

(ii) Wind-tunnel experiments on scaled reservoir models. A scaled model of a ring-tank resting on flat terrain would be subjected to a range of wind strengths. Water losses from the model reservoir could then be measured both with and without windbreaks in place. This would provide quantitative information on the effects of both the tree spacing and reservoir banks on evaporation rates. This part of the study would be

specifically tailored to the reservoir problem, while taking advantage of major experimental components already in place.

Research Scientist: 12 days at \$800 per day	\$ 9600
Senior Technical Officer: 4 day at \$750 per day	\$ 3000
Laboratory expenses	<u>\$ 1000</u>
Total	\$13600

(iii) The field study component would measure the modification of flow and turbulence behind real trees suitable for reservoir windbreaks. The results could be applied directly to the problem of determining the influence of wind-breaks on evaporation. However, they would be even more valuable when combined with the wind-tunnel results to provide reliable information on optimal windbreak configurations for a wide range of conditions.

Research Scientist: 20 days at \$800 per day	\$16000
Senior Technical Officer: 10 days at \$750 per day	\$ 7500
Per diems: 2 x 5 days at \$150 per day	\$ 1500
Field equipment	<u>\$ 3000</u>
Total	\$28000

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APPENDIX 4



CSIRO
AUSTRALIA

Division of
Water Resources

Minimising evaporation from off-river storages on cotton farms

Report of field trip to Northern NSW

March 1995

by

Anthony Scott
CSIRO Division of Water Resources
Canberra Laboratory

Technical Memorandum 95.12
July 1995
CSIRO
Division of Water Resources

Summary

A field trip to six cotton farms in Northern NSW was undertaken in March 1995 by Geoff Sainty (Sainty and Associates), Anthony Scott (CSIRO Division of Water Resources) and Scott Condey (CSIRO Centre of Environmental Mechanics). The aim of the trip was to obtain data on water management practices associated with irrigation cotton farming, and discuss with farmers potential methods of reducing water loss through evaporation.

a) Cost of Evaporation losses from off-river storages on cotton farms

Pan evaporation in the cotton growing districts of northern NSW is over 2000mm per year. The cotton industry estimates that up to 50% of water in off-river storages is lost to evaporation. The cost of evaporation losses for a 700ML storage on the Wyadrigah cotton farm was estimated as follows; Evaporation losses were 1.2 metres between March 1994 and January 1995. This equals 420ML of water, and (assuming 6ML/hectare of cotton) is equivalent to 70 hectares of cotton. At a price of \$500/bale this equals lost production of \$200,000.

All the cotton farmers interviewed considered the loss of water from evaporation as one of their major problems and were very keen to learn about techniques of reducing these losses.

b) Deeper storages reduce the evaporation losses.

Constructing deeper storages reduces the amount of water lost through evaporation since there is less water surface area from which evaporation can occur. For instance a 500ML storage which is 2 metres deep has a surface area of 25 hectares, whereas a 500ML storage which is 4 metres deep only has a surface area of 12.5 hectares. Therefore evaporation rates are halved. Although the cost of building storages increases with depth, all farmers interviewed considered it worthwhile to build storages which were 4 (or more) metres deep so that evaporation losses would be reduced and the area of land taken up by the storage would be minimised. However, there was concern expressed at building storages with earth walls higher than 5 to 6 metres due to the risk of a failure.

c) Split large storages into cells.

Another method of reducing evaporation is to split large storages into 2 (or more) cells. Rather than have the entire storage only half full (which is a common occurrence), the water is all stored in one cell. This halves the surface area of water and hence halves the losses due to evaporation. Alternatively, if there are two storages on the cotton farm that are half full, evaporation losses can be reduced by transferring all the water to one storage and leaving the other storage empty. This type of water management is practised on a number of cotton farms including Norwood.

d) Use of windbreaks to reduce evaporation

There are suggestions that if the storages are lined with trees, these will act as windbreaks and reduce the rate of evaporation. However, many farmers expressed concern that planting trees on or near the earth walls might cause them to crack and ultimately lead to a failure. Another suggestion is to plant trees along custom built embankments within the storage. This suggestion overcomes the problem of planting trees on the main storage walls, but has the disadvantage of the added costs associated with building extra walls within the storage. These extra walls (or

embankments would also reduce the capacity of the storage facility. Additionally, there was some concern about the quantity of water that the trees themselves might consume and whether this might be greater than the savings created by the effects of having a windbreak.

e) Place plastic rings on the surface of the water

Reducing evaporation by placing plastic rings on the surface of the water, was considered by all farmers interviewed as a proposal worth pursuing and were keen to see further tests carried out. Plastic rings, or for that matter any other material that covers the water surface, will significantly reduce evaporation losses. Although all the farmers mentioned practical problems with the placing of large numbers of rings on their storages, most felt that there would be ways of overcoming these problems and provided a number of suggestions.

1. Background to field trip

In 1995 the Cotton Research & Development Corporation provided funding for a project initiated by Sainty and Associates to evaluate different methods of reducing evaporation from off-river storages located on cotton farms. As part of this study, a field trip to 6 cotton farms in northern NSW was undertaken in March 1995. This report summarises the information obtained from the field trip.

Most cotton farms in northern NSW and southern Queensland store irrigation water in large off-river storages. These storages are used to try and ensure that a supply of water is available during the cotton growing season in spring and summer. The supply of water from regulated rivers passing through the irrigation areas (such as the Namoi and Gwydir Rivers) is highly erratic and in some years, due to very low levels in the major dams upstream there have been no allocations at all. For this reason the efficient use of any water stored by the cotton farmers on their own farms is essential if they are to maximise the amount of cotton grown each year.

Measurements of water levels in the off-river storages located on cotton farms indicate that up to 50% of the stored water can be lost to evaporation. If practical methods of reducing this evaporation loss can be devised, there would be considerably more water available for irrigating cotton and hence large economic gains.

The off-river storages are generally square (or rectangular) in shape and consist of earth walls between 3 to 5 metres high that have been constructed by pushing up the surrounding soil with a bulldozer. The walls vary in length from a couple of hundred metres to over a kilometre long.

2. Discussion with Hugh Barrett of Barrett Purcell & Associates (Consulting Irrigation and Civil Engineers, 52 Dangar St Narrabri).

- Cost of construction of earth wall storages increases with the square of the height of the earth walls, and therefore deeper storages are more expensive to build.
- However deeper dams use up less land area and there is a saving associated with this (eg in Darling Downs 6m deep storages are used due to high land value of \$1200/acre).
- Most storages are not divided into cells (due to extra construction costs involved). However at Collymungle near Collarenebri (which is the largest privately owned cotton farm) the storage is divided into 4 cells.
- Multiple cell storages require more complex pipework and any more than two cells would generally not be practical.
- In many instances it might be easier to make a deeper storage than divide into cells

- Hugh Barrett has done a costing for a farmer to determine optimum cost, and got an answer of 6-7 metres depth. BUT this used a long term payback period of 20 yrs. It might be shallower if a shorter payback period was required. He used the following costs in his calculation;
 - \$330/ML marginal cost assuming a cotton price of \$400/bale (at present it is \$800/bale which is very high!)
 - \$50/ML for water costs (including cost of pumping)
 - \$1.50 per m³ for earthworks.
- Seepage; this can be a major loss of water in some cases, especially if there is a sandy soil near the surface. In some instances when the surface has been scraped up to form the earth wall, sand or gravel has been exposed and when the storage is filled there are major losses due to seepage. A careful assessment of soils is required.
- Pan evaporation is 2200mm class A at Moree.
- Trees on earth walls; this can be a problem because they can dry out the earth and cause cracking.
- Use of wind breaks; Windbreaks only have an effect over a distance of 10x the height of the windbreak
- Hugh's opinion was that opportunities for retrofitting existing storages with cells or higher walls was limited.
- In Narrabri district storages are generally about 3 metres deep whereas in Darling Downs where farms rely totally on ring tank supply the average depth is 6 metres.
- Earth wall storages have occasionally failed

3. Visit to John Watson, (Kilmarnock farm, 5km east of Boggabri)

- Located next to the Namoi River
- Has 2 storages; a 270 ML storage and a 140 ML(??) storage on adjacent farm which receives bore water.
- His 270 ML storage is often not full. It is 3m deep in middle and approx 4 metres deep in borrow pit. Surface area is 9 hectares. Over the last 12 months has been empty except for a 50 ML input in January which only lasted for 3-4 weeks. The 270 ML storage supplies 400 acres of irrigated farm. Cost of storage was \$60,000 for earthworks and \$30,000 for pump (though he did the pump on the cheap).
- His pump capacity is 25 ML/day. He has 2 pumps, one at river and another next to storage.

- Pipework and pumps generally make up 50-75% of total cost of storage
- John mentioned problem of digging too deep when building the earth walls and getting seepage problems if a more sandy soil is exposed.
- John mentioned that trend was to build deeper storages to reduce evaporation losses. He mentioned the GIO farm where they have built 3000ML storage which is 4-5 metres deep.
- Cotton production costs
 - total production costs = \$1800-\$2000 per hectare (excluding depreciation of equipment, interest payments etc)
 - pumping costs = \$8-10/ML (from river)
 - river water costs \$2-3/ML in water charges
 - pumping costs from bores = \$15-20/ML (they have bore water as well as river water)
 - water usage is 6ML/hectare
- Trees as windbreaks; John wasn't too keen since it might interfere with planes doing aerial spraying. Also trees are reputed to dry out and crack earth walls. However he was keen to have trees for reducing aerial drift of chemicals.
- Irrigation season starts with an initial watering in September prior to planting and then from mid December to end of February.
- Irrigation licenses are 970 ML if 100% allocation available. This figure was determined by DWR to allow irrigation of 400 acres.
- John Watson's dam on 2nd farm 10km(?) north of Boggabri. It has just been built but has seepage problems, it is 5 hectares in size and 150 ML volume. He did trial in bottom of storage by filling small shallow pit with 200 mm of water and lost it all to evaporation and seepage in 1 week. He is trying a compacter to pack down base of storage and if that doesn't work will try the more expensive option of applying tripolyphosphate to soil. This costs \$5000/ha.

4. Fred Barlow (Wyadrigah farm, 6km east of Mungindi)

- His farm is on the banks of the Barwon/Macintyre River
- Fred has 3 storages;
 - 700ML storage near his home (2 metre depth)
 - 1100 ML storage (2 metre depth) on adjacent farm which he also owns
 - a 3 year old 300 ML storage which is 5 metres deep. (it is so small and walls so big that borrow pit takes up entire inside of storage)

- His storage near home is 90 acres and it was built in 1985. He uses one pump system to take water from an offtake channel connected to the river into his storage. The offtake channel diverts water from the river a distance of about 150 metres to the pumps.
- Most older storages in this district are 3-3.5 metre walls and 2-3 metres deep. They are shallow since land was cheap. New storages are deeper, up to 5 metre depth with 6 metre walls.
- Fred mentioned the Cubbie irrigation Development in QLD on the Culgoa river. They have a dam with 8 metre walls which have 1:5 slopes on the inside and 1:3 slopes on the outside. The earth was compacted. This farm is growing 9000 acres of cotton this year.
- Fred commented that many people thinking of adding another storage next to original one and just making it into one large storage. This is what Fred did with the storage next to his house. and there is a bank across the middle that is nearly intact. Possibilities for very cheap splitting of this storage into two cells.
- Evaporation losses; Fred described one farmer who put 1000ML into an empty storage in March last year, used 450 ML for winter cereals and only had 100ML left by October. Therefore had lost 450 ML from March to October in evaporation and seepage. Fred's storage near his home was filled in March last year and by early January this year had lost 1.2metres despite not using any water.
- Trees as windbreaks - Fred said the prevailing wind is from the south-west. Prevailing winds; data can be obtained from a weather station that the farmers have put in to record wind speed and direction (this station is primarily for determining spray drift effects of pesticides) Fred was interested in the planting of trees for spray drift reasons.
- He has a line of young trees (natural regeneration) along the base of one side off his 1100ML storage. Up till now he hasn't taken them out but is worried they might dry out and crack the wall. (trees include black wattle, belah (casuarina) long leaved wattle and coolabah)
- (Observation; Potential for windbreak along disused wall in middle of Fred's storage near his home.)
- Bank erosion; On his 1100 metre storage Fred has alot of plants growing along the inside edge which are stopping erosion due to wave action.
- Bank erosion; Some farmers are putting kikuyu along the inside bank and watering it with drip irrigation to keep the bank from drying out. (Bourke farmers are doing this).The kikuyu prevents waves from eroding bank. But most farmers still use scorched earth policy. Grassed banks provides a much better image for the industry since is better looking and provides habitat for birds.

- Fred can grow a maximum of 2000 acres, though last year only grew 700 acres and this year only 250 acres.
- Mungindi; average rainfall is 19" and last year got 7" and the year before that 7".
- Pindari dam has just been enlarged by raising the wall. This river stopped flowing in April last year and only started flowing again (excluding releases from dam) in January this year. Farmers are helping pay for this enlargement by paying \$8/ML extra (plus 5% increase each year for rises in CPI) for next 17 years.
- The current base fee for allocated river water is \$2.50/ML.
- Water pumping costs; Fred estimated at \$6-8/ML for diesel pumps (direct costs only)
- There were no allocations this year on the Gwydir, Barwon or Border rivers. Fred used water he received last March to get this season's cotton crop going.
- Fred commented that the maximum allocation he could ever receive is 45% due to overallocation of these rivers
- If he was building a new storage he would make it a 6 metre wall which would contain 5 metres of water.. He believes that would be the most economical.
- Costing of evaporation losses in the storage near his house;
 - 700ML storage, 2 metres deep, 35 hectares.
 - Evap lost between March last year and January this year = 1.2 metres.
 - therefore evaporation losses = 420 ML = 70 hectares cotton = 400 bales cotton. Current price of cotton is \$700/bale and next year should be at least \$500/bale. Therefore using \$500/bale this represents \$200,000 gross.
- Some calculations on wall cross sections were made;
 - for 3 metre high wall, 4 metre wide flat top, 1:5 slope on inside and 1:1.5 slope on outside; cross sectional area = 42 square metres
 - for 4 metre high wall, 4 metre wide flat top, 1:5 slope on inside, 1:2 slope on outside; area = 72 square metres
 - 6 metre high wall, 5 metre flat top. 1:5 slop and 1:2 slope; area = 156 square metres.
- Cost of earthworks = \$0.75/cubic metre for small dams and \$0.90/cubic metre for larger dams and an extra \$0.20/cubic metre for compacting.
- Sample calculation worked through with Fred;
 - for 5000ML dam of depth 5 metres; (walls = 6 metres)
 - Area = 100 hectares; length of walls = 4 x 1km = 4000m x cross sectional area for 6m high walls
 - = 4000m x 156 square metres = 624000 cubic metres earth

= approx \$600,000

Now do similar calculations for 2 metre deep storage of same volume; (walls = 3 metres)

surface area of storage = 250 hectares, sides = 1500 by 1600 m therefore total length of walls = 6200metres.

cross-sectional area = 42 square metres

6200m x 42 square metres = 260400 cubic metres = \$200,000 cost

Cost of extra land needed; 150 hectares at \$500/acre (\$1250/ha) = \$187,000

Therefore the 3 metre deep dam is approx \$200,000 cheaper. BUT it will have much higher evap losses.

- In Macquarie valley recently, water was sold on free market for \$140/ML.
- Storage failure; Fred's comment; Some storages have been known to fail or develop leaks.
- Fred said that one farmer he knows had an empty storage for a couple of years which had kikuyu growing on top of it. He filled the storage and it failed. There were cracks in the wall that you could put your arm down due to drying out. When they dug into the bank to investigate they found kikuyu roots running down these cracks, and they attributed the failure to the kikuyu drying out the bank. (My comment; I have my doubts about this theory; I feel it might have dried out anyway. The kikuyu might increase the rate of drying out but should not be seen as the main cause.

5. Evan Cleland (Warendi farm, 15 km south-east of Boggabilla on the Dumaresq River.)

- Evan is part of a private irrigation scheme called Merrawah Water Users Association which consists of a group of neighbouring farmers who use the same river pumping station and supply channels.
- The scheme takes water from a lagoon (or billabong) which is connected to the river 5km away (I'm not sure whether it is pumped into the lagoon or flows freely. I do know it is gauged at lagoon entrance by DWR) a set of pumps then pump it up into the irrigation supply channel. Lagoon must be kept at a depth of at least 2 metres due to DWR requirements.
- Evan had data on the losses from his storages; On 29.5 hectare storage he lost 162 ML (drop in height of 5.2 metres to 4.6 metres) between 6/4/94 and 4/10/94. There was no rainfall over this period. In a 11.5 hectare storage he lost 120 ML (drop in height from 4.0 m to 2.9 metres between 4/3/94 and 4/10/94. He lost a further 36 ML between 26/10/94 and 28/12/94 from the 11.5 ha storage (it was nearly empty at this stage)
- His new storage is 29.5 ha, only built a couple of yrs ago. It is built on a slope with 5.5m walls at low end and 3.5 m walls at high end. Didn't want to build walls higher than 5.5metres, since he was worried they might fail or leak.

- His smaller dam is the original one and it is 13 years old; and has 4.5 metre walls, 11.5 ha area.
- He is growing lots of vegetation along the banks of this storage to prevent erosion. This appears to have been very successful. Evan believed couch was very good to grow on the banks, since it appears to re-establish as water levels fluctuate.
- Evan also takes runoff from the floodway that goes through his property. This runoff comes from 10km by 15km catchment consisting of grazing country. In January he got 300ML by doing this.
- His new dam which was completed in Nov 92 is now full and has only been full once before.
- This new dam cost \$530,000 total of which \$230,000 was the cost of pumping station and associated pipework.
- Evan doesn't think he needs any more storage space. His ratio of storage to water allocation and crop acreage is OK.
- Namoi Valley has more reliable supply from river and therefore ring tanks don't need to be as big.
- Evaporation losses from supply and drainage channels can be enormous so they make every effort to keep them empty by pumping any water back into storages

6. Will Kirkby (Glen Prairie farm, 5 km north-west of Moree)

- Industry uses ballpark figure of 50% losses due to evaporation
- 300,000 ML of off-river storages in Gwydir valley (confirm this with DWR figures)
- People have been known to put plastic lining on bottom of storages in spots where seepage is occurring.
- Will suggested that the plastic evaporation rings that Geoff Sainty is trialling could be tied together with cable to prevent them blowing away. Could also then pull them off easily by tugging on cable.
- Will suggested why not put solar cells over the dam, thus reducing radiation and hence evaporation and at same time generate electricity.
- Will said water losses from evaporation are great and since water is the limiting factor, evaporation is a big issue and all farmers are interested in methods of reducing it.

- Logs are used to stop wash and hance erosion of banks by some farmers.
- Will suggested that if storage is split into two cells, then you could pump into one cell, fill it first and then have a spillway to the second cell. A drain and return line from the second cell would direct water back to the pump station when required.
- Will said everyone uses 4m depth around this district.
- He was concerned about trees on dam walls drying them out.
- Auscott uses scorched earth policy and has all earth walls bare except for kikuyu along waterline. Will has grass on his walls
- Contractor called Tony Hiles plants African lovegrass and kikuyu along waterline as a business.
- Will commented that there has been severe erosion on some big storages and that grassing is important.
- Costing for evaporation losses. The following example we went through with Will.
 - 50 hectare storage, 4 metres deep = 2000ML volume.
 - Assume it is half full therefore 1000 ML volume and 2 metre depth.
 - Assume 1 metre is lost to evaporation = 500ML water.
 If dam was split into two cells and the water was put into one cell; volume = 1000 ML and depth = 4 metres.
 - Evaporation (and seepage) is halved since half the surface area = 250 ML. Therefore 250 ML saved.
 - Need 6ML/hectare therefore 250ML is equivalent to approx 40 hectares cotton = approx 250 bales and at \$600/bale this is equivalent to an extra \$150,000 per annum.
- Will's storage = 55 hectares and cost \$120,000 in earthworks. Pump station cost \$100,000
- To split this storage would cost; $\$120,000/4 = \$30,000$.
- Will's storage has only been full 3 times in 5 years. Often only 25-50% full.
- Will is more inclined to increase wall height rather than build a new one since this saves on land and also don't need a new pumping station.
- Will pumps 280ML/day with 2 pumps.
- Will has 1600 ha that can be irrigated.
- Will's figure for cost of earth moving was \$1/m³.

- Windbreaks - Will suggested using fences (perhaps with holes in them).
- The use of trees as windbreaks - Will concerned about how much water trees use, and gave the example of willows which he said use a lot of water.
- Also if an island or shallower bit in middle of storage is built for trees to grow on, he was worried about the decrease in storage capacity that this causes.
- Will wants to see the performance of the ring or covers compared with trees as windbreaks quantified.
- Will commented on problem of covers and access for ducks.
- Covers, Will suggested using huge covers, rather than 1 metre diameter rings to save on cost. Perhaps use covers as large as 50ft diameter or even rectangular. need to think about how to stop wind getting under them.
- DWR has information on everyone's storages, and they would know how many hectares these cover.
- Alan Robinson - Moree DWR could help with this. or Randall Hart (Regional Controller at Moree)
- Quick assessment of cost of evaporation to the Gwydir valley.
 Assume 300,000ML storage and 3 metres deep. Therefore there is 10,000 hectares.
 Assume 1.5 metres evaporation which = 150,000ML. Assume 8 ML/ha needed to grow cotton = 18750 ha cotton and 7.1 bales per hectare is average yield in this valley = 131,250 bales and assume \$500/bale (although it was higher price this season) = \$65,000,000 lost revenue. If this evaporation could be halved there would be a saving of \$33 million. in the Gwydir valley alone.

7. Peter Glennie Norwood farm, 5km north-west of Moree, next to Will Kirkby)

- Use of rings - water level fluctuations would pose a problem to them.
- When new storage area is built he will have 8000ML storage capacity (including surge areas and channels) and he assumes a loss of 50% to evaporation/seepage.
- He is building a new 100 ha dam at present.
- Currently has 190 hectares of storage and at 1.8m evap/seepage = 3420 ML lost per year.

- BUT Peter stated that it would be a huge area to try and cover with rings. - points to consider are; - cost of rings, durability in sunlight, maintenance, do they handle rain, strong winds. Would also need to keep away from inlets/outlets.
- Trees - he has two small mounds in one of his storages with willows on them.
- Worried that vegetation on dams causes drying and cracking of walls
- He felt that a ring of trees inside dams would be okay if on other side of borrow pit.
- If whole dam was covered with plastic what would be the effect on water quality?
- Rings would need to be anchored to prevent them being lifted by strong winds.
- His 500ML dam leaks due to gravel below surface that was exposed in bottom of borrow pit.
- Peter's storages are;
 - 500 ML
 - 590 ML
 - 250 ML
 - 1300ML
 and is building a new 4000ML dam.
- He also has 'surge pits where he collects storm runoff from floodway and fields and eventually pumps it into the storages when there is room.
- Due to trouble with a gravel layer below the surface he is putting borrow pits on outside of storages. These depressions then become surge areas. gravel under surface is common problem in Moree district.
- Peter also has good groundwater supply and has 5 bore pumps. Good groundwater supplies in the Moree district.
- In his new storage he couldn't put wall down middle to make it into two cells since he would have to dig into ground and might expose gravel.
- Peter's new storage, he is using walls of following dimensions; outside bank; 1:3 slope, middle bank; 5 metre high, 6 metre wide, inside bank; 1:8 slope and final 2 metres (vertical) a slope of 1:2.
- A slope of 1:8 is being used to try and prevent wave erosion of the inside bank. The steeper slope at the lower end of this bank is to reduce the amount of earth that has to be moved. This design takes about the same amount of soil as using a 1:5 slope for entire inside slope.

- The entire Norwood farm is enclosed by drains and that collect all tailwater, storm runoff from fields and even runoff from nearby woodland and the floodway. Peter has 4 irrigation licenses plus bore pumps.
- Peter's small storage had a non-seeding grass along the inside bank.
- Conclusion about Peter's farm; He is already using a 'cell-like' system simply by having numerous dams and moving water from shallow storages to the deepest storage to reduce surface area. He pumps out channels for the same reason when they are not being used. he is very aware of reducing surface area. he also gets alot of water form surface runoff from his farm and surrounding bushland as well as the floodway that passes through his property, and also borewater. He managed to get 50% of his cotton crop grown this year despite very little water, due to good water management

8. John Grellman's farm (Beechworth and Sandhurst, west of Wee Waa)

- Sandhurst (1084 ha) is 40 km west of Wee Waa
- (Beechworth (206ha), there other property is approx 20km west-north-west of Wee Waa.)
- Proximity to rivers; Sandhurst is on the northern banks of the Namoi River.
- Sandhurst; 900 ML new storage built last winter, 3 metres deep in middle and 4.5 metres deep in borrow pit., rectangular in shape.
- Evaporation at Sandhurst; has lost 40cm since filling in mid-January due to evaporation and seepage.
- Soil; grey-black cracking clay many metres deep. Parent material is basalt from Nandewar Ranges 100km to the east. Texture is heavy clay of approx 55% clay content. It gets heavier down the profile. it is highly cracking. No distinct zones in profile. pH of soil is 7.2 at surface and 9.0 at 1 metre depth, and hence a moderately alkaline soil. The soil holds water very well, but it is prone to compaction. At 20 metre depth a sand aquifer is reached.
- Crops; 300 ha of land developed for irrigation crops such as cotton, and dolichus lab lab (a legume for nitrogen fixing?) Most of this irrigated land was developed in early 80's.
- Grellman's new wetland
 - Aim of wetland is to help reduce chemical load in runoff. The wetland is also a temporary storage area during high rainfall events.
 - Wetland earthworks - large earth walls were constructed in early March 1995. The storage area is approx 700 metres long and 250 metres wide. The wetland would be located in the borrow pit along the eastern side of the storage and would be 700 metres long by 15 metres wide.

- Water will pass along the wetland and then drain through a pipe out of the storage area into a taildrain. An alternative is to send the water through the wetland and then back around the other side of the wetland (via borrow pit) back to main pumping station. To do this would require more earthworks and a 2 channel system (an upper and lower channel) near pump station (Upper layer where water runs to wetland, and lower layer for return water.)