Department of Natural Resources and Mines

Methods for Reducing Evaporation from Storages used for Urban Water Supplies

Final Report

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Executive Summary

There has been an increased focus on evaporation control techniques that can be applied to urban water storages due to the severe drought conditions in many parts of Australia. This report was commissioned by the Department of Natural Resources and Mines on behalf of the Drought Urban Water Task Force. It contains a summary of the different strategies to reduce evaporation from water storages including:

- Physical;
- Chemical; and
- Other methods.

Where possible examples of actual products available are included but it is not an exhaustive list. A brief description of the strategies available and their methods of operation can be found in the table below.

Description of Evaporation Reduction Techniques

Method	Description
Floating Covers	Floating covers act as an impermeable barrier against evaporation. Many different materials have been trialled in the past including polyethylene, wax, foam and polystyrene. Covers are one of the most effective evaporation reduction techniques.
Floating Objects	Floating objects use the same principle as floating covers, however rather than a continuous cover multiple individual units are used, often floating freely. This allows for easier installation and maintenance of the cover but reduces the evaporation reduction efficiency.
Shade Structures	Shade structures reduce the energy available for evaporation; reduce wind action over the water surface and trap humid air under the cover, all factors that contribute to evaporation. These structures are generally suited to smaller water storages.
Chemical 'covers'	Chemical covers are based on the use of long chain alcohols to form a thin layer on the surface of the water to reduce evaporation. These layers are biodegradable and need to be reapplied every 1 to 4 days. Chemical methods are not as effective as physical methods.
Design Features	Water storages may be constructed or altered to proportionally reduce the evaporation rates by using methods such as: ◗ Deeper storages with smaller surface areas; ◗ Cellular construction which divides large storages into smaller ones to reduce wind action and allows water depth to be maximised by shifting water between cells; and ◗ Using windbreaks. Design features are generally easier to build into a new storage, when site selection can be altered, than retrofitting into an existing storage.
Biological Covers	Some biological covers, such as lily pads and duckweed, have the potential to reduce the evaporation from the water surfaces they live on. The evaporation reduction efficiency is much lower than other methods available and so these methods have had little emphasis placed on them.

There are a number of advantages and disadvantages associated with each method including:

- Floating covers are highly effective at evaporation reduction, though they can have impacts on water quality, severe impacts on aquatic life and are relatively expensive to install;
- Floating objects are not as effective at evaporation reduction as covers though the impacts upon the water storage are not as great and they are easier to install and maintain;
- Shade structures can have a similar evaporation reduction efficiency to floating objects and do not have significant water quality impacts though are more expensive than both covers and floating objects;
- Chemical evaporation retardants have lower evaporation reduction efficiency than physical methods but have reduced environmental impacts, health impacts and with little or no capital expenditure required. The operational costs are greater due to the chemical costs;
- Design features have varying evaporation efficiencies and can be combined with any of the above methods to maximise evaporation control. They are most easily integrated during construction but can be retrofitted into existing storages;
- Biological covers have low evaporation reduction efficiencies, may cause environmental impacts and are suitable in only some circumstances.

Preliminary cost estimates based on the cost per hectare and the water saved have been undertaken for the physical and chemical evaporation reduction techniques. The design features and biological control methods have been excluded from this study, as the costs are site specific. The following table summarises the costs per ML saved for differing strategies for evaporation reduction. The cost estimates have been developed for the purpose of comparing and evaluating competing options and cannot be used for budget setting purposes.

Cost per ML Water Saved Results

				Evaporation Reduction			
Evaporation Control Method	**Installation Cost Per hectare (100% coverage)**	**Annual Dosing Cost**	**Evaporation Reduction Efficiency Assumed**	**Water Saved per Year (ML/ha) (1.5 m/yr)**	**Cost per ML (1.5m/year)**	**Water Saved per Year (ML/ha) (2.5 m/yr)**	**Cost per ML (2.5m/yea**
E-VapCap - Floating Cover	$60,000	-	95%	14.25	$421	23.75	$253
Aquacap - Floating Object	$136,000	-	70%	10.5	$1,295	17.5	$777
AquaSpan - Shade structure	$300,000	-	75%	11.25	$1,778	18.75	$1,067

Evaporation Control Method	Installation Cost Per hectare (100% coverage)	Annual Dosing Cost	Evaporation Reduction Efficiency Assumed	Evaporation Reduction			
				Water Saved per Year (ML/ha) (1.5 m/yr)	Cost per ML (1.5m/year)	Water Saved per Year (ML/ha) (2.5 m/yr)	Cost per ML (2.5m/yea
Water$avr							
- Chemical method	-	$1,825	30%	4.5	$406	7.5	$243
Hydrotect							
- Chemical method	-	$2,738	30%	4.5	$608	7.5	$365

Important conclusions and recommendations from this study are:

- Evaporation control methods for large water bodies primarily consist of physical and chemical methods;
- Physical evaporation reduction methods are able to “save” a greater percentage of water, between 70%-100% and entail a large capital cost and lower operations and maintenance costs;
- Chemical evaporation control methods “save” a lower percentage of water, between 20%-40% and have little capital cost but higher operations and maintenance costs;
- All of the potential measures will impact upon the aquatic ecosystems on water storages to some extent, physical control methods are likely to have a greater impact than chemical controls;
- Size of the storage and local conditions may dictate the evaporation control techniques that are applicable to a water storage;
- Chemical control techniques can be used as required where as physical control methods are more permanent;
- If evaporation reduction methods are required in environmentally sensitive areas, a chemical evaporation retardant be employed;
- Physical evaporation control methods only be employed in areas with little or no environmental significance;
- If high levels of evaporation reduction are required then a physical reduction method be employed;
- When designing new water storages that evaporation control techniques such as deeper storages, cellular construction and windbreaks be included in the design if feasible.

1. Introduction

1.1 Background

The prolonged drought affecting Queensland has had an impact upon the urban water supplies for communities around the State. A task force, the “Drought Urban Water Task Force,” consisting of representatives from the Department of Natural Resources and Mines, the Department of Local Government and Planning, the Local Government Association of Queensland and other government agencies has been formed to address the water supply issues facing these communities. As part of the investigations into providing water supplies to communities the Department of Natural Resources and Mines, on behalf of the Task Force, commissioned GHD to report to Water Industry Compliance on Strategies for Reducing Evaporation from Urban Water Storages.

1.2 Objectives

The objectives of this study include:

- To determine the methods and strategies available to reduce evaporation from urban water storages; and
- Investigate the advantages and disadvantages for the different options; including
  - Water quality issues;
  - Environmental issues;
  - Safety;
  - Effectiveness;
  - Ease of installation and use;
  - Cost; and
  - Availability.

1.3 Concurrent Studies

The Rural Water Use Efficiency Unit will be funding R&D to evaluate a range of methods for reducing evaporation from farm storages. While the projects to receive funding have yet to be finalized, it is expected that they will be in the general categories of floating covers, monolayers (e.g. cetyl and stearyl alcohols) and shading. A final report on the outcomes of the research is due by December 2004.

2. Evaporation Reduction Methods and Strategies

2.1 General

Many urban water storages are located in areas of high evaporation. The use of evaporation reduction techniques has the potential to provide greater security of supply. The following methods of evaporation reduction are not a complete listing of all methods, however an example of each type of strategy is included to illustrate the advantages and disadvantages of each type and indicative costs.

2.2 Physical

2.2.1 Covers - E-VapCap

General

Covers provide a physical barrier between the water and atmosphere to prevent evaporation occurring. Many different types of covering materials including foam, wax polystyrene, bamboo, etc, have been trialled with varying levels of evaporation reduction and cost effectiveness. One product that has been receiving much attention recently is E-VapCap.

E-VapCap is a product produced in Australia by a joint venture of Sealed Air Australia Pty Ltd, Evaporation Control Systems (ECS) Pty Ltd and Darling Downs Tarpaulins Pty Ltd. The product is a multi-layered polyethylene (PE) membrane approximately 0.5mm thick containing buoyancy cells trapped within the layers. E-VapCap reduces evaporation by covering the surface area available for evaporation. The top layer of PE is coloured white and UV stabilised to reflect sunlight away from the water surface and reduce UV degradation, enhancing product life. The bottom layer is coloured black to reduce the sunlight penetration to reduce biological activity below the cover (ECS Pty. Ltd. Website). E-VapCap has been installed on approximately 20–30 water storages ranging from small tanks to storages of 4 hectares around southwest Queensland and northern New South Wales (PersComm, Max Brady).

Water Quality Issues

There are a number of water quality issues associated with the use of floating covers including reduction of oxygen transfer to the water, possibly causing anaerobic conditions. Possible effects include increased iron, manganese and ammonia levels in the water due to anaerobic conditions formed in the water storage. This may require extra water treatment processes to maintain potable water quality. Depending on the severity of depletion it may be necessary to add oxygen to the water storage by aerating to avoid anaerobic conditions. This will impact upon the cost effectiveness of the operation and may result in increased evaporation.

The cover materials themselves may have an impact upon the water quality depending on the material used in the cover. Most covers are made from PE of varying thicknesses, which are relatively stable and do not leach chemicals into the water storage. Any materials that come into contact with potable water should be tested according to AS 4020: Testing of products in contact with drinking water.

E-VapCap is made from polyethylene (PE) in two qualities, normal or food grade, available on request. The cost of the food grade PE is 10% greater than the normal grade. It is unlikely that there would be any contamination of the water supplies from the materials.

Environmental Issues

The installation of covers will block sunlight and oxygen from entering the water storage. This would result in the loss of habitat for both flora and fauna.

The prevention of sunlight entering the water storage could stop the growth of photosynthetic life, especially plant life, disrupting the entire ecosystem. In off stream storages this can destroy the ecosystem by removing the basic food source from the bottom of the food chain. In an in-stream storage the lack of sunlight could stop any plant life growing underneath the covers, the impact upon the rest of the water body would have to be determined on a case-by-case basis. A potentially positive impact from covers is the reduction in algal growth.

Materials used for floating covers are generally impermeable to oxygen, which can lead to anaerobic conditions in the water storage. This is generally more of a risk for off-stream storages than in-stream storages as the turn over time for in-stream storages is often shorter. The potential effects are discussed in the health section above.

The exact environmental impacts would depend on the storage in question. The suitability of using floating covers should be assessed on a site-by-site basis. For example it may be more acceptable to cover an artificial dam rather than a section of natural creek.

Safety Issues

The main safety issue with E-VapCap would be people walking on the covers. This is not recommended and the practise should be banned. Fences should be erected to prevent public access to the site and prevent animals from damaging the covers. From discussions with Warrick Hill, patent holder for E-VapCap, there have been situations where bore water with high sulphate levels has been stored in covered dams under the anaerobic conditions resulting in the production H_2S. The effects of H2S production may include unpleasant odours around the site and occupational health and safety risks in higher concentrations.

Effectiveness

The efficiency of evaporation reduction is dependent on the proportion of the storage that is covered. In areas that are covered evaporation is reduced by close to 100%. The edge of E-VapCap is embedded into the wall of the storage to prevent movement in the wind, ensuring that the water surface remains protected. If access to the waters edge is required then the covers can be anchored to the shore using wires.

Ease of Installation and Maintenance

The ease of installation for E-VapCap is related to the surrounding conditions, the size of the storage to be covered and weather conditions. Experience in covering irrigation water storages in the St George region shows that adverse weather conditions can create problems during installation as sections of the covers are welded together on the water surface so any wind and wave action complicates this procedure. However as more experience is gained in installing E-VapCap it is expected that these problems may be overcome or avoided. Installing E-VapCap on in-stream storages has not been attempted and may have teething difficulties, though it would be expected that these could be overcome.

Low levels of maintenance are required by E-VapCap once it is installed. As the product is relatively new it is likely that there are still a number of minor problems to be dealt with. Visual checks of the covers should be undertaken as part of the weekly water storage checks to rapidly identify any problems before they become an issue.

Cost

The cost of installing E-VapCap on water storages is approximately $60,000 per hectare. This price is comprised of the supply price of the material, preparation of the material by the installer at the warehouse, installation at the site and includes transport to a site in southern Queensland. This price does not include the cost of a fence around the storage. If the demand for E-VapCap increases the supply price for the material would drop as the manufacturer achieves economies of scale.

Storage size

Currently the largest storage that has been covered is 4 hectares, Warrick Hill expects that covers of 100's of hectares will be possible. The product is currently undergoing research at National Centre for Engineering in Agriculture (NCEA) to determine the effects on water quality and how much larger the covers can be made. It is likely that there would be issues to be overcome with larger covers.

Availability

All the components for the product are manufactured in Australia with the time from order to supply of product approximately 4 weeks. The time to weld together the product and install it is reliant on the local conditions and size of the storage.

2.2.2 Floating Objects – Aquacap

General

Many types of floating objects have been trialled to reduce evaporation from water storages. These include natural objects such as bamboo and reed bundles and man made objects such as polystyrene beads, wax and drinking water bottles. Many of these methods were trialled due to their availability and ease of installation. There are issues with using many of these methods as their suitability and environmental impacts are often questionable. This section will focus on a developing technology called Aquacap.

A research program is developing Aquacap as a method to reduce evaporation from open water storages by covering the water surface with small modular domes. There are a number of other benefits including reduced algal growth and reduced erosion as the domes minimise wave action. Each dome is independent of the other domes and they are reported to be stable in winds of approximately 70 km/h as the dome extends below the water level. This product is still in the research phase and is not ready for commercial use. Figure 1 below shows the Aquacap process in research trials (Burston *et al.*).

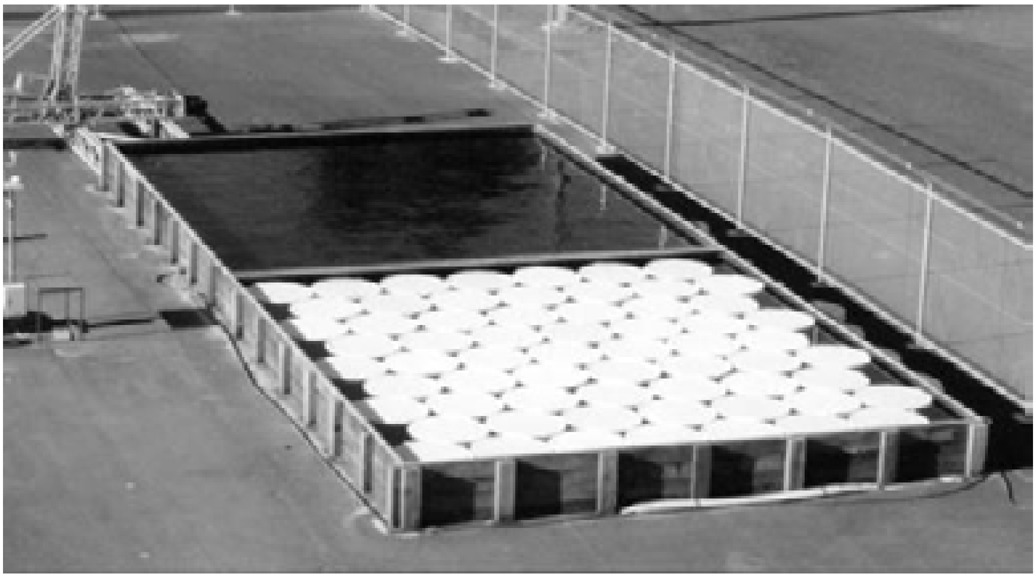

Figure 1 Aquacap, RMIT (Royal Melbourne Institute of Technology), Bundoora Campus trial and control ponds[1]

Water Quality Issues

There may be long term issues with the use of Aquacap depending on the materials that are use in their construction. The water quality issues will be similar to those for floating covers though should be less severe as some of the surface is left uncovered. Any materials in contact with potable water should be tested in accordance with AS 4020: Testing of products in contact with drinking water. From discussions with Ian Burston, the researcher who is responsible for their development, they will be constructed with materials that will not impact upon the water quality.

Environmental Issues

It would be expected that there are similar issues as for E-VapCap as the modules prevent oxygen transfer and light penetration to the water surface and reduce wave action (and hence oxygen transfer). Due to the spaces between the modules the impacts of the Aquacap would not be as great as that for continuous covers, including that of reduced algal growth.

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[1] Source: Evaporation Reduction From Open Water Storages, Ian Burston, A. Akbarzadeh and C. W. S. Dixon, RMIT.

Safety Issues

No safety issues have been identified as yet and none are anticipated. If a person fell into a storage covered with modules, they could maneuver between them and obtain some support from them to enable them to reach safety. It is possible that the modules may become airborne and pose a danger if they are exposed to very high winds.

Effectiveness

The modules can cover up to 90% of the water surface, though a level of approximately 80% is usual. When the Aquacap cover approximately 80% of the storage they reduce evaporation by approximately 70% under normal conditions and in areas that experience high levels of evaporation the performance can improve up to 90%.

Ease of Installation and Maintenance

The modules would be easier to install than conventional evaporation reduction techniques such as covers. Maintenance is also expected to be minimal, if there are any damaged modules they would be simply be removed from the storage and replaced with another module.

Cost

Preliminary cost analysis suggests that it would cost approximately $170,000 per hectare. This cost is expected to drop as the product is refined and enters mass production. This cost does not include the cost of a fence surrounding the storage if necessary.

Storage size

Currently the units have only been trialled on small storages (<500m^2). From correspondence with Ian Burston he is confident that they would be suitable for storages up to 25 hectares in size. This is provided that the modules have a minimum water depth of approximately 200mm to resist wind displacement.

Availability

Aquacap are not currently available for commercial use as they are still in the research and development stage. Ian Burston expects that they will be commercially available in January 2005.

2.2.3 Water Bladders

General

Water storage bladders use a similar concept to wine cask bladders. The bladder material, generally polyethylene, provides a complete lining, above and below the water storage. The cover and walls raise and lower with the water level in the storage, reducing both the evaporation and leakage losses from the storage. Wide Bay Water has installed a number of these bladders in place of potable water storage reservoirs. The bladders were installed in large earth craters, shaped and packed with material to support the geo-synthetic liner. The bladders installed by Wide Bay Water are relatively small in comparison to most water supply storages, the bladders range in size between 2.5-30 ML (PersComm, Brent Marshall). In the evaporation control sense this product is simply a floating cover that is joined to a liner, and would have similar advantages and disadvantages to floating covers. The small size of the water bladders may serve to reduce potential problems, as there is a relatively short detention time in storage. If the detention time is increased then more problems may be encountered. The effects of anaerobic conditions may be reduced because of lower organic levels as a result of the floor of the storage being lined; this would be dependent on the organic levels in the influent water (Perscomm, Max Brady).

2.2.4 Shade Structures

General

Shade structures involve the erection of suspended covers over water storages. They can act to reduce evaporation in a number of ways including:

- Reducing the direct sunlight on the water surface;
- Reducing the wind velocity across the water; and
- Increasing the humidity of the air under the cover.

Figure 2 shows a shade structure constructed by SuperSpan Pty Ltd over a water supply storage in East Gippsland, Victoria. This shade was constructed to prevent algal growth in the reservoir, though also provides evaporation reduction as well.

Figure 2 Shade Structure in East Gippsland, Victoria.

Water Quality Issues

It is expected that there would be few if any water quality issues associated with the installation of shading structures. There may be a positive impact from the reduction of algal growth in the storage.

Environmental Issues

The shade structures by SuperSpan prevent up to 95% of UV from reaching the water storage surface and have the potential to disrupt the entire ecosystem. It would have a similar impact upon the water storage as the blocking of sunlight described in the floating covers section.

This type of evaporation reduction technique does not restrict oxygen access to the water surface; however the reduction in wind action may reduce oxygen transfer to the water body. This would have to be determined on a case-by-case basis.

Safety Issues

There are no significant safety precautions to be taken, except for that of prohibiting anyone from walking in the structure. As the structure comes down to ground level the area should be fenced off, preventing public access and animals from damaging the covers.

Effectiveness

The CSIRO has recently conducted testing on the effectiveness of using shade structures to prevent evaporation (Finn and Barnes, 2002). The tests were done using small-scale equipment (1000L tanks). The results of the testing indicated that the evaporation reduction efficiency ranged from 59% to 76%. No testing has been undertaken on a large-scale basis.

Ease of Installation and Maintenance

The ease of installation of shade structures is dependent on the site conditions, any constraints placed by the client (such as not disturbing the water in the storage) and the weather conditions. The materials used are prefabricated and transported to site to allow rapid construction.

Once installed the structures are low maintenance, requiring only visual inspection for damage or other problems. Other shade structures erected by SuperSpan have lasted up to 20 years with very little maintenance before the need for replacement.

Cost

The cost of the shade structures from SuperSpan-Gale Pacific ranges from between $120,000 – $340,000 per hectare and is very dependent on the site conditions, the type of structure that is to be installed (eg no uprights inside), any constraints placed on the design by the client and the size of the structure.

Storage Size

Shade structures can be made in any size and shape to cover water storages. The largest structure designed so far is approximately 280 m by 320 m or (nearly 9 hectares), larger structures should be possible, though they may increase in price.

Availability

This type of cover would require a lead-time of approximately 12 weeks for completion. If the job is large or has difficult site conditions then it may require a longer period, conversely if it is a simple job then it may be installed in a shorter time.

2.3 Chemical Methods

The use of chemicals to control evaporation has been researched in Australia, the United States of America and India since the 1950s. Research has focused on the use of long chain fatty alcohols in particular. Generally chemicals have lower evaporation reduction efficiencies, have significantly lower capital costs and higher operating costs (mainly as the chemicals need to be reapplied every 1-3 days). Two such products are described below.

2.3.1 Water$avr™

General

Water$avr™ is a product using cetyl and stearyl alcohols to reduce evaporation from water bodies. Water$avr™ acts by reducing the evaporative partial pressure of the water vapour above the water surface resulting in a lower evaporation rate. It uses ionic repulsion to spread across the water by itself allowing manual application from the shore or boats on the water surface. The product is biodegradable and needs to be reapplied every 2-4 days depending on the conditions. It has been used in a number of successful applications in China, India and the United States of America. Water$avr™ is currently under trial at Capella, Peak Downs Shire where the water supply to the town has reached critically low levels. The trial commenced two months ago but no data is available at present.

Water Quality Issues

There are no known health issues with Water$avr™ as studies have shown it to be:

- Readily biodegradable;
- Non-toxic; and
- Permeable to oxygen;

It is registered with National Sanitation Foundation (NSF) International as a chemical suitable for use in potable water source and is listed by the United Nations Environment Program as an Environmentally Sound Technology (UNEP EST).

The chemical monolayer should not have a negative impact upon recreational activities as Water$avr™ is a food-safe version of Heat$aver, a product used on public swimming pools. However this would not be recommended as the recreational activities would break the monolayer and increase evaporation. Peak Downs Shire Council is using Water$avr™ on its town water storage without any noticeable impact.

Environmental Issues

The use of chemicals on water storages may have negative impacts on the local aquatic environment. The impacts of using evaporation reduction chemicals on water bodies with active ecosystems are poorly understood. An experiment carried out by the Water Resources Institute of Texas A&M University noted that potential negative impacts from the use of a long chain fatty alcohol that forms a monolayer on the water surface included:

- Reduced oxygen diffusion rate, up to 10%-15%, possibly leading to reduced oxygen levels in the water body;
- Reduction in the surface tension;
- Increase in temperature just below the layer;
- Increased growth of bacterial organisms (due to the biodegradable nature of the chemical);

Water$avr™ is claimed by the manufacturer to have no impact on the oxygen transfer rate. However the addition of biodegradable chemicals to the water has the potential to increase the microbiological activity in the water storage, potentially decreasing the oxygen content and increasing turbidity.

Safety Issues

The handling precautions for Water$avr™ recommended by the manufacturer are stated to be the same as for hydrated lime, gloves, dust mask and safety glasses\goggles. The product is non-flammable.

Effectiveness

Chemical covers are generally susceptible to wind and wave interference as they form a monolayer on the water surface. Once broken the layer reforms at a slow rate than when first applied which leaves the water surface be exposed to evaporation until after the wind ceases. Water$avr™ product information obtained from Ondeo-Nalco states that in trials in China, India and the United States of America the evaporation reduction efficiency was between 20 to 42%. The dose rate required is dependent on site conditions and ranges from 0.5-1 kg/ha every 2-4 days.

Ease of Installation and Maintenance

Application methods may vary depending on the available technology of the region, however it can be successfully applied using manual labour only. After application the product spreads at a rate of approximately 10 km per hour due to ionic repulsion, allowing simplified application. The only capital expenditure required by Water$avr™ is the chemical storage area, if required, and any application equipment, if manual application is not used.

Cost

Water$avr™ is available in 22kg bags and costs $15.00 per kg or $13.00 per kg if the results of the trials are made available to the supplier. The cost per ML saved is dependent on the dose required and frequency of dosing.

Storage Size

There is no upper or lower limit to the size of water storage that can benefit from using Water$avr™. However the product has limitations placed on it by the surrounding environment including wind and wave action as these disrupt the monolayer. An assessment of the individual site would be required to determine the suitability.

Availability

Water$avr™ is available as required from the Australian distributor Ondeo-Nalco Pty Ltd.

2.3.2 Hydrotect

Hydrotect is a water evaporation retardant that is an emulsion of 60% water and 40% aliphatic alcohols. The product is claimed to be non-toxic, biodegradable and is suitable for application to drinking water reservoirs. It uses the same method of action that Water$avr™ uses and achieves similar levels of evaporation reduction. The application of the product involves the creation of a solution and then the application of that solution to the water surface. Methods proposed for application in Africa included using local fire trucks, spray equipped trucks and manual labour. The method selected was the manual application, in this case from boats on the water. The direction of the wind needs to be taken into account to ensure the best spreading of the product across the water.

Water Quality Issues

According to a study undertaken in Ouagadougou, Burkina Faso, Africa in 1998 there are no adverse health effects.

Environmental Issues

Environmental observations during the study noted a number of impacts including:

- An increase in water temperature by up to 3-4 degrees Celsius;
- Decreased oxygen levels at the water surface, though no change below the surface;
- Slightly elevated bacterial activity.
- No impact upon aquatic life;

Safety Issues

No safety issues were raised with the product, subject to the correct use of application equipment.

Effectiveness

A study carried out in Ouagadougou, Burkina Faso, Africa using Hydrotect to reduce evaporation from the water storage reservoirs in 1998 (Witting, 1998). The conclusions stated that evaporation could be reduced by up to 50% in small water storages (0.5 ha) and 25-35% in larger water storages. The application rate for an unbroken monolayer is 1-3 kg/ha/d. The evaporation reduction efficiency is similar to that of Water$avr™ though with increased application rates.

Ease of Installation and Maintenance

As with Water$avr™ the product is relatively easy to apply to the water surface requiring minimal capital expenditure. The study recommended that to improve the performance of Hydrotect that application should take place twice a day and that activity on the water surface should be restricted.

Cost

Hydrotect is delivered in 190 kg drums at a cost of $5.00 per kg. The cost per ML saved is dependent on the dose required.

Storage Size

As for Water$avr™ there is no upper or lower limit to the water storage size. However the product has limitations placed on it by the surrounding environment including wind and wave action as these disrupt the monolayer. An assessment of the individual site would be required to determine the suitability.

Availability

Hydrtect is made to order overseas and shipped to Australia for distribution by Swift and Co Ltd. As the product is made to order and then shipped to Australia from overseas it is likely that is would take a significant period of time from order placement to fulfillment.

2.4 Other

Apart from physical and chemical methods there are a number of other methods available to reduce evaporation from water storages. These include design features and biological covers.

2.4.1 Design Features

Design features to reduce evaporation from storages include:

- Building deeper storages;
- Construct storages to reduce wind action over their surface eg wind breaks;
- Cellular construction combined with windbreaks and keeping water depth as great as possible.

When designing new storages all these features can be combined to achieve a greater evaporation reduction. It may be possible to retrofit these features to an existing storage, though this would likely require the emptying of the storage to do so.

Deeper Storages

The construction of deeper storages allows a greater volume of water to be stored while exposing the same amount of surface area available for evaporation. This reduces the evaporation in proportion to the volume of water stored. Deeper storages may encourage stratification of the water storage creating water quality issues. Methods to destratify the water storage may result in increased levels of evaporation.

The cost of constructing deeper storages is dependent on the site conditions and the type of storage that is required, either in-stream or off-stream. This extra cost must be balanced against the volume of water saved. This method is more likely to be useful in the construction of new storages rather than upgrading existing storages.

Windbreaks

Windbreaks are employed to reduce the wind speed across a water storage, as wind speed is a factor in determining the evaporation rate from a water body. Windbreak construction can range from building high walls around a storage to planting trees around the storage. Care must be taken in the placement of tree lines as windbreaks to prevent the structural integrity of the dam wall becoming compromised.

The siting and shape of a water storage can have a significant effect on the wind passing over the storage. The storage should be sited to avoid having long exposed sections of water along the axis of the prevailing winds. Where possible storages should be sited to take advantages of natural terrain, eg hills, to reduce the wind velocity around them. Windbreaks can be combined with other evaporation reduction methods, for example putting windbreaks on the internal walls of a cellular water storage.

Cellular Storage

Storages can be constructed using cellular storage methods, where a large storage is divided into smaller sections. This allows a number of potential evaporation savings such as reduced wind action over the water surface, especially if windbreaks are placed along the internal walls of the cells. By pumping water from partially empty cells together to maximise the depth of the water the surface area available for evaporation can be minimised. The cost for the internal walls must be balanced against the volume of the water saved.

2.4.2 Biological

Some biological covers may have the potential to provide a small decrease in the volume of evaporation. This is dependent on the species of plant involved and care is required as many species increase the level of evaporation. Studies in Thailand have shown that duckweed can reduce evaporation by up to 10%. It is unlikely that duckweed or other plant would be acceptable for use on water supply storages as it would prevent the use of the water body for secondary uses, such as recreational activities, would potentially create issues for water quality and would impact the existing environment (for in-stream storages). There is also a risk of introducing foreign species that may spread beyond the intended areas.

2.5 Summary of Evaporation Control Methods

The evaporation control methods described above have been complied into a tabular form, Table 1 below, for easy reference.

Table 1 Comparison of Evaporation Reduction Options

Evaporation Reduction Method	Effectiveness	Water Quality Impacts	Environmental Impacts	Ease of Construction and Maintenance	Product Availability
Floating Covers	Close to 100%	Potential impacts from anaerobic conditions including increased iron, manganese and ammonia levels. Possible positive impact from reduced algal growth	Severe impacts on the environment, loss of habitat, disruption of existing ecosystems, possible anaerobic conditions in water body	Relatively complex installation procedure, once installed low levels of maintenance required	E-VapCap is manufactured in Australia, approximately 8-12 weeks, possibly more for large or difficult storage
Floating Objects	Depends on objects – Aquacap approx 70%	As above – possibly less severe as some surface is left uncovered	As above – possibly less severe as some surface is left uncovered	Easier installation due to modular construction, low maintenance once installed	Aquacap is unlikely to be available before 2005
Shade Structures	Up to 75%	Possible positive impact from reduced algal growth	Severe impacts on the environment, loss of habitat, disruption of existing ecosystems	Relatively complex installation procedure, once installed low levels of maintenance required	AquaSpan takes approximately 12 weeks for standard storage, less for easy conditions and more for harder conditions
Chemical Evaporation Retardants	Between 20%-40% depending on site conditions, chemical used and application rates	No health impacts	Relatively minor impacts – possibly including reduced oxygen levels and increased bacterial activity	Very little or no capital construction require and easy application techniques suitable	Water$avr is available in Australia, Hydrotect is available from overseas.
Design Features	Dependent on site conditions and methods used	No health impacts	No Environmental Impacts unless retrofitted into existing storage	More complex construction required	N/A

3. Cost Estimates

3.1 Cost Estimates

Preliminary cost estimates have been prepared for the physical and chemical control methods described above. The design features and biological control methods have been excluded from this study, as the costs are site specific. These products can be sourced in Australia; in the case of Aquacap the product should be availably commercially by 2005.

To provide a common ground for the comparison of options the cost per ML of water saved has been calculated on a per hectare basis. The comparison has been made using two different evaporation levels to show the impact of higher evaporation rates. A number of assumptions were made for the purposes of this exercise and are detailed in Table 2 below. The physical methods are based on the amount of water saved over the life of the product, whereas the costs for chemical methods are determined over one year.

The preliminary cost estimates presented in this section have been developed solely for the purpose of comparing and evaluating competing options. They are sufficiently accurate to serve this purpose. They cannot be used for budget-setting purposes as common elements between options may have been omitted and/or the works not fully scoped. A functional design is recommended if a budget estimate is required. The maintenance costs for the physical methods have not been included, though they are not expected to be high.

Table 2 Assumptions Made in Cost Estimates

Evaporation Control Method	Assumptions
E-VapCap	The assumptions used in costing for E-VapCap include: ◗ Cost per hectare is $60,000; ◗ The evaporation reduction efficiency is 95%; ◗ The product has an effective life of 10 years; ◗ No allowance for O&M; ◗ No allowance for fencing around the storage.
Aquacap	The assumptions used in costing for Aquacap include: ◗ Cost per hectare is $170,000; ◗ Approximately 80% coverage by the modules; ◗ The evaporation reduction efficiency is 70%; ◗ The product has an effective life of 10 years; ◗ No allowance for O&M.

Evaporation Control Method	Assumptions
AquaSpan	The assumptions used in costing for AquaSpan include: ◗ Cost per hectare is $300,000; ◗ The evaporation reduction efficiency is 75%; ◗ The product has an effective life of 15 years; ◗ No allowance for O&M; ◗ No allowance for fencing around the storage.
Water$avr	The assumptions used in costing for Water$avr include: ◗ A conservative application rate of 1 kg/ha; ◗ Application frequency every 3 days; ◗ Cost of Water$avr is $15.00 per kilogram; ◗ The evaporation reduction efficiency is 30%.
Hydrotect	The assumptions used in costing for Hydrotect include: ◗ Application rate of 1.5 kg/ha; ◗ Application frequency every day; ◗ Cost of Hydrotect is $5.00 per kilogram; ◗ The evaporation reduction efficiency is 30%.

Table 3 below summarises the results of the cost estimates using the assumptions listed above.

Table 3 Cost per ML Water Saved Results

				Evaporation Reduction			
Evaporation Control Method	**Cost Per hectare (100% Coverage)**	**Annual Dosing Cost**	**Evaporation Reduction Efficiency Assumed**	**Water Saved per Year (ML) (1.5 m/yr)**	**Cost per ML (1.5m/year)**	**Water Saved per Year (ML) (2.5 m/yr)**	**Cost per ML (2.5m/year)**
E-VapCap	$60,000	-	95%	14.25	$421	23.75	$253
Aquacap	$136,000	-	70%	10.5	$1,295	17.5	$777
AquaSpan	$300,000	-	75%	11.25	$1,778	18.75	$1,067
Water$avr	-	$1,825	30%	4.5	$406	7.5	$243
Hydrotect	-	$2,738	30%	4.5	$608	7.5	$365

4. Conclusions

Important conclusions from this study include:

- Evaporation control methods for large water bodies primarily consist of physical and chemical methods;
- Physical evaporation reduction methods are able to "save" a greater percentage of water, between 70%-100%;
- Chemical evaporation control methods "save" a lower percentage of water, between 20%-40%;
- All of the potential measures will impact upon the aquatic ecosystems on water storages to some extent, physical control methods are likely to have a greater impact than chemical controls;
- Physical control methods entail a large capital expenditure and lower operations and maintenance costs;
- Chemical control methods require little capital expenditure but have a higher operations and maintenance cost due the chemicals;
- Size of the storage and local conditions may dictate the evaporation control techniques that are applicable to a water storage;
- Chemical control techniques can be used as required where as physical control methods are more permanent;
- The following table summarises the cost per ML of water saved for different evaporation control methods and different evaporation rates.

	Evaporation Reduction	
Evaporation Control Method	**Cost per ML (Evaporation Rate 1.5m/year)**	**Cost per ML (Evaporation Rate 2.5m/year)**
E-VapCap[1]	$421	$253
Aquacap[1]	$1,295	$777
AquaSpan[1]	$1,778	$1,067
Water$avr[2]	$304	$183
Hydrotect[2]	$608	$365

Notes:

1. Permanent installations – costs are calculated over the life of the product
2. Non permanent method – costs are calculated over one year

5. Recommendations

Important recommendations from this study include:

- If evaporation reduction methods are required in environmentally sensitive areas a chemical evaporation retardant be employed;
- Physical evaporation control methods only be employed in areas with little or no environmental significance;
- If high levels of evaporation reduction are required then use a physical reduction method;
- When designing new water storages that evaporation control techniques be included in the design;

6. References

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- Jones, F., 1991, *Evaporation of Water With Emphasis on Applications and Measurements*, Lewis Publishers, USA;
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- Varma, C.V.J., 1996, *Manual On Evaporation And Its Restriction From Free Water Surfaces*, A.A. Balkema Publishers, USA;
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Appendix A

Project Brief

Brief for Consultancy Services for GHD
Methods for Reducing Evaporation

Project

The purpose of the project is to review and report to Water Industry Compliance[2] on the methods and strategies available to minimise evaporation from storages used for urban water supplies.

Background

The Government has established a Drought Urban Water Task Force to address water supply problems arising because of the prolonged drought conditions in Queensland. The Task Force has asked for a review of methods available to minimise evaporation from storages used for urban water supplies.

Project Deliverable

The consultant will provide a report based on a desktop study that will review the methods and strategies of reducing evaporation from storages (dams, weirs, off stream storages) used as a water source for urban water supply. The review will discuss and evaluate:

- methods and strategies available [eg reservoir design, thin film technology (cetyl and stearyl alcohols), cover materials and structures, any other methods identified by the consultant]
- advantages and disadvantages of the methods / strategies
  - health issues (eg materials and chemicals in contact with drinking water and affect on water quality; changes in water quality parameters due to modified environment)
  - environmental issues
  - safety issues
  - effectiveness
  - affect of wave and wind action and solar radiation
  - frequency of applications
  - ease of use / set up
  - cost
  - availability of products (Queensland, Australia, overseas)
  - Storage Size

The report should include summary recommendations on the suitability of the technologies for reducing evaporation from urban water supply storages.

The review should consider work that has been done / is being done by the Rural Water Use Efficiency unit of NR&M (contact Ken Smith, telephone 3405 6968, mobile 0429 622 293)

Project Outcome

The project outcome will be a report that can be easily read by technical and non-technical persons.

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[2] Water Industry Compliance is a Division of the Department of Natural Resources and Mines.

Reporting

The Manager, Urban water Supply Services (Anne Woolley) will be the Project Officer and will be responsible for the management of this project.

Contact details are:

Phone: 3224 8556
Fax: 3224 7999
E-mail: anne.woolley@nrm.qld.gov.au

Timing

This project is to be completed by 28 March 2003.

Payment

Payment will be based on the consultant's hourly rates and paid fortnightly.

Any extensions to the project are to be negotiated by GHD's Project Manager and the Manager, Urban Water Supply Services, NR&M.

Any travel and associated costs for approved site visits associated with the work will be paid by NR&M.

Payments will be made on a fortnightly basis upon presentation of an invoice authorised by the Manager, Urban Water Supply Services, NR&M.

Material Provided

For the purpose of this project NR&M will make available information and contacts it has compiled on the subject of evaporation methods and strategies. This information will remain the property NR&M and will be returned on completion or termination of the contract.

Material Produced

Any material produced by the consultant for this project becomes the property of NR&M.

Termination of Brief

Normally the work will terminate upon satisfactory completion by GHD of the services outlined in this brief and upon payment of all fees.

NR&M reserves the right to terminate this contract at any time.

Submission of Offer

The work will be carried out under NR&M Standing Offer NRM 316 *Provision of Consultancy Services in Water Industry Compliance Management*. GHD will submit an estimate of cost including personnel and corresponding hourly rate/s.

Appendix B

Cost Estimates

Methods for Reducing Evaporation from Storages used for Urban Water Supplies

Evaporation Comparison Model

Evaporation Control Method	Cost Per hectare	Installation Cost (per hecatre)	Evaporation Reduction Efficiency	Water Saved per Year (ML) (1.5 m/yr evap)	Cost per ML (1.5m/year)	Water Saved per Year (ML) (2.5 m/yr evap)	Cost per ML (2.5m/year)
E-VapCap	$60,000	$60,000	95%	14.25	$421	23.75	$253
AquaCaps	$170,000	$136,000	70%	10.5	$1,295	17.5	$777
AquaSpan	$300,000	$300,000	75%	11.25	$1,778	18.75	$1,067
Water$avr	$1,825	$1,825	30%	4.5	$406	7.5	$243
Hydrotect	$2,738	$2,738	30%	4.5	$608	7.5	$365

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